Eutrophication, water clarity, and divergent responses to variation in lake level

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You are never further than 20 miles from a lake in Wisconsin.
Distance to a lake in Wisconsin

Source: National Hydrography Dataset. All Lakes > 0.1 ha. Lakepond: a standing body of water with a predominantly natural shoreline surrounded by land.

Distance to a lake association?

Hillary Dugan
Center for limnology

lake clarity sites measured by volunteer scientists
Managing watershed inputs

Cleaning up old farms

Bank stabilization

retention ponds, rain gardens, rock gabion

Photos Rod Olsen
10 miles to a cleaner lake
No swimming for several years during high water
Land-use and changing climate hinder water quality

- Changing precipitation
- Loss of wetlands
- Urban expansion
- Dairy farms
- Row crops
- Phosphorus legacy

(Yahara 2070)
How will a changing hydrology impact water clarity in WI?

Near decadal oscillation in NE Wisconsin lakes and aquifers

![Water clarity in Wisconsin](image)

Watras et al. 2014 GRL
Conventional wisdom:

Drought should result in a clearer water column.

- Reduced phosphorus loads
- Reduced shoreline erosion
- Ultraviolet bleaching

Wet years should result in a turbid lake

- Increased nutrient loads
- Increased sediments
- Increased shoreline erosion

L.M. Mosley 2015 earth science reviews
Conventional wisdom: opposite response can also be true.

Drought can increase severity of harmful algal blooms.

- warmer surface temps
- internal mixing, P recycling
- concentration of key nutrients

While higher lake levels result can in clearer lake!

- Reduced water temperatures
- Deeper lake, increased stratification
- Flushing of nutrients

see L.M. Mosley 2015 earth science reviews
Wisconsin lakes are generally clearer during dry years.

- Clear water lakes are the most sensitive to precipitation
- ~3.5 feet clearer in a dry year versus a wet year

Rose et al. 2017 Ecological applications.
Does water clarity in “my lake” fluctuate like neighboring lakes when hydrology shifts?
Case study in northwest Wisconsin. Citizen scientist Secchi depth time series.

Award winning citizen scientists.
Case study in northwest Wisconsin. Citizen scientist Secchi depth time series
Case study in northwest Wisconsin. Citizen scientist Secchi depth time series
Secchi disk time-series

Citizen science data
July & August Secchi depth
Time period: 1987 to 2014
Secchi disk time-series

Citizen science data
July & August Secchi depth
Time period: 1987 to 2014

hydrologic explanatory time-series

Palmer drought index

ground water height
Barron county

Shell Lake WI
Lake level

Previous year precipitation
“borrowing strength” from a collection of datasets

secchi depth

Indicator(s)
(lake level, palmer drought index, groundwater)

Trend(s)

Errors

State space modeling, Dynamic factor analysis
“MARSS” package R. Holmes et al. 2013
Results: divergent response of water clarity to hydrology

eutrophic lakes

Oligotrophic lakes

(+)
increase in lake level results in a clearer lake

(-)
increase in lake level results in a turbid lake
Phosphorus (TP) and mixing tendency explain different responses
Drought results in a clearer water column in oligotrophic lakes

Silver Lake shore after flooding
Robertson et al. 2009 USGS
Drought results in a clearer water column in oligotrophic lakes

Example from Silver Lake WI

Silver Lake shore after flooding
Robertson et al. 2009 USGS
Potential explanation for opposite responses in eutrophic lakes

Drought years:
- sediment re-suspension in shallow lakes
- Increased nutrient concentration
- Increased surface temperature

Flood years:
- Nutrient dilution and flushing
- Increased stratification and Fe stripping
What drives a divergent response in water clarity to changes in lake level?

eutrophic lakes

(+) increase in lake level results in a **clearer** lake

stratification,
Fe stripping of P
dilution, flushing

oligotrophic lakes

(-) increase in lake level results in a **turbid** lake

Nutrient loading
DOC inputs
Hydrologic regimes will continue to change and impact water clarity

Phosphorus, land-use, and mixing tendency can help explain divergent trends.

Watras et al. 2014 GRL
Hydrologic regimes will continue to change and impact water clarity.

Phosphorus, land-use, and mixing tendency can help explain divergent trends.

LTER Crystal Lake through 11/14/2016

Watras et al. 2014 GRL
Recent lake level increase 2015-2016

Expected change

Standardized secchi depth

-3 -2 -1 0 1 2 3

24) Stone

Recent lake level increase 2015-2016

Expected change

Updated result

**Graphs:**
- **Lake Level Covariate:**
  - Y-axis: Lake level covariate

- **Standardized Secchi Depth:**
  - Y-axis: Standardized secchi depth

- **2015-2016 Increase:**
  - Highlighted in blue,
  - Graph shows a notable increase in lake level during this period.
Divergent response of water clarity to hydrology

**Eutrophic lake**

(+) increase in lake level results in a **clearer** lake

Shallow lakes, polymictic lakes, agricultural

**Oligotrophic lakes**

(-) increase in lake level results in a **turbid** lake

Deep dimictic, forested
Does water clarity in “my lake” fluctuate like neighboring lakes when hydrology shifts?
Eutrophication not only changes the mean secchi depth, but also the natural response of water clarity to a changing hydrology.
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Daniel Schindler, Steve Carpenter, Pete McIntyre, Emily Stanley, Richard Lathrop for input.
Lake level

Effect of lake level

(+)
increase in lake level
results in a \textit{clearer} lake

(-)
increase in lake level
results in a \textit{turbid} lake

Secchi disk time series
Relationship of Water Level and Clarity of Stone Lake

The graphs represent the relationship of water depth and the clarity of Stone Lake over the past 14 years. The graphs include "trend lines" that have been created mathematically to create a visual representation of the direction the data (water depth and clarity) is moving with time.

As the water elevation has increased due to higher rainfall, the clarity of the water has decreased. This is apparently due to the added particulates in the rain as well as increased particulates from the runoff reaching the lake from the adjacent land. As the weather cycle again reverts to a drier period, the trend should reverse - less particulate laden water will be entering the lake and the particulates accumulated during the rainy years will settle out.

This is a natural cycle. However, it indicates how sensitive the lake is to runoff from your property. Avoiding the runoff of nutrients and chemicals by maintaining a natural shoreline is essential to a healthy lake.

The preceding is an observation, not a scientific study. The lake level and clarity data is based on data recorded by Stone Lake shore owners and reported to the UW Stevens Point Citizen's Lake Monitoring program. It is provided for information only.
Macro-scale studies reveal high degree of heterogeneity in water clarity trends through time.

Lottig et al. 2014