Empirical Reservoir Response Model (Bathtub) Approach

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Wisconsin River TMDL Technical Stakeholder Meeting
November 13, 2013

Modeling Objectives

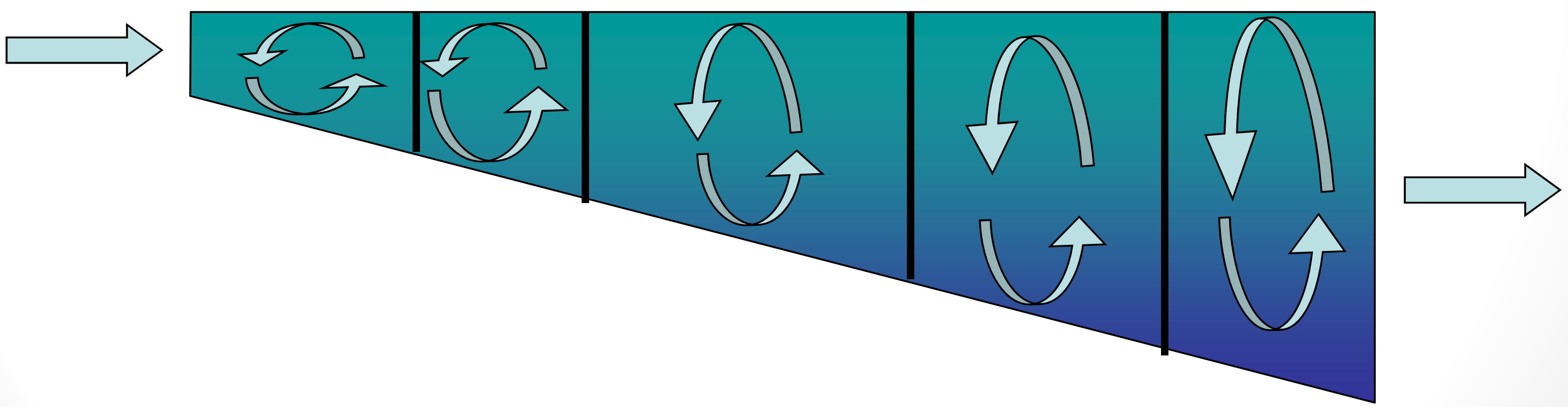
- Diagnostic:
  - Water and nutrient balances
    - Inform SWAT modeling
  - Identify factors controlling trophic response
  - Identify critical conditions
- Predictive:
  - Assess impacts of changes in inputs
    - Flow and concentration
  - Assess impacts of changes in pool elevation
  - Determine assimilative capacity for TMDL

Model Selection

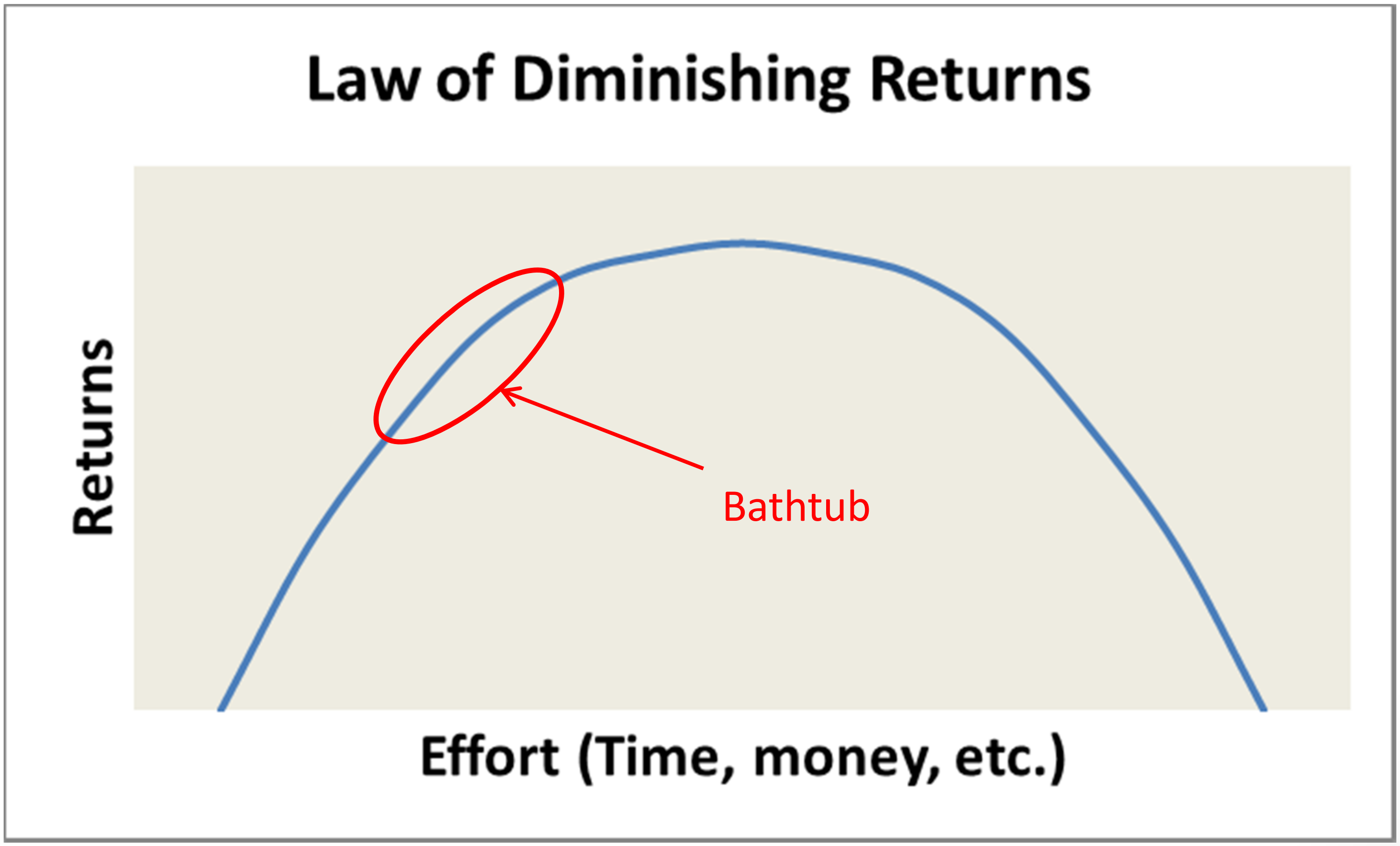
- Simplified Procedures for Eutrophication Assessment and Prediction
  - Flux
    - Estimate nutrient loads
  - Profile
    - Reduction and analysis of pool water quality data
  - Bathtub
    - Empirical trophic response
- Bathtub is part of a modeling system
  - System relies heavily on quantifying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

Model Selection

- Steady State with Complete Mixing:
  - segmentation allowed
  - water balance
  - nutrient balance



Bathtub is an Adequate Tool

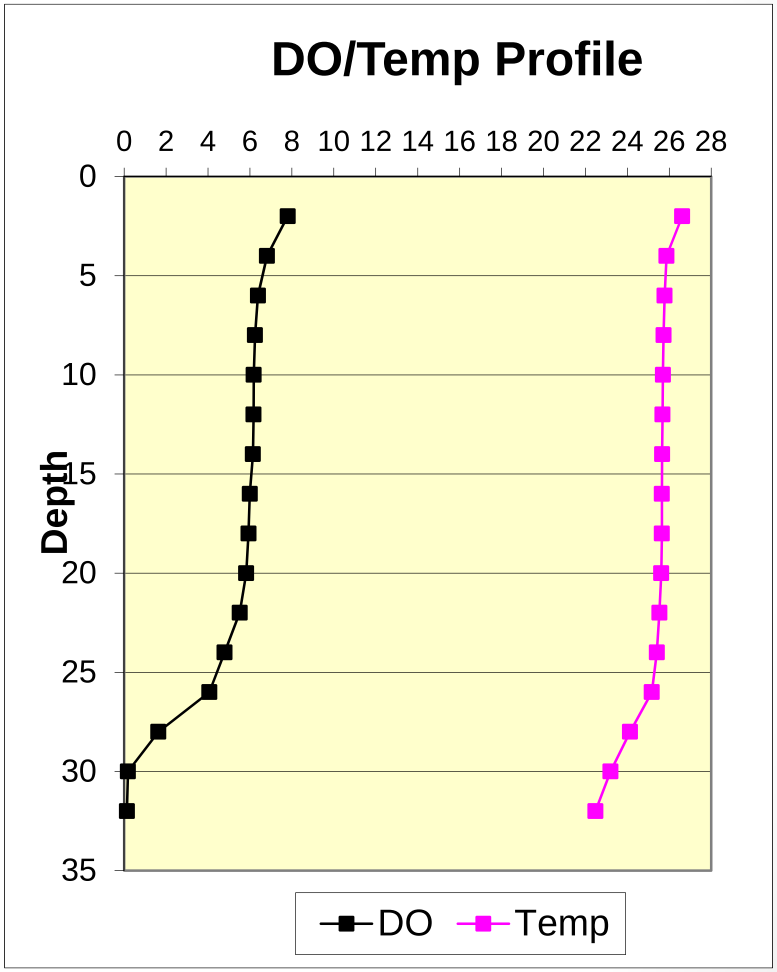


Model Selection

- 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

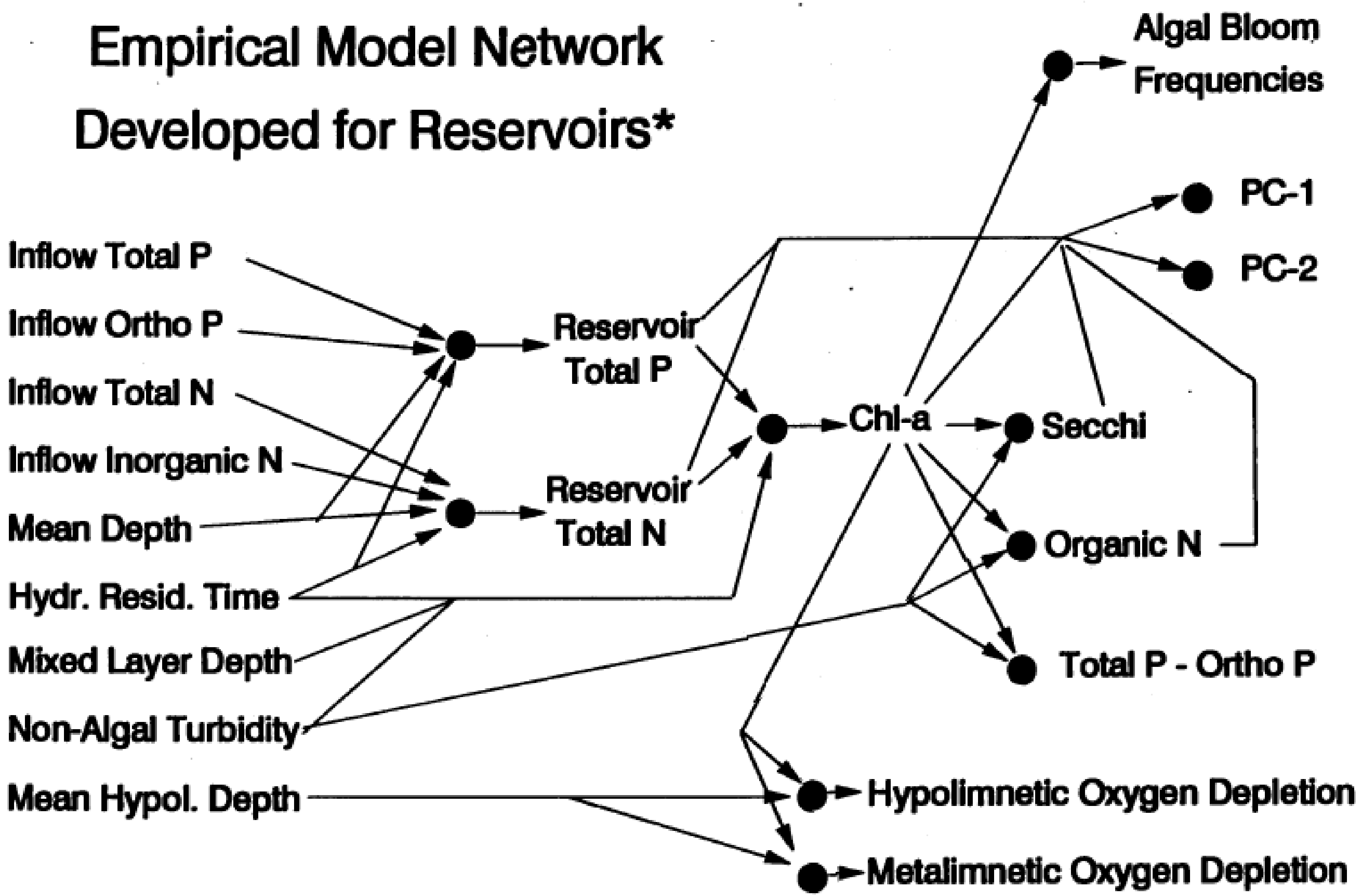
- Vertical profile(s)
- Horizontal (longitudinal) patterns.
- Constituents of interest.
  - Temperature
  - Nutrients
  - Chlorophyll
  - transparency



Data collection and inputs

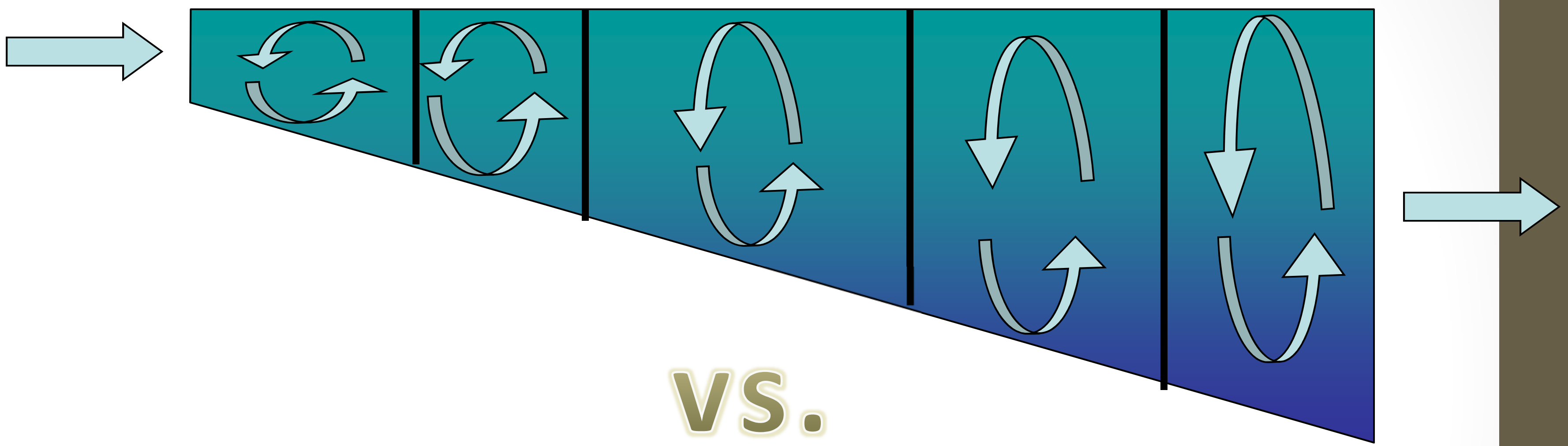
Reservoir	Reservoir Monitoring Period (May – September)	# In-Lake Sites	Measured Sediment P Release
Big Eau Pleine Reservoir	2010 – 2013	4	Yes
Lake DuBay	2010 – 2013	3	Scheduled
Lake Dexter	2010 – 2012	1	No
Lake Wisconsin	2010 – 2013	3	Scheduled
Reservoir	**Tributary Monitoring Period**	**Tributary Monitoring Sites**	
Big Eau Pleine Reservoir	October 2009 – Nov. 2013	Big Eau Pleine River, Fenwood Creek, Freeman Creek	
Lake DuBay	May 2009 – Nov. 2013	Wisconsin River, Big and Little Eau Pleine Rivers	
Lake Dexter	October 2009 – Nov. 2013	Yellow River	
Lake Wisconsin	October 2009 – Nov. 2013	Wisconsin and Baraboo Rivers	

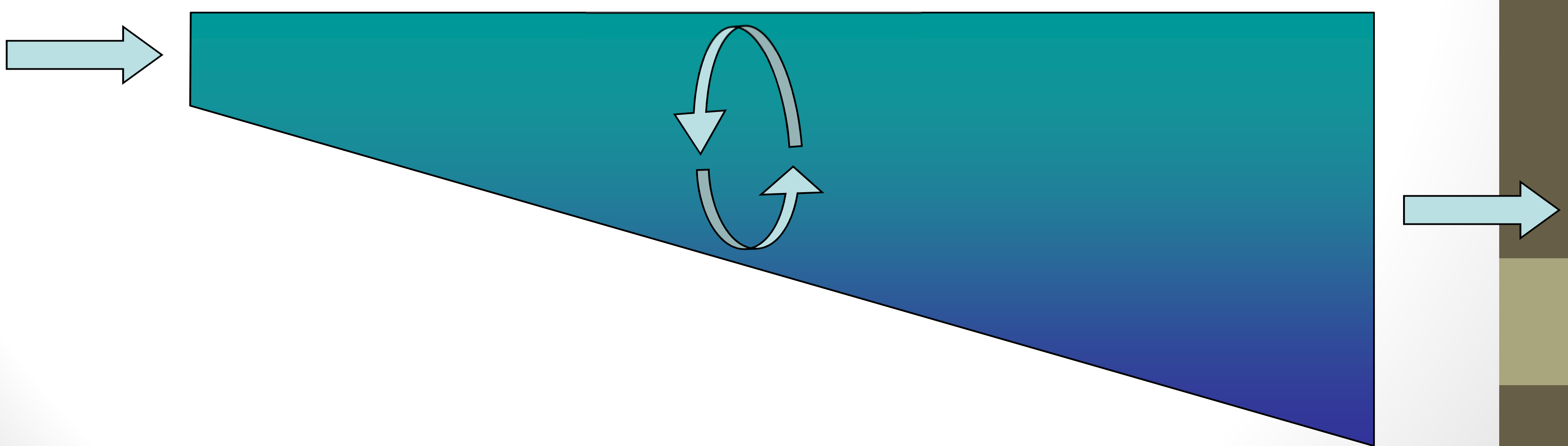
BATHTUB
Empirical Model Network
Developed for Reservoirs*



* But Still Useful for Lakes

Model Configuration





Model Configuration

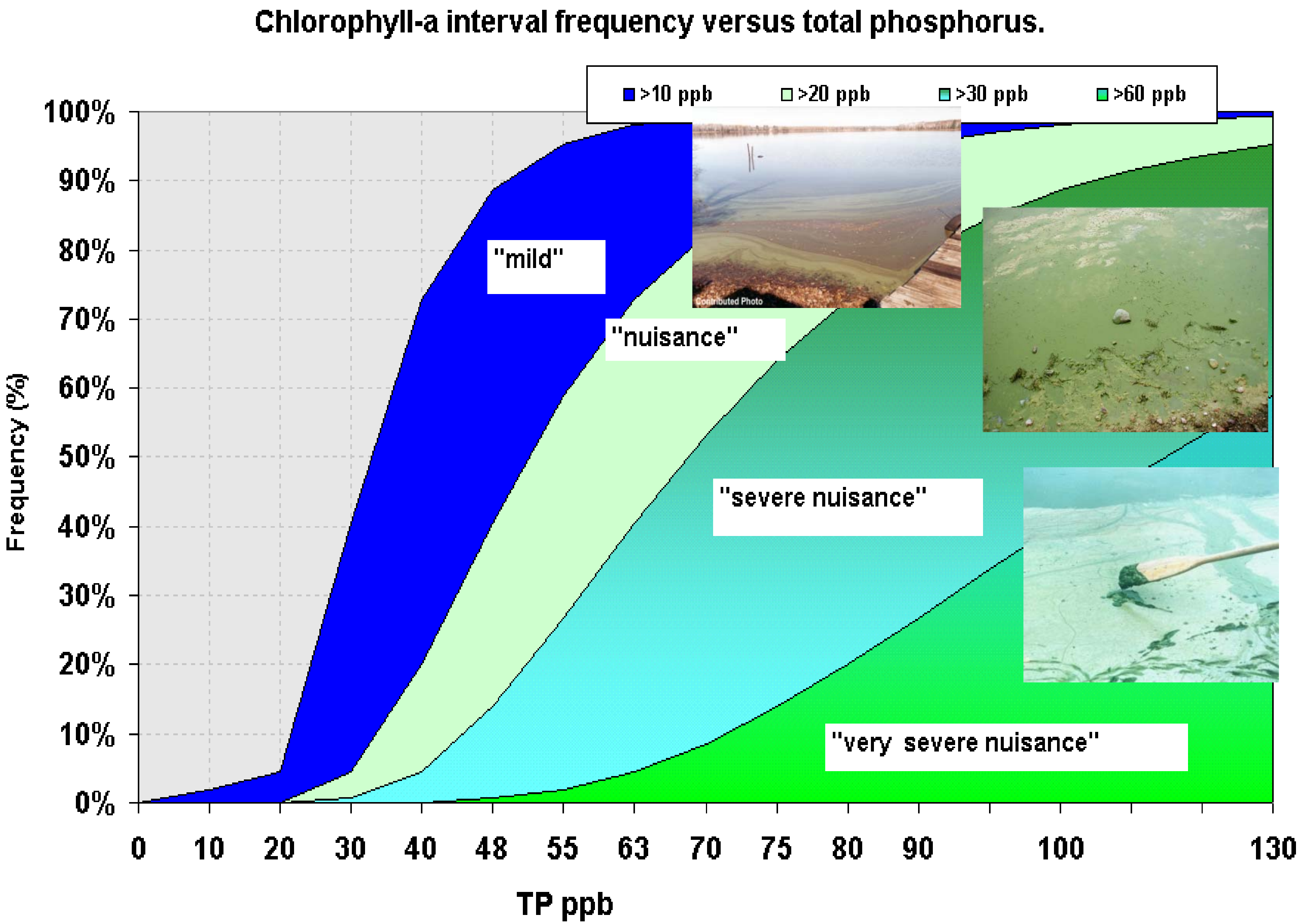
- Monitoring strategy assumed longitudinal changes due to reservoir bathymetry
  - Is this true?
  - What are the advantages and disadvantages to lumping?
- Most reservoirs have short residence time
  - Annual vs. seasonal load?
  - Check for violation of steady-state assumption

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

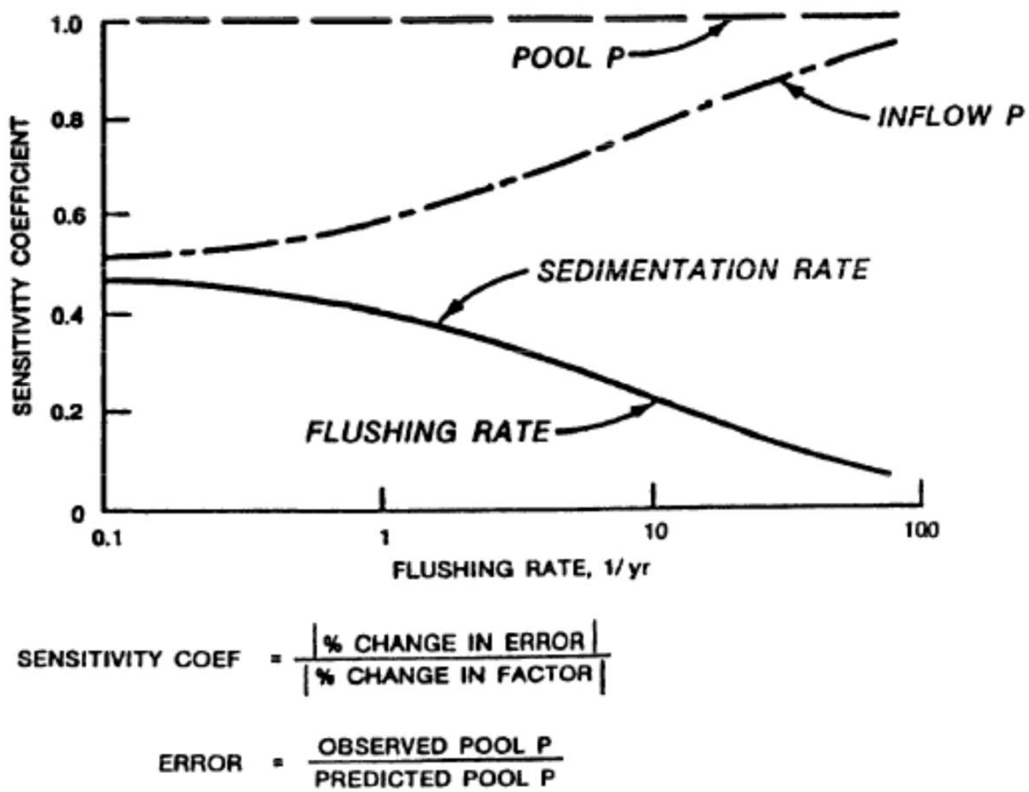
- Prediction of Trophic Response (Seasonal Average)
  - Phosphorus
  - Nitrogen
  - Chlorophyll
    - Mean
    - Bloom frequency
  - Secchi transparency



Chlorophyll-a interval frequency versus total phosphorus.
>10 ppb
>20 ppb
>30 ppb
>60 ppb
"mild"
"nuisance"
"severe nuisance"
"very severe nuisance"
Frequency (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
48
55
63
70
75
80
90
100
130
TP ppb

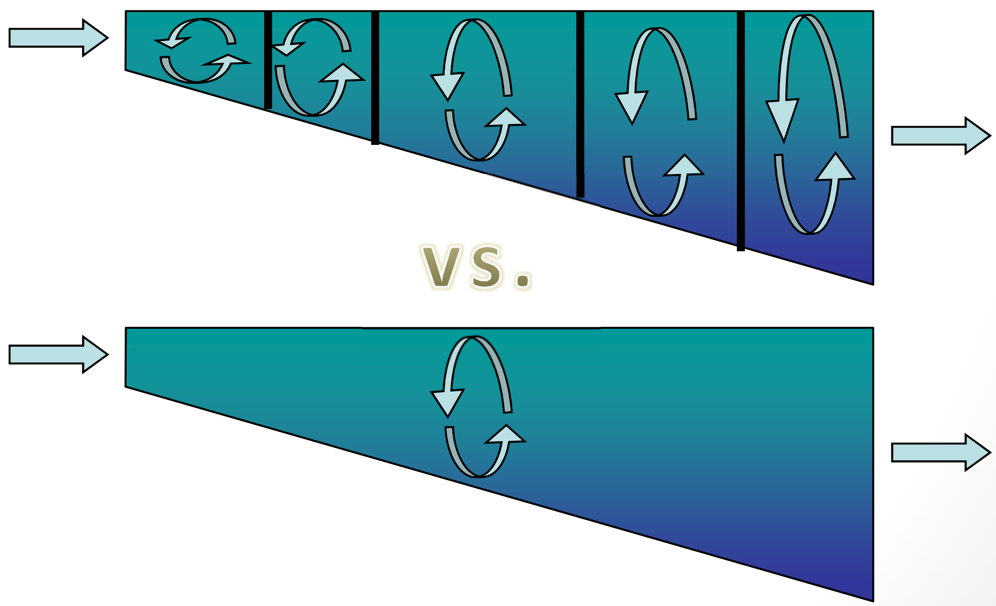
Sensitivity Analysis – Built In

- 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?

Error Source	Calibration
Random Measurement Error	NO
Measurement Bias	YES ?
Data Entry Error	NO
Model Implementation Error	NO
Underestimation of Load	
Sampling Missed Important Events	NO
Overlooked Important Sources	NO
Unrepresentative Lake Sampling (Temporal, Spatial)	NO
Model Error: Actual Response <> Predicted Response	
Structure (Missing/Misrepresenting Important Process)	NO ?
Parameter Estimate	YES

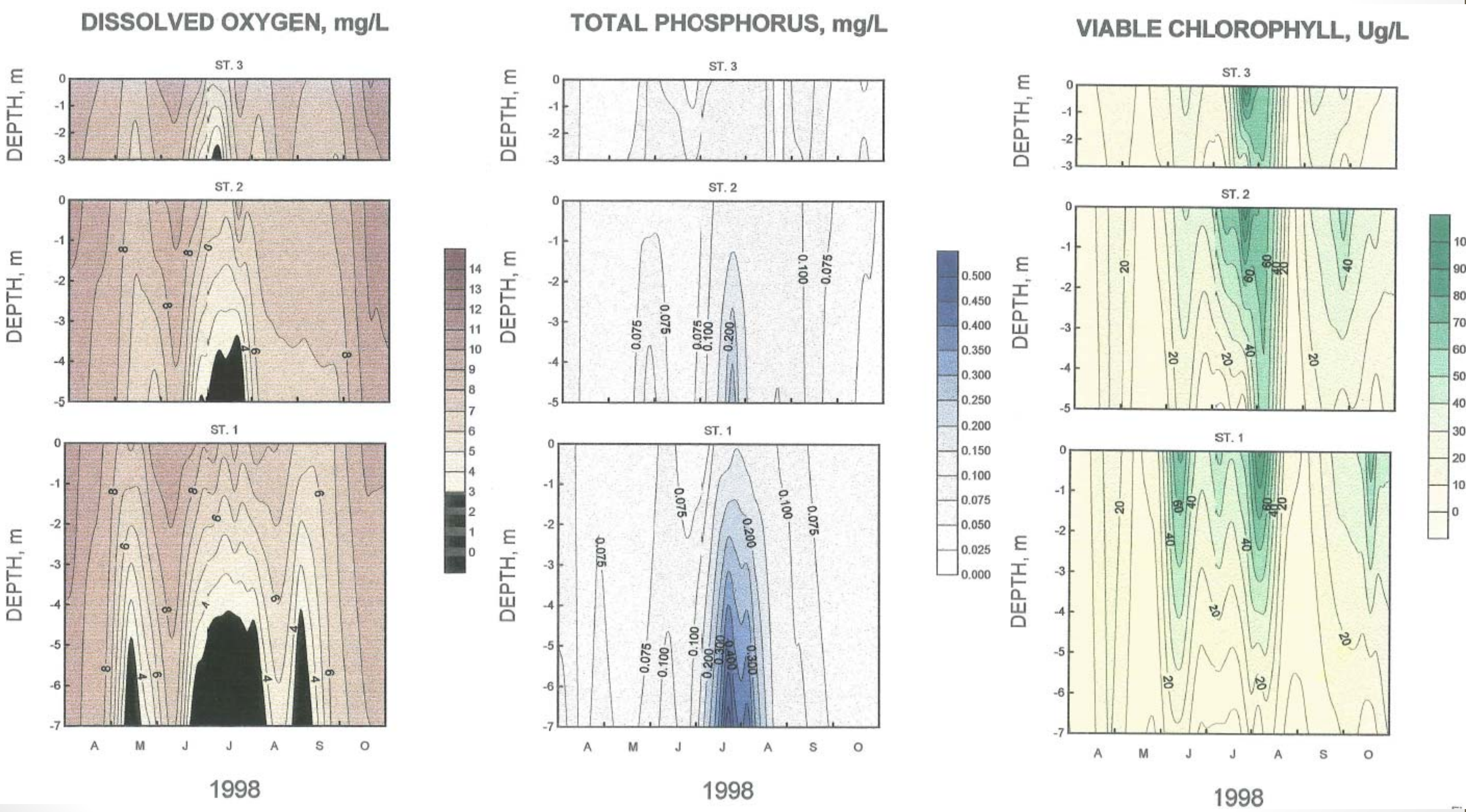
Validation

- 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.

Tributary	Total P		
	LOAD, kg/d	CONC.	CV
Eau Claire River	24.1	0.076	0.067
Hay Creek	2.5	0.116	0.138
Muskrat Creek	0.7	0.071	0.112
Discharge	52.9	0.151	0.056

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.

Station	Oxic Rate	Anoxic Rate
1	1.4 (0.3)	14.9 (1.4)
2	0.9 (0.4)	9.9 (0.6)
3	1.0 (0.4)	15.1 (0.6)