Identifying early warning indicators of eutrophication to inform real-world management:
engaging long-term datasets, ecosystem modeling, committed citizen scientists, and remote sensing

Nicole K. Ward[1], Bethel Steele[2], Kathleen C. Weathers[2], Kathryn L. Cottingham[3], Holly A. Ewing[4], Paul C. Hanson[5], Robert Wood[6], June Fichter[6], Cayelan C. Carey[1]

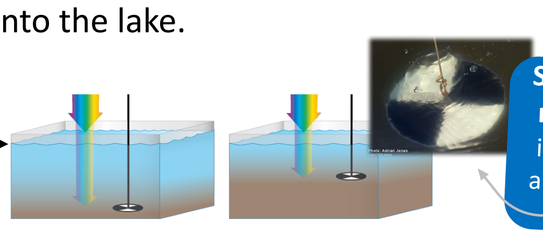
[1]Virginia Tech, Blacksburg, VA, USA; [2]Cary Institute of Ecosystem Studies, Millbrook, NY, USA; [3]Dartmouth College, Hanover, NH, USA; [4]Bates College, Program in Environmental Studies, Lewiston, ME, USA; [5]University of Wisconsin-Madison, Madison, WI, USA; [6]Lake Sunapee Protective Association, Sunapee, NH, USA

Motivation for Research:

Lake Sunapee has been a recreation destination for generations. Over the past few decades, residents and researchers have observed changes in the lake and surrounding area, and are increasingly concerned about future water clarity.

Phosphorus (P), which is often a limiting nutrient to harmful algal blooms and in turn decreases water clarity through a process called "eutrophication," is increasing in the streams that flow into the lake.

15 P Phosphorus 30.973761



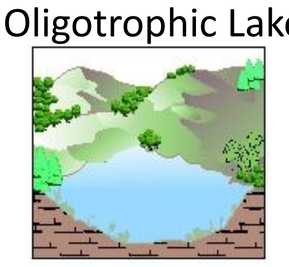
Secchi Depth is a common measure of water clarity: it is the depth you can lower a Secchi disk in the water and still see it.

GOAL:

Help citizens avoid a eutrophic future by bringing together a lake ecosystem simulation model, long term datasets, and satellite imagery.

Eutrophication in Lakes: A nearly irreversible process

Oligotrophic Lake



- Low nutrients
- Low phytoplankton
- High clarity

Natural Eutrophication *occurs over centuries* from natural sources of nutrients and sediments

Anthropogenic Eutrophication *occurs over decades* from human-induced runoff, waste, fertilizers, and erosion

Eutrophic Lake

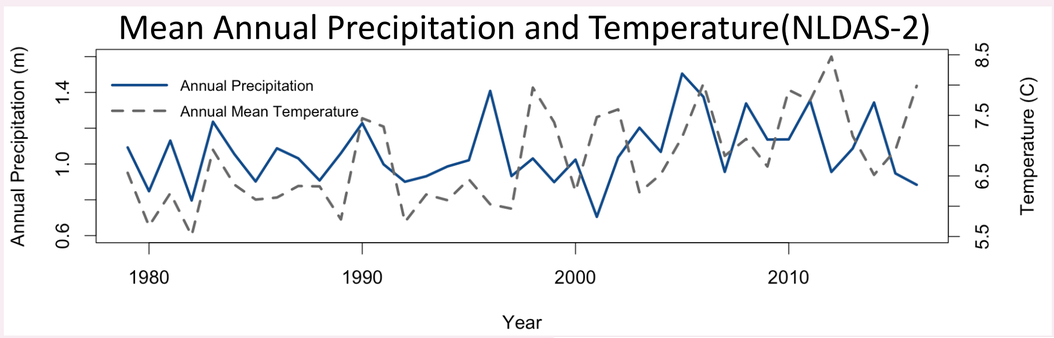
- High nutrients
- High phytoplankton
- Low clarity

EWIs might be able to tell us if a lake is approaching a transition from oligotrophy to eutrophy.

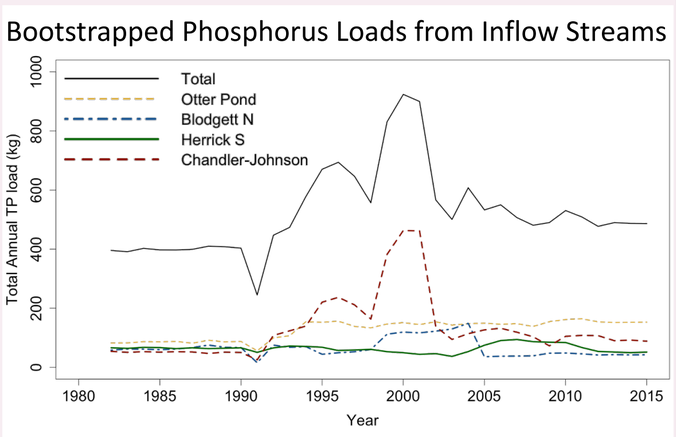
Research Questions:

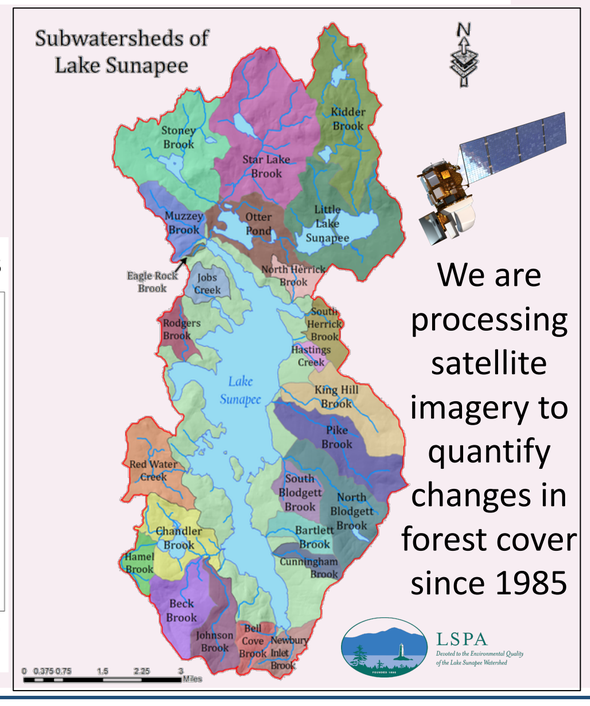
1. How are land cover and climate change affecting water quality in an oligotrophic lake over three decades?

Historical Conditions 1985 – 2015



Phosphorus loading, land cover, and climate have changed in the Lake Sunapee watershed from 1985 – 2015



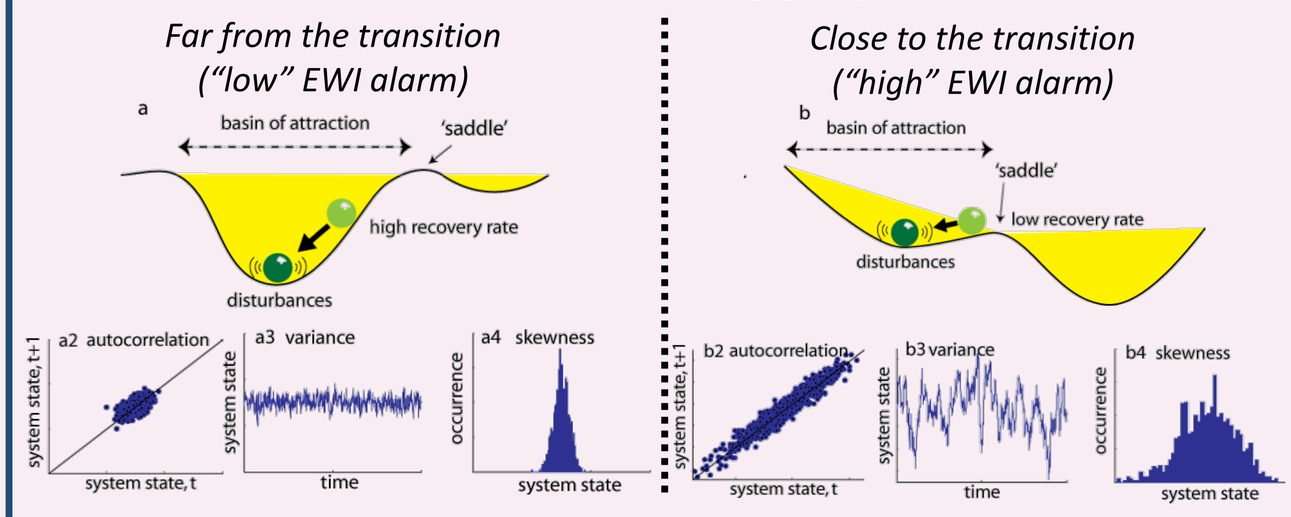


We are processing satellite imagery to quantify changes in forest cover since 1985

2. Can we use Early Warning Indicators (EWIs) to manage water quality in a real-world oligotrophic lake?

Early Warning Indicator (EWI) Analysis Background

Dakos et al., early-warning-signals.org



We are determining if it is possible detect EWIs from model output

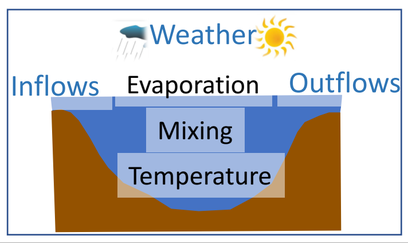
1. If EWIs are present in base simulation, can we "turn-off" alarms by lowering P inputs?
2. If EWIs are not present, can we "force" them to show up by increasing P inputs?

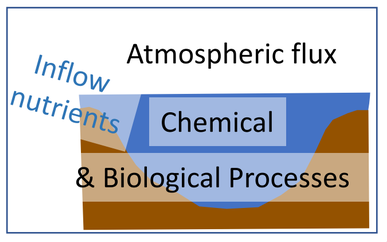
This novel use of EWI metrics may help the citizens of Lake Sunapee decide when, where, and to what extent they need to control P pollution to maintain their oligotrophic lake!

A lake hydrodynamic and ecosystem model is used to address both questions:

Use intermittent long-term data and high-frequency short-term data to calibrate and validate a lake model

GLM: General Lake Model - AED: Aquatic EcoDynamics
(Hipsey, Bruce, & Hamilton, 2014)

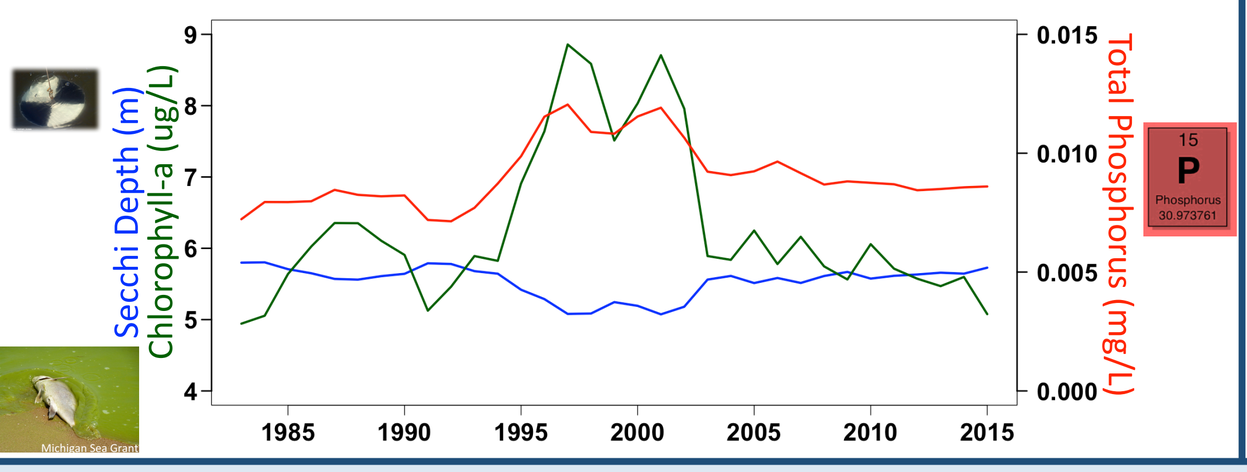




Run simulation from 1985 – 2015: use daily values of phosphorus (P), chlorophyll-a and Secchi depth

Simulated lake water quality parameters

Simulated water column P and chlorophyll-*a* concentration was highest between 1996-2002



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PRELIMINARY MODEL OUTPUT
EWI ANALYSIS
From Perturbed Sunapee Sim.
(high chl-a after 2002)

This point, where autocorrelation, standard deviation, and skewness increase while return rate decreases indicates the system is approaching transition (though that may not be a transition to a eutrophic state… it simply indicates chl-a is exhibiting different patterns)

NEXT STEPS:

-Identify which variables and what level of EWI alarm actually indicate a change from oligo- to eutrophic state.

-Use the distributed computing GRAPLEr platform to test 1,000's of scenarios in lake.

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