2. PCB Releases and Pathways

This chapter summarizes information on the releases of PCBs from paper company facilities located along Portage Creek and the Kalamazoo River, and describes the transport pathways of the released PCBs in the KRE. The DOI regulations specify that a pathway determination be conducted as part of the injury determination phase of an NRDA [43 C.F.R. §11.63]. The purpose of the pathway determination is to determine the route through which the released hazardous substances are transported from the release points to the exposed natural resources [43 C.F.R. §11.61(c)(3)]. The pathway determination thus establishes the link between PCB releases into the KRE and the natural resources exposed to and injured by the PCBs. The presence of this link is important in establishing that the injuries in question result from the PCB releases from PRP facilities.

This chapter documents that the PRP facilities have released PCBs into the KRE and that the PRP facilities are the dominant source of PCBs to the KRE. Then the transport pathways of PCBs in the KRE are described. Finally, the PCB contamination that has resulted from PCB releases and transport in the KRE is described.

2.1 PCBs

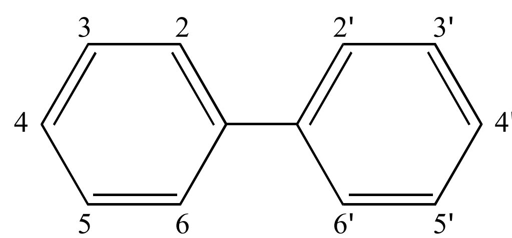

Figure 2.1. Biphenyl molecular structure.

PCBs constitute a class of chemical compounds that have differing numbers and positions of chlorine atoms substituted on a biphenyl ring (Figure 2.1) (Erickson, 1997). PCB formulations used in industrial processes, such as those released from KRE paper companies, were sold as commercial mixtures that contained many different individual PCB compounds (called "congeners"). PCBs were widely used in part because they are relatively resistant to chemical or biological degradation, and this property also makes them relatively persistent in the environment once released (Erickson, 1997). Monsanto Corporation, which was the sole commercial producer of PCBs in the United States, sold PCB mixtures under the trade name "Aroclor." Monsanto manufactured several Aroclor formulations that differed in the total amount of chlorine added to biphenyl (the last two numbers in most Aroclor designations indicate this percentage of chlorine, by weight, in the final mixture). Consequently, the mixture of congeners present in the formulation varies from Aroclors containing primarily lower chlorinated congeners (e.g., Aroclor 1242) to those containing primarily higher chlorinated congeners (e.g., Aroclor 1260; Erickson, 1997).

There are 209 individual PCB congeners that differ in the number and position of chlorine atom substitutions on the biphenyl ring (Erickson, 1997). For example, there are three different monochloro biphenyl congeners that have the single chlorine atom attached to the biphenyl structure in different positions (positions 2, 3, and 4 in Figure 2.1 — positions 5 and 6 are equivalent to positions 3 and 2, respectively, when only a single chlorine atom is attached). The most highly chlorinated congener is decachloro biphenyl, which has chlorine atoms at each of the ten available positions shown in Figure 2.1.

Congeners vary in their physical, chemical, and toxicological properties in ways that are dependent on the number and position of the chlorine atoms. For example, congeners with fewer chlorine atoms tend to be more water soluble, have higher vapor pressures, and bioaccumulate in organisms less than congeners with more chlorine atoms (Erickson, 1997). Furthermore, congeners with chlorine atoms in the 4 or 4' position (in Figure 2.1) and without any chlorine atoms at the 2, 6, 2', or 6' positions, called the "coplanar" congeners because the two phenyl rings can lie flat relative to each other, tend to be the most toxic congeners to fish, birds, and mammals. The coplanar congeners cause toxicity to fish, birds, and mammals through the same toxicological mechanism as dioxin (or 2,3,7,8-tetrachloro-*p*-dibenzodioxin), and are sometimes referred to as "dioxin-like" PCB congeners. Different Aroclor mixtures differ in the absolute and relative amounts of the dioxin-like PCB congeners present, as well as in the amounts of the other congeners that can cause toxicity through other mechanisms. Therefore, it is the PCB congeners present in an Aroclor mixture that determine the environmental fate, transport, bioaccumulation, and toxicity of the PCBs once released into the environment.

2.2 PCB Releases from PRP Facilities

PCBs were released into the KRE from various paper company facilities in Kalamazoo and Plainwell (see Figure 1.2). In the process of deinking and repulping recycled paper, paper mills produced substantial quantities of PCB contaminated waste, which was released to the KRE [Kalamazoo River Study Group v. Rockwell Int'l Corp., 107 F. Supp. 2d 817 (W.D. Mich. 2000)]. When the recycled paper stream included carbonless copy paper with PCBs, PCBs were present in the paper mill waste streams. The Trustees have identified Allied Paper, Inc. and its parent company, Millennium Holdings, Inc. (Allied); the Georgia-Pacific Corporation (Georgia-Pacific); Plainwell Inc. (Simpson Plainwell); and the Fort James Operating Company, Inc. (Fort James) as PRPs for the PCB releases (see Section 1.4). The Trustees may consider notifying other PRPs at a later date as information becomes available.[1]

1. EPA has identified Weyerhaeuser as an additional PRP.

Figure 1.2 shows the general locations of PRP paper mills (or former paper mills) in the Kalamazoo and Plainwell areas. Allied mills include the former Monarch and Bryant Mills on Portage Creek in Kalamazoo and the King Mill on Lake Street in Kalamazoo. Georgia-Pacific mills include several mills on the bank of the Kalamazoo River in Kalamazoo. Simpson Plainwell mills include a mill on the bank of the Kalamazoo River in Plainwell. Fort James mills include the Paperboard Packaging Mill and the KVP Specialty Papers Mills in Kalamazoo. The facilities of these PRPs also include various landfills and other areas where PCB-containing paper waste was handled or disposed.

2.2.1 History of PCB use at PRP facilities

During the post-World War II period from 1946 to 1953, the National Cash Register Company (NCR) conducted research and development of carbonless copy paper using a micro-encapsulation technique for imprinting images (Appleton Papers, 1987). Commercial sales of carbonless copy paper, which became known as “NCR paper,” began in March 1954 (Appleton Papers, 1987). Carbonless copy paper manufactured between 1954 and 1971 contained Aroclor 1242 (A1242) as an ink carrier or solvent. The A1242 was used as a solvent for certain dyes that were encapsulated in small spheres and applied to one or both sides of the paper during the coating process. The walls of the spheres would rupture and release the dye when subjected to pressure. The average A1242 content in a sheet of carbonless copy paper was 3.4% by weight (Carr et al., 1977; Rockwell Int’l Corp., 107 F. Supp. 2d 817).

Production records show that between 1957 and 1971, about 44,162,000 lbs of A1242 were used in the production of carbonless copy paper (Carr et al., 1977). This amount accounted for an estimated 28% of all the PCBs that the Monsanto Chemical Company (the sole domestic producer of PCBs) sold for plasticizer applications during this period, and 6.3% of Monsanto’s total domestic sale of PCBs for the 15 year period from 1957-1971 (Carr et al., 1977; Rockwell Int’l Corp., 107 F. Supp. 2d 817). Information on production prior to 1957 is not available.

Aroclor 1254 (A1254), another commercial PCB mixture, was also used to a limited extent in printing inks beginning in 1968 (Rockwell Int’l Corp., 107 F. Supp. 2d 817). It is estimated that the total usage of A1254 in carbonless copy paper was 50,000 lbs (Rockwell Int’l Corp., 107 F. Supp. 2d 817).

According to Carr et al. (1977), approximately 19% of carbonless copy paper was being recycled across the country in 1976 and a greater proportion may have been recycled in previous years. Assuming an average recycling effort of 20% for this paper over the 18-year period when PCBs were in the paper, then recycled paper streams across the country contained 20% of the 44 million lbs of PCBs used in the carbonless copy paper, a total of some 8.8 million lbs of PCBs in recycled paper pulp over the 18 years. Although PCB use in the manufacturing of carbonless copy paper was discontinued in 1971, the paper recycled by the Kalamazoo area paper companies continued to contain PCBs for many years after 1971. For example, samples of waste paper that was recycled at a KRE Fort James mill in 1976 contained up to 11,313 mg/kg PCBs (Rockwell Int'l Corp., 107 F. Supp. 2d 817).

The PCBs in the carbonless copy paper that paper mills deinked and repulped either became integrated into new paper products or became part of the paper company waste stream. Deinking and pulping the recycled stock would break the spheres in the paper containing the PCB-laden dyes. These PCBs were then distributed throughout the paper recycling process, including in the waste stream. Some of the PCBs in the carbonless copy paper, however, remained in the recycled pulp and subsequently were incorporated in the new paper products. For example, PCB concentrations up to 433 mg/kg were measured in paperboard used for cereal packaging in 1971 (Carr et al., 1977).

Deinking and repulping recycled paper produces a substantial quantity of paper waste. The handling and disposal of paper waste was similar at each of the PRP deinking mills from the mid-1950s to early 1970s. Figure 2.2 provides a schematic of the fate of paper waste from the mills. Raw paper waste, containing water, clay, and fibrous waste, was pumped to a clarifier that separated out much of the settleable solids. The waste from the clarifier included wastewater (effluent) and residual clay and fibrous solids (underflow, or residuals; Blasland, Bouck & Lee, 1992).

Typically, the effluent from the clarifier was either recycled through the process systems, discharged to the river, or discharged to a municipal wastewater treatment plant (WWTP) (Figure 2.2). The underflow from the clarifier was pumped into residuals dewatering lagoons (Figure 2.2) and allowed to dry by evaporation for several months. The resulting dried residuals, consisting mostly of the grey clay and wood fibers, were then removed from the dewatering lagoons and deposited in disposal areas (Blasland, Bouck & Lee, 1992). The disposal areas, which are discussed in detail in the following sections, were located along the banks of the Kalamazoo River near the mills.

Studies in the past 20 years have shown that much of the paper residuals from the late 1950s to the early 1970s contained highly elevated concentrations of PCBs as a result of the deinking and repulping of recycled carbonless copy paper.

Monitoring of direct PCB releases from PRP facilities into the Kalamazoo River and Portage Creek is limited because effluent or residuals were not tested for PCBs until several years after the use of PCBs in carbonless copy paper was discontinued in 1971. However, there is direct evidence of PCB contamination in drainages that lead from paper mills to surface water and in groundwater beneath the disposal areas of several paper company facilities. Additionally, PCB-

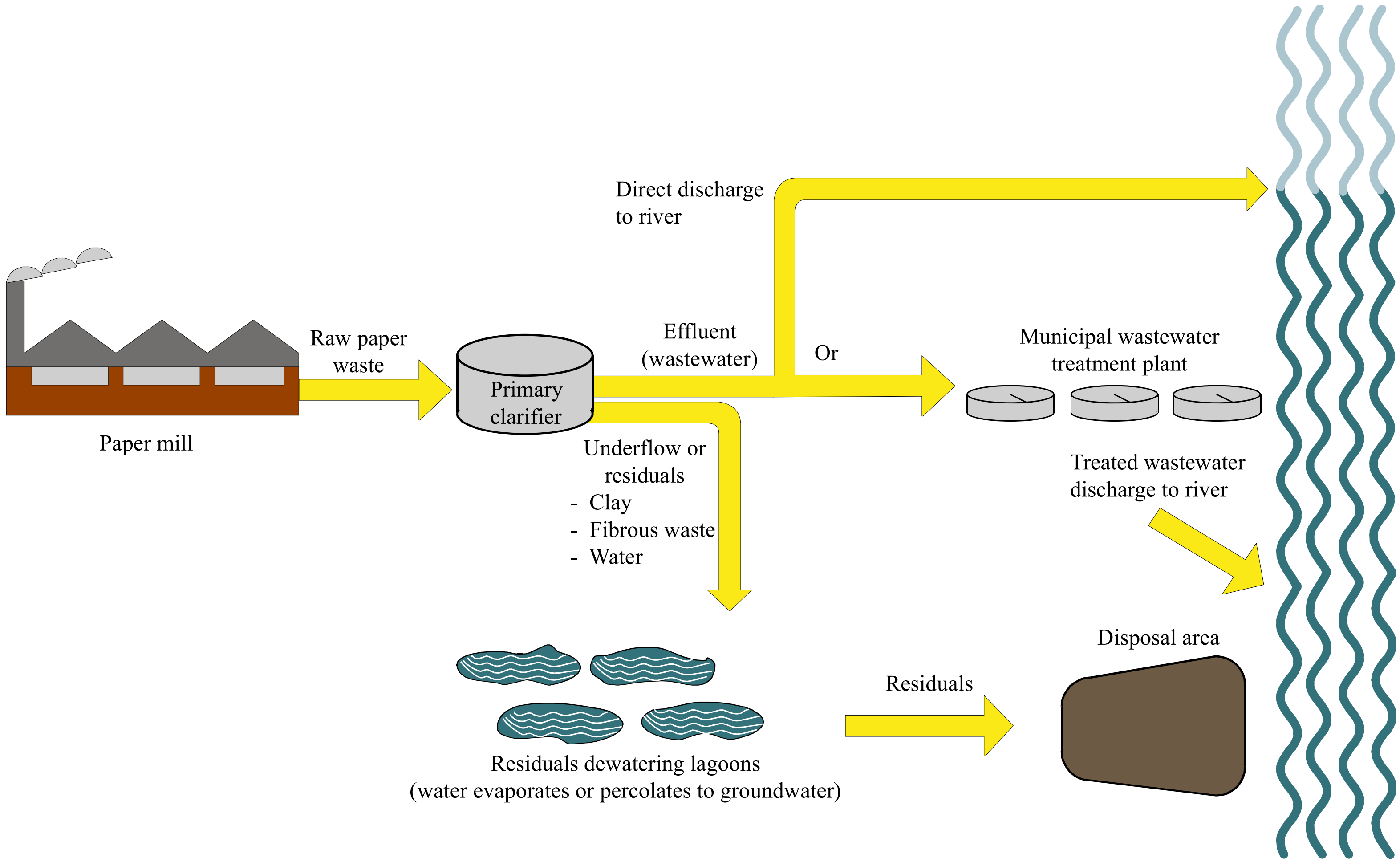

Figure 2.2. Typical fate of paper mill waste during the period when carbonless copy paper contained PCBs (1954-1971).

contaminated residuals in disposal areas along the Kalamazoo River and Portage Creek have eroded and continue to erode into surface water, releasing PCBs directly into surface water (Rockwell Int'l Corp., 107 F. Supp. 2d 817).

2.2.2 Evidence of PCB releases from Allied facilities

The Allied Paper company was formed by the merger of the Monarch, Bryant, and King Mills in 1922 (Figure 2.3 shows the locations of these mills). The Bryant Mill and the King Mill deinked carbonless copy paper from the mid-1950s through at least 1971, the period when the paper contained PCBs. The combined deinking capacity of the Allied mills was listed at 100 tons of paper per day in 1960 and 1962, and at 350 tons of paper per day in 1965. As the largest paper manufacturer of the four PRP facilities, it is likely that Allied discharged the most waste. It has been estimated that Allied released between 895,000 and 1,790,000 lbs of PCBs in its waste stream from 1960 to 1979 (Rockwell Int'l Corp., 107 F. Supp. 2d 817).

Before 1953, wastewater was discharged directly from the Monarch Mill to Portage Creek (Rockwell Int'l Corp., 107 F. Supp. 2d 817). Monarch installed a clarifier in 1953, and discharged the effluent from the Monarch clarifier to Portage Creek upstream of Bryant Mill Pond beginning in the mid-1950s (Figure 2.3). The Bryant clarifier also discharged effluent to Portage Creek upstream of Bryant Mill Pond (Figure 2.3). The King Mill clarifier effluent was discharged to the Kalamazoo River through the King Street storm sewer. In 1961, Allied discharged 156,494 lbs per day of suspended solids to Portage Creek and the Kalamazoo River through the clarifiers. Additional suspended solids were discharged to Portage Creek and the Kalamazoo River in waste water that bypassed the clarifiers (Rockwell Int'l Corp., 107 F. Supp. 2d 817).

Residuals waste from the deinking and repulping process was disposed of at several facilities, including the Monarch HRDL, the Bryant HRDL, and the former Bryant Mill Pond, formed by the former Bryant Mill Dam on Portage Creek (Figure 2.3).

PCBs have been detected in several media on the Allied property (Table 2.1). The MDNR reported soil and sediment PCB concentrations in samples taken from a former channel that evidently discharged effluent or raw paper waste from the Bryant clarifier directly to the Bryant Mill Pond in Portage Creek (United Environmental Technologies, 1990). PCBs were detected in all 13 samples collected, at concentrations up to 37 mg/kg, demonstrating that the wastewater discharge in this channel carried PCBs to Portage Creek (MDNR, 1990b; United Environmental Technologies, 1990).

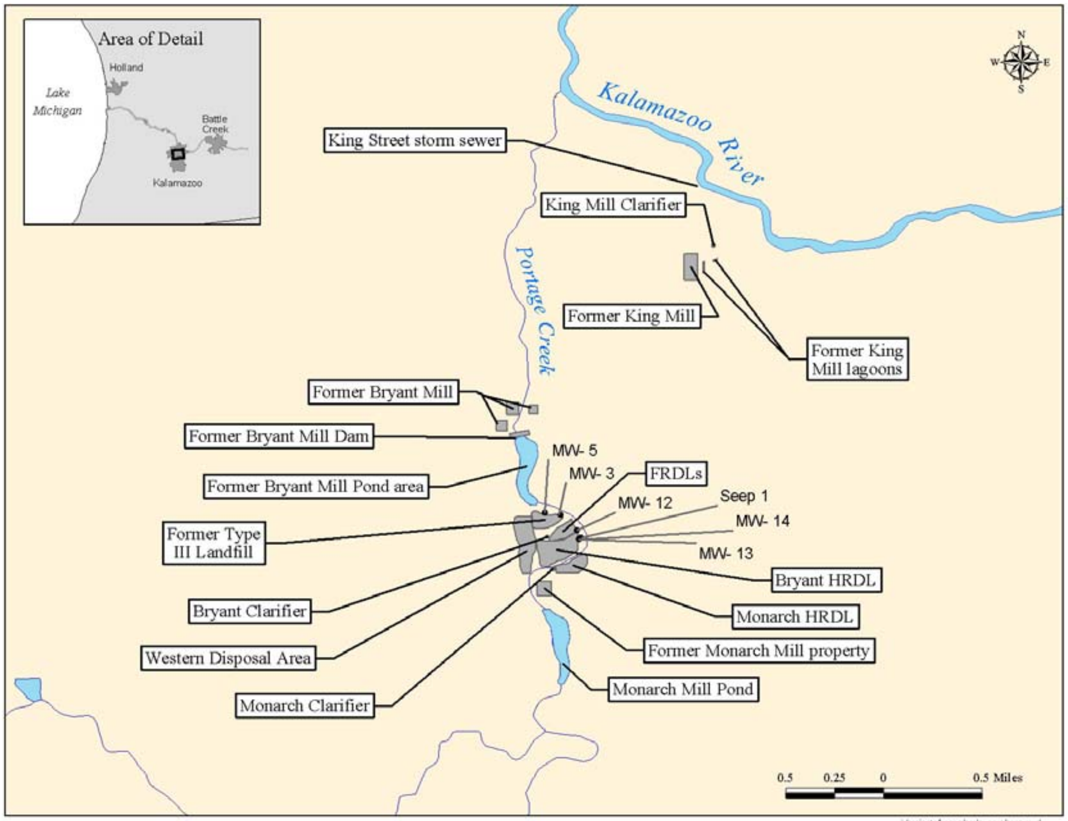

Figure 2.3. The Allied paper mills and surrounding facilities.

In 1976, the MDNR (1976a) analyzed leachate released from the former residuals decanting lagoons (FRDLs; still used at the time) into a ditch that fed directly to Portage Creek. PCBs were detected in the leachate at a concentration of 0.4 µg/L (Table 2.1; Figure 2.3).

In 1972, the Bryant Mill Pond was drained, washing sediments contaminated with PCBs downstream. In 1976, the water level in Bryant Mill Pond was again lowered, and sediments were washed downstream into the Kalamazoo River. Surface water samples collected in Portage Creek contained PCB concentrations ranging from 92.7 to 292 µg/L (Rockwell Int'l Corp., 107 F. Supp. 2d 817) (Table 2.1). Another sample of surface runoff draining from a settling basin to Portage Creek was collected by the Michigan Water Resources Commission (MWRC, 1973a) in 1972. The PCB concentration in this sample was reported at 56 µg/L (MWRC, 1973a). A sample collected in runoff from the Monarch HRDL in 1985 contained 0.33 µg/L PCBs (Blasland, Bouck & Lee, 1992).

Table 2.1. Demonstrated PCB releases from Allied facilities

Location	Medium	Year	PCB concentration	Reference
Former channel from Bryant clarifier to Bryant Mill Pond/Portage Creek	Soil/sediment	1989	0.06-37 mg/kg; PCBs detected in 13 of 13 samples	United Environmental Technologies, 1990; MDNR, 1990b
Ditch draining FRDLs into Portage Creek	Leachate	1976	0.4 µg/L	MDNR, 1976a
Portage Creek downstream of Bryant Mill Pond, during dewatering of pond	Surface water	1976	92.7-292 µg/L	Rockwell Int'l Corp., 107 F. Supp. 2d 817
Discharge from settling basin to Portage Creek	Surface runoff	1972	56.0 µg/L	MWRC, 1973a
Runoff from Monarch HRDL, near Monarch clarifier	Surface runoff	1985	0.33 µg/L	Blasland, Bouck & Lee, 1992
Monitoring well located east of former Type III landfill, adjacent to Portage Creek (MW-3)	Groundwater	1986	0.52 µg/L	MDNR, 1987a
Monitoring well located north of HRDLs, ~100 ft from Portage Creek (MW-12)	Groundwater	1986	0.35 µg/L	Limno-Tech, 1987
		1989	0.10 µg/L	Blasland, Bouck & Lee, 1992
Monitoring well located east of HRDLs, ~100 ft from Portage Creek (MW-13)	Groundwater	1986	0.13 µg/L	Limno-Tech, 1987
Monitoring well located east of HRDLs, ~20 ft from Portage Creek (MW-14)	Groundwater	1986	0.37 µg/L	Limno-Tech, 1987
Monitoring well located north of Bryant clarifier and former Type III Landfill, ~150 ft from Portage Creek (MW-5)	Groundwater	1985	2.1 µg/L 1.7 µg/L	Limno-Tech, 1987
		1986	1.4 µg/L	Blasland, Bouck & Lee, 1992
			0.56 µg/L	MDNR, 1987a
		1988	0.79 µg/L 0.61 µg/L 0.76 µg/L	Blasland, Bouck & Lee, 1992
		1989	3.3 µg/L	Blasland, Bouck & Lee, 1992

Table 2.1. Demonstrated PCB releases from Allied facilities (cont.)

Location	Medium	Year	PCB concentration	Reference
Seep located east of HRDLs, ~50 ft from Portage Creek (Seep 1)	Groundwater to surface water seep	1985-1986	26 µg/L[a] 10 µg/L[a] na/4.4 µg/L[b] 3.3/2.5 µg/L[b] 4.8/1.8 µg/L[b] 2.3/1.2 µg/L[b] 5.8/1.6 µg/L[b]	Blasland, Bouck & Lee, 1992

a. Samples reported to contain sediment particles resuspended during sampling.
b. Split samples. The value on the left is the PCB concentration reported by Allied; the value on the right is the PCB concentration reported by MDNR.

PCB contaminated groundwater has been found on the Allied property in several locations (Table 2.1). For example, groundwater PCB concentrations outside the former Type III landfill, adjacent to Portage Creek, were over 0.5 µg/L (MDNR, 1987a). The groundwater in three locations north of the Monarch and Bryant HRDLs and within 100 ft of Portage Creek contained 0.10 to 0.37 µg/L PCBs (Limno-Tech, 1987; Blasland, Bouck & Lee, 1992). One well north of the Bryant clarifier has consistently contained PCBs in groundwater at concentrations ranging from 0.56 to 3.3 µg/L (Limno-Tech, 1987; MDNR, 1987a; Blasland, Bouck & Lee, 1992).

PCBs were also detected at concentrations up to 26 µg/L in a groundwater seep near the bank of Portage Creek east of the Monarch and Bryant HRDLs (Table 2.1). In other samples from the same seep, PCBs ranged from 2.3 to 5.8 µg/L (Allied) or 1.2 to 4.4 µg/L (MDNR) in split samples (Blasland, Bouck & Lee, 1992). These data show that PCBs contaminated groundwater that is subsequently released at the surface through the seep.

PCB contamination has been found in the HRDLs at both the Monarch and the Bryant Mill sites (Table 2.2). The Monarch HRDL contains an estimated 170,000 yd^3 of waste and covers approximately 3 acres at an average depth of 15 feet (Blasland, Bouck & Lee, 1993, 1997).

Evidence gathered by Blasland, Bouck & Lee (1993) from samples collected before 1990 shows that the Monarch HRDL contained an average PCB concentration of 13 mg/kg, with a maximum concentration of 61 mg/kg. PCB concentrations in residuals samples collected in 1993 from the Monarch HRDL were up to 140 mg/kg. The Bryant HRDL originally contained an estimated 390,000 yd^3 of waste, covered approximately 13 acres, and was approximately 15 ft deep (Blasland, Bouck & Lee, 1993, 1997; Table 2.2). In 1999, approximately 150,000 yd^3 of dredged material from the former Bryant Mill Pond was disposed of in the Bryant HRDL and the FRDLs (Rockwell Int'l Corp., 107 F. Supp. 2d 817). In January 2000, the disposal area into which material from the former Bryant Mill Pond had been placed was stabilized with sheetpile

Table 2.2. PCB concentrations in residuals, sediment, and soil at the Allied Operating Unit

Location	Area (acres)[a]	Estimated volume (yd^3)	Approx. depth (ft)	PCB concentration pre-1990 (mg/kg)[a]		PCB concentration in native soil 1993 (mg/kg)[b]	PCB concentration in residuals 1993 (mg/kg)[b]
				Mean	Range		
Monarch HRDL	3	170,000[b]	15[a]	13	ND-61	ND-0.47	0.53-140
Bryant HRDL	13	390,000[b, c]	15[a]	47	ND-1,200	ND-100	3.0-650
FRDLs	5	62,000[b]	Up to 16[b]	—	—	ND-7.0	ND-19
Former Type III Landfill	7.8	250,000[a]	20[a]	ND	ND	ND-2.4	0.14-2,000
Area north of landfill	—	—	Up to 5[a]	4	0.012-37	—	—
Western Disposal Area	—	380,000[b]	Up to 20[b]	ND	ND	ND-0.41	ND-2,500
Former Bryant Mill Pond	22	150,000[c]	Up to 8[a]	84	ND-1,000	ND-510	14-60

ND = not detected.
a. Blasland, Bouck & Lee, 1993.
b. Blasland, Bouck & Lee, 1997.
c. These figures represent the status of the Bryant HRDL and the Bryant Mill Pond prior to remediation of the former Bryant Mill Pond Area. In September 1999, EPA removed 150,000 yd^3 of PCB contaminated sediments from the former Bryant Mill Pond area and placed them in the Bryant HRDL and the FRDLs (Rockwell Int'l Corp., 107 F. Supp. 2d 817).

between the disposal area and Portage Creek (Blasland, Bouck & Lee, 2000b). Prior to the addition of sediments from the former Bryant Mill Pond in 1999, the Bryant HRDL contained an average PCB concentration of 47 mg/kg with a maximum of 1,200 mg/kg PCBs (Blasland, Bouck & Lee, 1993). For comparison, Portage Creek sediments upstream of the Monarch HRDL contained an average of 0.54 mg/kg PCBs, and the Michigan Part 201 generic residential cleanup criterion is 4.0 mg/kg.

The FRDLs cover 5 acres between the Bryant HRDL and the former Type III Landfill (Figure 2.3), and contain an estimated 62,000 yd^3 of waste (Blasland, Bouck & Lee, 1993, 1997). The former Type III Landfill covers an area of 7.8 acres and is estimated to contain 250,000 yd^3 of waste (Blasland, Bouck & Lee, 1993, 1997). PCB concentrations in residuals collected in 1993 from the FRDLs ranged from below detection to 19 mg/kg and in soil from the FRDLs ranged from below detection to 7.0 mg/kg. PCB concentrations measured in the former landfill were as high as 2,000 mg/kg (Blasland, Bouck & Lee, 1997). PCB concentrations in an area to the north of the landfill, bordering on Portage Creek, ranged from 0.012 to 37 mg/kg (Blasland, Bouck & Lee, 1993). In the early 1990s, erosion control measures were taken at the FRDLs and at the former Type III Landfill (Blasland, Bouck & Lee, 2000b).

The Western Disposal Area is estimated to contain 380,000 yd^3 of waste (Figure 2.3; Table 2.2) (Blasland, Bouck & Lee, 1997). PCB concentrations in residuals samples from this location are up to 2,500 mg/kg, and in soil samples are up to 0.41 mg/kg (Blasland, Bouck & Lee, 1997).

In September 1999, EPA removed 150,000 yd^3 of sediments containing approximately 10 tons (9,000 kg) of PCBs from the former Bryant Mill Pond (Rockwell Int'l Corp., 107 F. Supp. 2d 817; Blasland, Bouck & Lee, 2000b). Prior to this removal action, the mean and maximum measured PCB concentrations in samples in the Bryant Mill Pond were 84 mg/kg and 1,000 mg/kg, respectively (Table 2.2) (Blasland, Bouck & Lee, 1993, 1997). PCB concentrations in residuals samples collected in 1993 ranged from 14 to 60 mg/kg, and were up to 510 mg/kg in subsurface soil samples (Blasland, Bouck & Lee, 1997). Approximately 92% of verification samples collected after the removal action had PCB concentrations of less than 1 mg/kg (Blasland, Bouck & Lee, 2000b).

Little PCB sampling has been performed at the former King Mill site in Kalamazoo (Figure 2.3). The MDNR took three surface soil samples from the former King Mill property in 1987 (Creal, 1987). Two samples contained PCBs, at concentrations of 4.5 and 9.1 mg/kg. Blasland, Bouck & Lee (1994e) collected six cores from the former King Mill lagoons in 1994. PCB concentrations in these samples were up to 79 mg/kg (Blasland, Bouck & Lee, 1994e, 2000b). In 1999, approximately 11,000 yd^3 of residuals were removed from one of the former lagoons and disposed of at the King Highway Landfill (see Figure 2.4; Blasland, Bouck & Lee, 2000b). However, due to construction at the King Highway Landfill, excavation activities at the former King Mill lagoons stopped before all waste was removed (MDEQ, 1997b). During the 1950s and 1960s, the paper waste from the former King Mill lagoons was deposited at the A-Site Disposal Area (now owned by Georgia-Pacific). PCB concentrations in the A-Site Disposal Area are covered in the next section.

2.2.3 Evidence of PCB releases from Georgia-Pacific facilities

The Georgia-Pacific paper mills were owned and operated by the Kalamazoo Paper Company from 1899 to 1967. Originally the facility consisted of five mills, three for making paper products and two for finishing and converting (Figure 2.4). Mills 1 and 3 both performed deinking operations in the 1950s and 1960s. Mill 3 discontinued deinking in the late 1960s, was refurbished, and resumed operations in 1975. Mill 1 deinked continuously until the late 1970s (Blasland, Bouck & Lee, 1992). Georgia-Pacific deinked up to 200 tons of waste paper per day, second only to Allied in scale; it has been estimated that Georgia-Pacific released between 560,000 and 1,120,000 lbs of PCBs from its mills from 1960 to 1979 (Rockwell Int'l Corp., 107 F. Supp. 2d 817).

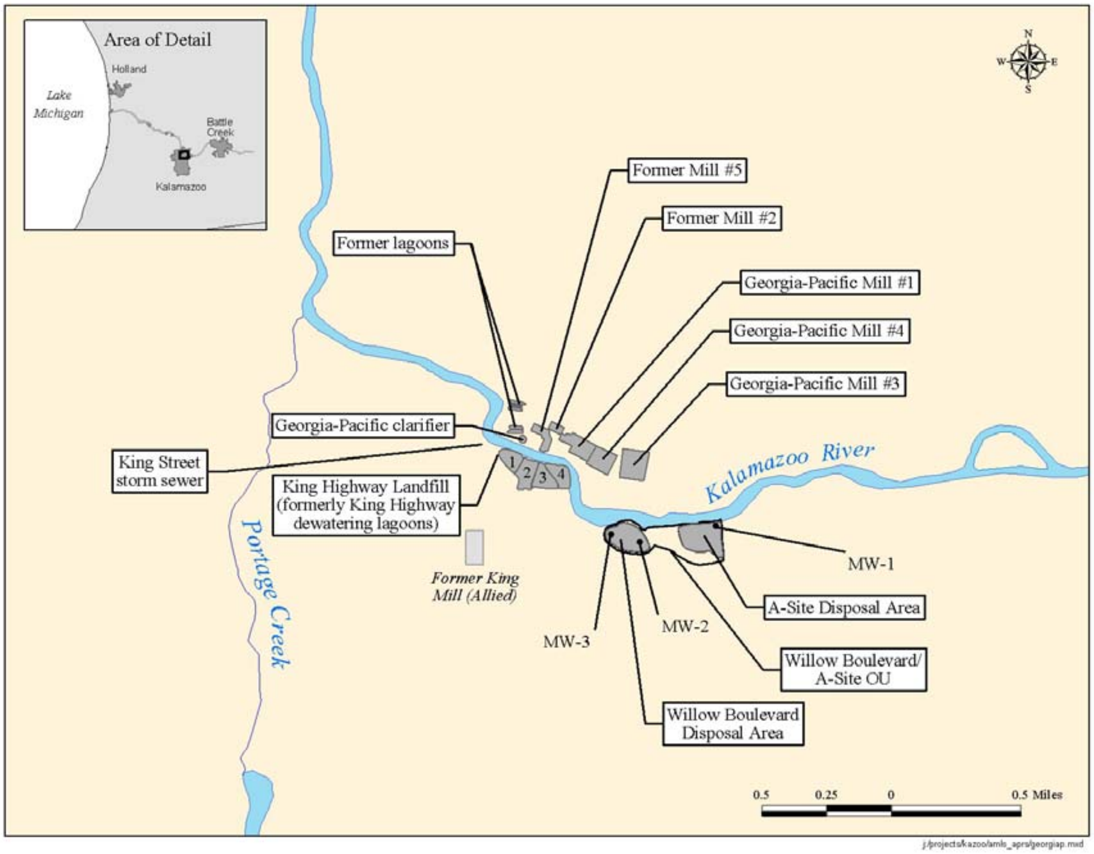

Figure 2.4. The Georgia-Pacific paper mill and surrounding facilities.

Before 1954, all industrial wastewater from Georgia-Pacific was discharged directly to the Kalamazoo River (Rockwell Int'l Corp., 107 F. Supp. 2d 817). Beginning in 1954, raw paper waste was routed to a clarifier. The clarifier effluent was pumped into the Kalamazoo River until 1964, when it was re-routed to the Kalamazoo WWTP. Figure 2.5 provides a flow chart of the fate of Georgia-Pacific paper waste from 1954 to the present.

The residuals from the Georgia-Pacific clarifier have been dewatered and disposed of at various locations (Figure 2.5). From 1954 until the late 1950s, the residuals were placed in the former lagoons next to the Georgia-Pacific clarifier. In the late 1950s, Georgia-Pacific began using the King Highway dewatering lagoons on the south side of the Kalamazoo River (site of the current King Highway Landfill; Figure 2.4) to dewater residuals. The original lagoons were then used as an emergency backup system when necessary.

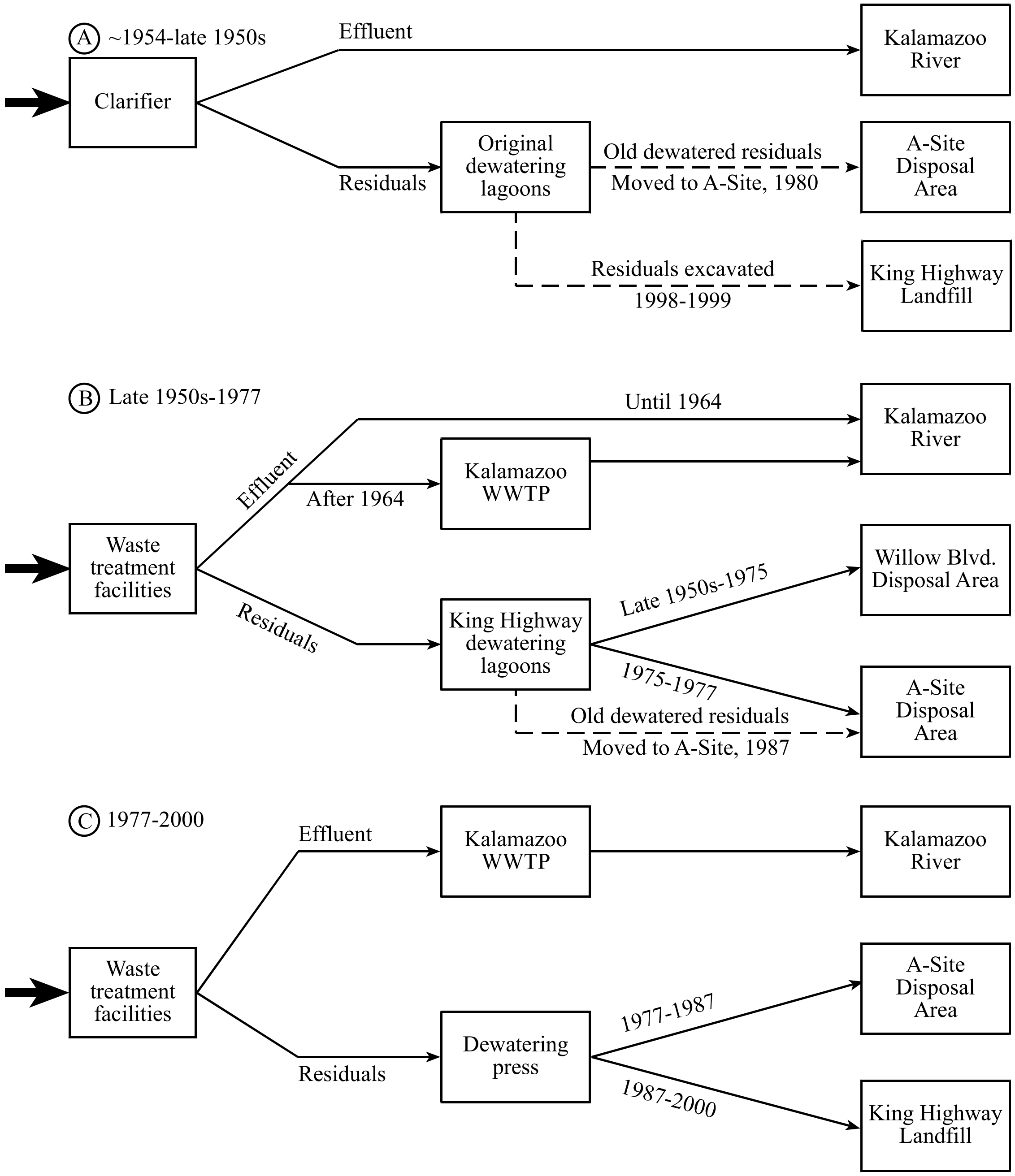

Figure 2.5. Simplified flow chart of the fate of Georgia-Pacific paper waste, 1954 to 2000.

Source: Blasland, Bouck & Lee, 1992.

From the late 1950s until 1977, Georgia-Pacific dewatered residuals in the King Highway dewatering lagoons. Until 1975, the dried residuals from the King Highway dewatering lagoons were excavated and disposed of at the Willow Boulevard Disposal Area (Figure 2.4). By 1975, the Willow Boulevard Disposal Area was filled to capacity, and Georgia-Pacific purchased the A-Site Disposal Area from Allied. Georgia-Pacific used the A-Site Disposal Area for residuals from 1975 until 1987 (Blasland, Bouck & Lee, 1992). In addition, residuals from the former lagoons next to the Georgia-Pacific clarifier were moved to the A-Site Disposal Area in 1980 (Blasland, Bouck & Lee, 1992).

In 1977, Georgia-Pacific began using dewatering presses that eliminated the need for dewatering lagoons (Blasland, Bouck & Lee, 1992). From 1977 until 1987, the residuals from the dewatering presses were deposited at the A-Site Disposal Area. In 1987, the King Highway dewatering lagoons were converted into a licensed Type III landfill. Since 1987, all Georgia-Pacific residuals have been deposited at the King Highway Landfill (Blasland, Bouck & Lee, 1992).

Cores were collected in the Georgia-Pacific former lagoons in 1994 (Figure 2.4). Despite the removal in 1980, residuals were found at a maximum depth of 4.5 ft (Blasland, Bouck & Lee, 1994e). PCBs were detected in both residuals and native soil samples collected from the former lagoons. Concentrations ranged from below detection (at a detection limit of 0.073 mg/kg) to 110 mg/kg in a surface sample. In 1998 and 1999, approximately 33,000 yd^3 of residuals were excavated from the former lagoons and 5,000 yd^3 of sediments were excavated from the floodplain adjacent to the lagoons. The materials were disposed of at the King Highway Landfill and riprap and geotextiles were used to stabilize soils (Blasland, Bouck & Lee, 2000b). After the removal of the residuals and verification sampling, the area of the former lagoons was backfilled, seeded, and stabilized with geotextile and riprap (MDEQ, 1997a).

Groundwater PCB contamination is evident in the areas near the A-Site and Willow Boulevard Disposal Areas. Table 2.3 shows elevated PCB concentrations in the groundwater beneath these two disposal areas. Elevated concentrations of PCBs have consistently been measured in the MW-1 well at the A-Site Disposal Area, located about 100 ft from the Kalamazoo River in the northeast corner of the disposal area. In 1988, concentrations measured at the well were up to 22 µg/L; however, it is possible that this elevated concentration was due to the disturbance from well drilling (Georgia-Pacific, 1988). Subsequent samplings have lower (though still elevated) concentrations of PCBs, ranging from 0.4 to 1 µg/L (Dell Engineering, 1989; Blasland, Bouck & Lee, 1992).

Table 2.3. PCB concentrations in groundwater beneath Georgia-Pacific disposal areas, 1988-1990

Location	Minimum PCB concentration (µg/L)	Mean PCB concentration (µg/L)	Maximum PCB concentration (µg/L)
A-Site Disposal Area (MW-1)	0.4	3.3	22.0
Willow Boulevard Disposal Area, west side (MW-3)	0.04	0.48	1.35
Willow Boulevard Disposal Area, east side (MW-2)	0.04	0.23	0.6

Sources: Dell Engineering, 1988, 1989; Georgia-Pacific, 1988; Blasland, Bouck & Lee, 1992.

In 1988, PCBs were detected in groundwater underlying the Willow Boulevard Disposal Area, approximately 100 to 150 ft from the Kalamazoo River. During one sampling event, the PCB concentration measured in well MW-3 on the west side of the disposal area was 1.35 µg/L, and the concentration measured at MW-2 on the east side of the disposal area was 0.6 µg/L (Dell Engineering, 1988) (Table 2.3). In two subsequent sampling events, the PCB concentrations at both wells were 0.06 µg/L during the first sampling event and 0.04 µg/L during the second sampling event (Dell Engineering, 1988).

PCBs have been released to the Kalamazoo River via the King Street storm sewer to the west of the King Highway Landfill. In 1976, the MDNR (1976c) analyzed a discharge from the storm sewer to the river and found 0.19 µg/L PCBs in the discharge. PCB concentrations in sediments in the storm sewer have been measured at 5.1 mg/kg in clay and 64 mg/kg in silt (Blasland, Bouck & Lee, 1992), and up to 190 mg/kg in sediments extending into the Kalamazoo River (Rockwell Int'l Corp., 107 F. Supp. 2d 817). It is not known whether the PCBs that have been discharged from this sewer originated at the former King Mill (Allied) or at the King Highway Landfill (Georgia-Pacific; S. Cornelius, MDEQ, personal communication). The volume of these residuals was estimated at over 33,000 yd^3 (Rockwell Int'l Corp., 107 F. Supp. 2d 817). In 1999, approximately 5,000 yd^3 of soils and residuals were excavated from the King Street storm sewer area and disposed of at the King Highway Landfill (Blasland, Bouck & Lee, 2000b). Riprap and geotextiles were used to stabilize the area along the river.

PCB contaminated waste has been found in all three of the Georgia-Pacific disposal areas (Willow Boulevard, A-Site, and King Highway Landfill; Table 2.4). The Willow Boulevard Disposal Area covers approximately 11 acres, on the south side of the Kalamazoo River (Figure 2.4), and contains 145,000 yd^3 of paper waste (Blasland, Bouck & Lee, 1995). PCB concentrations in surface residuals and soils collected in 1987 were up to 143 mg/kg, and up to 160 mg/kg in residuals and soils collected from the bottom layers of the disposal area (Swanson Environmental, 1987). PCB concentrations in residuals collected in 1993 ranged from below

Table 2.4. PCB concentrations in residuals/soils of Georgia-Pacific disposal areas

Location	Material	Year	PCB concentration (mg/kg)	Source
Willow Boulevard Disposal Area	Surface residuals/soil	1987	ND-143	Swanson Environmental, 1987
Willow Boulevard Disposal Area	Bottom residuals/soil	1987	3-160	Swanson Environmental, 1987
Willow Boulevard Disposal Area	Residuals	1993	ND-270	Blasland, Bouck & Lee, 1995
Willow Boulevard Disposal Area	Soil	1993	ND-4.7	Blasland, Bouck & Lee, 1995
Kalamazoo River adjacent to Willow Boulevard Disposal Area	Sediment/residuals	1993	0.16-44	Blasland, Bouck & Lee, 1995
A-Site Disposal Area	Bottom residuals/soils	1990	ND-14.8	Swanson Environmental, 1990
A-Site Disposal Area	Residuals	1993	ND-330	Blasland, Bouck & Lee, 1995
A-Site Disposal Area	Soil	1993	ND-61	Blasland, Bouck & Lee, 1995
King Highway Landfill — Cell 2	Residuals	1987	5.4	Blasland, Bouck & Lee, 1992
King Highway Landfill — Berm between Cell 1 and Kalamazoo River	Residuals	1989	ND-47.9	Environmental Resources Management, 1989
King Highway Landfill — Cell 2	Residuals two cores at approximately 13-30 in. deep	1991	ND-28	Blasland, Bouck & Lee, 1992; Environmental Resources Management, 1991
King Highway Landfill — Cells 1-4 and berm	Residuals/soil	1993	ND-310	Blasland, Bouck & Lee, 1994g

detection to 270 mg/kg, and in native soils from below detection to 4.7 mg/kg (Blasland, Bouck & Lee, 1995). In addition, the average PCB concentration in 5 sediment/residuals samples collected from the Kalamazoo River adjacent to the Willow Boulevard Disposal Area was 11 mg/kg (Blasland, Bouck & Lee, 1995). In 1999 and 2000, approximately 7,000 yd^3 of sediments were excavated and relocated within the Willow Boulevard Disposal Area (Blasland, Bouck & Lee, 2000b). A temporary sand cap was placed over the area at this time.

The A-Site Disposal Area is located to the east of the Willow Boulevard Disposal Area along the Kalamazoo River (Figure 2.4). It covers 23 acres, at depths of up to 27 ft, and is estimated to contain 475,400 yd^3 of paper waste (Blasland, Bouck & Lee, 1995). Residuals and soils collected from the bottom layers of the A-Site Disposal Area in 1990 contained PCB concentrations ranging from below detection to 14.8 mg/kg (Swanson Environmental, 1990). PCB concentrations in residuals samples collected in 1993 ranged from below detection to 330 mg/kg, and in native soils from below detection to 61 mg/kg (Blasland, Bouck & Lee, 1995). In 1998, a 2,000 foot long sheetpile wall was installed along the edge of the A-Site Disposal Area to stabilize the berm that separates it from the Kalamazoo River (Blasland, Bouck & Lee, 2000b).

The King Highway Landfill is an operational licensed Type III landfill used for disposal of paper waste by Georgia-Pacific (Figure 2.4). The operable unit in the NPL site covers over 23 acres, 12.3 of which consist of cells 1-3 of the landfill (Blasland, Bouck & Lee, 1994g). Unit 4 covers 3.1 acres, was excavated to the water table before 1982, and collects surface water runoff. The remaining acreage contains access roads, dike slopes, berms, and buffer areas. The majority of the historical residuals from the former King Highway dewatering lagoons have been removed and placed in the Willow Boulevard or A-Site Disposal Areas. However, PCB concentrations indicate that not all PCB contaminated materials have been removed. A residuals sample collected from cell 2 in 1987 contained 5.4 mg/kg PCBs (Blasland, Bouck & Lee, 1992) and residuals collected from the berm between cell 1 and the Kalamazoo River in 1989 contained PCB concentrations as high as 47.9 mg/kg (Environmental Resources Management, 1989). Two cores collected from cell 2 contained concentrations up to 28 mg/kg (Environmental Resources Management, 1991; Blasland, Bouck & Lee, 1992). PCBs were detected in samples from all four cells and the berms collected in 1993 (Blasland, Bouck & Lee, 1994g). PCB concentrations in these samples were up to 310 mg/kg. Remedial actions begun in 1996 have been taken at the King Highway Landfill site, including relocation of residuals, the installation of a sheetpile wall, and construction of a Type III landfill cover system (Blasland, Bouck & Lee, 2000b). Georgia-Pacific ceased operations at the Kalamazoo plant in December 2000 (PaperAge, 2000; Georgia-Pacific, 2001).

2.2.4 Evidence of PCB releases from Simpson Plainwell facilities

The current Simpson Plainwell Mill was started in 1886 by the Michigan Paper Co., who operated the Plainwell Mill until 1956. Since then, the mill has been owned and operated by entities known as the Hamilton Paper Company (1956-1964), Weyerhaeuser (1964-1970), Plainwell Paper Company, Inc. (1970-1988), Simpson Plainwell Paper Co. (1988-1997), Plainwell Paper Company (1997-1998), and Plainwell, Inc. (1998-present) (Jackowski, 2002).

Carbonless copy paper was deinked at the Simpson Plainwell Mill from 1957 to 1962 (Blasland, Bouck & Lee, 1992; Figure 2.6). In 1962, the Simpson Plainwell Mill reported that 60 tons of paper per day was deinked (Rockwell Int'l Corp., 107 F. Supp. 2d 817). It has been estimated that Simpson Plainwell released between 254,000 and 507,000 lbs of PCBs from its mills from 1960 to 1979 (Rockwell Int'l Corp., 107 F. Supp. 2d 817).

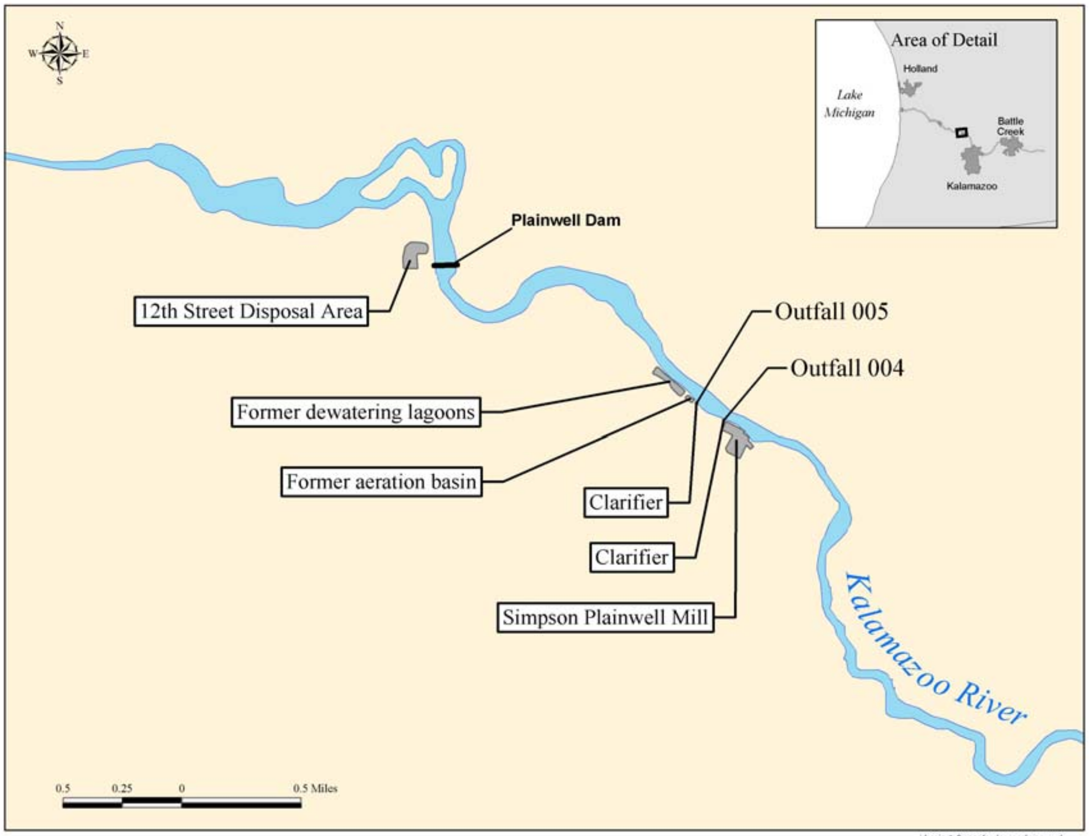

Figure 2.6. The Simpson Plainwell paper mill and surrounding facilities.

The treatment of the paper waste from the deinking operations was similar to that at the other Kalamazoo-area mills. Wastewater was discharged directly to the Kalamazoo River until 1954, when a clarifier was installed (Blasland, Bouck & Lee, 1994e; Rockwell Int'l Corp., 107 F. Supp. 2d 817). A document summarizing disposal of waste through 1960 indicates that 300 to 900 tons of paper were deinked per month and suspended solids discharges to the river averaged 14,000 to 34,000 lbs per day (Rockwell Int'l Corp., 107 F. Supp. 2d 817). After 1954, waste was pumped to the primary clarifier, clarifier effluent was pumped to the Kalamazoo River, and the underflow was pumped to on-site dewatering lagoons. The residuals from the lagoons were then trucked to the 12th Street Disposal Area for disposal (Figure 2.6). In 1981, the Plainwell Mill started using a new residuals dewatering process that supplanted the use of dewatering lagoons. At that time, the remaining residuals in the on-site lagoons were disposed of at the 12th Street Disposal Area, the lagoons were backfilled, and a new secondary clarifier and a treatment system were built on top of them (Blasland, Bouck & Lee, 1992).

PCBs have been detected in the Simpson Plainwell Mill effluent discharge. Table 2.5 summarizes data showing PCBs in effluent discharges; detectable PCB concentrations range from 0.039 to 0.13 : g/L. PCBs have not been detected in other effluent analyses from the Simpson Plainwell Mill.

Table 2.5. PCB concentrations in Simpson Plainwell Mill effluent

Effluent	Year	PCB concentration (μg/L)	Source
Clarifier effluent (Outfall 005)	1973	0.13	MWRC, 1975
Mill cooling water discharge (Outfall 004)	1978	0.10	MDNR, 1978b
Clarifier effluent (Outfall 005)	1978	0.10	
Unknown outfall	1985	0.039	Blasland, Bouck & Lee, 1992

Environmental PCB data related to the Simpson Plainwell Mill and 12th Street Disposal Area are limited. As of this writing, no PCB analyses of seep or runoff from the vicinity of the former dewatering lagoons on site or from the 12th Street Disposal Area have been published. One study conducted in 1994 did not find detectable PCBs in groundwater sampled from monitoring wells at the 12th Street Disposal Area at a detection limit of 0.00005 mg/L (Geraghty and Miller, 1994).

The 12th Street Disposal Area is located along the Kalamazoo River (Figure 2.6). No consistent berm or storm water collection system was used in this disposal area, and the current berm is constructed of paper residuals mixed with sand and gravel (Rockwell Int'l Corp., 107 F. Supp. 2d 817). Residuals in the disposal area have been measured to be as thick as 24.5 ft, and the total volume of waste in the landfill is approximately 200,000 yd^3 (Geraghty and Miller, 1994). Residuals are largely within the disposal area, but extend as far as 60 ft beyond the current berm of the disposal area (Geraghty and Miller, 1994). Several investigations have found elevated soil PCB concentrations in and near the disposal area (Table 2.6). Split samples of residuals were collected by MDNR and the Plainwell Paper Company in June 1987. MDNR recorded PCB concentrations up to 39 mg/kg, and the Institute of Paper Chemistry (for the Plainwell Paper Company) found 18 mg/kg PCBs in the split of that sample (RMT Engineering and Environmental Management Services, 1990; Blasland, Bouck & Lee, 1992). Ten of fourteen sludge and soil samples collected by the Plainwell Paper Company in September 1987 contained elevated PCBs, with a maximum recorded concentration of 21 mg/kg (RMT Engineering and Environmental Management Services, 1990; Blasland, Bouck & Lee, 1992). Similarly, all six samples collected in January 1989 contained elevated PCBs, including one sample with a concentration of 120 mg/kg (RMT Engineering and Environmental Management Services, 1990;

Table 2.6. PCB concentrations in residuals and soil samples collected at the Simpson Plainwell Mill and the 12th Street Disposal Area, 1987-1994

Location	Date	Number of samples (detected/total)	Minimum PCB concentration (mg/kg)	Mean PCB concentration (mg/kg)	Maximum PCB concentration (mg/kg)
12th St. Disposal Area, outside berm	June 1987[a]	3/3	2.6 (5)[b]	23.9 (12.3)[b]	39 (18)[b]
12th St. Disposal Area, outside berm	Sept. 1987[a]	10/14	< 0.5	7.4[c]	21
12th St. Disposal Area, outside berm	Jan. 1989[a]	6/6	0.16	30.0	120
12th St. Disposal Area, test pits	May 1993[d]	63/83	< 0.035	15.53[c]	158
Simpson Plainwell Mill, former aeration basin and dewatering lagoons	June 1994[e]	13/18	< 0.05	0.25[c]	1.6
Simpson Plainwell Mill, near mill	June 1994[e]	9/12	< 0.04	20.7[c]	240

a. Sources: RMT Engineering and Environmental Management Services, 1990; Blasland, Bouck & Lee, 1992.
b. Split sample. The first value is the result presented by the MDNR. Samples analyzed by the Institute of Paper Chemistry on behalf of Plainwell Paper are presented in parentheses.
c. A value of ½ the detection limit was used to calculate the mean in samples where PCBs were not detected.
d. Source: Geraghty and Miller, 1994.
e. Source: Blasland, Bouck & Lee, 1994e.

Blasland, Bouck & Lee, 1992). Finally, 63 of 83 samples collected from test pits throughout the 12th Street Disposal Area in 1993 contained detectable PCB concentrations. The mean PCB concentration in these samples was 15.53 mg/kg, and the maximum concentration was 158 mg/kg (Geraghty and Miller, 1994). Remedial activities conducted in 1984 included the capping of the disposal area (Blasland, Bouck & Lee, 2000b).

Additional sampling was conducted by Blasland, Bouck & Lee (1994e) in 1994 near the Simpson Plainwell Mill building and in the former aeration basin and dewatering lagoons area (Figure 2.6). PCBs were detected in samples from both locations (Table 2.6). Concentrations in the former aeration basin and dewatering lagoons averaged 0.25 mg/kg PCB with a maximum concentration of 1.6 mg/kg. Samples collected near the mill building had an average concentration of 20.7 mg/kg. The maximum concentration, 240 mg/kg PCB, was in a sample collected from the end of a discharge pipe that historically conveyed water to the Kalamazoo

River (Blasland, Bouck & Lee, 1994e). Additionally, sediment sampled from a sump along an outfall on the Simpson Plainwell Mill property in 1996 contained PCBs at a concentration of 7.2 mg/kg (Blasland, Bouck & Lee, 2000b). Drainage pipes leading to that outfall were cleaned in 1997 and sediment and flush water were disposed of off-site.

2.2.5 Evidence of PCB releases from Fort James facilities

The Fort James Corporation and its predecessors (James River, KVP Sutherland, and Brown Company) have operated two mills along the Kalamazoo River since 1939 (Rockwell Int'l Corp., 107 F. Supp. 2d 817). The first, the Fort James KVP Mill (consisting of two mill buildings), is located in Parchment, and the second, the Fort James Paperboard Mill (formerly known as the Sutherland Mill), is located in Kalamazoo (Figure 2.7). From 1939 to the mid-1970s wastewater from lagoons at the KVP Mill was discharged directly to the Kalamazoo River. A clarifier and sludge dewatering system was installed in the mid- to late 1970s. At the Paperboard Mill, wastewater was discharged to the Kalamazoo River until the late 1960s. It has been estimated that between 512,000 and 1,025,000 lbs of PCBs were released from the Fort James mills from 1960 to 1979 (Rockwell Int'l Corp., 107 F. Supp. 2d 817).

The Fort James Disposal Area covers approximately 40 acres to the east of the Kalamazoo River (Wilkins & Wheaton Testing Laboratory and STS Consultants, 1986). A Type II landfill of approximately 15 acres was used for disposal of general mill waste as early as the 1930s (Figure 2.7; STS Consultants, 1989). Between the 1960s and 1981, when the former Type II landfill was closed, residuals were the primary material disposed of at the landfill. Another Paper Residuals Disposal Area of approximately 25 acres, to the north of the disposal area, received residuals as well (Figure 2.7). Both the KVP Mill and the Paperboard Mill disposed of paper waste residuals at the Fort James Disposal Area (Wilkins & Wheaton Testing Laboratory and STS Consultants, 1986).

Samples of waste paper to be recycled in the Paperboard Mill collected in 1976 contained PCBs with reported concentrations up to 11,313 mg/kg (Rockwell Int'l Corp., 107 F. Supp. 2d 817). In the same year, samples of filtered solid waste from the mill had reported PCB concentrations of between 12.7 and 125.7 mg/kg (Rockwell Int'l Corp., 107 F. Supp. 2d 817). Another solid waste sample collected in 1977 had a PCB concentration of 180.6 mg/kg.

PCBs have been detected in discharge from the Fort James mills (Table 2.7). Concentrations as high as 0.65 µg/L have been detected in samples collected in 1972 of cooling and waste water discharged to the Kalamazoo River (MWRC, 1972b). Additionally, a PCB concentration of 0.04 µg/L was detected in one groundwater sample collected from the Fort James Disposal Area in 1988 (STS Consultants, 1989).

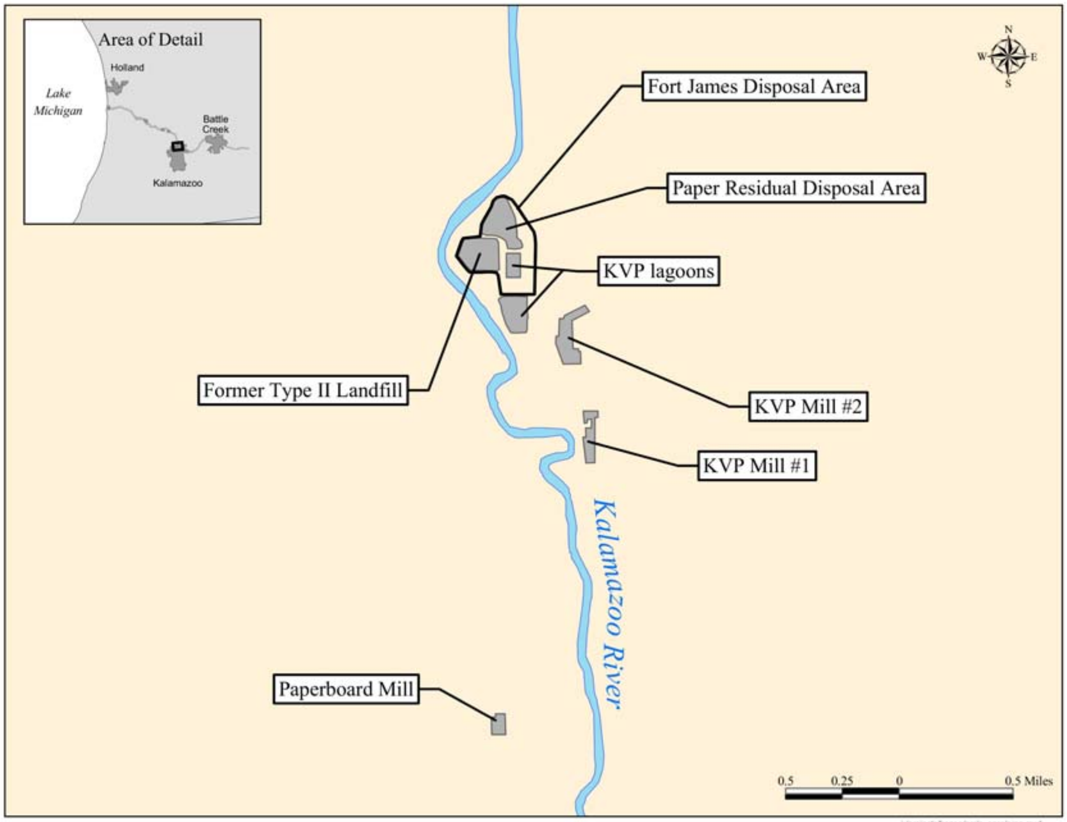

Figure 2.7. The Fort James mills and surrounding facilities. See Figure 1.2 for general location.

Table 2.7. PCBs detected in discharge from Fort James mills

Location	Sample date	PCB concentration (µg/L)	Source
KVP Mill #1 discharge to Kalamazoo River	August 22, 1972 August 23, 1972	0.65 0.39	MWRC, 1972b
KVP Mill #2 discharge to Kalamazoo River	April 3, 1973 August 16, 1976	0.31 0.17	MWRC, 1973b; MDNR, 1976b
KVP Lagoon discharge to Kalamazoo River	April 3, 1973 May 19, 1987	0.16 0.11	MWRC, 1973b; Koivuniemi, 1987

Soil and residuals samples collected from locations in the Fort James Disposal Area in 1987 (see Figure 2.7) contained PCBs. PCB concentrations in these samples as reported by MDNR ranged from below detection (at a detection limit of 0.75 mg/kg) to 7.3 mg/kg (Koivuniemi, 1987). Split samples from these same locations were also analyzed by laboratories on behalf of Fort James, and reported results ranged from below detection (at a detection limit of 0.1 mg/kg PCB) to 2.2 mg/kg PCB (James River Corporation, 1988). Additional samples from the Fort James Disposal Area analyzed on behalf of Fort James ranged from less than 0.01 mg/kg PCB to 1.81 mg/kg PCB (James River Corporation, 1988).

2.3 PCB Transport Pathways

Once PCBs are released into Portage Creek or the Kalamazoo River, the primary transport pathway is downstream movement with the flowing surface water (Blasland, Bouck & Lee, 2000b). The PCBs can be dissolved in the water or attached to particulate matter (e.g., sediment, plant material) as it moves downstream. As the PCBs adsorbed to particulate matter move downstream, they can be deposited in bed, bank, or floodplain areas of the river. These PCBs can be buried permanently in place by the deposition of additional sediment, or buried temporarily if erosion or scouring causes the PCBs to be remobilized and transported farther downstream.

Blasland, Bouck & Lee (2000b) calculated annual mass loads of PCBs in Portage Creek and at several locations along the Kalamazoo River using surface water data collected in 1994. The annual PCB load contributed by Portage Creek into the Kalamazoo River was estimated at 4.2 kg (Table 2.8). Annual PCB loads in the Kalamazoo River increase from an estimated 10 kg/year at River Street in Kalamazoo to an estimated 28 kg/year in Plainwell. The estimated load at the M-89 bridge downstream of Allegan Dam is 25 kg/year.

Table 2.8. Estimated annual PCB load in Portage Creek and locations along the Kalamazoo River, 1994

Location	Estimated PCB load[a] (kg/year)
Portage Creek	4.2
Kalamazoo River	
River Street, Kalamazoo	10
Michigan Avenue, Kalamazoo	12
Farmer Street, Plainwell	28
M-222, Allegan	26
M-89, downstream of Allegan Dam	25

a. Loads were estimated using a flow-stratified method that takes into account different PCB concentrations at different flow rates.
Source: Blasland, Bouck & Lee, 2000b.

The MDEQ conducted a study on PCB concentrations and loadings across Morrow Pond and Lake Allegan using monthly data collected from May 2001 — October 2002 (Camp Dresser & McKee, 2003a). Loadings of PCBs into and out of Morrow Pond ranged from 0.001 lbs/day to 0.025 lbs/day. The average loading both into and out of Morrow Pond over the period of study was 0.009 lbs/day. Thus MDEQ concluded that Morrow Pond was neither a source, nor a sink for PCBs. Loading at the inlet of Lake Allegan ranged from 0.014 lbs/day to 0.199 lbs/day of PCBs with an average of 0.1 lbs/day, while loading at the outlet was much lower, ranging from 0.001 lbs/day to 0.048 lbs/day and an average 0.015 lbs/day. These data suggest that Lake Allegan was acting as a sink for PCBs from upstream areas in the Kalamazoo River, as well as acting as an ongoing source for downstream areas.

There is also evidence that PCBs are transported by the Kalamazoo River into Lake Michigan via the surface water pathway. Data from a 1994-1995 mass balance study on PCB loadings show that the Kalamazoo River contributed approximately 36.8 kg (or 12%) of the 304.4 kg of PCBs contributed annually to Lake Michigan by its tributaries during this time period (Figure 2.8; U.S. EPA, 2000). From 1994-1995, the Kalamazoo River was the third largest tributary contributor of PCBs to the lake, behind the Lower Fox River (186 kg/yr) and the Grand Calumet River (37.2 kg/yr), and the largest contributor on the eastern shore of Lake Michigan (Figure 2.9; U.S. EPA, 2000). Therefore, these data demonstrate that PCBs are transported from the Kalamazoo River into Lake Michigan.

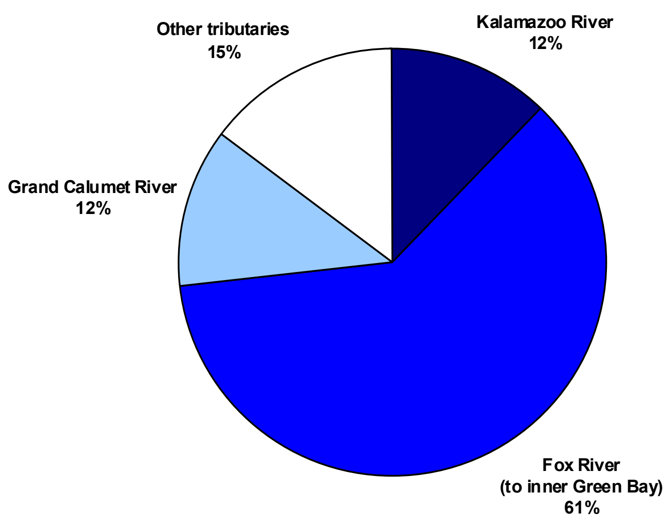

Figure 2.8. 1994-1995 tributary loadings of PCBs to Lake Michigan.

Source: U.S. EPA, 2000.

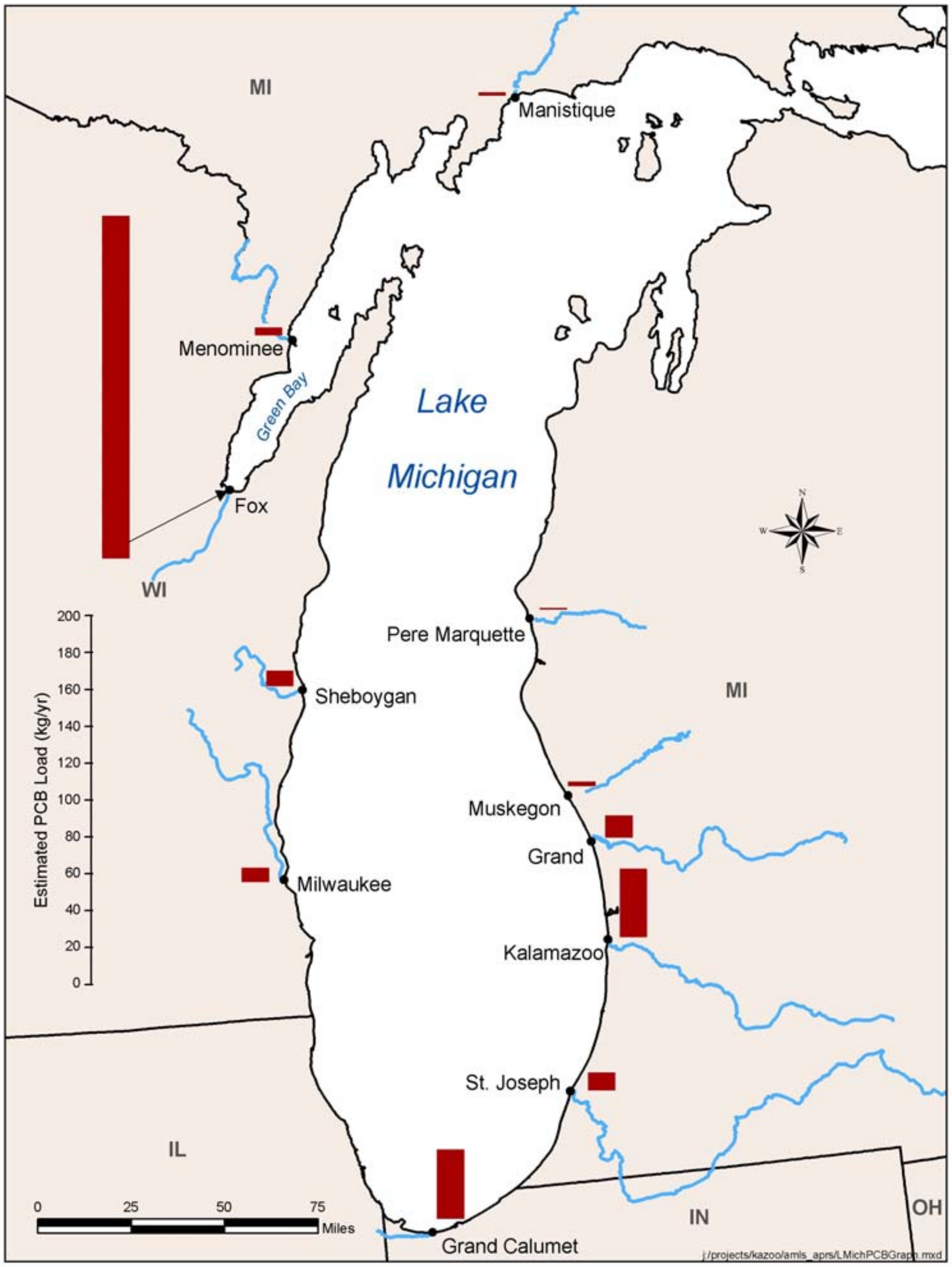

Figure 2.9. Spatial distribution of 1994-1995 tributary loadings of PCBs to Lake Michigan.

PCBs were deposited in instream sediments of the Kalamazoo River, and a large quantity of PCBs remains in the sediments. Blasland, Bouck & Lee (2000b) used data from cores sampled in the Kalamazoo River to estimate sediment area, volumes, and PCB mass (Table 2.9). They estimated that there are over 9 million yd^3 of PCB contaminated sediment in the Kalamazoo River from Morrow Lake to Lake Allegan Dam, and that this sediment contains over 29,000 kg of PCBs (Blasland, Bouck & Lee, 2000b). Approximately 70% of the total PCBs in Portage Creek and the Kalamazoo River, an estimated 20,363 kg, is stored in Lake Allegan sediments. Morrow Lake, located upstream of the NPL site, contains approximately 10% of the PCBs in the river between Morrow Lake and Lake Allegan Dam.

Table 2.9. Sediment area, volume, and mass estimates in reaches of the Kalamazoo River and Portage Creek

Reach	Reach description	Total sediment area (acres)	Total sediment (yd^3)	PCB-containing sediment (yd^3)	PCB mass (kg)
—	Morrow Lake	1,000	—	2,541,000	2,831
A1	Morrow Dam to Portage Creek	112	350,000	58,000	345
—	Portage Creek	7	33,600	23,050	162
A2	Portage Creek to Main St., Plainwell	331	950,000	341,000	754
B	Main St., Plainwell to Plainwell Dam	44	99,000	53,000	241
C	Plainwell Dam to Otsego City Dam	96	415,000	224,000	695
D	Otsego City Dam to Otsego Dam	83	290,000	191,000	306
E	Otsego Dam to Trowbridge Dam	131	542,000	263,000	719
F	Trowbridge Dam to Allegan City Line	190	450,000	258,000	476
G	Allegan City Line to Allegan City Dam	127	748,000	417,000	2,562
H	Allegan City Dam to Lake Allegan Dam	1,649	10,163,100	5,143,000	20,363
Total	Portage Creek and Kalamazoo River	3,770	14,040,700	9,512,050	29,484

Source: Blasland, Bouck & Lee, 2000b.

PCBs were also deposited in impoundments behind the former Plainwell, Otsego, and Trowbridge dams, which have now been drained and exposed as floodplain sediments (Blasland, Bouck & Lee, 2000b). These former impoundments cover an estimated area of 510 acres, and contain close to 3 million yd^3 of sediment (Table 2.10). Estimates of PCB mass made using cores collected by Blasland, Bouck & Lee (2000b) suggest that there are approximately 3,200 kg of PCBs in the former Plainwell impoundment, 6,300 kg of PCBs in the former Otsego impoundment, and 15,400 kg of PCBs in the former Trowbridge impoundment (Table 2.10).

Table 2.10. Former impoundment size and PCB mass estimates

Former impoundment	Area (acres)	Average depth (ft)	Volume (yd^3)	PCB mass (kg)
Plainwell	59	3.8	360,000	3,200
Otsego	77	4.4	540,000	6,300
Trowbridge	374	3.1	1,900,000	15,400

Source: Blasland, Bouck & Lee, 2000b.

PCBs are continuing to be released into the Kalamazoo River. The sources of these releases include erosion from PCB contaminated soils along the banks above the Plainwell, Otsego and Trowbridge Dams; re-releases from river sediment; periodic flooding of these soils; surface water runoff from PCB contaminated residuals at the Willow Boulevard and A-Site Disposal Areas; and groundwater containing PCBs that reaches the ground surface near the Bryant Mill Pond and flows into Portage Creek.

2.4 PCB Contamination and Persistence in the KRE

2.4.1 PCB contamination in the KRE

PCB contamination in the KRE has been documented by many different investigators over the years. Because of their persistence and tendency to bioaccumulate, PCBs can contaminate entire ecosystems once they are introduced into the environment. Such is the case in the KRE.

Studies have documented the presence of PCB concentrations greater than reference area concentrations in KRE abiotic media, such as surface water, sediment, and soil. Figures 2.10-2.12 show the distribution of PCBs in surface sediment and surface floodplain soils throughout the KRE. Concentrations are low in Morrow Lake, increase downstream of PRP facilities, and remain elevated throughout the KRE downstream to Lake Michigan. The highest PCB concentrations are seen in depositional areas of the river, behind current and former dams.

Similarly, PCB concentrations greater than reference area concentrations have been documented in many different kinds of biota, including many species of plants, invertebrates, fish, amphibians, reptiles, birds, and mammals (Figure 2.13). PCBs are present in every component of the KRE ecosystem that has been studied to date, including in the entire aquatic, terrestrial, and wetlands-based food chains.

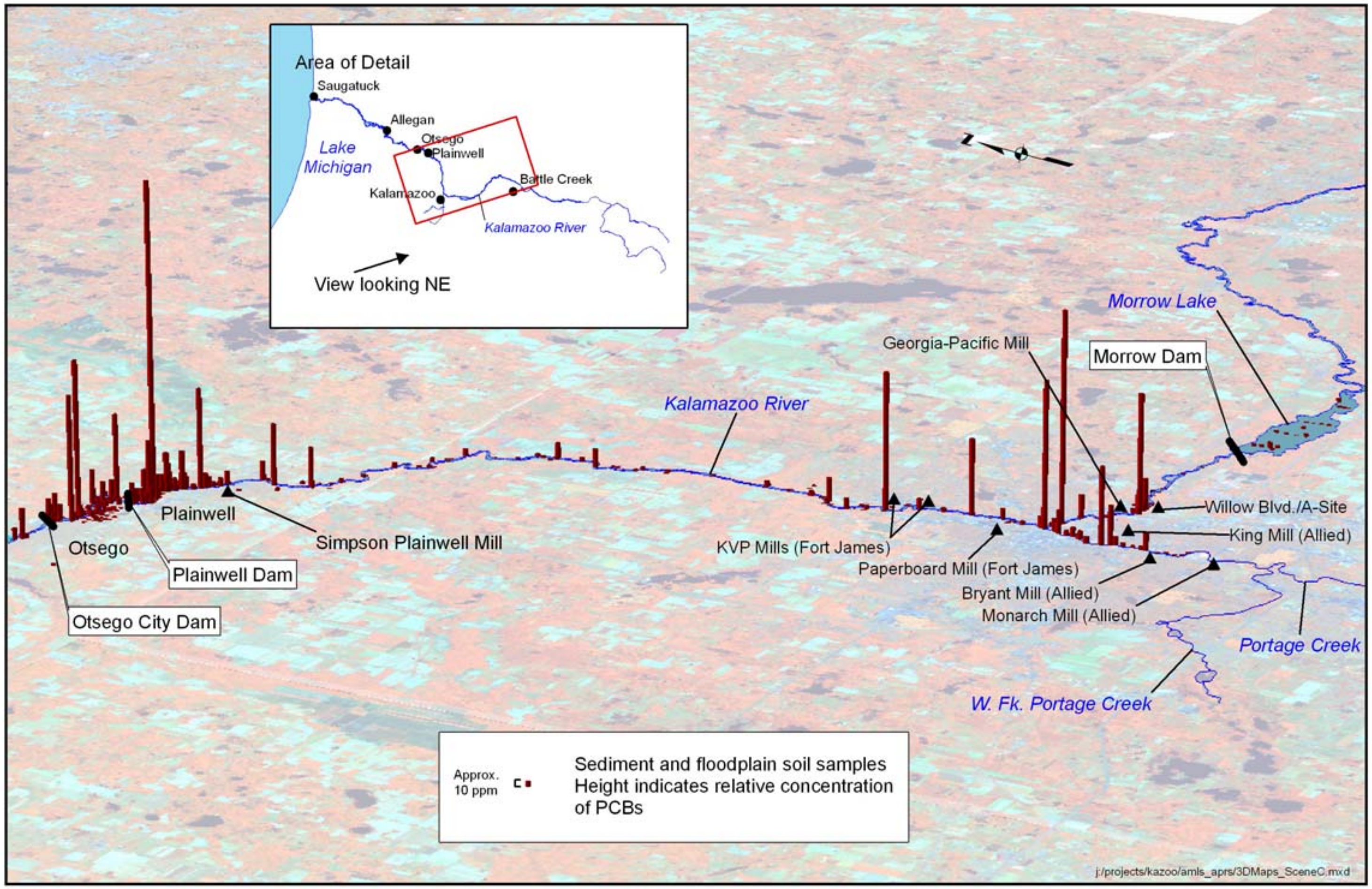

Figure 2.10. PCB concentrations in surface sediments and floodplain soils from Morrow Lake to the Otsego City Dam.

Sources: Blasland, Bouck & Lee, 2001; Camp Dresser & McKee, 2002a.

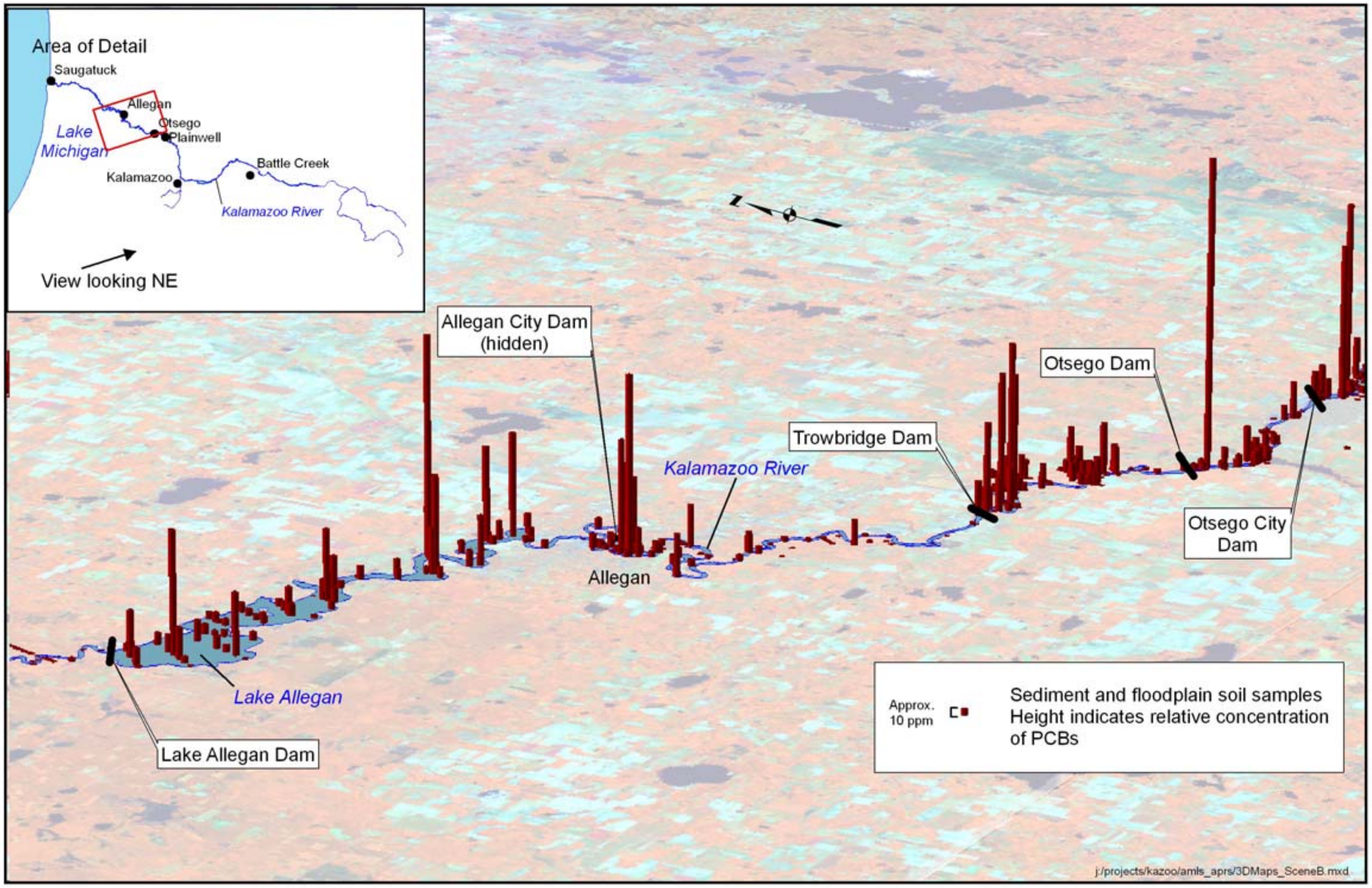

Figure 2.11 PCB concentrations in surface sediments and floodplain soils from the Otsego City Dam to the Lake Allegan Dam.

Sources: Blasland, Bouck & Lee, 2001; Camp Dresser & McKee, 2002a.

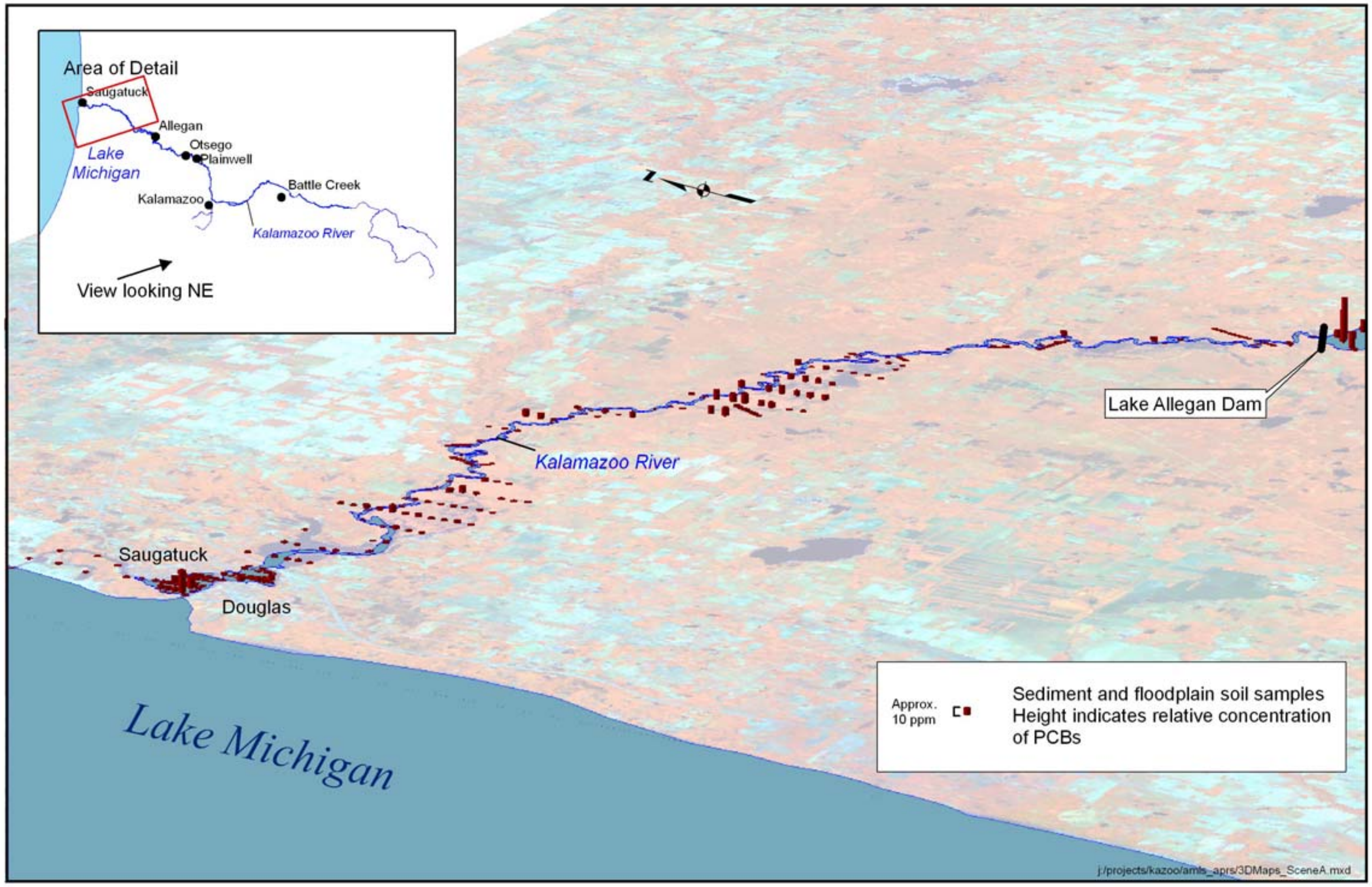

Figure 2.12. PCB concentrations in surface sediments and floodplain soils from the Lake Allegan Dam to the mouth of the Kalamazoo River at Lake Michigan.

Sources: Blasland, Bouck & Lee, 2001; Camp Dresser & McKee, 2002a.

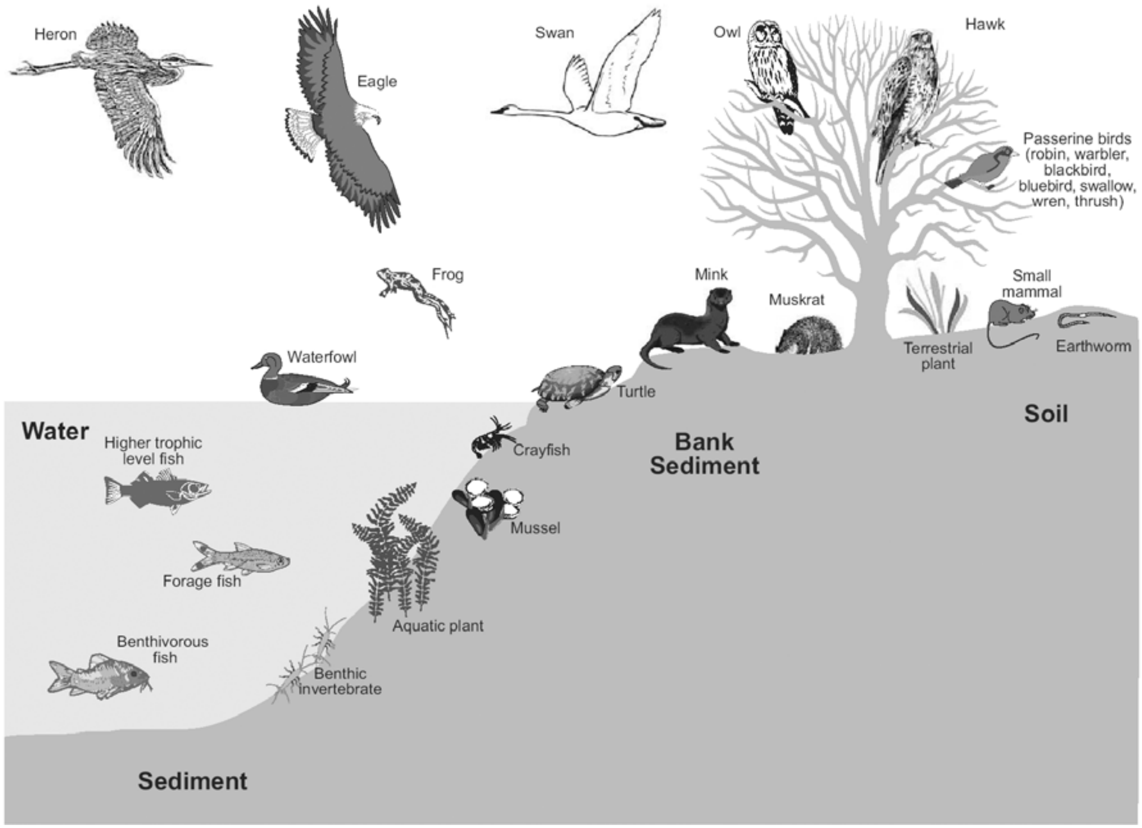

Figure 2.13. KRE natural resources in which PCB contamination has been documented (see Table 2.11 for maximum PCB concentrations measured in each resource).

Source: Swan, heron, hawk, and muskrat graphics adapted from U.S. FWS. Swan drawing by Bob Hines, heron drawing by Tom Kelley, hawk drawing by Paul Kerris, and muskrat drawing by Timothy Knepp (U.S. FWS, 2003a).

PCBs are lipophilic and thus tend to preferentially accumulate in the fatty tissue of organisms. Biota can be exposed to PCBs through routes such as dietary uptake or uptake across the gill surface. Dietary uptake is typically the primary mechanism by which animals are exposed to and subsequently bioaccumulate PCBs (Robertson and Hansen, 2001). Biota can be exposed to PCBs that are attached to the external surfaces of their food (e.g., PCBs deposited from the air onto plant tissue) and to PCBs incorporated within the food item. Ingestion of contaminated soil or sediment while feeding (either as part of the feeding strategy, such as for earthworms, or incidentally) can also contribute to the dietary intake of PCBs. Some direct uptake across the gill surface can also occur for aquatic biota (fish and invertebrates) (Niimi, 1996).

Table 2.11. Maximum total PCB concentrations measured in biota in the KRE

Biota	Maximum total PCB concentration	Source
Benthic invertebrate	1.56 mg/kg ww (composite)	Michigan State University Aquatic Toxicology Laboratory, 2003
Aquatic plant	0.047 mg/kg ww	Michigan State University Aquatic Toxicology Laboratory, 2001
Crayfish	1.93 mg/kg ww (whole body)	Michigan State University Aquatic Toxicology Laboratory, 2002a
Benthivorus fish	109.9 mg/kg ww (fillet)	MWRC, 1972a
Forage fish	38.42 mg/kg ww (fillet)	MWRC, 1972a
Higher trophic level fish	34.1 mg/kg ww (fillet)	MDNR, 1987b
Turtle	8.1 mg/kg ww (muscle)	Blasland, Bouck & Lee, 2001
Green frog	0.826 mg/kg dw (larvae)	Glennemeier and Begnoche, 2002
Waterfowl	4.8 mg/kg ww (whole body)	MDNR, 1987b
Swan	1.6 mg/kg ww (eggs)	MDNR, 1987b
Heron	44.38 mg/kg ww (eggs)	Mehne, 2000
Terrestrial plant	0.2 mg/kg ww	Michigan State University Aquatic Toxicology Laboratory, 2001
Earthworm	9 mg/kg (whole body)	MDNR, 1987d
Small mammal	3.15 mg/kg ww (whole body)	Michigan State University Aquatic Toxicology Laboratory, 2002f
Mink	12.5 mg/kg ww (liver)	Camp Dresser & McKee, 1997
Muskrat	1.18 mg/kg ww (liver)	Camp Dresser & McKee, 1997
Passerine bird	14.5 mg/kg ww (eggs)	Michigan State University Aquatic Toxicology Laboratory, 2002d
Owl	90.8 mg/kg ww (eggs)	Mehne, 2000
Hawk	27 mg/kg ww (eggs)	Mehne, 2000
Eagle	122 mg/kg ww (eggs)	Best, 2002

Table 2.11 lists the maximum PCB concentrations that have been measured in various kinds of KRE biota. The highest concentrations have been measured in bald eagle eggs (up to 122 mg/kg wet weight, or ww), owl eggs (up to 90 mg/kg ww), and in fish tissue (up to 109.9 mg/kg ww). As described in subsequent chapters of this report, these PCB concentrations in the KRE are much higher than PCB concentrations in similar biota from reference areas. The information in the table demonstrates that PCB contamination is found throughout the biota sampled in the KRE.

Figure 2.14 depicts the primary pathways through which KRE biota become exposed to PCBs in the environment. The releases of PCBs have resulted in the contamination of sediment, surface water, and soil throughout the KRE. From there, PCBs are transported through the aquatic and terrestrial food chains primarily through dietary pathways. The PCBs typically reach their highest concentrations in upper trophic level organisms, such as great-horned owl, bald eagle, and other piscivorous animals.

2.4.2 Persistence of PCBs in the KRE

PCBs are generally persistent in the environment and degrade very slowly (Erickson, 1997). Nevertheless, once released into a riverine environment such as the KRE, PCBs can be removed from the system through burial, degradation, or volatilization.

PCBs can undergo microbial biodegradation in the environment, but the extent of biodegradation, if any, is often slow and incomplete (Erickson, 1997). PCBs can undergo degradation by microbial communities in aerobic (i.e., in the presence of oxygen) and anaerobic (i.e., with oxygen absent) conditions (Abramowicz, 1990). Aerobic biodegradation of PCBs can completely break down some PCBs, producing carbon dioxide, chloride, and water (Erickson, 1997). However, aerobic biodegradation is effective only for PCBs with fewer than three chlorine atoms in their structures. In addition, there is little evidence that aerobic degradation removes any significant mass of PCBs from riverine systems such as the KRE (Erickson, 1997).

Anaerobic biodegradation of PCBs has been documented in sediments from several PCB contaminated aquatic systems (Brown and Wagner, 1990). Anaerobic microbes preferentially remove chlorine atoms from the more highly chlorinated PCBs, producing PCBs with lesser chlorination. Thus anaerobic degradation does not remove PCBs from the system, but changes the PCB congener mixture that is present. The rate of PCB anaerobic degradation is dependent on many environmental factors (Liu et al., 1996). The concentration of PCBs in sediment is one of the main factors that determines the rate of microbial degradation: degradation rates increase with increasing PCB concentration. For example, measurable dechlorination occurs in Hudson River sediments only when PCB concentrations are above approximately 30 mg/kg (U.S. EPA, 1997b). Analysis of chromatographic patterns in sediment cores from Lake Allegan and the Otsego City impoundment suggests that anaerobic degradation may be occurring in some sediments in selected areas of the Kalamazoo River (Blasland, Bouck & Lee, 2000b). However, the areas of any dechlorination in the river are most likely limited because PCB concentrations in KRE sediments are generally well below the 30 mg/kg concentration associated with measurable dechlorination in river sediments (U.S. EPA, 1997b).

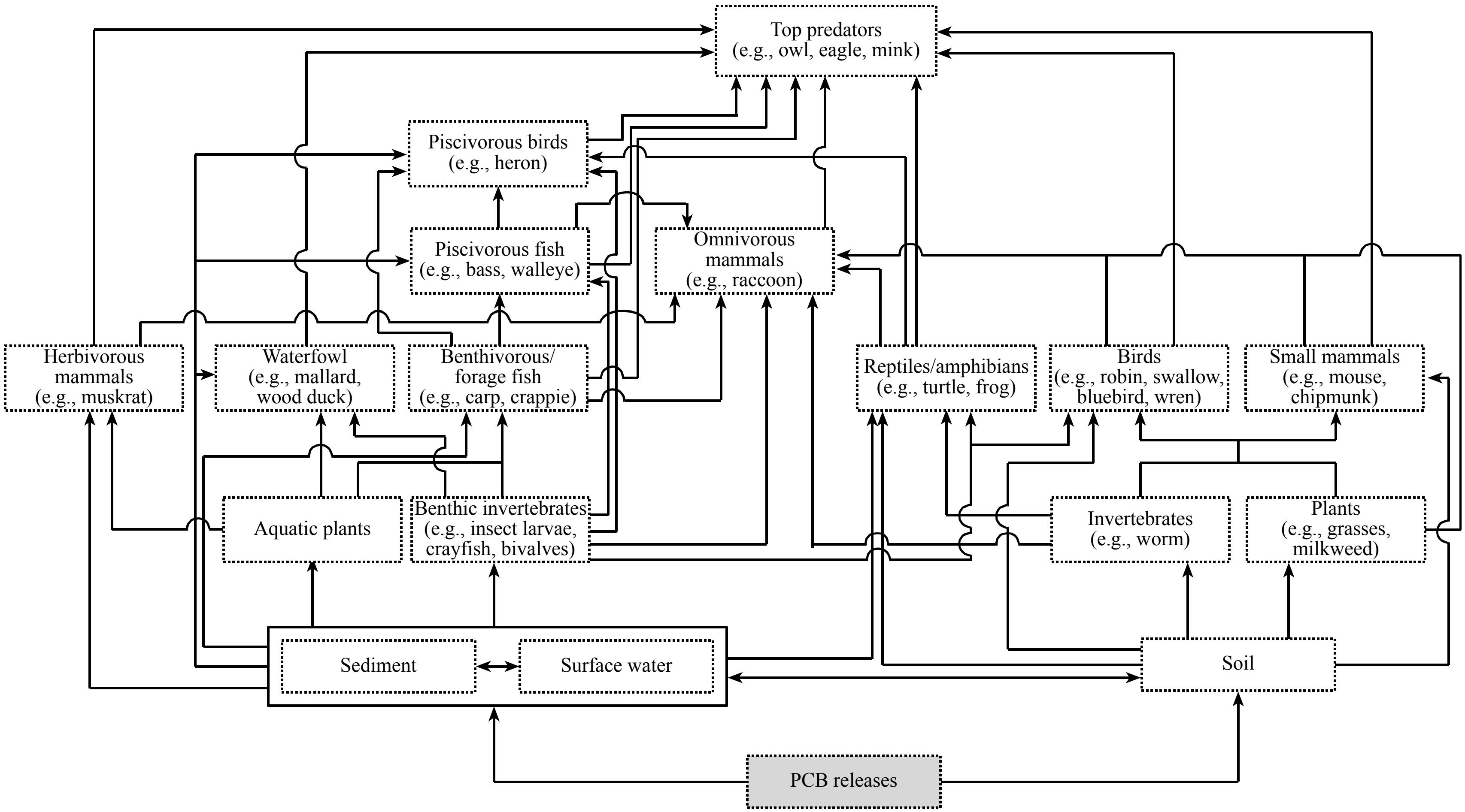

Figure 2.14. PCB exposure pathways.

PCBs can also be volatilized into the atmosphere. The lower chlorinated congeners have higher vapor pressures and tend to volatilize more readily than the higher chlorinated congeners (Mackay et al., 1992). Thus, the atmosphere tends to become enriched in the lower chlorinated congeners relative to the water column. The lower chlorinated congeners can then be carried by air currents and redistributed throughout the environment. This continuous process has produced a "global fractionation" of PCB congeners, in which the PCBs transported via air currents to northern latitudes are enriched in the lower chlorinated congeners (Muir et al., 1996). A PCB mass balance model was used to estimate the mass of PCBs lost through volatization in the open water environment of Green Bay (Wisconsin), and the model concluded that volatization accounted for a substantial portion of the PCB losses (second only to sediment burial in PCB mass removed; DePinto et al., 1994). The mass of PCBs lost through volatization in a riverine system such as the KRE is difficult to measure or predict accurately, but loss through volatization can be a significant pathway through which PCBs are removed from the KRE and subsequently transported elsewhere.

Burial in sediment is the primary mechanism by which PCBs can be removed from the water column and surface sediment environments of the KRE. Sediment burial is an important fate process for PCBs in most aquatic systems (e.g., DePinto et al., 1994; Quantitative Environmental Analysis, 1999). However, in active riverine systems such as the KRE, PCBs buried in deeper sediment layers can be re-exposed as the river bottom topography changes due to high flow events, stream channel meandering, impoundment management, or channel maintenance (Wisconsin Department of Natural Resources, 1999; Rheaume et al., 2002). Therefore, although deeper sediments contain a substantial amount of the PCBs present in the KRE, it cannot necessarily be assumed that these PCBs are in permanent isolation.

The PRPs conducted a sediment core study in 1994 in which cores were collected from Allegan City Impoundment and Kalamazoo Lake and analyzed for radionuclides and PCBs (Blasland, Bouck & Lee, 1994c). Radionuclide analysis of sediment cores can provide information on the approximate time period in which the sediments of different sections of the core were deposited. According to the dating analysis presented in Blasland, Bouck & Lee (1994c), PCB concentrations are highest in sediment deposited during the 1960s, when PCB use and direct discharge of PCBs to the river was highest. Sediment deposited after the period of peak PCB discharge to the river contains lower PCB concentrations, and concentrations have remained relatively unchanged. Blasland, Bouck & Lee (1994c) state: "The deposition rates estimated from ^{137}Cs analyses indicate that PCB deposition has been steady at least since approximately 1980," and ". . . although PCB may be present in the environment upstream, amounts being transported and deposited downstream have decreased substantially, and remained steady at relatively low concentrations." Thus the dated sediment core analysis presented in Blasland, Bouck & Lee (1994c) indicates that PCB concentrations in surficial river sediment decreased after the periods of peak releases to the river, but have since remained relatively constant. This fact demonstrates the environmental persistence of the PCBs that have been released into the KRE.

2.5 Conclusions: PCB Releases, Pathways, and Contamination

PRP facilities released large quantities of PCBs into the KRE through the release of effluent and paper waste containing PCBs. It has been estimated that the total amount of PCBs released by Allied, Georgia-Pacific, Simpson Plainwell, and Fort James totaled between 2.2 and 4.4 million lbs (1 and 2 million kg; Rockwell Int'l Corp., 107 F. Supp. 2d 817). Additionally, PRP facilities are the predominant source of PCBs in the KRE. Recent and ongoing PCB releases include erosion and diffusion from impoundment banks, re-release from sediment and the Willow Boulevard landfill, and seeps in the Bryant Mill Pond area. These PCBs have migrated downstream in surface water, and have been deposited in instream sediments and in floodplain soils. PCBs are persistent in the environment and degrade slowly, and thus are likely to be present in the KRE for many years to come. All abiotic and biotic components of the KRE that have been measured are contaminated with PCBs released into the KRE. Active remediation that provides for the physical removal of the PCBs from the KRE would ensure that the PCB exposure pathways are permanently eliminated.