This research is funded by U.S. EPA - Science To Achieve Results (STAR) Program

Grant # G4K10778

Understanding Ecological Thresholds in Aquatic Systems: Progress Review

June 7-8, 2007, Washington D.C.

Eutrophication Thresholds - Assessment, Mitigation and Resilience in Landscapes and Lakes

Daniel Collins	Center for Sustainability and the Global Environment, and Center for Limnology (dbcollins@wisc.edu)
Stephen Carpenter	Center for Limnology (srcarpenter@wisc.edu), Principal Investigator
Monica Turner	Dept. Zoology
Jonathan Foley	Center for Sustainability and the Global Environment
	University of Wisconsin - Madison

Synopsis

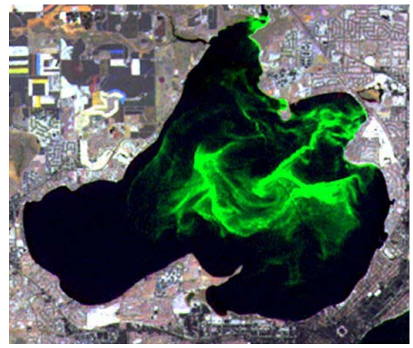
1. Background
2. Bayesian analysis
3. Terrestrial thresholds
4. Watershed modeling
5. Summary

1. Background

"A limnologist is a zoologist who, during the summertime, studies chemical and botanical aspects of geological problems in readily accessible lakes, 15 m deep, located in the vicinity of universities".

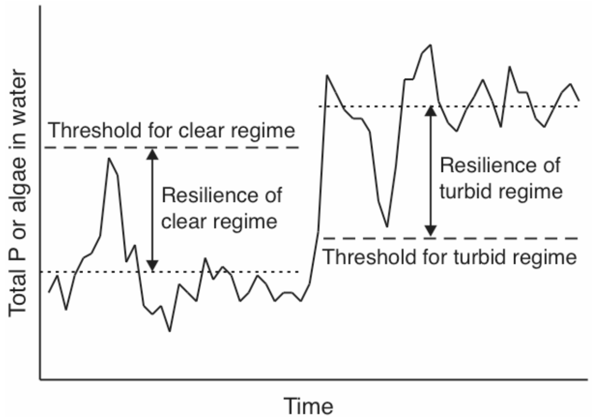
J.R. Vallentyne, 1969. Limnology and Oceanography 14(5):815

1. Background: Study site



Lake Mendota has been studied for more than 100 years. Over the years, the water quality has deteriorated, leading to eutrophication.

1. Background: Bi-stable lakes

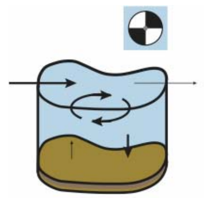


Eutrophication is a persistent environmental problem characterized by turbid water, toxic algae, fish kills, and waterborne disease, leading to a loss of aquatic ecosystem services centered on recreation.

This graph represents a hypothetical lake.

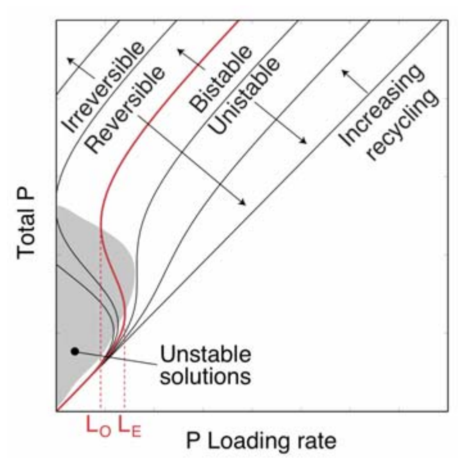
1. Background: Eutrophication dynamics

5



$$\frac{dP}{dt} = L - (s+h)P + \frac{r P^a}{P^a + m^a}$$

P = total P
L = loading rate
s = sedimentation
h = outflow
r = recycling
m, a = parameters

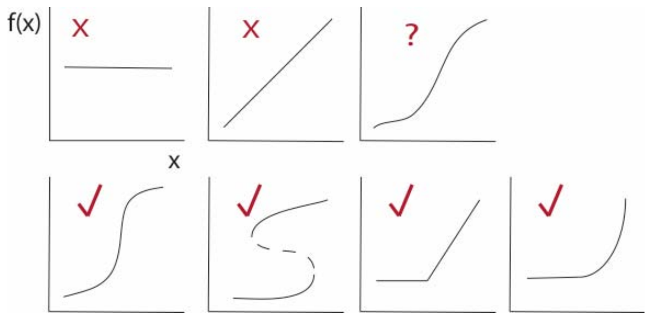


The straight diagonal line in the box represents a clean lake. As phosphorus increases, the lake passes the first threshold, moving from the unistable state to the bistable state. If phosphorus continues to increase, the lake moves past the next threshold to the irreversible state.

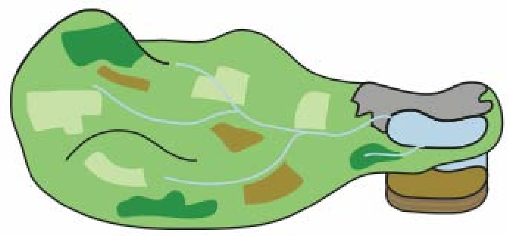
1. Background: "Threshold"

"The separation between two distinct system behaviors."

$$x_{crit} \equiv \text{threshold, iff } \frac{d^n f(x)}{dx^n}\Big|_{x \to x_{crit}^-} \neq \frac{d^n f(x)}{dx^n}\Big|_{x \to x_{crit}^+}, \text{for any } n$$



1. Background: Thinking outside the lake



1. Background: Objectives

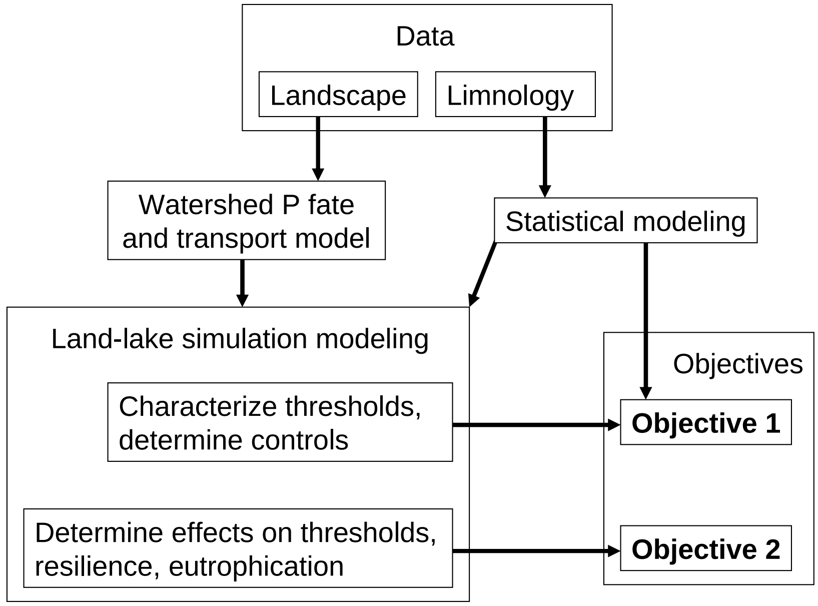
Objective 1

What thresholds in the transport and recycling of P in lakes and watersheds cause lakes to switch between clear-water and eutrophic states?

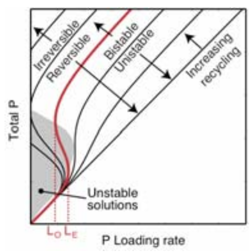
Objective 2

How can these thresholds be manipulated to mitigate eutrophication, or increase the resilience of clear-water lakes?

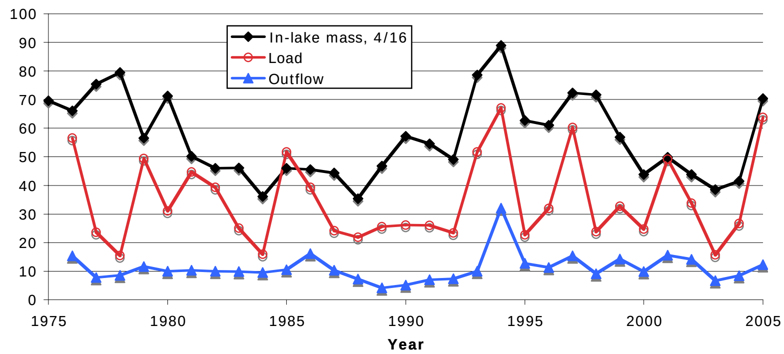
1. Background



2. Bayesian Analysis

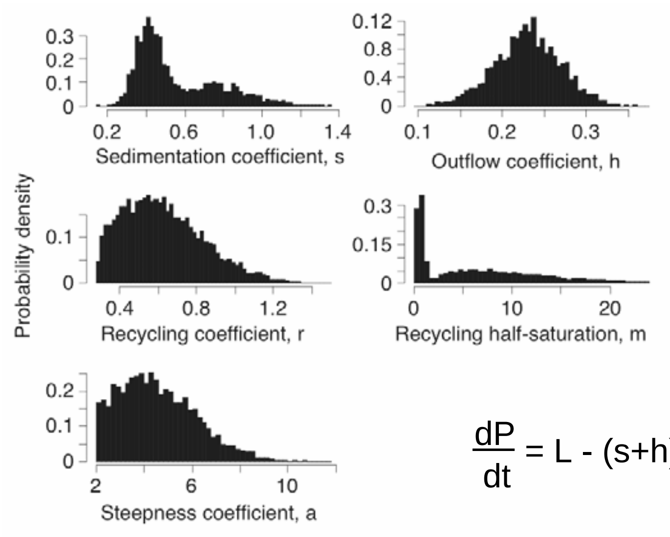


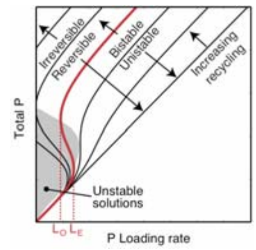
Is the lake bi-stable?
Where are the thresholds?
How sure can we be?



2. Bayesian Analysis: Posterior probability distributions

Markov chain Monte Carlo sampling using WinBUGS
(http://www.mrc-bsu.cam.ac.uk/bugs)



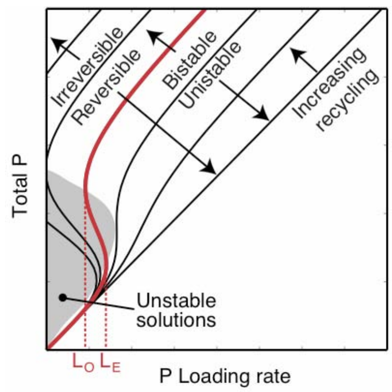


$$\frac{dP}{dt} = L - (s+h)P + \frac{rP^a}{P^a + m^a}$$

2. Bayesian Analysis: Results

There's a 3.4% chance Lake Mendota is uni-stable
90.3% reversibly bi-stable
6.3% irreversibly bi-stable

There's a 32% chance that L_E has been exceeded
15% loads have not dropped below L_O



3. Terrestrial Thresholds

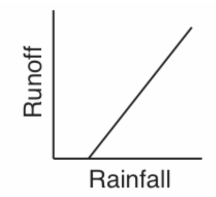
What terrestrial thresholds control P loading?

Independent variable	*Dependent variable*
Rainfall	Runoff
Soil temperature	Runoff
Runoff	Erosion
Soil temperature	Erosion
Topographic slope	Erosion
Vegetation cover	Erosion
Channel discharge	Floodplain deposition
Soil P	P through-put
Wetland condition	Wetland condition
Density/location of wetlands, paving, …	Hydrological connectivity

3. Terrestrial Thresholds: Example 1

14

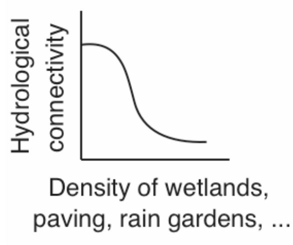
Point-scale runoff generation



Threshold:	Yes
Knowledge:	High
Manageability:	High
Impact:	High
Threshold altered by:	Soil type, ag practices
Position along curve altered by:	Climate change

3. Terrestrial Thresholds: Example 2

Hydrological connectivity

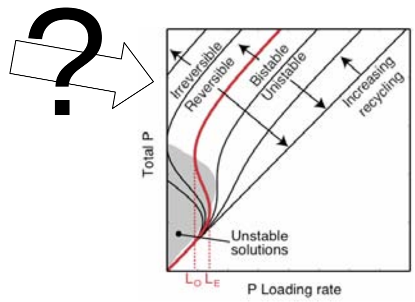


Threshold:	?
Knowledge:	Low
Manageability:	Medium
Impact:	?
Threshold altered by:	Climate, geology
Position along curve altered by:	Land cover change and configuration

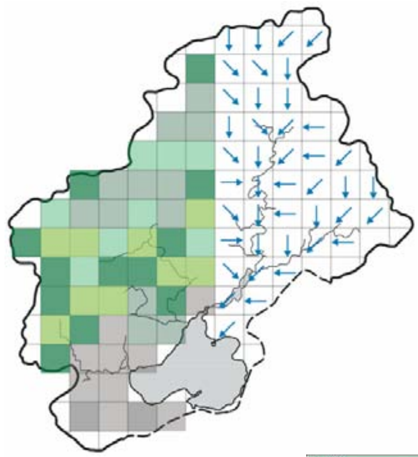
3. Terrestrial Thresholds

Independent variable	*Dependent variable*
Rainfall	Runoff
Soil temperature	Runoff
Runoff	Erosion
Soil temperature	Erosion
Topographic slope	Erosion
Vegetation cover	Erosion
Channel discharge	Floodplain deposition
Soil P	P through-put
Wetland condition	Wetland condition
Density/location of wetlands, paving, …	Hydrological connectivity

How do we assess their effects?

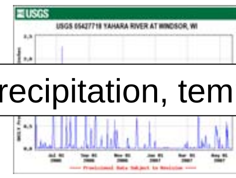


4. Watershed Modeling

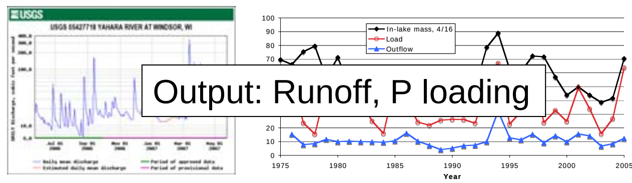


Distributed watershed modeling

- Discretize space
- Land use, soil type
- Water and P routing



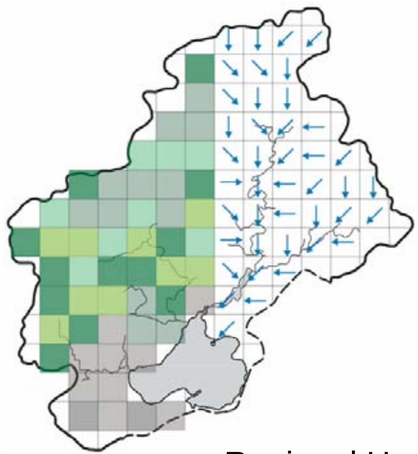
Input: Precipitation, temperature



Output: Runoff, P loading

This is a biophysically based model, routing water and P across a discretized landscape.

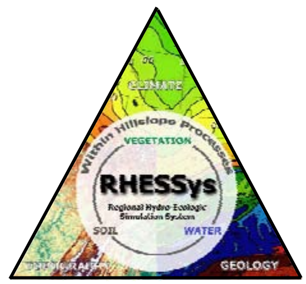
4. Watershed Modeling



Distributed watershed modeling
- Discretize space
- Land use, soil type
- Water and P routing

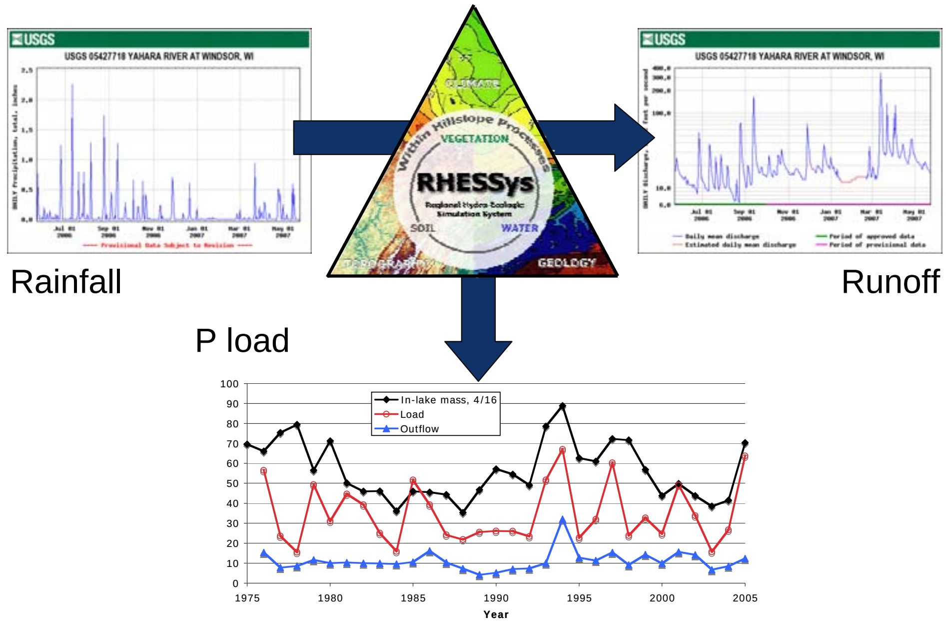
Regional Hydro-Ecological Simulation System

(http://fiesta.bren.ucsb.edu/~rhessys/)



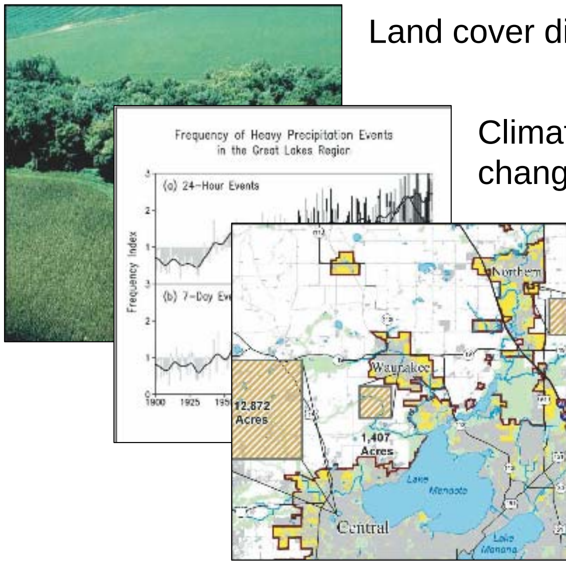
4. Watershed Modeling: Calibration

19



Calibration work is in progress.

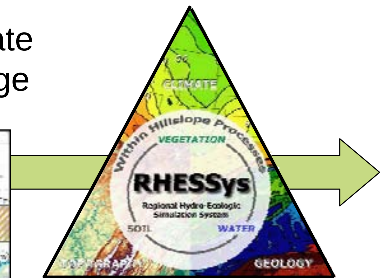
4. Watershed Modeling: Simulation modeling



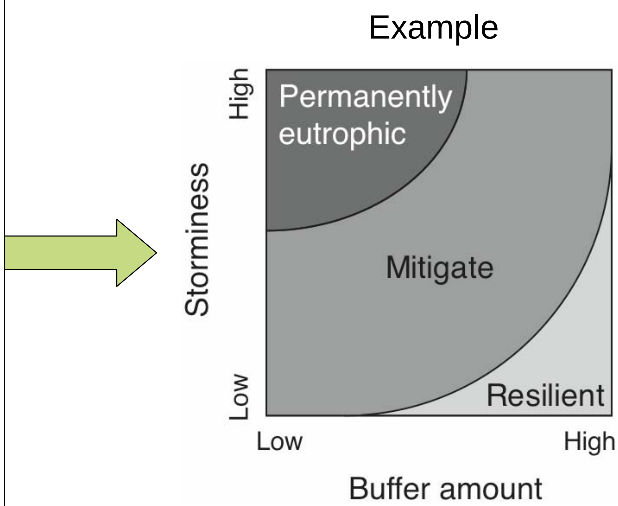
Land cover distribution

Climate change

Land use change



4. Watershed Modeling: Hypothetical results



Determine trophic responses across the terrestrial state space

5. Summary: Results

1. The location of thresholds can be highly uncertain.
2. At present, Lake Mendota is most probably bi-stable but reversible.
3. Thresholds are common across the terrestrial-aquatic watershed. This increases uncertainties but also the options for mitigation.

5. Summary: Implications

1. Evaluations of eutrophication should be based on risk rather than on point estimates (c.f. TMDLs).

2. Lowering P loads to Lake Mendota can reduce the chance of surpassing the eutrophy threshold, and increase the chance of falling below the oligotrophy threshold should eutrophy occur.

3. Threshold-based mitigation of eutrophication should consider both the watershed and the lake.

5. Summary: Dynamic definitions

"A limnologist is a zoologist who, during the summertime, studies chemical and botanical aspects of geological problems in readily accessible lakes, 15 m deep, located in the vicinity of universities".

J.R. Vallentyne, 1969. Limnology and Oceanography 14(5):815

Referee's comment:
"A modern limnologist is best defined as a biogeochemist and self-taught systems analyst, whose favorite systems are imbedded in an exponentially increasing matrix of septic tanks."

E.S. Deevey, 1969. Limnology and Oceanography 14(5):815

This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # G4K10778

Understanding Ecological Thresholds in Aquatic Systems Progress Review

June 7, 2007, Washington D.C.

Discussion

A participant asked how, given the yield type of relationship between P and the biomass, there could be only two systems. Dr. Collins stated that there could be any number of stable states. Recycling changes the lake system, forcing the relationship to change by depleting phosphorus over time. The model used in this research is conditioned on the current state; this will change over time.

Another participant asked how a time frame is determined for declaring a watershed to be in an irreversibly stable state. Dr. Collins responded that this is an issue that he and his colleagues have struggled with.

Another participant asked how important it is to know the residence time of the phosphorus in a lake system and if this was considered in the research. Dr. Collins believes the most important information is related to recycling. Some lakes are able to manage eutrophication and some are not. Residence time also is important.

One participant asked if recycling is a function of concentration. Dr. Collins confirmed that it is.

This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # G4K10778

Discussion (Continued)

Iris Goodman asked if the Wisconsin Department of Natural Resources (DNR) is considering how it might use some of these ideas in its management of lakes. Dr. Collins stated that the project has had strong ties with the Wisconsin DNR for many years.

A participant asked whether the modeling system discussed would be transferable to other lakes, specifically to Minnesota lakes. Dr. Collins stated that the landscape and the climate in Wisconsin and Minnesota are similar. The time series analysis (Bayesian analysis) and physical modeling could be useful for the study of Minnesota lakes.

Another participant asked why Dr. Collins chose to use the Regional Hydro-Ecological Simulation System (RHESSys). Dr. Collins stated that other models were considered, including Top Model. Top Model is a topography-based qualitative model used to study water that infiltrates from hidden areas down to streams. However, Top Model does not work well with shallow landscapes, so it was not appropriate for this study. RHESSys does not include phosphorus loading, but it still is a useful model. The modeling work currently is in progress.

This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # G4K10778

Understanding Ecological Thresholds in Aquatic Systems Progress Review

June 7, 2007, Washington D.C.

Discussion (Continued)

Another participant asked how the model is tied to ecological endpoints. Dr. Collins does not yet know how the model will be linked to rebounding systems. Iris Goodman added that she could send the participants materials on other studies that have used social issues (e.g., fisheries, odor, etc.) as endpoints.

A participant asked if the modeling exercise would be extended to include the lake itself. Dr. Collins stated that work would begin on a lake model after the terrestrial model is completed.

Another participant emphasized the importance of coming to an agreement on the definition of a threshold. Iris Goodman pointed out that time was scheduled the following day for discussion of this and other topics.

Iris Goodman added that she knew of one study that successfully used time series modeling to predict threshold exceedance 9 or 10 years before it actually occurred.