


Final Report

Remedy Effectiveness Assessment for Great Lakes Legacy Act Project in the Ashtabula River Area of Concern

April 11, 2017

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Mission Support Services Contract EP-R5-11-07


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The U.S. Environmental Protection Agency (U.S. EPA) funded and managed, or partially funded and collaborated in, the research described herein. It has been subjected to the Agency's peer and administrative review and has been approved for publication. Any opinions expressed in this report are those of the authors and do not necessarily reflect the views of the Agency; therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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List of Acronyms and Abbreviations

ANOVA	Analysis of Variance
AOC	Area of Concern
BUI	Beneficial Use Impairment
°C	Degrees Celsius
COC	Contaminants of Concern
DMU	Dredge Management Unit
DO	Dissolved Oxygen
ft	Foot/feet
GLLA	Great Lakes Legacy Act
GLNPO	Great Lakes National Program Office
GLRI	Great Lakes Restoration Initiative
HCB	Hexachlorobenzene
HCBD	Hexachlorobutadiene
IBI	Index of Biotic Integrity
ICI	Invertebrate Community Index
in.	Inch(es)
kg	Kilogram
lb	Pound
LOE	Line of Evidence
m	Meter
mg/kg	Milligrams per Kilogram
MIwb	Modified Index of Well-being
NOAA	National Oceanic and Atmospheric Administration
NPL	National Priority List
NRDA	Natural Resource Damage Assessment
Ohio DNR	Ohio Department of Natural Resources
Ohio EPA	Ohio Environmental Protection Agency
ORD	Office of Research and Development
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
pCi/g	picoCuries/gram
QHEI	Qualitative Habitat Evaluation Index
REA	Remedy Effectiveness Assessment
RM	River Mile
RPG	Remedial Project Goal
SPMD	Semipermeable Membrane Device
SWAC	Surface Weighted Average Concentration
TEM	Tail Extent Momentum
TOC	Total Organic Carbon
TSCA	Toxic Substances Control Act
U.S. EPA	U.S. Environmental Protection Agency
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WRDA	Water Resources Development Act
yd^3	Cubic Yards

1 Introduction

1.1 The Ashtabula River

The Ashtabula River drains 137 square miles of northeastern Ohio and western Pennsylvania as it flows into Lake Erie. The 40-mile long Ashtabula River is part of the Lake Erie central basin and adjacent to the city of Ashtabula, Ohio. Regulated and unregulated discharges of hazardous wastes from the 1940s to 1970s caused the River's sediments to become significantly contaminated, resulting in degraded physical and biological conditions. In 1985, the lower 2.32 miles of the Ashtabula River, Ashtabula Harbor, and the adjacent Lake Erie nearshore were designated as a Great Lakes Area of Concern (AOC) by the International Joint Commission (Figure 1-1) [3]. Contaminants of concern (COCs) for the entire area include polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs); hexachlorobenzene (HCB), hexachlorobutadiene (HCBD), metals, and low-level radionuclides including radium, thorium, and uranium [3]. PCBs were the primary COC for remedation activities with an estimated 19,422 pounds (lb [8,810 kg]) of PCBs in River sediments (see BOX 1 for a description of PCBs) [3, 4].

Figure 1-1. Ashtabula River Watershed (inset), Extent of Area of Concern, Fields Brook Superfund Site, and the Great Lakes Legacy Act (GLLA) Project Boundary.

Beneficial use impairments (BUIs) are used to describe and document the extent of impairment to an AOC. An impairment of beneficial use means that there is degradation or restrictions in one of 14 specific uses (see Appendix A). In 1991, the Ashtabula River Partnership detailed six BUIs for the AOC [5]:

- BUI #1: Restrictions on Fish and Wildlife Consumption,
- BUI #3: Degradation of Fish and Wildlife Populations,
- BUI #4: Fish Tumors and Other Deformities,
- BUI #6: Degradation of Benthos,
- BUI #7: Restrictions on Dredging Activities, and
- BUI #14: Loss of Fish and Wildlife Habitat.

BOX 1: PCBs are a group of 209 synthetic compounds, individually called congeners. PCBs were globally manufactured and used for their superior insulating and long-term degradation resistance. PCBs have 10 levels of chlorination. The degree of chlorination and placement of the chlorine atoms on the parent biphenyl molecule differentiates individual PCB congeners, and produces different physical and chemical properties between congeners. Aroclors are specific PCB congener mixtures that are identified by a four-digit number code. The first two digits indicate the type of mixture, and the second two digits indicate the approximate chlorine content by weight percent [1].

1.2 History of Contamination in the Ashtabula River

Contamination of the Ashtabula River sediments largely originated from historic industrial discharges within two tributaries that converge near the Upper Turning Basin. Fields Brook was the dominant contaminant source. It is a 5.6-square mile watershed where up to 20 separate industrial facilities, including metal fabricators and chemical producers, have operated since the 1940s [6]. Sediment and soils from the Fields Brook floodplain were significantly contaminated with a variety of contaminants, including PCBs, metals, and chlorinated solvents. In 1983, Fields Brook was added to the Superfund National Priorities List (NPL) (Figure 1-1) [6, 7].

Strong Brook, which empties into the Ashtabula North Slip (Figure 1-2), was found in 2007 to have contributed PCBs to the Ashtabula North Slip and a small area of the Ashtabula River, but to a much lesser extent than Fields Brook. PCB Aroclor patterns were distinctly different in the Ashtabula North Slip, indicating Strong Brook as a separate and distinct source of PCBs from Fields Brook. Cleanup efforts at industrial facilities along Strong Brook and at the source were completed, mitigating future contamination to the River [7, 8].

1.3 Remediation and Restoration Efforts in the Ashtabula River

There have been several remediation and restoration actions in the Ashtabula River AOC. A summary of these activities is outlined in Table 1-1. As demonstrated, the Ashtabula River AOC has been dredged at different times and in different segments. Between 2006 and 2013, over 700,000 cubic yards (yd^3) of contaminated sediment have been removed from the Ashtabula River AOC as a whole; the U.S. Environmental Protection Agency (U.S. EPA) through the Great Lakes Legacy Act (GLLA) removed 508,383 yd^3 of sediments, and the U.S. Army Corps of Engineers (USACE) removed a total of 287,814 yd^3 of sediments through multiple projects in the Harbor, lower River, and upper River [9, 10]. Significant remediation efforts have also occurred within tributaries to the River, particularly through Superfund efforts along Fields

Brook and enforcement of the Toxic Substances Control Act (TSCA) at upland locations along portions of Strong Brook [8].

Table 1-1. Timeline of Events for the Ashtabula River.

Year(s)	Event Description
1940s – 1970s	Industrial contaminants from Fields Brook, Strong Brook, and Ashtabula River are transported to Ashtabula River sediments.
1985	The Lower Ashtabula River and Harbor are designated a Great Lakes Area of Concern (AOC) by the International Joint Commission.
1991	Ohio Environmental Protection Agency (Ohio EPA) publishes the first remedial action plan for the AOC detailing six beneficial use impairments (BUIs) for the AOC. BUI #1: Restrictions on Fish and Wildlife Consumption BUI #3: Degradation of Fish and Wildlife Populations BUI #4: Fish Tumors and Other Deformities BUI #6: Degradation of Benthos BUI #7: Restrictions on Dredging Activities BUI #14: Loss of Fish and Wildlife Habitat
1994	Formation of the Ashtabula River Partnership – public/private partnership among State and Federal agencies and local industries.
2001	Ashtabula River Comprehensive Management Plan is published.
2003	Initial remediation of the Fields Brook Superfund site is completed.
2006 – 2007*	***Great Lakes Legacy Act (GLLA) sediment dredging activities completed between the Upper Turning Basin and the 5th Street Bridge. A total of 497,383 cubic yards (yd^3) of sediments are removed from the project area [11].***
2007	U.S. Army Corps of Engineers (USACE) conducts operation and maintenance dredging in the federal navigation channel; removing 129,814 yd^3 of sediments from the 5th Street Bridge north into Ashtabula Harbor [10].
2009 – 2010	GLLA habitat restoration includes installation of a fish shelf and native plantings within an 800-foot stretch of riverbank beginning at 5½ Slip.
2011	Ohio EPA, under a Great Lakes Restoration Initiative (GLRI) grant, completes additional habitat restoration including construction of approximately 1,600-foot (ft) habitat shelf between 5½ Slip and Upper Turning Basin.
2013	GLLA project at the Ashtabula North Slip (Jack's Marine) – dredging of 11,000 yd^3 of sediment and placement of sand cover.
2012-2013	USACE conducts strategic navigation dredging and removes 158,000 yd^3 of sediment in the navigation channel between the 5th Street Bridge and the 24th Street Bridge [9].
2013	Ohio EPA utilizes Natural Resource Damage Assessment (NRDA) funds to conduct additional habitat restoration on the 5½ Slip peninsula. Project focuses on the inner peninsula habitat restoration and creation of a connecting channel between the 5½ Slip and the Ashtabula River.
2014	Three BUIs are removed from the Ashtabula River AOC. BUI #1: Restrictions on Fish and Wildlife Consumption BUI #3: Degradation of Fish and Wildlife Populations BUI #14: Loss of Fish and Wildlife Habitat

* This project is the focus of this REA document

While most of the contamination in the River came from historic releases from the nearby Fields Brook Superfund site, this site is not within the AOC boundary (Figure 1-1). Sediment remediation at the Fields Brook Superfund site occurred in 1999-2001. Additional post-remediation efforts have also occurred [12].

Habitat restoration efforts of the River shoreline at the 5½ Slip have been conducted by multiple agencies and programs (Figure 1-2). Through a combination of GLLA, Great Lakes Restoration Initiative (GLRI), and Natural Resource Damage Assessment (NRDA) funding, nearly 11 acres of shallow water and riparian habitat have been restored along the Ashtabula River [13-16]. While there have been multiple remediation and restoration efforts completed in the Ashtabula River AOC, the focus of this document is to assess the impact of the GLLA remediation effort that occurred in 2006 and 2007 in collaboration with nonfederal sponsors.

Below is a description of the key features and river segments of the GLLA project (Figure 1-2). The project area begins at the Upper Turning Basin (River Mile [RM] 1.8) and ends at the 5th Street Bridge (RM 0.6). For purposes of the document, the GLLA project was organized into the following segments:

- Upper Turning Basin (approximate RM 1.8 to 1.6) – The upstream boundary of the project including the confluence of Fields Brook and the Ashtabula River.
- Ashtabula North Slip (Jack's Marine, approximate RM 1.7) – Located southwest of the Upper Turning Basin at the confluence of Strong Brook and the Ashtabula River.
- River Run (approximate RM 1.5 to 1.1) – An approximate 1,300-ft stretch of the Ashtabula River, immediately downstream of the Upper Turning Basin and the confluence of Fields Brook and the Ashtabula River to the Lower Turning Basin.
- ORD Study Area – A subset of River Run where U.S. EPA's Office of Research and Development (ORD) conducted dredge residual and monitoring research studies before, during, and after remediation.
- 5½ Slip (approximate RM 1.1) – An area east of River Run where multiple habitat restoration projects have been conducted, including an 800-ft segment funded through the GLLA.
- Lower Turning Basin (River Bend, approximate RM 1.0 to 0.6) – The area just downstream of the River Run and south of the 5th Street Bridge where the Ashtabula River 'bends' to the west.
- 5th Street Bridge (RM 0.6) – The most downstream point and northern boundary of the GLLA project area.

Additional locations mentioned within this report for discussion purposes, but not within the GLLA project include the following:

- Conneaut Creek – Located approximately 13.5 miles (22 kilometers) east of the Ashtabula River (Figure 1-2). This is the Ohio EPA designated reference site for the Ashtabula River.
- Upstream (RM >1.8) – Area upstream of the GLLA project area, utilized for collection of "background" data to support ORD studies.

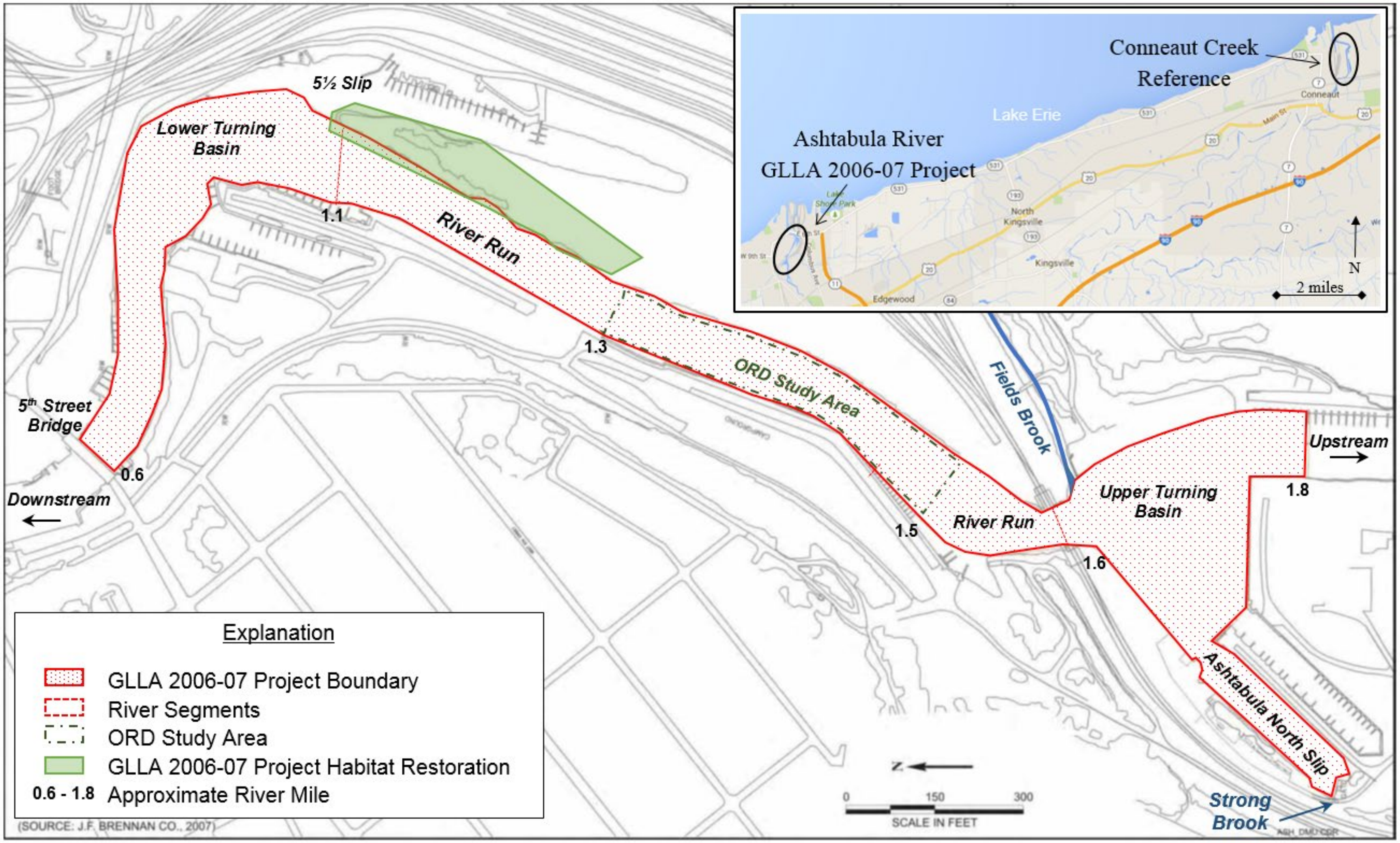


Figure 1-2. GLLA Project Boundary and Associated River Segments.

2 Scope and Data to Perform the Remedy Effectiveness Assessment

2.1 Purpose of a Remedy Effectiveness Assessment

A remedy effectiveness assessment (REA) is a systematic approach to determining changes in environmental conditions following a remedial action. REAs can range from a basic comparison of pre- and post-remediation conditions to larger ecosystem level assessments that can inform additional restoration decisions, such as removing BUIs or the need for further restoration activities. In addition, these formal assessments can inform the greater GLLA remediation program by assessing the performance of various remedial techniques and/or metrics used to gauge the effectiveness of the remedy actions.

Planning a REA is a multi-step process that can be conducted in parallel with the overall remediation project planning process. While the two processes are independent, they each include similar planning steps that can influence the other. As depicted within Figure 2-1, the output of a REA can be used to direct further actions as needed following a remediation effort.

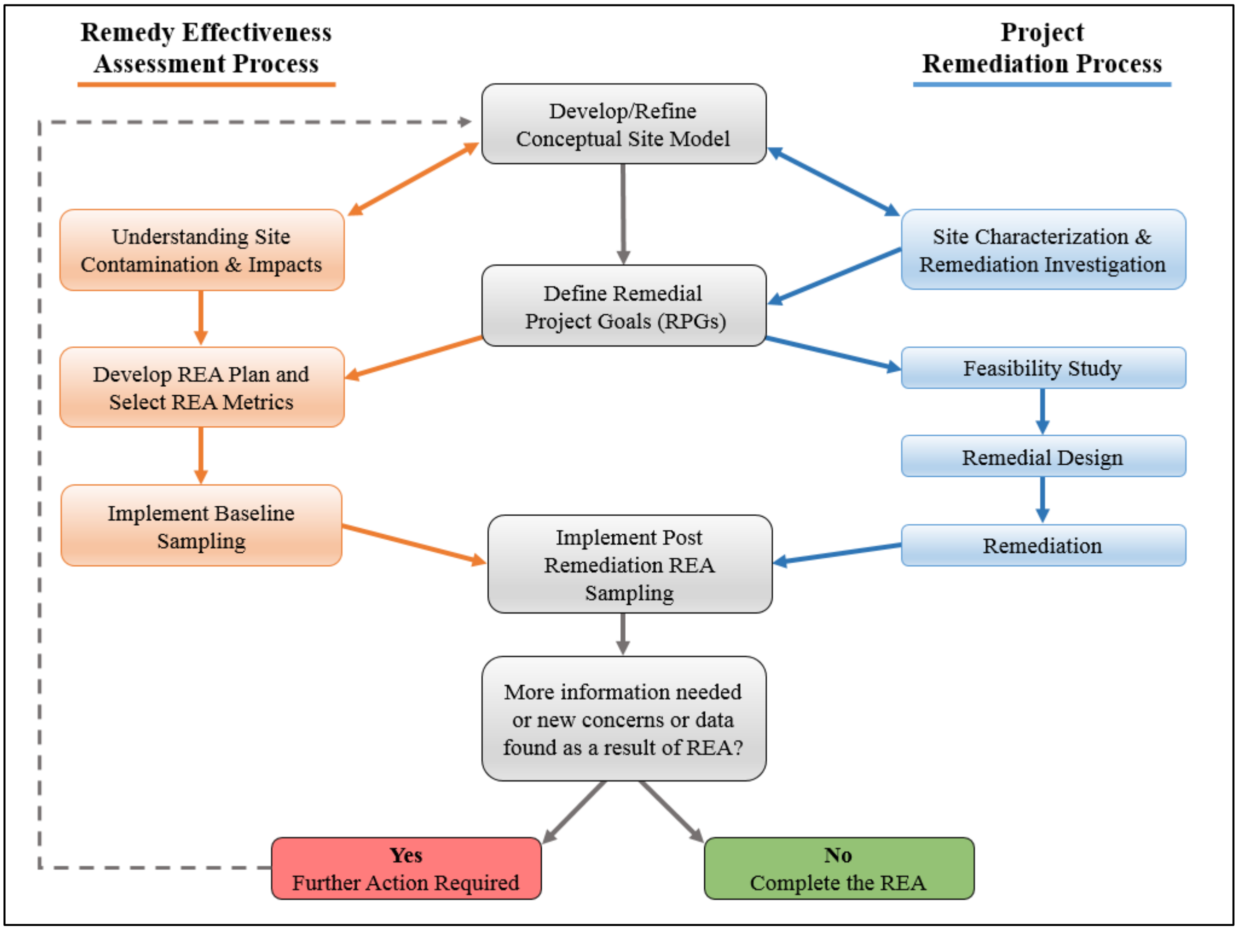


Figure 2-1. Planning Steps for a Remedy Effectiveness Assessment Process and an Associated Project Remediation Process.

Remedial project goals (RPGs) should be formulated with information from a conceptual site model that outlines the inputs and extent of contamination (Figure 2-1). RPGs are then used to select the appropriate metrics and develop the sampling design for collecting the required pre- and post-remediation data. Every remediation action has multifaceted environmental impacts that span physical, biological, and chemical changes. Thus, data collected from all three lines of evidence (LOEs) are needed to determine the range of environmental effects caused by a remediation.

A REA can be used to guide the collection of different forms and types of data that can ultimately be used to ascertain if a remedy was successful at meeting its established RPGs. The REA baseline sampling design should be completed and implemented prior to remedial actions. This ensures that all data collected will be from similar locations using consistent sampling and analytical methods. This consistency provides the basis for robust pre/post statistical analyses of the appropriate metrics to accurately assess changes in environmental conditions following a remedial action.

2.2 Scope and Purpose of this Remedy Effectiveness Assessment

This report describes the environmental changes resulting from the GLLA remediation of the Ashtabula River that occurred between September 2006 and October 2007. The goal of the REA is to provide pre- and post-remedy comparisons using a combination of quantitative and qualitative metrics to assess environmental changes. Environmental impact data along three LOEs (physical, biological, and chemical) are detailed herein. The collective analyses of these changes are used to develop a multifaceted assessment of the remediation effects, and to demonstrate the status of the RPGs. The Ashtabula River GLLA project has been extensively studied and has a robust dataset available for conducting a REA [6, 8, 11, 16-25]. As such, this REA may serve to inform future sediment remediation and management efforts within the GLLA.

2.3 GLLA Objectives and Remedial Project Goals

The GLLA project set out to remove as much contaminant mass as feasible given constructability constraints, restore navigational use of the River, and create a depositional zone for newly deposited sediments to reduce surficial contamination concentrations. These objectives were established with the ultimate goal of eventually removing BUIs that relate to contaminated sediments in the Ashtabula River. However, this REA did not use BUI changes as a metric for success of the implemented GLLA remedy [11, 14]. The status of each of the 14 BUIs at the Ashtabula River AOC is provided in Appendix A.

The design plans for the GLLA project outlined six RPGs during the planning process to assist in tracking progress of the remediation effort [11, 14]:

1. Post remedy surface sediment contaminant concentrations equal to or lower than pre-remedy surficial sediment concentration.
2. Remove PCB-containing sediments greater than the TSCA limit of 50 milligrams per kilogram (mg/kg) and associated scour-risk mass.
3. Remove 82% of the PCB sediment mass within the GLLA project area.

4. Immediately following the dredging activities, achieve a post-dredge surface weighted average concentration (SWAC) of 7.5 mg/kg of PCBs.
5. Achieve long-term SWAC for PCBs of 0.25 mg/kg, and for radionuclides (radium-226, radium- 228, and uranium) of 2 picoCuries/gram (pCi/g) or average background.
6. Reestablish 800 ft of in-water littoral shoreline habitat along the eastern bank of River Run running south from 5½ Slip.

2.4 Data for this Remedy Effectiveness Assessment

The primary pre-dredge sediment characterization survey of the GLLA project area was collected between June and August 2006 by U.S. EPA's Great Lakes National Program Office (GLNPO) [26]. Additionally, GLNPO worked with U.S. EPA ORD to jointly initiate a comprehensive project to develop and evaluate methods and metrics for assessing remedy effectiveness, and to monitor progress on the Ashtabula River GLLA project site using those approaches. The joint effort included the collection and analysis of surface sediments, sediment cores, macroinvertebrates, and indigenous fish. Data from these studies were collected annually from 2006 to 2011 to provide data before, during, immediately after, and for multiple years following GLLA activities. This ORD effort included an intensive sampling for a portion of the remedial project area (ORD Study Area) [26]. Those data that were directly relevant to interpretation of the project goals and the REA are reported herein. They focus on the observed changes in sediment concentrations between 2006 (pre-remediation) and 2011 (post-remediation). Additional agencies and programs participated in the post-remediation (2011) sampling efforts at the AOC (within and beyond the GLLA project area). These include: National Oceanic and Atmospheric Administration (NOAA), Ohio EPA, USACE, U.S. Fish and Wildlife Service (USFWS), and U.S. Geological Survey (USGS).

Data utilized for the REA were generated via numerous efforts by multiple entities, and for most of the available datasets the original purpose was not to assess remedy effectiveness, but rather to answer specific scientific questions of interest to the particular organization. Some datasets were collected more broadly within the AOC, but only data points collected from within the GLLA project area were used for this REA.

Datasets with corresponding pre- and post-remediation time points that were relevant to the GLLA sediment remediation project and REA are discussed in detail here. Additional, non-paired data will also be included where relevant. Each of the available datasets were sorted by LOE (physical, biological, or chemical) then paired into pre- and post-remediation timeframes (Table 2-1). Quantitative, statistical analyses were conducted between the pre- and post-remediation datasets where possible. Some datasets had insufficient power to allow statistical analysis; for these datasets, a qualitative comparison of changes observed pre- and post-remediation are presented within this REA. A full list of the available data collected at the Ashtabula River AOC, arranged by LOE, can be found within Appendix B.

Table 2-1. Summary of Applicable REA Data by Line of Evidence and Contributing Agency

		Agency					
Data Type		Ohio EPA	NOAA	USGS	GLNPO	ORD	**Reference(s)**
Physical Line of Evidence							
Bathymetry	Pre-				√		[23]
	Post-				√		[27]
Qualitative Habitat Evaluation Index (QHEI)	Pre-	√					[4]
	Post-	√					[20]
Biological Line of Evidence							
Invertebrate Community Index (ICI)	Pre-	√					[20]
	Post-	√					
Macroinvertebrate Tissue Analysis	Pre-				√		[28]
	Post-					√	[19, 26]
Amphipod Survival	Pre-			√	√		[25, 28]
	Post-		√				[29]
Riparian Spiders	Post-			√		√	[30]
Index of Biotic Integrity (IBI)	Pre-	√					[20]
	Post-	√					
Modified Index of Well-being (MIwb)	Pre-	√					[20]
	Post-	√					
Sport Fish Fillet Total PCBs	Pre-	√					[8, 20]
	Post-	√					
Brown Bullhead Whole Fish Total PCBs	Pre-				√	√	[19, 23]
	Post-					√	[31, 32]
Caged Channel Catfish Total PCBs	Pre-				√		[28]
Brown Bullhead Internal/External Fish Histopathology	Pre-			√			[17]
	Post-			√		√	[19, 33]
Brown Bullhead Blood and Liver DNA Damage	Pre-					√	[19]
	Post-					√	
Chemical Line of Evidence							
PCB Surface Weighted Average Concentrations (SWAC)	Pre-				√		[3, 28]
	Post-				√	√	[11, 27, 34]
Sediment PCB Mass	Pre-					√	[24, 26]
	Post-					√	
Radionuclides (Radium, Thorium, Uranium)	Pre-				√		[28]
	Post-				√	√	[34, 35]

2.5 Implementation of Multiple Lines of Evidence within a REA

Remedial actions will have multifaceted environmental impacts that span physical, biological, and chemical conditions. Therefore, data collected from all three LOEs are needed to characterize the full extent of environmental effects of the remediation. Changes in physical characteristics (e.g., river depth [bathymetry], sediment composition) are useful for demonstrating volume removal goals, assessing changes in habitat, and estimating sediment deposition and erosion. Changes in biological characteristics (e.g., contaminant concentrations within tissues, fish histopathology) and biological indices measuring key populations of biota (e.g., fish, macroinvertebrates) provide measures of the bioavailability/bioaccumulation of assessed COCs, demonstrate the quality and quantity of species present, and provide data regarding the project goals and objectives related to habitat restoration. Biologically focused cleanup goals, such as consumption advisories, utilize specific species of fish to serve as indicators of contamination to the food web via sediments and porewater. Chemical analyses of environmental samples (surface sediment, water, etc.) can quantify changes in contaminant concentrations, and indicate whether project cleanup goals, such as SWAC and mass removal, were met. Collectively, physical, biological, and chemical data sources can reflect the broad range of environmental impacts resulting from remedial actions.

3 Remedy Effectiveness Assessment - Physical Line of Evidence

Remediation of contaminated sediments often results in large-scale physical changes to the sediment, hydrodynamics, and geomorphology of the system. These changes impact the overall water depth (bathymetry), water flow, and sediment composition. Changes in bathymetry can be used to estimate changes in sediment volume (volume of remediated sediments) and corresponding contaminant mass within the sediments.

These resulting physical changes also impact the natural flora and fauna in a project area. The GLLA remediation project dredged the Ashtabula River from the Upper Turning Basin to the 5th Street Bridge and the Ashtabula North Slip, deepening the Ashtabula River channel. Bathymetric measurements of the water depth were key parameters for ensuring that specific dredge cut lines were met in addition to assessing two of the RPGs: remove 82% of PCB mass within the project area and establish in-water littoral shoreline habitat.

The primary physical measurement taken at most dredge remediation sites is bathymetry, and the change in bathymetry before and after dredging is a primary physical indicator used to inform a REA. In addition, the Qualitative Habitat Evaluation Index (QHEI) score is another tool to help assess physical changes in an ecosystem. The QHEI is an Ohio EPA metric for evaluating the habitat of streams and rivers, and their ability to support diverse aquatic communities. QHEI is also the primary metric used to inform the removal of BUI #14 Loss of Fish and Wildlife Habitat. Bathymetry and QHEI are used together herein to evaluate the physical changes in the GLLA project area.

3.1 Bathymetry and Remediated Sediment Volume

Bathymetry measurements were collected just prior to the start of the GLLA project (2006), after dredging was completed (2007), and in the years following its completion (2009, 2011). The 2006, 2007 and 2009 surveys were conducted in collaboration between ORD and GLNPO to support dredging operations, and for longer-term studies being conducted. Comparisons of the 2007 and 2009 post-dredge bathymetry results were reported previously [32]. The 2011 bathymetric survey of the project area was conducted by USACE. This REA focuses on the physical removal of sediment during the GLLA 2006-2007 project using bathymetry surveys that were conducted prior to dredging in 2006 and after dredging operations were complete in 2007, as described below.

3.1.1 Pre-Remediation - Bathymetry

From April 24 through May 5, 2006, a bathymetric and geophysical survey of the GLLA project area was conducted to determine water depth and sediment elevations (Figure 3-1) [14, 23]. This survey calculated an average sediment thickness of 16.2 ft and a total sediment volume of 3,178,428 yd^3 within the GLLA project area [23].

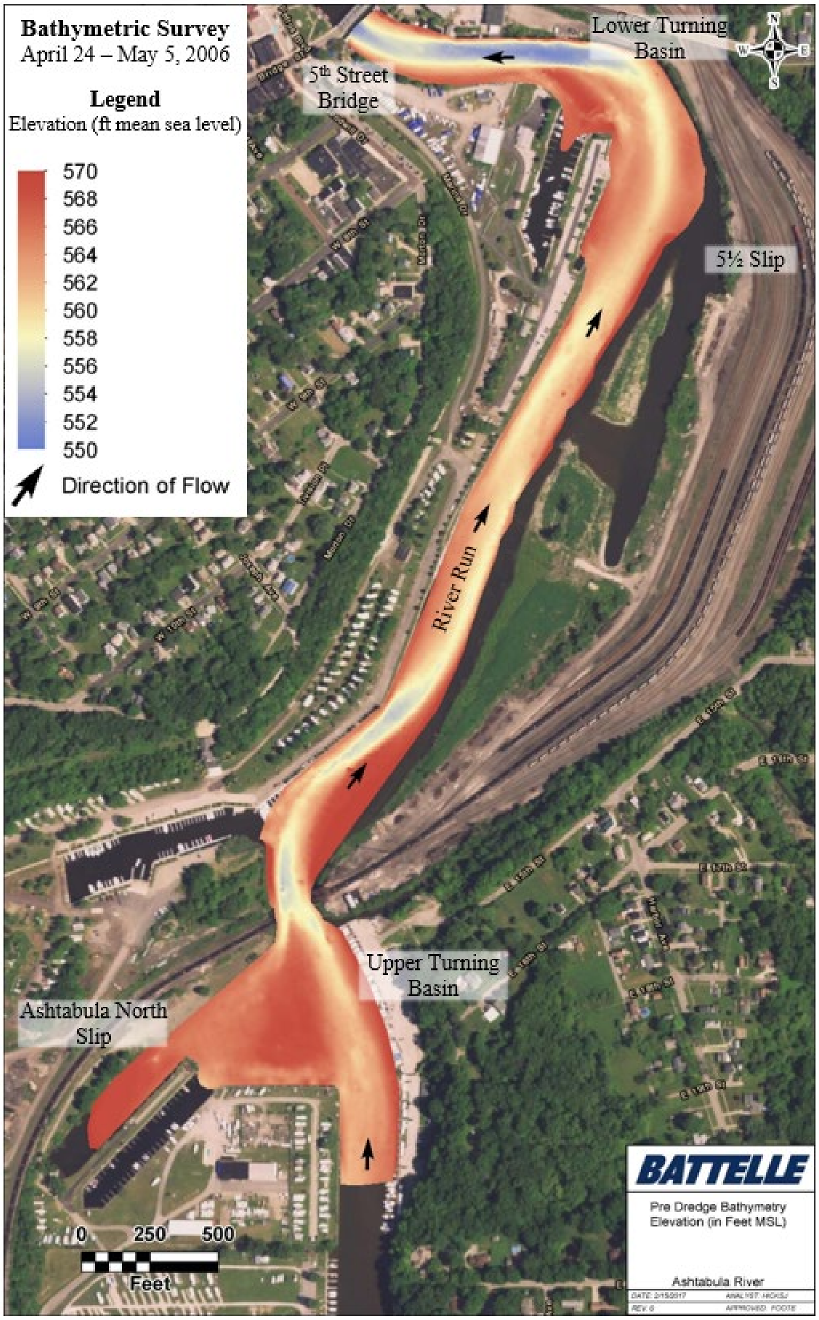


Figure 3-1. 2006 Pre-Remediation Bathymetric Contours of the GLLA Project Area. Sources: U.S. EPA [14], U.S. EPA [23]

3.1.2 Post-Remediation - Bathymetry

Bathymetry measurements were collected immediately post-dredging in 2007. These results were compared to pre-dredge data obtained in 2006 to estimate the total volume of sediment removed from the GLLA project area. Figure 3-2 shows the November 2007 post-dredge bathymetric contours of the GLLA project area.

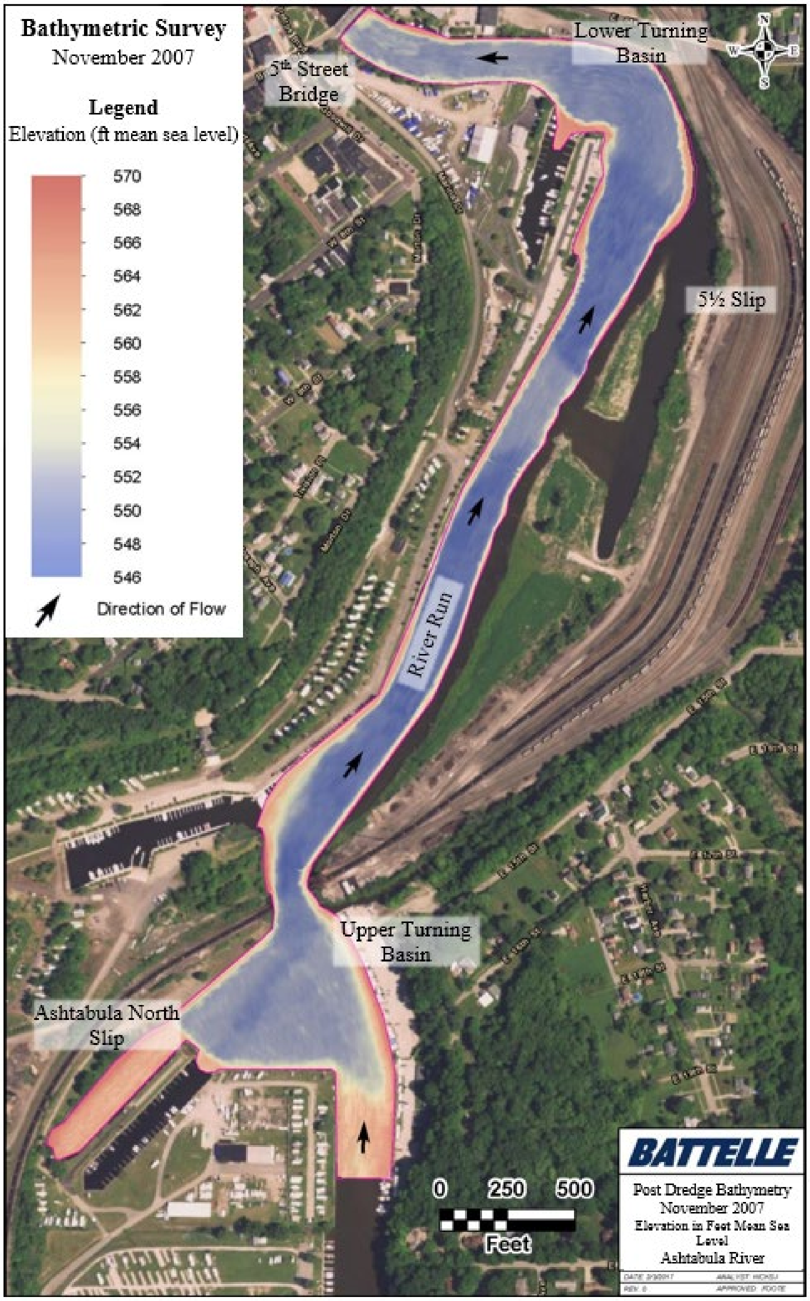


Figure 3-2. Post-Remediation Bathymetric Contours of the GLLA Project Area. Source: U.S. EPA [11]

3.1.3 Changes in Bathymetry over Time

Pre- and post-dredge surveys conducted in 2006 (Figure 3-1) and 2007 (Figure 3-2), respectively, were used to estimate the volume of sediment removed during dredging. Sediment dredged from the project area ranged in thickness from 1 ft to greater than 20 ft in some areas, depending upon the initial riverbed elevations [11]. Figure 3-3A shows the change in elevation feet between 2007 and 2006, indicating the change in sediment thickness. Approximately 62,000 yd^3 of sediment were removed from the Upper Turning Basin in 2006, and an additional 435,383

yd^3 of sediment were removed downstream in 2007, for a total dredge volume of 497,383 yd^3 of sediment [11].

Sediment removal resulted in the average water depth within the project area to increase to approximately 16 ft from the average pre-remedy water depth of approximately 8 ft, increasing the boat draft available for recreational and commercial vessels. Volumetrically, over 90% of the originally estimated 545,000 yd^3 of contaminated sediments that were anticipated to be present between the Upper Turning Basin and the 5th Street Bridge were removed during the GLLA project [13, 14].

Over time, cleaner sediments have been transported from upstream and redeposited within the project area. Figure 3-3B shows the change between post-dredge activities in 2007 versus bathymetry measurements approximately 4 years later in 2011. Significant redeposition of sediments is noted in areas of the Ashtabula River. Prior to dredging, limited data estimated an annual sediment deposition rate of approximately 1.5 inches (in.) within the ORD Study Area [27]. Bathymetric measurements obtained in 2007 (following dredging) indicate that much of the area is depositional, and the rate of sediment deposition has been greater than 1.5 in. per year in some areas of the River. This increase is possibly due to changes in hydrology and sediment resettling following the dredging work [27].

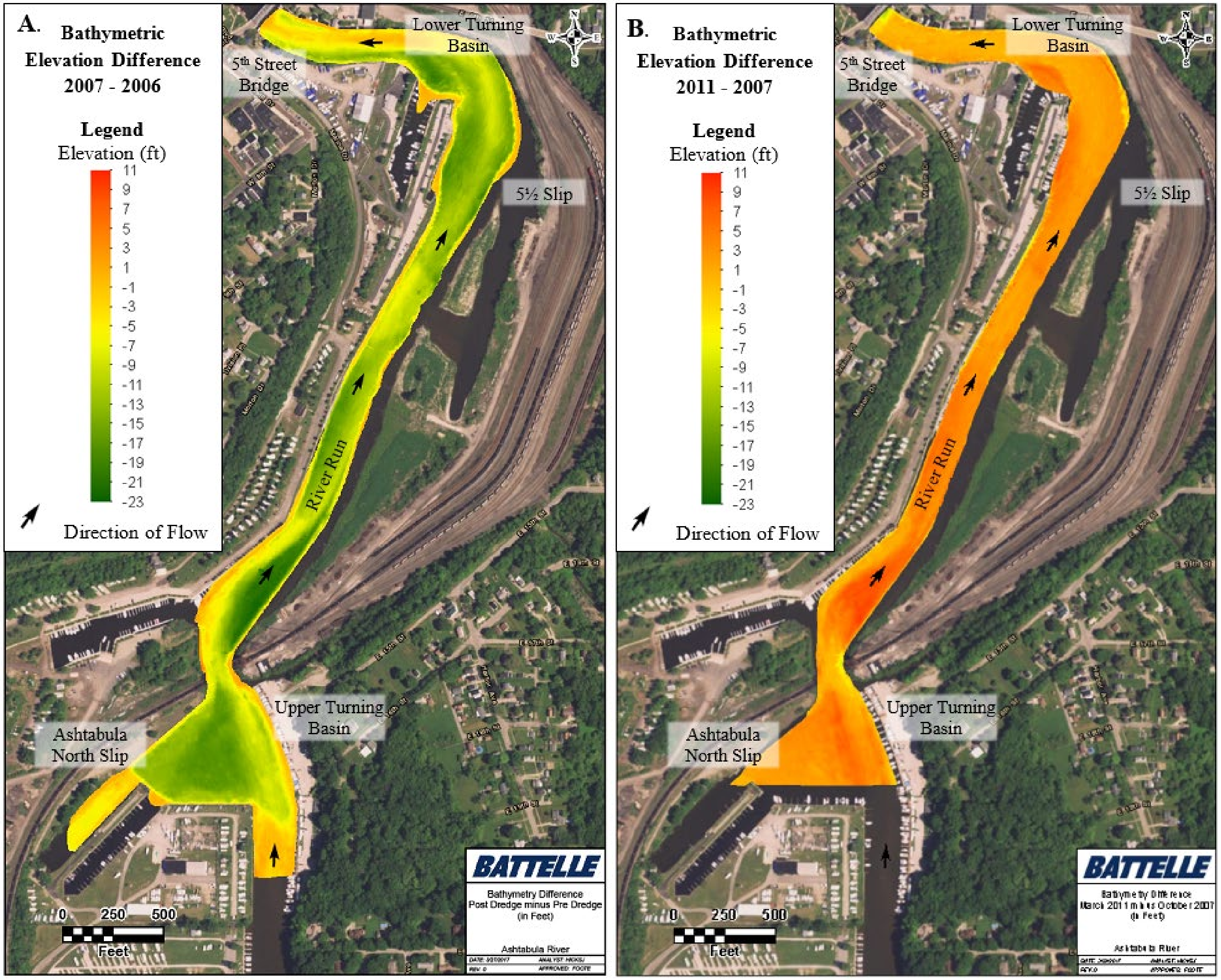


Figure 3-3. Post-Dredge Bathymetric Difference Maps Comparing A. 2007 to 2006 and B. 2011 to 2007. Sources: U.S. EPA [23], U.S. EPA [27]

3.2 Qualitative Habitat Evaluation Index (QHEI)

The QHEI is a method developed by Ohio EPA for use in streams and rivers in Ohio to quantitatively assess physical habitat. The index monitors attributes of a river that contribute to establishing viable, diverse aquatic communities. These attributes include type and quality of substrate, amount of in-stream cover, channel morphology, extent of riparian canopy, pool and riffle development and quality, and stream gradient. These metrics are used by Ohio EPA to generate a QHEI score for a stream segment [4]. The higher the score, the better the habitat quality for aquatic populations. A QHEI score of 55 or greater is the Ohio EPA target value for lacustuary river segments, such as the GLLA project area of the Ashtabula River [36].

3.2.1 Pre-Remediation - QHEI

In the years preceding the GLLA project (1989-2005), Ohio EPA regularly assessed the physical habitat of two locations (River Run and 5½ Slip, Figure 3-4) using the QHEI [4]. In 2005, physical habitat conditions were comparable between the two sampled sites. Together these data averaged a QHEI score of 42.5 (Table 3-1). Sand, muck, and silt dominated the bottom substrate, while lesser amounts of hardpan, boulders, and detritus were found. Average amounts of aquatic vegetation of waterweed, wild celery, Eurasian milfoil, and cattails were found at both sites [4].

3.2.2 Post-Remediation - QHEI

In 2011, Ohio EPA assessed the physical habitat of seven locations (Table 3-1) [20]. The average QHEI score obtained in 2011 was 50.5, less than the Ohio EPA lacustuary QHEI target value of 55. However, the 2011 assessment was conducted shortly after the construction of a GLRI-funded fish habitat shelf near RM 1.25. The temporary disturbances caused by the construction negatively impacted much of this area, resulting in a score of 33 at RM 1.25 (Figure 3-4; Table 3-1). Therefore, Ohio EPA surveyed that particular location within River Run again in 2013 to attain a post-construction QHEI value [20]. The reassessed average QHEI score for the GLLA project area for 2011 (which incorporates the new 2013 value at RM 1.25) resulted in an average QHEI index of 56.6 for the GLLA project area, surpassing the Ohio EPA lacustuary QHEI target value.

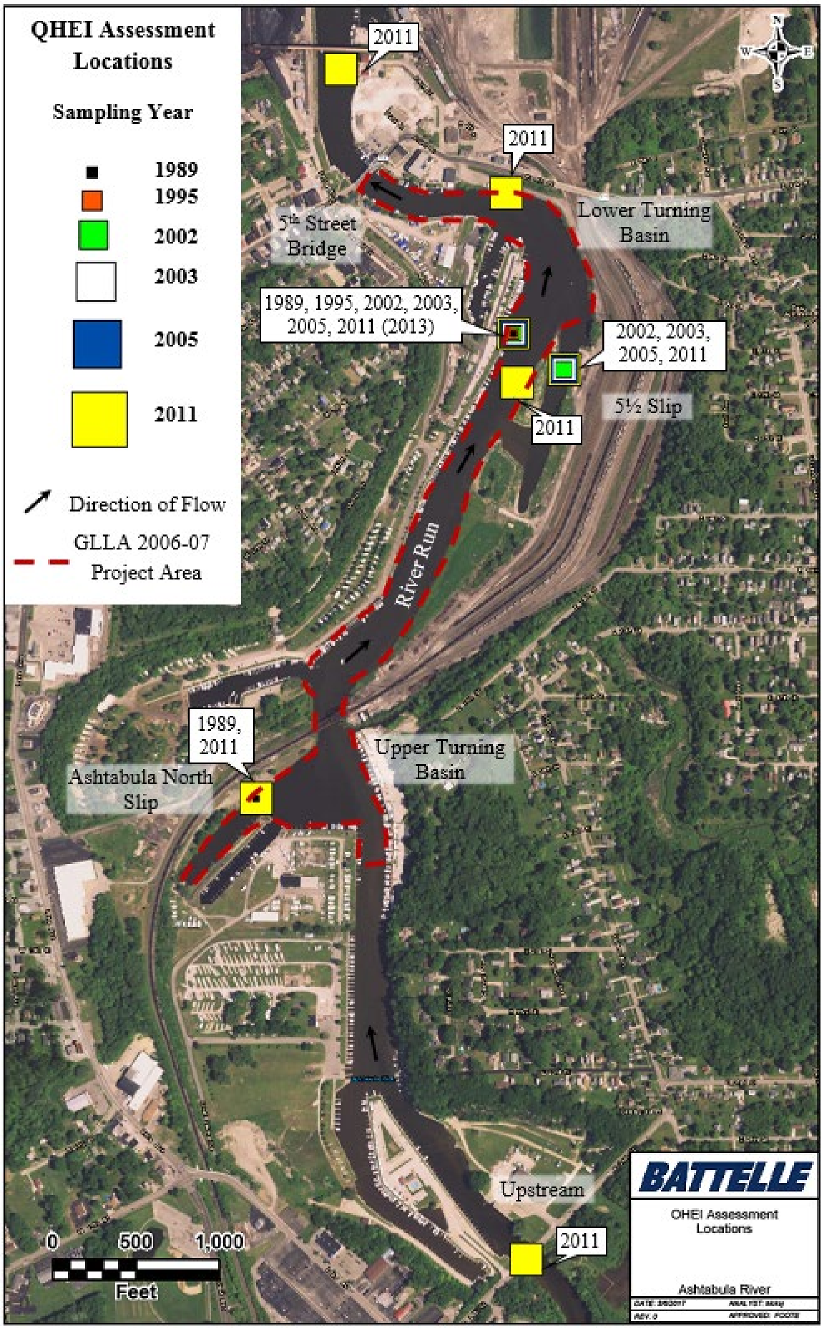


Figure 3-4. Ohio EPA QHEI Assessment Locations Map. Source: Ohio EPA [20]

3.2.3 Restoration Activities

Following the completion of dredging efforts, under the GLLA, habitat restoration was conducted at the northern tip of 5½ Slip. From November 2009 through June 2010, habitat restoration efforts focused on an 800-ft stretch of the eastern bank of the Ashtabula River extending from 5½ Slip south along River Run (Figure 3-5A). The project included work to mitigate any disruption caused from the dredging activities, and to re-establish in-water littoral shoreline habitat within the project area. Other project activities included: 1) excavation of a shelf, 2) riprap placement along the water/land interface slope, 3) placement of rock piles and tree revetments, 4) live stakes along the upland shoreline, and 5) planting native vegetation cover within the created shelf (Figure 3-5B) [11, 37].

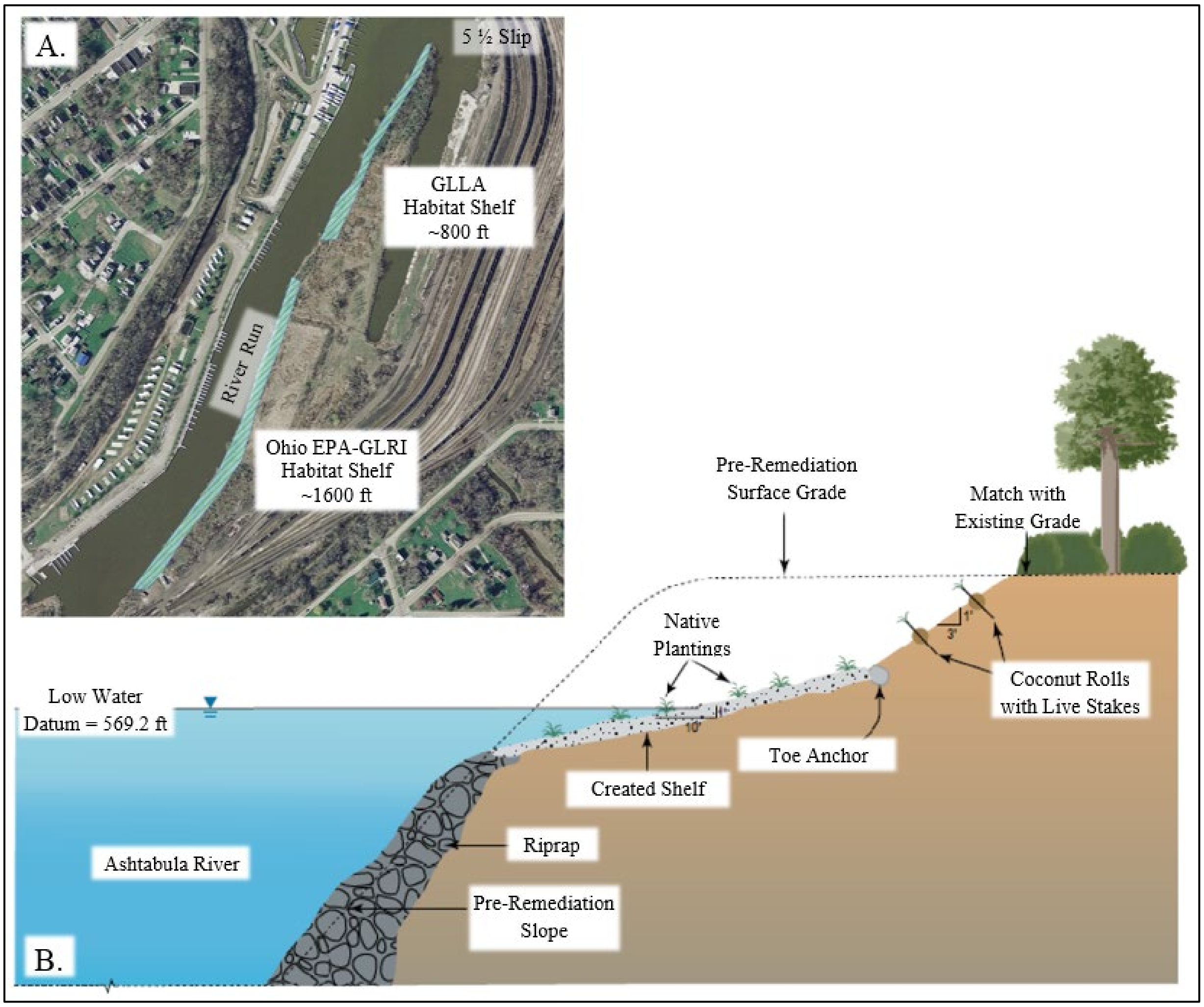


Figure 3-5. A) Location of GLLA and Ohio EPA-GLRI Fish Shelves. B) GLLA Habitat Restoration Diagram. Sources: U.S. EPA [11], U.S. EPA [27], U.S. EPA [37]

3.2.4 Changes in QHEI over Time

The QHEI score within the GLLA project area increased from 42.5 in 2005 to 56.6 by 2013 [20]. As shown through the QHEI scores, removal of the contaminated sediments and habitat restoration efforts since initiating the GLLA project has allowed for the natural river fauna and flora to recover and surpass Ohio EPA's lacustuary QHEI minimum target value (Table 3-1; Figure 3-6).

Table 3-1. Pre- and Post- GLLA QHEI Survey Data

Approximate River Mile	*River Segment*	*1989*	*1995*	*2002*	*2003*	*2005*	*2011 (2013)*
0.6	5th Street Bridge						45
0.9	Lower Turning Basin						67
1.1	5½ Slip			39	44	41	54.5
1.2	River Run						65
1.25	River Run	41.5	43	38.5	44.5	44	33[b] (69.5)
1.8	Upper Turning Basin	55					38.5
2.0	Upper Turning Basin		54.5				
2.32	*Upstream [a]*						*53*
GLLA Project Average		48.3	43.0	38.8	44.3	42.5	50.5 (56.6)
Ohio EPA Lacustuary Target					55		

[a] The Upstream sampling location was not part of the GLLA project, but is shown as a reference value for comparison purposes. [b] The 2011 QHEI assessment in River Run at River Mile 1.25 was obtained shortly after the construction of a GLRI fish habitat shelf. The temporary disturbances caused by the construction negatively impacted much of this area; therefore, the area was reassessed in 2013 to attain a post-construction QHEI value. Values given in red do not meet the Ohio EPA Lacustuary Target, values in green meet or exceed the target. Sources: Ohio EPA [4], Ohio EPA [20]

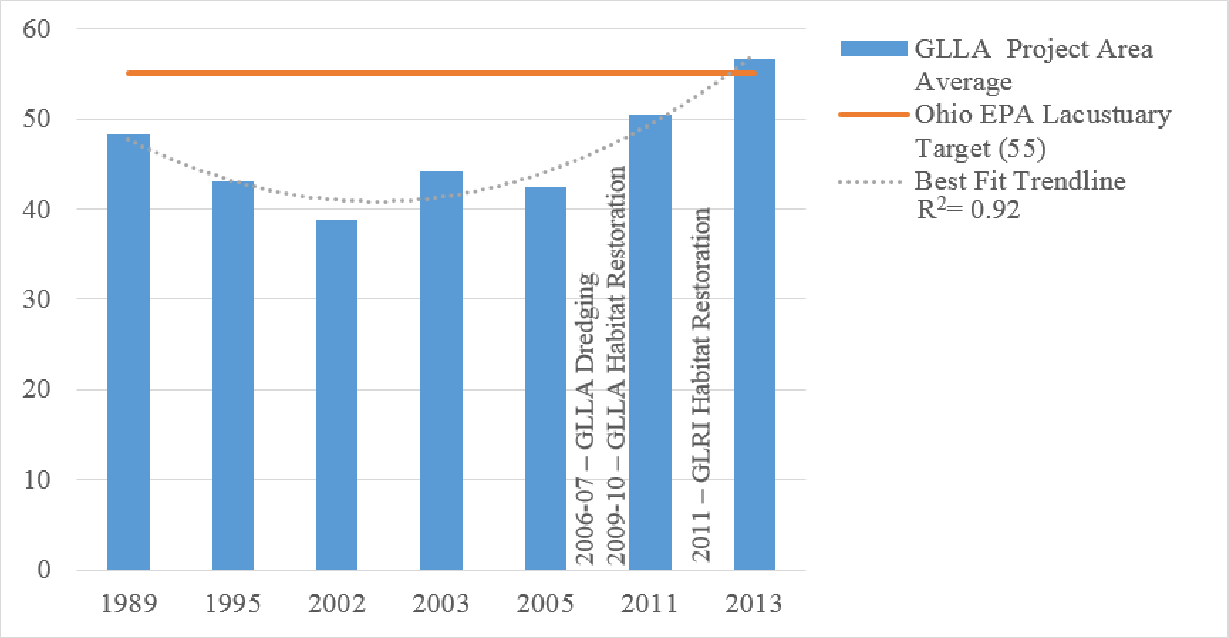


Figure 3-6. Average QHEI Scores for the GLLA Project Area. Source: Ohio EPA [20]

3.3 Discussion of the Physical LOE and Changes Pre- and Post-Remediation

The physical changes to the project area as a result of dredging and restoration are considerable. Bathymetric comparisons of pre- and post-remedy surveys result in removal of 497,383 yd^3 of the originally estimated 545,000 yd^3 of contaminated sediment in the project area. This equates to a 91% removal by volume of sediment and the associated contaminants between the Upper Turning Basin and the 5th Street Bridge [13]. Removing contaminated sediments yielded a deeper, more navigable River.

QHEI surveys of the habitat within the project area show that the removal of sediments and subsequent habitat restoration efforts helped reestablish in-water littoral shoreline. By 2013, the average QHEI value surpassed the Ohio EPA lacustuary target value, indicating an improvement to the aquatic habitat within the GLLA project area [20].

Key Physical Outcomes:

- 497,383 yd^3 of sediments were removed from the project area.
- Removing sediments yielded a deeper River.
- QHEI values increased, indicating improvement of aquatic habitat.

4 Remedy Effectiveness Assessment - Biological Line of Evidence

Data collected along the biological LOE help demonstrate the biological community response to a remedial action, and help inform biologically focused clean-up goals. Contaminants, such as PCBs, in sediments can bioaccumulate in tissues; therefore, the fate and transport of contaminants within the food chain can have significant impacts on the well-being of an ecological community, and be reflected within biological metrics.

Within the project area, multiple biological assays for several organisms have been conducted. Contaminant concentrations within sport fish fillets are the key input parameter for removing BUI #1: Restrictions of Fish and Wildlife Consumption and to inform whether cleanup goals designed to reduce fish tissue contaminant concentrations were met. Fish are analyzed for bioaccumulative contaminants that could pose a threat to human health if consumed in excessive amounts [8].

Bottom-feeding fish, such as the brown bullhead catfish (*Ameiurus nebulosus*), are monitored through a variety of tools (PCB concentrations in whole fish, tumor and anomaly incidence, and DNA damage within tissues) because they can bioaccumulate COCs through dermal exposure and/or ingestion of benthic organisms [19]. Tissue analysis of sediment dwelling macroinvertebrates are indicative of short-term changes, such as those that may occur during or immediately following a remedy action, as these organisms can have relatively short life spans (e.g., some species live 30 to 90 days) when compared to fish species and other higher trophic-level organisms [19]. Riparian spiders were collected post-remediation only and characterize residual contaminant bioavailability. These spiders feed predominately on emergent aquatic insects from within a small geographic area, and as such, PCB residues detected in these species can be effective tools to characterize contaminant bioavailability in localized areas [30].

In addition, biological surveys or metrics that measure the presence, condition, and population distributions of specific types of fish, insects, algae, plants, and aquatic life are used to assess the overall health of the community and quality of the associated habitat in the GLLA project area.

The biological metrics used to assess ecosystem health were: the Invertebrate Community Index (ICI), the Index of Biotic Integrity (IBI), and the Modified Index of well-being (MIwb). Together they can also be used to indicate the status of several BUIs including, BUI #3: Degradation of Fish and Wildlife Populations, BUI #4: Fish Tumors and Other Deformities, and BUI #6: Degradation of Benthos.

4.1 Fish Analyses

4.1.1 Index of Biotic Integrity and Modified Index of Well-Being

Two biological metrics are used by Ohio EPA to evaluate the health of the fish community within a river [36]. The IBI and MIwb reflect the total native fish species composition, indicator species composition, pollutant intolerant and tolerant species composition, and overall fish health [36, 38]. For both measures, the higher the index value, the healthier the fish community. IBI takes into account the abundance and diversity of fish species, whereas the MIwb is a calculation of fish community abundance and diversity with specific pollutant tolerant species of fish factored out to prevent false high readings for polluted streams with large pollutant-tolerant fish populations [36]. The IBI and MIwb can be used to indicate ecological change over time as they use biological information of the current conditions of resident populations.

Ohio EPA has suggested a minimum target IBI score of 38, and a minimum target MIwb score of 8.2 for lacustuary river segments, such as the Ashtabula River GLLA project area [36]. Meeting both minimum targets is critical to removing BUI #3: Degradation of Fish and Wildlife Populations.

4.1.1.1 Pre-Remediation – IBI and MIwb

The fish populations in the Ashtabula River have been monitored by Ohio EPA for many years [20]. Two locations within the project area (RM 1.1 and 1.25) were repeatedly monitored before the GLLA project (Table 4-1 and Table 4-2). Though the average IBI and MIwb values show declines in select years (2005 for IBI and 2004 for MIwb), the overall trend was a gradual increase in both metrics prior to initiating the GLLA remedial dredging. Between 1989 and 2005, the average IBI measured within the project area ranged from 31.6 to 42.0, while the MIwb ranged from 5.53 to 8.76.

4.1.1.2 Post-Remediation – IBI and MIwb

Additional surveys were completed by Ohio EPA to ascertain the IBI and MIwb values within the project area in 2009 and 2011, following GLLA dredging and habitat restoration efforts [20]. In general, both the IBI and MIwb values increased following the GLLA remediation work, although the trend was not consistent. The IBI increased from 36.8 to 45 between 2005 and 2009 before decreasing to 42.7 in 2011 (Figure 4-1A). Similarly, the MIwb initially decreased from 8.76 to 8.55 following the GLLA dredging (2009) before increasing again in 2011 to 9.21 (well beyond the minimum Ohio EPA lacustuary target of 8.2 [Figure 4-1B]). By 2011, both metrics surpassed the Ohio EPA lacustuary target value.

4.1.1.3 Changes in IBI and MIwb Metrics over Time

IBI and MIwb measurements have been collected within the project area since 1989. However, note that in 2011, six areas of the project area were assessed and averaged for IBI and MIwb, whereas between the years 1989 and 2009, only two locations within the project area were observed. The additional data collected in 2011 resulted in a more robust dataset compared to previous years and strengthened the overall average. Even when only matching RMs are compared, the average IBI and MIwb values are still above the Ohio EPA minimum lacustuary targets (i.e., the 2011 average of RM 1.1 and 1.25 yields an IBI of 41.4 and a MIwb of 8.84) (Figure 4-1). As such, in 2014 BUI #3: Degradation of Fish and Wildlife Populations was removed from the Ashtabula River AOC [20].

Table 4-1. Pre- and Post-Remediation IBI Values (1989-2011)

Approximate River Mile	*River Segment*	*Pre-Remediation*					*Post-Remediation*	
		1989	*1998*	*2003*	*2004*	*2005*	*2009*	*2011*
0.6	5th Street Bridge	27						42
0.9	Lower Turning Basin							40
1.1	5½ Slip		32.5	44	40	37.5	44	37
1.2	River Run							46
1.25	River Run	31.4	33.5	34.5	44	36	46	45.8
1.6	Upper Turning Basin							45.5
1.8	Upper Turning Basin	36.4						
2.3	*Upstream* [a]		44					44
GLLA Project Area Average		31.6	33.0	39.3	42.0	36.8	45.0	42.7
Ohio EPA Lacustuary Target		38						

[a] The Upstream sampled location was not part of the GLLA project, but is shown as a reference value for comparison purposes. Values given in red do not meet the Ohio EPA Lacustuary Target, values in green meet or exceed the target. Source: Ohio EPA [20].

Table 4-2. Pre- and Post- Remediation MIwb Values (1989-2011)

Approximate River Mile	*River Segment*	*Pre-Remediation*					*Post-Remediation*	
		1989	*1998*	*2003*	*2004*	*2005*	*2009*	*2011*
0.6	5th Street Bridge	2.59						9.3
0.9	Lower Turning Basin							9.35
1.1	5½ Slip		8.19	8.49	7.85	8.86	8.72	8.71
1.2	River Run							9.92
1.25	River Run	6.02	7.47	8.16	7.59	8.65	8.37	8.96
1.6	Upper Turning Basin							9.01
1.8	Upper Turning Basin	7.97						
2.3	*Upstream* [a]		9.27					9.01
GLLA Project Area Average		5.53	7.83	8.33	7.72	8.76	8.55	9.21
Ohio EPA Lacustuary Target		8.2						

[a] The Upstream sampled location was not part of the GLLA project, but is shown as a reference value for comparison purposes. Values given in red do not meet the Ohio EPA Lacustuary Target, values in green meet or exceed the target. Source: Ohio EPA [20].

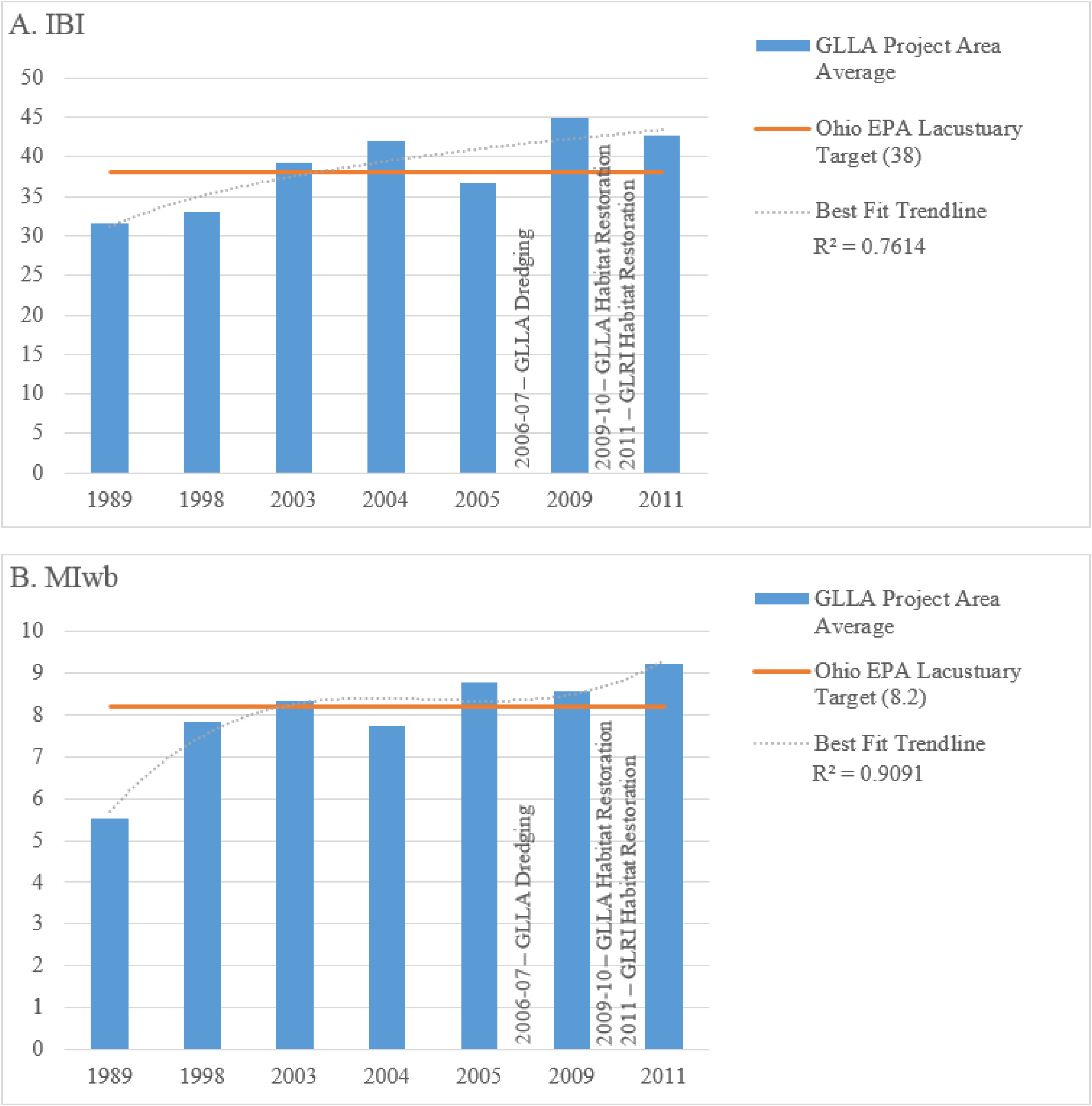


Figure 4-1. Biological Assessment Metrics for the Ashtabula River GLLA Project Area (1989 – 2011). A) IBI and B) MIwb. Source: Ohio EPA [20]

4.1.2 Contaminant Concentrations in Sport Fish Fillets

Ohio EPA regularly collects fish fillet samples for PCB monitoring under Ohio's Sport Fish Tissue Monitoring Program [20]. The monitoring program ranks PCB concentrations of consumed fish species into five levels of recommended consumption frequency for the protection of human health (Table 4-3). Depending upon the average PCB concentration within each sampled species, different fish species may be issued separate recommended consumption rates.

Table 4-3. Ohio Fish Consumption Advisory Chemicals: Fillet Chemical Upper Bound Limit Concentrations (mg/kg) and Advised Meal Consumption Rate.

PCBs (mg/kg)	*Recommended Consumption Rate*
<0.050	Unrestricted
0.050 - 0.220	1 / week
0.220 - 1.000	1 / month
1.000 - 1.999	1 / 2 month
>1.999	Do Not Eat

Source: Ohio EPA [20]

4.1.2.1 Pre-Remediation Sport Fish Tissue PCB Concentrations

Sport fish caught within the Ashtabula River have historically carried a consumption advisory due to high levels of PCBs (Table 4-4). As a proactive measure for protecting human health during the GLLA project dredging activities, a “Do Not Eat Any Fish” advisory for sport fish was issued in 2007 by the Ohio Department of Health, Ohio Department of Natural Resources (Ohio DNR), and Ohio EPA [20].

Table 4-4. Summary of Ashtabula River AOC Fish Consumption Advisories (1983 - Present).

Year(s)	*Species*	*Contaminant(s)*	*Advisory Frequency*
1983 - 1997	All	PCBs, Hexachlorobenzene, Pentachlorobenzene, Tetrachloroethane	Do Not Eat Any Fish
1998 – 2003	Smallmouth Bass	PCBs	1 Meal / Week
	Largemouth Bass, Walleye	Mercury, PCBs	1 Meal / Month
	Channel Catfish, Common Carp	PCBs	1Meal / 2 Months
2004 – 2007	Channel Catfish, Common Carp	PCBs	1 Meal / 2 Months
	Brown Bullhead, Yellow Bullhead	PCBs	1 Meal / Month
	Largemouth Bass, Walleye	Mercury, PCBs	1 Meal / Month
2007 – 2013	All	PCBs	Do Not Eat Any Fish
2013	Common Carp, Freshwater Drum		1 meal / Month

Source: Ohio EPA [20]

4.1.2.2 Post-Remediation Sport Fish Tissue PCB Concentrations

In 2011, PCB concentrations in smallmouth bass, common carp, and freshwater drum fillets collected by the State of Ohio’s Sport Fish Tissue Monitoring Program within the AOC boundary averaged 0.11 mg/kg, 0.64 mg/kg, and 0.37 mg/kg, respectively (Table 4-5) [8, 20].

Table 4-5. 2011 Total PCB Aroclor Concentrations (mg/kg) in Ashtabula River Fish Tissue Samples.

Species	*Number of Fish in Skin Off Fish Filet Composite*	*Approximate River Mile*	*Location*	*PCB Aroclor 1254 (mg/kg)*	*PCB Aroclor 1260 (mg/kg)*	*Total PCB Aroclors (mg/kg)*
			Ashtabula River AOC Fish			
Largemouth Bass	3	1.3	Fields Brook Area	<0.050	<0.050	-
	4	1.3	Fields Brook Area	<0.050	<0.050	-
	3	0.5	Near 5th St. Bridge	<0.050	<0.050	-
	3	0.5	Near 5th St. Bridge	<0.050	<0.050	-
				Mean Value		**-**
Smallmouth Bass	2	1.3	Fields Brook Area	0.074	0.119	0.193
	2	1.3	Fields Brook Area	<0.050	<0.050	0.050
	2	0.5	Near 5th St. Bridge	<0.050	0.054	0.079
				Mean Value		**0.107**
Common Carp	3	1.3	Fields Brook Area	0.112	0.270	0.382
	4	0.5	Near 5th St. Bridge	0.091	0.812	0.903
				Mean Value		**0.642**
Freshwater Drum	2	1.3	Fields Brook Area	0.055	0.254	0.309
	2	0.5	Near 5th St. Bridge	0.137	0.288	0.425
				Mean Value		**0.367**
			Lake Erie Fish			
Common Carp				**Mean Value**		**0.749** 2.381*
Freshwater Drum				**Mean Value**		**0.398**

* In 2011, the average length of common carp individuals caught in the Ashtabula River AOC was 20.75 inches (in.) (minimum of 15.75 in. and maximum of 23.50 in.). The common carp from Lake Erie with the 2.381 mg/kg PCB concentration came from an individual that was 26.73 in. in length, warranting a more stringent consumption advisory. Sources: Ohio EPA [8], Ohio EPA [20]

4.1.2.3 Changes in Sport Fish Tissue PCB Concentrations over Time

The average PCB concentrations collected in 2011 sport fish were less than the one meal per month upper concentration limit, and were not significantly different from the background Lake Erie fish of similar size and species. Therefore, a one meal per month advisory for both species was permitted, which is the established removal criteria for BUI #1: Restrictions on Fish and Wildlife Consumption. In 2014, this BUI was removed from the Ashtabula River AOC [36].

4.1.3 Contaminant Concentrations in Whole Brown Bullhead Catfish

Brown bullhead catfish (*Ameriurus nebulosa*), sediment-dwelling fish with short-range habits, were assessed within the River by ORD [19]. Brown bullhead catfish are opportunistic benthivores that often burrow into soft sediment, exposing the fish externally to sediment contaminants and internally through ingestion of contaminated prey, including macrobenthos [33, 39, 40].

PCB concentrations within fish are controlled by many factors, including fish species, size, lipid content, sex, age, home range, etc. Therefore, efforts were made to measure the weight, length, sex, and age of each brown bullhead specimen collected for analysis. Brown bullheads aged three years or older (based on size) were targeted during each sampling event. Lipid-normalized fish tissue data reduce the potential for skewed data due to variations in lipid content. Thus, lipid-normalized data may be useful to compare PCB concentrations between species and sites, and aid in risk assessment calculations for human consumption [41]. Both normalized and non-normalized data are presented.

4.1.3.1 Pre-Remediation – Brown Bullhead PCB Concentrations

Homogenized whole brown bullhead fish samples collected in 2006 (pre-remediation) within the GLLA project area by ORD resulted in an average total PCB congener concentration of 2.3 mg/kg wet weight (Figure 4-2A, 2006). This value increased to an average total PCB congener concentration of 4.8 mg/kg wet weight in the fish samples obtained shortly after remediation efforts (Figure 4-2A, 2007). These fish would have been present during dredging, and therefore the elevated PCB concentration seen in 2007 is indicative of pre-remediation exposure in addition to exposures during remediation [19].

4.1.3.2 Post-Remediation –Brown Bullhead PCB Concentrations

In the years following the GLLA project, brown bullhead samples collected by ORD within the Ashtabula River contained lower concentrations of average total PCB congeners. The lowest PCB concentrations collected within fish samples in the River were obtained in 2009 (1.0 mg/kg wet weight; Figure 4-2A). The 2011 average concentration was marginally, but not statistically, higher (1.6 mg/kg wet weight; Figure 4-2A) [19, 32].

4.1.3.3 Changes in Contaminant Concentrations in Fish over Time

The Ashtabula River and Conneaut Creek reference area fish samples were analyzed by two different laboratories. Due to divergent laboratory methods, a list of PCB congeners ($n = 93$) “common” to both laboratories’ analyses was developed as a way to present and compare average total PCB congener concentration results between the two locations [32]. The wet weight average total PCB congener concentration in brown bullhead from the Ashtabula River varied similarly whether aggregated as the full PCB congener list or the “common” PCB congener list. Furthermore, the Conneaut Creek PCBs were significantly lower in concentration than the Ashtabula River samples regardless of aggregation method [32].

The total PCB congener concentrations did not differ significantly with regard to sex, weight, or length from either the Ashtabula River or Conneaut Creek, and were thus treated the same for all analyses. As shown in Figure 4-2, the fish samples analyzed from the reference sites at Conneaut Creek had significantly lower total PCB congeners than samples acquired from within the Ashtabula River ($p \leq 0.05$). The 2007 PCB concentrations were the highest (4.8 mg/kg wet weight). These fish were present prior to and during active dredging operations. In subsequent years, the PCB concentrations significantly decreased within the GLLA project area ($p \leq 0.05$) [19]. Similar trends were noted when the PCB concentrations were lipid-normalized, with a shift in maximum concentration from 2007 to 2008 (~110 mg/kg lipid, Figure 4-2B). However, the standard deviations of the average suggest that this shift was not significant. Lipid-normalized PCB concentrations significantly declined between pre- (2006) and post-remediation (2011) [19]. The PCB concentrations in the brown bullhead from the Conneaut Creek reference area were low and ranged from 0.11 to 0.26 mg/kg wet weight from 2006 to 2011 (Figure 4-2A, no

Conneaut Creek samples were collected in 2009). Lipid-normalized data from Conneaut Creek were similar [32].

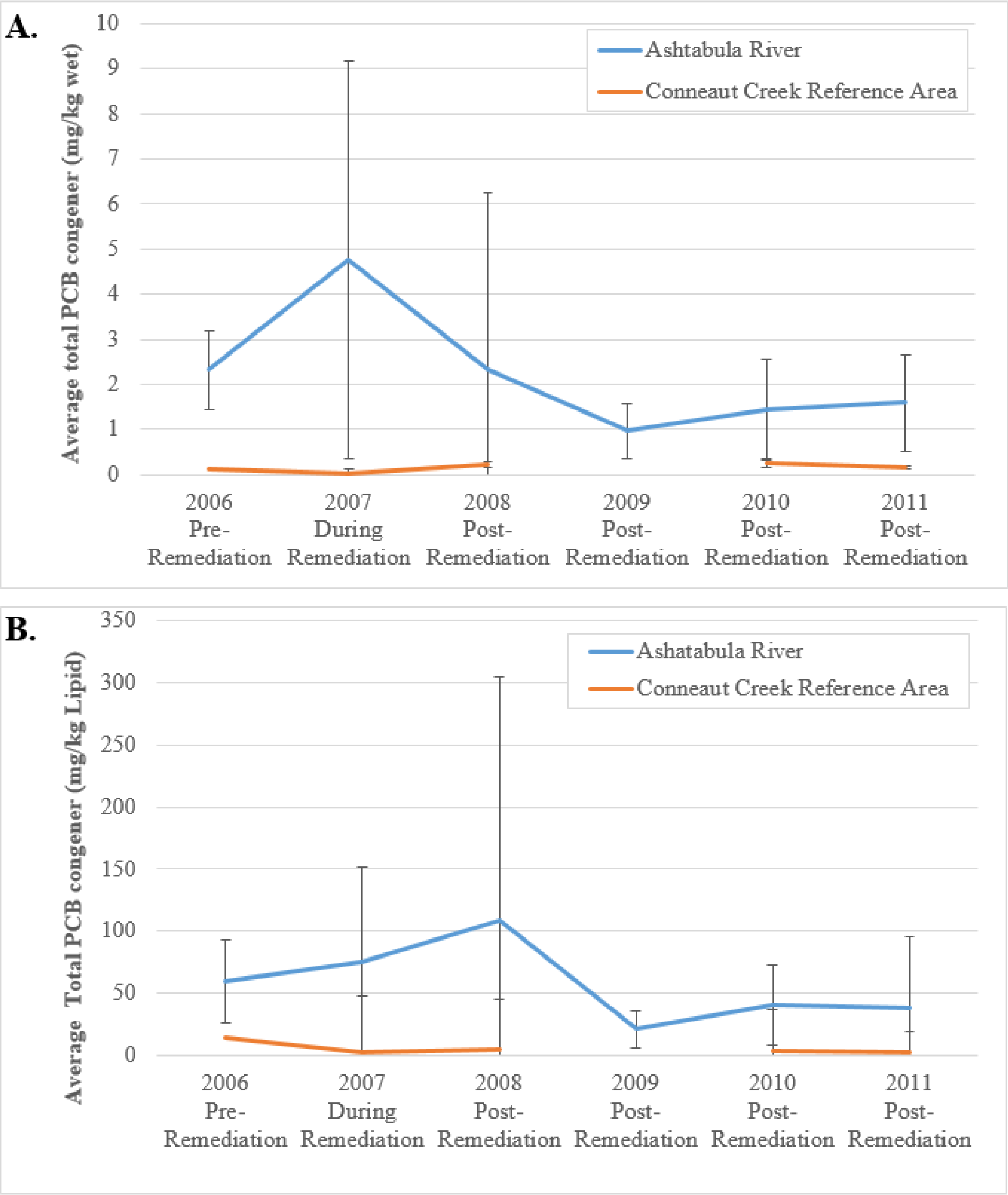


Figure 4-2. Pre- and Post-Remediation Total PCB Congener Concentrations (mg/kg wet weight [A], and mg/kg lipid-normalized [B]) with Error Estimates (Standard Deviations) in Indigenous Brown Bullhead Collected from the Ashtabula River and Conneaut Creek. Source: U.S. EPA [32]

4.1.4 Contaminant Concentrations in Caged Channel Catfish – Pre-Remediation Only

Caged fish were deployed in 2006 by GLNPO to obtain a baseline measure of PCBs prior to dredging activities. Whole fish samples were obtained from live caged channel catfish (*Ictalurus punctatus*) that had been held 14 days in one of seven locations within the GLLA project area. Results indicated elevated PCB concentrations within fish exposed in the Upper Turning Basin and River Run. The average PCB concentration (as homologs) per lipid-gram within the Upper

Turning Basin samples (3,668 total PCB mg/kg-lipid, Figure 4-3) was over three times higher than in the River Run (1,127 total PCB mg/kg-lipid), and at least six times higher than any other sampled locations [28].

Fish deployed in the cages were subject to high stress conditions when placed in the River. High flow conditions, feeding constraints, and fish number and proximity were all factors considered in the deployment design. Regardless of the design, the conditions for deployment were not conducive for a healthy population, and high mortality was observed. Therefore, caged fish deployments were not repeated during or following dredging activities.

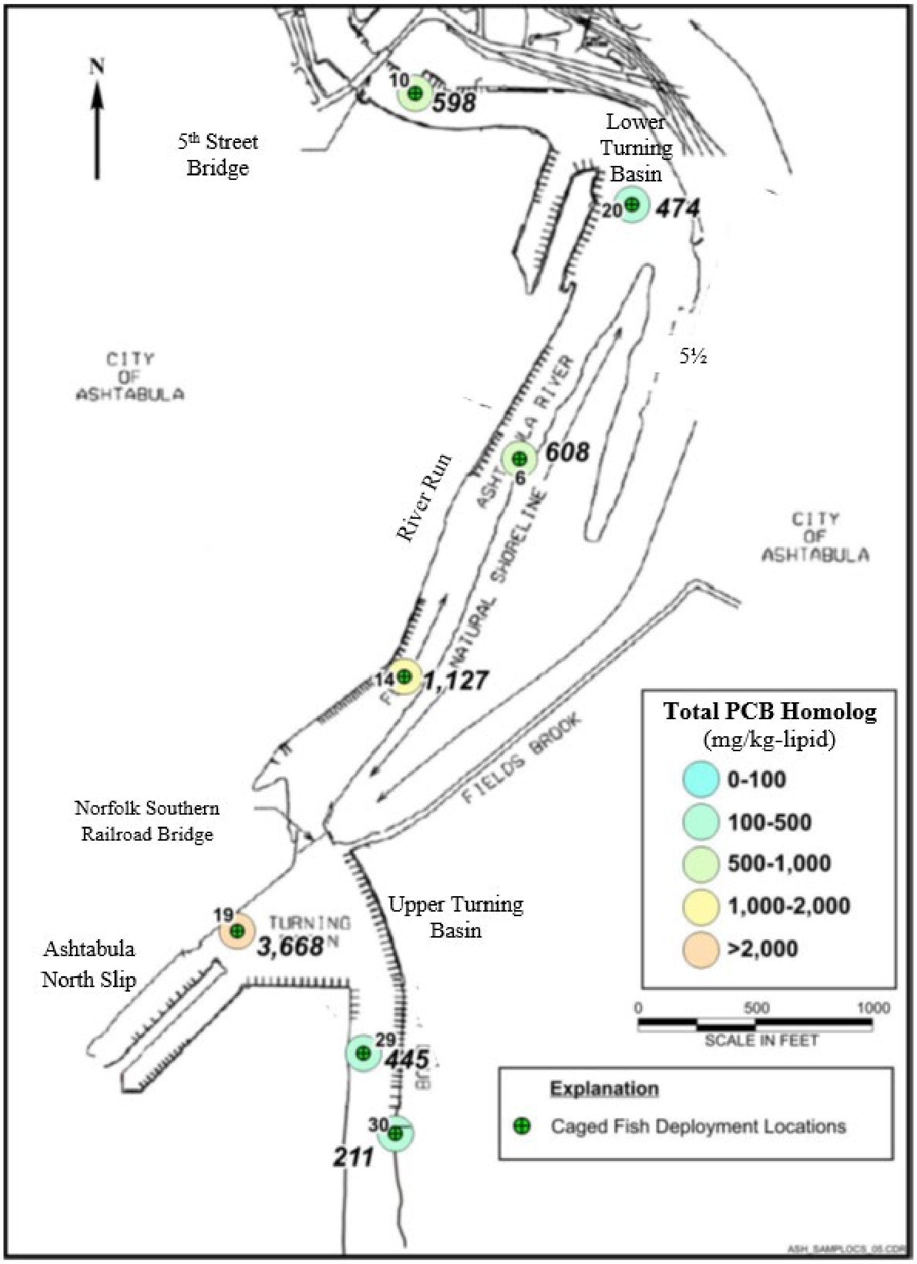


Figure 4-3. Pre-Remediation Caged Channel Catfish Total Average Lipid-Normalized PCB Homolog Concentrations. Source: U.S. EPA [28]

4.1.5 Tumors and Anomalies in Brown Bullhead Catfish

Adverse effects of COCs can be monitored though comprehensive physical fish health assessments. External anomalies may be caused or exacerbated by environmental factors, and often indicate the presence of multiple sublethal stressors to fish [36]. As opportunistic benthivores, brown bullheads are typically monitored for internal and external lesions, abnormalities, and tumors. Brown bullheads often burrow into soft sediment. Their sediment dwelling lifestyle makes brown bullheads an ideal indicator species for skin and liver tumor incidence within warm-water aquatic ecosystems [33, 40]. Ohio EPA uses the incidence of deformities, eroded fins, lesions, and tumors in native fish and the incidence of liver tumors in brown bullheads as the key inputs to removing BUI #4: Fish Tumors and Other Deformities [36]. Liver tumor incidence in brown bullheads is most often attributed to PAH exposure [40]. PCBs, the primary COC in the GLLA project area, and PAHs can often be collocated [36, 40].

The incidence of tumors and anomalies within the Ashtabula River indigenous fish populations is used as an indicator of the long-term effects of removing contaminated sediments. Multiple factors may induce tumors and anomalies in fish; therefore, any change in tumor or anomaly incidence within native Ashtabula River fish cannot be solely attributed to the GLLA remediation efforts.

4.1.5.1 Pre-Remediation - Tumors and Anomalies in Brown Bullhead Catfish

Between 2002 and 2004, 99 brown bullheads were collected from the Ashtabula River AOC by USGS [17]. Of these 99 fish, abnormal barbels were noted on 48% of the fish, raised lesions were seen on 10%, and liver neoplasms were seen in 13% [17].

4.1.5.2 Post-Remediation - Tumors and Anomalies in Brown Bullhead Catfish

In 2011, 39 brown bullheads were collected from within the Ashtabula River AOC in a combined effort by USGS and ORD [19, 33]. Abnormal barbels were seen on 28% of the fish, raised lesions on 23% of the fish, and liver neoplasms were seen on 7.5% of the specimens [19, 33].

4.1.5.3 Changes in Incidence of Tumors and Anomalies in Brown Bullhead Catfish over Time

Ohio EPA targets a maximum brown bullhead liver tumor prevalence rate of 5% [36]. The 2011 survey of brown bullheads did not meet this requirement. While the tumor incidence rate has decreased over time, the tumor incidence rate remains above BUI #4 removal recommendation limits.

External tissues (skin) are in constant contact with the water and sediments. Thus, skin lesion risk factors are typically associated with chemical concentrations within the water and surface sediments. Exposure of liver tissues requires adsorption and/or metabolism of an environmental stressor before tumor development. While it is known that exposure to carcinogenic compounds, such as PAHs and to a lesser extent PCBs, can induce tumors, other factors such as age, gender, and season of observation can also contribute variability in observed prevalence rates [33, 40, 42]. These initial findings demonstrate an improvement in the prevalence of tumors and anomalies within the brown bullheads of the Ashtabula River, however, the decline cannot be solely attributed to the GLLA remediation activities.

4.1.6 DNA Damage in Brown Bullhead Catfish

Monitoring internal and external lesions is a common practice for evaluating the physical health of fish. However, more recently, measurements of DNA damage within select tissues have been used as a sensitive, rapid, and economical biomarker method for detecting genetic damage in natural aquatic biota [19].

Comet assays were used to quantify the relative amount of DNA damage in brown bullhead blood and liver tissue samples collected from both the Ashtabula River AOC and Conneaut Creek reference site. Tail extent momentum (TEM) values, the ratio of the distance the damaged DNA traveled within the assay multiplied by the percent of DNA that traveled in the tail, are reported. The larger the TEM, the more extensive the cellular DNA damage within the sample.

4.1.6.1 Pre-Remediation – DNA Damage in Brown Bullhead Catfish

In 2006, DNA damage within blood as measured by ORD was higher in the Ashtabula River brown bullheads than those collected in the Conneaut Creek reference area as measured through TEM (6.0 µm and 4.3 µm, respectively) (Figure 4-4). On the contrary, the TEM values of liver samples collected within brown bullhead samples collected at both locations were uniform in 2006 (both were 3.2 µm) [19].

4.1.6.2 Post-Remediation – DNA Damage in Brown Bullhead Catfish

DNA damage within blood samples from brown bullhead of the Conneaut Creek reference area were highest among the 2011 samples (3.3 µm TEM) (Figure 4-4). TEM values within brown bullhead samples collected in the Ashtabula River were relatively uniform between blood and liver tissues in 2011 (1.9 µm and 2.2 µm, respectively) [19].

4.1.6.3 Changes in DNA Damage in Brown Bullhead Catfish over Time

The degree of DNA damage within the assessed indigenous fish tissues declined following the GLLA remediation. An analysis of variance (ANOVA) comparing sampling year to the site of fish collection (Ashtabula River vs. Conneaut Creek) found that DNA damage in brown bullhead blood and liver samples was significantly different before and after dredging ($p < 0.01$). However, this significant difference was also noted in samples collected at the undredged Conneaut Creek reference area. Therefore, the observed decrease in DNA damage cannot be solely attributed to the GLLA dredging.

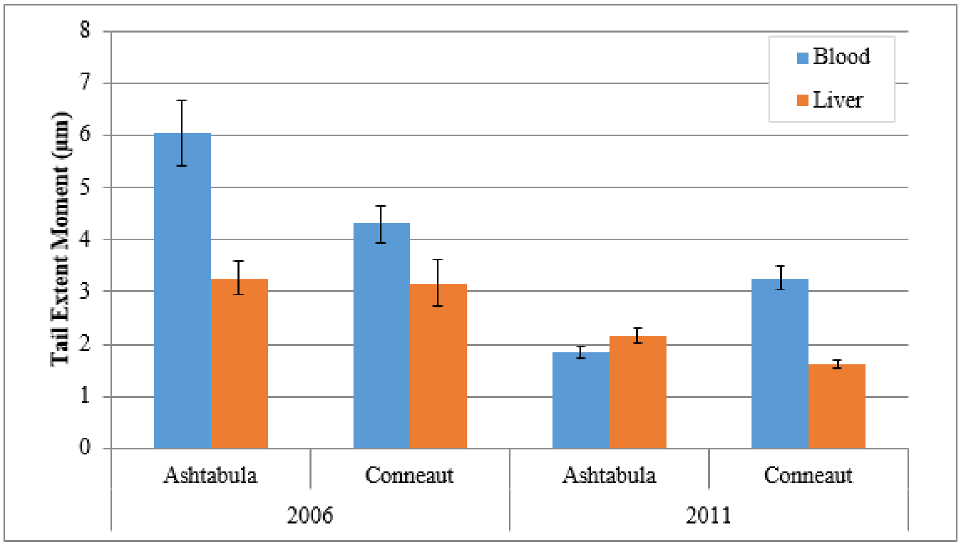


Figure 4-4. DNA Damage as Expressed Through Tail Extent Moment (TEM, µm) with Error Estimates (Standard Error about the Mean) in Indigenous Brown Bullhead Blood and Liver Samples Collected from the Ashtabula River and Conneaut Creek. Source: Meier, Lazorchak [19]

4.2 Analysis of Macroinvertebrates

4.2.1 Invertebrate Community Index (ICI) for Macroinvertebrates

The ICI is a multi-metric index that accounts for richness, trophic composition, diversity, presence of pollution-tolerant individuals or species, abundance of biomass, and the presence of diseased or abnormal organisms [36]. An ICI evaluation of the macroinvertebrate community of a stream or river is particularly useful for evaluating stream health as there are a wide variety of pollution tolerant and pollution intolerant macroinvertebrate species.

Ohio EPA has suggested a minimum target ICI score of 34 for lacustuary river segments, such as the GLLA project area of the Ashtabula River [36]. Meeting this minimum target is the key data input to removing BUI #6: Degradation of Benthos.

4.2.1.1 Pre-Remediation - ICI

Ohio EPA conducted ICI surveys within the Ashtabula River AOC in 2003 (Table 4-6). Multiple locations within the GLLA project area were assessed for ICI prior to the remediation activities. When averaged together, the ICI value within the project area was 27.7, well below the Ohio target value of 34. However, ICI metrics collected within locations upstream of the GLLA project area surpassed the minimum Ohio EPA target value.

4.2.1.2 Post-Remediation - ICI

Ohio EPA conducted ICI surveys in 2011 following the GLLA project. Note that the exact locations sampled in 2003 and 2011 were not identical, but rather sampling efforts were focused on obtaining information within the same general proximity. In 2011, the ICI values within the Upper Turning Basin were lower than the other River locations that were sampled. The lowest ICI value (12) was located at RM 1.6 in the Upper Turning Basin. While areas sampled downstream of the Upper Turning Basin yielded higher ICI values, each location was still lower than the Ohio EPA target value (34). The average post-remedy average ICI value for the project area was 23.2 (Table 4-6) [43].

4.2.1.3 Changes in the ICI Metric over Time

The ICI dataset consisted of only one pre- and one post-remedy survey, and was less robust than some other index datasets. When comparing the 2003 to 2011 data, only one sample was collected at the same RM in 2003 and 2011 (RM 1.1; 5½ Slip). When these data were grouped into River segments, only three common areas were sampled during both surveys (5th Street Bridge, 5½ Slip, and Upper Turning Basin, Table 4-6).

The overall average of the available 2011 data shows a slight decrease in ICI following the GLLA project (from 27.7 in 2003 to 23.2 in 2011); however, there were no samples collected in the River Run in 2011 (Table 4-6). These ICI values indicates that the macroinvertebrate community remains impaired in certain areas within the GLLA project area.

Table 4-6. Pre- and Post-Remediation ICI Values

Approximate River Mile	***River Segment [a]***	***Pre-Remediation 2003***	***Post-Remediation 2011***
0.3	*Downstream*		*24*
0.6	5th Street Bridge	44	24
0.9	5½ Slip		28
1.1	5½ Slip	32	32
1.3	River Run	30	
1.5	River Run	28	
1.58	Upper Turning Basin	22	
1.6	Upper Turning Basin		12
1.65	Upper Turning Basin	16	
1.66	Upper Turning Basin	22	
1.8	Upper Turning Basin		20
1.86	*Upstream*	*42*	
1.95	*Upstream*	*48*	
2.15	*Upstream*	*56*	
2.4	*Upstream*	*50*	*44*
GLLA Project Average		**27.7**	**23.2**
BUI Removal Target		34	

[a] The Upstream and Downstream sample locations were not part of the GLLA project, but are shown as reference values for comparison purposes. Values given in red do not meet the BUI Removal Target; values in green meet or exceed the target. Sources: Ohio EPA [4], Ohio EPA [43]

4.2.2 Contaminant Concentrations in Macroinvertebrates

Reductions in contaminant concentration in the tissue concentrations of benthic macroinvertebrate species (e.g., chironomids, tricoptera, amphipods, annelids) indicate short-term changes in uptake potential of contaminated surface sediments. PCBs within aquatic systems tend to concentrate within the lipid fraction of organisms [41]. Studies have shown a significant positive correlation between the accumulation of hydrophobic chemicals and the lipid content of an organism. Lipid-normalized PCB concentrations can be also be used to extrapolate between sites and species [41]. Average PCB concentrations and lipid-normalized PCB concentrations are both given herein.

Macroinvertebrate tissues collected within the GLLA project area were dominated by chironomids, but tricoptera, ephemeroptera, diptera, odonatan, amphipods, and annelids were also analyzed [19]. PCB concentrations within these macroinvertebrates tissues are reflective of a short-term exposure duration, as the benthic invertebrates collected within the project area used collection methods that targeted organisms with life cycles lasting 30 to 90 days [19].

Macrobenthos samples were collected annually by ORD before, during, and after the GLLA project in three locations of the Ashtabula River: Upper Turning Basin, Lower Turning Basin, and Upstream Ashtabula River [19, 26]. The Upper Turning Basin and Lower Turning Basin samples were collected within the GLLA project area, while the Upstream and Conneaut Creek samples were used to represent in-River and out-River control samples, respectively [32, 33]. All macroinvertebrate samples were analyzed for percent total lipid content and total PCBs through the summation of approximately 140 individual PCB congeners [32].

4.2.2.1 Pre-Remediation –Contaminant Concentrations in Macroinvertebrates

In 2006, macroinvertebrate tissues collected from within the Upper Turning Basin (104 mg/kg lipid) were five times higher than the reference samples collected Upstream of the GLLA project (22 mg/kg lipid) (Figure 4-5). Samples collected within the Lower Turning Basin (46 mg/kg lipid) were two times higher than the reference samples [32].

4.2.2.2 Post-Remediation –Contaminant Concentrations in Macroinvertebrates

Following the GLLA remediation project, the total PCB congener concentration within the Upper Turning Basin and Lower Turning Basin macroinvertebrates initially increased (140 mg/kg lipid and 68.0 mg/kg lipid, respectively, in 2007) followed by a dramatic decrease (11.0 mg/kg lipid and 26.6 mg/kg lipid, respectively, in 2008; Figure 4-5). The initial immediate post-remediation spike was anticipated, as the organisms present in 2007 were likely exposed to highly contaminated sediments that had been resuspended during the dredging process.

The samples obtained from the Upper Turning Basin showed a slight increase in 2009 and 2010 followed by another decline in 2011 (23 mg/kg lipid; Figure 4-5). In contrast, the 2009 to 2011 Lower Turning Basin lipid-normalized PCB data were more similar to the Upstream and Conneaut Creek reference area (average value of the three, 3.5 mg/kg Lipid) (note: the Conneaut Creek reference area was not sampled before 2009). In 2011, the average total PCB congener concentration within macroinvertebrate tissues collected in the Upper Turning Basin was approximately twice as high as those collected in the Lower Turning Basin (Figure 4-5) [32].

4.2.2.3 Changes in Contaminant Concentrations in Macroinvertebrates over Time

Macroinvertebrate samples were collected by ORD from two locations within the GLLA project area. Comparisons of macrobenthos contaminant concentrations from these two locations show that the Upper Turning Basin average total PCB congener concentrations were greater than the Lower Turning Basin macroinvertebrate concentrations. For both locations, the average total PCB congener concentration was less in 2011 compared to 2006 (Figure 4-5). An ANOVA confirmed the observed decrease in total PCB congener concentrations within the GLLA project area, as both spatial and temporal changes in the data were each significant ($p \leq 0.05$ for each metric) [32]. When grouped, a significant difference ($p < 0.05$) was also observed between the remediated locations (Upper Turning Basin and Lower Turning Basin) and the unremediated control sites (Upstream, Conneaut Creek) [19]. However, while the post-remediation macrobenthos contaminant concentrations within the project area were significantly lower than pre-remedy concentrations, they remain elevated in comparison to the control locations. This indicated that while the bioaccumulation potential for sediment dwelling macroinvertebrates significantly declined following the GLLA project activities, PCB bioaccumulation was still observed.

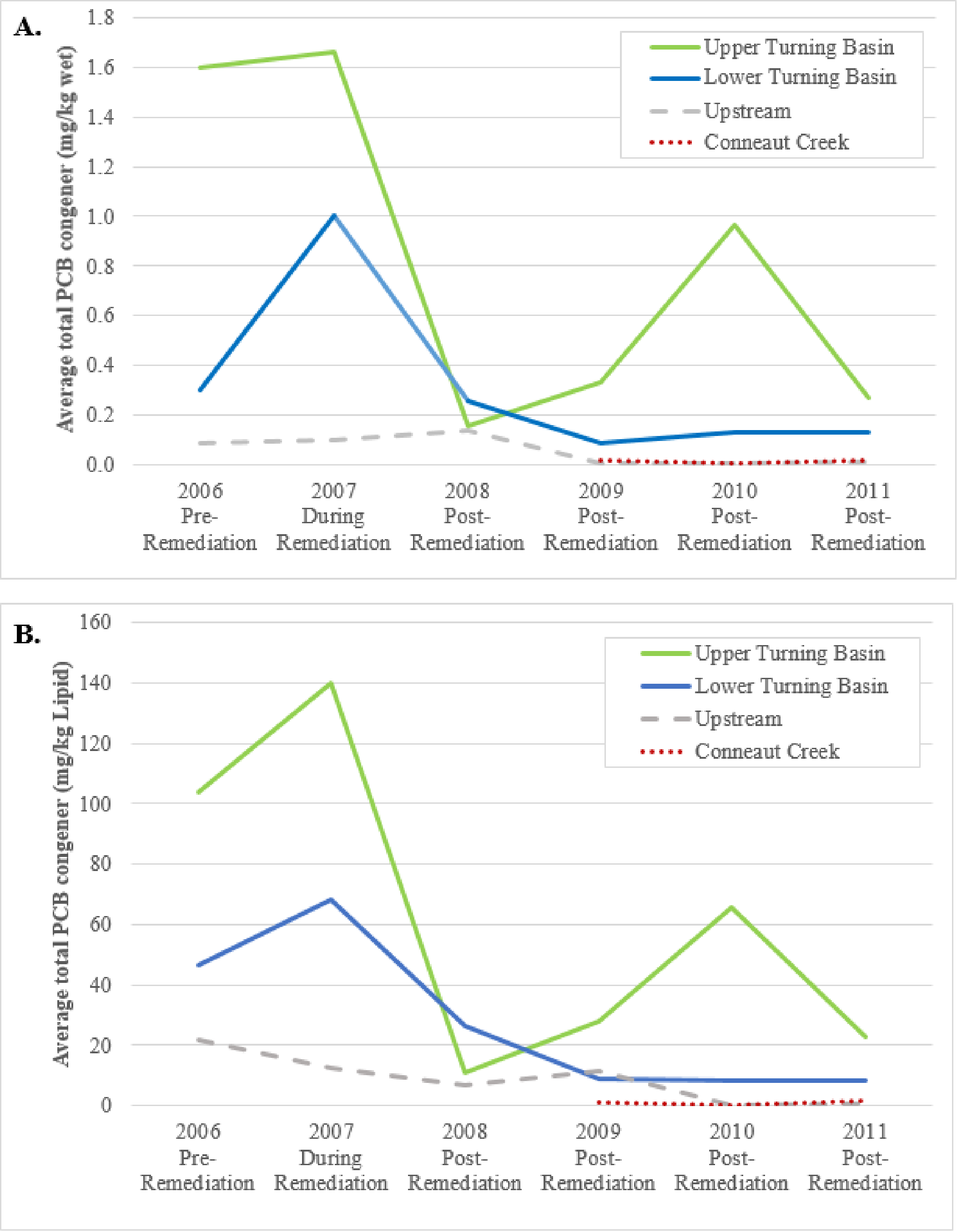


Figure 4-5. Average Total PCB Concentration (mg/kg) in Macroinvertebrate Tissues by Year. A) Wet Weight Basis B) Lipid Normalized. Source: U.S. EPA [32]

4.2.3 Amphipod Survival Analyses

Hyalella azteca is one of the most common benthic amphipod crustaceans within the North American lakes. Therefore, solid-phase sediment tests are commonly used to assess survival of young *H. azteca* in direct contact with surface sediments over a designated period of time [44]. Assessment of survival of *H. azteca* is performed over a specific exposure period to establish acute and chronic toxicity [44]. While PCBs may impact the survival of *H. azteca*, PAHs within sediments are more commonly associated with amphipod toxicity [45].

4.2.3.1 Pre-Remediation – Amphipod Survival

In 2004, USGS assessed the toxicity of sediment core samples from five locations within the Upper Turning Basin using a 28-day whole-sediment toxicity test with the amphipod *H. azteca* [25]. In 2006, six surficial sediment samples were collected by GLNPO from within the GLLA project area for assessing amphipod survival [28] (Table 4-7).

While the USGS determined that the surface sediments collected from within the Upper Turning Basin in 2004 were not toxic to *H. azteca*, Upper Turning Basin samples collected by GLNPO in 2006 found that *H. azteca* growth was significantly reduced ($p \leq 0.05$) compared to the control organisms [25, 28]. River Run samples collected in 2006 also showed a significant ($p \leq 0.05$) reduction in *H. azteca* growth and survival after 28 days of exposure [28] (Table 4-7).

Table 4-7. Pre-Dredging Surface Sediment 28-Day H. azteca Toxicity Results

	Station ID	River Segment[a]	*H. azteca* % survival	Average length (mm)	Average dry weight (mg)
USGS 2004	Ash-01-A	Upper Turning Basin	97.5	3.9	
	Ash-02-A	Upper Turning Basin	92.5	3.98	
	Ash-03-A	Upper Turning Basin	90	3.94	
	Ash-04-A	Upper Turning Basin	95	3.92	
	Ash-05-A	Upper Turning Basin	97.5	4.15	
	West Bearskin Control Sediment		98.6	3.77	
GLNPO 2006	10	5th Street Bridge	91.7		0.332
	6	River Run	95		0.286*
	14(a)	River Run	77.5*		0.361
	19	Upper Turning Basin	89.2		0.309*
	20	Upper Turning Basin	95.8		0.324*
	29	Upper Turning Basin	88.8		0.327
	30	*Upstream*	*93.3*		*0.353*
	Toxicity Control		95.8		0.389

[a] The Upstream sampled location was not part of the GLLA project, but is shown as a reference value for comparison purposes. * Indicates results that were significantly ($p \leq 0.05$) different from the control measurements. Sources: USGS [25], U.S. EPA [28]

4.2.3.2 Post-Remediation – Amphipod Survival

In 2012, following the GLLA project, NOAA collected 12 additional surface sediment samples under the Mussel Watch Program to gain a general assessment of the sediment contamination in the AOC as a whole [29]. Of the 12 samples, one sample within Lower Turning Basin and two samples within River Run (three total) were located within the GLLA project area (Table 4-8, Figure 4-6). Each of the 12 samples was assessed through three toxicity tests: whole-sediment 10-day amphipod *H. azteca* survival, Microtox-solid-phase tests, and Microtox-solvent-extract tests. For the *H. azteca* survival assay, samples were considered toxic when survival was significantly different ($p \leq 0.05$) from the synthetic control sediment. The Microtox assays measure toxicity based from an EC50, the light output of bioluminescent bacteria exposed to sediment extracts. Sediment extracts were considered toxic when EC50 values were significantly lower ($p \leq 0.05$) than the reference site sediments [29].

The post-remediation results indicate that sediments toxic to amphipods remain within the dredged area. As shown in Table 4-8, 10-day *H. azteca* survival measures indicated that the surface sediments collected from the Lower Turning Basin and River Run remained toxic relative to the reference control. The two Microtox assays yielded contradicting information for the GLLA project area samples [29].

The NOAA AOC-wide assessment also looked at various water quality measurements. Bottom-water pH and temperature were noted to be stable within the AOC, however bottom-water dissolved oxygen (DO) varied within the AOC. As shown in Table 4-8, the DO ranged from 2.48 to 8.75 mg/L. The three locations within the GLLA footprint averaged only 3.6 mg/L. DO concentrations ranging from 2 to 5 mg/L are considered fair to moderate for benthic fauna; therefore, DO may be a limiting factor in the overall health of the benthic community [29].

Table 4-8. 2012 Post-Dredge Surface Sediment 10-Day H. azteca Survival Results

Station ID	River Segment[a]	Amphipod Survival	Microtox-Solid-Phase	Microtox-Solvent-Extract	pH	Temp. °C	DO (mg/L)
A01	*Harbor*	*Toxic*	*Non-Toxic*	*Non-Toxic*	*8.8*	*23.7*	*7.16*
A02	*Harbor*	*Non-Toxic*	*Non-Toxic*	*Non-Toxic*	*8.7*	*23.4*	*7.06*
A04	*Harbor*	*Toxic*	*Non-Toxic*	*Non-Toxic*	*8.5*	*23.6*	*7.47*
A05	*Harbor*	*Toxic*	*Non-Toxic*	*Non-Toxic*	*8.7*	*24.2*	*8.05*
A03	*Downstream*	*Toxic*	*Non-Toxic*	*Non-Toxic*	*8*	*23.7*	*5.44*
A10	Lower Turning Basin	Toxic	Toxic	Non-Toxic	7.7	23.7	4.80
A06	River Run	Toxic	Toxic	Non-Toxic	7.5	24	3.52
A12	River Run	Toxic	Non-Toxic	Toxic	7.4	23.9	2.48
A07	*5½ Slip*	*Toxic*	*Toxic*	*Non-Toxic*	*7.5*	*23.9*	*3.57*
A09	*Upstream*	*Toxic*	*Toxic*	*Toxic*	*7.5*	*23.9*	*4.03*
A11	*Upstream*	*Non-Toxic*	*Non-Toxic*	*Non-Toxic*	*7.9*	*24*	*6.43*
A08	*Upstream*	*Toxic*	*Toxic*	*Toxic*	*8.6*	*24.1*	*8.75*
GLLA Project Average					**7.5**	**23.9**	**3.60**

[a] The Upstream sampled location was not part of the GLLA project, but is shown as a reference value for comparison purposes. Toxicity based off a significant difference ($p \leq 0.05$) from the reference controls
Source: Cooksey, Balthis [29]

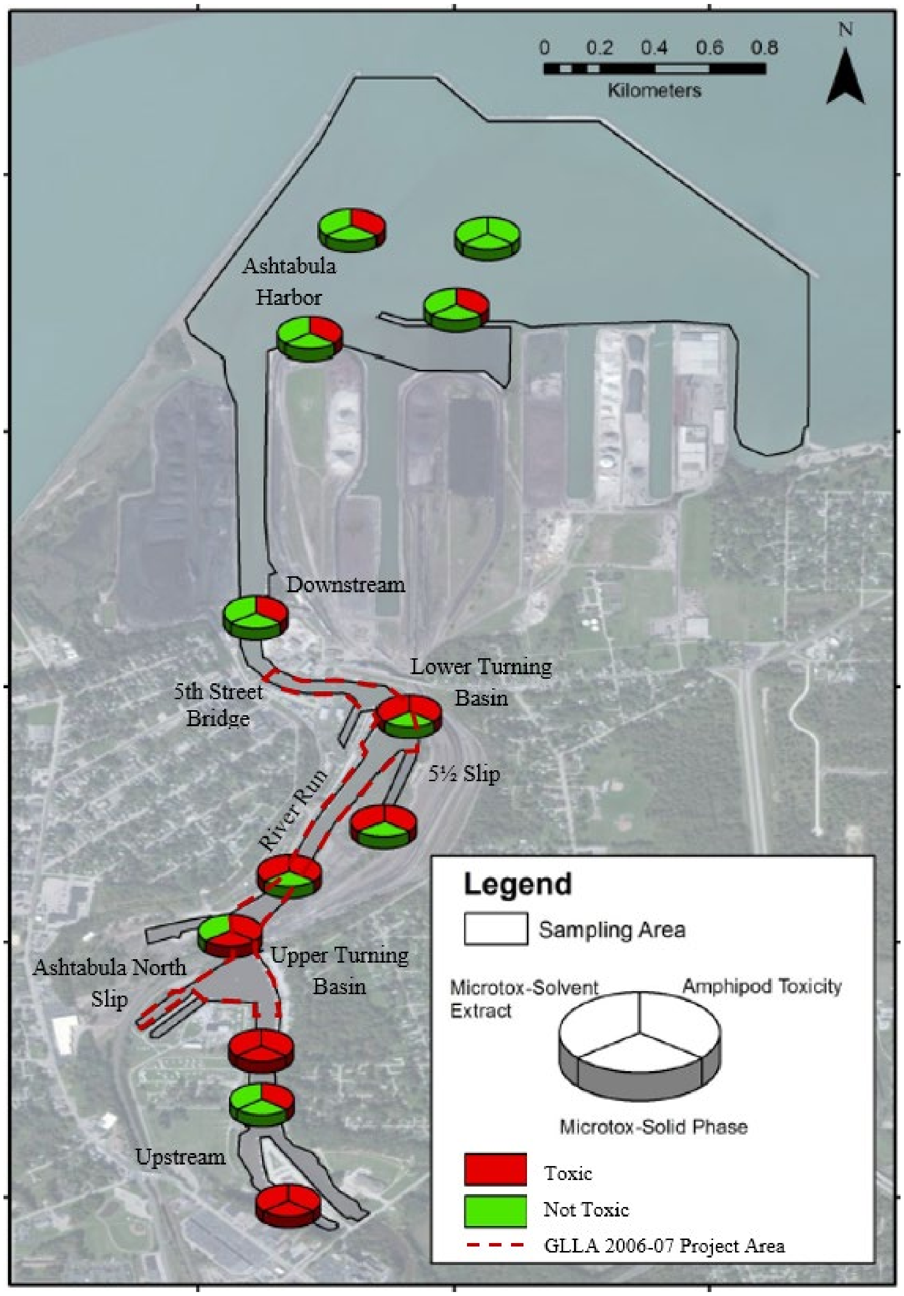


Figure 4-6. 2012 Post-Remediation Toxicity Assessments Collected AOC-Wide. Source: Cooksey, Balthis [29]

4.2.3.3 Changes in Amphipod Survival over Time

Prior to the GLLA project, amphipod survival within surface sediments collected from the GLLA project area was significantly lower than control samples [25]. When *H. azteca* survival was reassessed in 2012, several years post-remediation, 10-day survival remained significantly less than the laboratory reference control [29]. In 2012, limited water quality measurements noted minimal DO concentrations within bottom-water samples, [29]. Previous work within the Ashtabula River had suggested that PCBs, PAHs, and ammonia contribute to the observed toxicity to sediment-dwelling organisms [45].

4.3 Contaminant Concentrations in Riparian Spiders – Post-Remediation Only

Riparian spiders (Tetragnathidae and Araneidae: Aranea) were collected in 2011 to determine the potential bioavailability of PCBs in the food web. Riparian spiders feed on emergent aquatic insects [46]. These spiders and their aquatic insect prey have very limited ranges; therefore, PCB residues detected in these species can be effective methods in characterizing contaminant bioavailability and tracing PCB sources within tight geographic ranges [30].

For this dataset, total PCB congeners and PCB homologues were quantified and reported in mg/kg wet weight. Total PCBs and homologs were calculated by summing measured concentrations for all congeners and for each homolog group, respectively. Percent lipids were gravimetrically obtained in order to report findings as percent lipids on a wet weight basis [30].

In 2011, spiders collected at Upstream reference sites had negligible PCB concentrations. Spiders collected at the Ashtabula North Slip near the confluence of Strong Brook were nearly seven times higher than the reference location (Araneid sum of PCB homologs 0.35 mg/kg wet weight at the Ashtabula North Slip, and an average of 0.047 mg/kg wet weight Upstream [Figure 4-7A]). Spiders collected at the Upper Turning Basin near the confluence of Fields Brook were nearly four times higher than the reference locations (Araneid sum of PCB homologs 0.19 mg/kg wet weight within the Upper Turning Basin [Figure 4-7A]). Concentrations gradually decreased moving downstream from the Ashtabula North Slip [30]. When lipid-normalized, the data show comparable variability across sampling sites (Figure 4-7B). While pre- and immediately post-remediation data are not available for comparison, these 2011 results suggest the potential for ongoing PCB bioavailability to macrobenthos in the sediment.

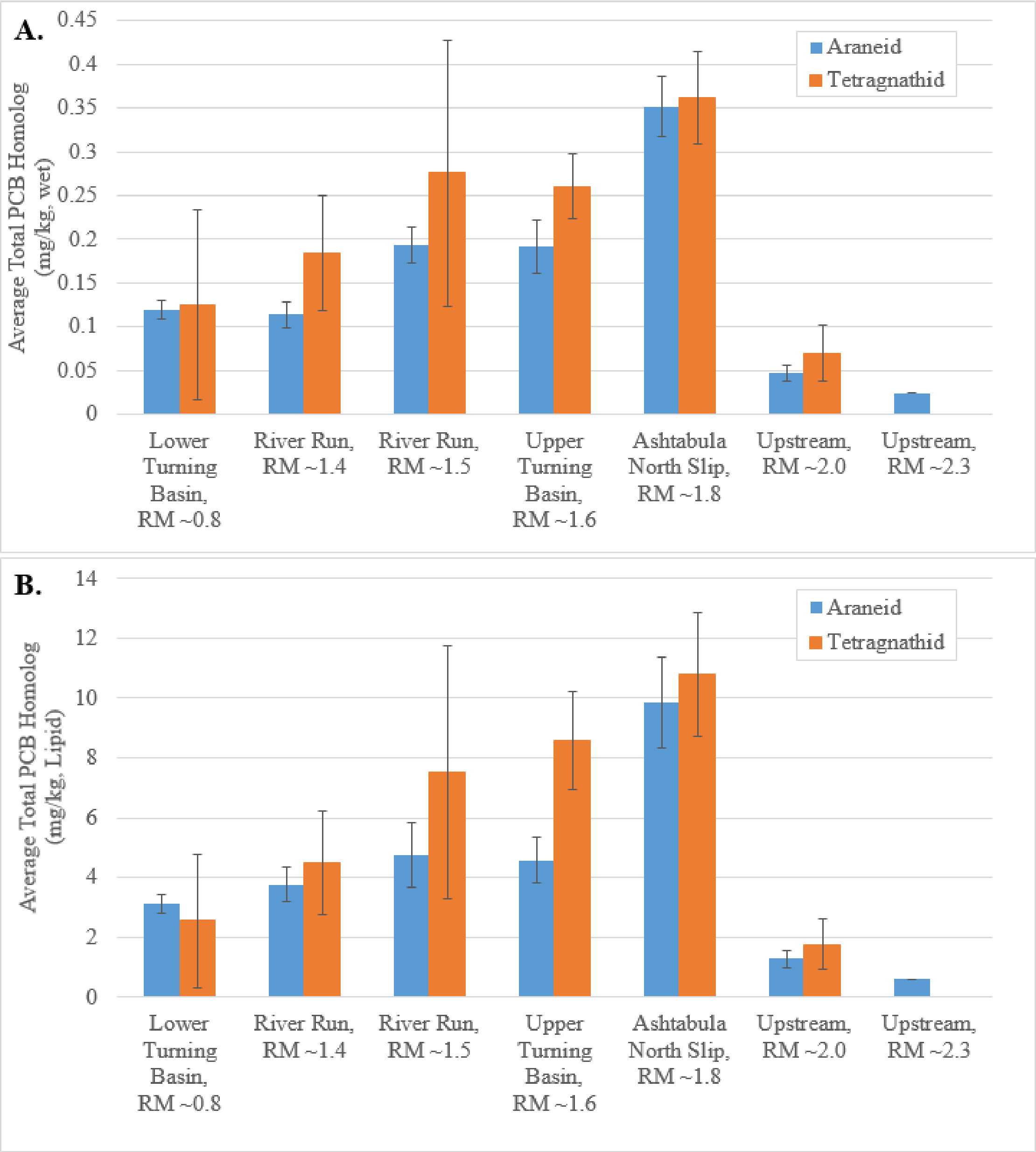


Figure 4-7. 2011 Post-remediation Spider Analysis: Total PCB Congener Concentrations (µg/kg wet weight [A], and mg/kg lipid-normalized [B]) with Error Estimates (Standard Deviations) in Indigenous Riparian Araneid and Tetragnathid Spiders. Source: Kraus, Walters [30]

4.4 Discussion of the Biological LOE and Changes Pre- and Post-Remediation

Biological data collected at the GLLA project area focused on: ICI, IBI, and MIwb metrics and PCB concentrations in sport fish fillets, brown bullhead catfish, caged channel catfish, macrobenthos, and riparian spiders. Changes in tumor prevalence and DNA damage to specific tissues were also presented as supporting evidence to the overall health of the indigenous fish community.

Changes in IBI, MIwb, and ICI metric values are demonstrated by plotting the pre-remediation value for a location on the x-axis and the post-remediation counterpart value from the same or similar location on the y-axis (Figure 4-8). When data are plotted in this manner, points that converge on the 1:1 line demonstrate less change from before versus after remediation, while points that diverge from the line indicate more change. When pre-/post-remediation metrics from the same sampling locations are plotted, the IBI at River Run improved post-remediation, while the IBI at 5½ Slip and both MIwb points converged on the 1:1 line. However, the ICI points are all at or below the 1:1 line, signifying an overall decrease in the macroinvertebrate species richness and diversity in 2011, following completion of the GLLA project.

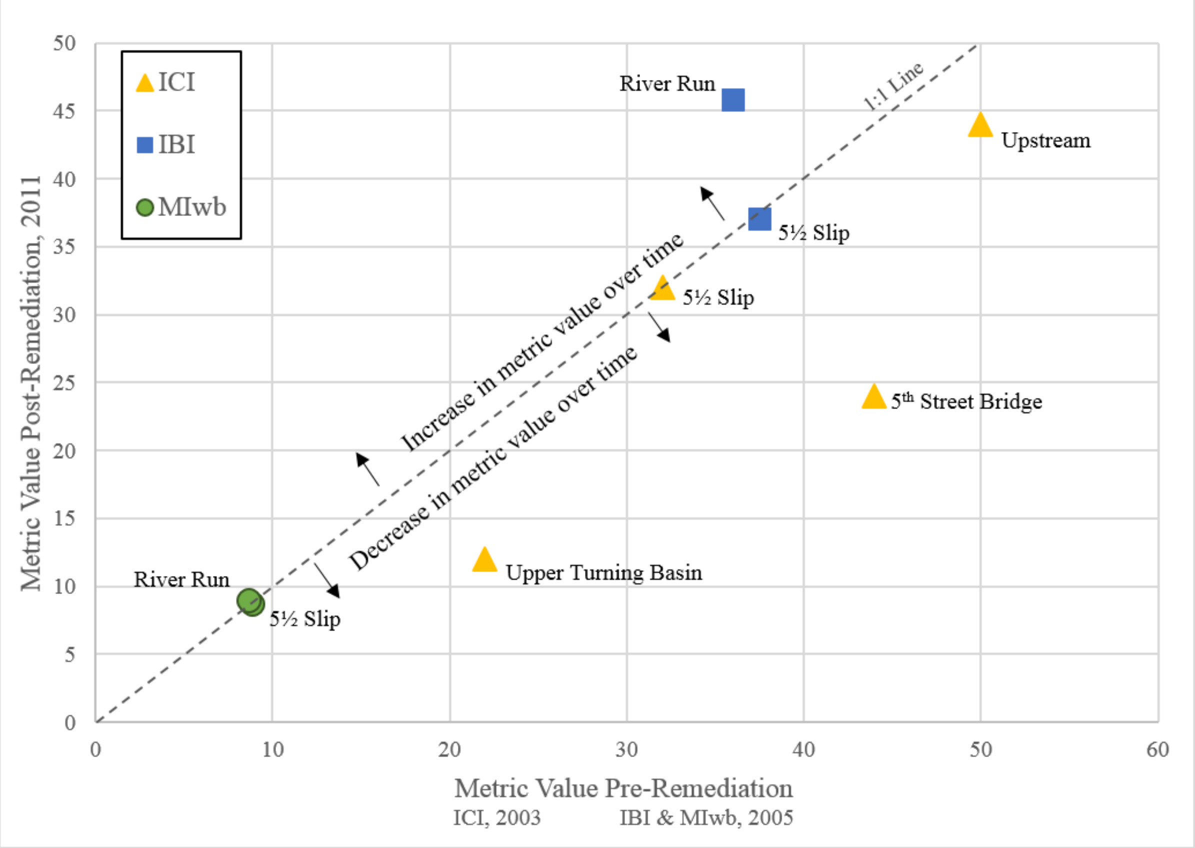


Figure 4-8. Plot of Individual Ohio EPA Metrics Pre- Versus Post-Remediation. Sources: Ohio EPA [20], Ohio EPA [43]

IBI and MIwb metrics, which measure fish community health, were slowly trending toward recovery even before the GLLA project began. This increasing trend continued through multiple years of post-remediation assessments. In the most recent assessments, both IBI and MIwb surpassed the minimum Ohio EPA target values for lacustuary river segments. Conversely, ICI measures indicated a decline in macrobenthos community health following the remediation efforts.

The analysis of contaminant concentrations in sport fish fillets, brown bullheads, caged channel catfish, and benthic macroinvertebrates provides an indication of bioaccumulation within various trophic levels of the food chain. The results presented indicated that the bioavailable PCBs increased during and immediately following remediation, before significantly declining.

However, a comparison of dredged to undredged reference locations also indicated that while the GLLA remediation significantly reduced the bioavailable PCBs and allowed BUI #1: Restrictions on Fish and Wildlife Consumption to be removed in 2014, PCBs remain bioavailable to benthic macroinvertebrates and riparian spiders. PCB concentrations within brown bullhead catfish followed a similar, yet temporally delayed trend as PCB concentrations within fish increased immediately following dredging activities before a decline was observed in following years.

Health of the indigenous fish was monitored through a survey of tumor incidence and DNA damage pre- and post-remediation within brown bullhead catfish. Declines in the incidence of liver tumors and extent of DNA damage indicated an overall healthier fish community since the GLLA remediation. However, due to the number of factors that can contribute to these anomalies (sex, age, season, confounding chemical agents, etc.), their decline cannot be solely attributed to the GLLA project.

The increase in IBI and MIwb scores (two biologic endpoints in fish), and decrease in total PCB concentrations within macroinvertebrates suggest that sediment remediation has led to reduced contaminant uptake by the biota and increased fish diversity.

Key Biological Outcomes:

- PCB concentrations within Ashtabula River sport fish have reduced over time following remediation, such that they are at background Lake Erie levels in fish of similar size and species.
- IBI and MIwb surpassed the minimum Ohio EPA target values for lacustuary river segments.
- ICI measures indicated a decline in macrobenthos community health.
- Bioavailable PCBs increased during and immediately following remediation, before significantly declining; however, PCBs remain bioavailable post-remediation.

5 Remedy Effectiveness Assessment - Chemical Line of Evidence

Typical metrics for chemical LOE include concentration of contaminants in surface sediments and the mass of chemical contaminants removed. Sediment contaminant data is useful for multiple purposes. Sediment concentration measurements can be used to determine human and aquatic life exposure assessments, sediment remediation goals, potential causes and sources of biological impairment, and help determine appropriate disposal strategies for dredged sediment [47].

Sediment surface concentrations are often expressed as a surface weighted average concentration (SWAC) value. Individual surface sediment concentrations could inadequately represent the total contaminant exposure to mobile receptors. Therefore, SWAC values are used to better exhibit the exposure domain for potential receptors within biologically active surface sediments. Bioaccumulative compounds, such as PCBs, are often monitored through SWAC values, as bioavailable surface area can be correlated to the fate and transport of contaminants within the food chain.

The remedial goals for the Ashtabula River GLLA project were to remove 82% or as much contaminant mass as possible (including all TSCA-level PCB-containing sediments and associated scour-risk mass) and to achieve a short- and long-term PCB SWAC of 7.5 and 0.25 mg/kg, respectively. Given that the data included in this section vary in how they were analyzed, a brief discussion on PCBs and various analytical methods can be found in BOX 2.

5.1 Surface Weighted Average Concentrations of PCBs

Initial investigations of the Ashtabula River were conducted in the late 1990s to characterize the nature and extent of contamination within the AOC. These results were used to develop the remedial action goals and to plan for the GLLA remediation effort [3]. In addition to the investigations that contributed to the remedial design, GLNPO conducted a baseline characterization in 2006 that focused on gathering surface sediment concentration information immediately prior to the remedy. A similar investigation was conducted in 2011 for comparative purposes.

BOX 2: Analytical analysis of environmental PCB concentrations can be conducted through multiple methods. Often two divergent approaches are used to assess total PCB concentrations: Aroclor analyses or summation of individual congeners [2]. Studies that use an individual congener approach often simply report the total sum of PCBs. However, depending upon the actual analytical method used, the number of identified congeners can vary from 10 to all 209. Therefore, care must be taken when comparing PCB concentrations derived from different analytical methodologies. In this REA, both qualitative and quantitative evaluations have been made for pre- and post-remedy comparisons of PCB concentrations. The type of analytical methodologies was considered and noted in the text.

PCB SWAC is the weighted total PCB concentration over a surface area. SWAC for a river segment is calculated through a four-step process [13]:

1) Each sediment sample location is assigned an identifier.
2) The total river bottom surface area for the project is divided into separate polygons that each contain a single sediment sample location.
3) The weighted concentration for each polygon (Cw_i) is calculated by multiplying the concentration (C_i) by the area (A_i) of that polygon, or:

$$Cw_i = C_i * A_i$$

4) The weighted concentration for each polygon (Cw_i) is averaged across the entire surface area for the river bottom project surface area.

$$SWAC_{river} = \frac{\sum_{i=1}^{n} Cw_i}{A_{river}}$$

PCB SWAC concentrations can be related to the bioaccumulative potential within the food web, as previously described. Average total PCB surface sediment concentrations were monitored in different locations of the project area within multiple studies conducted by ORD, before (2006), immediately following (2007), and multiple years after dredging (2009, 2011). The data were used by GLNPO to calculate PCB SWAC values [24, 27, 28, 32]. While PCB data were acquired for each sampling effort, sample locations, analysis methods, and analytical laboratories were not necessarily consistent among the various efforts. An overview of the surface sediment chemistry data used to assess the pre- and post-remedy PCB SWAC comparisons is described below.

5.1.1 Pre-Remediation – PCB SWAC

In 2006, GLNPO designed and implemented a pre-remedy characterization for the GLLA project area [28]. A total of 30 sample stations were identified and placed in the GLLA project area using a randomized grid design. At each station, surface sediment samples were collected to a depth of 4 in. and analyzed for total PCBs using a homolog method. PCB homologs were measured based on a calibration using the first and last congeners of each level of chlorination, and summed to provide total PCB homolog concentrations on a dry weight basis [26].

The 2006 surficial sediment PCB concentrations were plotted using Earth Vision™ software, and a two-dimensional minimum tension gridding was applied with spacing of 15 ft by 15 ft in the *x* and *y* dimensions. The contoured data are shown in Figure 5-1. The pre-remediation average total PCB homolog concentration in the GLLA project area was 0.51 mg/kg-dry weight. A maximum concentration of 6.60 mg/kg-dry weight was detected within the Ashtabula North Slip [18]. The elevated PCB concentrations within the Ashtabula North Slip and the western portion of the Upper Turning Basin, compared to River Run and Lower Turning Basin [18], led to subsequent investigations that identified a secondary source originating from upstream in Strong Brook.

A SWAC analysis using this sediment surface data yielded a total PCB congener SWAC of 0.76 mg/kg dry weight for the GLLA project area [18].

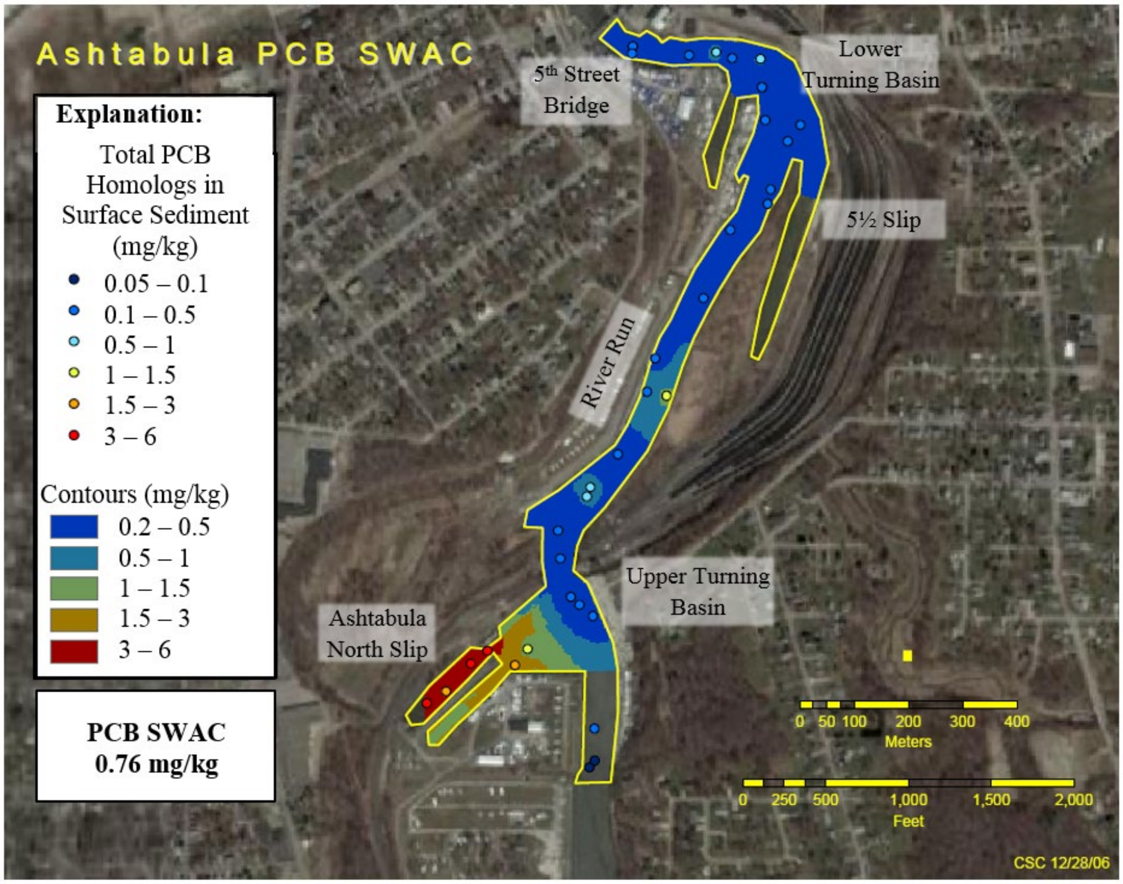


Figure 5-1. 2006 Pre-Remediation Total PCB Homolog Surface Concentration Contours and Surface Weighted Average Concentration (SWAC). Source: U.S. EPA [18]

5.1.2 Post-Remediation – PCB SWAC

A post-remedy SWAC analysis was conducted using surface sediment PCB concentrations obtained in 2007, 2009, and 2011 by GLNPO. Surface sediment samples (the top 0-6 in.) were divided from each of the Dredge Management Units (DMUs) shown in Figure 5-2. In 2007 and 2009, surface sediment samples were assessed for total PCBs (as measured through both Aroclors and congeners) [11, 13].

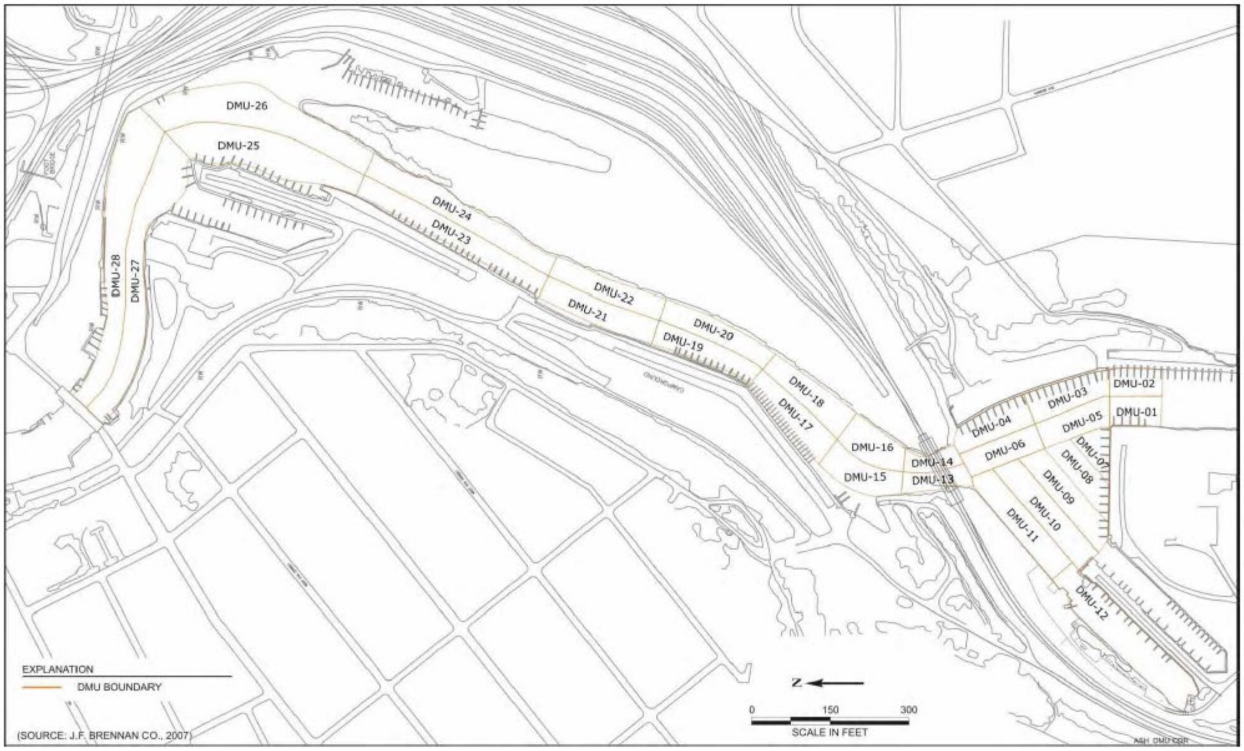


Figure 5-2. Dredge Management Units (DMUs) for the GLLA Project Area.
Source: U.S. EPA [24]

The 2007 data were used to calculate an immediate post-dredge SWAC and to ensure that dredging activities did not result in elevated levels of PCBs in surface sediments. SWAC was again calculated in 2009 and 2011 to assess long-term trends. The 2007 total PCB concentrations in surface sediments collected immediately post-remediation were used as "baseline" measurements for comparing long-term changes in residual contamination and possible recontamination in the years following the GLLA project. The immediate post-dredge PCB SWAC was determined to be 1.35 mg/kg in 2007; in 2009 the SWAC had decreased to 0.39 mg/kg [11].

In 2011, GLNPO and ORD conducted a sediment sampling survey consisting of four discrete sampling efforts each with specific objectives [27]. Of the four events, three included the collection of surface sediment samples and the fourth was a core collection effort. The following describes the four efforts, hereafter identified as Studies 1 through 4. Figure 5-3 shows the combined Study 1-4 sample locations, which totaled 94 samples, 70 of which were in the GLLA project area. PCBs as assessed through the summation of nine Aroclors were used to calculate a 2011 SWAC value [13, 34].

Study 1: Surface sediment samples were collected from the top 6 in. at 54 locations including the Ashtabula North Slip and the confluence of Strong Brook and within the Upper Turning Basin, River Run, and Lower Turning Basin. Thirty-three of the 54 total samples were within the GLLA project area. Each sample was analyzed for PCB Aroclors.

Study 2: Additional surface sediment samples were collected from a depth of 6 in. at 17 locations within the Ashtabula North Slip and adjacent to Strong Brook. These samples were all within the GLLA project area and were analyzed for PCB Aroclors.

Study 3: Eight additional core samples were collected from within the Ashtabula North Slip to depths ranging from 3 to 10 ft. Each core was processed into unique segment lengths and analyzed for PCB Aroclor and PCB congeners. Only the PCB results for the top 6 in. of each core were utilized for this REA.

Study 4: Fifteen additional surface sediment samples were collected from stations containing macrobenthos sampler and passive sampler devices. These surface sediments were collected from the top 6 in. and analyzed for PCB congeners. Of the 15 total stations, 12 were within the GLLA project boundary.

The PCB results for Study 1-4 were used to estimate the surface sediment concentrations after dredging; however, it is noted that the samples were analyzed by three different analytical laboratories using different methodologies [27]. Study 1, 2 and 3 samples were analyzed for PCB-as-Aroclor by each of the three laboratories; Study 4 samples were analyzed for PCBs-as-congeners. Total PCB concentrations for Study 4 were derived from the summation of 100 individual PCB congeners, which comprise approximately 98% of the total PCBs in most environmental samples. The fact that these data were developed by three separate laboratories using varying methodologies has implications on data comparability. Methods that sum Aroclors can be especially susceptible to implementation differences [27].

Total PCBs concentrations for each of the stations in Study 1-4 were used to create sediment surface contours. Figure 5-4A shows the PCB surface sediment concentrations by dry weight and Figure 5-4B shows PCB surface sediment normalized to total organic carbon (TOC) content [27]. While TOC content did vary spatially, TOC-normalized surface sediment concentrations did not vary considerably within the GLLA dredge area. The resulting total PCB Aroclor concentrations yielded a 2011 PCB SWAC value of 0.41 mg/kg [34].

Figure 5-4 also depicts elevated PCB concentrations within the Ashtabula North Slip. In 2011, surface sediment samples within the Ashtabula North Slip averaged 1.94 mg/kg, about five times higher than the PCB concentrations that were observed downstream.

Figure 5-3. Post-Remediation Surface Sampling Locations for Studies 1-4. Source: U.S. EPA [32]

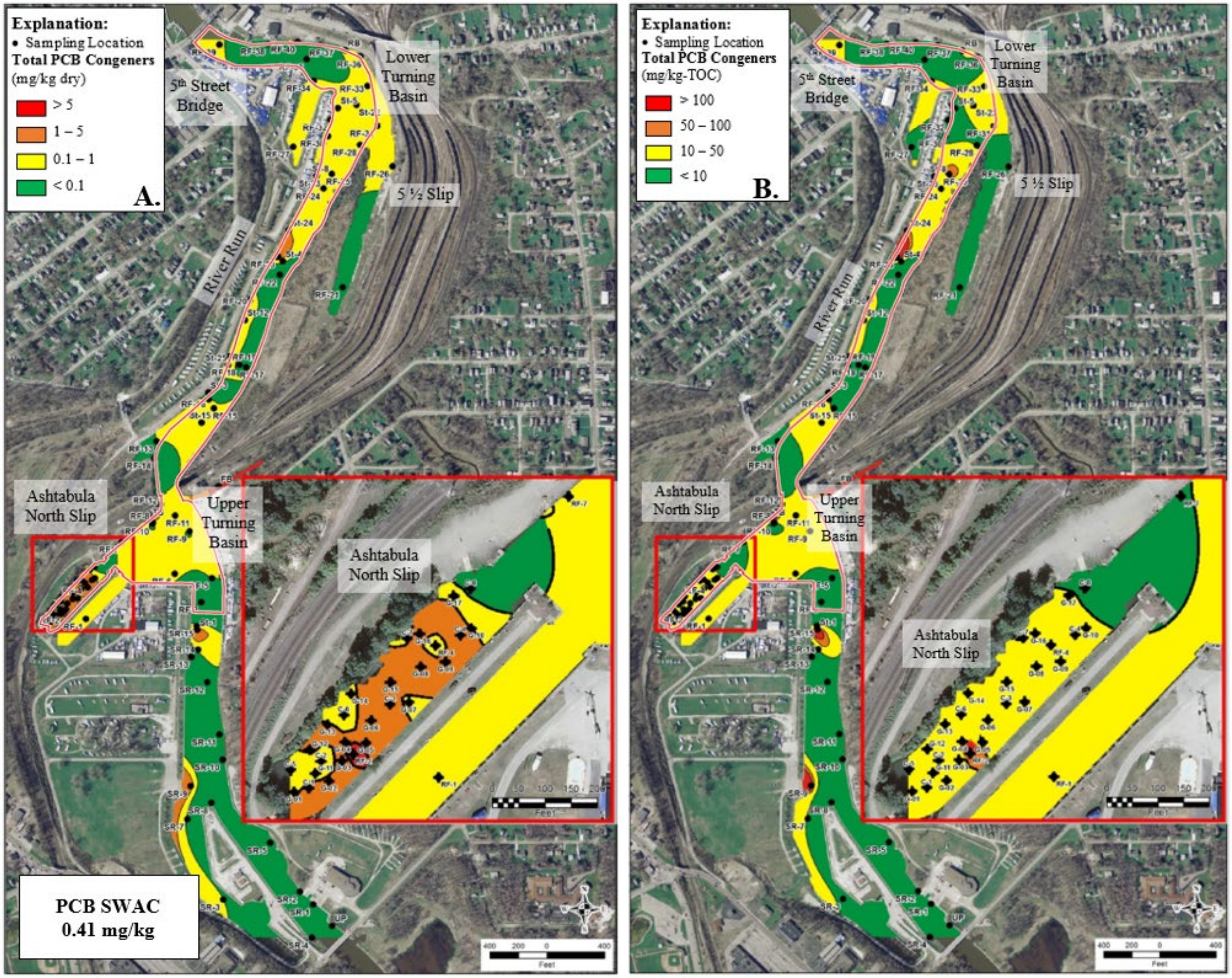


Figure 5-4.2011 Post-Remediation Surface Sediment Total Average PCB Congener Concentration Contours and Calculated SWAC value: A) Total PCB Approximation Contours on a Dry-Weight Basis (mg/kg dry weight) B) Total Organic Carbon (TOC)- Normalized Total PCB Approximation Contours (mg/kg-TOC). Source: U.S. EPA [32]

5.1.3 Changes in PCB SWAC over Time

A plot of individual total average PCB surface sediment concentrations pre-remediation versus post-remediation for samples collected from approximately the same locations is shown in Figure 5-5. The plot shows a cluster of points near the origin; these indicate low PCB concentrations with very little change pre- to post-remediation within the Upper Turning Basin, River Run, and Lower Turning Basin. Elevated concentrations were observed at single locations within River Run and the Upper Turning Basin; however, differences in analysis methods may account for some of the observed differences [27].

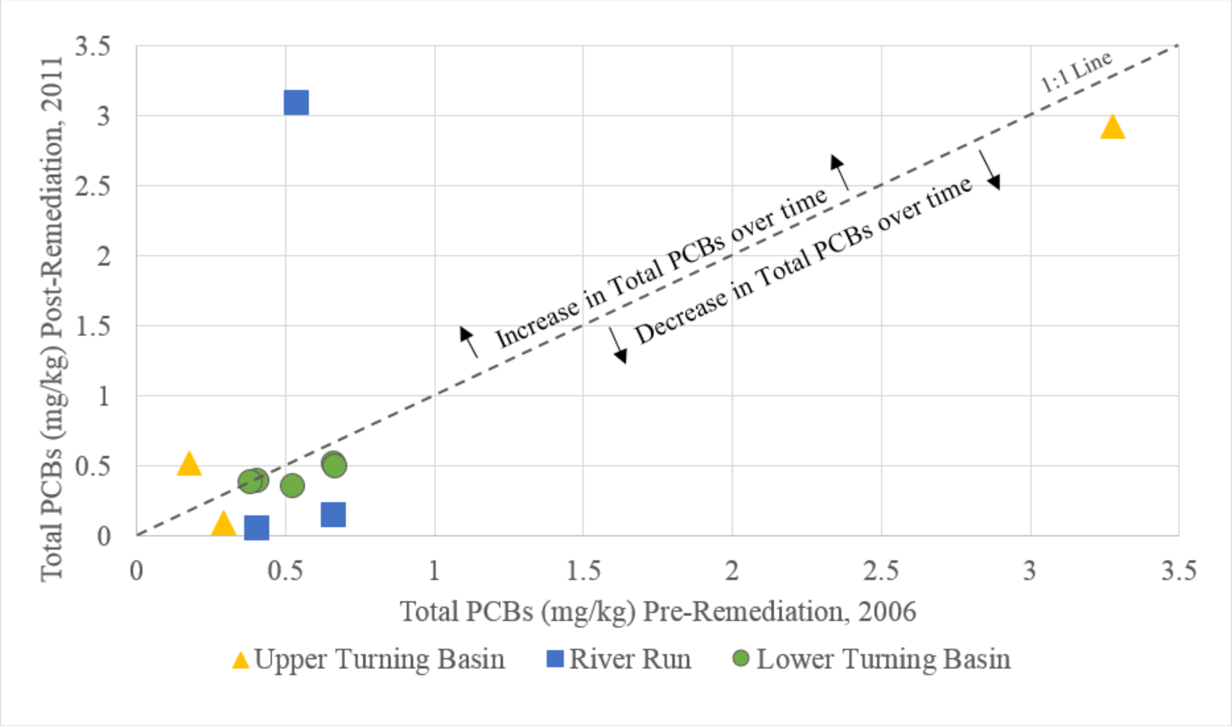


Figure 5-5. Plot of Individual Total Surface Sediment PCB Congener Concentrations (mg/kg, dry weight) Collected from Similar Locations Pre- and Post-Remediation. Sources: U.S. EPA [27], U.S. EPA [28], U.S. EPA [32]

While the average surface concentrations increased slightly after dredging, by 2011 surface sediments within the main stem of the River recovered to near pre-dredge concentrations due, in part, to natural deposition of uncontaminated sediments transported from upstream locations. As shown in Figure 5-6 the actual PCB SWAC values obtained within the GLLA project area in 2007 were well below the immediate post-remediation goal of 7.5 mg/kg. While the PCB SWAC in 2009 and 2011 were lower than the 2007 immediate post-remediation PCB SWAC, the rate of decline decreased. A best fit power trendline of the very limited dataset in Figure 5-6 shows that PCB SWAC values are projected to meet the long-term (10-year) post-GLLA project goal of 0.25 mg/kg; however, more data are needed to develop confidence with such few data points.

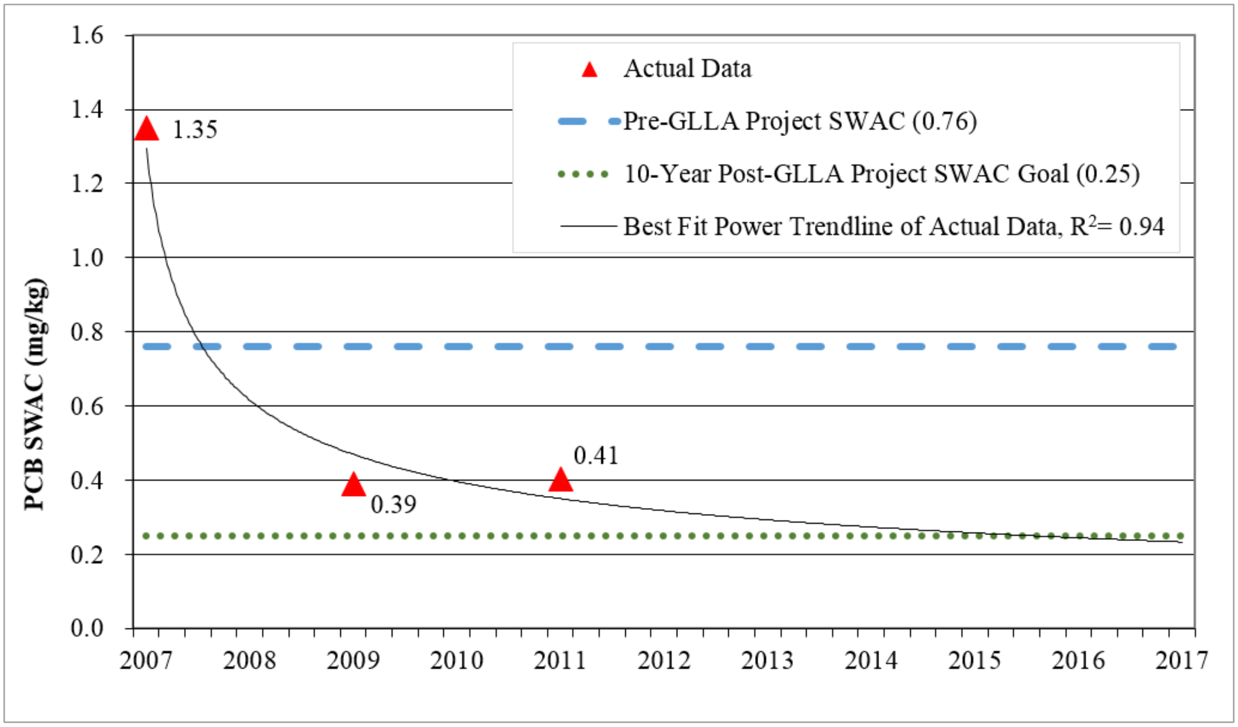


Figure 5-6. Post-Remediation Actual and Estimated PCB SWAC Values.
Sources: U.S. EPA [11], U.S. EPA [34]

Table 5-1. PCB SWAC Values Pre- and Post-Remediation within the GLLA Project Area

	Pre-Remediation		***Post-Remediation***				
			Baseline Goal	*Actual Values*			*10-Year Goal*
	1995/96	*2006*	*2007*	*2007*	*2009*	*2011*	*2017*
Surface Weighted Average Concentration (SWAC) Total PCBs (mg/kg)	*6.29*	*0.76*	*7.5*	*1.35*	*0.39*	*0.41*	*0.25*

Sources: Ashtabula River Partnership [3], U.S. EPA [24], U.S. EPA [34]

5.2 Subsurface PCB Mass Estimates

Sediment core samples enable temporal chemical analysis to be obtained at a single location (the deeper the sediment core, the older the accumulated sediments). Multiple cores distributed over a study area can also be developed into a three-dimensional spatial representation of the COCs. Sediment core concentration profiles can be used to estimate the total mass of COCs in a given volume by applying an average COC concentration profile from the core against an estimated sediment volume within a bounded space (dredge area). Using three-dimensional modeling, an estimate was developed for the mass in specified areas. Sediment core profiles were used to determine the pre-dredge contaminant mass in the Ashtabula River, whereas a comparison of pre- and post-remedy bathymetric surveys were used to determine the total volume of sediment removed. Applying the known volume of sediment removed against pre-remedy contaminant concentration estimates from core profiles enabled a post-remediation PCB mass removal to be determined. One of the GLLA RPGs was to remove 82% or as much PCB mass as possible. The following sections describe the pre- and post-remediation datasets to assess PCB mass removal.

5.2.1 Pre-Remediation Subsurface PCB Mass Estimates

In an effort to understand the extent of PCBs in the GLLA project area, the Ashtabula River Group collected core samples in 1989/90 and 1995/96 [3]. The maximum average PCB concentrations obtained within cores during these two sampling events was 660 mg/kg and 160 mg/kg, respectively. Figure 5-7 shows sampling locations and both plan and side-views of sample locations that exceeded 50 mg/kg total PCBs, the PCB concentration at which sediments must be addressed per TSCA regulations [3].

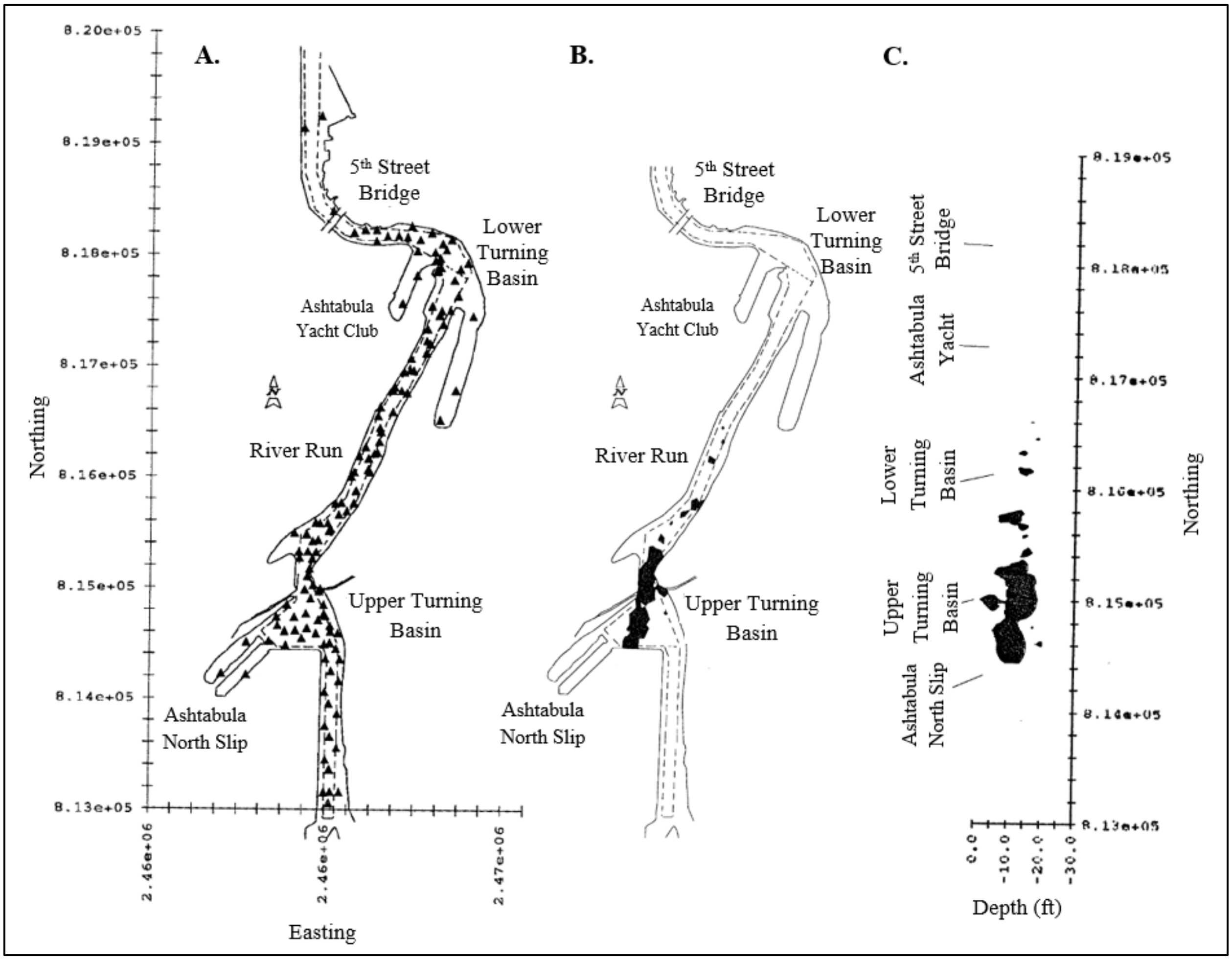


Figure 5-7. Pre-Remediation 1989/90 and 1995-96 A) Core Sediment Sampling Locations. B) Plan view of PCB Plume Greater than 50 mg/kg. C) Side view of the PCB Plume Greater than 50 mg/kg. Source: Ashtabula River Partnership [3]

Core results from these sampling events were used to estimate a total pre-remediation mass of 19,422 lb (8,810 kg) of PCBs within the GLLA project area [3].

In 2006, prior to dredging, ORD collected additional sediment cores in the River Run between RM 1.3 and 1.5 (Figure 5-8). The purpose of this investigation was to evaluate metrics and methods to measure dredge residuals [32]. Representative total PCB sediment profiles for select cores are shown in Figure 5-9 and Figure 5-10 for RM 1.3 and 1.5, respectively. The pre-dredge 2006 PCB concentrations (shown in red) were greatest at mid-depth within each core and less at the core maximum depth and at the surface of each core sample.

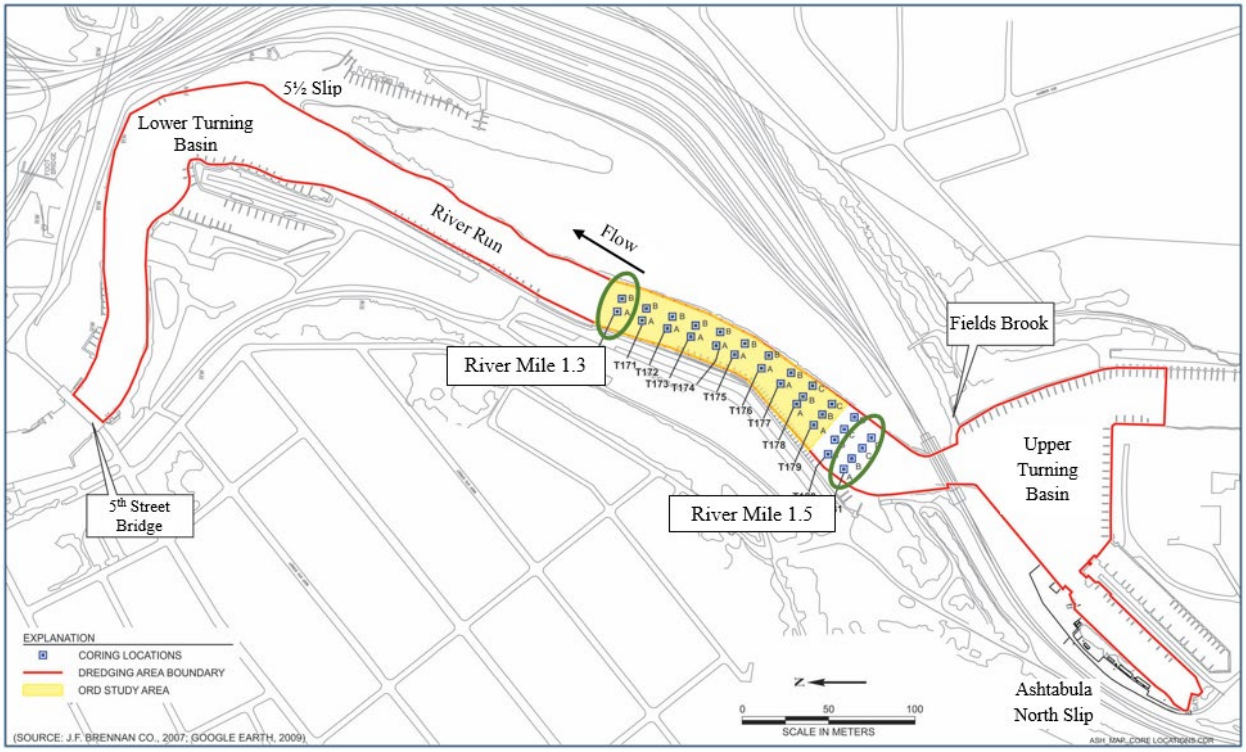


Figure 5-8. U.S. EPA's Sediment Core Sample Locations within the GLLA Project Area. Source: U.S. EPA [32]

5.2.2 Post-Remediation Subsurface PCB Mass Estimates

Thirty sediment cores were again collected at locations in the River Run to the point of refusal in 2007 and 2011 by ORD. Each core collected was analyzed for total PCBs using a congener method. Immediate post-remediation cores (shown in blue, Figure 5-9 and Figure 5-10) were the shallowest core samples attained (since significant sediment depth was removed during dredging). The elevated 2007 PCB concentrations are indicative of dredge residuals present immediately following the dredging activities [24]. Due to the accumulation of cleaner sediments between 2007 and 2011, sediment PCB concentrations within the full length of the cores had returned to pre-dredge surface sediment levels or lower (2011, shown in green) [32].

5.2.3 Changes in Subsurface PCB Mass Estimates over Time

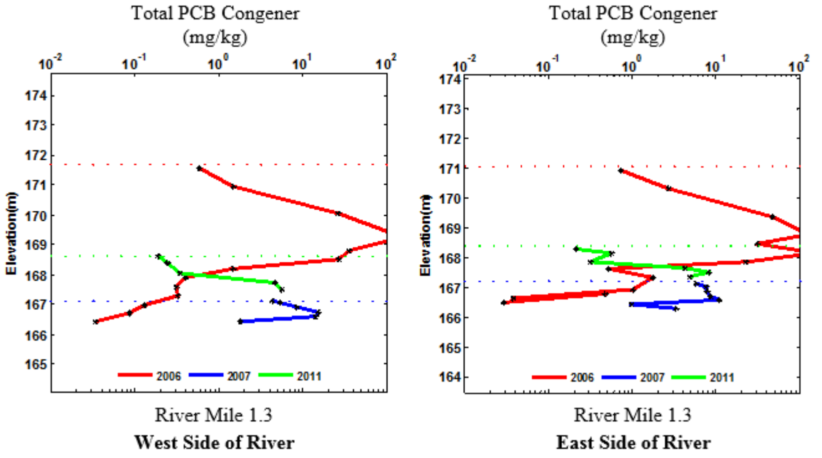
Representative total PCB sediment profiles for select cores are shown in Figure 5-9 and Figure 5-10 for RM 1.3 and RM 1.5, respectively, in 2006, 2007, and 2011. At RM 1.3 the River width supported only the collection of two cores that were collected on equal lateral spacing, whereas the River width allowed for four equally laterally spaced cores at RM 1.5. While data for all the collected cores are available in the U.S. EPA report [32], these figures are representative of the other 10 core transect locations in the study area. Each transect was spaced on 98 ft (30 meter) intervals. The color-coded dashed lines in the figures represent the sediment surface elevations at the time the core samples were collected.

While these data were not necessarily intended for a REA, the core samples were collected and processed using a uniform and consistent sampling and analysis protocol for each time point; therefore, these samples were included to further characterize sediments in the project area. Sediment cores were collected at locations shown in Figure 5-8 at time points to include 2006, 2007, and four years post-remediation in 2011.

There was a considerable increase in total PCB concentration in the surface sediments at core locations from 2006 to 2007 within the River Run investigation, followed by a trending decrease from 2007 to 2011. This increase was likely due to elevated dredge residuals immediately post dredging. Over time, cleaner sediment from upstream was deposited atop the more contaminated surface sediments. Statistical analyses (paired t-test, a nonparametric sign test, and a nonparametric Wilcoxon Signed Rank test) indicated that the observed decline in PCB concentrations was significant within the observed years from 2006 to 2011 and from 2007 to 2011 ($p \leq 0.05$). Thus, there is sufficient statistical evidence that a significant decrease in the mean (and median) PCB concentration occurred from 2006 to 2011, and from 2007 to 2011 within the study area.

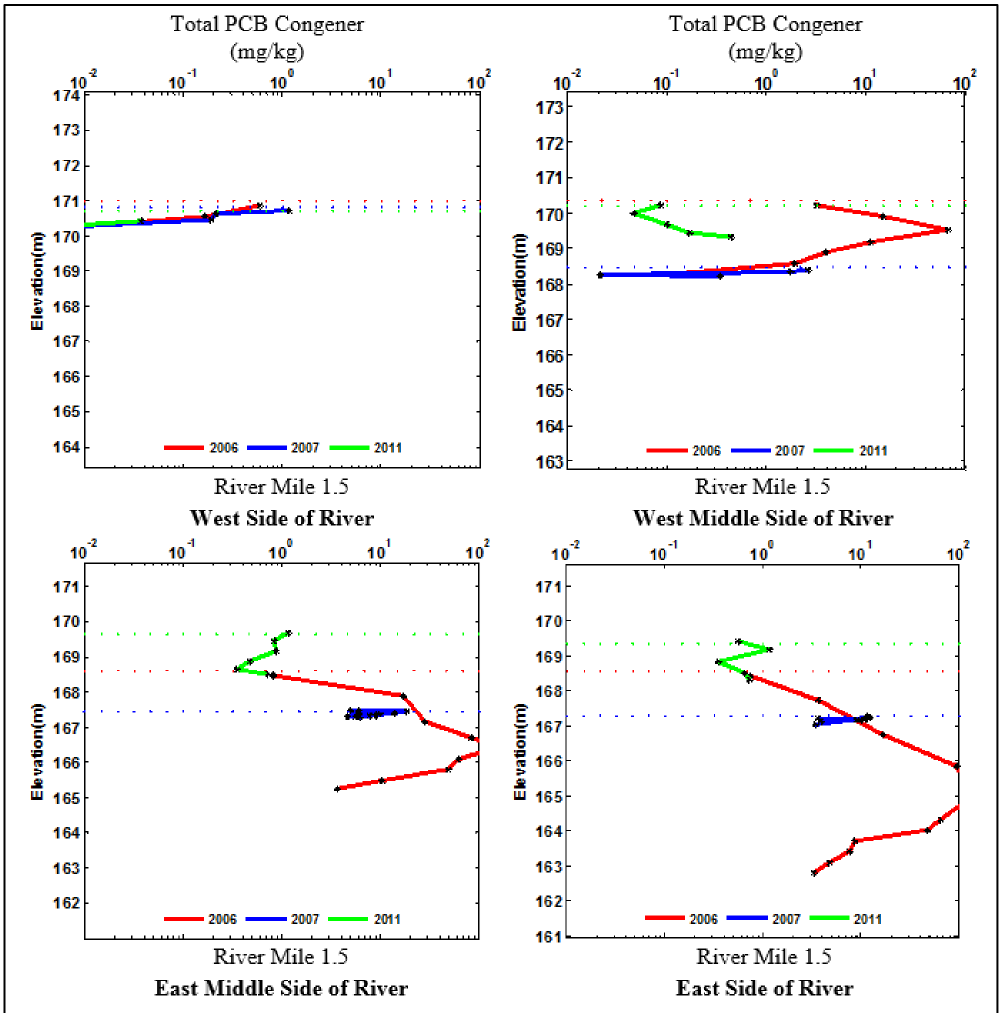
Much of the PCB mass that was removed was in deep, historic sediments. Total PCB concentrations for surface sediments (<6 in.) were relatively low prior to the start of the remediation (average pre-remediation total PCB concentration 0.51 mg/kg, dry weight) [26]. Core samples collected pre-dredge from within the ORD study area found the highest PCB concentrations at sediment depths of 2 to 10 ft, with most high PCB concentrations being observed within sediments collected 5 to 8 ft below the surface (average maximum PCB concentration within 2006 ORD study area core samples, 92.5 mg/kg) [24]. In 2011, the total PCB concentration within 79 surface samples collected within the GLLA project area ranged from not detected (in 15 of the 79 samples) to 18 mg/kg dry weight, and averaged 0.01 mg/kg dry weight [27].

Core samples indicate that an estimated 14,324 lb (6,497 kg) of the original 19,432 lb (8,814 kg) of PCB mass was removed from the GLLA project area [11]. This represents 74% of the originally estimated PCB mass present within the project area.



The color-coded dashed lines across each figure represent the sediment surface elevations at the time the cores were collected.

Figure 5-9. Total PCB Congener Concentrations (mg/kg) in Pre- (2006) and Post-Dredge (2007 and 2011) Cores at River Mile 1.3. Source: U.S. EPA [32]



The color-coded dashed lines across each figure represent the sediment surface elevations at the time the cores were collected.

Figure 5-10. Total PCB Congener Concentrations in 2006, 2007, and 2011 Core Samples Collected at River Mile 1.5. Source: U.S. EPA [32]

5.3 Radionuclide Activities in Sediment

Specific radionuclides were found in sediments in the Ashtabula River during initial site characterization [3]. The investigation identified radium, thorium, and uranium. Ohio Department of Health has mandated that any wastes containing radionuclides above background levels could not be commingled with other landfill wastes, and must therefore be separately monitored and contained [13]. Prior to and following remediation, surface sediments were collected and analyzed to determine pre- and post-remediation activity levels for these specific radionuclides. The RPGs established a maximum radium and uranium concentration goal of 2 pCi/g or average background levels.

5.3.1 Pre-Remediation Radionuclide Activities in Sediment

In 2006, surface sediments from seven locations within the River (five within the GLLA project area and two upstream) were collected by GLNPO and analyzed to determine radionuclide activities (Table 5-2) [28]. Pre-remediation levels of total radium surpassed the 2 pCi/g target limit within Lower Turning Basin, River Run, and Upper Turning Basin (2.16, 2.55, and 2.20 pCi/g, respectively). Elevated activities of total thorium were found in River Run (2.18 pCi/g) [28].

5.3.2 Post-Remediation Radionuclide Concentrations in Sediment

In 2011, GLNPO analyzed seven surface sediment samples within the GLLA project area and four surface sediment samples upstream of the project area for radium-226, radium-228, total thorium, and total uranium (Table 5-2) [35].

When the 2011 radium-226 and radium-228 activities are observed separately, only one sample collected from River Run yielded a radium-226 activity above the 2 pCi/g RPG (2.16 pCi/g) (Table 5-2). When radium-226 and radium-228 are totaled, the average total radium (226/228) activity for the GLLA project area (2.74 pCi/g) was not statistically different from the total average radium activity observed within samples collected upstream of the GLLA project area (2.63 pCi/g; $p > 0.05$) (Table 5-2) [35].

The sum of thorium (228/230/232) activities were relatively uniform across the GLLA project area in 2011 (average sum 1.09 pCi/g) [35]. The thorium activities found within the GLLA project area were not statistically different from the thorium activities observed within the unremediated upstream Ashtabula River samples collected in 2011 ($p > 0.05$).

In 2011, the Upper Turning Basin yielded an elevated concentration of total uranium (233/234/235/238) when compared to all other collected samples (2.61 pCi/g) [35]. When the 2011 average sum of upstream uranium activity is compared to the average GLLA total uranium activity, a significant difference was noted between the two areas ($p < 0.05$). However, the average uranium activity within the GLLA project area still met the RPG of less than 2 pCi/g (GLLA average 1.38 pCi/g).

5.3.3 Changes in Radionuclide Activities in Sediments over Time

The average radionuclide activities of the sum of radium (226/228) and sum of uranium (233/234/235/238) increased in 2011 when compared to 2006 activities, while the sum of thorium (228/230/232) just slightly decreased (Table 5-2). However, the post-remediation concentrations were comparable to the average concentrations observed upstream of the GLLA project area. In 2011, only the average total uranium activity within the GLLA project area was significantly elevated compared to the average activity observed upstream of the GLLA project area ($p < 0.05$). Slightly elevated activities downstream are believed to be the result of deposition from sediments transported from upstream locations.

The radionuclide goal for the GLLA project was to ensure that the average long-term (10-year) activities for radionuclides radium-226, radium-228, and the sum of uranium were less than 2 pCi/g or below the average background levels. In 2011, the only a single surface sediment sample collected within River Run surpassed the 2 pCi/g RPG for radium-226. Activity levels for radium-228, sum of thorium, and sum of uranium were all below the 2 pCi/g goal, in 2011. The average sum of radium within the project area was not significantly different from the average upstream activity level. Therefore, this RPG was attained.

Table 5-2. Pre- and Post- GLLA Project Radionuclide Activities

Study Location Name 2006	*Study Location Name 2011*	*Approximate River Mile*	*River Segment* [a]	*2006 ΣRadium*	*2011 Radium-226*	*2011 Radium-228*	*2011 ΣRadium*	*2006 ΣThorium*	*2011 ΣThorium*	*2006 ΣUranium*	*2011 ΣUranium*
				pCi/g				*pCi/g*		*pCi/g*	
10	-	0.6	5th Street Bridge	1.86	-	-	-	0.40	-	0.69	-
20	RF-37	0.9	Lower Turning Basin	2.16	1.24	1.30	2.54	1.80	1.35	0.64	1.23
-	RF-31	1.0	Lower Turning Basin	-	1.15	1.53	2.68	-	0.85	-	ND
-	RF-28	1.1	5½ Slip	-	2.16	1.22	3.38	-	0.99	-	ND
6	RF-24	1.2	River Run	2.55	1.16	1.14	2.30	2.18	1.03	0.71	0.87
14	RF-16	1.5	River Run	1.32	1.14	1.73	2.87	1.19	1.00	0.42	1.25
19	RF-12	1.7	Upper Turning Basin	2.20	1.61	1.95	3.56	0.29	1.27	0.56	2.61
-	RF-4	1.75	Ashtabula North Slip	-	1.10	0.72	1.82	-	1.16	-	0.94
29/30	*SR-13/ SR-4/ SR-7/ SR-8*	*>1.8*	*Average Upstream*	*2.86*	*1.29*	*1.35*	*2.63*	*1.55*	*1.13*	*0.52*	*0.89*
GLLA Project Average				2.02	1.37	1.37	2.74	1.17	1.09	0.60	1.38
Project Target Goal Maximum				2.0							

[a] The Upstream sampled location was not part of the GLLA project, but is shown as a reference value for comparison purposes. ND- Not detected above the method detection limit. Values given in red do not meet the RPG Target of 2 pCi/g, values in green meet or are below the target. Sources: U.S. EPA [28], U.S. EPA [35]

5.4 Discussion of the Chemical LOE and Changes Pre- and Post-Remediation

While datasets for PCBs in the sediment surface were derived from different laboratories using different methods for quantifying total PCB concentrations, these data were utilized to make qualitative and some quantitative comparisons between pre- and post-remediation conditions. These data showed no significant change in surface sediment concentrations in 2011, four years post-remediation. However, it is important to note that dredge residuals immediately post-remediation were covered via processes of natural sediment accretion and deposition by cleaner sediments. As such, two of the intermediate RPGs for the GLLA project that focused on PCB surface sediment and PCB SWAC were ultimately attained. While the long-term PCB SWAC goal of 0.25 mg/kg has yet to be confirmed, estimated PCB SWAC concentrations are expected to be met (Figure 5-6). An additional RPG was to ensure that PCB concentrations were below TSCA regulation levels (< 50 mg/kg) at all sampled locations. This goal was met both immediately post-remediation in 2007 and again in 2011 investigations.

Core samples estimate 14,324 lb (74%) of the original PCB mass present within the project area were removed with the GLLA dredging.

Surface sediment radionuclide samples collected before and after dredging indicated that activities for the sum of radium (226/228) and the sum of uranium (233/234/235/238) increased following the GLLA project, while the sum of thorium (228/230/232) just slightly decreased. The average total radium activities within the project area was not significantly different from the average upstream background activities, but the average was above the 2 pCi/g project goal. Average total thorium was not statistically different from the upstream background activity. While the average total uranium within the project area was statistically higher than the average upstream activity in 2011, the average total uranium was still less than the 2 pCi/g goal. Therefore, this RPG was attained.

Key Chemical Outcomes:

- 14,324 lb (6,497 kg) of PCB mass was removed from the GLLA project area.
- Short-term PCB SWAC goal was met; long-term PCB SWAC goal of 0.25 mg/kg has yet to be confirmed.
- PCB concentrations within all sampled sediments were below TSCA regulation levels.
- Average activity levels for radium-226, radium-228, sum of thorium, and sum of uranium were all below the 2 pCi/g goal, in 2011.

6 Conclusions

The GLLA project outlined six RPGs to track progress of the remediation effort [11, 14]. Project goals were focused on the change in COCs, particularly PCBs, over time, and consequently these project-specific goals were associated primarily with data from the chemical LOE. However, the remediation also had physical and biological outcomes, and therefore changes in physical and biological data were also examined to assess remedy effectiveness. Each RPG outcome is summarized in Table 6-1. Note that most goals are supported by data from multiple LOEs.

Efforts undertaken by federal, state, and local entities to monitor remediation activities at the Ashtabula River have been combined to present the overall changes observed between pre- and post-remediation. The 2006-2007 GLLA project removed 497,383 yd^3 of contaminated sediments with an associated 14,324 lb (6,497 kg) of PCB mass, and rebuilt 800 ft of habitat near the 5½ Slip. Table 6-2 summarizes the observed environmental changes, organized by data type. Of the 12 types of data presented, nine indicate statistically significant positive change following the GLLA remediation (indicated through the ++ demarcation).

It is noted that not all of the data used in this remedy effectiveness assessment or used in the comparisons between before and after dredging activities were derived from precisely the same locations, nor always analyzed using the same analytical processes. As physical, biological, and chemical characteristics can change significantly over spatial and temporal scales, the variation in deployment locations is recognized as a limitation. Likewise, differences in analytical techniques have the potential to impact the comparability of the data. These factors have been considered, and both quantitative and qualitative comparisons of paired and unpaired datasets have been formulated to show both positive and negative impacts, as well as overall trends.

Since the 2006-2007 GLLA remediation effort, cleaner sediments from upstream have deposited within the project area. The accumulation of these sediments and additional habitat restoration efforts in the 5½ Slip and into River Run have resulted in lower PCB SWAC values, reduced concentrations of PCBs within sport fish, improved QHEI, IBI, and MIwb metrics, and reduced concentrations of bioavailable PCBs. Additional time and/or resources may be needed to further reduce residual low-level PCB bioavailability and improve the macrobenthos community index (ICI). Overall, the 2006-2007 GLLA project was effective in removing historic PCBs and improving the environmental quality of the Ashtabula River.

Table 6-1. Status of Meeting GLLA Project Goals

Remedial Project Goals (RPG)	Remediation Status	Data Outcomes and Associated Line of Evidence (LOE)
Leave residual sediment surface contaminant concentration no worse than existing surficial sediment concentration.	Achieved	• Chemical LOE: Surface sediment samples did not show a significant change in PCB congener concentrations within samples collected from similar locations in 2006 and 2011. • Biological LOE: Decline in total PCB concentrations for both whole fish and macroinvertebrate samples at post-remediation is indicative of a reduction in PCB bioavailability in surface sediments.
Remove PCB-containing sediments greater than TSCA limit of 50 mg/kg and associated scour-risk mass.	Achieved	• Chemical LOE: All sediment samples collected post-remediation contained less than 50 mg/kg PCBs on a dry weight basis.
Remove 82% or as much as possible of the PCB mass within the project area	Achieved	• Chemical LOE: 74% (14,324 lb) of the original estimated 19,422 lb of PCB mass was removed from the project area. • Biological LOE: Decline in total PCB concentrations for both whole fish and macroinvertebrate samples at post-remediation is indicative of a reduction in PCB bioavailability in surface sediments. • Chemical LOE: Sediment core samples collected within a sub-set of the GLLA project area indicate a statistically significant decrease in the mean PCB concentration when pre- and post-dredge samples are compared.
Immediately following dredging activities, achieve a post-dredge SWAC of less than 7.5 mg/kg of PCBs.	Achieved	• Chemical LOE: SWAC immediately post-dredging (2007) was 1.35 mg/kg PCBs.
Achieve long-term SWAC for PCBs of 0.25 mg/kg, and for radionuclides (radium-226, radium- 228, and uranium) of 2 pCi/g or average background.	Anticipated Achievement	• Chemical LOE: Estimates using post-remediation measurements are anticipated to meet the long-term (10-year) 0.25 mg/kg PCB SWAC goal, however more data are needed to confirm these findings. (2009- 0.39 mg/kg; 2011- 0.41 mg/kg) • Chemical LOE: The available average radionuclide surface sediment activities are consistent with the average background concentrations observed upstream of the GLLA project area.
Reestablish in-water littoral shoreline habitat along the eastern bank of River Run from 5½ Slip south 800-ft.	Achieved	• Physical LOE: 800-ft of shoreline was physically recreated in 2009-10 under the GLLA. Additional work under the GLRI extended the effort in subsequent years. • Physical LOE: Increasing QHEI values indicate physical habitat restoration increased the habitat quality for aquatic populations. • Biological LOE: Post-remediation IBI and MIwb values showing increasing trends are indicative of the reestablishment of habitat for native fish populations.

Table 6-2. Environmental Changes Following Remediation by Line of Evidence

Line of Evidence	Relative Change*	Remarks
Physical		
Bathymetry	++	497,383 yd^3 (91%) of the estimated contaminated sediment volume was removed within the project area [11].
Qualitative Habitat Evaluation Index (QHEI)	++	Increasing QHEI values indicate that the physical habitat within the project area is able to support a diverse biological community [20]. BUI# 14 Loss of Fish and Wildlife Habitat removed in 2014.
Biological		
Invertebrate Community Index (ICI)	-	ICI indicates an overall decline in macroinvertebrate diversity and population [43]. BUI #6: Degradation of Benthos remains impaired.
Macroinvertebrate Tissue PCBs	++	Significantly lower concentrations of total PCB congeners were seen within the project area after remediation [32].
Index of Biotic Integrity (IBI); Modified Index of Well-Being (MIwb)	++	Increasing IBI and MIwb values indicate fish mass, density, diversity, and populations have recovered [20]. Note: This trend was also seen prior to the GLLA project. BUI# 3 Degradation of Fish and Wildlife Populations removed in 2014.
Sport Fish Fillet PCBs	++	PCB concentrations in smallmouth bass, common carp, and freshwater drum fillets collected in the Ashtabula River post-remediation were not different from the background Lake Erie fish of similar size and species [20]. BUI# 1 Restrictions on Fish and Wildlife Consumption removed in 2014.
Whole Brown Bullhead PCBs	++	The total PCB congener concentrations in brown bullhead significantly decreased after remediation [19].
Brown Bullhead Tumors/ Anomalies	+	Rate of skin and liver tumor incidence decreased, however rates remain above the minimum removal criteria for BUI #4: Fish Tumors or Other Deformities [33].
Brown Bullhead DNA Damage	++	DNA damage in blood and liver samples decreased [19].
Other		Caged Channel Catfish: Pre- remediation PCB concentrations increased, but not repeated post-remediation [14]. Amphipod Survival: Limited studies suggest presence of toxic sediments pre- and post-remediation [28, 29]. Riparian Spiders: Post-remediation samples suggest ongoing PCB bioavailability [30].
Chemical		
PCB SWAC	++	PCB SWAC concentrations obtained post-remediation met project goals, and are projected to meet the 10-year post-remediation goal (2007- 1.35 mg/kg; 2009- 0.39 mg/kg; 2011- 0.41 mg/kg) [11, 34].
Subsurface PCB Mass	++	14,324 lb (74%) of the original estimated PCB mass was removed from the project area [11]. Core samples collected post-remediation in the ORD Study Area had lower concentrations of PCBs [32].
Surface Sediment Radionuclides	0	The activities of total radium and total uranium slightly increased; total thorium slightly decreased. Post-remediation average activities were consistent with average background concentrations [35].

*Relative change when comparing pre-remediation to post-remediation data discussed in this report.

++	Indicates an overall improvement with statistical confidence.
+	Indicates a general improvement that was not statistically significant or statistics were unavailable.
0	Measures were unable to differentiate a change.
-	Indicates a general decline that was not statistically significant or statistics were unavailable.
--	Indicates an overall decline with statistical confidence.

7 References

[1.] ATSDR. Toxiocological Profile for Polychlorinated Biphenyls (PCBs). Agency for Toxic Substances and Disease Registry, US Department of Health and Human Services, Public Health Service. 2000.

[2.] Gibson PP, Mills MA, Kraus JM, Walters DM. A Modeling Approach to Compare ΣPCB Concentrations Between Congener-Specific Analyses. Integrated Environmental Assessment and Management. 2016;13(2).

[3.] Ashtabula River Partnership. Comprehensive Management Plan Volume 1: Remedial Actions for Environmental Enhancement and General Navigation, Dredging & Disposal of Contaminated Sediments. https://www.epa.gov/ashtabula-river-aoc/ashtabula-river-comprehensive-management-plan-2001; 2001.

[4.] Ohio EPA. Biological Study of the Lower Ashtabula River and Conneaut Creek- Ashtabula River NRDA Project 2005. Ohio EPA Report EAS/2006-6-3; 2006.

[5.] Ohio EPA. Ashtabula River Remedial Action Plan: Stage I Investigation Report. Ohio Environmental Protection Agency Division of Water Quality Planning and Assessment, 1991.

[6.] USFWS, Ohio EPA. Final Natural Resource Restoration Plan & Environmental Assessment for the Fields Brook Superfund Site. Ohio EPA Division of Emergency & Remedial Response, US Fish and Wildlife Service, Region 3, Ecological Services. 2004.

[7.] U.S. EPA. Site Information for Fields Brook Washington, DC: U.S. EPA; 2016 [cited 2016 10.6.16]. Available from: https://cumulis.epa.gov/supercpad/cursites/dsp_ssppSiteData2.cfm?id=0504723#Sample

[8.] Ohio EPA. Biological and Water Quality Study of the Ashtabula River and Select Tributaries, 2011. Division of Surface Water, Ohio Environmental Protection Agency. Ohio EPA Technical Report EAS/2014-01-01; 2014.

[9.] U.S. EPA. Restoring Ashtabula River AOC (timeline) Washtington, DC: U.S. EPA; 2016 [updated April 25, 2016; cited 2016 10.6.16]. Available from: https://www.epa.gov/ashtabula-river-aoc/restoring-ashtabula-river-aoc-timeline.

[10.] Diggs IW, Case JL, Rule RW, Snyder M, Vriesen SA, editors. Remediating Contaminated Sediments in the Ashtabula Harbor as Part of the Ashtabula River Area of Concern: A Collaboration Success Story - 9521. WM2009 Conference; 2009 March 1-5, 2009; Phoenix, AZ.

[11.] U.S. EPA. Remediation of the Ashtabula River Area of Concern DRAFT. Great Lakes Legacy Program Office, U.S. Environmental Protection Agency. 2010.

[12.] U.S. EPA. Explanation of Significant Differences for Fields Brook Superfund Site. Superfund Division, U.S. Environmental Protection Agency. 352346; 2009.

[13.] U.S. EPA. Draft Remedial Action Report, Ashtabula River AOC. WA No. 021-RARA-1523/ Contract No. EP-S5-06-01; 2008.

[14.] U.S. EPA. Basis of Design Report Ashtabula River Area of Concern, Final Design. U.S. Environmental Protection Agency. WA No. 251-RDRD-05ZZ/Contract No. 68-W6-0025; 2006.

[15.] U.S. EPA. Draft Basis of Design Ashtabula River Area of Concern Great Lakes Legacy Act Habitat Restoration. WA No. 043-RDRD-1523 / Controact No. EP-S5-06-01; 2009.

[16.] U.S. EPA. Ashtabula River Area of Concern Synthesis Report: Applicability of 2011 Data on Fish Tumors and Benthos Beneficial Use Impairments. Great Lakes National Program

Office, U.S. Environmental Protection Agency. Contract Number EP-R5-11-07, TO 18; 2014.

[17.] Blazer VS, Iwanowicz LR, Baumann PC. Final Report: Fish Health Study Ashtabula River Natural Resource Damage Assessment. U.S. Geological Survey, Report OF2006-1137; 2006.

[18.] U.S. EPA. The U.S. EPA's Great Lakes Legacy Act Ashtabula River Clean-Up. https://clu-in.org/download/contaminantfocus/sediments/Scotts-Ashtabula-Presentation.pdf; 2008.

[19.] Meier JR, Lazorchak JM, Mills M, Wernsing P, Baumann PC. Monitoring Exposure of Brown Bullheads and Benthic Macroinvertebrates to Sediment Contaminants in the Ashtabula River Before, During, and After Remediation. Environmental Toxicology and Chemistry. 2015;34(6).

[20.] Ohio EPA. Removal Recommendations for Three Beneficial Use Impairments in the Ashtabula River AOC. 2014.

[21.] USACE. Ashtabula Harbor Sediment Evaluation Southern Reach: Station 198+00 to 213+36. U.S. Army Corps of Engineers, 2011.

[22.] USACE. Addendum to Evaluation of Ashtabula Harbor River Channel (Southern Reach) Sediments. U.S. Army Corps of Engineers, 2012.

[23.] U.S. EPA. Basis of Design Report Ashtabula River Area of Concern, Appendix A. U.S. Environmental Protection Agency. WA No. 251-RDRD-05ZZ/Contract No. 68-W6-0025; 2006.

[24.] U.S. EPA. Field Study on Environmental Dredging Residuals: Ashtabula River Volume 1. Final Report. Land Remediation and Pollution Control Division, National Risk Management Research Laboratory, Office of Research and Development. EPA/600/R-10-126; 2010.

[25.] USGS. Toxicity Assessment of Sediment Cores Collected from the Ashtabula River in Northeastern Ohio with the Amphipod *Hyalella azteca*. CERC-8335-FY04-20-11; 2005.

[26.] U.S. EPA. DRAFT Final Report Field Studies on Environmental Dredging at the Ashtabula River 2006 to 2011. Contract number EP-W-09-024; 2014.

[27.] U.S. EPA. Ashtabula River Area of Concern Report on PCB Source Tracking and Apportionment. Final Report. Great Lakes National Program Office, U.S. Environmental Protection Agency. 2012.

[28.] U.S. EPA. Final Data Summary for the Ashtabula Baseline Sediment Assessment. Great Lakes National Program Office, U.S. Environmental Protection Agency. Contract No. EP-W-04-021; 2006.

[29.] Cooksey C, Balthis L, Chung K, DeLorenzo M, Dubick J, Fulton M, et al. Cruise Report: Assessment of Ecological Condition and Stressor Impacts within Great Lakes Region Areas of Concern (AOCs): Ashtabula River and Milwaukee Estuary. NOAA Technical Memorandum NOS NCCOS 168; 2013.

[30.] Kraus J, Walters D, Mills M. Polychlorinated Biphenyl (PCB) Contamination in Riparian Spiders at Ashtabula River Area of Concern, 2011. US Geological Survey and US Environmental Protection Agency, 2014.

[31.] U.S. EPA. Data Report on Ecosystem Monitoring for the Ashtabula River Environmental Dredging Project. U.S. Environmental Protection Agency, Office of Research and Development. EPA/600/R-11/102; 2011.

[32.] U.S. EPA. Methods and Metrics for Evaluating Environmental Dredging at the Ashtabula River Area of Concern. Office of Research and Development National Risk Management REsearch Laboratory, U.S. Environmental Protection Agency. EPA/600/R-16/322; 2016.

[33.] Blazer VS, Mazik PM, Iwanowicz LR, Braham RP, Hahn CM, Walsh HL, et al. Assessment of the Fish Tumor Beneficial Use Impairment in Brown Bullhead (Ameiurus nebulosus) at Selected Great Lakes Areas of Concern: U.S. Geolological Survey Open-File Report 2014-1105. 2014.

[34.] U.S. EPA. Neptune Statistical Support Task Order 66 - DRAFT. U.S. Environmental Protection Agency. Contract No. EP-C-08-007; 2012.

[35.] U.S. EPA. WA2-13 SWAC Samples - Radionuclide Results - DRAFT 10-3-11. [Excel Workbook]. 2011.

[36.] Ohio EPA. Delisting Guidance and Restoration Targets for Ohio Areas of Concern. 2014.

[37.] U.S. EPA. Great Lakes Legacy Act Habitat Restoration Project Ashtabula River Area of Concern- Final Design. U.S. Environmental Protection Agency, Work Assignment No 043-RDRD-1523; Contract No. EP-S5-06-01; 2009.

[38.] Ohio EPA. Biological Criteria for the Protection of Aquatic Life: Volume I: The Roll of Biological Data in Water Quality Assessment. Ecological Assessment Section Division of Water Quality, State of Ohio Environmental Protection Agency. 0055e/0015e; 1988.

[39.] U.S. EPA. Species Profile: Brown Bullhead 2000 [cited 2014 10.28.2014]. Available from: http://www.epa.gov/region1/ge/thesite/restofriver/reports/final_era/B%20-%20Focus%20Species%20Profiles/EcoRiskProfile_brown_bullhead.pdf.

[40.] Iwanowicz LR, Blazer VS, Hitt NP, McCormick SD, DeVault DS, Ottinger CA. Histologic, Immunologic and Endocrine Biomarkers Indicate Contaminant Effects in Fishes of the Ashtabula River. Ecotoxicology. 2011;21(1).

[41.] Schlechtriem C, Fliedner A, Schäfers C. Contributions to the Revision of TG OECD 305: Lipid Measurement. Schmallenberg, Germany: Fraunhofer Institute for Molecular Biology and Applied Ecology, 2009 March 30, 2009. http://www.oecd.org/chemicalsafety/testing/48470247.pdf.

[42.] Baumann PC, Smith IR, Metcalfe CD. Linkages Between Chemical Contaminants and Tumors in Benthic Great Lakes Fish. Journal of Great Lakes Research. 1996;22(2).

[43.] Ohio EPA. 2011 ICI data. Ohio EPA, 2014.

[44.] De Cooman W, Blaise C, Janssen C, Detemmerman L, Elst R, Persoone G. History and Sensitivity Comparison of Two Standard Whole-Sediment Toxicity Tests with Crustaceans: the Amphipod *Hyalella azteca* and the Ostracod *Heterocypris incongruens* Microbiotest. Knowl Manag Aquat Ecosyst. 2015;(416).

[45.] Ingersoll CG, Kemble NE, Kunz JL, Brumbaugh WG, MacDonald DD, Smorong D. Toxicity of Sediment Cores Collected from the Ashtabula River in Northeastern Ohio, USA, to the Amphipod *Hyalella azteca*. Arch Environ Contam Toxicol. 2009;57(2).

[46.] Kraus JM, Gibson PP, Walters DM, Mills MA. Riparian Spiders as Sentinels of Polychlorinated Biphenyl Contamination Across Heterogeneous Aquatic Ecosystems. Environmental Toxicology and Chemistry. 2016;

[47.] Ohio EPA. Guidance on Evaluating Sediment Contaminant Results. Division of Surface Water, Ohio Environmental Protection Agency. http://epa.ohio.gov/portals/35/guidance/sediment_evaluation_jan10.pdf; 2010.

[48.] CSRA LLC. Pre and Post-Remediation Characterization of the Ashtabula River, Ashtabula Ohio: Surface Weighted Average Concentrations (SWAC) for Total PCBs as Congeners and Total PCBs as Aroclors. Technical Approach for SWAC Development. CSRA LLC, 2020.

Appendix A: Ashtabula River AOC BUI Status

BUI	***Ashtabula River AOC Status***
1. Restrictions on fish and wildlife consumption	**Removed 2014-** A "Do Not Eat" advisory for any fish caught in the Ashtabula River was in effect until 2013.
2. Tainting of fish and wildlife flavor	Not Impaired
3. Degradation of fish and wildlife populations	**Removed 2014-** Previous physical alterations and chemical contaminants within the river have been addressed to allow the improvement in the fish community index scores: Index of Biotic Integrity (IBI) and Modified Index of Well-being (MIwb).
4. Fish tumors or other deformities	**Impaired** – Internal (liver) and external deformities and tumors prevalence rates in brown bullheads exceed standard criteria (5%).
5. Bird or animal deformities or reproductive problems	Not Impaired
6. Degradation of benthos	**Impaired** –Invertebrate Community Index (ICI) scores are lower than the standard criteria for warm-water-habitat streams and rivers for some areas of the Ashtabula River AOC.
7. Restrictions on dredging activities	**Impaired** – Prior to the most recent dredging operations, river sediments were classified as highly polluted and toxic due to concentrations of heavy metals, polychlorinated biphenyls (PCB), and other organic compounds.
8. Eutrophication or undesirable algae	Not Impaired
9. Restrictions of drinking water consumption, or taste and odor problems	Not Impaired
10. Beach closings (recreational use)	Not Impaired
11. Degradation of aesthetics	Not Impaired
12. Added costs to agriculture or industry	Not Impaired
13. Degradation of phytoplankton or zooplankton populations	Not Applicable
14. Loss of fish and wildlife habitat	**Removed 2014**– Previous physical alterations and chemical contaminants within the River have been addressed to allow the improvement in the aquatic habitat index score Qualitative Habitat Evaluation Index (QHEI).

Appendix B: Ashtabula River Data by Line of Evidence

Physical Lines of Evidence

Agency	*Pre/ Post*	*Year*	*Description of the Study*	*Sample Type*	*PCB*	*PAH*	*Other*	*References*
OEPA	Pre	2005	Summary document for 3 BUI removal recommendations and their associated data. BUI #1 Fish Consumption: only post concentration values given pre-data is an assumed advisory. BUI #3 Degradation of fish and wildlife populations (IBI, MIwb for fish). BUI #14 Loss of fish and wildlife habitat (QHEI).	QHEI metrics				Ohio EPA [1]
OEPA	Post	2011	Summary document for 3 BUI removal recommendations and their associated data. BUI #1 Fish Consumption: only post concentration values given pre-data is an assumed advisory. BUI #3 Degradation of fish and wildlife populations (IBI, MIwb for fish). BUI #14 Loss of fish and wildlife habitat (QHEI).	QHEI metrics				Ohio EPA [1]
USEPA/ORD	Pre	2007	Pre-remediation bathymetry	Multi-beam sonar			bathymetry	U.S. EPA [2]
USACE	Post	2011	Post-remediation bathymetry- conducted by USACE but included within the USEPA/ORD study results	Multi-beam sonar			bathymetry	U.S. EPA [3]; U.S. EPA [4]
OEPA	Pre	2003	ICI metrics and QHEI metrics - also IBI and MIwb	QHEI				Ohio EPA [5]
NOAA	Post	2012	Benthic and water column assessment of 12 sites within the Ashtabula. At each station samples were collected for the analysis of benthic macroinfauna community structure and composition; concentrations of chemical contaminants in sediments; sediment toxicity; and other basic habitat characteristics such as temperature, dissolved oxygen, turbidity, pH, sediment grain size, and organic carbon content. No results are available for the macroinvertebrate analyses or chemical sediment analyses.	Surface sediment			Depth, DO, pH, conductivity, turbidity	Cooksey [6]

Biological Lines of Evidence

Agency	*Pre/ Post*	*Year*	*Description of the Study*	*Sample Type*	*PCB*	*PAH*	*Other*	*References*
USGS	Pre	2004	Brown bullhead and Largemouth Bass were collected from Ashtabula and Conneaut Creek and compared to determine a baseline analysis for general fish physical health.	Fish				Iwanowicz [7]
USGS/ USFWS	Pre	2003	Pre-remediation analysis of tumors and liver lesion prevalence in brown bullhead fish collected from Ashtabula and Conneaut Creek. Document gives statistical comparison of reference site to Ashtabula samples.	Fish	tPCB(H)		lesions/ abnormalities and comet assay for DNA damage	Blazer [8]
USEPA/ ORD	Pre	2006	Brown bullhead tissue were assessed for changes in PCB and PAH concentrations, lesions and anomalies. Benthic macroinvertebrates were assessed for changes in DNA damage in liver and blood. PCBs and PAHs were assessed for surface sediment samples. Conneaut Creek samples used as a reference site.	Fish Tissue	tPCB(C)	tPAH16 tPAH34	comet assay for DNA damage; raised lesion and liver neoplasm counts	Meier [9]; U.S. EPA [10]
USGS/ USFWS	Post	2011	Large scale analysis of multiple Ohio AOCs for analysis for fish tumors, liver lesions, and general fish health. Ashtabula included in 2011 sampling efforts.	Fish			raised lesion and liver neoplasm counts	Blazer [11]; Blazer [12]
USEPA/ ORD	Post	2011	Brown bullhead tissue were assessed for changes in PCB and PAH concentrations, lesions and anomalies. Benthic macroinvertebrates were assessed for changes in DNA damage in liver and blood. PCBs and PAHs were assessed for surface sediment samples. Conneaut Creek samples used as a reference site.	Fish Tissue	tPCB(C)	tPAH16 tPAH34	comet assay for DNA damage; raised lesion and liver neoplasm counts	Meier [9]
OEPA	Post	2011	Summary document for 3 BUI removal recommendations and their associated data. BUI #1 Fish Consumption: only post concentration values given pre-PCB concentration data is an assumed advisory. BUI #3 Degradation of fish and wildlife populations (IBI, MIwb for fish). BUI #14 Loss of fish and wildlife habitat (QHEI).	Fish Tissue	tPCB unknown method			Ohio EPA [1]
OEPA	Pre	2003	ICI metrics and QHEI metrics - also IBI and MIwb	ICI				Ohio EPA [5]
OEPA	Post	2011	ICI metrics for 7 locations within the Ashtabula and 2 reference at Conneaut Creek	ICI				Ohio EPA [13]

Biological Lines of Evidence (Continued)

Agency	*Pre/ Post*	*Year*	*Description of the Study*	*Sample Type*	*PCB*	*PAH*	*Other*	*References*
USEPA/ ORD	Pre	2006	Caged Asian clams *(Corbicula)* and *Lumbriculus variegates* were deployed in 2006 to assess PCB bioaccumulation in tissue over a 28-day exposure period. However, after the 1-month deployment little to no biomass remained within any of the cages. No further bivalve or worm deployments were used.	Macroinvertebrates				U.S. EPA [10]
USEPA/ ORD	Pre	2006	Macroinvertebrate samples co-located with sediment and water samplers. Select data published within Meier 2015 comparing Brown bullhead tissues (PCBs, PAH, DNA damage in liver and blood) to sediment and macroinvertebrate samples. There are no IBI values for this data set.	Macroinvertebrates	tPCB(C)	tPAH16		Meier [9]; U.S. EPA [10]
USEPA/ ORD	Post	2011	Macroinvertebrate samples co-located with sediment and water samplers. Data published within Meier 2015 comparing brown bullhead tissues to sediment and macroinvertebrate samples. There are no IBI values for this data set.	Macroinvertebrates	tPCB(C)	tPAH16 tPAH34		Meier, Lazorchak [9]; U.S. EPA [10]; U.S. EPA [3]
USGS	Post	2011	Characterize AOC by assessing contaminant exposure in riparian spiders to determine sources of PCBs.	Spiders	tPCB(H) tPCB(C) Aroclor			Kraus [14]
OEPA	Pre	2005	Summary document for 3 BUI removal recommendations and their associated data. BUI #1 Fish Consumption: only post concentration values given pre-PCB concentration data is an assumed advisory. BUI #3 Degradation of fish and wildlife populations (IBI, MIwb for fish). BUI #14 Loss of fish and wildlife habitat (QHEI).	MIwb and IBI				Ohio EPA [1]
OEPA	Post	2011	Summary document for 3 BUI removal recommendations and their associated data. BUI #1 Fish Consumption: only post concentration values given pre-PCB concentration data is an assumed advisory. BUI #3 Degradation of fish and wildlife populations (IBI, MIwb for fish). BUI #14 Loss of fish and wildlife habitat (QHEI).	MIwb and IBI				Ohio EPA [1]

Biological Lines of Evidence (Continued)

Agency	*Pre/ Post*	*Year*	*Description of the Study*	*Sample Type*	*PCB*	*PAH*	*Other*	*References*
GLNPO	Pre	2006	Additional chemical analyses were conducted for surface sediment samples co-located with water samples and caged catfish.	Surface sediment	tPCB(H)	tPAH34	toxicity tests, radionuclides, heavy metals, AVS-SEM	U.S. EPA [15]
GLNPO	Pre	2006	Additional chemical analyses were conducted for surface sediment samples co-located with caged catfish.	Surface sediment	tPCB(H)	tPAH34	toxicity tests	U.S. EPA [15]
NOAA	Post	2012	Sediment benthic and water column assessment of 12 sites within the Ashtabula. At each station samples were collected for the analysis of benthic macroinfauna community structure and composition; concentrations of chemical contaminants in sediments; sediment toxicity; and other basic habitat characteristics such as temperature, dissolved oxygen, turbidity, pH, sediment grain size, and organic carbon content. No results are available for the macroinvertebrate analyses or chemical sediment analyses.	Surface sediment			toxicity - preliminary	Cooksey [6]
GLNPO	Pre	2006	Live catfish were deployed in cages at 7 locations throughout the GLLA study area. These locations were co-located with surficial sediment collection stations. Twelve live fish were deployed in each cage, and live fish remaining after 28 days of exposure were collected and analyzed for PCBs, wet weight and lipid content.	Fish	tPCB(H)		wet weight, lipid content	U.S. EPA [15]

Chemical Lines of Evidence

Agency	*Pre/ Post*	*Year*	*Description of the Study*	*Sample Type*	*PCB*	*PAH*	*Other*	*References*
GLNPO	Pre	2006	Sediment core samples were collected from three locations in a slip adjacent to Ashtabula North Slip (Jack's Marine) using a vibracore unit.	Sediment Cores	tPCB(H)		heavy metals, TOC, PSD, moisture DRO, TRPH	U.S. EPA [15]
USEPA/ ORD	Pre	2006	30 sediment cores were collected to give a full PCB vertical profile of the sediment above and below the target cut line	Sediment Cores	tPCB(C)		TOC TSS VSS	U.S. EPA [2]
USEPA/ ORD	Post	2011	35 sediment cores were collected to give a full PCB vertical profile of the sediment above and below the target cut line	Sediment Cores	tPCB(C)			U.S. EPA [3]
USEPA/ ORD	Pre	2006	SPMD and SPME samplers to measure uptake of PCBs within samplers located along the sediment surface and in the water column	SPMD	tPCB(C)	tPAH16		U.S. EPA [10]
USEPA/ ORD	Post	2011	SPMD samplers to measure uptake of PCBs within samplers located along the sediment surface and in the water column	SPMD	tPCB(C)	tPAH16 tPAH34		U.S. EPA [10]; U.S. EPA [3]
USEPA/ ORD	Pre	2006	PCBs and PAHs were assessed for surface sediment samples. Conneaut Creek samples used as a reference site. Select data published within Meier 2015 comparing brown bullhead tissues (PCBs, PAH, DNA damage in liver and blood) to sediment and macroinvertebrate samples.	Surface sediment	tPCB(C)	tPAH16	TOC	Meier [9]; U.S. EPA [10]; U.S. EPA [2]; U.S. EPA [3]
GLNPO	Pre	2006	Pre-remediation analysis of the sediments within the AOC. PCB homologs, HCB, HCBD and PAHs were all attained from the sediment samples alongside limited co-located water, fish and worm analyses.	Surface sediment	tPCB(H)	tPAH16 tPAH34	HCB HCBD TOC PSD wet and dry bulk density	U.S. EPA [15]; U.S. EPA [10]
GLNPO/ ORD	Post	2011	Post remediation analysis of the sediments within the AOC. PCB homologs, HCB, HCBD and PAHs were all attained from the sediment samples alongside limited co-located water, fish and worm analyses. The study focused on the central portion of the GLLA site.	Surface sediment	tPCB(H)	tPAH16 tPAH34	HCB HCBD	U.S. EPA [10]; U.S. EPA [3]
USEPA/ ORD	Post	2011	PCBs and PAHs were assessed for surface sediment samples. Conneaut Creek samples used as a reference site. Brown bullhead tissue were assessed for changes in PCB and PAH concentrations, lesions and anomalies. Benthic macroinvertebrates were assessed for changes in DNA damage in liver and blood.	Surface sediment	tPCB(C)	tPAH16 tPAH34	TOC	Meier [9]; U.S. EPA [10]; U.S. EPA [3]

Chemical Lines of Evidence (Continued)

Agency	*Pre/ Post*	*Year*	*Description of the Study*	*Sample Type*	*PCB*	*PAH*	*Other*	*References*
GLNPO/ ORD	Post	2011	Four studies were conducted in 2011 to understand the surface sediment conditions of the entire GLLA dredge footprint. Studies 1 and 4 focused on the GLLA footprint while Studies 2 and 3 focused on the confluence of Strong Brook and Ashtabula River (Ashtabula North Slip).	Surface sediment	tPCB(C) Aroclor			U.S. EPA [10]; U.S. EPA [3]
USFWS	Pre	2001	High Volume Water Column Samples comparing dissolved phase PCB and HCB concentrations in 2001 to 2011.	Water column	tPCB(C) tPCB(H)		HCB	Banda [16]
USFWS	Post	2011	High Volume Water Column Samples comparing dissolved phase PCB and HCB concentrations in 2001 to 2011.	Water column	tPCB(C) tPCB(H)		HCB	Banda [16]
USEPA/ ORD	Pre	2006	Bulk water column samples co-located with sediment surface samples and SPMDs. Select data published within Meier 2015 comparing brown bullhead tissues (PCBs, PAH, DNA damage in liver and blood) to sediment and macroinvertebrate samples.	Water column	PCB(H)	tPAH16	TOC TSS VSS	U.S. EPA [15]
GLNPO	Pre	2006	Water samples were co-located with sediment samples and caged catfish.	Water column	tPCB(H)		TOC, TSS-VSS	U.S. EPA [15]
USEPA/ ORD	Post	2011	Bulk water column samples co-located with sediment surface samples and SPMDs	Water column	tPCB(C) tPCB(H)	tPAH16 tPAH34	TOC TSS VSS	U.S. EPA [10]; U.S. EPA [3]

Other Data Sources for Ashtabula

Agency	*Pre/ Post*	*Year*	*Description of the Study*	*Sample Type*	*PCB*	*PAH*	*Other*	*References*
USACE	Post	2011	Additional chemical, physical and biological testing for the southern reach portion of Ashtabula. These data are outside the GLLA footprint.	Surface sediment	tPCB(C)		toxicity tests	U.S. Army Corps of Engineers [17]
USACE	Post	2010	This document includes chemical, physical and biological analysis data of sediments immediately south of the GLLA footprint and within the harbor itself. These data are outside the GLLA footprint.	Surface sediment				U.S. Army Corps of Engineers [18]

References

[1.] Ohio EPA. Removal Recommendations for Three Beneficial Use Impairments in the Ashtabula River AOC. 2014.

[2.] U.S. EPA. Field Study on Environmental Dredging Residuals: Ashtabula River Volume 1. Final Report. Land Remediation and Pollution Control Division, National Risk Management Research Laboratory, Office of Research and Development. EPA/600/R-10-126; 2010.

[3.] U.S. EPA. DRAFT Final Report Field Studies on Environmental Dredging at the Ashtabula River 2006 to 2011. Contract number EP-W-09-024; 2014.

[4.] U.S. EPA. Basis of Design Report Ashtabula River Area of Concern, Appendix A. U.S. Environmental Protection Agency. WA No. 251-RDRD-05ZZ/Contract No. 68-W6-0025; 2006.

[5.] Ohio EPA. Biological Study of the Lower Ashtabula River and Conneaut Creek- Ashtabula River NRDA Project 2005. Ohio EPA Report EAS/2006-6-3; 2006.

[6.] Cooksey C, Balthis L, Chung K, DeLorenzo M, Dubick J, Fulton M, et al. Cruise Report: Assessment of Ecological Condition and Stressor Impacts within Great Lakes Region Areas of Concern (AOCs): Ashtabula River and Milwaukee Estuary. NOAA Technical Memorandum NOS NCCOS 168; 2013.

[7.] Iwanowicz LR, Blazer VS, Hitt NP, McCormick SD, DeVault DS, Ottinger CA. Histologic, Immunologic and Endocrine Biomarkers Indicate Contaminant Effects in Fishes of the Ashtabula River. Ecotoxicology. 2011;21(1).

[8.] Blazer VS, Iwanowicz LR, Baumann PC. Final Report: Fish Health Study Ashtabula River Natural Resource Damage Assessment. U.S. Geological Survey, Report OF2006-1137; 2006.

[9.] Meier JR, Lazorchak JM, Mills M, Wernsing P, Baumann PC. Monitoring Exposure of Brown Bullheads and Benthic Macroinvertebrates to Sediment Contaminants in the Ashtabula River Before, During, and After Remediation. Environmental Toxicology and Chemistry. 2015;34(6).

[10.] U.S. EPA. Data Report on Ecosystem Monitoring for the Ashtabula River Environmental Dredging Project. U.S. Environmental Protection Agency, Office of Research and Development. EPA/600/R-11/102; 2011.

[11.] Blazer VS, Mazik PM, Iwanowicz LR, Braham R, Hahn C, Walsh HL, et al. Monitoring of Wild Fish Health at Selected Sites in the Great Lakes Basin—Methods and Preliminary Results: U.S. Geological Survey Open-File Report 2014-1027. 2014.

[12.] Blazer VS, Mazik PM, Iwanowicz LR, Braham RP, Hahn CM, Walsh HL, et al. Assessment of the Fish Tumor Beneficial Use Impairment in Brown Bullhead (Ameiurus nebulosus) at Selected Great Lakes Areas of Concern: U.S. Geolological Survey Open-File Report 2014-1105. 2014.

[13.] Ohio EPA. 2011 ICI data. Ohio EPA, 2014.

[14.] Kraus J, Walters D, Mills M. Polychlorinated Biphenyl (PCB) Contamination in Riparian Spiders at Ashtabula River Area of Concern, 2011. US Geological Survey and US Environmental Protection Agency, 2014.

[15.] U.S. EPA. Final Data Summary for the Ashtabula Baseline Sediment Assessment. Great Lakes National Program Office, U.S. Environmental Protection Agency. Contract No. EP-W-04-021; 2006.

[16.] Banda J. Draft Ashtabula Remedy Effectiveness Water Chemistry 2014_06_13 2014.

[17.] USACE. Addendum to Evaluation of Ashtabula Harbor River Channel (Southern Reach) Sediments. U.S. Army Corps of Engineers, 2012.

[18.] USACE. Ashtabula Harbor Sediment Evaluation Southern Reach: Station 198+00 to 213+36. U.S. Army Corps of Engineers, 2011.