Use of Human Health- and Ecological-Based Goals in Developing a Whole River Sediment Strategy: Fox River, Wisconsin

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The Wisconsin Department of Natural Resources (WDNR) has been working with the Fox River Coalition (FRC), a planning and implementation group composed of local, state, and federal partners, to develop a whole river sediment strategy. It was evident early in the process that numeric criteria alone would not suffice in developing a cost-effective whole river sediment strategy. Numeric criteria alone cannot address issues regarding local benefits of remediation in numerous river reaches or evaluate benefits of reducing PCB transport to Green Bay in lieu of local fish tissue reductions. Other techniques that could factor in the size of the existing problem and unique features of the Fox River Basin were needed.

This presentation reviews one alternative approach. The approach relies on the tools and data generated during the Green Bay Mass Balance Study (GBMBS) to help identify and prioritize remediation areas and attempts to quantify the benefits of remediation in terms of reduced PCB transport to Green Bay and reductions in fish tissue concentrations. To date, efforts have focused on developing a basic set of remediation scenarios that illustrate the environmental benefit and implementation considerations of varying levels of sediment remediation. The next step will be to develop preliminary costs for these scenarios. With "ballpark" costs linked to the associated environmental benefits and implementation issues, these scenarios will help the FRC and WDNR develop a whole river sediment strategy. The strategy will strive for cost-effective progress toward achieving established water quality goals and elimination of fish consumption advisories.

The Fox River and Green Bay were studied as part of the 1989 Green Bay Mass Balance Study (GBMBS) (Beltran, 1992). The study focused on the transport and fate of PCBs from the outlet of Lake Winnebago through the entire Lower Fox River and into Green Bay, as well as the accumulation of PCBs in the aquatic food web of Green Bay and the Fox River downstream of DePere. One significant conclusion of the GBMBS is that the source of essentially all (>99 percent) of the PCBs transported by the river originates from the river sediments. Further, a 1989 inventory of sediment PCBs estimates the Fox River sediments contain 4,000 kg (8,800 lbs) and 26,000 kg (57,200 lbs) of PCBs upstream (32 miles) and downstream of the DePere dam (7 miles), respectively.

Sediment remedial action scenarios for the Fox River were simulated by using the WASP5 model (Water Quality Analysis Program) for the Fox River upstream of DePere (WDNR, 1995) and the IPX (In-Place Pollutant eXport) model for downstream of DePere (Velleux et al., 1996). These water quality models developed during the GBMBS were useful tools for evaluating how PCBs moved through the Fox River/Green Bay System during 1989. As demonstrated through a post-auditing procedure, the Fox River water quality models can predict PCB concentrations to within 20 percent to 30 percent of observed PCB concentrations. The post-audit results indicate that the Fox River models are excellent tools for evaluating the impact and effectiveness of proposed sediment remediation efforts.

With the intent of making model simulations realistically represent implementation issues, two assumptions were made. The post-remediation residual PCB concentration used for the simulations was set to 2.5 ppm for the uppermost sediment layer. Also, to simplify the simulation of multiple remediation scenarios, all remediation was assumed to occur at one point in time—July 1, 2000. July 1, 2000, was chosen to represent the midpoint of a 5-year period from early 1998 through the end of 2002.

The Fox River PCB transport models were used to predict PCB concentrations in fish for different reaches of the river as well as PCB mass transported over the

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DePere dam and to Green Bay from January 1, 1996, to December 31, 2020. Both models predict surface sediment PCB concentrations and PCB mass transport over time. Predicted surface sediment PCB concentrations were used to calculate PCB concentrations in fish tissue using a simple model, biota-sediment accumulation factor (BSAF) (Di Toro et al., 1991). The BSAF is a measure of site-specific bioaccumulation potential of fish from exposure to contaminated sediments. The model is relatively simple and describes bioaccumulation based on the lipid (fat) content in fish and the amount of contamination and organic carbon content of the sediment. A site-specific BSAF can be calculated as:

$$BSAF = (C_f/f_l) / (C_s/f_{oc}) \quad (1)$$

where C_f is the pollutant concentration in fish, f_l is the fraction of lipid content in fish, C_s is the pollutant concentration in sediment, and f_{oc} is fraction of organic carbon in sediment. For ease of evaluating the remedial scenarios, the BSAF was applied instantaneously to simulated surface sediment PCB concentrations to simulate fish tissue concentrations over the 25-year model simulation. The fraction of lipid in fish and the fraction of organic carbon in sediment were assumed to remain equal to preremediation conditions.

Site Selections

A nonparametric statistical model, based on fuzzy set theory, was employed to prioritize contaminated sediment sites both upstream of DePere and in the 7 river miles downstream of DePere. This fuzzy set analysis provides a systematic technique for comparing a set of alternatives and identifying more preferable ones based on multiple decision criteria or factors (Table 1).

Table 1. Variables used for fuzzy set ranking of contaminated sediment sites.

PCB mass	Bioavailability Index (OC-normalized PCB in top layer)
PCB mass/area	PCB mass remaining—25-yr “no action” scenario
PCB mass/volume	PCB mass delivery during Mass Balance Study year
Mercury concern	PCB mass delivery under a modeled 100-yr storm event
River position	PCB mass delivery—25-yr “no action” scenario

In general, PCB mass delivery under a simulated 25-yr “no action” scenario and bioavailability were the most important variables while river position and mercury were the variables of least importance.

The prioritizing of sediment sites was conducted separately for upstream and downstream of DePere based on the individual model’s configuration. Upstream of DePere, the sites were prioritized by river segment. The IPX model used downstream of DePere artificially divides the last 7 miles of river into 96 Sediment Management Units (SMU). Site prioritization downstream of DePere was by SMU. Upstream of DePere, the five top-ranked river segments contain Deposits A, POG, C, D/E, N, and EE/GG/HH. Deposits A, C, D/E, and POG are all within the first river reach from the outlet of Lake Winnebago, which is locally known as Little Lake Butte des Morts (LLBdM).

The site rankings were used to assemble four sediment remediation scenarios that attempt to accommodate remediation upstream of DePere while balancing the importance of reducing PCB bioaccumulation into fish tissue downstream of DePere with reductions of PCB transport to Green Bay. The four scenarios are:

- No Action [Figure 1 (1)].
- Deposits A, C, POG upstream of DePere and the 3 top SMUs downstream of DePere [Figure 1 (2)].
- Deposits A, C, POG upstream of DePere and the 17 top SMUs downstream of DePere [Figure 1 (3)].
- Deposits A, D/E, POG, N upstream of DePere and the 50 top SMUs downstream of DePere [Figure 1 (4)].

Endpoints

To provide a base level of communication that should be easily recognized and understood by the majority of the public, changes in risk associated with the three scenarios were expressed in terms of allowable fish consumption rates. The proposed Uniform Great Lakes Sport Fish Consumption Advisory Protocol (GLSFATF, 1993) was selected because it recognized the limitations and inadequacy of the FDA tolerances for marketplace fish and set forth a protocol based on a weight-of-evidence health protection value. The protocol provides a range of consumption advice expressed in consumption terms, which provides adequate protection but also allows people to selectively eat sport fish as often as they wish. The advisory categories for PCBs are listed in Table 2.

Table 2. Proposed uniform Great Lakes sport fish consumption advisory levels.

Consumption Rate (227g/meal)	Tissue PCB concentration
Unrestricted consumption (225 meals/year)	<0.05 ppm
One meal per week	0.05 to 0.22 ppm
One meal per month	0.22 to 0.95 ppm
Six meals per year	0.95 to 1.89 ppm
Do Not Eat	> 1.89 ppm

To incorporate ecological concerns into the evaluation of the three remediation scenarios, fish tissue concentrations that would be protective of fish-consuming birds and mammals were also included. Using methodologies from the Great Lakes Water Quality Initiative (USEPA, 1995), an ecologically protective fish tissue concentration of 0.023 ppm derived from mink data was included in the evaluations of the scenarios.

Typical Model Simulation Results

Figure 1 illustrates the type of results generated by this modeling approach. Results have been limited to single fish species in only two distinct river segments (LLBdM and downstream of DePere) and PCB transport to Green Bay. Similar results can be generated for any parameter listed in Table 1 (except river position) in any particular river reach. Other fish species or tissue types (i.e., whole fish) can be easily substituted for the species analyzed provided there are enough data to estimate the average PCB concentration around 1990 for locations above DePere and around 1995 for below DePere.

Conclusions

General conclusions of the modeling done to date include:

- The problem is large and environmental benefit of sediment remediation is directly proportional to the effort expended.
- Remediation of select "hot spots" upstream of the DePere dam has little influence on transport to Green Bay.
- Remediation upstream of the DePere dam has little influence on fish tissue downstream of DePere.
- Remediation of large areas with low PCB concentrations achieves greater reductions in transport with similar reductions in fish tissues.
- Remediation of areas downstream of DePere has greatest influence on fish tissue concentrations downstream of DePere and PCB transport to Green Bay.
- Remediation decreases the time necessary to achieve a specific fish tissue endpoint.

Next Steps

With the goal of a cost-effective whole river sediment strategy in mind and the environmental benefits of these scenarios in hand, attention will shift toward developing total costs of these scenarios. Critical to this step will be developing unit costs for the remedial techniques most likely to be used. These costs could be applied across the board to each scenario, resulting in "ballpark" costs. Alternatively, each scenario could be reviewed in detail and specific techniques and costs applied to each sediment area or group of areas. Most likely, an iterative combination of these approaches will be attempted. Ultimately, with discussions focused on the cost of achieving specific environmental benefits, a cost-effective whole river strategy can be refined from this basic set of scenarios.

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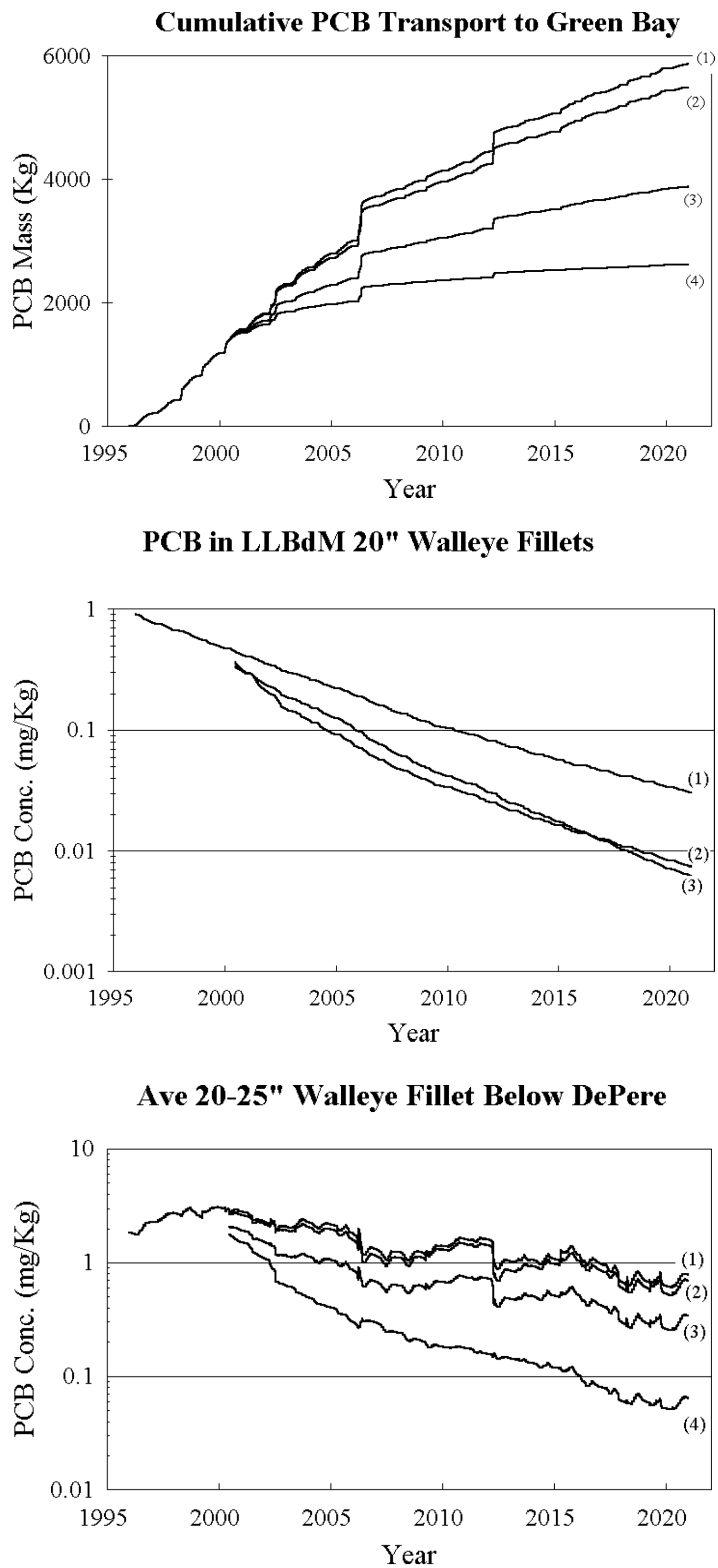

Figure 1. Typical remediation simulation results.

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