



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

**Chapter A: Statistical Analysis and Field Study**

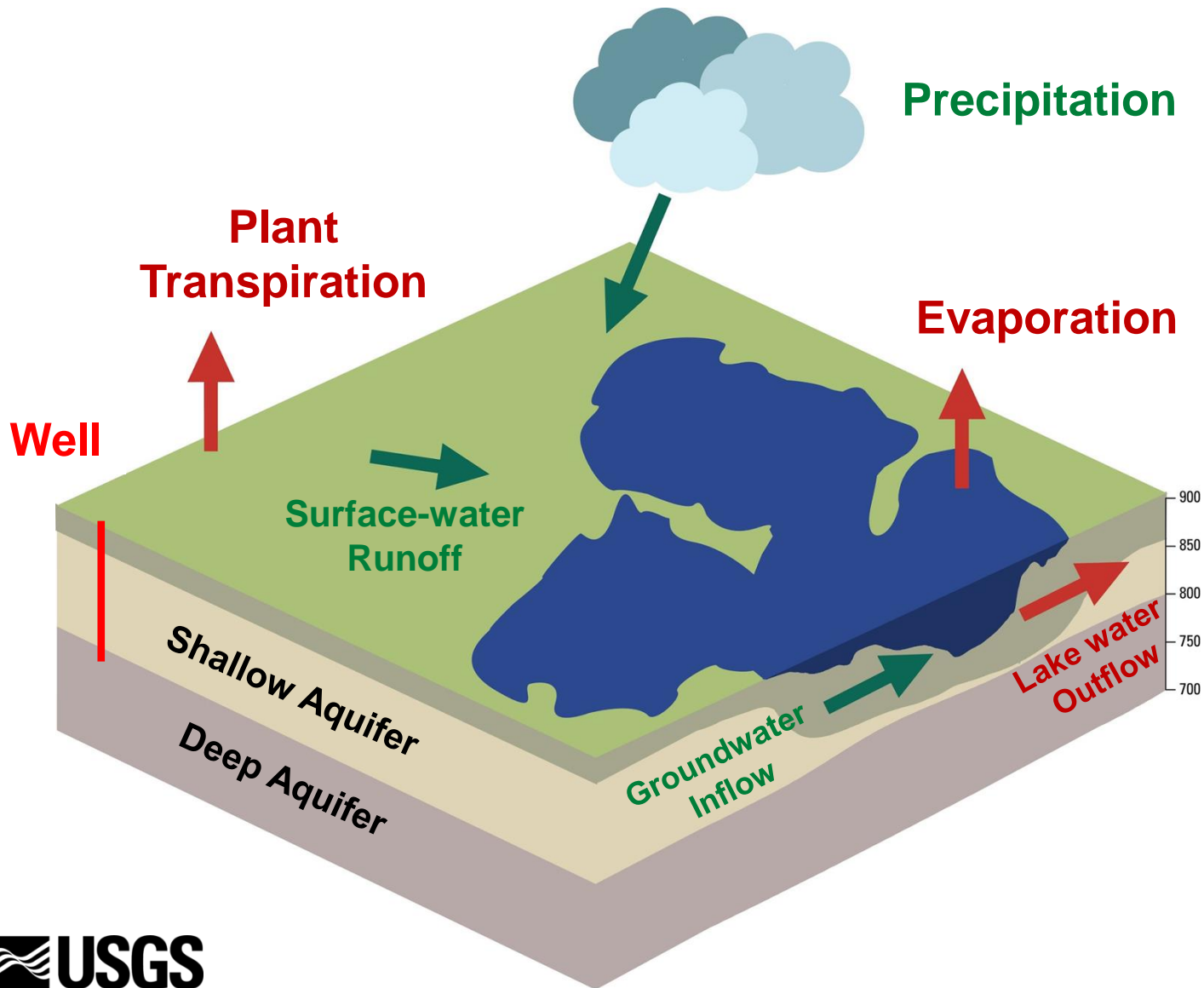
**Chapter B: Groundwater-Flow Simulation**

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## **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. “**

# General Lake Water Budget



# **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**

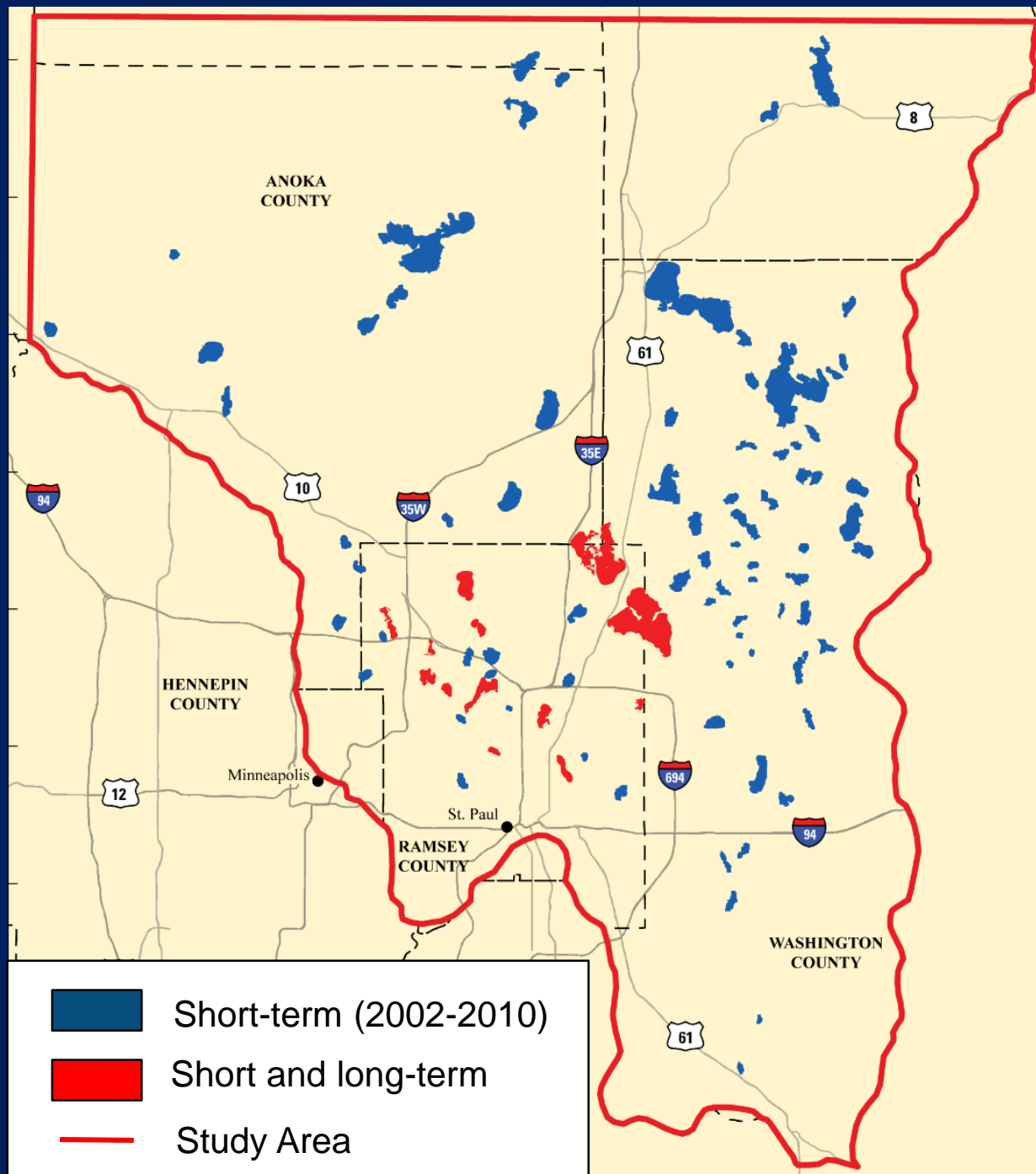
**Evaluate temporal relations between precipitation and lake levels**

# Statistical Lake-Level Analysis

Short-term  
(2002-2010)  
96 lakes

Long-term  
(1925-2014)  
14 lakes

Selected based on  
lake-level data

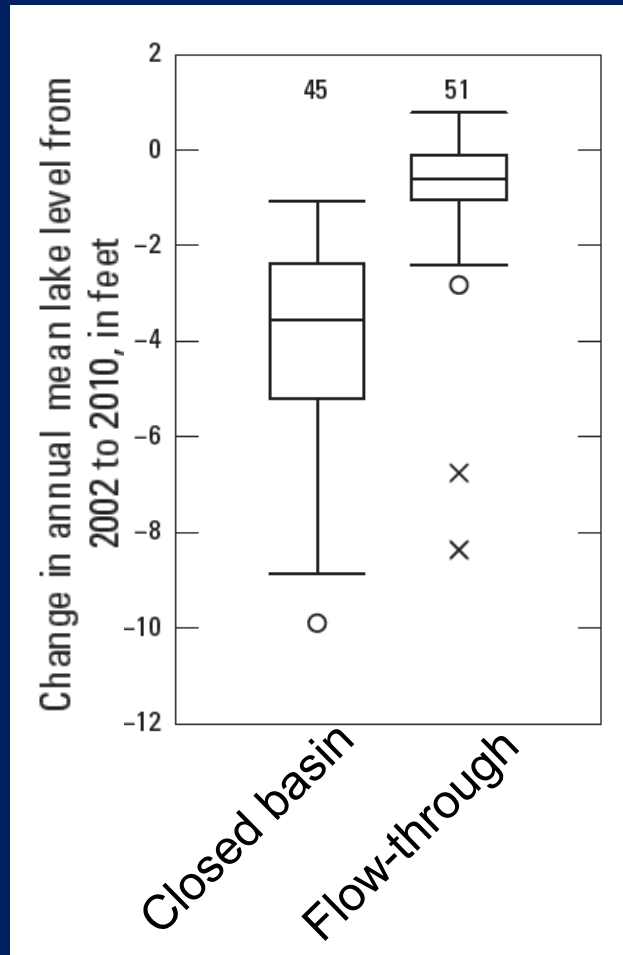


# Lake-level variability – based on lake type

## Closed-basin Lake

no active surface-water outlet

**Turtle Lake**



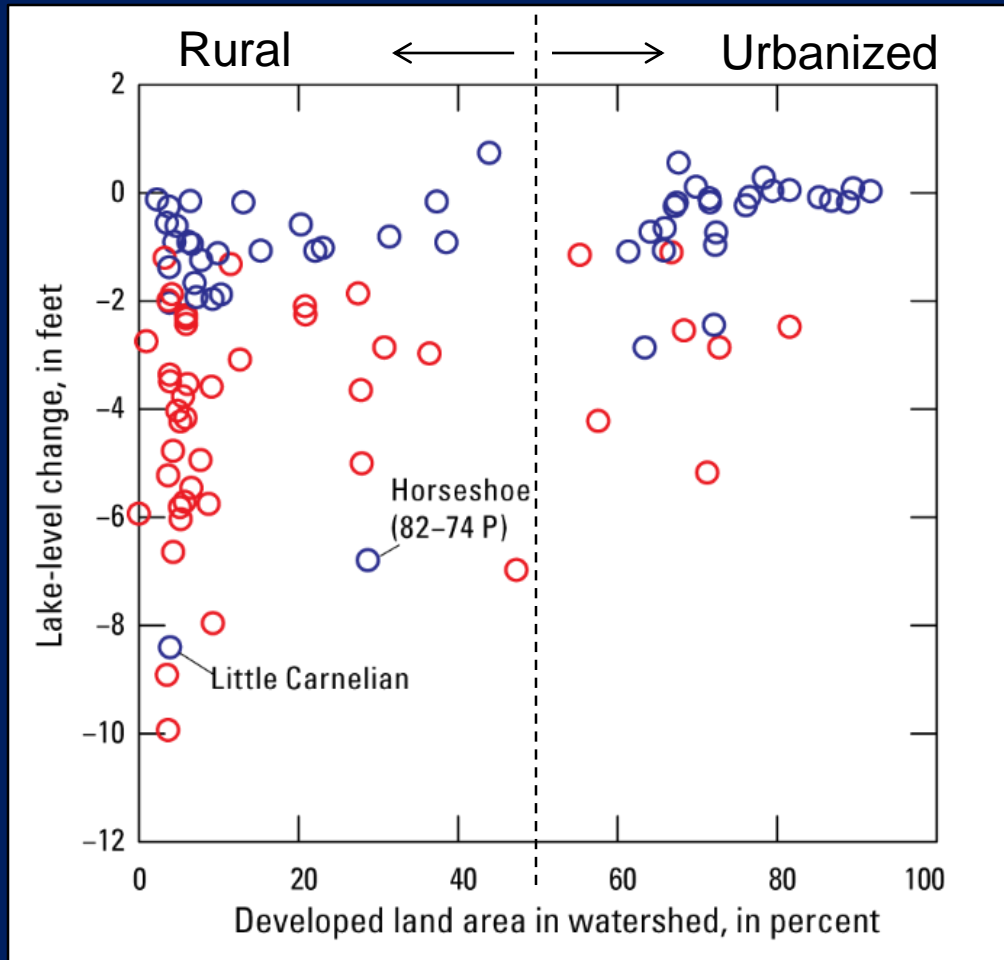
## Flow-through Lake

active surface-water outlet

**Pleasant Lake**



# Lake levels more stable in urbanized areas

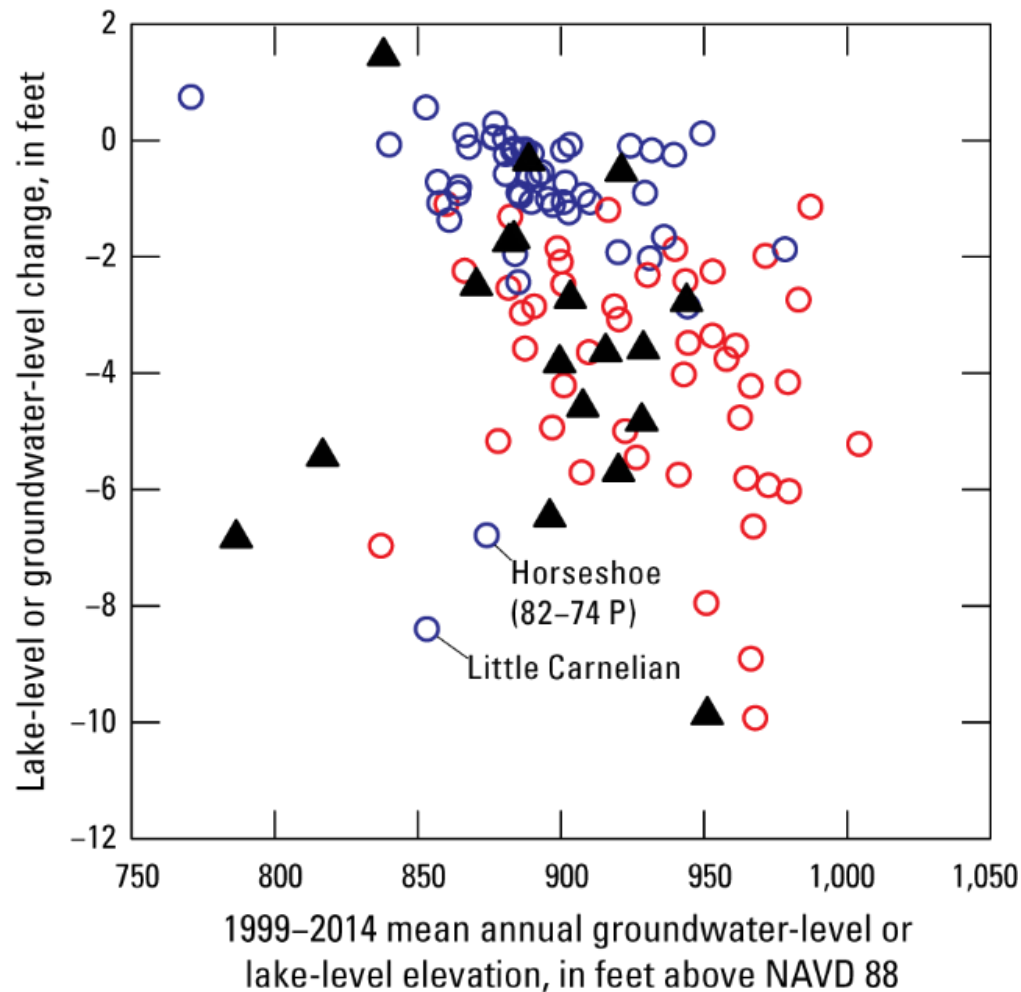


- most urban lakes are flow-through
- most rural lakes are closed-basin

## EXPLANATION

- Closed-basin lake
- Flow-through lake

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

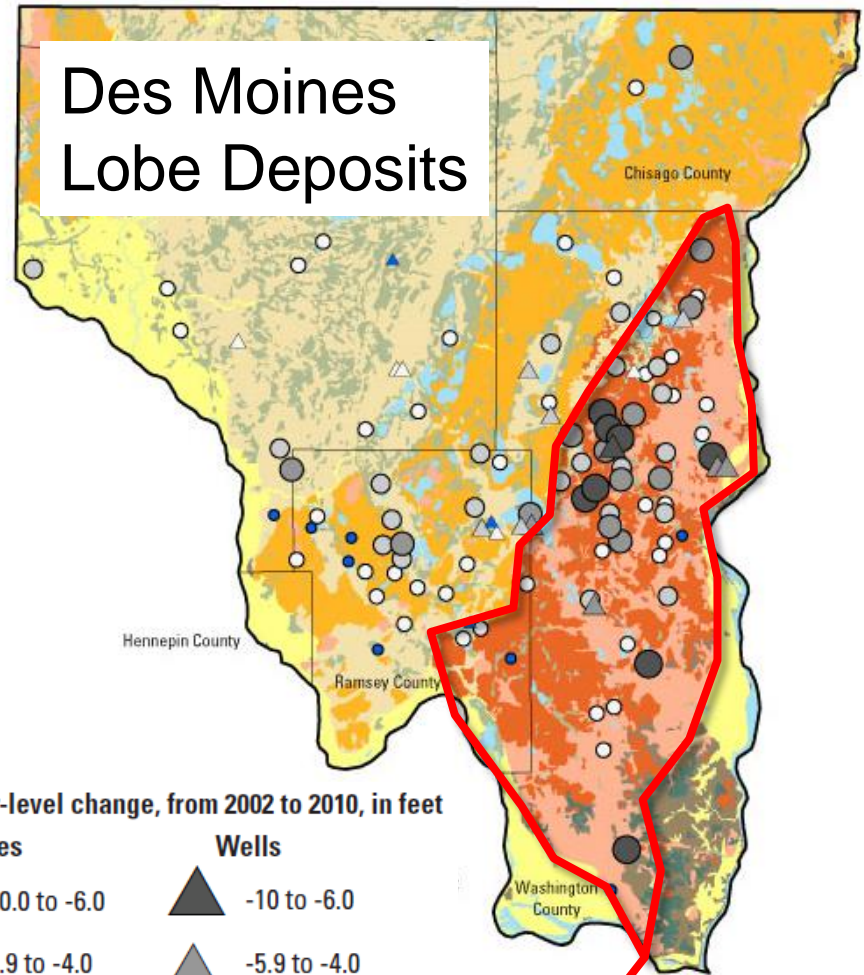
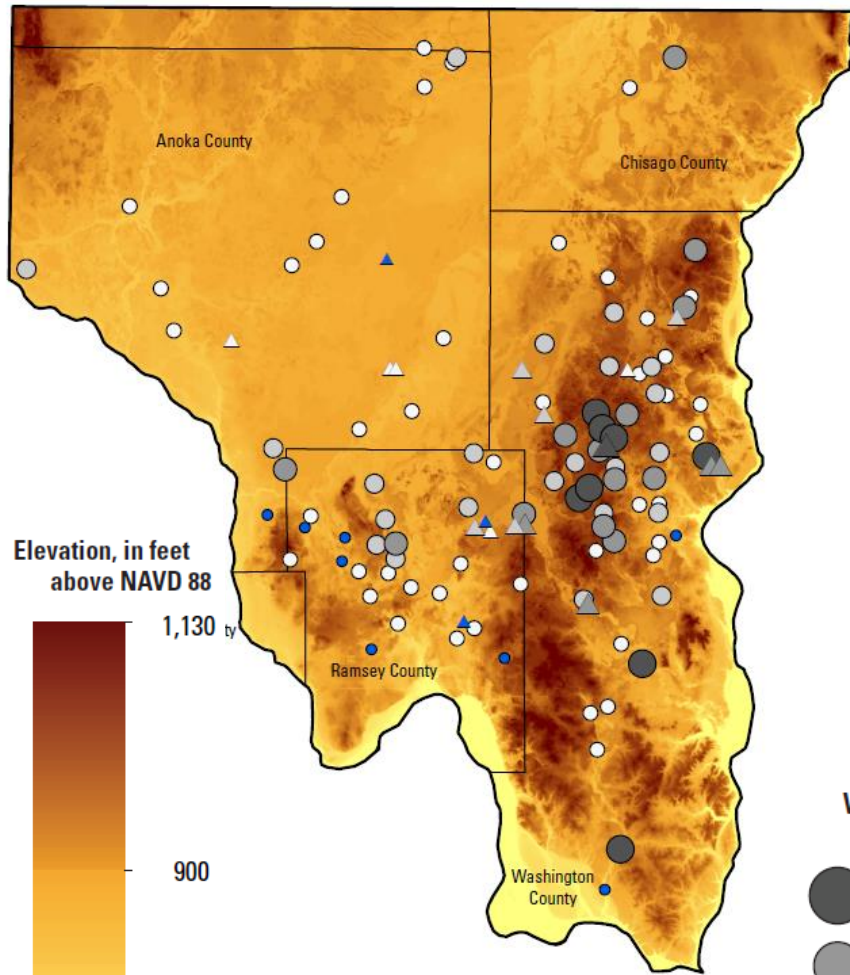


## EXPLANATION

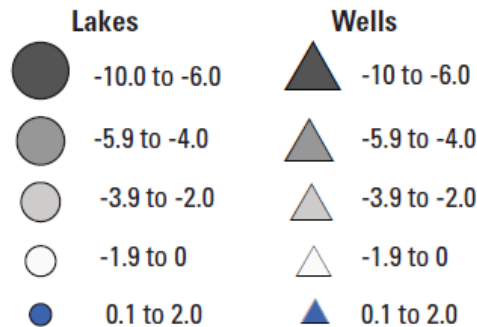
- Closed-basin lake
- Flow-through lake
- ▲ Well



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



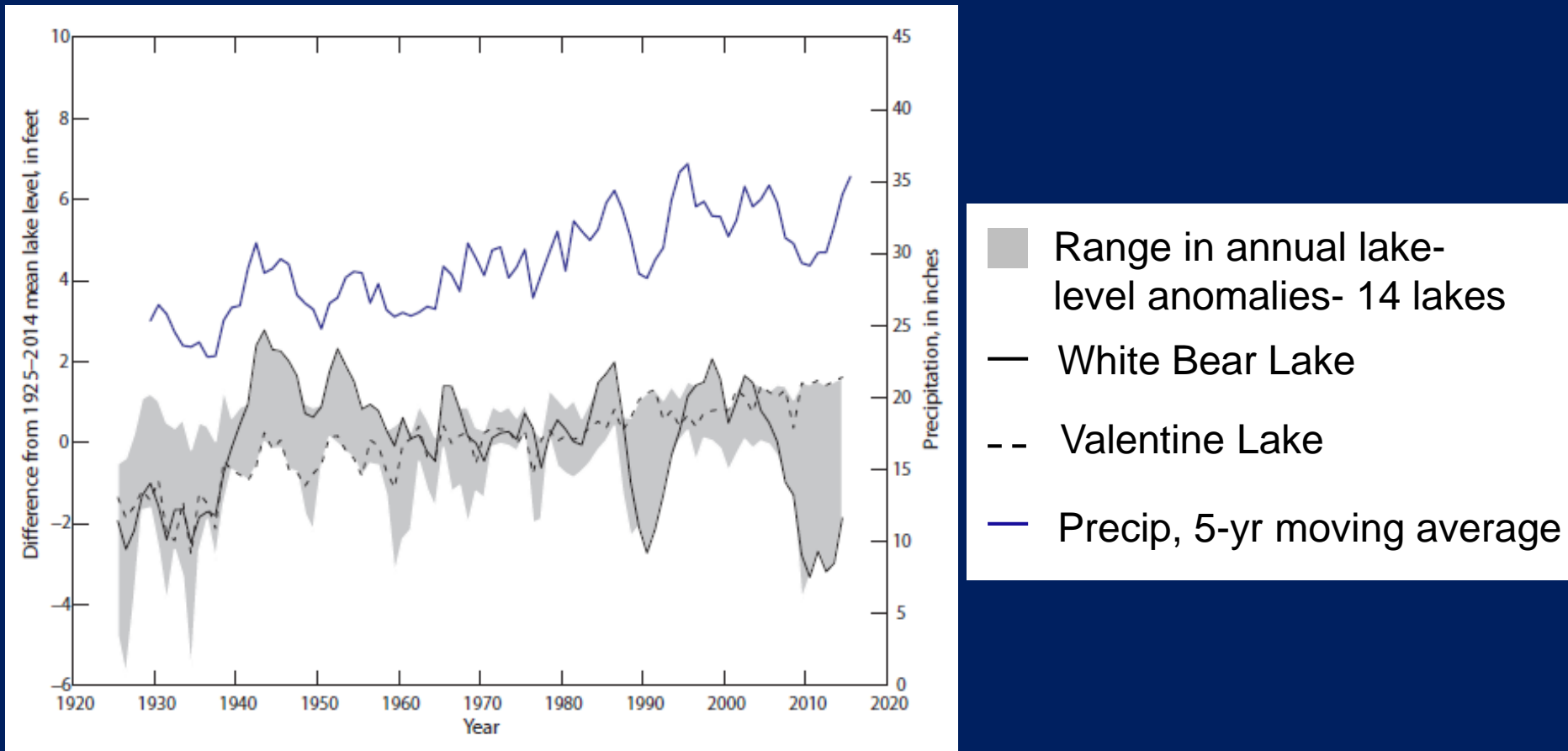
Water-level change, from 2002 to 2010, in feet



Superior Lobe Deposits

# Long-term analysis (1925-2014)

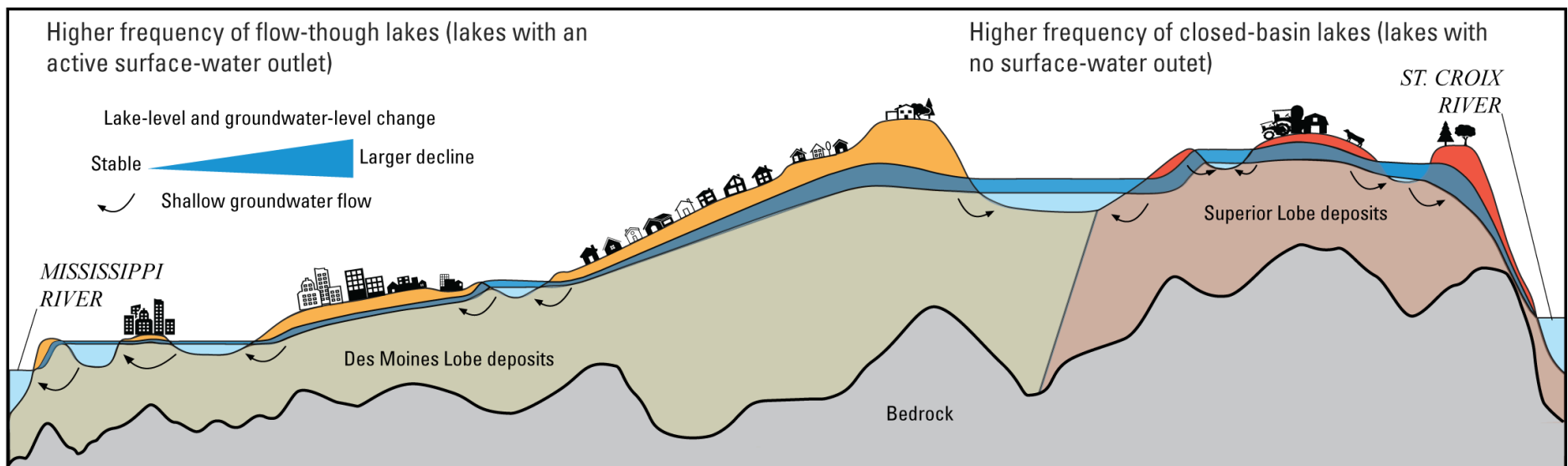
## White Bear Lake – most variable level



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

# Variables Affecting Lake-level Variability

- Lake type (flow-through/closed-basin)
- Elevation
- Development (urban and rural)
- Glacial geology



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

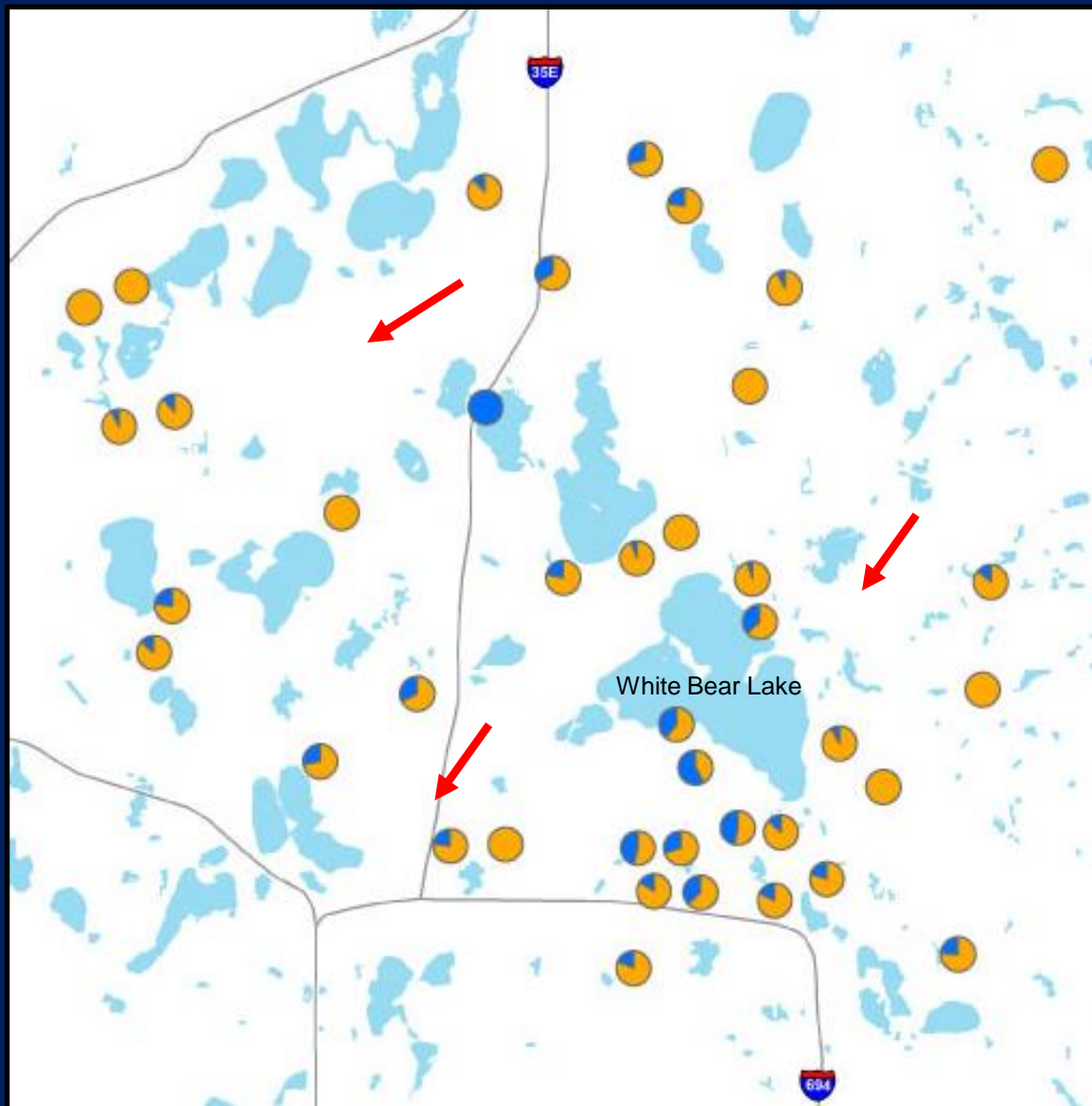
**Water-quality Analyses – Stable Isotope/Age-dating**

**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**

# Surface-water contribution – Stable Isotopes



Sampled 40 wells

October 2014

Prairie du Chien Group /  
Jordan Sandstone (PDCJ)

Percentage of Contribution

Groundwater

Surface  
water



General Groundwater  
Flow Direction (PDCJ)

# Water-borne Geophysical Survey – Continuous Seismic Reflection

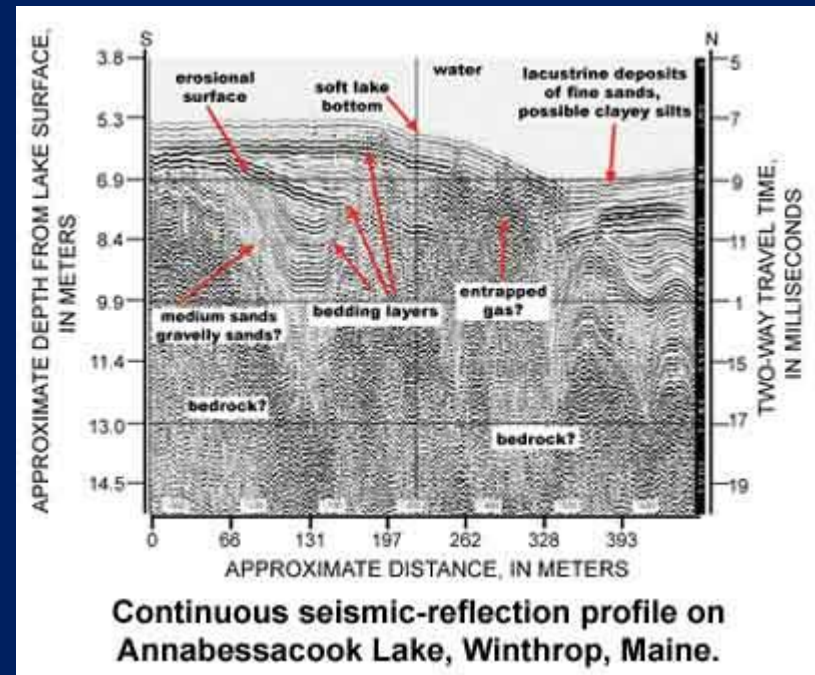
Determine subsurface structure and geology below lake bottom

Conducted in November 2013

White Bear, Turtle, Pleasant, South School Section, Big Marine,  
and Lake Elmo



Towfish with cables

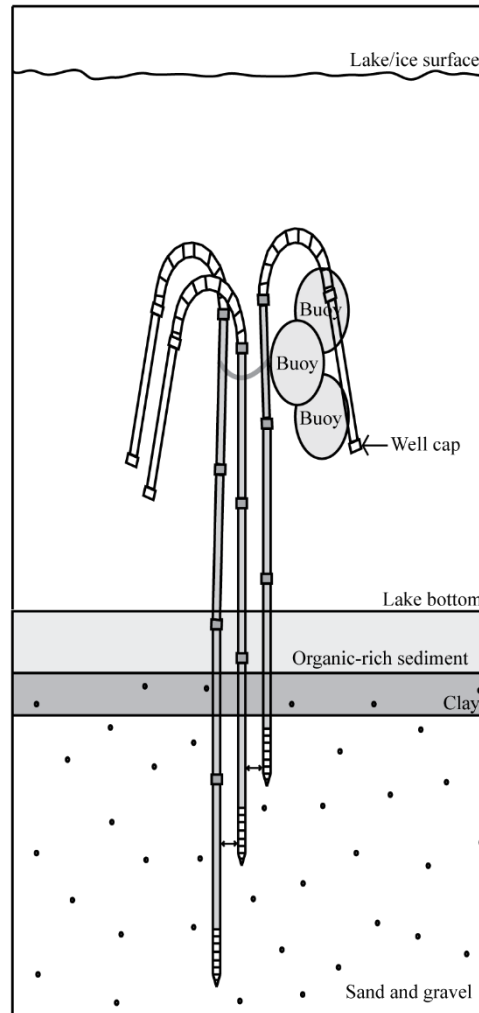
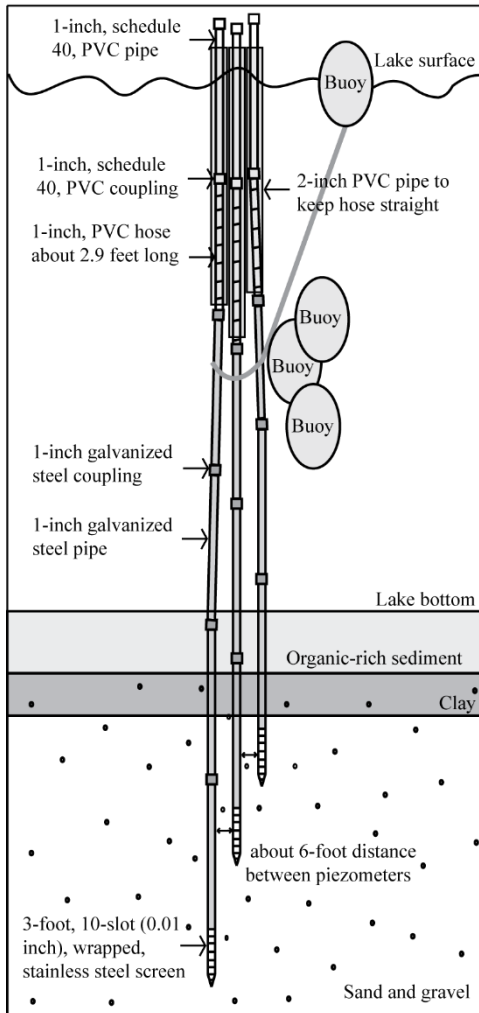


Continuous seismic-reflection profile on  
Annabessacook Lake, Winthrop, Maine.

# White Bear Lake – Deepwater Piezometer Nests

## Ice in/out

## Ice formation/thaw

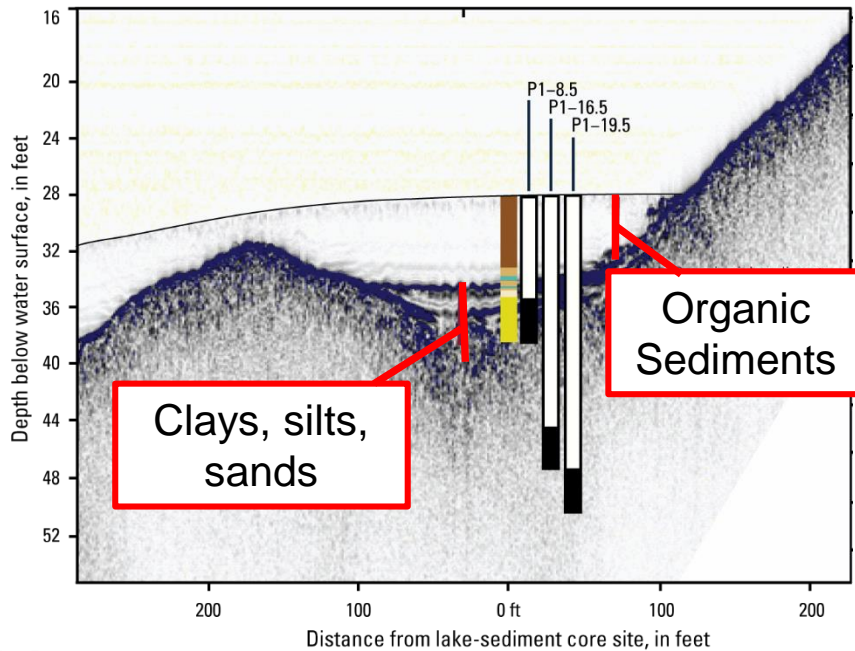


# White Bear Lake – Lake Sediment

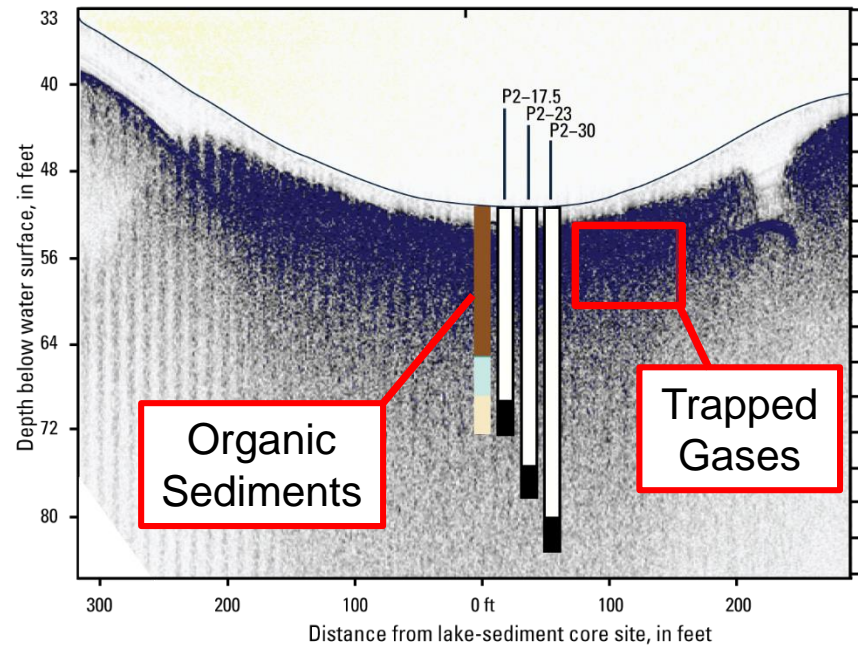
## No trapped gases

## Trapped gases

### P1



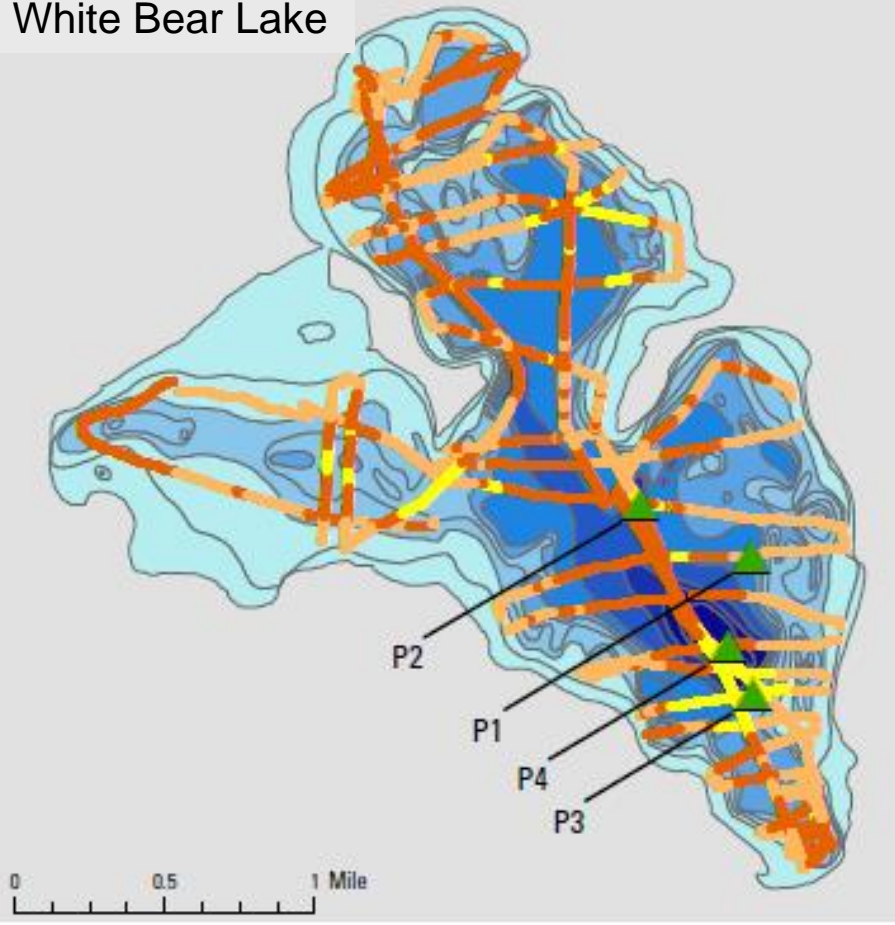
### P2



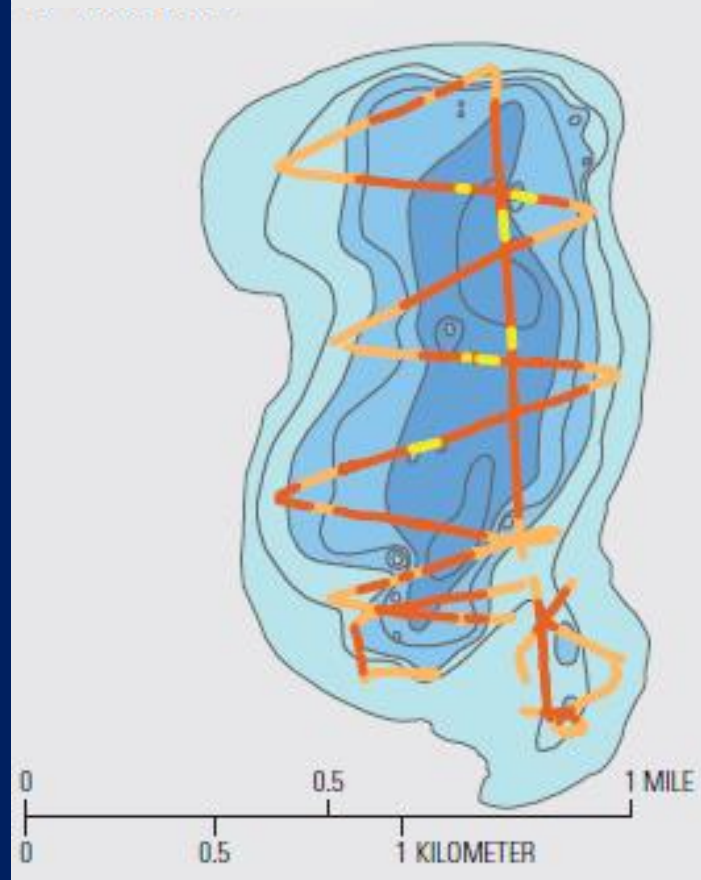


# Continuous Seismic-Reflection

White Bear Lake



Turtle Lake

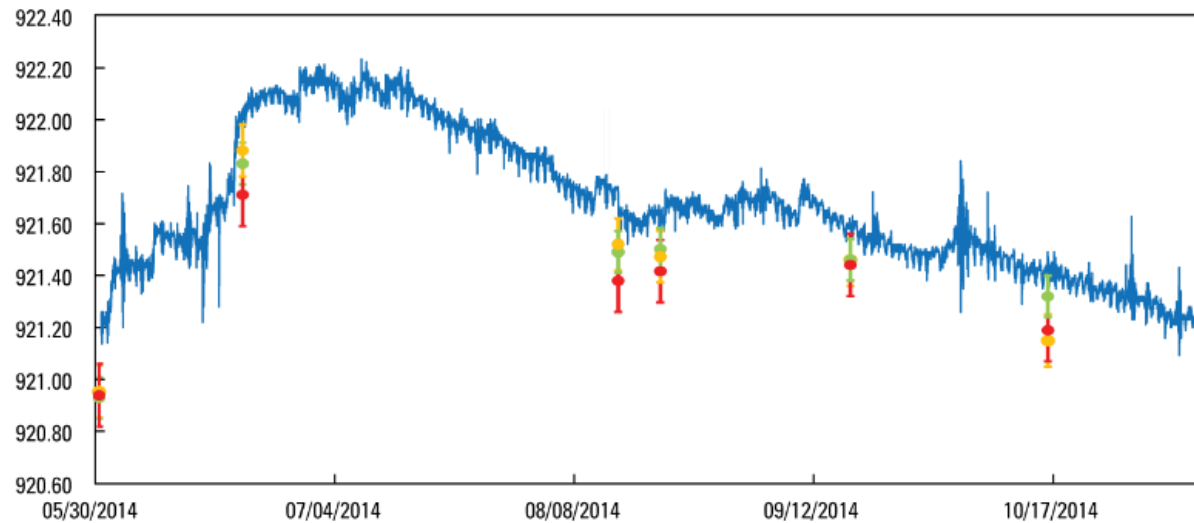


## Seismic-Reflection Profile Pathlines

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

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

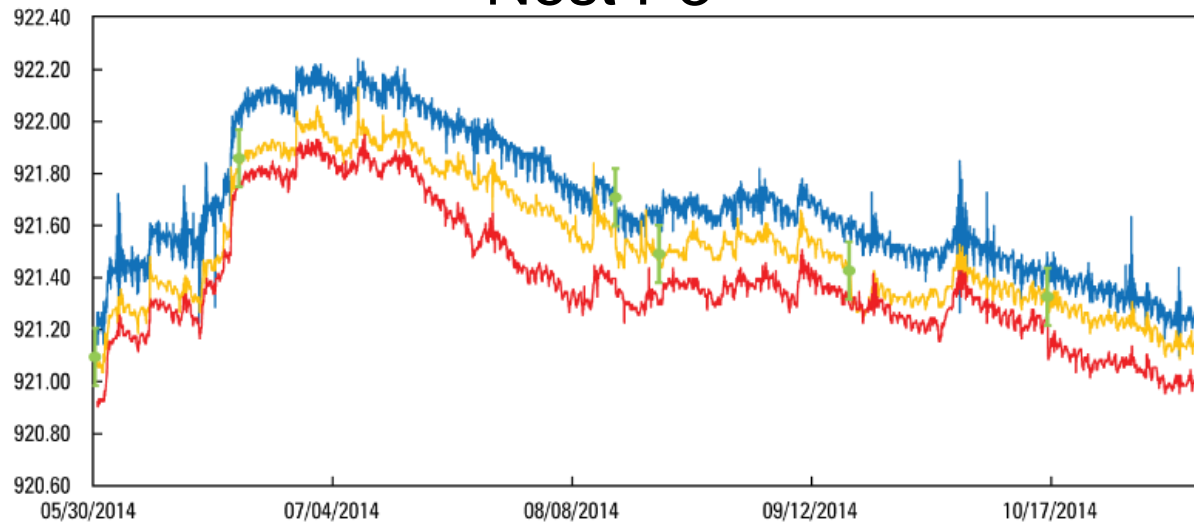
## Nest P1



### 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



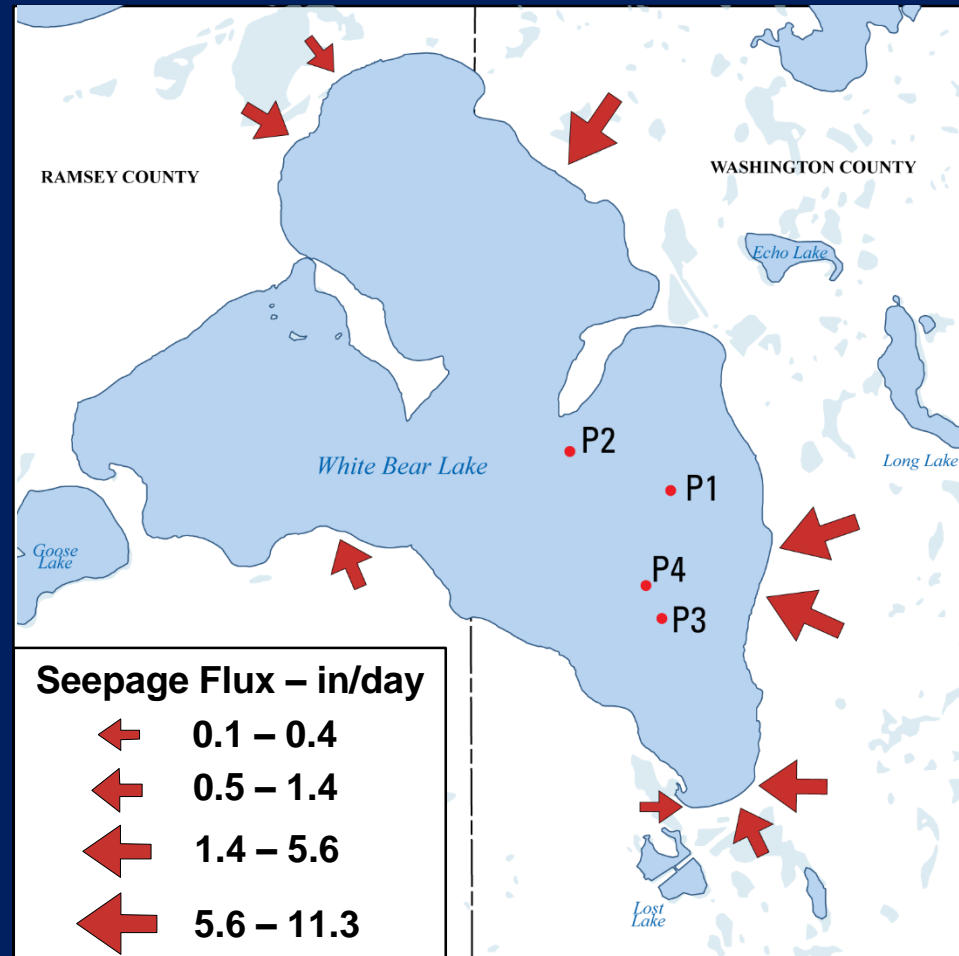
### EXPLANATION

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

# 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



# Field Assessment - Results

## Stable isotope ratios

- 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

# **NE Metro Lakes Groundwater-flow (NMLG) Model**

**Develop groundwater-flow model (tool) to assess**

- **Groundwater and surface-water interactions in lakes**
- **Effects of groundwater withdrawals and precipitation on lake levels**

**Run nine steady-state MODFLOW model simulations**

- **2003-2013 Average**
- **eight hypothetical scenarios**
  - $\pm$  30% change in groundwater withdrawals**
  - $\pm$  5% change in precipitation**
  - combination of precipitation/groundwater withdrawal changes**

# Groundwater-flow Model Design

## Based on Metro Model 3 (MM3)

Using bedrock elevations, hydraulic conductivity zones, and some boundary conditions

## New configurations/packages

- Finer model grid, more detailed
- Quaternary layering, four versus one layer
- Updated recharge
- Lake Package: applied to 6 lakes
- Refined RIV Package: rivers, other lakes, and streams

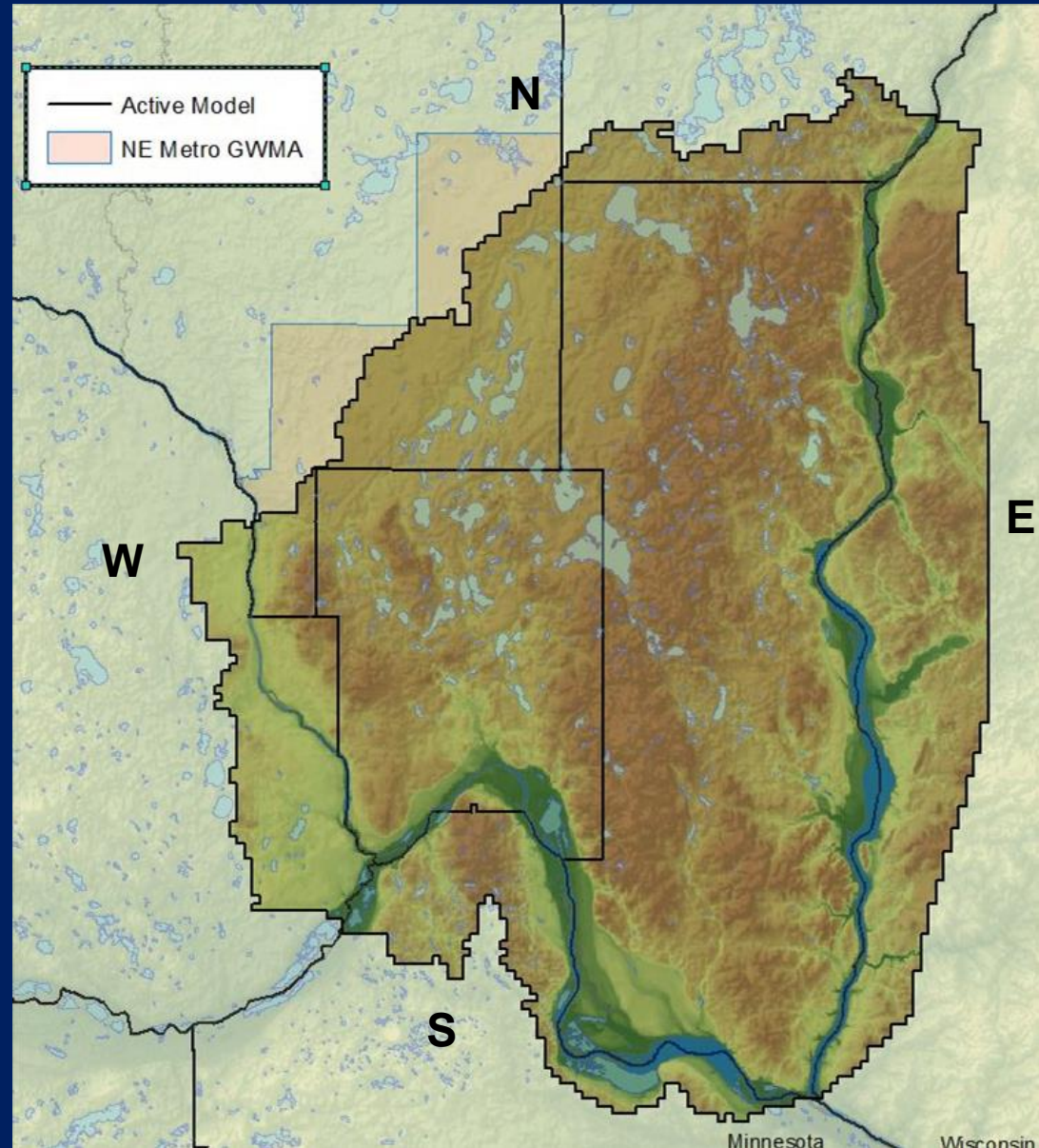
# NEML Model Boundary

East - MM3 boundary

North - DNR Level 8  
watersheds

West/South - DNR Level 8  
watersheds or 5  
km perpendicular  
to river

Encompasses most of  
North/East Metro GWMA



# Lake Package

Used in model for representing 6 lakes

Simulates water balances for lakes

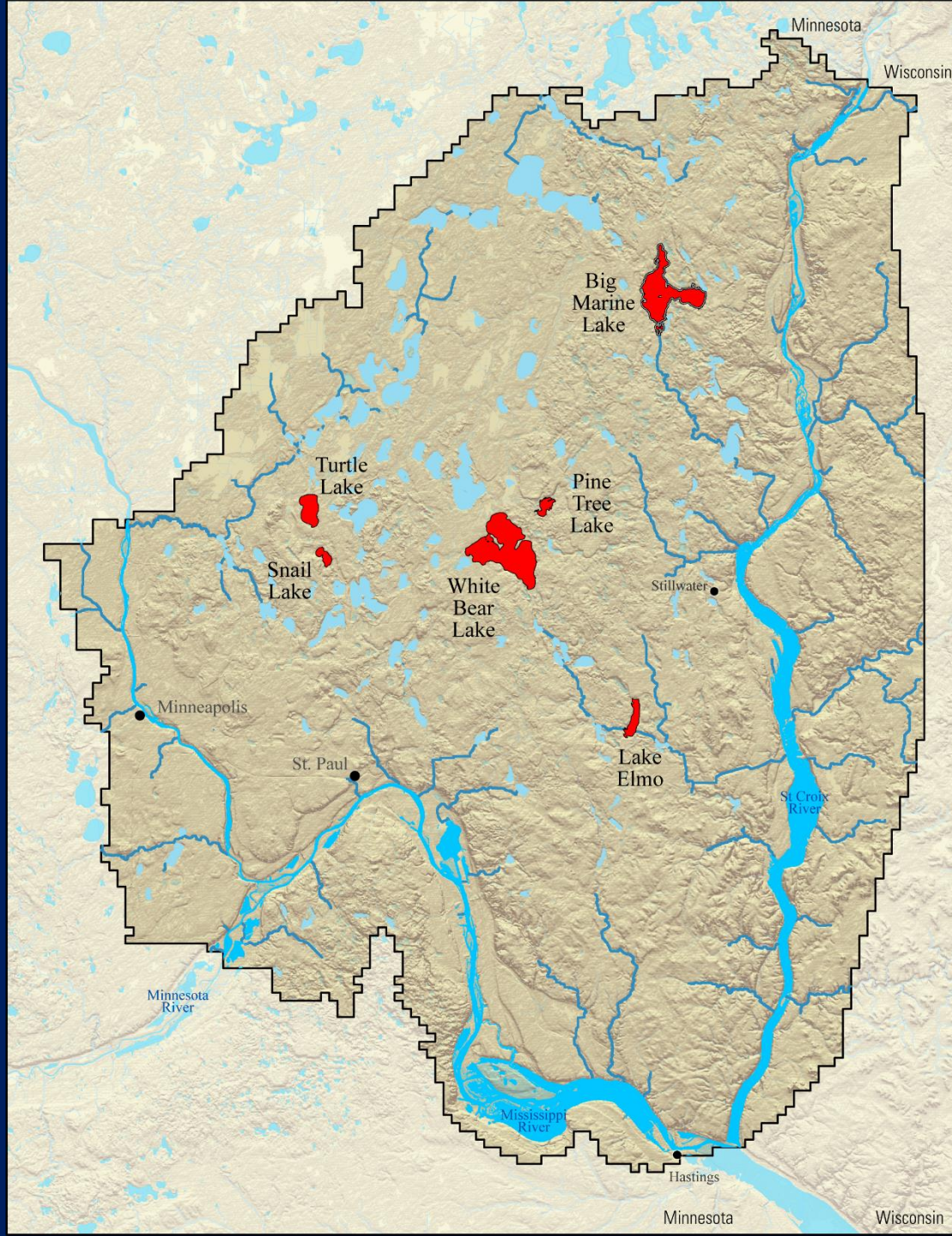
## Lake Criteria

Max lake depth > 25 feet

Surface Area > 75 acres

More than 3 miles from model boundary

Lake-level data in at least 50 percent of months during 2003-2013





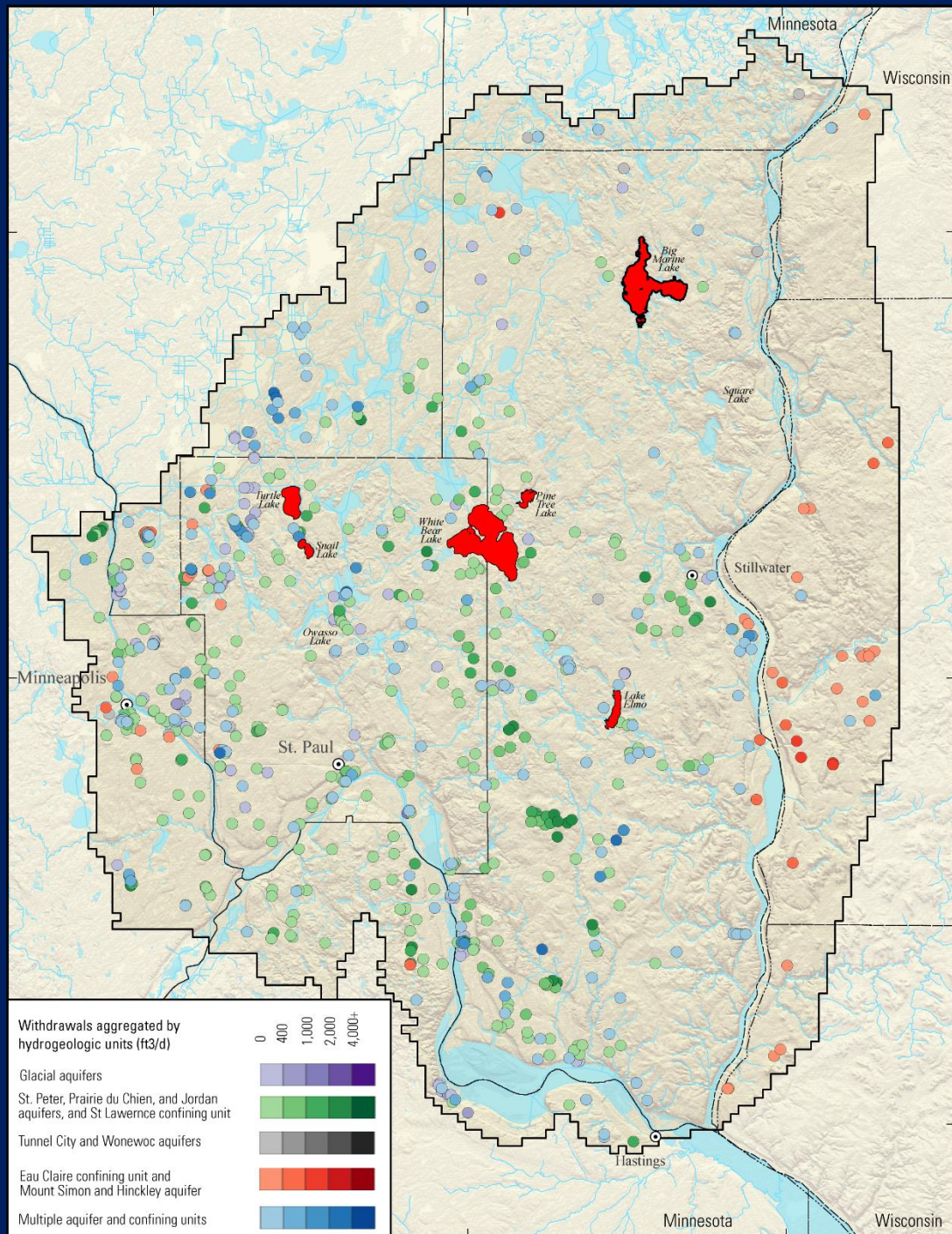
# Pumping Wells

Modelled with Multi-node Well (MNW2) package

High capacity wells from MDNR Source Water database

838 wells

New wells added since MM3 was produced



# **Model Calibration – Groundwater-flow Model**

## **Calibration Targets**

**Sources - USGS, BCWD, RCWD, VCWD, MNDNR**

**Groundwater levels – 3,392 observation wells**

**Streamflow (low flows) - 5 stream gages**

**Lake Levels – MNDNR – 6 lakes (Lake Package)**

## **PEST – Parameter ESTimation tool**

**Calibration data was weighted based on quality**

**Model parameters were estimated**

## **Model results**

**Overall, model calibrated well over the  
Northeast Twin Cities Metropolitan Area**

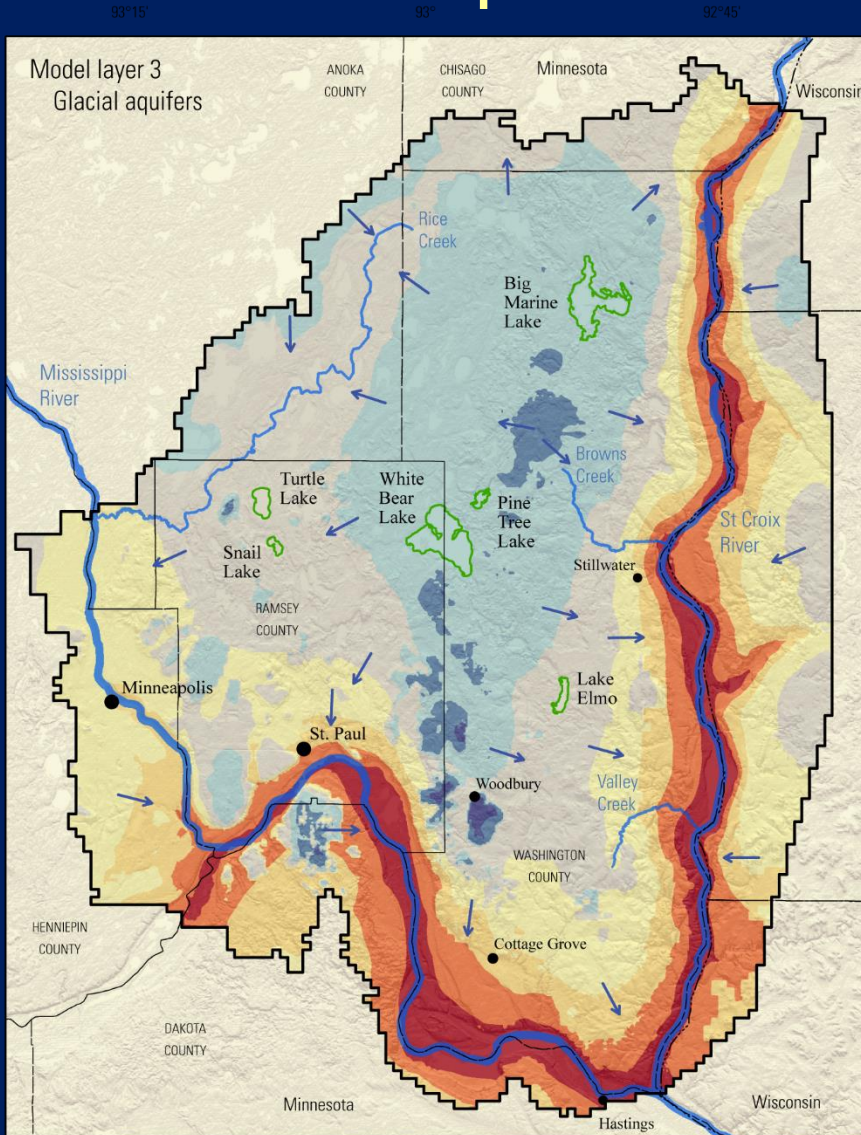
**Groundwater withdrawals and precipitation  
can affect lake-water levels and budgets**

**Effects of groundwater withdrawals on the lake-  
water levels varied with the number of wells and  
amount of withdrawals from wells near the lakes**

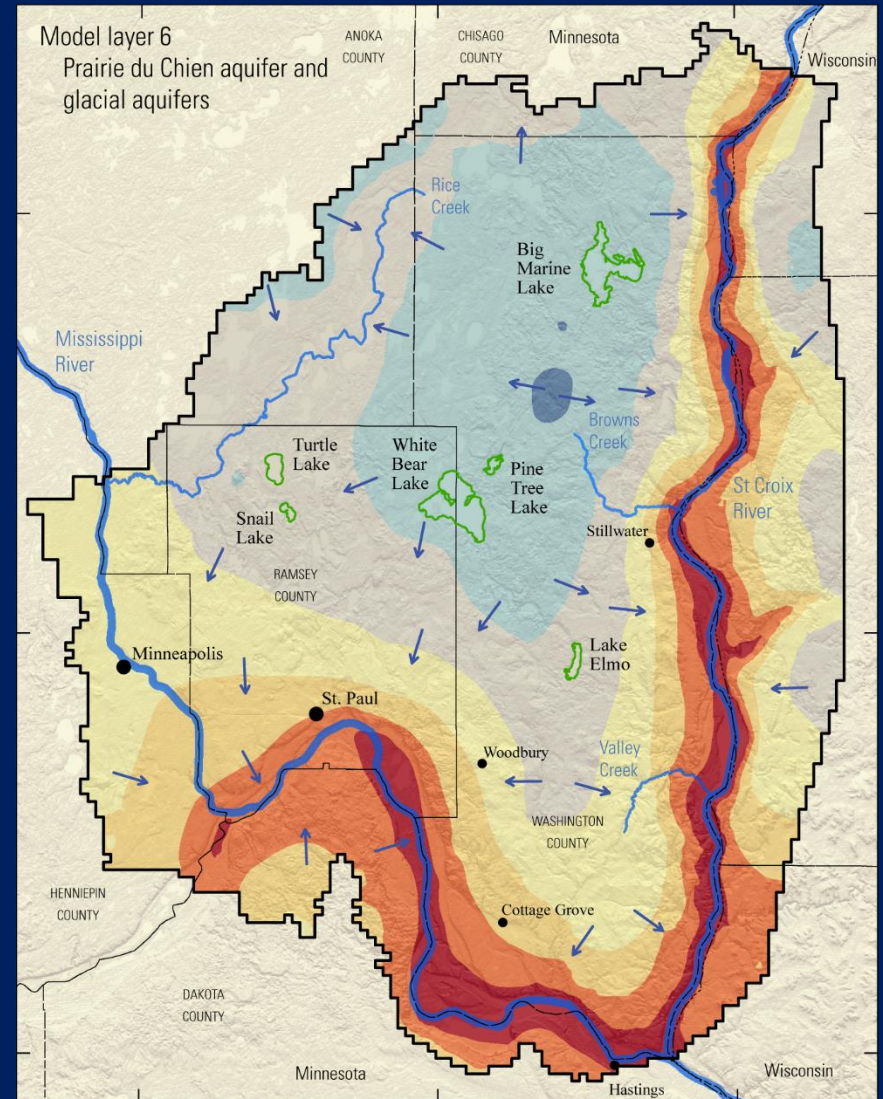
**Lakes are providing water to underlying aquifers**

# Potentiometric Surfaces – Groundwater-Flow Directions

## Glacial aquifer



## Prairie du Chien and parts of Glacial aquifer



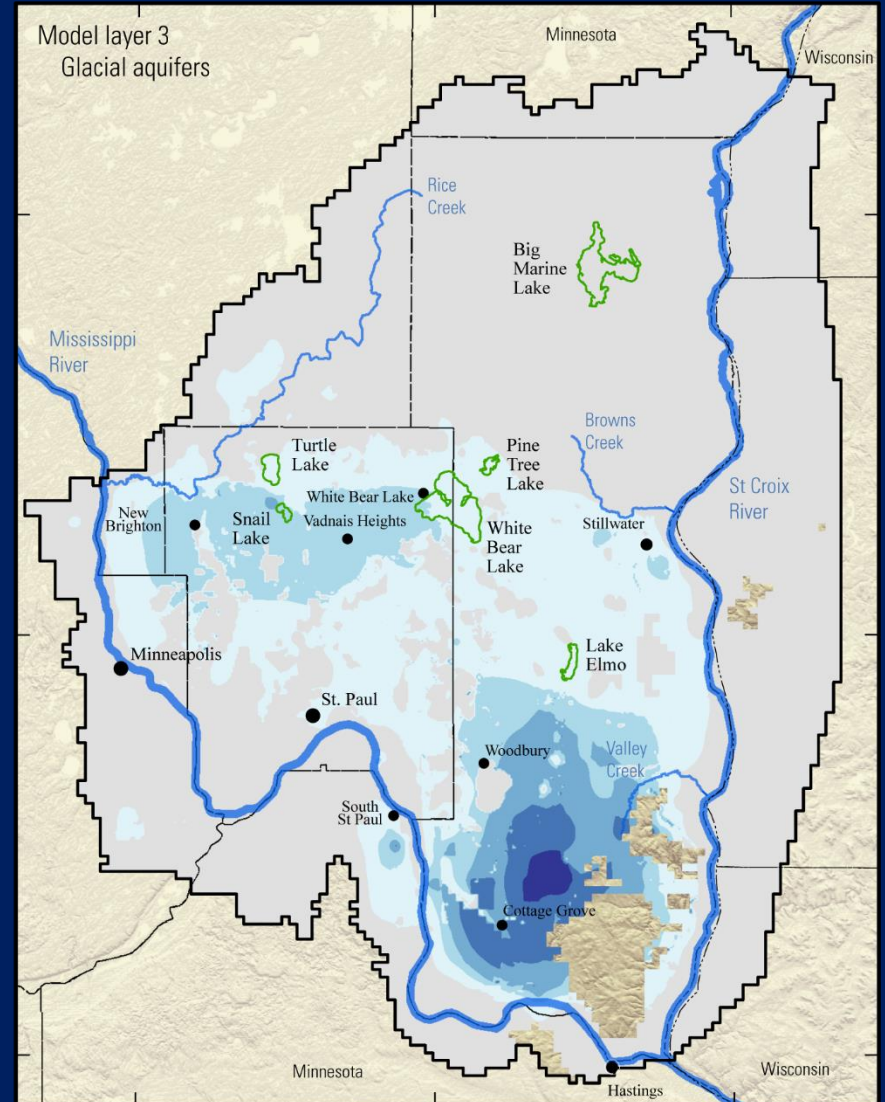
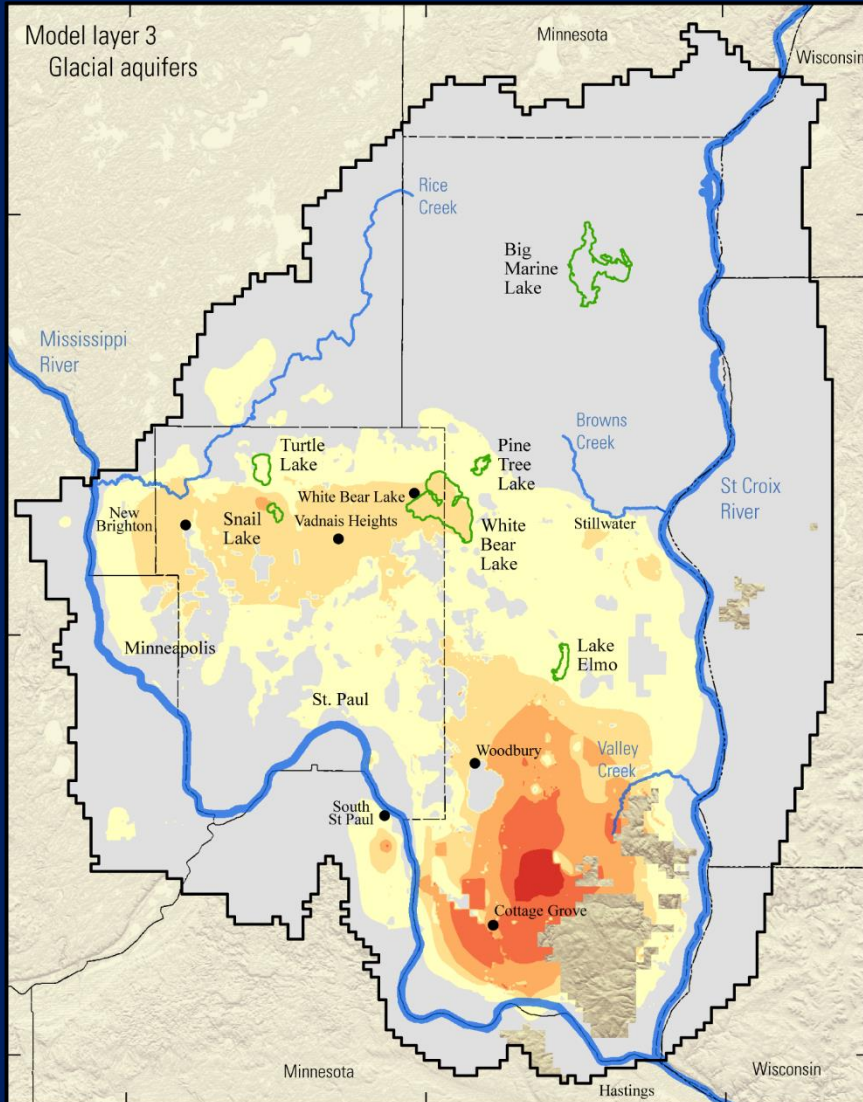
# Simulated Lake Water Budgets 2003-13 Average Percentages

<u>Lake</u>	<u>Inflow</u>			<u>Outflow</u>		
	<u>Direct Precip</u>	<u>Surface-Water Runoff</u>	<u>Ground Water</u>	<u>Evapo Trans.</u>	<u>Surface Water</u>	<u>Ground Water</u>
<b>Big Marine</b>	56	30	14	52	3	45
<b>Lake Elmo</b>	21	18	61	18	35	47
<b>Snail</b>	42	42	17	36	0	64
<b>White Bear</b>	51	24	25	44	1	55

# Water-level Changes, in feet – Glacial aquifer

## 30% GW withdrawal increase

## 30% GW withdrawal decrease



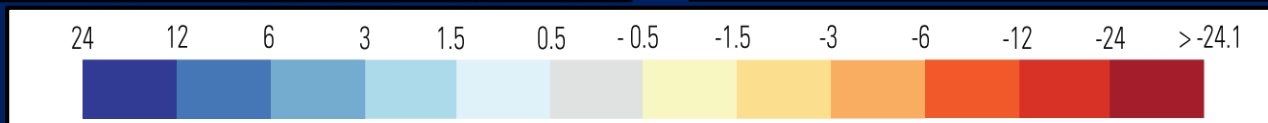
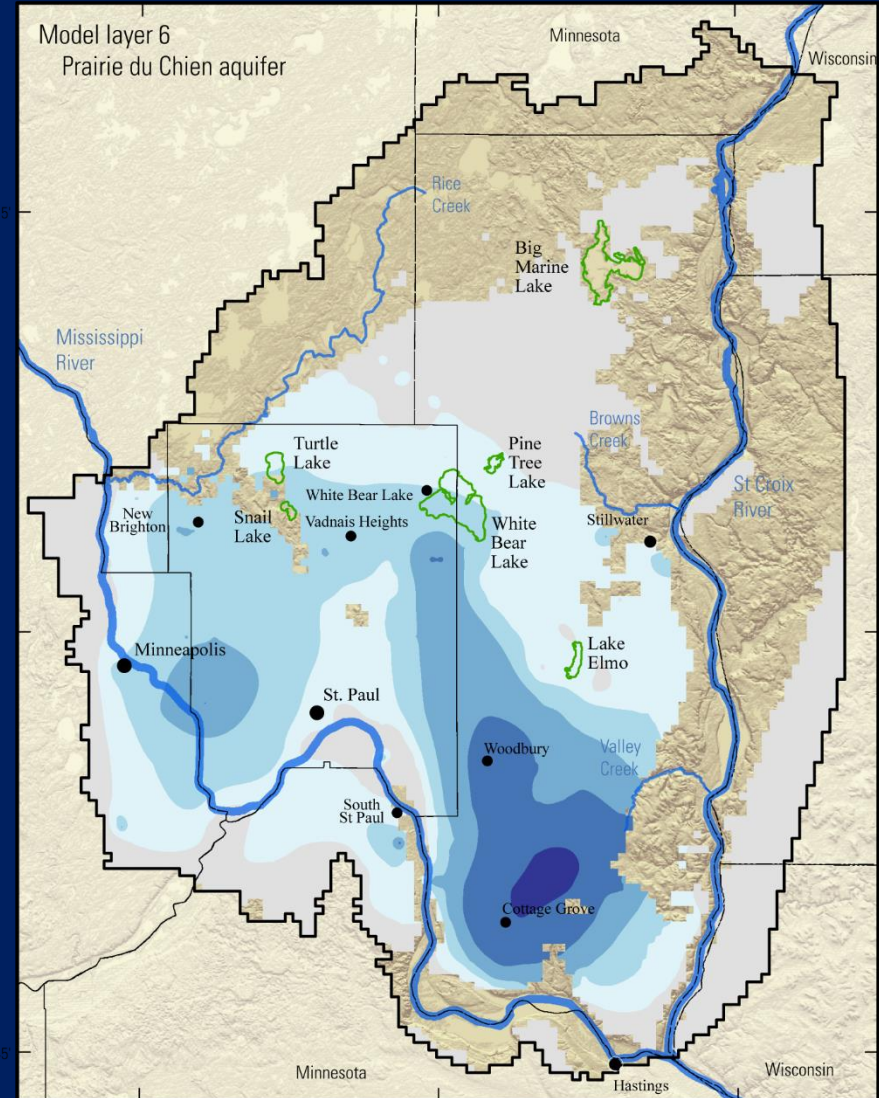
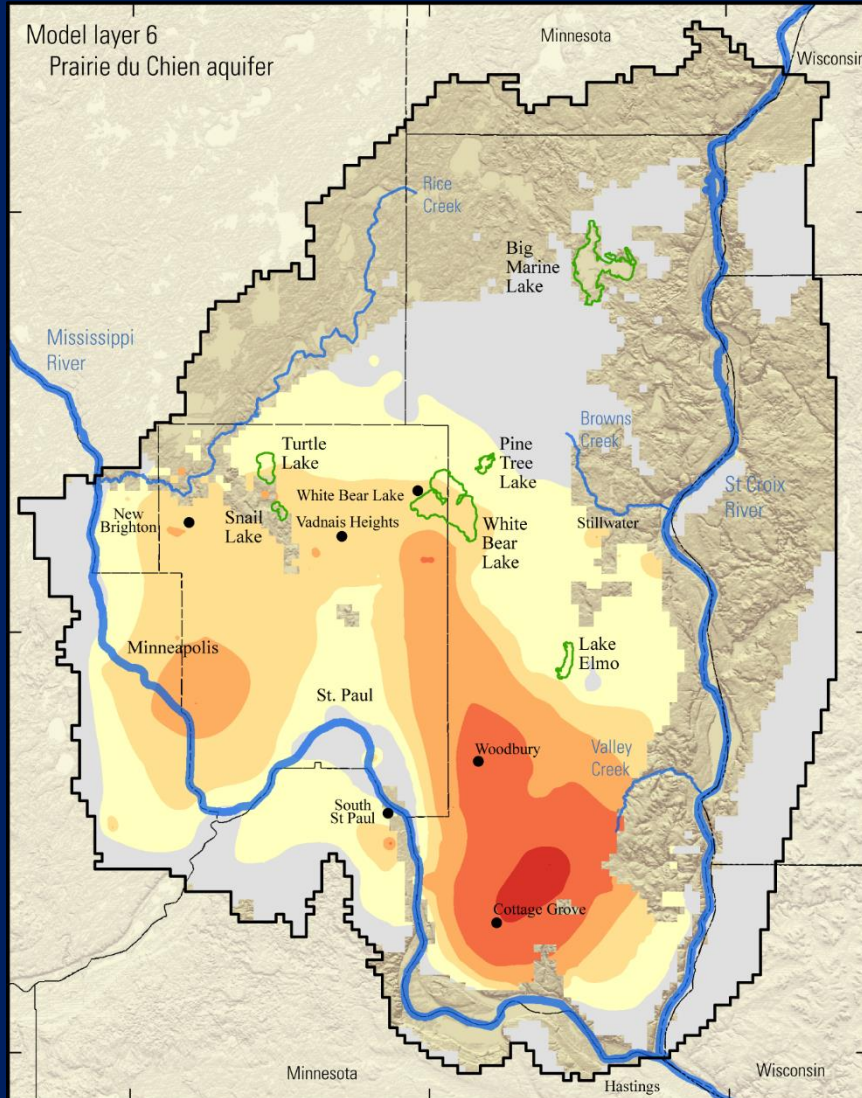
24 12 6 3 1.5 0.5 -0.5 -1.5 -3 -6 -12 -24 >-24.1



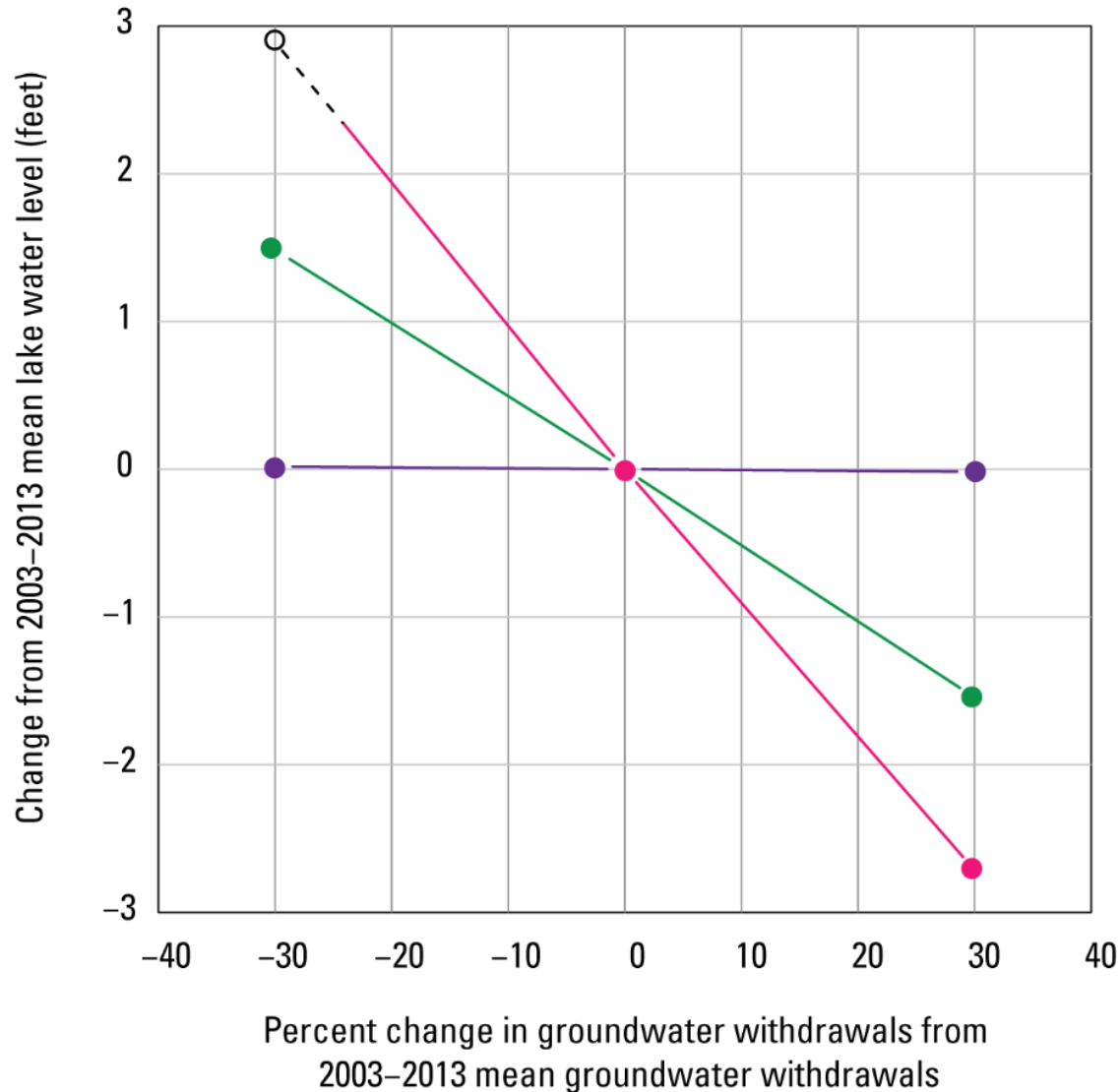
# Water-level Changes, in feet - Prairie du Chien aquifer

## 30% GW withdrawal increase

## 30% GW withdrawal decrease



# Lake-water Levels for Different Groundwater Withdrawal Simulations

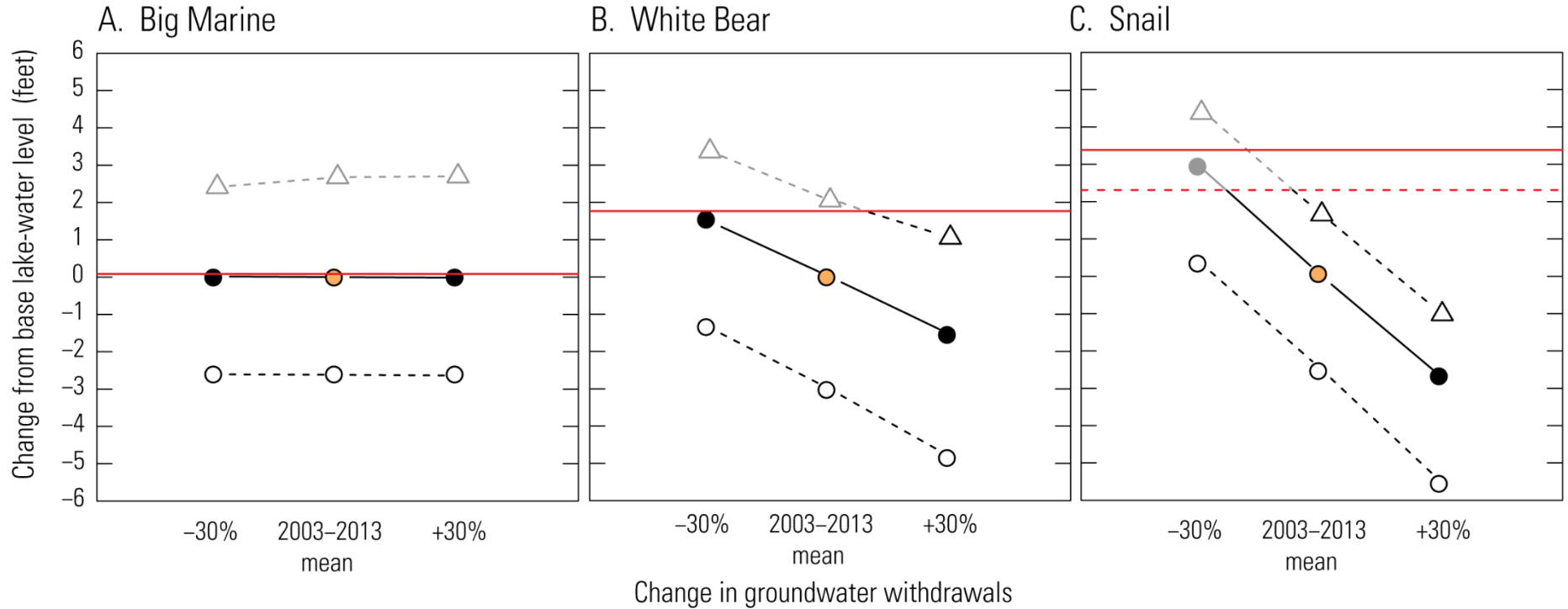


## EXPLANATION

- Big Marine Lake
- Snail Lake
- White Bear Lake
- - - - Simulated lake levels and relations above the lake outlet elevation



# Lake-water-level Changes – Groundwater Withdrawal and Precipitation Change Simulations



## Explanation

- Five percent lower precipitation
- 2003-13 mean precipitation (32.3 inches per year)
- △-- Five percent higher precipitation
- Outlet elevation
- - - Maximum bathymetric elevation specified in LAK package input

—●— 2003-13 calibrated model

Note: Simulated lake levels and relations above the lake outlet elevation (red line) or the maximum specified lake bathymetry elevation used in the LAK package (red dotted line) are overestimated and represented in gray.

## **Potential other future work**

**Characterization of glacial sediments and buried bedrock valleys below lakes – i.e. White Bear Lake**

**Groundwater-flow model – develop transient simulations**

**Common Lake Information data base**

# USGS Reports

Available online

<http://dx.doi.org/10.3133/sir20165139>

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

Questions?

