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	
11:30	Lunch (provided for pre-registered attendees)	
12:30	Regroup - Introduction to Technical Presentations	**Chris Grundler**
	Green Bay Model Results and Projections	
12:40	Teamwork/Modeling Approach/Validity/ Model Outputs/Scenarios	**William Richardson/ Dale Patterson**
2:00	Scientific Credibility as a Basis for Management Confidence in the Green Bay Study	**Dr. Dominic Di Toro**
2:20	Review Panel - Question and Answer Discussion **Dr. Dominic Di Toro, William Richardson, Dr. Victor Bierman, Dr. John Connolly, Jeff Steuer, Dale Patterson, Dr. Wilbert Lick, Dr. Deborah Swackhamer, Dr. Joseph DePinto**	
3:30	Break	
3:45	Management and Technical Lessons Learned	**Dave Devault/John Konrad**
4:15	Cost/Benefits: What Does Mass Balance Really Cost and Does it Pay Its Own Freight?	**Lyman Wible**
4:45	Day's Impressions/Introduction and Invitation to Evening Poster Session/Reception	**Chris Grundler**
5:00	Dinner (On your own)	
7:30	Poster Session/Reception/Recognition of Efforts Extraordinaire	**Chris Grundler**

(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 Great Lakes Water Quality	**Dr. Joseph DePinto**
8:45	Regulatory Framework to Address Air Toxics Deposition to the Great Lakes	**Gary Gulezian**
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

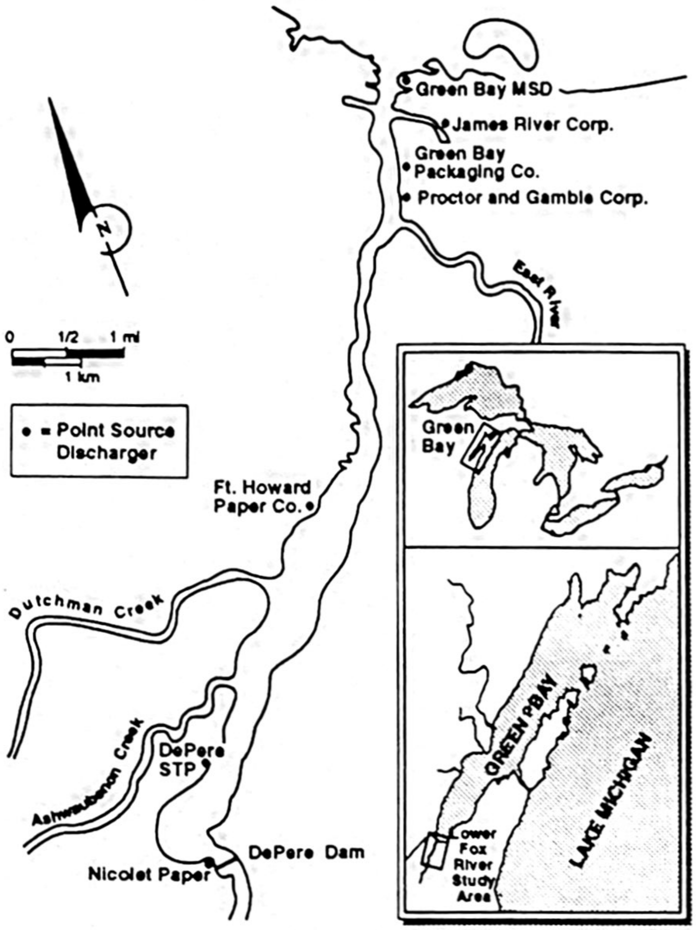
Salvatore Pagano, Director, New York State Dept. of Environmental Conservation Div. of Water

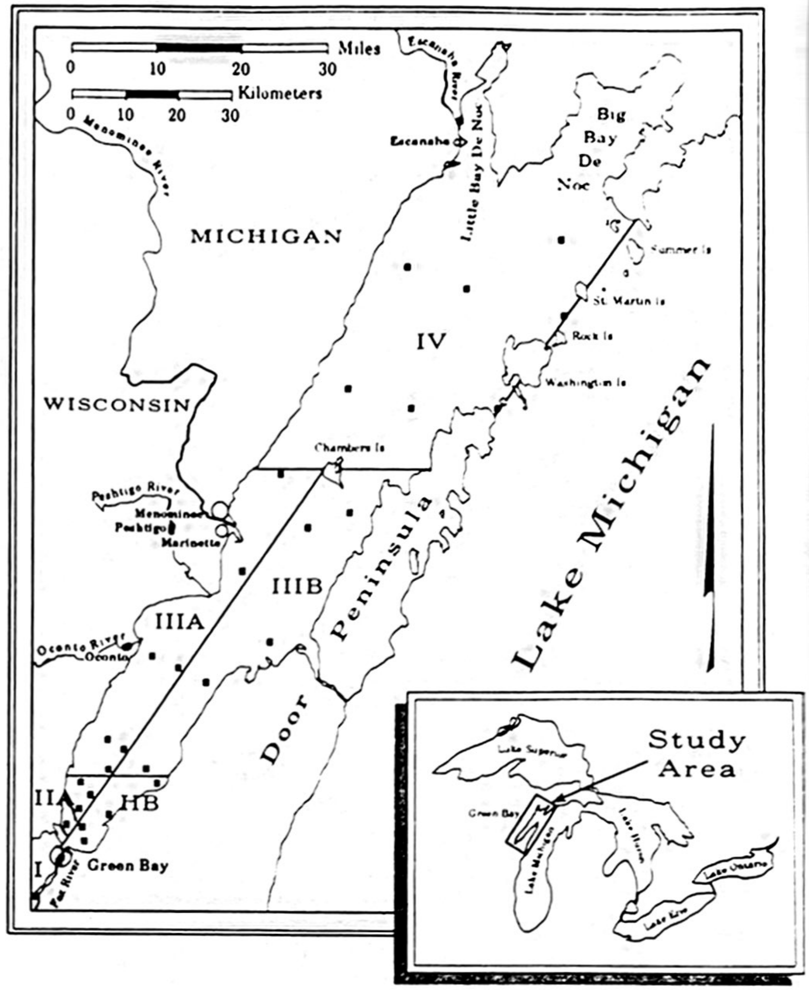
Tim Eder, Regional Executive, National Wildlife Federation

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	**Chris Grundler**
12:00	Poster Session Concludes	

Lower Fox River Study Area





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

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
Green Bay Mass Balance Food Chain Modeling	Russell G. Kreis, Jr. 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

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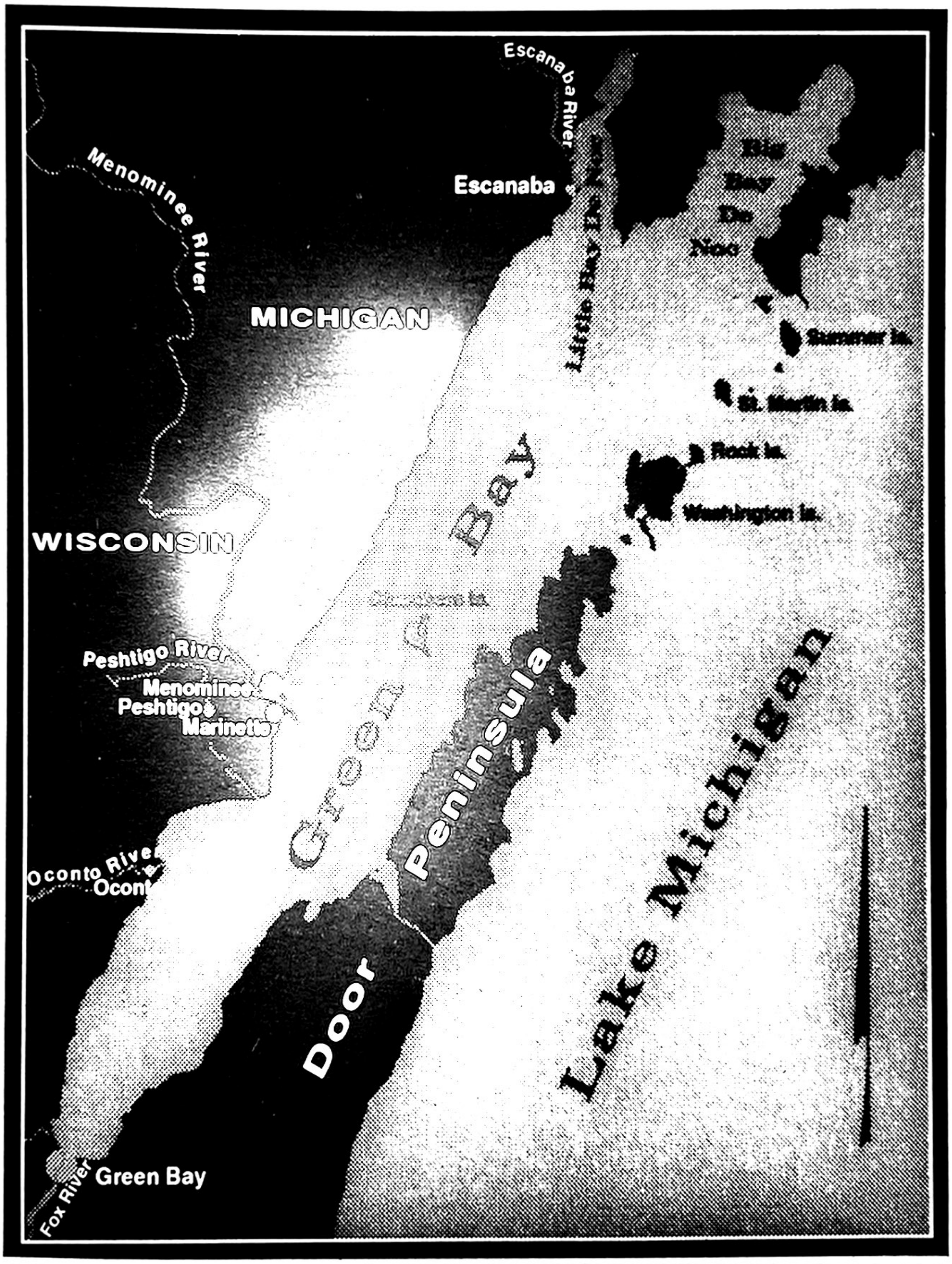
GREEN BAY/FOX RIVER MASS BALANCE STUDY

Preliminary Management Summary



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The Green Bay/Fox River Mass Balance Study

Management Summary

Preliminary Management Summary

Prepared by: Robert F. Beltran
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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.

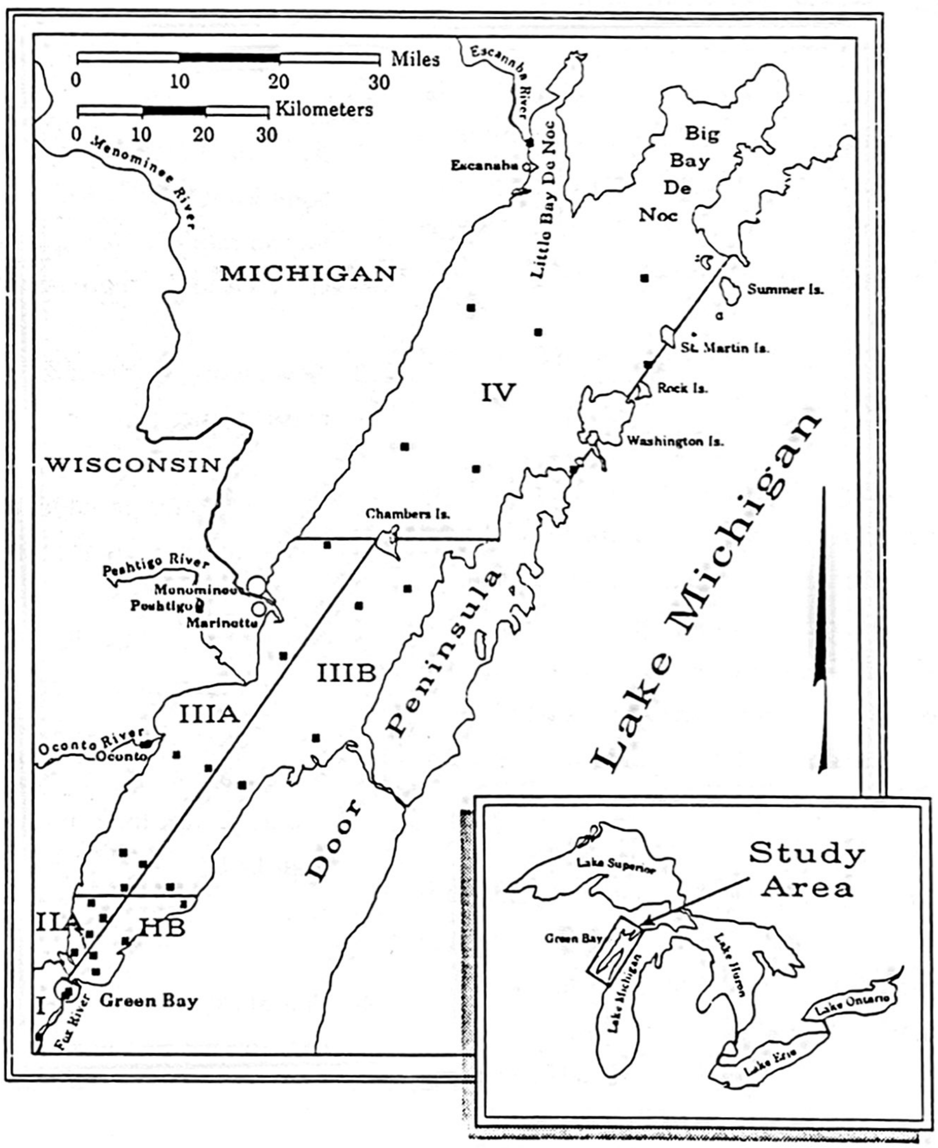
5. Green Bay and the Fox River comprise a seriously impacted aquatic system internationally designated as a Great Lakes area of concern. In response, the appropriate federal, state, local, and academic institutions had already made a high level of commitment to their assessment and remediation.

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.

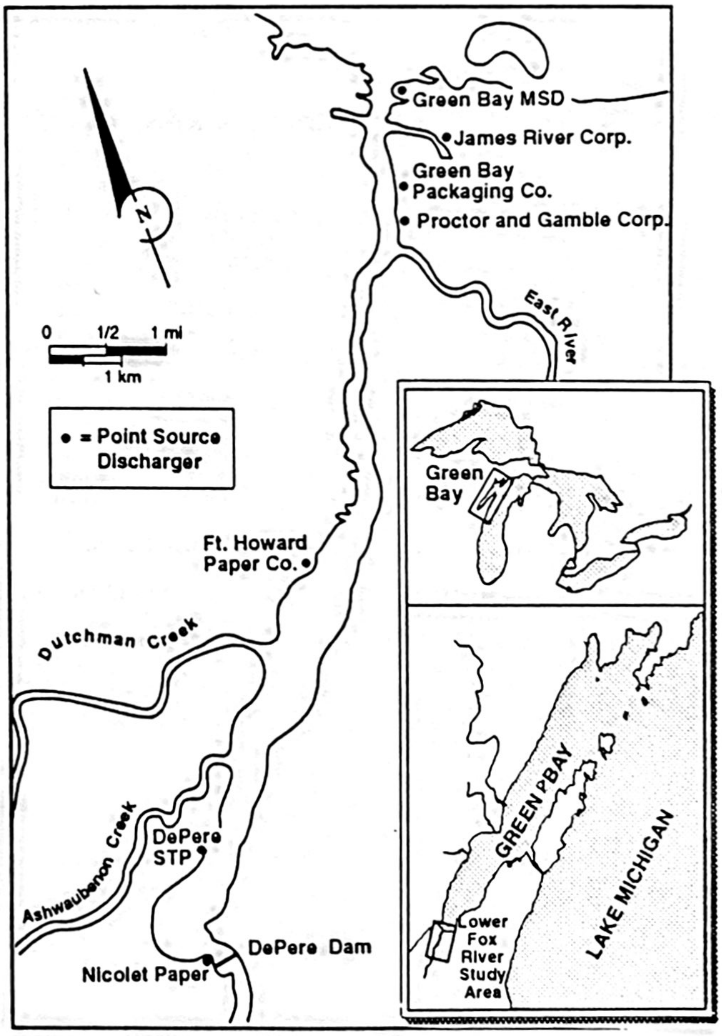
Metals

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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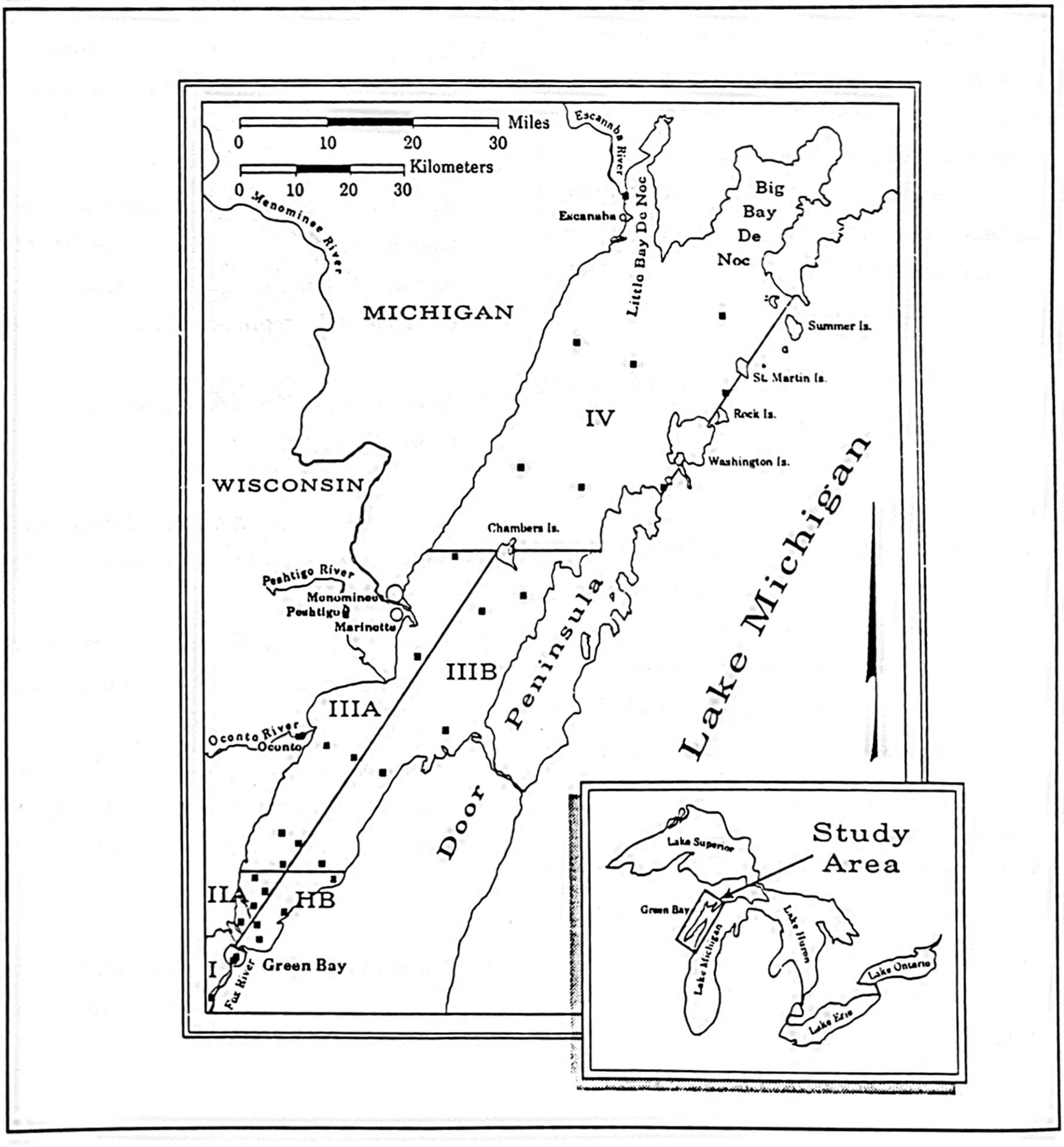

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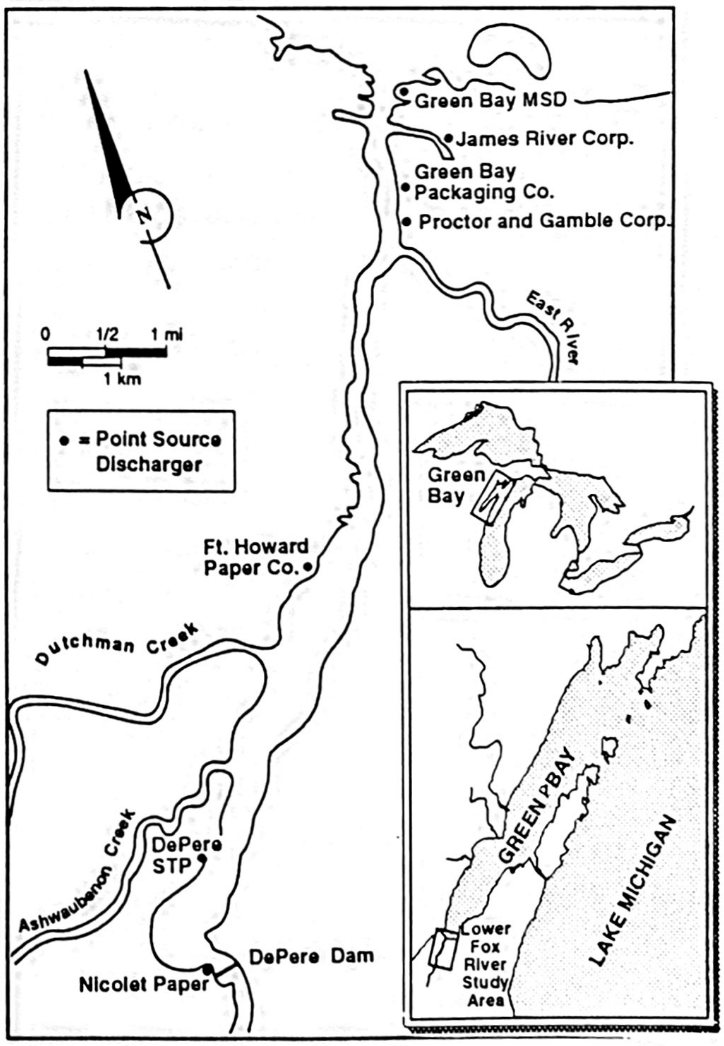


Organic Toxicants

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, devel opmental, 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

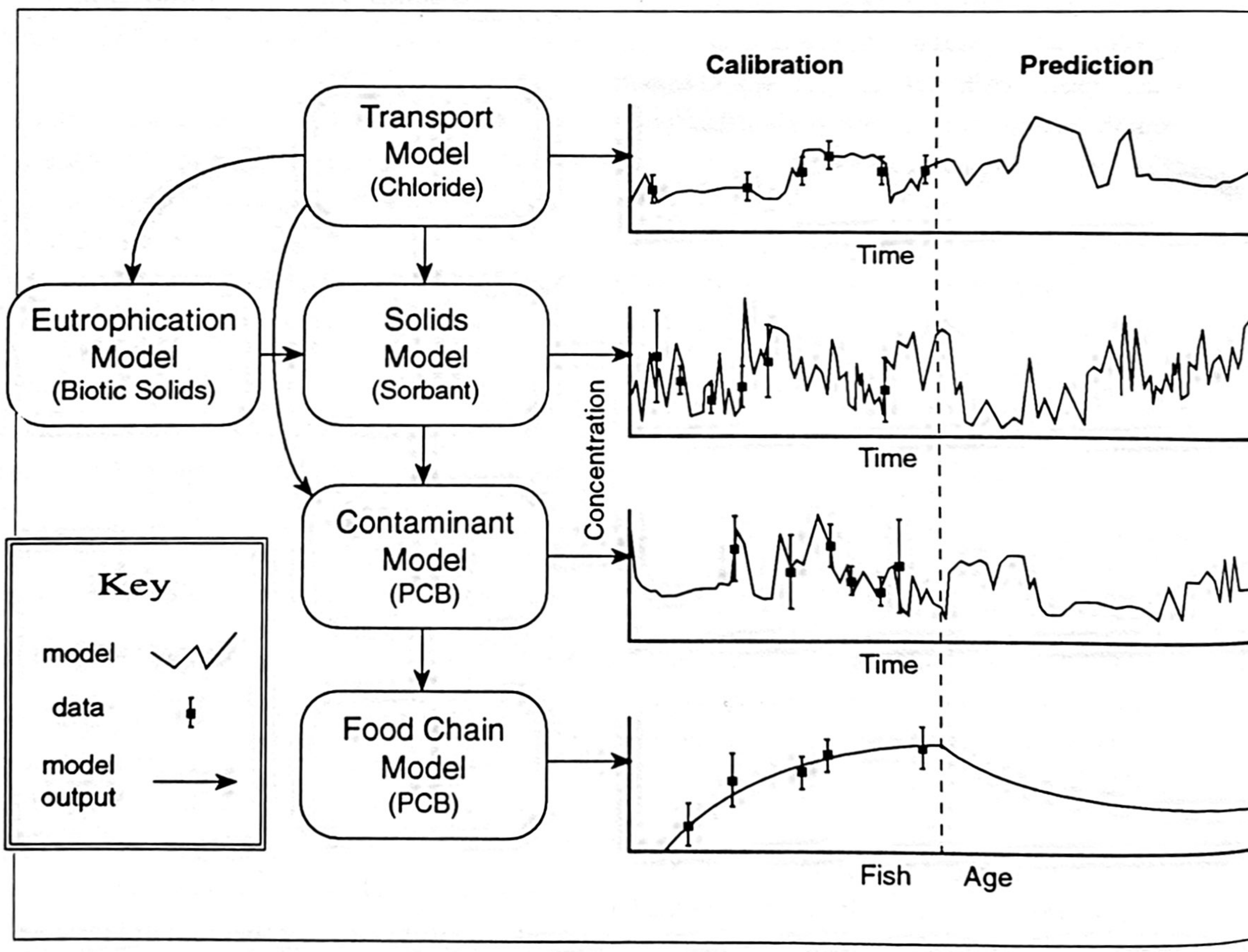


Figure 1. Green Bay Modeling Process

computed concentrations match the measured concentrations. Future concentrations are predicted by calculating conditions beyond the calibration period.

The more specific model framework is shown in Figures 2 and 3. Figure 2 shows the interactions occurring between air and water, water and sediment, and the food chain. The model, in essence, links the sources of the contaminant to the mass in water, sediment, and biota in space and time. Therefore the model, once calibrated and deemed valid, can be used to compute future concentrations under any altered load condition.

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

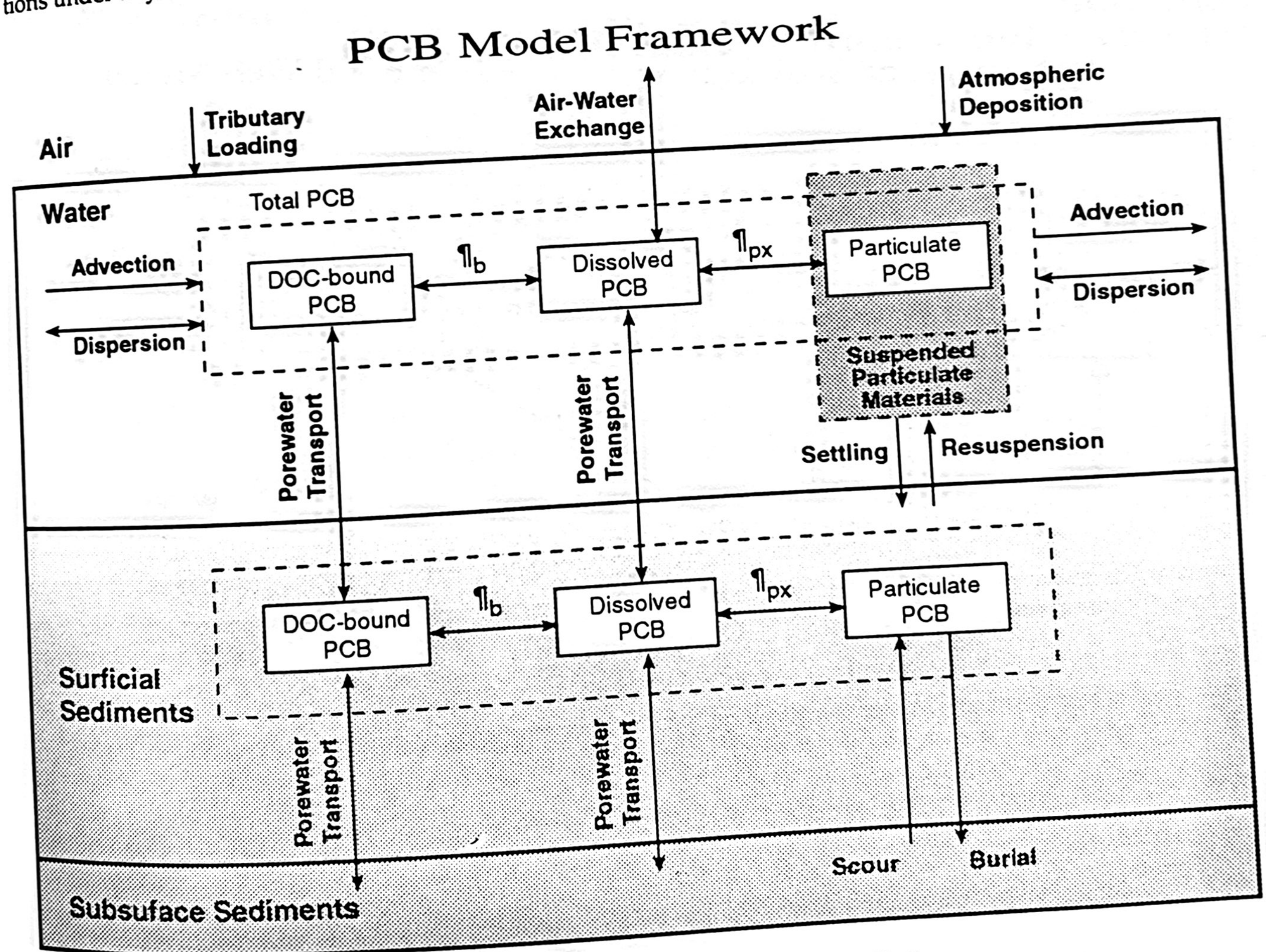


Figure 2. Interactions among Air, Water, Sediment, and the Food Chain.

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.

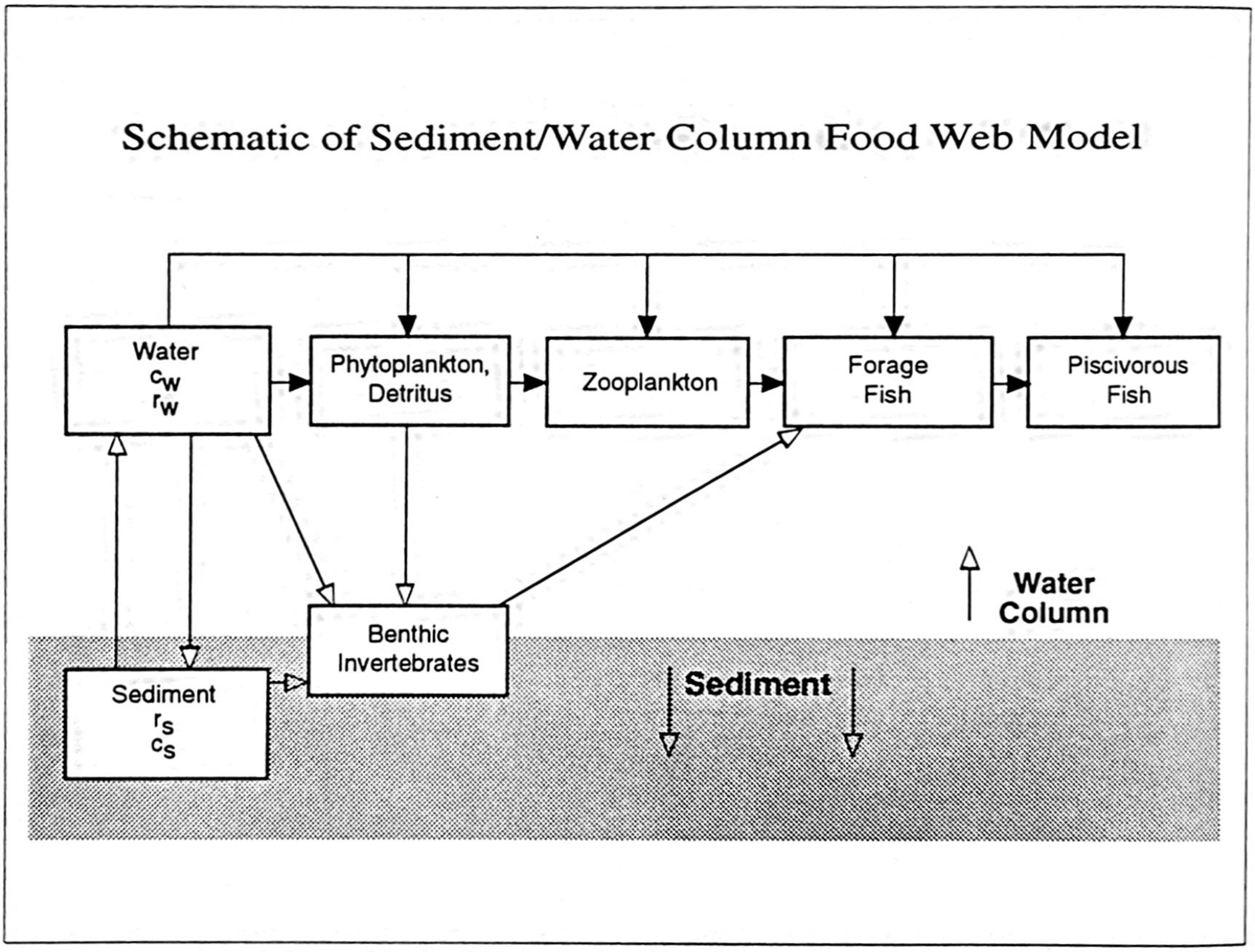
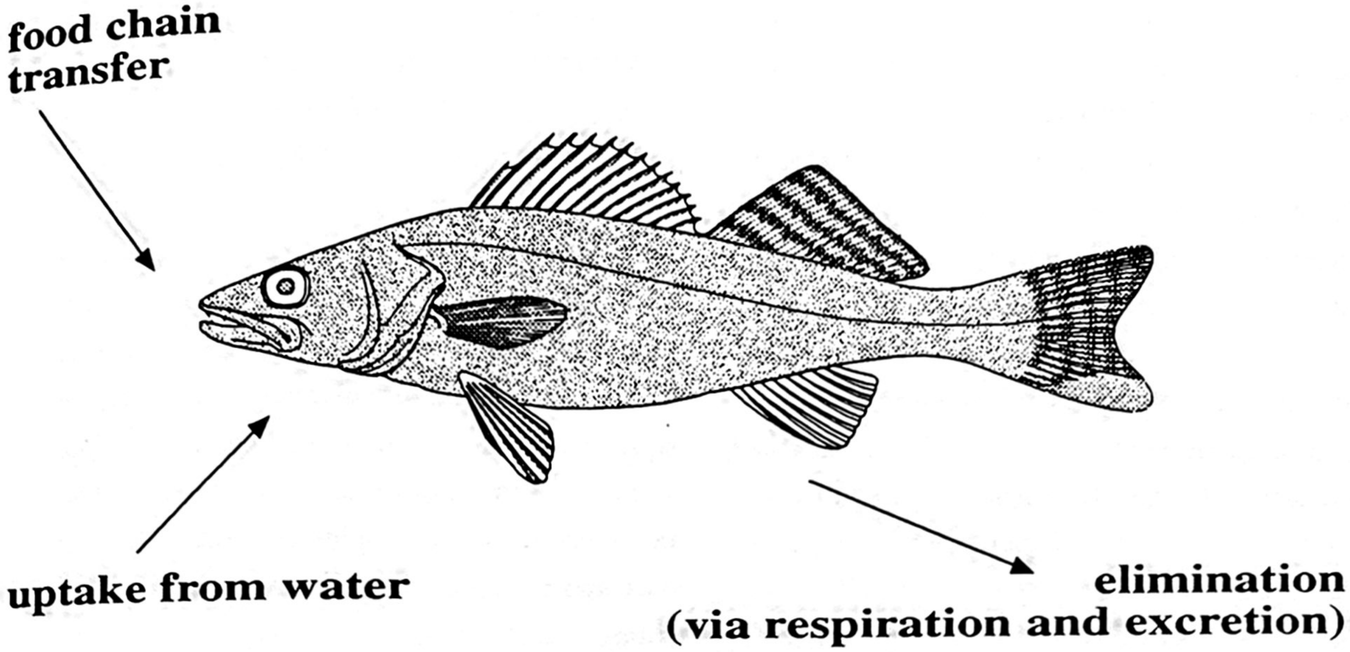


Figure 3. Food Chain Model Framework

Bioaccumulation Model Process



bioaccumulation = uptake from water + food chain transfer - elimination - growth dilution

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. Success 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 adequately quantified under laboratory conditions, they remain significant potential sources of modeling 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 predictions.

The model must incorporate values for a wide range of variables, loading of chemicals, circulation, 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 "snapshot" of one or more years, the loading from the multitude of tributaries, point sources, and nonpoint sources. These sources include the atmosphere, 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 determines the quality of the model results. This equates to the considerable expense involved in an intensive monitoring program. Much of this expense may later be recouped in two ways:

- Redesign and optimization of routine monitoring 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 technniques 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).

Project Sponsors

USEPA - Great Lakes National Program Office (GLNPO)
USEPA - Office of Research and Development (ORD)
Environmental Research Laboratory - Duluth (ERL)
Large Lakes Research Station (LLRS)
USEPA - Region V Water and Waste Management Divisions
US Geological Survey (USGS)
Wisconsin Department of Natural Resources (WDNR)
National Oceanic and Atmospheric Administration - Great Lakes Environmental Research Laboratory (NOAA-GLERL)
Michigan Department of Natural Resources (MDNR)
University of Wisconsin Sea Grant Institute

Other Participants

US Fish and Wildlife Service
US Coast Guard
US Department of Energy - Argonne National Laboratory (USDOE-ANL)
Illinois State Water Survey
Wisconsin State Lab of Hygiene
DePaul University
University of Michigan (U of MI)
University of Wisconsin
University of Minnesota (U of MN)
Clarkson University
Manhattan College
Notre Dame University
Heidelberg College
University of California-Santa Barbara (UC-SB)
Green Bay Remedial Action Plan Implementation Committee

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

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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:

Schedule of Activities

	FY 1987	FY 1988	FY 1989	FY 1990	FY 1991	FY1992
Study Plan	X	X	X	X	X	X
Quality Assurance		X	X	X	X	X
Field Reconnaissance	X	X				X
Modeling	X	X	X	X	X	X
Monitoring		X	X	X		
Sample Analysis		X	X	X		
Interim Reports		X	X	X		
Data Evaluation		X	X	X	X	X
Final Reports						X

I. Inputs

Identify and quantify sources of contaminants entering the system.

A. Tributaries

1. General — USGS
2. Fox River Upstream — USGS
3. Fox River at DePere Dam — WDNR
4. Fox River Mouth — USGS/GLNPOWDNR

B. Point Sources — WDNR

C. Atmosphere — Illinois State Water Survey/ DePaul — UUSEPA

D. PCBs from Landfills — WDNR/MDNR

E. PCBs from Urban Areas — WDNR/MDNR

F. Groundwater Contributions — WDNR

II. Outputs

Identify and quantify pollutants leaving the Bay.

A. Water volume transport — NOAA-GLERL

B. Sediment Flux and Resuspension — NOAA-GLERL

C.SedimentResuspension Quantification` — NOAA-GLERL/UC-SB

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 — WDNR

B. Water Column — U of MI/UW-M/GLNPO/ERL-Duluth

IV. Biota - characterize biotic pathways of contaminants — WDNR/LLRS

V. Quality Assurance and Data Handling — USDOE-ANL/GLNPO/U. of MN

VI. Administration — GLNPO/WDNR

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	WDNR
Lower Fox River Model	USEPA - LLRS
Green Bay Sediment Transport Model	Wilbert Lick

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	USEPA 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

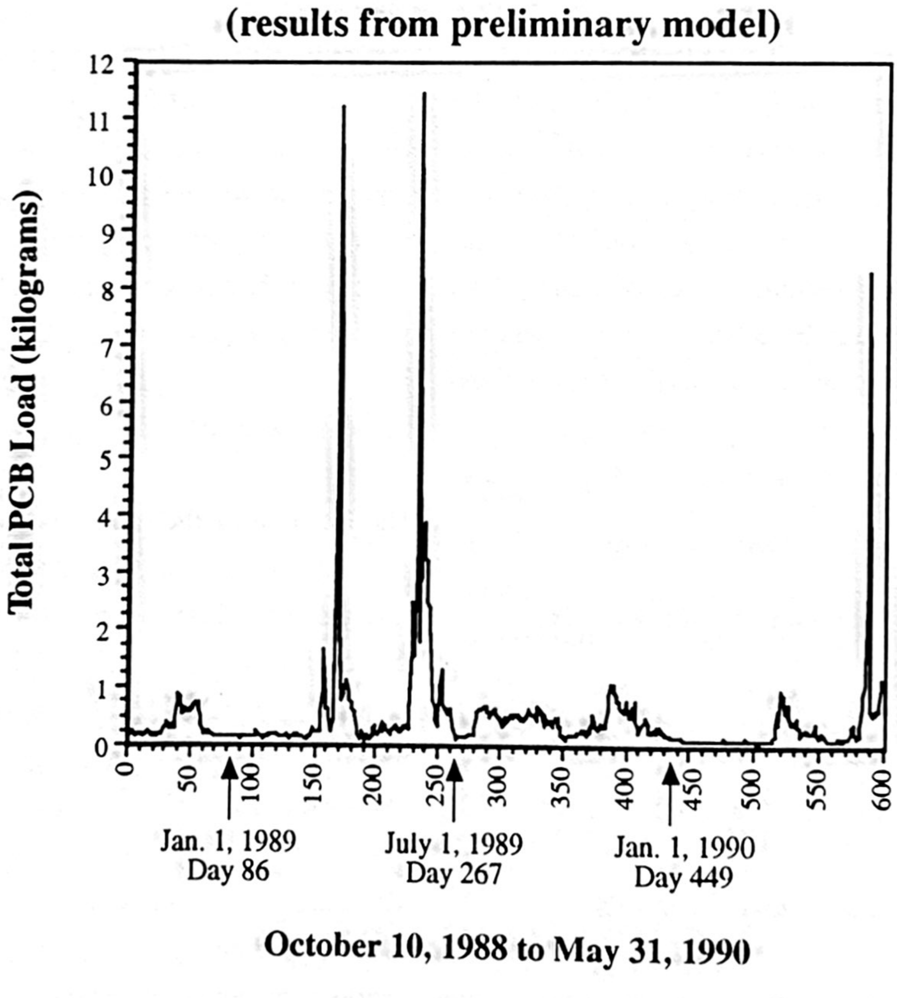

Figure 4 Lower Fox River PCB Loads to Green Bay in 1989

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.

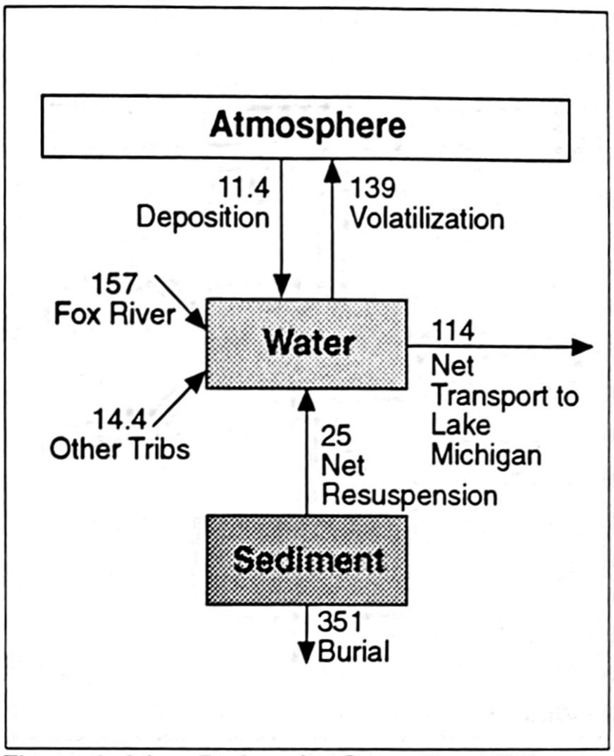

Figure 6. Mass Budget for Green Bay 1989

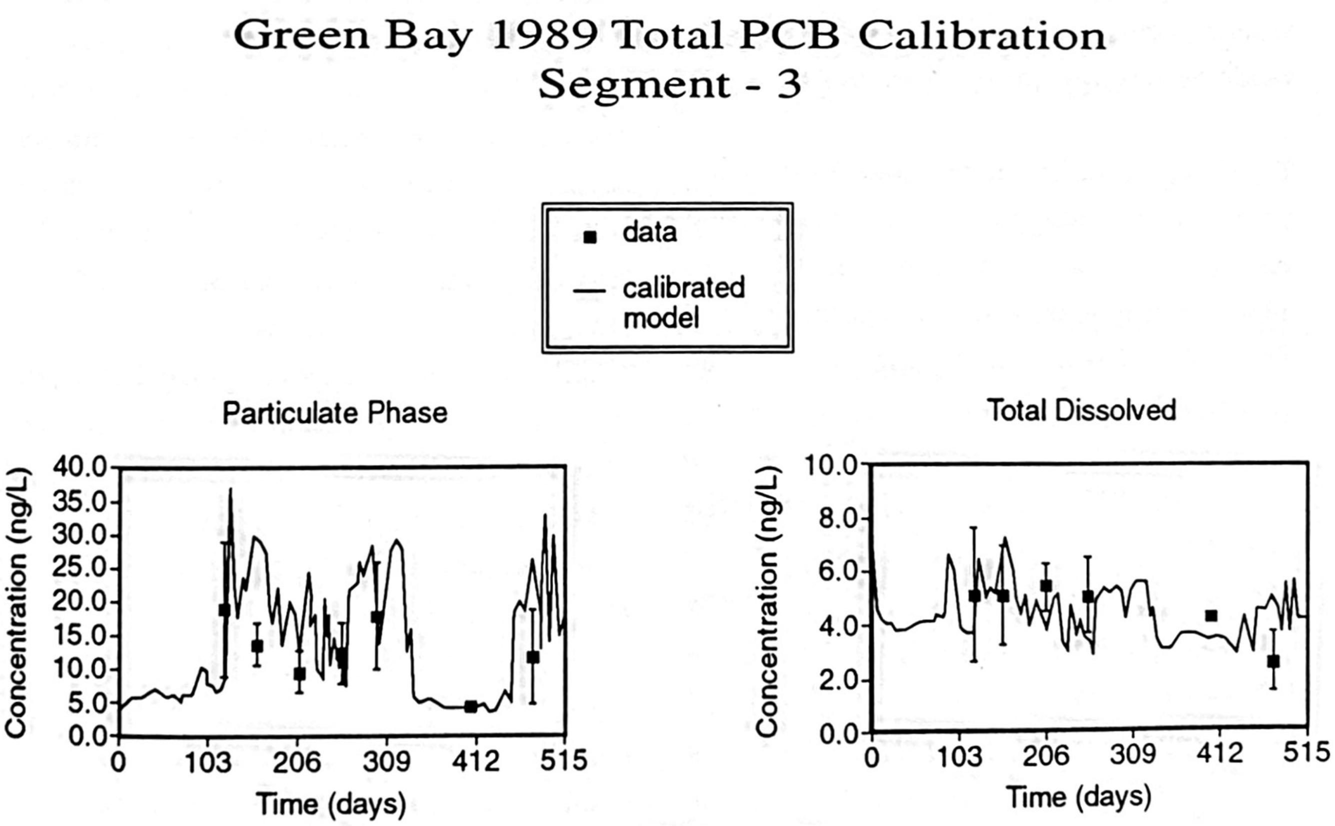

Figure 5. Green Bay Model Calibration

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 multiple federal and state agencies and private institutions established a standard of interagency cooperation in environmental monitoring and planning.

- The leadership role played by both USEPA - GLNPO and WDNR in planning and funding the study at its outset.
- Inclusion of all participating agenciew 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 "Flow Clipping" (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-

change rates that will apply to all of Lake Michigan.

In addition, a level one model has been prepared for Lake Ontario. The Lake Ontario Coordinating Committee has agreed to pursue a long-term monitoring program designed to better characterize Lake Ontario loadings to reduce the degree of uncertainty associated with this first effort.

SUMMARY

Lake Michigan's Green Bay is a large, primarily shallow freshwater estuary having many of the characteristics of a whole Great Lake. It suffers from many of the same nutrient and toxicant problems as the rest of the Great Lakes system, including eutrophication and a biotic population impaired by PCBs, pesticides, and metals. The dynamics of loading, transport, and fate of those contaminants are complex and are readily understood only with the assistance of complex mathematical models based upon quality monitoring data.

Despite the complexities of such models, major costs are associated primarily with enhanced monitoring. These costs can be at least partially recouped through resulting refinements in subsequent monitoring programs. Various levels of modeling can be performed, depending upon the specific objectives of the exercise and the acceptable confidence levels needed. Use of the models makes it possible to set realistic, defensible loading reduction targets and to design and operate more cost-effective monitoring networks.

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:

Bierman, Victor J., Jr. et al, *Development and Validation of an Integrated Exposure Model for Toxic Chemicals in Green Bay*, Lake Michigan—Final Report, Nov. 1992, Unpublished.

Bierman, Victor J., Jr., Strength and Weaknesses of a Mass Balance Approach for Toxic Chemicals in the Great Lakes. In R.L. Eshenroder, J.H. Hartig, and J.E. Gannon. *Lake Michigan: An Ecosystem Approach for Remediation of Critical Pollutants and Management of Fish Communities*, Great Lakes Fisheries Commission Special Publication 91-2, 58 p.

DeVault, David and H.J. Harris/U. S. Environmental Protection Agency, Great Lakes National Program Office, *The Green Bay/Fox River Mass Balance Study (Study Plan)*, April, 1989.
Harris, H.J., (Untitled), (Unpublished).

Kreis, Russel G., Personal correspondence, Nov. 1992.

Richardson, William L., P.E., *Influence of Modeling in Planning Large Scale, Integrated Water Quality Studies*, (Unpublished).

Richardson, William L., P.E., Personal correspondence, Nov. 1992.

University of Wisconsin - Green Bay, *The State of the Bay* - 1990.

U.S. Environmental Protection Agency, Office of Water, *The Green Bay Mass Balance Project*, September, 1990.

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ADDENDUM

TO THE

GREEN BAY/FOX RIVER MANAGEMENT SUMMARY REPORT

PREPARED BY

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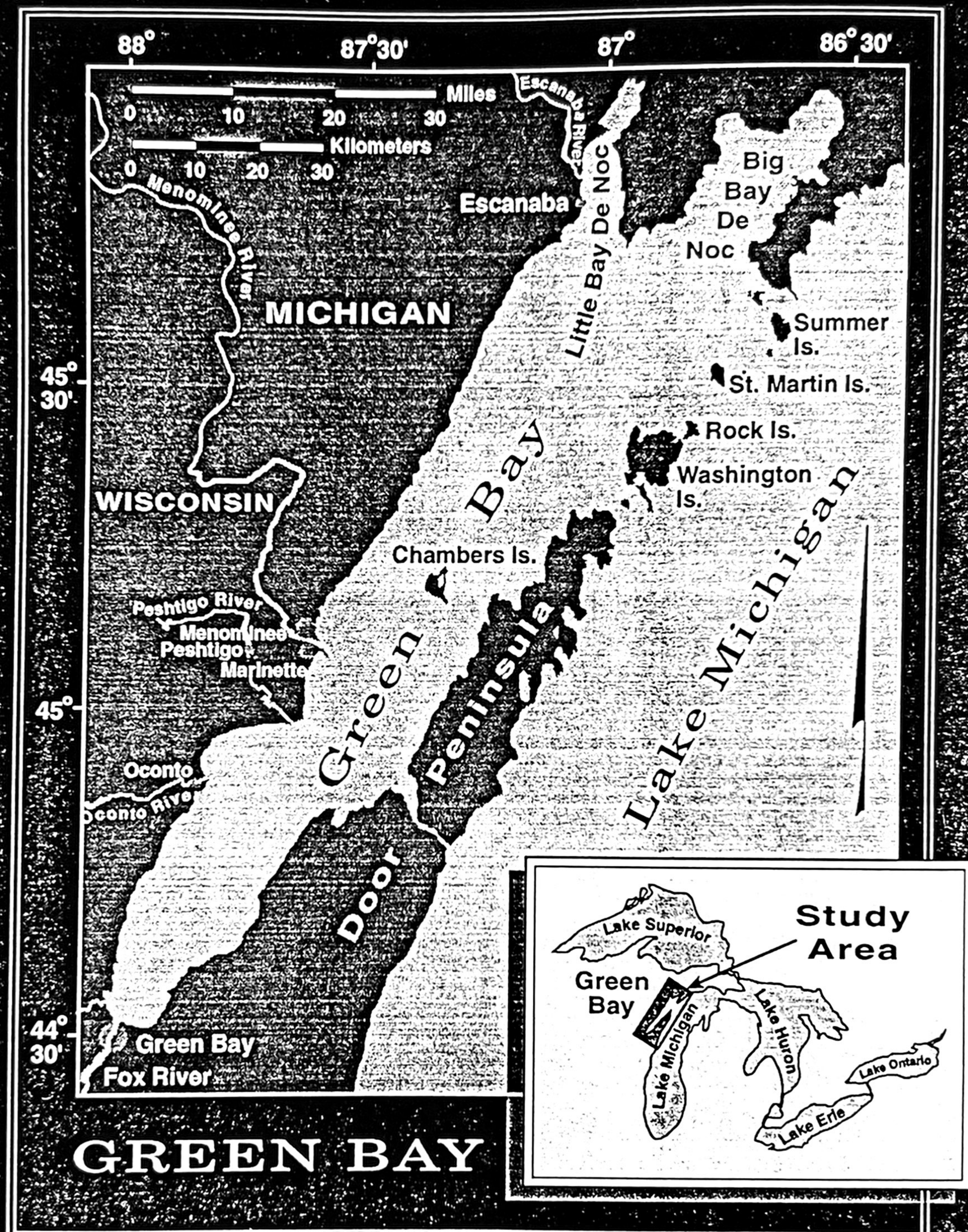
DALE PATTERSON	WISCONSIN DEPARTMENT OF NATURAL RESOURCES

THIS ADDENDUM INCORPORATES THE INITIAL TECHNICAL FINDINGS OF THE GREEN BAY/FOX RIVER MODELING TEAM FOR THE FATE AND TRANSPORT OF PCBS IN THE WATER, SEDINMENT, AND BIOTA OF THE FOX RIVER AND LOWER GREEN BAY. WORK CONTINUES ON THE UPPER SEGMENTS OF THE BAY AND OTHER PARAMETERS.


88°
87°30'
87°
86°30'
Miles
0 10 20 30
Kilometers
0 10 20 30
Escanaba River
Escanaba
Menominee River
MICHIGAN
WISCONSIN
Little Bay De Noc
Big Bay De Noc
Summer Is.
St. Martin Is.
Rock Is.
Washington Is.
Chambers Is.
Green Bay
Lake Michigan
Peshtigo River
Menominee
Peshtigo
Marinette
Door Peninsula
Oconto
Oconto River
45° 30'
45°
44° 30'
Green Bay
Fox River
GREEN BAY
Lake Superior
Study Area
Green Bay
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie

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.

8

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.

Green Bay Modeling Team

Green Bay

Loads Transport Chloride	Scott Martin, Youngstown State University Thomas Young, Clarkson University
Eutrophication Solids	Victor Bierman, Notre Dame/LTI
Toxics Fate	Joseph DePinto, U. Buffalo Ramish Raghunathan, U. Buffalo Paul Rodgers, LTI, Ann Arbor
Food Chain	John Connolly, Manhattan College
Uncertainty	Dominic Di Toro, Manhattan College

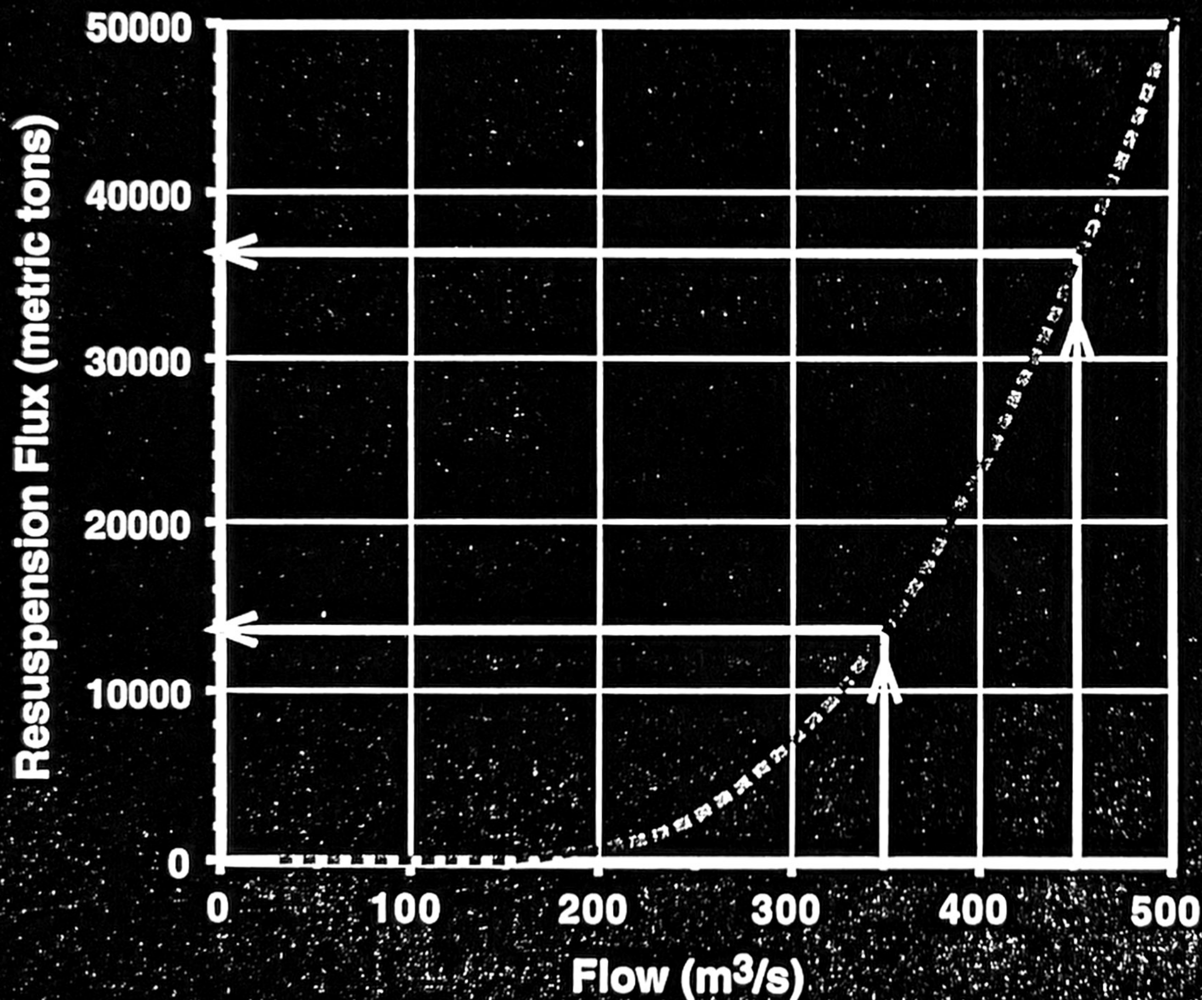
Lower Fox

Hydrodynamic	Wilbert Lick, U. California at Santa Barbara Joseph Gailani, U. California at Santa Barbara
Water Quality	Mark Velleux, AScI, LLRS, Grosse Ile Kirk Freeman, CSC, LLRS, Grosse Ile Doug Endicott, EPA-ORD-ERLD-LLRS, Grosse Ile

Upper Fox

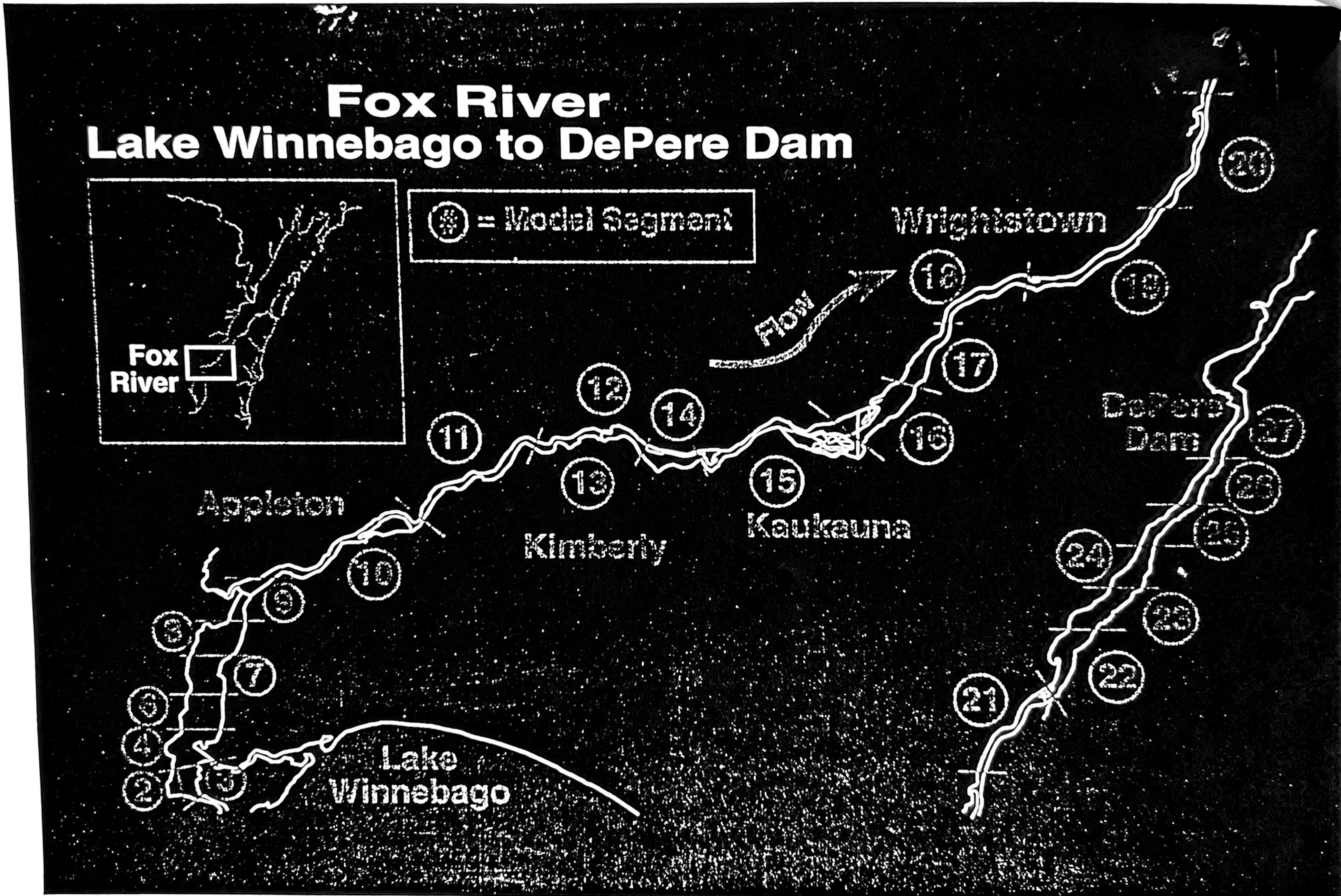
Water Quality	Jeff Steuer, Wisconsin DNR/USGS

Predicted Relationship Between Resuspension and Flow in the Lower Fox River



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.



Fox River
Lake Winnebago to DePere Dam
= Model Segment
Fox River
Flow
Appleton
Kimberly
Kaukauna
Wrightstown
DePere Dam
Lake Winnebago
2
3
4
6
7
8
9
10
11
12
13
14
15
16
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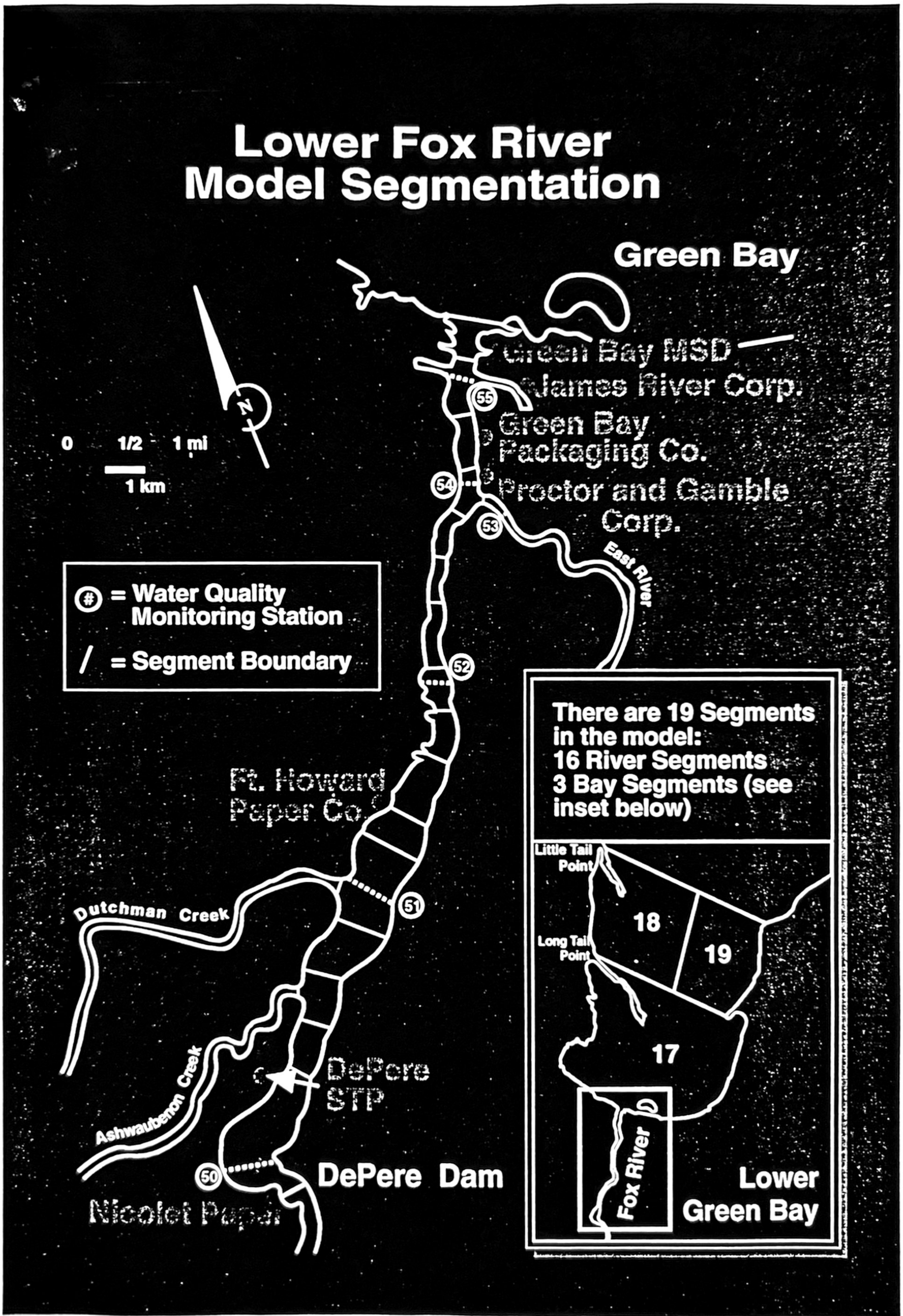
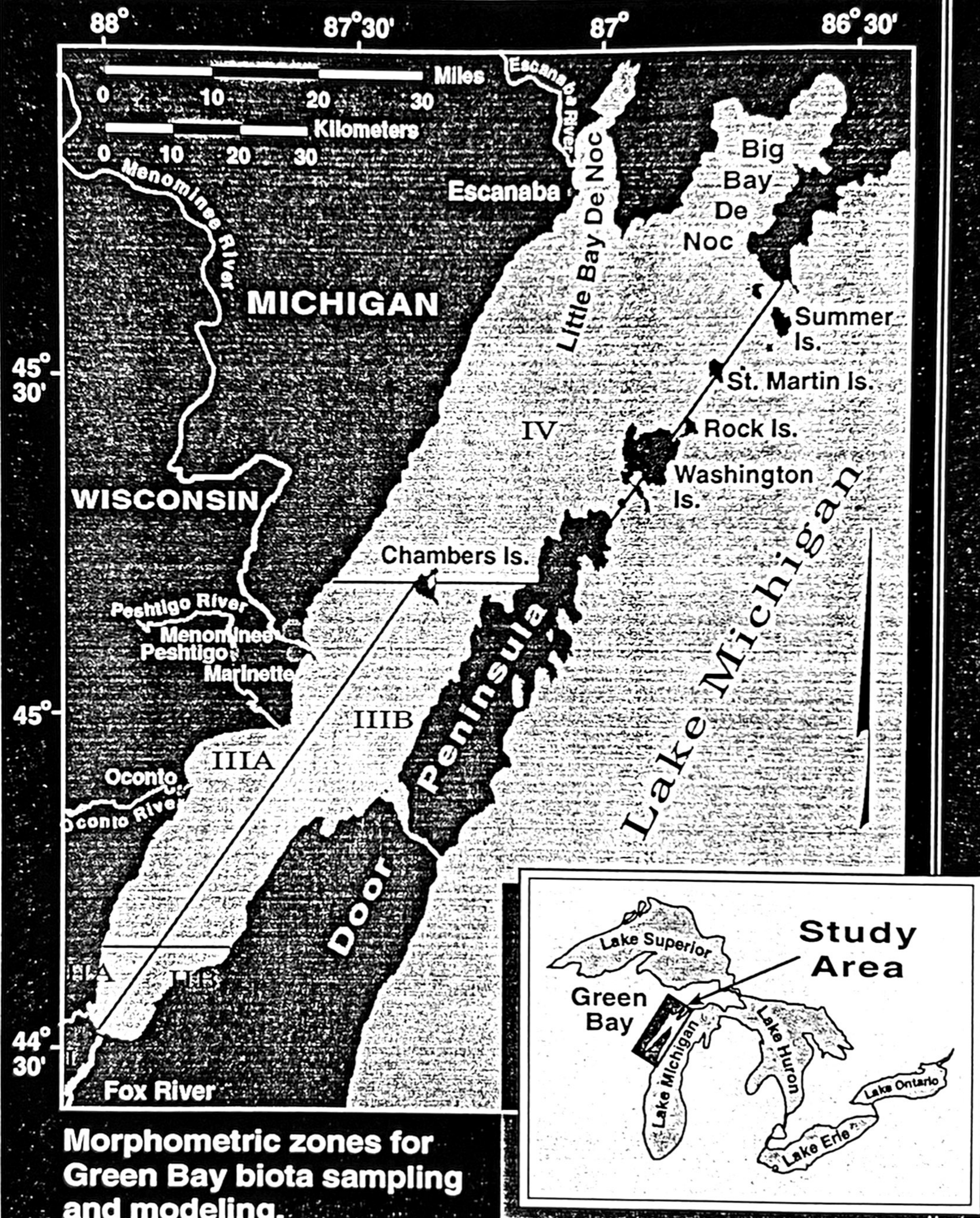
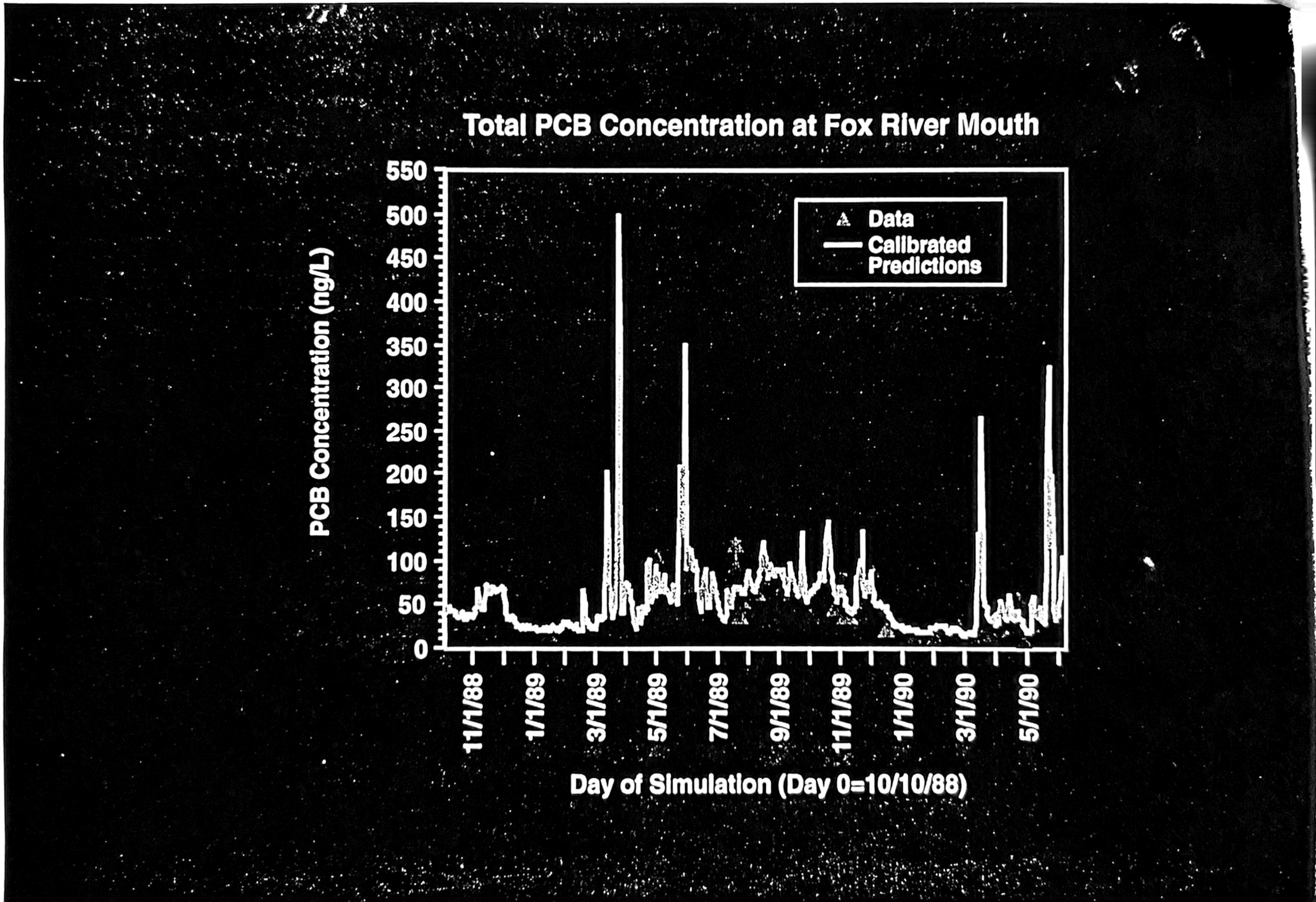

Lower Fox River
Model Segmentation
Green Bay
Green Bay MSD
James River Corp.
Green Bay
Packaging Co.
Proctor and Gamble
Corp.
East River
N
0 1/2 1 mi
1 km
= Water Quality
Monitoring Station
/ = Segment Boundary
55
54
53
52
51
50
Ft. Howard
Paper Co.
Dutchman Creek
Ashwaubenon Creek
DePere
STP
DePere Dam
Nicolet Paper
There are 19 Segments
in the model:
16 River Segments
3 Bay Segments (see
inset below)
Little Tail
Point
Long Tail
Point
18
19
17
Fox River
Lower
Green Bay

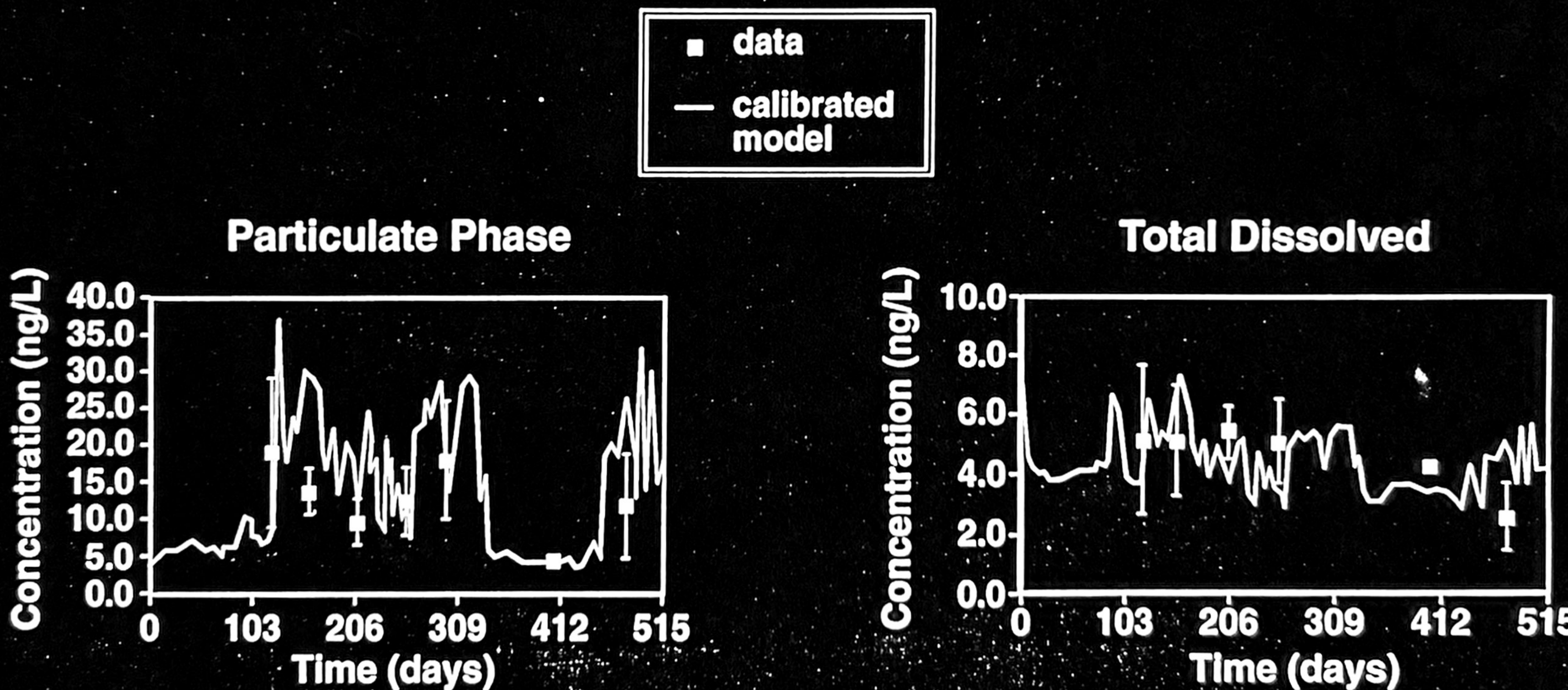
19



Morphometric zones for Green Bay biota sampling and modeling.

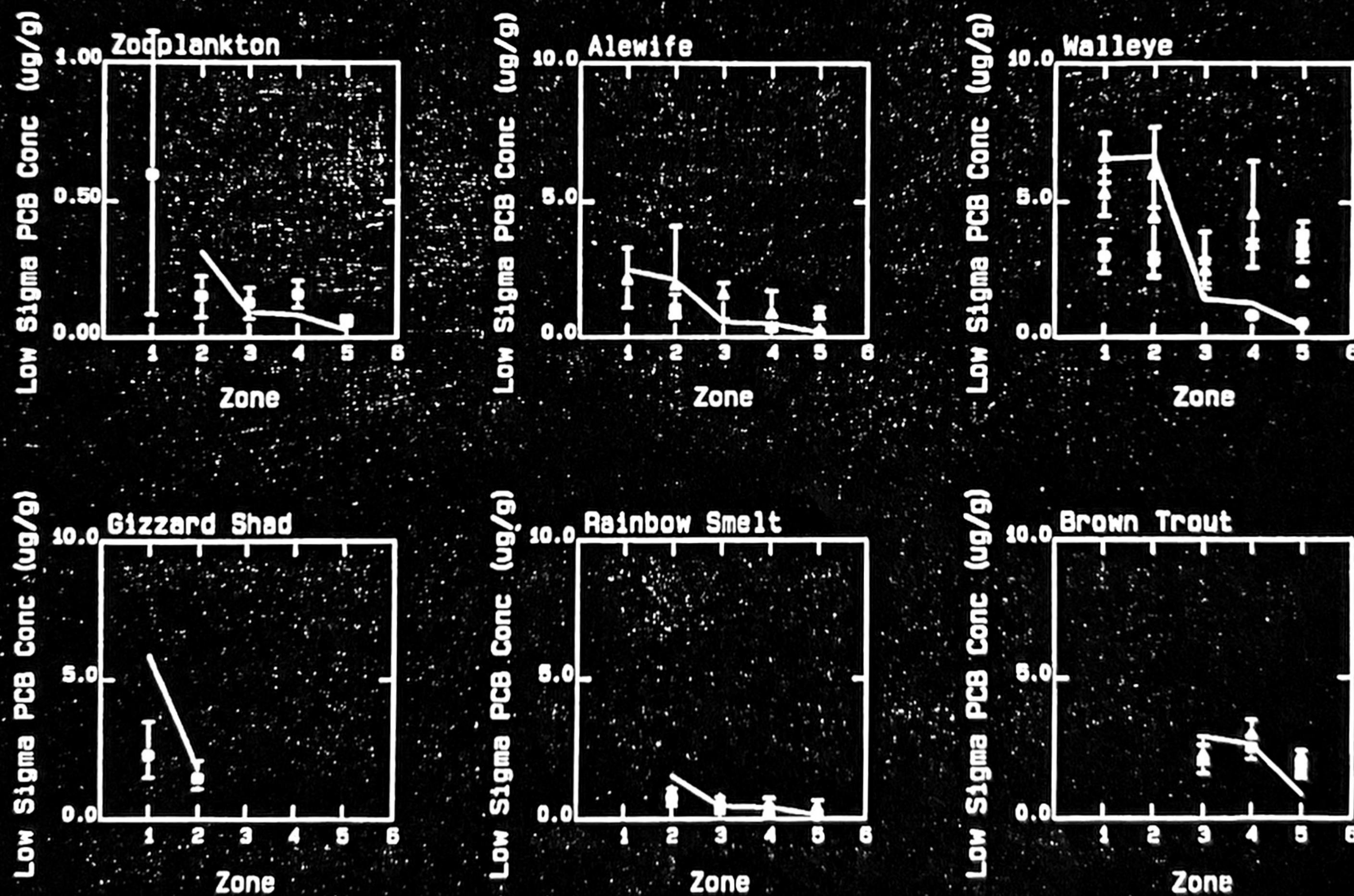

Total PCB Concentration at Fox River Mouth
PCB Concentration (ng/L)
550
500
450
400
350
300
250
200
150
100
50
0
Data
Calibrated Predictions
11/1/88
1/1/89
3/1/89
5/1/89
7/1/89
9/1/89
11/1/89
1/1/90
3/1/90
5/1/90
Day of Simulation (Day 0=10/10/88)

Green Bay 1989 Total PCB Calibration
Segment - 3

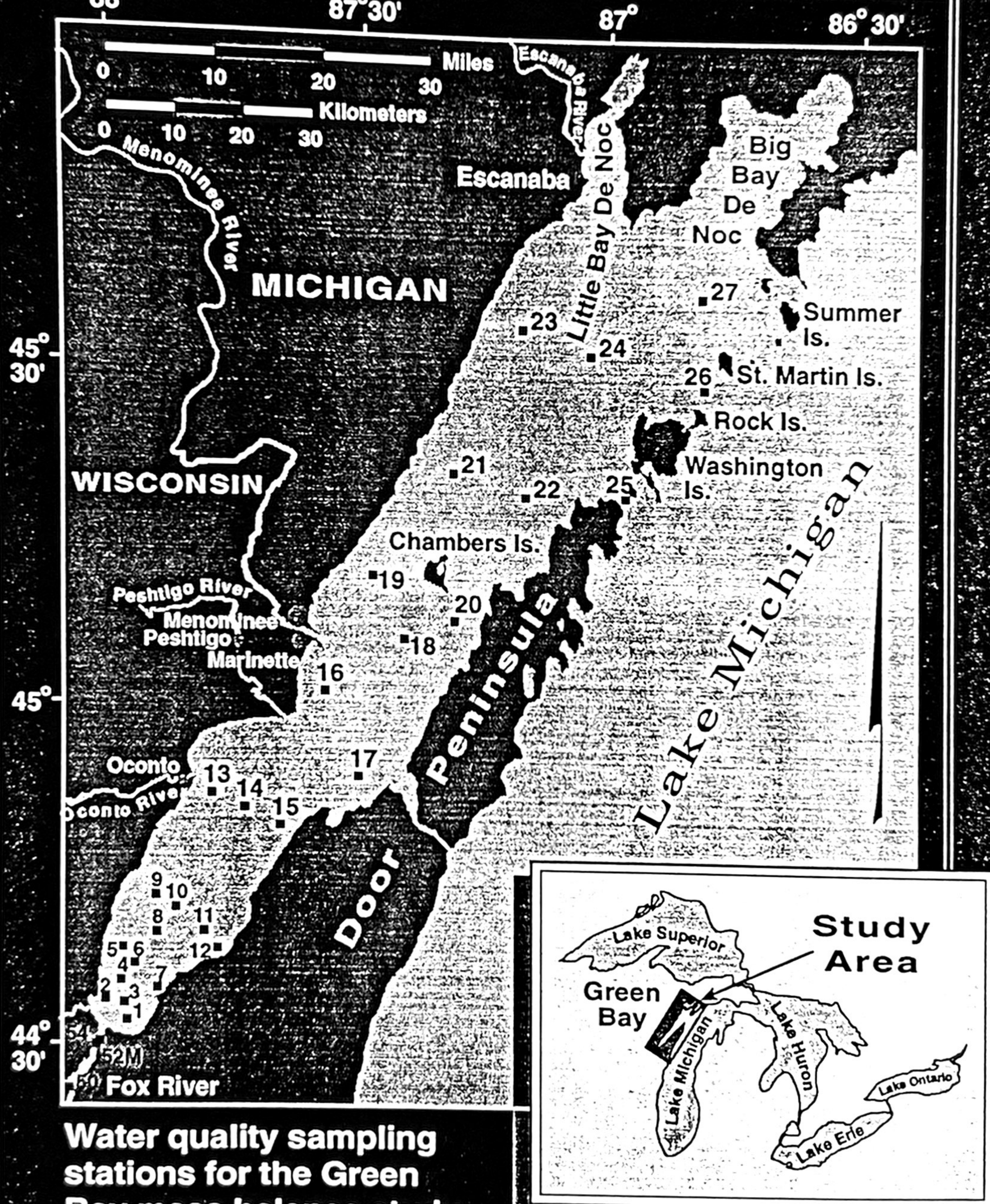


Food Chain Model Calibration for Total PCBs

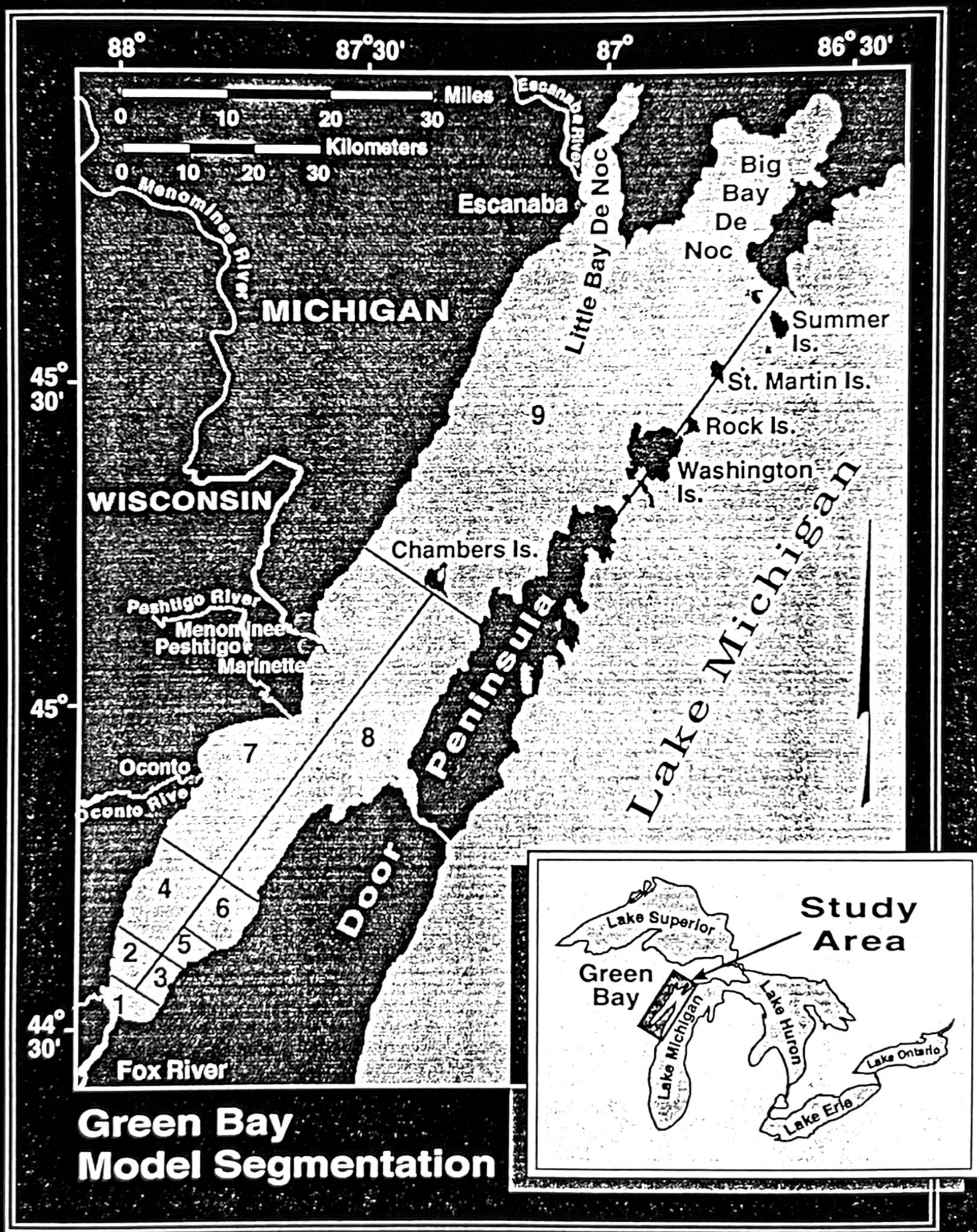
Comparison of average observed (points) and predicted (line) concentrations



Results and Answers to Management Questions



Water quality sampling stations for the Green Bay mass balance study.



Green Bay Model Segmentation

68

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

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Methodology of Scenario Runs

Fox River Only - No Point Sources or Other Tributaries

Models Run in Cascade Fashion

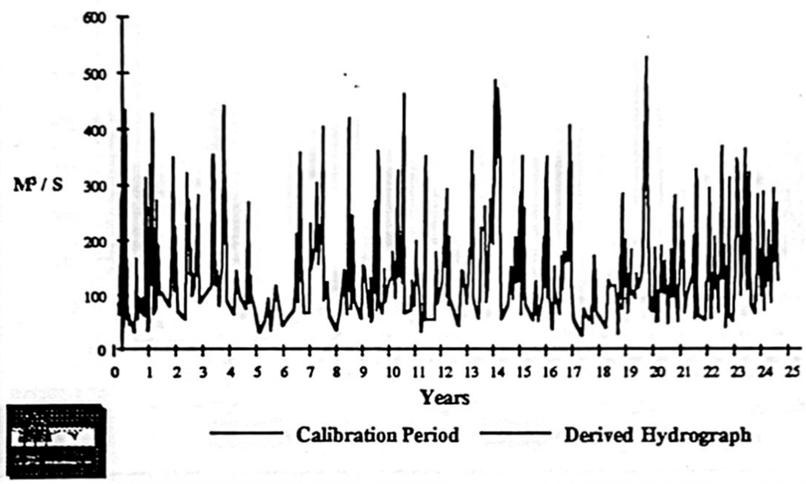
Boundary Conditions

25 Year Hydrograph

Repeated 1989 Bay Circulation

Bay model sensitivity showed very little difference when circulation patterns were altered plus or minus 15%

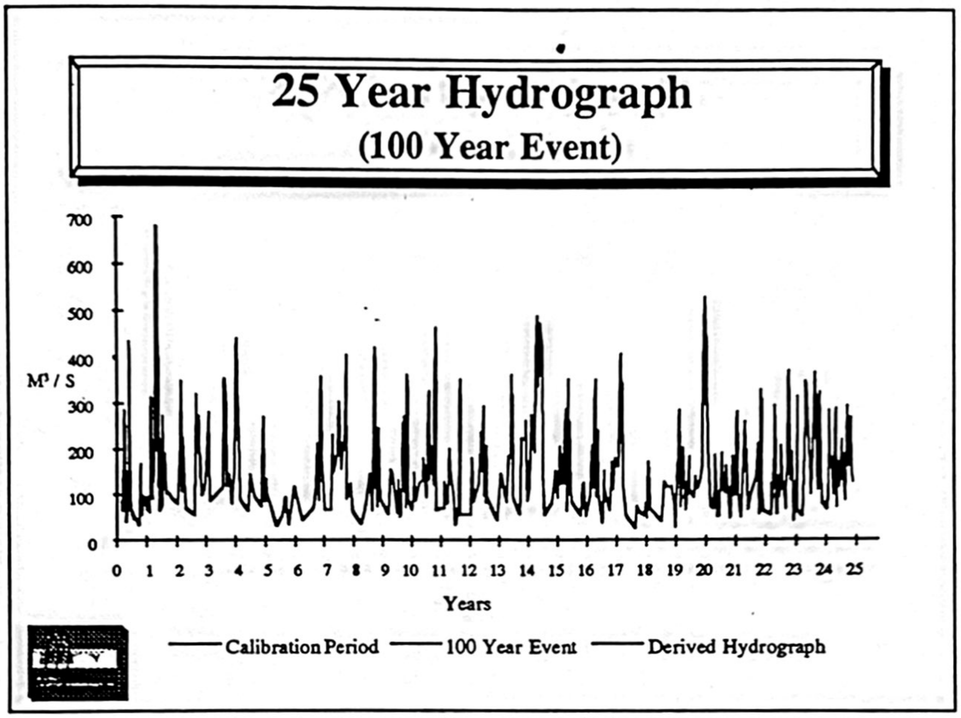
25 Year Hydrograph



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.

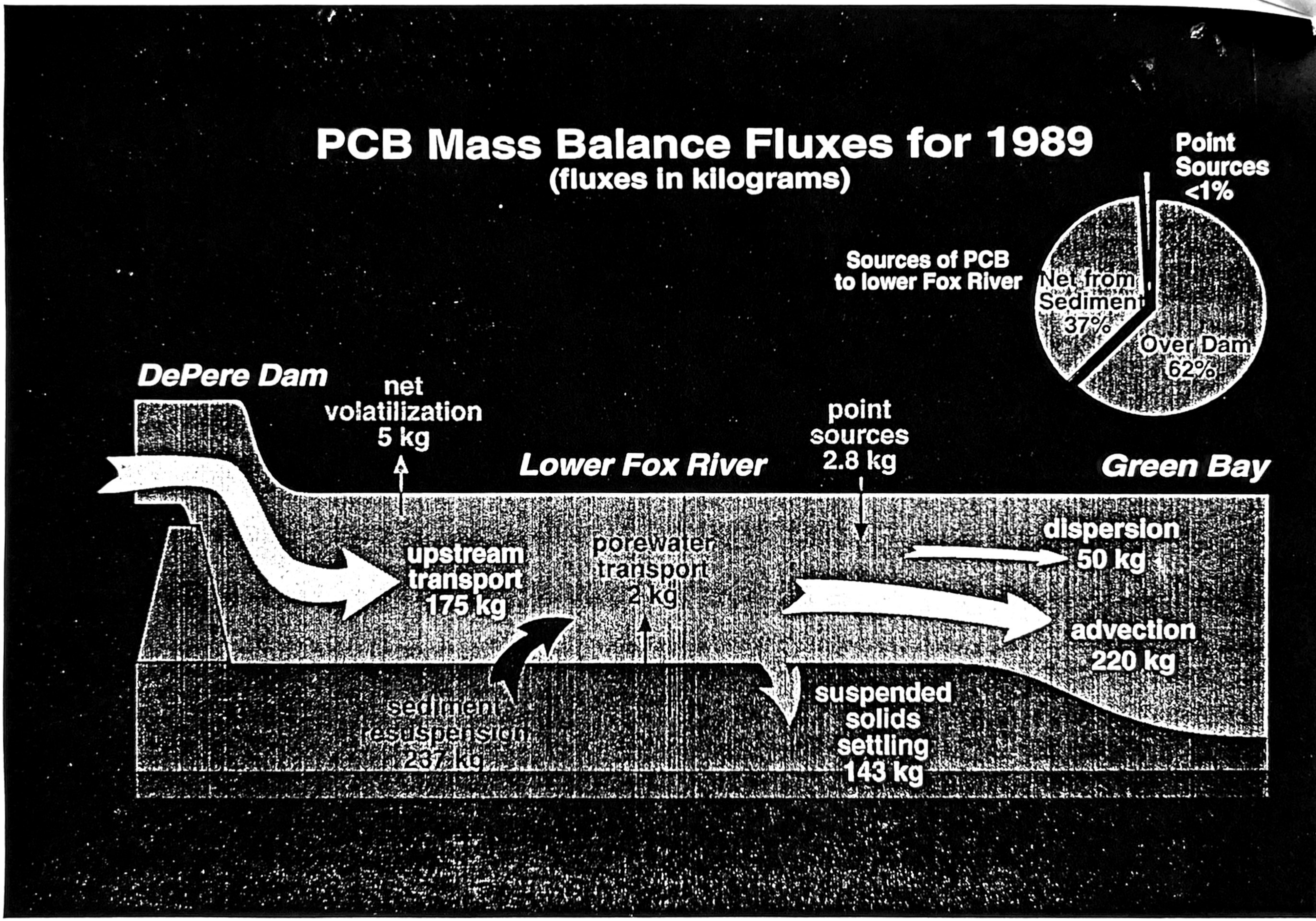
There will be uncertainty associated with the hydrograph we chose as opposed to other possibilities

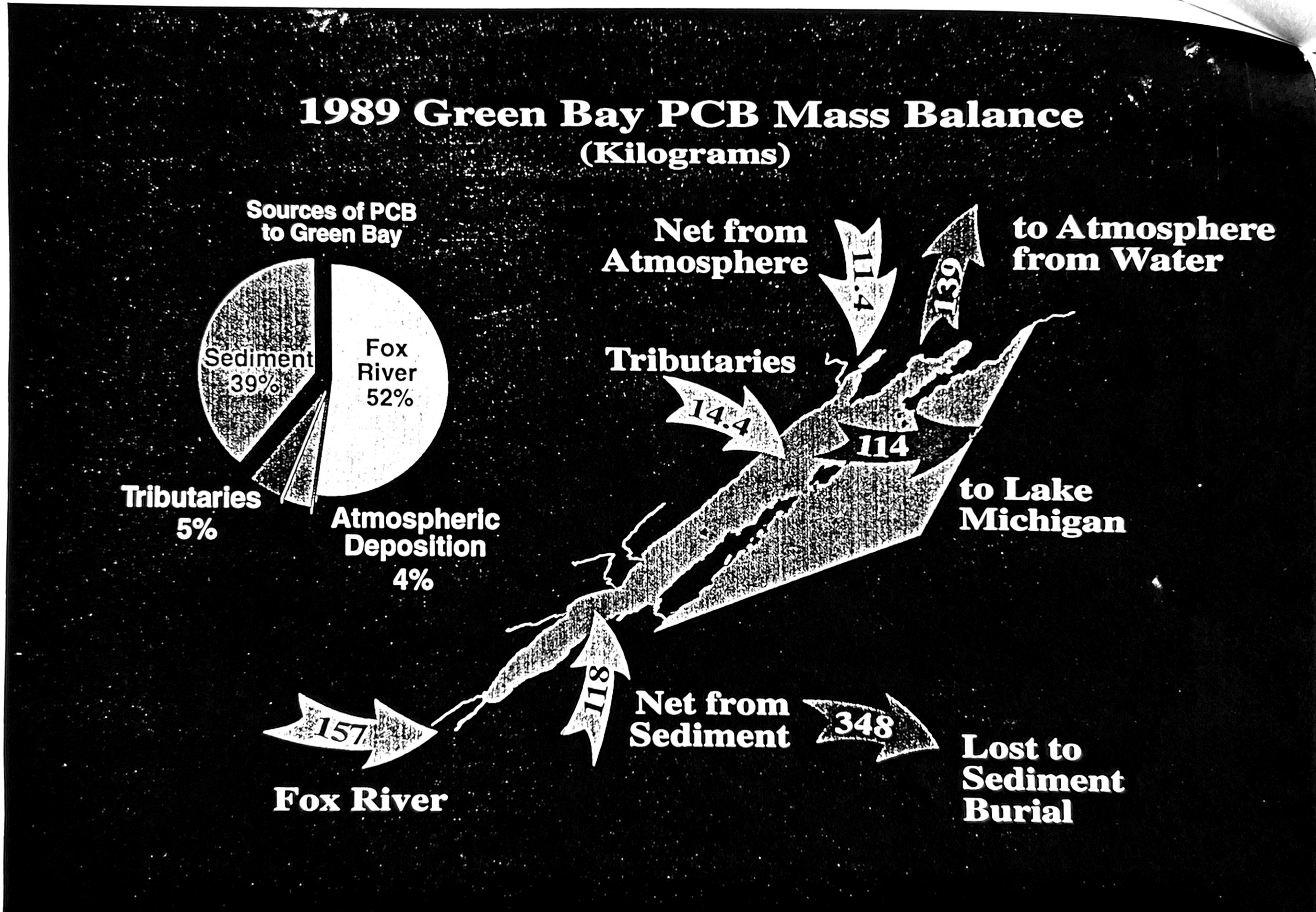


100 year event came at the beginning of the simulation. Interpretation of the results are dependant on where you place the event.

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

- 1960


PCB Mass Balance Fluxes for 1989
(fluxes in kilograms)
Sources of PCB to lower Fox River
Point Sources <1%
Net from Sediment 37%
Over Dam 62%
DePere Dam
net volatilization 5 kg
Lower Fox River
point sources 2.8 kg
Green Bay
upstream transport 175 kg
porewater transport 2 kg
dispersion 50 kg
advection 220 kg
sediment resuspension 237 kg
suspended solids settling 143 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
11.4
139
to Atmosphere from Water
Tributaries
14.4
114
to Lake Michigan
157
Fox River
118
Net from Sediment
348
Lost to Sediment Burial

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.

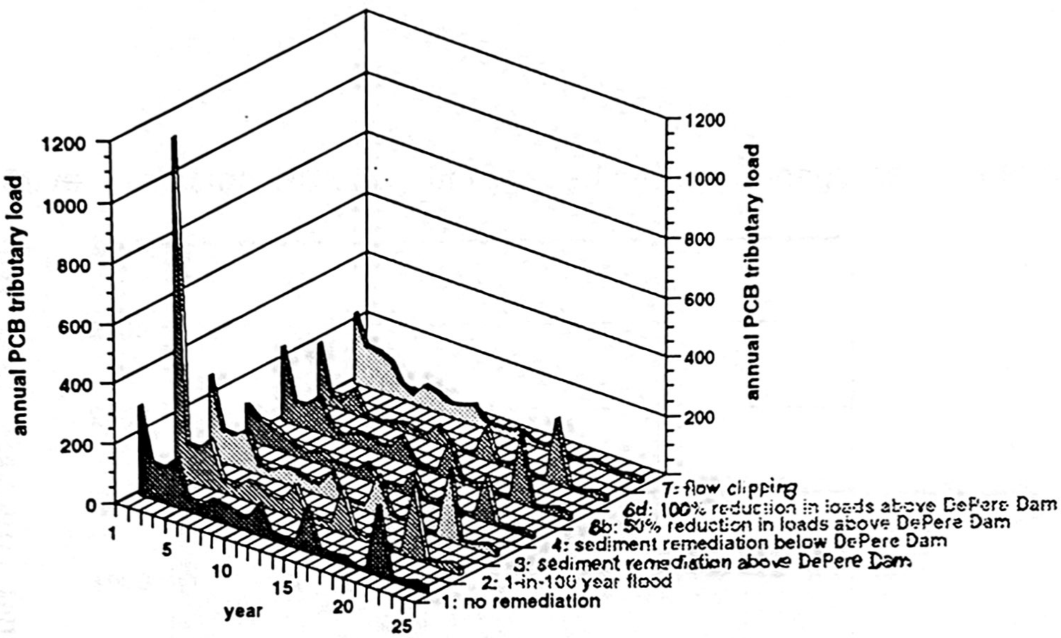
For the management scenarios, the models were coupled to predict the sequential transport of PCBs, originating from contaminated river sediments, downstream through the Fox River into Green Bay.

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:

Predicted Annual PCB Tributary Loading from Fox River Management Scenarios

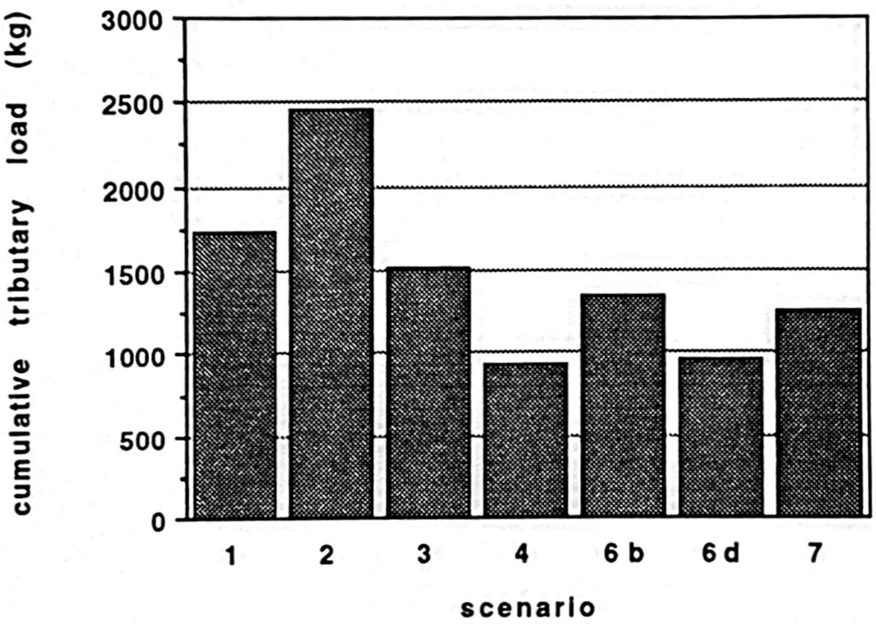


PCB tributary loading and concentrations in the Fox River are predicted to decline over time in all scenarios. This is because the PCBs originate from contaminated river sediments, which are buried or depleted over time.

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:

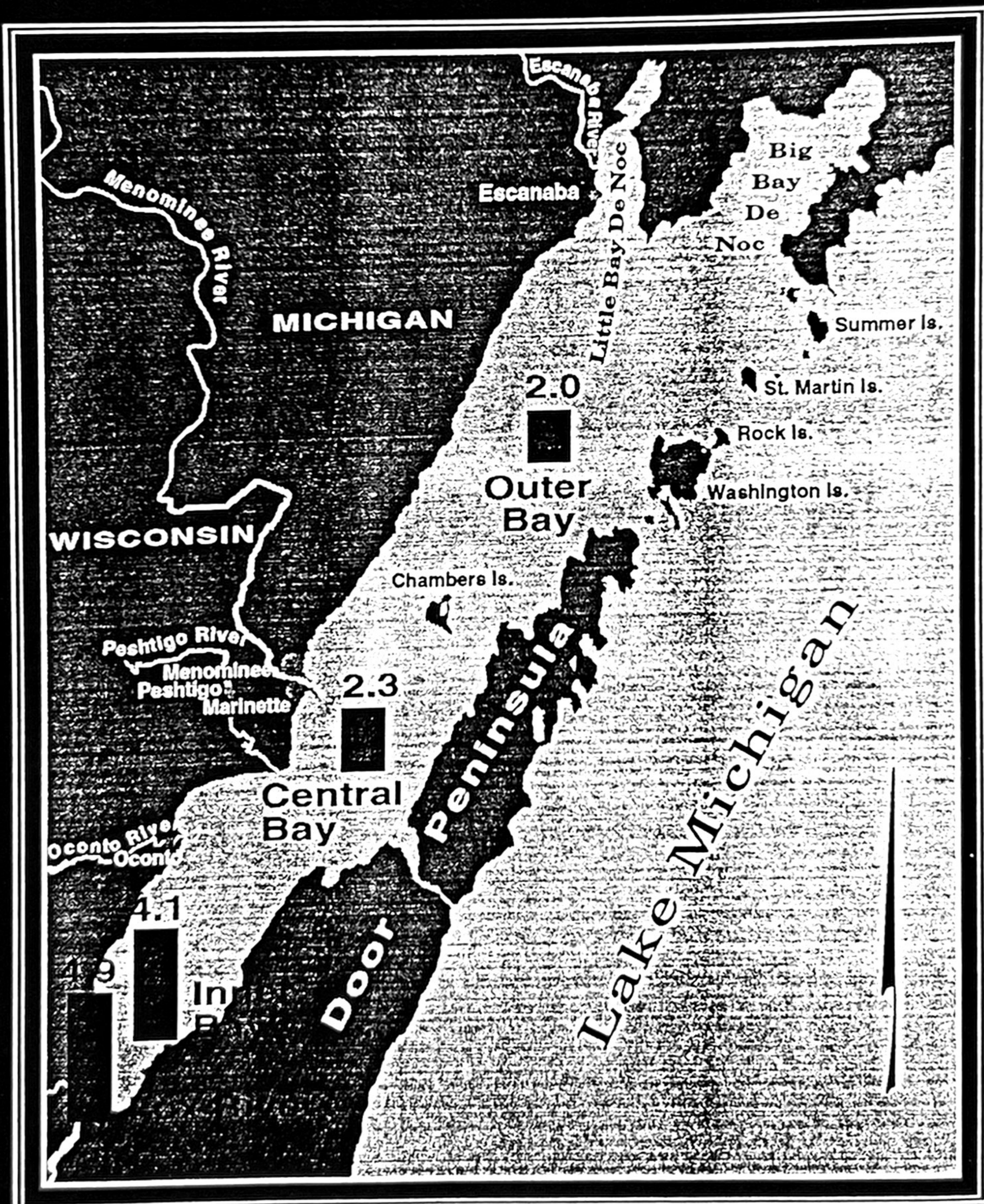
Cumulative Predicted PCB Tributary Loading for Management Scenarios



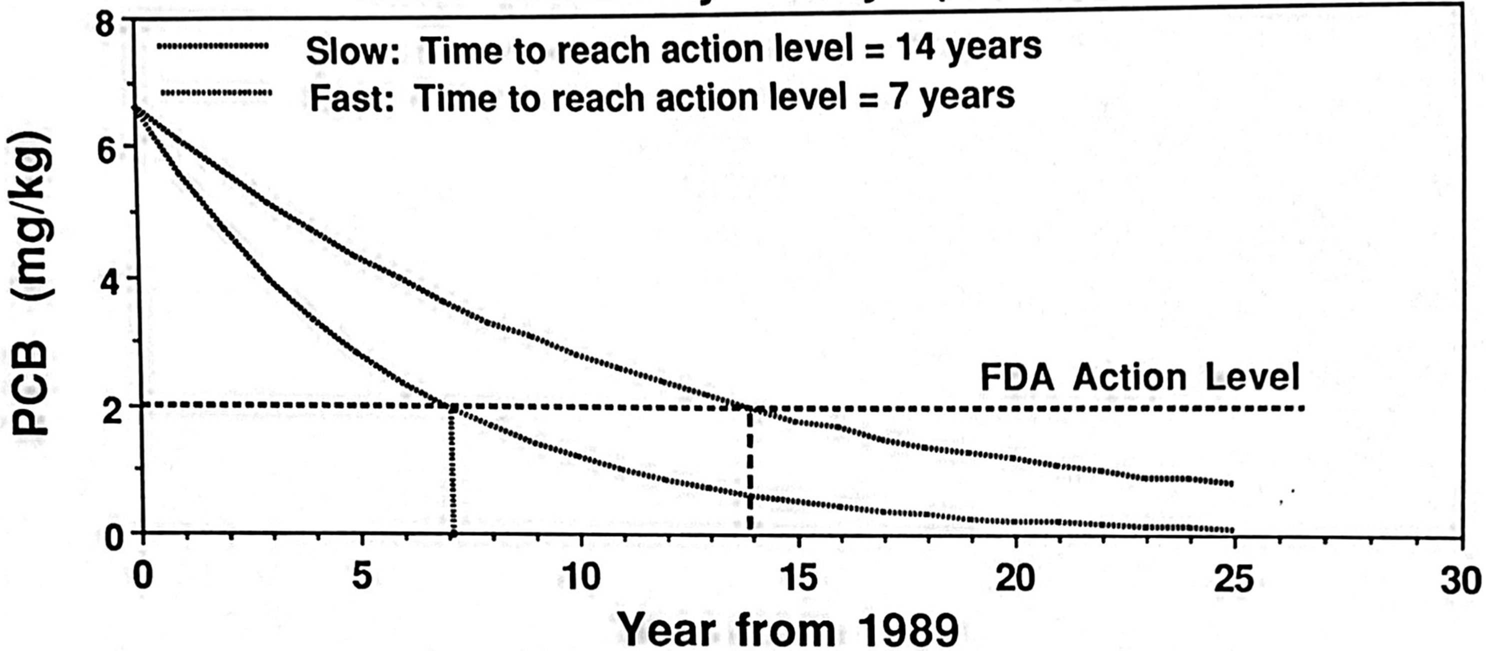
The potential for migration of the estimated 25,000 - 40,000 kilograms of PCBs from the lower Fox River sediments into Green Bay is a significant environmental concern. The model prediction for scenario 1 (no remediation) suggests that only 2% of this in-place reservoir is transported to Green Bay over 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.

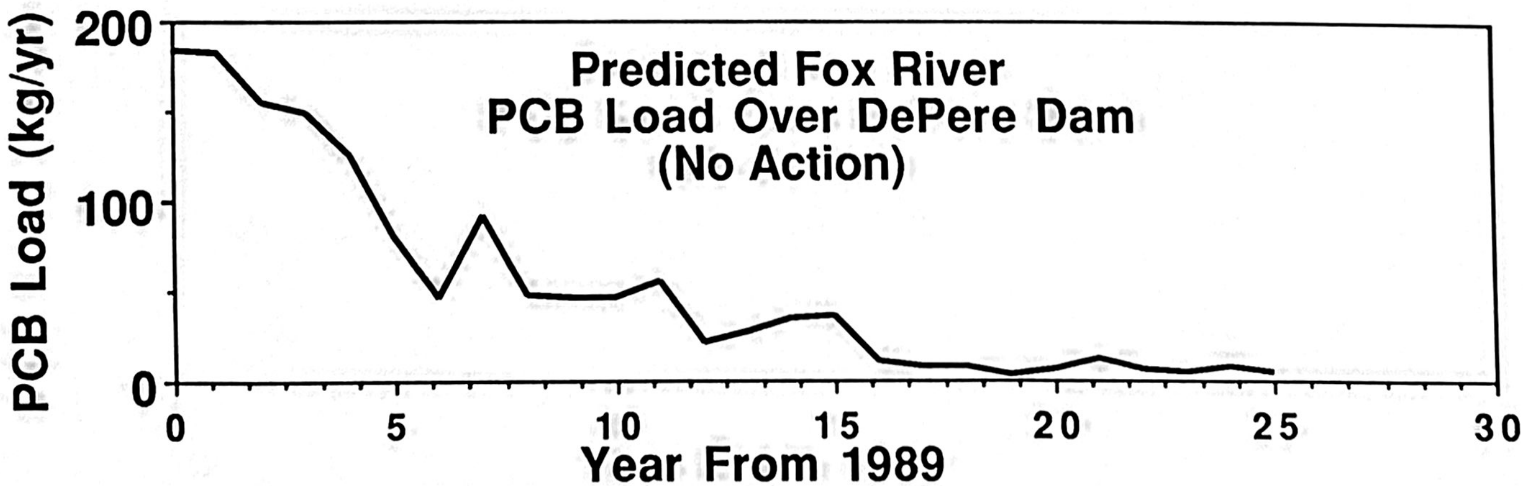
Mean PCB (mg/kg) in Walleye, 1989

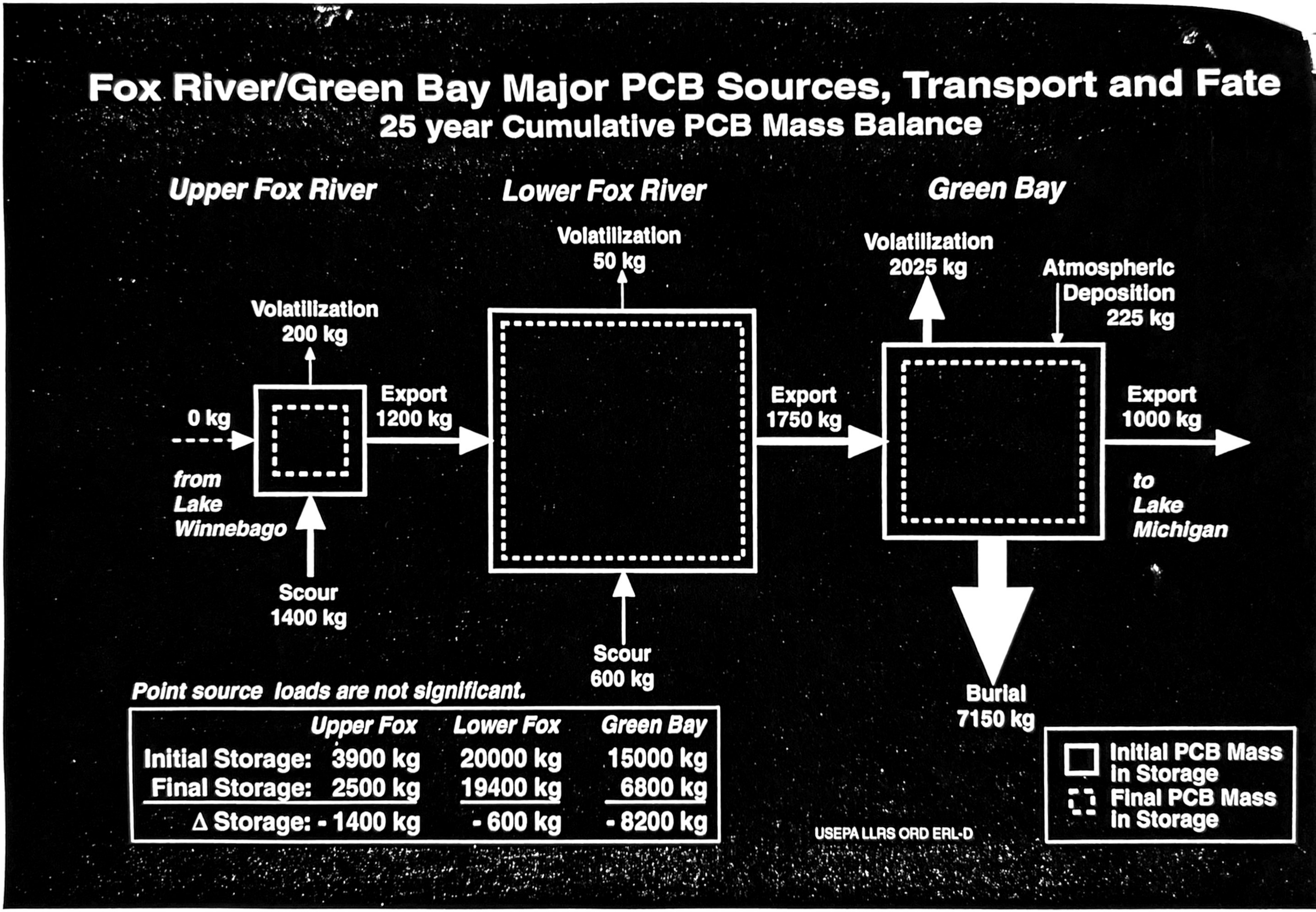
Wet Weight, Whole Fish, All Seasons, All Age Classes

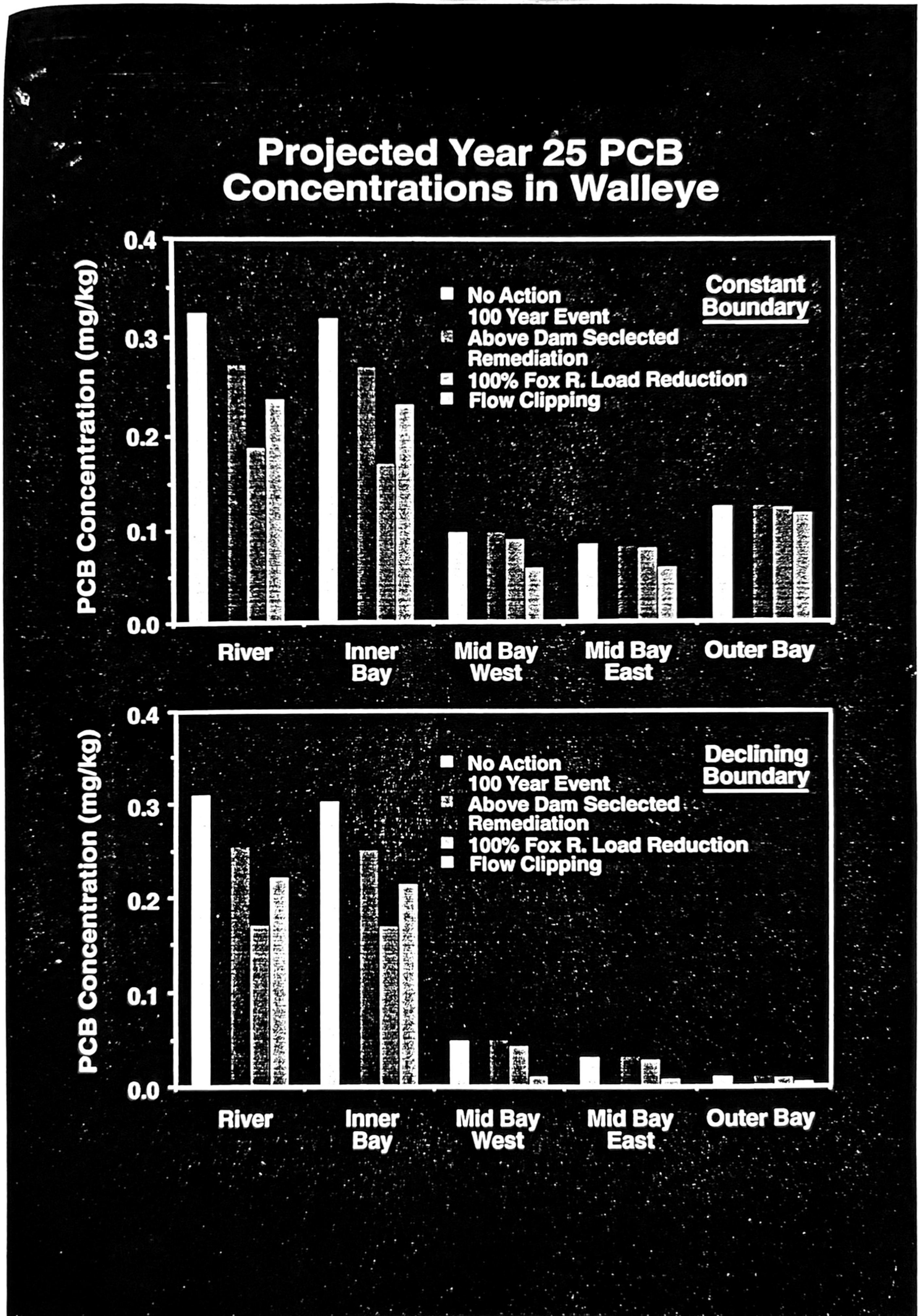


Predicted Average PCB Concentration
Inner Green Bay Walleye (No Action)



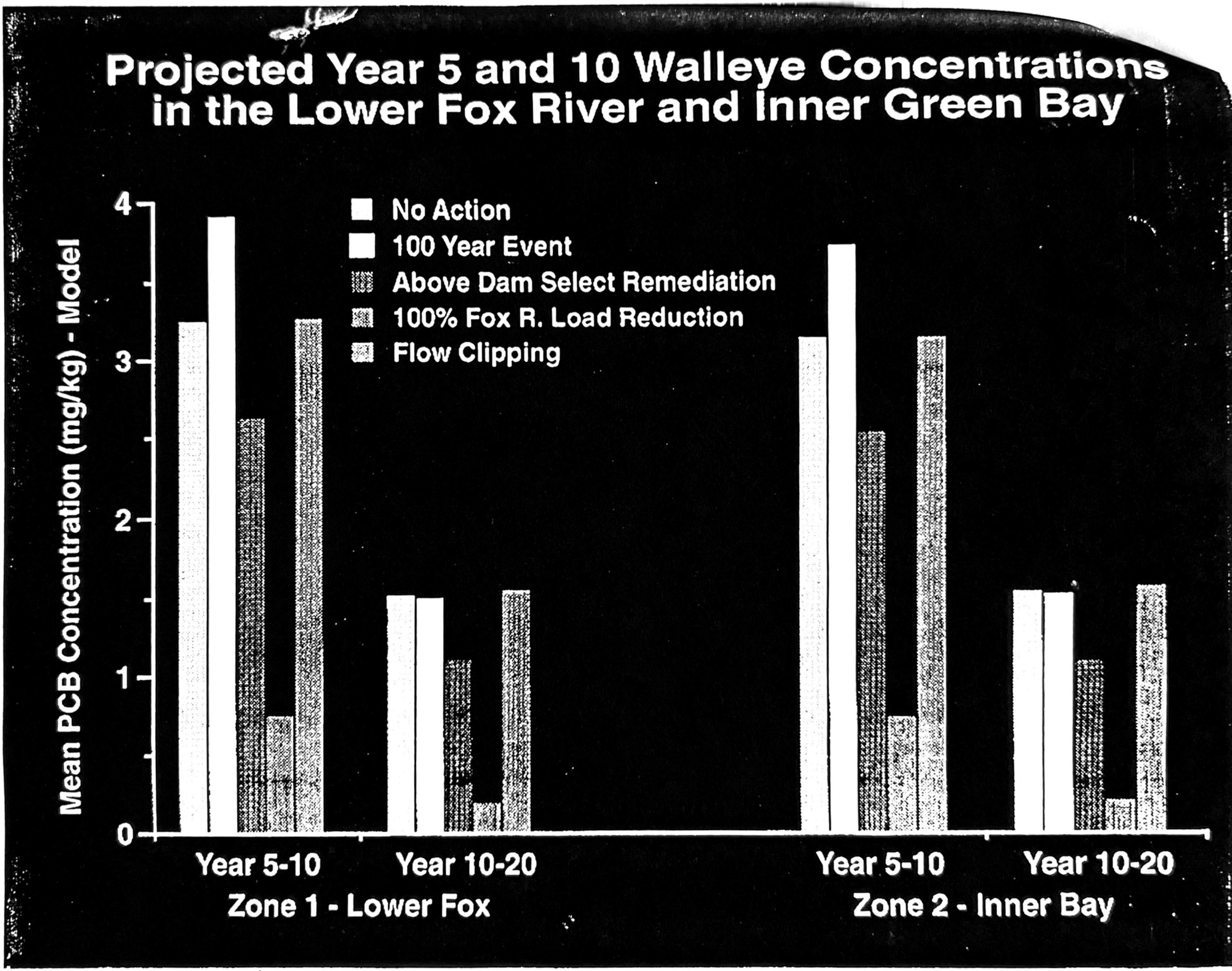



Fox River/Green Bay Major PCB Sources, Transport and Fate
25 year Cumulative PCB Mass Balance
Upper Fox River
Lower Fox River
Green Bay
Volatilization 200 kg
0 kg
from Lake Winnebago
Export 1200 kg
Scour 1400 kg
Volatilization 50 kg
Export 1750 kg
Scour 600 kg
Volatilization 2025 kg
Atmospheric Deposition 225 kg
Export 1000 kg
to Lake Michigan
Burial 7150 kg
Point source loads are not significant.
Upper Fox
Lower Fox
Green Bay
Initial Storage: 3900 kg 20000 kg 15000 kg
Final Storage: 2500 kg 19400 kg 6800 kg
Δ Storage: - 1400 kg - 600 kg - 8200 kg
Initial PCB Mass in Storage
Final PCB Mass in Storage
USEPA LLRS ORD ERL-D


Projected Year 25 PCB
Concentrations in Walleye
PCB Concentration (mg/kg)
0.4
0.3
0.2
0.1
0.0
No Action
100 Year Event
Above Dam Seclected Remediation
100% Fox R. Load Reduction
Flow Clipping
Constant Boundary
River
Inner Bay
Mid Bay West
Mid Bay East
Outer Bay
PCB Concentration (mg/kg)
0.4
0.3
0.2
0.1
0.0
No Action
100 Year Event
Above Dam Seclected Remediation
100% Fox R. Load Reduction
Flow Clipping
Declining Boundary
River
Inner Bay
Mid Bay West
Mid Bay East
Outer Bay

~~17~~ 15

30


Projected Year 5 and 10 Walleye Concentrations in the Lower Fox River and Inner Green Bay
Mean PCB Concentration (mg/kg) - Model
4
3
2
1
0
No Action
100 Year Event
Above Dam Select Remediation
100% Fox R. Load Reduction
Flow Clipping
Year 5-10
Year 10-20
Zone 1 - Lower Fox
Year 5-10
Year 10-20
Zone 2 - Inner Bay