



# Characterizing Groundwater and Surface-Water Exchanges in Selected Northeast Twin Cities Lakes

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# Project Objectives

- **Statistical assessment of lake-level fluctuations**
  - Determine climatic, landscape, or geologic characteristics can explain lake-level variability
- **Characterize groundwater/surface water exchanges**
  - Deeper parts of White Bear Lake
  - Other NE TCMA lakes
- **Develop groundwater-flow model of NE TCMA**
  - Groundwater/surface water exchanges
  - Regional effects of groundwater withdrawals on NE TCMA lake levels

# **Field Assessment of Groundwater and Surface-Water Exchanges**

**Water-quality Analyses – Stable Isotope/Age-dating**

**Continuous Seismic-Reflection (6 lakes)**

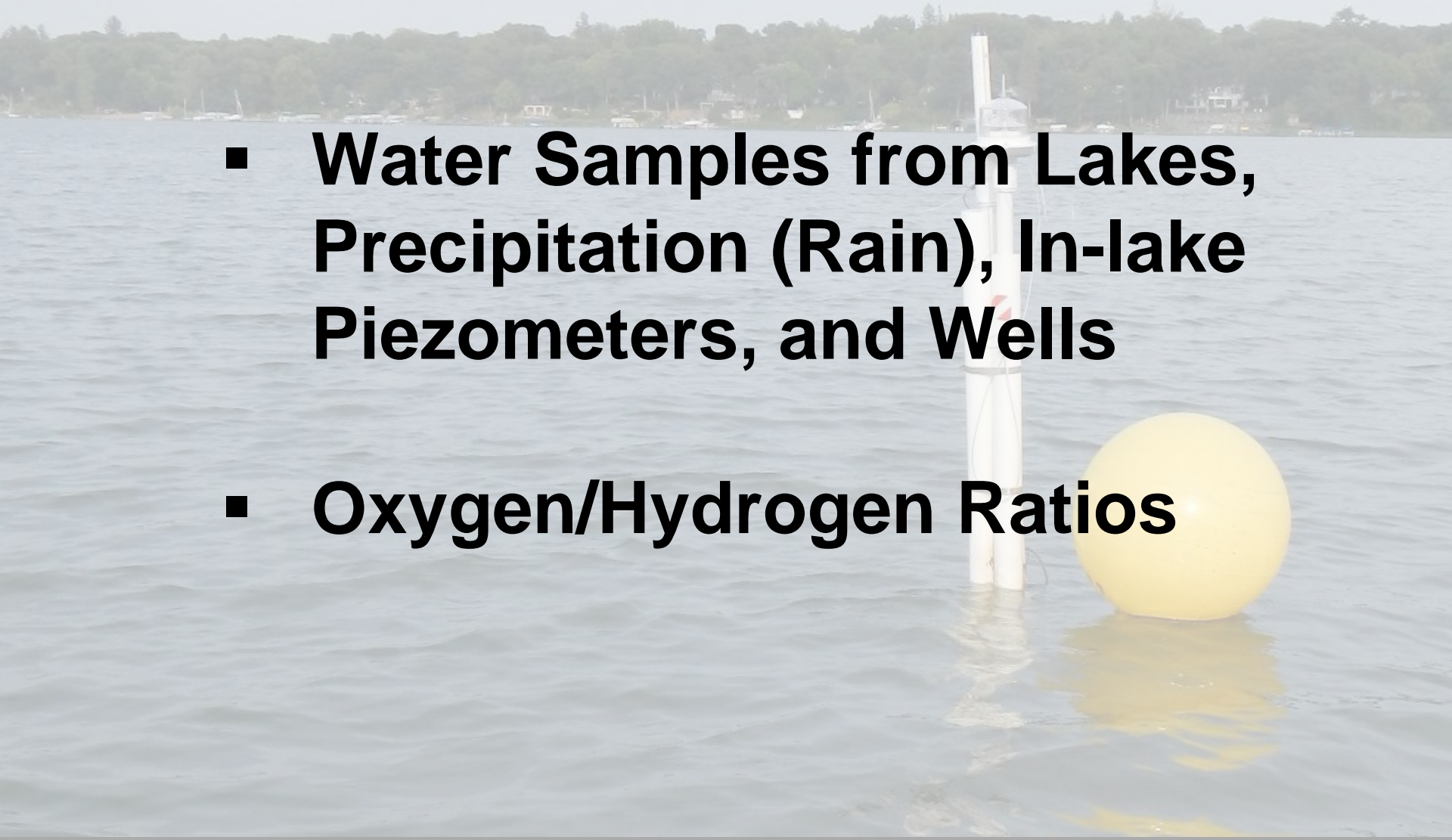
**White Bear Lake – Shallow and Deep waters**

- 1) Lake-sediment Coring**
- 2) Water Levels – Deep-water Piezometers**
- 3) Seepage-Flux Measurements**



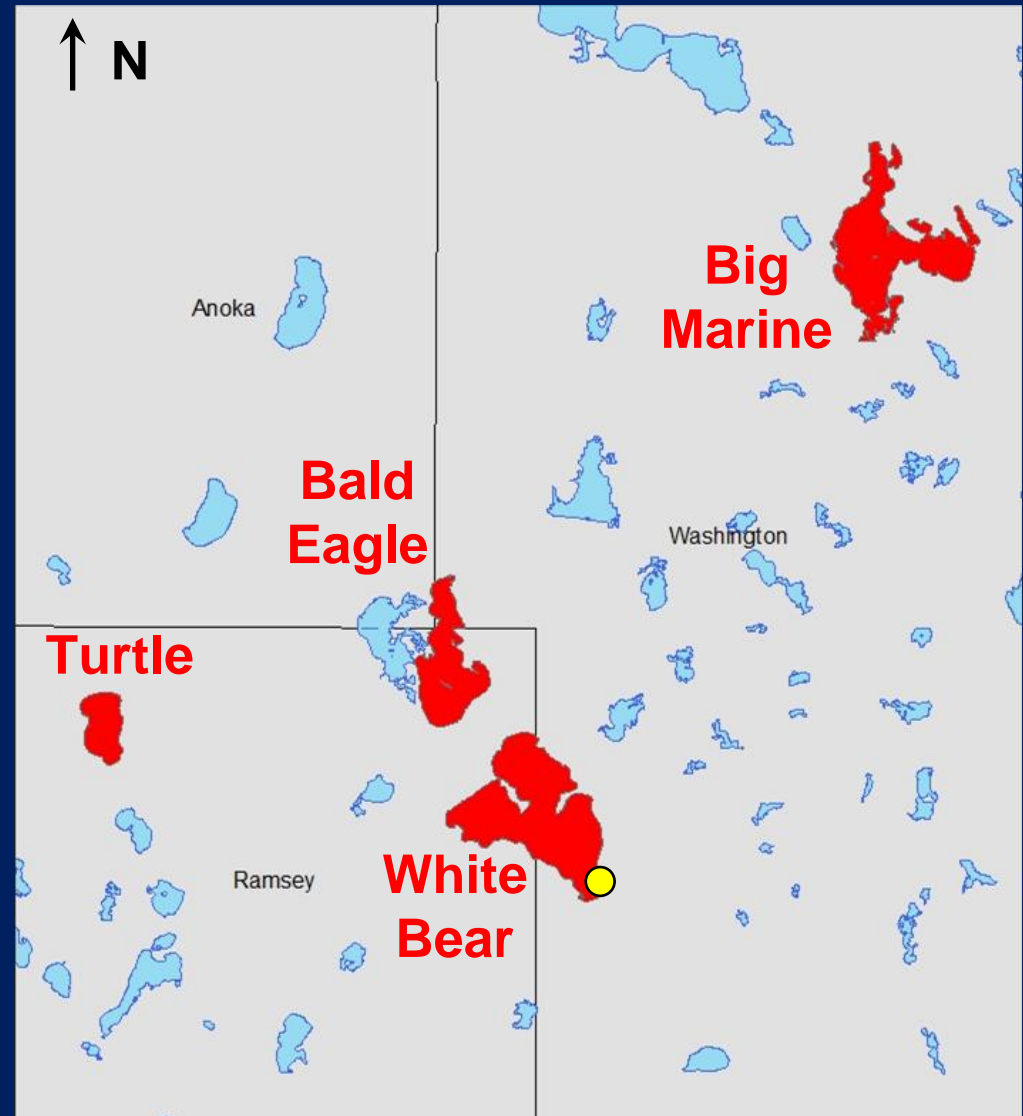
# 2014 Stable Isotope Assessment

- **Water Samples from Lakes, Precipitation (Rain), In-lake Piezometers, and Wells**
- **Oxygen/Hydrogen Ratios**



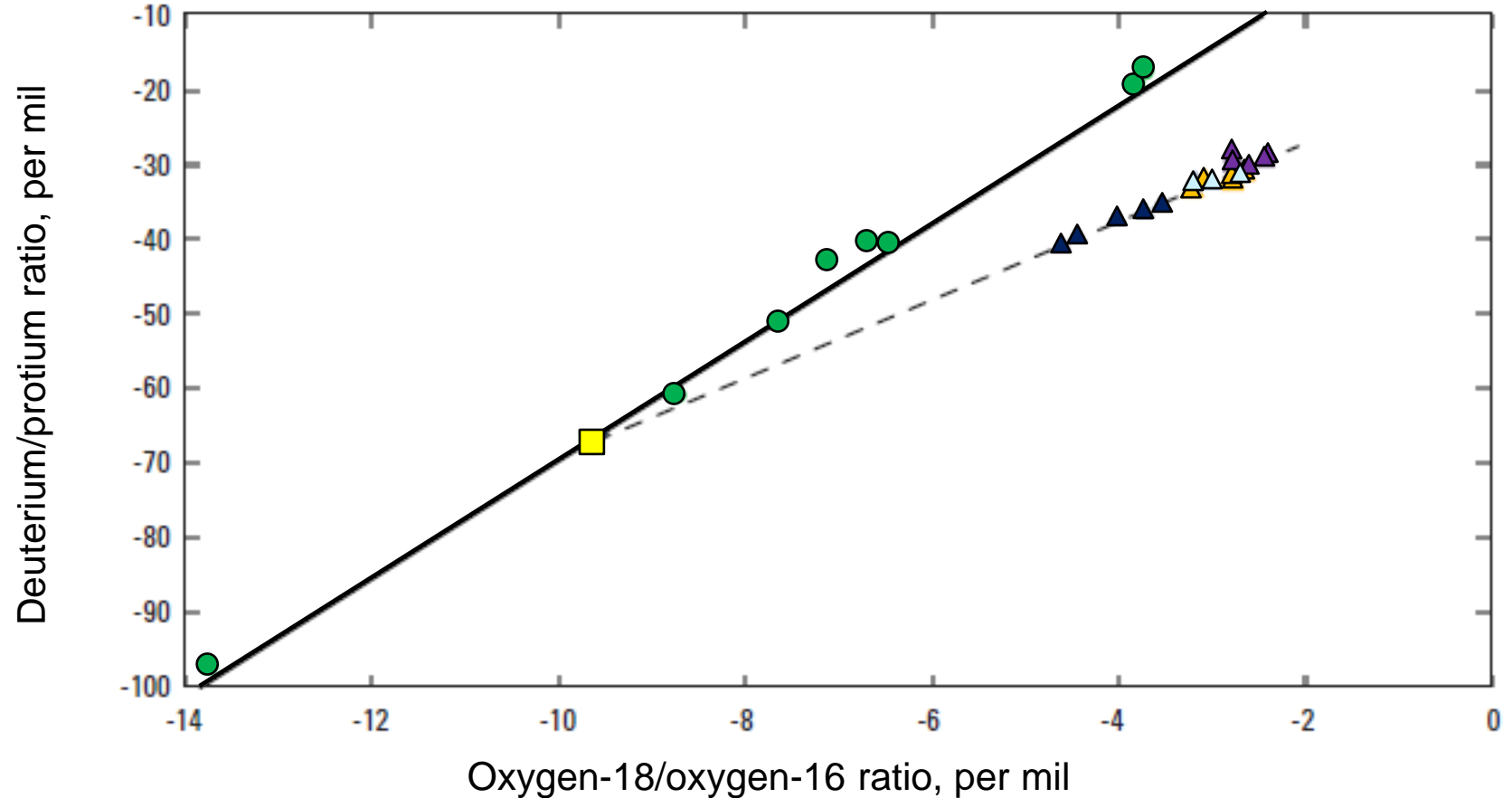
# Stable Isotope Analysis - 2014 Lakes and Precipitation

- Lake water sampled monthly at four lakes
- May - October, 2014
- Establish seasonal trend in lake-water isotope ratios
- Precipitation samples at White Bear Lake



● Precipitation sampling station

# Stable Isotope Analysis - 2014 Lakes and Precipitation



- Meteoric waterline, Princeton, MN (Landon and others, 2000)
- - Lake evaporation trend line
- Bulk precipitation (rain) samples
- Approximate weighted mean isotope composition of rain

## Lake-Water Samples

- ▲ Bald Eagle Lake
- △ Big Marine Lake
- ▲ Turtle Lake
- ▲ White Bear Lake

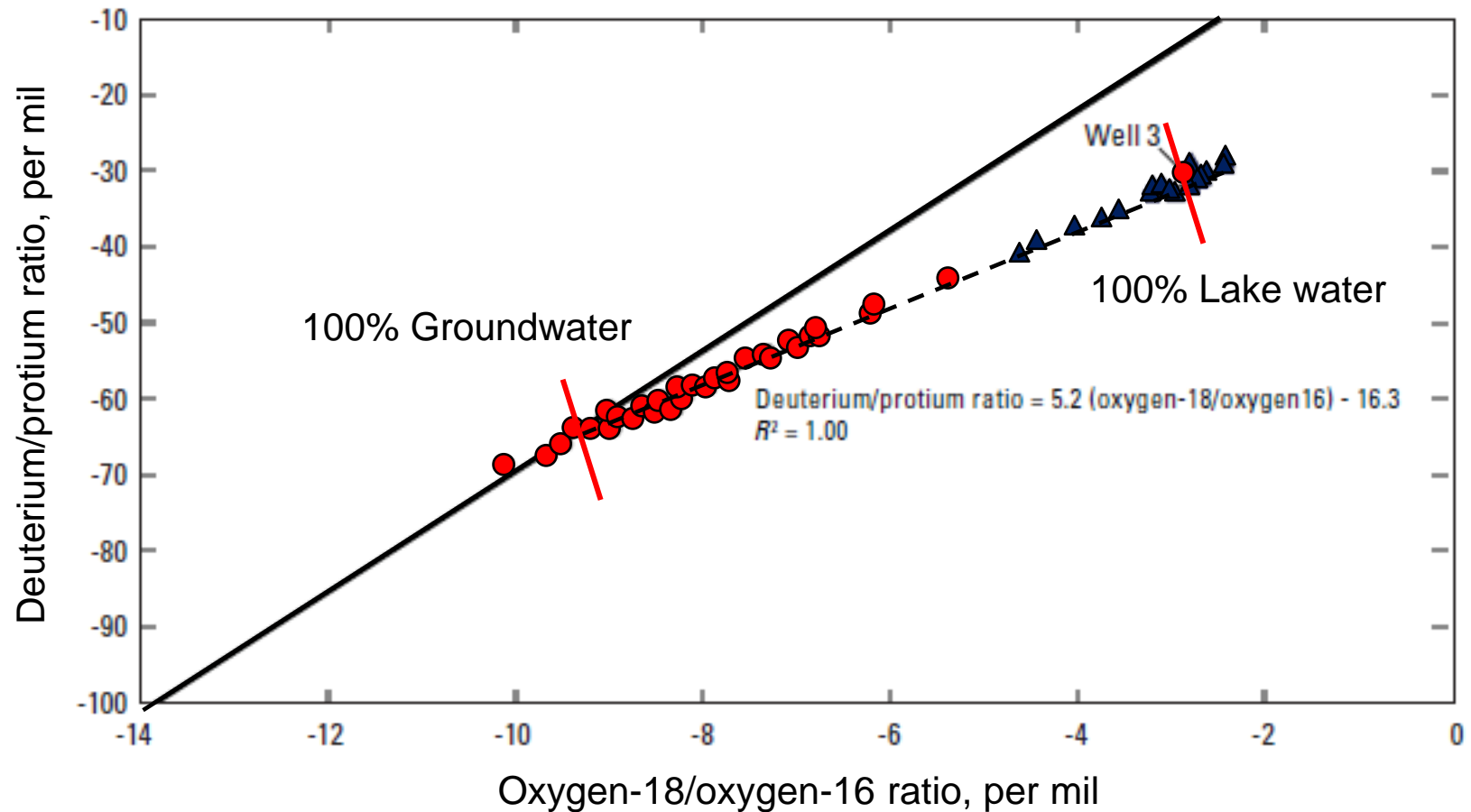


# Stable Isotope Analysis - Wells

- Collect water samples from 40 wells – October 2014
- Wells open to Prairie du Chien, Jordan, or both
- Stable Isotope: Oxygen, hydrogen



# Stable Isotope Analysis - 2014 Wells and Lakes



- Meteoric waterline, Princeton, MN (Landon and others, 2000)
- - Groundwater and lake-water isotope mixing model
- ▲ Lake-water samples
- Well-water samples



# Surface-water contribution – Stable Isotopes

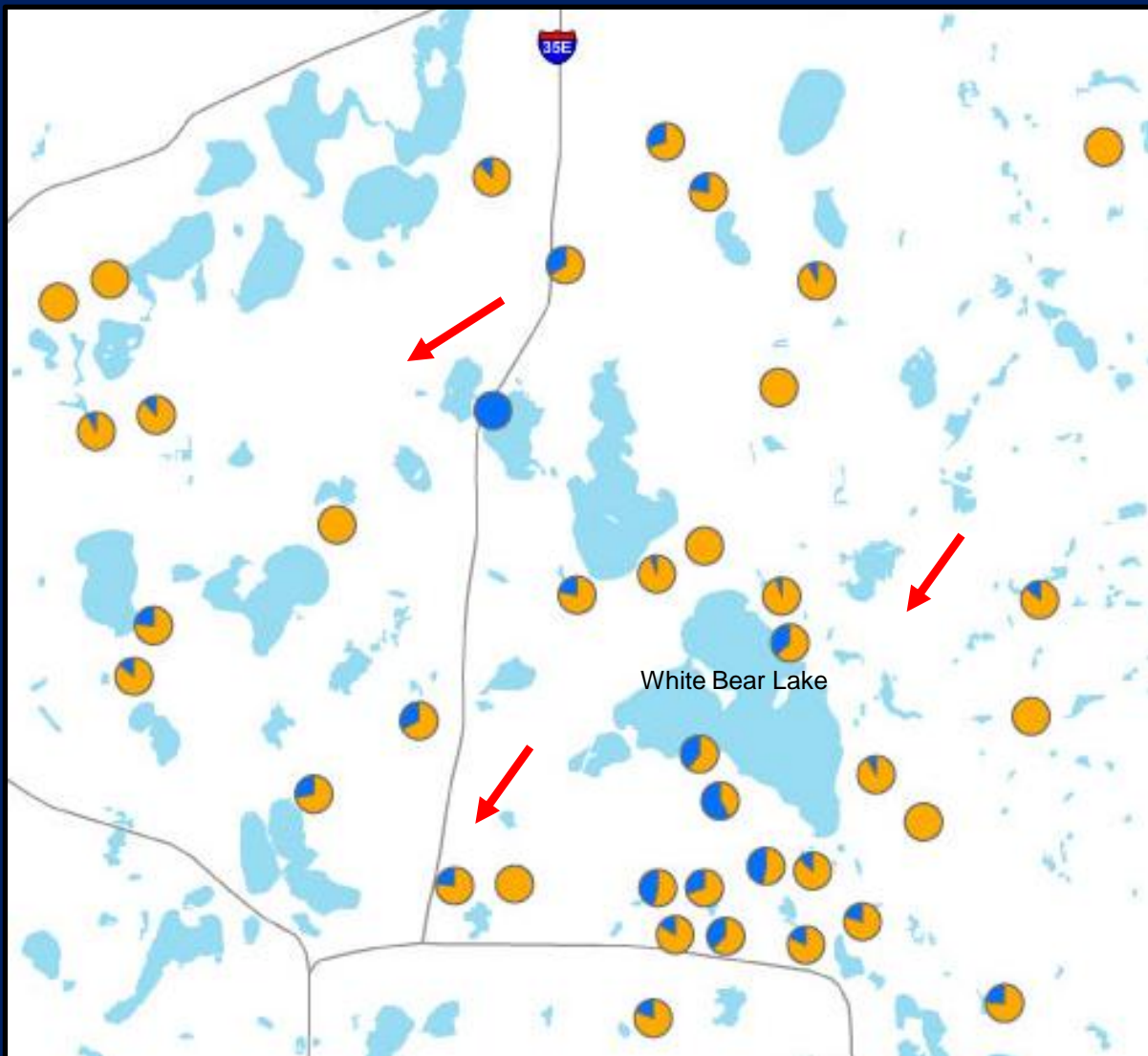
October 2014

Prairie du Chien Group /  
Jordan Sandstone (PDCJ)

Percentage of Contribution



General Groundwater  
Flow Direction (PDCJ)

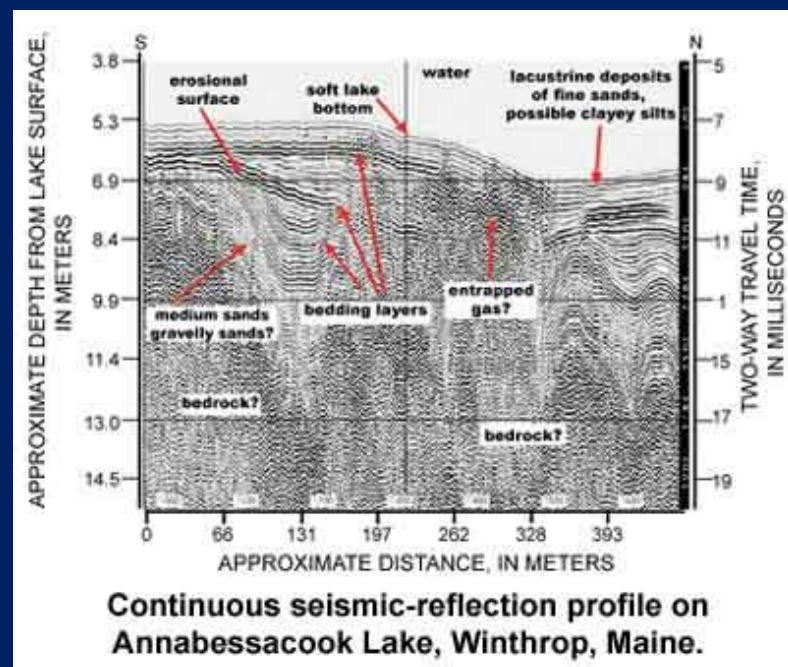


# Water-borne Geophysics – Continuous Seismic Reflection

- Determine subsurface structure and geology
- Conducted in November, 2013
- White Bear, Turtle, Pleasant, South School Section, Big Marine, and Lake Elmo



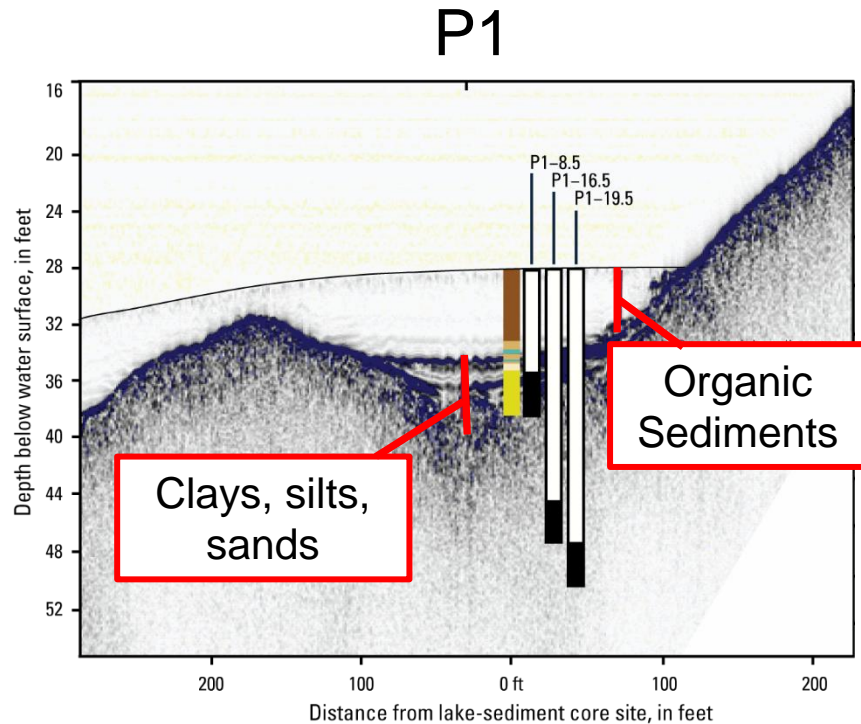
Towfish with cables



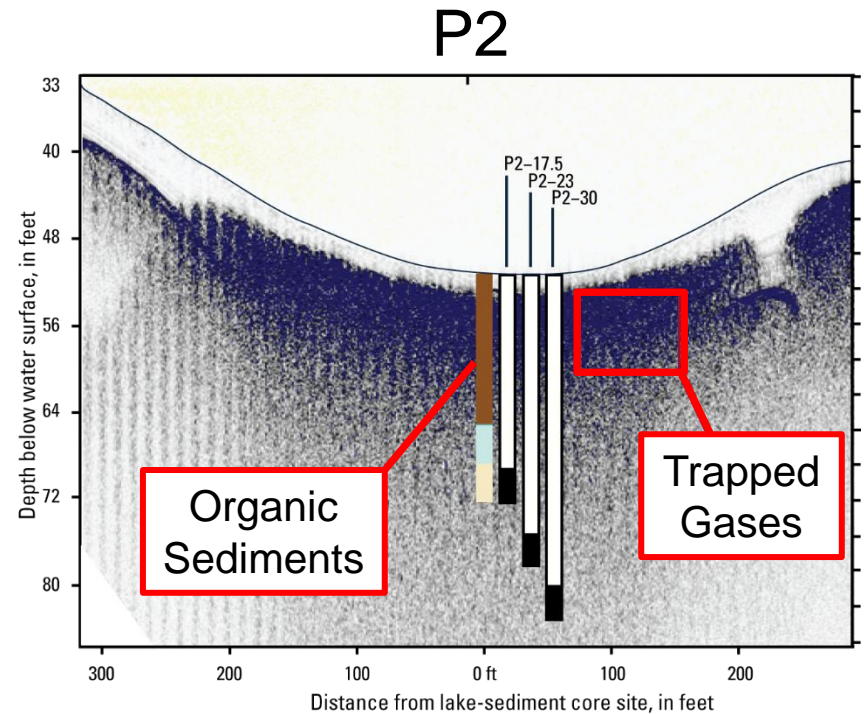
Continuous seismic-reflection profile on Annabessacook Lake, Winthrop, Maine.

# White Bear Lake – Lake Sediment

## No trapped gases



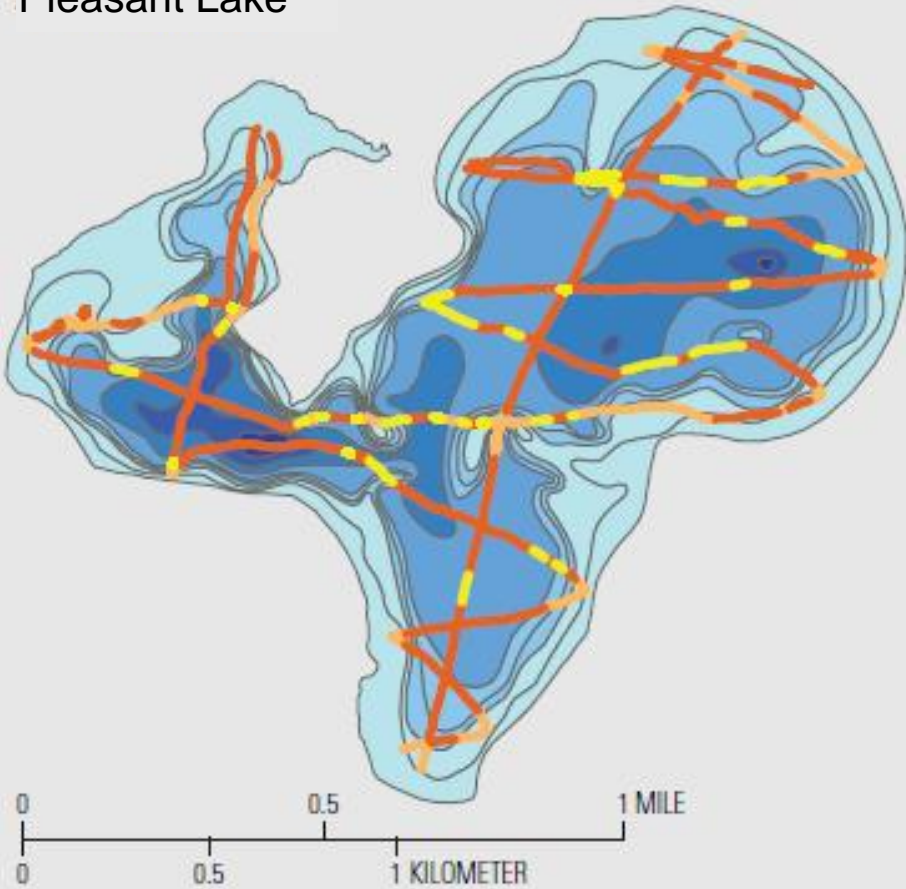
## Trapped gases



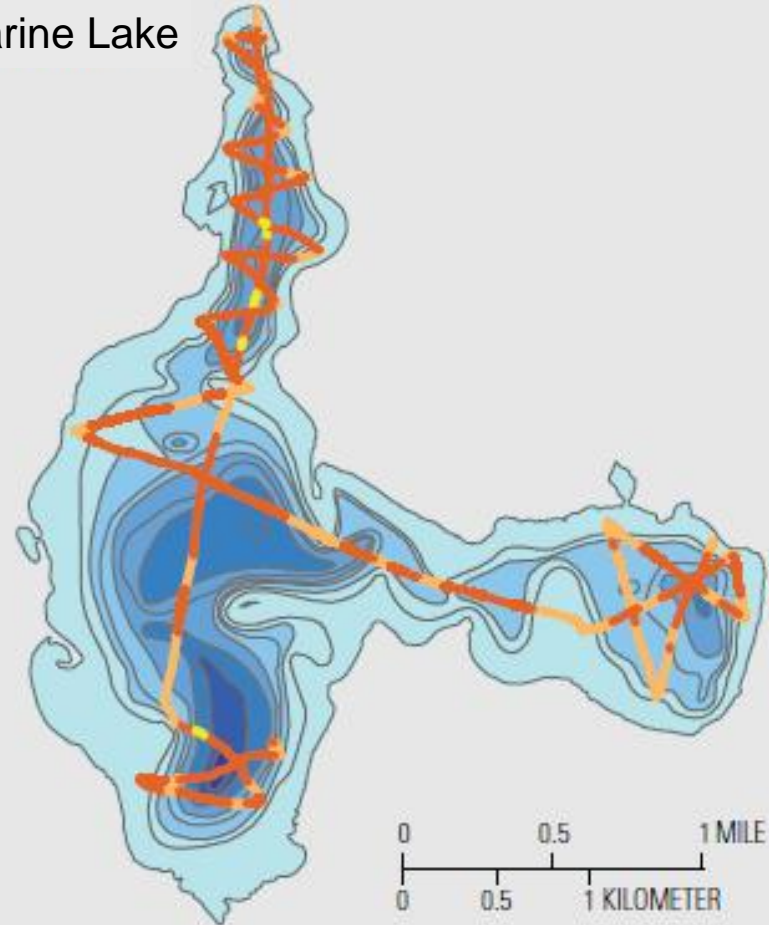


# Continuous Seismic-Reflection

Pleasant Lake



Big Marine Lake



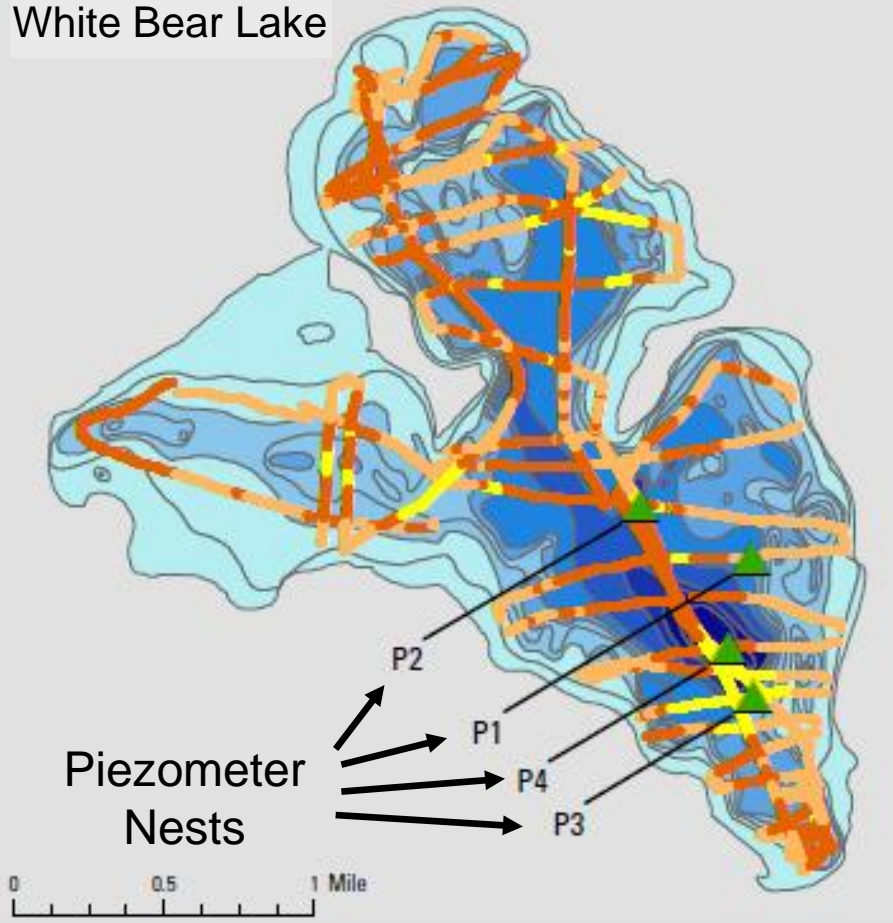
## Seismic-Reflection Profile Pathlines

- Gas-filled sediments
- Low gas sediments in shallow waters
- Low gas sediments in deeper waters

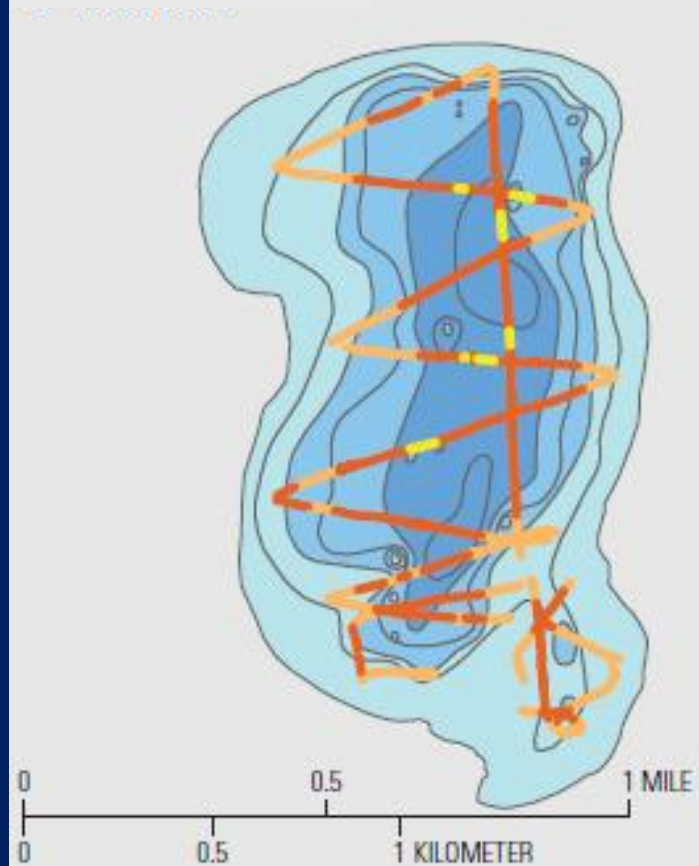


# Continuous Seismic-Reflection

White Bear Lake



Turtle Lake



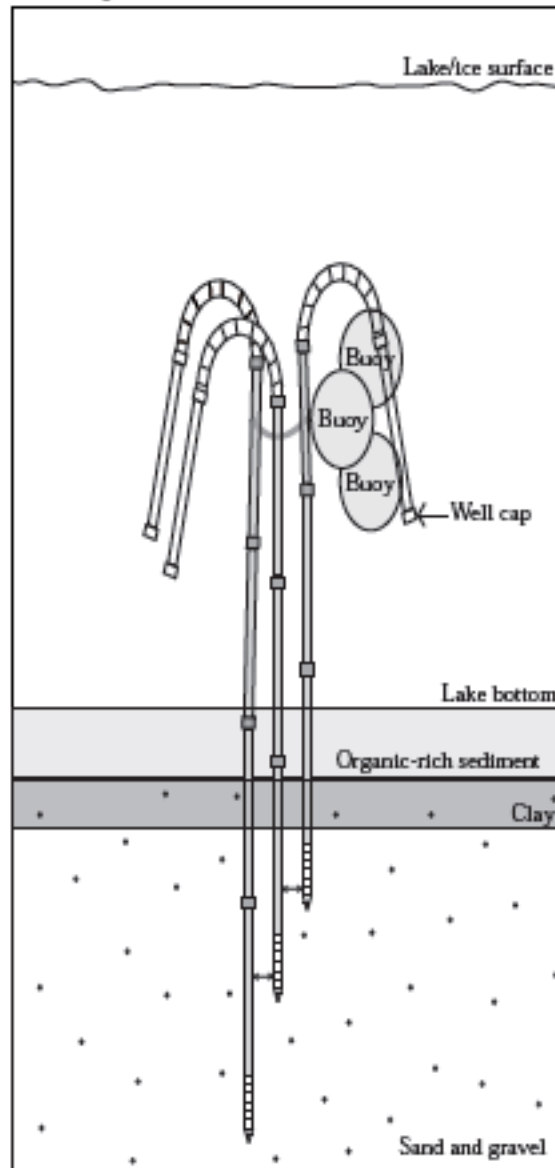
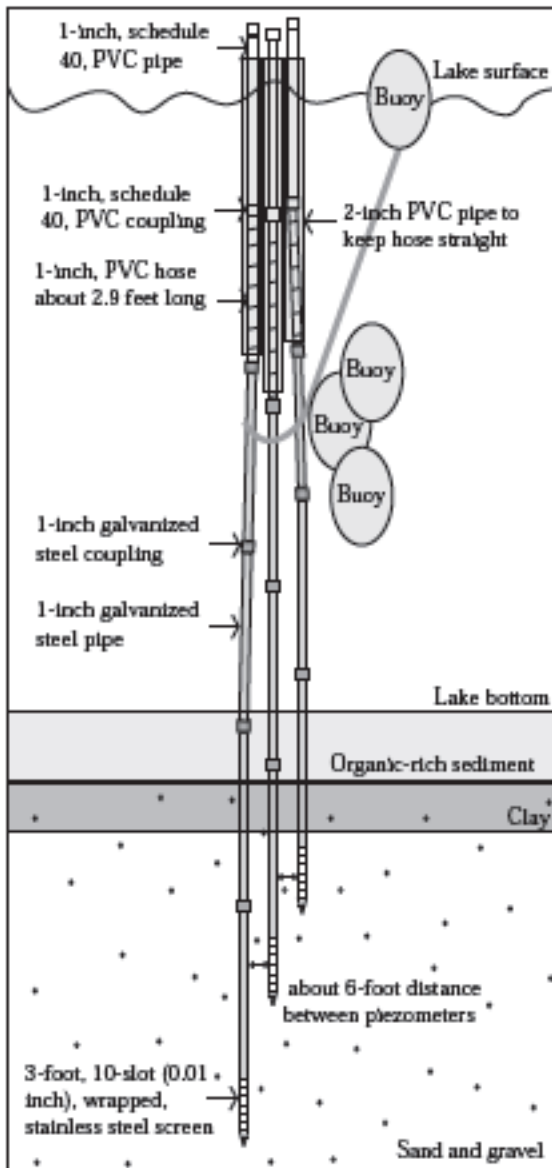
## Seismic-Reflection Profile Pathlines

- Gas-filled sediments
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- Low gas sediments in deeper waters

# White Bear Lake – Deepwater Piezometer Nests

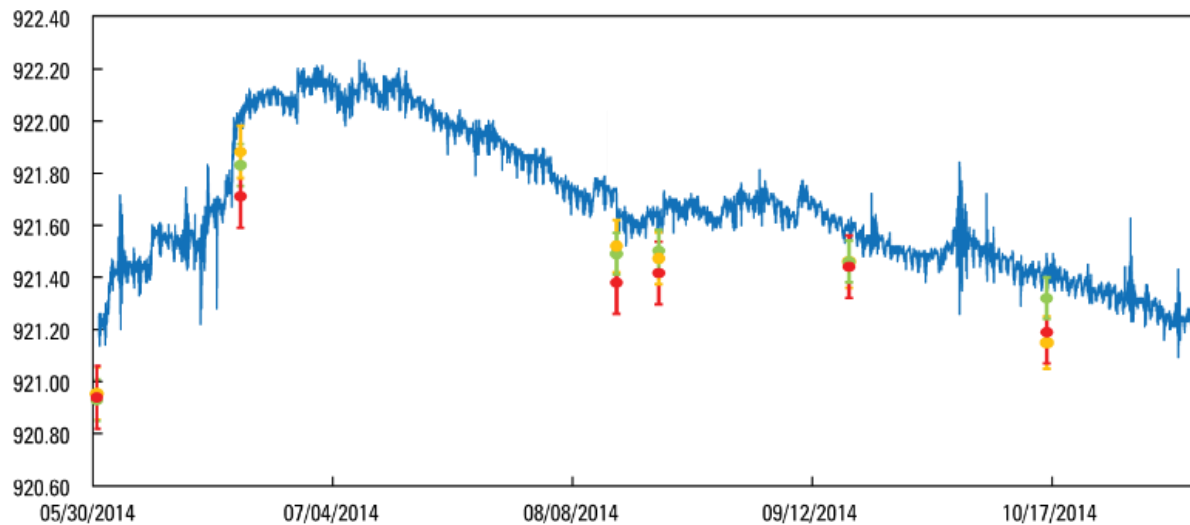
Ice in/out

Ice formation/thaw



# White Bear Lake – Lake and Piezometer Water Levels, 2014

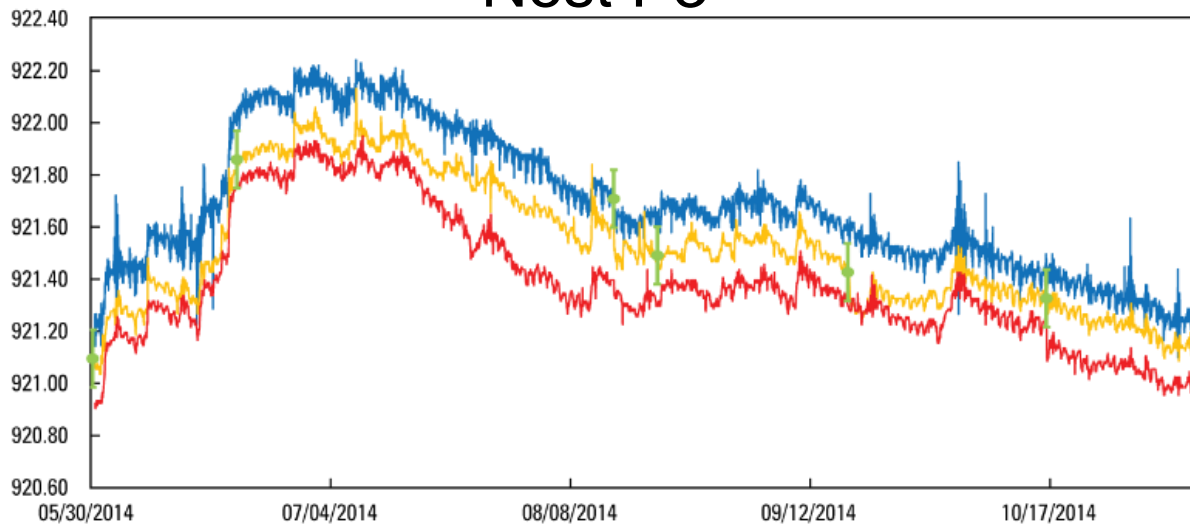
## Nest P1



### EXPLANATION

- White Bear Lake water level elevation
- P1-8.5 water level elevation
- P1-16.5 water level elevation
- P1-19.5 water level elevation

## Nest P3

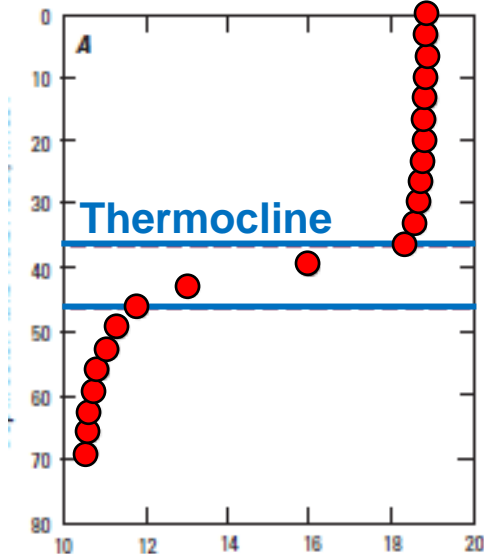


### EXPLANATION

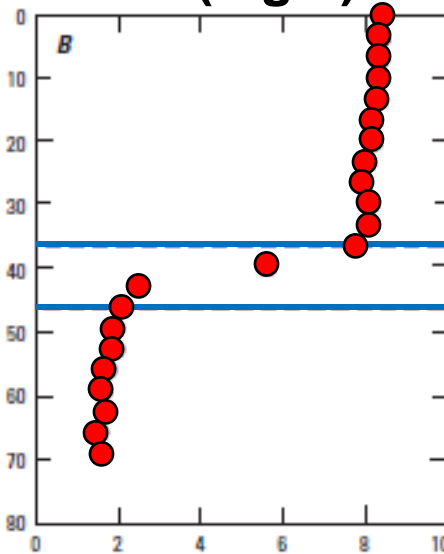
- White Bear Lake water level elevation
- P3-9 water level elevation
- P3-13.5 water level elevation
- P3-18.5 water level elevation

# White Bear Lake – Water-Quality versus Depth

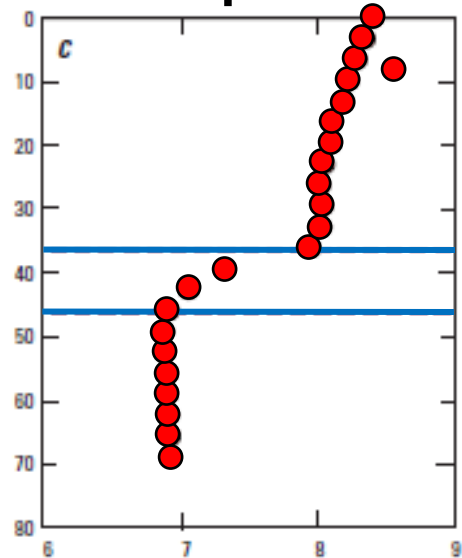
Temp (°C)



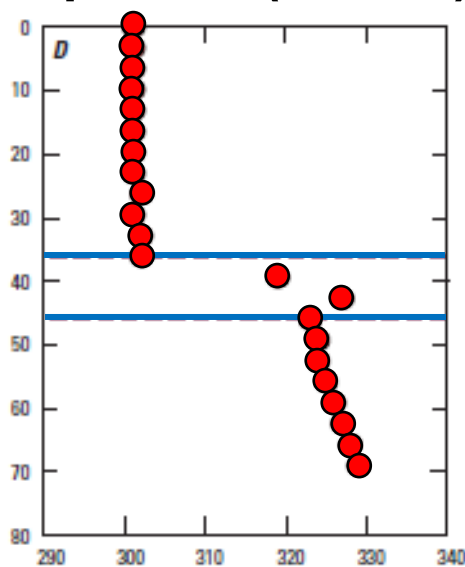
DO (mg/L)



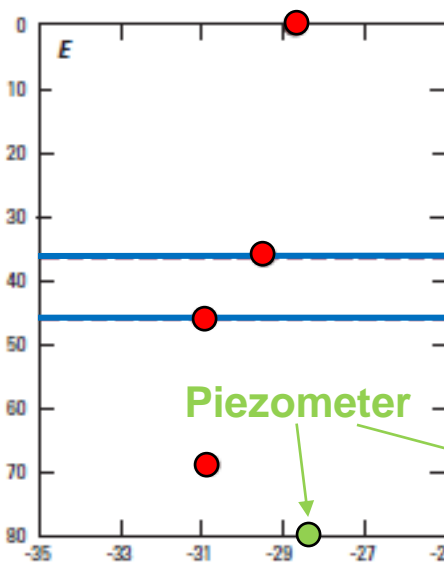
pH



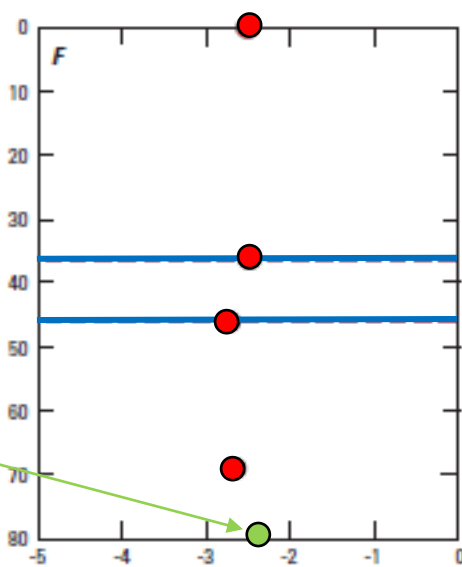
Sp Cond (mS/cm)



H3/H2 ratio



O18/O16 ratio

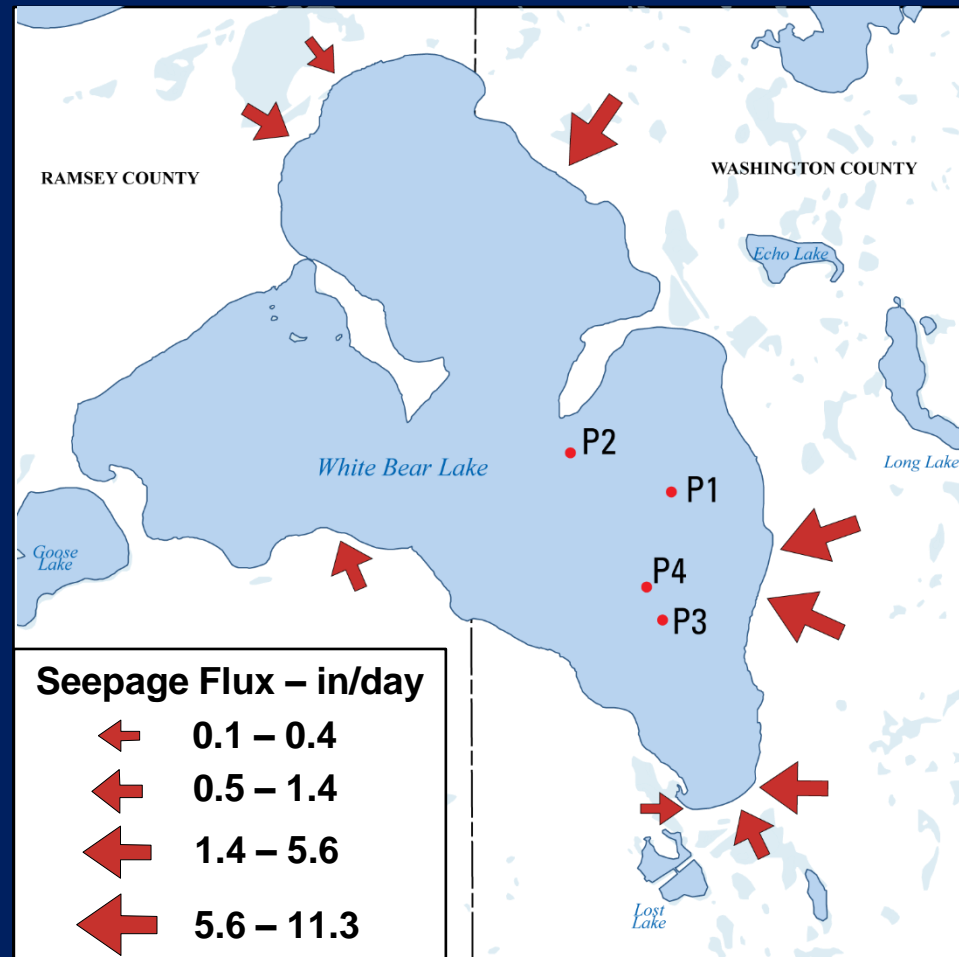




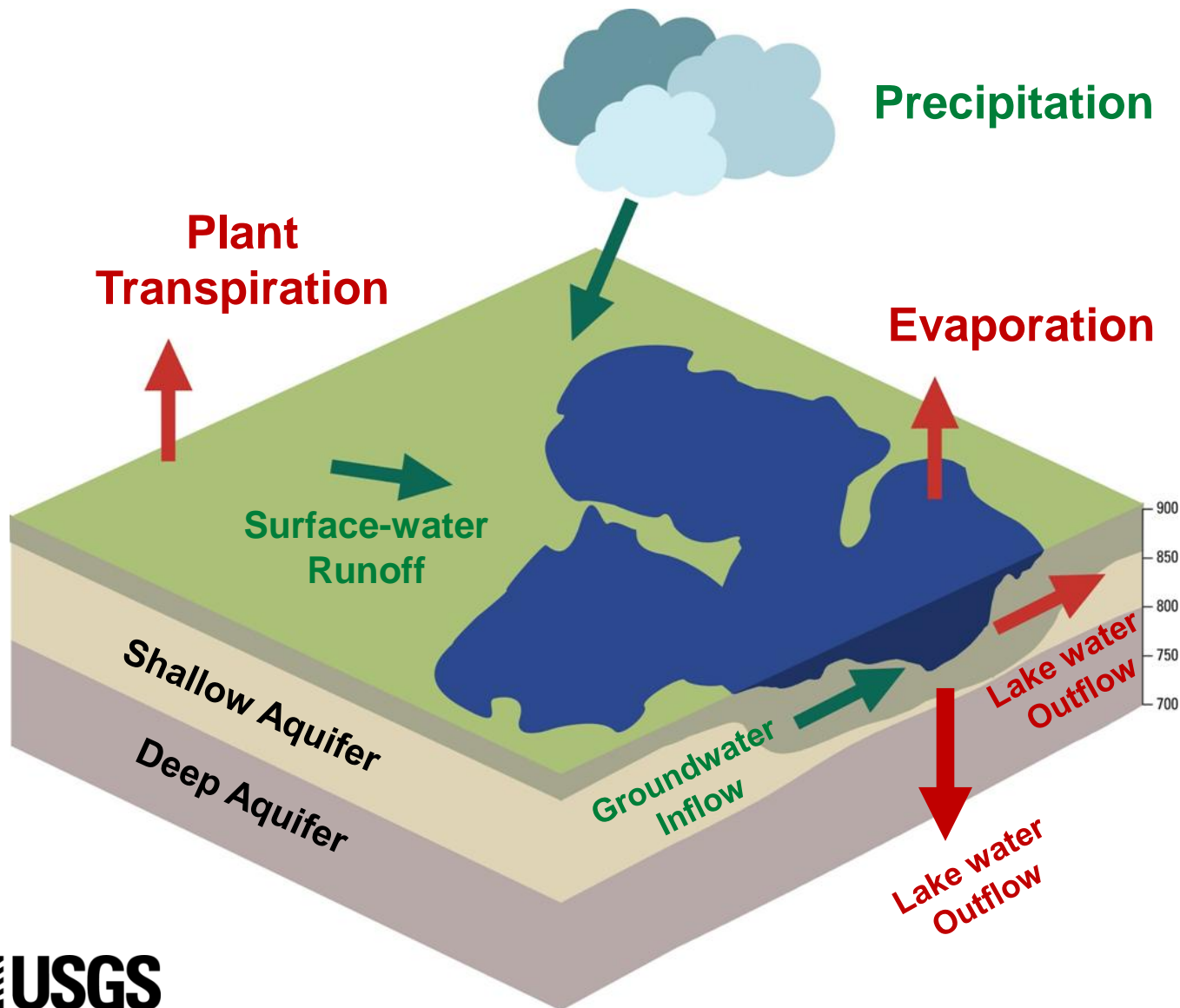
# Seepage-Flux Measurements – 2014

Deep water (P1-P4) (March)  
lake water outflow  
0.04 – 1.0 in/day

Nearshore (August)  
groundwater inflow  
0.1 - 11.3 in/day



# Shallow versus Deep Water Exchanges



# Field Assessment - Results

**Stable isotope ratios indicated a mixture of surface water and groundwater is reaching Prairie du Chein aquifer in part of NE TMCA**

## Interactions in White Bear Lake

- Nearshore: Groundwater flows into lake**
- Deepwater: Lake water flows into sediments**
- Seepage flow rates: Nearshore > Deepwater**

# USGS Report

Available online

<http://dx.doi.org/10.3133/sir20165139A>



Prepared in cooperation with the Metropolitan Council and Minnesota Department of Health

## Statistical Analysis of Lake Levels and Field Study of Groundwater and Surface-Water Exchanges in the Northeast Twin Cities Metropolitan Area, Minnesota, 2002 through 2015

Chapter A of  
Water Levels and Groundwater and Surface-Water  
Exchanges in Lakes of the Northeast Twin Cities  
Metropolitan Area, Minnesota, 2002 through 2015

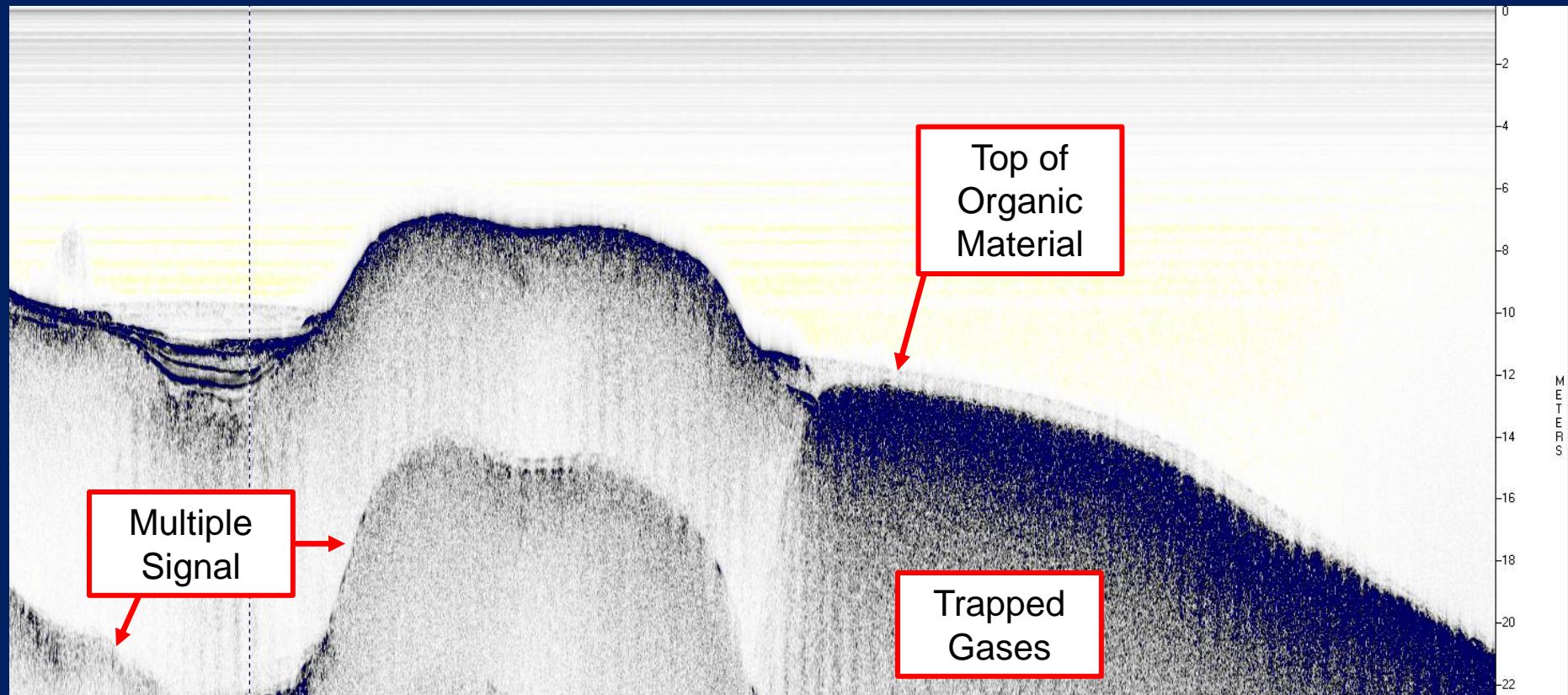


Scientific Investigations Report 2016–5139

U.S. Department of the Interior  
U.S. Geological Survey



# White Bear Lake – Continuous Seismic-Reflection Profiling Example





Questions?







# **Statistical Analysis of Lake Levels - Objectives**

## **Short-term (1999-2014) analysis**

- Assess lake-level fluctuations across region**
- Determine if climatic, landscape, or geologic characteristics (40 variables) can explain lake-level variations**

## **Long-term (1925-2014) analysis**

**Evaluate temporal relations between precipitation and lake levels**

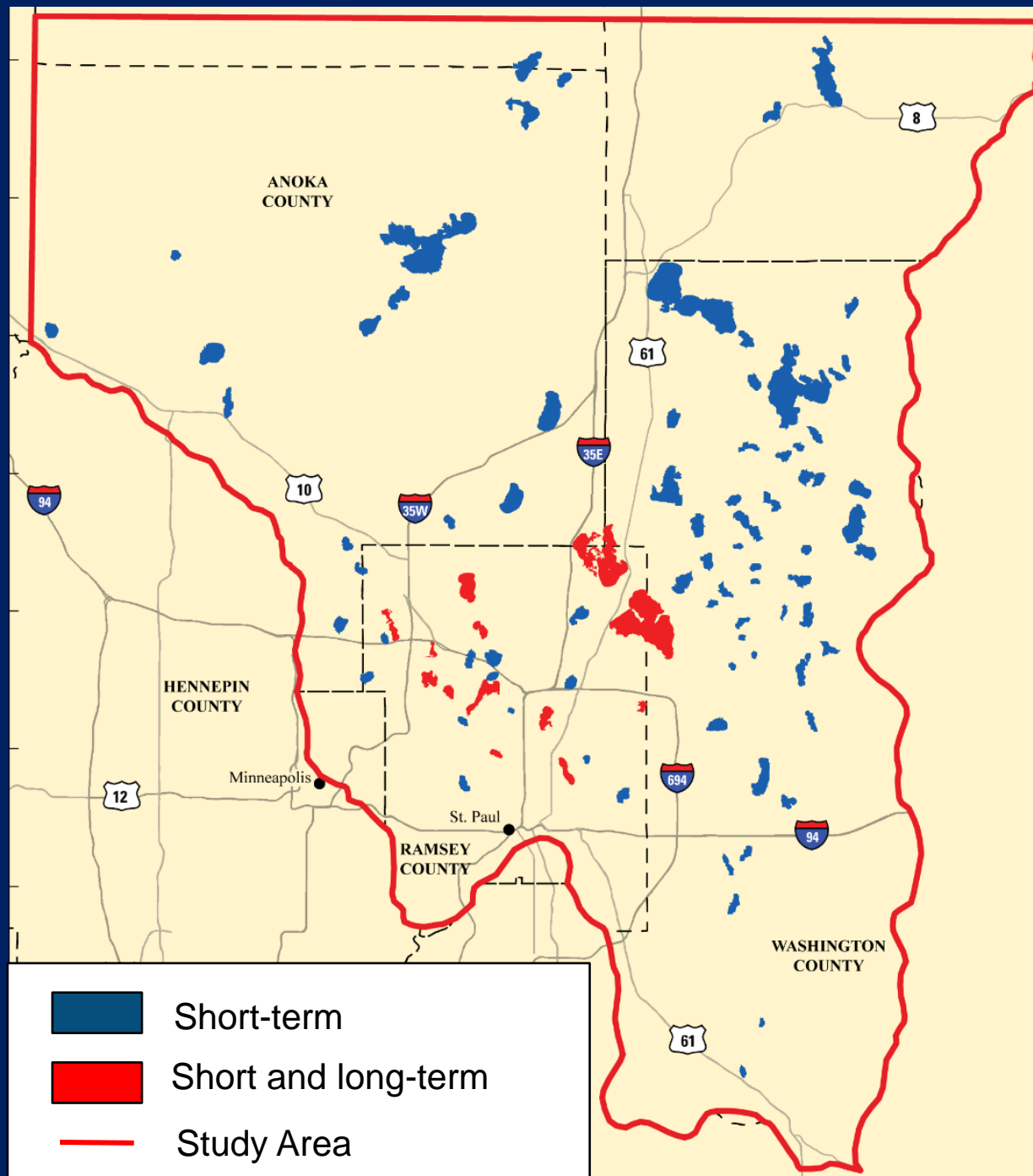


# Statistical Lake-Level Analysis

Short-term  
96 lakes

Long-term  
14 lakes

Selected based  
on lake-level data

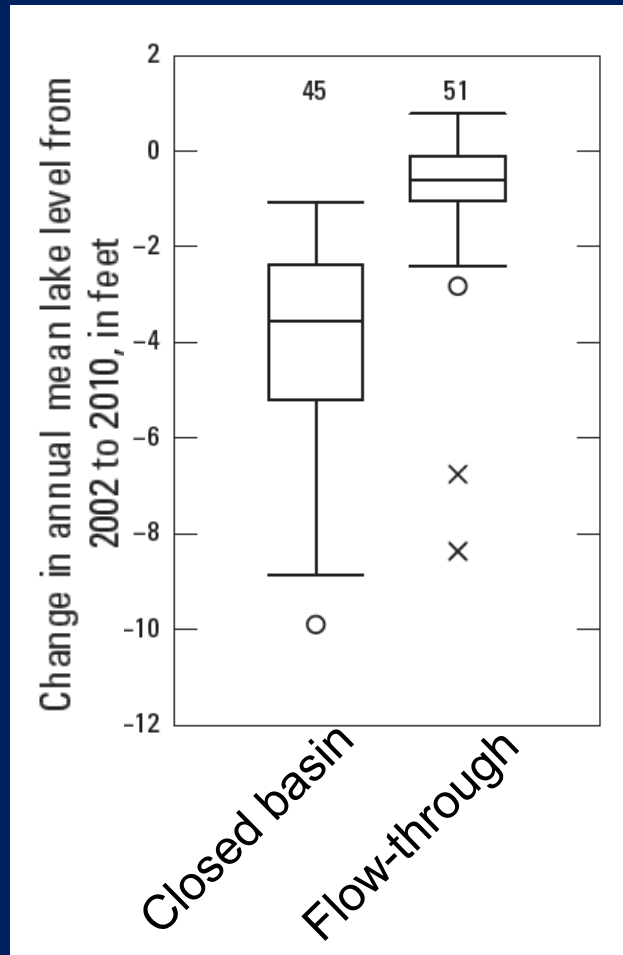


# Lake-level variability – based on lake type

## Closed-basin Lake

no active surface-water outlet

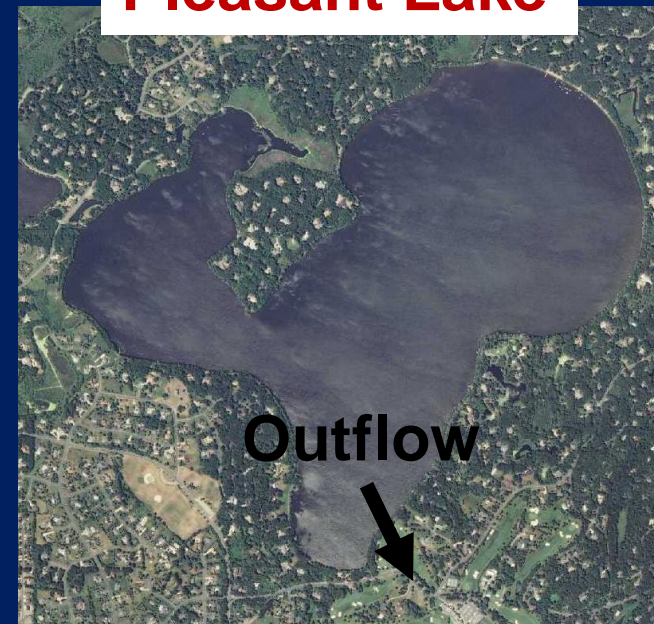
**Turtle Lake**



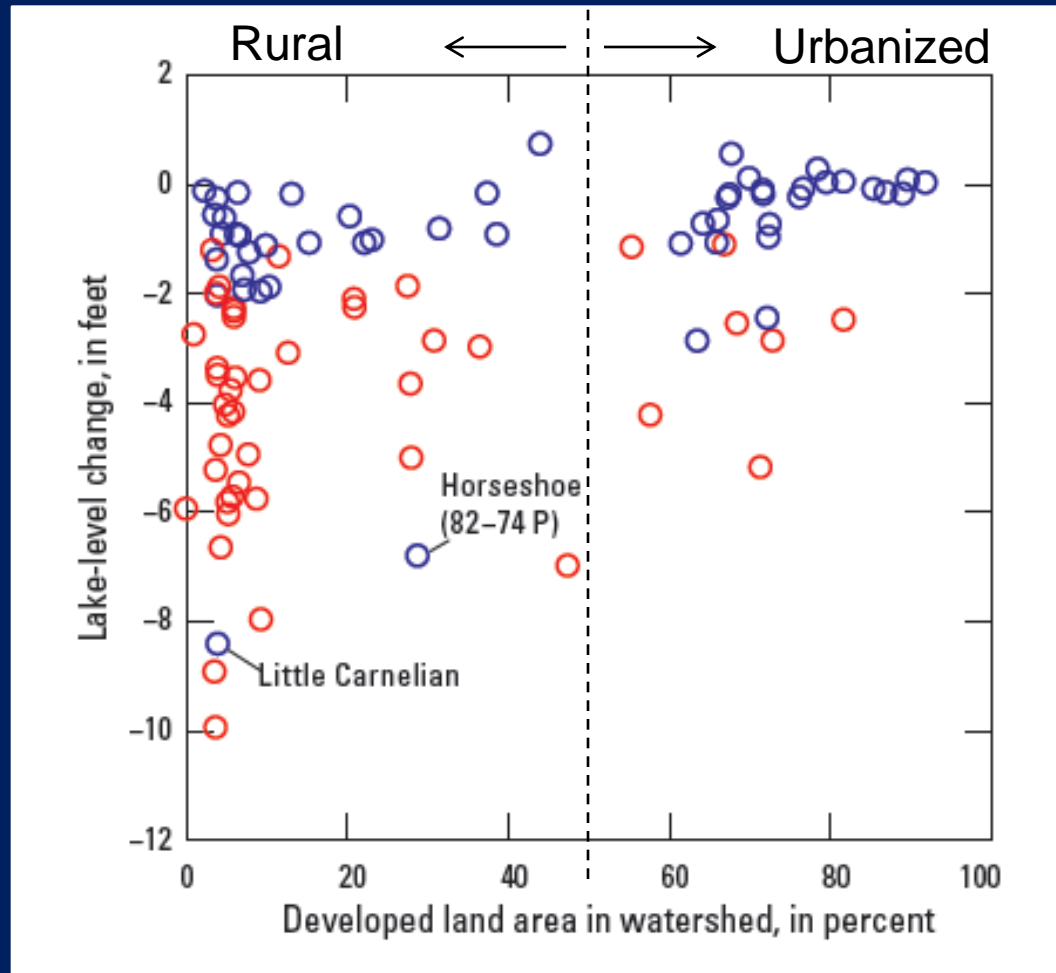
## Flow-through Lake

active surface-water outlet

**Pleasant Lake**



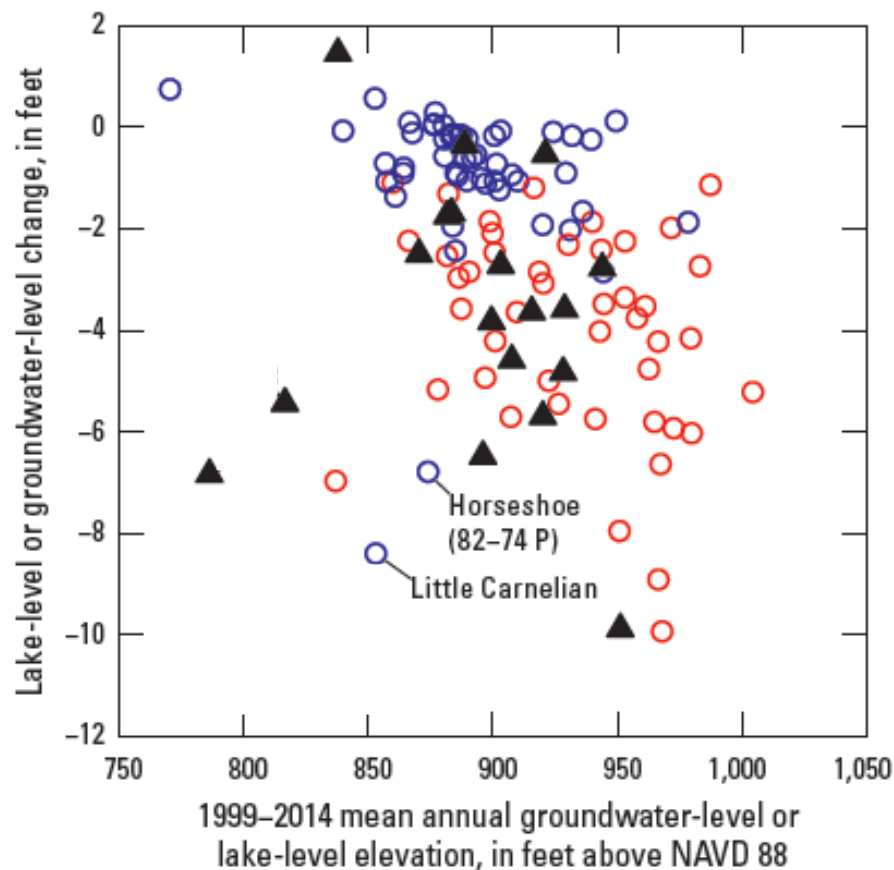
# Lake levels more stable in urbanized areas



- most urban lakes are flow-through
- most rural lakes are closed-basin

EXPLANATION	
<span style="color: red;">○</span>	Closed basin lake
<span style="color: blue;">○</span>	Flow-through lake

# Closed-basin lake levels declined more at higher elevations similar to groundwater levels

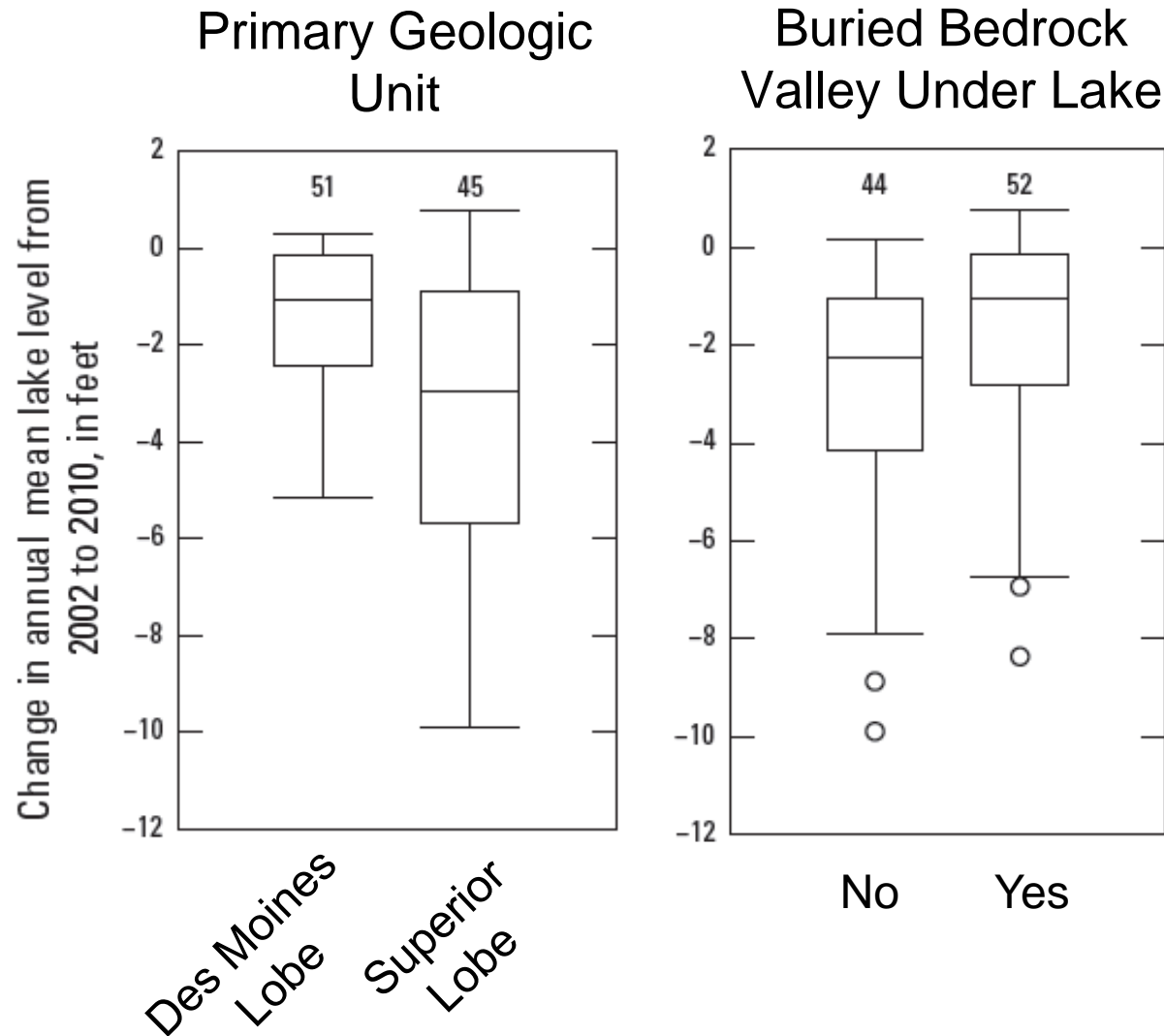


## EXPLANATION

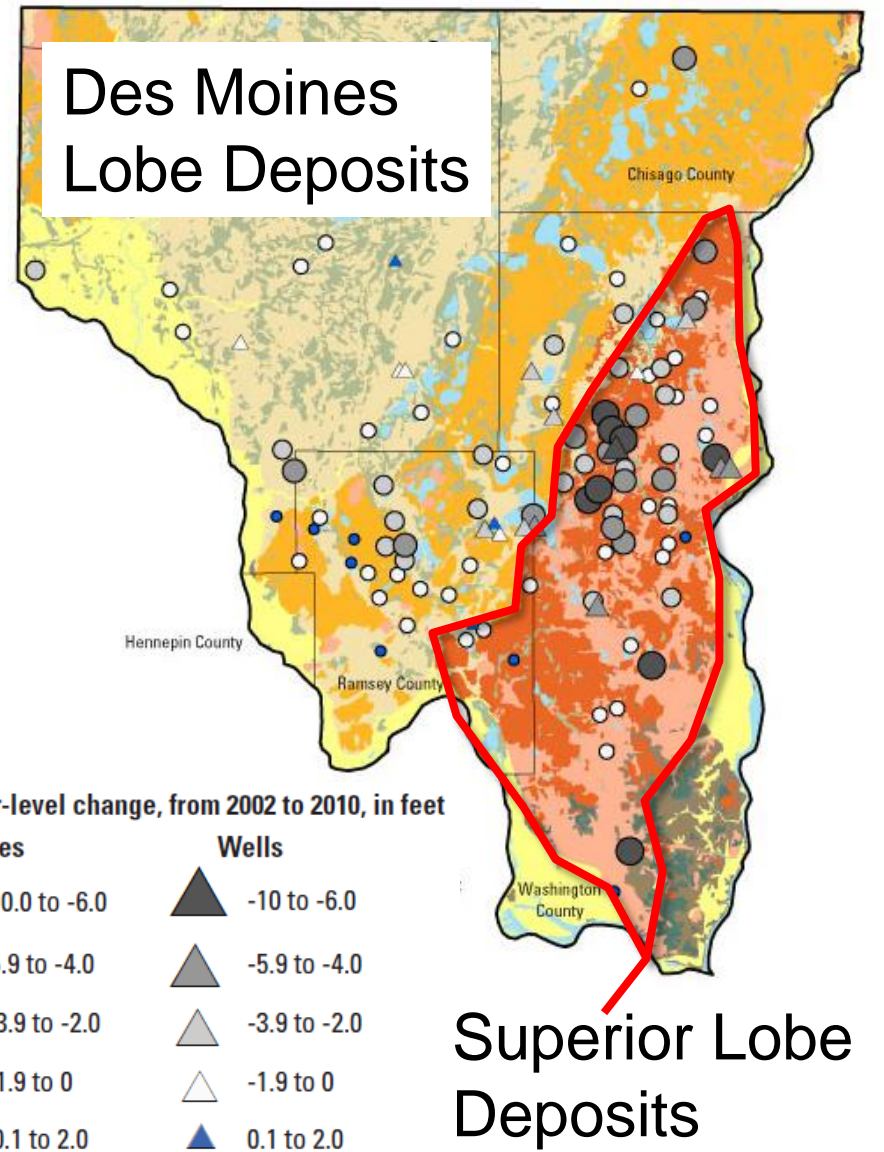
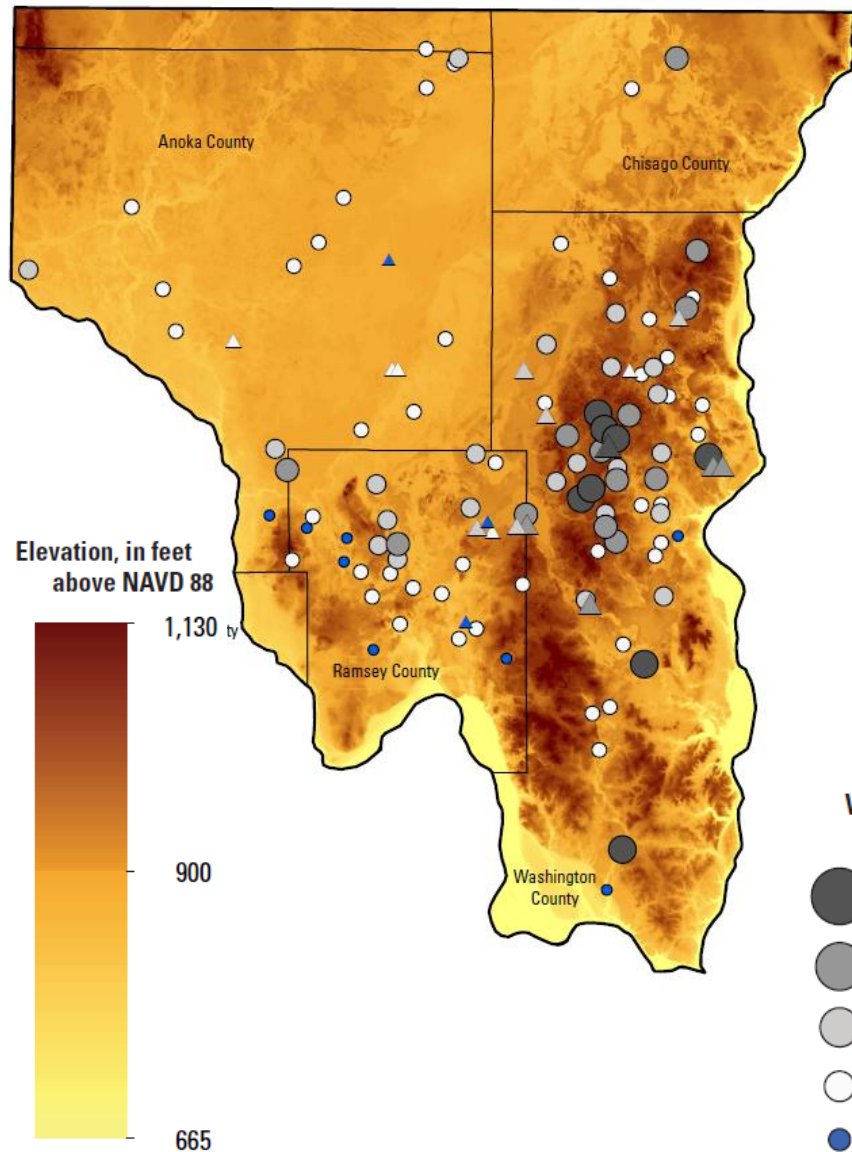
- Closed basin lake
- Flow-through lake
- ▲ Wells



# Geologic Characteristics vs. Lake-level Change (2002-2010)

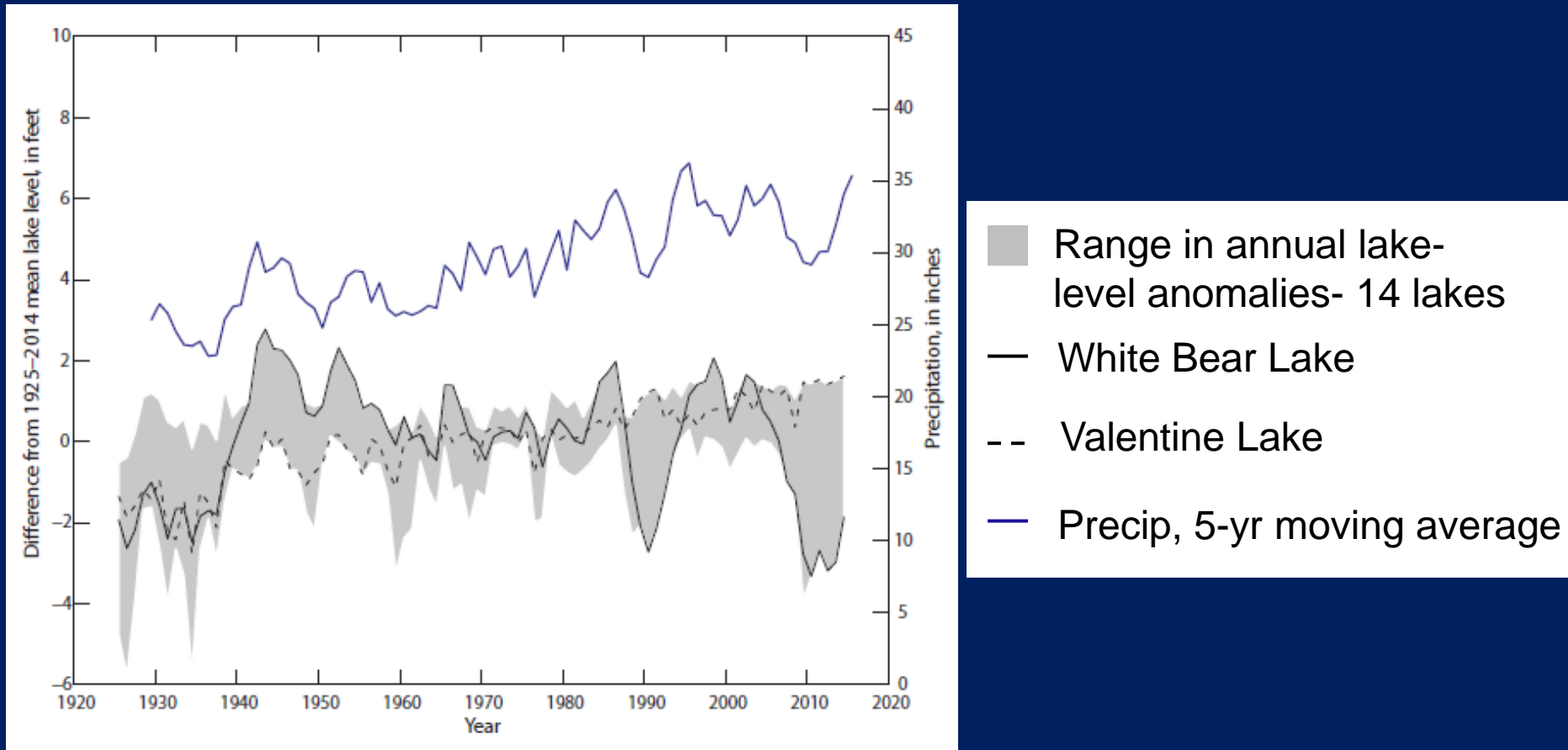


# Closed- basin lakes – water levels more variable at high elevations, in Superior Lobe deposits



# Long-term analysis (1925-2014)

## White Bear Lake – most variable level

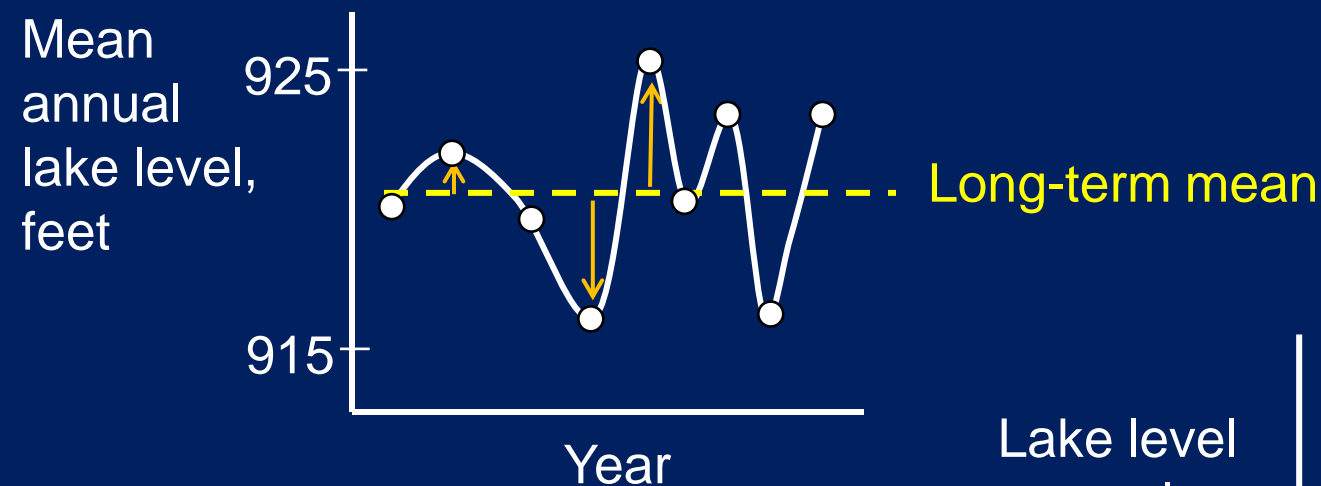


Annual lake-level anomaly =  
mean annual lake level – long-term mean

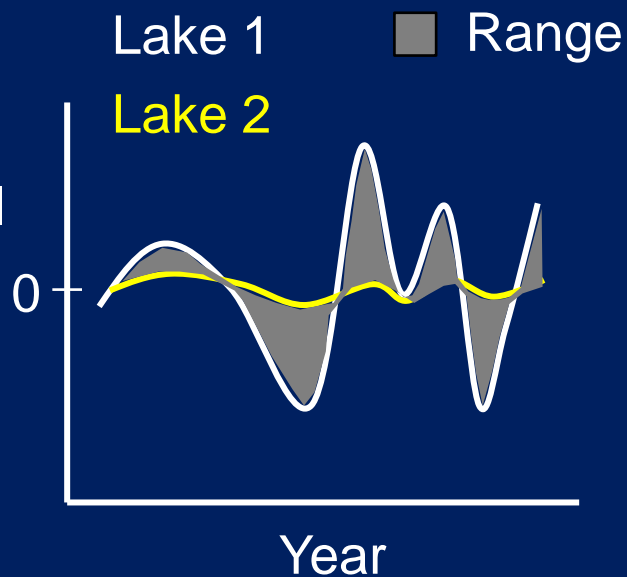
# Long-term analysis (1925-2014)

## Lake Level Anomalies

Annual lake level anomaly = mean annual lake level – long-term mean



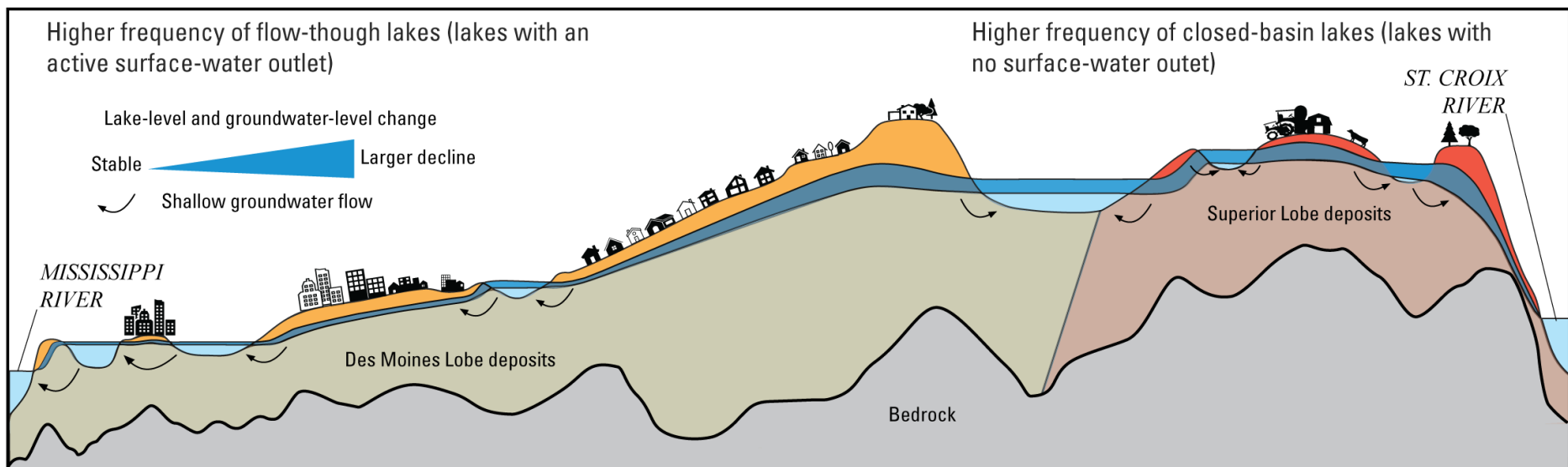
Lake level anomaly, feet





# Statistical Analyses of Lake Levels - Results

Lake type (flow-through/closed-basin), elevation, development, and glacial geology were variables affecting lake-level variability



## **Background: 2013 Minnesota Legislation Chapter 137, Article 2, Section 9(b)**

**“...with the United States Geological Survey to investigate groundwater and surface-water interaction in and around White Bear Lake and surrounding northeast metropolitan lakes, including seepage rate determinations, water quality of groundwater and surface water, isotope analyses, lake level analyses, water balance determination, and creation of a calibrated groundwater-flow model, including a comparison of water levels with lakes bordering the study area. The council shall use the results to prepare guidance for other areas to use in addressing groundwater and surface water interaction issues. “**

# **Report: Groundwater and Surface-Water Exchanges and Water Levels in Lakes of the northeast Twin Cities Metropolitan Area, Minnesota, 2002 through 2015**

**Chapter 1: Field Study and Statistical Analysis (Perry Jones and Jared Trost)**

**Chapter 2: Groundwater-flow Modeling Analysis (Jason Roth and Perry Jones)**

# Chapter 1 Methods

- **Lake-level statistical analysis - long-term (1925-2014) and short-term (1999-2014)**
- **Water-quality analyses**
  - Stable isotopes (oxygen and hydrogen)
  - Age dating
- **Geophysics and Hydrogeology**
  - Continuous seismic-reflection profiling
  - Lake-sediment cores
  - Water levels in piezometers
  - Water flow in seepage meters

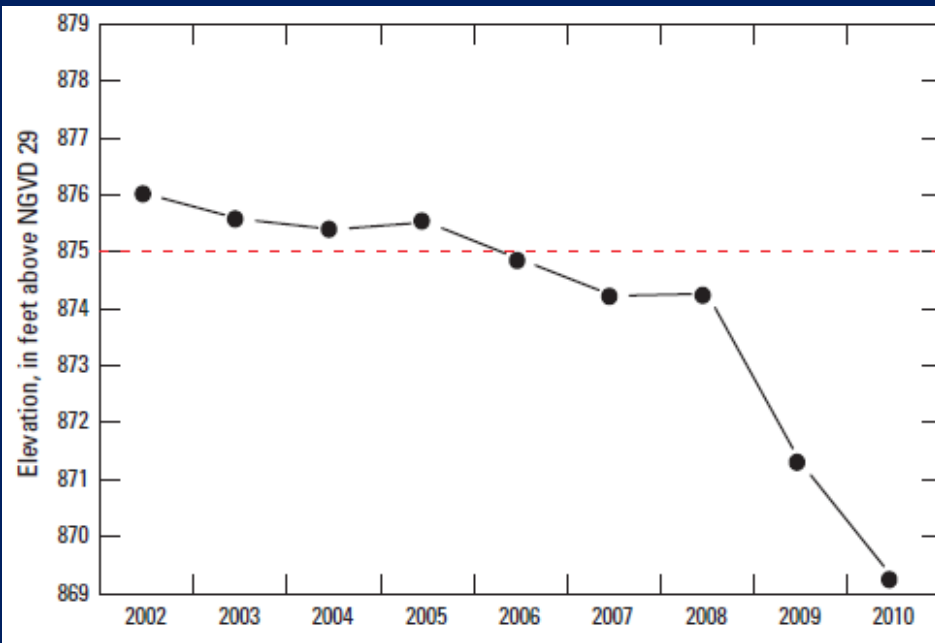


# Potential Future Work

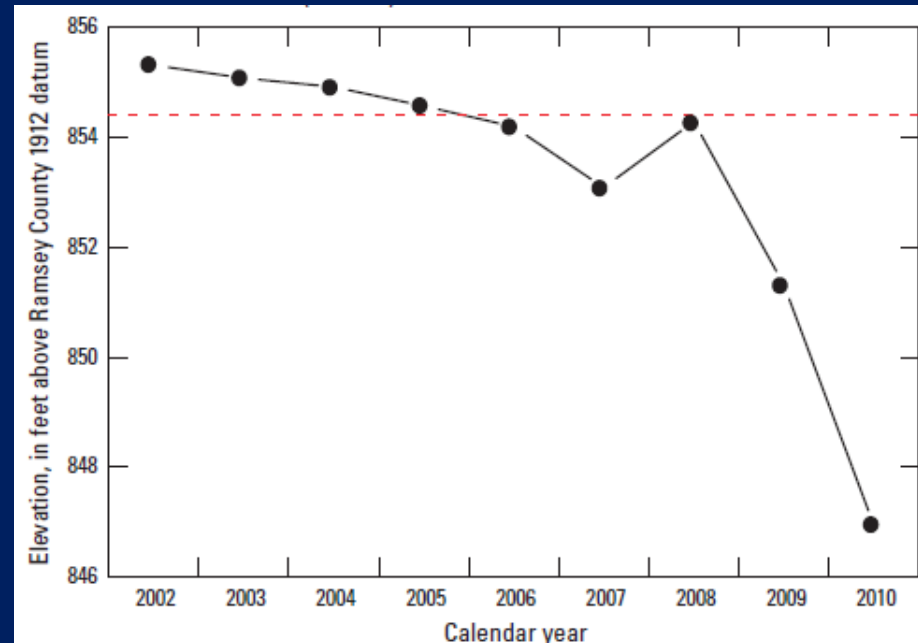
- Need a better understanding of geology/ hydrogeology below NE Metro lakes
- Construction of lake depth maps, potentially using continuous seismic-reflection data
- Better repository for storm-water/ lake outflow structure data

# Change from Flow-through to Closed-basin conditions

## Horseshoe Lake



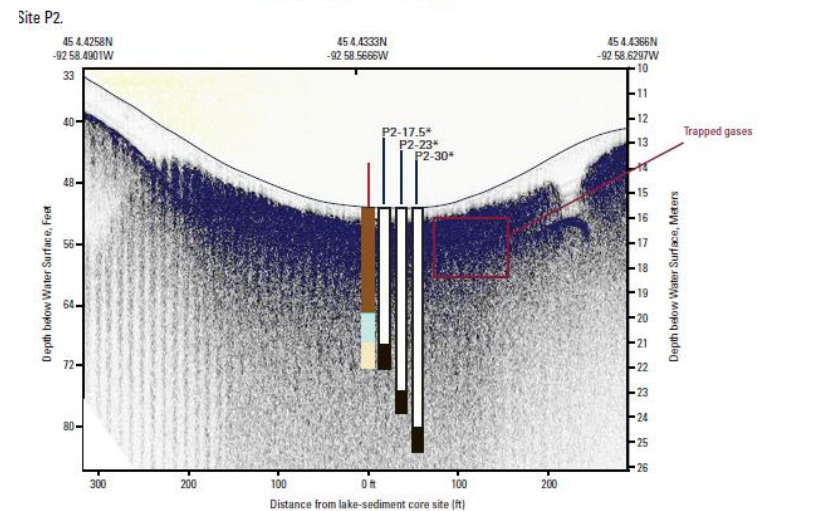
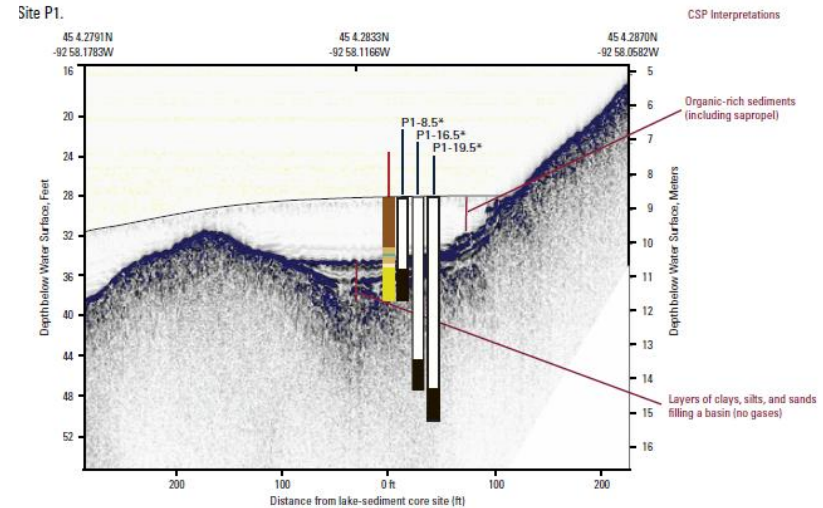
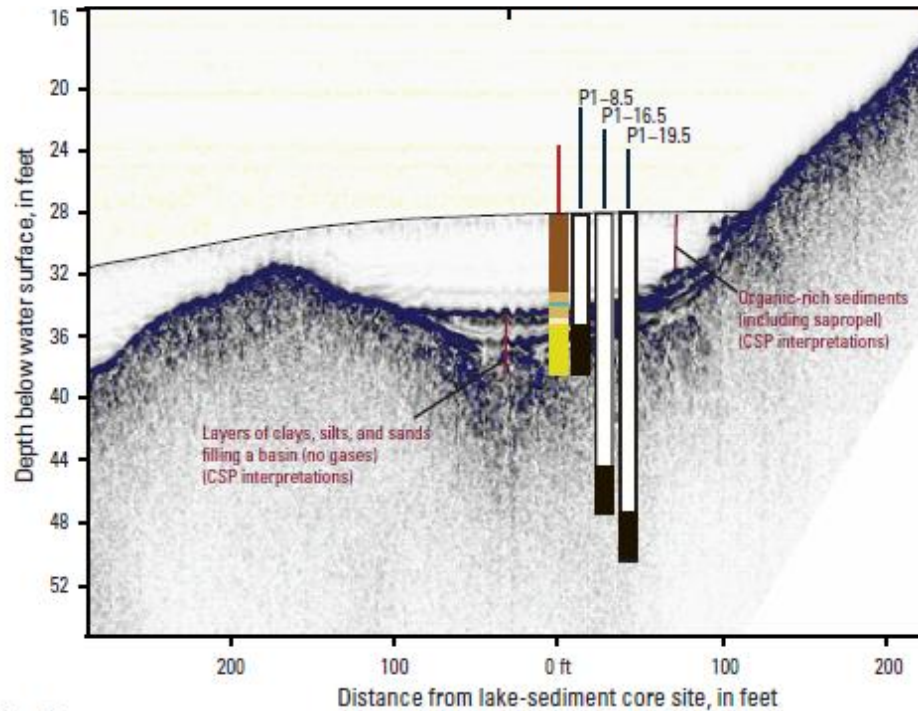
## Little Carnelian Lake



### EXPLANATION

- Annual mean lake level
- - - Outflow elevation

# White Bear Lake – Deepwater Piezometers



## Explanation

Lake Sediment Core Lithology			Piezometer Construction	
	Sapropel and clay			Casing in lake sediment
	Silt, clay, and sand			Screen
	Sand			Piezometers located approximately 6 feet from core
	Gravel and sand			number indicates site number
				Lake bottom

# Points regarding statistical analyses

- Landscape factors were more important than local weather spatial variability (average precipitation and evaporation) across the northeast metro area
- Contributing area for closed-basin lakes are dynamic through time, not well captured in the watershed area datasets used

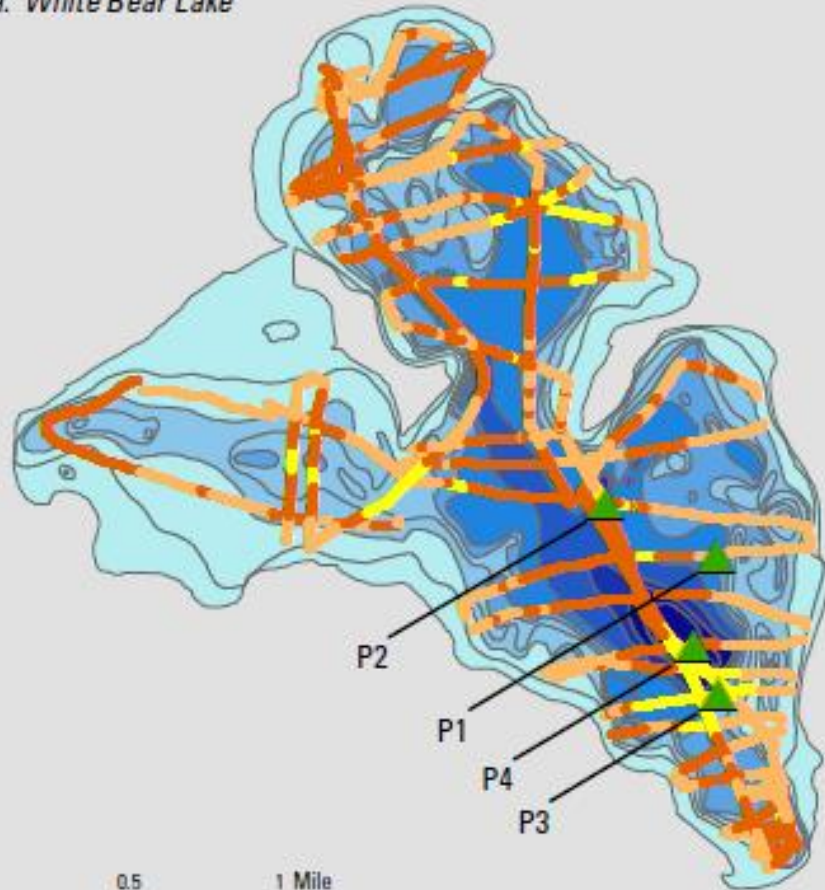


# Statistical Analysis of Lake Levels

- Blah blah

# White Bear Lake – Lake Sediment

a. White Bear Lake



## Seismic-Reflection Profile Pathlines

- Gas-filled sediments
- Low gas sediments in shallow waters
- Low gas sediments in deeper waters

