Fact Sheet FS–116–96

The Fox River PCB Transport Study - Stepping Stone to a Healthy Great Lakes Ecosystem

Sharon A. Fitzgerald and Jeffrey J. Steuer

Polychlorinated Biphenyls (PCBs) in the Great Lakes

Despite being banned since the 1970's, polychlorinated biphenyls (PCBs) continue to pose a threat to the environment because of their persistence and toxicity to organisms ranging from minute algae to fish, waterfowl, and human beings. PCBs, a set of 209 related chlorinated organic compounds, had various industrial uses such as in hydraulic fluids, cutting oils, sealants, and pesticides. Despite the manufacturing ban in the mid-1970's, PCBs remain ubiquitous in the environment. In the Laurentian Great Lakes of the Midwest, PCBs and other toxic compounds contaminate bottom sediments at almost all designated "areas of concern" (AOC)(figure 1, upper left inset). The International Joint Commission, a binational group from Canada and the United States, has identified these AOCs in their efforts to restore and protect Great Lakes ecosystems. One such area, the Fox River which flows into Green Bay, has been the focus of much scientific study in an effort to improve not only that river but to apply lessons learned to other AOCs. The final goal is a healthy Great Lakes food chain with fish and waterfowl that are safe to consume.

PCBs in the Fox River

The Lower Fox River extends 63km (39 miles) from Lake Winnebago to Green Bay, Wis., (figure 1, lower right). The land use is varied and includes industrial, residential and agricultural areas. Some 270,000 people, or 6% of the State's population, live in the city of Green Bay and other communities along the Lower Fox River. There are 16 pulp and paper mills, one of the highest concentrations in the world (Wisconsin Department of Natural Resources, 1992). Wastewater from the pulp and paper mills is treated by municipal wastewater treatment plants or in industrial treatment facilities prior to discharge into the Lower Fox River. Historically, PCB wastes associated with pulping and de-inking operations have been, at times, discharged directly to the river.

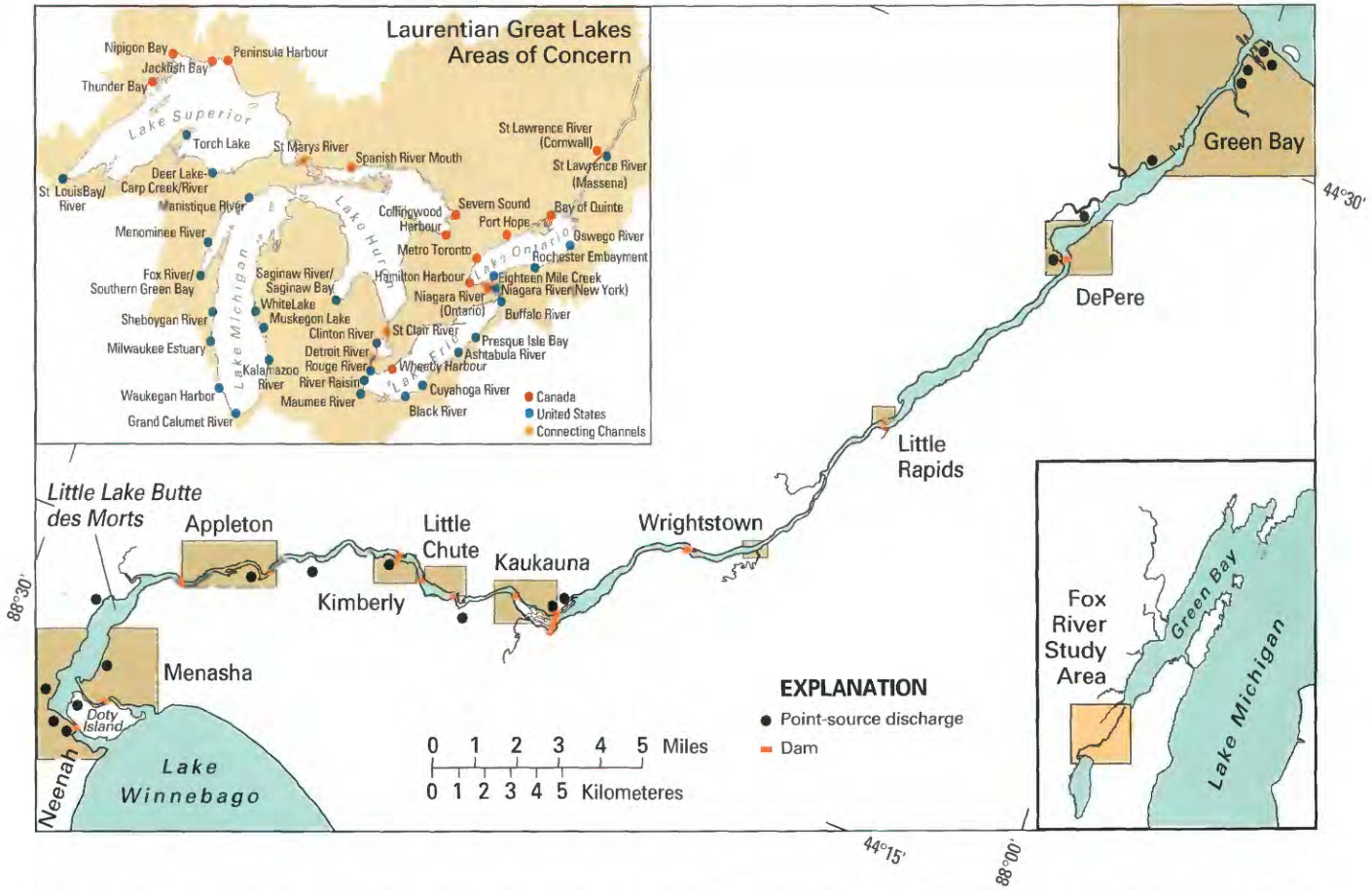

Figure 1. Location of the Laurentian Great Lakes "areas of concern" (AOCs) and the Lower Fox River PCB transport study (Source: U.S. Environmental Protection Agency Large Lakes Research Station).

The Lower Fox River is highly contaminated by PCBs and other toxic synthetic organic chemicals and trace metals. The Wisconsin Department of Natural Resources (WDNR) issued a fish consumption advisory (Sheffy, 1980) for the river in 1979 and a waterfowl consumption advisory in 1985. In 1984, more than 100 hazardous chemicals were identified in bottom sediments from the river (Sullivan and others, 1983). Both the fish and waterfowl advisories from Lake Winnebago to the mouth of the Fox River continue to this day (Amrhein and Anderson, 1994). It was from these earlier efforts that the Lower Fox River Study emerged. This fact sheet primarily summarizes study results from the Fox River study upstream of the DePere Dam as documented in the final report "A Deterministic PCB Transport Model for the Lower Fox River between Lake Winnebago and DePere, Wisconsin", by Jeffrey S. Steuer, Steven Jaeger, and Dale Patterson (WDNR PUBL 389-95). The dam at DePere, Wis., the last progressing downstream, is 11 km (6.8 miles) upstream from the mouth at Green Bay, Wis., and completes the 48-m (157 ft) drop in elevation from Lake Winnebago.

The Lower Fox River Study

Although it was generally acknowledged that PCBs from soft sediment deposits in the Lower Fox River were sources of PCBs to the water column, little was known about factors controlling transport of PCB-laden bottom sediments from these sites or the magnitude of other sources such as sewage treatment plant effluents, industrial waters, urban runoff, or landfill leaching. Nor was it understood how much PCB was being transported to Green Bay and Lake Michigan, what amount moved to the atmosphere, or what PCB conditions would be like in the next 25 years. The Lower Fox River Study addressed these questions.

This study, conducted in concert with the larger Green Bay Mass Balance Study (GBMBS), was funded by the U.S. Environmental Protection Agency (USEPA), the WDNR, and the U.S. Geological Survey (USGS). Collection of the data necessary to answer the above questions was conducted primarily from May 1989 to April 1990 between Lake Winnebago and the DePere Dam. There were over 130 water column, 1,000 bottom sediment, 175 point-source effluent, 5 landfill wells, and 10 urban stormsewer samples that were analyzed for PCBs.

Using these data as a foundation, a mathematical, physical process-based model was constructed to help answer the PCB transport questions. The four-year modeling effort used the Water Quality Analysis Program (WASP4) (Ambrose and others, 1988) as a framework, and consisted of three major components: water column transport, solids mass balance (both suspended and bottom), and physiochemical processes.

Fox River Study Results

The report "A Deterministic PCB Transport Model for the Lower Fox River between Lake Winnebago and DePere, Wisconsin" (Steuer and others, 1995) indicates that contaminated bottom sediments are the primary source of PCBs to the water column (figure 2). Most of these PCBs are transported over DePere dam; however, significant amounts also are transferred to the atmosphere. The PCB reservoir in sediments that load the water column upstream of DePere Dam consists of 4,275 kg of PCB in approximately 2,100,000 m3 (2,700,000 cubic yards) of contaminated sediments between Lake Winnebago and the DePere Dam (figure 3). These PCBs are not distributed uniformly over the river bed; 18% are contained within one relatively small (2% of total surface area) deposit in the southwestern part of Little Lake Butte Des Mortes (LLBDM). Much of the remaining PCB mass is elsewhere in LLBDM or in the 8-km long impoundment behind the DePere Dam.

A large reservoir of PCBs (25,000 kg) also is located in the bottom sediments between the DePere Dam and the Fox River mouth (Dale Patterson, Wisconsin Department of Natural Resources, written commun., 1993). This area is being investigated in 1996 to further understand the PCB distribution and the possibility of these PCBs being transported to Green Bay and Lake Michigan. Understanding the mobility of these sediments is critical because they contain three times as much PCBs than are presently in all of Green Bay (Manchester, 1993). These deposits represent a potential toxic legacy to present and future generations living along the Lower Fox River and Green Bay

The study predicted that over the course of 25 years, 1,300 kg of PCB would be transported over the DePere Dam and 200 kg would be emitted to the atmosphere. Much of the PCB remaining in the Lower Fox River sediment would be in the semi-isolated deposits in LLBDM (900 kg) and immediately upstream of the DePere Dam (1,400 kg). Furthermore, the amount of PCB transported over the DePere Dam should decrease by 50% every 5 years (figure 4). This analysis assumed several factors, including that no intense short-duration rainfalls would occur in the vicinity of the Neenah Slough, nor would there be extreme high flows on the Fox River. For example, a theoretical high flow event in 1995 could have transported 2,100 kg of PCB instead of the 50 kg as predicted in figure 4, an effect that would linger for years after. Despite having to make several assumptions, bolstered with follow-up data the predictive model capabilities may be valuable for making management decisions about the future of the river.

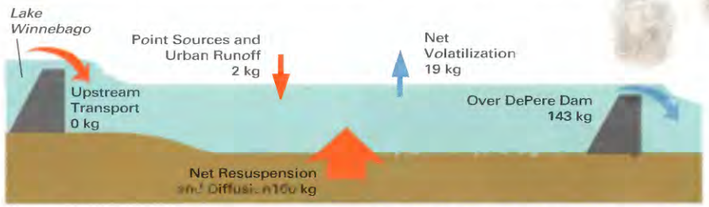

Figure 2. PCB mass fluxes; May 1, 1989 to May 1, 1990. Fluxes are in kilograms.

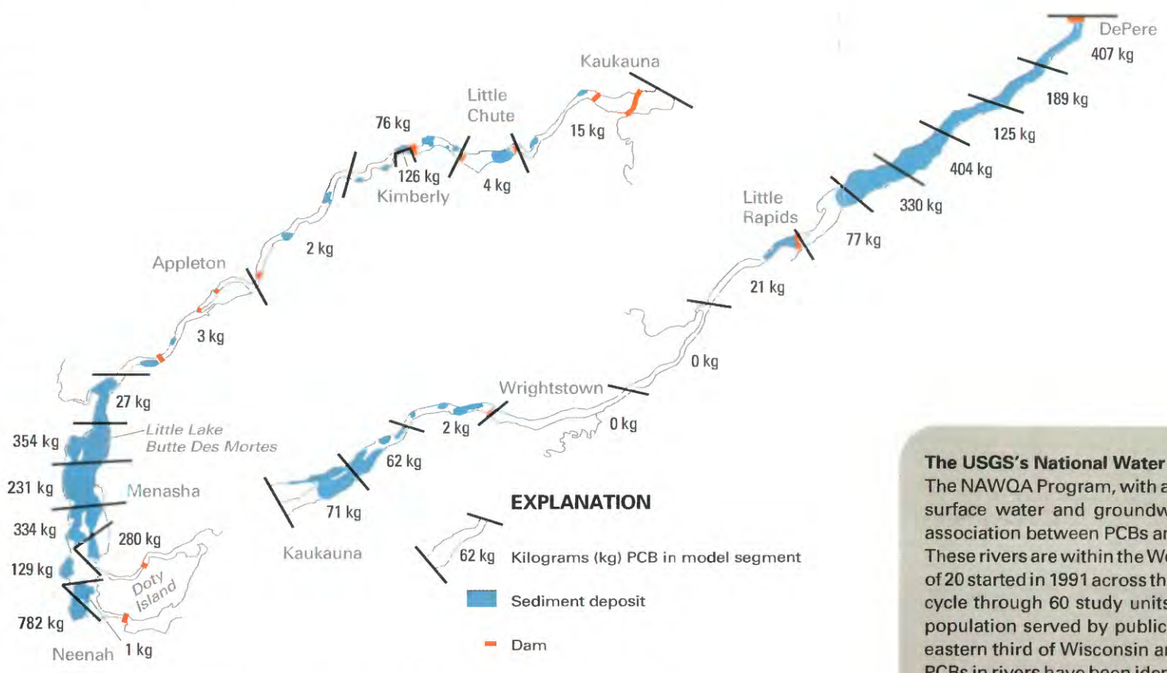

Figure 3. Model segmentation and initial mass of PCBs.

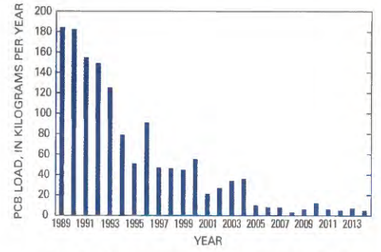

Figure 4. Simulated PCB transport over DePere dam from 1989 to 2014.

Simulated PCB Transport

From the Lower Fox River Study, significant factors affecting PCB transport appeared to be: the concentration and composition of suspended particulate matter (controlled by settling and resuspension velocities), the initial concentration of PCB in bed sediments, and the river flow. These factors sometimes interacted in complex ways. Of these factors, PCB transport in the Lower Fox River was controlled mostly by the deposition and resuspension of suspended particulate matter.

In general, the amount of PCB transported (the mass in kilograms) increases as one proceeds downstream (figure 5). Water entering the Lower Fox River from Lake Winnebago had low, and sometimes immeasurable, concentrations of PCBs. By the time the water reached the DePere Dam, total PCB concentrations ranged from 50 to 90 ng/L (nanograms per liter = 10^{-9} grams per liter) in summer and about 10% of that amount in winter, showing a strong seasonal response. Maximum PCB concentrations occurred at high flow and during the summer. PCB concentrations in water exceeded 100 ng/L only under high flow conditions (that is, during storm events). Greater than 60% of the PCB transported over the DePere Dam occurred during only 20% of the year, times when discharge was above the annual mean of 120 m^3/s (4,257 ft^3/s). These events are represented as the steep increases in the cumulative PCB transport during the summer high flow-event and spring runoff in Figure 5.

In contrast to the relatively high rate of PCB transport observed during the summer and during spring runoff, PCB transport during winter was significantly lower, even for water velocities greater than in the summer. These periods are represented by the relatively flat portions of the curves in Figure 5. Also, reduced resuspension in winter increased the relative importance of porewater diffusion compared to the rest of the year. Thus, there is a strong seasonal component to PCB transport in the Fox River.

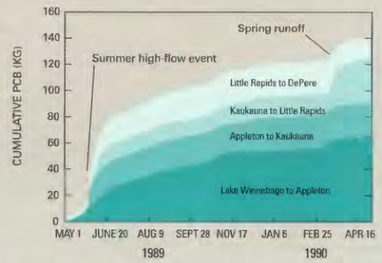

Figure 5. Simulated cumulative PCB transport at four Fox River sites.

The USGS's National Water Quality Assessment (NAWQA) Program

The NAWQA Program, with a goal of describing the status and trends of the Nation's surface water and groundwater resources, partially funded investigation of the association between PCBs and algae in the Fox, Milwaukee, and Manitowoc Rivers. These rivers are within the Western Lake Michigan Drainages (WMIC) Study unit, one of 20 started in 1991 across the country. Eventually, the 30-year NAWQA program will cycle through 60 study units that incorporate most of the Nation's water use and population served by public water supply. The WMIC Study Unit is located in the eastern third of Wisconsin and includes a part of the Upper Peninsula of Michigan. PCBs in rivers have been identified as a major water-quality issue in the WMIC Study unit.

Lessons learned from the Fox River Study have benefited other basins in the Great Lakes

The Lower Fox River study was an examination of factors that control PCB transport and fate (see "Simulated PCB transport" box). As such, the study played a part in developing the Lake Michigan Tributary Monitoring Study which supports the Lake Michigan Mass Balance Study. The Lake Michigan Study, co-funded by USEPA, WDNR, and USGS will answer many of the PCB transport questions but on the much larger scale of a Great Lake. Specifically, it is hoped that the amount of PCB entering and leaving Lake Michigan from rivers, the atmosphere, groundwater, and bottom sediments on an annual basis can be determined. Modeling tools similar to those refined in the Lower Fox River Study will be used in this larger study of Lake Michigan. The result is intended to be a better understanding of how contaminants such as PCBs reach the Great Lakes and what their fate is once there. Development of potential cost effective remediation procedures depends on such understanding.

Another study directly spawned from the Lower Fox River Study is the Milwaukee/Manitowoc Rivers Study, conducted at four sites along these two rivers in southeast Wisconsin. This study was co-funded by USEPA, WDNR, and the National Water Quality Assessment (NAWQA) Program of the USGS (see "NAWQA" Box). A major objective of this study was to further investigate the potential link seen initially in the Lower Fox River Study between the distribution, transport, and fate of PCBs and algae in these rivers (see "PCBs and Algae" box). Specifically, the relation between the concentration of PCBs and the amount of algae present was examined. If true, refinements to the theoretical model that describes PCB concentration would be required to adequately represent transport of these contaminants in rivers.

PCBs and Algae

Water column PCB samples were collected and fractionated into "particulate" and "dissolved". For modeling purposes, the particulate fraction was further subdivided into "biotic" (mainly representing algae) and "abiotic" (mainly representing resuspended or tributary sediment) fractions. An especially interesting result from the Lower Fox River Study was that water-column concentrations of PCBs at several sites on the Lower Fox River differed by an order of magnitude between summer and winter under similar flow regimes. Concurrently measured chlorophyll-a (the most common algal pigment) concentrations collected during low flow suggest that increased particulate PCB concentrations in the Lower Fox River at Kaukauna and Appleton, Wisconsin may be linked to algal productivity (figure 6). This relation between chlorophyll-a and particulate PCBs indicates that algal dynamics (growth, predation, sinking, etc.) may be an important process controlling the transport and fate of PCBs in the river, effectively linking the biology and chemistry. Moreover, incorporation of PCBs into algae, the "base" of the river food web, provides a pathway for these compounds into other organisms including fish and humans.

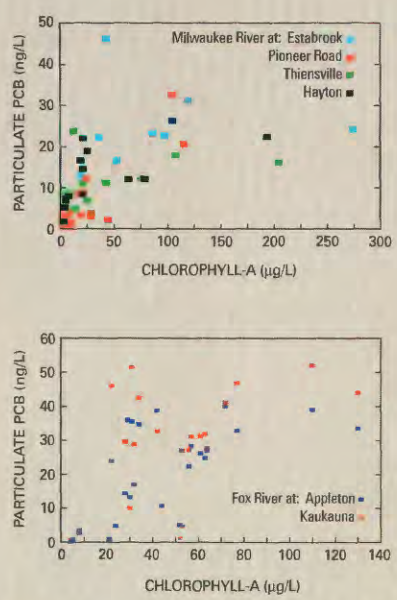

Figure 6. Chlorophyll-a particulate PCB association at six river sites.

This apparent association between a phytoplankton indicator (chlorophyll-a) and PCB concentrations in the water was explored further in the Milwaukee/Manitowoc Rivers Study (see "NAWQA" box). Here, the concentration of particulate PCB is positively related to chlorophyll-a at all sites, as it was in the Fox River (Fitzgerald and Steuer, USGS, unpublished data) (figure 6). PCBs, being only sparingly soluble in water, tend to associate with organic-rich particles such as phytoplankton cells. Thus the factors that control phytoplankton (for example, nutrient and light availability, predation, sinking, and resuspension, etc.) may indirectly control PCB distribution, transport, and fate in rivers.

How will these results affect me?

First and foremost, the results will have immediate benefit for the evaluation of alternate remediation strategies for the river. For example, the Fox River coalition, a group comprised of government and private entities designed to coordinate remedial actions and help pay for restorative measures, will use these results to help identify the best approach to clean up the river. Fox River Study results are currently used in designing an efficient, cost effective remediation method for a contaminated deposit in southwest Little Lake Butte des Morts known as "Deposit A" (House, 1995; Steuer and others, 1995). Additionally, the U.S. Fish and Wildlife Service is using the study results in their Natural Resources Damage Assessment. Thus the Fox River Study was and continues to be a useful step towards a healthy Great Lakes ecosystem. A healthy Great Lakes ecosystem will benefit all.

References

Ambrose, R.B. Jr., Wool, T.A., Connolly, J.P., and Schanz, R.W., 1988, WASP4 - A hydrodynamic and water quality model - model theory, user's manual and program guide: EPA/600/3-87/039. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Ga.

Amrhein, J.F. and Anderson, H., 1994, Health guide for people who eat sportfish from Wisconsin waters: April 1994, Wisconsin Department of Natural Resources and Wisconsin Division of Public Health, Publ-IE-019.

House, L.B., 1995, Distribution and transport of polychlorinated biphenyls in Little Lake Butte Des Morts, Fox River, Wisconsin, 1987-88: Open File Report 93-31, 43 p.

Manchester, J.B., 1993, The role of porewater in the remobilization of sediment-bound polychlorinated biphenyl congeners: Ph.D. dissertation, University of Wisconsin, Madison, Wis.

Sheffy, T.B., St. Amant, J.R., 1980, Toxic substances survey of Lake Michigan, Superior, and tributary streams: First Annual Report, Wisconsin Department of Natural Resources Technical Publication, 107 p.

Steuer, J.J., Jaeger, S, and Patterson, D., 1995, A deterministic PCB transport model for the Lower Fox River between Lake Winnebago and DePere, Wisconsin: Wisconsin Department of Natural Resources, Publ. WR 389-95, 283 p.

Sullivan, J.R., Delfino, J.J., Beulow, C.R., and Sheffy, T.B., 1983, PCB concentrations in the Lower Fox river fish and sediments: Bulletin of Environmental Contamination and Toxicology, 30:58-64.

United States Environmental Protection Agency, 1989, Green Bay/Fox River mass balance study: U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, Ill., EPA-905/8-89/001.

Wisconsin Department of Natural Resources, 1992, Wisconsin water quality assessment report to Congress - 1992: Wisconsin Department of Natural Resources, Publ. WR254-92-REV, 220 p.

For more information, please contact:

NAWQA Chief
U.S. Geological Survey
6417 Normandy Lane
Madison, WI 53719
(608) 276-3810

U.S. Department of the Interior
U.S. Geological Survey
Fact Sheet FS–116–96