4. Injuries to Sediment

As noted in Chapter 3, surface water resources are defined in the DOI regulations to include both surface water and sediments suspended in water or lying on the bank, bed, or shoreline [43 C.F.R. § 11.14(pp)]. Injury to surface water was discussed in Chapter 3, and injury to bed sediments is discussed in this chapter.

Ecosystem services provided by sediment include habitat for fish, benthic macroinvertebrates, semiaquatic and amphibious animals, and aquatic and riparian vegetation; hydrologic flux; and nutrient and energy cycling.

4.1 Injury Definitions

In this chapter, injuries to sediment resources are determined using the following injury definition:

- Concentrations . . . of substances sufficient to have caused injury . . . to groundwater, air, geologic, or biological resources when exposed to . . . sediments [43 C.F.R. § 11.62(b)(1)(v)].

4.2 Stage I Injury Assessment Approach

Table 4.1 outlines the approaches taken in this chapter to assess injury to sediment. Concentrations of PCBs measured in instream sediment are compared to appropriate toxicity reference values associated with adverse effects in benthic invertebrates and mink.

4.3 Comparison to Concentrations Affecting Benthic Invertebrates

Benthic invertebrates are invertebrates that live or feed on the bottom of aquatic habitats. Examples include clams, snails, mussels, and the larval forms of some insects (e.g., dragonflies, midges, mayflies). They are vitally important in the aquatic food chain, playing essential roles in energy and nutrient transfer from primary producers such as algae and phytoplankton to predatory fish and as decomposers. Benthic invertebrates can be exposed to PCBs in sediment via ingestion or accumulation across the gills. In this section, the potential for PCBs in the sediment of Portage Creek and the Kalamazoo River to injure benthic invertebrates is assessed.

Table 4.1. Approaches to evaluate injury to sediment

Injury definition	Stage I injury assessment approach	Chapter section
Concentrations of . . . substances sufficient to have caused injury . . . to ground water, air, geologic, biological or surface water resources that are exposed to . . . sediments [43 C.F.R. § 11.62(b)(1)(v)]	Compare surface sediment concentrations to consensus-based sediment effect concentrations for benthic invertebrates.	4.3
	Compare surface sediment concentrations to site specific thresholds for causing risk to mink via food chain exposure.	4.4

4.3.1 Data sources

Data used to evaluate injury to benthic invertebrate resources from exposure to sediment are drawn from the following source:

- Sediment PCB concentrations in samples collected from 1993 to 2000 by Blasland, Bouck & Lee (2001).

Sediment samples were collected in reference and assessment sites in Portage Creek and the Kalamazoo River in 1993, 1994, 1997, 1999, and 2000 and analyzed for PCBs as Aroclors (Blasland, Bouck & Lee, 2001). The methods used are outlined in the RI/FS Draft Technical Memorandum 12 (Blasland, Bouck & Lee, 1994c), the RI/FS Draft Memorandum 10 (Blasland, Bouck & Lee, 1994a), and Appendix S-1 of the Supplement to the Kalamazoo River RI/FS (Blasland, Bouck & Lee, 2000c). All concentrations in sediment are expressed on a dry weight basis, unless specified otherwise.

The sediment data presented in this evaluation include only the surface sections of sediment cores and surface grab samples, because surface sediment concentrations are the most biologically relevant to benthic organisms. A depth-weighted average concentration over all sampled segments from 0 to 6 inches of each core was calculated by multiplying the PCB concentration in each sample of a core from 0 to 6 inches by the core length of that sample, summing all such products for the core, and dividing this sum by total core length of these samples (typically 6 inches). The majority of cores (95%) had sampled segments representative of the entire 0-6 in. range. The remaining cores either did not extend as deep as 6 inches (such as surface grab samples) or did not have a complete surface section. In these cases, a depth-weighted average concentration was calculated using the available portions of these cores between 0 and 6 inches. For this evaluation, sampled segments in which no PCBs were detected were assigned a value of one half of the reported detection limit.

Only data for which coordinate information was available are included in this evaluation. The PCB sediment sampling locations in Portage Creek and the Kalamazoo River were organized by the Trustees into reaches (Table 4.2 and Figure 4.1). These reaches are based on the reaches used in the draft RI/FS prepared by the PRPs (Blasland, Bouck & Lee, 2000a). The approximate lengths of these reaches ranges from 1.6 to 25.2 miles.

Table 4.2. Reach designations for sediment samples

Reach designation	Approximate length (miles)	Reach description	Reference or assessment
Kalamazoo River (upstream)	NA	Upstream of Morrow Dam	Reference
Reach A1 (upstream)[a]	2.7	Morrow Dam to Georgia Pacific A-Site	Reference
Reach A1 (downstream)[a]	2.0	Georgia Pacific A-Site to Portage Creek confluence	Assessment
Portage Creek	3.1	Portage Creek (downstream of Allied)	Assessment
Reach A2	14.2	Portage Creek confluence to Main Street, Plainwell	Assessment
Reach B	1.8	Main Street, Plainwell to Plainwell Dam	Assessment
Reach C	1.6	Plainwell Dam to Otsego City Dam	Assessment
Reach D	3.3	Otsego City Dam to Otsego Dam	Assessment
Reach E	4.5	Otsego Dam to Trowbridge Dam	Assessment
Reach F	7.1	Trowbridge Dam to the Allegan City line	Assessment
Reach G	1.7	Allegan City line to Allegan City Dam	Assessment
Reach H	10.0	Allegan City Dam to Lake Allegan Dam	Assessment
Reach I	25.2	Lake Allegan Dam to Lake Michigan	Assessment

a. The spatial distribution of the available sediment data allowed Reach A1 to be separated into A1 upstream of all PRP facilities and A1 downstream of any PRP facilities.

4.3.2 Toxicity reference value derivation

To evaluate the potential for PCBs in sediments to cause toxicity to benthic macroinvertebrates, several different regulatory agencies or research groups have developed sediment effect concentrations (SECs). These SECs provide a means of evaluating the potential for contaminated sediment to cause toxicity to sediment-dwelling aquatic biota. However, no national or state regulatory criteria or standards have been developed for sediments.

MacDonald et al. (2000) reviewed and assembled published SECs for PCBs that were empirically based, relying on databases of sediment contamination and effects to invertebrates. The SECs assembled by MacDonald et al. (2000) differ in the underlying databases used to develop them, the statistical approaches employed to derive SECs from the databases, and the interpretations of the results of the statistical approaches.

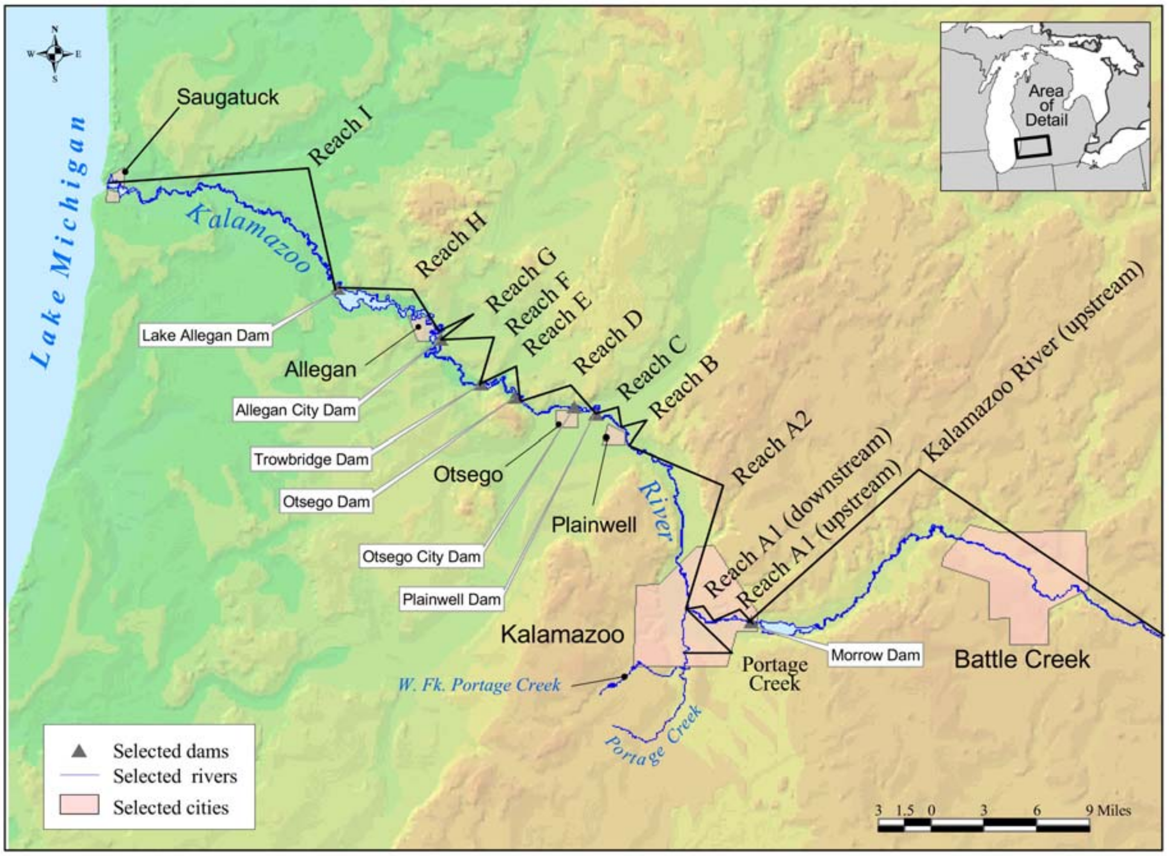

Figure 4.1. Locations of reach designations for sediment samples.

MacDonald et al. (2000) then classified the SECs into three categories: a threshold effect concentration (TEC), a midrange effect concentration (MEC), and an extreme effect concentration (EEC). TECs are intended to identify contaminant concentrations below which harmful effects to sediment-dwelling organisms are not expected to occur. The TECs include selected published minimal effect thresholds, lowest effect levels, and screening level concentrations, and they are intended to protect 85 to 90% of sediment-dwelling organisms. The MECs are intended to identify contaminant concentrations above which harmful effects on sediment-dwelling organisms are expected to occur frequently. The MECs include selected published effect range median concentrations, probable effect levels, moderate apparent effect thresholds, and probable apparent effects thresholds. The EECs are intended to identify contaminant concentrations above which harmful effects are usually or always observed. The

EECs include selected published highest apparent effect thresholds, toxic effect thresholds, and severe effect levels.

Using the geometric means of the three categories of SECs, MacDonald et al. (2000) derived "consensus-based" SECs and evaluated their predictive ability. Of the samples with PCB concentrations less than the TEC, 84% were not toxic to invertebrates. Of the samples with PCB concentrations greater than the MEC and EEC, 68% and 83%, respectively, were toxic to invertebrates. Thus, MacDonald et al. (2000) concluded that the consensus-based SECs are effective at predicting the toxicity of PCBs in freshwater sediments.

The consensus MEC and EEC are used in this Stage I Assessment as potential injury thresholds. Table 4.3 presents the PCB MEC and EEC values, and includes the TEC for comparison.

Table 4.3. SECs for invertebrate exposure to PCBs in freshwater sediment

Name	Definition	Basis	Sediment PCB concentration (mg/kg dry wt)
Consensus TEC	Concentration below which adverse effects are not likely to occur	Geometric mean of 12 TECs	0.04
Consensus MEC	Concentration above which adverse effects are frequently observed	Geometric mean of 12 MECs	0.4
Consensus EEC	Concentration above which adverse effects are usually or always observed	Geometric mean of 5 EECs	1.7

Source: MacDonald et al., 2000.

4.3.3 Results

Depth-weighted mean surface sediment concentrations are higher downstream of PRP facilities than in upstream reference reaches (Figure 4.2). The maximum measured depth-weighted mean surface sediment concentration in the assessment reaches, 117 mg/kg in Reach B, is 63 times higher than any concentration measured in samples taken upstream of PRP facilities.

The consensus sediment effect concentrations are exceeded more often and by a greater magnitude downstream of PRP facilities than upstream, and are exceeded in all of the assessment reaches. Concentrations in 37% of all surface sediment samples collected from assessment reaches exceed the MEC and 17% exceed the EEC. In upstream reference reaches, 18% of samples are higher than the MEC and 3% are higher than the EEC. The percentage of surface samples in assessment reaches which exceed the MEC ranges from 18.1% in Reach A1 to 85.7%

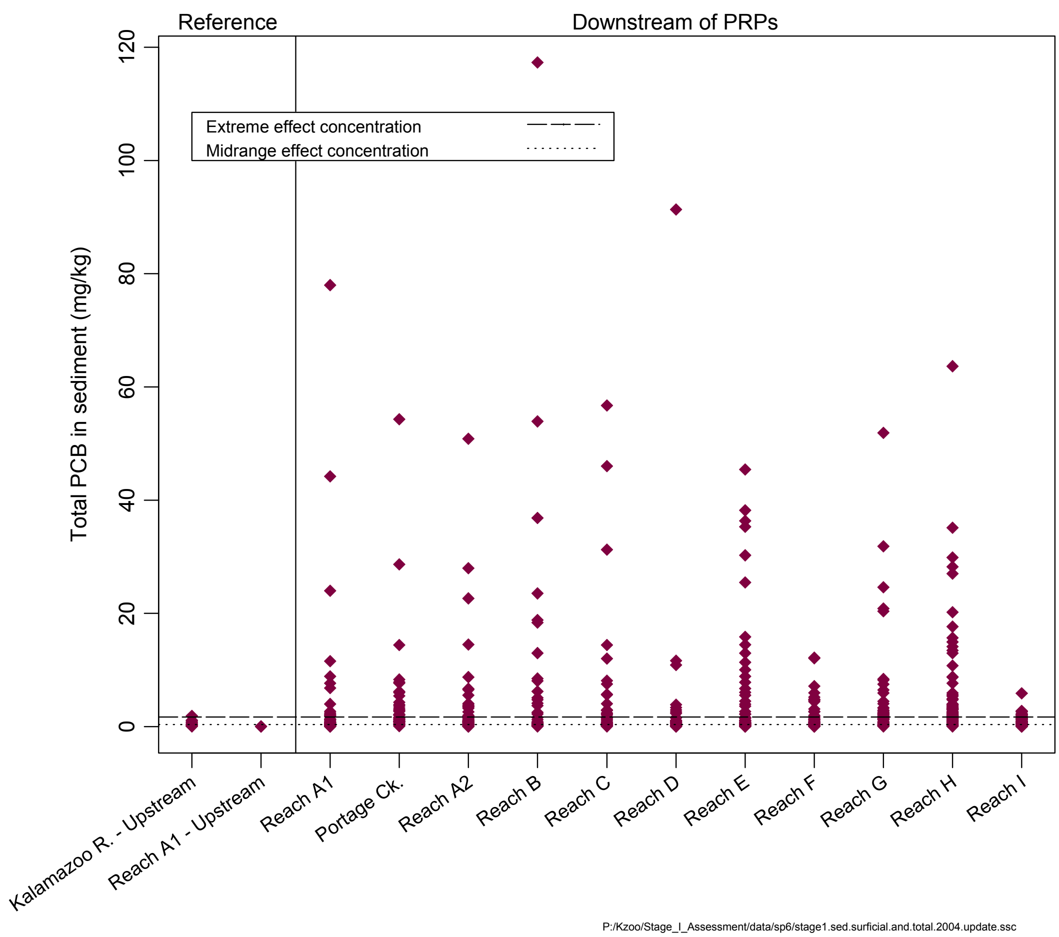

Figure 4.2. Depth-weighted mean PCB concentrations in surficial sediment from cores collected in Portage Creek and the Kalamazoo River compared to consensus-based sediment effect concentrations.

Sources: MacDonald et al., 2000; Blasland, Bouck & Lee, 2001.

in Portage Creek and the percentage which exceed the EEC ranges from 4.4% in Reach I to 53% in Reach H (Table 4.4). In most assessment reaches, some samples have PCB concentrations greater than ten times the EEC. Therefore, because of the frequency and magnitude of exceedences of the PCB MEC and EEC, PCB concentrations in sediment most likely are sufficient to cause injury to benthic invertebrates.

Table 4.4. Exceedences of consensus-based MEC and EEC by depth-weighted mean PCB concentrations in surficial sediment of Portage Creek and the Kalamazoo River

Reach	Number of samples	PCB concentration (mg/kg)[a]	% exceeding MEC[b]	% exceeding MEC by > 10 times	% exceeding EEC[c]	% exceeding EEC by > 10 times
Kalamazoo River – upstream	22	0.39 (0.03-1.88)	31.8	0	4.55	0
Reach A1 – upstream	17	0.03 (0.02-0.05)	0	0	0	0
Reach A1	166	1.33 (0.02-78)	18.1	4.22	8.43	1.81
Portage Creek	49	4.03 (0.07-54.3)	85.7	20.4	44.9	4.08
Reach A2	282	0.79 (0.02-50.8)	19.5	3.19	6.38	1.06
Reach B	70	4.87 (0.04-117)	37.1	18.6	22.9	8.57
Reach C	88	2.58 (0.03-56.7)	36.4	11.4	18.2	3.41
Reach D	75	1.97 (0.02-91.3)	32.0	4.00	10.7	1.33
Reach E	163	2.29 (0.02-45.4)	35.0	11.0	14.1	3.68
Reach F	88	1.09 (0.02-12.2)	39.8	10.2	15.9	0
Reach G	90	3.01 (0.03-51.9)	56.7	13.3	40.0	5.56
Reach H	136	3.97 (0.03-63.7)	82.4	16.9	52.9	5.15
Reach I	227	0.40 (0.03-5.91)	28.6	0.44	4.41	0

a. Mean (minimum – maximum).
b. 0.4 mg/kg.
c. 1.7 mg/kg.
Source: Blasland, Bouck & Lee, 2001.

4.4 Dietary Exposure to Mink

PCBs are not readily degraded and are persistent in the environment, and their concentrations can increase up a food chain once they enter a food chain. PCBs in the KRE that accumulate in fish can be consumed by piscivores such as mink. Fish comprise a large portion of the mink diet, although mink also consume muskrats, crayfish, small rodents, and birds (Camp Dresser & McKee, 2003b). Thus mink can be exposed to PCBs that are accumulated by fish from KRE sediment and surface water.

As part of the ecological risk assessment for the KRE site, EPA and the State of Michigan prepared a PCB food chain model (Camp Dresser & McKee, 2003b). The model incorporates a quantitative link between PCB concentrations in surficial sediments of the Kalamazoo River and PCB concentrations in fish, and thus allows for the prediction of PCB concentrations in fish based on PCB concentrations in surficial sediment in areas where the fish live and forage. Given a PCB concentration in fish that causes injury to mink that consume the fish, the model can thus be used to back-calculate the surficial sediment PCB concentration that corresponds to the mink injury. The model thus can be used to identify areas where PCB concentrations in surficial sediment are sufficient to cause injury to mink via the mink's consumption of fish exposed to the PCB contaminated sediment.

4.4.1 Data sources

The data used to evaluate injury to sediment based on mink dietary exposure are the same as were used to evaluate injury to sediments based on invertebrate SECs and are described in Section 4.3.1. As in Section 4.3, data are summarized by reaches. Foraging ranges for mink are consistent with the approximate lengths of these reaches (U.S. EPA, 1993), and thus it is reasonable to evaluate mink exposure to PCBs in river sediment on this basis.

4.4.2 Toxicity reference value derivation

The April 2003 MDEQ Baseline Ecological Risk Assessment (ERA) (Camp Dresser & McKee, 2003b) developed by the MDEQ for the Portage Creek/Kalamazoo River site derived site-specific sediment thresholds from a dietary exposure model for higher trophic level organisms that consume fish, including mink.

Mink were the most sensitive species identified in the ERA and were thus used to develop a sediment threshold concentration. The MDEQ developed no and low effect toxicity reference values (TRVs) for mink from exposure-response curves compiled from the results of numerous toxicity studies. The no effect TRV is an estimate of the highest dietary dose of PCBs that mink can consume without adverse effects occurring, and the low effect TRV is an estimate of the lowest dietary dose at which adverse effects occur. MDEQ derived a no effect TRV of 0.5 mg PCB/kg ww diet, based on the effects of Aroclor 1254 on the number of live kits per mated female and kit body weight. The low effect TRV of 0.6 mg PCB/kg ww diet developed by MDEQ was based on the effects of Aroclor 1254 on the number of live kits per mated female.

Using observed data for surface water and fish PCB concentrations, MDEQ calculated a site-specific bioaccumulation factor (BAF) of 305,000, which represents the observed ratio of PCB concentration in fish to PCB concentration in water in the KRE (Camp Dresser & McKee, 2003b). MDEQ assumed that the mink diet is comprised of 100% fish, and derived surface water thresholds corresponding with the no effect and low effect TRVs for mink using the equation:

$$\textit{surface water PCB threshold} = \frac{\textit{no effect or low effect TRV}}{\textit{site-specific BAF}}.$$

The corresponding sediment threshold was calculated using a site-specific sediment to surface water partition factor (K_d) of 302,000, which represents the observed ratio of PCB concentration in sediment to PCB concentration in water in the KRE (Camp Dresser & McKee, 2003b). Finally, a sediment threshold corresponding with the no effect TRV (0.5 mg/kg) and the low effect TRV (0.6 mg/kg) for mink was derived using the formula:

$$\textit{sediment PCB threshold} = \textit{surface water PCB threshold} * \textit{site-specific } K_d.$$

These concentrations (Table 4.5) represent the ERA's estimate of sediment PCB concentrations that would result in mink being exposed to PCBs in their diet at the no effect and low effect levels.

Table 4.5. Site-specific sediment thresholds for the protection of mink

Species	No effect TRV (mg PCB/kg sediment dw)	Low effect TRV (mg PCB/kg sediment dw)
Mink	0.5	0.6

Source: Camp Dresser & McKee, 2003b.

This Stage I injury assessment uses low effect TRVs or LOECs as injury thresholds. Although LOECs may overestimate true injury thresholds (i.e., underpredict toxicity and injury), the Trustees used the LOECs in this assessment because they represent dose or exposure concentrations where adverse effects have been shown to occur and therefore, provide a more certain estimate of injury than no effect concentrations, or NOECs. Therefore, the Trustees selected the mink low effect TRV of 0.6 mg/kg dw to evaluate injury to sediments.

4.4.3 Results

The site-specific TRV for mink is exceeded in all of the assessment reaches from Portage Creek and the city of Kalamazoo as far downstream as Lake Michigan (Figure 4.3). Across all of the assessment area, PCB concentrations in 31% of the surface sediment samples exceed the TRV for mink. In upstream reference reaches, 15% of samples have concentrations that are higher than the low effect TRV for mink.

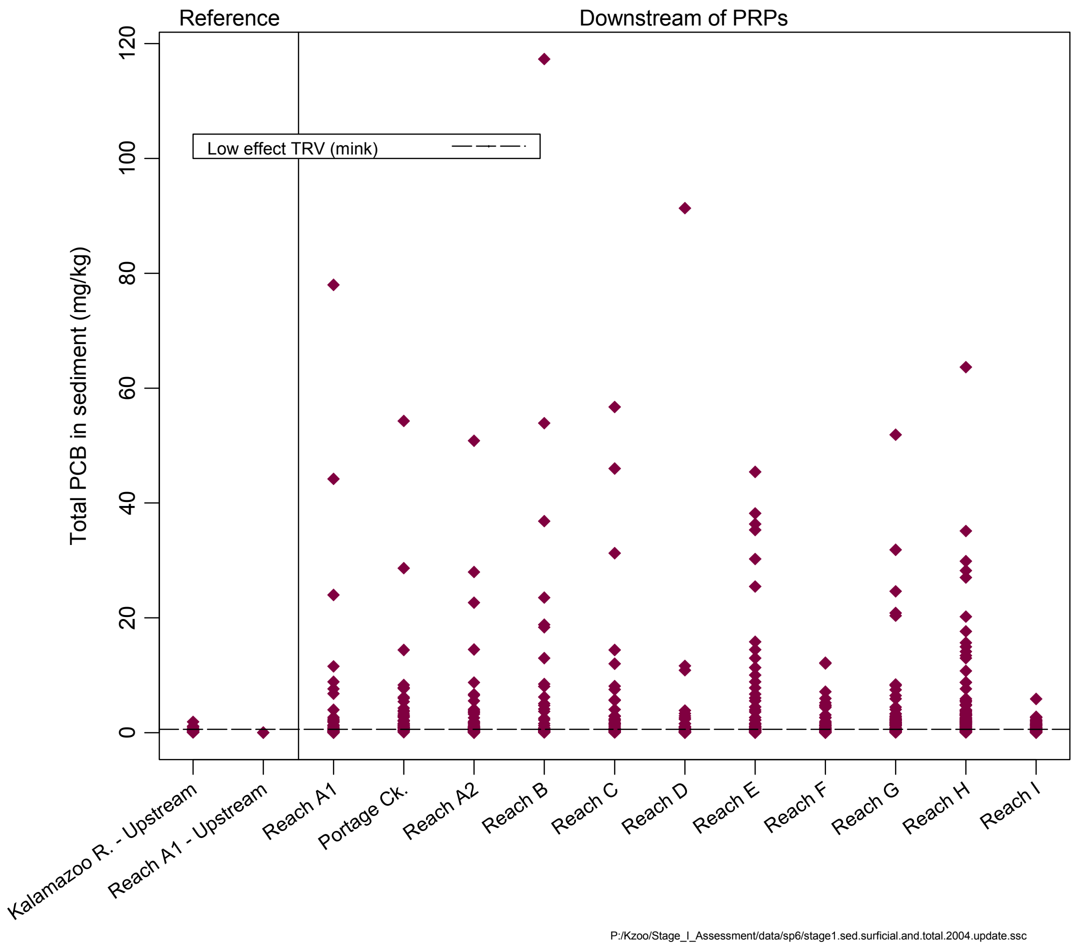

Figure 4.3. Depth-weighted mean PCB concentrations in surficial sediment from cores collected in Portage Creek and the Kalamazoo River compared to site-specific TRV for mink.

Sources: Blasland Bouck & Lee, 2001; Camp Dresser & McKee, 2003b.

Within individual assessment reaches, the percentage of surface samples which exceed the TRV for mink ranges from 15.1% in Reach A1 to 79.6% in Portage Creek (Table 4.6). In all assessment reaches except for Reach I, some samples have PCB concentrations greater than ten times the TRV for mink. These high PCB concentrations in surface sediment exceed the TRVs that the Trustees selected, and therefore, the Trustees believe that the data support the conclusion that mink (and, potentially, other biota with similar exposure and sensitivity to PCBs) are impaired by PCBs in sediments that enter the aquatic food chain. Because of the history of PCB releases from paper company facilities into the KRE, these adverse effects are likely to have begun decades ago.

Table 4.6. Exceedences of site-specific TRV for mink by depth-weighted mean PCB concentrations in surficial sediment of Portage Creek and the Kalamazoo River

Reach	Number of samples	PCB concentration (mg/kg)[a]	% exceeding TRV for mink[b]	% exceeding TRV for mink by > 10 times
Kalamazoo River – upstream	22	0.39 (0.03-1.88)	27.3	0
Reach A1 – upstream	17	0.03 (0.02-0.05)	0	0
Reach A1	166	1.33 (0.02-78)	15.1	4.22
Portage Creek	49	4.03 (0.07-54.3)	79.6	14.3
Reach A2	282	0.79 (0.02-50.8)	15.2	2.48
Reach B	70	4.87 (0.04-117)	31.4	14.3
Reach C	88	2.58 (0.03-56.7)	29.5	7.95
Reach D	75	1.97 (0.02-91.3)	28.0	4.00
Reach E	163	2.29 (0.02-45.4)	25.8	9.82
Reach F	88	1.09 (0.02-12.2)	34.1	3.41
Reach G	90	3.01 (0.03-51.9)	54.4	10.0
Reach H	136	3.97 (0.03-63.7)	77.9	11.8
Reach I	227	0.40 (0.03-5.91)	19.8	0

a. Mean (minimum – maximum).
b. 0.6 mg/kg.
Source: Blasland, Bouck & Lee, 2001.

4.5 Temporal Extent

This chapter evaluates injuries to sediments using PCB concentrations in surface sediments collected between 1993 and 2000. Information on surface sediment concentrations in the past can be gained from consideration of dated sediment cores (see Section 2.4.2). Analysis of dated sediment cores indicates that PCB concentrations are highest in sediment deposited in the 1960s, when PCB releases were also high (Blasland, Bouck & Lee, 1994c). Although PCB concentrations have decreased after the periods of peak releases to the river, deposition of PCBs in sediments has been steady since approximately 1980 (Blasland, Bouck & Lee, 1994c). Thus, injuries to sediments have occurred since the time of the initial releases from PRP facilities, and were likely higher in the past than they are today.

4.6 Conclusions

The Trustees conclude that PCB concentrations in surface sediment of Portage Creek and the Kalamazoo River downstream of PRP facilities are sufficient to have caused injury for decades.

Concentrations are up to nearly three orders of magnitude greater than a consensus-based extreme effect concentration above which toxicity to benthic invertebrates is expected to occur. Additionally, PCB concentrations in surface sediment are sufficient to have caused injury to mink and bald eagles based on food chain dietary exposure. Concentrations are as high as three orders of magnitude greater than a site-specific low effect TRV for mink. Concentrations in samples from all assessment reaches in Portage Creek and in the Kalamazoo River from the city of Kalamazoo to Lake Michigan exceed the mink TRV. Based on the history of PCB releases from the facilities (see Chapter 2) and the history of PCB concentrations from sediment core data, it is likely that PCB concentrations in sediment have been sufficient to have caused and will continue to cause injuries until the sediment PCB-to-receptor pathway is broken. Thus, the Trustees conclude that sediment is and has been injured throughout the KRE according to the injury definition in 43 C.F.R. § 11.62(b)(1)(v).