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SEDIMENTS

Mr. James Saric
Remedial Project Manager
USEPA Region 5
77 West Jackson Boulevard
Mail Code: SR-6J
Chicago, IL 60605-3507

Subject:
Final Generalized Conceptual Site Model
Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site

Date:
May 21, 2009

Contact:
Michael J. Erickson

Phone:
810.225.1924

Email:
michael.erickson@
arcadis.com

Our ref:
B0064524

Dear Mr. Saric:

On behalf of the Kalamazoo River Study Group (KRSG), please find enclosed the final version of the *Generalized Conceptual Site Model* (Generalized CSM).

The Generalized CSM, which was developed and submitted to satisfy the requirements of Section 1.2.1.4 of the Statement of Work (SOW) attached to the Administrative Settlement Agreement and Order on Consent (AOC) for the Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site (Comprehensive Environmental Response, Compensation, and Liability Act [CERCLA] Docket No. V-W-07-C-864), was originally submitted in June 2007. KRSG revised and resubmitted the document in April 2008, October 2008, and March 2009 in response to comments from U.S. Environmental Protection Agency (USEPA) and the Michigan Department of Environmental Quality (MDEQ). USEPA approved the March 2009 version on May 18, 2009.

If you have any questions, please do not hesitate to contact us.

Sincerely,

ARCADIS

Michael J. Erickson

Michael J. Erickson, P.E.
Associate Vice President

Enclosures: James Saric (two hard copies)

Copies:
Jeff Keiser, CH2M HILL (one hard copy)
Paul Bucholtz, MDEQ (two hard copies)
Garry Griffith, Georgia-Pacific, LLC
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Mark P. Brown, Ph.D., Waterviews, LLC
Richard Gay, Weyerhaeuser
Kathy Huibregtse, RMT, Inc.

Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site

Generalized Conceptual Site Model

Kalamazoo River Study Group

May 2009

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

REPLY TO THE ATTENTION OF:

May 18, 2009

SR-6J

Mr. Michael J. Erickson
Associate Vice President/Principal Engineer
ARCADIS
10559 Citation Drive, Suite 100
Brighton, MI 48116

RE: March 2009 Revised Draft Generalized Conceptual Site Model

Dear Mr. Erickson:

The United States Environmental Protection Agency (EPA) has completed its review of the March 20, 2009, revised Generalized Conceptual Site Model (CSM) for the Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site.

This revised CSM includes a response to comment document and redline/strikeout version of the CSM. The CSM has adequately addressed EPA's previous comments and incorporated them into the document.

Therefore, EPA approves the March 2009 revised CSM. A final version of the CSM document, incorporating the changes in the March 2009 draft version, must be submitted within (30) thirty days of receipt of this letter.

Please contact me at (312) 886-0992 if you have any questions regarding this matter.

Sincerely,

James A. Saric
Remedial Project Manager
SFD Remedial Response Branch #1

cc: Paul Bucholtz, MDEQ
Gary Griffith, Georgia-Pacific
Richard Gay, Weyerhaeuser

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Allied Paper, Inc./Portage Creek/
Kalamazoo River Superfund Site

Supplemental Remedial Investigations/
Feasibility Studies

Generalized Conceptual Site Model

Kalamazoo River Study Group

May 2009

ARCADIS

Michael J. Erickson, P.E.
SRI/FS Project Coordinator

Generalized Conceptual Site Model

Allied Paper, Inc./Portage Creek/
Kalamazoo River Superfund Site

Supplemental Remedial
Investigations/Feasibility Studies

Prepared for:
Kalamazoo River Study Group

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Our Ref.:
B0064524.500

Date:
May 2009

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1. Background

On February 21, 2007 Georgia-Pacific Corporation and Millennium Holdings, LLC—collectively referred to as the Kalamazoo River Study Group, or KRSG—voluntarily entered into an Administrative Settlement Agreement and Order on Consent (AOC) with the U.S. Environmental Protection Agency (USEPA). This agreement, which describes a series of supplemental remedial investigations and feasibility studies (SRIs/FSs) that will be carried out over the next several years, is referred to as the SRI/FS AOC (Comprehensive Environmental Response, Compensation, and Liability Act [CERCLA] Docket No. V-W-07-C-864). The SRI/FS work will take place primarily in Operable Unit 5 (OU5) of the Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site (Site or Superfund Site), located in Kalamazoo and Allegan counties in southwest Michigan (Figure 1-1). OU5 encompasses 80 miles of the Kalamazoo River, including a stretch of Portage Creek from Alcott Street to its confluence with the Kalamazoo River (Figure 1-1).

The SRI/FS AOC includes a Statement of Work (SOW) as Attachment A that sets forth the requirements for conducting the SRI/FSs and defines seven specific Areas within OU5. The seven Areas of OU5 to be addressed during the SRI/FS activities are:

- Area 1: Morrow Dam to Plainwell Dam, which includes a stretch of Portage Creek from Alcott Street to its confluence with the Kalamazoo River
- Area 2: Plainwell Dam to Otsego City Dam
- Area 3: Otsego City Dam to Otsego Dam
- Area 4: Otsego Dam to Trowbridge Dam
- Area 5: Trowbridge Dam to the Allegan City Dam
- Area 6: Allegan City Dam to Lake Allegan Dam
- Area 7: Lake Allegan (also known as the Calkins Dam) Dam to Lake Michigan

The boundaries of each of the seven Areas are shown on Figure 1-1.

The SOW also requires investigation of four former paper mill properties (Mill Properties) to determine whether each Mill Property is a source or a potential source of polychlorinated biphenyls (PCBs) to the Site.

In Part III of the SOW, a series of tasks that must be completed as part of the SRI/FS activities is described, and requirements for a series of Multi-Area SRI/FS Planning Documents are outlined. The primary goal of the Multi-Area documents, as stated in the SOW, is to "set forth general approaches and concepts with the intent of streamlining preparation of work plans and minimizing review times for future deliverables." A secondary goal is to set forth a framework for a consistent investigation and assessment approach between Areas and/or OUs of the Site, as appropriate.

One of the Multi-Area documents required by the SOW is a Generalized Conceptual Site Model (Generalized CSM). The Generalized CSM is to describe, from an overall perspective, potential contaminant sources, fate and transport routes, and exposure pathways for the Site.

This *Generalized Conceptual Site Model for the Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site* (Generalized CSM) was prepared for OU5 (the Kalamazoo River and Portage Creek) as required by the SOW. As SRI/FS activities unfold in each of the seven Areas of OU5, Area-specific information will be used to refine the Generalized CSM and tailor it for each Area. Evaluation of each Area-specific CSM will be done in an iterative fashion, starting with the SRI Planning Documents required for each individual area (for example, the Area-specific Work Plans) and continuing through completion of the Area-specific Feasibility Study Report. This Generalized CSM will provide a starting point for development of Area-specific CSMs, to the extent they are developed for each Area.

The Site is large and river conditions within the Site vary greatly. The entire Site spans nearly 80 miles of river and traverses urban, rural, forested, agricultural, and marshland areas. Flow conditions vary intermittently between free-flowing and impounded reaches. Topography adjacent to the river varies as well, ranging from an incised valley with narrow floodplains in the upper reaches of the Site to flatter topography with adjacent marshes downstream of Lake Allegan. The unique aspects of the different reaches will be addressed in the respective Area-specific conceptual models as SRI/FS activities progress in each of the seven Areas of OU5.

Site data have been collected by the KRSG over the past 15 years as part of Agency-approved RI-based efforts and a series of supplemental studies in support of the RI/FS activities. Extensive data have also been collected by government agencies and their representatives (i.e., United States Geologic Survey [USGS], USEPA, Michigan Department of Environmental Quality (MDEQ), Michigan Department of Community Health [MDCH], Weston, Camp Dresser & McKee [CDM]). While all KRSG data were collected in accordance with MDEQ-approved guidance documents (i.e., Field Sampling Plan [FSP], Quality

Assurance Project Plan [QAPP], Health and Safety Plan [HASP]), the work plans developed for the KRSG's series of supplemental RI/FS studies were not reviewed or approved by MDEQ or USEPA, and the associated data have not been formally assessed by the agencies. As described in the 2007 SRI/FS AOC and associated SOW, the USEPA is currently in the process of determining the usability of historical data (including those gathered during the supplemental studies) for use in the SRI/FS. The KRSG initiated this data useability review in a letter to the USEPA dated August 30, 2007 and the process is ongoing. The development of this Generalized CSM was developed with consideration of all the historical data. Future use of Site data in CSM development or refinement will be guided by the outcome of the USEPA data usability determination. New data collected as part of the SRI/FS efforts, which will be generated under work plans reviewed and approved by USEPA, will also be used to refine this generalized CSM as appropriate and develop the Area-specific conceptual models.

1.1 Introduction to the Generalized Conceptual Site Model

The development of this Generalized CSM for the Kalamazoo River Superfund Site is consistent with USEPA guidance (USEPA 1988, 2002, and 2005), and as appropriate, guidance developed by ASTM International (ASTM 2003). Key among the USEPA guidance considered was the 2002 *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (USEPA 2002). The fourth of USEPA's eleven risk management principles is to "Develop and Refine a Conceptual Site Model that Considers Sediment Stability." As described in that principle, this Generalized CSM includes a discussion of sources of contamination (Section 1), mechanisms of fate and transport (Section 1), types of contaminants and affected media (Section 4), existing and potential exposure pathways (Section 5), and the known or potential human and ecological receptors (Section 5). The concept of understanding the stability of sediments is particularly important because the interrelationships between sediments, other media, and receptors are often complex; the sediments are likely to go through temporal, physical, and chemical changes over time and across miles of river; and the stability of the sediments may influence the availability of contaminants to receptors and plans for management of potential risks associated with PCBs. As described above and consistent with the fifth risk management principle, this Generalized CSM will be updated in an iterative fashion for individual Areas with both historical information (as appropriate) and new data collected as part of the SRI/FS work.

As described in USEPA guidance (USEPA 2005), a CSM is to serve as a representation of the environmental system and the physical, chemical, and biological processes that determine the transport of contaminants from sources to receptors. The CSM is generally an important element in the evaluation of risk and risk reduction approaches, and can be used to help identify and define data gaps. Points of uncertainty with respect to key aspects of the CSM are identified; however, data gaps are not specifically addressed. Data needs will be addressed in Area-specific work plans or through Area-specific refinements of the CSM.

At the Kalamazoo River Site, the KRSG, USEPA, and the State of Michigan have conducted numerous investigations over the past 15 years that have resulted in the generation of an extensive database. This Generalized CSM incorporates currently available Site data to present a general understanding of spatial and historical trends. The additional work planned as part of ongoing and upcoming SRI efforts will include the collection of new data which will be used to assess if historical trends continue and to reduce uncertainty with respect to rates of attenuation of PCB exposure concentrations and the influence of source control or residual sources.

The Site data, which have been presented in a variety of documents, indicate that PCBs are the primary contaminant of concern (COC). PCBs are persistent environmental pollutants that bioaccumulate in the upper levels of the food chain—particularly in fish. As explained in more detail in Section 1.3, the propensity for PCBs to accumulate in fish owes to their general affinity for fats and similar substances, as well as the relatively small capacity of PCBs to dissolve in water. The MDCH considers a range of PCB concentrations in fish tissue to set fish consumption advisories for both the general population and women and children (women over the age of 15 and children under 15). Fish consumption advisories are in place for women and children upstream of the Site, and for all populations from Morrow Dam downstream to Lake Michigan (MDCH 2007). Reducing PCB concentrations in Kalamazoo River fish to acceptable levels in terms of human health and ecological risk is a primary remedial goal for the Site. In consideration of the significance of fish tissue PCB concentrations in regards to decision-making at the Site, this Generalized CSM includes a summary of current fish tissue PCB data, observed historical trends in PCB within various media, and a summary of the status of the current fish consumption advisories in relation to PCB concentrations in fish.

The organization of this Generalized CSM is as follows.

- A brief history of the Superfund Site, characteristics and transport of PCBs, PCB composition within the Site, and ongoing sources of PCBs to the river are discussed in the remainder of Section 1.
- In Section 2, the hydrology and hydrogeology of the Site are described.
- The overall geomorphology and physical characteristics of the Site are presented in Section 3.

- A summary of PCB distributions and trends in various media within the Site is included in Section 4.

- PCB exposure pathways for ecological and human receptors are described in Section 5.

1.2 History of the Superfund Site

The Kalamazoo River Superfund Site, located in southwest Michigan, was added to the National Priorities List (NPL) in 1990 in response to the presence of PCBs in fish, sediment, and surface water. Site investigations have included the lower three miles of Portage Creek from Alcott Street to its confluence with the river, and spanned 90 miles of the Kalamazoo River, from Battle Creek, through Morrow Lake, and downstream to Saugatuck and Lake Michigan (see Figure 1-2). The KRSG companies were named as potentially responsible parties (PRPs) for the Site based on historical recycling of paper products that contained PCBs. From the time of the placement on the NPL until August 2001, the State of Michigan had the regulatory lead at the Site, and work was conducted in accordance with an AOC issued by the Michigan Department of Natural Resources (MDNR)[1] (MDNR 1991). In August 2001 the USEPA effectively assumed the lead agency role—a role that became official in July 2002.

Historical data collection efforts have been focused on the areas from Morrow Dam downstream to Lake Allegan Dam, although investigations have also been carried out in the river upstream of the Site and from Lake Allegan Dam to Lake Michigan. The Site database includes information on river sediments; floodplain soils; exposed sediments in the former Plainwell, Otsego City, Otsego, and Trowbridge Impoundments; surface water; and biota, particularly fish. Samples have been assessed for a variety of constituents—including polychlorinated dibenzodioxins and dibenzofurans (PCDDs/PCDFs) and USEPA Contract Laboratory Program Target Compound List/Target Analyte List (TCL/TAL) constituents such as pesticides and polycyclic aromatic hydrocarbons (PAHs)—but the focus of the work and the COC that is presumed to drive risk at the Site has always been PCBs. Highlights of investigations of the various Site media are summarized below.

- River Sediments: More than 3000 sediment cores and 6000 sediment samples from the river (including Morrow Lake) and Portage Creek have been collected to date, with major sampling efforts conducted in 1993/94 and 1999/2000. Sufficient data are available to

[1] In October 1995, the environmental quality divisions were split from the MDNR and placed in the newly created MDEQ.

establish general geographic and temporal trends; although further characterization will be needed to define spatial distribution of PCBs in some areas and to test continuation of observed historical trends. PCBs in sediments are discussed in Section 4.1.

- Floodplain Soils: Historical investigations in the floodplains of the Kalamazoo River and Portage Creek were designed to assess whether sediments containing PCBs or other constituents have been transported to the floodplains in significant concentrations. Based on PCB data collected in flood-prone areas in 1993, the primary conclusions presented in the *Technical Memorandum #3 – Results of the Floodplain Soil Investigation* (BBL 1994) were that "flooding of the Kalamazoo River has not transported PCB to the floodplain in significant amounts" and that "the focus of further RI/FS activities to address PCB in the floodplain is appropriately placed on the floodplains which comprise the exposed sediments of the three former impoundments (this Memorandum was approved by MDEQ)." Subsequent sampling was completed in floodplain soils along Portage Creek and the Kalamazoo River in 1995 and 2000, which included samples targeted to low-lying floodplain areas with potentially higher PCB concentrations to further assess PCB concentrations in natural floodplain soils (i.e. floodplain soils outside of the exposed former sediment areas). The 1995 and 2000 data also indicated low PCB concentrations in floodplain soils. Further investigation of PCBs in floodplain soils in Area 1 is included in the *Supplemental Remedial Investigation/Feasibility Study Work Plan – Morrow Dam to Plainwell Dam* (Area 1 SRI/FS Work Plan; ARCADIS BBL 2007), which will provide additional data on the potential significance of floodplain exposure in non-impounded areas. Currently available data on PCBs in floodplain soils are discussed in Section 4.2.

- Exposed Sediments: As described in more detail in Section 1.5, exposed sediments in areas of the Site that were underwater when PCB discharges were at their peak but then exposed when certain dams were opened and then partially dismantled are areas of importance in regards to assessment of potential human and ecological risks. These formerly impounded areas have been the subject of extensive historical sampling and investigation. Some of these areas are relatively low-lying and subject to intermittent wetting and drying with varying river stages throughout the year. Vegetation has covered the exposed sediments in the current floodplains of the former impoundments; however, based on data collected by the KRSG between 1999 and 2001 in the former Plainwell, Otsego, and Trowbridge impoundments, erosion of the PCB-containing materials in the often-steep river banks is an ongoing residual source of PCBs to the river. See Section 4.3 for a discussion of PCBs in the exposed sediments[2] at the Site.

- Surface Water: Surface water PCB data and flow measurements available from the mid-1980s through 2006 provide for the characterization of PCB transport in the river and Portage Creek, as well as spatial and temporal trends in the PCB concentrations. The surface water PCB data are presented in Section 4.4.

- Biota: PCB levels in fish have been the principal focus of work related to the assessment of potential risks to human and ecological receptors. The historical data set includes PCB measurements in many species of fish, including repeat sampling of select species as indicators of long-term trends in fish tissue PCB concentrations. Other biota data include dietary studies and PCB tissue samples for various aquatic and terrestrial-feeding receptors. These data establish that PCB concentrations in fish are a key risk driver for both human and ecological receptors at the Site. A more detailed discussion of PCB concentrations in fish is provided in Section 4.5.

Four areas used historically to dispose of paper-making wastes and residuals have been designated as OUs. These include the Allied Paper, Inc. OU (OU1), the Willow Boulevard/A-Site OU (OU2), the King Highway Landfill OU (OU3), and the 12th Street Landfill OU (OU4). Work at each of these four OUs is proceeding separately from work in OU5—the River and Portage Creek—and extensive cleanup work has already taken place across the Site, particularly at locations that were used as disposal sites for paper-making residuals and wastes. Several disposal areas were recognized as potential residual sources of PCBs to the river and Portage Creek—control of potential sources in these areas has been conducted under prior agreements and is ongoing. In addition, as a result of a second AOC between the USEPA and KRSG signed on February 21, 2007 a Time-Critical Removal Action (TCRA) is currently underway in the former Plainwell Impoundment (TCRA AOC; CERCLA Docket No. V-W-07-C-863). Work on the TCRA began in April 2007, and removal activities and restoration activities are expected to be complete in the spring of 2009.

Past response actions to control sources, and those that are underway or planned, are summarized in Table 1-1.

[2] A note on terminology. The sediments that were exposed as a result of water levels dropping behind the dams are referred to as exposed sediments. The soils that comprised the natural floodplains are referred to as floodplain soils.

Table 1-1. Response Actions to Control Sources of PCBs to the Kalamazoo River

Location	Response Actions
Past Response Actions	
Allied Paper Inc., Operable Unit	• Excavated 146,000 cubic yards (cy) of materials from Bryant Mill Pond • Removed 2,000 cy of materials from along Portage Creek and consolidated at the OU • Stabilized berms and installed sheetpile walls along Portage Creek • Installed groundwater monitoring network (monitored quarterly, primarily for water level) and groundwater recovery and treatment system • Installed 18-acre landfill cap
King Highway Landfill Operable Unit (KHL OU)	• Excavated 58,000 cy of materials from areas directly adjacent to the KHL OU, King Street Storm Sewer, Kalamazoo Mill Lagoons, King Mill Lagoons, and other locations • Capped 23-acre site • Stabilized berms and installed sheetpile walls along the Kalamazoo River • Installed groundwater monitoring network (monitored quarterly) • Installed gas probes
Willow Boulevard/A-Site Operable Unit	• Excavated 7,000 cy sediment from river • Stabilized A-Site berms and installed sheetpile walls along the Kalamazoo River • Consolidated materials at Willow Boulevard Site, regraded area, and installed temporary sand/soil cover • Constructed bridge over Davis Creek for access
(Simpson) Plainwell Mill	• Cleaned storm sewers
Kalamazoo Mill/Hawthorne Mill TCRA	• Removal of 50,000 cy soil
Ongoing Response Actions	
Former Plainwell Impoundment TCRA	• Removal of 120,000 cy sediment and soil • Offsite disposal • Reconstruction/stabilization of river banks
Planned Response Actions	
Willow Boulevard/A-Site Operable Unit	• Removal of approximately 13,800 cy of materials and consolidation with other materials onsite – planned for 2010
12th Street Landfill OU *(Weyerhaeuser Co. is the responsible party, not the KRSG)*	• Record of Decision signed in 2001 • Consent Decree finalized in 2005 • Remedy calls for consolidation of PCB-containing materials and installation of a cap over the OU • Work will also include response actions at the Plainwell Mill

1.3 PCB Characteristics and Transport

The chemical properties of PCBs (e.g., solubility, volatility, biodegradability, affinity to nonaqueous phases such as solids and organic particles) influence the mode of transport and the ultimate fate of PCBs in the environment. These characteristics vary greatly among the 209 PCB congeners, resulting in different behavior between the lighter, less-chlorinated PCB molecules and the heavier, more-chlorinated PCB molecules. Due to the generally low solubility and consequent high affinity of PCBs for adsorption to natural solids (particularly organic matter fractions of those solids), the transport and fate of PCBs in river systems is closely tied to the transport and fate of solids. This chemical affinity for solids makes sediment in depositional areas a sink for PCBs. These sediments can act as a reservoir supplying PCBs to the water column and biota within the aquatic ecosystem.

Not All PCBs Are Alike

PCBs are a group of 209 different compounds, referred to individually as “congeners,” that differ in the number and arrangement of chlorine atoms on the biphenyl molecule. In the United States, PCBs were produced as mixtures of PCB congeners for commercial purposes exclusively under the trade name Aroclor. Although most PCBs produced in the United States were used in manufacturing electrical transformers and capacitors, they were also used in other applications, including hydraulic fluids, cutting oils, heat transfer fluids, quench oils, and from 1957 through 1971, PCBs were used in the manufacture of carbonless copy paper.

The average chlorine content of a particular Aroclor product is, in most cases, evident in the specific product name. For example, Aroclor 1242 is 42% chlorine by weight, while Aroclor 1254 is 54% chlorine by weight. The PCBs discharged from paper mills were predominately derived from Aroclor 1242, which was used in carbonless copy paper. Aroclor 1242 also was used in capacitors operated at facilities throughout the watershed.

The propensity for PCBs to accumulate in fish owes to their general affinity for fats and similar substances, as well as their relatively small capacity to dissolve in water. The octanol-water partition coefficient (K_{ow}), is a chemistry term that is related to the propensity for chemicals to accumulate in aquatic organisms. K_{ow} is basically the ratio of: 1) the extent to which PCBs accumulate in the fat-like substance octanol to 2) the extent to which PCBs remain in a dissolved phase. Scientists have developed estimates of K_{ow} values for the 209 different PCB congeners and for the Aroclor mixtures.

K_{ow} values also have been useful to account for how PCBs move from sediment into aquatic organisms. Parkerton et al. (1993) summarized available field data relating PCB levels found in aquatic animals (on a fat basis) to PCB levels in surface sediment (on an organic carbon basis). The ratios of the two, known as biota to sediment accumulation factors (BSAFs) were in turn related to the K_{ow} values of PCBs. The data show an increase in BSAFs with increasing K_{ow}. Over the range of log K_{ow} values for Aroclor 1242 and 1254 (5.6 to 6.5, respectively, according to the Agency for Toxic Substances and Disease Registry [ATSDR 2000]), the data show that BSAFs increase by slightly more than a factor of three. In future sampling and analysis efforts, quantifying the PCB congeners present in Site media may be useful in developing an understanding of the potential current and future influence of different sources of PCBs.

Biodegradation of PCBs is another characteristic that influences the presence and movement of PCBs in a system. In general, biodegradability of PCBs in aerobic systems decreases as the degree of chlorination increases. Mono-, di-, and tri- chlorinated biphenyls aerobically biodegrade relatively rapidly, tetrachlorinated biphenyls biodegrade slowly, and higher-chlorinated biphenyls are resistant to biodegradation. Abramowicz (1990) indicates that no aerobic microorganisms have been reported to degrade the more highly chlorinated commercial mixture Aroclor 1260. Anaerobic dechlorination of PCBs that occurs in sediments reduces the levels of higher chlorinated biphenyls and results in the accumulation of lower chlorinated biphenyls. The more highly chlorinated PCBs are extremely resistant to conventional aerobic transformation, but they can undergo anaerobic reductive dechlorination.

PCB transport within the Kalamazoo River system is governed by river flow and sediment transport processes. The amount of PCBs transported annually is affected not only by hydrologic variables that influence river flow, but also by the spatial distribution and nature of PCB sources to the water column. Prior to the restrictions placed on the use and disposal of PCBs in the 1970s, and the resulting reductions in point source discharges, the water column served as a significant source of PCBs to the sediment, conveying PCB containing material downstream and depositing it with sediments primarily in low-energy areas. Since then, characteristics of PCB transport have shifted emphasis to resupply from the exposed former sediments in the former impoundments and from the sediment bed to the water column in many areas of the river.

Monitoring of bank profiles (Rheaume et al. 2002) and modeling studies (Wells et al. 2003, Wells et al. 2007, Langendoen and Wells 2006, Syed et al. 2005) have shown erosion of banks in the former impoundments to be a significant continuing external source mechanism, delivering PCB-impacted materials to the river sediments and water column. Uncertainty remains concerning the magnitude of other potential source mechanisms associated with the exposed former sediments, such as periodic inundation of portions of the exposed sediment and groundwater flow through these materials. Water column monitoring shows that the formerly impounded sections of the river are a source of PCBs to the water column. In Lake Allegan, water column monitoring at the lake inlet and outlet conducted by MDEQ have shown that the sediments of Lake Allegan continue to be a net sink for PCBs transported from upstream (MDEQ 2007).

1.4 PCB Composition within the Site

The KRSG and its predecessors operated a number of paper mills in the Kalamazoo River watershed, primarily in and around Kalamazoo. Starting in the 1950s, the mills began to recycle waste paper from government offices, businesses, and schools for stock to conserve resources and stay competitive (Walters 2001). Mixed in with the paper sent to the mills for recycling was carbonless copy paper, which between 1957 and 1971 contained PCBs in the form of Aroclor 1242 as an ink carrier/transfer agent or solvent (Versar Inc. 1977). Although Aroclor 1254 was used in a limited fashion within the paper industry in "flexographic" inks that were used on plastic packaging, since this packaging was primarily plastic or paper containing plastic adhesives that contained negligible amounts of fiber, it would not have been an attractive stock for recycling. Versar Inc. (1977) concluded that these Aroclor 1254-derived inks were unlikely to have significantly contributed to PCB waste streams within the paper industry. This is confirmed in the samples of paper-making residuals collected from the landfill operable units during the 1993 RI – 99.2% of the PCB mass in these samples was quantified as Aroclors 1016, 1242, and 1248, while just 0.6% was quantified as Aroclor 1254.

Standards representing the different Aroclors are used to quantify total PCB results, and it is important to understand that there is some uncertainty associated with the correspondence of the Aroclor standards used in the laboratory to the PCB mixtures in source material from the Site. The quantification of specific Aroclor mixtures in fish tissue (and other types of biota samples) is affected by metabolism and a variety of physical and biological processes that can differentially affect uptake and retention in fish tissue of the PCB congeners of the original PCB mixture released to the environment. Environmental transport and dechlorination processes can also alter the congener composition of PCB mixtures over time. As a result, Aroclor mixtures can become more difficult to identify as the original mixture becomes altered through environmental and biological processes. The quantification of specific Aroclors based on standards used for Total PCB quantification can, however, be a useful indicator as to the potential importance of different source Aroclors in affecting the PCB mixture in samples. Other methods, including congener analysis, can provide greater insights into how PCBs from various source mixtures may contribute to Total PCB concentrations. This may be useful in understanding potential contribution of residual sources of different Aroclors to future concentrations of PCBs in fish tissue at the Site.

1.5 Ongoing Sources

A series of response actions have been implemented to control or eliminate potential sources of PCBs at the former mill properties and the Site's OUs, as summarized in Table 1-1 above.

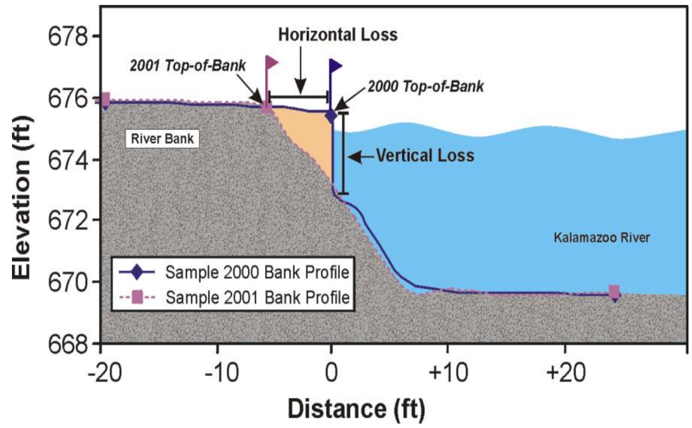
Further, implementation of the TCRA in the former Plainwell Impoundment is a significant step toward controlling the largest ongoing source of PCBs to the river—the erosion of the steep, unstable PCB-containing river banks in formerly impounded areas of the Site.

Of these formerly impounded areas, the most extensive information is available for the former Plainwell, Otsego, and Trowbridge Impoundments. The dams that created these three impoundments were constructed in the late 1800s and early 1900s for the production of hydroelectric power. After power generation ceased in 1965, the dams were deeded to a predecessor of MDNR. Each of these dams impounded a significant volume of water that covered many acres (123 acres in Plainwell, 330 acres in Otsego, and 546 acres in Trowbridge [Miller 1966]), and PCBs were buried in the fine-grained materials deposited in these quiescent areas. When the dams were opened in the 1970s and then removed down to their sills in 1987, water levels dropped quickly (by approximately 5 to 10 feet), and consequently the river carved a new channel into the lacustrine sediment bed. As a result, previously submerged sediments were exposed—these materials are now the floodplains and part of the banks in the three former impoundments. The river channel has not yet reached a new equilibrium in these areas. Continuing changes in channel shape and position is evident by the sloughing and erosion of the steep banks that were created following the drawdown of each Impoundment. A similar mechanism of bank erosion may be a factor in the Otsego City Impoundment, although this area has not been studied as extensively. Additional data on bank erosion sources of PCBs and extent of PCBs in the Otsego City Impoundment will be addressed as part of SRI activities in that area.

The low-head characteristics of the flow diversion dam in the Plainwell No. 2 Dam Area did not create a historical impoundment (see Section 3.2 for more detail on this dam), but the inundation frequency was increased as compared to natural floodplains along the river. Eroding banks containing PCBs are also present in this area, but to a lesser extent than in the former Plainwell Impoundment. The Plainwell No. 2 Dam Area is the subject of a focused investigation included in the Area 1 SRI activities.

The KRSG has conducted a series of erosion pin surveys in the former Plainwell, Otsego, and Trowbridge Impoundments to characterize the changes along the banks of the river, estimate rates of river bank erosion, and estimate the volume and mass of solids—as well as the mass of PCBs—contributed by the banks on an annual basis. Results to date have confirmed that the river banks in these areas serve as an ongoing source of PCBs. The illustration (to right, top) shows an example of horizontal and vertical bank loss observed during the survey, and the photo (to right, bottom) is representative of the current conditions in many parts of the former impoundments. Uncertainty remains concerning other potential source mechanisms associated with the exposed former sediments, such as a groundwater-related pathway and release to the river during periodic inundation. These mechanisms will be explored as appropriate as part of the Area-specific investigations.

Example of Horizontal and Vertical Bank Loss



Steep, eroding bank in a former impoundment

One objective of the TCRA currently underway in the former Plainwell Impoundment is to address the eroding banks as the source of PCBs in this area. TCRA activities include the targeted removal of more than 130,000 cubic yards of bank soils and sediments with offsite disposal, stabilization and revegetation of the river banks. Much of the remaining Plainwell Dam spillway will be removed along with the berm constructed for the former powerhouse structure, and after this work is complete, the river will be returned to its historical pre-dam channel (to the west of the current channel) and a free-flowing condition.

In addition to the sources associated with exposed sediments, other ongoing sources of PCBs to the Site—including contributions from urban non-point source runoff, atmospheric deposition, and contributions from upstream sources via discharge over Morrow Dam—continue, albeit at lower levels. The significant number and variety of legacy industries in the watershed that were documented users and dischargers of PCBs—for example the automobile industry and the numerous supporting operations, including foundries, parts manufacturers, machining operations, and metal recycling that maintained a significant presence in southern Michigan for most of the 20th century—may also continue to serve as sources of PCBs to the river. As concentrations of PCBs within the Site decline, the influence of these more diffuse watershed sources may become more significant.

Transport via groundwater contacting PCB-containing materials – such as the exposed former sediments – is also a potential source of PCBs to the river and is being investigated in the former Plainwell Impoundment as part of Area 1 SRI activities.

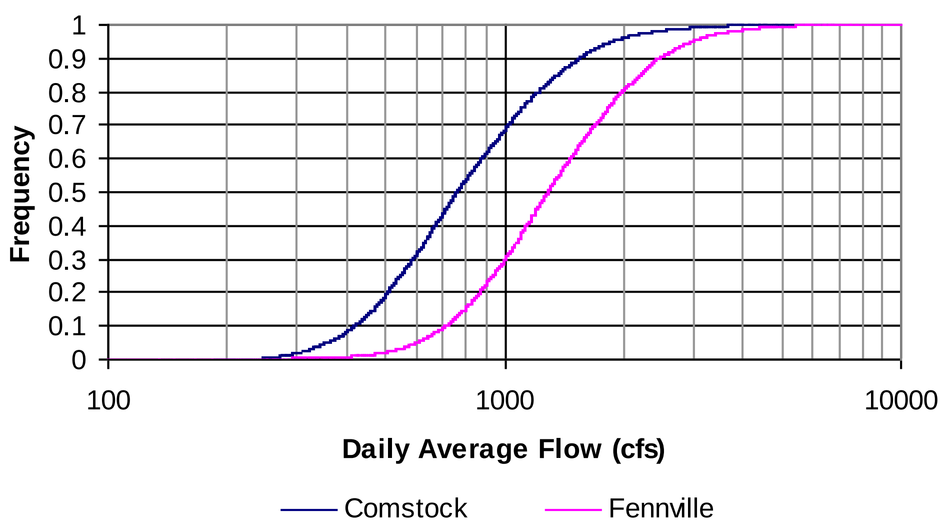
2. Site Hydrology

The Kalamazoo River watershed is located in the southwest portion of Michigan's Lower Peninsula. It drains approximately 2,020 square miles in ten counties: Allegan, Barry, Calhoun, Eaton, Hillsdale, Jackson, Kalamazoo, Kent, Ottawa, and Van Buren. The watershed is approximately 162 miles long and varies in width from 11 to 29 miles. The mainstem of the Kalamazoo River is 175 miles long and is fed by 899 miles of tributaries (Brown 1944); the largest of these include the North Branch Kalamazoo, Battle Creek, Gun, and Rabbit Rivers and Wabascon, Augusta, and Portage Creeks. Locations of tributaries entering the portion of the river within the Site are shown in Figure 1-2.

The USGS has recorded long-term flow data in the river at two gages: one currently-operating gage located 1.2 miles downstream of Morrow Lake at River Street in Comstock near the upstream end of the Site; and one at Fennville, about four miles downstream of Lake Allegan Dam, which was taken out of service in 1993. The annual average flow at Comstock is 870 cubic feet per second (cfs). Groundwater discharge and tributary flows between the gaging stations contribute an additional 570 cfs, resulting in an annual average of 1440 cfs at Fennville.

Flow in the Kalamazoo River is generally stable, as illustrated by cumulative frequency distributions for daily flow records from the Comstock and Fennville gages (Figure 2-1 below). The 5% exceedence flow at Comstock (i.e., the flow that is exceeded 5% of the time) is 1870 cfs; this is approximately 2.5 times the median flow of 758 cfs.

Figure 2-1. Cumulative Frequency Distributions for Daily Flow Records



There are 110 dams in the Kalamazoo River watershed registered with the MDEQ, including 15 on the mainstem of the river. These dams play an important role in regulating flows within the river, along with the well-drained nature of watershed soils and the relatively limited extent of development of the watershed.

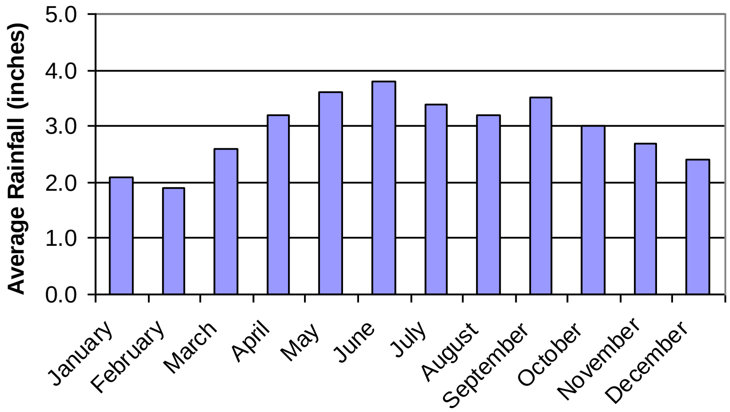
The effect of natural and impoundment-related flow regulation is evident by comparing USGS peak flow data to daily mean flow data. Peak flow measured by the USGS is the maximum flow recorded for a 15-minute period, while daily mean flow is the average of all 15-minute recorded flows for a 24-hour period. In a river with unstable flow, the peak flows will occur in quick succession to significant precipitation and flow will subside quickly, and typically daily mean flow will be considerably less than the highest instantaneous flow for that day.

A comparison of annual peak flows (the highest 15-minute recorded flow per year) to daily mean flows for the corresponding days indicates close agreement between the two parameters in the Kalamazoo River. At the Comstock gage, the difference between the average instantaneous peak flow (3,174 cfs) and the average daily flow for the corresponding days (3,064 cfs) is only 110 cfs. The 15-minute peak flow is, on average, only 4.2% higher than the corresponding 24-hour average flow, which is indicative of sustained flood flows with relatively gradual rises and declines. At the Fennville gage the average difference between peak and daily mean flows is approximately 11% (503 cfs).

The hydrology of the Kalamazoo River watershed is strongly influenced by glacial deposits (predominantly outwash sands and gravels) that comprise the majority of the surficial geology (Wesley 2005). The permeable nature of these outwash sands and gravels allows for groundwater discharge from surficial aquifers and contribute to stable flows in the Kalamazoo River. For one year (August 1987 to August 1998), the USGS monitored the river stage on the Kalamazoo River (at a gage at Comstock) and the groundwater elevation at a well about 1,000 feet away from the river near the upstream end of Morrow Lake, and determined that the river and shallow aquifer are hydraulically connected (Rheaume 1990).

Annual precipitation across the watershed is approximately 34 inches. Regions near the mouth and along the lower reaches of the river receive substantial lake effect snow fall—80 inches per year compared to 40 inches per year in the headwaters. The majority of precipitation is returned to the atmosphere by evapotranspiration. Watershed flow yield is approximately 0.98 cfs per square mile per year. The heaviest precipitation, associated with passing cold fronts and air mass instability, occurs in May and June for most of the basin (Figure 2-2, below).

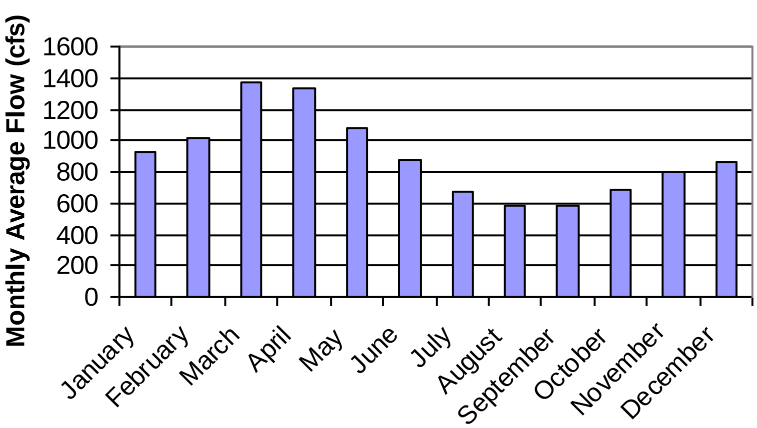
Figure 2-2. Average Monthly Precipitation in the Kalamazoo River Basin



Note: Rainfall data recorded at the Kalamazoo State Hospital, 1931-1995

As is typical in northern temperate climates, the highest average daily flows occur in the spring as a result of snowmelt, precipitation, and higher runoff rates. In the Kalamazoo River, the highest average daily flows occur in March and April—a function of snowmelt, precipitation, and storm flows flowing over frozen ground. The lowest flows occur in late summer and early fall, when water losses to soil infiltration and evapotranspiration are greatest. The lowest monthly average flow occurs in August (Figure 2-3).

Figure 2-3. Kalamazoo River Monthly Average Flow at Comstock, MI



Note: Data recorded by USGS at the gage at River Street in Comstock.

3. Physical Characteristics of the Site

Understanding the major physical characteristics of the Kalamazoo River is important in the development of the overall CSM. This section is used to:

- Describe the general geomorphology and physiography of the Site
- Catalog the dams found on the mainstem of the Kalamazoo River within the Site
- Present the general characteristics of the seven Areas of OU5
- Discuss five general types of reaches found within the Site
- Describe processes governing sediment stability at the Site

3.1 General Geomorphology and Physiography

The Kalamazoo River flows westerly from Morrow Lake, turns to the north at the City of Kalamazoo toward Plainwell, and then meanders northwest to Lake Michigan at Saugatuck (Figure 3-1). The Kalamazoo River basin was formed by the retreat of continental glaciation about 10,000 years ago. Glacial moraines (masses of rock and soil materials deposited directly by glaciers) and melt water flows shaped much of the surficial geology in the basin, and have a major influence on local hydrology, channel morphology, and river and tributary gradients within the basin.

Between Morrow Dam and Lake Allegan, the river channel meanders through a valley with adjoining moraine features, and is sporadically confined by the valley walls. Floodplains are generally limited in extent. River gradients within the Site are greatest in this section. Upstream of the former Plainwell Impoundment, gravels and coarse sands comprise much of the channel. Between Plainwell and Allegan City, the channel is generally more confined within a relatively narrow glacial-fluvial valley. Sediment types are intermittent, varying from gravel and sands to silts as a function of variable flow velocities generally caused by increasing water depth through the impoundments.

Lake Allegan is a broad shallow impoundment with characteristics more typical of a shallow lake than a river. Below Lake Allegan Dam, the river meanders freely across a lacustrine plain and flows 26 miles to Lake Michigan. This lower section of the river is characterized by predominately low banks, broad floodplains, and adjoining wetlands and marshes (Swan Creek Marsh, Koopman Marsh, and Ottawa Marsh). Sand and silts predominate in river sediments in this reach. Great Lakes migratory fish can move from Lake Michigan 26 miles upstream to the Lake Allegan Dam.

The river channel increases in width near Lake Michigan where it flows through coastal dunes. The channel is up to one-half mile wide at Kalamazoo Lake. Adjoining the City of Saugatuck, Kalamazoo Lake is 190 acres in area, with an average depth of 5 feet.

From an overall perspective, the free-flowing reaches of the river are steeper, have higher water velocities, and are generally erosional in nature with rocky and cobbly bottoms. The impounded areas are quiescent and serve as sediment traps as the river slows and sediments deposit—these areas tend to accumulate more fine-grained sediment rich in natural organic material. In the areas of the impounded historical river channels, thick deposits of sediments have accumulated over the native cobbles and coarse gravel bed. Reaches of the river between the dams exhibit multiple channels, sandbars, and extensive meandering—these areas represent a transient sediment bed that fluctuates in response to flow and sediment transport conditions.

Construction and operation of the dams fragmented the river, resulting in slow-flowing areas more typical of shallow lake environments. Five of the seven dams within the Site (the Plainwell No. 2, Plainwell, Otsego, Otsego City, and Trowbridge Dams– see Section 3.2) have been dismantled and drawn down to some extent. These draw-downs created deposits of exposed sediments that were once submerged, or in the case of the Plainwell No. 2 Dam, bank soils that accumulated PCB-containing material as a result of relatively frequent historical inundation. Some of these exposed sediments are now present as bank soils and are eroding into the river, and the channel in these areas may still be moving toward a new equilibrium as a result of the lowering of water levels behind the dams.

3.2 Dams

There are seven dams on the Kalamazoo River between Morrow Dam and Lake Michigan. Morrow Dam is an operating hydroelectric dam at the upstream end of the Site. The seven dams located within the Site (along with their operating status) are listed in upstream to downstream order below.

- Plainwell No. 2 Dam (drawn down to sill)
- Plainwell Dam (drawn down to sill)
- Otsego City Dam (retired hydroelectric dam; drawn down)
- Otsego Dam (drawn down to sill)

- Trowbridge Dam (drawn down to sill)
- Allegan City Dam (retired hydroelectric dam)
- Lake Allegan (Calkins) Dam (operating hydroelectric dam)

These seven dams were all constructed for hydroelectric power generation and were generally constructed in areas with high stream gradient.

Unlike the other dams at the Site, the Plainwell No. 2 Dam—which actually consists of four separate structures (two diversion structures, a head gate, and a waste gate)—was constructed in 1856 to create and control water levels in a mill race/power canal. The diversion structures directed water from the main stem of the river into a mill race/power canal that was once used to generate water power for a flour mill, the City of Plainwell, and several other businesses. The Plainwell No. 2 Dam impounded less water than the other formerly impounded areas—the operation of the structures never created a lake-type environment and the historic floodplains upstream of this dam were inundated to a lesser extent and with less frequency than in the other four formerly impounded areas. By 1979, the Plainwell Paper Company owned the dam and no power was being generated (U.S. Army Corps of Engineers [USACE] 1979). According to the MDEQ, the dam and associated structures were partially removed in the early 1980s such that there is no longer any "significant amount of water" (Hayes 1998) impounded in the area. The waste gate structure's lift gate and stoplog guides were still present in 1980, and at that time there were no active operational procedures in place other than to permanently leave all discharge control structures adjusted so that they will permit maximum discharge capacity (USACE 1979).

The Plainwell, Otsego, and Trowbridge Dams were constructed in the late 1800s and early 1900s for the production of hydroelectric power. After power generation ceased in 1965, the dams were deeded to a predecessor of MDNR. Each of these dams impounded a significant volume of water that covered many acres (123 acres in Plainwell, 330 acres in Otsego, and 546 acres in Trowbridge [Miller 1966]). The dams also created quiescent areas on the river where fine-grained materials were deposited and where PCBs were buried. These three dams were opened in the 1970s and then removed down to their sills in 1987, which is their present condition.

The Otsego City Dam, also known as the Menasha Paper Company Dam, is located in the City of Otsego, near the Farmer Street Bridge. Maintenance of the dam is the responsibility of the City of Otsego. According to the USGS, the Otsego City Dam was built in the 1840s in an effort to create a freight business on the Kalamazoo River (Dalrymple 1972, as cited in Rheaume et al. 2002). The original dam was 5 feet high and contained a lock for the passage of barges, canoes, or rafts. Over the years, the dam was rebuilt and repaired (Rheaume et al. 2002).

Available information indicates that the former Otsego City Impoundment was drawn down in mid-March 1982 when stoplogs were removed from the dam (Hayes 1982), and again in May 1991 when the dam was dismantled to its sill level. The impact on water level due to the 1982 action is not known, but the MDNR estimated that the 1991 action lowered water levels by 2 to 3 feet (Hayes 1991).

The Allegan City Dam ceased power generation in 1997 and was purchased by the City of Allegan to maintain the waterfront as an attraction to the City (Wesley 2005). The dam was upgraded and repaired by the City in 2002.

Morrow Dam and Lake Allegan Dam (also known as the Calkins Dam) are operating hydroelectric dams. Under licenses issued by the Federal Energy Regulation Commission (FERC), all hydroelectric operations on the Kalamazoo River operate in run-of-river mode (outflow roughly equals inflow); however, instantaneous fluctuations in flow associated with variable turbine utilization for increased power generation during day light hours periodically occurs.

Substantial inventories of PCB-impacted sediments are present in the Allegan City and Lake Allegan impoundments. As such, these dams play an important role in the fate and transport of PCB within the system.

3.3 General Characteristics of Areas of OU5

This Generalized CSM will be refined for each of the seven individual Areas of OU5 where SRI/FS activities will be implemented, per the AOC SOW. A summary of the river length, slope, depth, width and area in each reach is provided in Table 3-1.

Table 3-1. General Physical Characteristics of OU5

River Reach/ Area	Length (miles)	Slope (ft/mile)	Average Water Depth (ft)	Average River Width[1] (ft)	Area (acres)
Area 1 – Morrow Dam to Plainwell Dam	21.9	2.7	3.4	181	487
Area 1 – Portage Creek	2.0	1.9	2.3	32	8
Area 2 – Plainwell to Otsego City Dam	1.7	0.88	2.5	450	96
Area 3 – Otsego City to Otsego Dam	3.4	4.3	3.8	200	83
Area 4 – Otsego to Trowbridge Dam	4.7	1.5	5.0	248	131
Area 5 – Trowbridge to Allegan City Dam	9.1	2.1	4.3	292	317
Area 6 – Lake Allegan	9.8	1.2	6.7	1,500	1,650
Area 7 – Allegan Dam to Lake Michigan	26	0.68	5.5	212	670

Note:
1. Average widths represent the actual water widths of transects excluding islands or sandbars.

3.4 General Reach Characterizations

Within the Site, the river characteristics vary from location to location based on changes in the watershed and effects of the dams on flow conditions. Five general types of reaches are present within the Site:

- Urbanized/industrialized reaches: In the urbanized areas, in particular within the vicinity of the City of Kalamazoo, shorelines have been extensively altered as a result of industrial and municipal construction. Engineered, hardened banks are present in some locations, as are multiple bridge and utility crossings. Multiple point source discharges are found, including waste water treatment plants, industrial point sources, and storm water outfalls. Localized sedimentation may be impacted by shoreline structures, historical excavation/filling activities, and/or point sources in these areas.

- Free-flowing reaches: Throughout most of the Site upstream of Lake Allegan Dam, pre-impoundment river slopes were generally characterized by relatively high flow velocities that generally sustained non-depositional conditions. Where the effects of the impoundments are not present, free flowing conditions still exist, river bed materials are predominantly coarse grained sediments, and the channel meanders within its valley where it is unconfined. Relatively little fine grained sediment exists in these reaches.

- Formerly impounded areas: These reaches are still moving toward equilibrium as the channel continues to incise and meander within the former sediments that were deposited during the period of impoundment. Sediments that had been buried were exposed when the dams were opened and dismantled. Steep, unstable river banks were created in some areas; these continue to slough and erode into the river, which in some cases provide an ongoing source of PCBs to the river. Prior to impoundment, the streambed in these reaches consisted of cobbles, coarse gravel, and medium to coarse sand. Lacustrine deposits consisting of interbedded, organic-rich silt and clay and fine-to medium sand accumulated in each impoundment after the dams were constructed in the late 1800s and early 1900s. Since the impoundments were drawn down—resulting in an increase in the river gradients, velocities, and erosion of the Impoundment riverbed—alluvial deposits (consisting of mostly sand and gravel) have accumulated on the eroded lacustrine surface. The coarser material surface is a result of the higher velocities and river gradients. The alluvial deposits appear to act as an armor layer over the lacustrine deposits (Rheaume et al. 2002 and 2004; Rachol et al. 2005). The gradients in the impoundments are still lower than pre-impoundment conditions.

- Currently impounded areas: These areas slow the flow of the river, interrupt sediment transport during flood events, and act as overall sinks for sediment and PCBs. The existing impoundments have accumulated large quantities of fine-grained sediments and contain the majority of the PCB-containing sediment volume and PCB mass within the Site (for example, approximately 86% of the total mass of PCB-containing sediment within the river channel resides in Allegan City Impoundment and Lake Allegan [BBL 2000]).

- Low-gradient, free-flowing reaches: Downstream of Lake Allegan to the mouth at Lake Michigan, the river gradient is much lower as the river traverses an ancient lake plain. Forest lands and extensive wetlands and marshes adjoin the river. In the marshes, the water table is above the soil surface most of the growing season. The broad floodplains and marshes of the lower river accommodate flood flows and accumulate sediments that settle out in quiescent backwater areas.

These general classifications provide a starting point for description of each Area-specific conceptual model, and will be refined for individual Areas.

3.5 Sediment Stability

Sediment stability will be an important consideration in the assessment of depositional areas of the Site in particular, but also in each individual Area from the standpoint of understanding the relationship between sediment transport processes and the fate and transport of PCBs. Natural sediment transport processes of importance within the Site include:

- erosion and deposition of fine grained materials in response to variation in river flow

- transport of bed load materials during high-flow events

- sources and contributions of clean sediment to the river

- erosion of PCB-containing exposed sediments from within the former impoundments

- sediment burial and mixing processes within depositional zones

Free-flowing conditions created the original channel of the Kalamazoo River. Over time, the channel has been subject to numerous alterations as a result of dam construction and operations and land use practices. The construction of dams and associated flow regulation, such as the regulation of flows from Morrow Lake, reduced river forces and allowed accretion of sediments—some of which were impacted by PCBs—in certain areas of the Site. The stability of these sediments is subject to ongoing geomorphic processes of the river channel. In northern climes, scour forces associated with damming by river ice flows has also been an important factor affecting river bed stability in free flowing reaches.

In the impounded reaches, sediment stability is dependent on of the velocity regime, sediment supply, water depth (where waves or wildlife feeding/reproduction may be a factor), and sediment cohesion (or ability to resist erosion). Additionally, the structural integrity and maintenance of the existing dams plays an obvious role in determining the stability of an impoundment's sediments. Radio-dating studies by KRSG document the presence of a stable sediment column with long-term burial by progressively cleaner sediments in depositional areas of Lake Allegan (see Section 4.7 for more detail). A variety of other factors such as wind waves, boat wakes, prop wash, fluctuations in water levels, dam operations, and biological impacts such as fish and wildlife feeding, burrowing, and spawning also potentially affect sediment stability and thus PCB fate and transport within the sediment.

Assessment of sediment stability will be included as appropriate in individual Area-specific conceptual models to provide a basis for understanding the cause/effect relationships between bed stability and long-term PCB fate and transport. In addition, the potential influence of venting groundwater (i.e., groundwater flowing vertically upward through the sediment bed into the river), which can impact the fate of PCBs in sediment by facilitating the release of PCBs through enhanced pore water advection, will be evaluated on an Area-specific basis, as appropriate.

4. PCBs in the Kalamazoo River

Much of the PCB data from the Kalamazoo River has been collected during one of three primary sampling investigations:

- The 1993/1994 Remedial Investigations, which focused primarily on the Kalamazoo River between Morrow Dam and Lake Allegan Dam and lower three miles of Portage Creek

- The 2000 investigation of the lower Kalamazoo River, marshes, and floodplain between Allegan Dam and Lake Michigan

- The 2000/2001 Supplemental Investigation, which focused again primarily on the Kalamazoo River between Morrow Lake and Lake Allegan Dam

In addition, as part of a long-term monitoring program, the MDEQ has collected surface water and fish tissue PCB data since 1999.

Much of the existing understanding of the distribution of PCBs in the river is based on the 1993/1994 RI data, which is the most spatially comprehensive dataset. PCB concentrations in media in the lower river—now referred to as Area 7—are typically low compared to the concentrations upstream of Lake Allegan Dam. Because the lower river contains comparatively low PCB concentrations compared to the upper river, the discussion of PCB distributions focuses primarily on the Morrow Dam to Lake Allegan section.

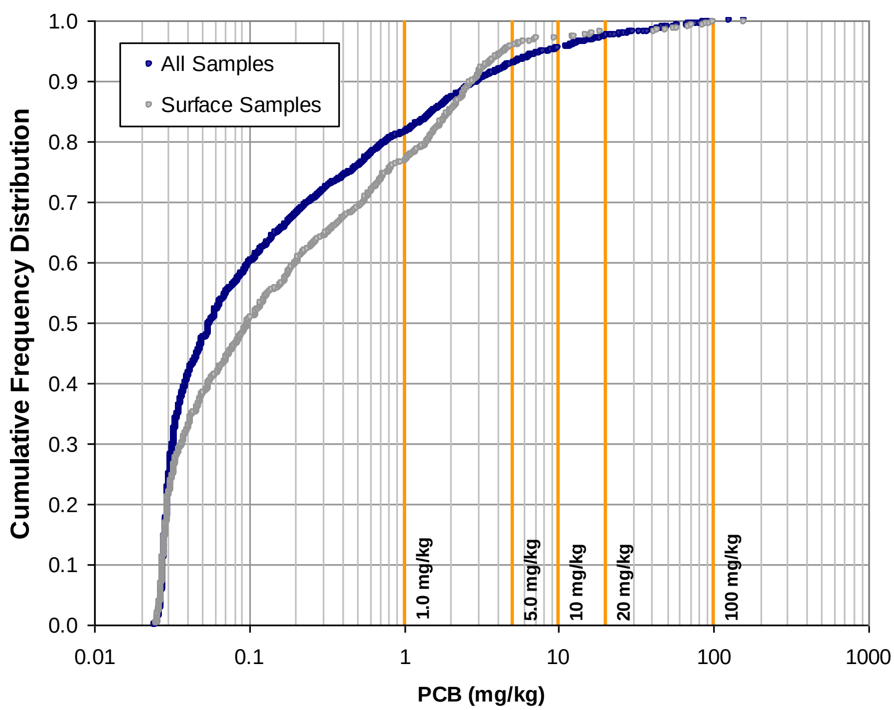
Some of the data collected by KRSG, while collected in accordance with agency-approved sampling and analytical methods, have not yet been formally reviewed by a regulatory agency. USEPA is in the process of determining the useability of those and other existing data. Future refinement or development of CSM information will reflect the results of USEPA’s data usability determination. Historical temporal trends in PCBs and the description of spatial distributions of PCBs overviewed in this section may also require reassessment depending on USEPA’s data usability determination to refine the understanding of spatial and temporal variability in PCBs at the Site. New data collected as part of Area-specific investigations and data gathered as part of long-term monitoring programs will be used to refine the understanding of spatial and temporal variability in PCBs in Site media and reduce uncertainty with respect to whether or not historical trends of attenuating PCB concentrations in river water, surface sediment, and fish continue and at what rates.

4.1 PCBs in In-Stream Sediment

In this section, the distribution of PCB concentrations and PCB mass inventories in Kalamazoo River sediments are summarized (Section 4.1.1), along with general PCB concentration variations with sediment depth in the impoundments (Section 4.1.2).

As shown in Figure 4-1 (inset below), based on 2,437 sediment samples collected in 1993 and 1994 as part of the RI efforts between Morrow Dam and Lake Allegan Dam, PCBs were not detected or were less than 1 mg/kg in 82% of all RI sediment samples and in 77% of the surficial sediment samples (top 2 inches). Treating all samples equally, 4% of all samples collected between Morrow Dam and Lake Allegan Dam contained PCBs at concentrations greater than 10 mg/kg, and that number is reduced to 3% when considering only surface samples. In comparison, when the data are spatially-weighted to account for the biased sampling of fine sediments, the associated percentage of the Site sediment area and volume with PCBs exceeding these concentrations are lower still.

Figure 4-1. Cumulative Frequency Distribution of PCB Concentrations in Kalamazoo River Sediment between Morrow Dam and Lake Allegan Dam



Note:
1. Non-detects included at one-half the detection limit.

The top 2 inches of sediment is of particular interest as it has been historically sampled at the Site to represent the approximate depth over which fish and other biota are exposed to PCBs in the sediment—the bioavailable zone. Sutter et al. (2000) reviewed data on the biologically active zone and concluded that, while some species may burrow to a depth as great as 10 cm, most species are active in the upper 5 cm (2 inches). Federal monitoring programs evaluating potential sediment toxicity often sample only the upper layer of the biologically active zone (e.g., 2-3 cm) (NOAA 2007, USEPA 1998). PCBs found deeper in the sediment bed are less available to biological receptors that live and feed in the surface sediment layer (e.g., benthic organisms). Sediment bed mixing and in-bed PCB transport processes (e.g., pore water diffusion) can supply PCBs to the bioavailable zone; however, in the absence of significant influence of these processes, PCBs deeper in the sediment bed are unavailable to biota (normal bioturbation processes only affect surface sediments in the bioavailable zone). The impact of mechanisms such as discharging groundwater and hyporheic flow on sediment bed stability are undetermined at this point, and will be assessed as appropriate as part of the Area-specific investigations.

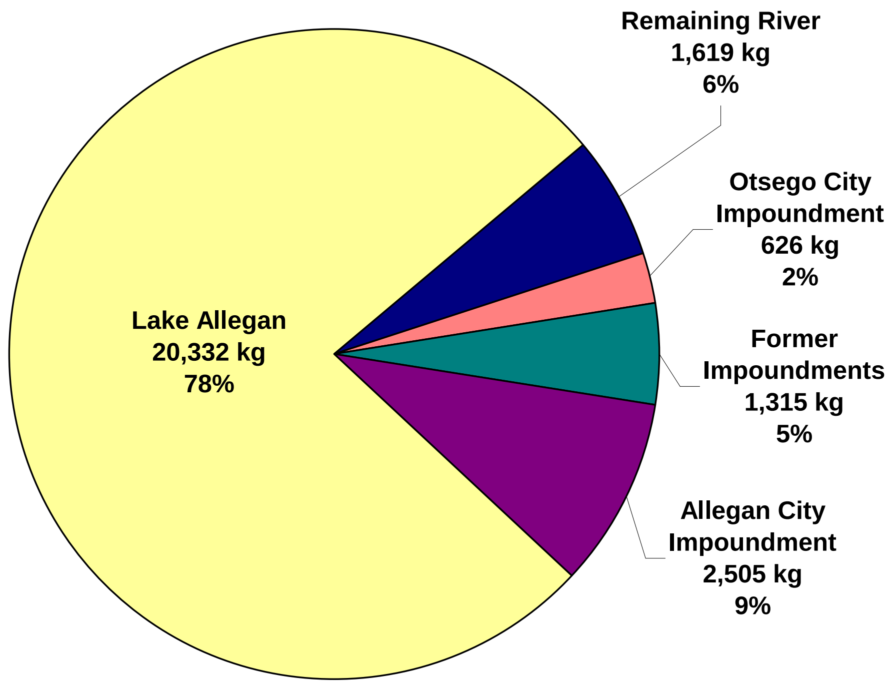
PCB concentrations along the river from both the 1993/1994 RI and the 2000 supplemental sediment data are shown in Figures 4-2 (surface sediment) and 4-3 (subsurface sediment).

4.1.1 In-Stream Sediments: PCB Mass Distributions

Although PCB concentrations are highest in the reaches containing the former Plainwell, Otsego City, Otsego, and Trowbridge Impoundments, the majority (77%) of the PCB mass in the river sediments between Morrow Dam and Lake Allegan Dam is contained within Lake Allegan (see Figure 4-4, inset below – this figure depicts mass in in-stream sediments only; exposed sediments are not included). Since PCB mass is the product of PCB concentrations and the volume of sediment in which the PCBs occur; a large volume of sediment with relatively low concentrations could contain a significant mass of PCBs compared to other areas. In the Kalamazoo River, Lake Allegan covers approximately 1,600 acres and has sediment thicknesses ranging from approximately 0.3 to 20 feet. Lake Allegan is a net sink for upstream sediments and a net sink for PCBs as well (i.e., more sediment and PCB flow into the Lake than leaves the lake), as concluded from water column PCB monitoring data collected by MDEQ (CDM 2003a).

The second largest PCB mass inventory between Morrow Dam and Lake Allegan Dam is in the Allegan City Impoundment (9%). Collectively, the former Plainwell, Otsego City, Otsego, and Trowbridge Impoundments contain approximately 5% of the PCB mass inventory in in-stream sediment, and 6% of the PCB mass inventory is distributed throughout the rest of the Site.

Figure 4-4. Distribution of PCB Mass in Kalamazoo River In-Stream Sediment: Morrow Dam to Lake Allegan Dam



The inventory of PCB mass in in-stream sediment shown above was calculated based on the 1993/1994 RI data. The 1993/1994 RI data are the most consistent, spatially comprehensive dataset from which comparable estimates can be made among reaches. More recent data, including sediment data collected in the former Plainwell Impoundment in support of the TCRA design were not included so as not to bias the PCB mass comparison temporally, spatially, or with data collected for reasons other than characterization of Site-wide PCB distributions.

4.1.2 Distribution of PCB with Sediment Depth

Geomorphic processes affecting the sediment bed in each reach in conjunction with the source history of PCB discharges to the Kalamazoo River have caused different trends in PCB concentrations with depth in different sections of the river. To illustrate the overall patterns, the geometric mean PCB concentration observed in individual sediment depth layers from data collected in 1993 and 1994 was computed within specific reaches. The geometric mean is used as a measure of central tendency of the PCB data in each reach because of the lognormal distribution of the data.

In Lake Allegan and the Allegan City Impoundment—the most significant continuing depositional areas of the Site—the highest geometric mean PCB concentrations are found in the deeper sediments and there is a regular pattern in sediment cores from these areas of steadily increasing concentrations with depth to the peak concentration. This is consistent with a conceptual model of burial by progressively cleaner sediments in these depositional zones as PCBs transport from upstream declines over time. In these impoundments, the highest geometric mean concentrations in 1993 and 1994 were found in the 6- to 12-inch depth interval of fine-grained sediment (Figure 4-5).

In the reaches of the Site upstream of the Allegan City line (i.e., upstream of the Allegan City Impoundment), which overall are not areas of significant continuing deposition, the highest geometric mean concentrations of PCBs occur at the surface. Although the impoundments upstream of Allegan City were historically depositional over much of their length, the opening and dismantling of the dams changed these reaches to erosional environments, and the channel is still evolving toward equilibrium as it cuts through the exposed sediment deposits.

Additional data will be collected as part of Area-specific investigations to assess continuity and rates of deposition in the Allegan City Impoundment and Lake Allegan. Based on radio-dated sediment cores collected from depositional areas of these impoundments in 2000, estimates of average annual sedimentation rates in Lake Allegan since 1963 range from 0.28 inches per year to greater than 0.71 inches per year. In Allegan City Impoundment, the estimated sediment deposition rate using one radio-dated sediment core collected in 2000 was 0.55 inches per year.

4.2 PCBs in Floodplain Soil

The current floodplains of the Kalamazoo River include naturally-occurring floodplain soils as well as the exposed sediments in the formerly impounded areas. PCB distributions in floodplain soils are determined by sediment transport processes during floods whereby suspended sediments become trapped by deposition on floodplain soils when floodwaters recede. Sediment deposition on the floodplain is dependent on the frequency and duration of inundation, which is a function of topographic elevation. Floodplain soils become inundated during high flow conditions and as a result are subject to PCB impacts by deposition of suspended sediments carried by the river. The amount of PCB-containing sediments deposited in the floodplains is controlled by the frequency of inundation and localized flow velocities during flooding. Floodplain soil data collected in 1993 between Morrow Dam and Lake Allegan Dam and along Portage Creek show that the highest PCB concentrations are typically found closest to the river where ground surface elevations are lowest. The majority of the PCB results from the 1993 sampling event were below 1 mg/kg. Per the USEPA-approved Work Plan for the river between Morrow Dam and Plainwell Dam (ARCADIS BBL 2007), selected focused soil samples will be collected from areas within the floodplain to confirm the earlier conclusions and identify potential areas for additional sampling, as necessary. In addition, the Work Plan calls for the delineation of the Portage Creek floodplain and subsequent sampling as necessary.

4.3 PCBs in Former Impoundment Exposed Sediment

PCB distributions in the exposed sediments of the formerly impounded areas are predominantly a function of depositional processes during the period of impoundment, when these areas were underwater. These depositional processes varied spatially as a result of impoundment morphology, resulting in a wide area of thicker PCB-containing material compared to the natural floodplains. These deposits were typically thickest in the center of the pre-impoundment river channel. Furthermore, since these areas were impounded and accumulating sediment in the 1960s and 1970s during the period of peak usage of PCBs, they tend to contain distinctly higher PCB concentrations than the natural floodplains.

In the former Plainwell, Otsego, and Trowbridge Impoundments (the formerly impounded areas for which there is the most data), PCB concentrations tend to be highest in the uppermost layer of exposed sediment and generally decrease with depth (Figure 4-6). The horizontal distribution of PCB was influenced by the morphology of each impoundment. In the more channelized former Plainwell and Otsego Impoundments, PCB concentrations decrease more quickly with distance from the current river channel than in the former Trowbridge Impoundment (Figure 4-7). The former Trowbridge Impoundment, which was flatter, wider, and lower energy than its two upstream counterparts, shows more uniform spatial distribution of PCB across the exposed former sediments. Based on the 1993/1994 RI data, the arithmetic average surficial PCB concentrations in the former Plainwell, Otsego, and Trowbridge Impoundments are similar, with mean values of 15 mg/kg, 13 mg/kg, and 15 mg/kg, respectively.

On average, the distribution of PCB concentrations in the exposed sediments was represented by the 1993/1994 RI sampling program. In 2001, USEPA conducted Phase I and Phase II sampling in the former Plainwell Impoundment to provide additional measurements of PCBs in the exposed sediment at focused locations – including some with elevated PCB concentrations – and to further characterize the area. The spatially-weighted average concentration (SWAC) of PCB in the surface soils is 17 mg/kg based on 2001 USEPA data alone, and 16 mg/kg based on the 2001 USEPA and 1993/1994 RI data together. The average concentration did not change significantly as a result of the additional focused sampling efforts conducted following the systematic sampling program implemented in 1993/1994.

The exposed sediment data suggest that that the thickness of PCB-containing sediment is greatest near the banks of the current channel. The increased thickness of material near the current channel is likely due to the fact that these areas represented the deepest parts of the impoundment prior to the drawdown of the dams where the rate of sediment deposition was the highest. The presence of the thickest sediment deposits in the deepest parts of the impoundment suggest that the materials scoured from the channel after the drawdown may have contained some of the highest PCB concentrations.

Since the PCBs in the exposed sediment were deposited during impounded conditions—which coincided with the peak historic PCB discharge—the exposed sediments contain significant inventories of PCB. Estimates of PCB mass in the exposed sediment of the former Plainwell, Otsego, and Trowbridge Impoundments are graphically compared in Figure 4-8 (below), and range from approximately 3,200 kg in the former Plainwell Impoundment, to 6,300 kg in the former Otsego Impoundment, to approximately 15,400 kg in the former Trowbridge Impoundment. Results of USEPA's Phase I and Phase II sampling in 2001 within the former Plainwell Impoundment exposed sediment corroborate the mass estimate derived from the RI data collected in 1993/94. Using the arithmetic means of the reported Phase I and Phase II PCB concentration data only, the mass of PCBs within the former Plainwell Impoundment exposed sediment is estimated to be 3,100 kg. The consistency in these results suggests that the 1993/94 RI sampling reasonably represented the inventory of PCBs and mean surface PCB concentrations in the exposed sediment within the former impoundments and is further indication that the distributions of PCBs in exposed sediment can be well represented by non-biased sampling approaches.

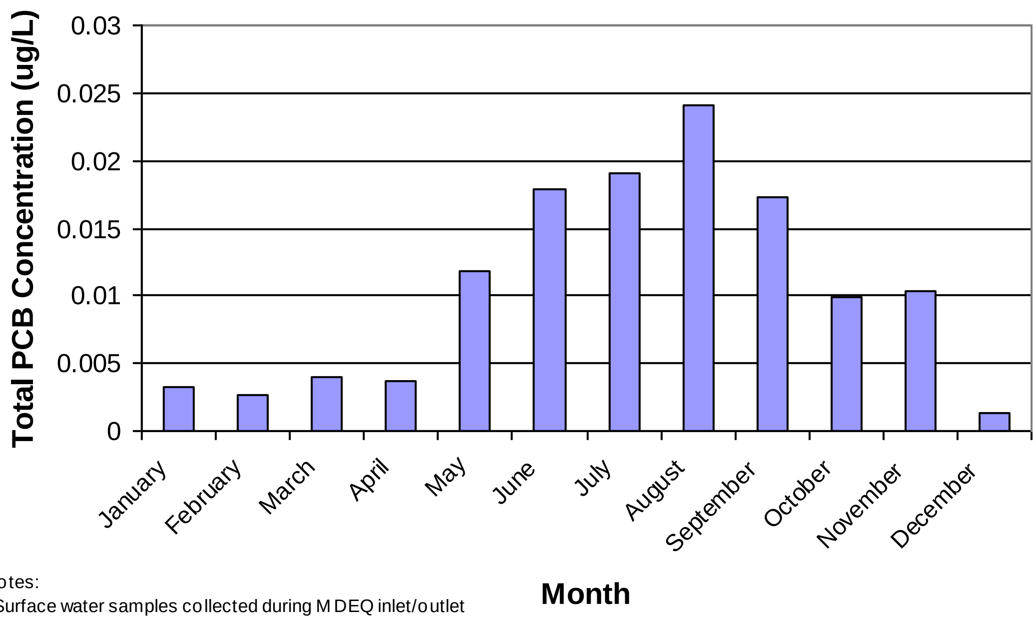
Figure 4-8. Estimated PCB Mass in the Former Impoundment Exposed Sediment

4.4 PCBs in Surface Water

Sediment supply to the river and transport through the Site is significantly greater during high precipitation and runoff events than base flow periods; however, the relatively stable flow regime of the Kalamazoo River does not result in extreme fluctuations in suspended sediment or PCB concentrations with variations in flow. Total suspended solids (TSS) and PCB correlations are not well correlated with flow, and the range of concentrations is similar over low and high flow periods.

During low flow conditions, PCB concentrations vary with temperature and seasonally variable base flows. Warmer temperatures result in increased desorption of PCBs from particles and also cause increased flux of PCB from the sediments to the water column as a result of various processes, including increased activity by organisms living in and/or feeding within the sediments. Temperature-related influences can increase the net flux of PCBs from the sediment to the water column, which in conjunction with lower river flows causes seasonally elevated river water PCB concentrations during warm weather months. The available water column PCB data for the Kalamazoo River reflect this seasonal trend, as depicted in Figure 4-9 below. Long-term trends are discussed in Section 4.7.

Figure 4-9. Mean Surface Water PCB Concentrations at Lake Allegan Inlet



Notes:
• Surface water samples collected during MDEQ inlet/outlet sampling 5/15/01 - 10/14/02.
• Mean represents arithmetic average of left, mid, and right channel samples.

Spatial patterns in surface water PCB concentrations in the Kalamazoo River reflect the relative gain or loss of PCB in transport as the river flows downstream from Morrow Dam through the Site. Average PCB concentrations from several surface water investigations in the Kalamazoo River since 1985 are plotted against distance in Figure 4-10. Water column PCB concentrations are low but have been frequently detected at Comstock, just downstream of Morrow Dam. The 1985 data reflect a substantial gain in PCB concentrations in the vicinity of the City of Kalamazoo and the Portage Creek confluence, followed by increasing PCB concentrations downstream to Lake Allegan. Since the early 1980s, PCBs available for transport in the system have decreased significantly as a result of a variety of source control measures (including the cessation of PCB production and use) and the influence of natural processes. The downstream trends in the 1994 and more recent data show an increase in surface water PCB concentrations in the Kalamazoo area, then variable, but generally steadily gaining concentrations to Allegan City, followed by a decrease at Lake Allegan. PCB concentrations flowing into Lake Allegan are higher than PCB concentrations flowing out of the lake, reflecting losses from deposition (and to a lesser extent, volatilization) across Lake Allegan Dam. PCB concentrations are approximately the same throughout the reach between Lake Allegan Dam and Lake Michigan. Inlet and outlet sampling by the MDEQ (CDM 2003a) confirmed indications from prior data that Lake Allegan is a net sink of PCBs, retaining PCBs via deposition of sediment.

Estimated PCB transport from the major surface water PCB investigations is shown in Figure 4-11. The data show a large reduction in the amount of PCBs in transport in the system occurred between 1985 and 2002. Based on the 1985 data, approximately 135 kg of PCBs per year were entering Lake Allegan. The most recent data suggest that this has been reduced to approximately 20 kg per year. Based on the 2001-2002 MDEQ inlet/outlet study data and using a flow-stratified approach, annual transport over Lake Allegan Dam in 2001-2002 was estimated to be approximately 10 kg per year—evidence of Lake Allegan being a net sink for incoming PCBs. Independent calculations based on daily loads measured by CDM led to the conclusion in the MDEQ inlet-outlet study report that, on average, PCB loading at the inlet to Lake Allegan is approximately 6 times greater than at the outlet (CDM 2003a).

The most recent synaptic transport data for the whole the Site are the 2000-2001 KRSG data, which show that the highest load gain of PCBs occurs across the Plainwell to Allegan City reach of the river, followed by a decline across Lake Allegan, and then essentially conservative transport of the load below Lake Allegan to Lake Michigan (Figure 4-11).

Data collected downstream of Morrow Dam show that there are ongoing sources of PCBs upstream of the Site. Based on the 2001-2002 MDEQ inlet/outlet data, approximately 1.2 kg of PCBs per year originates upstream of Morrow Dam. By comparison, this is equivalent to approximately 10% of the PCBs that flow over Lake Allegan Dam each year.

4.5 PCBs in Fish

Fish tissue PCB measurements have been regularly collected since the 1980s, and long-term records are available for certain species, in particular smallmouth bass and carp. Sampling for these species has been regularly conducted at locations throughout the Site, providing a basis to assess spatial and temporal trends in bioavailability of PCBs to fish.

The most recent fish PCB data—the average and 95% confidence interval PCB concentrations observed in carp and smallmouth bass fillets collected by the MDEQ in 2006—are presented by location in Figure 4-12. These data are not controlled for age, size, lipid content, or other factors. Maximum PCB concentrations in both species are observed at Plainwell, with elevated but lower concentrations downstream to Lake Allegan, and declining concentrations below Lake Allegan Dam toward Lake Michigan. PCB concentrations in fish from Kalamazoo Lake are nearly equivalent to PCB concentrations in fish from Morrow Lake, which is upstream of the Site. The high concentrations in carp observed at locations like Plainwell may in part be due to the large size and high lipid content of the fish. Relatively large fish were collected from Plainwell compared to other locations—for example, one carp was almost three feet long, weighed 22 pounds, and produced a fillet sample that was 25% lipid. In assessing underlying trends in PCBs within the system, the influence of such samples is important to consider, due to the long period of exposure these fish reflect. Data from size-restricted, younger fish show lower and less variable PCB concentrations.

Fish lipid content is variable based on seasonal, dietary, and growth factors, including size, weight, health, gender, time of year collected, and age. As a fish's lipid content varies, PCB concentrations in the fish can vary as well due to the tendency of PCBs to partition into the lipids. To correct for the effect of lipid variability, the average lipid-adjusted PCB concentrations (the mass of PCB per mass of lipid) and associated confidence intervals for carp and smallmouth bass fillets are presented in Figure 4-13. These data exhibit more uniform spatial trends and reflect a pattern from upstream to downstream that is similar to that observed for surface water.

Comparing PCB concentrations on a lipid-adjusted basis in fish from sampling stations within the Site to fish collected in Morrow Lake reveals that PCB bioavailability to fish is considerably higher at most locations within the Site than in Morrow Lake. However, this is not the case for all species at all monitoring locations – lipid-adjusted PCB concentrations in carp in Kalamazoo Lake are approximately the same as for carp in Morrow Lake, and lipid-adjusted PCB concentrations in smallmouth bass at three sampling stations within the Site are similar or less than in Morrow Lake. The variability in these data indicate that understanding the potential influence of upstream sources on fish tissue PCB concentrations may be important in understanding trends within the Site.

4.6 Fish Consumption Advisories

Given the importance of fish consumption advisories established by the MDCH as an indication of the degree of impairment to the Kalamazoo River, an understanding of the status of the current fish consumption advisories relative to the most recent fish data is germane to the Generalized CSM.

The MDCH fish consumption advisory has remained unchanged since 2004. Based on the analyses of the 2001, 2003, and 2006 MDEQ fish data (three years of data were considered together to account for variations in concentrations over time), some of the current fish consumption advisories established by the MDCH are more stringent than the State's data indicate are necessary, and could potentially be relaxed or eliminated. Between Morrow Dam and Lake Allegan, channel catfish and smallmouth bass could now be considered edible in some amount by the general population and the more sensitive group of women and children, and from Lake Allegan Dam to Lake Michigan, both smallmouth bass and carp could be eaten in varying amounts depending on the species and the population. These potential revisions are in contrast to the MDCH's existing "do not eat" advisories for all species throughout the Site-however, the current advisories remain in effect until updated or changed by the MDCH. The achievement of less restrictive advisories is one of MDEQ's stated remediation goals, and although the advisories have not yet changed, the data indicate measurable progress toward that goal. PCB concentrations in individual fish samples collected from the Site do continue to exceed some of MDCH's concentration thresholds. When considering the less restrictive federal consumption advisory criteria, only 1 of the 55 smallmouth bass fillets collected in 2006 between Morrow Dam and Lake Allegan Dam had PCB concentrations greater than 2 parts per million (ppm), the Food and Drug Administration (FDA) tolerance level used to set consumption advisories for the general population.

4.7 Historical PCB Time Trends

Data collected as part of a series of sampling programs conducted since the 1980s indicate that PCB concentrations in fish, sediment, and water have, in general, been declining in most areas of the Site. Data collected within the former impoundments show that declines in PCB concentrations in these areas are not occurring at the same rates as observed elsewhere. A summary of observed historical trends of PCB concentrations within Site media is provided here. Uncertainty concerning the rates of decline and whether or not historically observed trends (where evident) will continue into the future will be assessed through continued monitoring as part of SRI/FS activities and other long-term monitoring activities.

Although there is more than one way to analyze available PCB data to develop a current understanding of historical trends, PCB attenuation within the Site fish, sediment, and water column can be approximated for purposes of this Generalized CSM by fitting first-order decay models to the data, using linear regression on log-transformed data to approximate the first-order decay curve. Alternate methods for further analysis of PCB trend data for SRI/FS purposes may be required. Appropriate methods for more detailed trend analysis in the various Site media, including uncertainty analysis for trend analysis, will be selected through discussion with USEPA.

The applicability of the first-order model is better for some datasets and questionable for others—in particular where concentrations are slowly declining, or not declining—but is a common approach for assessing environmental trends that result from the cessation of historical loading of an environmentally persistent constituent, which is then attenuated by environmental processes over time. In their review of the MDEQ fish contaminant monitoring program and associated recommendations, Exponent (2003) found that:

> *"One source for such an expected decline is the modeling literature. Mathematical models of PTS [persistent toxic substance] dynamics in whole ecosystems often produce predictions about the long-term decline of PTS in biota expected under different loading scenarios, including the extreme case of system depuration with no further external loading (e.g., see Endicott et al. 1990, 1992a,b; Mackay et al. 1992, 1994; Gobas et al. 1995). The predictions of these models provide information about both the shape and the likely rate of decline of PTS in aquatic biota. According to these models, declines of PTS in aquatic biota are expected to follow a first-order or pseudo-first order process because the underlying loss processes are first-order."*

In addition to characterization of trends, the first order attenuation equation allows calculation of half-times, which is the amount of time it takes for concentrations to be reduced to one-half the current level. Existing data suggest that PCB concentrations have historically declined by approximately half every 4 to 15 years, depending on the specific location and medium. This range is a function of real variability in attenuation rates among locations and media (e.g., fish versus surface water), but also variability in the measurements themselves that is unrelated to the underlying rate. The calculated half-times for multiple time-series data sets for different media (e.g., surface sediments, fish tissue, dated sediment core PCB profiles) consistently fall within this range for many media- and location-specific data sets, including Morrow Lake. In some areas, including the former impoundments, historical PCB trends have not been as evident, or distinct, or if present are occurring at slower rates. Whether or not declines will continue at rates observed historically, or if and how PCB trends will be affected by source control actions is uncertain. Additional data collected as part of the future Area-specific work will be used to assess changes in PCB exposure concentrations over time. Uncertainty in projected rates of decline based on historical data will need to be understood if empirical projections are to be used as a basis for remedial alternatives evaluation.

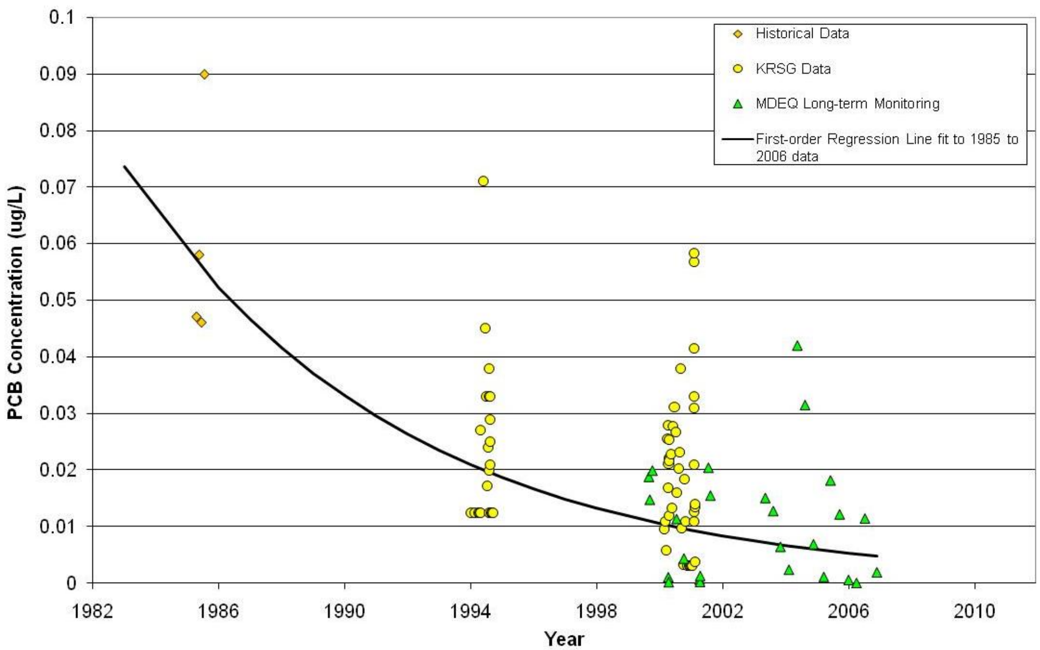
In 2000, the KRSG performed a series of supplemental studies in which sediment was sampled between Morrow Dam and Lake Allegan Dam to be compared with the sediment data collected in the 1993/1994 RI. The data, which are currently being reviewed by USEPA as part of a useability determination, offer a comprehensive snapshot of changes in PCB concentrations in sediment over a period of seven years. That comparison shows that 72% of the river area between Morrow Dam and Lake Allegan Dam exhibited declines in surface sediment PCB concentrations and declines in surface sediment TOC-adjusted PCB concentrations (TOC-adjusted concentrations provide an estimate of bioavailable concentrations as opposed to bulk sediment concentrations). When weighted by the proportion of surface area of fine and coarse sediment within each reach (currently referred to as Areas), the overall reduction of the SWAC of PCB was 56% over the seven year period (see Figure 4-14). The overall reduction between 1993/94 and 2002 in TOC-adjusted PCBs in surface sediments, a measure of the relative bioavailable PCBs, between Morrow Dam and Lake Allegan Dam, was estimated to be 61%.

Radio-dating of finely-sectioned sediment cores from depositional areas provides another means to assess attenuation trends. Radiodating is based on identifying the depth interval of the peak activity of Cesium-137, which is associated with atmospheric nuclear weapons testing. This testing produced measurable levels of Cesium-137 in the environment circa 1954, and peak levels in 1963. The 1954 time horizon and 1963 peak markers provide a basis to estimate the year of deposition of sediment layers (i.e., the geochronology of deposition) and thereby compute the rate of decline of surface sediment PCB concentrations at the core location. Several sediment cores collected from depositional areas of Lake Allegan and the Allegan City Impoundment in 2000 (using collection and analysis methods consistent with the MDEQ-approved Geochronological Investigation conducted in 1993 and 1995) and representative results for cores that exhibited declining trends are shown in Figure 4-15.

The radio-dated cores show a confluence of surface sediment concentrations toward low levels of the heavier-weight PCBs, commonly associated with Aroclors 1254 and 1260. Figure 4-16 provides an example of this in the Allegan City Impoundment; however, factors causing uncertainty in the quantification of specific Aroclor mixtures (as described in Section 1.4) are also relevant in this analysis. Much of the PCB variability in the older deeper sediment was due to presence of PCBs quantified as the lighter Aroclors (i.e., Aroclor 1242) associated with the then-active paper-related discharges occurring along the river. Following cessation of those discharges in the late 1960s and early 1970s, there was a decline in PCB concentrations.

Surface water PCB concentrations show a similar historical decline over the same period of time as sediment PCB concentrations. Figures 4-10 and 4-11 show PCB concentrations and loads in surface water over distance and over time, respectively. In addition to the spatial patterns previously discussed, both graphs illustrate the declines of measured transport in the river since the mid 1980s associated with the ban on PCB use, a variety of source reduction activities throughout the watershed, a reduction in (and eventual cessation of) paper recycling activities at the mills and operations at the associated landfills, and natural processes. An example of the past trends in surface water PCB concentrations—based on historical data and data collected by KRSG—is provided in Figure 4-17 (below), which shows the surface water data from Farmer Street (downstream of the Otsego City Dam) over time and across a wide range of flow, temperature, and suspended solids conditions. Whether or not past trends continue in the future will be assessed through additional monitoring.

Figure 4-17. Surface Water PCB Concentrations at Farmer Street (Downstream of Otsego City Dam)



Fish tissue PCB concentrations have also declined historically at many of the fish monitoring locations within the Site. In other locations, particularly those within the former impoundments where there are continuing sources of PCBs (associated with the exposed former sediments), declines in fish PCB concentration are not apparent. Carp and smallmouth bass PCB data from 1985 through 2006 are presented for several historical aquatic biota sampling areas (ABSAs) established within the Site on Figure 4-18 (wet-weight PCB concentrations in carp and smallmouth bass). These same data are presented in Figure 4-19 on a lipid-adjusted basis. Also shown on Figure 4-19 are results of a preliminary trend analysis based on a first-order regression of the size-restricted data. The data were size-restricted to reduce variability introduced by large fish of varying ages. Further evaluation of fish trend data for SRI/FS purposes may also require control for other growth variables.

The most fish PCB data are available for Lake Allegan, which in addition to being monitored by the MDEQ and KRSG, has also been a long-term monitoring station for the MDCH's state-wide fish contaminant monitoring program. Figures 4-18 and 4-19 include the MDCH whole-body carp and smallmouth bass data plots as separate panels. These data provide the largest continuous fish PCB trend monitoring dataset available for Lake Allegan. Shown in Figure 4-19, the PCB trends in this dataset are consistent with those indicated by carp and smallmouth bass fillets collected by KRSG and MDEQ.

5. Exposure Pathways and Receptors

Humans and ecological receptors can be exposed to chemicals in the environment via many different exposure pathways. As part of prior risk assessment activities at the Site (CDM 2003b and c), exposure pathways have been identified and in many cases risks have been estimated. The findings of these prior risk assessments provide a basis for understanding which exposure pathways require quantitative assessment during the Area-specific SRI/FS process to determine whether exposure and risk reduction are necessary. Similarly, the prior assessments indicate which pathways are not likely to be significant and hence will not require specific, directed exposure reduction. Risk assessments prepared during each Area-specific SRI/FS will build upon the prior work to focus on the most significant exposure pathways.

Because the historical assessments of the river on which the Generalized CSM is based were focused on the reach of the river between Morrow Dam and Lake Allegan Dam, it may not be inclusive of all habitats and/or receptors that may occur in the lower reaches of the River. These additional habitats and/or receptors will be assessed on an Area-specific basis, and pathways and receptors will be added or removed as necessary.

In this section of the Generalized CSM, the suite of possible exposure pathways for human and ecological receptors associated with the various environmental media at the Site are discussed, and examples of those pathways that are expected to be quantitatively assessed are provided. As risk assessment activities proceed on an Area-by-Area basis, each exposure pathway will be evaluated to determine if it is both complete and relevant, and an Area-specific adaptation of this Generalized CSM will be developed.

5.1 Ecological Exposure Pathways

Sources of PCBs and their distribution in Site media have been discussed in Sections 1 and 4. In this section, potential mechanisms for ecological exposure PCBs in Site media (i.e., formerly impounded floodplain sediments, in-stream sediment, and surface water) are discussed.

To identify complete exposure pathways, ecological guilds (i.e., groups of species that use the same set of resources in a similar manner) were identified based on the potential for organisms in these guilds to either reside in or obtain a significant portion of their diet from the Site.

Ecological guilds that have been identified as including organisms potentially occurring in the terrestrial environment are plants; soil invertebrates; and herbivorous, insectivorous, omnivorous, and carnivorous birds and mammals. Ecological guilds identified in the aquatic areas include aquatic plants; aquatic and sediment invertebrates; amphibians and reptiles; and herbivorous, insectivorous, omnivorous and carnivorous birds and mammals. The complete and potentially significant exposure pathways identified at the Site for terrestrial and aquatic areas are summarized below. These pathways may be quantitatively evaluated in the Area-specific risk assessments.

Complete pathways for aquatic receptors include:

- benthic invertebrates: direct contact with Site sediments

- aquatic life (i.e., plants, invertebrates and amphibians): direct contact with Site surface water

- aquatic-feeding herbivorous or piscivorous mammals: ingestion of Site sediment and impacted plant or fish tissue

- piscivorous birds: ingestion of Site sediments and impacted fish tissue

Complete pathways for terrestrial receptors include:

- omnivorous and carnivorous mammals: ingestion of Site soil and impacted plant or prey tissue

- omnivorous and carnivorous birds: ingestion of Site soil and impacted plant or prey tissue

Figure 5-1 depicts the CSM for ecological exposure pathways and identifies those pathways that may be evaluated quantitatively in the various Area-specific risk assessments. Groundwater is identified as a potential transport mechanism that may supply PCBs to exposure media (surface soils, sediments and pore water, or surface water).

5.1.1 Minor Pathways

A number of pathways identified as potentially complete are not likely to be quantitatively evaluated because their contribution to potential risks at the Site is expected to be minimal compared to the other pathways evaluated. For example, the pathway for dermal contact of birds and mammals with Site soil, sediment, or surface water will not be quantitatively evaluated because the food, sediment, and water ingestion pathway is expected to be the primary exposure route for these receptors and will be the key driver for any potential risks.

5.2 Human Exposure Pathways

Consumption of PCB-impacted fish from the Kalamazoo River and Portage Creek has long been considered the critical exposure pathway driving potential risks to human health at the Site. The emphasis on the fish consumption pathway was clearly stated in CDM's human health risk assessment (2003c): "Fish ingestion is the primary exposure pathway for the Site", and this conclusion was confirmed in the risk assessment performed on behalf of the KRSG (Crouch et al. 2001). Humans may also potentially be exposed to PCBs at the Site through contact with impacted sediments, surface water or groundwater (where PCBs can be dissolved or bound to suspended solids), or air (PCBs can enter the air through volatilization or binding to airborne particulates).

With respect to potential pathways other than fish consumption, whether and how they are addressed in Area-specific risk assessments will be evaluated on an Area-specific basis at the work plan stage in a manner consistent with the Risk Assessment Framework. The exposed sediments in the former Plainwell, Otsego, and Trowbridge Impoundments are public lands of the State of Michigan, and as such are not eligible for residential development. (Ownership of the areas around the Plainwell No. 2 Dam and Otsego City Dam is a subject of current or future research.) Whether current or future residential exposure currently occurs at each Area will depend on, for example, zoning ordinances and other institutional controls, and will be individually assessed for each area. The extent of recreational use of different Areas of the Site is highly variable, depending on adjacent property ownership, the urban or rural nature of the setting, and ease of and facilities for access. Recreational uses may include fishing, boating, swimming, picnicking, hiking or sightseeing, and wild bird and animal observation. All of these activities present opportunities for people to come in contact with Site sediments or soils, and in some cases surface water (through incidental ingestion, dermal contact, and inhalation). Prior risk assessments have quantitatively evaluated risks associated with PCB exposure under the following scenarios:

- Anglers – fish ingestion
- Residents – incidental ingestion of, dermal contact with, and inhalation of particles and vapors from soils/sediments
- Resident/Gardener – incidental ingestion of and dermal contact with soil/sediment and ingestion of vegetables grown in soil/sediment
- Recreationalists – incidental ingestion of, dermal contact with, and inhalation of particles and vapor from soils/sediments
- Recreationalists/Residents/Workers – inhalation of vapors from former impoundments

- Recreationalists/Residents/Workers – inhalation of vapors from river water
- Swimmers – dermal contact with river water

Certain other human exposure pathways—including exposure to groundwater, inhalation of PCBs volatilizing from surface water, and ingestion of waterfowl by recreationalists—have been identified as potentially complete but have not been quantitatively evaluated in prior risk assessments. The CDM (2003c) human health risk assessment did not discuss groundwater exposures, but identified the other two pathways as potentially significant. Based on Site conditions, none of these pathways is expected to contribute significantly to human health risk; however, uncertainties remain and future work plans will include the collection of groundwater data. The need to quantify risks associated with potential exposures via these and other pathways will be evaluated on an Area-specific basis and discussed in risk assessment work plans.

Figure 5-2 depicts the CSM for human exposure pathways and identifies those pathways expected to be evaluated in the various Area-specific risk assessments, subject to refinement in Area-specific conceptual models in risk assessment work plans. Due to the bioaccumulative nature of PCBs, consumption of fish has regularly been identified as the exposure pathway that poses the greatest potential exposures and risks at the Site, and hence is the most significant consideration in discussions regarding the extent of risk reduction necessary at the Site. Fish consumption will continue to be the most important exposure pathway for quantitative evaluation in each Area-specific risk assessment.

5.2.1 Minor Pathways

Other activities by nearby residents or recreationalists may or may not result in exposures and risks at levels of concern depending on conditions at each Area of the Site. The decision whether to carry residential or recreational exposure pathways through quantitative evaluation during the risk assessment for a particular Area will be made as part of the SRI/FS process for that Area.

Exposures to Site-related PCBs due to inhalation of vapors from the former impoundments or river water, and dermal contact with and incidental ingestion of river water or sediments while swimming or wading have been estimated in prior assessments and found to be insignificant (CDM 2003c, Crouch et al. 2001). Any exposure or associated risk posed by participating in these activities is considered insignificant in general and in proportion to those presented by other activities. Further quantitative assessment of these exposures and risks is not anticipated.

6. References

Abramowicz, D.A. 1990. “Aerobic and Anaerobic Biodegradation of PCBs: A Review,” *Critical Reviews in Biotechnology*, 10(3), pp. 241-251.

ARCADIS BBL. 2007. *Supplemental Remedial Investigation/Feasibility Study Work Plan – Morrow Dam to Plainwell* (Area 1 SRI/FS Work Plan). February 2007.

ASTM. 2003. *Standard Guide for Developing Conceptual Site Models for Contaminated Sites*. Designation: E 1689-95.

ATSDR. 2000. Toxicological Profile for Polychlorinated Biphenyls, November 2000

BBL. 1994. Technical Memorandum 3 – Results of the Floodplain Soils Investigation. Syracuse, NY, Gebruary, 1994.

BBL. 2000. Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site *Remedial Investigation Report - Phase I.* (Syracuse, NY: October 2000).

Brown, C.J.D. 1944. Michigan streams - their lengths, distribution and drainage areas. Michigan Department of Natural Resources, Fisheries Division, Miscellaneous Publication 1, Ann Arbor. As referenced in Wesley, J.K. 2005. Kalamazoo River assessment. Michigan Department of Natural Resources, Fisheries Division, Special Report 35, Ann Arbor, pp.4.

CDM. 2003a. *Allied Paper, Inc./Portage Creek/ Kalamazoo River Superfund Site - Inlet - Outlet Investigation.* June 2003.

CDM. 2003b. *Final (Revised) Baseline Ecological Risk Assessment – Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site*. Prepared on behalf of the MDEQ Remediation and Redevelopment Division. April 2003.

CDM. 2003c. *Final (Revised) Baseline Human Health Risk Assessment – Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site*. Prepared on behalf of the MDEQ Remediation and Redevelopment Division. May 2003.

Crouch, E., M. Ames, and L. Green. 2001. *A Quantitative Health Risk Assessment for the Kalamazoo River PCB Site.* Prepared on behalf of the KRSG. June 1, 2001.

Endicott, D.D., W.L. Richardson, and D.M. DiToro. 1990. Lake Ontario TCDD modeling report. In: Lake Ontario TCDD Bioaccumulation Study Final Report. Chapter 8. U.S. Environmental Protection Agency, New York State Department of Health, and Occidental Chemical Corporation.

Endicott, D.D., W.L. Richardson, and D.J. Kandt. 1992a. MICHTOX: A mass balance and bioaccumulation model for toxic chemicals in Lake Michigan. U.S. EPA Large Lakes Research Station, Grosse Ile, MI.

Endicott, D.D., W.L. Richardson, T.F. Parkerton, and D.M. DiToro. 1992b. A steady state mass balance and bioaccumulation model for toxic chemicals in Lake Ontario. Report to the Lake Ontario Fate of Toxics Committee, Environmental Research Laboratory, Duluth, MN.

Exponent. 2003. Fish Contaminant Monitoring Program: Review and Recommendations. Prepared for Michigan Department of Environmental Quality Water Division.

Gobas, F.P.C., M.N. Z'graggen, and X. Zhang. 1995. Time response of Lake Ontario ecosystem to virtual elimination of PCBs. *Environmental Science and Technology*, vol. 29, no. 8, pp. 2038−2048.

Hayes, J. 1982. MDNR. Telephone messages re: Otsego City Dam, March 19, 1982.

Hayes, J. 1991. MDNR. Notes to the file, June 6, 1991.

Hayes, J.. 1998. MDEQ. Personal Communication with D.E. Penniman, BBL re: Kalamazoo River dams. July 21, 1998.

Langendoen, E.J. and R.R. Wells. 2006. Numerical Simulation of Channel Adjustment of the Kalamazoo River Following the Removal of Two Low-Head Dams Between Otsego and Plainwell, Michigan. Proceedings of the 8th Federal Interagency Sedimentation Conference, April 2-6, 2006, Reno Nevada.

Mackay, D., S. Sang, M. Diamond, P. Vlahos, E. Voldner, and D. Dolan. 1992. Mass balancing and virtual elimination. A Peer Review Workshop at University of Toronto. A report to the Virtual Elimination Task Force.

MDEQ. 2007. Allied Paper Inc./Portage Creek/Kalamazoo River Superfund Site Inlet/Outlet Investigation, Final Report. August, 2007.

MDCH. 2007. *2007 Michigan Family Fish Consumption Guide*. Accessed online June 11, 2007 at http://www.michigan.gov/documents/FishAdvisory03_67354_7.pdf

MDNR. 1991. *Administrative Order on Consent – Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site*, DFO-ERD-91-001.

Miller, H. 1966. Memorandum, Subject: Hydroelectric Impoundments on the Kalamazoo River. Michigan Recreation Resource Planning Division. As referenced in USEPA. 2007. Appendix 1 to the Administrative Settlement Agreement and Order on Consent for Removal Action (CERCLA Docket No. V-W-07-C-864). Memorandum, Subject: Enforcement Action Memorandum, pp.4.

NOAA. 2007. *Magnitude and Extent of Contaminated Sediments and Toxicity in Chesapeake Bay*. NOAA Technical Memorandum NOS NCCOS 47.

Parkerton, T.F., J.P. Connolly, R.V. Thomann, and C.G. Uchrin. 1993. "Do Aquatic Effects or Human Health End Points Govern the Development of Sediment-Quality Criteria for Nonionic Organic Chemicals?" *Environmental Toxicology and Chemistry*, vol. 12, no. 3, pp. 507-523.

Rachol, C.M., F.A. Fitzpatrick, T. Rossi. 2005. USGS Scientific Investigations Report 2005-5044. *Historical and Simulated Changes in Channel Characteristics of the Kalamazoo River, Plainwell to Otsego, Michigan.*

Rheaume, S.J. 1990. *Geohydrology and Water Quality of Kalamazoo County, Michigan, 1986-1988*, USGS.

Rheaume, S.J., C.M. Rachol, D.L. Hubbell, and A. Simard. 2002. USGS Water-Resources Investigations Report 02-4098. *Sediment Characteristics and Configuration within Three Dam Impoundments on the Kalamazoo River, Michigan, 2000.*

Rheaume, S.J., D.L. Hubbell, C.M. Rachol, A. Simard, and L.M. Fuller. 2004. USGS Water-Resources Investigations Report 03-4218. *Sediment Characteristics and Configuration within the Otsego City Dam Impoundment on the Kalamazoo River, Michigan, 2001-02.* Accessed online at http://pubs.usgs.gov/wri/wrir03-4218/

Sutter, G.W., R.A. Edroxmson, B.E. Sample, and D. Jones. *Ecological Risk Assessments for Contaminated Sites*. CRC Press 2000.

Syed, A.U., J.P. Bennett, and C.M. Rachol. 2005, A pre-dam-removal assessment of sediment transport for four dams on the Kalamazoo River between Plainwell and Allegan, Michigan: U.S. Geological Survey Scientific Investigations Report 2004-5178, 41 p.

USACE. 1979. National Dam Safety Program Inspection Report, Kalamazoo River Basin, Plainwell No. 2 Dam, August, 1979.

USEPA. 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA.* OSWER Directive 9355.3-01. Office of Emergency and Remedial Response, EPA/540/G-89/004. October 1988.

USEPA. 1998. *Sediment Quality of the NY/NY Harbor System*. EPA/902-R-98-001, March 1998.

USEPA. 2002. *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites*. OSWER Directive 9285.6-08. Office of Solid Waste and Emergency Response. February 12, 2002.

USEPA. 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. OSWER Directive 9355.0-85. Office of Solid Waste and Emergency Response. EPA-540-R-05-012. December 2005 (http://www.epa.gov/superfund/resources/sediment/guidance.htm)

Versar, Inc. 1977. *PCBs Involvement in the Pulp and Paper Industry*. Prepared for the USEPA, USEPA/560/6-77/005 February 25, 1977.

Walters, B. 2001. *Kalamazoo was once a paper manufacturing giant*, *Kalamazoo Gazette*, September 2, 2001.

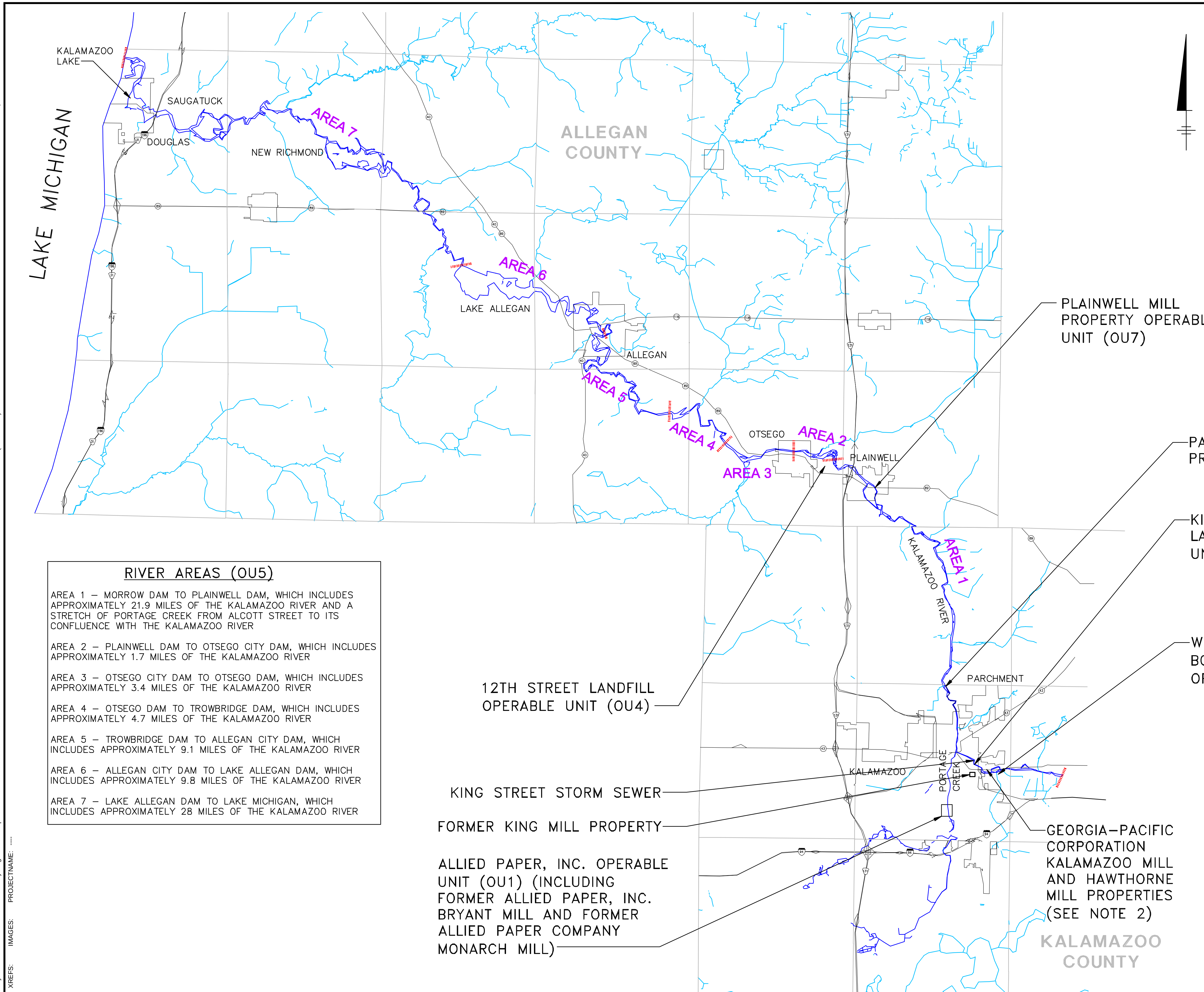
Wells, R.R., E.J. Langendoen, and A. Simon. 2003. Numerical Simulation of Sediment Loads and Channel Changes along the Kalamazoo River between Plainwell and Otsego, Michigan. USDA Research Report No. 44. December, 2003.

Wells, R.R., E.J. Langendoen, and A. Simon. 2007. Modeling Pre- and Post-Dam Removal Sediment Dynamics: the Kalamazoo River, Michigan. Journal of American *Water Resources Association*, 43(3): 773-785.

Wesley, J.K. 2005. Kalamazoo River assessment. Michigan Department of Natural Resources, Fisheries Division, Special Report 35, Ann Arbor.

ARCADIS

Figures



RIVER AREAS (OU5)

AREA 1 – MORROW DAM TO PLAINWELL DAM, WHICH INCLUDES APPROXIMATELY 21.9 MILES OF THE KALAMAZOO RIVER AND A STRETCH OF PORTAGE CREEK FROM ALCOTT STREET TO ITS CONFLUENCE WITH THE KALAMAZOO RIVER

AREA 2 – PLAINWELL DAM TO OTSEGO CITY DAM, WHICH INCLUDES APPROXIMATELY 1.7 MILES OF THE KALAMAZOO RIVER

AREA 3 – OTSEGO CITY DAM TO OTSEGO DAM, WHICH INCLUDES APPROXIMATELY 3.4 MILES OF THE KALAMAZOO RIVER

AREA 4 – OTSEGO DAM TO TROWBRIDGE DAM, WHICH INCLUDES APPROXIMATELY 4.7 MILES OF THE KALAMAZOO RIVER

AREA 5 – TROWBRIDGE DAM TO ALLEGAN CITY DAM, WHICH INCLUDES APPROXIMATELY 9.1 MILES OF THE KALAMAZOO RIVER

AREA 6 – ALLEGAN CITY DAM TO LAKE ALLEGAN DAM, WHICH INCLUDES APPROXIMATELY 9.8 MILES OF THE KALAMAZOO RIVER

AREA 7 – LAKE ALLEGAN DAM TO LAKE MICHIGAN, WHICH INCLUDES APPROXIMATELY 28 MILES OF THE KALAMAZOO RIVER

NOTES:

1. ALLEGAN AND KALAMAZOO COUNTY MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEM.
2. OU6 IS CURRENTLY A RELATIVELY SMALL PART OF THE PARCEL COMPRISING BOTH MILLS.

LEGEND:

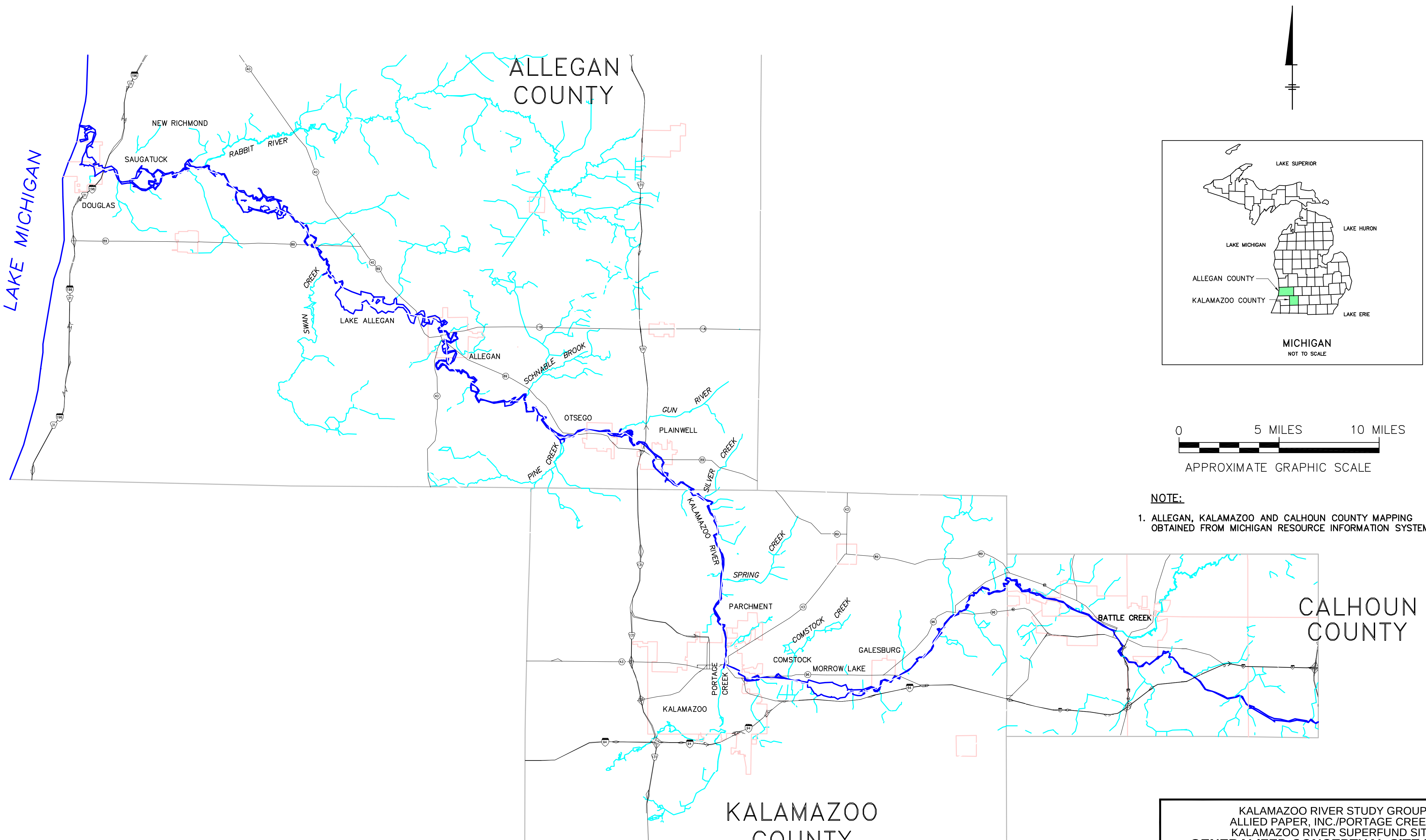
LIMITS OF RIVER AREAS WITHIN OU5

KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/
KALAMAZOO RIVER SUPERFUND SITE
GENERALIZED CONCEPTUAL SITE MODEL

AREAS OF THE SITE

ARCADIS

FIGURE
1-1



NOTE:

1. ALLEGAN, KALAMAZOO AND CALHOUN COUNTY MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEM.

KALAMAZOO RIVER STUDY GROUP
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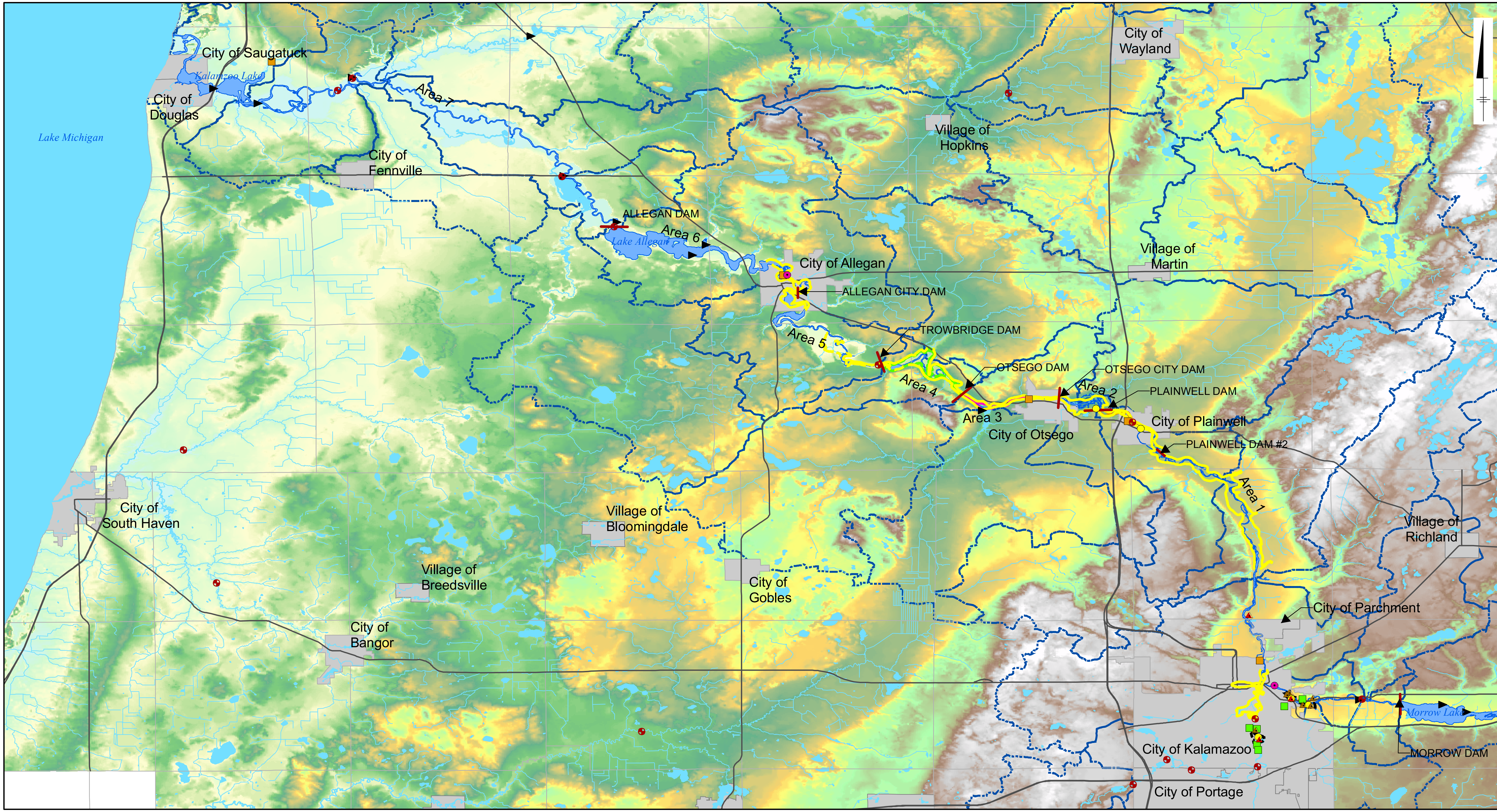
KALAMAZOO RIVER SUPERFUND SITE
GENERALIZED CONCEPTUAL SITE MODEL

KALAMAZOO RIVER
BATTLE CREEK TO LAKE MICHIGAN

ARCADIS

FIGURE
1-2



LEGEND:

- MILL RELATED LANDFILL
- LANDFILL REMEDIATION SITE
- USGS GAGE STATION
- BOAT ACCESS SITE
- OTHER SUPERFUND SITE
- WASTEWATER TREATMENT PLANT
- FORMER MILL LOCATION
- OPERABLE UNIT
- DAM LOCATION (AND SRI/FS AREA BOUNDARY)
- 100 YEAR FLOODPLAIN
- ROAD
- FORMER PLAINWELL IMPOUNDMENT BOUNDARY
- FORMER TROWBRIDGE IMPOUNDMENT BOUNDARY
- FORMER OTSEGO IMPOUNDMENT BOUNDARY
- TOWNSHIP BOUNDARY
- INCORPORATED AREA
- WATERSHED BOUNDARY

TOPOGRAPHY
ELEVATION (ft):
High : 1124.9
Low : 576.724

NOTE:

1. IMAGERY DOWNLOADED FROM THE MICHIGAN CENTER FOR GEOGRAPHIC INFORMATION (MCGI) http://www.michigan.gov/cgi

0 4 8 Miles
GRAPHIC SCALE

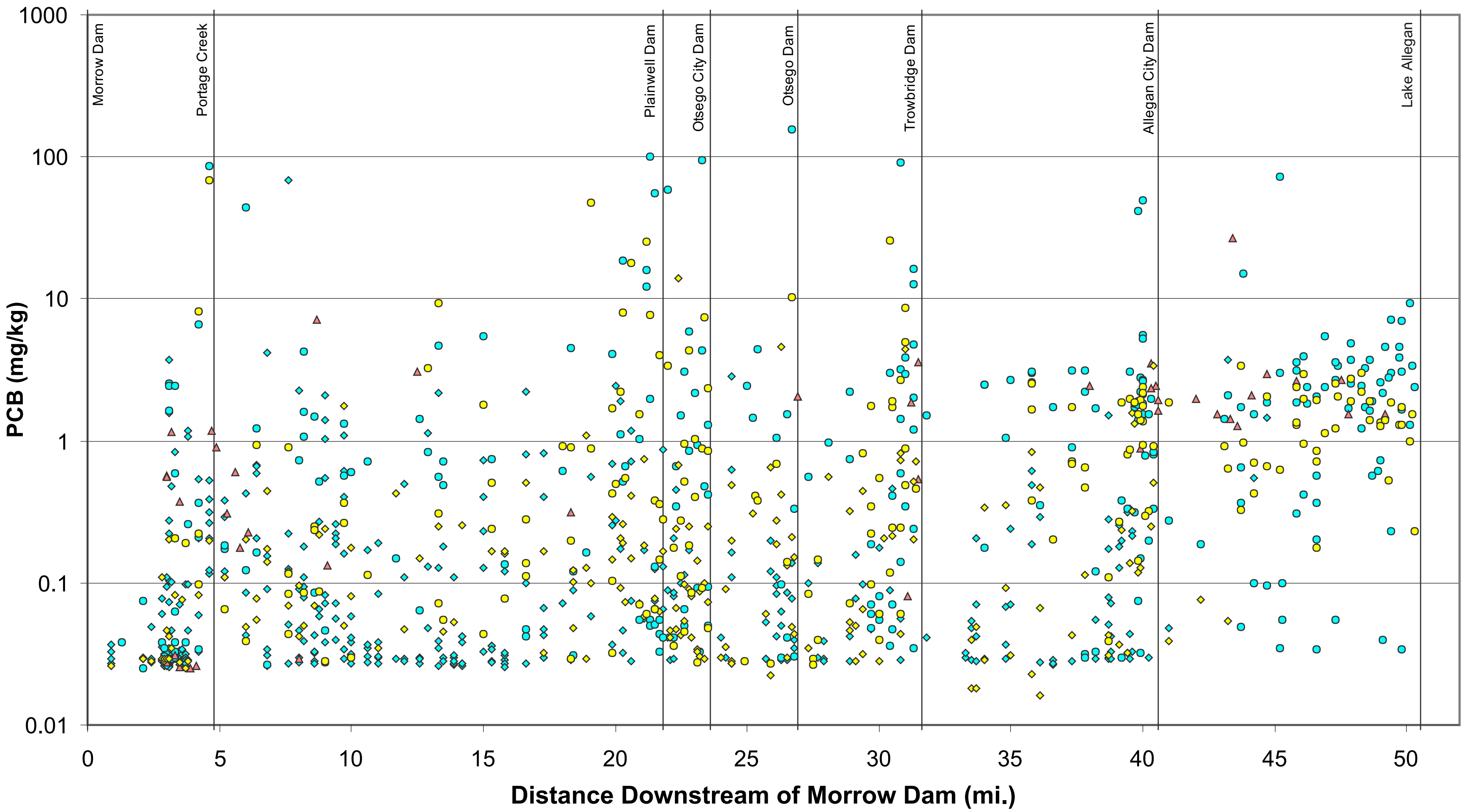
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/
KALAMAZOO RIVER SUPERFUND SITE
GENERALIZED CONCEPTUAL SITE MODEL

KALAMAZOO RIVER TOPOGRAPHY

ARCADIS

FIGURE
3-1

[SYR-85 MTK] SYR-85 JCR
KRSG (64524.500)
Q:\KRSG\ConceptualSiteModel\General\mxd\Topography.mxd - 1/5/2009 @ 4:41:20 PM



LEGEND:

- 1993 Coarse-grained sample (0"-2")
- 1993 Fine-grained sample (0"-2")
- 2000 Focused sample
- 2000 Coarse-grained sample (0"-2")
- 2000 Fine-grained sample (0"-2")

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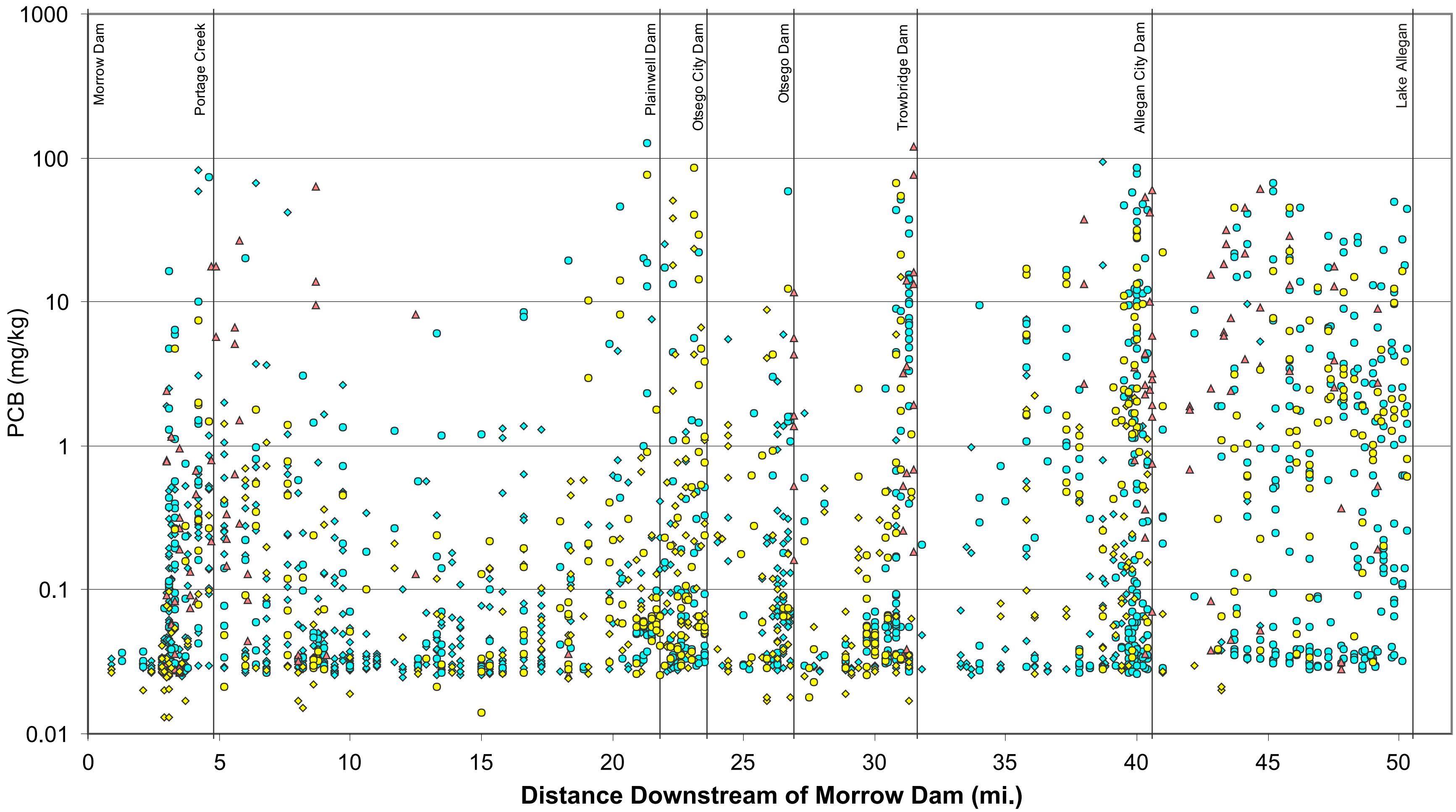
KALAMAZOO RIVER SUPERFUND SITE

GENERALIZED CONCEPTUAL SITE MODEL

TOTAL PCB CONCENTRATIONS IN SURFICIAL SEDIMENT

ARCADIS

FIGURE
4-2



LEGEND:

- 1993 Coarse-grained sample
- 1993 Fine-grained sample
- 2000 Focused sample
- 2000 Coarse-grained sample
- 2000 Fine-grained sample

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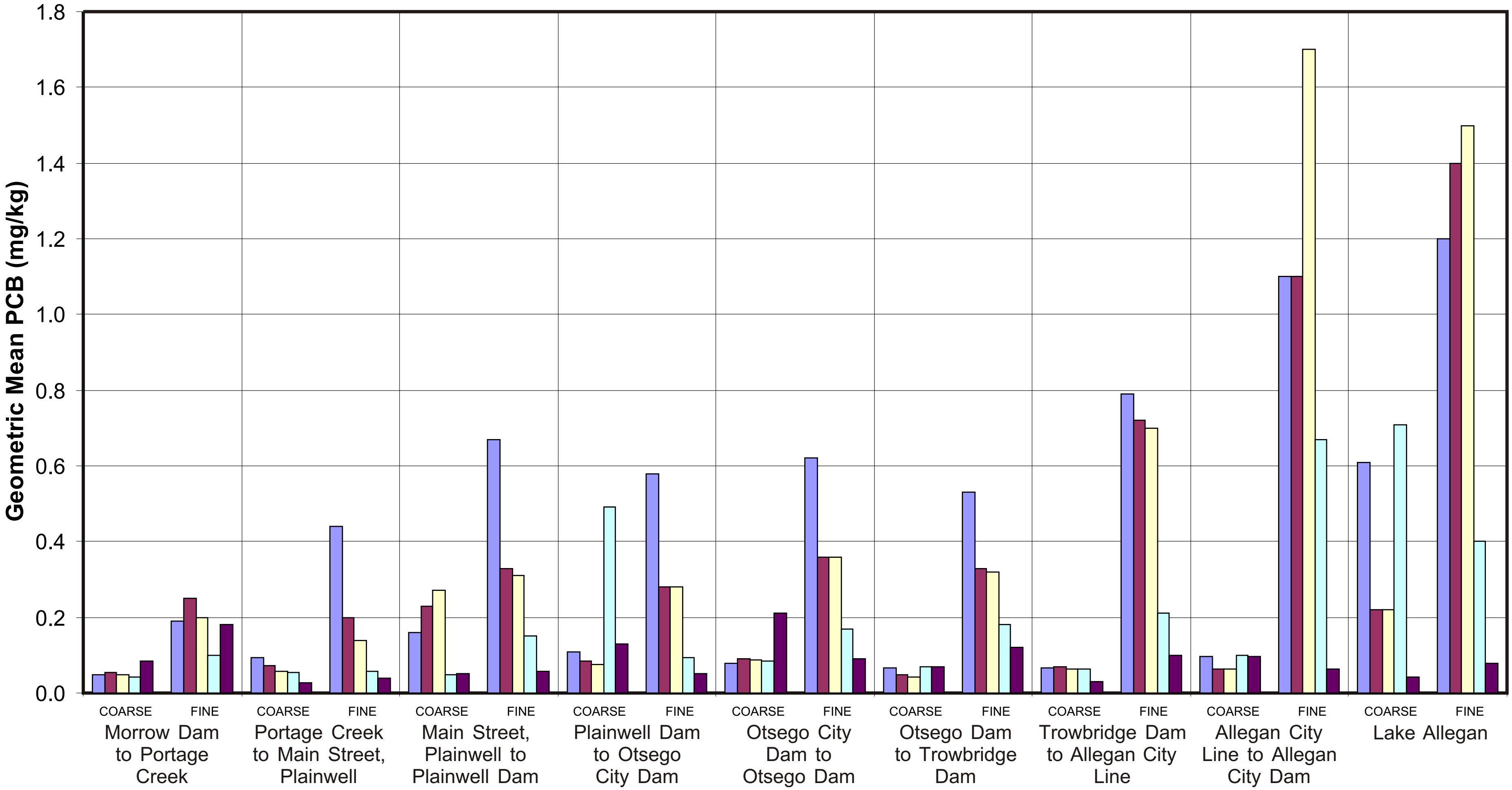
KALAMAZOO RIVER SUPERFUND SITE

GENERALIZED CONCEPTUAL SITE MODEL

TOTAL PCB CONCENTRATIONS IN SUBSURFACE SEDIMENT

ARCADIS

FIGURE **4-3**



LEGEND:

- 0" - 2" depth interval
- 2" - 6" depth interval
- 6" - 12" depth interval
- 12" - 24" depth interval
- Samples deeper than 24"

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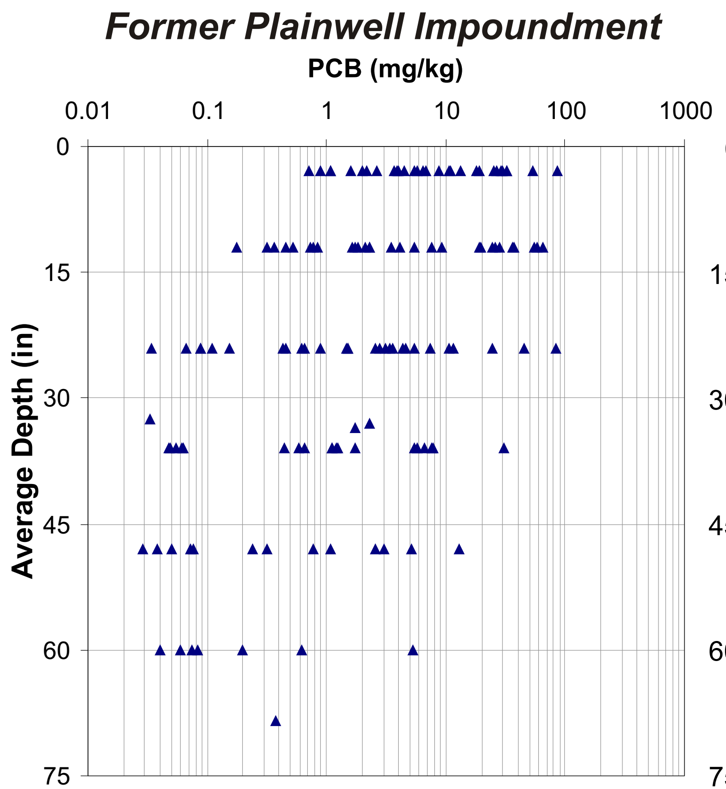
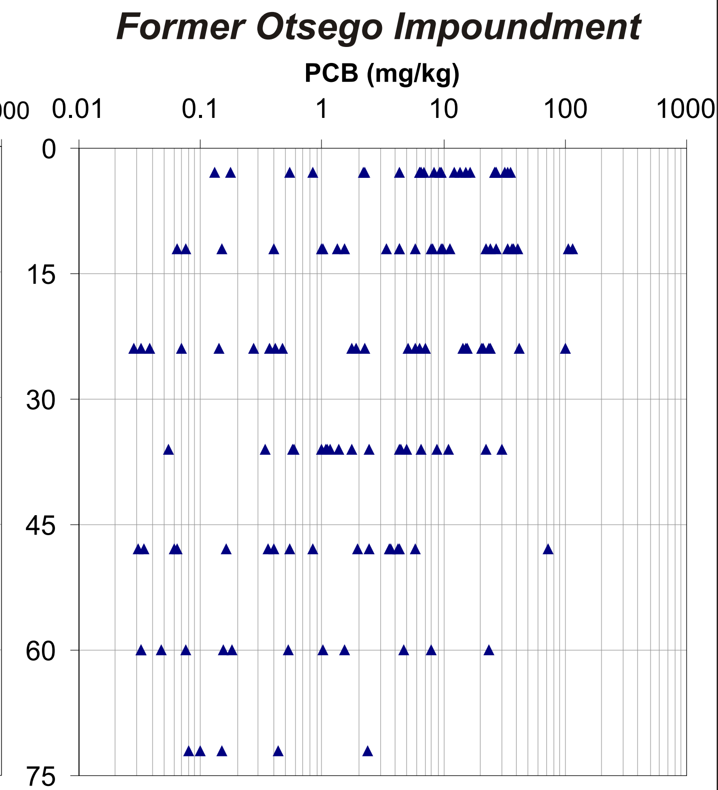
GENERALIZED CONCEPTUAL SITE MODEL

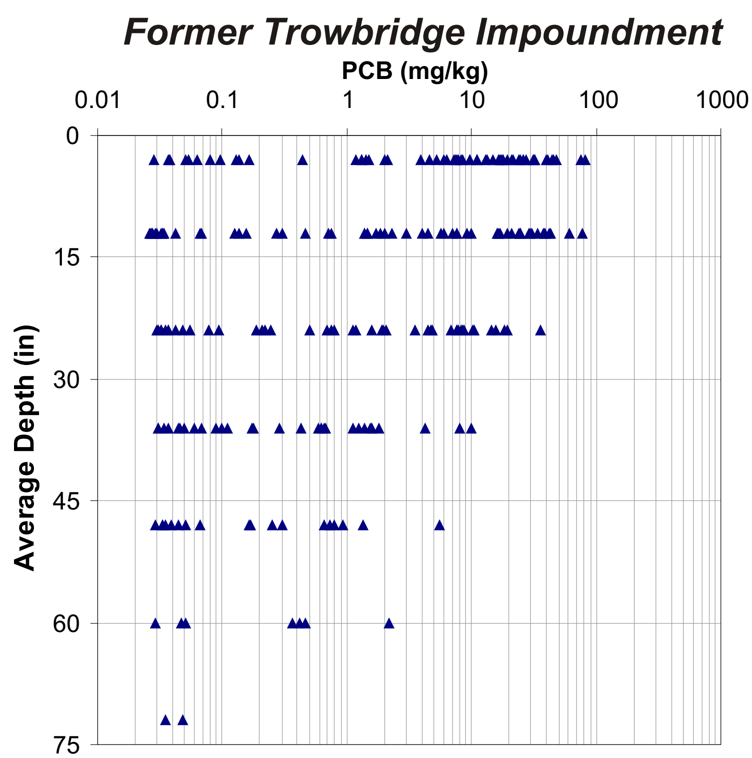
GEOMETRIC MEAN PCB CONCENTRATIONS IN SEDIMENT BY TEXTURE AND DEPTH

ARCADIS

FIGURE
4-5







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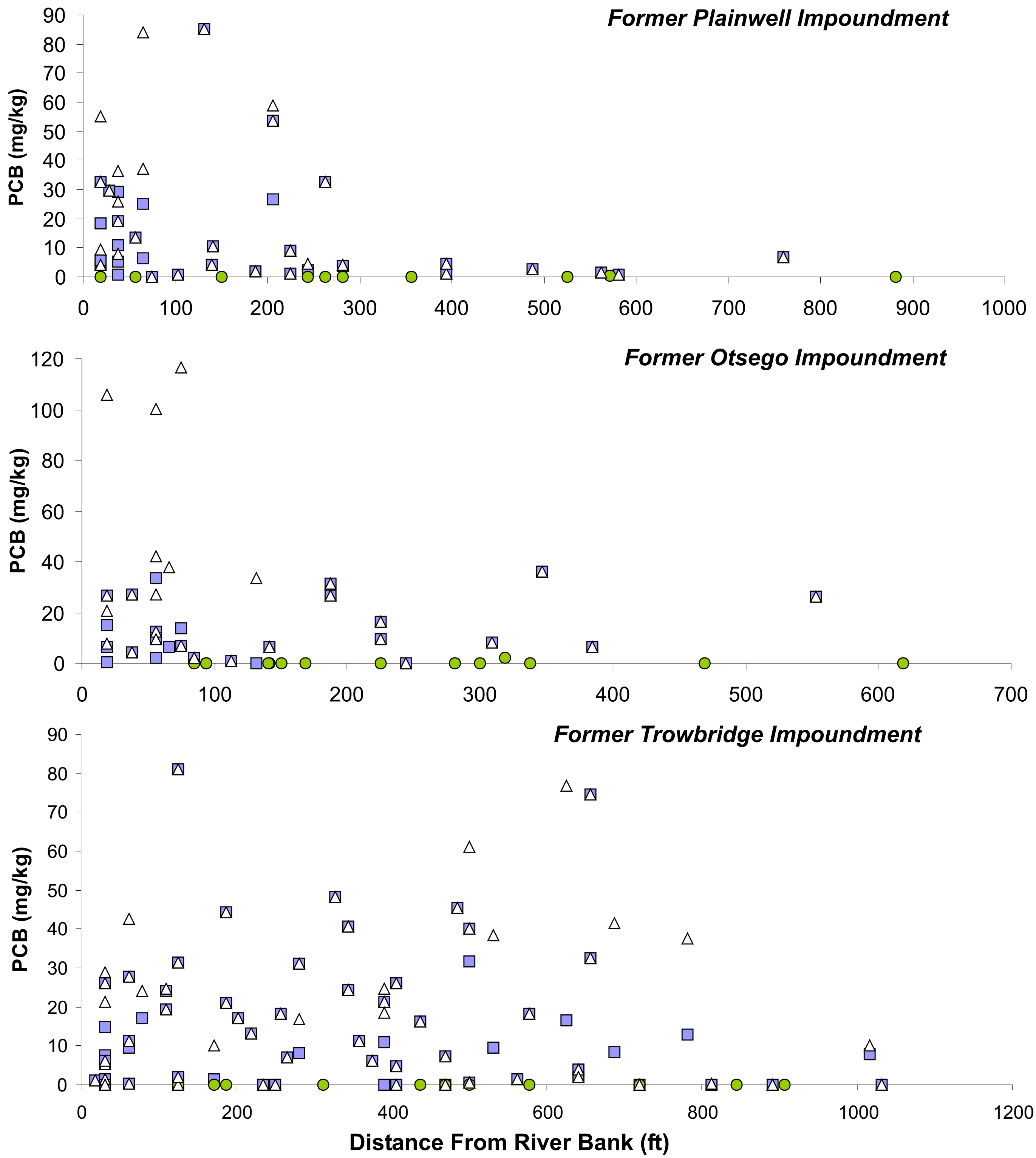
GENERALIZED CONCEPTUAL SITE MODEL

RELATIONSHIP OF PCB CONCENTRATION AND SAMPLE DEPTH - FORMER IMPOUNDMENT EXPOSED SEDIMENT

ARCADIS

FIGURE 4-6

12/23/08 SYR-141ENV-DJH KLS
B0064524\0000\00500\GCSM\CDR\64524G21.CDR



LEGEND:

- ■ Surface PCB Concentration Within Former Impoundments
- ● Surface PCB Concentration Outside the Former Impoundments
- △ Maximum PCB Concentration in Core

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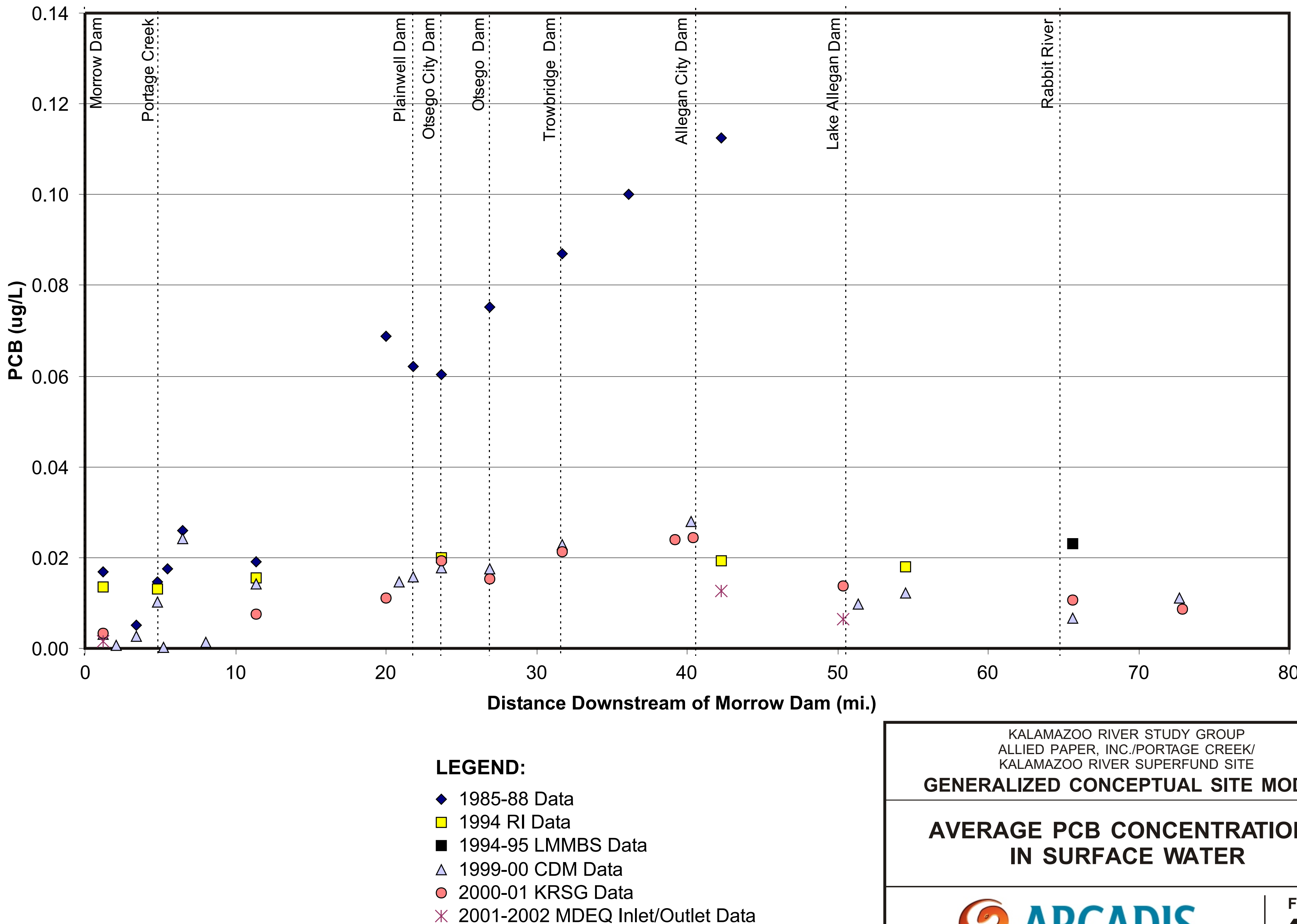
GENERALIZED CONCEPTUAL SITE MODEL

RELATIONSHIP OF FORMER IMPOUNDMENT TRANSECT PCB CONCENTRATION AND DISTANCE FROM RIVER BANK

ARCADIS

FIGURE
4-7

12/23/08 SYR-141ENV-DJH KLS
B0064524\0000\00500\GCSM\CDR\64524G22.CDR



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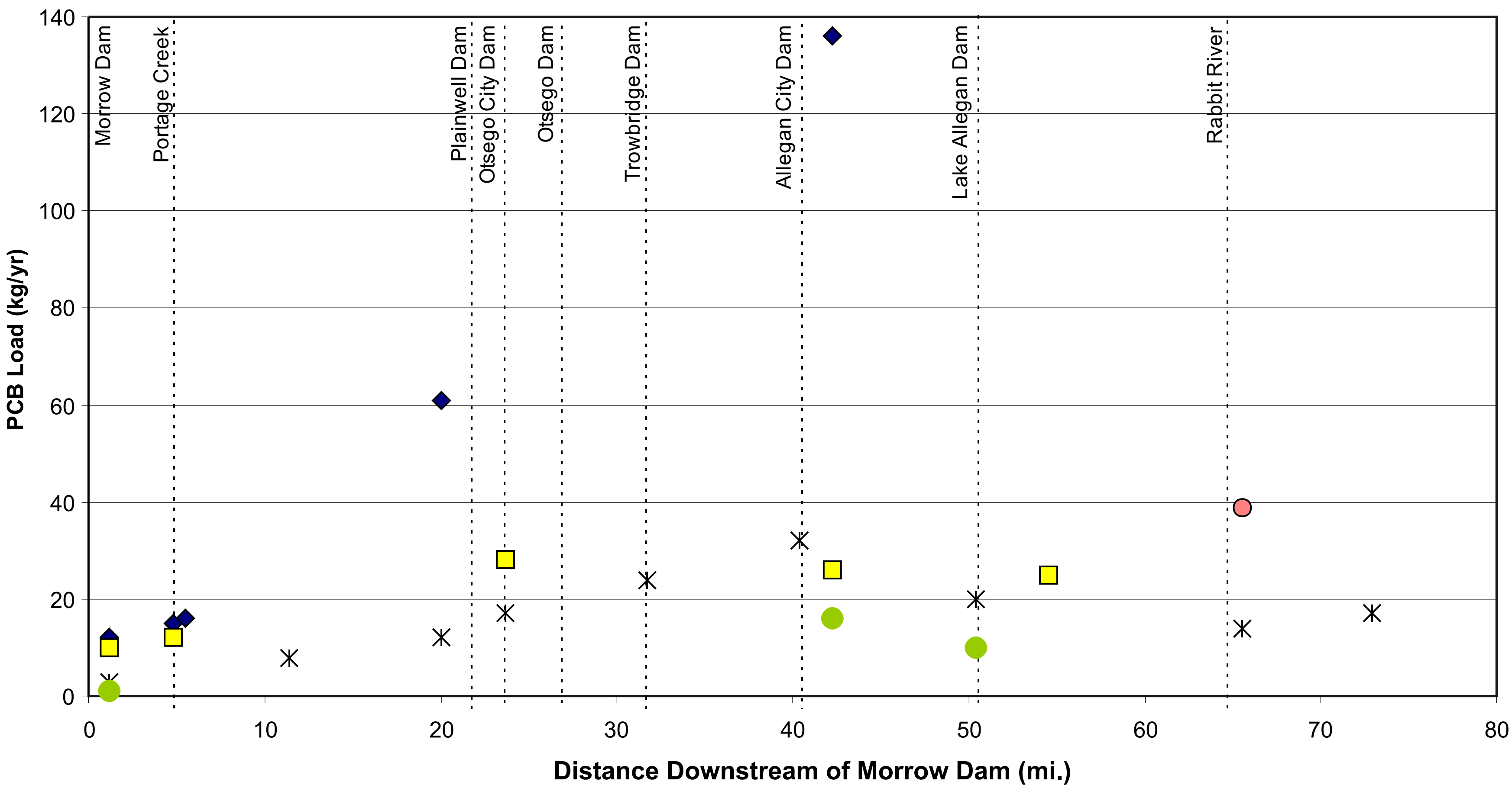
GENERALIZED CONCEPTUAL SITE MODEL

AVERAGE PCB CONCENTRATIONS IN SURFACE WATER

ARCADIS

FIGURE **4-10**



LEGEND:

- 1985-88 Data
- 1994 RI Data
- 1994-95 LMMBS Data
- 2000-01 KRSG Data
- 2001-2002 MDEQ Inlet/Outlet Data

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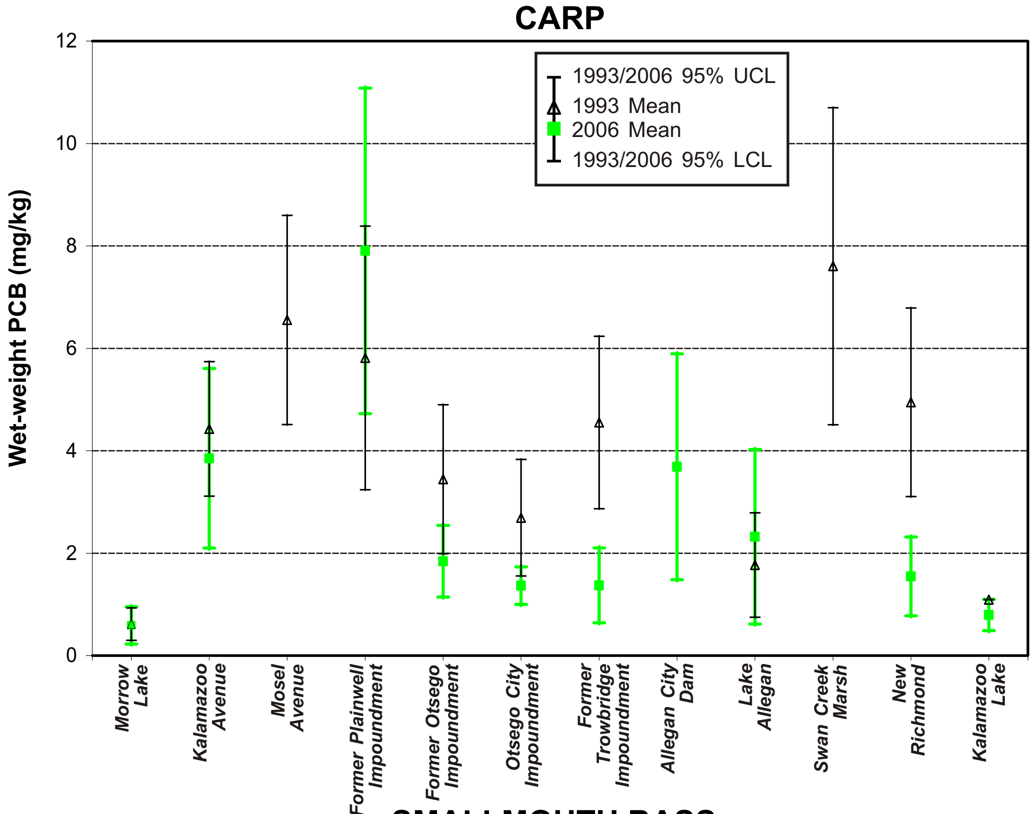
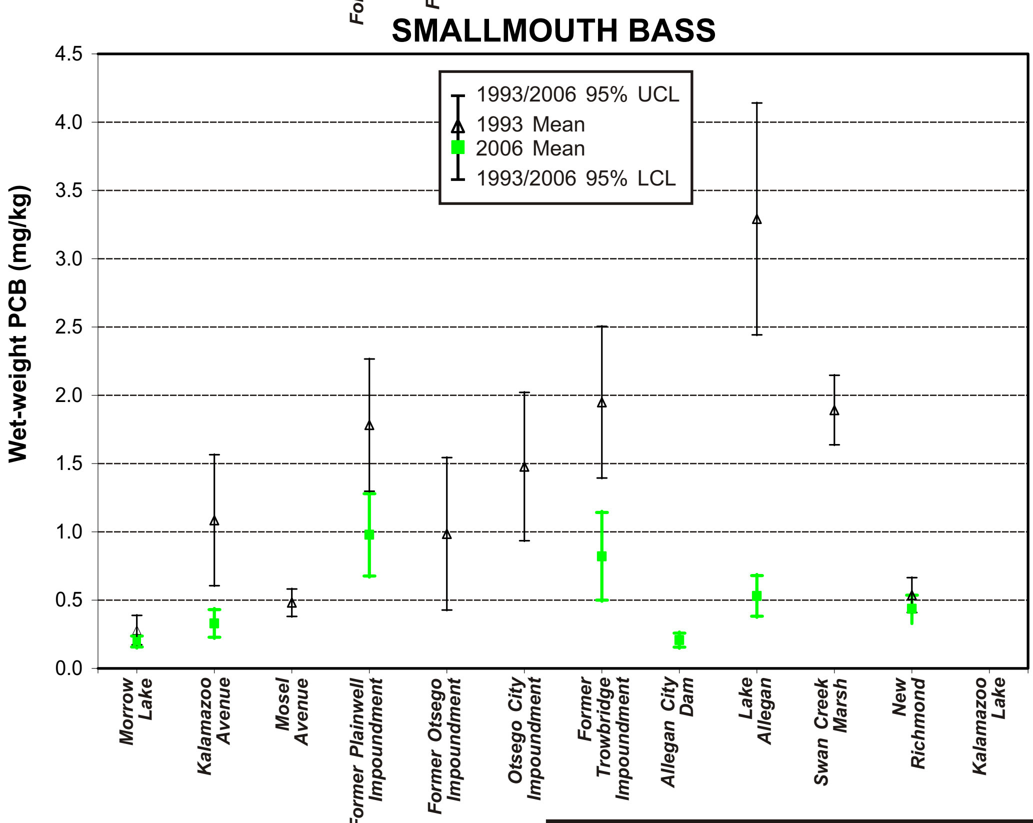
GENERALIZED CONCEPTUAL SITE MODEL

ESTIMATED ANNUAL PCB LOAD IN THE KALAMAZOO RIVER

ARCADIS

FIGURE
4-11





NOTE:
1. Half detection limit used in computation of mean for non-detect values.

KALAMAZOO RIVER STUDY GROUP
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KALAMAZOO RIVER SUPERFUND SITE

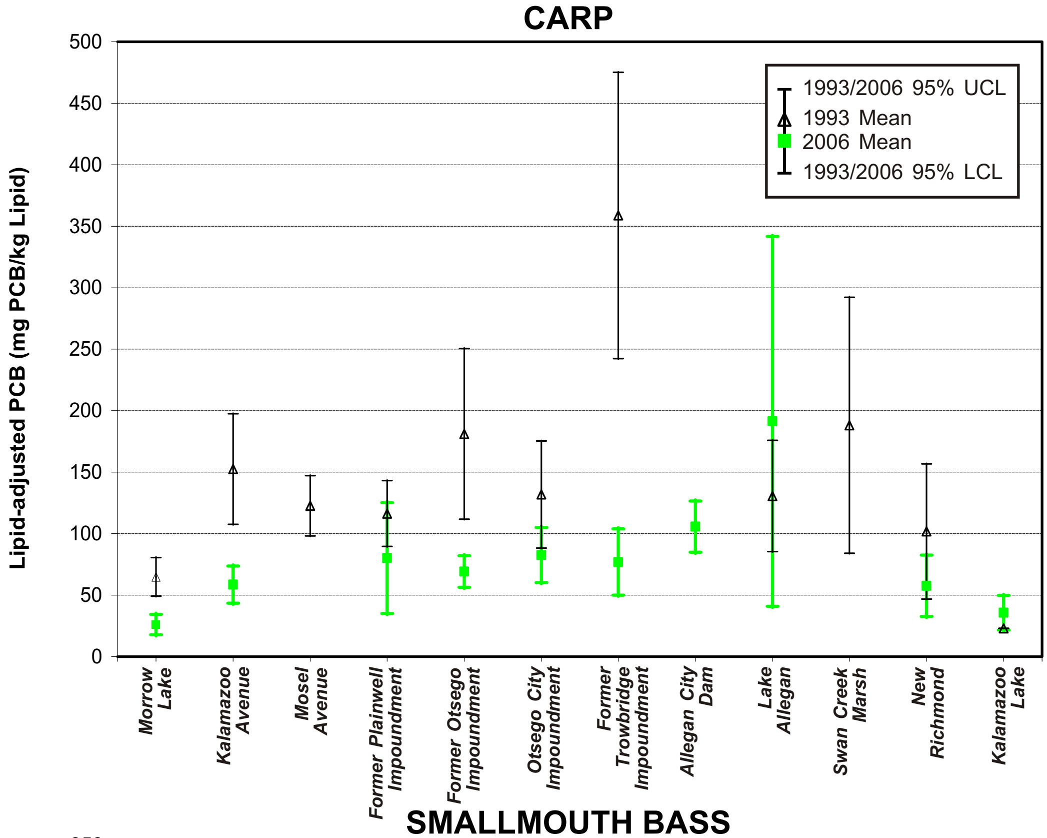
GENERALIZED CONCEPTUAL SITE MODEL

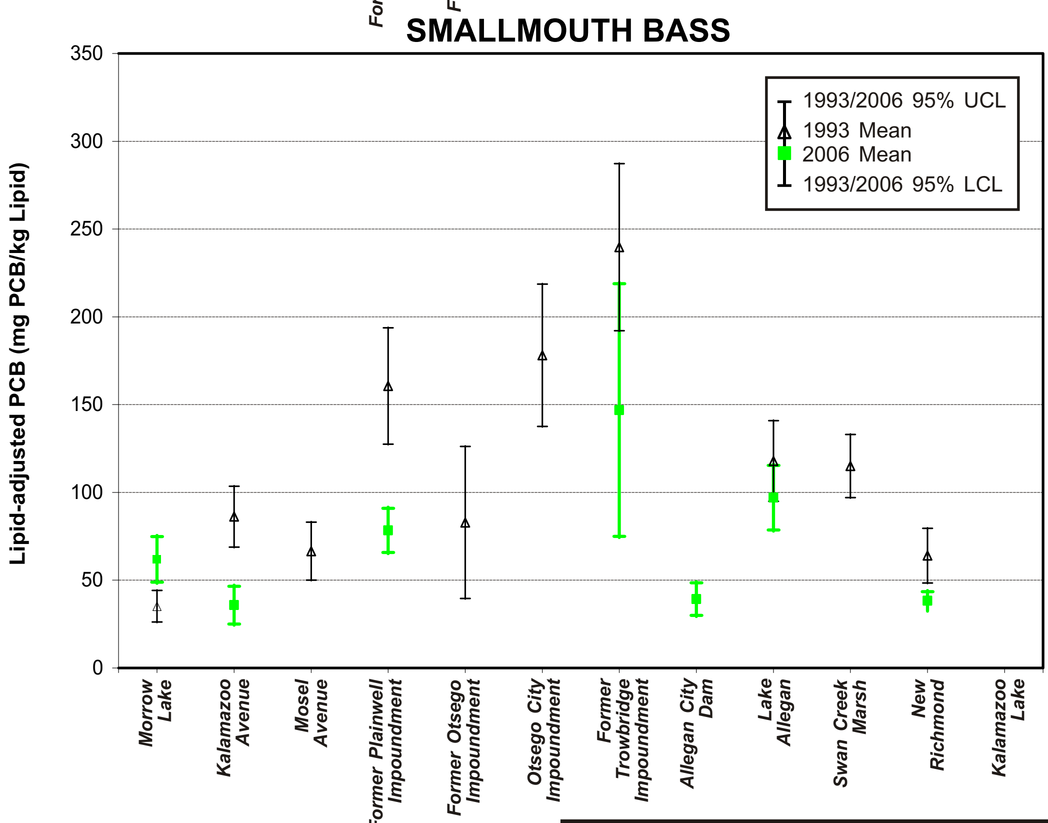
COMPARISON OF 1993 RI FISH DATA WITH 2006 MDEQ FISH DATA - WET-WEIGHT PCB

ARCADIS

FIGURE **4-12**

12/23/08 SYR-141ENV-DJH KLS
B0064524\0000\00500\GCSM\CDR\64524G26.CDR





NOTE:
1. Half detection limit used in computation of mean for non-detect values.

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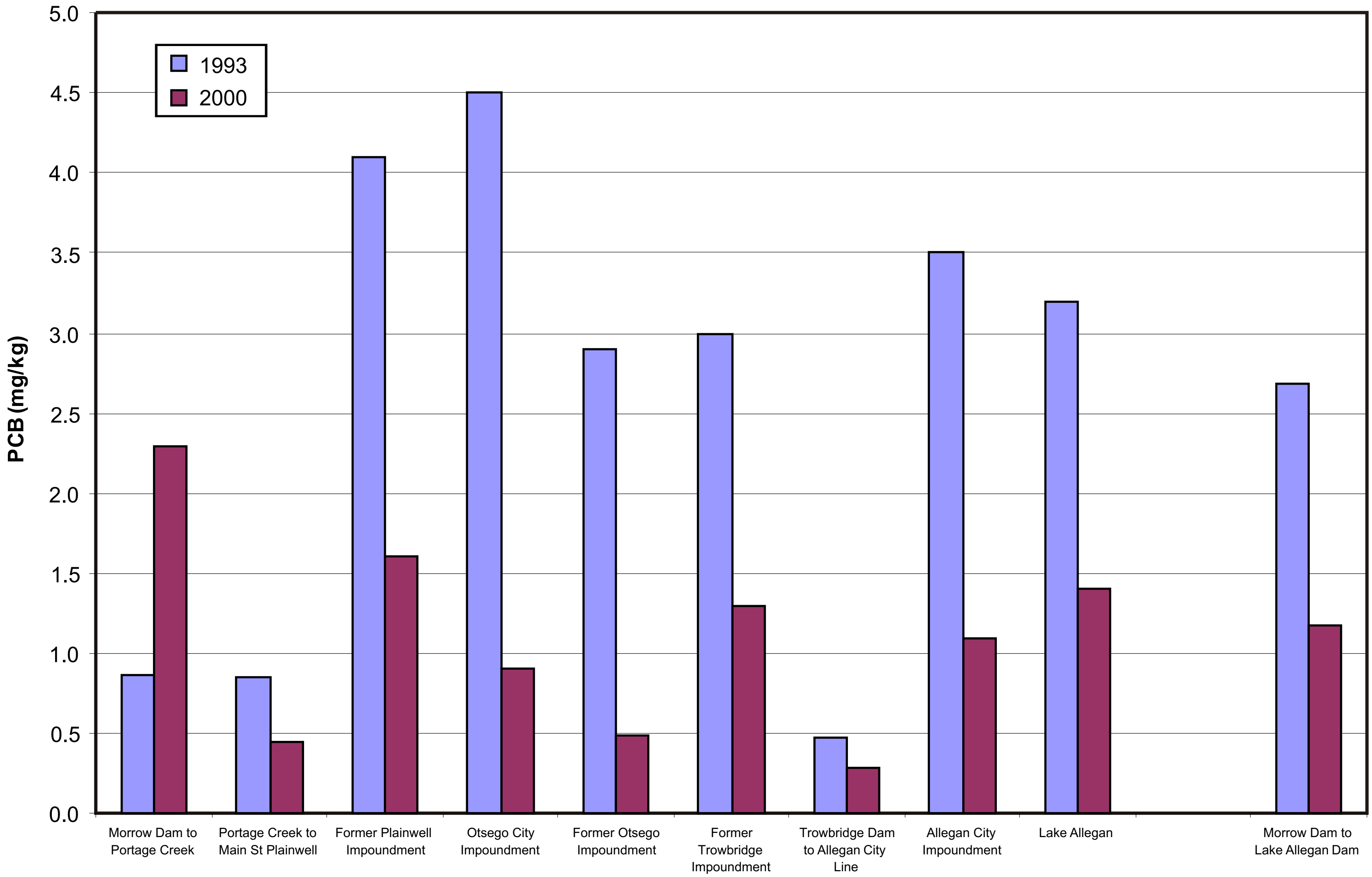
GENERALIZED CONCEPTUAL SITE MODEL

COMPARISON OF 1993 RI FISH DATA WITH 2006 MDEQ FISH DATA - LIPID-ADJUSTED PCB

ARCADIS

FIGURE
4-13

12/23/08 SYR-141ENV-DJH KLS
B0064524\0000\00500\GCSM\CDR\64524G27.CDR



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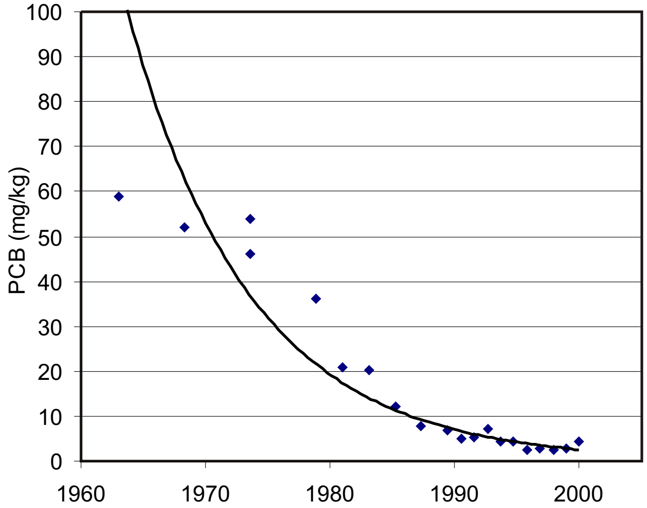
GENERALIZED CONCEPTUAL SITE MODEL

PCB CONCENTRATIONS IN SURFACE SEDIMENT: 1993 VS. 2000

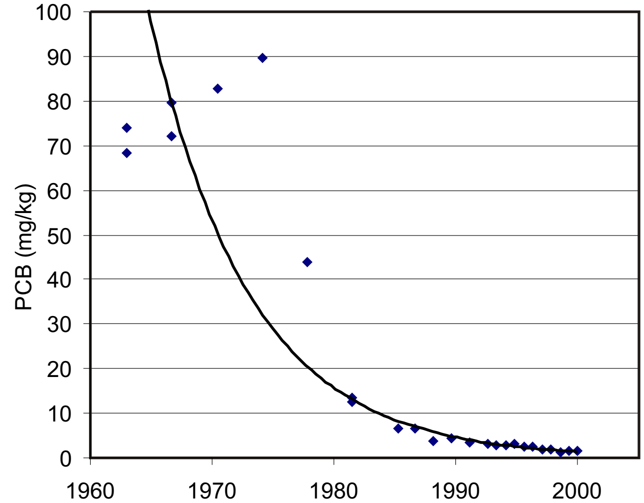
ARCADIS

FIGURE
4-14

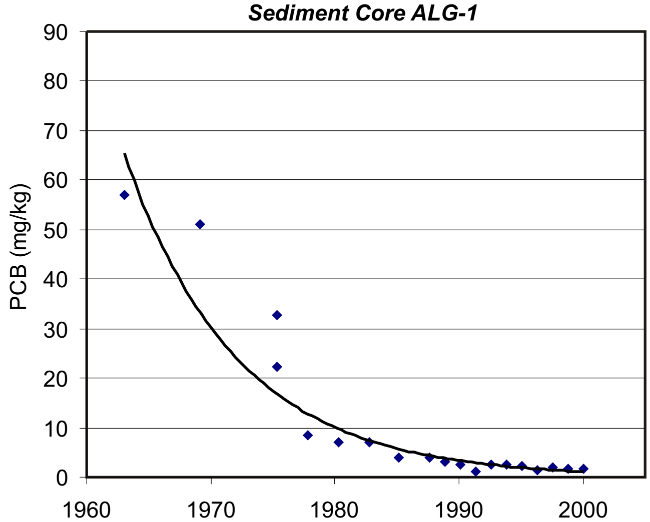
Trowbridge Impoundment Sediment Core TBG-2



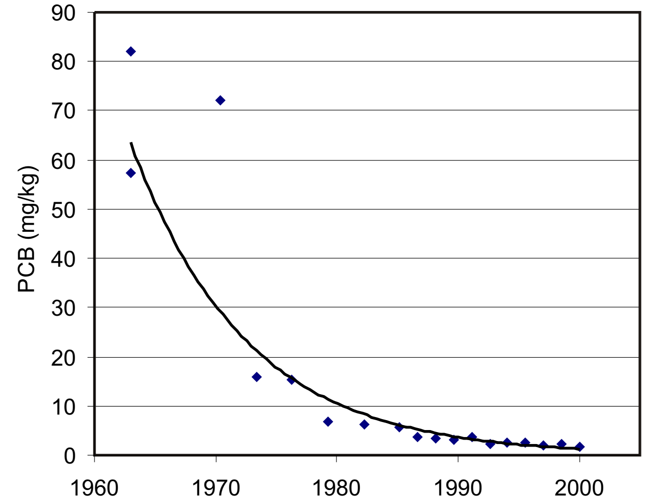
Allegan City Impoundment Sediment Core ACG-1



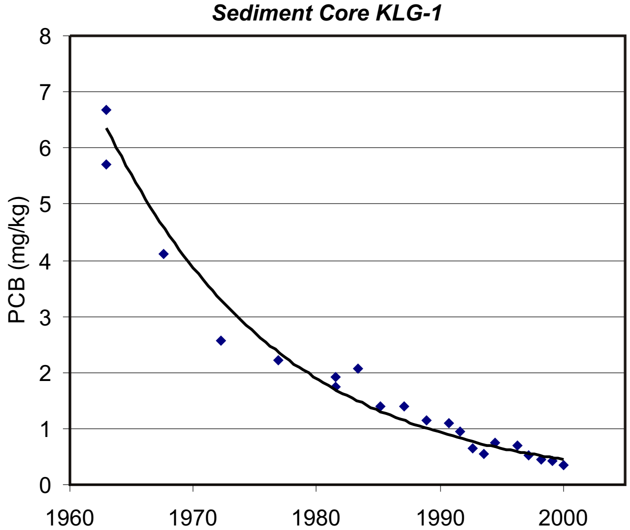
Lake Allegan Sediment Core ALG-1



Lake Allegan Sediment Core ALG-2



Kalamazoo Lake Sediment Core KLG-1



NOTE:

1. Trend lines are from regression analyses on PCB data since peak cesium fallout in 1963.

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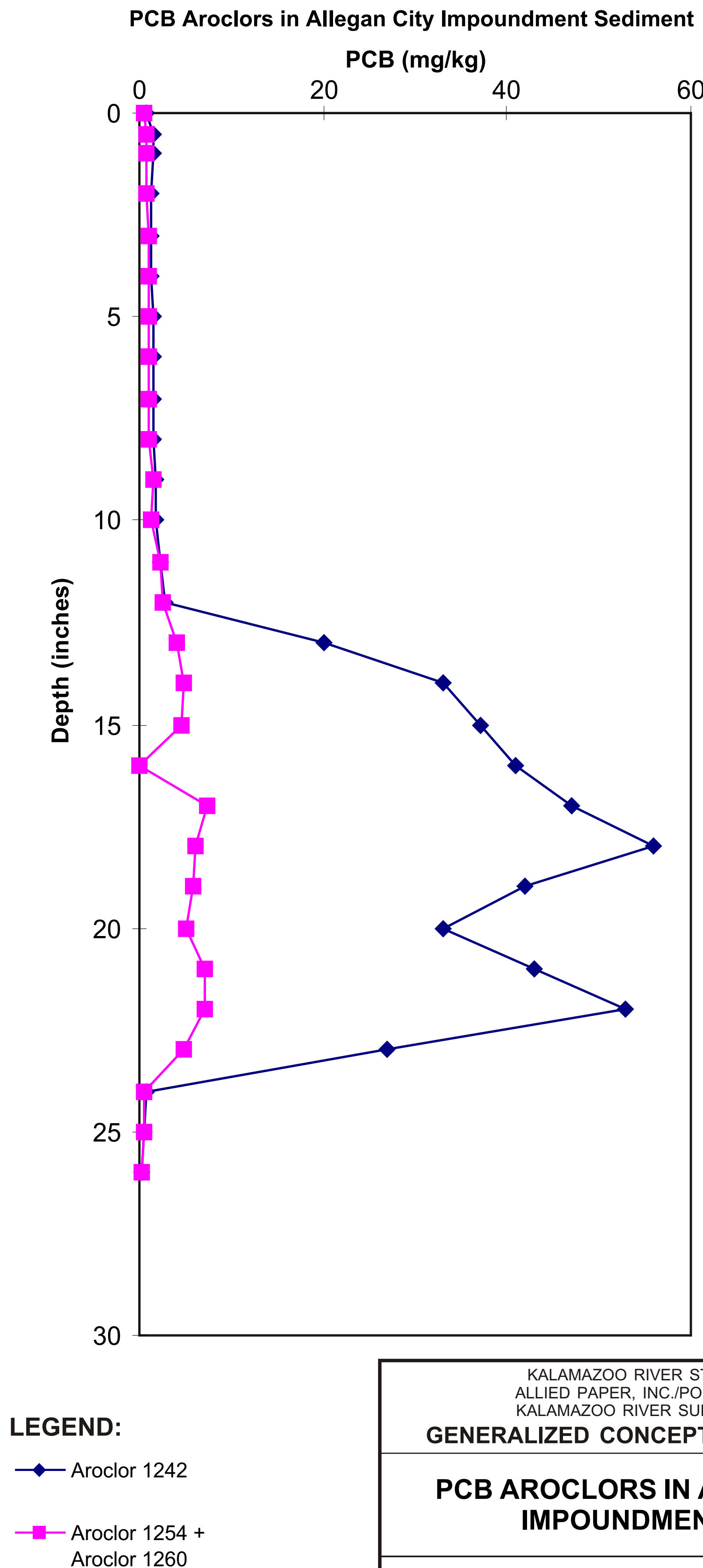
GENERALIZED CONCEPTUAL SITE MODEL

CHRONOLOGY OF PCB CONCENTRATIONS IN KALAMAZOO RIVER SEDIMENT CORES

ARCADIS

FIGURE **4-15**

12/23/08 SYR-141ENV-DJH KLS
B0064524\0000\00500\GCSM\CDR\64524G14.CDR



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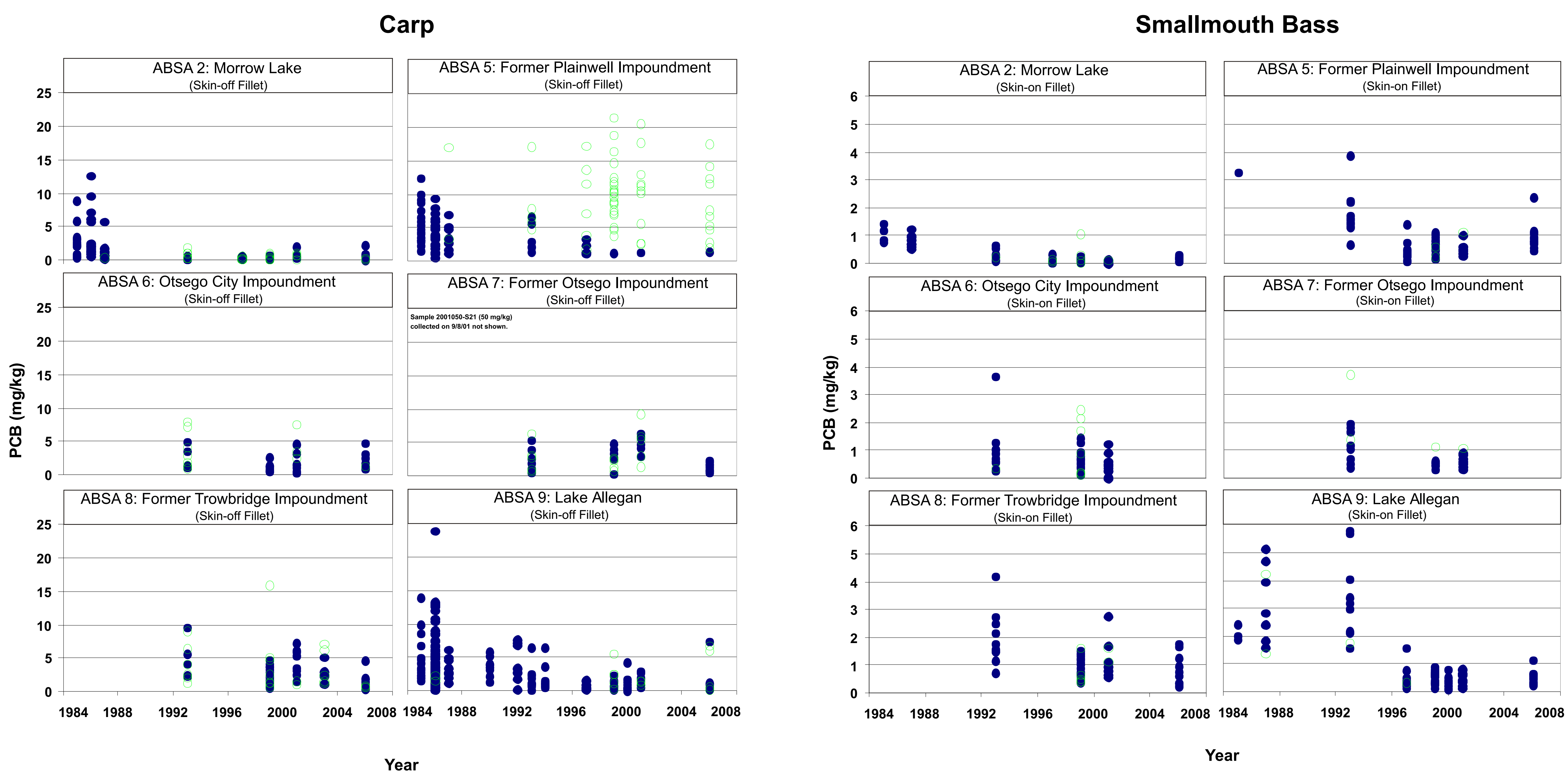
GENERALIZED CONCEPTUAL SITE MODEL

PCB AROCLORS IN ALLEGAN CITY IMPOUNDMENT CORE

ARCADIS

FIGURE
4-16

12/23/08 SYR-141ENV-DJH KLS
B0064524\0000\00500\GCSM\CDR\64524G13.CDR



LEGEND

Non-length restricted data result (Carp ≥ 22 inches and smallmouth bass ≥ 16 inches)

Length restricted data result (Carp < 22 inches and smallmouth bass < 16 inches)

NOTE:
Plots include carp and smallmouth bass fillet data collected by MDEQ (1985-2006) and/or KRSG (1993-1999) and whole body carp data collected by MDEQ (1990-2005).

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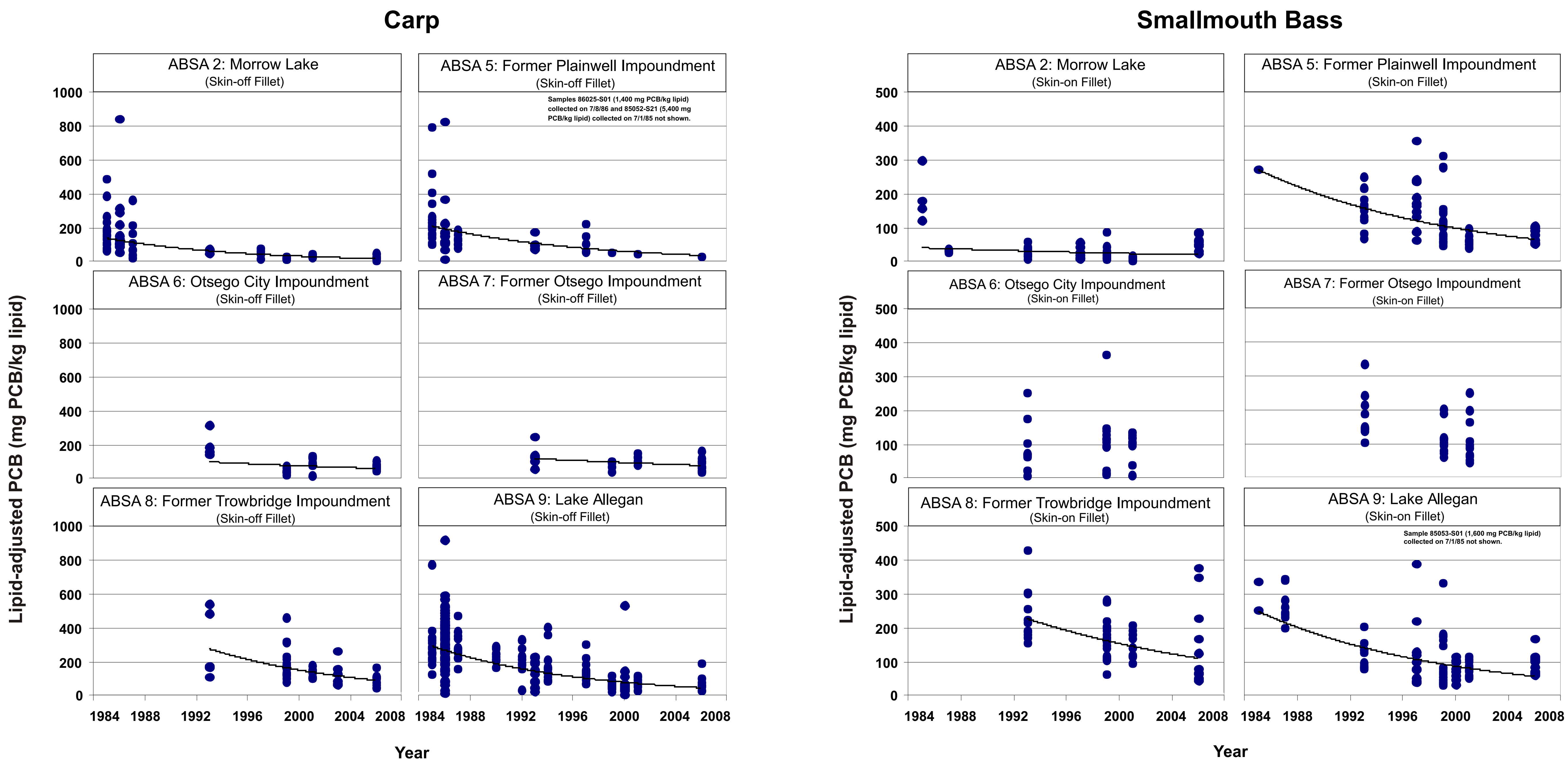
GENERALIZED CONCEPTUAL SITE MODEL

WET-WEIGHT PCB CONCENTRATION IN CARP AND SMALLMOUTH BASS

ARCADIS

FIGURE
4-18

12/23/08 SYR-141ENV-DJH KLS
B0064524\0000\00500\GCSM\CDR\64524G30.CDR



LEGEND

● Length restricted data result (Carp < 22 inches and smallmouth bass < 16 inches)

—— First-order regression line

NOTE:

Plots include carp and smallmouth bass fillet data collected by MDEQ (1985-2006) and/or KRSG (1993-1999) and whole body carp data collected by MDEQ (1990-2005). Regressions are shown only on data sets with four or more sampling events.

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KALAMAZOO RIVER SUPERFUND SITE

GENERALIZED CONCEPTUAL SITE MODEL

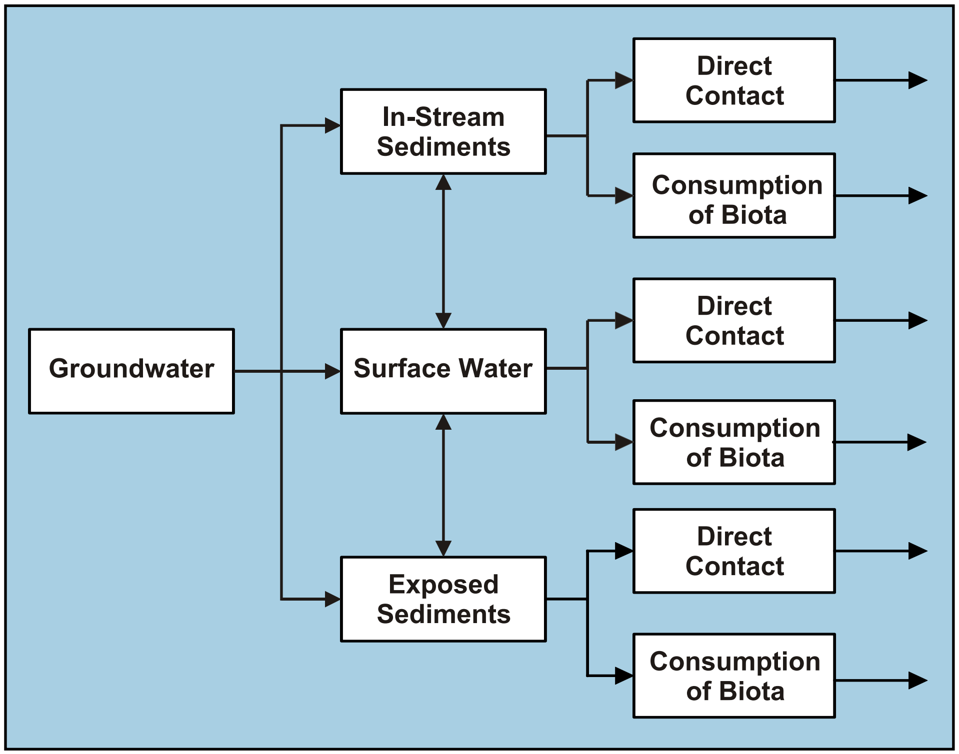
LIPID-ADJUSTED PCB CONCENTRATION IN LENGTH RESTRICTED CARP AND SMALLMOUTH BASS

ARCADIS

FIGURE
4-19

12/23/08 SYR-141ENV-DJH KLS
B0064524\0000\00500\GCSM\CDR\64524G31.CDR

EXPOSURE MEDIUM	EXPOSURE POINT



POTENTIAL EXPOSURE ROUTES	In-Stream Aquatic				Former Impoundments Terrestrial	
	Aquatic Life[1]	Benthic Invertebrates	Piscivorous Birds	Herbivorous & Piscivorous Mammals	Omnivorous & Carnivorous Birds	Omnivorous & Carnivorous Mammals
Uptake[2]		●				
Ingestion			●	●		
Dermal Contact			♦	♦		
Ingestion			●	●		
Uptake[2]	●	●				
Ingestion			●	●	●	●
Dermal Contact			♦	♦		
Ingestion			●	●		
Uptake[2]						
Ingestion					●	●
Dermal Contact					♦	♦
Ingestion					●	●

LEGEND

- ● Potentially complete exposure pathway
- ♦ Potentially complete exposure pathway expected to be minor; not quantitative evaluated
- ☐ Incomplete exposure pathway

NOTES:
1. Aquatic Life includes aquatic plants, invertebrates, fish, and amphibians
2. Uptake is defined as all exposure routes (i.e., absorption, ingestion, and inhalation)
3. Not all pathways will be complete in each Area of the Site

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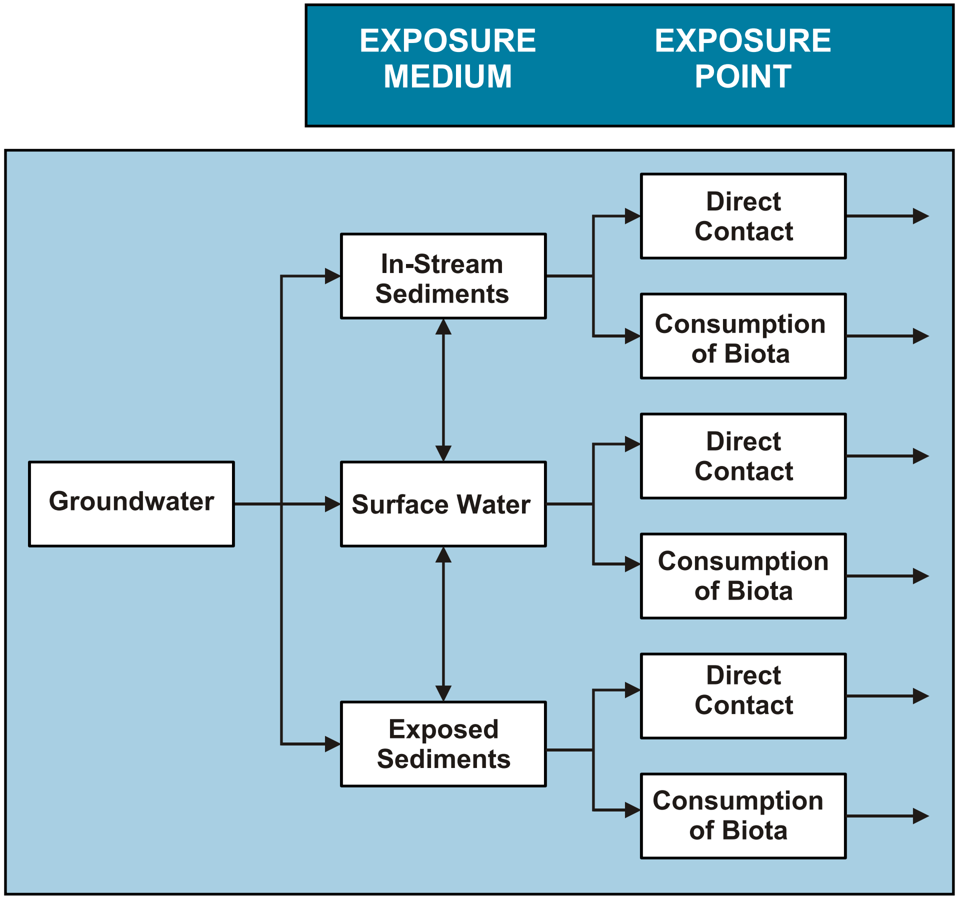
ECOLOGICAL EXPOSURE PATHWAYS

ARCADIS

FIGURE
5-1



POTENTIAL EXPOSURE ROUTES	Anglers	Recreationalists	Residents
Ingestion	♦	●	
Dermal Contact	♦	●	
Inhalation	♦	♦	
Ingestion	●		
Ingestion	♦	♦	
Dermal Contact	♦	♦	
Inhalation	♦	♦	
Ingestion	●		
Ingestion	♦	●	●
Dermal Contact	♦	●	●
Inhalation	♦	♦	♦
Ingestion		♦	

LEGEND

- ● Potentially complete exposure pathway
- ♦ Potentially complete exposure pathway expected to be minor; not quantitatively evaluated
- ▭ Incomplete exposure pathway

NOTE:
1. Not all pathways will be complete in each Area of the Site

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HUMAN EXPOSURE PATHWAYS

ARCADIS

FIGURE
5-2