BALANCING THE BAY: IMPLICATIONS OF THE GREEN BAY/FOX RIVER MASS BALANCE STUDY MEETING
HOTEL SOFITEL
CHICAGO, IL
DECEMBER 3-4, 1992
Green Bay/Fox River Mass Balance Study

December 3 - 4, 1992

Day 1

8:30  Registration

Background

9:30  Welcome and Introduction
Valdas Adamkus
9:45  The Modeling Approach
Dr. Donald O’Conner
10:25  Mass Balance Modeling from GLNPO’S Perspective
Chris Grundler
10:55  Mass Balance Modeling from WDNR’S Perspective
Lyman Wible
11:15  WDNR Film on Green Bay/Fox River Mass Balance Study
Chris Grundler
11:30  Lunch (provided for pre-registered attendees)

Green Bay Model Results and Projections

12:40  Teamwork/Modeling Approach/Validity/
William Richardson/Dr. Dominic Di Toro
Model Outputs/Scenarios
12:50  Scientific Credibility as a Basis for Management Confidence in
Dave Devault/John Konrad
the Green Bay Study
2:00  Review Panel - Question and Answer Discussion
Lyman Wible
Dr. Dominic Di Toro, William Richardson, Dr. Victor Bierman,
Dr. John Connolly, Jeff Steuer, Dale Patterson, Dr. Wilbert Lick,
Dr. Deborah Swackhammer, Dr. Joseph DePinto
3:30  Break

Day 2

3:45  Management and Technical Lessons Learned
Chris Grundler
4:15  Cost/Benefits: What Does Mass Balance Really Cost and
Gary Gulezian
Does it Pay Its Own Freight?
4:45  Day’s Impressions/Introduction and Invitation to Evening
Senior Great Lakes Basin Environmental Managers
Poster Session/Reception
5:00  Dinner (On your own)

Day 2

7:30  Poster Session/Reception/Recognition of Efforts Extraordinaire

(Technical Poster Session Runs Concurrently with Evening Reception.
Attendees May Also View Posters During Breaks and Lunch.)

Day 2

8:00  Reconvene

8:05  Recap of Day 1/Comments on Evening Discussions and Posters
Chris Grundler
8:15  Importance of Atmospheric Contribution to the Mass Balance of
Dr. Joseph DePinto
Great Lakes Water Quality
8:45  Regulatory Framework to Address Air Toxics Deposition
Gary Gulezian
to the Great Lakes
9:05  Panel Discussion: Is Mass Balance the Management Approach
to Take in the Great Lakes? Followed by Open Discussion
Senior Great Lakes Basin Environmental Managers
Kevin Bricke, Moderating, Deputy Director, USEPA Region II Water
Division
Dale Bryson, Director, USEPA Region V Water Division
Gary Gulezian, Branch Chief, USEPA Region V Air and Radiation
Division
Bruce Baker, Director, Wisconsin Dept. of Natural Resources, Bureau
of Water Resources Mgmt.
Richard Powers, Assistant Division Chief, Michigan Dept. of Natural
Resources Surface Water Quality Division
Salvatore Pagano, Director, New York State Dept. of Environmental
Conservation Div. of Water
Tim Eder, Regional Executive, National Wildlife Federation
Bruce Robertson, Environmental Affairs Manager, James River
Corporation and Green Bay Rap Citizen’s Advisory Committee
10:15  Summary/Wrap-up - Sense of the Chairs
Chris Grundler/Lyman Wible
10:25  Final words/General Adjournment to Lunch (On Your Own)
and Poster Session
12:00  Poster Session Concludes

Chris Grundler
Scenarios Selected for Simulation

- Bay Flushing-all loads and BC 0.0
- Base Run-1989 load and BC constant
1. No Man Made Remediation
2. Fox River Hundred Year Peak Flow Event
3. Above DePere Selected Remediation
4. Above and Below DePere Selected Remediation
5. 10 Yr. Hindcast (not run - technical reasons)
6. Step PCB Load Reductions Above DePere
7. Fox River Peak Flow Clipping
8. Fox River Phosphorus Load Step Reductions
POSTER SESSION

GREEN BAY/FOX RIVER MASS BALANCE STUDY
MANAGEMENT SUMMARY

The principal investigators who performed the research, monitoring, and modeling for the Green Bay/ Fox River Mass Balance Study have agreed to present their findings to the participants of the Management Summary meeting. Their posters represent the fruition of at least several months and, in most cases, years of work. Each Investigator's poster attempts to present a strand of the fabric of the Green Bay/ Fox River Mass Balance Study.

The posters presented include:

Sampling the Water Columns of Major Tributaries for Concentrations of PCBs

Peter Hughes
R. Waschbusch
U.S. Geological Survey, Madison, WI

Sediment and Contaminant Transport and Fate

Wilbert Lick
University of California, Santa Barbara

Lower Fox River Sediment Transport and Mass Balance Models

Douglas Endicott
U.S. EPA-LLRS, Grosse Ile, MI
M. Valleux
ASci, LLRS, Grosse Ile, MI
J. Gailani
CSC, LLRS, Grosse Ile, MI
W. Lick
University of California, Santa Barbara

Fox River Polychlorinated Biphenyl Transport Model

Dale Patterson
Wisconsin Dept. of Natural Resources
J. Steuer
U.S. Geological Survey, Madison, WI
R. Hammond
Wisconsin Dept. of Natural Resources

Green Bay Water Column PCB Concentrations, 1989-90

David DeVault
T. Bodell
U.S. EPA-Great Lakes National Program
J. Filkins
P. Cook
U.S. EPA-LLRS, Grosse Ile, MI
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| Measurement of Atmospheric Deposition                                | Thomas B. Sweet  
Illinois State Water Survey                                           |
| The Green Bay PCB Volatilization Experiment                          | Steven J. Eisenreich  
S.J. Hornbuckle  
D.R. Achman  
Gray freshwater Biological Institute                                  |
| Development and Validation of an Integrated Exposure Model for Toxic Chemicals in Green Bay | Victor J. Bierman, Jr.  
LTI-Limno-Tech Corp., Ann Arbor, MI  
J.V. De Pinto  
University of Buffalo, New York  
T.C. Young  
Clarkson University, New York  
P.W. Rodgers  
S.C. Martin  
R. K. Raguhunathan  
S.C. Hintz  
T.A.D. Slawecki  
S.A. Roberts  
LTI-Limno-Tech, Corp., Ann Arbor, MI                                   |
| Bioaccumulation of PCBs in Phytoplankton: Green Bay                  | Robert Skoglund  
K. Stange  
D. Swackhamer  
University of Minnesota-Minneapolis                                    |
| Measures of Reproductive Success and PCB Residues in Eggs and Chicks of Forster's Tern on Green Bay, Lake Michigan | Hallett J. Harris  
Thomas C. Erdman  
University of Wisconsin-Green Bay  
G.T. Ankley  
U.S. EPA-ERL, Duluth, MN  
K.B. Lodge  
University of Minnesota-Duluth                                           |
U.S. EPA-LLRS, Grosse Ile, MI                                            |
| Q.A./Q.C. Program for Green Bay: How are the Data?                   | Deborah Swackhamer  
University of Minnesota-Minneapolis                                      |
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### BALANCING THE BAY: IMPLICATIONS OF THE GREEN BAY/FOX RIVER MASS BALANCE STUDY

#### ROSTER ADDENDUM

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GREEN BAY/FOX RIVER
MASS BALANCE STUDY

Preliminary Management Summary

Prepared By: Robert F. Beltran
U.S. Environmental Protection Agency
Great Lakes National Program Office
The Green Bay/Fox River Mass Balance Study

Management Summary

Preliminary Management Summary

Prepared by: Robert F. Beltran
U.S. Environmental Protection Agency
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With the assistance of: William Richardson, Director,
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A publication of the Green Bay/Fox River Mass Balance Study Management Committee

Produced by the Illinois-Indiana Sea Grant Program
OVERVIEW
This report presents the Green Bay/Fox River Mass Balance Study experience as a model and a lesson in large scale interagency cooperation to apply the mass balance approach. The report will incorporate the fundamentals of the mass balance approach and identify some lessons learned in the Green Bay experience while looking forward to the implications for future — and even larger scale — effort to apply a mass balance approach to the management of toxics for an entire Great Lake.

The Green Bay/Fox River Mass Balance Study is intended to evaluate the feasibility of mass balance modeling for toxic substances as a basic planning and management tool in restoring Great Lakes water quality. Successful application of the methodologies employed in the Study offer an accurate basis for pollution control and a foundation for setting objectives for Lakewide Management Plans and Remedial Action Plans.

OBJECTIVES OF THE GREEN BAY/FOX RIVER MASS BALANCE STUDY

The Green Bay/Fox River Mass Balance Study was conducted as a pilot to test the feasibility of using a mass balance approach to assess the sources and fates of toxic pollutants spreading throughout the Great Lakes food chain. It was intended to validate and refine monitoring and analytical assumptions made by the coordinating agencies, and to rigorously test the models. Specific objectives included:
- Assessing the technical and economic feasibility of the mass balance approach for use in the management of pollutant loadings and impacts on Great Lakes ecosystems.
- Calibrating the mass balance model for sources, transport routes, and fates of pollutants in the Great Lakes ecosystem.
- Identifying the major sources of selected pollutants entering the Green Bay ecosystem and ranking their relative significance.
- Demonstrating methods and priorities for further studies of toxic pollutants in the Great Lakes.

SELECTION OF GREEN BAY
Green Bay was selected over other potential sites for the Great Lakes mass balance pilot project for six primary reasons:

1. It presents a wide range of environmental conditions representative of much of the Great Lakes.

2. By virtue of its size and its limited number of significant tributaries, Green Bay fit into the logical modeling progression from connecting channels to the more daunting Great Lakes.

3. Several ongoing studies of the Bay employ the mass balance concept.

4. There is a substantial historical database of the Bay’s environmental conditions on the Bay.

5. Green Bay and the Fox River comprise a seriously impacted aquatic system internationally designated as a Great Lakes area of concern. In response, the appropriate federal, state, local, and academic institutions had already made a high level of commitment to their assessment and remediation.

6. The Study would offer a substantial boost in decision-making power to the developers of the
Remedial Action Plan, better enabling them to select and prioritize remedial, management, and enforcement alternatives for the River and Bay.

GREEN BAY AND THE FOX RIVER

Green Bay can be characterized as a long, relatively shallow extension of northwestern Lake Michigan. Fourteen tributaries drain about 15,675 mi.² of watershed in both Wisconsin and Michigan, comprising about one-third of the total Lake Michigan drainage basin. The southern portion of the Bay and its largest tributary, Wisconsin’s Fox River, have been acknowledged as a polluted water system, and have been designated by the United States and the International Joint Commission as a Great Lakes Area of Concern. The Fox River Valley is heavily industrialized and contains the world’s largest concentration of pulp and paper mills. The Bay nevertheless remains a major recreational resource in the region, providing excellent boating and outstanding walleye fishing, despite fish consumption advisories established by the states.
CONDITION OF THE BAY

Green Bay is impacted by three categories of contaminants: nutrients, metals, and organic toxicants. Each deserves a brief discussion:

Nutrients
The lower Fox River and southern Green Bay had been naturally mesotrophic to eutrophic due to drainage from adjacent fertile uplands prior to the 19th century. This condition changed when lumbering, agricultural and other land use practices of the 19th and 20th centuries, exacerbated by municipal and industrial wastewater discharges, led to a hypereutrophic condition at the Bay's southern extreme, grading to mesotrophic-oligotrophic in its northern one-third.

This eutrophication has had distinct effects upon the Bay:
- Nutrient richness in the River and Bay results in considerable biological productivity and a high organic sedimentation rate.
- Since the early 1960s, excessive nutrient loading has been responsible for episodes of oxygen depletion and algal blooms in the lower Fox River and southern Green Bay.

Since 1970, some $338 million in wastewater quality improvements have helped alleviate the worst of these events.

Metals
Cadmium, lead, and mercury are known to have serious toxic effects upon biota and are present at levels of concern in the sediments and biota of the lower Fox River and southern Green Bay. Each of these metals is bioaccumulative, but relatively little study has yet been devoted to their distribution in and their effects upon all compartments of the Green Bay ecosystem.

However, past studies have given us some information on their concentrations:
- Lead and mercury are known to be concentrated in the southern portion of the Bay at levels substantially above those of the northern Bay and Lake Michigan.
- Mercury, especially, is concentrated (up to 60 mg/Kg) in sediments behind dams in the Fox River system.

Improvements in industrial processes and wastewater treatment have reduced most external sources of metals to the River and Bay. These contaminants nevertheless continue to cycle into the system from their reservoir in the sediments.
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Organic Toxicants
Primarily a product of post-WWII technology, certain organic toxicants — particularly organochlorines such as PCBs and the pesticides dieldrin and DDT — tend to break down slowly. Heavy industrial development has resulted in severe environmental contamination by organic toxicants ranging from PCBs to dioxins. These chemicals, particularly PCBs, are found at levels of concern in Great Lakes water, sediment, and biota, and are believed to be responsible for reproductive, developmental, and perhaps behavioral disorders at the higher levels in the foodchain, including Green Bay and Lake Michigan waterfowl, raptors, mammals, and fish.

For Green Bay, specifically, there is cause for concern:
- The elevated levels of PCBs and dieldrin have led to fish consumption advisories and restrictions on commercial harvesting of walleye, carp, and salmon.
- Organic contaminants have led to reproductive impairments among fish-eating birds.
- Sediments of the lower Fox River contain some of the heaviest concentrations of PCBs in the United States, and water column concentrations of up to 250 nanograms/liter (ng/L), 100 times that of the open waters of Lake Michigan.
- In Green Bay, PCB water column concentrations grade from 120 ng/L near the Fox River mouth down to Lake Michigan’s level of 1-2 ng/L in the north. Sediment levels of PCBs follow a similar, though steeper gradient, and are believed to be the primary source to the Bay’s water and biota.

THE MANAGEMENT DILEMMA
Acting in response to the environmental problems evident in Green Bay and the Fox River, public agencies, the private sector, and individual citizens have reacted on a broad front to identify and reduce loadings of both nutrients and toxicants.

Agencies utilized the authorities granted them under the landmark federal environmental statutes — the Clean Water Act, the Clean Air Act, Superfund legislation, and others — to regulate discharges from both active sources and waste sites. In the watersheds, land management and agricultural agencies at all levels worked with private landowners to abate nonpoint source contributions. Municipalities, industries, and environmental agencies constructed waste treatment facilities and remediated waste sites, and implemented new approaches to waste materials handling, reduction, treatment, reuse, and recycling. Literally billions of dollars, public and private, have been and are now being spent to save the Bay.

Still, problems persist in the Green Bay system. Fish consumption advisories remain in place. Contaminant levels in Green Bay biota continue to decline, but for a number of substances, this decline appears to be leveling off. Bottom-dwelling organisms, the base for a large component of the food chain, continue to be particularly exposed via the sediments, which persist as a continuing reservoir of contaminants to the system.
In addition, predator fish, birds, and fish-eating mammals may be suffering from reproductive, development, and cognitive disorders. While no "smoking gun" has been found, a number of respected researchers have pointed out strong correlations between such factors as reduced hatching success or deformities and levels of PCBs and other contaminants in the studied populations.

**PROJECT FRAMEWORK**

From the outset, the Management Committee recognized that no single agency had sufficient resources nor expertise to manage, fund, and conduct the entire project. The fundamental operating principle was that each involved agency, program, laboratory, and investigator would benefit from the products of the other parties. Each piece of the project would then fit together to build the whole and each would “own” the whole.

It was also recognized that a project plan should follow an agreed-to process including:

- Specification of management questions to be addressed including the chemicals of concern.
- Definition of the modeling framework needed to address the management questions.
- Development of alternative modeling, sampling, experimental designs for preliminary management review to narrow the range of expectations and budgets.
- Development and application of a screening model to test the sensitivity of various model components and to prioritize modeling data needs.
- Statistical analyses of historical data to determine optimal sampling design.
- Specification of sampling design and selection of cooperators.
- Implementation of sampling, experimental, and modeling projects.
- Maintenance of a continuing dialog among project partners to provide continuing critiques, peer review, and to maintain consensus building.
- Application of the model to answer the management questions.
- Documentation of project results and models and delivery of models to regulatory offices.

**Management Questions**

The principal question concerned the feasibility of using a mass balance approach to manage toxic chemicals in the Great Lakes. However, more specific environmental questions for Green Bay concerned the continuing, chronic problems associated with PCBs. The specific management questions which directed the remainder of the project included:

- What are the absolute loading inputs to the Bay from all significant point and non-point sources, including in-place contaminated sediments?
- If no additional regulatory or mitigative actions are taken, will concentrations in fish decline, to
what level, and will they fall below the regulatory action level of 2 mg/kg?

- What additional regulatory or mitigative actions need to be taken to reduce PCB levels below the action level or to other specified levels?

**Modeling Framework**

Considering the management questions, the modeling committee determined that the Green Bay Model could build on the basic model framework that had been previously developed for Saginaw Bay and for the Great Lakes. This would involve a time variable model, as shown in Figure 1, starting with a water transport model coupled to a nutrient driven eutrophication model. The eutrophication model generates organic carbon-related solids which are input to a solids model. Output of the solids model form an input to the contaminant exposure model the output of which forms the input to the food chain model.

Each model produces output in the form of concentrations computed at different locations in the Bay and at future times. The calculated concentrations are compared to data which, for this study, was collected in 1989. The model is calibrated by changing model process coefficients so that the

![Diagram of Green Bay Modeling Process](image)

*Figure 1. Green Bay Modeling Process*
PCBs enter the Green Bay system from the atmosphere, and from tributaries, primarily the Fox River. There exists a reservoir of PCBs in bottom sediments which may resuspend with sediments during storm events, and then desorb and become available to the food chain. PCBs are lost from the system through volatilization to the atmosphere, burial to deep sediment, and possible transport to Lake Michigan.

The computer model program keeps track of the mass of PCBs in space and time. It is called a “mass balance model” because the principal thermodynamic law of conservation of mass is maintained at
all times. Thus, if mass is lost from one physical, chemical, or biological component of the model it must be gained in another.

A conceptual view of the food chain bioaccumulation model is shown in Figure 3. Chemical accumulation results from direct uptake from water and from food chain transfer with feeding. The bioaccumulation model is based upon a mass balance equation for each organism in the food chain. The model simulates the accumulation of chemical concentrations along each step of the aquatic food chain in response to the organisms’ chemical exposure via food, water, and sediments. Calculation of this exposure is itself based upon the simulation provided by the aquatic mass balance model.

These inputs to the organism are balanced by elimination processes, and are diluted within the organism as a result of growth. Green Bay field data was used to refine the mathematical assumptions derived from earlier experimentation. For PCBs, food chain transfer has been shown to be highly effective, resulting in increasing chemical concentrations at higher trophic levels.

Figure 3. Food Chain Model Framework
Bioaccumulation Model Process

Bioaccumulation = uptake + food chain transfer - elimination - growth dilution

(food chain transfer)
(uptake from water)
(elimation (via respiration and excretion))
The food chain model is depicted in more detail in Figure 3. A separate computer program uses output from the physical/chemical model to quantify the available contaminant in the water column. This form of toxicant is available to each level of the food chain and "bioconcentrates" the chemical. In addition, each level preys on the lower level and "bioaccumulates" more of the chemical. The chemical may return to the water via death or excretion. The speed at which the uptake and excretion occur are important factors in the model and must be determined through experimentation and refined by calibration to field data.

**Design of the Monitoring Plan**

The model "requires" field data for two primary purposes:
- To provide loads, initial conditions, and boundary conditions.
- To provide ambient concentrations in water, sediment, and biota for comparison to calculated concentrations for "calibration" of the model.

In addition the model requires site-specific "rate" information to include as model coefficients. The rate data can be obtained in three different manners, all employed in the Green Bay project:
- From previous research as reported in scientific literature.
- From new experiments conducted in the system being modeled.
- By tuning or calibrating to field data.

**THE MASS BALANCE RATIONALE**

**Mass Balance Defined**

A mass balance model can be defined simply as an equation where matter and energy entering a system, minus matter and energy leaving the system, equal matter and energy stored, transformed, or degraded within the system.

More precisely, a mass balance model is an accounting device to ensure that differences between inputs and outputs during any particular interval of time, within any particular volume in space, are equal to the net sum of the production, retention, and decay processes within the volume. In practice, there are many complex processes that influence the transport, transformation, and fate of toxic chemicals in the Great Lakes.

Mass balance models can be run at any of several levels, or tiers. A screening model — a preliminary approach — utilizing existing data, can be run at very minimal cost to give very rough ideas of the magnitude of a lake's toxicants problem. A loadings model — an intermediate approach — can be used to identify whole lake total maximum daily loadings (TMDLS). A full mass balance study — a complete approach — is needed, however, to set specific wasteload allocations for individual sources.

The suite of toxicants to be modeled exerts a profound influence upon the study's budget. For example, the Green Bay effort (designed as a pilot to tell us how much we need to know) involved analysis for all PCB congeners, but another study might look only at total PCBs, quartering the analytical expense.
The degree of complexity actually incorporated in any particular model (and the level of confidence it obtains) depends upon:
- The objectives of the analysis
- The amount and quality of the data available to run and validate the model
- The resources and time available for a specific study

Mass Balance Capabilities

Mass balance modeling has four special strengths:
1. **Models establish a framework for organization and synthesis of data.**
   Models can be used as experimental design tools to identify data gaps and needs for monitoring and research. The inputs needed to run the models dictate important objectives to incorporate into study designs, and help researchers to focus upon key processes to refine the models.

2. **Models provide a basis for managers to minimize costs and enhance information flow.**
   Researchers and managers can recoup and minimize many costs by focusing upon the parameters that the model had shown to be responsive to management. Those involved can also use model output to design monitoring networks for sampling at locations and frequencies that will cost-effectively augment the model database, yet avoid oversampling.

3. **Models are useful tools for understanding processes that lie behind the data.**
   Model equations are mathematical representations of our understanding of natural processes. The model validation process enables researchers to introduce field observations into the equations; the law of conservation of mass and energy compels researchers to adjust their formulae or look for missing elements. This process results in both more accurate, site-specific models, and in redirection of research and monitoring to identify and quantify the natural processes.

4. **Models demonstrate linkages between inputs and system responses.**
   As powerful decision-making tools, managers can use models to test alternate loading hypotheses, predicting the response of the system to various management scenarios. Models can help prioritize candidates for source reduction and the environmental effectiveness of various control options.

Modeling can likewise be employed to calculate loading reductions needed to stabilize water column or biota contaminant levels at some given level. This information can also be used as a basis for establishing target loads (total maximum daily loads, or TMDLs), wasteload allocations, and permit limits as interim goals for the ultimate attainment of zero discharge and virtual elimination of toxic substances. This approach was used to determine the phosphorus loadings targets identified in the Supplement to Annex 3 of the 1978 Great Lakes Water Quality Agreement.

Mass Balance Limitations

Mass balance models have four principal limitations:
1. **Toxic chemical mass balance models conceptually oversimplify natural processes.**
   Although models are deliberate simplifications of reality, imperfect understanding of important
governing processes can lead to errors. Models are
based upon current scientific understanding of
physical, chemical, and biological processes. Suc-
cess of the model depends upon the degree to
which researchers understand and can quantify
the sediment-water, air-water, and water-biota
exchange processes or the mechanisms governing
breakdown and transformation of toxic chemicals.
Although many of these processes have been ade-
quately quantified under laboratory conditions,
they remain significant potential sources of mod-
eling uncertainty when applied in the field to
whole lake situations.

Our imperfect understanding of these processes
forces the model to represent a simplification of
reality. Nevertheless, the modeling approach forces
scientists to assign values quantifying process
rates—reducing ambiguity and subjectivity. If
values are not well-known, further experimental
research is conducted to increase confidence. In
the final analysis, the model is tested by its ability
to simulate and predict actual occurrences. To test
the validity of the model, extensive surveillance
data are required.

2. Mass balance models have extensive data
requirements.
Mass balance models require three categories of
data:
- Input data to drive the model.
- Current ambient conditions to calibrate and
  verify the model.
- Future (anticipated or hypothesized) conditions
  and input to frame the management scenarios.

If ultimate validation of the model is needed, it is
also necessary to obtain future actual ambient data
as a basis for comparison with the model predic-
tions.

The model must incorporate values for a wide
range of variables, loading of chemicals, circula-
tion, basin morphometry, temperatures, etc. to
produce an output-predicting water column.
Linkage to a food chain model demands the
products of the water-sediment-air model and
requires data on the forage base, biotic body
burdens, and fish migration patterns to produce
a projection of load-response contaminant
concentration trends in fish.

Realistic load estimates are the basis of any mass
balance effort, and comprise the preponderance of
its costs. Since loading mass is dependent upon
loading rates from many sources over a specified
time period, it is critical to characterize, in a "snap-
shot" of one or more years, the loading from the
multitude of tributaries, point sources, and
nonpoint sources. These sources include the at-
mosphere, groundwater, waste sites, urban and
agricultural runoff, and sediment deposits.

The more extensive the chemical analysis, the
longer the period modeled. The more statistically
representative the acquired datapoints are of the
loading regimes, the greater will be the reliability
and precision will be of the final product. In other
words, the quality and quantity of the data deter-
mines the quality of the model results. This equates
to the considerable expense involved in an inten-
sive monitoring program. Much of this expense
may later be recouped in two ways:
- Redesign and optimization of routine monitor-
ing programs.
- Selection of more cost-effective source control
  approaches.
3. There are no rigorous methods for quantifying model prediction uncertainty.

It is now possible to quantify some sources of uncertainty, such as station density, sampling frequency, and sample replication. In addition, valid statistical estimates can be made for uncertainty in model coefficients and for comparison of results with experimental and field observations. However, these techniques do not quantify predictive capability because they may not detect, and cannot identify, conceptual errors in model formulation. For example, the model used for Green Bay does not account for the effects of zebra mussels.

4. Mass balance modeling exercises can challenge the support infrastructure.

In addition to the expense incurred in modeling a major waterbody, a mass balance exercise can overload the analytical capacity and personnel resources of the involved institutions as indicated below:

- Monitoring equipment and personnel required for a mass balance study may not be in place or available. Generally, several agencies and institutions must be prepared to dedicate their expertise, time, and equipment to the project while continuing to carry on other, unrelated monitoring activities. (Several agencies, especially the USEPA, have already greatly increased their monitoring capability in anticipation of expanding their mass balance efforts to entire Great Lakes.

- Analytical laboratory capacity in a high-level mass balance study may be overwhelmed by the sheer number of samples to be analyzed within a limited time period.

**MASS BALANCE — IN SUMMARY**

While mass balance modeling cannot make absolutely precise and accurate predictions, the concept remains sound and has been thoroughly field validated. The expense of the higher level models is primarily incurred due to greatly increased resolution of ambient monitoring and analysis. These costs, however, are largely or entirely offset by enabling managers to initiate less expensive, more refined routine monitoring programs. Substantial cost reduction may be affected by fitting the level of modeling to the need.

The approach provides a rational basis for setting load reduction targets and priorities, as well as management and regulatory policy. The alternative of setting arbitrary reduction targets and conducting follow-up ambient trend monitoring to determine target adequacy proves to be much more fiscally and environmentally expensive. Inordinate efforts may be expended to control and correct the least consequential sources. Given the response lag of most environmental systems, the poor efficacy of such misdirected resources may not be evident for many years.

**THE GREEN BAY PLAYERS**

Responding to provisions of the 1978 Great Lakes Water Quality Agreement and the resolutions of the 1986 Mackinaw Island “Large Lakes of the World” international conference, the USEPA’s Great Lakes National Program Office (GLNPO) initiated planning among the environmental agencies in 1986. An agreement was reached to share overall coordination between the GLNPO and the Wisconsin Department of Natural Resources (WDNR).
Committee Structure

The Study has operated through a three-tiered committee structure:

The Management Committee deals with administrative and budgetary matters:
Conducts overall management, coordinates interagency planning; obtains funding commitments from participating agencies.

The Technical Coordinating Committee addresses scientific and technical issues:
Coordinates activities of operational committees; recommends study designs and resolutions to technical disputes to the Management Committee.

Four technical committees address specific study tasks:
Modeling; Biota; Field and Technical Operations; and Field and Analytical Methods.

Planning the Field Program

In March, 1988, the Modeling Committee prepared the planning document, Report on Project Planning for the Green Bay Physical-Chemical Mass Balance and Food Chain Models. This report provided detailed information for use in selecting a final monitoring plan including costs for alternative levels of complexity and precision. The final design was based on a series of discussions among managers, modelers, and those responsible for monitoring and experimentation.
In March, 1989, the Green Bay Mass Balance Management Committee approved the Green Bay/Fox River Mass Balance Study Plan: A Strategy for Tracking Toxics in the Bay of Green Bay, Lake Michigan. The plan was partitioned into six major divisions reflecting particular requirements of the model. Each division was subdivided into study components. Study participants were each assigned an appropriate specific study component:

I. Inputs
II. Outputs
III. Active Pools and Interface
IV. Biota
V. Quality Assurance and Data Management
VI. Administration

MODEL FRAMEWORK
Working from the precept that the project would build upon existing knowledge, the Management Committee sought to contain costs and to leverage existing activities. Only essential monitoring and experimentation would be funded. Four toxicants, themselves representative of larger groups of chemicals, were selected for investigation:

PCBs (total, homologs, and congeners) — toxic metals: lead is available in an organic form; cadmium as an ion. Based upon the Technical Coordinating Committee and the Modeling Subcommittee, WASP IV was selected as the computer program for the toxicant fate model. A transport model was coupled to eutrophication, solids, exposure, and food chain models. Walleye, brown trout, and carp were specified as target species.

The physical-chemical model simulates and predicts concentrations of the modeled toxicant in the sediment and water given a specific loading (input) to Green Bay from any source. The models and computer programs have been combined into a unified model, WASP IV, the computer program chosen for the Green Bay model. The simulated concentrations of the dissolved chemical species in the water are then used as input to WASTOX, the food chain model.

THE GREEN BAY/FOX RIVER MASS BALANCE STUDY PLAN

The plan was partitioned into six major divisions reflecting particular requirements of the model. Each division was subdivided into study components. Study participants were each assigned appropriate specific study components to accomplish:

The physical-chemical model simulates and predicts concentrations of the modeled toxicant in the sediment and water given a specific loading (input) to Green Bay from any source. The models and computer programs have been combined into a unified model, WASP IV, the computer program chosen for the Green Bay model. The simulated concentrations of the dissolved chemical species in the water are then used as input to WASTOX, the food chain model.
I. Inputs
Identify and quantify sources of contaminants entering the system.

A. Tributaries
1. General
2. Fox River Upstream
3. Fox River at DePere Dam
4. Fox River Mouth

B. Point Sources
C. Atmosphere

D. PCBs from Landfills
E. PCBs from Urban Areas
F. Groundwater Contributions

II. Outputs
Identify and quantify pollutants leaving the Bay.

A. Water volume transport
B. Sediment Flux and Resuspension
C. Sediment Resuspension Quantification
D. Desorption Kinetics, Sedimentation Rates, and Volatilization, University of Wisconsin Sea Grant Institute-Madison/Milwaukee

III. Active Pools and Interfaces
Characterize principal contaminant reactors within the Bay.

A. Lower Fox River Sediments
B. Water Column

IV. Biota - characterize biotic pathways of contaminants

V. Quality Assurance and Data Handling

VI. Administration

STUDY PRODUCTS
A multitude of reports have been produced from this study. Cooperative efforts to share technology, explore alternative management scenarios, and build consensus on remedial choices are ongoing. Preliminary results are available for a few studies.

Product

Author(s)

Fox River PCB Transport Model
Lower Fox River Model
Green Bay Sediment Transport Model
Green Bay Food Chain Model  John Connoly
Green Bay Toxics Model  USEPA - LLRS
Fox River-Green Bay Modeling Compendium  USEPA - LLRS
Comprehensive Final Report  Interagency
Technical Symposium Proceedings  Various Researchers

Individual researchers will also be publishing results and follow-up studies independently in scientific journals.

A less quantifiable product of the Green Bay/Fox River Mass Balance Study is its contribution to the “state of the art” of modeling. The very scale, duration, and intensity of the study; its extensive field calibration; and continuing empirical verification will validate certain modeling assumptions and will better quantify others. This will serve to not only improve our understanding of critical exchange and transformation processes, but will help to reduce both model uncertainty and data requirements.

Model Development and Project Results

Four primary models were developed and linked:

1) Fox River solids and chemical transport model
2) Exposure model for toxic chemicals
3) A model of PCBs in Green Bay walleye and brown trout and their food web
4) A PCB transport and exposure model of the Fox River above DePere Dam, and
5) A hydrodynamic and sediment transport model for the lower Fox River.

Reports and other products from the Green Bay Project have or will be produced as follows:

Lower Fox River Mass Balance Model

The Lower Fox River Mass Balance Model is a transport and fate model for PCBs in the Fox River between DePere Dam and the River mouth at Green Bay. The Model simulates point and non-point sources, sediment (including episodic transport of in-place PCBs during floods), volatilization, and dispersion (due to Bay-induced seiching). These factors all affect the mass balance of PCBs along the lower seven miles of the River. The model was calibrated using chloride, suspended solids, and PCB concentration data from samples collected at DePere Dam, the River mouth, and at five sampling stations in the lower River, as part of the Mass Balance Study.

The function of the model is twofold. First, it predicts the transport of PCBs from the Fox River to Green Bay. This prediction then becomes a load to the Green Bay Mass Balance Model. Accuracy in this prediction is critical because transport from the Fox River provides the largest source of PCBs to Green Bay.

The mass balance modeling approach incorporates, refines, and goes beyond conventional tributary loading estimates. Model predictions account for factors affecting PCB transport at both low
flow (mixing due to seiches) and high flow (sediment bed erosion) that confound the loading estimates. Furthermore, the mass balance model can predict future PCB transport from the Fox River over the long duration necessary to simulate water quality management scenarios.

The second function of the model is to predict water column concentrations of PCBs in the Fox River. These concentrations are used by the Green Bay bioaccumulation model to define PCB water exposure for fish that seasonally reside in the River.

Output of the Lower Fox River Mass Balance Model in terms of 1989 loading of PCBs to Green Bay is shown in Figure 4. This data formed part of the input for the Green Bay Model.

GREEN BAY RESULTS

Model Calibration

In the final analysis the validity and credibility of the model is determined by its ability to simulate existing conditions. Ideally, the model would be validated by predicting some future occurrence

Figure 4  Lower Fox River PCB Loads to Green Bay in 1989
and testing the prediction with an independent data set. In this situation, an independent data set does not exist. However, the model output in Figure 5 shows that the model does match the data collected in 1989. This fact provides enough credibility at this time to use the model for management purposes.

**PCB Mass Budget**

The first management question regarded the PCB loadings to the Bay. An accounting of all PCB inputs and fluxes provides an answer. As summarized in Figure 4, the majority of PCBs enter the Bay via the Fox River. However, in 1989 there is an equal flux from the bottom sediment to the water column. Considerable loss of PCB occurs to the atmosphere via volatilization and transport to Lake Michigan.

**Green Bay 1989 Total PCB Calibration**

**Segment - 3**

![Green Bay Model Calibration](Figure 5. Green Bay Model Calibration)
Management Applications

As the project evolved and interim results became available, it grew evident that the major management consideration for Green Bay and Fox River concerns the in-place, contaminated sediment. An approximately 25 to 30 thousand kg reservoir of PCBs exists in deposits below DePere Dam. Also, an additional 3 to 4 thousand kg reservoir of PCB contaminated sediments resides in Little Lake Butte des Mort, above DePere Dam. Resuspension and diffusion of PCBs from these deposits above and below the dam appear to be the major sources of PCBs to Green Bay.

Under normal meteorological and hydrological conditions these sediments slowly deplete either through transport downstream, slow biodegradation, and perhaps permanent burial. The question remains, however, as to the possible disruption of these deposits and transport downstream and into Green Bay. It is unclear under what conditions significant quantities would be released and what would be the downstream consequences.

The Management Committee asked the Modeling Committee to address these questions near the project’s conclusion. Additional resources and efforts are being expended to provide the answers. The results will be presented separately, and at the December 1992 Conference.

CHALLENGES FACED AND LESSONS LEARNED

A primary original intent of the participants was to challenge themselves, both organizationally and technically. They sought to test their ability to develop and calibrate mass balance models at the level of precision necessary to make sound toxic regulatory and management decisions and to do that within the context of the complex jurisdictional framework which exists on the Great Lakes.

The Project’s success can be attributed to several factors:

- The leadership role played by both USEPA - GLNPO and WDNR in planning and funding the study at its outset.
- Inclusion of all participating agency and academic institutions early in the planning phase.
- Establishment of, and adherence to, a formal organizational structure for study planning, funding, and dispute resolution.
- Recognition of the Study’s importance by both government agencies and academic participants, and individual initiative in addressing and resolved technical and organizational issues.

Logistical and technical challenges were anticipated due to the magnitude of the study and the number of actors involved. Quality assurance protocols defined at the Study’s outset established rigorous standards for both field sampling and laboratory analysis.

- Early retention of a recognized analytical expert to address quality assurance issues during the study enabled development of a “Study Quality Assurance Plan” prior to collection of samples and certification of laboratories.

- Laboratory capability and capacity were severely taxed. Participating laboratories have extended and expanded their capabilities so
that they now are able to perform higher volume and higher quality analyses than ever before.

- The study's sampling intensity, which accounted for the spatial and temporal variability in the system, has provided a design basis for future sampling efficiencies (fewer samples).

THE MANAGEMENT SCENARIOS

The Management Committee requested the modelers to prepare several alternative management scenarios. Some alternatives in this suite were selected in part to demonstrate distinct contrasts among management approaches. Others were selected specifically to identify best management alternatives and to enable managers to better ascertain cost effectiveness among those alternatives. For each scenario, the Fox River Modeling Team provided its results to the Green Bay Water/Sediment Modelers and to the Green Bay/Fox River Food Chain Model.

Weather conditions are an important driver for the scenarios. This was the basis for the selection of the 100-year, 60-day high flow event for Scenario 2. To provide realism, the modelers utilized the past 60 year's weather and flow records to simulate the weather for the next 60 years.

The scenario results are not presented here. Some scenarios were still being developed as this publication was being finalized for delivery at the December 3–4, 1992 Green Bay/Fox River Management Summary Meeting. An addendum to be provided at the meeting will present complete results of the final runs since the Green Bay/Fox River Food Chain Model is the last link in the chain of models, and is only touched upon here. Interpretation of Food Chain Model results for all scenarios will also be presented separately at the meeting.

Scenario 1 Base Run — 1989 conditions and loads repeated for 25 years.

Scenario 2 No Action
A) Constant boundary conditions
B) Lake Michigan Boundary condition decaying at .15/yr., atmospheric at .19/yr.
C) Similar to scenario 1B, but Lake Michigan exchange increasing at .15/yr.
D) Similar to scenario 1A, but Lake Michigan exchange decreasing at .15/yr.

Scenario 3 100-yr. Flow Event
A) Constant boundary conditions
B) Decaying Boundary Conditions

Scenario 4 Upstream Remediation
A) Constant boundary conditions
B) Decaying Boundary Conditions

Scenario 5 DePere Dam Load Reductions
A) 50% upstream load reduction with constant boundary conditions
B) 50% upstream load reduction with decaying Boundary Conditions
C) 100% upstream load reduction with constant boundary conditions
D) 100% upstream load reduction with decaying Boundary Conditions

Scenario 6 "FlowClipping" (controlling high flow events)
A) Constant boundary conditions
B) Decaying Boundary Conditions
STUDY FINDINGS AND CONCLUSIONS

As this document goes to print, the effort to define, identify, and evaluate the effects of various management scenarios is still underway. An addendum will present the full range of model scenario results, not presented here because some elements of the modeling effort must await the completion of other, precursor elements. Their results must be scrutinized and validated in the light of environmental results. Inevitably, these and other environmental management scenarios will be implemented. The choice is whether to select and implement them by design or to accept the scenarios that serendipity and misfortune deal out by default.

The Green Bay/Fox River Mass Balance Model is a tool to be used. While that means managers will be able to draw certain conclusions by pulling the study results off the shelf and reviewing the existing scenario runs. Much of the real power, however, resides in a manager’s ability to ask the modelers to rerun the model using new parameters reflecting newly conceived or previously unanticipated circumstances. Any conclusions listed here now, and for a considerable time to come, must therefore be considered preliminary.

WATER/SEDIMENT QUALITY MODEL FINDINGS

Two classes of findings emerged in the scenarios:

1) Findings applicable to the whole Bay, generally as annually averaged, and
2) Findings applicable to either the inner (southern) Bay or the outer (northern) Bay

The water and sediment models for Green Bay and the Fox River targeted total PCB concentration endpoints in the water column and sediments after the time periods, and under the management schemes defined in the six scenarios. While the models looked specifically at a suite of PCB phases in the water and sediment, for management purposes, they are here, with few exceptions, grouped generally into water or sediment phases.

FOOD CHAIN MODEL FINDINGS

As previously stated, only the most preliminary results of the Green Bay/Fox River Food Chain Model are available as this document goes to print. More complete data will be made available at the Management Summary Meeting and in the addendum to this report.

The Green Bay Food Chain Model results are particularly important to decisionmakers, since the food chain is the vehicle for bioconcentration of PCBs and many other substances to reach toxic levels in the biota; it is this trait that makes even the comparatively low levels of PCBs found in the Green Bay water column a matter of concern.

The Model was run using field-collected Green Bay PCB data for phytoplankton, zooplankton, three forage fish, and two top predator fish species. The Food Chain Model was then linked to and driven by results from the Fox River and Green Bay Water Quality Models. Substantive decreases in water column total PCBs predicted by the water quality models suggest parallel, but delayed, decreases in PCB concentrations within the Green Bay food chain under several management scenarios. This predicted reduction applies to Green Bay top predator fish. At this writing, specific scenario results are still being analyzed.
PRELIMINARY MANAGEMENT

CONCLUSIONS

Not all results are yet available as this report goes to press. Conclusions must be drawn in light of the remaining scenarios, and further analysis is certainly called for and will be made available at the Management Summary Meeting. At this writing, however, the following is evident based upon the 1989 field year and the scenarios so far run under the model:

There are four primary sources of total PCBs to Green Bay. These may be divided into internal sources (1) and external sources (2). The overwhelming internal source is Green Bay sediments. The external sources are, in order of importance, the Fox River (primarily its sediments), Lake Michigan (its water column), and the atmosphere. While Green Bay also loses PCBs to both the atmosphere and Lake Michigan, only the atmosphere takes on more total PCBs from the Bay, overall, than it contributes.

It is not the function of this document nor of the presenters to come to ultimate conclusions for the environmental managers, even were all of the scenario and analytical results now available. Clearly, however, managers and investigators alike must combine model results with intuition and common sense, available resources, and statutory and popular mandates. Once a scenario is chosen for action, the task will be to accomplish it.

A factor to keep in mind while ruminating these results is that the Green Bay/Fox River Mass Balance Study was performed as a prototype. Its results are not likely to be mirrored elsewhere, but its approach and methods have established a framework that is imitable in greater and lesser waterbodies everywhere.

Any conclusions will warrant further validation through continued monitoring to ensure that the model coincides with our real-time and real-life experience. The modeling and monitoring community will need to continue to refine both the models and the validity of the data used to drive them.

ON THE HORIZON — WHAT’S NEXT

Use of the mass balance approach is becoming recognized as an effective means of determining contaminant reduction objectives as called for under the Great Lakes Water Quality Agreement, and as an important tool in the lakewide management planning process. Its cost is a function of the level of certainty desired to support management decisionmaking and the concurrent level of monitoring needed to describe toxicant loading to the system. Regardless of the chosen level of certainty, the models are valuable tools in the design of more cost-effective monitoring programs and in the organization, interpretation, and application of environmental data.

Groundwork has already been laid for a Lake Michigan mass balance study to begin in 1992. This exercise will require less intensive monitoring than Green Bay:

- Lake Michigan is a more stable, slower response system that better integrates the sum of its inputs.
- The substantial Green Bay portion of the Lake Michigan loadings picture is now complete.
- The more intensive effort in Green Bay has afforded insights into toxicant loading and ex-
The Green Bay/Fox River Mass Balance Study was the first effort to conduct a large-scale, multiparametric mass balance model for toxicants in a large freshwater body. The Study utilizes a combination of nutrient and toxicant models with a bioaccumulation model. It employs an unprecedented multi-gency team approach over a scheduled five year period.

Challenges encountered in the Green Bay/Fox River Mass Balance Study have established an experience base for future efforts in whole lake modeling, and have afforded the opportunity to learn what works and what doesn’t work in a large-scale, intensive toxicant monitoring and analysis project.
This Report was prepared, in part, using information derived from the following:


Harris, H.J., (Untitled), (Unpublished).


Funding for this report was made possible by a grant from USEPA, Great Lakes National Program Office, to NOAA, National Sea Grant College Program. The project was administered by the Illinois-Indiana Sea Grant Program.

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ADDENDUM

TO THE

GREEN BAY/FOX RIVER
MANAGEMENT SUMMARY REPORT

PREPARED BY

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WISCONSIN DEPARTMENT OF NATURAL RESOURCES

Management Questions

1. What are the loading rates of chemicals from point and non-point sources including in-place contaminated sediment?

2. Is the Bay a source or sink of contamination to Lake Michigan?

3. What is the response in the Bay water, sediment, and biota to alternative loading reductions including "No Action"?

4. Subsequent questions concerned specific actions that might be taken to mitigate contaminated sediments in the Fox River.
Model Framework Requirements

1. Able to simulate concentrations in water, sediment, and biota in space and time as a function of loadings and interaction with solids.

2. Able to simulate transport of water.

3. Able to simulate transport, settling, and resuspension of solids as a function of wind and flow.

4. Able to simulate production of biotic solids as a function of nutrient loadings.
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<thead>
<tr>
<th>Green Bay Modeling Team</th>
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<tbody>
<tr>
<td><strong>Green Bay</strong></td>
</tr>
<tr>
<td>Loads</td>
</tr>
<tr>
<td>Transport Chloride</td>
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<tr>
<td>Eutrophication Solids</td>
</tr>
<tr>
<td>Toxics Fate</td>
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<tr>
<td>Food Chain</td>
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<td>Uncertainty</td>
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<tr>
<td>Water Quality</td>
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Jeff Steuer, Wisconsin DNR/USGS
The sediment transport model predicts that as peak flow increases from 350 to 450 m$^3$/s (30% increase), resuspension flux will increase from 14,000 to 36,000 metric tons (160% increase). The potential mobilization of in-place PCBs will similarly increase with peak flow.

Based upon this relationship, peak flow in the Fox River was limited to 350 m$^3$/s in Scenario 7.
Lower Fox River Model Segmentation

Green Bay

Green Bay MSD
Green Bay Packaging Co.
Proctor and Gamble Corp.

There are 19 Segments in the model:
16 River Segments
3 Bay Segments (see inset below)

0 1/2 1 mi
1 km

= Water Quality Monitoring Station
\ = Segment Boundary

Ft. Howard Paper Co.

Dutchman Creek
Ashwaubenon Creek
Nicolet Paper
DePere STP
DePere Dam
Little Tail Point
Long Tail Point
Fox River
Lower Green Bay

19
Morphometric zones for Green Bay biota sampling and modeling.
Total PCB Concentration at Fox River Mouth

Data
Calibrated Predictions

PCB Concentration (ng/L)

Day of Simulation (Day 0=10/10/88)

550
500
450
400
350
300
250
200
150
100
50
0

11/1/88 1/1/89 3/1/89 5/1/89 7/1/89 9/1/89 11/1/89 1/1/90 3/1/90 5/1/90
Green Bay 1989 Total PCB Calibration Segment - 3

- data
- calibrated model

Particulate Phase

Total Dissolved

Concentration (ng/L)

Time (days)
Food Chain Model Calibration for Total PCBs
Comparison of average observed (points) and predicted (line) concentrations

- Zoo plankton
- Alewife
- Walleye
- Gizzard Shad
- Rainbow Smelt
- Brown Trout
Results and Answers to Management Questions
Water quality sampling stations for the Green Bay mass balance study.
Scenarios Selected for Simulation

- Bay Flushing-all loads and BC 0.0
- Base Run-1989 load and BC constant
- 1 No Man Made Remediation
- 2 Fox River Hundred Year Peak Flow Event
- 3 Above DePere Selected Remediation
- 4 Above and Below DePere Selected Remediation
- 5 10 Yr. Hindcast (not run - technical reasons)
- 6 Step PCB Load Reductions Above DePere
- 7 Fox River Peak Flow Clipping
- 8 Fox River Phosphorus Load Step Reductions
Methodology of Scenario Runs

Fox River Only - No Point Sources or Other Tributaries

Models Run in Cascade Fashion

Boundary Conditions

25 Year Hydrograph

Repeated 1989 Bay Circulation

Bay model sensitivity showed very little difference when circulation patterns were altered plus or minus 15%
We used the 25 years hydrograph using real data. We did not run the model using multiple hydrographs covering all potential conditions.

Time and money would not allow this to occur.

There will be uncertainty associated with the hydrograph we chose as opposed to other possibilities.
100 year event came at the beginning of the simulation. Interpretation of the results are dependant on where you place the event.

The 100 year event was an actual flow event taken from real data.

- 1960
PCB Mass Balance Fluxes for 1989
(fluxes in kilograms)

Point Sources <1%

Sources of PCB to lower Fox River

Net from Sediment 37%

Over Dam 62%

DePere Dam

net volatilization 5 kg

Lower Fox River

point sources 2.8 kg

Green Bay

dispersion 50 kg

advection 220 kg

upstream transport 175 kg

porewater transport 2 kg

suspended solids settling 143 kg

sediment resuspension 237 kg
1989 Green Bay PCB Mass Balance (Kilograms)

Sources of PCB to Green Bay

- Sediment: 39%
- Fox River: 52%

Tributaries
- 5%

Atmospheric Deposition
- 4%

Net from Atmosphere
- to Atmosphere from Water
- to Lake Michigan

Net from Sediment
- to Sediment Burial

Lost to Sediment

Fox River

348

114

14.4

139

Net from Tributaries

39

52

Tributaries
The suite of Fox River/Green Bay models were applied to predict the long-term trends in PCB concentrations for six remediation scenarios. While work continues to revise and confirm these predictions, they provide useful qualitative information as to future trends in PCB concentrations - and the effectiveness of various remedial actions to alter those trends.

For the management scenarios, the models were coupled to predict the sequential transport of PCBs, originating from contaminated river sediments, downstream through the Fox River into Green Bay.

The lower Fox River model was used to predict PCB tributary loading to Green Bay. The model was also used to predict PCB water concentrations for bioaccumulation modeling in the river. However, the most important prediction is of tributary loading, because this is a major component of the PCB mass balance in Green Bay. Ultimately, the effect of these scenario predictions will be expressed as PCB concentrations in Green Bay fish.

Five of the management scenarios prescribed remedial actions for the river, or examined the consequences of natural events there. The two river mass balance models were essential to relate these scenarios to PCB tributary loading from the Fox River.

The predicted PCB tributary loadings (in kilograms/year) from the Fox River, for each management scenario, are presented together in a three-dimensional graph:
PCB tributary loading and concentrations in the Fox River are predicted to decline over time in all scenarios. This is because the PCBs originate from contaminated river sediments, which are buried or depleted over time.

The most significant factor affecting the tributary loading predictions is the hydrograph, or time series of river flow. Scenarios 1, 3, 4 and 6 were based upon a common hydrograph, synthesized from historical river data. The common hydrograph is reflected in similarities in the predicted tributary loads for these scenarios.
Differences in the predicted PCB tributary loading for the management scenarios can be seen by comparing the cumulative 25 year Fox River tributary loading:

The potential for migration of the estimated 25,000 - 40,000 kilograms of PCBs from the lower Fox River sediments into Green Bay is a significant environmental concern. The model prediction for scenario 1 (no remediation) suggests that only 2% of this in-place reservoir is transported to Green Bay over 25 years. Even a 1-in-100 year flood (scenario 2) increases transport from this reservoir to only 3%. Work is underway to confirm these results, based upon a model under development specifically for predicting transport and fate of in-place pollutants.
Mean PCB (mg/kg) in Walleye, 1989
Wet Weight, Whole Fish, All Seasons, All Age Classes
Predicted Average PCB Concentration
Inner Green Bay Walleye (No Action)

Slow: Time to reach action level = 14 years
Fast: Time to reach action level = 7 years

FDA Action Level

Predicted Fox River
PCB Load Over DePere Dam
(No Action)
Fox River/Green Bay Major PCB Sources, Transport and Fate
25 year Cumulative PCB Mass Balance

Upper Fox River

Volatilization 200 kg

0 kg

Export 1200 kg

Volatilization 50 kg

Lower Fox River

Scour 1400 kg

Export 1750 kg

Green Bay

Volatilization 2025 kg

Atmospheric Deposition 225 kg

Export 1000 kg

Scour 600 kg

Burial 7150 kg

Point source loads are not significant.

<table>
<thead>
<tr>
<th></th>
<th>Upper Fox</th>
<th>Lower Fox</th>
<th>Green Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Storage:</td>
<td>3900 kg</td>
<td>20000 kg</td>
<td>15000 kg</td>
</tr>
<tr>
<td>Final Storage:</td>
<td>2500 kg</td>
<td>19400 kg</td>
<td>6800 kg</td>
</tr>
<tr>
<td>△ Storage:</td>
<td>-1400 kg</td>
<td>-600 kg</td>
<td>-8200 kg</td>
</tr>
</tbody>
</table>

USEPA LLRS ORD ERL-D
Projected Year 25 PCB Concentrations in Walleye

PCB Concentration (mg/kg)

- No Action
- 100 Year Event
- Above Dam Selected Remediation
- 100% Fox R. Load Reduction
- Flow Clipping

**Constant Boundary**

- River
- Inner Bay
- Mid Bay West
- Mid Bay East
- Outer Bay

**Declining Boundary**

- River
- Inner Bay
- Mid Bay West
- Mid Bay East
- Outer Bay
Projected Year 5 and 10 Walleye Concentrations in the Lower Fox River and Inner Green Bay

- No Action
- 100 Year Event
- Above Dam Select Remediation
- 100% Fox R. Load Reduction
- Flow Clipping

<table>
<thead>
<tr>
<th>Year 5-10</th>
<th>Year 10-20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1 - Lower Fox</td>
<td>Zone 2 - Inner Bay</td>
</tr>
</tbody>
</table>

Mean PCB Concentration (mg/kg) - Model