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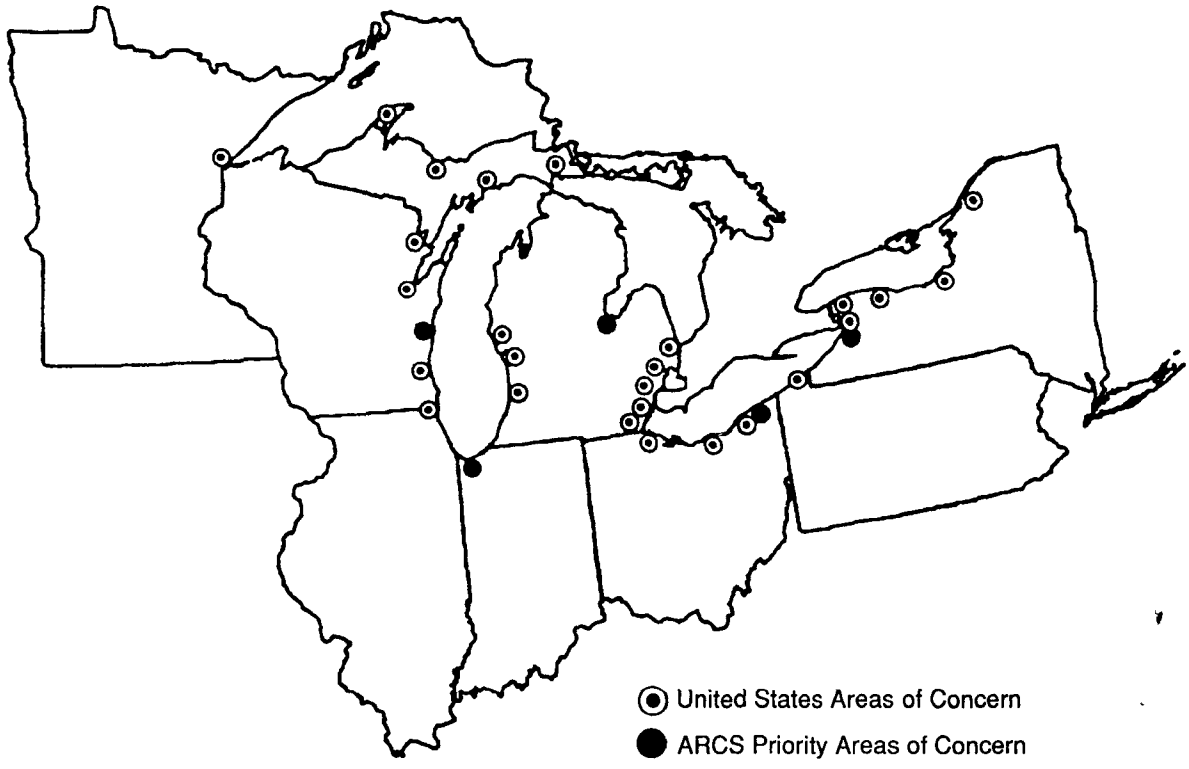
Baseline Risk Assessment for Aquatic Life for the Buffalo River, New York Area of Concern



BASELINE RISK ASSESSMENT FOR AQUATIC LIFE FOR THE BUFFALO RIVER, NEW YORK, AREA OF CONCERN

by

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ABSTRACT

The Great Lakes National Program Office of the U.S. Environmental Protection Agency initiated the Assessment and Remediation of Contaminated Sediments (ARCS) program to address concerns of environmental degradation at 43 Areas of Concern in the Great Lakes. In our first report (Passino-Reader et al. 1992), we developed a generic approach for baseline hazard evaluation of aquatic life in the Great Lakes Areas of Concern. In this report, we demonstrate the application of the generic approach to the Buffalo River (New York) Area of Concern. Using available historical data on residues in sediments, water, and biota, we evaluated exposure for 41 contaminants from the Buffalo River for eight taxa of fish and invertebrates representing the major trophic levels in the Buffalo River. By comparing exposure concentrations with reference toxicities, we calculated risk to the eight receptor organisms for typical and worst cases of exposure to the 41 contaminants. For mixtures of the contaminants present at the Buffalo River, primarily metals and polyaromatic hydrocarbons, we compared sediment concentrations with effects range-low (ER-R) values as reference values for toxicity of mixtures to estimate risk to aquatic biota.

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CHAPTER 1

EXECUTIVE SUMMARY

The 1987 amendments to the Clean Water Act, in Section 118(c)(3), authorized the U.S. Environmental Protection Agency's (USEPA) Great Lakes National Program Office (GLNPO) to initiate the Assessment and Remediation of Contaminated Sediments (ARCS) Program. The Buffalo River in New York State is one of five Areas of Concern in the Great Lakes that is being used to demonstrate assessment and clean-up techniques. In this report, we have developed and applied assessment techniques appropriate to determine a baseline hazard evaluation for aquatic life exposed primarily to contaminated sediments at the Buffalo River Area of Concern.

The baseline aquatic life hazard assessment is a first step in a comprehensive risk assessment. This assessment follows, where possible, the approach derived for human health risk assessment at the Buffalo River Area of Concern (Crane 1993). The assessment follows the Remedial Action Plan (RAP) for the site and provides a means of quantifying reference levels of risk posed by chemicals determined to be of potential concern. The reference level results reflect a conservative estimate of the potential exposures and risks experienced by Buffalo River aquatic species. A conservative estimate of risk is determined because: 1) it is impossible to characterize with a known level of accuracy, individual specific exposures and risk and 2) in the estimation of risk it is desired to error on the side of increased risk in order to be protective of aquatic health in decisions concerning remediation. The baseline or reference level risk estimates are used in conjunction with other information to determine the need to remediate the site. If remediation strategies are developed, the baseline risk levels are then used as a reference level risk by which to judge the relative effectiveness of remediation alternatives. The process of developing remediation strategies and determining residual risks is performed in a comprehensive risk assessment following the baseline.

Typically, the determination of which chemicals to include in an exposure and risk assessment involves a two step procedure. First, a monitoring study is conducted and samples are analyzed for all chemicals included on a standard list of hazardous chemicals such as the EPA priority pollutant list. Those contaminants that are "frequently" detected above recommended limits (e.g., sediment quality criteria) are included in the assessment of aquatic life exposure and risk. In the case of contaminated sediments there are no sediment quality criteria for the majority of the chemicals, but only water quality criteria (WQC). Aquatic toxicologists are developing the following approaches to sediment quality criteria: Apparent Effects Threshold (AET), Effects Range-Low (ER-L), Sediment Quality Triad (SQT), Screening Level Concentration (SLC), and Equilibrium Partitioning (EP). Therefore, for single chemicals the approach taken in this assessment is to include estimates of exposure for all chemicals of potential hazard and detected in the sediment sampling programs conducted in the Buffalo River. Risk estimates are then characterized for those chemicals or groups of chemicals for which toxicity end points (i.e., SQC, EP, WQC, NOEAL, QSAR) are available. Also, for mixtures we utilized available values for ER-L, AET, SQT, and SLC.

The following contaminants were considered in this risk assessment on the basis of their presence in either sediment samples, as monitored in 1985 and 1989, or aquatic biota as measured between 1977 and 1989:

METALS:	Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Nickel, Silver, Zinc
PAHs:	Acenaphthene, Acenaphthylene, Anthracene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)flouoranthene, Benzo(ghi)perylene, Benzo(k)fluoranthene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Napthalene, Phenanthrene, Pyrene
PESTICIDES:	alph-BHC, beta-BHC, Lindane (gamma-BHC), Aldrin, Chlordane, Dieldrin, Endrin, Heptachlor, Heptachlor epoxide, Hexachlorobenzene, Mirex, p,p'DDD, p,p'DDE, p,p'DDT
PCBs:	Total PCBs

The typical concentrations for sediment based exposures were estimated using the average of all samples taken in the most recent sediment sampling study (i.e., 1989). Reasonable worst-case concentrations were estimated from sediment data collected in 1985. Typical and reasonable worst-case concentrations for water quality were derived using two different techniques. For organic contaminants, sediment data representing typical and reasonable worst-case conditions were used along with a chemical specific partitioning coefficients and an assumption of equilibrium to compute a water quality value. Metal concentrations in the water are derived from a review of STORET data representative of samples taken from the Buffalo River between 1983 and 1987.

In characterizing exposure and risk, both typical and 'reasonable worst-case' conditions were investigated for five pathways for eight organisms in the food web: (1) gill absorption from water, (2) ingested food, (3) ingested sediment, (4) dermal contact with sediment, and (5) dermal absorption from water. The distinction between typical and reasonable worst case was based solely on the environmental concentration data used to compute exposure and risk.

In the generic document for aquatic risk assessment (Passino-Reader et al., 1992), the methods for human health assessment (Crane 1993; USEPA 1989a, 1989b, 1992a, 1992b) were adapted to develop new methods for aquatic baseline risk assessment. Using this approach, a model and equations to calculate uptake of each of the 41 contaminants by five uptake routes for each of the eight receptor organisms were developed for the Buffalo River AOC. The eight receptor organisms were pumpkinseed fish, gizzard shad, carp, brown bullhead, zooplankton, aufwuchs, surface benthos, and subsurface benthos. However, large gaps existed for parameters in the model, e.g., partitioning of contaminants over dermal surfaces for aquatic organisms and assimilation efficiencies during ingestion of food and sediment for the eight receptor organisms and 41 chemicals. Hence, in this case study of aquatic risk assessment for the Buffalo River, we have turned to the more commonly used methods in aquatic risk assessment, i.e., comparisons of concentrations in the media with reference toxicities.

First, we constructed a matrix of the media by which each of the eight receptor organisms were exposed, including which types of food they ate. Then we determined the concentrations of the 41 contaminants in each of the media, including residues in the specific foods eaten by each receptor organism. The

contaminant residues were generally higher in fish than in invertebrates. Next, we estimated reference toxicities for each medium and receptor organism. For water, water quality criteria have been established by USEPA for some of the contaminants. For contaminants lacking water quality criteria, we estimated reference toxicities for water using NOAEL, chronic toxicity data, acute toxicity data, or quantitative structure-activity relationships (QSAR), specifically the linear solvation energy relationship model (LSER) (Hickey and Passino-Reader 1991). For sediments, interim sediment quality criteria were used when available. For other chemicals, we used equilibrium partitioning thresholds (EP). For the majority of chemicals we used the water reference toxicities and calculated the corresponding sediment concentrations, using the approach of Burmaster et al. (1991).

No reference toxicities are established for contaminant exposure of aquatic organisms by food. Comparable food reference toxicities for humans include USFDA guidelines. Hence, we proposed a new term, "food quality criteria", which would be analogous to water quality criteria or sediment quality criteria. Exposure to contaminated food is a necessary component of aquatic risk assessment. Therefore, we developed the following method to estimate food quality criteria for use in the baseline aquatic risk assessment. We developed a basic equation:

$$FQC = WQC * BCF$$

where FQC = food quality criteria, WQC = water quality criteria for the predator, and BCF = bioconcentration factor for the prey.

Risk for noncarcinogenic chemicals was quantified by a hazard quotient (USEPA 1989a), i.e.:

$$\text{Hazard quotient} = \frac{\text{Exposure level}}{\text{Reference dose}}$$

For pumpkinseed and brown bullhead that were eating both fish and invertebrates, the calculated risk from eating fish was generally higher than the risk of eating invertebrates. The relative importance of different exposure routes may be assessed by examining the risks calculated for each pathway (Tables 9.1 to 9.16). The relative risks varied depending upon the receptor organism and the type of chemical (See Chapter 9). Risk was not summed across all chemicals because of the unknown contributions of chemicals below threshold levels of toxic effects.

Table 1.1 presents for each of the eight receptor organisms only those chemicals that have a risk (total hazard quotient) greater than one. These results show that for the **typical case** cadmium, chromium, copper, iron, lead, mercury, pyrene, and heptachlor epoxide present a significant risk to most of the eight receptor organisms. For the **worst case**, the above compounds plus zinc, indeno(1,2,3-cd)pyrene, endrin, and total PCBs represent a significant risk to aquatic receptors.

In considering the conclusions, one must understand the twofold intent of the baseline assessment. The objective is to develop a reference value for risk at the Area of Concern. This risk value is used in two ways. First, it is used as an 'indicator' of the potential for adverse affects. It is intentionally conservative to ensure that risks are not underestimated. The second use of the baseline risk estimate is to use the risk estimates as a reference point in the analysis of residual risks of remediation alternatives.

Table 1.1. Summary of contaminant risk associated with all exposure pathways for aquatic receptor organisms in the Buffalo River AOC. Only chemicals with risk greater than one are shown. Typical and worst cases are shown seperately.

CASE Typical

CHEMICAL	ORGANISM							
	Subsurface Benthos	Surface Benthos	Aufwuchs	Zooplankton	Brown Bullhead	Carp	Gizzard Shad	Pumpkinseed
Cadmium	2.1	3.9	3.9	1.8	1.8	1.8	1.8	2.7
Chromium	56.0	58.0	58.0	3.6	3.6	3.6	3.6	3.2
Copper	180.0	180.0	180.0	1.1	1.3	1.1	1.1	1.2
Iron	2900.0	2900.0	2900.0	3.8	3.8	3.8	3.8	3.8
Lead	12.0	17.0	17.0	5.1	5.0	5.0	5.1	7.6
Manganese	51.0	51.0	51.0					
Mercury	18.0	32.0	32.0	25.0	26.0	25.0	25.0	21.0
Nickel	19.0	19.0	19.0					
Zinc	20.0	21.0	21.0					
Benzo(a)anthracene	3.2	3.3	3.3					
Benzo(a)pyrene	18.0	18.0	18.0					
Benzo(a)fluoranthene	10.0	10.0	10.0					
Benzo(ghi)perylene	5.2	5.4	5.4					
Chrysene	3.6	3.8	3.8					
Indeno(1,2,3-cd)pyrene	15.0	16.0	16.0	1.1				
Pyrene	13.0	16.0	16.0	2.6	2.4	2.4	2.6	3.8
Lindane (gamma-BHC)					1.6	2.5		
Chlordane					110.0			
Dieldrin					4.0			
Heptachlor epoxide	2.1	4.0	4.0	3.9	4.3	3.9	3.9	3.5
Mirex					1.2			
PCBs (total)					610.0	1.5		3.8

Table 1.1. (Continued)

CASE Worst

CHEMICAL	ORGANISM							
	Subsurface Benthos	Surface Benthos	Aufwuchs	Zooplankton	Brown Bullhead	Carp	Gizzard Shad	Pumpkinseed
Cadmium	11.0	15.0	15.0	3.8	3.8	3.8	3.8	5.5
Chromium	470.0	470.0	470.0	17.0	17.0	17.0	17.0	3.2
Copper	660.0	660.0	660.0	2.2	6.5	2.3	2.2	1.8
Iron	5600.0	5600.0	5600.0	7.5	7.5	7.5	7.5	7.5
Lead	540.0	550.0	550.0	11.0	11.0	11.0	11.0	14.0
Manganese	75.0	76.0	76.0					
Mercury	93.0	110.0	110.0	79.0	97.0	79.0	79.0	33.0
Nickel	30.0	30.0	30.0					
Silver	710.0	710.0	710.0					
Zinc	98.0	99.0	99.0	2.0	2.0	2.0	2.0	
Benzo(a)anthracene	25.0	26.0	26.0	1.2				
Benzo(a)pyrene	74.0	76.0	76.0	1.5				
Benzo(a)fluoranthene	18.0	18.0	18.0	1.3				
Benzo(ghi)perylene	63.0	66.0	66.0	4.5				
Benzo(k)fluoranthene	13.0	14.0	14.0					
Chrysene	7.9	8.2	8.2					
Indeno(1,2,3-cd)pyrene	190.0	200.0	200.0	14.0	3.2	3.2	3.3	3.4
Phenanthrene	2.1	2.2	2.2					
Pyrene	51.0	61.0	61.0	10.0	9.2	9.2	10.0	15.0
alpha-BHC	1.7	1.8	1.8					
beta-BHC	1.1	1.2	1.2					
Lindane (gamma-BHC)					6.7	6.7		1.7
Chlordane					4.1	4.1		1.0
Endrin	23.0	24.0	24.0	1.6	1.5	1.5	1.6	1.9
Heptachlor epoxide	3.7	7.2	7.2	7.6	7.0	7.0	7.6	5.8
PCBs (total)	460.0	480.0	480.0	17.0	1300.0	50.0	17.0	45.0

In this sense, it is used to estimate the relative reduction of risk that would occur given the implementation of various alternative remediation strategies.

With this in mind, an appropriate interpretation of the conclusions is that there is a need to further refine the baseline estimates. The following is a list of specific recommendations for further work to be performed in order to refine the estimates of risk reported here:

1. The occurrence of 'hot spots' in the Buffalo River is an open question. The 1985 sediment sampling shows heightened levels of contamination in a small portion of the river. The 1989 sediment sampling data is not sufficient to conclude that the high concentrations measured in 1985 have decreased. Further, neither the 1985 nor the 1989 sediment data sets is sufficient for determining the number of locations of other hot spots. It is recommended that a sampling strategy be developed and implemented to address the need related to locating and sampling currently existing hot spots.

2. This baseline assessment assumes that all risks experienced as a result of exposure within the Buffalo River are due solely to contaminated sediments. This implies that there are no additional sources of contamination. However, there are additional sources of contamination, such as combined sewer overflows and abandoned hazardous waste sites. The extent to which these sources contribute to exposures and risks is unknown. Before any remediation strategies are selected, it will be important to accurately inventory existing sources and to estimate their individual and collective impact on future water and sediment conditions in the Buffalo River.

3. After the above recommendations have been addressed, the baseline estimate of exposures and risks should be updated. Incorporation of current data on residues, toxicity, and benthic community structure at the Buffalo River is critical for completion of the comprehensive aquatic hazard evaluation.

CHAPTER 2

INTRODUCTION

2.1. Background

The Great Lakes Water Quality Board of the International Joint Commission has identified 42 Areas of Concern in the Great Lakes Basin where the objectives of the 1978 Great Lakes Water Quality Agreement and other jurisdictional standards, criteria or guidelines are exceeded. Erie, Pennsylvania, was recently added to become the 43rd Area of Concern. For these Areas of Concern remedial measures are necessary to restore beneficial uses.

The 1987 amendments to the Clean Water Act, in Section 118(c)(3), authorized the U.S. Environmental Protection Agency's (USEPA) Great Lakes National Program Office (GLNPO) to coordinate and conduct a 5-year study and demonstration project relating to the control and removal of toxic pollutants in the Great Lakes, with emphasis on removal of toxic pollutants from bottom sediments (USEPA/GLNPO 1989). Five areas were specified as requiring primary consideration: Saginaw Bay, Michigan; Buffalo River, New York; Grand Calumet River, Indiana; Ashtabula River, Ohio; and Sheboygan Harbor, Wisconsin. In response, GLNPO initiated the Assessment and Remediation of Contaminated Sediments (ARCS) Program. Information from ARCS Program activities will be used to guide the development of RAPs for the 43 Areas of Concern.

2.2 Objectives

The primary objective of the RAM Work Group applicable to this report is as follows--"Hazard Evaluation: To evaluate exposures to, and impacts resulting from, contact with contaminated sediments and media contaminated by sediment contaminants incurred by all receptors of concern under the 'no action' alternative and other remedial alternatives. This evaluation will draw upon the development and integration of predictive tools to describe future hazards and risks".

The objectives of the baseline aquatic hazard evaluation of the Buffalo River Area of Concern are as follows:

1. To provide a generic assessment approach to be used in the ARCS Program to describe actual and potential hazards of contaminated sediments to aquatic life (receptors) of concern in the Great Lakes.
2. To apply this generic approach to the following site in the ARCS Program: Buffalo River, NY.
3. To identify aquatic receptors being impacted by sediment-related contaminants and those requiring protection.
4. To develop preliminary remediation goals for sediment contaminants based on health of aquatic receptors.
5. To identify information gaps that would be required to fully describe the risks to aquatic receptors.

2.3 Organization of Report

This report is organized into sections, essentially based on the steps for human health risk assessment (USEPA 1987a, 1989a). Chapter 3 describes in generic terms, the framework developed here for conducting risk assessments for aquatic life exposed to contaminated sediments. Chapter 4 characterizes the exposure setting of the Buffalo River in terms of the natural setting, land use, abiotic and biotic factors in the aquatic habitat, and sources and types of pollutants. Chapter 5 presents data compilation and evaluation, primarily for contaminant residue data but also biological and toxicological data. Chapter 6 presents the framework for hazard identification, including the receptor species (invertebrates and fish). Chapter 7 presents the exposure assessment in terms of the receptor species at the Buffalo River, exposure pathways, and chemical uptake. Chapter 8 combines dose-response data and exposure-response data to provide a toxicity assessment. Chapter 9 contains the risk characterization for chemicals of concern at the Buffalo River. Chapter 10 analyzes the uncertainty associated with the risk characterization.

CHAPTER 3

RISK ASSESSMENT FRAMEWORK

The purpose of this section is to outline a general framework for conducting baseline hazard evaluations for aquatic life at Great Lakes Areas of Concern. The Buffalo River AOC will be used as an example to illustrate the application of this method. The components of the baseline risk assessment are shown in Figure 3.1.

3.1 Overview of the Procedures and Data Requirements

Figure 3.1 illustrates the sequence of steps necessary to perform a baseline risk assessment for aquatic life at sites where sediments are assumed to be the primary source of contamination.

The overall aim of the baseline risk assessment is to establish the following: 1) what contaminants are present at potentially significant levels in the Area of Concern, 2) the manner, magnitude, and frequency of exposure of aquatic receptors (fish and invertebrates), and 3) a "characterization" of the potential adverse health effects resulting from exposure of aquatic receptors. The characterization of baseline risk is site-specific and quantitative to the extent possible using available data. Where there is an absence of data about the specific Area of Concern, the assessment includes appropriate assumptions and utilizes published data from other studies.

3.2 Site Characterization

The site characterization step is intended to focus the risk assessment on those contaminants and aquatic receptors of primary concern, i.e., those contaminants that show the greatest potential for resulting in substantial adverse effects. The site characterization should include information on the location of the site, a history of industrial development, likely contaminants of concern, and a description of the environmental setting of the site (USEPA 1989a). Inputs to this step include previous assessments, monitoring study results, historical and present land use patterns, aquatic species present, lists of hazardous chemicals (e.g., the Priority Pollutant List), and abiotic and biotic factors of the aquatic habitat. No detailed quantitative analyses are included in this step. The input material is reviewed and used to define the nature and limits of contaminant hazard to aquatic life.

3.3 Review and Evaluation of Environmental Quality Data

The objective of this step is to assemble the most complete and current data set possible representing contamination levels in all relevant media, i.e., sediment, water, and biota. Ideally, the data would be sufficient to fully describe the level of contamination for each chemical on spatial and temporal scales and ideally all potential exposures to aquatic receptors. Thus the task within a baseline assessment becomes one of organizing those site specific data that do exist in order to draw as complete a picture as possible of the degree and distribution of contamination at the site.

All data used in the assessment should undergo a quality assurance/quality control (QA/QC) review. This involves collecting information related to the sampling and analytical techniques used in generating the data. For use in the ARCS Program, this step is conducted using a quantitative system (Chapter

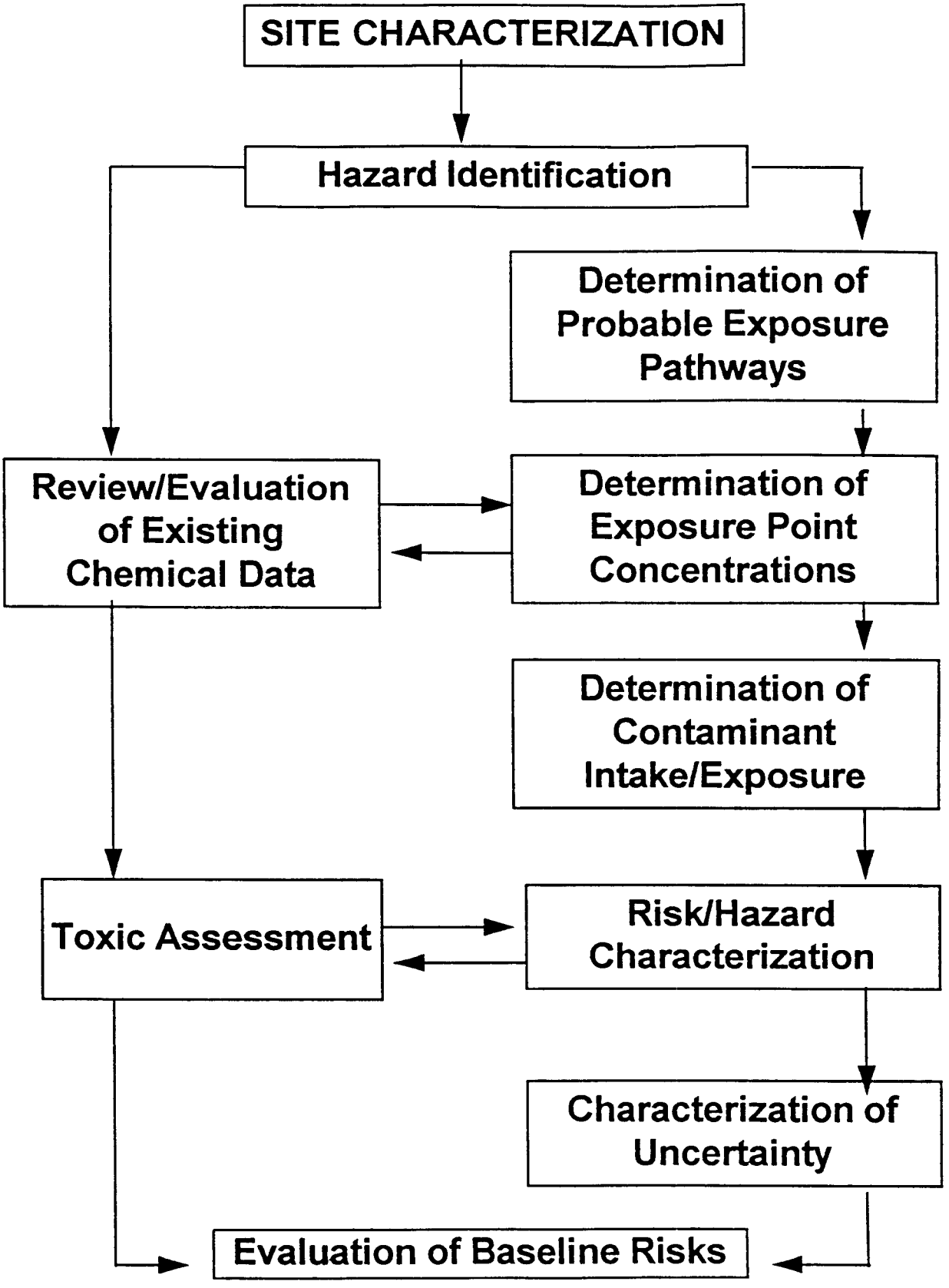

Figure 3.1. Baseline risk assessment.

5 of this report; Schumacher and Conkling 1990) that scores data sets with respect to accuracy, precision, spike recovery, blanks, and other procedures.

3.4 Hazard Identification

Hazard identification continues the process begun in the site characterization step to define the contaminants of concern for the aquatic hazard evaluation. "The qualitative assessment or hazard identification part of risk assessment contains a review of the relevant biological and chemical information bearing on whether or not an agent may pose a carcinogenic hazard" (USEPA 1987). For the purpose of the ARCS hazard evaluation, noncarcinogenic responses were considered in detail as well. Since chemicals seldom occur in a pure state and are often transformed in the body, the review should include available information on degradation products of contaminants and metabolites.

3.5 Exposure Assessment

Exposure assessment includes an identification of exposed and potentially exposed receptors (fish, benthos, plankton) at the AOC; descriptions of probable exposure pathways for each type of receptor; determination of exposure point concentrations for each chemical; and estimation of intake for each chemical and receptor.

Information required for the exposure assessment includes the site characterization, exposure concentrations, and protocols for computing exposure of each receptor species. A description of each pathway and a mathematical expression that permits computation of exposure for each pathway and receptor is necessary. Below are listed the exposure pathways that should be considered in an aquatic assessment of risk due to contaminated sediments:

Ingestion of water
Ingestion of food
Ingestion of sediment
Dermal contact with water
Dermal contact with sediments
Gill contact with water
Gill contact with sediments

Only those pathways that are "active" at a particular AOC and receptors need to be included in the risk assessment. In all cases site specific data is preferred over regional or national averages.

3.6 Toxicity Assessment

Exposure-response and dose-response (concentration response) data from laboratory studies will be combined with field data on exposure-response, when available, to estimate exposures to which receptors of interest are subjected. Emphasis will be placed on adverse effects of chemicals on relevant species resulting from sediment exposure.

Site specific data from the Toxicity/Chemistry Work Group of ARCS were used when available. Acute and chronic toxicity data on single chemicals were used for initial screening of the list of chemicals from the contaminated sediments and water at the Buffalo River AOC. Bioassay data using whole sediments were used from the Toxicity/Chemistry Work Group to enable more accurate evaluation of risk. To complement these data from laboratory bioassays, data on benthic community structure from the AOC are a necessary component from the field. While laboratory studies can show relationships between receptors and

individual or combined stressors under controlled conditions, field studies show the integrated response of receptor populations and communities to all stressors under natural conditions.

3.7 Risk Characterization

Risk characterization is composed of two parts. One is a presentation of the numerical estimates of risk; the other is a framework to help judge the significance of the risk. Risk characterization includes the exposure assessment and dose-response (concentration-response) assessment. It is critical that the numerical estimates not be allowed to stand alone, separated from the various assumptions and uncertainties upon which they are based.

Pending data availability, the evaluation will incorporate the use of Apparent Effects Threshold (AET), the Sediment Quality Triad (SQT), and Screening Level Concentration (SLC) as "risk characterization" techniques. Risk should be characterized for both individual chemical and multiple chemical exposure. Risk will be estimated across pathways and across media.

3.8 Uncertainty Analysis

EPA guidelines specify that each risk assessment include a discussion of uncertainty. Statistics implies thinking in terms of uncertainties. Statistics are used to reason from the sample to the population. Samples used in this risk assessment may have been impacted for example by poor sampling design (nonrandom), inadequate field gear (hole in net), poor laboratory technique (contamination), errors in data entry, and always by chance. These problems of precision and accuracy will modify our inferences on the subject of interest, i.e., sediment concentration or body burden of a particular metal. Statistics supplies scientist with procedures to correct these problems and to state how often we are right on the average. However, many times available data are of unknown quality and may not be representative of the spatial, temporal, or environmental media of interest to the risk assessor. In the uncertainty analysis we will attempt to point out problems of accuracy and where possible estimate the precision of various parameter estimates.

CHAPTER 4

CHARACTERIZATION OF THE EXPOSURE SETTING: BUFFALO RIVER AREA OF CONCERN

4.1 General Description of AOC

The Buffalo River is located in the vicinity of the city of Buffalo in northwestern New York State (Figure 4.1). With its three main tributaries--Cayuga, Buffalo, and Cazenovia Creeks--it has a drainage basin of about 1,150 km^2 (446 mi^2) (see NYDEC 1989). The Buffalo River proper is only 12.5 km (7.8 mi) long, originating at the confluence of Buffalo and Cayuga Creeks and flowing westward into Lake Erie. A navigable channel is maintained in the lower 8.8 km (5.5 mi) to allow the passage of large lake vessels to the industrial facilities located along the lower river.

The AOC (Figure 4.2) includes the entire 12.5 km of the Buffalo River (128 ha), as well as the Buffalo Ship Canal (13.4 ha), Outer Harbor (365 ha), Times Beach Confined Disposal Facility (18 ha), and the Erie Basin Marina (11 ha). The AOC is characterized by heavy industrial development which began during the 1800's when the Erie Canal was completed. Both industrial and residential growth increased through the 1950's, but with changes in transportation patterns and migration of industries from the Northeast, some of the industrial and commercial activities ceased along the river. The Buffalo River still remains a site of considerable industrial activity, and to aid transportation, the navigable channel is maintained by dredging. However, the quality of the dredged sediments exceed criteria for open water disposal for arsenic, barium, copper, iron, lead, manganese, zinc and cyanide. The dredged sediments are presently placed in the Times Beach Confined Disposal Facility which is expected to be filled by the mid-1990's.

The sources of past and present pollution to the AOC (NYSDEC 1989) are as follows: (1) wastewater facility discharges, mainly from industrial chemical production, specialty chemical production (dye related products), coke production, oil refining, steel production, and grain milling firms; (2) inactive hazardous waste sites, of which 32 exist in the Buffalo River watershed; (3) sewer system overflows with 23 overflows in the Buffalo River and 16 in the lower Cazenovia Creek; (4) bottom sediments, which are a sink for contaminants from water and air and potentially a source of contaminants to water and air; (5) other point and non-point sources.

4.2 Abiotic Factors of Aquatic Habitat

The Buffalo River averages about 100 m (64-275 m) in width with the navigable portion trough shaped (6.8 m deep) and running two-thirds of the cross sectional area. The rest of the cross sectional area contains shallow zones on one or both sides averaging around 3 m in depth near the diked shore and sloping to 5.4 m near the navigational channel. Makarewicz et al. (1982) reported the substrate in shallow areas as sandy and the channel substrate as a gray-black gyttja or dark grey clay. Bergantz (1977) found a mean percentage sand/silt/clay of 15/51/34 and total organic carbon to average 3.25% (1.33-4.85%). The gradient of the river is very small, less than 17 cm km^{-1}. During average (17 m^3s^{-1}) and low flows (1.4 m^3s^{-1}), the river is

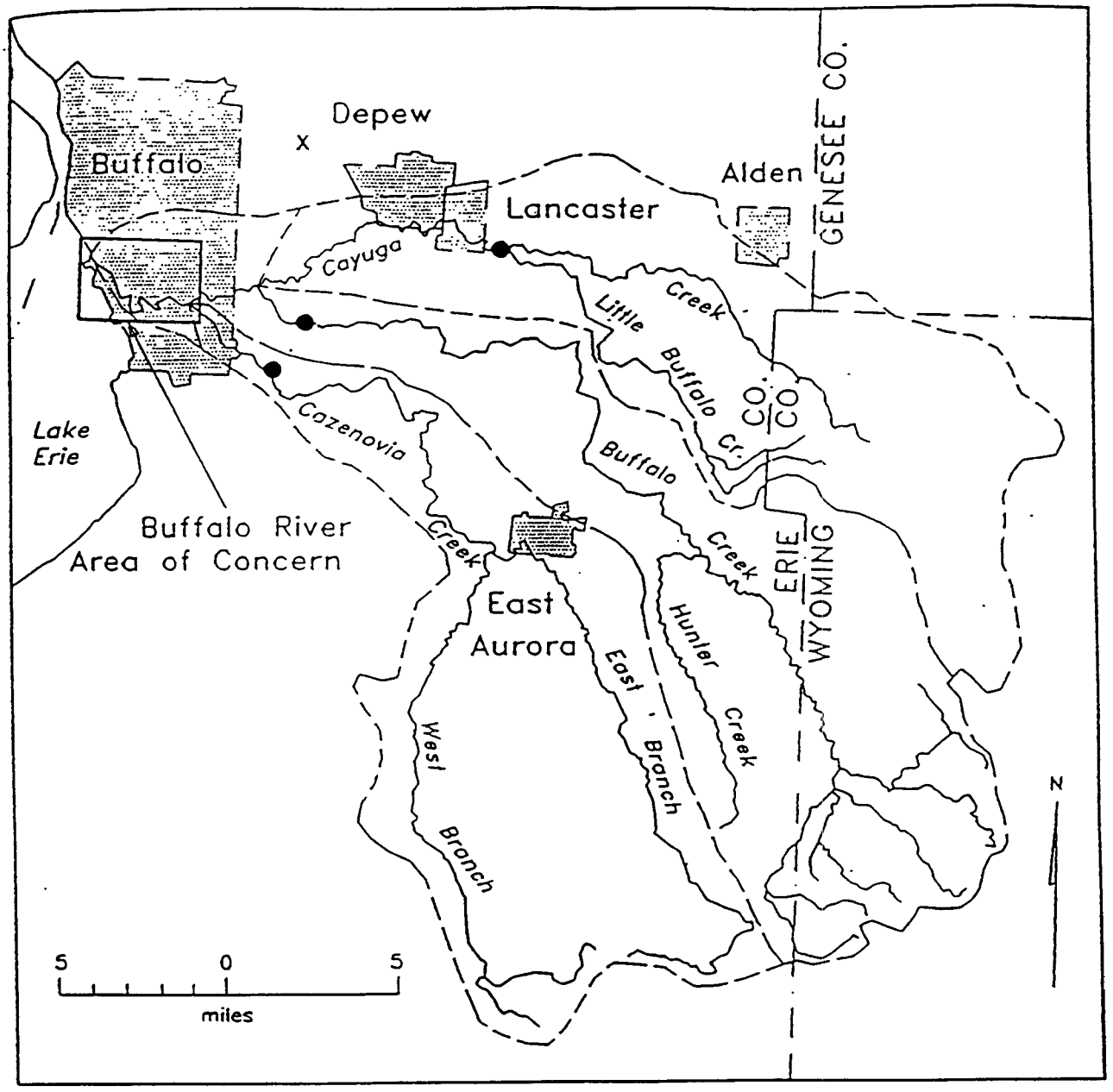

FIGURE 4.1. The Buffalo River watershed and Area of Concern. The locations of U.S. Geological Survey gauging stations (•) and the Buffalo Airport (X) are shown. From Irvine et al. (1992).

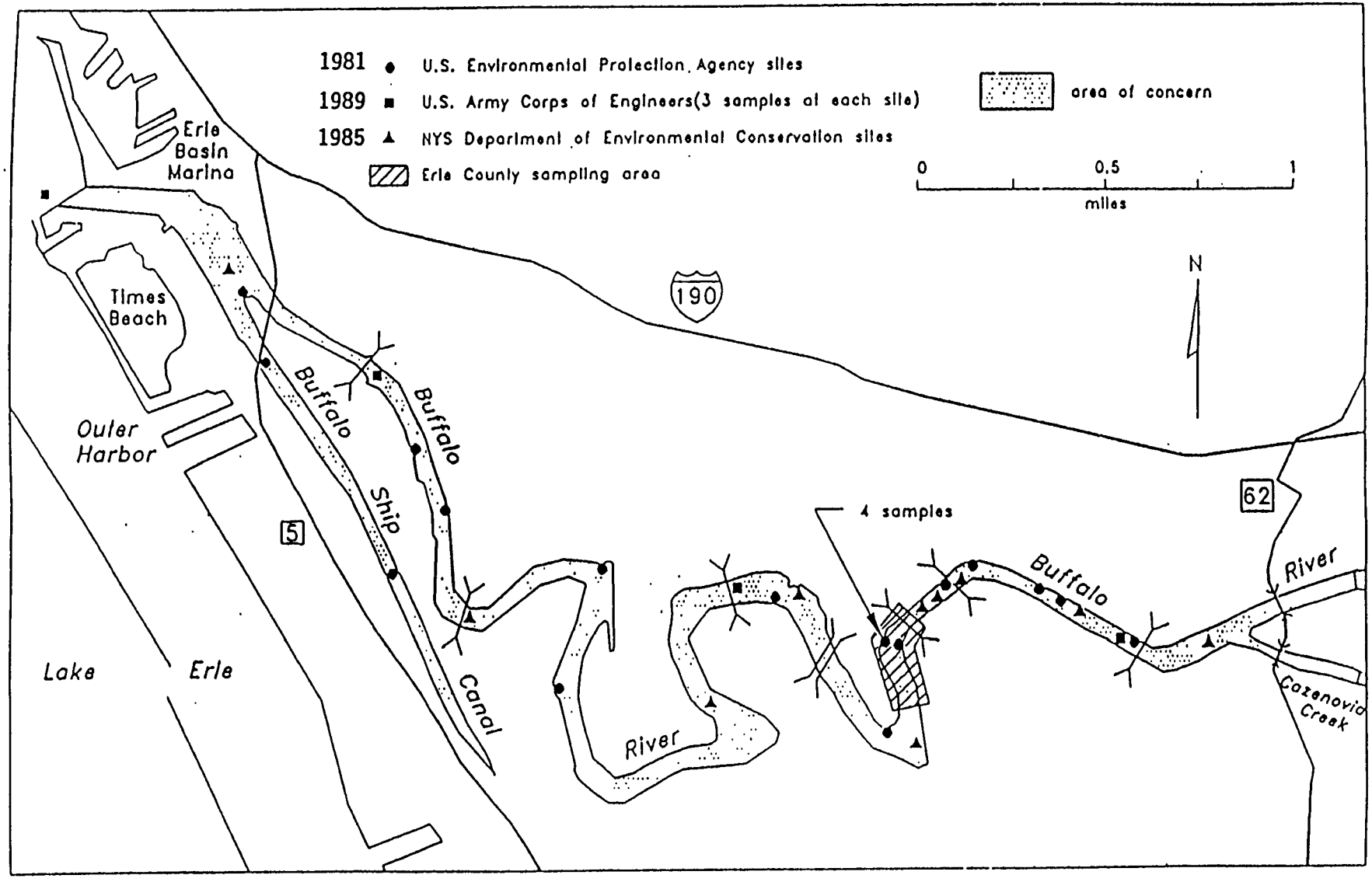

FIGURE 4.2. Location of sediment sampling sites in the Area of Concern (from NYSDEC, 1989). Sample locations for the Aqua Tech (1989) report are similar to those of the USEPA. From Irvine et al. (1992).

influenced by lake level variation associated with the passage of storms across Lake Erie and seasonal thermal differences between lake water and river water. The lake may rise 3.7 m above low water datum and a 24-hr increase of Lake Erie elevation up to 1 m can cause flow reversals and influence the entire 12.5 km of the Buffalo River. For high flows (in excess of 849 m^3s^{-1}), the waterway has a riverine character. Surface velocities of 1 ms^{-1} have been documented, but during average summertime conditions, velocities are less than 0.02 ms^{-1} and average resident times may exceed 5 days. Upstream velocities of 0.13 ms^{-1} have been measured (Sargent 1975). The Buffalo River Improvement Corporation was formed in the late 1960's to supply water from the Buffalo Harbor to five major industries along the Buffalo River for process and cooling purposes. The water is pumped from Lake Erie and ultimately augments flow in the Buffalo River. Designed to supply 5.3 m^3s^{-1} it currently discharges about 1 m^3s^{-1} (about 5% of average flow).

The wider portion of the Buffalo River serves as the most efficient trap area and collects sediments under high flow conditions while much of the remainder of the river system is scoured and sediments deposited in the outer harbor. At discharges above 566 m^3s^{-1}, even sand particles are transported. Based on average annual peak daily flow of 340 m^3s^{-1} in the Buffalo River for a 45 year period (1940-1985), the average annual suspended sediment yield for the drainage basin has been estimated as 95,600 metric tons.

The Buffalo River does not freeze over in the winter and may reach 32°C around mid to late July. The river does stratify vertically with differences between surface and bottom layers of 13.5°C. Longitudinal temperature difference up to 12°C can also result with the intrusion of cold Lake Erie water up into the river. Dissolved oxygen values in the summer are usually depressed (50-70% saturation) and levels as low as 1.0 mgL^{-1} have been measured as recently as 1988 (Adrian and Merckel 1988). Conductivity ranges from 240 to 440 $umhoscm^{-1}$, alkalinity from 63 to 105 mg $CaCO_3$/L and total solids from 195-412 mgL^{-1}. In 1987, total phosphorus averaged 105 μgL^{-1}. Secchi disk readings range from 0.5 to 3 m and transparency at the downstream station at times was twice that of the upstream station (Ward 1980; Carnes 1981; Ecology and Environment 1982).

Temperatures in the embayments and small boat harbors may reach around 24°C in late July and these areas may freeze over in February. Longitudinal differences in temperature of 9.3°C may occur in surface temperatures between shallow and deep areas of the embayments during the summer. Percent oxygen saturation usually exceeds 80% except for a low value (52%) under ice cover in February. Conductivity in the embayments ranges from 283 to 462 $\mu mhos\ cm^{-2}$ and alkalinity from 60 to 93 mg $CaCO_3\ L^{-1}$. Percent light transmission to the bottom usually exceeds the compensation point (<1%) up to 3m (Carnes 1981). The Buffalo Ship Canal is a long (250-275 m), narrow slip dredged to 5-6 m deep. About 50% of the area is shallow and located at the southern end. The dredged site is characterized by a very steep drop-off from shallow shore areas containing many old pier posts. Bottom sediments are gray-black gyttja (Makarewicz et al. 1982).

4.3 Biotic Factors of Aquatic Habitat

Biological sampling of the Buffalo River AOC began in the 1960s, and investigations of all the trophic levels have been carried out at least once over the last 30 years. Benthic invertebrate sampling has had the best temporal and spatial resolution. The following is a brief summary of biological collections to date.

No quantitative phytoplankton data has been collected from the Buffalo River AOC except for a cursury look at Times Beach CDF plankton by Stafford et al. (1987). Ward (1980) did measure chlorophyll a as an estimate of algal biomass. Chlorophyll a ranged from 0.373 to 20.3 μgL^{-1}. The highest values were recorded in late July at the upstream station adjacent to the entrance of Cazenovic Creek. The overall highest volumes were at either upstream or downstream stations.

Thirteen species of submersed aquatic macrophytes have been reported by Carnes (1981) and Makarewicz et al. (1982) from the Buffalo River-Harbor area (Table 4.1). Vallisneria americana, Heteranthera dubia and Elodea canadensis were the most abundant, especially in Cargill Bay and the nearby small boat harbor (Carnes 1981). Carnes (1981) found Vallisneria to have a strong positive association with a sand substrate while Elodea and Heteranthera were associated with silt and clay. Makarewicz et al. (1982) noted high densities of Myriophyllum, Vallisneria, and various species of Potamogeton at the COE Disposal Site 1. They also observed high densities in the small boat harbor and in the vicinity of the north breakwall. Sparse macrophytes were also noted at several shallow areas in the harbor, the river mouth, entrance to the ship canal and at a wide area of the river 4.5 miles upstream. Also, large cubical blocks used for shoreline protection in the harbor develop luxurious growths of the macroalgae Cladophora by August (Makarewicz et al. 1982). The wetland area of the Times Beach CDF is dominated by Carex stipata, Phragmites australis, Scirpus atrovirens and Typha latifolia (Marquenie et al. 1987). The aquatic area contains dense populations of submersed aquatic macrophytes. A cursury examination of the plankton and benthos was made by Stafford et al. (1987) and typical planktonic forms (Asterionella, Bosmina, and cyclopoids) and benthic groups (Oligochaeta, amphipods, mayflies, Diptera) were found.

Ward (1980) made monthly surveys of crustacean zooplankton in the Buffalo River between Michigan Street Bridge and the ConRail tracks in 1979 and collected 35 different taxa (Table 4.2). She found densities to be greatest at either the upstream or downstream stations, i.e., densities in August were eight times higher at the two extreme stations than in the middle four stations. Typically 70 to 100% of the specimens collected were immature copepods (nauplii and copepodites). The highest density recorded was 400 copepods L^{-1} at the upstream station in July of which 76% were nauplii. Densities ran around 100 L^{-1} in June, July, and August; 18 L^{-1} in May; and 2-3 L^{-1} in September and October. Mature zooplankton species were most abundant between June and August with higher densities usually occurring at the furthest downstream station (Table 4.3). Of the common taxa, Bosmina is most numerous, and during its peak abundance in June was evenly distributed throughout the river. Biomass was estimated based on Ward's (1980) numerical data and average weight of various groups. Biomass ranged from 1.4 to 525.4 mg/L dry weight with estimates peaking in June.

Benthic populations have been sampled in the Buffalo River since 1963 (Blum 1963). Blum found no benthic invertebrates in the dredged section of the river, but by the late 1970's - early 1980's, densities of invertebrates averaged around 40,000 m^{-2} (Table 4.4) in the downstream 6 miles of the river (Bergantz 1977, Ecology and Environment, Inc. 1982). The most recent investigation of the river (Canfield et al. 1992) in 1989 found the fauna of the river bottom composed of 12 major groups of invertebrates with at least 37 distinct taxa. Oligochaetes have been the most abundant and diverse group and usually make up over 90% of the fauna. Oligochaete densities up to 130,000 m^{-2} have been recorded but densities have recently dropped to levels less than 10,000 m^{-2} (Table 4.4), which is typical of less eutrophic situations. Eight species of oligochaetes have been collected with 4 species of Limnodrilus dominating (L. hoffmeisteri, L. claparediamus, L. cervic, L. udekiamus) in

Table 4.1. Submersed aquatic macrophytes in Buffalo Harbor, 1978 (Carnes 1981).

Pondweed Family
Potamogeton pectinatus
Potamogeton pusillus
Potamogeton foliosus
Potamogeton richardsonii
Potamogeton crispus
Zannichellia palustris
Naid Family
Najas flexilis
Frog's-Bit Family
Elodea canadensis
Vallisneria americana
Pickerelweed Family
Heteranthera dubia
Hornwort Family
Ceratophyllum demersum
Water-Milfoil Family
Myriophyllum spicatum
Muck-grass
Chara sp.

Table 4.2. Crustacean zooplankton collected in the Buffalo River and Harbor during 1977 and 1979 (after Ward 1980).

Study	River	Harbor
Cladocera		
Alona spp. (*affinis, guttata, quadrangula, rectangula)*	X	X
Bosmina with mucro	X	X
Ceriodaphnia lacustris	X	X
Chydorus sphaericus	X	X
Daphnia ambigua	X	-
D. galeata menodtae	X	X
D. longiremis	X	X
D. parvula	X	-
D. pulex	X	-
D. retrocurva	X	X
Diaphanosoma leuchtenbergianum	X	X
Eubosmina coregoni	X	X
Holopedium gibberum	X	X
Ilyocryptus sordidus	X	-
Leptodora kindtii	X	X
Macrothrix laticornis	X	-
Moina rectirostris	X	-
Scapholeberis kingi	X	-
Copepoda		
Calanoida		
Diaptomus ashlandi	X	X
D. minutus	X	X
D. oregonensis	X	X
D. sicilis	X	X
D. siciloides	X	X
Eurytemora affinis	X	X
Cyclopoida		
Cyclops bicuspidatus thomasi	X	X
C. vernalis	X	X
Eucyclops agilis	X	X
Mesocyclops edax	X	X
Paracyclops fimbriatus poppei	X	X
Tropocyclops prasinus mexicanus	X	X
Harpacticoida		
Attheyella illinoisensis	X	-
Canthocamptus robertcokeri	X	X

Table 4.3. Month and area of maximum abundance of common zooplankton species in the Buffalo River (after Ward 1980).

Taxa	Peak Average Abundance (No./L)	Month of Peak Abundance	Location of Peak Abundance
Bosmina spp.	20	June	even
Daphnia pulex	7	August	downstream
Cyclops bicuspidatus	4	June	downstream
Diaphanosoma sp.	4	July-August	downstream
Daphnia retrocurva	3	July	downstream
Mesocyclops edax	3	August	downstream
Daphnia galeata	2	July	downstream
Diaptomus oregonensis	1	July-August	downstream

Table 4.4. Densities (No. m^{-2}) of major benthic invertebrate groups found in the sediments of the channelized portion of the Buffalo River, 1969-1990.

Group	1969[1]	1970[2]	1972[3]	1977[4]	1982[5]	1989[6]
Oligochaetes	2530	1890	2100	39000	38840	8730
Chironomids	80	18	2	38	240	430
Fingernail clams	3	-	6	312	94	70
Snails	14	10	18	40	460	59
Leeches	-	-	1	10	60	8
Flatworms	-	3	-	-	15	-
Mayflies	-	-	-	2	-	8
Caddisflies	-	-	-	-	-	3
Amphipods	-	-	-	-	-	9

[1] Sweeney 1970. [2] Sweeney 1971. [3] Sweeney and Merckel 1972. [4] Bergantz 1977.
[5] Ecology and Environment 1982. [6] Canfield et al. 1992.

1976-77 (Bergantz 1977) but L. hoffmeisteri, Quistadrilus multisetosus, and L. cervic dominating in 1989 (Canfield et al. 1992). The fingernail clams, Pisidium and Sphaerium, and the chironomid genera, Chironomus and Procladius, are the only other taxa routinely collected in bottom grabs (Bergantz 1977; Simpson 1980) through the 1970's.

Overall the benthic collections in 1989 (Canfield et al. 1992) indicated a marked improvement in the benthic community of the Buffalo River. The reduction in abundance of oligochaetes, the increased abundance and diversity of chironomids (11 taxa), the presence of several mayflies, caddisflies, and amphipods on soft sediments, and the collection of single specimens of a crayfish and dragonfly all suggest a more balanced and diverse community. The differences were most obvious at the extreme upper and lower stations on the river which are influenced by upstream and Lake Erie effects (source of invertebrates, deposition of clean sediments, etc.). However, the high density of oligochaetes and the absence of the above groups at station 6-8 suggest a continued degraded condition in the middle section of the river.

The majority of the species listed from the river in Table 4.5 were collected by New York State's Biological Stream Monitoring Project using artificial substrate samplers (Hester-Dendy) installed 0.9 m below the surface water. The river at the dual railroad bridge has been sampled in 1976, 1982, 1987, and 1988 (R. Bode, NYDEC, personal communication). Although up to 31 species have been found at a particular date the presence of large numbers of tolerant species indicates a severely to moderately impacted area. The chironomid Dicrotendipes simpsoni and the oligochaetes Nais variabilis, Dero nivea, Dero digitata dominated the 1987-88 multiplate samples.

Makarewicz et al. (1982) sampled benthos in the harbor at a shallow weed choked embayment and along the outer wall of the south breakwall. The embayment samples were dominated by snails and clams, accounting for 94.5% of 11,000 to 21,000 invertebrates collected. Species of Amnicola, Valvata and Pisidium made up the bulk of the specimens. The mixed cobble and sand substrate in the breakwater was difficult to sample and yielded only around 50 organisms per square meter. Besides snails and clams, several species of chironomids were relatively abundant.

There have been 43 species of fish collected from the Buffalo River AOC (Table 4.6, 4.7) in recent history, all of which occur in Lake Erie proper or its tributaries. This compares with a 100 species found in Lake Erie plus an additional 30 that occur only in tributaries to Lake Erie (Bailey & Smith 1981). Twenty-seven species were collected in the Buffalo River proper in 1981 with pumpkinseed, carp, goldfish, gizzard shad, brown bullhead, yellow perch and white sucker abundant year around residents (Makarewicz et al. 1982). Emerald and spottail shiners are common in May when they utilize the river for spawning. More recent collections by Adrain & Merckel (1988) had a similar fish fauna (29 species) but with some shift in dominance rank. In 1988 the dominant species was gizzard shad, followed by pumpkinseed, golden shiner, goldfish, emerald shiner, carp and brown bullhead. Smallmouth and largemouth bass were the dominant piscivores. Pumpkinseed, yellow perch, white suckers, carp, and goldfish are also common in the ship canal (Makarewicz et al. 1982). Several larval yellow perch were collected in the river by Makarewicz et al. (1982) in 1981 suggesting possible use as a spawning or nursery area and pumpkinseeds were observed nesting in shallow areas in the river. Adrain and Merckel (1988) collected 292 fish larvae of which 71% were gizzard shad. Eight other taxa made up the rest of the catch. Thirty-six species of fish were collected in the harbor in 1981 with permanent population dominated by yellow perch, carp, rock bass, pumpkinseed, white sucker and smallmouth bass (Makarewicz et al. 1982). Emerald and spottail

Table 4.5. Taxa list of benthic invertebrates in the Buffalo River and Harbor area (from Bergantz 1977, Simpson 1980, Makarewicz et al. 1982, Canfield et al. 1992, Robert Bode, NYDEC, personal communication).

	River	Harbor Proper	Harbor Embay-ments
Turbellaria			
Dugesia tigrina	X		X
Nematoda			
Prismatolaimus sp.	X		
Annelida			
Naididae			
Aulodrilus pigueti	X		
Aulophorus sp.	X		
Chaetogaster diaphanus	X		
Dero digitata	X		
Dero furcata	X		
Dero nivea	X		
Dero obtusa	X		
Nais barbata	X		
Nais bretscheri	X		
Nais communis	X		
Nais pardalis	X		
Nais simplex	X		
Nais variabilis	X		
Ripistes parasita	X		X
Stylaria lacustris	X		
Tubificidae			
Limnodrilus cervix	X		
Limnodrilus hoffmeisteri	X		
Limnodrilus udekianus	X		
Limnodrilus claparedianus	X		
Peloscolex multisetosus	X		
Potamothrix vejdovskyi	X		
Quistradrilus multisetosus	X		
Tubifex tubifex	X		
Hirudinea			
Helobdella stagnalis	X		
Crustacea			X
Asellus sp.	X		
Gammarus fasciatus	X		X
Gammarus pseudolimnaeus			
Insecta			
Trichoptera			X
Agraylea sp.		X	
Ceraclea sp.			
Cyrnellus fraternus	X		X
Leucotrichia sp.			X
Nectopsyche sp.			X
Neureclipsis sp.			
Orthotrichia sp.	X		
Ephemeroptera			
Caenis sp.	X		
Stenacron interpunctatum	X		
Coleoptera			
Stenelmis sp.	X		
Chironomidae			
Ablabesmyia mallochi	X		
Ablabesmyia monilis	X		
Chironomus decorus gr.	X		
Cladopelma sp.	X		
Coelotanypus	X		
Conchapelopia sp.	X		
Cricotopus bicinctus	X		
Cricotopus intersectus gr.	X		
Cricotopus sylvestris gr.	X		
Cricotopus tremulus gr.	X		
Cryptochironomus fulvus gr.	X	X	X
Dicrotendipes lucifer	X		
Dicrotendipes modestus	X		
Dicroptendipes simpsoni	X		
Eukiefferiella discolonipes gr.	X		
Glyptotendipes lobiferus	X		
Harnischia curtilamellata	X		
Microchironomus	X		
Nanocladius distinctus	X		
Nanocladius spiniplenus	X		
Parachironomus abortivus	X		
Parachironomus frequens	X		
Parakiefferiella sp.	X		
Paramerina sp.	X		
Paratanytarsus spp.	X		
Pentaneura sp.	X		
Phaenopsectra flavipes	X		
Polypedilum convictum	X		
Procladius sublettei	X	X	X
Pseudochironomus sp.	X		
Rheotanytarsus exiguus gr.	X		
Tanypus	X		
Tanytarsus glabrescens gr.	X		
Tanytarsus guerlus gr.	X		
Thienemanniomyia gr. spp.	X		
Tribelos spp.			X
Simulidae			
Simulium vittatum	X		
Gastropoda			
Amnicola binneyana		X	
Amnicola integra		X	X
Amnicola limosa		X	X
Bithynia tentaculata			X
Ferrissia rivularis	X		
Goniobasis livescens		X	X
Gyraulus parvus			X
Helisoma anceps			X
Helisoma trivolis			X
Laevapex fuscus	X		
Lymnaea emarginata			X
Menetus dilatatus	X		
Physa heterostropha	X		X
Pleurocera acuta			X
Pomatiopsis cincinnatiensis	X		
Valvata lewisi	X		
Valvata piscinalis	X		X
Valvata sincera			X
Valvata tricarinata		X	X
Viviparus georgianus			X
Pelecypoda			
Anodonta imbecillis	X		
Anodonta grandis	X		
Elliptio complanata	X		
Musculium	X		
Pisidium	X	X	X
Sphaerium corneum	X		
Sphaerium partumeum	X		
Sphaerium rhomboideum		X	X
Sphaerium simile	X		
Sphaerium transversum	X		

Table 4.6. Total number and capture frequency of fish collected monthly by electroshocking (60-m section) and experimental gillnetting (53 m long) from April, 1981 to January, 1982 in the Buffalo River and Outer Harbor of Buffalo River (after Makarewicz et al. 1982).

		Electroshocking		Gillnetting	
Common name	Scientific name	Total number	Capture frequency	Total number	Capture frequency
Alewife	Alosa pseudoharengus	-	-	3	2
Black crappie	Pomoxis nigromaculatus	2	1	8	4
Bluegill	Lepomis macrochirus	2	1	-	-
Bluntnose minnow	Pimephales notatus	2	3	-	-
Bridle shiner	Notropis bifrenatus	1	1	-	-
Brown bullhead	Ictalurus nebulosus	15	7	92	25
Brown trout	Salmo trutta	-	-	1	1
Carp	Cyprinus carpio	46	34	276	53
Carp x goldfish hybrid		3	3	12	4
Chinook salmon	Oncorhynchus tshawytscha	-	-	1	1
Coho salmon	Oncorhynchus kisutch	-	-	1	1
Common shiner	Notropis cornutus	4	6	-	-
Emerald shiner	Notropis atherinoides	47	19	-	-
Freshwater drum	Aplodinotus grunniens	9	12	20	9
Gizzard shad	Dorosoma cepedianum	51	24	64	16
Golden shiner	Notemigonus crysoleucas	27	19	20	10
Goldfish	Carassius auratus	36	26	13	9
Greater redhorse	Moxostome valenciennesi	-	-	1	1
Lake trout	Salvelinus namaycush	1	1	-	-
Largemouth bass	Micropterus salmoides	11	15	4	3
Logperch	Percina nigromaculatus	2	1	-	-
Muskellunge	Esox masquinongy	-	-	33	14
Northern hognose sucker	Hypentelium nigricons	-	-	2	1
Northern pike	Esox lucius	1	1	17	4
Pumpkinseed	Lepomis gibbosus	172	46	15	9
Quillback carpsucker	Carpiodes cyprinus	-	-	2	1
Rainbow trout	Salmo gairdneri	3	4	7	5
Rock bass	Ambloplites cuperstris	34	18	108	32
Shorthead redhorse	Moxostoma macrolepidotum	3	4	25	13
Slimy sculpin	Cottus cognatus	2	1	-	-
Smallmouth bass	Micropterus dolomieui	23	16	28	13
Smelt	Osmerus mordax	-	-	2	1
Spottail shiner	Notropis hudsonius	83	19	-	-
Stonecat	Noturus flavus	-	-	20	9
Trout-perch	Percopsis omiscomaycus	1	1	-	-
Walleye	Stizostedion vitreum	1	1	22	11
Warmouth	Chaenobryttus gulosus	3	4	-	-
White bass	Morone chrysops	1	1	2	1
White perch	Morone americana	1	1	8	4
White sucker	Catostomus commersoni	22	15	300	55
Yellow perch	Perca flavescens	76	29	479	62

Table 4.7. Species composition and relative abundance of fish in the Times Beach Confined Disposal Facility in 1988 (after Smith et al. 1989).

Species	No. Captured	%
Pumpkinseed	806	43.3
Rock Bass	315	16.9
Golden shiner	239	12.8
Goldfish X Carp hybrid	167	9.0
Carp	122	6.5
Goldfish	79	4.2
Brown bullhead	45	2.4
Bluntnose minnow	30	1.6
Yellow perch	22	1.2
Emerald shiner	9	0.5
Bluegill	8	0.4
Largemouth bass	8	0.4
White sucker	6	0.3
Northern pike	3	0.2
Spottail shiner	1	+
Freshwater drum	1	+
White crappie	1	+
Iowa darter	1	+
Total Captured	1863	

+ = less than 0.1%

shiners are common in the spring, and gizzard shad in the late summer and fall. The shallow embayments in the harbor are dominated by pumpkinseed, yellow perch, northern pike, muskellunge, and carp. Larval yellow perch, emerald shiners, and smelt along with yearling rock bass were collected in the harbor. Rock bass and smallmouth bass were observed nesting in the breakwalls of the harbor.

Smith et al. (1989) collected 18 species of fish inside the Times Beach Confined Disposal Facility (CDF) in 1989 (Table 4.7). Mark and recapture estimates on seven species (brown bullhead, goldfish, gold carp, golden shiner, pumpkinseed, rock bass, and largemouth bass) indicated a population size of approximately 40,000 fish (5000/ha). Growth of fish inside the CDF was similar to adjacent or nearby waters. Eighty-nine percent of the brown bullhead had at least one external abnormality (lip, papilloma, skin discoloration, stubbed barbels, blindness, body lesions, and parasites).

4.4 Sources and Types of Pollution

Through the 1970s and early 1980s five major industrial facilities discharged to the Buffalo River (NYSDEC 1989). The facilities were: Allied Chemical Corporation-Industrial Chemicals Division; Allied Chemical Corporation-Specialty Chemicals Division; Donner-Hanna Coke; Mobil Oil Corporation, and Republic Steel Corporation. Three of these (Donner-Hanna Coke, Mobil Oil and Republic Steel) have terminated production and substantial changes have taken place at the remaining two facilities (NYSDEC 1989). In the late 1970s the Industrial Chemical Division of Allied Chemical Corporation produced sulfuric acid, sulfur trioxide, oleum, nitric acid, oxalic acid, ammonium thiosulfate, potassium nitrite and heavy metal nitrates. Process and cooling water was supplied by the Buffalo River Improvement Corporation (BRIC) at the rate of about 15 mgd. Some of the facilities were sold to PVS Chemical Corporation in October 1981, and Allied Chemical discontinued all chemical production in November 1982. At present PVS Chemical produces sulfuric acid, sulfur trioxide, and oleum and discharges 10 mgd of non-contact cooling water.

The Specialty Chemical Division of Allied Chemical made as many as 1800 dye related products in 1970. Process and cooling water was supplied by BRIC at the rate of about 22 mgd. In 1971 a pretreatment facility for process wastewater was completed and these flows were diverted from the Buffalo River to the Buffalo Sewer Authority system. In 1977, the dye plant was sold to Buffalo Color Corporation. The company currently produces only eight chemical products. Current discharges average about 11 mgd of non-contact cooling water.

Donner-Hanna Coke produced metallurgical coke through May of 1982 when the operation was closed. The firm discharged BRIC - supplied process water and cooling water to the Buffalo River at about 16 mgd. Phenol recovery equipment was used to treat the discharge through December 1975, after which sedimentation facilities were added.

The Mobil Oil facility was a 43,000 barrel per day refinery until May 1981 when it ceased operation. BRIC supplied 21 mgd of water, of which 1.6 mgd was used in the refinery process and the remainder was used as once-through non-contact cooling water. The process water discharge, which was originally treated in an oil-water separator, was redirected from the Buffalo River to the Buffalo Sewer Authority system in November 1979. The facility currently serves only as a storage terminal.

Republic Steel Corporation discharge consisted of BRIC supplied non-contact cooling water at about 35 mgd and process water at 13 mgd. In the 1980's, the firm finished a wastewater treatment facility to eliminate process water discharges into the river but ceased operation in mid 1981.

In addition to these facilities, there are eleven other smaller firms that discharge into the Buffalo River whose combined flow of either sanitary, process water, stormwater runoff or non-contact cooling water is less then 10 mgd. Prior to 1981 many of the industrial discharges were handled by the Buffalo Sewage Authority which discharged directly into the Buffalo River. With the completion of the Kelly Island sewer project, the Sewage Authority discharges now into the Niagara River. In addition, the Waste Water Treatment Plants (WWTP) serving the towns in the watershed were tied into the Buffalo River Authority in 1977. The only WWTP discharging into the Buffalo River is the Village of East Aurora, whose plant originally provided secondary treatment and has recently been upgraded to advanced treatment.

From 1985 to 1987, wastewater from 8 of the 20 municipal and industrial dischargers into the Buffalo River were found to contain more than 0.1 lb. day^{-1} of priority pollutants (NYSDEC 1989). The highest concentrations were found in the discharge of Buffalo Color and PVS Chemical with particularly high levels of chloroform, zinc, methylene chlorine, chromium, and phenols (>1.4 lbs. day^{-1}).

There are 23 sewer system overflows into the Buffalo River and 16 in lower Cazenovia Creek. Since the early 1980's, the Buffalo Sewer Authority has been undertaking a sewer remediation program to upgrade the structural features of the system, a sewer cleaning program and an overflow structure backflow prevention program to improve system carrying capacity (NYDEC 1989). Some representative compounds and concentrations (µg/L) that could overflow based on influent concentration entering the treatment facility are: phenol (93), aniline (160), 4,4'DDT (0.10), acetone (140), 1,4-dichlorobenzene (23), toluene (110), copper (132), lead (67), and cyanide (16).

There are 32 currently listed inactive hazardous waste disposal sites in the Buffalo River Watershed (NYSDEC 1989). They range in size from 1 to 100 acres with contents ranging from calcium carbonate to PCB contaminated oils, cyanide salts and tetraethyl lead. At some sites (4), contaminant migration to surface water has been confirmed.

The discharge of chemicals into the Buffalo River over the last 60 years has resulted in a buildup of contaminants in the bottom sediments. Even if sources of toxic discharge are curtailed and new sediment buries the contaminated sediments, a rare hydrological event could redistribute the contaminant sediments to the mud-water interface again. The Buffalo River contains excessive levels of at least 26 organic compounds and 11 heavy metals. Lateral and vertical distributions of the contaminated sediments is unknown.

The major types of pollutants in the Buffalo River are as follows: polychlorinated biphenyls (PCBs), chlordanes, polynuclear aromatic hydrocarbons (PAHs), DDT and metabolites, metals, and cyanides. There are no permitted discharges of PCBs but because of their low solubility in water they are unlikely to be detected. PCBs have been found in almost every sediment sample taken with median values as high as 0.87 µg/g and they have been detected at several inactive waste sites. PCBs have been detected in the tissue of carp, white sucker, pumpkinseed, brown bullhead, spottail shiners, yellow perch, and rock bass. High levels of PCBs in carp have led to a fish consumption advisory for this species.

Chlordane, a pesticide banned in New York State since 1985, has not been analyzed in the water column of the Buffalo River. It has been found in 16 of 16 sediment samples in 1981 but has not been detected at any hazardous waste sites. Chlordane has been detected in the tissue of brown bullhead and carp and unacceptable levels in carp have led to a State fish consumption advisory for this species.

DDT (and metabolities), a banned pesticide in New York State since 1971, has not been found in water samples from the Buffalo River, or at any inactive waste sites. It was detected in only one out of seven samples of influent entering the Buffalo Sewer Authority WWTP. Bottom sediments (18 out of 28 samples in 1981) appear to be the only source. DDT has been detected in carp, white sucker, and brown bullhead.

PAHs are common in Buffalo River sediments, at five inactive hazardous waste sites, and at the Times Beach CDF. This group of chemicals have also been measured in water samples from the Buffalo River and in the influent to the Buffalo Sewer Authority WWTP. PAHs have also been detected in the tissue of the following fish species: yellow perch, pumpkinseed, rock bass, and carp.

Levels of arsenic, barium, copper, iron, lead, manganese, zinc, and cyanides in the Buffalo River sediments exceed the criteria for open lake disposal. Sources of these contaminants in the Buffalo River include inactive hazardous waste disposal sites (21), industrial wastewater facility discharges (4), and sewer system overflows (39). Metals and cyanides have been found in the tissue of the following species: yellow perch, pumpkinseed, rock bass, and carp.

CHAPTER 5

DATA COMPILATION AND EVALUATION

5.1 Introduction

This section identifies the existing contaminant data available for each location and media (water, sediment, biota) where there exists the potential for aquatic life contact. The task is to evaluate the data's timeliness and quality and to organize it in a logical and consistent manner. Quality here refers to a review and evaluation of the QA/QC procedures used in the collection and analysis of the original sampling data. This evaluation provides necessary input for the eventual interpretation of risk results, particularly concerning the uncertainty and thus level of confidence the assessor has in the characterization of risk. This assessment will include an estimate of both typical and reasonable worse case risks. The estimate of typical risk represents that risk determined using a combination of average contaminant concentration data and aquatic exposure scenarios that reflect actual site-specific conditions or assumptions that reflect typical or expected conditions. Reasonable worse case estimates of risk are determined by combining a statistical measure (e.g., 90^{th} percentile or one standard deviation) of a contaminant concentration value with assumptions that reflect professional judgement regarding realistic upper bound contact rates, e.g., exposures.

The source and content of the data sets represents information taken from reports produced by the principle investigators cited and values from the STORET water quality data base maintained by USEPA. In the organizational effort it was concluded that insufficient data were available on concentrations of organic contaminants in water. Organic pollutants in the water column were predicted from sediment quality, and these predictions were based on well-established equilibrium partitioning relationships as discussed in Appendix A.

The environmental data were discussed by media or vehicle of exposure. The source, content, and quality of each data set used in the assessment is summarized. The QA/QC evaluation followed in this study is summarized with the data section. Following this summary is a description of how the data sets are utilized within this assessment to provide environmental contamination data for both a typical and reasonable worst-case exposure/risk.

5.2 Sources and Data Summary

Available data (compiled in Lee et al. 1991 and discussed individually) were surveyed in order to establish exposure concentrations for the Buffalo River AOC for each location and media (e.g., sediment, benthos, fish, water column) to assess aquatic environmental health. A summary of contaminants detected in organisms in the Buffalo River is presented in Table 5.1 The sources of data available and used for each of these media are discussed below.

5.2.1 Sediment Data

Data for sediment concentrations were available from a number of sources. Surveys were conducted during 1981 by the US Environmental Protection Agency/ Great Lakes National Program Office (USEPA/GLPNO) (Rockwell et al. 1983) and

Table 5.1. Metal and Organic Contaminant Exposure Summary

Contaminant	algae /1	clams \1	mussels \2	worms \3	fish \3,4
PCBs	X	X	X	X	X
p,p'-DDD		X			X
o,p'-DDE			X		
p,p'-DDE			X		X
o,p'-DDT		X			
p,p'-DDT		X			
DDT total		X	X		X
aldrin/dieldrin					X
heptachlor & epoxide		X			
α-BHC		X			
β-BHC		X			
γ-BHC					
lindane group		X			
α-chlordane		X			
γ-chlordane		X			
total chlordane		X			
hexachlorobenzene		X	X	X	X
phenanthrene				X	X
anthracene				X	X
fluoranthene				X	X
pyrene				X	
3,6-dimethylphenanthrene				X	X
triphenylene				X	X
benzo(b)fluorene				X	
benzo(a)anthracene				X	
chrysene				X	
benzo(e)pyrene				X	
benzo(j)fluoranthene					
perylene				X	X
benzo(b)fluoranthene				X	X
benzo(k)fluoranthene				X	X
benzo(a)pyrene				X	
dibenzo(a,j)anthracene				X	
dibenzo(a,i)pyrene				X	

Table 5.1 (Continued)

Contaminant	algae /1	clams \1	mussels \2	worms \3	fish \3,4
benzo(g,h,i)perylene				X	X
indeno(1,2,3-c,d)pyrene				X	
3-methylcholanthrene					
anthanthrene				X	
Aluminum	X				
Arsenic	X			X	X
Cadmium	X			X	X
Chromium	X				
Cobalt	X				
Copper	X			X	X
Lead	X				
Manganese	X				
Mercury	X			X	X
Nickel	X				
Selenium	X				
Zinc	X				

\1 Ontario Ministry of the Environment 1984
\2 E. = Elliptio; Marquenie et al. 1986
\3 Marquenie et al. 1987
\4 NYSDEC RAP 1989

the US Army Corps of Engineers - Buffalo District (USACOE) (Pethybridge 1981), during 1983 and 1985 by the New York State Department of Environmental Conservation (NYSDEC) (NYSDEC 1985 as cited in NYSDEC 1989) and during 1989 by Aqua Tech Environmental Consultants Inc (Aqua-Tech 1989).

Data used for the risk assessment were from the studies conducted in 1985 by NYSDEC (NYSDEC 1985 as cited in NYSDEC 1989) and during 1989 by Aqua Tech Environmental Consultants Inc (Aqua-Tech 1989).

Figure 4.2. shows sampling locations for the different studies. (Lee et al. 1991).

5.2.1.1 1985 NYSDEC Data Summary

[Erie County, 1985 (Table A6 in NYSDEC 1989)] Sediment sampling was performed in 1985 by the Buffalo River Sediment Study, as a joint project of Erie County, the NYSDEC, and the USEPA. The sediment analyses are summarized in the "Draft Report Buffalo River Sediment Study" (NYSDEC 1985, as cited in NYSDEC 1989). The 1985 sediment data used in this report are summarized further in Table 5.2.

The goal of the 1985 study was to develop and field test procedures to estimate the character of river sediments. A total of 162 samples and 58 sediment cores (using a 1.2-m Vibracore tube) were collected along a 0.46 km foot section pilot study area of the Buffalo River between Mile Point 4.43 and 4.73 (Figure 4.2). An average of three cores per week were collected between June and October, 1985. In addition, sixteen Dredge grab samples were collected in the Buffalo River upstream from the confluence with Cazanovia Creek. These served as control samples since they were collected upstream from industrial waste discharges. The sediments were analyzed for metals, PAHs, pesticides and PCBs. The samples collected in 1985 were judged to be from the most contaminated areas of the river, and therefore indicative of a higher range of contaminants than a random sampling in the river.

5.2.1.2 1989 Buffalo River Sediment Study

[Aqua-Tech 1989] Sediment sampling was performed in the Buffalo Harbor area by Aqua Tech Environmental Consultants Inc., under contract to U.S. Army Corps of Engineers - Buffalo District. The results of this sampling is reported in "Sediment Analyses - Buffalo River and Harbor, Buffalo, NY" (Aqua-Tech 1989). The 1989 sediment data used in this report are summarized in Tables 5.2 and 5.3 as the typical case.

Twenty-two sediment samples were obtained at a depth of 10-20 cm by using a Petite Ponar grab sampler. Sampling occurred at sites in the Buffalo River and Harbor and in the Black Rock Canal. Three samples were taken within 15.2 m of each site location. Each site was analyzed for metals, PAHs, PCBs and pesticides. These sampling sites were distributed along the river and indicate a more average state of the surficial sediments within the river.

5.2.2 Water Quality Data

The only source of water quality data used in this assessment came from a NYSDEC monitoring study of the Buffalo River between 1982 to 1986.

5.2.2.1 NYSDEC Surveys (as cited in NYSDEC 1989)

Water samples were collected between April 1982 and March 1986 from the Ohio Street Bridge sampling station at 1.1 miles from the harbor on the Buffalo River (Figure 4.2). The data were stored in the STORET water

quality database and were, in part, included in the "Draft Buffalo River Remedial Action Plan" (NYSDEC 1989). A listing of the STORET summary statistics describing the water quality results was presented in the Remedial Action Plan and represents the primary sources of surface water quality for metals used in the aquatic health risk assessment.

Analytical detection limits were relatively high, resulting in non-detectable concentrations for a number of water quality constituents. Therefore, it was determined to estimate data for organic contaminants with reported non-detectable concentrations using partitioning relationships as described in Section 5.4.2.

5.2.3 Benthic Invertebrate Data

Benthos concentration data were available from surveys (see Figure 5.1) conducted during 1983 by the USACOE/WES (worms, Marquenie et al. 1987; mussels, Marquenie et al. 1986 and 1990) and the Ontario Ministry of the Environment (clams and algae, OME 1984).

5.2.3.1 1983 Marquenie Study - Worms (Marquenie et al. 1987) [USACOE, Buffalo District, TB, 1989 (Tables 9, 14, 19)] The survey was conducted to determine, in part, an inventory of contaminants in invertebrates inhabiting the Times Beach CDF. Native worms were collected at the Times Beach CDF and the reference area situated along the east side of the Niagara River (Figure 5.1). Samples of native worms were collected in 1983 by and were identified according to species. Tissues were analyzed for heavy metals, PCBs and hexachlorobenzene (Tables 5.4 and 5.8) as well as PAHs (Table 5.5). These were terrestrial worms, but their contaminant data was used to augment the scant data available to demonstrate this model.

5.2.3.2 1983 Marquenie Study - Mussels [USACOE, Info/AOC (Lee et al. 1991) (Table 6, 54)] Mussels, Elliptio dilatata, were collected (Marquenie et al. 1986 and 1990) from a pristine lake and exposed in the Buffalo River, Lake Erie and a confined disposal site, Times Beach, Buffalo, New York (Figure 5.1). The mussels were purged for 1 week in a remote spot of a pristine lake, then 15 randomly selected individuals were glued to 50 cm long strings of fine nylon. The batches were taken to the various sites and sunk to the bottom and allowed to burrow in the sediment with a suitable anchor. After a period of 36 days the mussels were recollected. The tissues were analyzed for 11 specific PCB congeners, *o,p'*-DDE and *p,p'*-DDE and hexachlorobenzene (HCB) (Tables 5.4 and 5.8).

5.2.3.3 1984 Niagara River Toxics Committee - Clams and Algae [USACOE Info/AOC (Lee et al. 1991) (Tables 6, 50, 51, 52, 55, 56)] Data for clams and algae were taken from a 1984 Report of the Niagara River Toxics Committee, Subproject 28, prepared for the Ontario Ministry of the Environment (OME 1984). The concentrations and detection limits for a series of organochlorine contaminants found in clams (Elliptio companatus) exposed to Lake Erie and Niagara River waters in 1981 are shown in Tables 5.4. and 5.8. Five clams each were exposed *in situ* to the sediment for 21 days at 15 separate sites. The residues were presented for total PCBs, three benzene hydrochlorides, hexachlorobenzene, two chlordanes, dieldrin, four DDT congeners, endosulfan sulfate, heptachlor epoxide, mirex, and octachlorostyrene. A measure of percent fat (lipid) for the clams was provided for 11 of the 15 sites. No further details were provided or

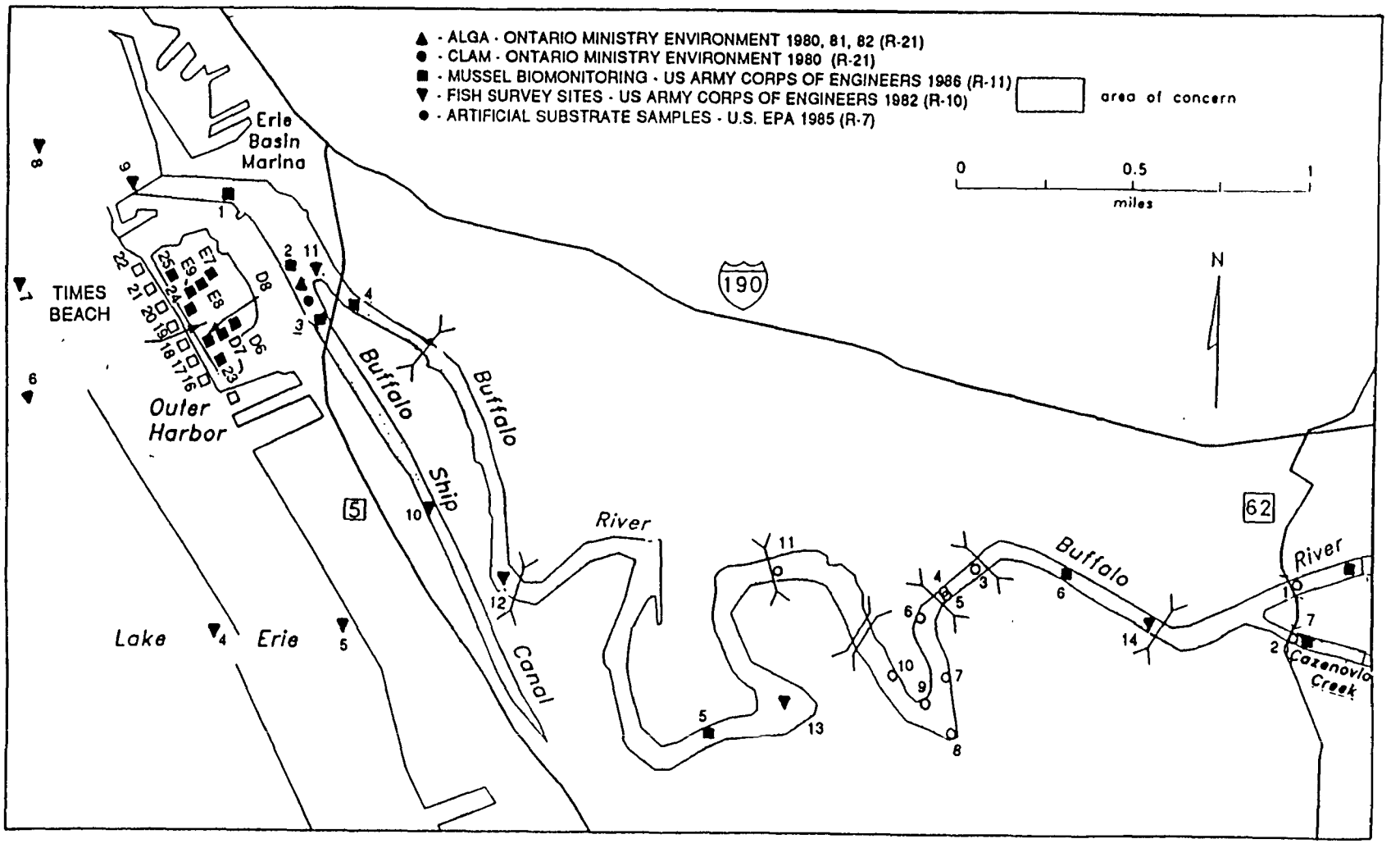

FIGURE 5.1. Location of sampling sites for fish, alga, clams, mussels biomonitoring and artificial substrates in the Buffalo River AOC. Worms collected at same sites as fish. From Lee et al. (1991) and Marquerie et al. (1987).

available. Also presented in Tables 5.4 and 5.8 (from the same 1984 report) are the concentrations (dry weight) of total PCBs, and 12 metals (arsenic, cadmium, lead, copper, mercury and zinc) found in a filamentous algae Cladophora glomerata at two sites in the Buffalo River. The data represent several different sampling periods over 2 years. No further details were available.

5.2.4 Fish Data

A comparative bioaccumulation assessment survey was performed in 1983 by the USACOE/WES for the USACOE, Buffalo District (Marquenie et al. 1987). NYSDEC had sampled spottail shiners in 1985 and 1987 and ongoing fish monitoring program (NYSDEC 1989) and sampled carp and brown bullheads in 1987 (Laniak et al. 1992, but no data were available).

The data sets used were Marquenie et. al 1987 and NYSDEC 1989.

5.2.4.1 1983 Marquenie study - fish (Marquenie, et al. 1987) [USACOE, Buffalo District, 1989 (Tables 11, 12, 16, 20-21)] The survey was conducted to determine, in part, an inventory of contaminants in fish inhabiting the waters in the Times Beach CDF. Fish species were collected in August 1983 from the open water of the Times Beach confined disposal site and from a reference area in the Buffalo River predominantly by seining and to a lesser extent by hook and line (Figure 5.1). Each species was pooled into one sample. Fillets of the lateral musculature were prepared. Liver tissues were prepared to evaluate the presence of contaminants on a physiological basis and to compare Times Beach with the reference site for contaminants that do not bioaccumulate in muscle tissue (e.g., cadmium). Individuals of the same species were pooled, packed in polyethylene bags, and stored at -20° C. Prior to dissection of livers and muscle tissue, all specimens were measured (total length) and weighed. Livers and muscle tissues were pooled by species and stored at -20° C in acid-washed containers. Tissues were analyzed for heavy metals, PCBs, hexachlorobenzene (Tables 5.6 and 5.9) as well as PAHs (Table 5.7).

5.2.4.2 Other Studies

(1) NYSDEC 1977-1984 Carp and others (Table 4.4, RAP; USACOE Info/AOC, Lee et al. 1991, Tables 6, 49)

(2) NYSDEC Spottail shiners (RAP, Table 4.9)

A fish monitoring program was administered by the New York State Department of Environmental Conservation through the Statewide Toxic Substances Monitoring Program, and published in the Toxic Substances in Fish and Wildlife technical report of 1987 (US Dept of Interior 1987; NYSDEC 1989). There are no reports for the dates of 1977-1984, for which the tissue samples are reported in Tables 5.6, 5.7, and 5.9. In 1985 and 1987, the NYSDEC collected young-of-year spottail shiners from the Buffalo River (NYSDEC 1989), and the tissue sample analyses are reported in Table 5.6, 5.7, and 5.9. No purpose of study, analytical methods, or QA/QC methods were reported with the data, although detection limits and action-level criteria were reported.

5.3 **QA/QC Results**

All of the data used in this risk assessment underwent a QA/QC review by Lockheed Engineering and Sciences Company (Lockheed-ESC) under a contract with the EPA Environmental Monitoring Systems Laboratory in Las Vegas, NV. A complete evaluation of the data could not be made because of difficulty with

obtaining the QA/QC data for most data sets. However, it appears that the data were generated following either established or contract laboratory protocols. These protocols generally comparable to if not more extensive in their incorporation of QA/QC samples than specified in the ARCS QA/QC program. Therefore, it was the opinion of Brian Schumacher, the ARCS QA/QC reviewer (formerly of Lockheed-ESC), that most data sets are acceptable for use in this risk assessment (Brian Schumacher (EPA Environmental Monitoring Systems Laboratory-Las Vegas), personal communication, 1991). With this caveat, the data were used in the present risk assessment principally to demonstrate the aquatic risk assessment model, in as much as no more current or acceptable data were made available.

5.4 Data Defining Typical Conditions

The key considerations when considering the organization of available environmental quality data into a form suitable for estimating aquatic exposure and risk are 1) the contaminants of concern and 2) spatial and temporal changes in contaminant concentration. The selection of chemicals for consideration might reasonably be determined by comparing the measured levels with recommended aquatic health-based levels. Those contaminants that are found to exceed the threshold levels are included in the exposure and risk assessment. However, there are no widely accepted aquatic-health-based standards for any contaminated environmental media. In the present assessment, all toxic compounds detected will be included in the exposure assessment. These baseline assessments are intended to help develop guidelines to aid in the selection of chemicals for future exposure and risk assessments. The data organization should also reflect any variation in aquatic contaminant concentrations with location ("hot spots") or time. Aquatic organisms are in constant contact with their environmental media (water, and/or sediment) and so the data were organized to reflect variability of measured data only.

For the Buffalo River sediment data sets available, it was determined that spatial variability within the data sets was not significant (no particular "hot spots' of high contamination were noted within each data set). Most recent information available indicates differences between stations evaluated for toxicity in the Buffalo River (Nelson et al. 1992). There was a significant difference in contaminant concentrations noted between the 1985 (NYSDEC 1985, as cited in NYSDEC 1989) and 1989 (Aqua-Tech 1989) sediment surveys. The 1985 sediment data generally contain higher contaminant residues than does the 1989 data set. Since the surveys were done at different sites in the Buffalo River, this difference is assumed to be location-specific (i.e., location of a contamination "hot spot") and not the result of the system cleansing itself over the intervening four years. Spatial variability will be considered here by using the 1989 sediment to represent typical exposure conditions, and the 1985 sediment data will represent a reasonable worst case situation. The data do not suggest that contaminant concentrations vary with time, and will not be a factor in the exposure assessment. Sections 5.4 and 5.5 describe the manner in which specific data were configured to develop the appropriate typical and worst case data sets, respectively. Also included are the actual data used for these conditions. These data will be reviewed later in view of other critical criteria. These data were used to demonstrate the model since more applicable data were not available at the time this report was prepared.

5.4.1 Sediment

(Aqua Tech 1989). The decision to use the means of all samples to compute exposure was based primarily on one consideration. There is generally relatively little variation in contaminant concentration that is location-specific (no "hot spots"), and so there is no justification by which to differentiate on the basis of location. In fact, the sampling was not performed in sufficient detail to detect hot spots. The mean of each set of measurements was computed and taken to be representative of the typical conditions in the superficial sediments of the Buffalo River. The means of the sample data were provided in Tables 5.2 and 5.3.

The organic compounds that were not detected in either the 1985 or 1989 exposure sediment data were not necessarily eliminated from consideration for the exposure assessment, exposure pathways, and toxicological (aquatic health risk) analysis. Organic contaminants that were present at detectable concentrations in the 1985 data, but were not observed at the detection limits of the 1989 sediment data, were considered not present for the typical case.

The metals data for 1989 constitute a complete set that can be used with the inclusion of all metals for concentrations above the detection limit. The typical conditions were represented by the arithmetic mean of the 1989 data (Table 5.2).

5.4.2 Water Column

"Total" metals data from the STORET data base and the Remedial Action Plan (NYSDEC 1989) are used directly as representative of the combined suspended particles and aqueous concentrations of metals. Because of the availability of means and standard deviations, the typical case has been represented as the mean metal concentration.

Water column concentrations reported in the STORET data base indicate that organics, if present, are at levels below detection limits. It is unreasonable to assume these organics are not present in the water column since they are detected in the sediments. A standard assumption in many risk assessments is to assume a concentration equal to half the detection limit, but is only valid if the compound is detected at some of the sites. However, in this assessment, an estimate of water column concentrations was determined based on chemical equilibrium. The assumption that water column concentrations are in equilibrium with sediment concentrations provides a conservative estimate and avoids the arbitrary nature of other methods of approximation. The details of the equilibrium-based approximation were described in Appendix A.

The mean contaminant concentrations in 1989 sediments are listed in Table 5.2, and the resulting water column concentrations used for analysis of typical aquatic health risks are also listed in Table 5.2 (Crane 1993).

Tables 5.2 and 5.3 list the typical water column concentrations derived using the above methodologies also detailed in the generic document. Those chemicals listed as non-detected in the water column were not detected in the sediments.

Table 5.2. Concentrations of contaminants in sediment and water (nonfood residue) for typical and worst cases.

	VEHICLE			
	Sediment		Water	
	CASE		CASE	
	Typical	Worst	Typical	Worst
CHEMICAL	CONC	CONC	CONC	CONC
Cadmium	8.00E-01	4.30E+00	2.00E-03	4.00E-03
Chromium	1.20E+01	9.97E+01	2.00E-02	2.00E-02
Copper	4.40E+01	1.57E+02	9.00E-03	1.30E-02
Iron	2.88E+04	5.55E+04	1.90E+00	3.76E+00
Lead	6.30E+00	2.94E+02	1.60E-02	2.90E-02
Manganese	5.00E+02	7.33E+02	1.89E-01	4.22E-01
Mercury	3.30E-01	1.71E+00	1.70E-04	2.60E-04
Nickel	3.00E+01	4.82E+01	5.00E-03	8.00E-03
Silver		8.50E-01	2.00E-05	2.00E-05
Zinc	2.49E+02	1.20E+03	2.90E-02	4.40E-02
Acenaphthene		1.00E+00		4.90E-03
Acenaphthylene		1.00E+00		9.77E-03
Anthracene	1.80E-01	1.50E+00	3.15E-04	2.63E-03
Benzo(a)anthracene	6.10E-01	4.80E+00	8.58E-05	6.75E-04
Benzo(a)pyrene	9.50E-01	4.00E+00	5.75E-05	2.42E-04
Benzo(a)fluoranthene	1.65E+00	2.90E+00	9.98E-05	1.75E-04
Benzo(ghi)perylene	4.50E-01	5.50E+00	1.49E-05	1.82E-04
Benzo(k)fluoranthene		2.20E+00		1.33E-04
Chrysene	6.90E-01	1.50E+00	9.52E-05	2.07E-04
Dibenzo(a,h)anthracene		6.20E+00		1.60E-04
Fluoranthene	1.57E+00	3.70E+00	9.94E-04	2.34E-03
Fluorene	3.30E-01	1.00E+00	1.03E-03	3.11E-03
Indeno(1,2,3-cd)pyrene	4.50E-01	5.70E+00	1.51E-05	1.91E-04
Naphthalene	3.10E-01	9.00E-01	7.77E-03	2.26E-02
Phenanthrene	7.70E-01	3.10E+00	1.32E-03	5.31E-03
Pyrene	9.30E-01	3.60E+00	6.15E-04	2.38E-03
alpha-BHC		4.60E-02		2.84E-04
beta-BHC		2.90E-02		1.79E-04
Lindane (gamma-BHC)				
Aldrin				
Chlordane				
Dieldrin				
Endrin		1.00E-02		2.42E-06
Heptachlor				
Heptachlor epoxide	4.00E-02	7.20E-02	3.90E-03	7.02E-03
Hexachlorobenzene				
Mirex				
p,p'DDD		5.00E-03		2.45E-07
p,p'DDE		1.90E-02		4.35E-07
p,p'DDT		1.30E-02		6.44E-07
PCBs (total)		3.80E+00		2.37E-04

Blank = not detected in sediment, Data from Laniak et al. 1992.
Metal concentrations in water from STORET data base.
Typical water concentrations are mean values.
Worst case water concentrations represent mean plus one standard deviation.
Concentrations = mg/kg for sediment and mg/L for water.

Table 5.3. Estimated partition coefficients and computed water concentrations[1].

Chemical	Log Kow[2]	Kow	Calc. Koc	Kp (1/Kg)	Mean 1989 Conc. in Sediments (mg/Kg)	"Typical" Calc. Conc. in Water (mg/L)	90 %tile 1985 Conc. in Sediments (mg/Kg)	Reasonable Worst Case Calc. Conc. in Water (mg/L)
Acenaphthene	4	1.00E+04	6.30E+03	7.90E+00	N/D		1.00E+00	4.90E-03
Acenaphthylene	3.7	5.01E+03	3.16E+03	4.00E+00	N/D		1.00E+00	9.77E-03
Anthracene	4.5	2.82E+04	1.78E+04	2.24E+01	0.18	3.15E-04	1.50E+00	2.63E-03
Benzo(a)anthracene	5.6	3.98E+05	2.51E+05	3.15E+02	0.61	8.58E-05	4.80E+00	6.75E-04
Benzo(a)pyrene	6.1	1.15E+06	7.23E+05	9.11E+02	0.95	5.75E-05	4.00E+00	2.42E-04
Benzo(b)fluoranthene	6.1	1.15E+06	7.23E+05	9.11E+02	1.65	9.98E-05	2.90E+00	1.75E-04
Benzo(ghi)perylene	6.5	3.24E+06	2.04E+06	2.57E+03	0.45	1.49E-05	5.50E+00	1.82E-04
Benzo(k)fluoranthene	6.1	1.15E+06	7.23E+05	9.11E+02	N/D		2.20E+00	1.33E-04
Chrysene	5.6	4.07E+05	2.57E+05	3.23E+02	0.59	9.52E-05	1.50E+00	2.07E-04
Dibenzo(a,h)anthracene	6.8	6.31E+06	3.98E+06	5.01E+03	N/D		6.20E+00	1.60E-04
Fluoranthene	4.9	7.94E+04	5.00E+04	6.31E+01	1.57	9.94E-04	3.70E+00	2.34E-03
Fluorene	4.2	1.58E+04	9.98E+03	1.26E+01	0.33	1.03E-03	1.00E+00	3.11E-03
Indeno(1,2,3-cd)pyrene	6.5	3.16E+06	1.99E+06	2.51E+03	0.45	1.51E-05	5.70E+00	1.91E-04
Napthalene	3.3	1.95E+03	1.23E+03	1.50E+00	0.31	7.77E-03	9.00E-01	2.26E-02
Phenanthrene	4.5	2.88E+04	1.82E+04	2.29E+01	0.77	1.32E-03	3.10E+00	5.31E-03
Pyrene	4.9	7.59E+04	4.78E+04	6.02E+01	0.93	6.15E-04	3.60E+00	2.32E-03
alpha-BHC	3.9	7.94E+03	5.00E+03	6.30E+00	N/D		4.60E-02	2.84E-04
beta-BHC	3.9	7.94E+03	5.00E+03	6.30E+00	N/D		2.90E-02	1.79E-04
Lindane	3.9	7.94E+03	5.00E+03	6.30E+00	N/D		N/D	
Aldrin	5.3	2.00E+03	1.26E+05	1.58E+02	N/D		N/D	
Chlordane	3.3	2.00E+03	1.26E+03	1.60E+00	N/D		N/D	
Dieldrin	3.5	3.16E+03	1.99E+03	2.50E+00	N/D		N/D	
Endrin	5.3	2.18E+05	1.37E+05	1.73E+02	N/D		1.00E-02	2.42E-06
Heptachlor	4.4	2.51E+04	1.58E+04	1.99E+01	N/D		N/D	
Heptachlor epoxide	2.7	5.01E+02	3.16E+02	4.00E-01	0.04	3.90E-03	7.20E-02	7.02E-03
Hexachlorobenzene	5.2	1.58E+05	9.98E+04	1.26E+02	N/D		N/D	
Mirex	7.4	2.51E+07	1.58E+07	1.99E+04	N/D		N/D	
p,p'-DDD	6.2	1.58E+06	9.98E+05	1.26E+03	N/D		5.00E-03	2.45E-07
p,p'-DDE	7	1.00E+07	6.30E+06	7.94E+03	N/D		1.90E-02	4.35E-07
p,p'-DDT	6.2	1.55E+06	9.76E+05	1.23E+03	N/D		1.30E-02	6.44E-07
PCBs	6.0	1.10E+06	6.91E+05	8.70E+02	N/D		3.8	2.37E-04

[1][Table 5.5 in Laniak 1992] Computations done using the equations. [2]Log K_{ow} from Mabey 1982. Cw (typical or reasonable worst case = $(C_s/K_d) + C_s * TSS$ where $K_d = f_{oc} * 0.63\ K_{ow} * 1L/kg$ (or $K_{oc} * f_{oc}$); C_w = total contaminant concentration in water; C_s = contaminant concentrations in sediment; TSS = total suspended sediment; K_d = "partition" coefficient between sediment and water; K_{ow} = octanol water partition coefficient; f_{oc} = % organic carbon content of sediment (here 3.25%); K_{oc} = sediment water partition coefficient (see Appendix A).

5.4.3 Benthos

Only limited data existed regarding contamination levels in Buffalo River benthos. The Ontario Ministry of the Environment studied the contamination to clams and algae collected in 1980-81. A summary of the data is reported in Lee et al. 1991. Marquenie et al. (1986, 1987, 1990) sampled the biota of the Times Beach confined disposal facility and the Buffalo River within the Area of Concern in 1983. For use in assessment, average contaminant levels for the various benthic organisms in the Buffalo River were used to quantify exposure and risk under typical exposure conditions. These values are given in Tables 5.4 and 5.5. Worms were used even though they were terrestrial to have an example in the model of a key food chain organism.

5.4.4 Fish

Only limited data existed regarding contamination levels in Buffalo River fish. The NYSDEC gathered and organized fish data collected between 1977 and 1984, and collected spottail shiners in 1985 and 1987. A summary of the data is reported in the Buffalo River RAP (NYSDEC 1989). Marquenie et al.1987 studied the population of the Times Beach CDF in 1983. For use in this assessment, average contaminant levels for the various fish were used to estimate exposure and risk in a CDF, not in the Buffalo River. These values are summarized in Tables 5.6 and 5.7.

5.5 **Data Defining Reasonable Worst Case Conditions**

Data for reasonable worst-case conditions were computed for each of four uptake media: sediment, water column, benthos, and fish. Contact by the organisms along the food chain with these media results in exposure and risk in the Buffalo River Area Of Concern. The data that were used to represent reasonable worst-case conditions for analysis are described below.

5.5.1 Sediment

Reasonable worst-case conditions were estimated using the sediment data from 1985 (NYSDEC 1985, as cited in NYSDEC 1989). In Tables 5.2 and 5.3, the 90^{th} percentile values of the available sample data distribution are shown for the 1985 data. The 90^{th} percentile of the sample data distribution for each set of 1985 measurements is considered to be representative of the Buffalo River, based on assumptions described earlier (Section 5.1). These data did not have an acceptable QA/QC, so the uncertainty associated with these data and any interpretation (or calculation) are high.

5.5.2 Water

Similarly to the typical case for organics in surface water, the worst-case for organic pollutants in the water column (Table 5.2) is based on equilibrium partitioning (see 5.4.2 and Appendix A).

The organic contaminant sediment concentrations associated with the worst case scenario (Table 5.3) were used to determine the water column concentrations. The resulting reasonable worst case water column concentrations are listed in Tables 5.2 and 5.3.

Table 5.4. Benthos Metal and Organochlorine Contaminant Residue Data for Typical Exposure Conditions

Contaminant	Algae[1] (C. glomerata) ug/g dry wt	Clams[1] (E. complanatus) ng/g wet wt	Mussels[2] (E. dilatata) ug/kg wet wt	Worms[3] (L. rubellus) ug/kg dry wt
PCBs, total	0.093	trace	25.16	each <40
p,p'-DDD		nd		
o,p'-DDE			0.57	
p,p'-DDE		2	1.50	
o,p'-DDT		nd		
p,p'-DDT		nd		
DDT total		2		
aldrin/dieldrin		nd		
heptachlor & epoxide		nd		
alpha-BHC		3		
beta-BHC		nd		
gamma-BHC		3		
lindane group		6		
alpha-chlordane		2		
gamma-chlordane		2		
total chlordane		4		
hexachlorobenzene		nd	0.59	13.
Aluminum	1740.			
Arsenic	9.2			10.3
Cadmium	0.6			20.0
Chromium	7.4			
Cobalt	2.5			
Copper	11.0			25.2
Lead	24.0			
Manganese	510.			
Mercury	0.06			0.51
Nickel	6.4			
Selenium	nd			
Zinc	83.			
% fat/lipid		1.0		

[1] C. = Cladophora, E. = Elliptio; Ontario Ministry of the Environment 1984
[2] E. = Elliptio; Marquenie et al. 1986. PCBs total of 11 congeners; all contaminant residues averaged over 11 sites
[3] L. = Lumbricus; Marquenie et al. 1987. PCBs total of 9 congeners and is average of two measurements; wet weight approximately 5x dry weight

Table 5.5. Benthos Polynuclear Aromatic Hydrocarbon (PAH) Residue Data for Typical and Reasonable Worst-Case Exposure Conditions

Contaminant	Typical Values worms[1] (L. rubellus) ug/kg dry wt	Worst Case worms[1] (L. rubellus) ug/kg dry wt
phenanthrene	0.14	0.28
anthracene	0.0069	0.095
fluoranthene	0.069	0.43
pyrene	(0.002)	0.27
3,6-dimethyl-phenanthrene	(0.0055)	0.014
triphenylene	(0.02)	0.75
benzo(b)pyrene	(0.01)	0.084
benzo(a)anthracene	0.017	0.375
chrysene	0.030	0.36
benzo(e)pyrene	(0.0035)	0.28
benzo(j)fluoranthene	(0.15)	(0.15)
perylene	0.0038	0.16
benzo(b)fluoranthene	0.029	0.36
benzo(k)fluoranthene	0.013	0.21
benzo(a)pyrene	0.014	0.45
dibenzo(a,j)-anthracene	(0.015)	0.123
dibenzo(a,i)pyrene	(0.015)	0.14
benzo(g,h,i)perylene	0.012	0.70
indeno(1,2,3-c,d)-pyrene	(0.015)	0.39
3-methylcholanthrene	(0.004)	(0.004)
anthanthrene	(0.003)	0.113

[1] L. = Lumbricus; Marquenie et al. 1987
Values in parentheses are approximate detection limits
wet wt. approx. 5x dry weight

Table 5.6. Fish Contaminant Residue Data (ug/g wet wt) for Typical Exposure Conditions. Detection limits in parentheses.

Contaminant	Carp[1]	White Sucker[1]	Pumpkinseed[1]	Brown Bullhead[1]	Yellow Perch[2]	Spottail Shiner[3]
PCBs, total	5.10	0.71	0.40 <0.048 \2	0.87	0.063	0.144
p,p'-DDD						0.008
p,p'-DDE						0.011
p,p'-DDT						(0.005)
DDT total	0.62	0.34	0.04	0.30		0.019
aldrin/dieldrin	0.03	0.01	(0.01)	0.01		(0.002)
endrin	(0.01)	(0.01)	(0.01)	(0.01)		
heptachlor & epoxide	0.01	(0.01)	(0.01)	(0.01)		
lindane group	0.02	(0.01)	(0.01)	(0.01)		(0.001)
mirex	0.01	(0.01)	(0.01)	(0.01)		(0.005)
total chlordane	0.19		0.01	0.10		(0.005)
hexachlorobenzene	0.04		(0.01) 0.0012 \2	(0.01)	0.00087	(0.005)
Arsenic			0.0965 \2		0.0319	
Cadmium			<0.005 \2		<0.004	
Copper			0.360 \2		0.380	
Mercury	0.13	0.29	0.16 0.132 \2		0.0847	
% fat/lipid	12.77	1.22	1.28	4.73		

[1] NYSDEC 1989 RAP; averaged values used where appropriate.
[2] Marquenie et al.; Buffalo River/muscle values.
PCB values are the totals of 9 congeners.
[3] NYSDEC 1989 RAP; 1987 values

Table 5.7. Fish Polynuclear Aromatic Hydrocarbon (PAH) Residue Data for Typical and Reasonable Worst-Case Exposure Conditions (ug/kg)[1]

Contaminant	Typical Conditions		Worst-Case Conditions			
	Yellow Perch	Pumpkinseed	Yellow Perch	Pumpkinseed	Rock Bass	Carp
phenanthrene	0.007	0.006	0.014	0.02	0.024	0.078
anthracene	0.0005	0.0040	0.005	0.008	0.004	0.019
fluoranthene	0.013	0.0002	0.005	0.012	0.006	0.019
pyrene	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
3,6-dimethyl-phenanthrene	(0.003)	(0.003)	0.001	(0.003)	(0.003)	(0.003)
triphenylene	(0.01)	(0.01)	0.011	0.030	(0.01)	(0.01)
benzo(b)fluorene	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
benzo(a)anthracene	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
chrysene	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
benzo(e)pyrene	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
benzo(j)fluoranthene	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
perylene	(0.0015)	(0.0015)	(0.0015)	(0.0015)	(0.0015)	0.002
benzo(b)fluoranthene	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	0.007
benzo(k)fluoranthene	0.0006	0.0006	0.0008	0.0005	0.0011	
benzo(a)pyrene	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0025)
dibenzo(a,j)-anthracene	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
dibenzo(a,i)pyrene	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
benzo(g,h,i)perylene	0.028	0.027	0.030	0.024		
indeno(1,2,3-c,d)-pyrene	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
3-methylcholanthrene	(0.0035)	(0.0035)	(0.0035)	(0.0035)	(0.0035)	(0.0035)
anthanthrene	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)

[1] Marquenie et al. 1987; muscle values; Values in parentheses are approximate detection limits

The worst-case for metals has been represented as the mean metal concentration reported in STORET plus one standard derivation. This is assumed to approximate a reasonable upper bound. (See Section 5.1)

5.5.3 Benthos

Because of the limited data available to represent benthos contamination, an attempt to describe the reasonable worst-case concentration levels was made. The resulting reasonable worst-case benthos contaminant concentrations are listed in Tables 5.5 (PAH) and 5.8 (all others).

5.5.4 Fish

Because of the limited data available to represent fish contamination, an attempt to describe the reasonable worst-case concentration levels was made. The worst case was taken to be the highest concentration data set. The resulting reasonable worst-case fish contaminant concentrations are listed in Tables 5.7 (PAH) and 5.9 (all others).

Table 5.8. Benthos Contaminant Residue Data for Reasonable Worst Case Exposure Conditions

Contaminant	Algae[1] (C. glomerata) ug/g dry wt	Clams[1] (E. complanatus) ng/g wet wt	Mussels[2] (E. dilatata) ug/kg wet wt	Worms[3] (L. rubellus) ug/kg dry wt
PCBs, total	220	1264	126.8	2746.5
p,p'-DDD		7		
o,p'-DDE			4.1	
p,p'-DDE		n/d	6.9	
o,p'-DDT		5		
p,p'-DDT		trace		
DDT total		12	11.0	
aldrin/dieldrin		n/d		
heptachlor & epoxide		3		
alpha-BHC		5		
beta-BHC		3		
gamma-BHC		n/d		
lindane group		8		
alpha-chlordane		13		
gamma-chlordane		13		
total chlordane		26		
hexachlorobenzene		2	2.27	315.0
Aluminum	2973.			
Arsenic	11.3			41.85
Cadmium	0.5			98.7
Chromium	13.7			
Cobalt	5.6			
Copper	21.7			59.0
Lead	60.0			
Manganese	1620.			
Mercury	0.13			1.64
Nickel	12.7			
Selenium	0.9			
Zinc	99.			
% fat/lipid		1.0		

[1] C. = Cladophora, E. = Elliptio; Ontario Ministry of the Environment 1984
[2] E. = Elliptio; Marquenie et al. 1986
[3] L. = Lumbricus; Marquenie et al. 1987. PCBs total of 9 congeners and is average of two measurements; wet weight approximately 5x dry weight.

Table 5.9. Fish Contaminant Residue Data (ug/g wet wt) for Reasonable Worst-Case Exposure Conditions.

Contaminant	Carp[1]	Rock Bass[1]	Pumpkinseed[1]	Yellow Perch[1]	Spottail Shiner[2]
PCBs, total	1.100	0.430	0.280	0.175	0.80
p,p'-DDD					0.034
p,p'-DDE					0.041
p,p'-DDT					(0.005)
DDT total					0.078
aldrin/dieldrin					0.005
endrin					
heptachlor & epoxide					
lindane group					(0.001)
mirex					(0.005)
total chlordane					(0.002)
hexachlorobenzene	0.038	0.007	0.0085	0.0075	
Arsenic	0.161	0.108	0.107	0.042	
Cadmium	<0.0055	<0.0070	<0.0035	<0.0025	
Copper	0.550	0.220	0.610	0.480	
Mercury	0.154	0.563	0.1325	0.229	

[1] Marquenie et al; Times Beach/muscle values.
PCB values are the totals of 9 congeners.
[2] NYSDEC 1989 RAP; 1985 values

CHAPTER 6

HAZARD IDENTIFICATION

Hazard identification is a qualitative assessment of chemical and biological information bearing on whether or not a chemical poses a hazard to individuals, populations, and communities within an ecosystem. The first step in the identification is to develop toxicity profiles of major contaminant groups in the Buffalo River. The following contaminant groups were considered based on their presence in either sediment or fish tissue: PCBs, chlorinated hydrocarbon insecticides, metals, and PAHs. The toxicity profiles will summarize physical and chemical properties of the group, metabolic and pharmacokinetic properties, and relevant structure activity correlations that support or argue against predicting its hazardous effect. The next step in the hazard identification is to discuss the type of response to a contaminant an aquatic receptor might exhibit, how we measure the response, and the type of endpoints we use.

6.1 Toxicity Profiles for Chemicals

Physical and chemical characteristics of contaminants that would make them suspect as a toxic substance include (1) persistence in the environment, (2) environmental mobility, (3) failure to form inert compounds, (4) toxicity, and (5) ability to sequester in lipids. Properties that can be used to predict these characteristics include: aqueous solubilities, partition coefficients, disassociation constants, formation of chemical complexes, degradation, hydrolysis or photolysis, volatilization, Henry's Law Constants, leaching and dissipation characteristics, and chemical structures.

The uptake of a chemical and its distribution within the animal's body, including accumulation, remobilization, and excretion, are strongly dependent on the above factors. Since chemical alterations may occur by metabolism, not only the effect of the parent compound, but also that of the metabolites, which often have different physical-chemical properties, must be considered. The basic mechanism by which a toxic agent exerts its injurious effect is fundamental for an understanding of biological responses of flora and fauna. A toxicity profile provides information on both the contaminant behavior in the environment and in the receptor. For further discussion of the above, see Butler (1978) and Passino-Reader et al. (1992). The toxicity profiles are provided in the generic document (Passino-Reader et al. 1992).

6.2 Receptor Responses to Hazards

Because of the complexity of natural systems, it is difficult to assess the hazards to all receptors and document all responses. Typically particular types of receptors and responses are selected to be "indicators" of potential harm to all components of the aquatic ecosystem under study. For example, benthic diversity at the community level has frequently been used to assess environmental quality. This approach avoids many of the sources of error associated with extrapolation from the laboratory into the field; however, it is not always possible to identify the cause of the observed degradation of the biological community. Selection of receptors usually is driven by practicality, as the receptors and responses selected tend to be those for which the most toxicity data were available, which is usually those species that can be tested reliably in the laboratory. See generic document (Passino-

Reader et al. 1992) for discussion of receptor responses and utility of field/laboratory studies for hazard evaluation.

6.2.1 Description of Major Receptors

Receptors can be categorized into various levels ranging from individual cells to ecosystems. We propose to focus at the community level (fish, zooplankton, aufwuchs, benthos, aquatic plants). At this level one can still involve processes at the cellular level and yet hypothesize impacts at the ecosystem level. Since a major exposure route in aquatic systems is through the food chain, the aquatic receptors in the Buffalo River and Harbor can be divided into 5 categories based on functional feeding groups of the major fish species (Table 6.1). The fish groups include a planktivore (gizzard shad), 4 omnivores (pumpkinseed, carp, white sucker, brown bullhead) and 1 piscivore (smallmouth bass). The aufwuchs group can be split into animal and plant species and the benthos into a surface and subsurface species. Aufwuchs are associated with hard substrate whereas surface benthos are associated with soft substrate. Cyclopoids and cladocerans make up the zooplankton group and submersed macrophytes the aquatic plant group.

Table 6.1. Major fish species and their presumed food habits in the Buffalo River, New York.

Fish Species	Food Habits Category				
	Plankton	Aufwuchs	Surface Benthos	Subsurface Benthos	Fish
Gizzard Shad	x				
Pumpkinseed	x		x		x
Carp		x	x	x	
White Sucker			x		
Brown Bullhead		x	x	x	x
Muskellunge					x
	Daphnia	Cladophora	Pisidium		Shad
	Cyclops	Dictotendipes	Gammarus	Limnodrilus	Pumpkinseed
	Bosmina	Asellas	Procladius	Chironomus	Shiners
	Diaphanosoma	Nias			
		Physa			

CHAPTER 7

EXPOSURE ASSESSMENT

Exposure can be defined as the contact of an organism with a chemical or physical agent. In an aquatic environment, an array of organisms will be present representing different levels in the food web and inhabiting different media in the environment, and so each may have a different set of exposure routes for any contaminant. The aquatic exposure assessment step results in a cumulative estimate of exposure to a series of identified contaminants over the lifetime of an organism.

Inputs to the exposure assessment include the characterization of the exposure setting, data compilation and evaluation of contaminant residues, and identification of receptor organisms at the site.

7.1 Identification of Probable Exposure Pathways

A major step in the exposure assessment is the identification of potentially significant pathways for each type of organism present in the aquatic environment at the site. The contaminant load at the site is presumed to result principally from an equilibrium with the sediment, and an examination of the data in Chapter 5 would tend to support this. The total exposure each organism receives will be a sum of the exposure by all media, i.e., sediment, water, and food.

7.1.1 Description of Each Pathway

A listing of probable exposure pathways for representative organisms present at the Buffalo River AOC aquatic environment is given in Table 7.1. Only the pathways assumed to be 'active' are included.

7.1.1.1 Gill absorption from water

The most vulnerable point of fish and some aquatic invertebrates to poisoning is the gills, where respiration takes place. The gills provide a direct pathway from the aquatic environment to the organism's bloodstream, bypassing the skin and digestive tracts, each with their own physical barriers and chemical detoxification mechanisms. The contaminant equilibrium between sediment and water column will tend to dictate aqueous contaminant concentration at the gills, and this may be augmented on occasion by direct discharge to the water and by equilibrium between air and water. Most of the contaminants of concern in the water column will then partition out at the gills into the more lipophilic environment of the bloodstream and be transported to sites of action. Although the gills are a primary surface for partitioning in fish, the entire body surface is important in invertebrates.

7.1.1.2 Ingested food

The data tables in sections 5.4 and 5.5 contain the available contaminant residue data for important resident organisms, and Tables 6.1 and 7.2 list the dietary habits of the major fish species for the Buffalo River AOC. The phenomenon of biomagnification along the food chain results in a greater concentration of contaminants at each level. A knowledge of the biomass of an organism's consumption rate, assimilation efficiency, and the duration of a particular diet over an organism's lifetime minus depuration

Table 7.1. Primary contaminant exposure pathways.

Gizzard Shad 1. Gill absorption from H_2O 2. Ingested food 3. Ingested sediment	Brown Bullhead and Carp 1. Gill absorption from H_2O 2. Dermal absorption from sediment 3. Ingested food 4. Ingested sediments 5. Dermal absorption from H_2O
Pumpkinseed 1. Gill absorption from H_2O 2. Ingested food	Zooplankton 1. Gill absorption from H_2O 2. Ingested sediment 3. Ingested food
Aufwuchs 1. Ingested sediments 2. Dermal absorption from sediment 3. Ingested food 4. Dermal absorption from H_2O 5. Gill absorption from H_2O	Surface Benthos 1. Gill absorption from H_2O 2. Dermal absorption from H_2O 3. Dermal absorption from sediment 4. Ingested sediment 5. Ingested food
Subsurface Benthos 1. Dermal absorption from sediment 2. Ingested sediment 3. Ingested food	

Table 7.2 Food sources used in calculating contaminant residues in food for each receptor organism.

Receptor	Food category* or method of calculation
Pumpkinseed	Worms (W), Plankton (P), Gizzard shad (G)
Gizzard shad	Plankton (P)
Brown bullhead	Worms (W), Fish (F)
Carp	Worms (W)
Zooplankton	Plankton (P)
Aufwuchs	C_s * 10
Surface benthos	C_s * 10
Subsurface benthos	C_s * 10

* Food categories are defined in Table 7.5. C_s = contaminant concentration in sediment (Table 5.2).

rate can determine the resultant body burden for a contaminant of concern for a particular species.

7.1.1.3 Ingested sediment

While all organisms in an aquatic environment may ingest suspended sediment, the amount is generally considered insignificant. Benthic inhabitants (bottom feeders) especially subsurface benthos would be expected to ingest more sediment than pelagic (water column) organisms.

7.1.1.4 Dermal contact with sediment

The benthic organisms have prolonged contact with the sediments, and so this becomes an important potential pathway for contaminant uptake. Consideration of duration and area of contact with the sediment, contaminant sediment-water partition coefficients and a measure of contaminant partitioning through the skin can be used to calculate exposure-point concentrations and body burden for this route.

7.1.1.5 Dermal absorption from water

For invertebrates, absorption directly from the water becomes a significant pathway. Use of the contaminant concentrations in the water column due to equilibrium with sediment, air and/or direct discharge into the water column, together with a measure of partitioning into the organism and appropriate bioconcentration factors can be used to calculate exposure point concentrations that may serve as the body burden for the organism.

7.1.2 Evaluation of Exposure Pathways and Concentrations

As described in the Generic Document (Passino-Reader et al. 1992), we initially derived equations and calculated uptake of each chemical by each receptor organism. The equations derived were adapted from those for uptake of contaminants by humans (Crane 1993; USEPA 1989a). However, attempting this approach underscored the large data gaps that made it difficult to successfully apply human exposure models to aquatic biota at the Buffalo River. Estimating uptake of each chemical by each receptor from ingestion of food was the most difficult because of sparse data on residues of the 41 chemicals in all trophic levels. Also little information was available to quantitate the ingestion and depuration rates of specific foods by each receptor and assimilation efficiencies for each chemical and receptor.

Subsequently, information in Tables 6.1 (food habits of fish) and 7.1 (exposure pathways) was used to construct a matrix (Table 7.3) showing the vehicles, both media and food, by which the different receptor organisms at the Buffalo River were exposed. Table 7.3 was also used in calculations of risk.

The next step was to determine the concentration of each contaminant in each vehicle to which each receptor was exposed. As compiled in Chapter 5, concentrations in water and sediment for typical and worst cases were shown in Table 5.2. The concentrations of each contaminant in the four types of food are shown in Table 7.5, which was compiled in part from Tables 5.4 to 5.9.

In Table 7.5, phytoplankton (P) residues (C_e) equalled water concentrations (C_w) times 100 for metals or times 1,000 for organic chemicals, where 100 for metals and 1,000 for organics represent estimated bioconcentration factors. Gizzard shad (G) residues are intended to represent chemical concentrations in forage fish. Measured organochlorine concentrations for spottail shiners (Tables 5.6 and 5.9) were included in the food category G for total PCBs, *p,p'*DDD, and *p,p'*DDE. In an earlier approach (Passino-Reader et al. 1992) in

Table 7.3. Vehicles by which receptor organisms are exposed at the Buffalo River AOC. This matrix table was used in calculating risk.

Receptor	Vehicle			
	Water	Sediment	Food	
			Invertebrate	Fish
Pumpkinseed	X	0	X	X
Gizzard shad	X	X	X	0
Brown bullhead	X	X	X	X
Carp	X	X	X	0
Zooplankton	X	X	X	0
Aufwuchs	X	X	X	0
Surface benthos	X	X	X	0
Subsurface benthos	0	X	X	0

which total contaminant exposure concentrations were calculated for gizzard shad, these calculated concentrations were included in food category G for all chemicals except those for which spottail shiner data existed. However, in the present approach, which does not include calculating total exposure concentrations, we estimated residue concentrations for food category G by multiplying the water concentration (C_w) for each chemical (Table 5.2) times the BCF values for fish (BCF_f) for each chemical (Table 7.4).

Since food of the subsurface benthos, surface benthos, and aufwuchs is primarily in contact with sediments, their food was considered to have chemical residue concentrations equal to a factor times the concentrations of the chemicals in the sediment (Table 5.2). The factor was chosen to be 10 for all 41 chemicals. For example, the concentration of cadmium in food (C_e) of subsurface benthos, surface benthos, and aufwuchs equals C_s * 10 = 0.80 * 10 = 8.0 mg/kg for the typical case.

To present explicitly the concentrations in food used for each receptor organism, based on food habits (Table 6.1) and concentrations in the types of food (Table 7.5), we constructed Tables 7.6 to 7.13.

7.2 Determination of Exposure Point Concentrations

The concentration data used in the analysis of exposure, and their origins, were discussed in the generic document and preceding sections. To estimate the exposure for each of the pathways in Table 7.1, data are required for sediment, water, benthos, and fish concentrations. Data for exposure due to organism concentrations by consumption along the food chain are taken from direct measurements of organism body burdens when available.

7.3 Estimation of Chemical Uptakes/Exposure

7.3.1 Bioaccumulation/Bioconcentration Factors for Chemicals in AOC

Measured bioconcentration factors (BCF) for invertebrates and fish are assembled in Tables VII.D.1-1 and VII.D.1-2 in Passino-Reader et al. (1992), for organic and inorganic contaminants, respectively. For contaminants for which no BCF values are listed in these two tables, we calculated values for BCF, using the regression equations given in Lyman et al. (1990). The values of BCF used for calculating the contaminant concentrations in organisms are presented in Table 7.4 of this report, which includes all available measured values plus calculated values where necessary.

7.3.2 Presentation of Uptake/Exposure Extent

The calculated values for uptake/exposure for representative receptor species and all chemicals selected in the hazard identification across all "active" exposure pathways are presented in tabular form here.

The contaminant residue values in the four types of food are given in Table 7.5. Values for C_s and C_w are found in Chapter 5.

The contaminant concentrations in the food of each of the eight receptor organisms are presented in Tables 7.6 to 7.13.

Table 7.4. Bioconcentration (BCF) values used in exposure point concentration determinations.

	Invertebrates	Fish	Comments
Cadmium	3,500	60,000	
Chromium	200	5	
Copper	200	300	
Iron	100	100	Not available. Default value.
Lead	1,700	50	
Manganese	100	100	Not available. Default value.
Mercury	40,000	64,000	As methyl mercury
Nickel	100	100	
Silver	100	100	Not available. Default value.
Zinc	1,130	432	
Acenaphthene	135*	646*	
Acenaphthylene	77*	382*	
Anthracene	900	1,549*	
Benzo(a)anthracene	2,757*	10,617*	
Benzo(a)pyrene	3,000	25,468*	
Benzo(b)fluoranthene	7,078*	25,468*	
Benzo(ghi)perylene	15,049*	51,286*	
Benzo(k)fluoranthene	7,078*	25,468*	
Chrysene	2,757*	10,617*	
Dibenzo(ah)anthracene	26,497*	86,696*	
Fluoranthene	10,000	3,119*	
Fluorene	197*	916*	
Indeno(1,2,3-bc)pyrene	15,049*	51,286*	
Naphthalene	131	200	
Phenanthrene	325	1,549*	
Pyrene	2,700	3,119*	
α-BHC	100	700	
β-BHC	100	700	
γ-BHC (Lindane)	100	700	
Aldrin	4,500	6,281	
Chlordane	7,300	990	
Dieldrin	2,800	13,000	
Endrin	1,920	13,000	
Heptachlor	2,500	21,300	
Heptachlor epoxide	1,700	66*	
Hexachlorobenzene	1,030	3,740	
Mirex	18,000	40,800	
p,p'DDD	9,100	2,710	
p,p'DDE	36,000	12,000	
p,p'DDT	2,560	12,000	
PCB (Total)	5,862*	1,500	

* Calculated by following equations from Lyman et al. (1990): For fish, Log BCF = 0.76 Log K_{ow} - 0.23. For invertebrates, Log BCF = 0.819 Log K_{ow} - 1.146.

Table 7.5. Concentrations of contaminants in food organisms used in exposure assessment, in mg/kg wet weight.

	FOOD							
	F		G		P		W	
	CASE		CASE		CASE		CASE	
	Typical	Worst	Typical	Worst	Typical	Worst	Typical	Worst
CHEMICAL	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC
Cadmium	2.00E-02		1.20E+02	2.40E+02	2.00E-01	4.00E-01	2.00E-02	9.87E-02
Chromium			1.00E-01	1.00E-01	2.00E+00	2.00E+00		
Copper	1.80E+00	3.05E+01	2.70E+00	3.90E+00	9.00E-01	1.30E+00	2.52E-02	5.90E-02
Iron			1.90E+02	3.76E+02	1.90E+02	3.76E+02		
Lead			8.00E-01	1.45E+00	1.60E+00	2.90E+00		
Manganese			1.89E+01	4.22E+01	1.89E+01	4.22E+01		
Mercury	1.45E+00	2.82E+01	1.09E+01	1.66E+01	1.70E-02	2.60E-02	5.10E-04	1.64E-03
Nickel			5.00E-01	8.00E-01	5.00E-01	8.00E-01		
Silver			2.00E-03	2.00E-03	2.00E-03	2.00E-03		
Zinc			1.25E+01	1.90E+01	2.90E+00	4.40E+00		
Acenaphthene				3.17E+00		4.90E+00		
Acenaphthylene				3.73E+00		9.77E+00		
Anthracene	2.00E-01	9.50E-01	4.88E-01	4.07E+00	3.15E-01	2.62E+00	6.90E-06	9.50E-05
Benzo(a)anthracene			9.11E-01	7.17E+00	8.58E-02	6.75E-01	1.70E-05	3.17E-04
Benzo(a)pyrene			1.46E+00	6.16E+00	5.74E-02	2.42E-01	1.40E-05	4.50E-04
Benzo(a)fluoranthene		3.50E-01	2.54E+00	4.47E+00	9.98E-02	1.75E-01	2.90E-04	3.60E-04
Benzo(ghi)perylene	1.40E+00	1.50E+00	7.63E-01	9.33E+00	1.49E-02	1.82E-01	1.20E-04	7.00E-04
Benzo(k)fluoranthene	3.00E-02	5.50E-02		3.39E+00		1.33E-01	1.30E-04	2.10E-04
Chrysene			1.01E+00	2.20E+00	9.52E-02	2.07E-01	3.00E-04	3.60E-04
Dibenzo(a,h)anthracene				1.38E+01		1.60E-01	1.50E-04	1.23E-04
Fluoranthene	6.50E-01	9.50E-01	3.10E+00	7.31E+00	9.94E-01	2.34E+00	6.90E-05	4.30E-04
Fluorene			9.40E-01	2.85E+00	1.03E+00	3.11E+00		
Indeno(1,2,3-cd)pyrene			7.72E-01	9.78E+00	1.51E-02	1.91E-01	1.50E-05	3.90E-04
Naphthalene			1.55E+00	4.51E+00	7.77E+00	2.26E+01		
Phenanthrene	3.50E-01	3.90E+00	2.04E+00	8.23E+00	1.32E+00	5.31E+00	1.40E-04	2.80E-04
Pyrene			1.92E+00	7.43E+00	6.15E-01	2.38E+00	2.00E-06	2.70E-04
alpha-BHC	3.00E-02			1.99E-01		2.84E-01	1.50E-02	2.50E-02
beta-BHC	3.00E-02			1.25E-01		1.79E-01		1.50E-02
Lindane (gamma-BHC)	3.00E-02						1.50E-02	4.00E-02
Aldrin	1.00E-01							
Chlordane	9.50E-01						2.00E-02	1.30E-01
Dieldrin	1.00E-01							
Endrin				3.15E-02		2.42E-03		
Heptachlor	5.00E-02							7.50E-03
Heptachlor epoxide	5.00E-02		2.57E-01	4.63E-01	3.90E+00	7.02E+00		7.50E-03
Hexachlorobenzene	2.00E-01	1.90E+00					1.30E-02	3.15E-01
Mirex	5.00E-02							
p,p'DDD	4.00E-02	3.40E-02	8.00E-03	3.40E-02		2.45E-04		3.50E-02
p,p'DDE	4.40E-02	4.10E-02	1.10E-02	4.10E-02		4.35E-04	1.00E-02	3.45E-02
p,p'DDT	1.00E-02	7.80E-02		7.72E-03		6.44E-04	1.00E-02	6.00E-02
PCBs (total)	2.55E+01	5.50E+01	1.44E-01	8.00E-01		2.37E-01	1.26E-01	2.75E+00

P = phytoplankton, where Ce = Cw * 100 for metals and Ce = Cw * 1,000 for organic chemicals.
W = clams, worms, and mussels (Tables 5.4, 5.5, and 5.8). The highest (most conservative) values were used. Also the dry weights were used (5 * wet weight).
G = gizzard shad where Ce = Cw * BCFf for each chemical except total PCBs, p,p'DDD, and p,p'DDE where spottail shiner residues were available (Tables 5.6 and 5.9).
F = fish (Tables 5.6, 5.7, and 5.9 except spottail shiners). Where muscle tissue values were used, a factor of 10 was used to approximate whole fish values.
Blank = not detected or no data

Table 7.6. Concentrations of contaminants in food consumed by Subsurface Benthos, mg/kg wet weight.

	CASE	
	Typical	Worst
	Organism Type	Organism Type
	Inverte-brate	Inverte-brate
	Food Type	Food Type
	Inverte-brate	Inverte-brate
CHEMICAL	Conc. mg/kg	Conc. mg/kg
Cadmium	8.00E+00	4.30E+01
Chromium	1.20E+02	9.97E+02
Copper	4.40E+02	1.57E+03
Iron	2.88E+05	5.55E+05
Lead	6.30E+01	2.94E+03
Manganese	5.00E+03	7.33E+03
Mercury	3.30E+00	1.71E+01
Nickel	3.00E+02	4.82E+02
Silver		8.50E+00
Zinc	2.49E+03	1.20E+04
Acenaphthene		1.00E+01
Acenaphthylene		1.00E+01
Anthracene	1.80E+00	1.50E+01
Benzo(a)anthracene	6.10E+00	4.80E+01
Benzo(a)pyrene	9.50E+00	4.00E+01
Benzo(a)fluoranthene	1.65E+01	2.90E+01
Benzo(ghi)perylene	4.50E+00	5.50E+01
Benzo(k)fluoranthene		2.20E+01
Chrysene	6.90E+00	1.50E+01
Dibenzo(a,h)anthracene		6.20E+01
Fluoranthene	1.57E+01	3.70E+01
Fluorene	3.30E+00	1.00E+01
Indeno(1,2,3-cd)pyrene	4.50E+00	5.70E+01
Naphthalene	3.10E+00	9.00E+00
Phenanthrene	7.70E+00	3.10E+01
Pyrene	9.30E+00	3.60E+01
alpha-BHC		4.60E-01
beta-BHC		2.90E-01
Lindane (gamma-BHC)		
Aldrin		
Chlordane		
Dieldrin		
Endrin		1.00E-01
Heptachlor		
Heptachlor epoxide	4.00E-01	7.20E-01
Hexachlorobenzene		
Mirex		
p,p'DDD		5.00E-02
p,p'DDE		1.90E-01
p,p'DDT		1.30E-01
PCBs (total)		3.80E+01

Table 7.7. Concentrations of contaminants in food consumed by Surface Benthos, mg/kg wet weight.

	CASE	
	Typical	Worst
	Organism Type	Organism Type
	Inverte-brate	Inverte-brate
	Food Type	Food Type
	Inverte-brate	Inverte-brate
CHEMICAL	Conc. mg/kg	Conc. mg/kg
Cadmium	8.00E+00	4.30E+01
Chromium	1.20E+02	9.97E+02
Copper	4.40E+02	1.57E+03
Iron	2.88E+05	5.55E+05
Lead	6.30E+01	2.94E+03
Manganese	5.00E+03	7.33E+03
Mercury	3.30E+00	1.71E+01
Nickel	3.00E+02	4.82E+02
Silver		8.50E+00
Zinc	2.49E+03	1.20E+04
Acenaphthene		1.00E+01
Acenaphthylene		1.00E+01
Anthracene	1.80E+00	1.50E+01
Benzo(a)anthracene	6.10E+00	4.80E+01
Benzo(a)pyrene	9.50E+00	4.00E+01
Benzo(a)fluoranthene	1.65E+01	2.90E+01
Benzo(ghi)perylene	4.50E+00	5.50E+01
Benzo(k)fluoranthene		2.20E+01
Chrysene	6.90E+00	1.50E+01
Dibenzo(a,h)anthracene		6.20E+01
Fluoranthene	1.57E+01	3.70E+01
Fluorene	3.30E+00	1.00E+01
Indeno(1,2,3-cd)pyrene	4.50E+00	5.70E+01
Naphthalene	3.10E+00	9.00E+00
Phenanthrene	7.70E+00	3.10E+01
Pyrene	9.30E+00	3.60E+01
alpha-BHC		4.60E-01
beta-BHC		2.90E-01
Lindane (gamma-BHC)		
Aldrin		
Chlordane		
Dieldrin		
Endrin		1.00E-01
Heptachlor		
Heptachlor epoxide	4.00E-01	7.20E-01
Hexachlorobenzene		
Mirex		
p,p'DDD		5.00E-02
p,p'DDE		1.90E-01
p,p'DDT		1.30E-01
PCBs (total)		3.80E+01

Table 7.8. Concentrations of contaminants in food consumed by Aufwuchs, mg/kg wet weight.

	CASE	
	Typical	Worst
	Organism Type	Organism Type
	Inverte-brate	Inverte-brate
	Food Type	Food Type
	Inverte-brate	Inverte-brate
CHEMICAL	Conc. mg/kg	Conc. mg/kg
Cadmium	8.00E+00	4.30E+01
Chromium	1.20E+02	9.97E+02
Copper	4.40E+02	1.57E+03
Iron	2.88E+05	5.55E+05
Lead	6.30E+01	2.94E+03
Manganese	5.00E+03	7.33E+03
Mercury	3.30E+00	1.71E+01
Nickel	3.00E+02	4.82E+02
Silver		8.50E+00
Zinc	2.49E+03	1.20E+04
Acenaphthene		1.00E+01
Acenaphthylene		1.00E+01
Anthracene	1.80E+00	1.50E+01
Benzo(a)anthracene	6.10E+00	4.80E+01
Benzo(a)pyrene	9.50E+00	4.00E+01
Benzo(a)fluoranthene	1.65E+01	2.90E+01
Benzo(ghi)perylene	4.50E+00	5.50E+01
Benzo(k)fluoranthene		2.20E+01
Chrysene	6.90E+00	1.50E+01
Dibenzo(a,h)anthracene		6.20E+01
Fluoranthene	1.57E+01	3.70E+01
Fluorene	3.30E+00	1.00E+01
Indeno(1,2,3-cd)pyrene	4.50E+00	5.70E+01
Naphthalene	3.10E+00	9.00E+00
Phenanthrene	7.70E+00	3.10E+01
Pyrene	9.30E+00	3.60E+01
alpha-BHC		4.60E-01
beta-BHC		2.90E-01
Lindane (gamma-BHC)		
Aldrin		
Chlordane		
Dieldrin		
Endrin		1.00E-01
Heptachlor		
Heptachlor epoxide	4.00E-01	7.20E-01
Hexachlorobenzene		
Mirex		
p,p'DDD		5.00E-02
p,p'DDE		1.90E-01
p,p'DDT		1.30E-01
PCBs (total)		3.80E+01

Table 7.9. Concentrations of contaminants in food consumed by Zooplankton, mg/kg wet weight.

	CASE	
	Typical	Worst
	Organism Type	Organism Type
	Inverte-brate	Inverte-brate
	Food Type	Food Type
	Inverte-brate	Inverte-brate
CHEMICAL	Conc. mg/kg	Conc. mg/kg
Cadmium	2.00E-03	4.00E-03
Chromium	2.00E-02	2.00E-02
Copper	9.00E-03	1.30E-02
Iron	1.90E+00	3.76E+00
Lead	1.60E-02	2.90E-02
Manganese	1.89E-01	4.22E-01
Mercury	1.70E-04	2.60E-04
Nickel	5.00E-03	8.00E-03
Silver	2.00E-05	2.00E-05
Zinc	2.90E-02	4.40E-02
Acenaphthene		1.26E+00
Acenaphthylene		2.51E+00
Anthracene	8.05E-02	6.71E-01
Benzo(a)anthracene	1.94E-02	1.53E-01
Benzo(a)pyrene	1.06E-02	4.46E-02
Benzo(a)fluoranthene	1.84E-02	3.23E-02
Benzo(ghi)perylene	1.83E-03	2.24E-02
Benzo(k)fluoranthene		2.45E-02
Chrysene	1.80E-02	4.67E-02
Dibenzo(a,h)anthracene		1.35E-02
Fluoranthene	2.49E-01	5.87E-01
Fluorene	2.62E-01	7.95E-01
Indeno(1,2,3-cd)pyrene	1.87E-03	2.37E-02
Naphthalene	3.00E-01	5.81E+00
Phenanthrene	3.00E-01	1.35E+00
Pyrene	1.55E-01	5.98E-01
alpha-BHC		7.30E-02
beta-BHC		4.60E-02
Lindane (gamma-BHC)		
Aldrin		
Chlordane		
Dieldrin		
Endrin		5.80E-04
Heptachlor		
Heptachlor epoxide	1.00E-01	1.81E+00
Hexachlorobenzene		
Mirex		
p,p'DDD		4.06E-05
p,p'DDE		2.74E-05
p,p'DDT		1.08E-04
PCBs (total)		4.43E-02

Table 7.10. Concentrations of contaminants in food consumed by Brown Bullhead, mg/kg wet weight.

	CASE			
	Typical		Worst	
	Organism Type		Organism Type	
	Fish		Fish	
	Food Type		Food Type	
	Fish	Inverte-brate	Fish	Inverte-brate
CHEMICAL	Conc. mg/kg	Conc. mg/kg	Conc. mg/kg	Conc. mg/kg
Cadmium	2.00E-02	2.00E-02		9.87E-02
Chromium				
Copper	1.80E+00	2.52E-02	3.05E+01	5.90E-02
Iron				
Lead				
Manganese				
Mercury	1.45E+00	5.10E-04	2.82E+01	1.64E-03
Nickel				
Silver				
Zinc				
Acenaphthene				
Acenaphthylene				
Anthracene	2.00E-01	6.90E-06	9.50E-01	9.50E-05
Benzo(a)anthracene		1.70E-05		3.17E-04
Benzo(a)pyrene		1.40E-05		4.50E-04
Benzo(a)fluoranthene		2.90E-04	3.50E-01	3.60E-04
Benzo(ghi)perylene	1.40E+00	1.20E-04	1.50E+00	7.00E-04
Benzo(k)fluoranthene	3.00E-02	1.30E-04	5.50E-02	2.10E-04
Chrysene		3.00E-04		3.60E-04
Dibenzo(a,h)anthracene		1.50E-04		1.23E-04
Fluoranthene	6.50E-01	6.90E-05	9.50E-01	4.30E-04
Fluorene				
Indeno(1,2,3-cd)pyrene		1.50E-05		3.90E-04
Naphthalene				
Phenanthrene	3.50E-01	1.40E-04	3.90E+00	2.80E-04
Pyrene		2.00E-06		2.70E-04
alpha-BHC	3.00E-02	1.50E-02		2.50E-02
beta-BHC	3.00E-02			1.50E-02
Lindane (gamma-BHC)	3.00E-02	1.50E-02		4.00E-02
Aldrin	1.00E-01			
Chlordane	9.50E-01	2.00E-02		1.30E-01
Dieldrin	1.00E-01			
Endrin				
Heptachlor	5.00E-02			7.50E-03
Heptachlor epoxide	5.00E-02			7.50E-03
Hexachlorobenzene	2.00E-01	1.30E-02	1.90E+00	3.15E-01
Mirex	5.00E-02			
p,p'DDD	4.00E-02		3.40E-02	3.50E-02
p,p'DDE	4.40E-02	1.00E-02	4.10E-02	3.45E-02
p,p'DDT	1.00E-02	1.00E-02	7.80E-02	6.00E-02
PCBs (total)	2.55E+01	1.26E-01	5.50E+01	2.75E+00

Table 7.11. Concentrations of contaminants in food consumed by Carp, mg/kg wet weight.

	CASE	
	Typical	Worst
	Organism Type	Organism Type
	Fish	Fish
	Food Type	Food Type
	Inverte-brate	Inverte-brate
CHEMICAL	Conc. mg/kg	Conc. mg/kg
Cadmium	2.00E-02	9.87E-02
Chromium		
Copper	2.52E-02	5.90E-02
Iron		
Lead		
Manganese		
Mercury	5.10E-04	1.64E-03
Nickel		
Silver		
Zinc		
Acenaphthene		
Acenaphthylene		
Anthracene	6.90E-06	9.50E-05
Benzo(a)anthracene	1.70E-05	3.17E-04
Benzo(a)pyrene	1.40E-05	4.50E-04
Benzo(a)fluoranthene	2.90E-04	3.60E-04
Benzo(ghi)perylene	1.20E-04	7.00E-04
Benzo(k)fluoranthene	1.30E-04	2.10E-04
Chrysene	3.00E-04	3.60E-04
Dibenzo(a,h)anthracene	1.50E-04	1.23E-04
Fluoranthene	6.90E-05	4.30E-04
Fluorene		
Indeno(1,2,3-cd)pyrene	1.50E-05	3.90E-04
Naphthalene		
Phenanthrene	1.40E-04	2.80E-04
Pyrene	2.00E-06	2.70E-04
alpha-BHC	1.50E-02	2.50E-02
beta-BHC		1.50E-02
Lindane (gamma-BHC)	1.50E-02	4.00E-02
Aldrin		
Chlordane	2.00E-02	1.30E-01
Dieldrin		
Endrin		
Heptachlor		7.50E-03
Heptachlor epoxide		7.50E-03
Hexachlorobenzene	1.30E-02	3.15E-01
Mirex		
p,p'DDD		3.50E-02
p,p'DDE	1.00E-02	3.45E-02
p,p'DDT	1.00E-02	6.00E-02
PCBs (total)	1.26E-01	2.75E+00

Table 7.12. Concentrations of contaminants in food consumed by Gizzard Shad, mg/kg wet weight.

	CASE	
	Typical	Worst
	Organism Type	Organism Type
	Fish	Fish
	Food Type	Food Type
	Inverte-brate	Inverte-brate
CHEMICAL	Conc. mg/kg	Conc. mg/kg
Cadmium	2.00E-03	4.00E-03
Chromium	2.00E-02	2.00E-02
Copper	9.00E-03	1.30E-02
Iron	1.90E+00	3.76E+00
Lead	1.60E-02	2.90E-02
Manganese	1.89E-01	4.22E-01
Mercury	1.70E-04	2.60E-04
Nickel	5.00E-03	8.00E-03
Silver	2.00E-05	2.00E-05
Zinc	2.90E-02	4.40E-02
Acenaphthene		1.26E+00
Acenaphthylene		2.51E+00
Anthracene	8.05E-02	6.71E-01
Benzo(a)anthracene	1.94E-02	1.53E-01
Benzo(a)pyrene	1.06E-02	4.46E-02
Benzo(a)fluoranthene	1.84E-02	3.23E-02
Benzo(ghi)perylene	1.83E-03	2.24E-02
Benzo(k)fluoranthene		2.45E-02
Chrysene	1.80E-02	4.67E-02
Dibenzo(a,h)anthracene		1.35E-02
Fluoranthene	2.49E-01	5.87E-01
Fluorene	2.62E-01	7.95E-01
Indeno(1,2,3-cd)pyrene	1.87E-03	2.37E-02
Naphthalene	3.00E-01	5.81E+00
Phenanthrene	3.00E-01	1.35E+00
Pyrene	1.55E-01	5.98E-01
alpha-BHC		7.30E-02
beta-BHC		4.60E-02
Lindane (gamma-BHC)		
Aldrin		
Chlordane		
Dieldrin		
Endrin		5.80E-04
Heptachlor		
Heptachlor epoxide	1.00E-01	1.81E+00
Hexachlorobenzene		
Mirex		
p,p'DDD		4.06E-05
p,p'DDE		2.74E-05
p,p'DDT		1.08E-04
PCBs (total)		4.43E-02

Table 7.13. Concentrations of contaminants in food consumed by Pumpkinseed, mg/kg wet weight.

	CASE			
	Typical		Worst	
	Organism Type		Organism Type	
	Fish		Fish	
	Food Type		Food Type	
	Fish	Inverte-brate	Fish	Inverte-brate
CHEMICAL	Conc. mg/kg	Conc. mg/kg	Conc. mg/kg	Conc. mg/kg
Cadmium	1.20E+02	1.10E-01	2.40E+02	2.49E-01
Chromium	1.00E-01	2.00E+00	1.00E-01	2.00E+00
Copper	2.70E+00	4.63E-01	3.90E+00	6.80E-01
Iron	1.90E+02	1.90E+02	3.76E+02	3.76E+02
Lead	8.00E-01	1.60E+00	1.45E+00	2.90E+00
Manganese	1.89E+01	1.89E+01	4.22E+01	4.22E+01
Mercury	1.09E+01	8.76E-03	1.66E+01	1.38E-02
Nickel	5.00E-01	5.00E-01	8.00E-01	8.00E-01
Silver	2.00E-03	2.00E-03	2.00E-03	2.00E-03
Zinc	1.25E+01	2.90E+00	1.90E+01	4.40E+00
Acenaphthene			3.17E+00	4.90E+00
Acenaphthylene			3.73E+00	9.77E+00
Anthracene	4.88E-01	1.58E-01	4.07E+00	1.31E+00
Benzo(a)anthracene	9.11E-01	4.29E-02	7.17E+00	3.38E-01
Benzo(a)pyrene	1.46E+00	2.87E-02	6.16E+00	1.21E-01
Benzo(a)fluoranthene	2.54E+00	5.00E-02	4.47E+00	8.79E-02
Benzo(ghi)perylene	7.63E-01	7.50E-03	9.33E+00	9.13E-02
Benzo(k)fluoranthene		6.50E-05	3.39E+00	6.66E-02
Chrysene	1.01E+00	4.78E-02	2.20E+00	1.04E-01
Dibenzo(a,h)anthracene		7.50E-05	1.38E+01	7.99E-02
Fluoranthene	3.10E+00	4.97E-01	7.31E+00	1.17E+00
Fluorene	9.40E-01	1.03E+00	2.85E+00	3.11E+00
Indeno(1,2,3-cd)pyrene	7.72E-01	7.54E-03	9.78E+00	9.55E-02
Naphthalene	1.55E+00	7.77E+00	4.51E+00	2.26E+01
Phenanthrene	2.04E+00	6.60E-01	8.23E+00	2.66E+00
Pyrene	1.92E+00	3.08E-01	7.43E+00	1.19E+00
alpha-BHC		7.50E-03	1.99E-01	1.54E-01
beta-BHC			1.25E-01	9.70E-02
Lindane (gamma-BHC)		7.50E-03		2.00E-02
Aldrin				
Chlordane		1.00E-02		6.50E-02
Dieldrin				
Endrin			3.15E-02	2.42E-03
Heptachlor				3.75E-03
Heptachlor epoxide	2.57E-01	3.90E+00	4.63E-01	3.51E+00
Hexachlorobenzene		6.50E-03		1.58E-01
Mirex				
p,p'DDD	8.00E-03		3.40E-02	1.76E-02
p,p'DDE	1.10E-02	5.00E-03	4.10E-02	1.75E-02
p,p'DDT		5.00E-03	7.72E-03	3.03E-02
PCBs (total)	1.44E-01	6.29E-02	8.00E-01	1.49E+00

CHAPTER 8

TOXICITY ASSESSMENT (DOSE-RESPONSE AND EXPOSURE-RESPONSE)

For aquatic organisms exposed to contaminants in media, exposure-response is described.

8.1 Aquatic Toxicity Estimates for Chemical Pollutants Present in Buffalo River Sediments (1985-1989)

8.1.1 Toxicity Estimates for Buffalo River Contaminants

The primary goal for this Buffalo River effort is to provide a baseline risk assessment for the area caused by the presence of contaminated sediments found in the river basin. As has been emphasized in previous sections of the report, a secondary consideration is to improve the capability for a risk forecast; this can be done using either a minimum number of new biota, water, sediment, etc. samples or, when data are available, using the previously collected information. The current Buffalo River assessment uses sampling and analytical data collected during 1985 and 1989. These data are not as complete as one would hope, but they do allow for a best available attempt at the baseline assessment and hopefully for the introduction of some modest improvements in the risk assessment process. Another basic area of consideration relates to the validation of risk procedures that assume "additivity" of risk following exposure to combinations of pollutant compounds (i.e., if specific toxicity data are not available for the actual mixture). The validity of this approach should be determined (through experimental studies) because there are several responses, other than an addition of separate effects, that can potentially occur. In some specific cases, the additive approach could be an underestimate of potential hazard. However, the additive approach can be very expensive in terms of clean-up costs if the actual effect is not as severe as the additive forecast suggests. See the generic document for further description and relevant tables for treatment of the data.

8.1.1.1 Reference Toxicities for Aquatic Organisms--single chemicals

(See Passino-Reader et al. 1992 for tables). To calculate risk to aquatic biota, standard reference toxicities to aquatic species are needed similar to the reference doses (RfD) values available for humans. To complete a set of "reference toxicity" values for compounds in sediments for the Buffalo River, we established the following priorities. We used interim sediment quality criteria (SQC) (USEPA 1988b) when available. When SQC were not available, we used sediment equilibrium partitioning (EP) thresholds (Long and Morgan 1990). When SQC and EP values were unavailable, we used water quality criteria values (USEPA 1986; Table VII.1.1-6 in Passino-Reader et al. 1992) and calculated the corresponding sediment concentration, using the approach of Burmaster et al.(1991) and assuming total organic carbon of the sediment equal to 3.25%. Lastly, we filled in the remaining "sediment reference toxicity" values with, first, NOAELs or, second, QSARs (Hickey and Passino-Reader 1991), using the approach of Burmaster et al. (1991) to calculate sediment concentrations. We have estimated NOAELs from the one data set that we have that includes most of the chemicals, viz., acute toxicity (Table VI.A.1 in Passino-Reader et al. 1992). To put the acute toxicity data into units comparable to the

exposure data, we converted the toxicity units of μg/L to mg/kg by multiplying by 1E-03, approximating the density of water by 1.00 g/mL. This approach also assumes that the toxicity to the organisms by chemicals in water can be used as an estimate of their total exposure to the same chemical by all routes. Next we used an application factor (AF) to calculate NOAEL from acute toxicity. Realizing that application factors can vary from greater than 1E-01 to less than 1E-02, we used a value of 1E-01 for the calculation. Thus, NOAEL values in Table VIII.1.1-5 (Passino-Reader et al. 1992) were calculated from acute toxicity values in Table VI.A.1 (Passino-Reader et al. 1992) with the following equation:

$$\text{NOAEL (mg/kg)} = \text{LC50 } (\mu\text{g/L}) \times (10^{-3} \text{ mg/}\mu\text{g}) \times (\text{L/kg}) \times \text{AF } (10^{-1})$$

In selecting acute toxicity data from Table VI.A.1 (Passino-Reader et al. 1992), we used Daphnia spp. to represent plankton. The order for selecting invertebrates to represent benthos and aufwuchs was as follows: Asellus, Gammarus, and Neanthes. For fish that are primarily in the water column, the order of priority was: rainbow trout, bluegill, yellow perch, large mouth bass, fathead minnow, and others. For fish that are primarily or somewhat in contact with the bottom, the order of priority was: bullhead, carp, and goldfish. "Reference toxicities" used in our risk assessment are listed in Table 8.1. The method used to obtain a value for sediment "reference toxicity" for each chemical is listed in the column labeled "source" in Table 8.1.

A similar approach was used to obtain water "reference toxicities". We used USEPA water quality criteria when available (U.S. Environmental Protection Agency 1986). Otherwise, we calculated a water "reference toxicity" by the same methods described above for sediment (except that we did not calculate sediment concentrations). The method used to obtain a value for each chemical is listed in the column labeled "source" in Table 8.2.

For evaluating the toxicity due to eating contaminants in food, we propose a new term, **"food quality criteria"**, which would be analogous to the standard terms, water quality criteria and sediment quality criteria. To obtain experimentally derived values for food quality criteria, organisms would need to be dosed by feeding them clean food that has been spiked with a single chemical. By feeding groups of animals a series of concentrations or treatments, dose-relationship curves and LC50 values could be obtained. Such data do exist for a very limited number of contaminants and aquatic species. The data are too sparse to consider establishing food quality criteria based on experimental data in a manner similar to which water or sediment quality criteria have been established. No standard protocols exist for deriving food quality criteria.

Exposure to contaminated food is a necessary component of aquatic risk assessment. Therefore, we developed the following method to estimate food quality criteria for use in the baseline aquatic risk assessment. We developed a basic equation:

$$FQC = WQC * BCF$$

where FQC = food quality criteria, WQC = water quality criteria for the predator, and BCF = bioconcentration factor for the prey. Three cases exist for the Buffalo River receptor organisms, i.e., invertebrates preying upon invertebrates (FQC_{ii}), fish preying upon invertebrates (FQC_{fi}), and fish

Table 8.1. Reference toxicities for receptors exposed to contaminants by sediment.

		ORGANISM TYPE	
		Fish	Inverte-brate
CHEMICAL	SOURCE	Conc. mg/kg	Conc. mg/kg
Cadmium	EP	3.10E+01	3.10E+01
Chromium	WQC	6.60E+00	6.60E+00
Copper	EP	1.36E+02	1.36E+02
Iron	WQC	1.50E+04	1.50E+04
Lead	EP	1.32E+02	1.32E+02
Manganese	NOAEL	2.50E+03	2.50E+03
Mercury	EP	3.00E-02	3.00E-02
Nickel	WQC	9.60E+02	9.60E+02
Silver	WQC	5.00E+00	5.00E+00
Zinc	EP	7.60E+02	7.60E+02
Acenaphthene	EP	6.60E+01	6.60E+01
Acenaphthylene	QSAR	3.39E+01	2.15E+01
Anthracene	EP	4.40E+01	4.40E+01
Benzo(a)anthracene	SQC	4.28E+01	4.28E+01
Benzo(a)pyrene	SQC	3.45E+01	3.45E+01
Benzo(a)fluoranthene	QSAR	3.77E+01	5.65E+00
Benzo(ghi)perylene	QSAR	2.19E+01	3.91E+00
Benzo(k)fluoranthene	QSAR	3.77E+01	5.65E+00
Chrysene	EP	4.60E+02	4.60E+02
Dibenzo(a,h)anthracene	NOAEL	1.29E+04	1.29E+04
Fluoranthene	SQC	6.12E+01	6.12E+01
Fluorene	NOAEL	3.24E+01	3.24E+01
Indeno(1,2,3-cd)pyrene	QSAR	5.56E+00	1.29E+00
Naphthalene	EP	4.20E+01	4.20E+01
Phenanthrene	SQC	5.66E+00	5.66E+00
Pyrene	SQC	4.26E+01	4.26E+01
alpha-BHC	QSAR	3.25E+00	4.55E-01
beta-BHC	QSAR	3.41E+00	4.39E-01
Lindane (gamma-BHC)	EP	1.40E-02	1.40E-02
Aldrin	EP	2.10E-02	2.10E-02
Chlordane	SQC	1.00E-02	1.00E-02
Dieldrin	WQC	1.23E-04	1.23E-04
Endrin	EP	2.32E-02	2.32E-02
Heptachlor	WQC	1.95E-03	1.95E-03
Heptachlor epoxide	NOAEL	2.05E-02	2.05E-02
Hexachlorobenzene	EP	2.80E-01	2.80E-01
Mirex	WQC	5.14E-01	5.14E-01
p,p'DDD	EP	1.30E+01	1.30E+01
p,p'DDE	EP	2.80E+01	2.80E+01
p,p'DDT	SQC	2.69E-01	2.69E-01
PCBs (total)	EP	2.80E+02	2.80E+02

EP = equilibrium partitioning
NOAEL = no observed adverse effect level
QSAR = quantitative structure-activity relationship
SQC = sediment quality criteria
WQC = water quality criteria

Table 8.2. Reference toxicities for receptors exposed to contaminants by water.

		ORGANISM TYPE	
		Fish	Inverte-brate
CHEMICAL	SOURCE	Conc. mg/L	Conc. mg/L
Cadmium	WQC	1.10E-03	1.10E-03
Chromium	WQC	1.10E-02	1.10E-02
Copper	WQC	1.20E-02	1.20E-02
Iron	WQC	1.00E+00	1.00E+00
Lead	WQC	3.20E-03	3.20E-03
Manganese	NOAEL	9.80E-01	9.80E-01
Mercury	WQC	1.20E-05	1.20E-05
Nickel	WQC	1.60E-01	1.60E-01
Silver	WQC	1.20E-04	1.20E-04
Zinc	WQC	1.10E-01	1.10E-01
Acenaphthene	WQC	5.20E-01	5.20E-01
Acenaphthylene	QSAR	3.30E-01	2.10E-01
Anthracene	QSAR	7.30E-02	5.50E-02
Benzo(a)anthracene	QSAR	3.80E-03	6.90E-04
Benzo(a)pyrene	QSAR	9.90E-04	1.80E-04
Benzo(a)fluoranthene	QSAR	1.60E-03	2.40E-04
Benzo(ghi)perylene	QSAR	3.30E-04	5.90E-05
Benzo(k)fluoranthene	QSAR	1.60E-03	2.40E-04
Chrysene	QSAR	3.80E-03	6.90E-04
Dibenzo(a,h)anthracene	NOAEL	1.00E-01	1.00E-01
Fluoranthene	FWAC	4.00E-01	4.00E-01
Fluorene	NOAEL	1.00E-01	1.00E-01
Indeno(1,2,3-cd)pyrene	QSAR	8.60E-05	2.00E-05
Naphthalene	WQC	6.20E-01	6.20E-01
Phenanthrene	NOAEL	4.50E+02	6.00E-02
Pyrene	NOAEL	2.60E-04	2.60E-04
alpha-BHC	QSAR	2.00E-02	2.80E-03
beta-BHC	QSAR	2.10E-02	2.70E-03
Lindane (gamma-BHC)	WQC	6.00E-05	6.00E-05
Aldrin	FWAC	3.00E-04	3.00E-04
Chlordane	WQC	4.30E-06	4.30E-06
Dieldrin	WQC	1.90E-06	1.90E-06
Endrin	WQC	2.30E-06	2.30E-06
Heptachlor	WQC	3.80E-06	3.80E-06
Heptachlor epoxide	NOAEL	2.00E-03	2.00E-03
Hexachlorobenzene	NOAEL	1.20E-03	1.20E-03
Mirex	WQC	1.00E-06	1.00E-06
p,p'DDD	NOAEL	7.00E-03	1.60E-03
p,p'DDE	NOAEL	3.20E-03	3.20E-03
p,p'DDT	NOAEL	4.80E-04	1.00E-04
PCBs (total)	WQC	1.40E-05	1.40E-05

FWAC = fresh water acute criteria
NOAEL = no observed adverse effect level
QSAR = quantitative structure-activity relationship
WQC = water quality criteria

preying upon fish (FQC_{ff}), where the first subscript refers to the predator and the second subscript refers to the prey. For the eight receptor organisms, these cases are shown in Table 7.3 (vehicles of exposure). The equations for the three cases are as follows:

$$FQC_{ii} = WQC_i * BCF_i$$
$$FQC_{fi} = WQC_f * BCF_i$$

$$FQC_{ff} = WQC_f * BCF_f$$

Values for BCF were obtained from Table 7.4, using the respective values for invertebrates or fish. The values for WQC were obtained from Table 8.2, using the respective values for invertebrates or fish. Using the three equations above, the resulting values for FQC are shown in Table 8.3.

8.1.1.2 Reference Toxicities for Aquatic Organisms--Mixtures

To represent reference toxicity values for chemicals present in environmental mixtures, we obtained values of effects range-low (ER-L) and effects range-median (ER-M) for sediments (Long and Morgan 1990) and present these in Table 8.4. These values were obtained from using environmental samples, and are the concentrations measured in the sediments at which an effect was seen on aquatic organisms. Presumably, the additive, synergistic, or antagonist interactions of the contaminants are accounted for. However, since not all contaminants are measured, the observed toxicity could be due to a contaminant that was not measured.

8.2 Summation of All Chemicals to which Receptors are Exposed

A summary of the contaminants that have been detected in which kinds of organisms in the Buffalo River AOC was presented in Table 5.1. Table 5.2 shows all contaminants measured in sediments.

8.3 Identification of Chemicals with No, or Inadequate, Toxicity Data

(See Passino-Reader et al. 1992 for tables.) Sediment quality criteria, equilibrium partitioning, and water quality criteria were used preferentially. Examination of Table VIII.1.1-5 of estimated NOAELs (Passino-Reader et al. 1992), based on acute toxicity data, shows the chemicals for which acute data were lacking to estimate a NOAEL for either a specific part of the foodweb, i.e., zooplankton, or for any representative aquatic receptor. For aquatic life risk assessment, NOAELs would be comparable to RfDs used in human health risk assessment. Acute data were assembled in Table VI.A.1 (Passino-Reader et al. 1992). The lack of general availability of NOAELs for chemicals and aquatic receptors of interest for risk assessment is due to the great cost of obtaining these values. Some data are available in the literature on chronic or subchronic toxicity for chemicals and receptors of interest and could be used in estimating NOAELs. In Tables 8.1 and 8.2, the compounds with "source" indicated as QSAR lacked measured toxicity values.

8.4 Identification of Toxicological Endpoints to be Assessed

8.4.1 Data for AOC from Toxicity/Chemistry Workgroup of ARCS

Nelson et al. (1992) reported results of toxicity tests with sediment samples collected from the Buffalo River AOC in 1989. Survival and growth were observed for the following test species and durations of tests: Hyalella azteca (Amphipoda) with 14- and 28-day flow-through exposures; Chironomus

Table 8.3. Reference toxicities for receptors exposed to contaminants by food.

CHEMICAL	ORGANISM TYPE: Fish; FOOD TYPE: Fish — Conc. mg/kg	ORGANISM TYPE: Fish; FOOD TYPE: Invertebrate — Conc. mg/kg	ORGANISM TYPE: Invertebrate; FOOD TYPE: Invertebrate — Conc. mg/kg
Cadmium	6.60E+01	3.85E+00	3.85E+00
Chromium	5.50E-02	2.20E+00	2.20E+00
Copper	3.60E+00	2.40E+00	2.40E+00
Iron	1.00E+02	1.00E+02	1.00E+02
Lead	1.60E-01	5.44E+00	5.44E+00
Manganese	9.80E+01	9.80E+01	9.80E+01
Mercury	7.68E-01	4.80E-01	4.80E-01
Nickel	1.60E+01	1.60E+01	1.60E+01
Silver	1.20E-02	1.20E-02	1.20E-02
Zinc	4.75E+01	1.24E+02	1.24E+02
Acenaphthene	3.36E+02	7.02E+01	7.02E+01
Acenaphthylene	1.26E+02	2.54E+01	1.62E+01
Anthracene	1.13E+02	6.57E+01	4.95E+01
Benzo(a)anthracene	4.03E+01	1.05E+01	1.90E+00
Benzo(a)pyrene	2.52E+01	2.97E+00	5.40E-01
Benzo(a)fluoranthene	4.07E+01	1.13E+01	1.70E+00
Benzo(ghi)perylene	1.69E+01	4.97E+00	8.88E-01
Benzo(k)fluoranthene	4.07E+01	1.13E+01	1.70E+00
Chrysene	4.03E+01	1.05E+01	1.90E+00
Dibenzo(a,h)anthracene	8.67E+03	2.65E+03	2.65E+03
Fluoranthene	1.25E+03	4.00E+03	4.00E+03
Fluorene	9.16E+01	1.97E+01	1.97E+01
Indeno(1,2,3-cd)pyrene	4.41E+00	1.29E+00	3.01E-01
Naphthalene	1.24E+02	8.12E+01	8.12E+01
Phenanthrene	6.97E+05	1.46E+05	1.95E+01
Pyrene	8.11E-01	7.02E-01	7.02E-01
alpha-BHC	1.40E+01	2.00E+00	2.80E-01
beta-BHC	1.47E+01	2.10E+00	2.70E-01
Lindane (gamma-BHC)	4.20E-02	6.00E-03	6.00E-03
Aldrin	1.88E+00	1.35E+00	1.35E+00
Chlordane	4.26E-03	3.14E-02	3.14E-02
Dieldrin	2.47E-02	5.32E-03	5.32E-03
Endrin	2.99E-02	4.42E-03	4.42E-03
Heptachlor	8.09E-02	9.50E-03	9.50E-03
Heptachlor epoxide	1.32E-01	3.40E+00	3.40E+00
Hexachlorobenzene	4.49E+00	1.24E+00	1.24E+00
Mirex	4.08E-02	1.80E-02	1.80E-02
p,p'DDD	1.90E+01	6.37E+01	1.46E+01
p,p'DDE	3.84E+01	1.15E+02	1.15E+02
p,p'DDT	5.76E+00	1.23E+00	2.56E-01
PCBs (total)	2.10E-02	8.21E-02	8.21E-02

riparius (Diptera) with 14-day exposure; and Chironomus tentans with 10-day static exposure. Antennal segment number and sexual maturation were also observed for H. azteca. Earlier studies have demonstrated the carcinogenicity of sediments from the Buffalo River to brown bullhead (Bauman et al. 1982; Black 1983; Black et al. 1985). Table 8.4 shows effects range values from Long and Morgan (1990). The Effects Range-Low (ER-L) is defined as the lower 10 percentile of concentrations of chemicals associated with adverse biological effects. The Effects Range-Median (ER-M) is defined as the median concentration of a chemical at which biological effects are measured in site-specific estuarine or marine sediment samples used in bioassays with aquatic organisms (Long and Morgan 1990). By comparing sediment concentrations at the Buffalo River AOC with ER-L and ER-M values, we can identify those contaminants that may pose a risk to aquatic biota at the Buffalo River.

8.5 Summation of All Chemicals to be Addressed in the Evaluation

All compounds shown in Table 8.1 will be used for the evaluation.

Table 8.4. Effects range-low (ER-L) and effects range-median (ER-M) for mixtures of chemicals in sediments (Long and Morgan 1990).

Chemical	Acute Marine (mg/L)	Chronic Marine (mg/L)
Cadmium	5.00 E + 00	9.00 E + 00
Chromium (hex)		
Copper	7.00 E + 01	3.90 E + 02
Iron		
Lead	3.50 E + 01	1.10 E + 02
Manganese		
Mercury	1.50 E - 01	1.30 E + 00
Nickel	3.00 E + 01	5.00 E + 01
Silver	1.00 E + 00	2.20 E + 00
Zinc	1.20 E + 02	2.70 E + 02
Acenaphthene	1.50 E - 01	6.50 E - 01
Acenaphthylene		
Anthracene	8.50 E - 02	9.60 E - 01
Benzo(a)anthracene	2.30 E - 01	1.60 E + 00
Benzo(a)pyrene	4.00 E - 01	2.50 E + 00
Benzo(b)fluoranthene		
Benzo(ghi)perylene		
Benzo(k)fluoranthene		
Chrysene	4.00 E - 01	2.80 E + 00
Dibenzo(a,h)anthracene	6.00 E - 02	2.60 E - 01
Fluroanthene	6.00 E - 01	3.60 E + 00
Fluorene	3.50 E - 02	6.40 E - 01
Indeno(1,2,3-cd)pyrene		
Naphthalene	3.40 E - 01	2.10 E + 00
Phenanthrene	2.25 E - 01	1.38 E + 00
Pyrene	3.50 E - 01	2.20 E + 00
α-BHC		
ß-BHC		
Lindane (gamma-BHC)		
Aldrin		
Dieldrin	2.00 E - 05	8.00 E - 03
Chlordane	5.00 E - 04	6.00 E - 03
Endrin	2.00 E - 05	4.50 E - 02
Heptachlor		
Heptachlor epoxide		
Hexachlorobenzene		
Mirex		
p,p'DDD	2.00 E - 03	2.00 E - 02
p,p'DDE	2.00 E - 03	1.50 E - 02
DDT (total)	3.00 E - 03	3.50 E - 01
PCBs (total)		

CHAPTER 9

RISK CHARACTERIZATION

The focus of this section is to characterize the risk of adverse aquatic life health effects due to exposure to contaminants found in the Buffalo River AOC. The characterization reflects how contaminant levels, species distribution, and contaminant toxicity combine to result in a risk to aquatic life health. Within a baseline risk assessment, many data and knowledge gaps exist that make a numerically accurate determination of risk impossible. Where either data or knowledge with which to perform a step in the assessment are lacking, it is necessary to develop assumptions. The purpose of the assumption is to fill the data gap and allow the assessment process to continue. An important characteristic of an assumption is that it should be developed with the overall objective of the work in mind. In the case of a baseline risk assessment, the objective is to characterize a range related to exposure and risk that bound the potential risk between likely and worst case. It is desired that this range reflect an overall conservative approach, that is, the assessor attempts to estimate the risk in such a manner that it is not underestimated. Therefore, when the need for an assumption surfaces within this baseline assessment, a consistent effort was made to fill the data gap in a 'reasonably conservative' manner. The important assumptions made within this baseline assessment are summarized in Chapter 10.

9.1 Individual Chemicals

Risk for noncarcinogenic chemicals was quantified by a hazard quotient (USEPA 1989a), i.e.:

$$\text{Hazard quotient} = \frac{\text{Exposure level}}{\text{Reference dose}}$$

For the baseline aquatic risk assessment, we calculated risk as a hazard quotient (HQ) by dividing the concentration (C)in each medium by the reference toxicity (QC) for that medium. The three basic equations were as follows:

$$HQ_s = \frac{C_s}{SQC}$$

$$HQ_w = \frac{C_w}{WQC}$$

$$HQ_e = \frac{C_e}{FQC}$$

where the subscripts s, w, and e refer to sediment, water, and food, respectively (the letter f had already been used for fish). The values for C were obtained from Tables 5.2 and 7.6 to 7.13. The values for QC were obtained from Tables 8.1 to 8.3.

The calculated risk from food is shown for each of the eight receptor organisms in Tables 9.1 to 9.8. The calculated risk for all media for each receptor organism and chemical is shown in Tables 9.9 to 9.16. Risk was summed across all media as in USEPA (1989a); however, **risk was not summed across all chemicals because of the unknown contributions of chemicals below the threshold levels of toxic effects (Dr. Rolf Hartung, personal communication).**

The values for risk from food for each receptor organism (Tables 9.1 to 9.8) can be examined to determine the relative importance of different foods. Two of the fish, brown bullhead and pumpkinseed, eat both fish and invertebrates (Table 7.3). Specifically, the brown bullhead eats worms (W) and fish (F) food categories from Table 7.2. For the brown bullhead, the calculated risk from eating fish was consistently higher than the risk of eating invertebrates for organic contaminants, but not necessarily for metals (Table 9.5). However, sufficient data were available to evaluate only three metals. Contaminant residues (Table 7.10) in fish were generally higher than in invertebrates for the food of brown bullhead. The food quality criteria (FQC_{ff}) for fish eating fish are generally higher than that for fish eating invertebrates (FQC_{fi}). The higher FQC_{ff} somewhat dampened the effects of eating fish with higher residues.

Similarly, for pumpkinseed fish that are eating worms (W), plankton (P), and gizzard shad (G) food categories, the contaminant residues in the fish were generally, but not always, higher than in invertebrates. Consequently, the risk from eating fish was generally higher than the risk from eating invertebrates. These results are consistent with the concept of bioaccumulation of contaminants up the food chain and higher risk from eating food higher in the food chain.

For receptors eating more than one kind of invertebrate, the contribution of different invertebrates may be compared. Gizzard shad and zooplankton are eating the plankton (P) food category, whereas carp are eating the worms (W) category. Table 7.5 shows that residues in the worms (W) category are generally lower than the plankton (P) category. One would assume worms (W) to be higher than plankton (P) because the benthic organisms are in contact with contaminated sediments. The worms category includes available measured residues for clams, worms, and mussels assembled from Tables 5.4, 5.5, and 5.8. The residues in the plankton category, which are assumed to be bioconcentrated from the water, were estimated by multiplying the water concentrations by either 100 for metals or by 1,000 for organics. Either the available measured values in clams, worms, and mussels are lower than expected relative to the sediment residues or the factors of 100 and 1,000 may be overly conservative or possibly the methods for calculating water concentrations from sediment concentrations overestimate the water concentrations. The above discussion underscores the importance of having synoptic, recently collected data on sediment, water, and biota to perform risk assessment at a site.

By examining the total risk (HQ total) to each receptor from exposure by all routes (Tables 9.9 to 9.16), the relative importance of different routes may

Table 9.1. Risk to Subsurface Benthos from eating contaminated food, where HQe = total risk from food.

	CASE			
	Typical		Worst	
	Organism Type: Inverte-brate; Food Type: Inverte-brate		Organism Type: Inverte-brate; Food Type: Inverte-brate	
CHEMICAL	HQ	HQe	HQ	HQe
Cadmium	2.1E+00	2.1E+00	1.1E+01	1.1E+01
Chromium	5.5E+01	5.5E+01	4.5E+02	4.5E+02
Copper	1.8E+02	1.8E+02	6.5E+02	6.5E+02
Iron	2.9E+03	2.9E+03	5.6E+03	5.6E+03
Lead	1.2E+01	1.2E+01	5.4E+02	5.4E+02
Manganese	5.1E+01	5.1E+01	7.5E+01	7.5E+01
Mercury	6.9E+00	6.9E+00	3.6E+01	3.6E+01
Nickel	1.9E+01	1.9E+01	3.0E+01	3.0E+01
Silver			7.1E+02	7.1E+02
Zinc	2.0E+01	2.0E+01	9.7E+01	9.7E+01
Acenaphthene			1.4E-01	1.4E-01
Acenaphthylene			6.2E-01	6.2E-01
Anthracene	3.6E-02	3.6E-02	3.0E-01	3.0E-01
Benzo(a)anthracene	3.2E+00	3.2E+00	2.5E+01	2.5E+01
Benzo(a)pyrene	1.8E+01	1.8E+01	7.4E+01	7.4E+01
Benzo(a)fluoranthene	9.7E+00	9.7E+00	1.7E+01	1.7E+01
Benzo(ghi)perylene	5.1E+00	5.1E+00	6.2E+01	6.2E+01
Benzo(k)fluoranthene			1.3E+01	1.3E+01
Chrysene	3.6E+00	3.6E+00	7.9E+00	7.9E+00
Dibenzo(a,h)anthracene			2.3E-02	2.3E-02
Fluoranthene	3.9E-03	3.9E-03	9.3E-03	9.3E-03
Fluorene	1.7E-01	1.7E-01	5.1E-01	5.1E-01
Indeno(1,2,3-cd)pyrene	1.5E+01	1.5E+01	1.9E+02	1.9E+02
Naphthalene	3.8E-02	3.8E-02	1.1E-01	1.1E-01
Phenanthrene	3.9E-01	3.9E-01	1.6E+00	1.6E+00
Pyrene	1.3E+01	1.3E+01	5.1E+01	5.1E+01
alpha-BHC			1.6E+00	1.6E+00
beta-BHC			1.1E+00	1.1E+00
Lindane (gamma-BHC)				
Aldrin				
Chlordane				
Dieldrin				
Endrin			2.3E+01	2.3E+01
Heptachlor				
Heptachlor epoxide	1.2E-01	1.2E-01	2.1E-01	2.1E-01
Hexachlorobenzene				
Mirex				
p,p'DDD			3.4E-03	3.4E-03
p,p'DDE			1.6E-03	1.6E-03
p,p'DDT			5.1E-01	5.1E-01
PCBs (total)			4.6E+02	4.6E+02

Table 9.2. Risk to Surface Benthos from eating contaminated food, where HQe = total risk from food.

	CASE			
	Typical		Worst	
	Organism Type: Inverte-brate; Food Type: Inverte-brate	HQe	Organism Type: Inverte-brate; Food Type: Inverte-brate	HQe
CHEMICAL	HQ	HQ	HQ	HQ
Cadmium	2.1E+00	2.1E+00	1.1E+01	1.1E+01
Chromium	5.5E+01	5.5E+01	4.5E+02	4.5E+02
Copper	1.8E+02	1.8E+02	6.5E+02	6.5E+02
Iron	2.9E+03	2.9E+03	5.6E+03	5.6E+03
Lead	1.2E+01	1.2E+01	5.4E+02	5.4E+02
Manganese	5.1E+01	5.1E+01	7.5E+01	7.5E+01
Mercury	6.9E+00	6.9E+00	3.6E+01	3.6E+01
Nickel	1.9E+01	1.9E+01	3.0E+01	3.0E+01
Silver			7.1E+02	7.1E+02
Zinc	2.0E+01	2.0E+01	9.7E+01	9.7E+01
Acenaphthene			1.4E-01	1.4E-01
Acenaphthylene			6.2E-01	6.2E-01
Anthracene	3.6E-02	3.6E-02	3.0E-01	3.0E-01
Benzo(a)anthracene	3.2E+00	3.2E+00	2.5E+01	2.5E+01
Benzo(a)pyrene	1.8E+01	1.8E+01	7.4E+01	7.4E+01
Benzo(a)fluoranthene	9.7E+00	9.7E+00	1.7E+01	1.7E+01
Benzo(ghi)perylene	5.1E+00	5.1E+00	6.2E+01	6.2E+01
Benzo(k)fluoranthene			1.3E+01	1.3E+01
Chrysene	3.6E+00	3.6E+00	7.9E+00	7.9E+00
Dibenzo(a,h)anthracene			2.3E-02	2.3E-02
Fluoranthene	3.9E-03	3.9E-03	9.3E-03	9.3E-03
Fluorene	1.7E-01	1.7E-01	5.1E-01	5.1E-01
Indeno(1,2,3-cd)pyrene	1.5E+01	1.5E+01	1.9E+02	1.9E+02
Naphthalene	3.8E-02	3.8E-02	1.1E-01	1.1E-01
Phenanthrene	3.9E-01	3.9E-01	1.6E+00	1.6E+00
Pyrene	1.3E+01	1.3E+01	5.1E+01	5.1E+01
alpha-BHC			1.6E+00	1.6E+00
beta-BHC			1.1E+00	1.1E+00
Lindane (gamma-BHC)				
Aldrin				
Chlordane				
Dieldrin				
Endrin			2.3E+01	2.3E+01
Heptachlor				
Heptachlor epoxide	1.2E-01	1.2E-01	2.1E-01	2.1E-01
Hexachlorobenzene				
Mirex				
p,p'DDD			3.4E-03	3.4E-03
p,p'DDE			1.6E-03	1.6E-03
p,p'DDT			5.1E-01	5.1E-01
PCBs (total)			4.6E+02	4.6E+02

Table 9.3. Risk to Aufwuchs from eating contaminated food, where HQe = total risk from food.

	CASE			
	Typical		Worst	
	Organism Type: Inverte-brate		Organism Type: Inverte-brate	
	Food Type: Inverte-brate	HQe	Food Type: Inverte-brate	HQe
CHEMICAL	HQ	HQ	HQ	HQ
Cadmium	2.1E+00	2.1E+00	1.1E+01	1.1E+01
Chromium	5.5E+01	5.5E+01	4.5E+02	4.5E+02
Copper	1.8E+02	1.8E+02	6.5E+02	6.5E+02
Iron	2.9E+03	2.9E+03	5.6E+03	5.6E+03
Lead	1.2E+01	1.2E+01	5.4E+02	5.4E+02
Manganese	5.1E+01	5.1E+01	7.5E+01	7.5E+01
Mercury	6.9E+00	6.9E+00	3.6E+01	3.6E+01
Nickel	1.9E+01	1.9E+01	3.0E+01	3.0E+01
Silver			7.1E+02	7.1E+02
Zinc	2.0E+01	2.0E+01	9.7E+01	9.7E+01
Acenaphthene			1.4E-01	1.4E-01
Acenaphthylene			6.2E-01	6.2E-01
Anthracene	3.6E-02	3.6E-02	3.0E-01	3.0E-01
Benzo(a)anthracene	3.2E+00	3.2E+00	2.5E+01	2.5E+01
Benzo(a)pyrene	1.8E+01	1.8E+01	7.4E+01	7.4E+01
Benzo(a)fluoranthene	9.7E+00	9.7E+00	1.7E+01	1.7E+01
Benzo(ghi)perylene	5.1E+00	5.1E+00	6.2E+01	6.2E+01
Benzo(k)fluoranthene			1.3E+01	1.3E+01
Chrysene	3.6E+00	3.6E+00	7.9E+00	7.9E+00
Dibenzo(a,h)anthracene			2.3E-02	2.3E-02
Fluoranthene	3.9E-03	3.9E-03	9.3E-03	9.3E-03
Fluorene	1.7E-01	1.7E-01	5.1E-01	5.1E-01
Indeno(1,2,3-cd)pyrene	1.5E+01	1.5E+01	1.9E+02	1.9E+02
Naphthalene	3.8E-02	3.8E-02	1.1E-01	1.1E-01
Phenanthrene	3.9E-01	3.9E-01	1.6E+00	1.6E+00
Pyrene	1.3E+01	1.3E+01	5.1E+01	5.1E+01
alpha-BHC			1.6E+00	1.6E+00
beta-BHC			1.1E+00	1.1E+00
Lindane (gamma-BHC)				
Aldrin				
Chlordane				
Dieldrin				
Endrin			2.3E+01	2.3E+01
Heptachlor				
Heptachlor epoxide	1.2E-01	1.2E-01	2.1E-01	2.1E-01
Hexachlorobenzene				
Mirex				
p,p'DDD			3.4E-03	3.4E-03
p,p'DDE			1.6E-03	1.6E-03
p,p'DDT			5.1E-01	5.1E-01
PCBs (total)			4.6E+02	4.6E+02

Table 9.4. Risk to Zooplankton from eating contaminated food, where HQe = total risk from food.

	CASE			
	Typical		Worst	
	Organism Type		Organism Type	
	Invertebrate		Invertebrate	
	Food Type		Food Type	
	Invertebrate	HQe	Invertebrate	HQe
CHEMICAL	HQ	HQ	HQ	HQ
Cadmium	5.2E-04	5.2E-04	1.0E-03	1.0E-03
Chromium	9.1E-03	9.1E-03	9.1E-03	9.1E-03
Copper	3.8E-03	3.8E-03	5.4E-03	5.4E-03
Iron	1.9E-02	1.9E-02	3.8E-02	3.8E-02
Lead	2.9E-03	2.9E-03	5.3E-03	5.3E-03
Manganese	1.9E-03	1.9E-03	4.3E-03	4.3E-03
Mercury	3.5E-04	3.5E-04	5.4E-04	5.4E-04
Nickel	3.1E-04	3.1E-04	5.0E-04	5.0E-04
Silver	1.7E-03	1.7E-03	1.7E-03	1.7E-03
Zinc	2.3E-04	2.3E-04	3.5E-04	3.5E-04
Acenaphthene			1.8E-02	1.8E-02
Acenaphthylene			1.6E-01	1.6E-01
Anthracene	1.6E-03	1.6E-03	1.4E-02	1.4E-02
Benzo(a)anthracene	1.0E-02	1.0E-02	8.0E-02	8.0E-02
Benzo(a)pyrene	2.0E-02	2.0E-02	8.3E-02	8.3E-02
Benzo(a)fluoranthene	1.1E-02	1.1E-02	1.9E-02	1.9E-02
Benzo(ghi)perylene	2.1E-03	2.1E-03	2.5E-02	2.5E-02
Benzo(k)fluoranthene			1.4E-02	1.4E-02
Chrysene	9.5E-03	9.5E-03	2.5E-02	2.5E-02
Dibenzo(a,h)anthracene			5.1E-06	5.1E-06
Fluoranthene	6.2E-05	6.2E-05	1.5E-04	1.5E-04
Fluorene	1.3E-02	1.3E-02	4.0E-02	4.0E-02
Indeno(1,2,3-cd)pyrene	6.2E-03	6.2E-03	7.9E-02	7.9E-02
Naphthalene	3.7E-03	3.7E-03	7.2E-02	7.2E-02
Phenanthrene	1.5E-02	1.5E-02	6.9E-02	6.9E-02
Pyrene	2.2E-01	2.2E-01	8.5E-01	8.5E-01
alpha-BHC			2.6E-01	2.6E-01
beta-BHC			1.7E-01	1.7E-01
Lindane (gamma-BHC)				
Aldrin				
Chlordane				
Dieldrin				
Endrin			1.3E-01	1.3E-01
Heptachlor				
Heptachlor epoxide	2.9E-02	2.9E-02	5.3E-01	5.3E-01
Hexachlorobenzene				
Mirex				
p,p'DDD			2.8E-06	2.8E-06
p,p'DDE			2.4E-07	2.4E-07
p,p'DDT			4.2E-04	4.2E-04
PCBs (total)			5.4E-01	5.4E-01

Table 9.5. Risk to Brown Bullhead from eating contaminated food, where HQe = total risk from food.

	CASE					
	Typical			Worst		
	Organism Type			Organism Type		
	Fish			Fish		
	Food Type			Food Type		
	Fish	Inverte-brate	HQe	Fish	Inverte-brate	HQe
CHEMICAL	HQ	HQ	HQ	HQ	HQ	HQ
Cadmium	3.0E-04	5.2E-03	2.8E-03		2.6E-02	2.6E-02
Chromium						
Copper	5.0E-01	1.1E-02	2.6E-01	8.5E+00	2.5E-02	4.3E+00
Iron						
Lead						
Manganese						
Mercury	1.9E+00	1.1E-03	9.5E-01	3.7E+01	3.4E-03	1.9E+01
Nickel						
Silver						
Zinc						
Acenaphthene						
Acenaphthylene						
Anthracene	1.8E-03	1.1E-07	9.0E-04	8.4E-03	1.4E-06	4.2E-03
Benzo(a)anthracene		1.6E-06	1.6E-06		3.0E-05	3.0E-05
Benzo(a)pyrene		4.7E-06	4.7E-06		1.5E-04	1.5E-04
Benzo(a)fluoranthene		2.6E-05	2.6E-05	8.6E-03	3.2E-05	4.3E-03
Benzo(ghi)perylene	8.3E-02	2.4E-05	4.2E-02	8.9E-02	1.4E-04	4.5E-02
Benzo(k)fluoranthene	7.4E-04	1.1E-05	3.8E-04	1.3E-03	1.9E-05	6.6E-04
Chrysene		2.9E-05	2.9E-05		3.4E-05	3.4E-05
Dibenzo(a,h)anthracene		5.7E-08	5.7E-08		4.6E-08	4.6E-08
Fluoranthene	5.2E-04	1.7E-08	2.6E-04	7.6E-04	1.1E-07	3.8E-04
Fluorene						
Indeno(1,2,3-cd)pyrene		1.2E-05	1.2E-05		3.0E-04	3.0E-04
Naphthalene						
Phenanthrene	5.0E-07	9.6E-10	2.5E-07	5.6E-06	1.9E-09	2.8E-06
Pyrene		2.8E-06	2.8E-06		3.8E-04	3.8E-04
alpha-BHC	2.1E-03	7.5E-03	4.8E-03		1.3E-02	1.3E-02
beta-BHC	2.0E-03		2.0E-03		7.1E-03	7.1E-03
Lindane (gamma-BHC)	7.1E-01	2.5E+00	1.6E+00		6.7E+00	6.7E+00
Aldrin	5.3E-02		5.3E-02			
Chlordane	2.2E+02	6.4E-01	1.1E+02		4.1E+00	4.1E+00
Dieldrin	4.0E+00		4.0E+00			
Endrin						
Heptachlor	6.2E-01		6.2E-01		7.9E-01	7.9E-01
Heptachlor epoxide	3.8E-01		3.8E-01		2.2E-03	2.2E-03
Hexachlorobenzene	4.5E-02	1.1E-02	2.8E-02	4.2E-01	2.5E-01	3.4E-01
Mirex	1.2E+00		1.2E+00			
p,p'DDD	2.1E-03		2.1E-03	1.8E-03	5.5E-04	1.2E-03
p,p'DDE	1.1E-03	8.7E-05	5.9E-04	1.1E-03	3.0E-04	7.0E-04
p,p'DDT	1.7E-03	8.1E-03	4.9E-03	1.4E-02	4.9E-02	3.2E-02
PCBs (total)	1.2E+03	1.5E+00	6.0E+02	2.6E+03	3.3E+01	1.3E+03

Table 9.6. Risk to Carp from eating contaminated food, where HQe = total risk from food.

	CASE			
	Typical		Worst	
	Organism Type: Fish		Organism Type: Fish	
	Food Type: Inverte-brate	HQe	Food Type: Inverte-brate	HQe
CHEMICAL	HQ	HQ	HQ	HQ
Cadmium	5.2E-03	5.2E-03	2.6E-02	2.6E-02
Chromium				
Copper	1.1E-02	1.1E-02	2.5E-02	2.5E-02
Iron				
Lead				
Manganese				
Mercury	1.1E-03	1.1E-03	3.4E-03	3.4E-03
Nickel				
Silver				
Zinc				
Acenaphthene				
Acenaphthylene				
Anthracene	1.1E-07	1.1E-07	1.4E-06	1.4E-06
Benzo(a)anthracene	1.6E-06	1.6E-06	3.0E-05	3.0E-05
Benzo(a)pyrene	4.7E-06	4.7E-06	1.5E-04	1.5E-04
Benzo(a)fluoranthene	2.6E-05	2.6E-05	3.2E-05	3.2E-05
Benzo(ghi)perylene	2.4E-05	2.4E-05	1.4E-04	1.4E-04
Benzo(k)fluoranthene	1.1E-05	1.1E-05	1.9E-05	1.9E-05
Chrysene	2.9E-05	2.9E-05	3.4E-05	3.4E-05
Dibenzo(a,h)anthracene	5.7E-08	5.7E-08	4.6E-08	4.6E-08
Fluoranthene	1.7E-08	1.7E-08	1.1E-07	1.1E-07
Fluorene				
Indeno(1,2,3-cd)pyrene	1.2E-05	1.2E-05	3.0E-04	3.0E-04
Naphthalene				
Phenanthrene	9.6E-10	9.6E-10	1.9E-09	1.9E-09
Pyrene	2.8E-06	2.8E-06	3.8E-04	3.8E-04
alpha-BHC	7.5E-03	7.5E-03	1.3E-02	1.3E-02
beta-BHC			7.1E-03	7.1E-03
Lindane (gamma-BHC)	2.5E+00	2.5E+00	6.7E+00	6.7E+00
Aldrin				
Chlordane	6.4E-01	6.4E-01	4.1E+00	4.1E+00
Dieldrin				
Endrin				
Heptachlor			7.9E-01	7.9E-01
Heptachlor epoxide			2.2E-03	2.2E-03
Hexachlorobenzene	1.1E-02	1.1E-02	2.5E-01	2.5E-01
Mirex				
p,p'DDD			5.5E-04	5.5E-04
p,p'DDE	8.7E-05	8.7E-05	3.0E-04	3.0E-04
p,p'DDT	8.1E-03	8.1E-03	4.9E-02	4.9E-02
PCBs (total)	1.5E+00	1.5E+00	3.3E+01	3.3E+01

Table 9.7. Risk to Gizzard Shad from eating contaminated food, where HQe = total risk from food.

	CASE			
	Typical		Worst	
	Organism Type		Organism Type	
	Fish		Fish	
	Food Type		Food Type	
	Inverte-brate	HQe	Inverte-brate	HQe
CHEMICAL	HQ	HQ	HQ	HQ
Cadmium	5.2E-04	5.2E-04	1.0E-03	1.0E-03
Chromium	9.1E-03	9.1E-03	9.1E-03	9.1E-03
Copper	3.8E-03	3.8E-03	5.4E-03	5.4E-03
Iron	1.9E-02	1.9E-02	3.8E-02	3.8E-02
Lead	2.9E-03	2.9E-03	5.3E-03	5.3E-03
Manganese	1.9E-03	1.9E-03	4.3E-03	4.3E-03
Mercury	3.5E-04	3.5E-04	5.4E-04	5.4E-04
Nickel	3.1E-04	3.1E-04	5.0E-04	5.0E-04
Silver	1.7E-03	1.7E-03	1.7E-03	1.7E-03
Zinc	2.3E-04	2.3E-04	3.5E-04	3.5E-04
Acenaphthene			1.8E-02	1.8E-02
Acenaphthylene			9.9E-02	9.9E-02
Anthracene	1.2E-03	1.2E-03	1.0E-02	1.0E-02
Benzo(a)anthracene	1.9E-03	1.9E-03	1.5E-02	1.5E-02
Benzo(a)pyrene	3.6E-03	3.6E-03	1.5E-02	1.5E-02
Benzo(a)fluoranthene	1.6E-03	1.6E-03	2.9E-03	2.9E-03
Benzo(ghi)perylene	3.7E-04	3.7E-04	4.5E-03	4.5E-03
Benzo(k)fluoranthene			2.2E-03	2.2E-03
Chrysene	1.7E-03	1.7E-03	4.5E-03	4.5E-03
Dibenzo(a,h)anthracene			5.1E-06	5.1E-06
Fluoranthene	6.2E-05	6.2E-05	1.5E-04	1.5E-04
Fluorene	1.3E-02	1.3E-02	4.0E-02	4.0E-02
Indeno(1,2,3-cd)pyrene	1.4E-03	1.4E-03	1.8E-02	1.8E-02
Naphthalene	3.7E-03	3.7E-03	7.2E-02	7.2E-02
Phenanthrene	2.1E-06	2.1E-06	9.2E-06	9.2E-06
Pyrene	2.2E-01	2.2E-01	8.5E-01	8.5E-01
alpha-BHC			3.7E-02	3.7E-02
beta-BHC			2.2E-02	2.2E-02
Lindane (gamma-BHC)				
Aldrin				
Chlordane				
Dieldrin				
Endrin			1.3E-01	1.3E-01
Heptachlor				
Heptachlor epoxide	2.9E-02	2.9E-02	5.3E-01	5.3E-01
Hexachlorobenzene				
Mirex				
p,p'DDD			6.4E-07	6.4E-07
p,p'DDE			2.4E-07	2.4E-07
p,p'DDT			8.8E-05	8.8E-05
PCBs (total)			5.4E-01	5.4E-01

Table 9.8. Risk to Pumpkinseed from eating contaminated food, where HQe = total risk from food.

	CASE					
	Typical			Worst		
	Organism Type			Organism Type		
	Fish			Fish		
	Food Type			Food Type		
	Fish	Inverte-brate	HQe	Fish	Inverte-brate	HQe
CHEMICAL	HQ	HQ	HQ	HQ	HQ	HQ
Cadmium	1.8E+00	2.9E-02	9.1E-01	3.6E+00	6.5E-02	1.8E+00
Chromium	1.8E+00	9.1E-01	1.4E+00	1.8E+00	9.1E-01	1.4E+00
Copper	7.5E-01	1.9E-01	4.7E-01	1.1E+00	2.8E-01	6.9E-01
Iron	1.9E+00	1.9E+00	1.9E+00	3.8E+00	3.8E+00	3.8E+00
Lead	5.0E+00	2.9E-01	2.6E+00	9.1E+00	5.3E-01	4.8E+00
Manganese	1.9E-01	1.9E-01	1.9E-01	4.3E-01	4.3E-01	4.3E-01
Mercury	1.4E+01	1.8E-02	7.0E+00	2.2E+01	2.9E-02	1.1E+01
Nickel	3.1E-02	3.1E-02	3.1E-02	5.0E-02	5.0E-02	5.0E-02
Silver	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01
Zinc	2.6E-01	2.3E-02	1.4E-01	4.0E-01	3.5E-02	2.2E-01
Acenaphthene				9.4E-03	7.0E-02	4.0E-02
Acenaphthylene				3.0E-02	3.8E-01	2.1E-01
Anthracene	4.3E-03	2.4E-03	3.4E-03	3.6E-02	2.0E-02	2.8E-02
Benzo(a)anthracene	2.3E-02	4.1E-03	1.4E-02	1.8E-01	3.2E-02	1.1E-01
Benzo(a)pyrene	5.8E-02	9.7E-03	3.4E-02	2.4E-01	4.1E-02	1.4E-01
Benzo(a)fluoranthene	6.2E-02	4.4E-03	3.3E-02	1.1E-01	7.8E-03	5.9E-02
Benzo(ghi)perylene	4.5E-02	1.5E-03	2.3E-02	5.5E-01	1.8E-02	2.8E-01
Benzo(k)fluoranthene		5.7E-06	5.7E-06	8.3E-02	5.9E-03	4.4E-02
Chrysene	2.5E-02	4.6E-03	1.5E-02	5.4E-02	9.9E-03	3.2E-02
Dibenzo(a,h)anthracene		2.8E-08	2.8E-08	1.6E-03	3.0E-05	8.2E-04
Fluoranthene	2.5E-03	1.2E-04	1.3E-03	5.9E-03	2.9E-04	3.1E-03
Fluorene	1.0E-02	5.2E-02	3.1E-02	3.1E-02	1.6E-01	9.6E-02
Indeno(1,2,3-cd)pyrene	1.8E-01	5.8E-03	9.3E-02	2.2E+00	7.4E-02	1.1E+00
Naphthalene	1.3E-02	9.6E-02	5.5E-02	3.6E-02	2.8E-01	1.6E-01
Phenanthrene	2.9E-06	4.5E-06	3.7E-06	1.2E-05	1.8E-05	1.5E-05
Pyrene	2.4E+00	4.4E-01	1.4E+00	9.2E+00	1.7E+00	5.5E+00
alpha-BHC		3.8E-03	3.8E-03	1.4E-02	7.7E-02	4.6E-02
beta-BHC				8.5E-03	4.6E-02	2.7E-02
Lindane (gamma-BHC)		1.3E+00	1.3E+00		3.3E+00	3.3E+00
Aldrin						
Chlordane		3.2E-01	3.2E-01		2.1E+00	2.1E+00
Dieldrin						
Endrin				1.1E+00	5.5E-01	8.3E-01
Heptachlor					3.9E-01	3.9E-01
Heptachlor epoxide	2.0E+00	1.1E+00	1.6E+00	3.5E+00	1.0E+00	2.3E+00
Hexachlorobenzene		5.3E-03	5.3E-03		1.3E-01	1.3E-01
Mirex						
p,p'DDD	4.2E-04		4.2E-04	1.8E-03	2.8E-04	1.0E-03
p,p'DDE	2.9E-04	4.3E-05	1.7E-04	1.1E-03	1.5E-04	6.3E-04
p,p'DDT		4.1E-03	4.1E-03	1.3E-03	2.5E-02	1.3E-02
PCBs (total)	6.9E+00	7.7E-01	3.8E+00	3.8E+01	1.8E+01	2.8E+01

Table 9.9. Risk to Subsurface Benthos from exposure to each medium and total risk, where HQe = food, HQs = sediment, and HQw = water.

	CASE					
	Typical			Worst		
	VEHICLE			VEHICLE		
	HQe	HQs	HQ Total	HQe	HQs	HQ Total
CHEMICAL	RISK	RISK	RISK	RISK	RISK	RISK
Cadmium	2.1E+00	2.6E-02	2.1E+00	1.1E+01	1.4E-01	1.1E+01
Chromium	5.5E+01	1.8E+00	5.7E+01	4.5E+02	1.5E+01	4.7E+02
Copper	1.8E+02	3.2E-01	1.8E+02	6.5E+02	1.2E+00	6.5E+02
Iron	2.9E+03	1.9E+00	2.9E+03	5.6E+03	3.7E+00	5.6E+03
Lead	1.2E+01	4.8E-02	1.2E+01	5.4E+02	2.2E+00	5.4E+02
Manganese	5.1E+01	2.0E-01	5.1E+01	7.5E+01	2.9E-01	7.5E+01
Mercury	6.9E+00	1.1E+01	1.8E+01	3.6E+01	5.7E+01	9.3E+01
Nickel	1.9E+01	3.1E-02	1.9E+01	3.0E+01	5.0E-02	3.0E+01
Silver				7.1E+02	1.7E-01	7.1E+02
Zinc	2.0E+01	3.3E-01	2.0E+01	9.7E+01	1.6E+00	9.9E+01
Acenaphthene				1.4E-01	1.5E-02	1.6E-01
Acenaphthylene				6.2E-01	4.6E-02	6.7E-01
Anthracene	3.6E-02	4.1E-03	4.0E-02	3.0E-01	3.4E-02	3.3E-01
Benzo(a)anthracene	3.2E+00	1.4E-02	3.2E+00	2.5E+01	1.1E-01	2.5E+01
Benzo(a)pyrene	1.8E+01	2.8E-02	1.8E+01	7.4E+01	1.2E-01	7.4E+01
Benzo(a)fluoranthene	9.7E+00	2.9E-01	1.0E+01	1.7E+01	5.1E-01	1.8E+01
Benzo(ghi)perylene	5.1E+00	1.1E-01	5.2E+00	6.2E+01	1.4E+00	6.3E+01
Benzo(k)fluoranthene				1.3E+01	3.9E-01	1.3E+01
Chrysene	3.6E+00	1.5E-03	3.6E+00	7.9E+00	3.3E-03	7.9E+00
Dibenzo(a,h)anthracene				2.3E-02	4.8E-04	2.3E-02
Fluoranthene	3.9E-03	2.6E-02	3.0E-02	9.3E-03	6.0E-02	6.9E-02
Fluorene	1.7E-01	1.0E-02	1.8E-01	5.1E-01	3.1E-02	5.4E-01
Indeno(1,2,3-cd)pyrene	1.5E+01	3.5E-01	1.5E+01	1.9E+02	4.4E+00	1.9E+02
Naphthalene	3.8E-02	7.4E-03	4.5E-02	1.1E-01	2.1E-02	1.3E-01
Phenanthrene	3.9E-01	1.4E-01	5.3E-01	1.6E+00	5.5E-01	2.2E+00
Pyrene	1.3E+01	2.2E-02	1.3E+01	5.1E+01	8.5E-02	5.1E+01
alpha-BHC				1.6E+00	1.0E-01	1.7E+00
beta-BHC				1.1E+00	6.6E-02	1.2E+00
Lindane (gamma-BHC)						
Aldrin						
Chlordane						
Dieldrin						
Endrin				2.3E+01	4.3E-01	2.3E+01
Heptachlor						
Heptachlor epoxide	1.2E-01	1.9E+00	2.0E+00	2.1E-01	3.5E+00	3.7E+00
Hexachlorobenzene						
Mirex						
p,p'DDD				3.4E-03	3.8E-04	3.8E-03
p,p'DDE				1.6E-03	6.8E-04	2.3E-03
p,p'DDT				5.1E-01	4.8E-02	5.6E-01
PCBs (total)				4.6E+02	1.4E-02	4.6E+02

Table 9.10. Risk to Surface Benthos from exposure to each medium and total risk, where HQe = food, HQs = sediment, and HQw = water.

CHEMICAL	CASE							
	Typical				Worst			
	VEHICLE				VEHICLE			
	HQe	HQs	HQw	HQ Total	HQe	HQs	HQw	HQ Total
	RISK	RISK	RISK	RISK	RISK	RISK	RISK	RISK
Cadmium	2.1E+00	2.6E-02	1.8E+00	3.9E+00	1.1E+01	1.4E-01	3.6E+00	1.5E+01
Chromium	5.5E+01	1.8E+00	1.8E+00	5.9E+01	4.5E+02	1.5E+01	1.8E+00	4.7E+02
Copper	1.8E+02	3.2E-01	7.5E-01	1.8E+02	6.5E+02	1.2E+00	1.1E+00	6.5E+02
Iron	2.9E+03	1.9E+00	1.9E+00	2.9E+03	5.6E+03	3.7E+00	3.8E+00	5.6E+03
Lead	1.2E+01	4.8E-02	5.0E+00	1.7E+01	5.4E+02	2.2E+00	9.1E+00	5.5E+02
Manganese	5.1E+01	2.0E-01	1.9E-01	5.1E+01	7.5E+01	2.9E-01	4.3E-01	7.6E+01
Mercury	6.9E+00	1.1E+01	1.4E+01	3.2E+01	3.6E+01	5.7E+01	2.2E+01	1.2E+02
Nickel	1.9E+01	3.1E-02	3.1E-02	1.9E+01	3.0E+01	5.0E-02	5.0E-02	3.0E+01
Silver			1.7E-01	1.7E-01	7.1E+02	1.7E-01	1.7E-01	7.1E+02
Zinc	2.0E+01	3.3E-01	2.6E-01	2.1E+01	9.7E+01	1.6E+00	4.0E-01	9.9E+01
Acenaphthene					1.4E-01	1.5E-02	9.4E-03	1.6E-01
Acenaphthylene					6.2E-01	4.6E-02	4.7E-02	7.1E-01
Anthracene	3.6E-02	4.1E-03	5.7E-03	4.6E-02	3.0E-01	3.4E-02	4.8E-02	3.8E-01
Benzo(a)anthracene	3.2E+00	1.4E-02	1.2E-01	3.3E+00	2.5E+01	1.1E-01	9.8E-01	2.6E+01
Benzo(a)pyrene	1.8E+01	2.8E-02	3.2E-01	1.8E+01	7.4E+01	1.2E-01	1.3E+00	7.5E+01
Benzo(a)fluoranthene	9.7E+00	2.9E-01	4.2E-01	1.0E+01	1.7E+01	5.1E-01	7.3E-01	1.8E+01
Benzo(ghi)perylene	5.1E+00	1.1E-01	2.5E-01	5.5E+00	6.2E+01	1.4E+00	3.1E+00	6.7E+01
Benzo(k)fluoranthene					1.3E+01	3.9E-01	5.5E-01	1.4E+01
Chrysene	3.6E+00	1.5E-03	1.4E-01	3.7E+00	7.9E+00	3.3E-03	3.0E-01	8.2E+00
Dibenzo(a,h)anthracene					2.3E-02	4.8E-04	1.6E-03	2.5E-02
Fluoranthene	3.9E-03	2.6E-02	2.5E-03	3.2E-02	9.3E-03	6.0E-02	5.9E-03	7.5E-02
Fluorene	1.7E-01	1.0E-02	1.0E-02	1.9E-01	5.1E-01	3.1E-02	3.1E-02	5.7E-01
Indeno(1,2,3-cd)pyrene	1.5E+01	3.5E-01	7.5E-01	1.6E+01	1.9E+02	4.4E+00	9.5E+00	2.0E+02
Naphthalene	3.8E-02	7.4E-03	1.3E-02	5.8E-02	1.1E-01	2.1E-02	3.6E-02	1.7E-01
Phenanthrene	3.9E-01	1.4E-01	2.2E-02	5.5E-01	1.6E+00	5.5E-01	8.9E-02	2.2E+00
Pyrene	1.3E+01	2.2E-02	2.4E+00	1.5E+01	5.1E+01	8.5E-02	9.2E+00	6.0E+01
alpha-BHC					1.6E+00	1.0E-01	1.0E-01	1.8E+00
beta-BHC					1.1E+00	6.6E-02	6.6E-02	1.2E+00
Lindane (gamma-BHC)								
Aldrin								
Chlordane								
Dieldrin								
Endrin					2.3E+01	4.3E-01	1.1E+00	2.5E+01
Heptachlor								
Heptachlor epoxide	1.2E-01	1.9E+00	2.0E+00	4.0E+00	2.1E-01	3.5E+00	3.5E+00	7.2E+00
Hexachlorobenzene								
Mirex								
p,p'DDD					3.4E-03	3.8E-04	1.5E-04	3.9E-03
p,p'DDE					1.6E-03	6.8E-04	1.4E-04	2.4E-03
p,p'DDT					5.1E-01	4.8E-02	6.4E-03	5.6E-01
PCBs (total)					4.6E+02	1.4E-02	1.7E+01	4.8E+02

Table 9.11. Risk to Aufwuchs from exposure to each medium and total risk, where HQe = food, HQs = sediment, and HQw = water.

	CASE							
	Typical				Worst			
	VEHICLE				VEHICLE			
	HQe	HQs	HQw	HQ Total	HQe	HQs	HQw	HQ Total
CHEMICAL	RISK	RISK	RISK	RISK	RISK	RISK	RISK	RISK
Cadmium	2.1E+00	2.6E-02	1.8E+00	3.9E+00	1.1E+01	1.4E-01	3.6E+00	1.5E+01
Chromium	5.5E+01	1.8E+00	1.8E+00	5.9E+01	4.5E+02	1.5E+01	1.8E+00	4.7E+02
Copper	1.8E+02	3.2E-01	7.5E-01	1.8E+02	6.5E+02	1.2E+00	1.1E+00	6.5E+02
Iron	2.9E+03	1.9E+00	1.9E+00	2.9E+03	5.6E+03	3.7E+00	3.8E+00	5.6E+03
Lead	1.2E+01	4.8E-02	5.0E+00	1.7E+01	5.4E+02	2.2E+00	9.1E+00	5.5E+02
Manganese	5.1E+01	2.0E-01	1.9E-01	5.1E+01	7.5E+01	2.9E-01	4.3E-01	7.6E+01
Mercury	6.9E+00	1.1E+01	1.4E+01	3.2E+01	3.6E+01	5.7E+01	2.2E+01	1.2E+02
Nickel	1.9E+01	3.1E-02	3.1E-02	1.9E+01	3.0E+01	5.0E-02	5.0E-02	3.0E+01
Silver			1.7E-01	1.7E-01	7.1E+02	1.7E-01	1.7E-01	7.1E+02
Zinc	2.0E+01	3.3E-01	2.6E-01	2.1E+01	9.7E+01	1.6E+00	4.0E-01	9.9E+01
Acenaphthene					1.4E-01	1.5E-02	9.4E-03	1.6E-01
Acenaphthylene					6.2E-01	4.6E-02	4.7E-02	7.1E-01
Anthracene	3.6E-02	4.1E-03	5.7E-03	4.6E-02	3.0E-01	3.4E-02	4.8E-02	3.8E-01
Benzo(a)anthracene	3.2E+00	1.4E-02	1.2E-01	3.3E+00	2.5E+01	1.1E-01	9.8E-01	2.6E+01
Benzo(a)pyrene	1.8E+01	2.8E-02	3.2E-01	1.8E+01	7.4E+01	1.2E-01	1.3E+00	7.5E+01
Benzo(a)fluoranthene	9.7E+00	2.9E-01	4.2E-01	1.0E+01	1.7E+01	5.1E-01	7.3E-01	1.8E+01
Benzo(ghi)perylene	5.1E+00	1.1E-01	2.5E-01	5.5E+00	6.2E+01	1.4E+00	3.1E+00	6.7E+01
Benzo(k)fluoranthene					1.3E+01	3.9E-01	5.5E-01	1.4E+01
Chrysene	3.6E+00	1.5E-03	1.4E-01	3.7E+00	7.9E+00	3.3E-03	3.0E-01	8.2E+00
Dibenzo(a,h)anthracene					2.3E-02	4.8E-04	1.6E-03	2.5E-02
Fluoranthene	3.9E-03	2.6E-02	2.5E-03	3.2E-02	9.3E-03	6.0E-02	5.9E-03	7.5E-02
Fluorene	1.7E-01	1.0E-02	1.0E-02	1.9E-01	5.1E-01	3.1E-02	3.1E-02	5.7E-01
Indeno(1,2,3-cd)pyrene	1.5E+01	3.5E-01	7.5E-01	1.6E+01	1.9E+02	4.4E+00	9.5E+00	2.0E+02
Naphthalene	3.8E-02	7.4E-03	1.3E-02	5.8E-02	1.1E-01	2.1E-02	3.6E-02	1.7E-01
Phenanthrene	3.9E-01	1.4E-01	2.2E-02	5.5E-01	1.6E+00	5.5E-01	8.9E-02	2.2E+00
Pyrene	1.3E+01	2.2E-02	2.4E+00	1.5E+01	5.1E+01	8.5E-02	9.2E+00	6.0E+01
alpha-BHC					1.6E+00	1.0E-01	1.0E-01	1.8E+00
beta-BHC					1.1E+00	6.6E-02	6.6E-02	1.2E+00
Lindane (gamma-BHC)								
Aldrin								
Chlordane								
Dieldrin								
Endrin					2.3E+01	4.3E-01	1.1E+00	2.5E+01
Heptachlor								
Heptachlor epoxide	1.2E-01	1.9E+00	2.0E+00	4.0E+00	2.1E-01	3.5E+00	3.5E+00	7.2E+00
Hexachlorobenzene								
Mirex								
p,p'DDD					3.4E-03	3.8E-04	1.5E-04	3.9E-03
p,p'DDE					1.6E-03	6.8E-04	1.4E-04	2.4E-03
p,p'DDT					5.1E-01	4.8E-02	6.4E-03	5.6E-01
PCBs (total)					4.6E+02	1.4E-02	1.7E+01	4.8E+02

Table 9.12. Risk to Zooplankton from exposure to each medium and total risk, where HQe = food, HQs = sediment, and HQw = water.

CHEMICAL	CASE							
	Typical				Worst			
	VEHICLE				VEHICLE			
	HQe	HQs	HQw	HQ Total	HQe	HQs	HQw	HQ Total
	RISK	RISK	RISK	RISK	RISK	RISK	RISK	RISK
Cadmium	5.2E-04	2.6E-02	1.8E+00	1.8E+00	1.0E-03	1.4E-01	3.6E+00	3.7E+00
Chromium	9.1E-03	1.8E+00	1.8E+00	3.6E+00	9.1E-03	1.5E+01	1.8E+00	1.7E+01
Copper	3.8E-03	3.2E-01	7.5E-01	1.1E+00	5.4E-03	1.2E+00	1.1E+00	2.3E+00
Iron	1.9E-02	1.9E+00	1.9E+00	3.8E+00	3.8E-02	3.7E+00	3.8E+00	7.5E+00
Lead	2.9E-03	4.8E-02	5.0E+00	5.1E+00	5.3E-03	2.2E+00	9.1E+00	1.1E+01
Manganese	1.9E-03	2.0E-01	1.9E-01	3.9E-01	4.3E-03	2.9E-01	4.3E-01	7.2E-01
Mercury	3.5E-04	1.1E+01	1.4E+01	2.5E+01	5.4E-04	5.7E+01	2.2E+01	7.9E+01
Nickel	3.1E-04	3.1E-02	3.1E-02	6.2E-02	5.0E-04	5.0E-02	5.0E-02	1.0E-01
Silver	1.7E-03		1.7E-01	1.7E-01	1.7E-03	1.7E-01	1.7E-01	3.4E-01
Zinc	2.3E-04	3.3E-01	2.6E-01	5.9E-01	3.5E-04	1.6E+00	4.0E-01	2.0E+00
Acenaphthene					1.8E-02	1.5E-02	9.4E-03	4.2E-02
Acenaphthylene					1.6E-01	4.6E-02	4.7E-02	2.5E-01
Anthracene	1.6E-03	4.1E-03	5.7E-03	1.1E-02	1.4E-02	3.4E-02	4.8E-02	9.6E-02
Benzo(a)anthracene	1.0E-02	1.4E-02	1.2E-01	1.4E-01	8.0E-02	1.1E-01	9.8E-01	1.2E+00
Benzo(a)pyrene	2.0E-02	2.8E-02	3.2E-01	3.7E-01	8.3E-02	1.2E-01	1.3E+00	1.5E+00
Benzo(a)fluoranthene	1.1E-02	2.9E-01	4.2E-01	7.2E-01	1.9E-02	5.1E-01	7.3E-01	1.3E+00
Benzo(ghi)perylene	2.1E-03	1.1E-01	2.5E-01	3.6E-01	2.5E-02	1.4E+00	3.1E+00	4.5E+00
Benzo(k)fluoranthene					1.4E-02	3.9E-01	5.5E-01	9.5E-01
Chrysene	9.5E-03	1.5E-03	1.4E-01	1.5E-01	2.5E-02	3.3E-03	3.0E-01	3.3E-01
Dibenzo(a,h)anthracene					5.1E-06	4.8E-04	1.6E-03	2.1E-03
Fluoranthene	6.2E-05	2.6E-02	2.5E-03	2.9E-02	1.5E-04	6.0E-02	5.9E-03	6.6E-02
Fluorene	1.3E-02	1.0E-02	1.0E-02	3.3E-02	4.0E-02	3.1E-02	3.1E-02	1.0E-01
Indeno(1,2,3-cd)pyrene	6.2E-03	3.5E-01	7.5E-01	1.1E+00	7.9E-02	4.4E+00	9.5E+00	1.4E+01
Naphthalene	3.7E-03	7.4E-03	1.3E-02	2.4E-02	7.2E-02	2.1E-02	3.6E-02	1.3E-01
Phenanthrene	1.5E-02	1.4E-01	2.2E-02	1.8E-01	6.9E-02	5.5E-01	8.9E-02	7.1E-01
Pyrene	2.2E-01	2.2E-02	2.4E+00	2.6E+00	8.5E-01	8.5E-02	9.2E+00	1.0E+01
alpha-BHC					2.6E-01	1.0E-01	1.0E-01	4.6E-01
beta-BHC					1.7E-01	6.6E-02	6.6E-02	3.0E-01
Lindane (gamma-BHC)								
Aldrin								
Chlordane								
Dieldrin								
Endrin					1.3E-01	4.3E-01	1.1E+00	1.7E+00
Heptachlor								
Heptachlor epoxide	2.9E-02	1.9E+00	2.0E+00	3.9E+00	5.3E-01	3.5E+00	3.5E+00	7.5E+00
Hexachlorobenzene								
Mirex								
p,p'DDD					2.8E-06	3.8E-04	1.5E-04	5.3E-04
p,p'DDE					2.4E-07	6.8E-04	1.4E-04	8.2E-04
p,p'DDT					4.2E-04	4.8E-02	6.4E-03	5.5E-02
PCBs (total)					5.4E-01	1.4E-02	1.7E+01	1.8E+01

Table 9.13. Risk to Brown Bullhead from exposure to each medium and total risk, where HQe = food, HQs = sediment, and HQw = water.

	CASE							
	Typical				Worst			
	VEHICLE				VEHICLE			
	HQe	HQs	HQw	HQ Total	HQe	HQs	HQw	HQ Total
CHEMICAL	RISK	RISK	RISK	RISK	RISK	RISK	RISK	RISK
Cadmium	2.7E-03	2.6E-02	1.8E+00	1.8E+00	2.6E-02	1.4E-01	3.6E+00	3.8E+00
Chromium		1.8E+00	1.8E+00	3.6E+00		1.5E+01	1.8E+00	1.7E+01
Copper	2.6E-01	3.2E-01	7.5E-01	1.3E+00	4.2E+00	1.2E+00	1.1E+00	6.5E+00
Iron		1.9E+00	1.9E+00	3.8E+00		3.7E+00	3.8E+00	7.5E+00
Lead		4.8E-02	5.0E+00	5.0E+00		2.2E+00	9.1E+00	1.1E+01
Manganese		2.0E-01	1.9E-01	3.9E-01		2.9E-01	4.3E-01	7.2E-01
Mercury	9.4E-01	1.1E+01	1.4E+01	2.6E+01	1.8E+01	5.7E+01	2.2E+01	9.7E+01
Nickel		3.1E-02	3.1E-02	6.2E-02		5.0E-02	5.0E-02	1.0E-01
Silver			1.7E-01	1.7E-01		1.7E-01	1.7E-01	3.4E-01
Zinc		3.3E-01	2.6E-01	5.9E-01		1.6E+00	4.0E-01	2.0E+00
Acenaphthene						1.5E-02	9.4E-03	2.4E-02
Acenaphthylene						3.0E-02	3.0E-02	6.0E-02
Anthracene	8.8E-04	4.1E-03	4.3E-03	9.3E-03	4.2E-03	3.4E-02	3.6E-02	7.4E-02
Benzo(a)anthracene	1.6E-06	1.4E-02	2.3E-02	3.7E-02	3.0E-05	1.1E-01	1.8E-01	2.9E-01
Benzo(a)pyrene	4.7E-06	2.8E-02	5.8E-02	8.6E-02	1.5E-04	1.2E-01	2.4E-01	3.6E-01
Benzo(a)fluoranthene	2.6E-05	4.4E-02	6.2E-02	1.1E-01	4.3E-03	7.7E-02	1.1E-01	1.9E-01
Benzo(ghi)perylene	4.1E-02	2.1E-02	4.5E-02	1.1E-01	4.4E-02	2.5E-01	5.5E-01	8.4E-01
Benzo(k)fluoranthene	3.7E-04			3.7E-04	6.8E-04	5.8E-02	8.3E-02	1.4E-01
Chrysene	2.9E-05	1.5E-03	2.5E-02	2.7E-02	3.4E-05	3.3E-03	5.4E-02	5.7E-02
Dibenzo(a,h)anthracene	5.7E-08			5.7E-08	4.6E-08	4.8E-04	1.6E-03	2.1E-03
Fluoranthene	2.6E-04	2.6E-02	2.5E-03	2.9E-02	3.8E-04	6.0E-02	5.9E-03	6.6E-02
Fluorene		1.0E-02	1.0E-02	2.0E-02		3.1E-02	3.1E-02	6.2E-02
Indeno(1,2,3-cd)pyrene	1.2E-05	8.1E-02	1.8E-01	2.6E-01	3.0E-04	1.0E+00	2.2E+00	3.2E+00
Naphthalene		7.4E-03	1.3E-02	2.0E-02		2.1E-02	3.6E-02	5.7E-02
Phenanthrene	2.5E-07	1.4E-01	2.9E-06	1.4E-01	2.8E-06	5.5E-01	1.2E-05	5.5E-01
Pyrene	2.8E-06	2.2E-02	2.4E+00	2.4E+00	3.8E-04	8.5E-02	9.2E+00	9.3E+00
alpha-BHC	4.8E-03			4.8E-03	1.3E-02	1.4E-02	1.4E-02	4.1E-02
beta-BHC	2.0E-03			2.0E-03	7.1E-03	8.5E-03	8.5E-03	2.4E-02
Lindane (gamma-BHC)	1.6E+00			1.6E+00	6.7E+00			6.7E+00
Aldrin	5.3E-02			5.3E-02				
Chlordane	1.1E+02			1.1E+02	4.1E+00			4.1E+00
Dieldrin	4.0E+00			4.0E+00				
Endrin						4.3E-01	1.1E+00	1.5E+00
Heptachlor	6.2E-01			6.2E-01	7.9E-01			7.9E-01
Heptachlor epoxide	3.8E-01	1.9E+00	2.0E+00	4.3E+00	2.2E-03	3.5E+00	3.5E+00	7.0E+00
Hexachlorobenzene	2.8E-02			2.8E-02	3.4E-01			3.4E-01
Mirex	1.2E+00			1.2E+00				
p,p'DDD	2.1E-03			2.1E-03	1.2E-03	3.8E-04	3.5E-05	1.6E-03
p,p'DDE	6.2E-04			6.2E-04	6.8E-04	6.8E-04	1.4E-04	1.5E-03
p,p'DDT	4.9E-03			4.9E-03	3.1E-02	4.8E-02	1.3E-03	8.0E-02
PCBs (total)	6.1E+02			6.1E+02	1.3E+03	1.4E-02	1.7E+01	1.3E+03

Table 9.14. Risk to Carp from exposure to each medium and total risk, where HQe = food, HQs = sediment, and HQw = water.

	CASE							
	Typical				Worst			
	VEHICLE				VEHICLE			
	HQe	HQs	HQw	HQ Total	HQe	HQs	HQw	HQ Total
CHEMICAL	RISK	RISK	RISK	RISK	RISK	RISK	RISK	RISK
Cadmium	5.2E-03	2.6E-02	1.8E+00	1.8E+00	2.6E-02	1.4E-01	3.6E+00	3.8E+00
Chromium		1.8E+00	1.8E+00	3.6E+00		1.5E+01	1.8E+00	1.7E+01
Copper	1.1E-02	3.2E-01	7.5E-01	1.1E+00	2.5E-02	1.2E+00	1.1E+00	2.3E+00
Iron		1.9E+00	1.9E+00	3.8E+00		3.7E+00	3.8E+00	7.5E+00
Lead		4.8E-02	5.0E+00	5.0E+00		2.2E+00	9.1E+00	1.1E+01
Manganese		2.0E-01	1.9E-01	3.9E-01		2.9E-01	4.3E-01	7.2E-01
Mercury	1.1E-03	1.1E+01	1.4E+01	2.5E+01	3.4E-03	5.7E+01	2.2E+01	7.9E+01
Nickel		3.1E-02	3.1E-02	6.2E-02		5.0E-02	5.0E-02	1.0E-01
Silver			1.7E-01	1.7E-01		1.7E-01	1.7E-01	3.4E-01
Zinc		3.3E-01	2.6E-01	5.9E-01		1.6E+00	4.0E-01	2.0E+00
Acenaphthene						1.5E-02	9.4E-03	2.4E-02
Acenaphthylene						3.0E-02	3.0E-02	6.0E-02
Anthracene	1.1E-07	4.1E-03	4.3E-03	8.4E-03	1.4E-06	3.4E-02	3.6E-02	7.0E-02
Benzo(a)anthracene	1.6E-06	1.4E-02	2.3E-02	3.7E-02	3.0E-05	1.1E-01	1.8E-01	2.9E-01
Benzo(a)pyrene	4.7E-06	2.8E-02	5.8E-02	8.6E-02	1.5E-04	1.2E-01	2.4E-01	3.6E-01
Benzo(a)fluoranthene	2.6E-05	4.4E-02	6.2E-02	1.1E-01	3.2E-05	7.7E-02	1.1E-01	1.9E-01
Benzo(ghi)perylene	2.4E-05	2.1E-02	4.5E-02	6.6E-02	1.4E-04	2.5E-01	5.5E-01	8.0E-01
Benzo(k)fluoranthene	1.1E-05			1.1E-05	1.9E-05	5.8E-02	8.3E-02	1.4E-01
Chrysene	2.9E-05	1.5E-03	2.5E-02	2.7E-02	3.4E-05	3.3E-03	5.4E-02	5.7E-02
Dibenzo(a,h)anthracene	5.7E-08			5.7E-08	4.6E-08	4.8E-04	1.6E-03	2.1E-03
Fluoranthene	1.7E-08	2.6E-02	2.5E-03	2.9E-02	1.1E-07	6.0E-02	5.9E-03	6.6E-02
Fluorene		1.0E-02	1.0E-02	2.0E-02		3.1E-02	3.1E-02	6.2E-02
Indeno(1,2,3-cd)pyrene	1.2E-05	8.1E-02	1.8E-01	2.6E-01	3.0E-04	1.0E+00	2.2E+00	3.2E+00
Naphthalene		7.4E-03	1.3E-02	2.0E-02		2.1E-02	3.6E-02	5.7E-02
Phenanthrene	9.6E-10	1.4E-01	2.9E-06	1.4E-01	1.9E-09	5.5E-01	1.2E-05	5.5E-01
Pyrene	2.8E-06	2.2E-02	2.4E+00	2.4E+00	3.8E-04	8.5E-02	9.2E+00	9.3E+00
alpha-BHC	7.5E-03			7.5E-03	1.3E-02	1.4E-02	1.4E-02	4.1E-02
beta-BHC					7.1E-03	8.5E-03	8.5E-03	2.4E-02
Lindane (gamma-BHC)	2.5E+00			2.5E+00	6.7E+00			6.7E+00
Aldrin								
Chlordane	6.4E-01			6.4E-01	4.1E+00			4.1E+00
Dieldrin								
Endrin						4.3E-01	1.1E+00	1.5E+00
Heptachlor					7.9E-01			7.9E-01
Heptachlor epoxide		1.9E+00	2.0E+00	3.9E+00	2.2E-03	3.5E+00	3.5E+00	7.0E+00
Hexachlorobenzene	1.1E-02			1.1E-02	2.5E-01			2.5E-01
Mirex								
p,p'DDD					5.5E-04	3.8E-04	3.5E-05	9.7E-04
p,p'DDE	8.7E-05			8.7E-05	3.0E-04	6.8E-04	1.4E-04	1.1E-03
p,p'DDT	8.1E-03			8.1E-03	4.9E-02	4.8E-02	1.3E-03	9.8E-02
PCBs (total)	1.5E+00			1.5E+00	3.3E+01	1.4E-02	1.7E+01	5.0E+01

Table 9.15. Risk to Gizzard Shad from exposure to each medium and total risk, where HQe = food, HQs = sediment, and HQw = water.

	CASE							
	Typical				Worst			
	VEHICLE				VEHICLE			
	HQe	HQs	HQw	HQ Total	HQe	HQs	HQw	HQ Total
CHEMICAL	RISK	RISK	RISK	RISK	RISK	RISK	RISK	RISK
Cadmium	5.2E-04	2.6E-02	1.8E+00	1.8E+00	1.0E-03	1.4E-01	3.6E+00	3.7E+00
Chromium	9.1E-03	1.8E+00	1.8E+00	3.6E+00	9.1E-03	1.5E+01	1.8E+00	1.7E+01
Copper	3.8E-03	3.2E-01	7.5E-01	1.1E+00	5.4E-03	1.2E+00	1.1E+00	2.3E+00
Iron	1.9E-02	1.9E+00	1.9E+00	3.8E+00	3.8E-02	3.7E+00	3.8E+00	7.5E+00
Lead	2.9E-03	4.8E-02	5.0E+00	5.1E+00	5.3E-03	2.2E+00	9.1E+00	1.1E+01
Manganese	1.9E-03	2.0E-01	1.9E-01	3.9E-01	4.3E-03	2.9E-01	4.3E-01	7.2E-01
Mercury	3.5E-04	1.1E+01	1.4E+01	2.5E+01	5.4E-04	5.7E+01	2.2E+01	7.9E+01
Nickel	3.1E-04	3.1E-02	3.1E-02	6.2E-02	5.0E-04	5.0E-02	5.0E-02	1.0E-01
Silver	1.7E-03		1.7E-01	1.7E-01	1.7E-03	1.7E-01	1.7E-01	3.4E-01
Zinc	2.3E-04	3.3E-01	2.6E-01	5.9E-01	3.5E-04	1.6E+00	4.0E-01	2.0E+00
Acenaphthene					1.8E-02	1.5E-02	9.4E-03	4.2E-02
Acenaphthylene					9.9E-02	3.0E-02	3.0E-02	1.6E-01
Anthracene	1.2E-03	4.1E-03	4.3E-03	9.6E-03	1.0E-02	3.4E-02	3.6E-02	8.0E-02
Benzo(a)anthracene	1.9E-03	1.4E-02	2.3E-02	3.9E-02	1.5E-02	1.1E-01	1.8E-01	3.1E-01
Benzo(a)pyrene	3.6E-03	2.8E-02	5.8E-02	9.0E-02	1.5E-02	1.2E-01	2.4E-01	3.8E-01
Benzo(a)fluoranthene	1.6E-03	4.4E-02	6.2E-02	1.1E-01	2.9E-03	7.7E-02	1.1E-01	1.9E-01
Benzo(ghi)perylene	3.7E-04	2.1E-02	4.5E-02	6.6E-02	4.5E-03	2.5E-01	5.5E-01	8.0E-01
Benzo(k)fluoranthene					2.2E-03	5.8E-02	8.3E-02	1.4E-01
Chrysene	1.7E-03	1.5E-03	2.5E-02	2.8E-02	4.5E-03	3.3E-03	5.4E-02	6.2E-02
Dibenzo(a,h)anthracene					5.1E-06	4.8E-04	1.6E-03	2.1E-03
Fluoranthene	6.2E-05	2.6E-02	2.5E-03	2.9E-02	1.5E-04	6.0E-02	5.9E-03	6.6E-02
Fluorene	1.3E-02	1.0E-02	1.0E-02	3.3E-02	4.0E-02	3.1E-02	3.1E-02	1.0E-01
Indeno(1,2,3-cd)pyrene	1.4E-03	8.1E-02	1.8E-01	2.6E-01	1.8E-02	1.0E+00	2.2E+00	3.2E+00
Naphthalene	3.7E-03	7.4E-03	1.3E-02	2.4E-02	7.2E-02	2.1E-02	3.6E-02	1.3E-01
Phenanthrene	2.1E-06	1.4E-01	2.9E-06	1.4E-01	9.2E-06	5.5E-01	1.2E-05	5.5E-01
Pyrene	2.2E-01	2.2E-02	2.4E+00	2.6E+00	8.5E-01	8.5E-02	9.2E+00	1.0E+01
alpha-BHC					3.7E-02	1.4E-02	1.4E-02	6.5E-02
beta-BHC					2.2E-02	8.5E-03	8.5E-03	3.9E-02
Lindane (gamma-BHC)								
Aldrin								
Chlordane								
Dieldrin								
Endrin					1.3E-01	4.3E-01	1.1E+00	1.7E+00
Heptachlor								
Heptachlor epoxide	2.9E-02	1.9E+00	2.0E+00	3.9E+00	5.3E-01	3.5E+00	3.5E+00	7.5E+00
Hexachlorobenzene								
Mirex								
p,p'DDD					6.4E-07	3.8E-04	3.5E-05	4.2E-04
p,p'DDE					2.4E-07	6.8E-04	1.4E-04	8.2E-04
p,p'DDT					8.8E-05	4.8E-02	1.3E-03	4.9E-02
PCBs (total)					5.4E-01	1.4E-02	1.7E+01	1.8E+01

Table 9.16. Risk to Pumpkinseed from exposure to each medium and total risk, where HQe = food, HQs = sediment, and HQw = water.

CHEMICAL	CASE					
	Typical			Worst		
	VEHICLE			VEHICLE		
	HQe	HQw	HQ Total	HQe	HQw	HQ Total
	RISK	RISK	RISK	RISK	RISK	RISK
Cadmium	9.2E-01	1.8E+00	2.7E+00	1.9E+00	3.6E+00	5.5E+00
Chromium	1.4E+00	1.8E+00	3.2E+00	1.4E+00	1.8E+00	3.2E+00
Copper	4.7E-01	7.5E-01	1.2E+00	6.8E-01	1.1E+00	1.8E+00
Iron	1.9E+00	1.9E+00	3.8E+00	3.8E+00	3.8E+00	7.6E+00
Lead	2.6E+00	5.0E+00	7.6E+00	4.8E+00	9.1E+00	1.4E+01
Manganese	1.9E-01	1.9E-01	3.8E-01	4.3E-01	4.3E-01	8.6E-01
Mercury	7.1E+00	1.4E+01	2.1E+01	1.1E+01	2.2E+01	3.3E+01
Nickel	3.1E-02	3.1E-02	6.2E-02	5.0E-02	5.0E-02	1.0E-01
Silver	1.7E-01	1.7E-01	3.4E-01	1.7E-01	1.7E-01	3.4E-01
Zinc	1.4E-01	2.6E-01	4.0E-01	2.2E-01	4.0E-01	6.2E-01
Acenaphthene				4.0E-02	9.4E-03	4.9E-02
Acenaphthylene				2.1E-01	3.0E-02	2.4E-01
Anthracene	3.4E-03	4.3E-03	7.7E-03	2.8E-02	3.6E-02	6.4E-02
Benzo(a)anthracene	1.3E-02	2.3E-02	3.6E-02	1.0E-01	1.8E-01	2.8E-01
Benzo(a)pyrene	3.4E-02	5.8E-02	9.2E-02	1.4E-01	2.4E-01	3.8E-01
Benzo(a)fluoranthene	3.3E-02	6.2E-02	9.5E-02	5.9E-02	1.1E-01	1.7E-01
Benzo(ghi)perylene	2.3E-02	4.5E-02	6.8E-02	2.8E-01	5.5E-01	8.3E-01
Benzo(k)fluoranthene	2.9E-06		2.9E-06	4.5E-02	8.3E-02	1.3E-01
Chrysene	1.5E-02	2.5E-02	4.0E-02	3.2E-02	5.4E-02	8.6E-02
Dibenzo(a,h)anthracene	1.4E-08		1.4E-08	8.1E-04	1.6E-03	2.4E-03
Fluoranthene	1.3E-03	2.5E-03	3.8E-03	3.1E-03	5.9E-03	9.0E-03
Fluorene	3.1E-02	1.0E-02	4.1E-02	9.4E-02	3.1E-02	1.3E-01
Indeno(1,2,3-cd)pyrene	9.0E-02	1.8E-01	2.7E-01	1.1E+00	2.2E+00	3.3E+00
Naphthalene	5.4E-02	1.3E-02	6.7E-02	1.6E-01	3.6E-02	2.0E-01
Phenanthrene	3.7E-06	2.9E-06	6.6E-06	1.5E-05	1.2E-05	2.7E-05
Pyrene	1.4E+00	2.4E+00	3.8E+00	5.4E+00	9.2E+00	1.5E+01
alpha-BHC	1.9E-03		1.9E-03	4.6E-02	1.4E-02	6.0E-02
beta-BHC				2.7E-02	8.5E-03	3.6E-02
Lindane (gamma-BHC)	6.3E-01		6.3E-01	1.7E+00		1.7E+00
Aldrin						
Chlordane	1.6E-01		1.6E-01	1.0E+00		1.0E+00
Dieldrin						
Endrin				8.0E-01	1.1E+00	1.9E+00
Heptachlor				2.0E-01		2.0E-01
Heptachlor epoxide	1.5E+00	2.0E+00	3.5E+00	2.3E+00	3.5E+00	5.8E+00
Hexachlorobenzene	2.6E-03		2.6E-03	6.4E-02		6.4E-02
Mirex						
p,p'DDD	2.1E-04		2.1E-04	1.0E-03	3.5E-05	1.0E-03
p,p'DDE	1.6E-04		1.6E-04	6.1E-04	1.4E-04	7.5E-04
p,p'DDT	2.0E-03		2.0E-03	1.3E-02	1.3E-03	1.4E-02
PCBs (total)	3.8E+00		3.8E+00	2.8E+01	1.7E+01	4.5E+01

be determined. For subsurface benthos, exposure by food was more important than exposure by sediment. For metal exposure of surface benthos, food generally posed the greatest risk, but for organics, risk from either sediment or water was sometimes greater than that for food. By this model for risk assessment, results for aufwuchs were the same as for surface benthos. Our earlier model based on calculating uptake rates for each pathway, showed some differences between these two receptor organisms. For zooplankton, risk from water was generally greater, although in some cases, e.g., anthracene, risk by water, sediment, and food were essentially the same.

For brown bullhead exposure by water and sediments to polyaromatic hydrocarbons generally resulted in a higher risk than exposure by food. Exposure data were only available by the food route for pesticides, especially for the typical case. For carp, exposure by sediment and water posed a great risk for organics than exposure by food, which was the worms (W) food category. Exposure by water and sediment resulted in similar risks, but food residues were available for only three metals.

Gizzard shad have higher risk from exposure by water and sediments than by food for metals and some polyaromatic hydrocarbons. For phenanthrene, exposure by sediments resulted in the highest risk. For the worst case where pesticide and PCB data were available, food posed the greatest risk for beta-BHC, but not for other pesticides. Pumpkinseed, a pelagic fish, were not considered to be exposed significantly by direct contact with sediment. Water posed the same or greater risk compared with food for metals. Food and water exposure to polyaromatic hydrocarbons resulted in similar risks. For the worst case, food resulted in a greater risk for pesticides beta-BHC, p,p'DDD, p,p'DDE, and p,p'DDT.

9.2 Multiple Chemicals

Apparent effects threshold (AET) and effects range-low (ER-L) are reference toxicities obtained for environmental sediment samples containing mixtures of contaminants tested by standard protocols for several organisms (Science Advisory Board 1989; Long and Morgan 1990). In Table 9.19 risk is calculated by a hazard quotient by dividing the typical sediment concentrations at the Buffalo River by the ER-L values. Although many of the 41 chemicals included in this report are missing ER-L values, chemicals with a hazard quotient greater than one could be tentatively considered to pose a significant risk to aquatic biota at the Buffalo River.

Nelson et al. (1992) reported on aquatic bioassays performed on whole sediment samples collected in October 1989 at the following stations in the Buffalo River AOC: BR-01-01, BR-01-03, BR-01-07, BR-01-08, and BR-01-09, which represents most of the reach of the river within the AOC. In their summary of their results, they stated that "Buffalo River sediments significantly reduced amphipod survival in the 28-d exposure at 80% of the stations. Survival of C. riparius was significantly reduced in the 14-d exposure in two stations (40%), but survival was not significantly reduced for C. tentans for any stations in the 10-d exposure. Amphipod 14-d growth identified 100% of the Buffalo River sediments as toxic, and significant differences from control for antennal segment number or sexual maturation was predicted by amphipod reductions in body length at 80% of the stations. Growth of C. riparius identified 20% of the Buffalo River sediments as toxic, and growth of C. tentans identified 40% of the stations as toxic" (Nelson et al. 1992). The presentation of the data did not indicate if particular contaminants in the sediments could be correlated with the toxic effects. Determination of contaminant concentrations correlated with reduced survival could guide setting

remediation goals.

Canfield et al. (1992) reported on studies of benthic community structure of one station (BR-01) sampled in 1989 and ten stations sampled in 1990. They also sampled the Saginaw River AOC and Indiana Harbor AOC and compared the results from the three AOCs. They stated that "comparisons between concentrations of simultaneously extracted metals (SEM), total PAH, and total PCB with measures of benthic invertebrate abundance demonstrates a consistent pattern of decreasing invertebrate abundance with increasing contamination." They stated that the "Buffalo River had the largest number of genera and species (n=33) present, followed by Saginaw River (n=20) and Indiana Harbor (n=14)." The Indiana Harbor is a degraded habitat. For comparison, Hudson et al. (1986) identified 101 taxa (genera and species) in the upper Detroit River, 98 in the upper St. Clair River, 95 in the lower St. Clair River, and 80 in the lower Detroit River. However, the Buffalo River AOC does not have the diversity of habitat that the above large river systems have, and the Buffalo River suffers from noncontaminant problems, such as low dissolved oxygen and physical loss of habitat.

Johnson (1992) published results of genotoxic tests on sediment samples collected from ten stations in the Buffalo River AOC in October 1989. He tested freshwater sediment extracts with a new activated Mutatox Genotoxicity Assay. Samples from all ten sites were genotoxic. He did not attempt to identify which contaminants were causing the observed genotoxicity.

9.3 Presentation of Risks/Hazards in Summary Format

Tables 9.17 and 9.18 present for each of the eight receptors only those chemicals that have a total hazard quotient greater than one and hence are considered to represent a significant risk to aquatic receptors. These results show that for the **typical case** cadmium, chromium, copper, iron, lead, mercury, pyrene, and heptachlor epoxide present a significant risk to most of the eight receptor organisms. For the **worst case**, the above compounds plus zinc, indeno(1,2,3-cd)pyrene, endrin, and total PCBs represent a significant risk to aquatic receptors.

In considering the conclusions, one must understand the twofold intent of the baseline assessment. The objective is to develop a reference value for risk at the Area of Concern. This risk value is used in two ways. First, it is used as an 'indicator' of the potential for adverse affects. It is intentionally conservative to ensure that risks are not underestimated. The second use of the baseline risk estimate is to use the risk estimates as a reference point in the analysis of residual risks of remediation alternatives. In this sense, it is used to estimate the relative reduction of risk that would occur given the implementation of various alternative remediation strategies.

With this in mind, an appropriate interpretation of the conclusions is that there is a need to further refine the baseline estimates. The following is a list of specific recommendations for further work to be performed in order to refine the estimates of risk reported here:

1) The occurrence of 'hot spots' in the Buffalo River is an open question. The 1985 sediment sampling shows heightened levels of contamination in a small portion of the river. The 1989 sediment sampling data is not sufficient to conclude that the high concentrations measured in 1985 have decreased. Further, neither the 1985 nor the 1989 sediment data sets is sufficient for determining the number or locations of other hot spots. It

is recommended that a sampling strategy be developed and implemented to address the need related to locating and sampling currently existing hot spots.

2) This baseline assessment assumes that all risks experienced as a result of exposure within the Buffalo River is due solely to contaminated sediments. This implies that there are no additional sources of contamination. However, there are additional sources of contamination, such as combined sewer overflows and abandoned hazardous waste sites. The extent to which these sources contribute to exposures and risks is, at this time, unknown. Before any remediation strategies are selected it will be important to accurately inventory existing sources and to estimate their individual and collective impact on future water and sediment conditions in the Buffalo River.

3) After the above recommendations have been addressed, the baseline estimate of exposures and risks should be updated and a comprehensive risk assessment conducted.

Table 9.17. Summary of total contaminant risk (HQ Total) associated with all exposure routes. Only HQ Total > 1 included.

CASE Typical

CHEMICAL	ORGANISM							
	Subsurface Benthos	Surface Benthos	Aufwuchs	Zooplankton	Brown Bullhead	Carp	Gizzard Shad	Pumpkinseed
Cadmium	2.1E+00	3.9E+00	3.9E+00	1.8E+00	1.8E+00	1.8E+00	1.8E+00	2.7E+00
Chromium	5.6E+01	5.8E+01	5.8E+01	3.6E+00	3.6E+00	3.6E+00	3.6E+00	3.2E+00
Copper	1.8E+02	1.8E+02	1.8E+02	1.1E+00	1.3E+00	1.1E+00	1.1E+00	1.2E+00
Iron	2.9E+03	2.9E+03	2.9E+03	3.8E+00	3.8E+00	3.8E+00	3.8E+00	3.8E+00
Lead	1.2E+01	1.7E+01	1.7E+01	5.1E+00	5.0E+00	5.0E+00	5.1E+00	7.6E+00
Manganese	5.1E+01	5.1E+01	5.1E+01					
Mercury	1.8E+01	3.2E+01	3.2E+01	2.5E+01	2.6E+01	2.5E+01	2.5E+01	2.1E+01
Nickel	1.9E+01	1.9E+01	1.9E+01					
Silver								
Zinc	2.0E+01	2.1E+01	2.1E+01					
Acenaphthene								
Acenaphthylene								
Anthracene								
Benzo(a)anthracene	3.2E+00	3.3E+00	3.3E+00					
Benzo(a)pyrene	1.8E+01	1.8E+01	1.8E+01					
Benzo(a)fluoranthene	1.0E+01	1.0E+01	1.0E+01					
Benzo(ghi)perylene	5.2E+00	5.4E+00	5.4E+00					
Benzo(k)fluoranthene								
Chrysene	3.6E+00	3.8E+00	3.8E+00					
Dibenzo(a,h)anthracene								
Fluoranthene								
Fluorene								
Indeno(1,2,3-cd)pyrene	1.5E+01	1.6E+01	1.6E+01	1.1E+00				
Naphthalene								
Phenanthrene								
Pyrene	1.3E+01	1.6E+01	1.6E+01	2.6E+00	2.4E+00	2.4E+00	2.6E+00	3.8E+00
alpha-BHC								
beta-BHC								
Lindane (gamma-BHC)					1.6E+00	2.5E+00		
Aldrin								
Chlordane					1.1E+02			
Dieldrin					4.0E+00			
Endrin								
Heptachlor								
Heptachlor epoxide	2.1E+00	4.0E+00	4.0E+00	3.9E+00	4.3E+00	3.9E+00	3.9E+00	3.5E+00
Hexachlorobenzene								
Mirex					1.2E+00			
p,p'DDD								
p,p'DDE								
p,p'DDT								
PCBs (total)					6.1E+02	1.5E+00		3.8E+00

Table 9.18. Summary of total contaminant risk (HQ Total) associated with all exposure routes. Only HQ Total > 1 included.

CASE Worst

CHEMICAL	ORGANISM							
	Subsurface Benthos	Surface Benthos	Aufwuchs	Zooplankton	Brown Bullhead	Carp	Gizzard Shad	Pumpkinseed
Cadmium	1.1E+01	1.5E+01	1.5E+01	3.8E+00	3.8E+00	3.8E+00	3.8E+00	5.5E+00
Chromium	4.7E+02	4.7E+02	4.7E+02	1.7E+01	1.7E+01	1.7E+01	1.7E+01	3.2E+00
Copper	6.6E+02	6.6E+02	6.6E+02	2.2E+00	6.5E+00	2.3E+00	2.2E+00	1.8E+00
Iron	5.6E+03	5.6E+03	5.6E+03	7.5E+00	7.5E+00	7.5E+00	7.5E+00	7.5E+00
Lead	5.4E+02	5.5E+02	5.5E+02	1.1E+01	1.1E+01	1.1E+01	1.1E+01	1.4E+01
Manganese	7.5E+01	7.6E+01	7.6E+01					
Mercury	9.3E+01	1.1E+02	1.1E+02	7.9E+01	9.7E+01	7.9E+01	7.9E+01	3.3E+01
Nickel	3.0E+01	3.0E+01	3.0E+01					
Silver	7.1E+02	7.1E+02	7.1E+02					
Zinc	9.8E+01	9.9E+01	9.9E+01	2.0E+00	2.0E+00	2.0E+00	2.0E+00	
Acenaphthene								
Acenaphthylene								
Anthracene								
Benzo(a)anthracene	2.5E+01	2.6E+01	2.6E+01	1.2E+00				
Benzo(a)pyrene	7.4E+01	7.6E+01	7.6E+01	1.5E+00				
Benzo(a)fluoranthene	1.8E+01	1.8E+01	1.8E+01	1.3E+00				
Benzo(ghi)perylene	6.3E+01	6.6E+01	6.6E+01	4.5E+00				
Benzo(k)fluoranthene	1.3E+01	1.4E+01	1.4E+01					
Chrysene	7.9E+00	8.2E+00	8.2E+00					
Dibenzo(a,h)anthracene								
Fluoranthene								
Fluorene								
Indeno(1,2,3-cd)pyrene	1.9E+02	2.0E+02	2.0E+02	1.4E+01	3.2E+00	3.2E+00	3.3E+00	3.4E+00
Naphthalene								
Phenanthrene	2.1E+00	2.2E+00	2.2E+00					
Pyrene	5.1E+01	6.1E+01	6.1E+01	1.0E+01	9.2E+00	9.2E+00	1.0E+01	1.5E+01
alpha-BHC	1.7E+00	1.8E+00	1.8E+00					
beta-BHC	1.1E+00	1.2E+00	1.2E+00					
Lindane (gamma-BHC)					6.7E+00	6.7E+00		1.7E+00
Aldrin								
Chlordane					4.1E+00	4.1E+00		1.0E+00
Dieldrin								
Endrin	2.3E+01	2.4E+01	2.4E+01	1.6E+00	1.5E+00	1.5E+00	1.6E+00	1.9E+00
Heptachlor								
Heptachlor epoxide	3.7E+00	7.2E+00	7.2E+00	7.6E+00	7.0E+00	7.0E+00	7.6E+00	5.8E+00
Hexachlorobenzene								
Mirex								
p,p'DDD								
p,p'DDE								
p,p'DDT								
PCBs (total)	4.6E+02	4.8E+02	4.8E+02	1.7E+01	1.3E+03	5.0E+01	1.7E+01	4.5E+01

Table 9.19 Risk from exposure to typical chemical sediment mixtures (sediment concentrations/ER-L) at the Buffalo River.

Chemical	1989 Sed. conc. (mg/kg)	ER-L Concentration (mg/L)	Sed. conc./ER-L
Cadmium	8.00 E - 01	5.00 E + 00	1.60 E -01
Chromium (hex)	1.20 E + 01		
Copper	4.40 E + 01	7.00 E + 01	6.29 E - 01
Iron	2.88 E + 04		
Lead	6.30 E + 01	3.50 E + 01	1.8 E + 00
Manganese	5.00 E + 02		
Mercury	3.30 E - 01	1.50 E - 01	2.20 E + 00
Nickel	3.00 E + 01	3.00 E + 01	1.00 E + 00
Silver	0.00 E + 00	1.00 E + 00	
Zinc	2.49 E + 02	1.20 E + 02	2.08 E + 00
Acenaphthene	0.00 E + 00		
Acenaphthylene	0.00 E + 00		
Anthracene	1.80 E - 01	8.50 E - 02	2.12 E + 00
Benzo(a)anthracene	6.10 E - 01	2.30 E - 01	2.65 E + 00
Benzo(a)pyrene	9.50 E - 01	4.00 E - 01	2.38 E + 00
Benzo(b)fluoranthene	1.65 E + 00		
Benzo(ghi)perylene	4.50 E - 01		
Benzo(k)fluoranthene	0.00 E + 00		
Chrysene	6.90 E - 01	4.00 E - 01	1.72 E + 00
Dibenzo(a,h)anthracene	0.00 E + 00	6.00 E - 02	
Fluoranthene	1.57 E + 00	6.00 E - 01	2.62 E + 00
Fluorene	3.30 E - 01	3.50 E - 02	9.43 E + 00
Indeno(1,2,3-cd)pyrene	4.50 E - 01		
Naphthalene	3.10 E - 01	3.40 E - 01	9.12 E - 01
Phenanthrene	7.70 E - 01	2.25 E - 01	3.42 E + 00
Pyrene	9.30 E - 01	3.50 E - 01	2.66 E + 00
alpha-BHC	0.00 E + 00		
beta-BHC	0.00 E + 00		
Lindane(gamma-BHC)	0.00 E + 00		
Aldrin	0.00 E + 00		
Dieldrin	0.00 E + 00	2.00 E - 05	
Chlordane	0.00 E + 00	5.00 E - 04	
Endrin	0.00 E + 00	2.00 E - 05	
Heptachlor	0.00 E + 00		
Heptachlor epoxide	4.00 E - 02		
Hexachlorobenzene	0.00 E + 00		
Mirex	0.00 E + 00		
p,p'DDD	0.00 E + 00	2.00 E - 03	
p,p'DDE	0.00 E + 00	2.00 E - 03	
DDT (total)	0.00 E + 00	3.00 E - 03	
PCBs (total)	0.00 E + 00		

CHAPTER 10

CHARACTERIZATION OF UNCERTAINTY

Baseline risk assessments utilize available data only. Many times available data are unknown quality and may not be representative of the spatial, temporal or environmental media of interest to the risk assessor. In these and other cases it is necessary to generate assumptions about the relationship between available data and more appropriate but unavailable data. This combination of unknown quality and necessary assumptions result, in a complex manner, in overall uncertainty associated with the level of risk reported within the risk assessment.

The primary role of this uncertainty analysis is to describe, qualitatively, the nature and basis for all assumptions used at each stage of the assessment of Buffalo River exposures and risks, and then to address the effect these assumptions will have on the reported exposure and risk levels.

10.1 Uncertainty in Data Compilation and Evaluation Step (Hazard Evaluation Procedure)

Environmental quality data forms the basis for conducting an exposure and risk assessment by defining the level of contamination associated with a particular area of concern. Of primary interest in organizing environmental quality data is the specification of contaminant levels in all niches of the aquatic ecosystem. The organisms would be expected to be in contact with the contamination to varying degrees (depending on their ecological niche) over their lifespan. While the data are quite limited in time span and location (the data sets could be considered as "snapshots" of the contamination at specific places and times), the available data must be configured to account for this long-term exposure. For the environmental quality data used in this study:

Assumption #1: The surficial sediment quality data for 1989 and 1985 represent typical and worst-case conditions, respectively, that are representative of current contaminant levels in Buffalo River sediments.

Uncertainty about the quality of sampling and analysis protocols employed for the sediment studies is large. The amount of descriptive information available about the protocols for the 1985 data set is minimal, thus the accuracy and precision of the data cannot be quantified. On a qualitative basis the 1985 data are also given low scores by those individuals responsible for the studies, because the analytical methodology was being developed during the study. The 1989 data set, based on the quantitative scoring system referenced in Section 5.3 is acceptable. One positive point is that the 1985 and 1989 data sets show contaminant levels that are similar in the overall range of concentrations reported, and by inference, are of similar quality.

The impact of these data upon estimates of risk is direct and linear. If a concentration is increased by a factor of two the estimate of risk would increase by the same factor. The question that cannot be addressed is how big a difference might exist between actual conditions in the Buffalo River and those characterized by the data.

Assumption #2: Spatial variation within the 1985 and 1989 sediment quality data sets is not significant, and therefore statistical measures can be applied to condense the data into single value estimates of typical and reasonable worst case sediment contamination levels per contaminant.

For each of the data sets, contaminant levels varied relatively little among the samples. For those portions of the river sampled, the contamination was essentially uniform. While samples within each study reflect little variation from site to site, two factors remain that cause uncertainty.

First, monitoring survey samples were collected either at mid-channel only (1989) or within a limited area (1985). Likely exposures occur uniformly throughout the aquatic environment. How truly these samplings represent the overall sediment contamination is unknown.

Second, within the context of an aquatic health risk assessment are locations within the area of concern that exhibit high contaminant concentrations. This generally occurs where sedimentation is enhanced, such as near bends in the river or where water slows considerably. These "hot spots" are important as exposure points due to organism contact with the relatively high contamination. While it appears that the site of the 1985 sampling represents a hot spot, there are insufficient data available to determine the existence of other sites of elevated contamination.

The difference between actual (sediment) conditions in the Buffalo River and those characterized by the 1989 and 1985 data cannot be estimated. Monitoring survey samples were collected either at mid-channel only (1989) or within a limited area (1985). Exposures occur uniformly throughout the aquatic environment. The 1985 and 1989 data sets (as well as the earlier reported data not used in this assessment) show contaminant levels that are similar in the overall range of concentrations reported, and by inference, are of similar quality. All of the sediment studies together represent a wide area of the Buffalo River. How truly these samplings represent the overall sediment contamination is unknown.

Assumption #3: Equilibrium partitioning, constrained by solubility limits, is an appropriate technique by which to estimate dissolved levels of hydrophobic organic compounds in the water column.

The need for this assumption arises due to the fact that water column concentrations for virtually all hydrophobic organics sampled were reported to be less than the applicable detection limit. It is unreasonable to assume that the contaminants are not present in the water column, when they are present in the sediments, and therefore an appropriate approximation is required. An option considered but not pursued was to assume that the organic concentrations were equal to their respective detection limits. While this is certainly a conservative assumption, the detection limits, themselves considered high, may be unnecessarily conservative. The use of equilibrium partitioning is also conservative but represents a practical upper limit as to what the concentrations may be.

The magnitude of uncertainty related to the use of equilibrium partitioning for water column contaminant concentrations cannot be quantified without significant sampling and/or modelling effort. These additional efforts would be required only if the exposure and risk estimates resulting from

the use of the equilibrium assumption were at levels causing concern. This assumption assures an overestimation of the risk.

Assumption #4: Historical water column metals data residing in STORET are representative of current conditions.

The only available source of metals concentration data in the water column of the Buffalo River are contained in the STORET data base maintained by EPA. The STORET data does not include descriptions of the sampling and analytical protocols and thus the quality of the data is unknown. The method errors may have been significant. The water column data taken from STORET were statistically manipulated to produce values reflecting a mean (i.e., typical) and upper bound (i.e., reasonable worst case), and are not meant to suggest known accuracy. Finally, the STORET data is specific to one location in the Buffalo River and with respect to locations where exposure occurs, is of unknown quality.

Assumption #5: The very limited data available describing contaminant levels in benthos (algae, clams, mussels, and worms) and fish are representative of current conditions.

Of all the data available describing the contamination of the Buffalo River, none are more important than those describing chemical concentrations throughout the food chain. The consumption of contaminated food through the food chain is a dominant aquatic health risk. This result is based on a limited number of samples and by itself would not be sufficient to draw definitive conclusions. Also, this assessment is based on a very limited sampling of a few species along the food chain including a worm that is not strictly aquatic and some representative fishes. The amount of descriptive information available about the protocols for most of the data sets (except for possibly mussels, worms and fish) is minimal, thus the accuracy and precision of the data cannot be quantified. The contaminants monitored in each data set are quite select, and there is very little continuity between data sets. Some data sets only analyze for specific members of a class (i.e., PCBs) and comparisons with other sets are difficult. The data sets for different organisms are for quite different time periods and often at somewhat different locations. It is feasible to compute the missing contaminant residue data for the various organisms as well as for missing members of the food chain using sediment data, but the bioconcentration factors can vary widely from species to species and from study to study for the same species, often differing by a factor of 100-1000. These BCFs are not available for every species, and the use of a representative species would introduce another unknown measure of uncertainty. Finally, in an effort to provide some estimate of reasonable worst-case contaminant levels, where two or more sets of data were available for analysis, the set with the highest levels (where obvious by visual inspection) was used.

The effect of these combinations of assumptions is to overestimate the risk due to consumption along the food chain. The few representative organisms for which some select residue data are available must be used to represent the aquatic food chain in the ecosystem. How well this series of data sets represents the actual population contaminant load is unknown, and it would require a significant sampling and modelling effort to quantify the answer. It is felt that additional information concerning current levels in a much wider benthos and fish sample for a wider range of contaminants (with higher degree of continuity of monitored contaminants between sampled

organisms) should be gathered before action is taken in response to the risks reported in this assessment.

10.2 Uncertainty in Exposure Assessment (Use of Existing Data)

The objective of this aquatic exposure assessment is to determine the long term average daily intake of individual contaminants due to contact with water, sediments and the food chain. There are two key sets of data required to estimate exposure: 1) characterization of the exposed organisms, and 2) specification of the frequency and duration of contact with contamination. Together these data constitute an exposure scenario. Due to insufficient information there is a need to formulate the exposure scenarios using assumptions about some key variables.

Assumption #6: Environmental quality data, developed in the data compilation and evaluation step, are representative of contaminant levels that the aquatic organisms contact in the Buffalo River.

Exposure is the contact (direct or indirect) between an organism (receptor) and a contaminated medium. All aquatic organisms are in contact with the Buffalo River water and sediment (some more than others). The sediment data specify contaminant levels at specific, small points at two (several) periods of time, and the STORET water column data represent an unspecified site (sites).

The uncertainty related to this assumption cannot be quantified. It is a function of two factors: 1) the quality of sediment and water quality data, and 2) how well the data represent the AOC in an exposure analysis. Both issues were addressed in Section 10.1. As to the uncertainty of contaminant levels throughout the AOC, the uncertainty focuses on the relationship between concentrations measured at two particular sites in the Buffalo River and the remainder of the aquatic AOC. There is no empirical way to extrapolate from contaminant residues found at two sampling locales to a description of any increase or decrease in contamination at any point in the general aquatic ecosystem.

To respond to this uncertainty, it is reasonable that if estimated exposures using the typical and reasonable worst case conditions are of marginal or greater concern, then an effort to further detail the sediment contaminant levels should be pursued.

Assumption #7 The available benthos and fish samples and their contaminant body burdens represent the current population size, variation, condition and activity of the aquatic organisms throughout the Buffalo River AOC.

The benthic and fish populations are much more varied than the sample population would indicate. The various sampling was done over approximately 10 years with little continuity of sampling locale and organism. Few indications of organism condition, age or gender were given. Species activity is very much dependent on age and gender (to a lesser degree), and will dictate the degree to which an organism is exposed to a contaminated medium. Differing species and ages can occupy different niches of the aquatic ecosystem and so perhaps different sites of the AOC, which can in turn influence contaminant profiles and concentrations. Contamination will affect different species, genders and ages often in widely different ways. Contaminant bioaccumulation and body burdens will vary similarly.

One uncertainty associated with this assumption occurs in all assessments, owing to the fact that specific individual organisms exposed to site-specific contamination are not explicitly addressed within a baseline exposure and risk assessment.

Another uncertainty in this assumption is that organism contaminant concentrations can vary significantly with life stage and species. The effects of this assumption may not be important because results may not change enough to alter any conclusions if all species and life stages could be defined.

These two uncertainties are potentially conflicting in the relative importance placed on species differentiation and life stage. The conflict may not be resolved without a great deal of field work and modelling. The uncertainty that cannot be quantified is the degree to which each affect the overestimation of risk.

Assumption #8: The extrapolations of current aquatic organism activity to represent long-term (lifetime) conditions are applicable to the Buffalo River.

The estimate of health risk as presented in this assessment represents effects of chronic exposure. Available toxicity measures of the various contaminants are primarily for acute (short-term) effects and only for a few of the present species. Very few data are available for chronic effects for all the contaminants and species. A conservative approach is to assume that the current exposures will continue sufficiently long to cause a relevant health effect within the lifetime of the organism. This assumption does not account for 1) the changes in organism activity over its lifetime or 2) the possibility that environmental contamination will be reduced with time. It is not possible to determine the extent to which this assumption causes risks to be overestimated in the Buffalo River AOC. It is only possible to say that this component of the exposure computation will contribute to an overestimation of risk.

10.3 Uncertainty in Risk Assessment (Cause and Effect Relationships)

The objective of the risk assessment is to characterize the risks of human health effects resulting from exposures estimated previously. Important data for this step include toxicity information for individual contaminants in the form of acute and chronic toxicity endpoints, and reference doses. The data are far from complete for all contaminants and species, and extrapolations must be made. There are various sources of aquatic health effects but there remain gaps in the data necessary to quantify all chemical specific risks. In cases where risk values are not available, a qualitative discussion of the possible health effects is presented. The following major assumptions were made for the risk characterization assessment.

Assumption #9: While a specific chemical contaminant may be found in the Buffalo River in many forms, some toxic and some not, it is assumed that all of the chemical is of the most toxic form.

Many chemicals may appear in the environment in various forms due to chemical speciation processes (e.g., metals) or are measured only as a total quantity (e.g., PAHs, PCBs). However, a toxicological profile and related measures of risk are specific to a particular chemical form. In the case of a risk assessment where the measured form of the contaminant and the form related to the toxicity measurement are not identical, an

assumption must be made. In this assessment, when a measured value for a contaminant includes many congeners or species, the toxicity of the most potent form is assumed to apply to the entire measured amount.

The impact of this assumption is to overestimate the actual risk. The degree to which risk is overestimated is unknown and may be significant.

Assumption #10: Current levels of exposure will remain constant over a time period commensurate with the period of exposure related to toxicity measures.

This assumption is paired with the exposure assumption concerning the long term constancy of aquatic organism activity that results in exposure. The level of contamination is assumed to remain constant over the long term. Contamination conditions will not remain identical over a period of decades. There are two sets of information that would be required if conditions of environmental contamination change in the future: 1) a source inventory that reflects present and future conditions, and 2) a detailed characterization of the Buffalo River AOC sufficient to allow use of predictive models. With these two sets of data, one could configure a modeling study and estimate the likely levels of future contamination. Because a baseline assessment does not include such data, assumptions concerning future conditions must be made. The nature of this assumption is conservative to assure an overestimation of risk.

Assumption #11: Health risks are additive.

In the absence of knowledge about the effects of simultaneous exposure to multiple contaminants, it is assumed that the risk associated with the combined exposure to multiple contaminants is simply the sum of the risks related to the individual chemicals. While it is known that both synergistic and antagonistic effects occur there are no guidelines for their application in a baseline assessment. The assumption of additivity of contaminant health effects is of unknown impact. Carcinogenicity is not viewed as a significant aquatic health effect for most contaminants and species in this assessment. Because of the unknown contributions of chemicals below threshold levels, we did not sum the risk across all chemicals.

10.4 Summary of Uncertainty

Uncertainty in the context of baseline assessment of aquatic health risk is large and ubiquitous. To quantify each of the major components of risk, it is necessary to formulate and use assumptions. Each assumption fills an information gap between existing information and information needed to quantify risk. The price paid for applying assumptions is uncertainty.

The two general ways to express uncertainty are qualitative and quantitative. A quantitative assessment of uncertainty is preferable because it uses specific knowledge of uncertainty sources and yields a statistically-based estimate of the (here) risk of adverse aquatic health effects. A quantitative uncertainty analysis requires its own unique set of data, which reflect the statistical distribution of values representative of each parameter used as input to the risk assessment. This type of data is not available in this assessment.

A qualitative uncertainty presentation is more descriptive and conceptual in nature. The expertise of the assessor is needed to discuss the combination of study objectives, approach, results, and the study limitations.

The conclusion concerning uncertainties in this assessment is that the estimates of aquatic exposure and resulting aquatic health risk within the Buffalo River AOC should be used for comparative purposes and not as estimates of actual exposure and risks.

Two valid conclusions can be drawn from this assessment. First, The risk to aquatic health is dominated by two factors, absorption at the gill and ingestion of food, and that exposure to contaminants by other pathways results in relatively low health risks. Second, risks characterized in this assessment can be used to compare with residual risks estimated to remain after various alternative clean-up actions are completed. By comparing the residual risks one can make a determination of the relative benefit from specific remediation protocols.

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APPENDIX A

Methods for Estimating Missing Water Quality Data (Laniak et al. 1992; Karickhoff 1981)

The approach used for estimating the concentration of hydrophobic organic compounds in surface water is to represent the total concentration of an organic pollutant in surface water as the combination of pollutant adsorbed to suspended particles and in aqueous solution. The total organic contaminant concentration in the water column can be taken as the sum of the particulate and dissolved fractions. This total may be described by

$$C_t = (C_s/K_d) + C_s*TSS$$

where C_t is the total contaminant concentration (dissolved + particulate), C_s is the sorbed concentration (mg contaminant/kg solids), and TSS is the solids concentration (kg-solids/L). K_d is a distribution coefficient (dimensionless, but multiplied by [1 L/1 kg-solids] conversion constant). A distribution constant, rather than an equilibrium constant, is used since complete equilibrium may not be achieved in the field. The dissolved concentration (assuming partitioning in the environment) may be estimated from C_s/K_d and the particulate concentration may be estimated from C_s*TSS. Therefore, if data are available for the sorbed concentration in the sediments, the partition coefficient, and the concentration of suspended solids in the water column, the dissolved and particulate fractions, as well as the total concentrations, may be estimated. The estimates of total concentrations derived using the above formulation are considered to be conservative since it is assumed that there is a reasonable equilibrium established between the sediments and the water column and that the materials in the water column are not reduced due to outflows (e.g., volatilization), or chemical (e.g., photolysis) or biological degradation.

For organic compounds where water quality data were not determined or measurements were either below a specified detection limit or not pursued rigorously, it was necessary to provide estimates of the water concentrations using the method described above. The calculation requires estimation of the distribution coefficient (K_d).

The value of the distribution coefficient (K_d) is typically estimated in three steps. First, an octanol-water partition coefficient (K_{ow}, a commonly available chemical parameter; e.g., see Lyman et al. 1990) is obtained for the chemical(s) of interest. The K_{ow} values are then assumed to be linearly related to an organic carbon partition coefficient (K_{oc}) by the fraction of organic carbon available on the sediments (f_{oc}), as illustrated below (Crane, 1993)

$$K_d = f_{oc} * 0.63\ K_{ow}$$

Table 5.3 provides a summary of the values used to calculate probable water concentrations followed by the estimated water concentrations. For this assessment, C_s was assumed to be equal to the sediment concentration. For TSS an average value of (= 1.8×10^{-5} mg/kg) reported in STORET was used. For K_{ow} values were obtained from the literature (Mabey et al. 1982). The sediment contaminant concentrations and fraction organic carbon were taken from the 1985 or 1989 surveys. The 1989 data indicated a fraction organic carbon, f_{oc}, on the order of 0.1 percent, but this value is below those typically observed

in Great Lakes sediments (1-5 percent) and is questionable. An average value of 3.25%, as reported in the 1985 sediment data, was used instead.

As an example, the water concentration of anthracene for the typical case was calculated as follows (Table 5.3):

$$C_t = (C_s/K_d) + C_s * TSS$$

$$K_d = f_{oc} * 0.63\ K_{ow}$$

$$K_d = 0.0325 * 0.63 * 2.82 \times 10^4 = 577\ L/kg$$

$$C_t = (0.180\ mg/kg)/(577\ L/kg) + 0.180\ mg/kg)\ (1.8 \times 10^{-5}\ kg/L)$$

$$C_t = 3.15 \times 10^{-4}\ mg/L = C_w$$

The assumption that there is no substantial contaminant concentration gradient between the sediment bed and the suspended particles in the surface water makes possible the estimation of surface water aqueous and absorbed concentrations. As to whether this assumption is valid, it can be noted that rapid circulation leading to the circulation of relatively clean waters over the contaminated sediments and slow diffusion processes in the bed can lead to substantial contaminant gradients and flux values.

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