WATER AND FISH: LONG-TERM INDICATORS OF SEDIMENT REMEDIATION PROGRESS ON THE LOWER FOX RIVER

D.M. Roznowski[1], R.D. French[2] and S.G. Lehrke[3]

ABSTRACT

The Lower Fox River (LFR) extends 62.7 kilometers (km) from the outlet of Lake Winnebago over a series of locks and dams to the mouth of the river where it discharges into Green Bay/Lake Michigan. The LFR is the most industrialized river in Wisconsin. Since the early 1900s, water quality has been degraded by expanding industries and communities discharging sewage and industrial wastes into the river. Polychlorinated biphenyls (PCB) were discovered in the LFR in the 1970s. Due to their persistence in the environment, PCBs remain the focus of current remediation efforts in the river. The river and bay are divided into five operable units (from upstream to downstream, OUs 1 through 5).

OU2 and OU3 extend approximately 43.4 km from Appleton Locks to De Pere Dam; OU2 is further divided by locks and dams into OU2A, 2B, and 2C. Sediment in OU2 has a scattered distribution with extensive bedrock exposures; in contrast, most of OU3 is covered by soft sediment. The Remedial Action (RA) in OU2 and OU3 began in 2009 and was completed in 2011, consisting of dredging and capping in the northernmost reaches of OU2 and dredging and capping throughout OU3. Earlier remedial actions in OU2 (Deposit N and O in the late 1990s) included dredging of PCB impacted sediments as a demonstration project. The primary remedial action over the remainder and majority of OU2 is monitored natural recovery (MNR).

The effectiveness of sediment remediation in the Fox River will ultimately be determined by a long-term reduction in the concentration of PCBs in water and fish. Progress towards this goal is monitored on an ongoing basis as remediation is completed in each OU. Long-term monitoring (LTM) of water and fish tissue PCB concentrations in OU2 and OU3 began in June 2012. This LTM, in conjunction with ongoing LTM in Lake Winnebago (background location) which began in 2010, and the baseline monitoring program conducted in 2006-2007 for all locations, is designed to monitor improvements in water and fish tissue as a result of the sediment RA in these OUs.

The LTM event for 2014 (the second post-RA LTM event) included water quality sampling for total suspended solids (TSS), total organic carbon (TOC), and PCB congeners. In addition, five fish species were collected in September and a subset of those species was analyzed for PCB Aroclors. The fish species include a primary and secondary species for monitoring human health risk (walleye and bass, respectively), a primary and secondary species for monitoring ecological risk (carp and drum, respectively), and a young-of-year (YOY) forage fish to provide an early indication of ecosystem recovery (gizzard shad).

This paper will discuss the details of the LTM design and implementation and provide statistical analysis of water and fish tissue data collected in the background location, OU2 and OU3 and compare the OU2/3 results to a companion effort in upstream OU1.

Keywords: contaminated sediments, long-term monitoring, PCBs, fish tissue, surface water

INTRODUCTION

Results of OU2-3 LTM in 2014 are being presented to provide an update on the effectiveness of remediation efforts in the LFR to lower the PCBs in fish tissue and surface water. OU2-3 LTM is being performed to assess progress

[1] Project Director, Foth Infrastructure & Environment, LLC, 2121 Innovation Court, Suite 300, De Pere, Wisconsin 54115, United States, T: 920-496-6756, Email: denis.roznowski@foth.com.

[2] Project Manager, Foth Infrastructure & Environment, LLC, 390 South Woods Mill Road, Suite 325, Chesterfield, Missouri 63017, United States, T: 314-682-1962, Email: ronald.french@foth.com.

[3] Technical Advisor, Foth Infrastructure & Environment, LLC, 2121 Innovation Court, Suite 300, De Pere, Wisconsin 54115, United States, T: 920-496-6894, Email: stephen.lehrke@foth.com.

toward achieving the remedial action objectives (RAO) specified in the *OU1/OU2 Record of Decision* (*ROD*) (USEPA, 2002); the *Record of Decision, Operable Units 3, 4, and 5, Lower Fox River and Green Bay Wisconsin* (USEPA, 2003); and the *Record of Decision Amendment: Operable Unit 2 (Deposit DD), Operable Unit 3, Operable Unit 4, and Operable Unit 5* (*River Mouth*) (USEPA, 2007) issued under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended; and the *Lower Fox River Remedial Design 100 Percent Design Report for 2010 and Beyond Remedial Actions,* Volume 2 of 2 (*100 Percent Design Report*), Appendix I (*Long-Term Monitoring Plan*) (*FR-LTMP*) (Tetra Tech et al., 2012).

The 2014 LTM program measured progress towards RAOs that are based on water and fish tissue PCB concentrations. The three RAOs considered during this evaluation include the following:

- Monitor reductions in water and fish tissue PCB concentrations;
- Monitor progress toward achieving human health risk reduction goals; and
- Monitor progress toward achieving ecological risk reduction goals.

In 2006-2007, baseline data were collected in Lake Winnebago (background location) and OUs 1-5, consisting of water chemistry collected over a full year, at monthly intervals, as well as fish tissue PCB concentrations during late summer/early fall (Anchor QEA, et al., 2009a). The purpose of the baseline data collection effort was to generate a data base upon which the performance of the LFR OU1-5 remedial action could be gauged. The 2006-2007 baseline data were collected during active remediation of OU1, which raised concern that baseline data may have been affected by the remediation work. However, a draft statistical analysis of historical water and fish tissue PCB data was conducted by the Wisconsin Department of Natural Resources (WDNR, 2011) which showed that any potential increase in 2006 was minimal in regard to the effect it would have on future comparisons to baseline data. Therefore, the timing of baseline data collection, during the early stages of active remediation in OU1, does not cause unacceptable uncertainty in the analysis.

Site Description

The LFR extends 62.7 km from the outlet of Lake Winnebago over a series of locks and dams to the mouth of the river where it discharges into Green Bay of Lake Michigan (Figure 1). The LFR is the most industrialized river in Wisconsin. Since the mid-1800s, water quality has been degraded by expanding industries and communities discharging sewage and industrial wastes into the river as well as by agricultural activity (USEPA, 2003). PCBs were discovered in the LFR in the 1970s. Due to their persistence in the environment, PCBs remain the focus of RA efforts.

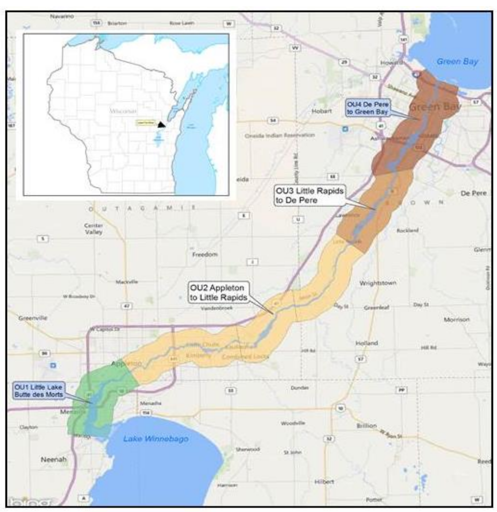

Figure 1. Project Study Area

The LFR is divided into five OUs, plus an upstream background location (Figure 1):

- Lake Winnebago is the upstream background location, situated above the influence of the historical industrial sources of contamination to the LFR.

- OU1 is also known as Little Lake Butte des Morts. The Neenah and Menasha Dams control the elevation of Lake Winnebago and discharge to the upstream end of OU1 at river mile (RM) 39. OU1 extends to the Upper Appleton Dam at RM 31.9.

- OU2 extends from the Upper Appleton Dam at RM 31.9 to the Little Rapids Dam at RM 13.1. OU2 contains the majority of the locks and dams in the LFR system and the greatest elevation drop and gradient. Sediments have a patchy distribution in this reach with extensive intervening bedrock exposures. Because of its length and diversity, OU2 is divided into three subunits (2A, 2B, and 2C). These three subunits are referenced throughout this paper as OU2A, OU2B, and OU2C.

- OU3 extends from the Little Rapids Dam to the De Pere Dam at RM 7.1. Soft sediment covers most of this unit.

- OU4 extends from the De Pere Dam to the river mouth at Green Bay. This unit contains a federally authorized navigation channel. The federal channel is currently maintained by the U.S. Army Corps of Engineers (USACE) downstream of the Fort James turning basin, but the section above the turning basin is currently unmaintained.

OU5 begins at the river's mouth and includes the entirety of Green Bay. Except for a relatively small PCB deposit on the river mouth delta, MNR is the selected remedy for OU5. Because of its breadth and depth, OU5 is divided into three sub-units (5A, 5B, and 5C).

Long-Term Monitoring Objectives

The objective of the LFR LTM program is to evaluate progress toward achieving the RAOs of reduced risk to humans and the environment, as presented in the RODs (USEPA, 2002 and 2003) and ROD Amendment (USEPA, 2007). The RAOs of relevance to the baseline and LTM programs include the following:

- Monitor Reductions in Water and Fish Tissue Concentrations. LTM is intended to verify that sediment RAs in the LFR result in substantive reductions in water column and fish tissue PCB concentrations. The *RODs* identified water and fish tissue as key media through which human and ecosystem exposures to PCBs and other contaminants may occur.

- Monitor Progress Toward Achieving Human Health Risk Reduction Goals. LTM is intended to verify progress toward achieving human health risk reduction goals through the analysis of recovery trends in water and fish tissue data. As described in the RODs, one of the goals of the RA is removal of fish consumption advisories for recreational and high-intake fish consumers. The results of the LTM program will be submitted to the WDNR Fish Consumption Advisory Program for consideration in determining if and when modification or removal of advisories is warranted.

- Monitor Progress Toward Achieving Ecological Risk Reduction Goals. LTM is intended to verify progress toward achieving ecological risk reduction goals through the analysis of recovery trends in water and fish tissue data. As described in the RODs, a goal of the RA is achievement of safe ecological thresholds for fish-eating birds and mammals. The results of the LTM program will be submitted to WDNR and USEPA risk assessors for their consideration in determining if and when ecological thresholds are achieved.

- Monitor Reductions in PCB Loadings to Green Bay. LTM is intended to verify that sediment RAs in the LFR result in substantive reductions of PCB mass loadings to Green Bay.

METHODS

Water Quality Monitoring

Sampling Locations and Schedule

Monthly water samples were collected from three locations and two depths along single transects in Lake Winnebago, OU2A, OU2B, OU2C, and OU3 during the eight warm-weather months (April through November) (Figure 2). Water

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sampling was generally conducted during the first 10 days of each month, with the exceptions of April and May. Due to the late ice recession, the April sampling event occurred on April 28 and 29, 2014; and the May 2014 event on May 19 and 20, 2014. The water sampling locations used for the OU2-3 LTM were the same as those sampled during the year 2012 LTM and baseline monitoring program.

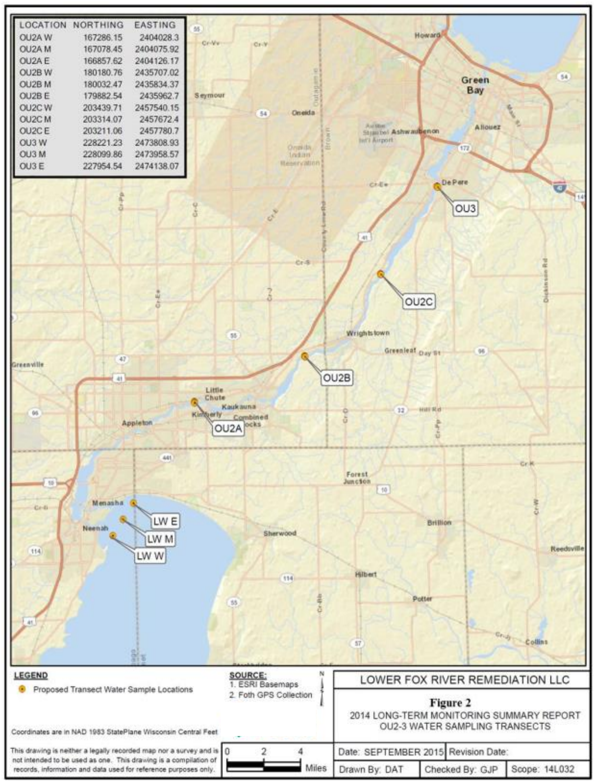


Figure 2. Water Quality Sampling Locations

Field Parameters

Temperature and turbidity were measured at each of the locations on each of the sampling transects. Measurements were taken at each location at multiple depths and were recorded in the field notes. Field notes from the monthly water quality monitoring events were taken and recorded.

Sampling Methods

The water samples were collected, in order, from upstream to downstream (i.e., Lake Winnebago to OU2 to OU3), over two days. Collection of water samples from upstream to downstream was established as a precedent during baseline monitoring. This approach collects water samples with lowest PCB concentrations (upstream locations) before collecting those with higher PCB concentrations (downstream locations) and was adopted during baseline monitoring to minimize any chance of cross-contamination of water samples with low PCB concentration by water samples with higher PCB concentrations.

Water quality monitoring stations were located within a target accuracy of approximately 1.82 meters. Water depths were determined to the nearest 3 centimeters. The channel transects were divided into three equal areas. Water sampling stations were positioned at the midpoint of each of the three equal areas at which discrete 1-liter water samples were collected at 0.2 and 0.8 times the depth of the water column. A minimum of four discrete samples per transect are required to meet completeness goals. Six discrete samples were collected from each transect during each of the eight monthly monitoring events for Lake Winnebago, OU2A, OU2B, OU2C, and OU3.

Compositing Scheme

Discrete, 1-liter water sub-samples were collected at each of the three locations and two depths for each transect, and then shipped to the analytical laboratory. Each set of six sub-samples was composited under clean laboratory conditions. In this way, one composite water sample was produced for each transect each month.

Analysis Plan

All water samples were analyzed for the following parameters:

- PCB Congeners (209 total; USEPA Method 1668A; high-resolution GC/MS);
- Total Suspended Solids (TSS; USEPA Method 160.2; SM 2540D); and
- Total Organic Carbon (TOC/DOC; USEPA Method 415.1; SM 5310C)

Fish Tissue Monitoring

Sampling Locations and Schedule

Fish monitoring stations in Lake Winnebago, OU2A, OU2B, OU2C, and OU3 are shown on Figure 3. Fish tissue samples were collected during the window specified in the *FR-LTMP*, and specifically over the period of September 2 through 9, 2014. Fish collection occurred on two consecutive days on Lake Winnebago and on two consecutive days each on OU2A, OU2B, OU2C, and OU3. Fish collection continued for an additional day on Lake Winnebago, OU2A, OU2B, OU2C, and OU3 after the initial round of collection to satisfy the level of effort specified in the *FR-LTMP*. This entailed utilizing boats/crews to stay within schedule.

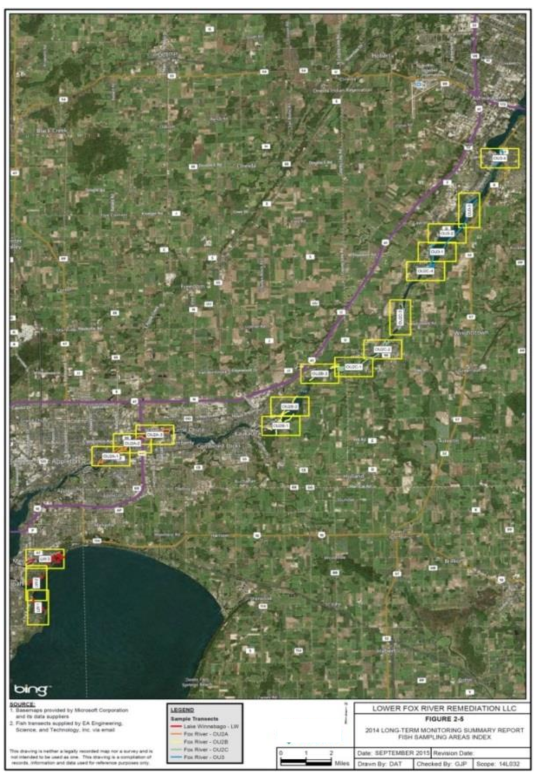


Figure 3. Fish Sampling Locations

Sampling Methods

The primary target fish species were walleye (human health), carp (ecological), and gizzard shad (YOY forage fish). The secondary target fish species (in the event adequate numbers of primary species could not be collected) were smallmouth bass (human health) and drum (ecological). Target size classes and completeness goals for each species are shown in Table 1.

Table 1. OU2-3 LTMP Target Fish Size Classes and Completeness Goals

Fish Size Classes (centimeters)	5-10	10-15	15-20	20-25	25-30	30-36	36-41	41-46	46-51	51-56	56-61	Optimum and (Minimum) Fish Sample Numbers
Primary Species												
Walleye					▥	■	■	■	■	■	▥	15 (8)
Carp					▥	■	■	■	■	■	▥	35 (7)
Gizzard shad	■	▥										175 (25)
Secondary Species												
Smallmouth bass				▥	■	■	■	■	■	▥		15 (15)
Drum					▥	■	■	■	■	■	▥	25 (5)

Notes: ■ Target size class
▥ Alternate size class

Various fish collection methods are suggested in the *FR-LTMP*, including electrofishing, seine nets, trawls, and guide-assisted hook and line. The selected method in 2014 was electrofishing. Each fish was individually logged using computer spreadsheets, along with fish length, weight, collection method and location, and pertinent observations regarding fish morphology (deformities, lesions, etc.) and condition. Gizzard shad were bagged into groups of 25 fish and assigned unique sample names.

Compositing Scheme

Fish species associated with human health (walleye and smallmouth bass) were analyzed as a skin-on filet for individual fish. In contrast, ecological index species (carp) and YOY forage fish species (gizzard shad) were analyzed as whole fish after one or more individual fish were combined to form a composite sample. Ideally, composite samples were created by combining fish of similar size. If optimum numbers of fish were collected, fish were composited as shown below:

- Seven carp composite samples each contain five individual carp (35 total carp)
- Seven gizzard shad composites each contain 25 gizzard shad (175 total gizzard shad)

Analysis Plan

All fish or fish composite samples were extracted by the following methods and analyzed for the following parameters:

- Automated Soxhlet extraction (USEPA Method 3541);
- PCB Aroclors (USEPA Method 8082A); and
- Lipid content (Randall et al., 1991).

RESULTS

Water

Surface water quality results indicate that year 2014 PCB concentrations significantly decreased from those observed during the 2006-2007 baseline monitoring for each OU. The water quality results measured during year 2014 also decreased in PCB concentration for each OU from those measured during year 2012. Statistical modeling determined that PCB concentrations in water in 2014 have decreased from baseline conditions, as shown in Table 2:

Table 2. PCB Concentration Decrease from Baseline Conditions in Water – 2014

	OU2A	OU2B	OU2C	OU3
2014 Decrease in Concentration from Baseline (2006-2007)	88%	83%	85%	83%
95 percent (%) Confidence Intervals for Above Estimates	84% to 92%	77% to 87%	80% to 89%	78% to 87%

The decrease in water column PCB concentration continues to be consistent with the broader statistical analysis of historical data from water samples as provided by the draft WDNR study (WDNR, 2011).

While year 2014 PCB concentrations in water illustrate a very significant decrease for the OUs (relative to their respective baseline conditions), concentrations remain elevated over background conditions of Lake Winnebago as shown in Table 3:

Table 3. PCB Concentration Percent Difference over Background in Water – 2014

	OU2A	OU2B	OU2C	OU3
% Difference over Lake Winnebago for Year 2014 PCB Concentrations	390%	640%	560%	750%

These differences are, however, substantially depreciated from those that were observed in year 2012 data.

Additionally, an evaluation of the post-remedial recovery rate of surface water was estimated with an exponential decay function. This analysis comprehensively assesses the post-remedy concentrations observed during the 2012 and 2014 monitoring events as they relate to both baseline and historical measurements. Comparing the recovery rate trend to PCB surface-weighted average concentration (SWAC) reduction goals and the *FR-LTMP* background criteria, the projected recovery rate trend line for PCBs in surface water meets these criteria in the year 2017 for OU2 and in the year 2023 for OU3. The projected recovery rate trend line also meets Lake Winnebago updated background average results in 2023 for OU2 and 2034 for OU3, well within a 30-year post-remediation period.

Fish Tissue

The ranges of total PCB concentrations observed in fish collected during the 2014 monitoring event are shown below:

- **Carp:** 35-171 microgram per kilogram (µg/kg) (median 104 µg/kg) in Lake Winnebago; 285-5040 µg/kg (median 1180 µg/kg) in OU2A; 118-955 µg/kg (median 536 µg/kg) in OU2B; 366-761 µg/kg (median 610 µg/kg) in OU2C, and; 435-1210 µg/kg (median 919 µg/kg) in OU3.

- **Gizzard Shad:** <12.5- µg/kg (median <12.5 µg/kg) in Lake Winnebago;
17-36 µg/kg (median 28.4µg/kg) in OU2A; <12.5-18 µg/kg (median 12.5 µg/kg) in OU2B; <12.5-33 µg/kg (median 16.6 µg/kg) in OU2C, and; 28-46/kg (median 45.4 µg/kg) in OU3.

- **Smallmouth Bass:** 66-473 µg/kg (median 98.8µg/kg) in OU2A.

- **Walleye:** 17-159 µg/kg (median 58 µg/kg) in Lake Winnebago; 59-468 µg/kg (median 83.5 µg/kg) in OU2B; 58-433 µg/kg (median 199 µg/kg) in OU2C, and; 53-1160 µg/kg (median 95.2 µg/kg) in OU3.

Fish tissue PCB concentrations decreased between OU-specific baseline and year 2014 values, with reductions in PCB concentrations being dependent on the fish species. The greatest concentration reductions occurred in all OUs for gizzard shad, and similar to the water quality results, the gizzard shad tissue concentrations also decreased from those measured during year 2012. Estimated PCB concentration decreases for gizzard shad between baseline and year 2014, range between 74% and 85% for the OUs.

Walleye PCB concentrations demonstrated a significant decrease in 2014 from baseline in OU2C. This was the first statistically significant decrease from baseline for walleye in OU2/3. Carp and smallmouth bass PCB concentrations measured in 2014 remain, in general, similar to those measured in 2012, with statistically significant reductions from baseline in OU2A, OU2B and OU3.

More specifically, the estimated percent reductions for each fish species between baseline and year 2014, along with the associated statistical significance levels, are as follows in Table 4.

Table 4. Estimated Fish Tissue Percent Reductions Between Baseline and Year 2014

	OU2A	OU2B	OU2C	OU3
	Carp			
Estimated Reduction Between Baseline and Year 2014	79%	80%	28%	47%
Associated Statistical Significance Level	p<0.001 [1]	p<0.001	p=0.08	p=0.013
	Gizzard Shad			
Estimated Reduction Between Baseline and Year 2014	83%	85%	74%	81%
Associated Statistical Significance Level	p=0.005	p<0.001	p=0.016	p=0.004
	Smallmouth Bass			
Estimated Reduction Between Baseline and Year 2014	40% [2]	NA	NA	NA
Associated Statistical Significance Level	p=0.001	NA	NA	NA
	Walleye			
Estimated Reduction Between Baseline and Year 2014	NA [2]	Indeterminable	54%	Indeterminable
Associated Statistical Significance Level	NA	p>0.5	p<0.001	p>0.5

1. The associated *p*-level indicates the probability of observing the given concentration decrease under the assumption that no concentration shift has occurred in the fish population between the baseline and 2014 sampling data. Low *p*-levels indicate a statistically significant change in concentrations has occurred.
2. Walleye not found during 2014 electrofishing in OU2A. Smallmouth Bass used a primary human-health species.

The LFR RA ecological risk reduction goal is for PCB concentrations in carp fish tissue to fall below the 7,600 µg/kg Lowest Observed Adverse Effects Concentration (LOAEC) level established for protection of ecological health by the Lower Fox River Ecological Risk Assessment (RETEC, 2002). The upper 95% confidence limits for each OU on the 2014 data for carp were below the 7,600 µg/kg value. **Therefore, fish tissue PCB concentrations in OU2A, OU2B, OU2C, and OU3 have achieved the ecological risk reduction goals.**

The LFR RA human health goal is the removal or relaxation of fish consumption advisories, with the unlimited consumption advisory level being < 50 µg/kg. This criterion, which is evaluated through upper 95% confidence intervals on the average, has not yet been achieved for walleye (or smallmouth bass - OU2A).

While the 2014 PCB tissue concentrations in fish generally illustrate a significant decrease over the OU-specific 2006-2007 baseline data, concentrations remain elevated over the year 2014 background conditions of Lake Winnebago, with the exception of gizzard shad in OU2B. For gizzard shad in OU2B, there continues to be no statistical difference with Lake Winnebago results. The gizzard shad results for OU2A, OU2C and OU3 also continue to show progress with tissue concentrations being 120% or less above the Lake Winnebago values. Carp and walleye still have a larger percentage PCB concentration above background (Lake Winnebago) in each OU, but are markedly reduced for walleye in OU2C and for carp in all OUs from those observed in 2012. For carp, PCB tissue concentrations are estimated at 340% to 880% above Lake Winnebago values. For walleye, concentrations are estimated at 580% to 1,400% above Lake Winnebago values.

An evaluation of the post-remedial recovery rate, comprehensively assessing year 2012 and year 2014 concentrations, as they relate to baseline and historical measurements, was also performed for carp, gizzard shad, smallmouth bass and walleye (see Figures 4 through 8). The projected recovery rate trend was compared to risk-based concentrations, SWAC-reduction goals, or background conditions. The post-remedial recovery rates to date are trending as expected, given the ecological niche of the species examined, with more quickly decreasing trends observed for gizzard shad (young-of-year) and more slowly decreasing trends observed for carp, smallmouth bass and walleye.

Figure 4. Regression Modeled Recovery Rate – OU2C and OU3 Carp

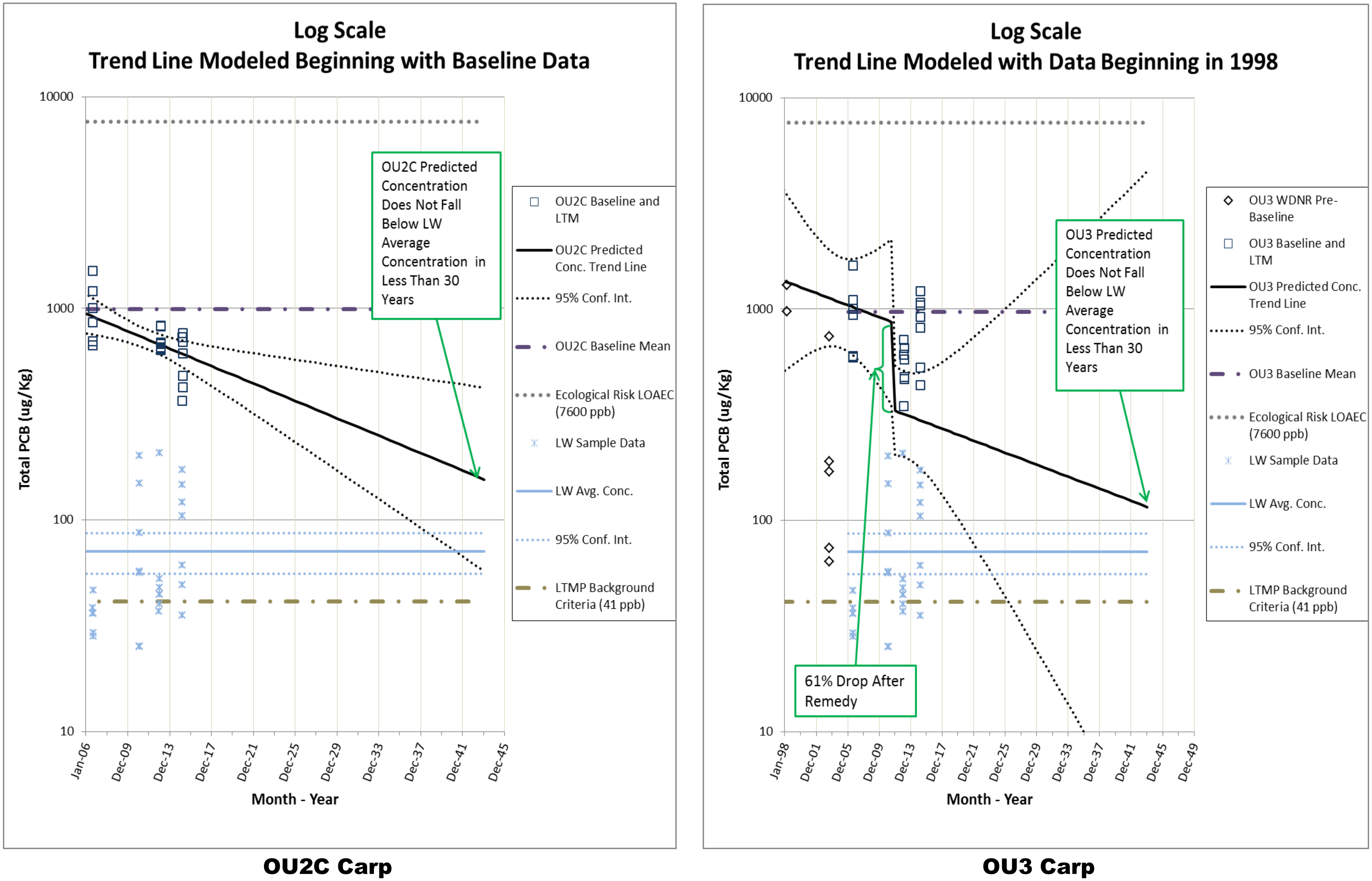
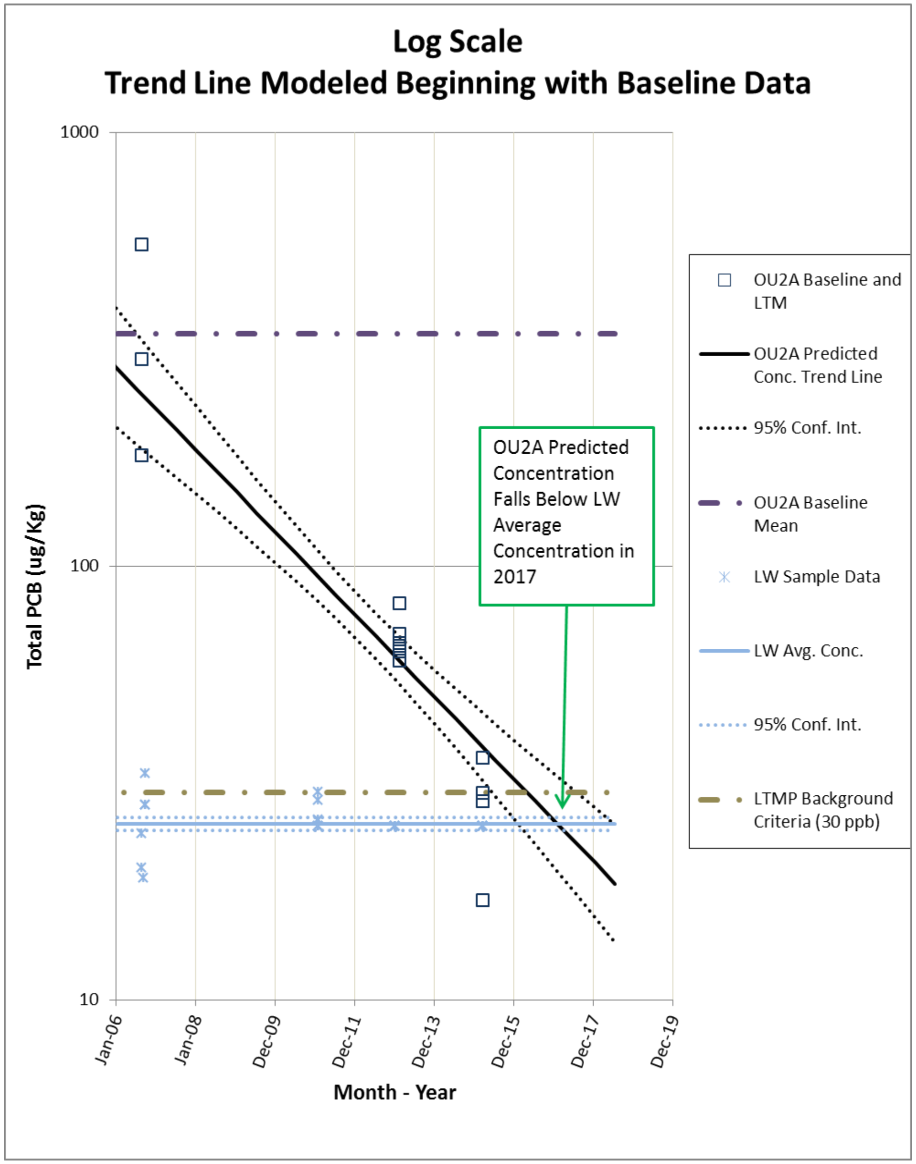
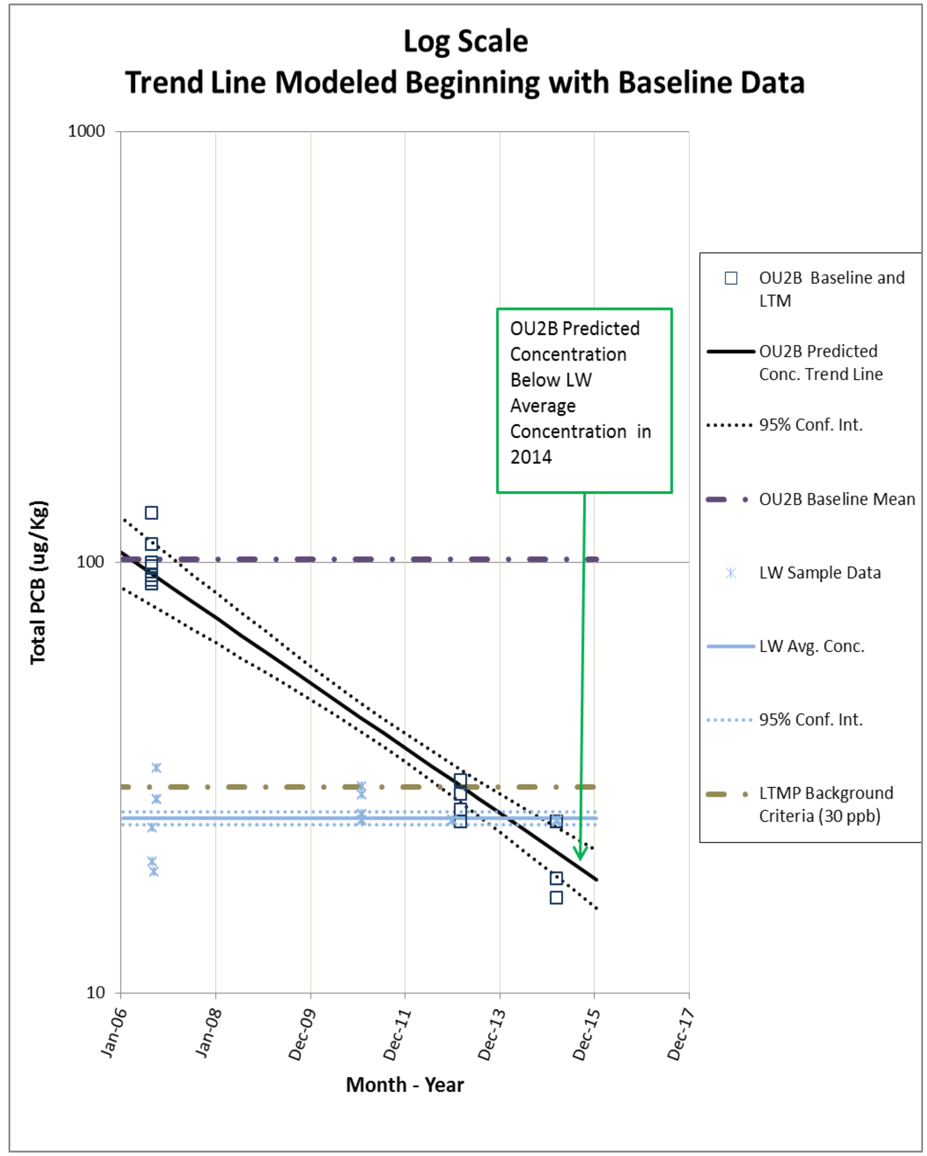


Figure 5. Regression Modeled Recovery Rate – OU2A and OU2B Gizzard Shad

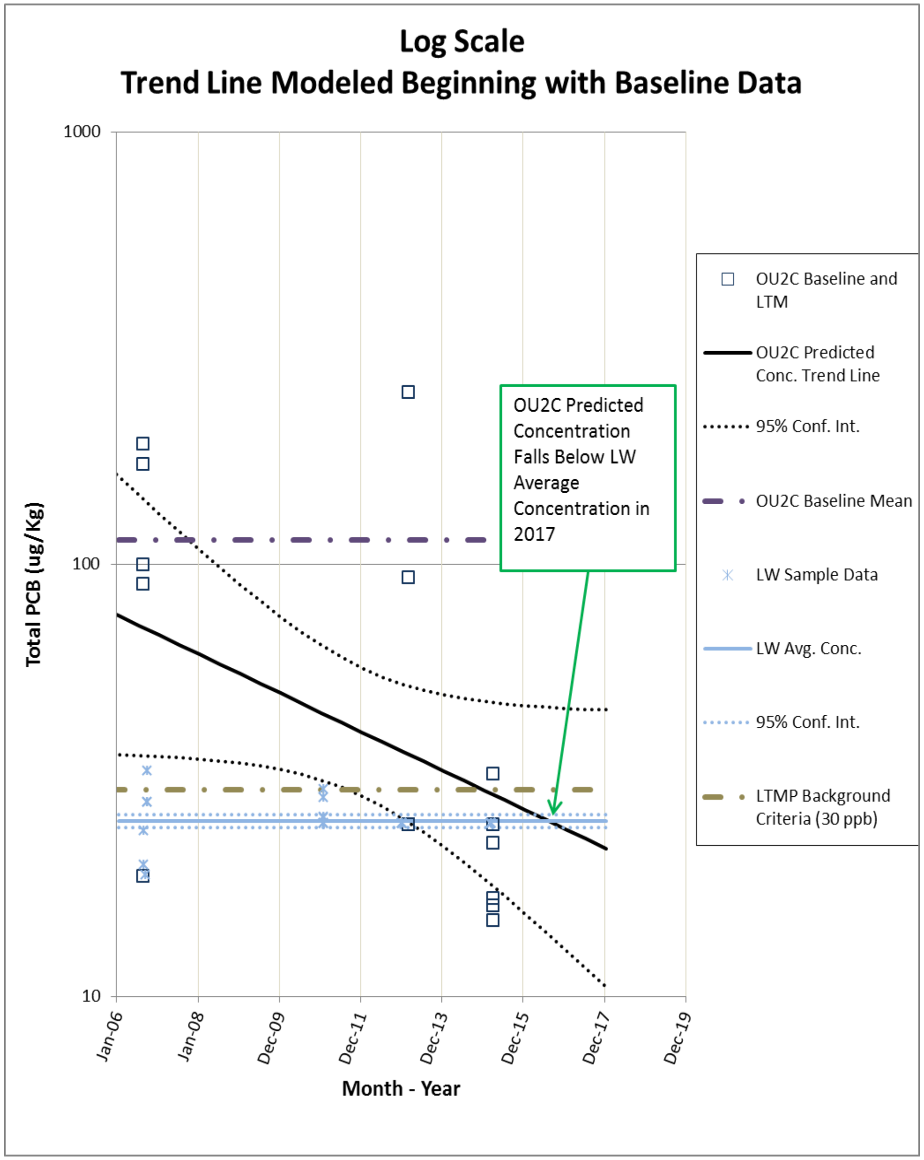


OU2A Gizzard Shad

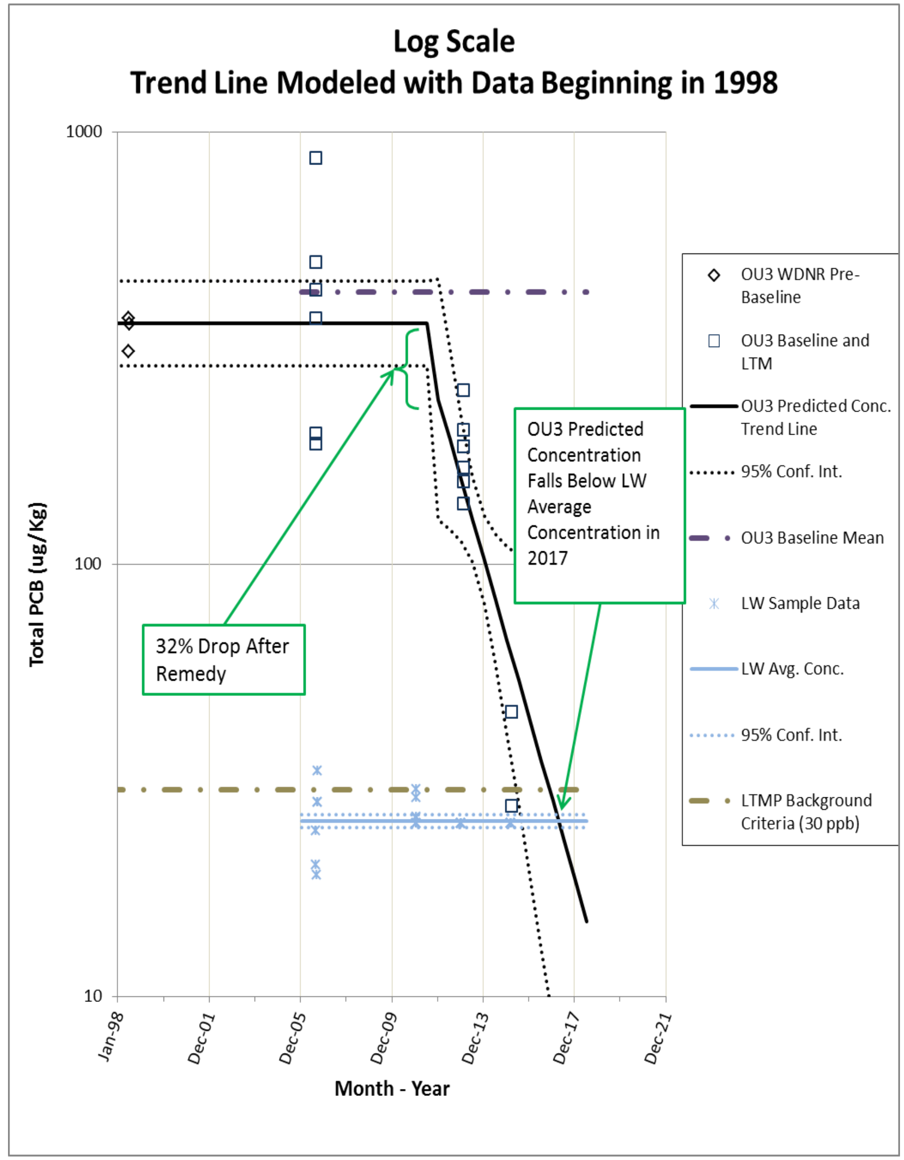


OU2B Gizzard Shad

Figure 6. Regression Modeled Recovery Rate – OU2C and OU3 Gizzard Shad



OU2C Gizzard Shad



0U3 Gizzard Shad

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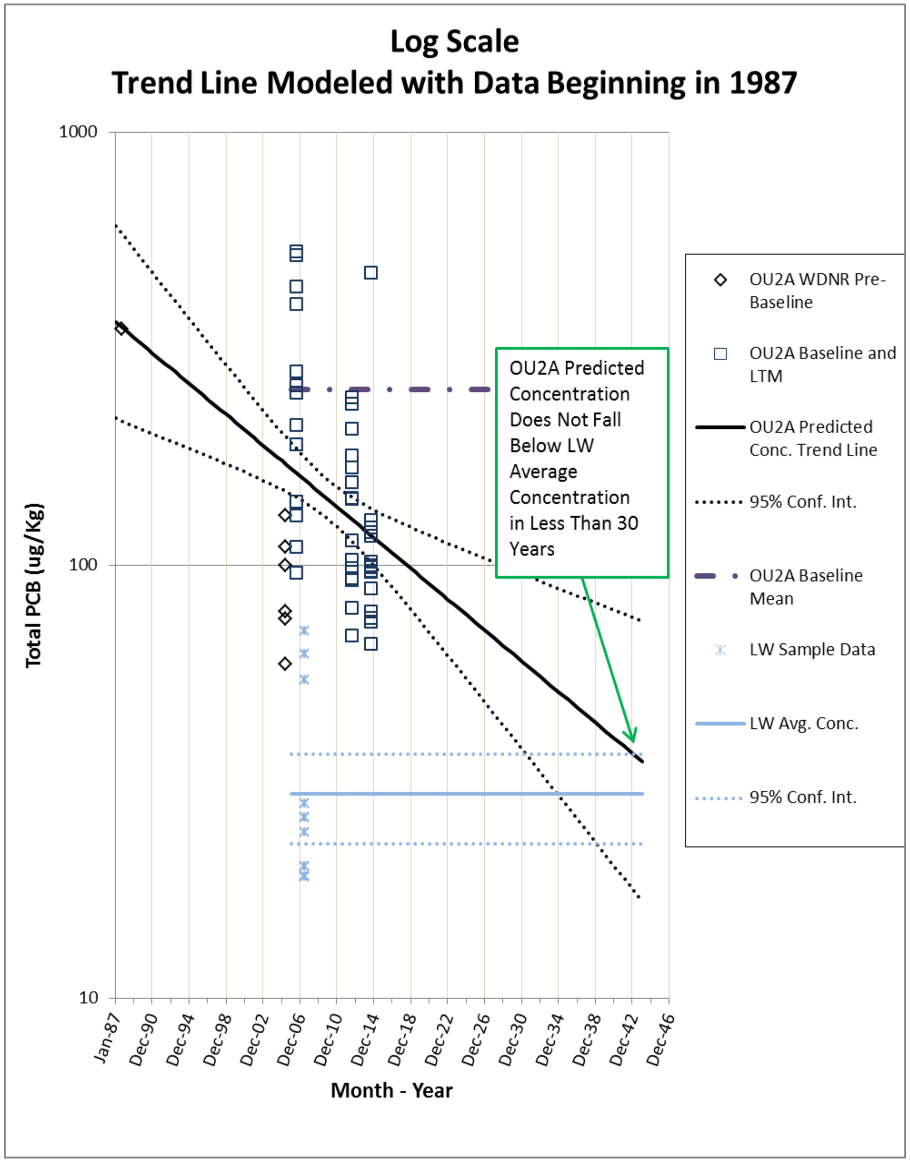
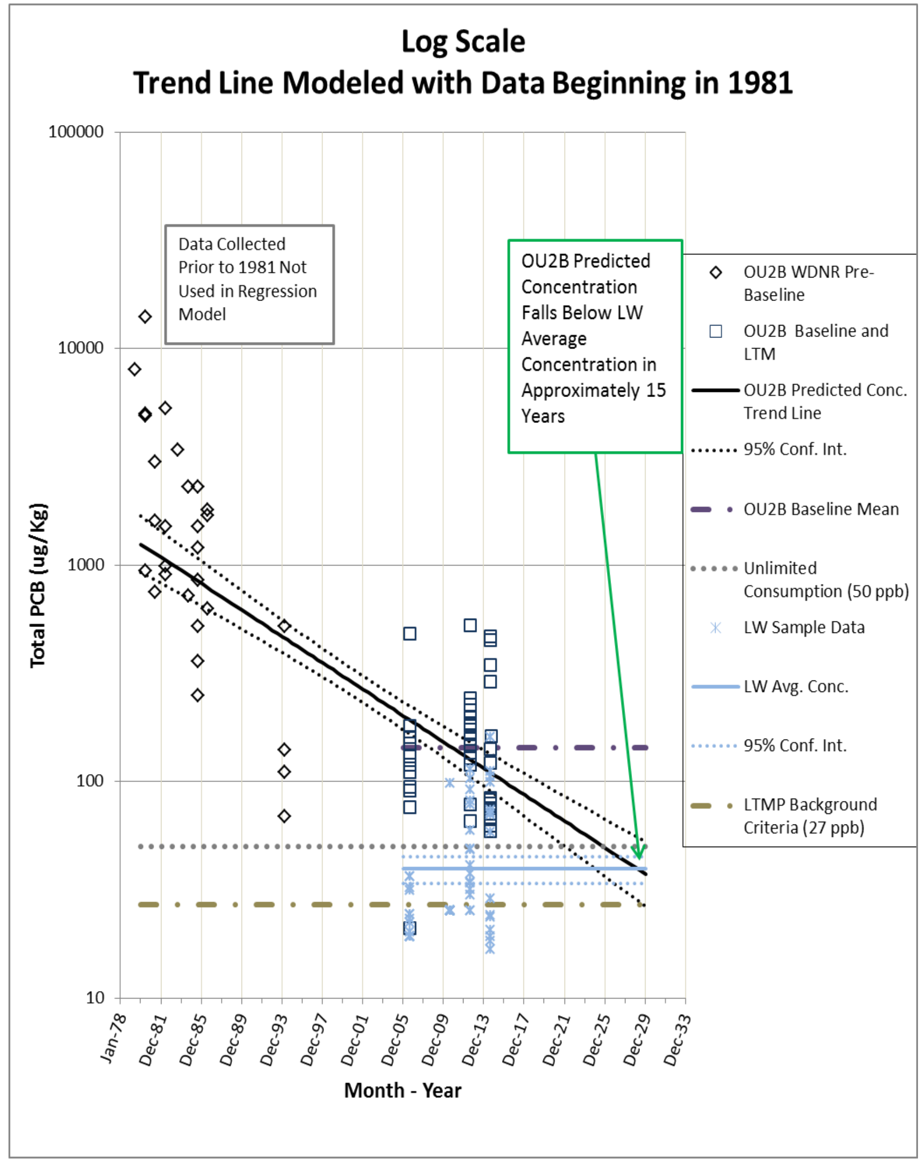
Figure 7. Regression Modeled Recovery Rate – OU2A Smallmouth Bass and OU2B Walleye



OU2A Smallmouth Bass



OU2B Walleye

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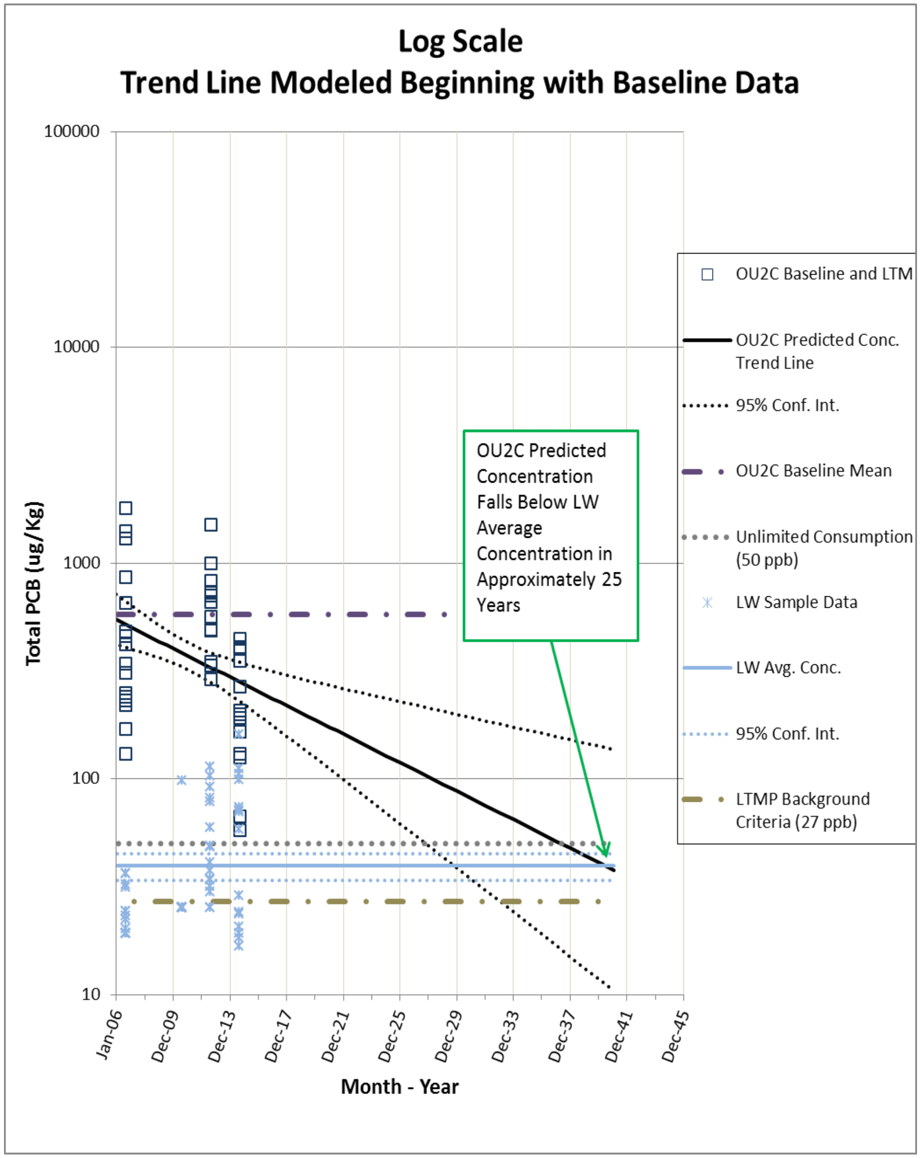
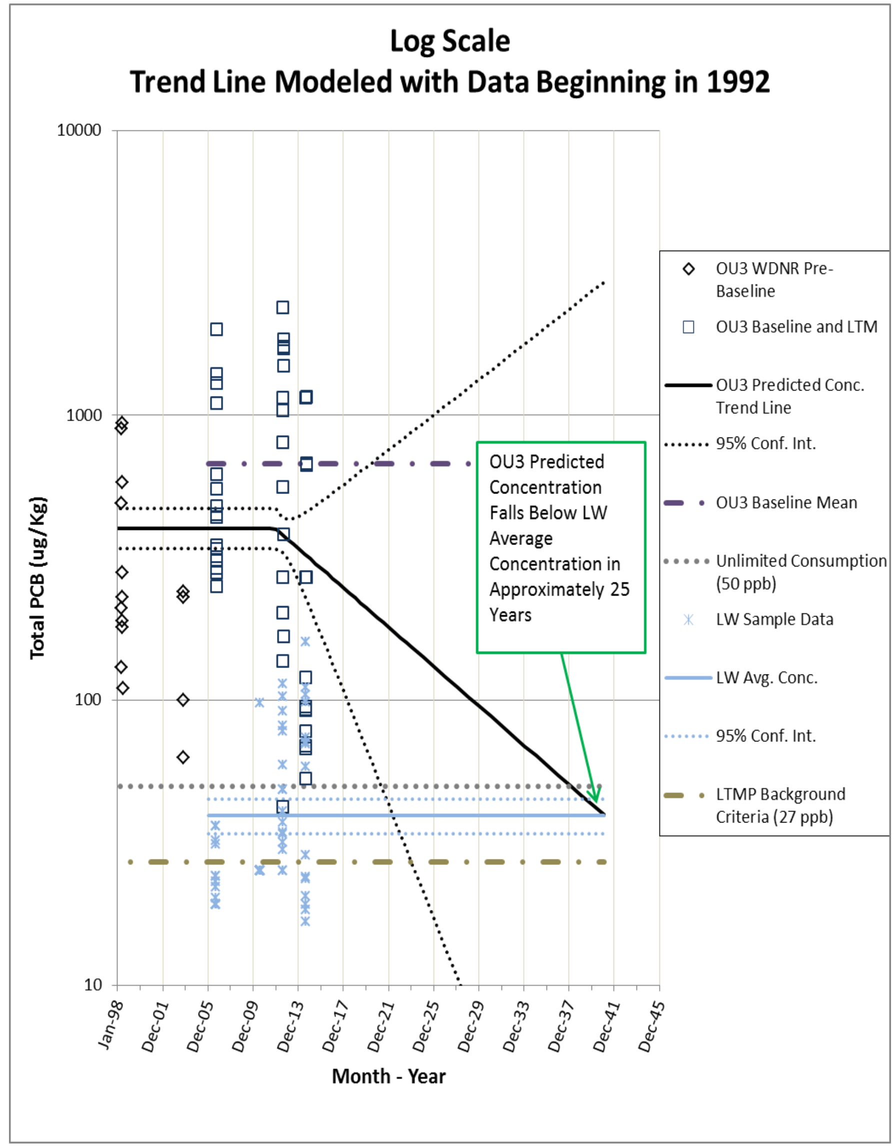
Figure 8. Regression Modeled Recovery Rate – OU2C and OU3 Walleye



OU2C Walleye



OU3 Walleye

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The post-remedial concentration trend for gizzard shad for OU2B is below the *FR-LTMP* background criteria, as well as the Lake Winnebago updated background average results. The trend line for gizzard shad in OU2A, OU2C and OU3 also are projected to meet these criteria by 2017.

The concentration trend line for carp is currently below ecological target concentrations, and based on the current recovery rate trend line, concentrations are projected to meet the Lake Winnebago updated background average results in 30 years for OU2A and 20 years for OU2B. The variation in the sample datasets for carp in OU2C and OU3, and smallmouth bass in OU2A preclude the ability, presently, to project with statistical confidence, the time when background conditions will be met. However, additional long-term monitoring data from future events, along with the anticipated natural elimination of the currently older fish from the population, should clarify the actual concentration trend.

Finally, based on the recovery trend data, walleye concentrations are projected to meet Lake Winnebago updated background average results in approximately 15 years for OU2B and 25 years for OU2C and OU3. The recovery rate trend line for walleye also is projected to meet human health target concentrations within these time frames.

CONCLUSIONS

Water

Surface water quality results indicate that year 2014 concentrations significantly decreased from those observed during the 2006-2007 baseline. Statistical modeling determined that year 2014 PCB concentrations are estimated to have decreased from baseline conditions by approximately 88% for OU2A, 83% for OU2B, 85% for OU2C, and 83% for OU3.

While 2014 PCB concentrations in water illustrate a very significant decrease for the OUs, concentrations remain elevated over background conditions of Lake Winnebago. As a percentage difference over Lake Winnebago, PCB concentrations in 2014 remain approximately 390% higher for OU2A, 640% for OU2B, 560% for OU2C, and 750% for OU3.

An evaluation of the post-remedial recovery rate was estimated with an exponential decay function, comparing the recovery rate trend to SWAC-reduction goals and background conditions from *FR-LTMP* exit criteria. Given the observed recovery rates and trends, concentrations are projected to meet these criteria in 2017 for OU2 and 2023 for OU3. Therefore, the recovery rate exit criteria for water assessed from evaluation of the exponential decay trend are anticipated to be met well within a 30-year post-remediation period.

Fish Tissue

Fish tissue PCB concentrations also decreased between baseline and 2014, with reductions in concentrations being dependent on the fish species. The 2014 upper 95% confidence limits for carp (2490 µg/kg for OU2A, 701 µg/kg for OU2B, 676 µg/kg for OU2C, and 1070 µg/kg for OU3) are below the 7,600 µg/kg LOAEC level established for protection of ecological health by the Lower Fox River Ecological Risk Assessment. Therefore, fish tissue PCB concentrations in OU2 and OU3 have achieved the ecological risk reduction goals.

Similar to water quality results, while the 2014 PCB concentrations in fish illustrate a significant decrease over the baseline data, concentrations remain elevated over the 2014 background conditions of Lake Winnebago. No comparisons are made for walleye in OU2A, as walleye were not present in OU2A in 2014. No comparisons are made for smallmouth bass in OU2A as smallmouth bass were not collected in Lake Winnebago in 2014.

An evaluation of the post-remedial recovery rate was performed for carp, gizzard shad, smallmouth bass and walleye, comparing the recovery rate trend to risk-based concentrations, SWAC-reduction goals, or background conditions. The recovery rate was estimated with an exponential decay function.

The concentration trend for carp is below ecological target concentrations for all OUs, and is projected to reach Lake Winnebago (background) average concentrations in approximately 30 years (2044) for OU2A and approximately 20 years (2032) for OU2B. Due to the level of variation in the OU2C and OU3 datasets, the current recovery rate trend lines for OU2C and OU3 do not achieve background conditions within a 30-year post-remedy time frame for

OU2C and OU3. However, these trends will be clarified with additional long-term monitoring data from future events, along with the anticipated natural elimination of the currently older fish from the population.

With regard to gizzard shad results, all OUs now show strong progress towards achieving Lake Winnebago concentrations. Gizzard shad concentrations currently meet background criteria for OU2B (no statistical difference from Lake Winnebago), and based on the estimated recovery rate trends, are projected to fall below this criterion for OU2A, OU2C and OU3 by the year 2017.

For smallmouth bass in OU2A, estimated recovery rate trends do not reach the background average for Lake Winnebago within the 30-year post-remedy time interval. (No background criteria are given for smallmouth bass in the *FR-LTMP*.) Future monitoring data are necessary to determine whether the estimated concentration trend line continues at the current rate, or whether sharper concentration reductions are observed.

The recovery rate trend line for walleye is projected to meet human health target concentrations and background conditions within 15 years for OU2B and within 25 years for OU2C and OU3.

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