A dynamic decision support tool for understanding the potential health impacts of different fish consumption patterns for mercury and PCBs in Great Lakes rivers

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www.mtri.org

GLEAMS review

- Partnership between MTRI and the Western Michigan University (WMU) Environmental Institute; funded by EPA ORD
- Goal: Address the legacy of contamination on the Great Lakes and their watersheds
  - Help local & state stakeholders understand this legacy
- Project developed watershed-scale methods to assess and protect human and ecosystem health
  - Used the Kalamazoo River watershed as an example site
  - Modeled PCB risk and water quality
  - Expanded PCB Dynamic Decision Support System (DSS) to Lower Fox River, WI
  - Developed Fox River mercury DSS tool
GLEAMS web portal

- Resource for Great Lakes information, esp. for Kalamazoo River & Lower Fox River as demonstrations of risk analysis web decision support tools of intensive data collection
- www.greatlakesdecisionsupport.org
  - Science
  - GIS and Decision Support Systems
  - Modeling
  - Outreach
  - Great Lakes information

Mercury decision support tool – predict human health risk using GIS data & models

- Goal: Develop a tool to help users understand if local fish consumption is likely to lead to mercury exposure above EPA reference doses, esp. for women of 18-45, using spatial sediment data as starting point
- Used documented Wisconsin DNR Lower Fox River database – Lower Fox River Environmental Database (J.Kreider) – for the WDNR Fox Environmental Information Management System (EIMS)
- Capture complexity of modeling health risk from mercury in a valid & user-friendly on-line mapping interface
  - http://maps.mtri.org/website/GLEAMS_foxriver/
- Enable user interaction, selection of scenarios: help community members to understand level & locations of risks
Mercury modeling issues

- Most common aquatic mercury chemical species:
  - Elemental, inert (Hg^0); Divalent, reactive (Hg^{2+}); Organic (MeHg)
- The first two, non-biologically available forms (elemental and divalent) are the most common often accounting for greater than 90% of total environmental mercury.
  - Opposite is true for biological uptake: > 90% of tissue-bound mercury is MeHg
- Mercury methylation typically occurs in the inactive, anoxic sediment layer of lakes and streams regulated by sulfate concentration, sulfate-reducing bacteria, pH, DOC/TOC, and temperature.
  - Speciation model is derived from a ‘finite element model’
  - Bioaccumulation – modeled using a generalized hydrophobic bioaccumulation model.
  - Wide species applicability and simplified calibration procedure
  - Challenging to incorporate the effects of weight and age, highly sensitive to changes in bioconcentration factor
- Human Health
  - Two methods to assess health risks. Both originate from EPA recommendations:
    1. RfD (reference dose) → acceptable blood mercury level that can be physiologically maintained resulting in no noticeable health effects → 0.0001 mg MeHg/kg body weight-day (female and children), 0.0003 (male)
    2. TRC (tissue residue criterion) → fish tissue concentration that when consumed will not result in a RfD above the recommended value
      - A relatively simple calculation involving body weight, dietary intake, and fish tissue concentration

Generalized Mercury Model Diagram

- Mercury Speciation
  - Inorganic: Hg^0, Hg^{2+}
  - Organic: MeHg
- Bioaccumulation
- Fish Tissue Concentration
- Human Health Risk
- Reference Dose
- Tissue Residue Criterion

**Example Data**

1998 Mercury sediment concentrations from WDNR Low Fox River Environmental Information Management System (Jeff Kreider)

<table>
<thead>
<tr>
<th>Polygon ID</th>
<th>Total Hg (Sediment)</th>
<th>Hg</th>
<th>Hg2</th>
<th>MeHg</th>
<th>Hg</th>
<th>Hg2</th>
<th>MeHg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1</td>
<td></td>
<td>0.096309</td>
<td>0.0034791</td>
<td>0.00090023</td>
<td>0.71135</td>
<td>0.38575</td>
</tr>
<tr>
<td>2</td>
<td>0.97</td>
<td></td>
<td>0.084926</td>
<td>0.0030679</td>
<td>0.00079383</td>
<td>0.62727</td>
<td>0.34016</td>
</tr>
<tr>
<td>3</td>
<td>0.49</td>
<td></td>
<td>0.042901</td>
<td>0.0015498</td>
<td>0.00040101</td>
<td>0.31687</td>
<td>0.17183</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td></td>
<td>0.087553</td>
<td>0.0031628</td>
<td>0.00081838</td>
<td>0.64667</td>
<td>0.35068</td>
</tr>
</tbody>
</table>

Predicted (μg/L - Water, mg/kg - Sediment)

<table>
<thead>
<tr>
<th>Known (mg/kg)</th>
<th>Water Column Sediment</th>
<th>Bioconc. Level</th>
<th>Fish Species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Carp</td>
<td>Perch</td>
</tr>
<tr>
<td>Min 0.0126</td>
<td>0.0115</td>
<td>0.0045</td>
<td></td>
</tr>
<tr>
<td>Mean 0.0425</td>
<td>0.0324</td>
<td>0.0444</td>
<td></td>
</tr>
<tr>
<td>Max 0.1257</td>
<td>0.1024</td>
<td>1.1404</td>
<td></td>
</tr>
</tbody>
</table>

**Example Health Risk Scenarios**

- Scenarios can be run under different bioconcentration levels to incorporate uncertainties associated with fish ecology (e.g. unconstrained movement ranges, size variability, age, etc.).
- Bioconcentration factors were calibrated to *in situ* fish tissue concentrations using a Monte Carlo-based optimization procedure.
- The range of bioconcentration factors allows the food web model to demonstrate a valid range of concentration predictions.

Information below available through a mapping DSS interface.

**Example Typical Consumption**

<table>
<thead>
<tr>
<th>Meals Kg/Month</th>
<th>Carp</th>
<th>Perch</th>
<th>Walleye</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25 - 0.30</td>
<td>0.03 - 0.20</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1.5 - 0.30</td>
<td>1.15 - 0.30</td>
<td>1.5 - 0.30</td>
<td></td>
</tr>
</tbody>
</table>

**Example High Consumption**

<table>
<thead>
<tr>
<th>Meals Kg/Month</th>
<th>Carp</th>
<th>Perch</th>
<th>Walleye</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25 - 0.30</td>
<td>0.03 - 0.20</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1.5 - 0.30</td>
<td>1.15 - 0.30</td>
<td>1.5 - 0.30</td>
<td></td>
</tr>
</tbody>
</table>

**Fish Tissue Residue Criterion (mg MeHg/kg)**

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>Age</th>
<th>Bioconc. Level</th>
<th>EPA Criterion</th>
<th>Typical</th>
<th>EPA Criterion</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man 78</td>
<td>30</td>
<td>0.0003</td>
<td>0.00005</td>
<td>0.00005</td>
<td>0.00005</td>
<td></td>
</tr>
<tr>
<td>Woman 65</td>
<td>30</td>
<td>0.0001</td>
<td>0.00005</td>
<td>0.00005</td>
<td>0.00005</td>
<td></td>
</tr>
<tr>
<td>Teenager 45</td>
<td>15</td>
<td>0.0001</td>
<td>0.00005</td>
<td>0.00005</td>
<td>0.00005</td>
<td></td>
</tr>
</tbody>
</table>
DSS entry page:
http://maps.mtri.org/website/GLEAMS_foxriver/

User selects area of interest
Mercury Tool Demo:
Querying data through tool for Lower Fox River

Mercury Tool Demo:
Bioaccumulation levels in fish
Mercury Tool Demo: Are the risk criteria exceeded?

Example consumption scenarios

- User can test different consumption scenarios.
- Example 1: 2 walleye & 1 perch per month, no carp
- Woman, age 30, 60 kg (132 lbs)
- Reference dose & fish tissue residue criterion exceeded
- 45 of 57 WDNR 1998 sediment surface samples had mercury concentrations higher than 0.49 mg/kg (which result in criteria being exceeded)
- Other scenarios can easily explored
Child scenario

- 41 kg (90 lb), 12-year-old girl, 2 walleye / month
- Mean vs. max bioconcentration factor
- With maximum bioconcentration, risk criteria are exceeded

Interactive concentration queries

- User can select the mercury concentration query tool & find all areas with total mercury above certain concentrations.
- Example: All 1998 samples with total Hg > 1.0 mg/kg = 20 locations along Lower Fox River
Future: display tools & tools with new mapping tools (Google Earth)

Tool flexibility

- User changeable variables – can replace modeled information:
  - Methyl mercury for sediment and water column
  - MeHG fish tissue concentration
- Bioconcentration factors – range of possible fish mercury concentrations (based on F. Gobas 1993 & WDNR fish tissue data) – helps capture fish mobility, diet changes, size variability
- Consumption variables:
  - Gender
  - Body weight
  - Age
  - Meals per month
- Flexibility is intended to provide ability for users to explore & discover mercury, food web, and consumption relationships & help stakeholders understand the science in a more accessible way
GLEAMS PCB tool

- Tool maps the concentrations of sediments contaminated with polychlorinated biphenyls (PCBs) in the Kalamazoo River
- Data comes from Potentially Responsible Parties (PRPs)
- Ties sediment concentrations into human health risks based on MDEQ ecological & human health risk model
- Uses ArcIMS web mapping technology
- Ties into a dynamic Decision Support System (DSS) tool that enables users to understand potential health risks of eating contaminated fish from the river
- New functionality:
  - Find the areas above 0.5 ppm PCB concentration
  - Evaluate exposure likely from more rain events causing increase in exposure from contaminated sediments

Example Decision Support System (DSS) Scenarios

- For Lake Allegan, Michigan, along the Kalamazoo River
  - Member of a local watershed group trying to understand risks
  - A community leader helping local citizens understand impacts of the legacy of pollution
  - Agency person working on fish consumption guidelines
- Where are the risky areas? What are the risks?
  - Kalamazoo River (Superfund site)
  - PCBs – cancer / immune system / reproductive health risks
- Used MDEQ reports for assessing risk:
  - Baseline Ecological Risk Assessment (263 pages)
  - Human Health Risk Assessment (169 pages)
Dams

Paper Companies
Risk Assessment

DISCLAIMER: PROVISIONAL DATA SUBJECT TO REVISION.
Many of the values presented are obtained using models. While these values are generated from standard EPA exposure models and represent a scientific 'best estimate', the modeled results may differ from actual field conditions.

<table>
<thead>
<tr>
<th>Sediment</th>
<th>Aquatic</th>
<th>Mammalian</th>
<th>Avian</th>
<th>Human</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentrations</td>
<td>1.81  mg/kg</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This is the concentration of PCBs measured in river sediments. This value is used to predict ecological and human health risk.

<table>
<thead>
<tr>
<th>Organic Carbon Fraction</th>
<th>0.02</th>
<th>(fraction)</th>
</tr>
</thead>
</table>

This is the portion of the river sediment that is composed of organic carbon. Greater values of Organic Carbon Fraction lead to lower concentrations in consumers.

<table>
<thead>
<tr>
<th>Smallmouth Bass</th>
<th>Carp</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB</td>
<td></td>
</tr>
<tr>
<td>Biotas-Sediment Accumulation Factor</td>
<td>0.44</td>
</tr>
<tr>
<td>Liquid Fracions</td>
<td>0.01</td>
</tr>
<tr>
<td>PCB Concentrations</td>
<td>0.56</td>
</tr>
<tr>
<td>PCB</td>
<td></td>
</tr>
<tr>
<td>Biotas-Sediment Accumulation Factor</td>
<td>0.64</td>
</tr>
<tr>
<td>Liquid Fracions</td>
<td>0.00</td>
</tr>
<tr>
<td>PCB Concentrations</td>
<td>0.31</td>
</tr>
</tbody>
</table>
Accumulation in people

Tool to display high PCB areas

(>0.5 ppm)

1) Click on “PCB .5ppm” tool button first
2) Click on “Remediation Parameter” button to create “PCB>0.5ppm” query next
3) Click on “Locate Remediation Areas” button 3rd to find these areas
Example of PCB 0.5ppm tool – areas in Lake Allegan with PCBs >0.5 ppm

Areas in Lake Allegan > 3.0 ppm
Climate Change scenario: 30% increase in BSAF due to storm events

- We are estimating sediment loads in the Kalamazoo River representing an increase in extreme rain event (climate change) scenario
  - Using “Biota-Sediment Accumulation Factor” (BSAF)
  - BSAF is representative of the average surface sediment in the vicinity of an organism
  - We are assuming that more extreme rain events have increased this sediment/water interface exposure value by 30%
- Yield is increased exposure to PCBs in the food chain
- We are assuming that the food chain is being exposed to more contaminated sediment because of an increase in storm events (disturbance of the sediment/water interface)
- How does this cascade through the food chain & impact human health?

Difference in health risk: Original vs. increased BSAF values

Risk with original BSAF values

Risk with increased BSAF values
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- GLEAMS Portal: www.greatlakesdecisionsupport.org
  - Mercury & PCBs – Fox River web mapping site: http://maps.mtri.org/website/GLEAMS_foxriver/
  - PCB Kalamazoo River web mapping site: http://maps.mtri.org/website/Gleams-Template/

- WMU Environmental Institute: www.wmich.edu/env/

- MTRI: www.mtri.org