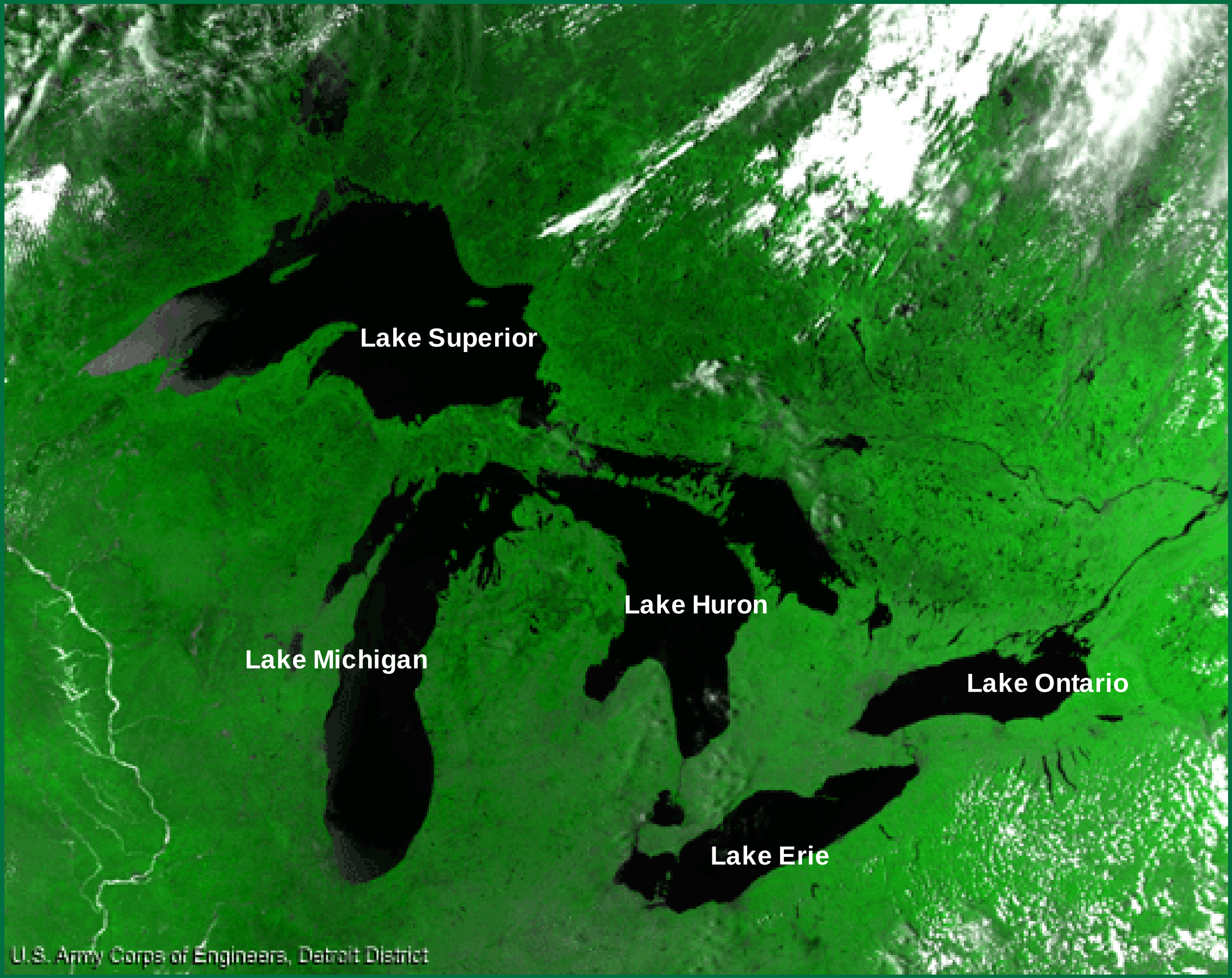
Water Availability and Use in Great Lakes Basin

Making a Great Lake Superior Conference

October 2007

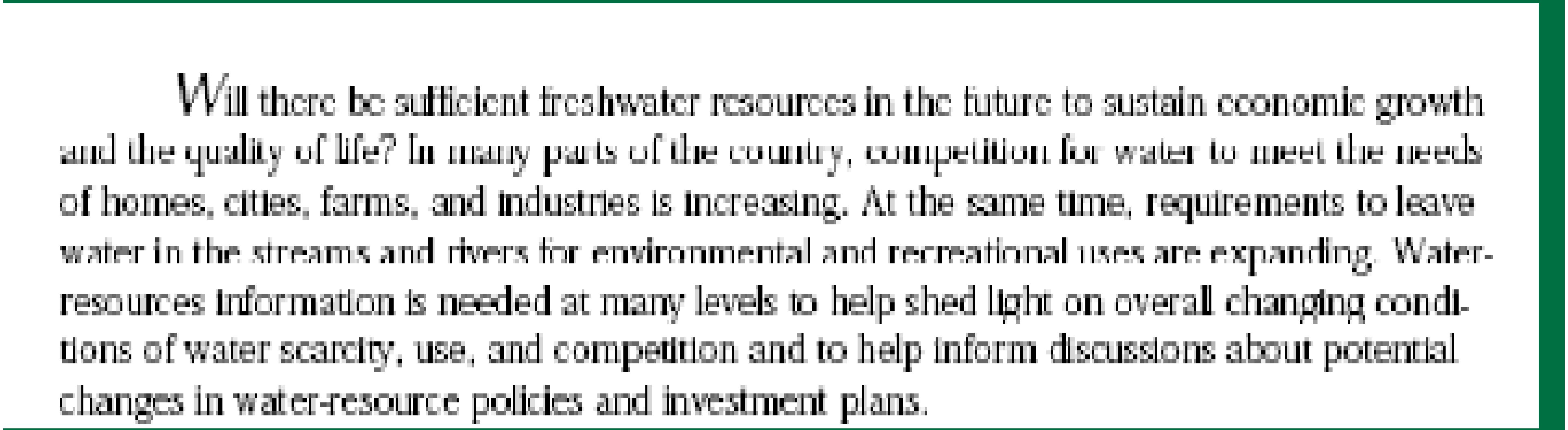
U.S. Department of the Interior
U.S. Geological Survey

The Great Lakes
An International Treasure



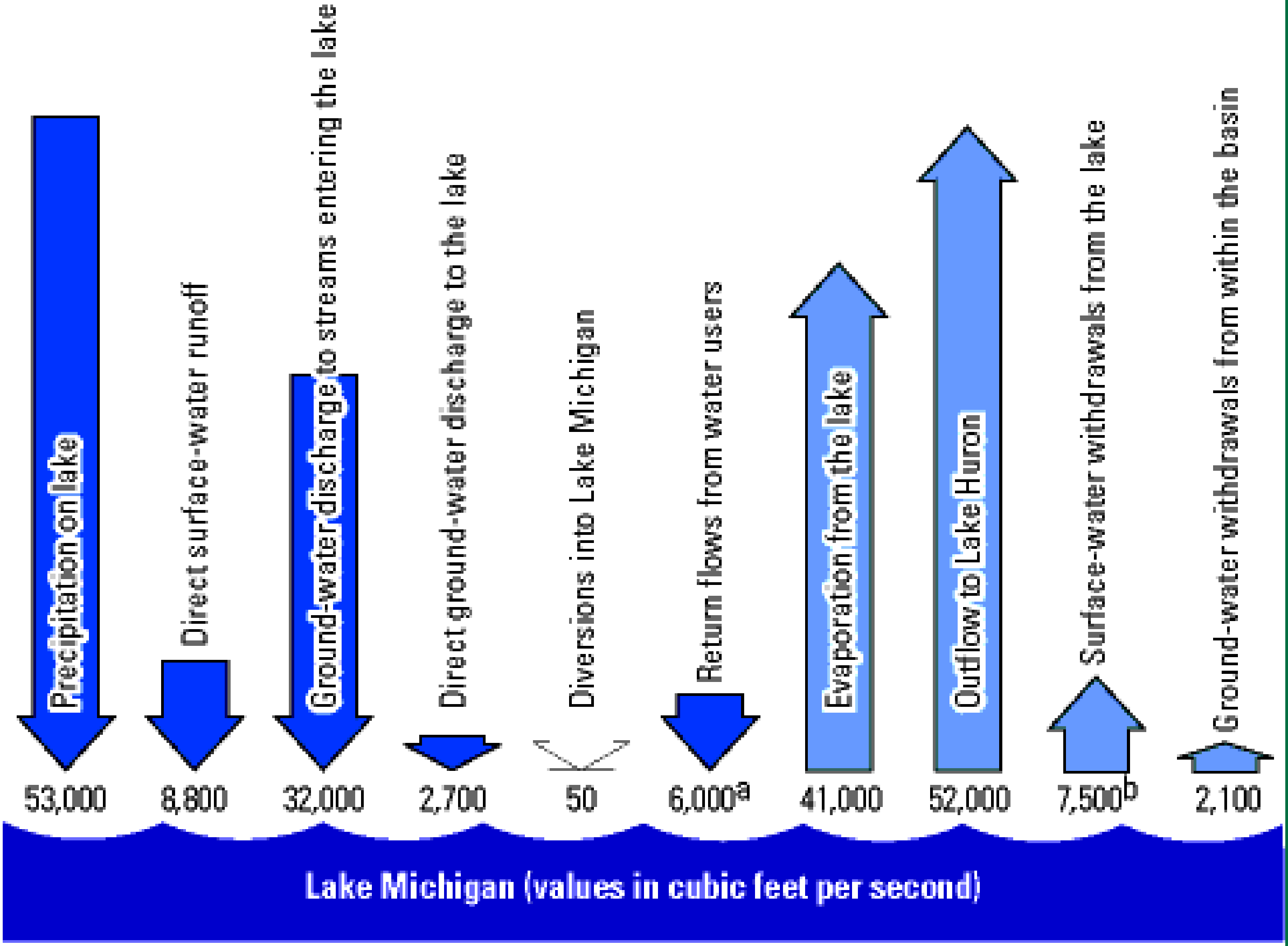
U.S. Army Corps of Engineers, Detroit District

Water Availability



Will there be sufficient freshwater resources in the future to sustain economic growth and the quality of life? In many parts of the country, competition for water to meet the needs of homes, cities, farms, and industries is increasing. At the same time, requirements to leave water in the streams and rivers for environmental and recreational uses are expanding. Water-resources information is needed at many levels to help shed light on overall changing conditions of water scarcity, use, and competition and to help inform discussions about potential changes in water-resource policies and investment plans.

Circular 1223



[a] Return flow is reduced by 3,200 ft^3/s that is diverted out of the basin at Chicago, Ill.

[b] Withdrawals for power plant cooling not included

Setting

- Twenty percent of fresh surface water on earth
- Fresh ground-water in storage is about another Lake Michigan in volume
- 9,400 miles of shoreline
- Major cities rely on surface water from lakes for supply
- Most places in the basin rely on ground water for supply

Components of Water Availability Study

- Storage
- Flows

Define resource

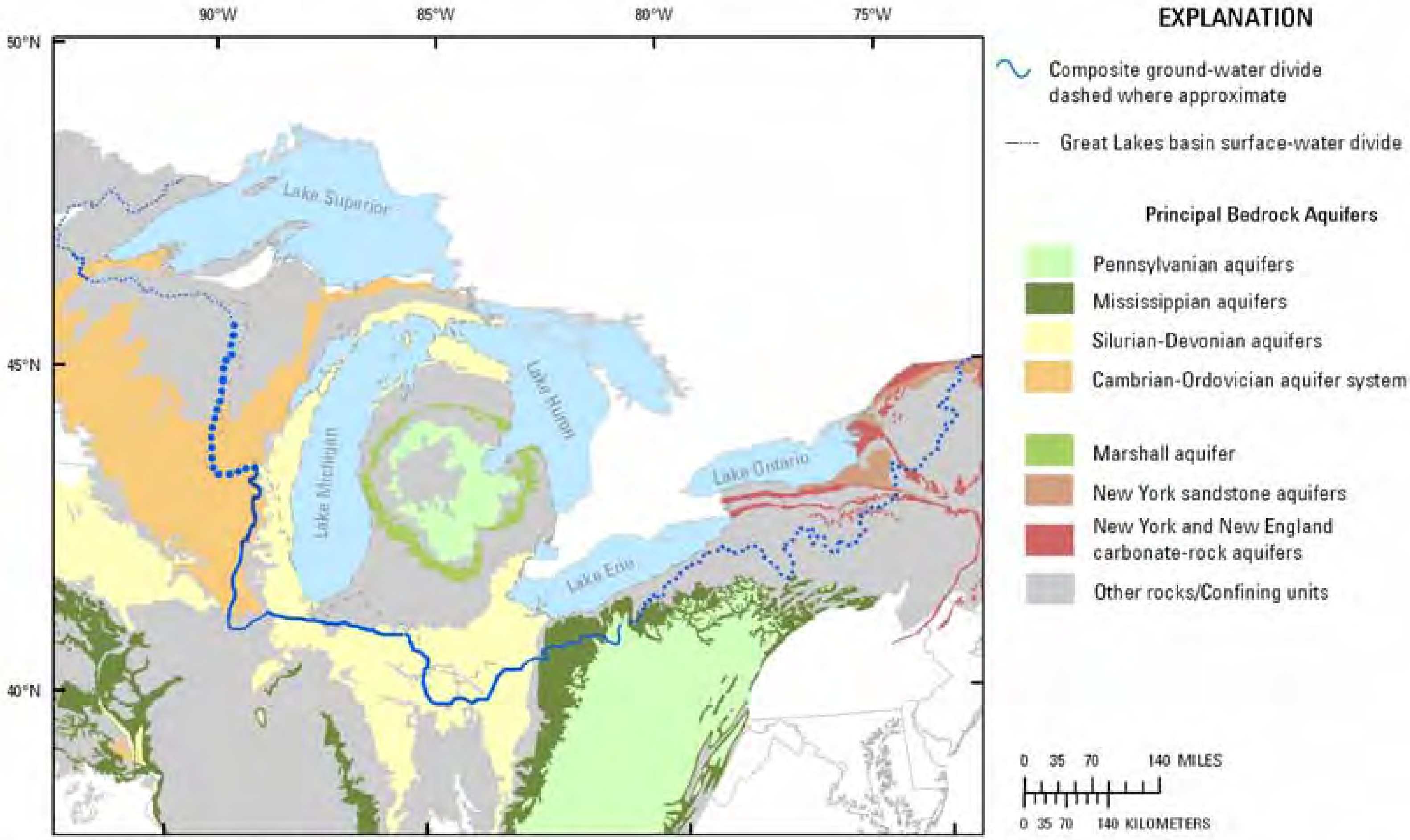
- Constraints
  - Water quality
  - In-stream flow requirements
  - Existing use

Key Indicators

- Surface Water Flows and Storage
  - Lake-level variation analysis for Great Lakes
  - Basin-wide estimates of characteristics
  - Basin-wide estimates of monthly flows
  - Real-time (last month) flows display
  - Network analysis
- Ground Water Flows and Storage
  - Basin-wide analysis of divides
  - Basin-wide analysis of storage
  - Basin-wide analysis of recharge
  - Ground-water-flow model of contributing area to Lake Michigan
  - Network analysis
- Water Use
  - Consumptive water-use coefficients for the Great Lakes Basin and climatically similar areas
  - Estimated Use of Water in the Great Lakes Basin by Hydrologic Unit Code in 2005
  - Seasonal and monthly water use and consumptive use for selected water-use categories and water-use types in Ohio
  - Network analysis

Initial Tasks

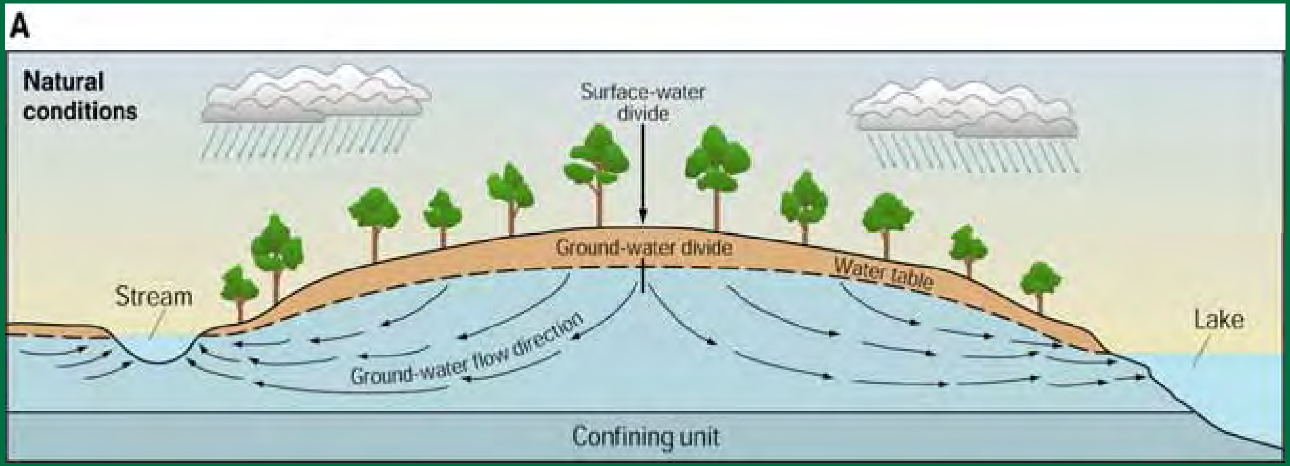
- **Ground-water divides**
- **Regional recharge estimates**
- **Ground-water storage**
- **Lake-level variation (ca. 4500 years)**

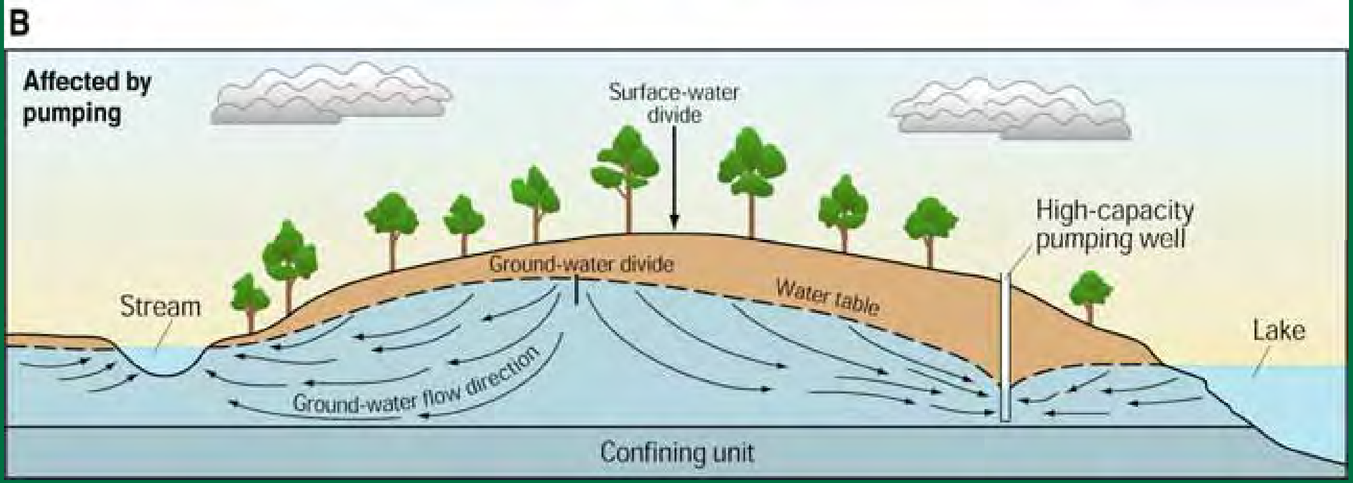


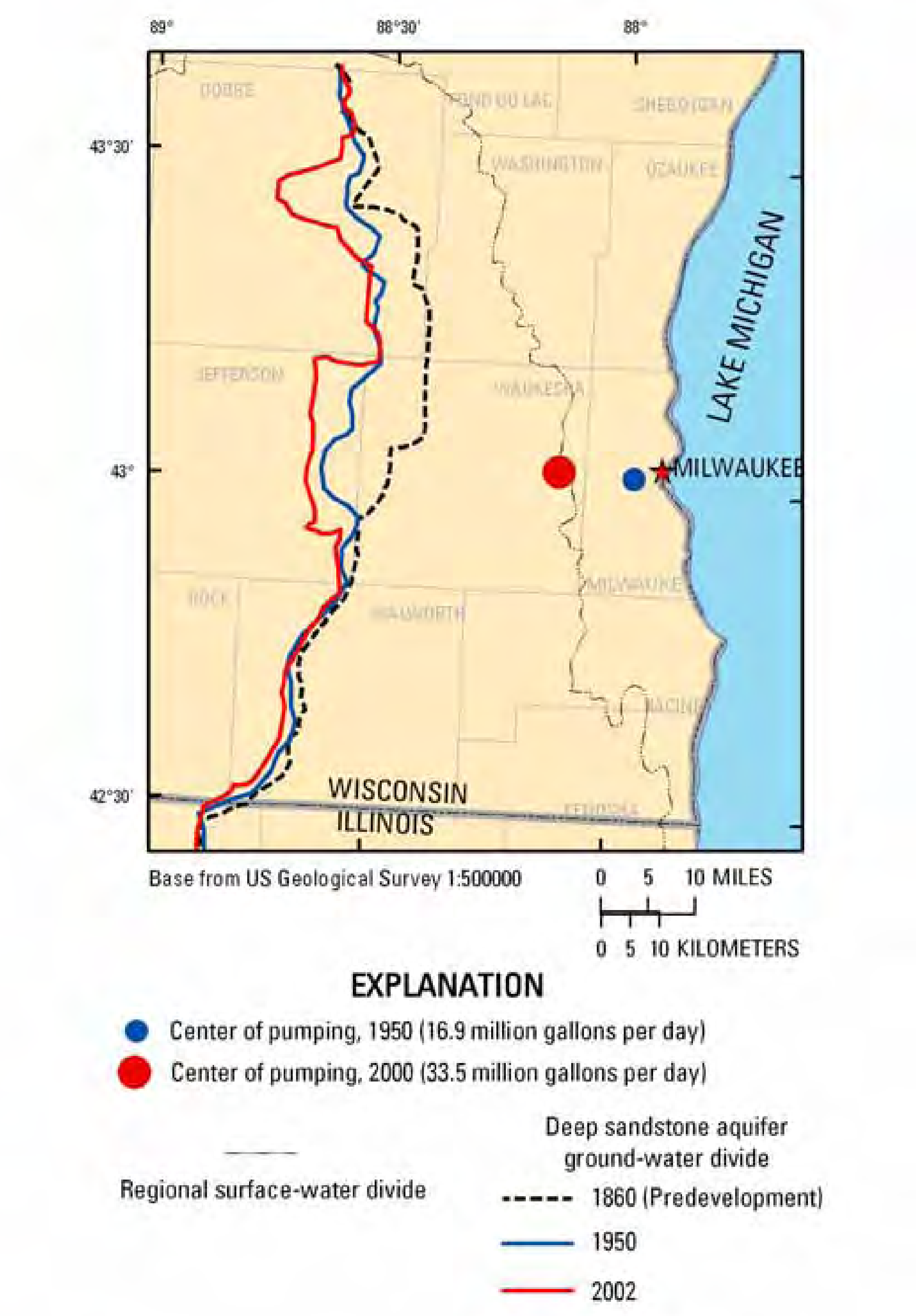
Base from Schruben, P.G., Arndt, R.E., and Bawiec, W.J., 1998, Geology of the Conterminous United States at 1:2,500,000 Scale - A Digital Representation of the 1974 P.B. King and H.M. Beikman Map: accessed July 6, 2005 at http://pubs.usgs.gov/dds/dds11/kb.html

Composite ground-water divide for the principal aquifers in the Great Lakes basin, United States.

Ground-Water Divides

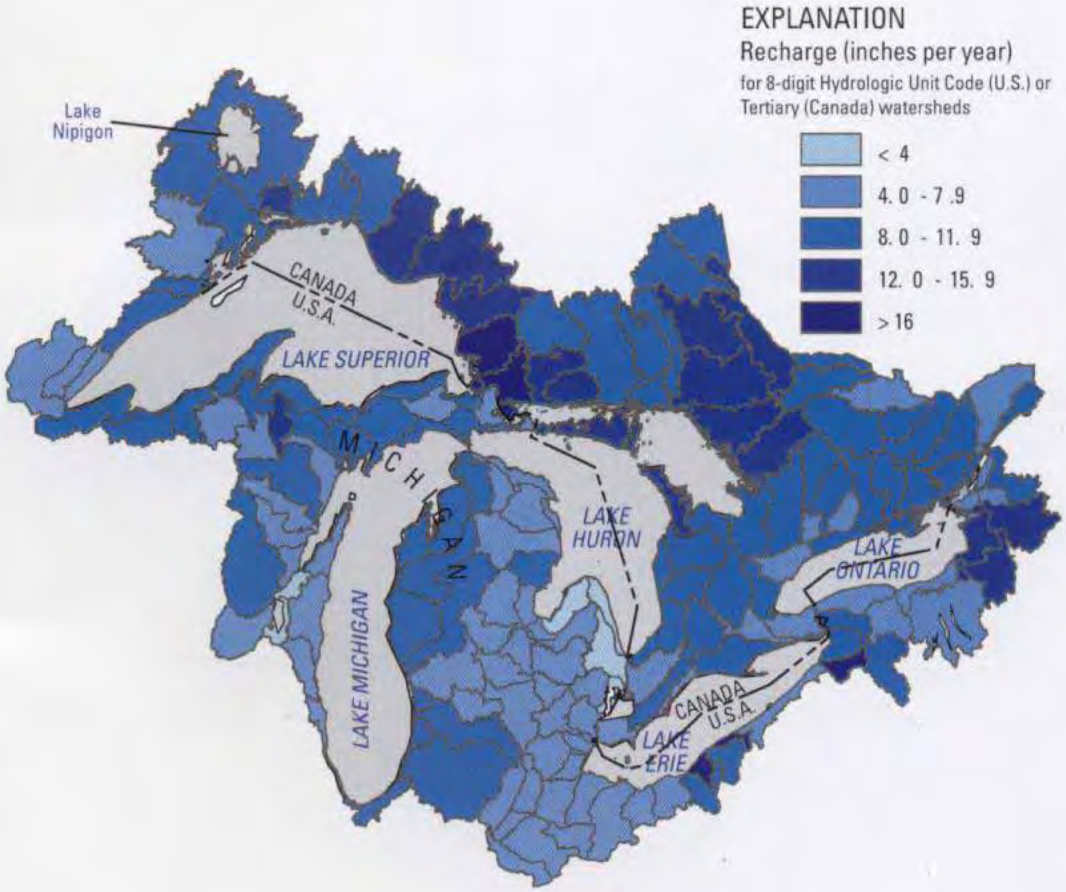




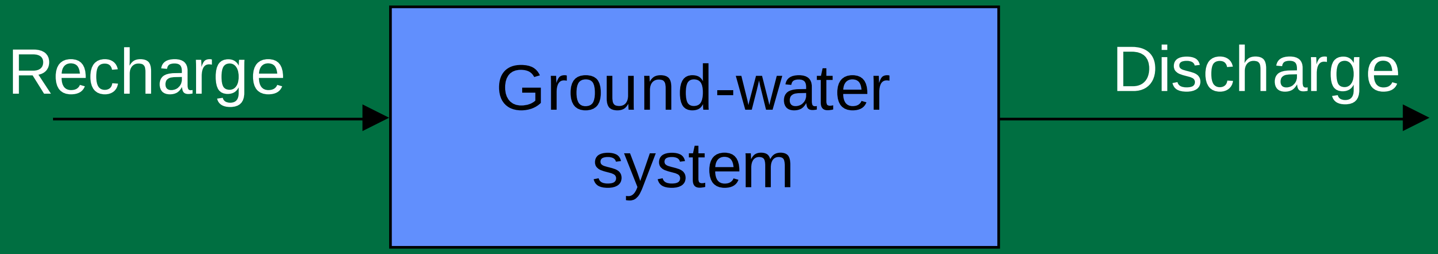

89°
88°30′
88°
43°30′
43°
42°30′
DODGE
FOND DU LAC
SHEBOYGAN
WASHINGTON
OZAUKEE
JEFFERSON
WAUKESHA
LAKE MICHIGAN
MILWAUKEE
MILWAUKEE
ROCK
WALWORTH
RACINE
WISCONSIN
ILLINOIS
KENOSHA
Base from US Geological Survey 1:500000
0 5 10 MILES
0 5 10 KILOMETERS
EXPLANATION
● Center of pumping, 1950 (16.9 million gallons per day)
● Center of pumping, 2000 (33.5 million gallons per day)
Regional surface-water divide
Deep sandstone aquifer ground-water divide
1860 (Predevelopment)
1950
2002

Ground-Water Recharge

Estimation of Shallow Ground-Water Recharge in the Great Lakes Basin



Predevelopment (recharge = discharge)

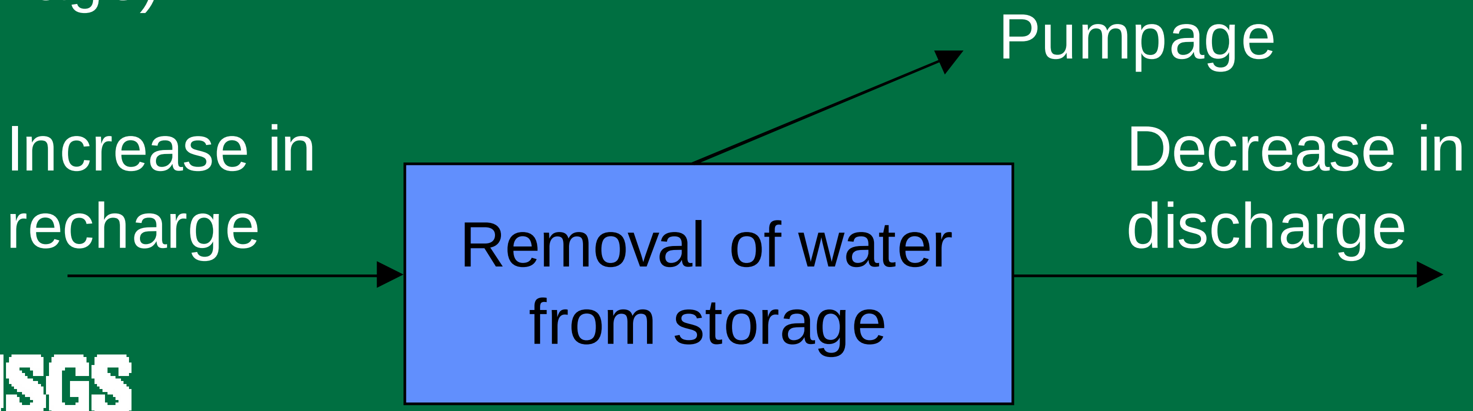


Recharge

Ground-water system

Discharge

Development (pumpage = new stress on system; water must come from an increase in recharge, a decrease in discharge, or a removal of water from storage)



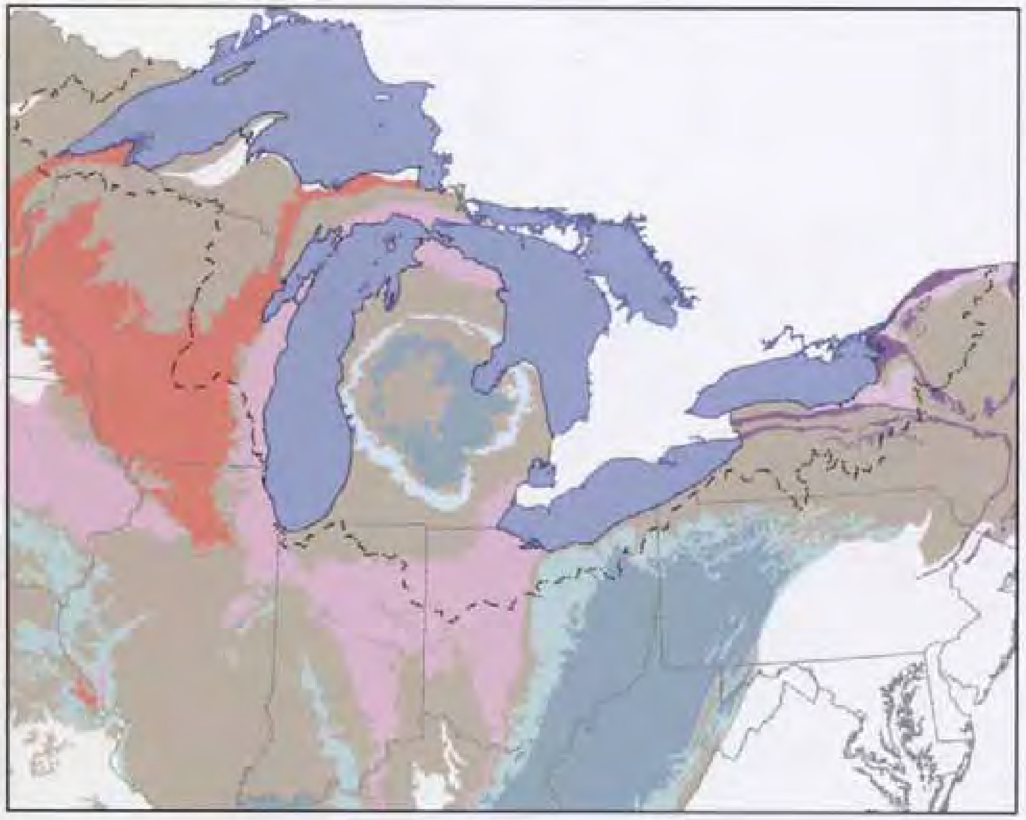
Pumpage

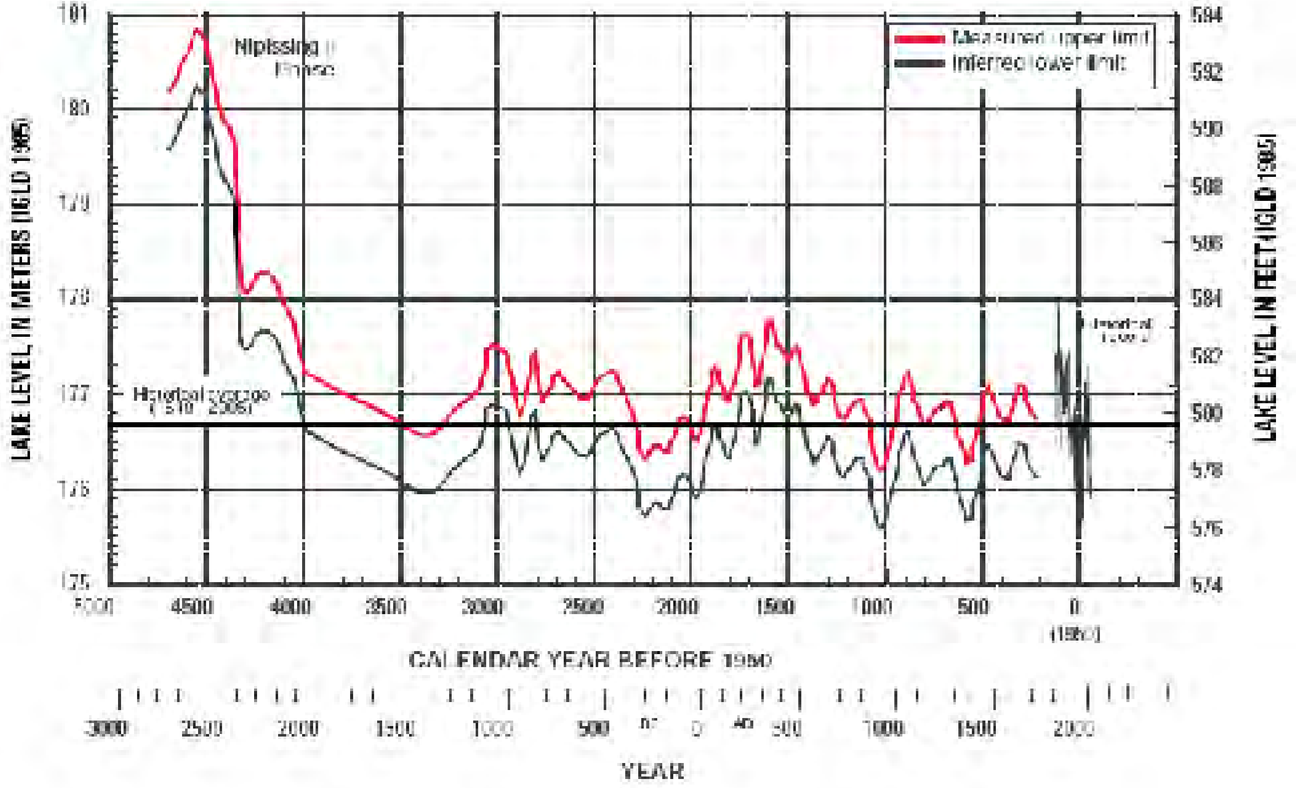
Increase in recharge

Removal of water from storage

Decrease in discharge

Estimate of Ground Water in Storage in the Great Lakes Basin, United States, 2006





Hydrograph of late Holocene lake level and historical lake level for Lakes Michigan and Huron. The red line is interpreted from beach-ridge studies, whereas the lower black line is an inferred lower limit using range of the historical record as a guide.

Vibracoring at Negwegon State park, Michigan. Vibracoring is an important tool needed to understand the subsurface geology of coastal systems throughout the Great Lakes.

Water Use

- **Need to know water use to estimate water availability**
- **Great Lakes water managers concerned with consumptive use estimation**
    - **Diversions or consumptive use remove water from the basin – *regional issue***
    - **Use with large return flows – *local issue***

Growing Demands and Competition for Water

Water Withdrawals - U.S. by Category

Livestock

Less than 1 percent

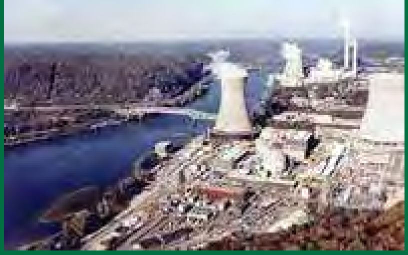
Domestic

Less than 1 percent

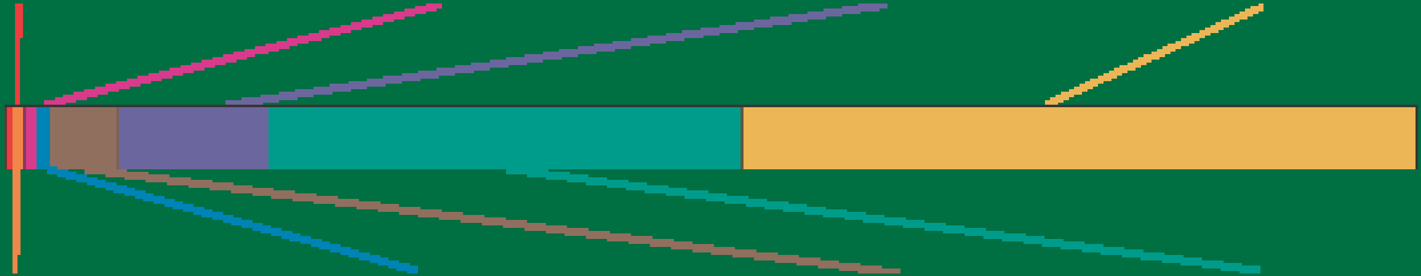
Public Supply

11 percent

Thermoelectric power



48 percent



Less than 1 percent

Mining

Less than 1 percent

Aquaculture

5 percent

Industrial

34 percent

Irrigation

Water Use Indicators

- Consumptive water-use coefficients for the Great Lakes Basin and climatically similar areas
- Estimated Use of Water in the Great Lakes Basin (U.S. side only) by Hydrologic Unit Code in 2005 (See Circulars 1200 and 1268)
- Seasonal and monthly water use and consumptive use for selected water-use categories and water-use types in Ohio

Surface-Water Trends

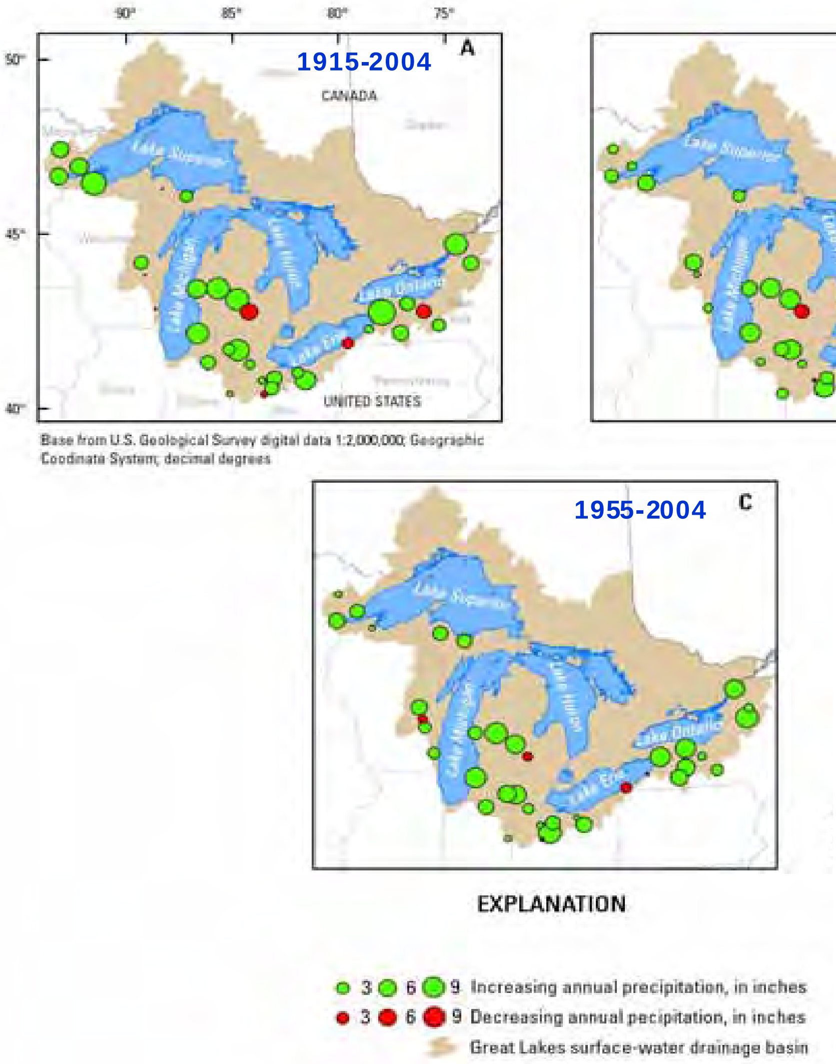
- **Why look at changes over time in precipitation and streamflow?**
  - **To help reveal the ongoing processes (human and natural) that may affect present and future surface-water and ground-water availability.**
    - **Precipitation and streamflow changes over time**
    - **Difference between these changes**

What was done?

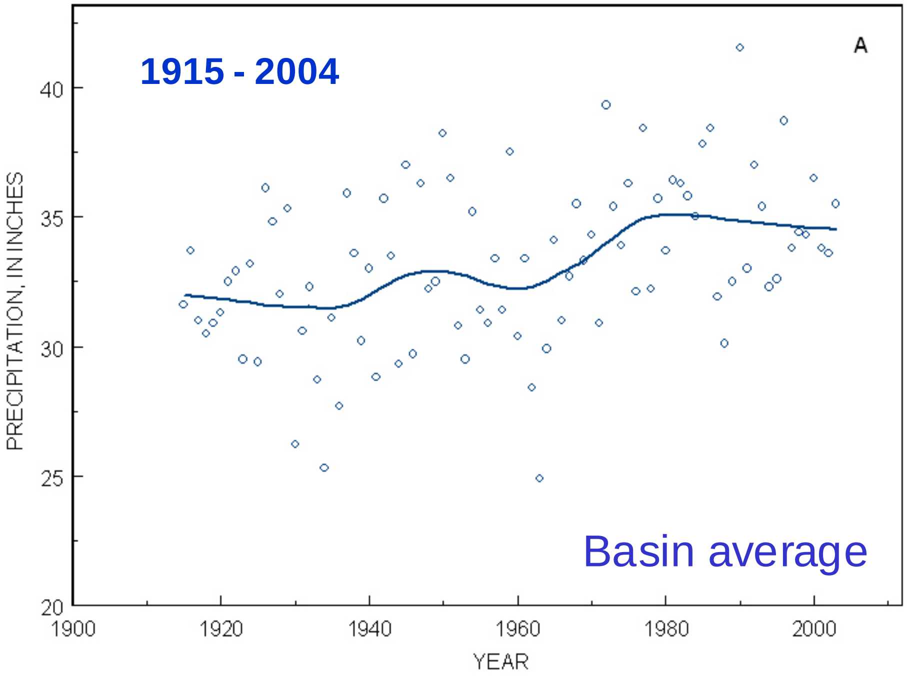
- **Magnitude of annual and monthly changes during the last 50, 70, and 90 years across the U.S. Great Lakes Basin**
  - **Precipitation**
  - **Streamflow**
    - **Relatively natural basins**
      - **Range of agricultural land use**
    - **Regulated basins (storage reservoirs)**
    - **Urbanized basins**

CHANGES IN ANNUAL PRECIPITATION

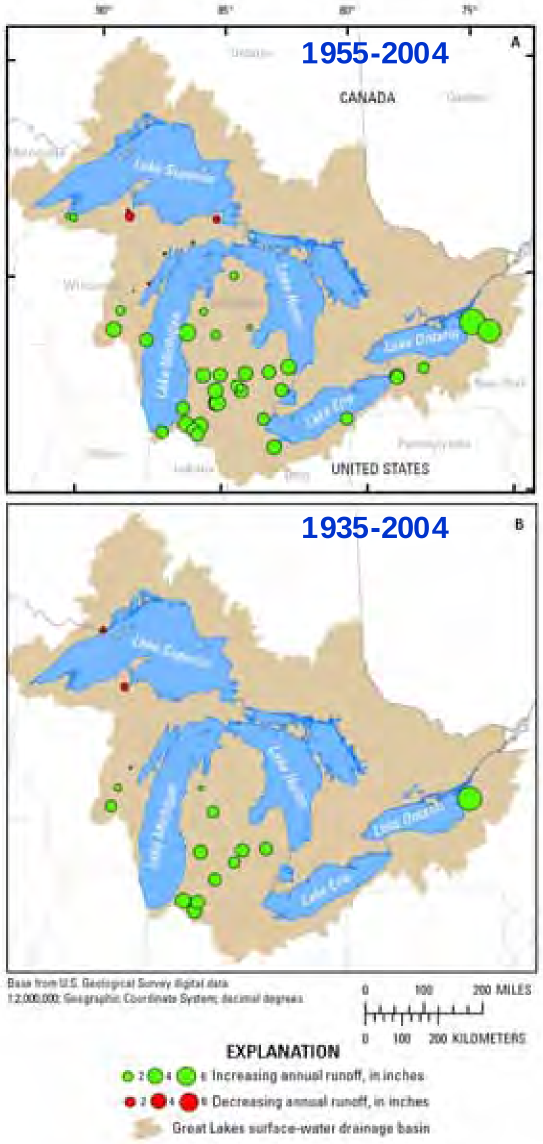
- **1915-2004: Increased by 4.5 in.** (average of 34 stations)
- **1935-2004: Increased by 3.5 in.** (average of 34 stations)
- **1955-2004: Increased by 4.2 in.** (average of 37 stations)



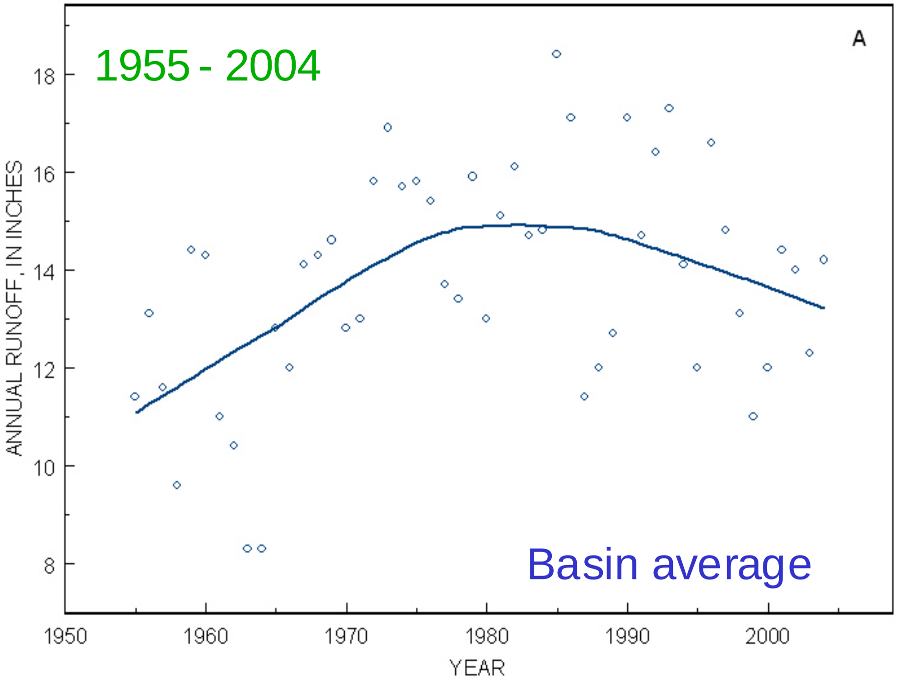
Base from U.S. Geological Survey digital data 1:2,000,000; Geographic Coodinate System; decimal degrees



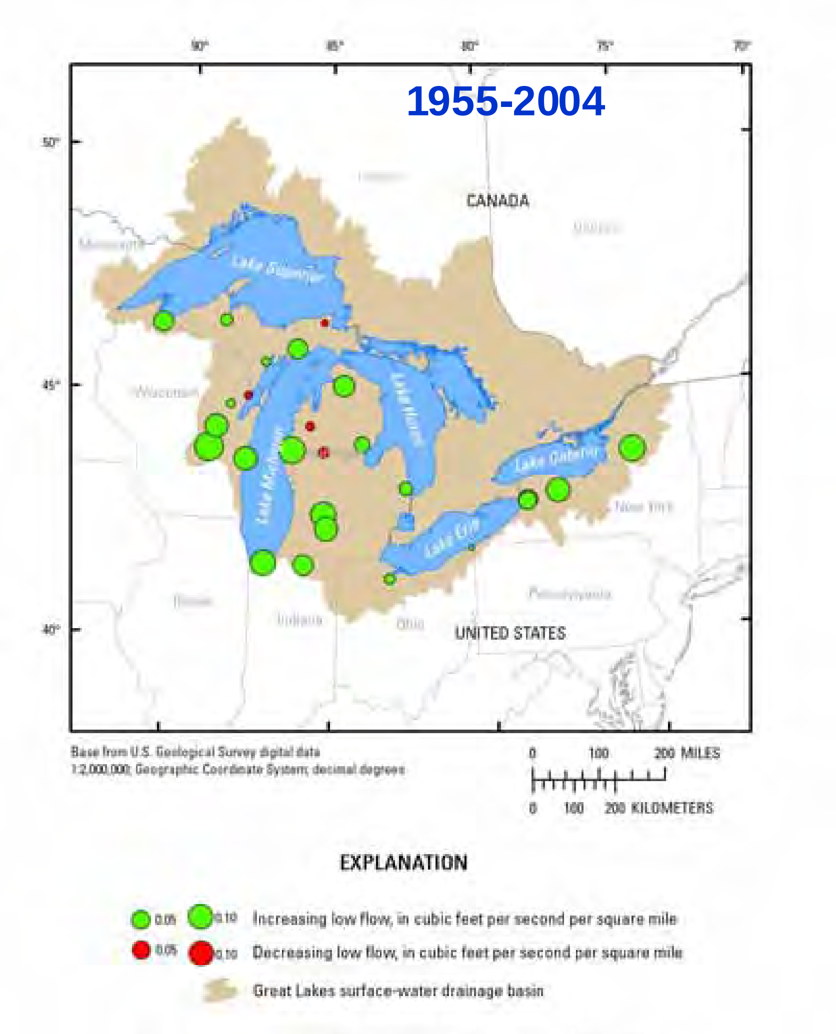
CHANGES IN MEAN ANNUAL RUNOFF



- **1955-2004: Increased by 2.6 in.** (average of 43 stations not substantially affected by regulation or urbanization)
- **1935-2004: Increases similar to 1955-2004 changes** (16 stations available)



CHANGES IN MEAN ANNUAL 7-DAY LOW RUNOFF



- **Increased by 0.048 $(ft^3/s)/mi^2$** (average of 27 stations not substantially affected by regulation or urbanization)

- Increases larger for some of the few highly urbanized and highly regulated stations analyzed than any of the 27 stations not substantially impacted by urbanization or regulation

Comparison of changes in monthly precipitation and runoff, 1955-2004

- November, December, January, July
  - Precipitation and runoff increases similar

- February, March, April
  - Precipitation and runoff changes different
  - Likely due to lower ratios of snowfall to rain and earlier snowmelt runoff in recent years

- May, June, August, September, October
  - Precipitation increases larger than runoff increases
  - Could be due to increases in basin evapotranspiration

Long-term perspective on changes

- Changes, even over periods as long as 90 years, can be part of larger cycles
- Previous studies of Great Lakes Basin precipitation and St. Lawrence River streamflow showed low precipitation and streamflow in the late 1800's and early 1900's relative to earlier and later periods
- In the relatively recent past, precipitation over the land part of the U.S. Great Lakes Basin was lower than at present for several decades
    - The average precipitation for 1915–35 was 10 percent lower than for the most recent 20 years.

Surface-Water Characteristics and Monthly flows

- Develop an estimator of monthly and annual streamflow to the Great Lakes that:
    - Conserves flow through the NHDPlus network
    - Provides a consistent estimator of flows through NHDPlus
    - Matches monthly and annual flow summaries at gaged reaches
- AFINCH

What is AFINCH?

- Streamflow accounting model
  - Accounts for monthly runoff in gaged basins
    - Measured flows at the nearest downstream gage
    - Any measured upstream flows
- Catchment runoff estimation model
  - Estimates monthly flows in all catchments by regression
    - Response variables
      - Measured flows at gaging stations
    - Explanatory variables
      - Land use and land cover variables (possibly time varying)
      - PRISM monthly precipitation and temperature data (1895 to present)
    - Estimation by basin type
      - Gaged—Constrained estimates to conserve mass at gages
      - Ungaged—Unconstrained estimates of flow
- Streamflow Network Model
  - Uses NHDPlus to connect flows from catchments through reaches to the Great Lakes

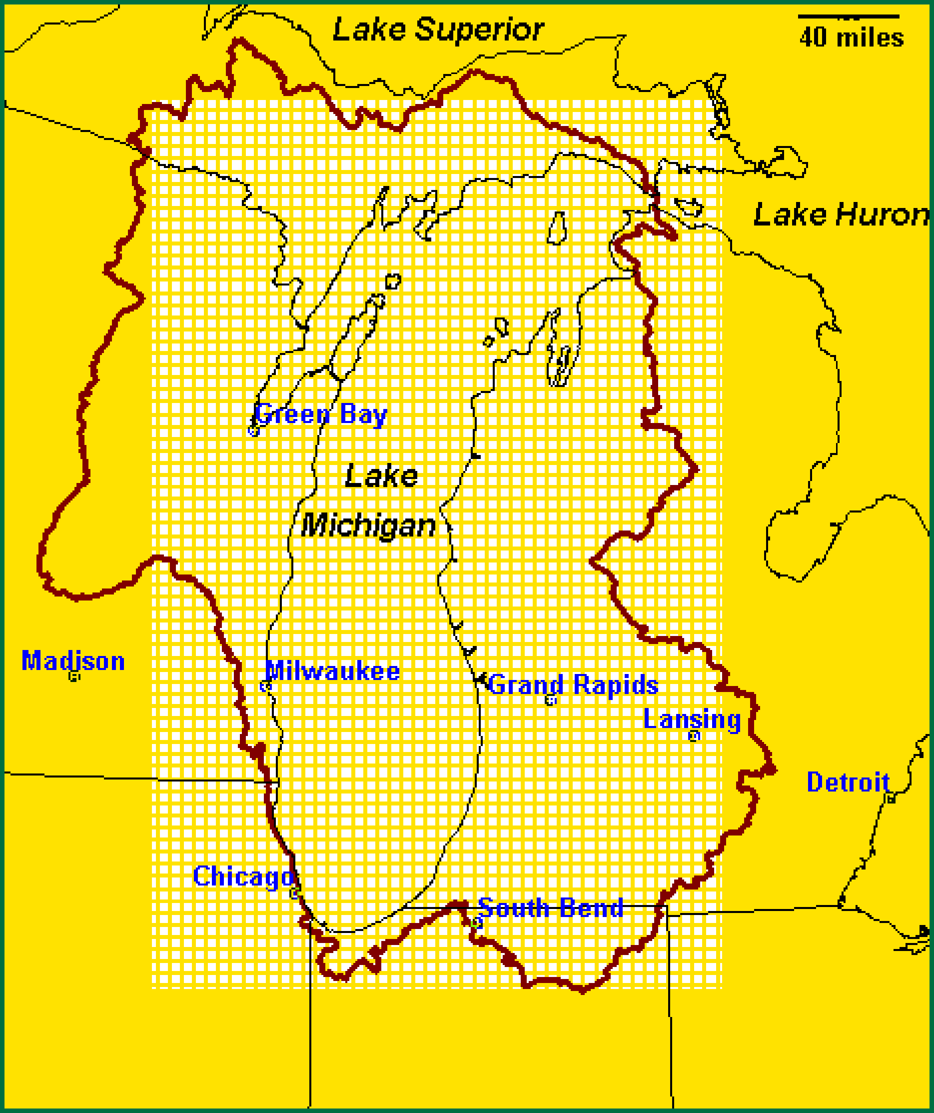
Why are we developing AFINCH?

- Integrates and extends streamflow data
  - From Point information at 300-400 gages
  - To Line Segments representing 132,000 mi of stream reaches averaging 1.2 mi long
  - To Areas representing 143,000 mi^2 of catchments averaging 1.1 mi^2 in size
- Can integrate water use and streamflow data
- Provides flow information in a GIS framework that is consistent with SPARROW for water quality modeling and TMDL analysis.
- Can provide monthly estimates of flow to the Great Lakes in real time for display with NWIS and WaterWatch

Ground-Water Model

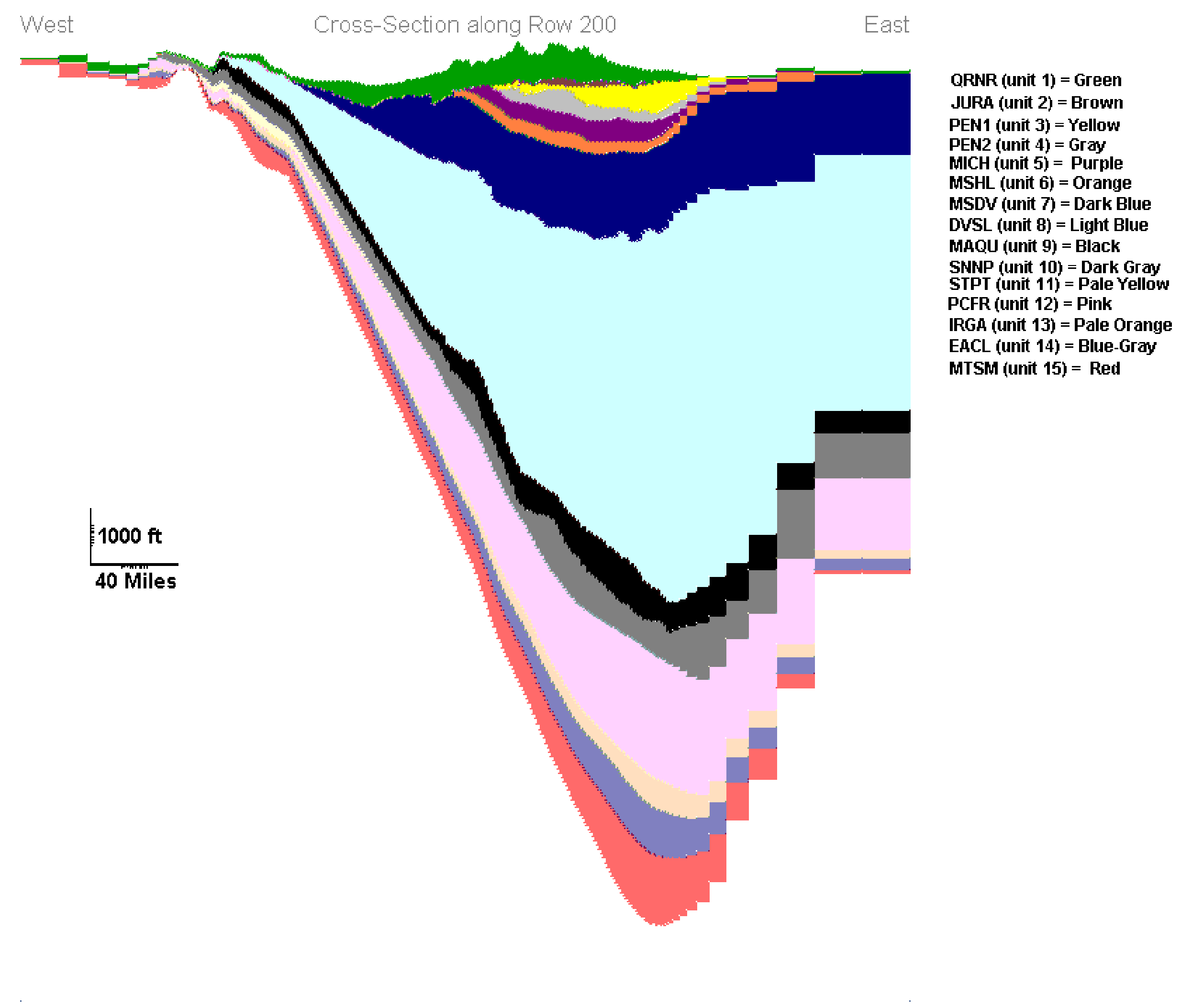
- Contributing Area to Lake Michigan
    - How can a regional model contribute to protecting waters of the Great Lakes Basin in the context of Annex 2001?
    - How can we improve our ability to address local questions of conjunctive use based on a regional model?
    - What is the effect of climate variability on recharge, shallow flow systems, and regional flow?
    - Can projected water use be combined with climate variability simulations to give information regarding future water availability?

- Model links indicators to processes
- Model links monitoring to analysis

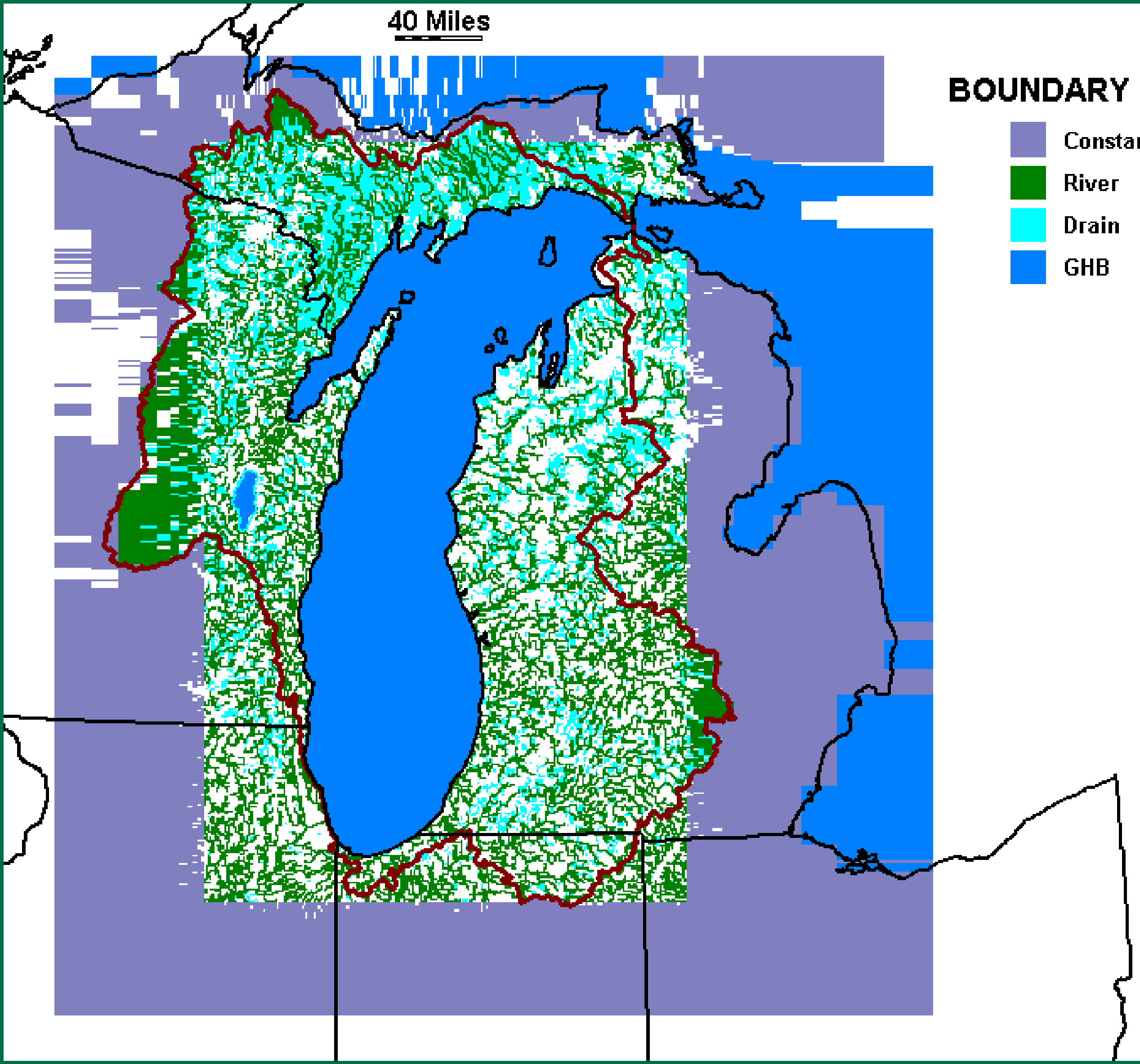


Lake Michigan Basin Model Domain

Overview of Lake Michigan Basin Model



Model hydrostratigraphy



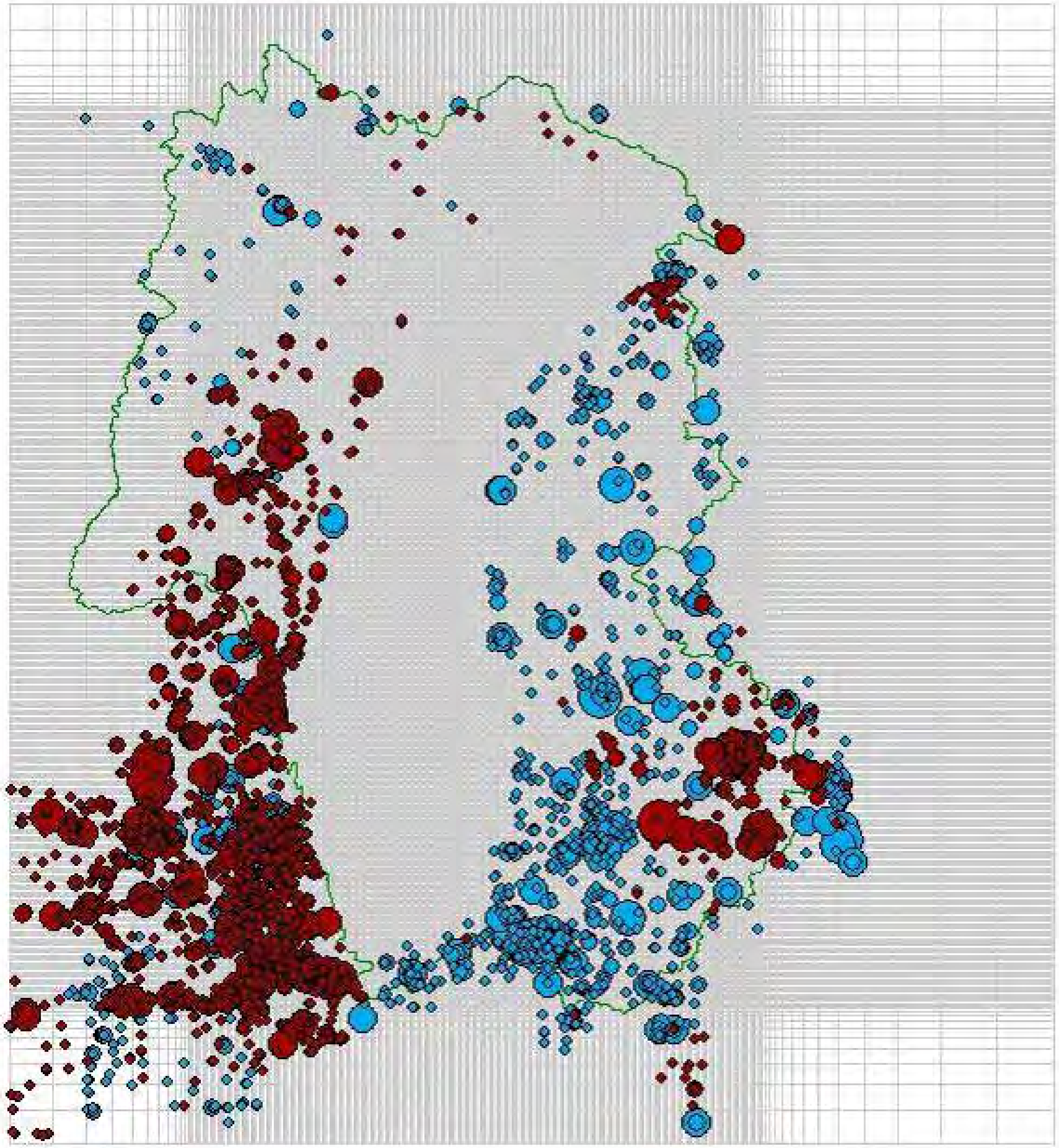
BOUNDARY CONDITIONS

🟪 Constant Head = *farfield*

🟩 River = *streams*

🟦 Drain = *water bodies*

🟦 GHB = *Great Lake*

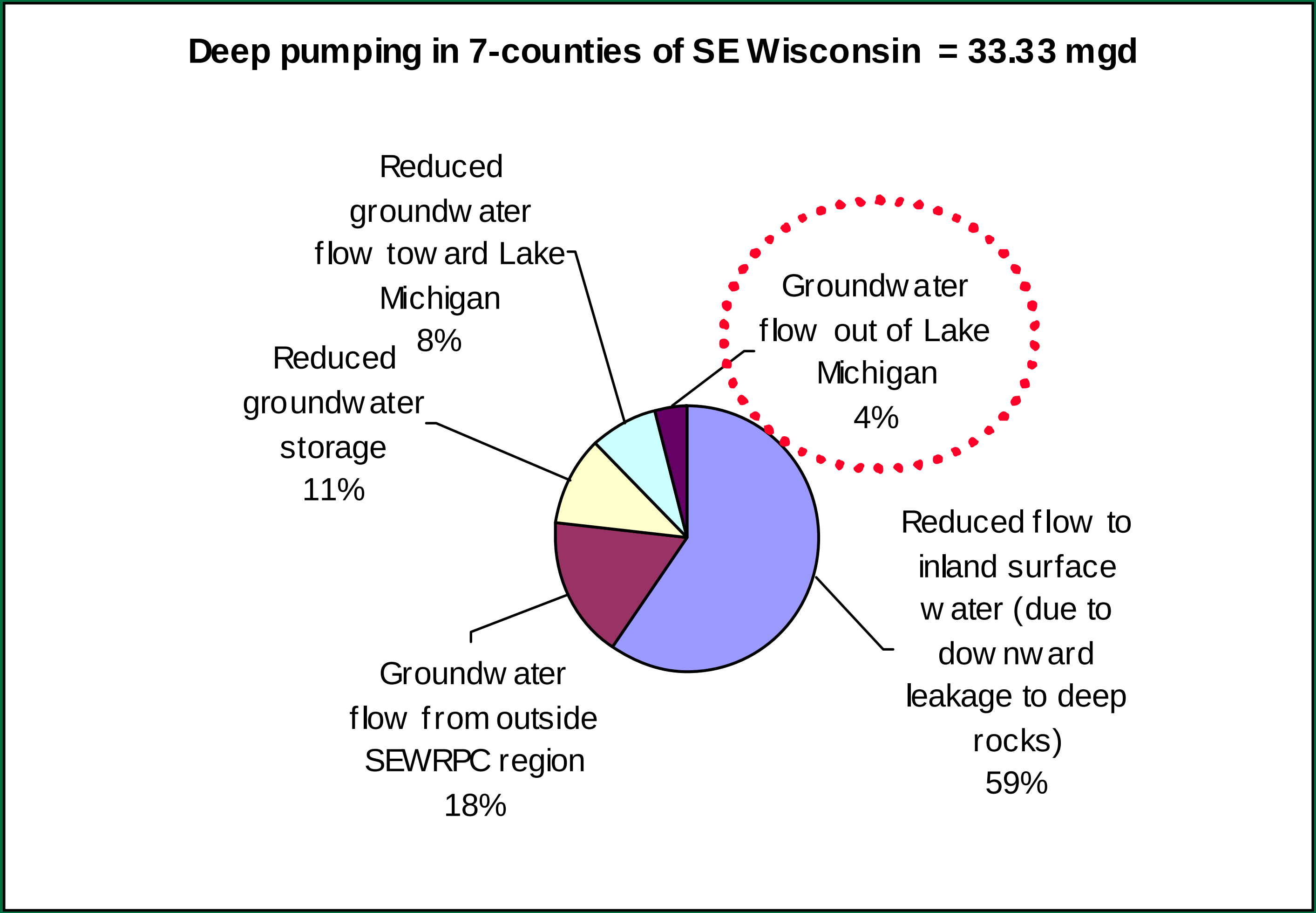


Public Supply, 2001 - 2004 Stress Period,
Blue -glacial wells, Brown - bedrock wells, 7600 total

How will this model be used?

Example water budget analysis from Southeastern Wisconsin ground-water-flow model

How much of the water that flows into the cone of depression to replenish water discharged by deep regional pumping (including discharge from Waukesha's deep wells) is flowing out of Lake Michigan itself?



USGS

UW Extension
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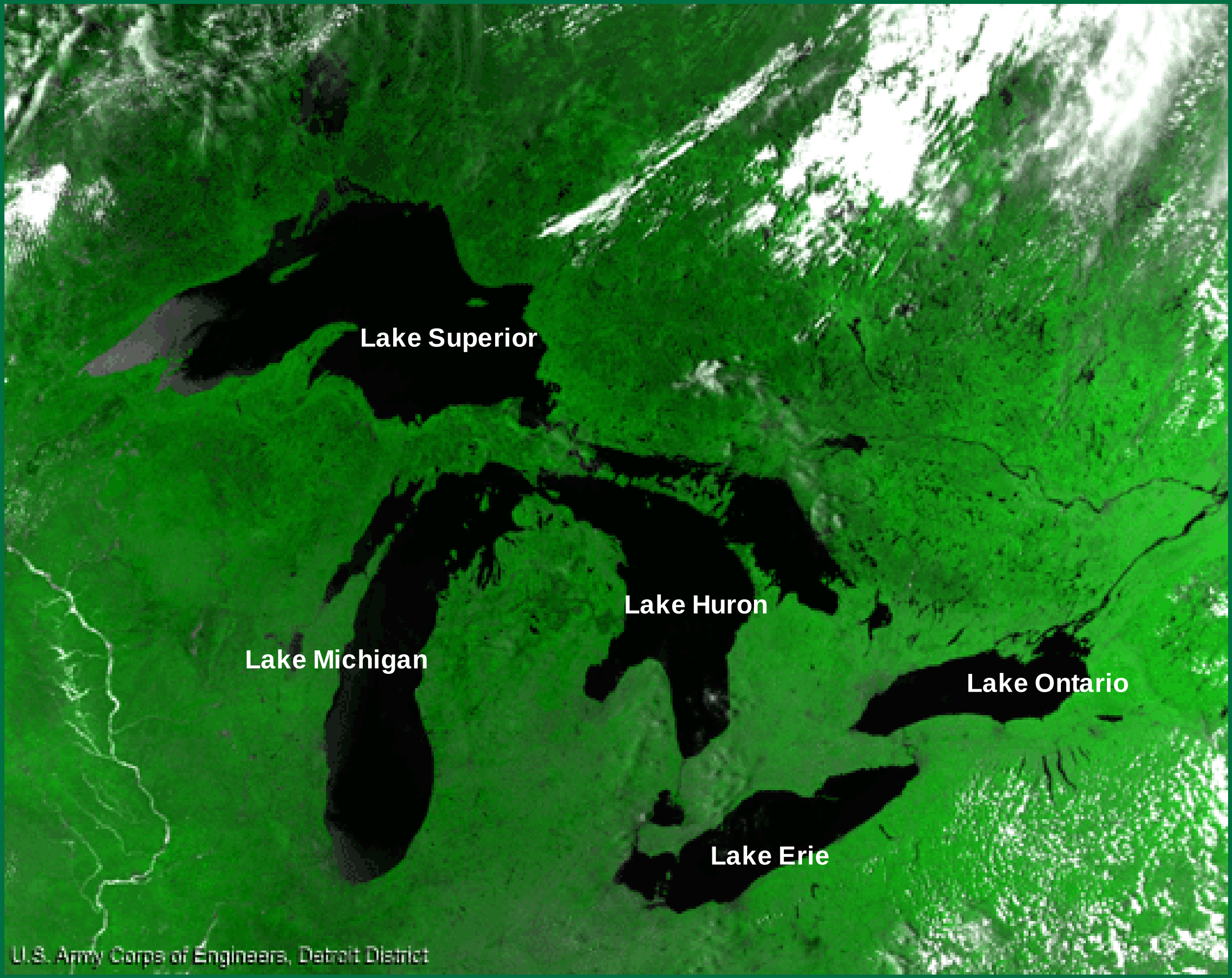

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