The Transport and Deposition of Dioxin
to Lake Michigan: A Case Study

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Presentation at:

“Using Models to Develop
Air Toxics Reduction Strategies:
Lake Michigan as a Test Case”

Milwaukee, Wisconsin, Nov 8-9, 2000

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The Transport and Deposition of Dioxin to Lake Michigan: A Case Study

Presentation Outline

- Policy Making Context and the potential role of models
- regarding atmospheric deposition, What Do We Need to Know? and How Well Do We Need to Know It?
- Atmospheric Deposition of Dioxin to Lake Michigan
- Uncertainty Analysis
- Conclusions and Recommendations
### POLICY MAKING CONTEXT

<table>
<thead>
<tr>
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<th>EFFECTS?</th>
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| 1. | Harmful effects on wildlife, public health?  
    | [what is the exposure? consequences of this exposure?] |   |

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<th>CAUSES?</th>
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| 2. | What is the relative contribution of different loadings pathways contributing to the harmful effects?  
    | And, for any given significant loading pathway, what are the relative contributions of different sources? |   |

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<th>COSTS?</th>
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| 3. | What are the technical options involved in reducing or eliminating the contributions from major sources?  
    | What are the costs to implement these options? |   |

**Decision Making: Need Info in All Three Areas**  
*Or, it doesn’t necessarily do you much good to have precise information in one area, if one or more of the other areas remain very uncertain*

**How much do we know regarding these questions for dioxin in Lake Michigan?**
THE ROLE AND POTENTIAL VALUE OF MODELS

ë MODELS are mathematical/conceptual descriptions of real-world phenomena

ë Necessarily a simplification; the real world is very complicated

ë Key processes must be sufficiently characterized

ë MODELS are POTENTIALLY VALUABLE for:

ë Examining different large-scale scenarios that cannot be easily tested in the real world (e.g., different emissions reduction scenarios).

ë Interpreting measurements

ë Filling in spatial and temporal gaps between measurements

ë MODELS are a TEST of our KNOWLEDGE:

ë Attempts to synthesize everything important about a given system.

ë If a model fails, we don’t understand enough about the system.

ë MODELS are USED IN developing approximate answers in ALL THREE fundamental policy information areas
Figure 1: Total Dioxin Emissions for 1996

Areal Density of Dioxin Emissions (µgrams TEQ/km²-yr)

- 0 - 0.1
- 0.1 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- 100 - 300
- 300 - 5000
- 5000 - 335000

No Data Available
Figure 4. Comparison of Model Predictions with Ambient Measurements at Month-Long Sample Sites [Total PCDD/F (TEQ)]

- Mohawk Mountain (1st three data points)
  - Model prediction
  - Measurement

- Vermont (last two data points)
  - Model prediction
  - Measurement
Mid-Range Estimate of the Contribution to 1996 Atmospheric Deposition of Dioxin to Lake Michigan (µgrams TEQ/km²-yr)

Contribution to Deposition
(µgrams TEQ/km²-yr)

- 0 - 0.01
- 0.01 - 0.1
- 0.1 - 1
- 1 - 10
- 10 - 100
- 100 - 1000
- 1000 - 7000

No Data Available
Estimates of the Percent of Lake Michigan Dioxin Loadings Attributable to the Atmospheric Deposition Pathway

<table>
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<tr>
<th>Study</th>
<th>Fraction of Current Loadings Contributed Through the Atmospheric Pathway</th>
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<tbody>
<tr>
<td><strong>Cohen et al.</strong></td>
<td>PCDD/F TEQ: 50-100</td>
</tr>
<tr>
<td></td>
<td>(central estimate ~ 88)</td>
</tr>
<tr>
<td><strong>Pearson et al.</strong></td>
<td>PCDD: 50-100</td>
</tr>
<tr>
<td></td>
<td>PCDF: 5-35</td>
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What Do We Need to Know, and. How Well Do We Need to Know It?

For most policy considerations, the exact contributions of individual sources do not need to be known.

It is generally sufficient to know about:

- **The geographical extent of the problem**

  C relative impact of local, regional, national, continental, and/or global sources

  C don’t need exact answers, e.g., if 70% or 50% of the contributing air sources arise from within 100 km of the Lake – the policy response will likely be similar in either case.

  C *Only if the estimates are grossly incorrect will policy deliberations be seriously affected.*

- **Which source categories are the most significant contributors?**

  C don’t need exact answers; e.g., it does not matter that much whether municipal solid waste incinerators contribute 20% or 40% to the deposition – the policy response will likely be very similar.

  C *Again, the estimates will be of little or no use only if they are extremely inaccurate.*
Figure 10. Percent of Total Emissions or Total Deposition of Dioxin (1996) Arising from Within Different Distance Ranges From Each of the Great Lakes

Lake Superior

Lake Huron

Lake Michigan

Lake Erie

Lake Ontario

Distance Range from Lake (km)

- Emissions
- Deposition
Figure 12. Contribution of Different Source Sectors to Atmospheric Deposition of Dioxin
\(\text{(pg TEQ deposition / km}^2\text{)} / \text{(person - year)}\)

(Each country's annual deposition flux contribution amount normalized by their total population)

- **Lake Erie**
  - Emissions Sector:
    - incin: 0.0
    - metals: 0.1
    - fuel: 0.0

- **Lake Michigan**
  - Emissions Sector:
    - incin: 0.6
    - metals: 0.5
    - fuel: 0.0

- **Lake Superior**
  - Emissions Sector:
    - incin: 0.4
    - metals: 0.2
    - fuel: 0.0

- **Lake Huron**
  - Emissions Sector:
    - incin: 0.8
    - metals: 0.6
    - fuel: 0.0

- **Lake Ontario**
  - Emissions Sector:
    - incin: 0.7
    - metals: 0.5
    - fuel: 0.0

- **Great Lakes Average**
  - Emissions Sector:
    - incin: 0.6
    - metals: 0.5
    - fuel: 0.0

United States
Canada

"incin" = waste incineration; "metals" = metallurgical processing; "fuel" = fuel combustion
Major Sources of Uncertainty in Atmospheric Dioxin Modeling

- Emissions Inventory
- Meteorological Data Used as Input to the Model
- Atmospheric Dispersion Simulation
- Atmospheric Fate Processes
  - Vapor/Particle Partitioning
  - Chemical Transformations
  - Wet Deposition
  - Dry Deposition
Other than uncertainties in the emissions inventory, the dry deposition modeling methodology is probably the most important factor influencing the results...

Sensitivity Analysis for Model Estimated Deposition to Lake Michigan
Factor Varied: Dry Deposition Algorithm (note: Default = #6)
Continuous Year Long Source of 2,3,7,8-TCDD at Center of Modeling Domain

Dry Deposition Algorithms: 1 - HYSPLIT_4 default; 2 - vpfin5f; 3 - Slinn & Slinn, 1980, no RH correction, for water, vpfin5f for other processes; 4 - EPA "best method" (ADOM-II) for particles, vpfin5f for gases; 5 - Williams (1982) for particles over water, vpfin5f for other processes; 6 - same as 3, but with RH correction, i.e., Slinn and Slinn (1980) with RH correction for particles over water, vpfin5f for other processes
What are the most important factors in the simulation uncertainty (other than the dry deposition methodology and the emissions inventory)?

Summary of Sensitivity Analyses
(for Factors Other than Dry Deposition Methodology or Emissions)

Sensitivity Analysis Series

Source Locations: "center" = center of modeling domain (lat/long = 40.95); "sf" = San Francisco; "milw" = Milwaukee.
Parameters: "wetr" = in-cloud particle wet deposition; "phot" = photolysis rate; "psd" = ambient particle conc. (affects V/P partitioning);
"height" = height of source; "timestep" = model time step; "partnum" = # of puffs simulated; "emmitfreq" = puff emissions frequency.
Effect of Different Deposition and Fate Methodologies on Percent Dioxin Deposition Contribution to Lake Michigan From Different Distance Ranges

Dry Deposition Algorithms:
1 - HYSPLIT_4 default
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Results from Different Sensitivity Simulations (using 28 standard source locations) on Emissions Sector Contributions to Lake Michigan Atmospheric Dioxin Deposition (for top 12 contributing sectors, 1996)

Percent of Total

- Municipal Waste Incineration
- Iron Sintering
- Medical Waste Incineration
- Cement Kilns Burning MW
- Backyard Waste Burning
- Secondary Copper Smelting
- Secondary Aluminum Smelting
- Residential Wood Burning
- Mobile Sources
- Utility Coal Combustion
- Electric Arc Furnaces
- Hazardous Waste Incineration

Dry Deposition Algorithms:
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Figure 3. Ranges in Estimated Deposition Arising from Uncertainties in Emissions and Fate Simulation
What could we do to improve the accuracy of atmospheric loading estimates?

- More information on non-atmospheric loading pathways needs to be collected in order to more accurately place the atmospheric contributions in their proper context.

- Ambient monitoring for dioxin must be increased in the Great Lakes region. This will allow model evaluation and independent semi-empirical estimates of atmospheric deposition to be made.

- Additional efforts to improve the accuracy of emissions inventories – including timely updates – must be made. Timely (e.g., annual) updates for at least the largest sources in the inventory would be extremely helpful, because often, these largest sources tend to drive the analysis. If they can be better characterized, the accuracy of the overall analysis can be greatly (and relatively easily) improved.