Polychlorinated Biphenyl (PCB) Contaminated Sediment in the Lower Fox River:

Modeling Analysis of Selective Sediment Remediation

Wisconsin Department of Natural Resources
Bureau of Watershed Management
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ACKNOWLEDGEMENTS

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Interpretation of data and graphical representations are solely those of Bureau of Watershed Management staff.

WDNR staff would like to thank the other members of the Fox River Coalition Technical Workgroup for contributions of time, funding, materials, and ideas. The Technical Workgroup included US Fish and Wildlife Service, US Environmental Protection Agency and US Army Corps of Engineers staff, and representatives of Fort Howard Corporation, P.H. Glatfelter Company, Wisconsin Tissue Mills, Green Bay Metropolitan Sewerage District, and the Green Bay Remedial Action Plan Science and Technical Advisory Committee.
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Develop a cost-effective, expedient sediment remediation strategy which leads to the protection of human health and restoration of the biological integrity of the Lower Fox River and lower Green Bay. Such a strategy will lead to protection of human health and fish and wildlife by removing or confining the factors causing impairment, primarily polychlorinated biphenyl-contaminated sediment.
INTRODUCTION AND BACKGROUND

* The 1989 - 1990 Lower Fox River/Green Bay Mass Balance Study (GBMBS) quantified PCB contamination in 39 miles of the Lower Fox River and began seven years of data gathering and water and fish quality model development.

* In response, the Fox River Coalition (FRC) formed in 1992, because it was clear that a human and wildlife health problem existed due to PCBs in the river and bay i.e., fish consumption advisories since the 1970's, water fowl consumption advisories since the 1980's, Forsters tern wasting syndrome, etc.

* The FRC's charge was to develop a process for cooperative action that would determine what to do and how to do it quickly and cost-effectively.

* From 1992 - 1995 a subset of the FRC and liaisons from the Green Bay Remedial Action Plan Science and Technical Advisory Committee met to discuss and develop consensus on a full range of technical issues. These included: examining all existing data and model results; prioritizing contaminated sites upstream and downstream of De Pere; managing a remedial investigation and feasibility study at selected sites upstream of De Pere; identifying the need and coordinating collection of detailed sediment data downstream of De Pere and developing methods to represent environmental benefits of various levels of remediation. This resulted in a draft technical package presented to the full FRC in January, 1996.

* The work reported in this document builds on the work of the GBMBS and the FRC Technical Workgroup.
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Document Purpose

The primary purpose of this document is to provide a data summary and the results of water and fish quality model performance evaluation and forecasts. This information provides a scientific foundation to help make sediment and risk management decisions for the Lower Fox River.

Data is summarized to illustrate:

- Trends and present day concentrations of PCBs in water, sediment and fish;
- A comparison of the fish concentrations to a range of criteria developed to protect people and animals which eat fish; and
- Our current knowledge of PCB contamination in the Lower Fox River sediment, which is the only significant source of PCBs to fish and wildlife at the present time.

Forecasts of water and fish quality models are presented to illustrate changes in water, sediment, and fish over the next 100 years and for a "worst case" situation (i.e., a 100 year flood event).

Forecasts reflect the environmental endpoints achievable without intervention and with varying levels of remediation.

This package does not discuss methods of remediation or cost.
Figure 1: Locations of Lower Fox River Contaminated Sediment Between Lake Winnebago and Green Bay

<table>
<thead>
<tr>
<th>River Reach</th>
<th>PCB Mass (Kg)</th>
<th>Sediment Volume (m$^3$)</th>
<th>Surface Area (m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LLBDM - Appleton</td>
<td>2,300</td>
<td>900,000</td>
<td>3,000,000</td>
</tr>
<tr>
<td>Appleton - Kaukauna</td>
<td>300</td>
<td>100,000</td>
<td>400,000</td>
</tr>
<tr>
<td>Kaukauna - Little Rapids</td>
<td>200</td>
<td>400,000</td>
<td>1,300,000</td>
</tr>
<tr>
<td>Little Rapids - De Pere</td>
<td>1,400</td>
<td>1,000,000</td>
<td>2,700,000</td>
</tr>
<tr>
<td>De Pere - River Mouth</td>
<td>26,500</td>
<td>6,000,000</td>
<td>5,000,000</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>30,700</strong></td>
<td><strong>8,400,000</strong></td>
<td><strong>12,400,000</strong></td>
</tr>
</tbody>
</table>
Environmental Concerns/Endpoints

Environmental endpoints are measures of biological integrity or established standards which can be used to guide development of a remediation strategy.

Three endpoints used in Lower Fox River planning included in this document are attainment of promulgated PCB water quality standards, export of PCBs to Green Bay and fish tissue PCB concentrations protective of birds, mammals and human health.

* Meeting existing water quality standards

Established PCB water quality criteria (NR 105 Wis. Adm. Code) applicable to the Lower Fox River are:

- 0.49 ng/L (parts per trillion; ppt) for a warm water fishery and
- 0.15 ng/L for the Great Lakes.

* Export of PCB from the Lower Fox River to Green Bay

The Lower Fox River is the source of 95% of the PCB load to Green Bay and is the single largest tributary load to Lake Michigan. Although no export reduction goals have been set by the Remedial Action Plan for Green Bay or the Lake Michigan Lakewide Management Plan, export reduction will reduce the spread of PCB into the Great Lakes and reduce the exposure of PCB to people and wildlife which use the bay.

* Protecting bird and mammal health

The Great Lakes Water Quality Initiative (GLI) identifies methods for developing fish tissue concentrations that would be protective of fish-consuming birds and mammals

For mink, the most sensitive species, a protective fish tissue PCB concentration is 0.023 mg/kg (parts per million; ppm).

* Protecting human health through safe fish consumption

WDNR staff and the FRC Technical Workgroup considered the effect of remediation on fish tissue PCB concentrations compared to a consumption advisory protocol developed by the Great Lakes Sport Fish Advisory Task Force (GLSFATF).
The Great Lakes Sport Fish Consumption Advisory is a uniform sport fish consumption advisory protocol for the protection of human health applicable to all the Great Lakes. It is based on a weight-of-evidence health protection value rather than Food and Drug Administration (FDA) tolerances for marketplace fish.

GLSFATF categories for PCBs¹ are:

<table>
<thead>
<tr>
<th>Consumption category</th>
<th>Fish concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted consumption (225 meals/year)</td>
<td>&lt;0.05 ppm</td>
</tr>
<tr>
<td>One meal per week</td>
<td>0.05 to 0.22 ppm</td>
</tr>
<tr>
<td>One meal per month</td>
<td>0.22 to 0.95 ppm</td>
</tr>
<tr>
<td>Six meals per year</td>
<td>0.95 to 1.89 ppm</td>
</tr>
<tr>
<td>Do Not Eat</td>
<td>&gt;1.89 ppm</td>
</tr>
</tbody>
</table>

¹ Skin-on fillet tissue values
Figure 2. Health Risks of Consuming PCB Contaminated Fish*

<table>
<thead>
<tr>
<th>PCB Concentration in fish fillets (ppm)</th>
<th>Risk to &quot;average angler&quot; 50th Percentile Angler (52 meals/yr, 7.7 slope factor)</th>
<th>Human Lifetime Cancer Risk Ranges (incorporating 2 slope factors and consumption ranges)</th>
<th>Current Fox River fish fillet PCB concentrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>-6 -</td>
<td>cancer 1 in 100</td>
<td>Cancer Range 1 in 100</td>
<td>Carp above &amp; below DePere (whole fish)</td>
</tr>
<tr>
<td>-5 -</td>
<td>liver abnormality</td>
<td>Cancer Range 1 in 1000</td>
<td>Walleye (&gt;20 in) below DePere</td>
</tr>
<tr>
<td>-4 -</td>
<td>thyroid/endocrine dysfunction/reproductive/behavior</td>
<td></td>
<td>White Bass below DePere</td>
</tr>
<tr>
<td>-3 -</td>
<td>cancer 1 in 1000</td>
<td></td>
<td>Walleye (16 in) below DePere</td>
</tr>
<tr>
<td>-2 -</td>
<td>cancer 1 in 5000</td>
<td></td>
<td>White Sucker below DePere</td>
</tr>
<tr>
<td>-1 -</td>
<td>motor function</td>
<td></td>
<td>Walleye (16 in) above DePere</td>
</tr>
<tr>
<td>-0.9 -</td>
<td>behavior/neuro-development/immunological effects/visual recognition memory</td>
<td></td>
<td>White Bass above DePere</td>
</tr>
<tr>
<td>-0.8 -</td>
<td>tumor function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.7 -</td>
<td>cancer 1 in 10,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.6 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.5 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.4 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
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<td>-0.3 -</td>
<td>cancer 1 in 100,000</td>
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<td>-0.2 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.1 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.09 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.08 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
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<tr>
<td>-0.07 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.06 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
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<tr>
<td>-0.05 -</td>
<td>cancer 1 in 100,000</td>
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<td>-0.04 -</td>
<td>cancer 1 in 100,000</td>
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<td>-0.03 -</td>
<td>cancer 1 in 100,000</td>
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<td>-0.02 -</td>
<td>cancer 1 in 100,000</td>
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<td></td>
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<tr>
<td>-0.01 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.009 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.008 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.007 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.006 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.005 -</td>
<td>cancer 1 in 100,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Risk endpoints relative to fish fillet PCB concentration derived from the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory (GLSFATF, 1993).
** GLSFATF = Great Lakes Sport Fish Advisory Task Force.
FDA = U. S. Food and Drug Administration. GLI = Great Lakes Initiative.
*** Cancer risk ranges based on consumption range from average Great Lakes angler & family (21 meals/yr) to 90th percentile angler (225 meals/yr) using risk slope factors of 4.95 and 7.7 mg/kg/d.
Data Collection Efforts

The GBMBS provided an extensive data base in the Lower Fox River and Green Bay. PCB sampling included the water, sediments, fish, point sources, and more. Since the end of the GBMBS data collection, several follow-up studies have occurred including this partial listing of data collected between 1991 and 1996.

* 1995 WDNR/EPA: detailed sediment data collection downstream of De Pere (sediment cores at 100 + locations).
1991-1996 data was used to:

* Evaluate river conditions 1991-1995
* Define trends in fish tissue contamination 1991-1996
* Compare sediment quality data to 1989-90 GBMBS data
* Estimate contaminated sediment volume and total PCB mass
* Conduct a water and fish quality model post-audit: a comparison of predictions from an existing model to observations gathered since the model was created to assess accuracy
* Forecast response to remediation and effects of no action
* Provide data for remediation design and cost estimates
Measured PCB concentrations in water at the Lower Fox River mouth suggest little difference between 1989 and 1995. PCBs continue to enter the water from sediments.
Average 1989 and 1995 sediment data shows little difference in PCB concentrations. While averages are less than 11 ppm, the concentrations ranged from no detectable PCB to 400 ppm. Variation in PCB concentrations (ppm) are seen by comparing ranges of observations:

<table>
<thead>
<tr>
<th>Core Type</th>
<th>1989</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity Cores</td>
<td>&lt; 0.05 - 84 ppm</td>
<td>&lt; 0.05 - 91 ppm</td>
</tr>
<tr>
<td>(Approx. ≤ 60 cm)</td>
<td>(n = 114)</td>
<td>(n = 222)</td>
</tr>
<tr>
<td>Deep Cores</td>
<td>&lt; 0.05 - 110 ppm</td>
<td>&lt; 0.05 - 400 ppm</td>
</tr>
<tr>
<td></td>
<td>(n = 137)</td>
<td>(n = 263)</td>
</tr>
</tbody>
</table>
Average PCB concentrations in walleye fillets declined as active wastewater discharges were reduced. The rate of decline has since slowed as the source of PCBs has shifted to the slow release from contaminated sediment. Consumption advice remains at one meal per month.
Figure 6. PCB Concentrations in Walleye Fillets Downstream of De Pere 1979-1996

Mean PCB (+/- 95% CI)

* The general trend in PCB concentration shows little change in 20" walleye and a slight downward trend in 15-18" walleye since 1985.

* White bass (not shown), another popular sport fish, have PCB tissue concentrations similar to 20" walleye and also show little change since 1985.
Data Summary and Conclusions

* Water column PCB concentrations have not changed in the last seven years (1989-1996) and exceed water quality standards.

* Average surficial sediment PCB concentrations downstream of De Pere have not changed in the last seven years (1989-1996).

* Average concentrations of PCB in walleye fillets from Little Lake Butte des Morts declined along with reductions in active wastewater discharge. The rate of decline since 1980 has slowed. Human consumption advice for LLBdM walleye remains at one meal per month.

* Fish tissue PCB concentrations since 1979 downstream of De Pere:

  20" walleye and white bass show little change in PCB tissue concentrations. Human consumption advice is for six meals per year.

  15-18" walleye tissue concentrations exhibit a slight downward trend. Human consumption advice is for one meal per month.

* Fish in the Lower Fox River continue to present a significant human health and ecological risk.
* A water quality model is a mathematical tool based on scientific and engineering principles, such as the conservation of mass, which describe the movement and distribution of particles and chemicals in water and sediment in a particular system such as the Lower Fox River.

* A fish quality model is also a mathematical tool which describes the relationship between chemical concentrations in water or sediments and in fish.

* Water and fish quality models can be used together to evaluate present and project future chemical concentrations in water, sediments and fish.

* Lower Fox River water quality models, first developed as part of the 1989-90 Green Bay Mass Balance Study, were refined to accurately predict future environmental conditions.

* A Fox River fish quality model was developed from field data collected during the GBMBS and 1995-96 sampling.

  - A Biota to Sediment Accumulation Factor (BSAF) was used to estimate fish tissue concentrations of PCB.

  - The BSAF model used assumes lipid (fat) content of fish and organic content of surface sediment do not change over time.

  - PCB concentration in fish is thus directly related to the average PCB concentration in the surface sediments where the fish live.
Evaluation of Model Performance

* A post-audit was performed to evaluate the predictive abilities of the Lower Fox River water and fish quality models.

* A post-audit is a comparison of model predictions to observations made AFTER the model was created and calibrated to assess the accuracy of predictions.

* Comparisons used to evaluate model predictions:

  for water column: a time series comparison and frequency distributions.

  for sediment: a point-in-time comparison.

  for fish tissue: a time series comparison.
PREDICTED WATER COLUMN PCB CONCENTRATIONS:
TIME SERIES COMPARISONS

A time series analysis is a graphical comparison of predictions to observations over time -- the closer the sets of data points representing predictions and observations are, the better the model performance. Qualitative evaluation of trends and seasonal patterns can be made.

Figure 7a. Predicted and Observed Water Column PCB Concentrations at Appleton: 1989-1995

Figure 7b. Predicted and Observed Water Column PCB Concentrations at the Fox River Mouth: 1989-1995

* Representative model results illustrate that for seven years from 1989 through 1995, model predictions for water column PCBs agree well with discrete observations and seasonal patterns.
PREDICTED WATER COLUMN PCB CONCENTRATIONS: FREQUENCY DISTRIBUTIONS

A frequency distribution analysis is a graphical comparison of the statistical properties (the cumulative frequency of occurrence) of the predictions and observations. The closer the symbols representing predictions come to those representing the observations, the better the model performance.

Figure 8a. Predicted and Observed Water Column PCB Concentrations at Appleton: 1989-1995

Figure 8b. Predicted and Observed Water Column PCB Concentrations at the Fox River Mouth: 1989-1995

* Again, model results show that for seven years from 1989 through 1995, model predictions mimic the shape and slope of the distribution of the observations and on average are within 15% of observations.
SEDIMENT
A Point-in-Time Analysis

A graphical comparison of how close predictions of PCB concentrations come to observations for a single point in time. The closer the bar representing predictions comes to the bar representing observations, the better the model performance.

Figure 9. Predicted and Observed Sediment PCB Concentrations Downstream of De Pere: 1995

* Model predictions for sediment PCBs agree within 30% of observations on the average.

* Differences in layers 1 and 2 are explained by uncertainty in model initial conditions due to fewer samples (37) taken in 1989 and used for model initial conditions for the post-audit.
PREDICTED FISH TISSUE PCB CONCENTRATIONS
A Time Series Comparison

The closer the predicted fish tissue concentrations match the average and trend of observations, the better the model performance.

Figure 10a. Predicted and Observed Water Column PCB Concentrations in 16" Walleye in LLbDm: 1989-1996

Figure 10b. Predicted and Observed Water Column PCB in 20" Walleye Downstream of De Pere: 1989-1996

* Model predictions for fish PCBs intersect the range of data in all years, but appear to trend downward faster than observations.
Model Performance Summary

* Lower Fox River models are a culmination of seven years of development:
  - extensively researched and documented with the most up to date understanding of sediment and contaminant transport;
  - independently peer reviewed and published in refereed journals.

* The evaluation of model performance incorporated hundreds of measurements, collected over a seven year period, of PCBs in water, sediments and fish from Lake Winnebago to the Lower Fox River mouth.

* Model performance indicates that models are sufficient to aid in making management decisions.
  - Average model water column PCB concentrations match observations within 15% over the post-audit period, and duplicate seasonal trends and the frequency distribution.
  - Average forecasted model sediment concentrations match observed sediment data to within 30% at the end of the post-audit.
  - Fish forecasts match observations well during the post-audit period.

* Model evaluations to date demonstrate the models are appropriate tools to forecast relative future trends in:
  - PCB concentrations in water, sediment and fish in the Lower Fox River,
  - PCB export from the Lower Fox River to Green Bay;
  - environmental benefits of remedial actions.
Model Forecast Uncertainty

* Uncertainty in the data, and the way models account for it, affect the interpretation of model forecasts and how managers should use the results.

* All models are simple representations of nature’s complexity, so they will have some uncertainty in forecasts.

* Uncertainty is caused by sample-to-sample variation in observations of water, sediment and fish, limited number and frequency of observations, and lab errors.

* Uncertainty caused by these factors can never be completely eliminated, but understanding model tendencies can help interpret model forecasts.

* Further data collection or model refinements should be considered only if the expected reduction in uncertainty will be significant enough to affect management decisions.

* Uncertainty in the present model indicates that more benefit will likely occur from remediation than is being forecasted.
How Uncertainty Affects Fox River Model Forecasts

* Predicted deep burial rates for PCBs in the river have been shown to be biased high i.e., they are slightly over-predicted (conclusion of the post-audit analysis of model performance relative to field measurement over time).

* As a result, the Lower Fox River water quality models predict PCB concentrations in water, sediment, and fish that are slightly lower than observed over time (See Figures 8, 9 and 10).

* This implies that the models have an over-prediction bias towards the benefits of "No Action".

Why?

* Measured sediment PCB concentrations do not decrease as quickly over time as predicted by the model. Consequently, PCB concentrations in water, sediment and fish will not decrease as quickly as predicted. The model over-predicts the recovery of the river and the benefits of "No Action".

* For the same reason, (actual PCB concentrations over time will be higher than predicted), the models will under-predict the time to meet environmental endpoints, (e.g., water quality criteria, fish contaminant consumption limits, etc.) and provide an optimistic bias to "No Action".

* Decision makers should be aware of the optimistic bias of the "No Action" model predictions. The actual difference in relative benefit of remediation versus "No Action" will be greater than that predicted by the model.
MODEL FORECASTS

* Model forecasts were constructed by using a future hydrograph and running the models for a 100 year period to forecast the water, sediment and fish PCB concentrations.

* Forecasts were made for "No Action" and three selected remediation scenarios.

* FRC Technical Workgroup and WDNR staff selected remediation scenarios for the river upstream of De Pere that could impact human health and local ecological conditions, primarily in Little Lake Butte des Morts.

* 1995 sediment data was incorporated into the water quality models and used to rank and select areas downstream of De Pere to include in remediation scenarios.

* Remediation scenarios which combined work upstream and downstream of De Pere were chosen to reflect a range of remediation effort and examine environmental response.

* For computational ease, all 100 year forecast runs begin on January 1, 1996 and go through December 31, 2095. Remediation forecasts assume all remediation of selected sediment areas are completed in July, 2000.

* Remediations were simulated by removing all PCB in all sediment layers at the remediation site except the surface. A PCB residual of 2.5 ppm was left in the uppermost model layer to represent a practical limit of common remediation techniques.
Hydrographs Used In Model Forecasts

- Model forecasts are results of mixing three representative remediation scenarios with three different river flow hydrographs.

The three hydrographs used were:

The "BASELINE" hydrograph: a hydrograph consisting of observed flows from 1962 through 1987 repeated four times to represent 100 years of flow.

The "100 YEAR EVENT" hydrograph: the baseline hydrograph with an actual observed 100-year flood event, which occurred in 1960, inserted in year 2003.

The "SMALL TRIBUTARY EVENT" hydrograph: the baseline hydrograph with the effects of an extreme flood down the Neenah Slough inserted in 1998 to represent a small tributary event hydrograph.
Four Representative Remediation Scenarios

"No Action"
This scenario does not include remediation but relies on the processes of dilution, dispersion and burial to reduce PCB concentrations. The "No Action" option is the basis for comparing the various environmental benefits of the three remediation scenarios.

"3 Up and 3 Down"
Remediate Deposits A, C, POG upstream of De Pere and three Sediment Management Units (SMUs) downstream of De Pere (Figure 11).

"3 Up and 17 Down"
Remediate Deposits A, C, POG upstream of De Pere and 17 SMUs downstream of De Pere (Figure 13).

"4 Up and 50 Down"
Remediate Deposits A, POG, D/E and N upstream of De Pere and 50 SMUs downstream of De Pere (Figure 14).

Table 1. Physical and Chemical Summary of Four Representative Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Included Deposits/Sites</th>
<th>PCB Mass (kg)</th>
<th>Contaminated Volume (m³)</th>
<th>Contaminated Surface Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;No Action&quot;</td>
<td>None</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3 Up 3 Down</td>
<td>A, C, POG 3 SMUs</td>
<td>5,100 (17%)</td>
<td>800,000 (10%)</td>
<td>1,100,000 (9%)</td>
</tr>
<tr>
<td>3 Up 17 Down</td>
<td>A, C, POG 17 SMUs</td>
<td>10,300 (34%)</td>
<td>1,600,000 (19%)</td>
<td>2,300,000 (19%)</td>
</tr>
<tr>
<td>4 Up 50 Down</td>
<td>A, POG, D/E, N 50 SMUs</td>
<td>18,200 (60%)</td>
<td>3,400,000 (40%)</td>
<td>3,900,000 (31%)</td>
</tr>
<tr>
<td>Whole River Totals</td>
<td></td>
<td>30,700</td>
<td>8,400,000</td>
<td>12,400,000</td>
</tr>
</tbody>
</table>

1 (%) indicates percentage of whole river value
Sites Used in Lower Fox River Computer Modeling
Three Areas Upstream of De Pere Dam and 3 Areas Downstream

Figure 11: Contaminated sediment areas and sediment management units combined to simulate remediation and forecast environmental effects.
Figure 12. Forecasted Sediment Surface PCB Concentration Downstream of De Pere for "No Action" and One Remediation Scenario

* Model results for the "3 Up 3 Down" scenario parallel the "No Action" forecast so closely (≤ 10% difference) that the simulation was dropped from further evaluation.
Sites Used in Lower Fox River Computer Modeling
Three Areas Upstream of De Pere Dam and 17 Areas Downstream

Figure 13: Contaminated sediment areas and sediment management units combined to simulate remediation and forecast environmental effects.
Sites Used in Lower Fox River Computer Modeling
Four Areas Upstream of De Pere Dam and 50 Areas Downstream

Figure 14: Contaminated sediment areas and sediment management units combined to simulate remediation and forecast environmental effects.
Water Column PCB Concentrations and PCB Mass Transport

Figure 15. Forecast of Water Column PCB Concentrations at Appleton for "No Action" and Two Remediation Scenarios

No Action

3 Deposits Remediated

4 Deposits Remediated

In nanograms per liter
Table 2. Time to Reach PCB Water Quality Criteria at Appleton

<table>
<thead>
<tr>
<th>NR 105 Water Quality Criteria</th>
<th>PCB Concentration (ng/L)</th>
<th>No Action</th>
<th>Remediate &quot;3 up and 17 Down&quot;</th>
<th>Remediate &quot;4 Up and 50 Down&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm Water Sport Fish(^2)</td>
<td>0.49</td>
<td>24</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>Great Lakes(^2)</td>
<td>0.15</td>
<td>62</td>
<td>59</td>
<td>58</td>
</tr>
<tr>
<td>Cold Water(^2)</td>
<td>0.14</td>
<td>64</td>
<td>61</td>
<td>60</td>
</tr>
<tr>
<td>Wild and Domestic Animal</td>
<td>3.0</td>
<td>12</td>
<td>12</td>
<td>10</td>
</tr>
</tbody>
</table>

1 Projections are for NR 105 Water Quality Criteria from 1996.
2 Human cancer criterion.

Water Column Results: Upstream of De Pere

* After initial declines, forecasted water column PCB concentrations level out due to small residual loadings (point sources were assumed to remain at 1989 levels) (Figure 15). This shows that further declines are dependent on what actually occurs to these and any other loads over time and cannot be forecast with the present model.

* All scenarios indicate that water column PCB concentrations fall below the NR 105 water quality criteria of 0.49 ng/L or 0.15 ng/L for a warm water fishery or Great Lakes community, respectively (Figure 15). However, the proposed Great Lakes Initiative criteria will not be attained by any of the 100 year simulations.

* Remediations in LLBdM result in attainment of the 0.49 ng/L criteria at least six to ten years sooner than "No Action" (Table 3).
Table 3. Forecasted Cumulative PCB Mass Transport Over the De Pere Dam-1996-2096

<table>
<thead>
<tr>
<th>MODEL SCENARIOS</th>
<th>PCB MASS TRANSPORT (kg)</th>
<th>RELATIVE TO &quot;No Action&quot; SCENARIO (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Baseline&quot; Hydrograph in the Lower Fox River.</td>
<td>&quot;No Action&quot;</td>
<td>911</td>
</tr>
<tr>
<td>Remediate 3 deposits (A, C, POG)</td>
<td>898</td>
<td>-13</td>
</tr>
<tr>
<td>Remediate 4 deposits (A, D/E, POG, N)</td>
<td>852</td>
<td>-59</td>
</tr>
<tr>
<td>Small tributary flood²</td>
<td>1084</td>
<td>+173</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MODEL SCENARIOS</th>
<th>PCB MASS TRANSPORT (kg)</th>
<th>RELATIVE TO &quot;No Action&quot; SCENARIO (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Baseline&quot; Hydrograph in the Lower Fox River including a single 100 year flood event.</td>
<td>&quot;No Action&quot;</td>
<td>1004</td>
</tr>
<tr>
<td>Remediate 3 deposits (A, C, POG)</td>
<td>990</td>
<td>-14</td>
</tr>
<tr>
<td>Remediate 4 deposits (A, D/E, POG, N)</td>
<td>964</td>
<td>-40</td>
</tr>
</tbody>
</table>

¹ Remediation date = 7/1/2000, residual PCB concentration = 2.5 mg/kg in surficial sediment (top 5 cm)
² Simulated by a modeled 100-year flood on the Neenah Slough during normal flow in the Lower Fox River. It was assumed that the flood scoured sediments at Deposit A.

PCB Transport: Upstream of De Pere

* The occurrence of a 100-year flood event in the Fox River upstream of De Pere increases the amount of PCB transport over the De Pere Dam by 10%.
Figure 16. Forecasts of Water Column PCB Concentrations at the Lower Fox River Mouth for "No Action" and Two Remediation Scenarios

In nanograms per liter
Table 4. Time to Reach PCB Water Quality Criteria at the Lower Fox River Mouth

<table>
<thead>
<tr>
<th>NR 105 Water Quality Criteria</th>
<th>PCB Concentration (ng/L)</th>
<th>No Action</th>
<th>Remediate &quot;3 up and 17 Down&quot;</th>
<th>Remediate &quot;4 Up and 50 Down&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm Water Sport Fish²</td>
<td>0.49</td>
<td>400</td>
<td>340</td>
<td>250</td>
</tr>
<tr>
<td>Great Lakes²</td>
<td>0.15</td>
<td>510</td>
<td>450</td>
<td>360</td>
</tr>
<tr>
<td>Cold Water²</td>
<td>0.14</td>
<td>520</td>
<td>450</td>
<td>360</td>
</tr>
<tr>
<td>Wild and Domestic Animal</td>
<td>3.0</td>
<td>220</td>
<td>160</td>
<td>90</td>
</tr>
</tbody>
</table>

¹ Projections are for NR 105 Water Quality Criteria from 1996.
² Human cancer criterion.

Water Column Results: Lower Fox River at the Mouth

* Water column PCB concentrations at the mouth of the Lower Fox River are 10 to 100 times higher than at Appleton in all the 100 year forecasts (Figures 15 and 16).

* Simulated remediations lower water column PCB concentrations up to 5 times farther than "No Action" (Figure 15).

* Simulated remediations do not achieve present NR 105 warm water sport fish classification criteria (0.49 ng/L) during the 100 year simulations. However, when model results are extrapolated to this endpoint, simulated remediations reduce the time to attain the criteria by 15-35% (Table 4).

* As upstream of De Pere, attaining the proposed Great Lakes Initiative water quality criteria will depend on the future PCB loading to the river. These loadings, however small, cannot be forecast with the present model.
Table 5. Forecasted Cumulative PCB Mass Exported to Green Bay 1996-2096

<table>
<thead>
<tr>
<th>MODEL SCENARIOS</th>
<th>PCB MASS TRANSPORT (kg)</th>
<th>RELATIVE TO &quot;No Action&quot; SCENARIOS (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Baseline&quot; Hydrograph in the Lower Fox River.</td>
<td>&quot;No Action&quot;</td>
<td>14,188</td>
</tr>
<tr>
<td></td>
<td>Remediate 3 deposits and 17 SMUs</td>
<td>7,658</td>
</tr>
<tr>
<td></td>
<td>Remediate 4 deposits and 50 SMUs</td>
<td>3,584</td>
</tr>
<tr>
<td>&quot;Baseline&quot; Hydrograph in the Lower Fox River including a single 100 year flood event.</td>
<td>&quot;No Action&quot;</td>
<td>18,162</td>
</tr>
<tr>
<td></td>
<td>Remediate 3 deposits and 17 SMUs</td>
<td>8,320</td>
</tr>
<tr>
<td></td>
<td>Remediate 4 deposits and 50 SMUs</td>
<td>3,770</td>
</tr>
</tbody>
</table>

1 Remediation date = 7/1/2000, residual PCB concentration = 2.5 mg/kg in surficial sediment (top 10 cm).

PCB Export: Lower Fox River to Green Bay

* Over the next century, approximately one-half of the estimated PCB in the Lower Fox River will be exported to Green Bay.

* A single high flow event (100 year flood) increases the amount of PCB exported to Green Bay by almost 30% (18,000 kg versus 14,000 kg).

* Remediation significantly reduces the PCB mass exported to Green Bay. Simulated remediation scenarios reduce PCB export by 50 - 80%.

* Remediation reduces flood event-related PCB transport even more dramatically -80% to 95% compared to "No Action".
Surface Sediment Concentrations

Figure 17. Forecasted Surface Sediment PCB Concentrations in Little Lake Butte des Morts: 1996-2096

* Sediment remediation results in lower average surface sediment PCB concentrations than "No Action".
* Both simulated remediations in LLBdM accomplish similar surface sediment PCB reductions.
* A high flow event in the Neenah Slough resuspends and redistributes PCB sediment from Deposit A throughout LLBdM resulting in increased sediment PCB concentrations for an extended period.
* Sediment remediation results in lower average surface sediment PCB concentrations than "No Action".

* Remediation of "3 Up and 17 Down" reduces average surface sediment PCB concentrations by 50% compared to "No Action".

* Remediation of "4 Up and 50 Down" reduces average surface sediment concentrations by more than 90% compared to "No Action".
Fish Tissue Concentrations

* Sediment remediation results in lower fish tissue PCB concentrations than "No Action".
* Both simulated remediations in LLBdM accomplish similar fish tissue reductions.
* A high flow event in the Neenah Slough resuspends and redistributes PCB sediment from Deposit A throughout LLBdM resulting in increased fish tissue PCB concentrations for an extended period.
Table 6. Time for Fish Tissue PCB Concentrations in Little Lake Butte des Morts to Reach Consumption Endpoints

<table>
<thead>
<tr>
<th>Consumption Endpoint</th>
<th>PCB Concentration (mg/kg)</th>
<th>Time in Years to Meet Criteria Under Three Scenarios¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Action</td>
<td>RemEDIATE &quot;3 up and 17 Down&quot;</td>
</tr>
<tr>
<td>Do Not Eat</td>
<td>&gt; 1.89</td>
<td>---</td>
</tr>
<tr>
<td>6 Meals per Year</td>
<td>1.89</td>
<td>---</td>
</tr>
<tr>
<td>1 Meal per Month</td>
<td>0.95</td>
<td>---</td>
</tr>
<tr>
<td>1 Meal per Week</td>
<td>0.22</td>
<td>3</td>
</tr>
<tr>
<td>Unlimited Consumption</td>
<td>&lt; 0.05</td>
<td>12</td>
</tr>
<tr>
<td>Wildlife</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Great Lakes Initiative⁴</td>
<td>0.023</td>
<td>18</td>
</tr>
</tbody>
</table>

16" Carp (whole fish)

| Wildlife             | 0.023                    | 30                               | 21                               |
| Great Lakes Initiative⁴| 0.023                    | 30                               | 21                               |

¹ Projections obtained directly from model output. Projections from 1996.
² Average PCB concentrations found during 1996 fish sampling was less than endpoint.
³ Remediation reduces average surface sediment PCB concentrations below that needed to exceed this fish tissue level using the BSAF model. Fish tissue PCB concentrations would be expected to fall below this consumption level following equilibration to the new exposure conditions.
⁴ Protection of most sensitive species - mink. Based on whole fish values.

* Both simulated remediations in LLBdM reduce the time to eliminating human health fish consumption advisories by 25% compared to "No Action".
* Both simulated remediations in LLBdM accelerate attainment of ecologically protective fish tissue PCB concentrations by 30-60% compared to "No Action".
Figure 20. Forecasted Fish Tissue PCB Concentrations Downstream of De Pere: 1996-2096

20+" Walleye Downstream of DePere

- The fish consumption advisory for 20+" walleye and white bass of one meal per month remains for the entire forecast period.

- Remediation of "3 Up and 3 Down" (not shown) results in less than a 10% difference in fish tissue concentration compared to "No Action".

- Remediation of "3 Up and 17 Down" reduces fish tissue concentrations by 50% compared to "No Action".

- Remediation of "4 Up and 50 Down" reduces fish tissue concentrations by more than 90% compared to "No Action".
Table 7. Time for Fish Tissue PCB Concentrations Downstream of De Pere to Reach Consumption Endpoints

### White Bass and 20+” Walleye (fillet)

<table>
<thead>
<tr>
<th>Consumption Endpoint</th>
<th>PCB Concentration (mg/kg)</th>
<th>No Action</th>
<th>RemEDIATE &quot;3 up and 17 Down&quot;</th>
<th>RemEDIATE &quot;4 Up and 50 Down&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do Not Eat</td>
<td>&gt; 1.89</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6 Meals per Year</td>
<td>1.89</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1 Meal per Month</td>
<td>0.95</td>
<td>49</td>
<td>9¹</td>
<td>6³</td>
</tr>
<tr>
<td>1 Meal per Week</td>
<td>0.22</td>
<td>142</td>
<td>89</td>
<td>12³</td>
</tr>
<tr>
<td>Unlimited Consumption</td>
<td>&lt; 0.05</td>
<td>235</td>
<td>191</td>
<td>80</td>
</tr>
<tr>
<td>Wildlife</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Lakes Initiative</td>
<td>0.023</td>
<td>284</td>
<td>245</td>
<td>147</td>
</tr>
</tbody>
</table>

### 16” Carp (whole fish)

| Wildlife              |                           |           |                             |                             |
| Great Lakes Initiative | 0.023                    | 341       | 306                         | 223                         |

1. Projections based on regression of last 50 years of model simulation. Projections from 1996.
2. Average PCB concentrations found during 1996 fish sampling was less than endpoint.
3. Projection obtained directly from model output.
4. Protection of most sensitive species - mink. Based on whole fish values.

* The "3 Up and 17 Down" remediation simulation reduces time to eliminate walleye and white bass fish consumption advisories by 20%.

* The "4 Up and 50 Down" remediation simulation reduces the time to eliminate walleye and white bass fish consumption advisories by 65%.

* The "3 Up and 17 Down" remediation simulation accelerates attainment of ecologically protective fish tissue PCB concentrations downstream of De Pere by 10%.

* The "4 Up and 50 Down" remediation simulation accelerates attainment of ecologically protective fish tissue PCB concentrations downstream of De Pere by 35%.
SUMMARY

Recent Trends in River Conditions

* Water column PCB concentrations throughout the river remain similar to 1989 conditions.

* Water column PCB concentrations at the river mouth continue to exceed established water quality criteria by ten to more than 800 times.

* The top 3 feet of sediment downstream of De Pere has changed very little in PCB concentration or mass between 1989 and 1995.

* PCB concentrations in popular sport fish species throughout the river are declining slowly, if at all, since the elimination of active PCB discharges.

* In 1996, PCB concentrations observed in popular sport fish fillets throughout the entire Lower Fox River pose a human health risk necessitating continued fish consumption advisories.

Model Post-Audit

* The model post-audit process illustrates the models’ unique forecasting capabilities.

* The demonstrated performance of the models indicates that they are appropriate tools to provide valuable insight and information for making management decisions.

Forecasts of Water Quality Improvement

* The large reservoir and slow release of PCB from the sediment will elevate water column PCB concentrations above water quality criteria for the foreseeable future.

* Sediment remediation reduces water column PCB concentrations and the amount of time to attain water quality criteria.

* Sediment remediation can substantially reduce PCB export to Green Bay.

* Greater reductions in PCB transport/export are gained when remediation addresses contaminated sediment sites with larger surface areas.

* The area downstream of De Pere holds the majority of the PCB in the river and accounts for the majority of PCB exported to Green Bay.
Forecasts of Fish Tissue PCB Concentrations

Upstream of De Pere

* Sediment remediation reduces fish tissue PCB concentrations and the amount of time to eliminate fish consumption advisories or attain fish tissue PCB concentrations protective of fish-consuming wildlife (e.g., mink).

* Remediation of large areas with lower PCB contamination produces similar fish tissue PCB concentrations as remediating smaller areas with higher contamination (Deposits A, D/E and POG versus A, C, and POG in LLBdM, respectively).

Downstream of De Pere

* Sediment remediation reduces fish tissue PCB concentrations and the amount of time to eliminate fish consumption advisories or attain fish tissue PCB concentrations protective of fish-consuming wildlife (e.g., mink).

* The greater the remediation effort, the greater the reduction in fish tissue PCB concentration and the shorter the time to eliminate consumption advisories.
PRELIMINARY CONCEPTUAL MODEL OF PCB DYNAMICS IN THE HOUSATONIC RIVER

Confidential - For Mediation Purposes

John Connelly

December 9, 1997
GE Housatonic River Project

Spatial Profile of Recent Sediment, Water, and Fish PCB Concentrations

Data at Cornwall is not Part of Young of Year Program
General Electric Company - Housatonic River Project
Spatial Profile of 1997 Water Column PCB Loading Data
March, 1997 Sampling Event

Housatonic River - Spatial Profiles of 1997 Water Column Data
Non Detect PCBs Plotted as Open Symbols at 0.5 MDL
Non Detect Loadings Plotted at 0.5 MDL
Woods Pond Surficial Sediment
PCB Concentration

Mean +/- 95% CI
Data derived from total PCB, TOC, and Cs137 data collected in 1995
Rising Pond Surficial Sediment
PCB Concentration

Approximate Year

Mean +/- 95% CI
Data derived from total PCB and 137Cs data collected in 1996
General Electric Company - Housatonic River Project
Temporal Profile of PCB Concentrations in Surface Sediments and Largemouth Bass from Wood Pond
Note: Lines represent linear regressions of the data
General Electric Company - Housatonic River Project
Temporal Decline of Normalized PCB Concentrations for Largemouth Bass and Surface Sediments in Woods Pond

Mean PCB Concentration Normalized to 1980's Value (± 95% Confidence)

- Largemouth Bass
- Surface Sediments
- Linear Regression of Data

Year
OVERVIEW OF RIVER CONDITIONS

- Surface sediment PCB concentrations decline by greater than a factor of 100 between the Plant Site and Cornwall, CT

- Fish and water column concentrations may decline more slowly with distance than does surface sediment concentrations, suggesting that downriver fish get a significant fraction of their PCBs from the water column

- Generally, between 60 and 120 g/d of PCBs enter the river water column between the Plant Site to Woods Pond headwaters

- Water column loadings typically drop by a factor of 2, or more, between Woods Pond headwaters and Woods Pond Dam

- Sampling during a high flow event in March 1997 indicated that solids and PCBs were deposited in the sediment between New Lenox Rd and Woods Pond headwaters, resulting in a factor of 4 drop in PCB loading

- TSS data and dated sediment cores indicate that sedimentation occurs in the following areas:
  - between New Lenox Road and Woods Pond
  - in Woods Pond
  - backwaters behind downstream dams

- Natural recovery is occurring as evidenced by PCB data from dated sediment cores
  - levels decline by about a factor of two in ten years
SEDIMENTS AS A SOURCE OF PCBS TO THE WATER COLUMN

• Mechanisms:

  Resuspension

  Diffusion  Groundwater Flow

• Rates of Flux:

  Resuspension is a function of:

  - PCB concentration on surface particles
  - rate of erosion of surface particles

  Diffusion and Groundwater Flow are functions of:

  - PCB concentration in surface pore water
  - diffusion rate or groundwater velocity
WHAT IS MEANT BY THE TERM SURFACE?

Surface refers to the layer that interacts with the water column and with the food chain

- layer reworked by organisms
- layer eroded during flood events
- layer from which PCBs can migrate to the water column
Housatonic River Resuspension Potential Data (2 ft/sec current)

Mean +/- 95% confidence interval

[Graph showing data for Fox River, Buffalo River, and TIP, Pawtuxet & Saginaw Rivers, with specific positions indicated by river mile markers: Woods Pond Dam, Columbia Mill Dam, Willow Mill Dam, Glenlake Dam, Rising Pond Dam, MA-CT Border, Falls Village Dam, and Bulls Bridge Dam.]
ConeSive Bed Erosion at 47,330 cfs (100 YF)

Legend

- Mile Markers
- Erosion (mm)
- -65 - -56
- -56 - -24
- -24 - -12
- -12 - -5
- -5 - 0
- Dams & Locks
- Shore

N
Horizontal Lines Represent 10, 50, and 100-Year Flood Flows

General Electric Company - Housatonic River Project
Hydrograph for Daily Discharge at the USGS Gaging Station in Great Barrington, MA
Fig. 4. Sample of logistic curve from equation (5) for one of the 71 congeners (236,2'3'4'5'6').


Fig. 6. Plot of maximum release from sterile sediments as contrasted to $K_{ow}$ values for 71 congeners.
# Observed Fluxes for the Four Polychlorinated Biphenyls Studied

<table>
<thead>
<tr>
<th>Day</th>
<th>Average flux (nmol m⁻² day⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2, 3', 5</td>
</tr>
<tr>
<td>4-12</td>
<td>0.22</td>
</tr>
<tr>
<td>12-25</td>
<td>0.12</td>
</tr>
<tr>
<td>49-74</td>
<td>0.02</td>
</tr>
</tbody>
</table>

SURFACE REFERS TO THE TOP FEW CENTIMETERS OF SEDIMENT

☐ Because river sediment fauna tend to be dominated by small worms and insect larvae, biological mixing of surface sediments occurs only in the upper few centimeters.

☐ Typically, only sediments within a few millimeters of the surface are eroded during a river flood event.

☐ Even rare floods erode only a few centimeters.

☐ Sorption minimizes the migration of subsurface PCBs to the surface by diffusion or groundwater advection.
RESUSPENSION

- erosion from muddy (cohesive) and sandy (non-cohesive) sediments

- requires that shear stress exceeds some critical value

- limited by bed armoring that occurs due to:
  - cohesive forces in muddy sediments
  - depletion of resuspendable sized particles in sandy sediments
Hudson River Project - 1997 TIP Float Survey Data

Spatial Plots of TSS Averaged Across Sampling Transects

Note: Open Square Represents PCRDMP Sample at Thompson Island Dam
ESTIMATED RESUSPENSION AND DEPOSITION IN THE THOMPSON ISLAND POOL OF THE HUDSON RIVER DURING LOW TO MODERATE RIVER FLOW

<table>
<thead>
<tr>
<th>River Flow (cfs)</th>
<th>Deposition Rate (metric tons/d)</th>
<th>Resuspension Rate (metric tons/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,500 (summer low flow)</td>
<td>6.0</td>
<td>0.0</td>
</tr>
<tr>
<td>5,000 (annual average)</td>
<td>1.2</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

December 9, 1997
Flow at Fort Edward

TIP above Snook Kill

TIP at McDonalds Dock

Thompson Island Dam

Run: 473
Upper Hudson River - Model and Data Comparison
EPA Phase II TSS Data (1994)
RESUSPENSION OCCURS ONLY DURING FLOOD EVENTS
ESTIMATION OF THE DIFFUSIVE FLUX IN THE HOUSATONIC RIVER

\[ \text{FLUX (mg/m}^2\text{-d)} = \text{mass transfer constant} \times \text{surface pore water PCB concentration} \]
Surface Pore Water PCB Concentration

- Net result of an equilibrium between adsorption and desorption reactions

- Organic matter is the only sorptive material of any consequence in natural sediments

- Pore water PCB concentration is directly proportional to the PCB concentration on the organic matter
Figure 21.—Comparison of eight PCB congener concentrations of >63 μm sized particles, ordinate, to <63 μm sized particles, abscissa (Stations 1-7). Top panel is for dry weight normalization; bottom panel is for organic carbon normalization. PCB congeners are IUPAC Nos 28, 52, 101, 118, 138, 153, 179 and 180. Data from [47].
Figure 17.—Comparison of PAH concentrations of the sand-sized- and low-density-fraction sediment particles ordinate to the clay/silt fraction abscissa (Stations 4, 5, 7). Top panels are for dry weight normalization; bottom panels are for organic carbon normalization. Data from [44].
Figure 24.—Comparison of organic carbon partition coefficient ($K_{oc}$) observed in toxicity tests (symbols) to $K_{oc}$ derived from laboratory $K_{ow}$ and Equation 11 (solid line). Symbols are sediment concentration ordinate, versus pore water concentration, abscissa. Solid line is $C_{s,oc} = K_{oc} * C_{o}$, where $\log_{10} K_{oc}$ is 3.76 for acenaphthene, 4.84 for endrin, 4.46 for phenanthrene, and 5.00 for fluoranthene. These $\log_{10} K_{oc}$ values are estimated from $\log_{10} K_{ow}$ values measured at the U.S. EPA Environmental Research Laboratory at Athens, Georgia. Data sources as indicated.
General Electric Company - Housatonic River Project
Spatial Profile of 1995 and 1996 Surface Sediment PCB Data (Top 6 Inches Only)
Note: Quanterra Data Recomputed as Aroclor Sum (A1254 + A1260) and Plotted as Open Symbols
Sediment PCB Levels Between the Plant Site and Woods Pond

- Variability is greatest near the Plant Site area (200 to 15,000 ppm OC)
- Sediments downstream of the Plant Site have similar concentrations over broad areas:
  - Between Holmes Road and New Lenox Road levels are mostly between 500 to 3,000 ppm OC
  - Between New Lenox Road and Woods Pond levels are mostly between 100 and 800 ppm OC

1Comparisons are made using carbon normalized PCB concentrations because PCB diffusive flux is determined by carbon-based concentrations
Symbols = Water Column Loadings
Lines = Predicted Loadings from 95 - 97 Sediment Data (k = 1 cm/day)

1989 to 1991 Total PCB Loading

1989 to 1991 Aroclor 1254 Loading

1989 to 1991 Aroclor 1260 Loading

Notes: 1989 - 1991 MDL = 65 ppt
Quanterra PCB Totals adjusted by adding 1254 @ MDL to 1260 in sediment data
"Fish" Samples included in 1995 to 1996 "Water Column Data"
Flows for water column loadings calculated using drainage basin proration
Surface sediment: Start Depth = 0; End Depth <= 6 inches
Backwaters included in Reach 1C
Area Weighted Mean used in Sediment Reach 1A
Error Bars Represent Maximum and Minimum Loading
Symbols = Water Column Loadings
Lines = Predicted Loadings from 95 - 97 Sediment Data (k = 1 cm/day)

1997 Total PCB Loading

1997 Aroclor 1254 Loading

1997 Aroclor 1260 Loading

Notes: 1997 MDL = 22 ppt
Quanterra PCB Totals adjusted by adding 1254 @ MDL to 1260 in sediment data
Flows for water column loadings calculated using drainage basin proration
Surface sediment: Start Depth = 0; End Depth <= 6 inches
Backwaters Included in Reach 1C
Area Weighted Mean used in Sediment Reach 1A
Error Bars Represent Maximum and Minimum Loading
SUMMARY OF SEDIMENT PCB SOURCE

- Derived from the top few centimeters of the sediment

- Resuspension is a factor only during flood events

- Diffusion accounts for the PCB loading increase observed during low to moderate river flows

- The largest PCB loading to the water column occurs in the region between New Lenox Road and Woods Pond: a consequence of the relatively large surface area in this region of the river

- The similarity of carbon normalized surface sediment PCB concentrations within broad river reaches indicates that the entire sediment surface contributes PCBs to the water column

- Reductions in PCB loading from sediments will occur in rough proportion to the reduction in contaminated surface area, i.e., elimination of PCBs in 50% of the river surface area will reduce PCB flux by about 50%
OTHER SOURCES

Potential Sources

- Inputs upstream of the Plant Site
- Unkamet Brook
- Silver Lake
- Plant Discharges
- West Branch of the Housatonic River

Basis for Evaluation

- measurements of PCBs and flow
Housatonic River
Low-Flow External Source Loading Summary

Estimate PCB Loading (g/day)

Source

Upstream
Unkament Brook
Silver Lake
* Plant Site
W. Branch
Total Ext.
Total Diff.

* NPDES Discharge: Estimated for Outfall 005, 007 & 009

* 12/5/97
OTHER SOURCES

- The potential sources examined appear to account for a few percent of the PCB loading to the water column between the Plant Site and Woods Pond.
OVERALL CONCEPTUAL MODEL

- In river sediments are the primary PCB source to the water column
  - measurements indicate that external sources are minor
  - estimated diffusive flux accounts for the measured loading to the water column

- Only the top few centimeters of sediment contribute PCBs to the water column (and to biota)
  - erosion does not mobilize deeper sediments
  - it is likely that benthic organisms are concentrated in the top few centimeters
  - sorption minimizes upward migration of PCBs from below the surface

- Sediments throughout the river bottom contribute PCBs to the water column
  - diffusive flux determined by pore water concentration which is in turn determined by carbon normalized sediment concentration
  - within broad river reaches the range in carbon normalized sediment concentrations is less than a factor of 10
OVERALL CONCEPTUAL MODEL CONT'D.

- Natural recovery has been occurring
  - PCBs in fish and sediment from Woods Pond have declined over time at similar rates
  - PCBs in Rising Pond sediments have declined over time
NEXT STEPS

• Refine the conceptual model
  - incorporate agency data
  - collect and incorporate additional data
    - monthly water column PCBs
    - dated sediment cores
    - adult fish in MA (part of EcoRisk workplan)
    - y-o-y fish in MA and CN

• Explore quantitative tests of the conceptual model
  - mass balance calculations