Empirical Reservoir Response Model (Bathtub) Approach

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Modeling Objectives

• Diagnostic:
  • Water and nutrient balances
    • Inform SWAT modeling
  • Identify factors controlling trophic response
  • Identify critical conditions

• Predictive:
  • Assess impacts of changes in inputs
    • Flow and concentration
  • Assess impacts of changes in pool elevation
  • Determine assimilative capacity for TMDL
Model Selection

- Simplified Procedures for Eutrophication Assessment and Prediction
  - Flux
    - Estimate nutrient loads
  - Profile
    - Reduction and analysis of pool water quality data
  - Bathtub
    - Empirical trophic response
- Bathtub is part of a modeling system
  - System relies heavily on quantifying errors
  - Handles some peculiarities of reservoirs
Model Selection

- Steady State with Complete Mixing:
  - segmentation allowed
  - water balance
  - nutrient balance
Bathtub is an Adequate Tool

Law of Diminishing Returns

Returns

Effort (Time, money, etc.)

Bathtub
Model Selection

• So if on the off chance it doesn’t work?
  • Test other empirical models for fit.
    • At least 20+ other phosphorus response models in the literature
  • Box models?
    • Limited data for fit
  • Simplified CE-QUAL runs?
    • Limited data for fit
Data collection and inputs

- Vertical profile(s)
- Horizontal (longitudinal) patterns.
- Constituents of interest.
  - Temperature
  - Nutrients
  - Chlorophyll
  - Transparency
## Data collection and inputs

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Reservoir Monitoring Period (May – September)</th>
<th># In-Lake Sites</th>
<th>Measured Sediment P Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Eau Pleine Reservoir</td>
<td>2010 – 2013</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>Lake DuBay</td>
<td>2010 – 2013</td>
<td>3</td>
<td>Scheduled</td>
</tr>
<tr>
<td>Lake Dexter</td>
<td>2010 – 2012</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Lake Wisconsin</td>
<td>2010 – 2013</td>
<td>3</td>
<td>Scheduled</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Tributary Monitoring Period</th>
<th>Tributary Monitoring Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Eau Pleine Reservoir</td>
<td>October 2009 – Nov. 2013</td>
<td>Big Eau Pleine River, Fenwood Creek, Freeman Creek</td>
</tr>
<tr>
<td>Lake DuBay</td>
<td>May 2009 – Nov. 2013</td>
<td>Wisconsin River, Big and Little Eau Pleine Rivers</td>
</tr>
<tr>
<td>Lake Dexter</td>
<td>October 2009 – Nov. 2013</td>
<td>Yellow River</td>
</tr>
<tr>
<td>Lake Wisconsin</td>
<td>October 2009 – Nov. 2013</td>
<td>Wisconsin and Baraboo Rivers</td>
</tr>
</tbody>
</table>
BATHTUB
Empirical Model Network
Developed for Reservoirs*

* But Still Useful for Lakes
Model Configuration

vs.

Model Configuration
Model Configuration

- Monitoring strategy assumed longitudinal changes due to reservoir bathymetry
  - Is this true?
  - What are the advantages and disadvantages to lumping?
- Most reservoirs have short residence time
  - Annual vs. seasonal load?
  - Check for violation of steady-state assumption
Model Selection

- Nutrient sedimentation models
  - 7 Nutrient sedimentation models
- Chlorophyll models
  - 5 Chlorophyll models
- Secchi models
  - 3 Secchi models
- Which model to choose?
  - Model fit
  - Ecological/physical reasons
  - Experience
Model Outputs

- Prediction of Trophic Response (Seasonal Average)
  - Phosphorus
  - Nitrogen
  - Chlorophyll
    - Mean
    - Bloom frequency
  - Secchi transparency
Chlorophyll-a interval frequency versus total phosphorus.

Frequency (%) vs. TP ppb

- >10 ppb
- >20 ppb
- >30 ppb
- >60 ppb

Categories:
- "mild"
- "nuisance"
- "severe nuisance"
- "very severe nuisance"

Image captions:
- "Protected Photo"
- "Up Close of Bottom Sediments"
Sensitivity Analysis – Built In

• Built in routines in Bathtub
  • Calculates variance estimates and confidence limits for each output variable
  • Sensitivity of predicted concentrations to deposition and dispersion coefficients.
Sensitivity Analysis – Manual

• Check sensitivity to critical assumptions by building alternate models
  • segmentation scheme
  • averaging period
  • sub-model selection
Calibration

“the author prefers a more parsimonious approach to calibration” - W.W. Walker 1995

• Goal: minimize calibration to the extent practicable
  • Are the observed and predicted values statistically different?
• Calibration can be done globally or by segment
  • Global preferred
  • Segment only where necessary (and logical)
## BATHTUB — Potential Sources of Error

Error = Observed Response – Predicted Response

When is Calibration Justified?

<table>
<thead>
<tr>
<th>Error Source</th>
<th>Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random Measurement Error</td>
<td>NO</td>
</tr>
<tr>
<td>Measurement Bias</td>
<td>YES ?</td>
</tr>
<tr>
<td>Data Entry Error</td>
<td>NO</td>
</tr>
<tr>
<td>Model Implementation Error</td>
<td>NO</td>
</tr>
<tr>
<td>Underestimation of Load</td>
<td></td>
</tr>
<tr>
<td>Sampling Missed Important Events</td>
<td>NO</td>
</tr>
<tr>
<td>Overlooked Important Sources</td>
<td>NO</td>
</tr>
<tr>
<td>Unrepresentative Lake Sampling (Temporal, Spatial)</td>
<td>NO</td>
</tr>
<tr>
<td>Model Error: Actual Response &lt;&gt; Predicted Response</td>
<td></td>
</tr>
<tr>
<td>Structure (Missing/Misrepresenting Important Process)</td>
<td>NO ?</td>
</tr>
<tr>
<td>Parameter Estimate</td>
<td>YES</td>
</tr>
</tbody>
</table>
Validation

• TBD
• Draft scope indicated use of all years of monitoring data for calibration
• Thoughts? Alternatives?
Bathtub Large Group Question:

• How do we approach internal phosphorus loading from an empirical modeling perspective, given that internal loading is implicitly included in the sedimentary loss coefficient/apparent settling velocity terms?

• Real world example for discussion –
  • Data and graphs from *Limnological analysis of Lake Eau Claire, Wisconsin*. James et.al. 1999
Lake Eau Claire Example
Lake Eau Claire Example:

Table 5. Summary statistics for summer (June-August) external loads to and discharges from Lake Eau Claire. CV represents the coefficient of variation.

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Total P</th>
<th>LOAD, kg/d</th>
<th>CONC.</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eau Claire River</td>
<td></td>
<td>24.1</td>
<td>0.076</td>
<td>0.067</td>
</tr>
<tr>
<td>Hay Creek</td>
<td></td>
<td>2.5</td>
<td>0.116</td>
<td>0.138</td>
</tr>
<tr>
<td>Muskrat Creek</td>
<td></td>
<td>0.7</td>
<td>0.071</td>
<td>0.112</td>
</tr>
<tr>
<td>Discharge</td>
<td></td>
<td>52.9</td>
<td>0.151</td>
<td>0.056</td>
</tr>
</tbody>
</table>

Table 3. Mean (± 1 S.E.) rates of phosphorus release from the profundal sediments (mg m⁻² d⁻¹) of various stations measured under oxic and anoxic conditions.

<table>
<thead>
<tr>
<th>Station</th>
<th>Oxic Rate</th>
<th>Anoxic Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.4 (0.3)</td>
<td>14.9 (1.4)</td>
</tr>
<tr>
<td>2</td>
<td>0.9 (0.4)</td>
<td>9.9 (0.6)</td>
</tr>
<tr>
<td>3</td>
<td>1.0 (0.4)</td>
<td>15.1 (0.6)</td>
</tr>
</tbody>
</table>