USGS
science for a changing world

Water Availability and Use in the Great Lakes Region

Howard W. Reeves, USGS Michigan Water Science Center

Michigan Chapter Soil and Water Conservation Society Seminar
A Matter of Balance: Energy, Water and Working Lands
March 7, 2012

USGS

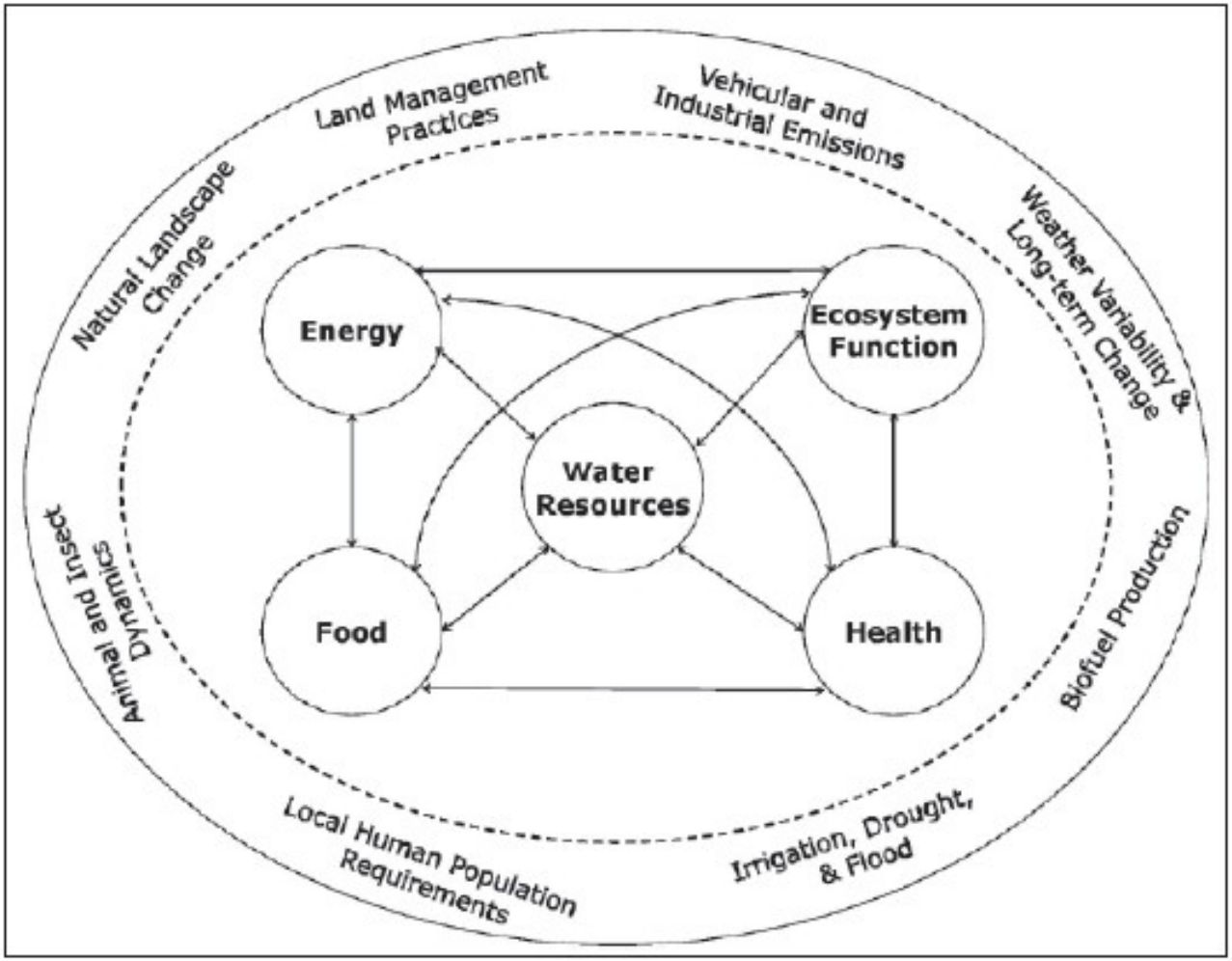
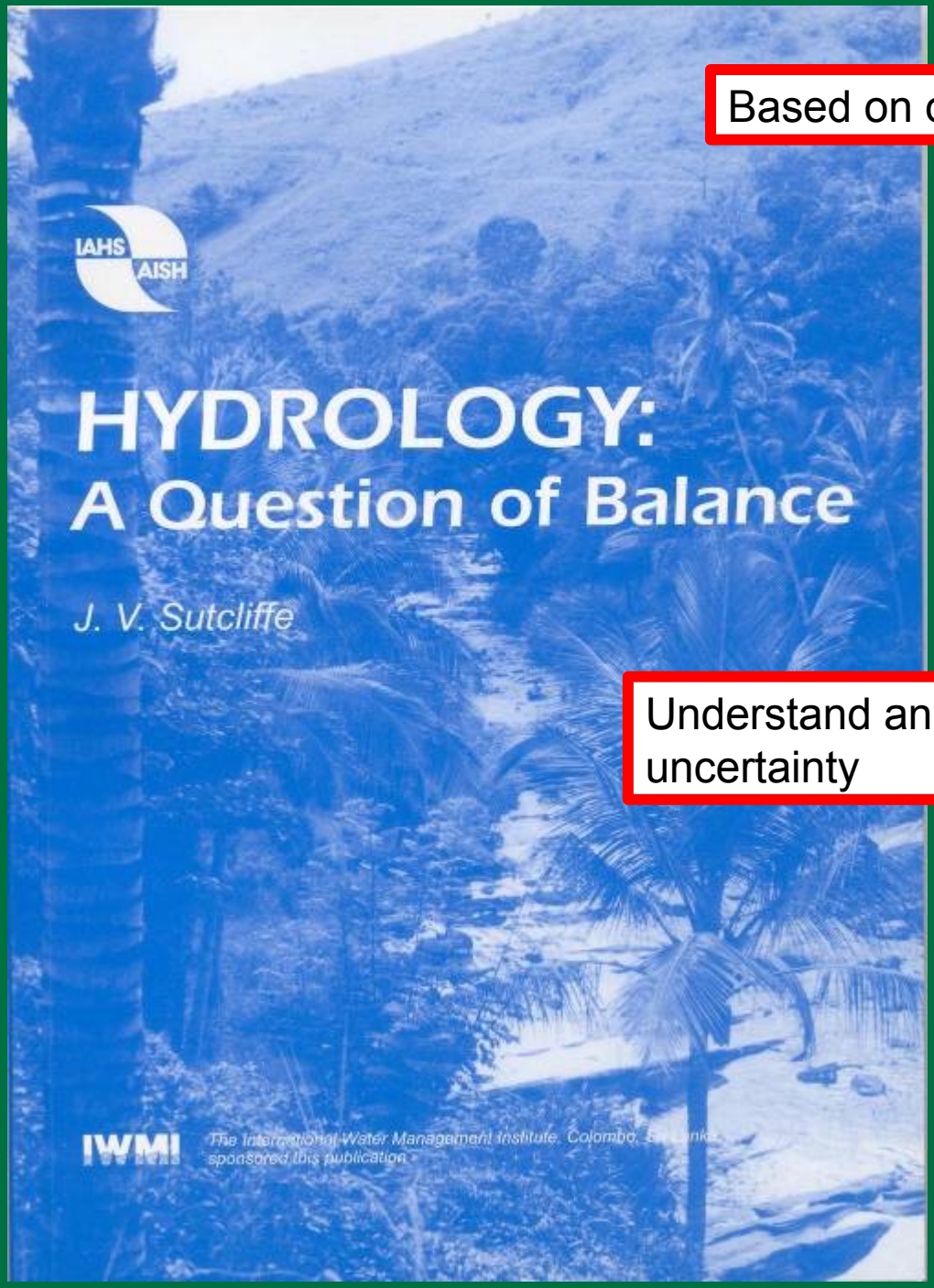


Fig. 1. The relationships among five key resources (water, food, energy, health, and ecosystem function). Outer ring shows a nonexhaustive list of stressors that affect availability or quality of the resources.

USGS

Hossain, Faisal; Niyogi, Dev; Adegoke, Jimmy; Kallos, George; and Pielke, Roger, 2011, Making sense of the water resources that will be available for future use: EOS, Transactions American Geophysical Union, v. 92, no. 17, pg. 144, doi: 10.1029/2011EO170005

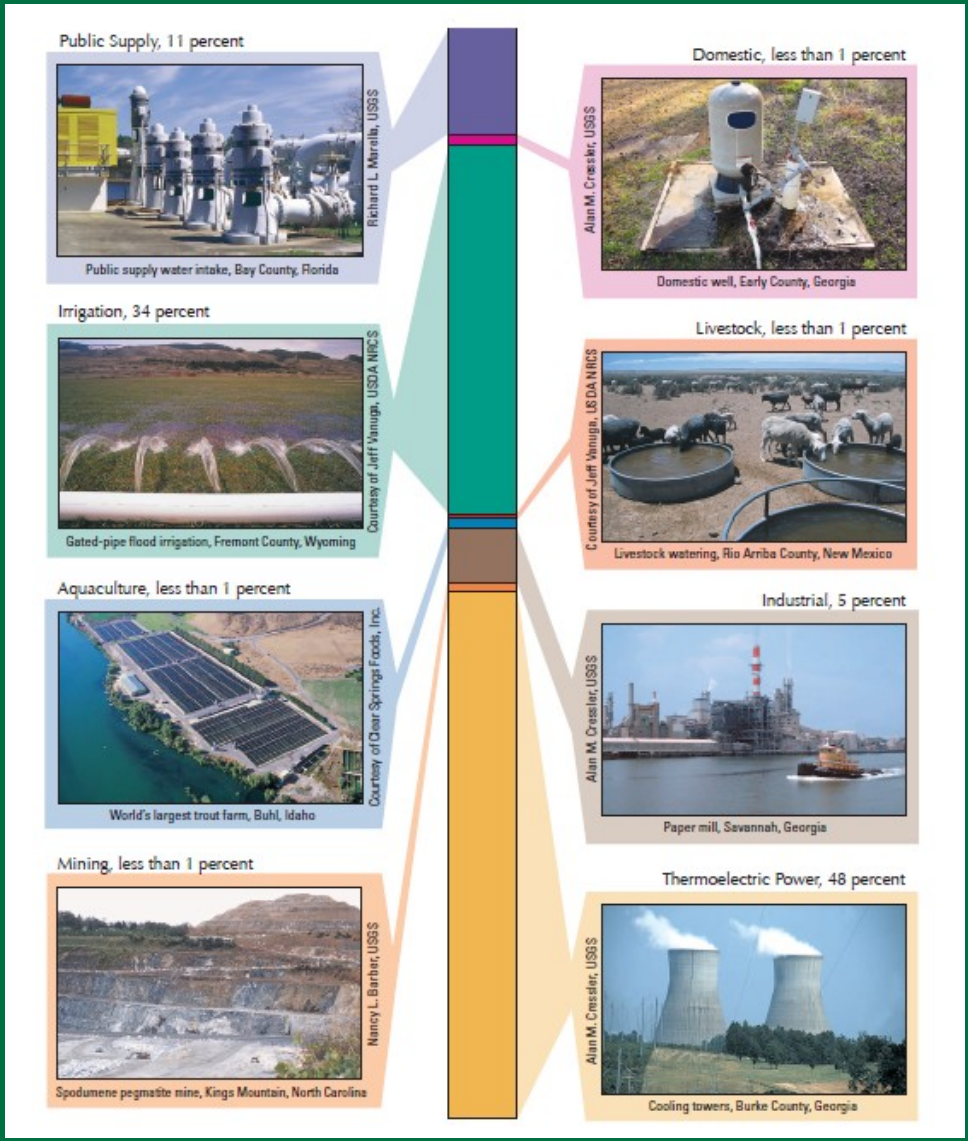


Based on observations

Understand and account for uncertainty

USGS

Water use in the U.S.



USGS

Hutson, S.S., Barber, N.L., Kenny, J.F., Linsey, K.S., Lumia, D.S., and Maupin, M.A., 2004, Estimated use of water in the United States in 2000: Reston, Va., U.S. Geological Survey Circular 1268, 46 p.

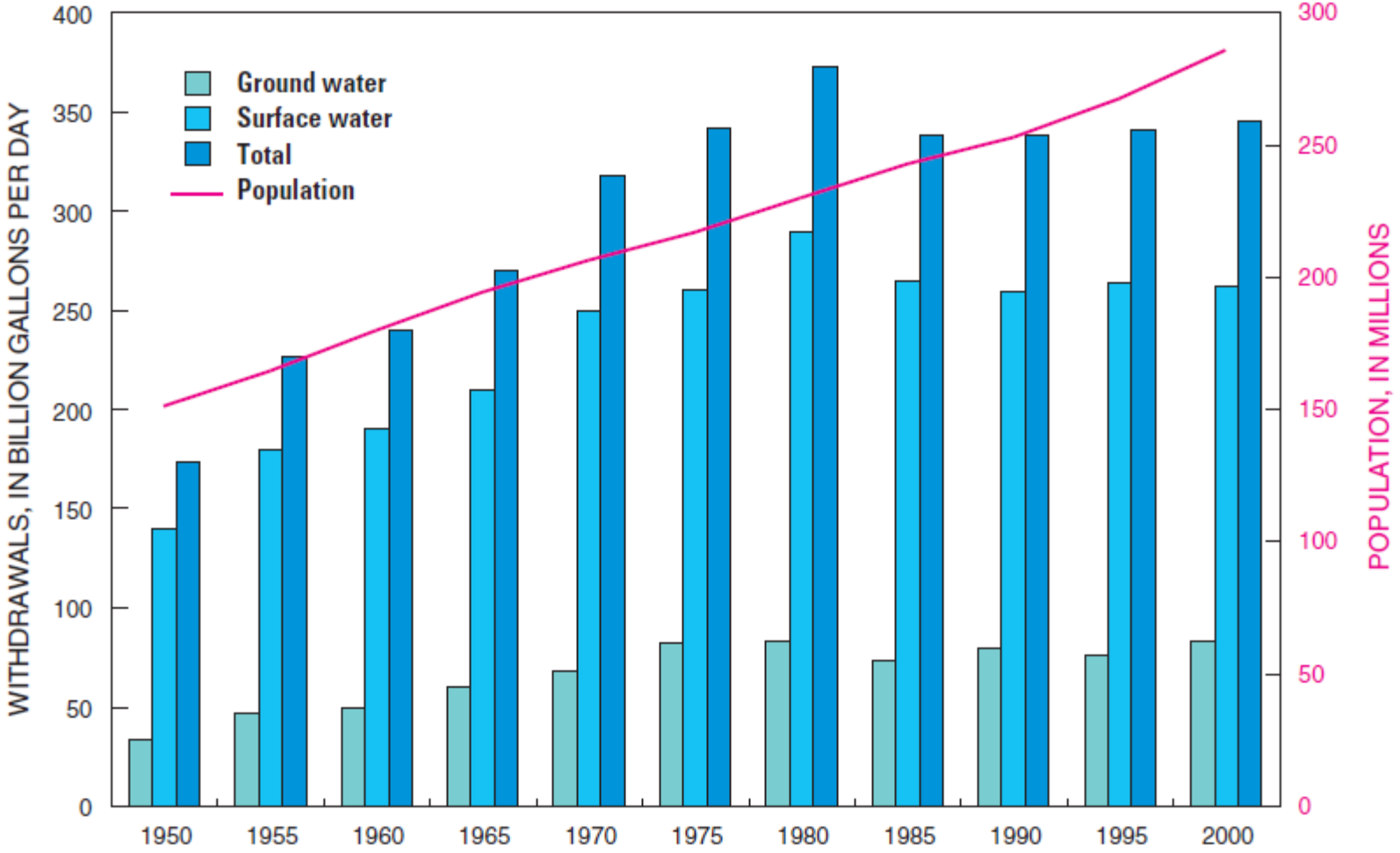


Figure 13. Trends in population and freshwater withdrawals by source, 1950–2000.

USGS

Hutson and others, 2004.

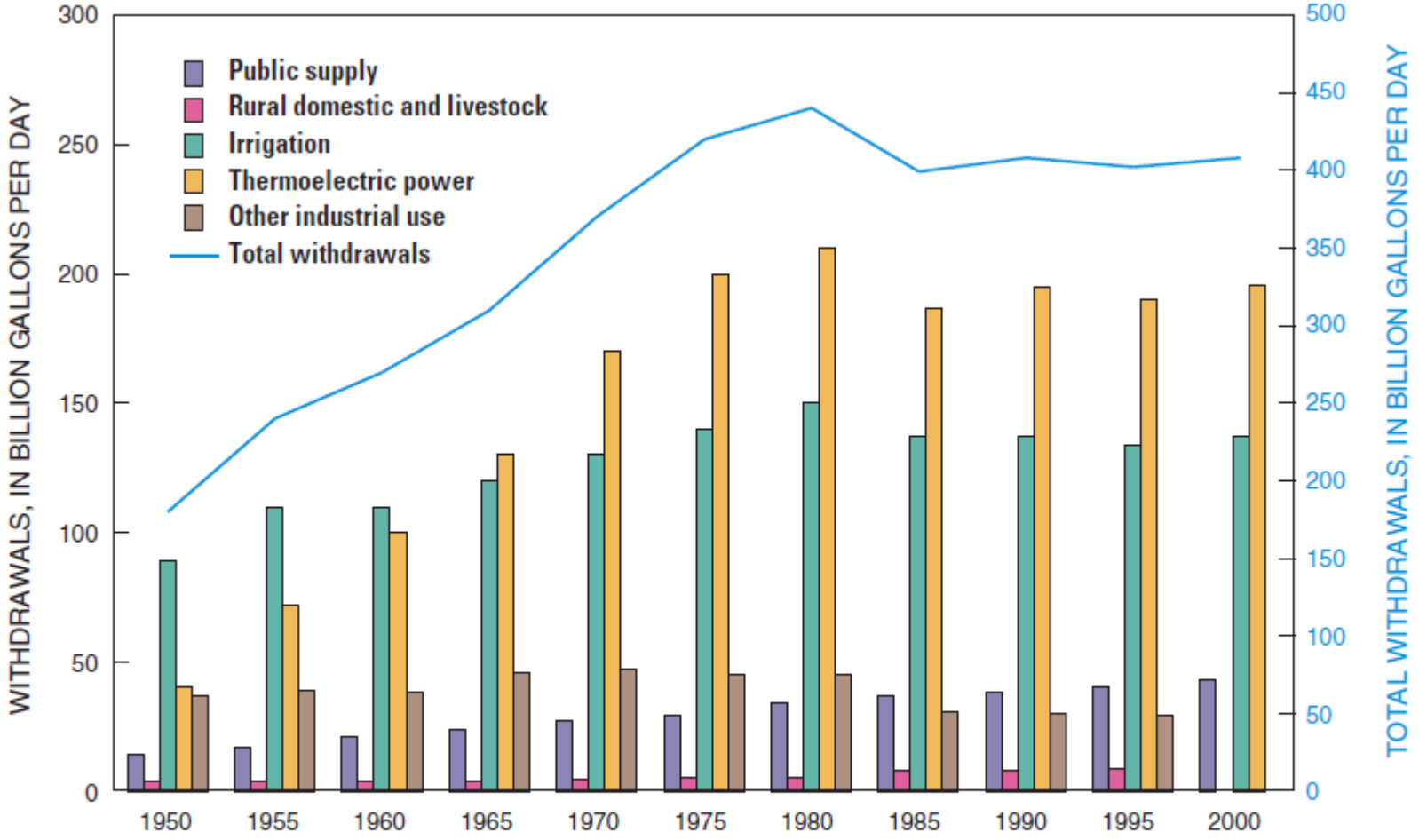


Figure 14. Trends in total water withdrawals by water-use category, 1950–2000. (Total withdrawals for rural domestic and livestock and for "other industrial use" are not available for 2000.)

USGS

Hutson and others, 2004.

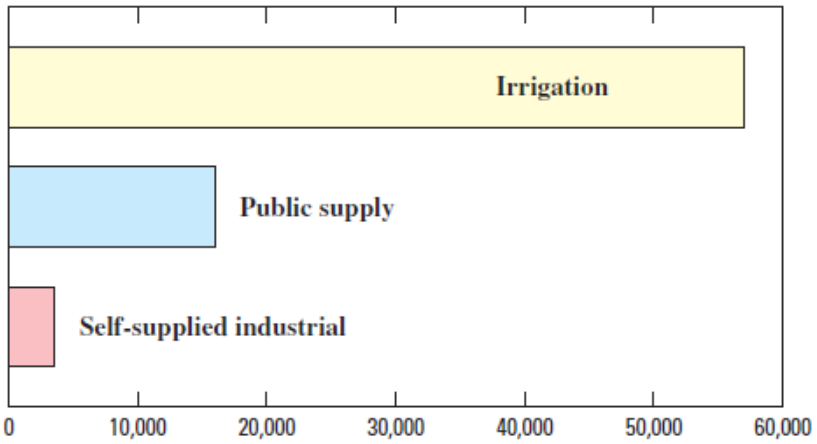


Figure 3. Total ground-water withdrawals, by water use, in the United States, 2000

Maupin, M.A., and Barber, N.L., 2005, Estimated withdrawals from principal aquifers in the United States, 2000: U.S.Geological Survey Circular 1279, 46 p.

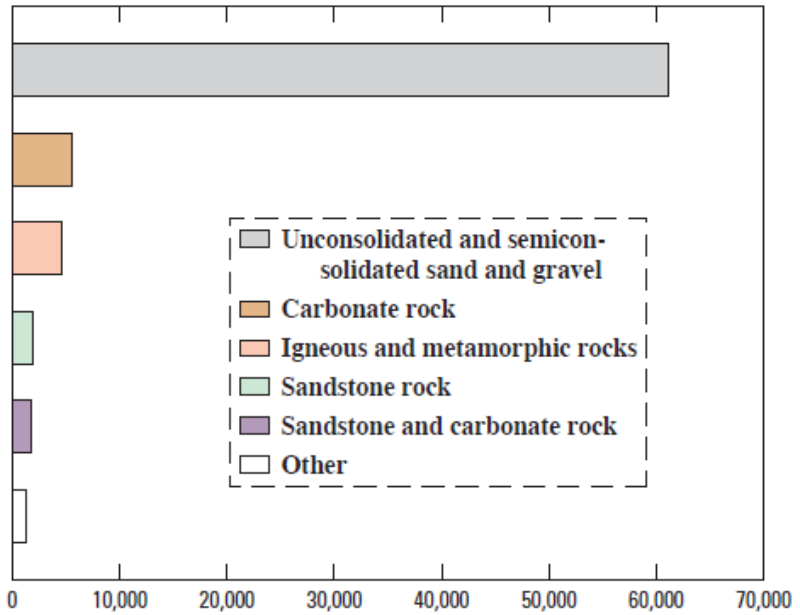


Figure 4. Total ground-water withdrawals, by lithologic group, in the United States, 2000

USGS

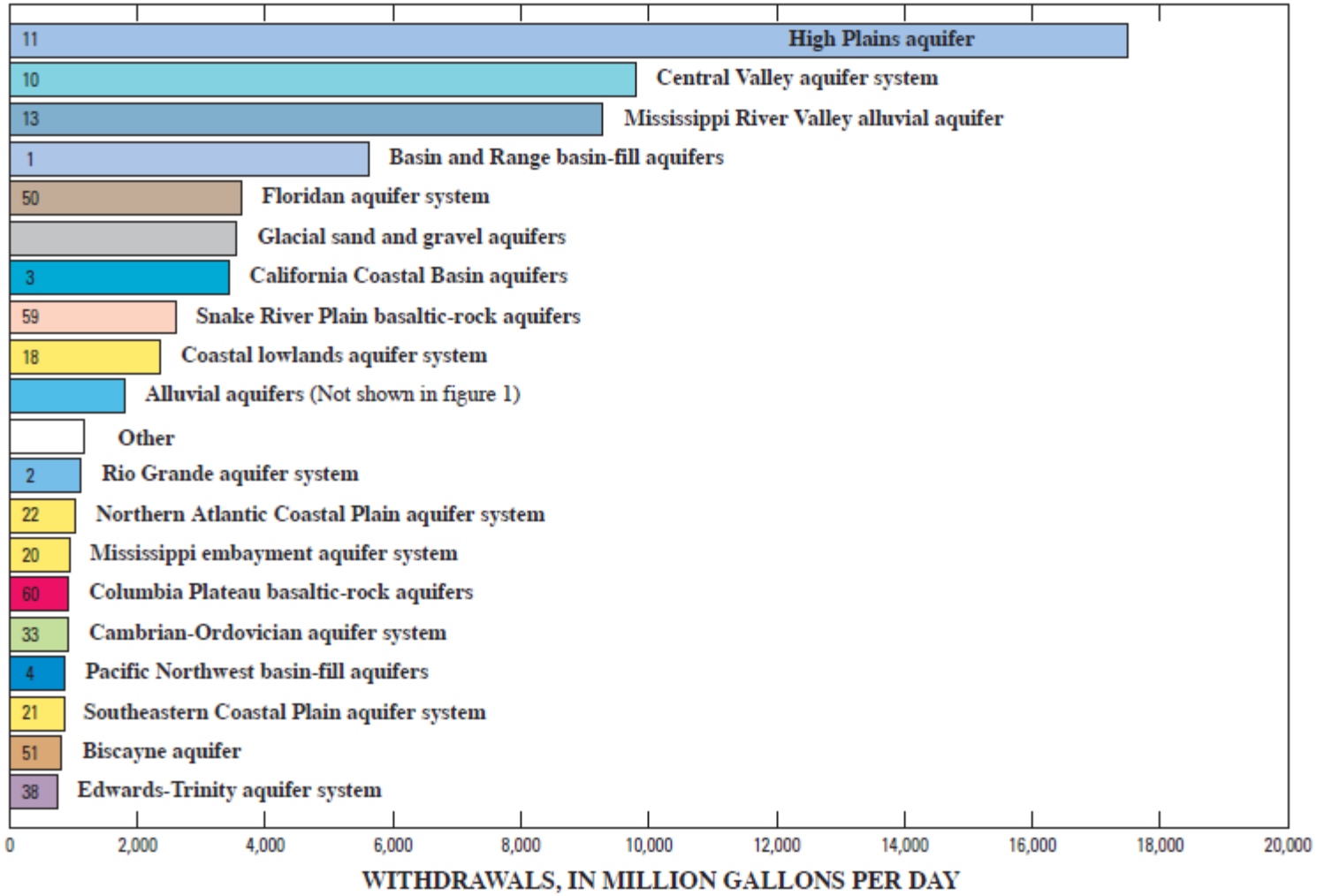


Figure 5. Aquifers that provided most of the total withdrawals for irrigation, public-supply, and self-supplied industrial water uses in the United States during 2000

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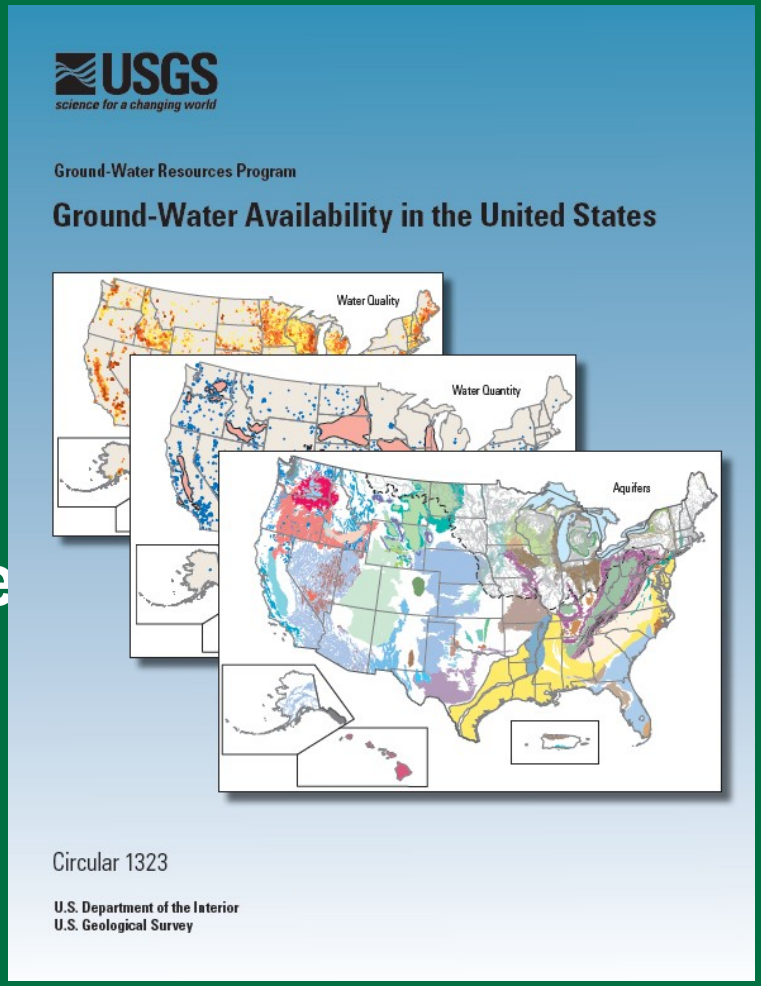
Maupin and Barber, 2005.

Regional Groundwater Availability Studies

- Status of groundwater resources for the nation
- Response of groundwater systems to development
- Potential response to future development and climate change



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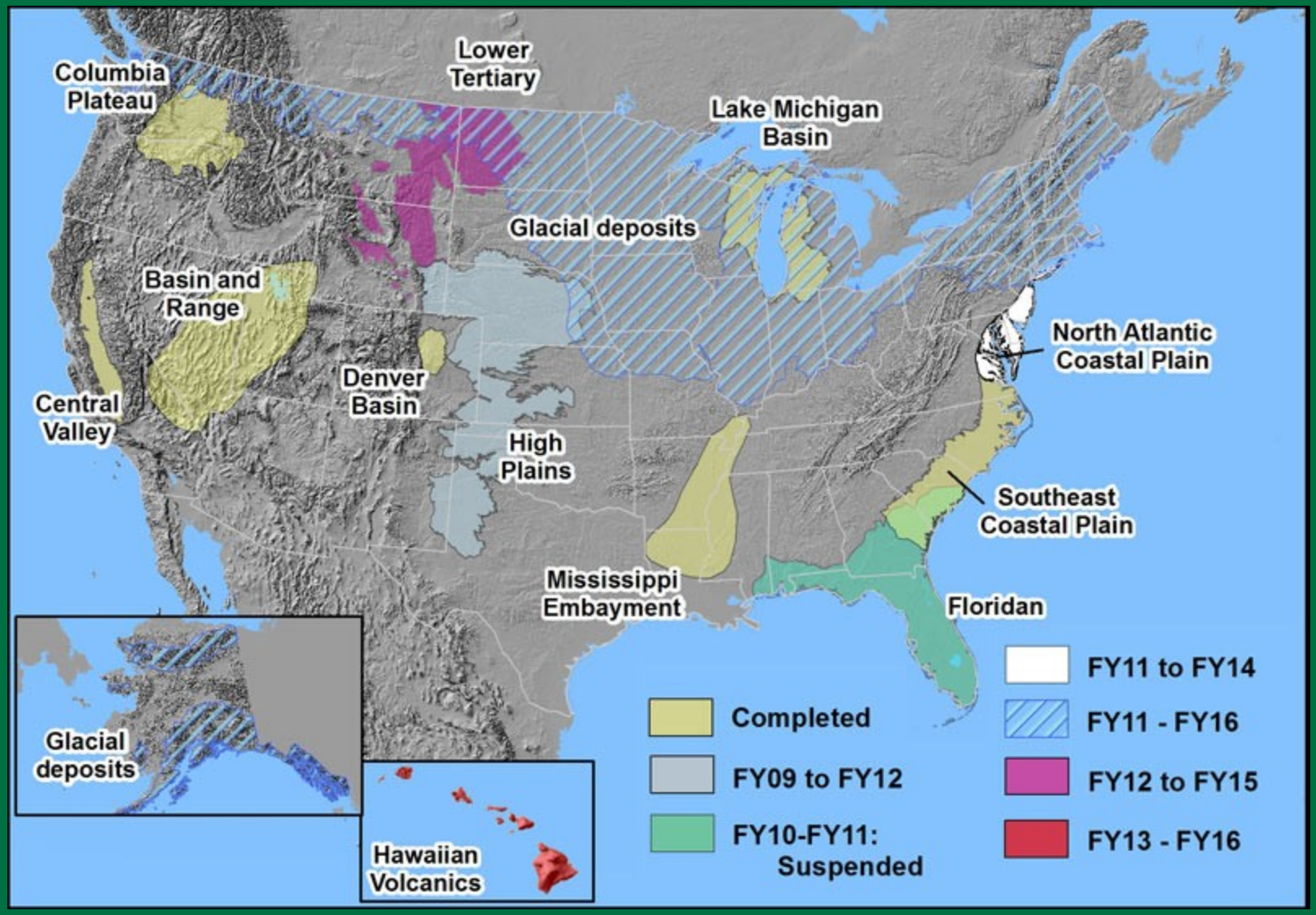


USGS

USGS Groundwater Resources Program regional groundwater availability studies (http://water.usgs.gov/ogw/gwrp/activities/regional.html)

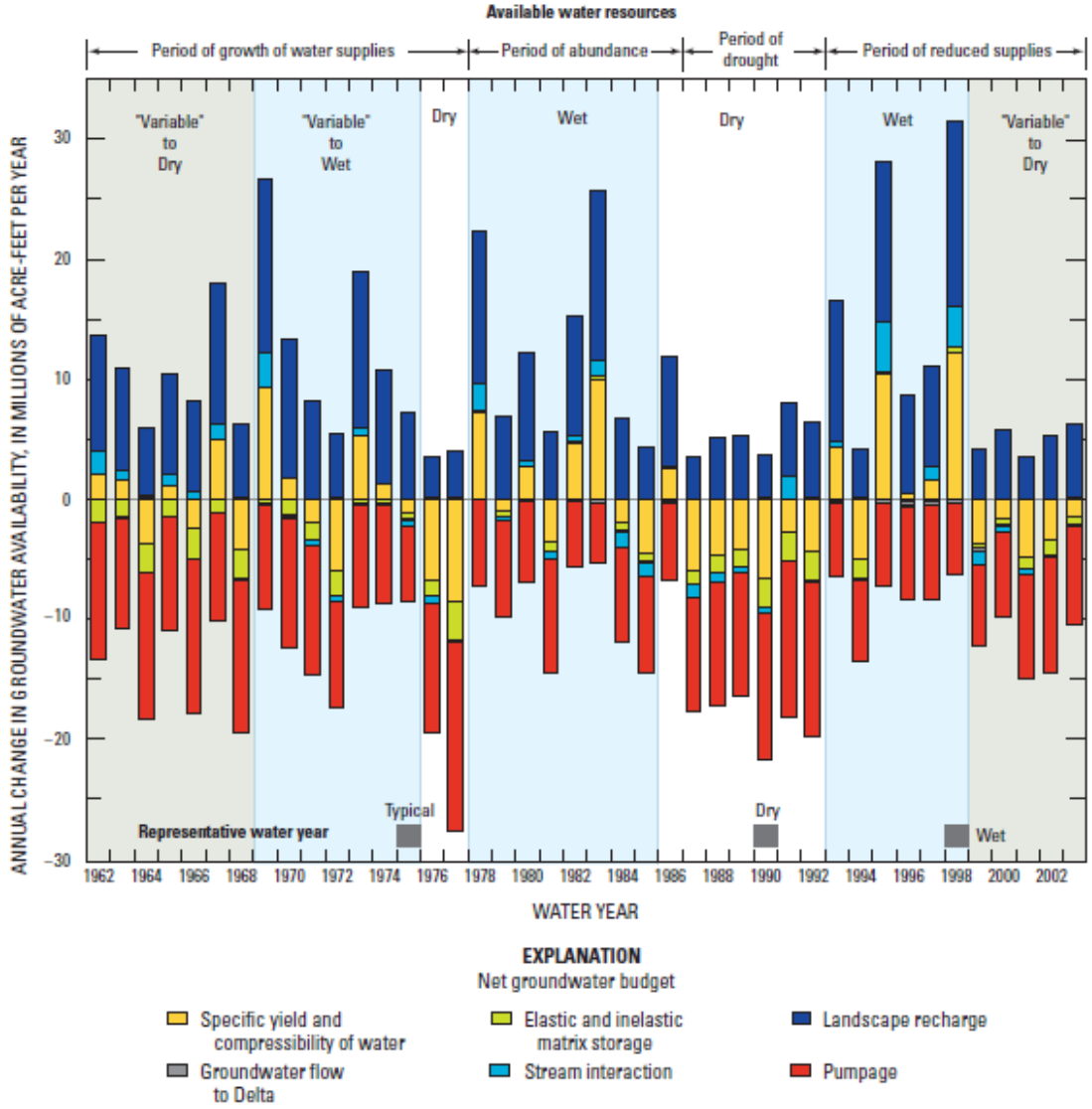
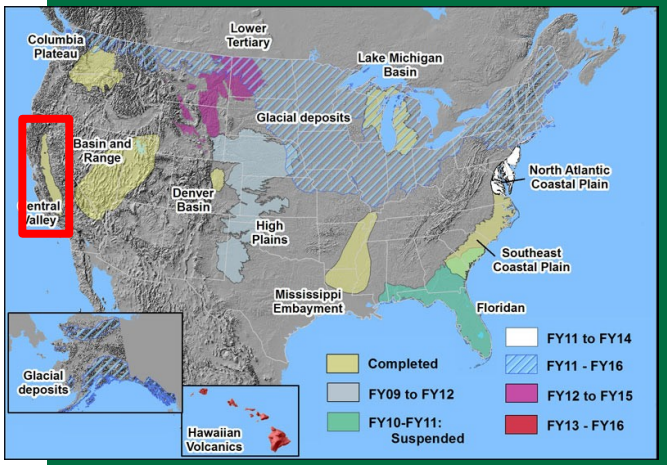


Figure B7. Simulated groundwater budget changes between water years 1962 and 2003 for the Central Valley, California.



USGS

Faunt, C.C. ed., 2009, Groundwater Availability of the Central Valley Aquifer: U.S. Geological Survey Professional Paper 1766, 225 p. Available at http://pubs.usgs.gov/pp/1766/.

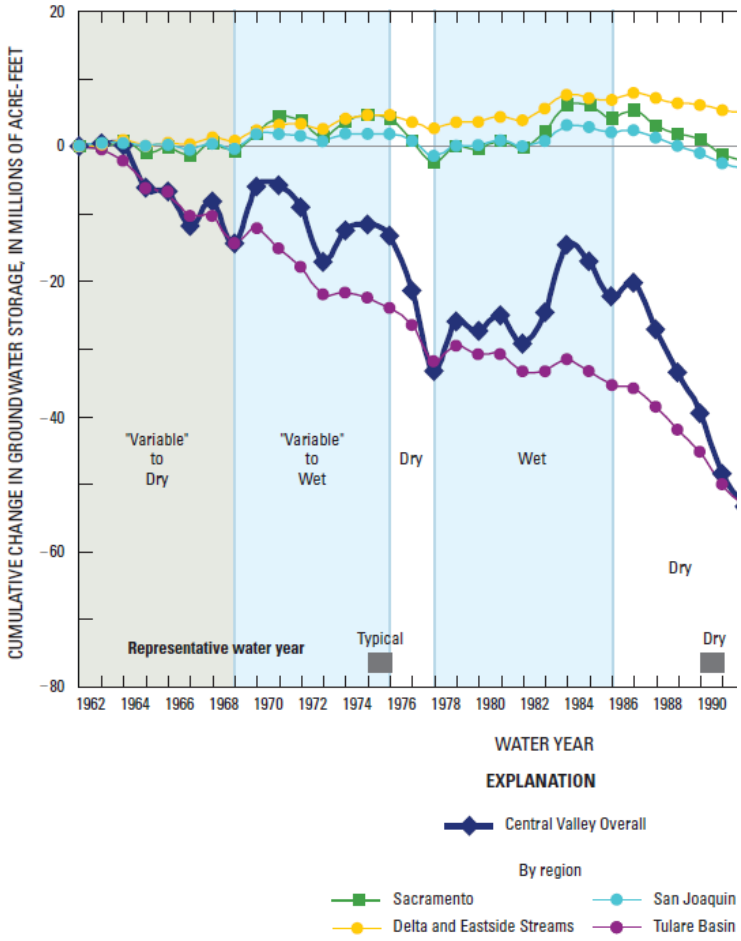


Figure B9. Simulated cumulative annual changes in aquifer-system storage between water y
California.

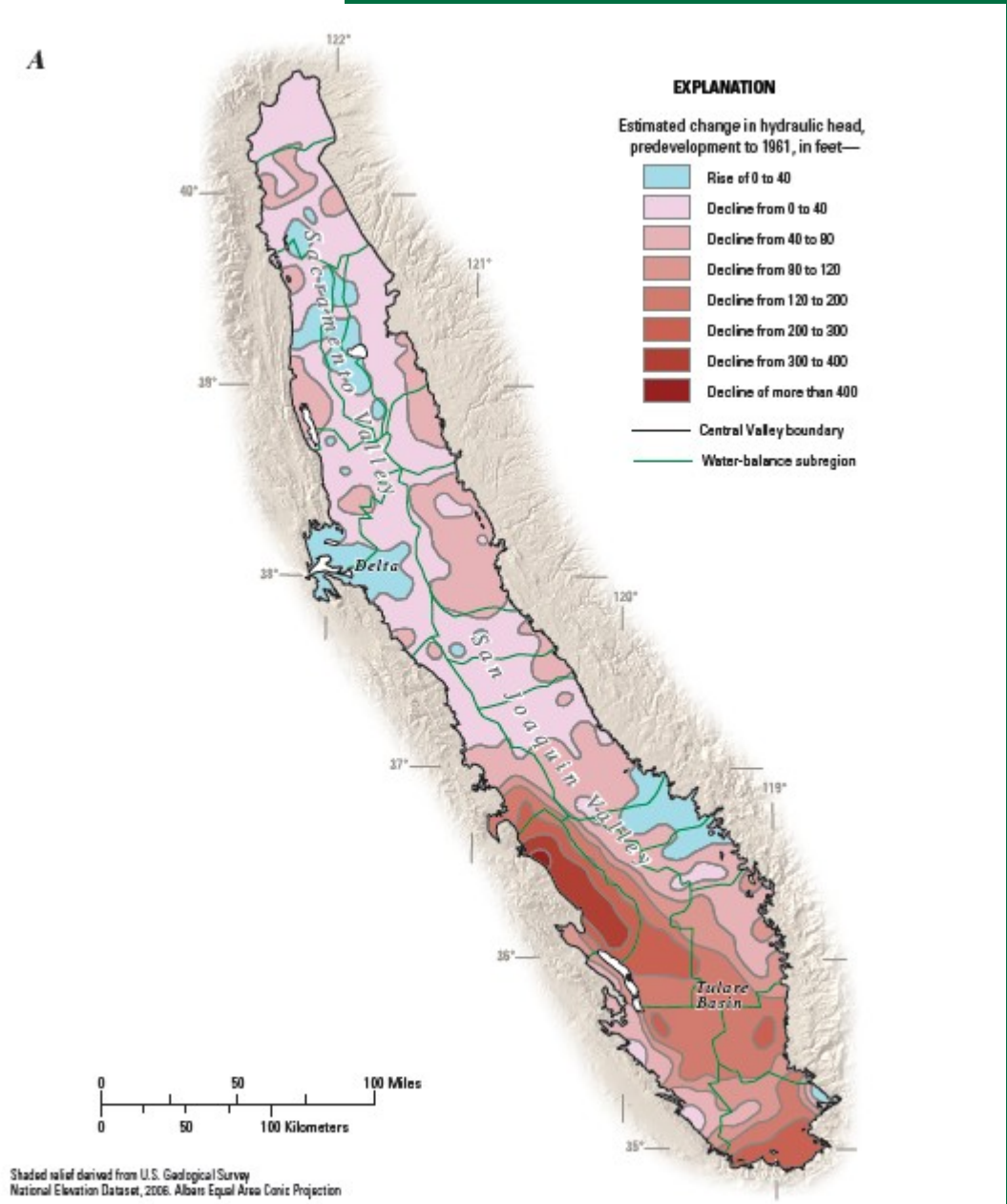
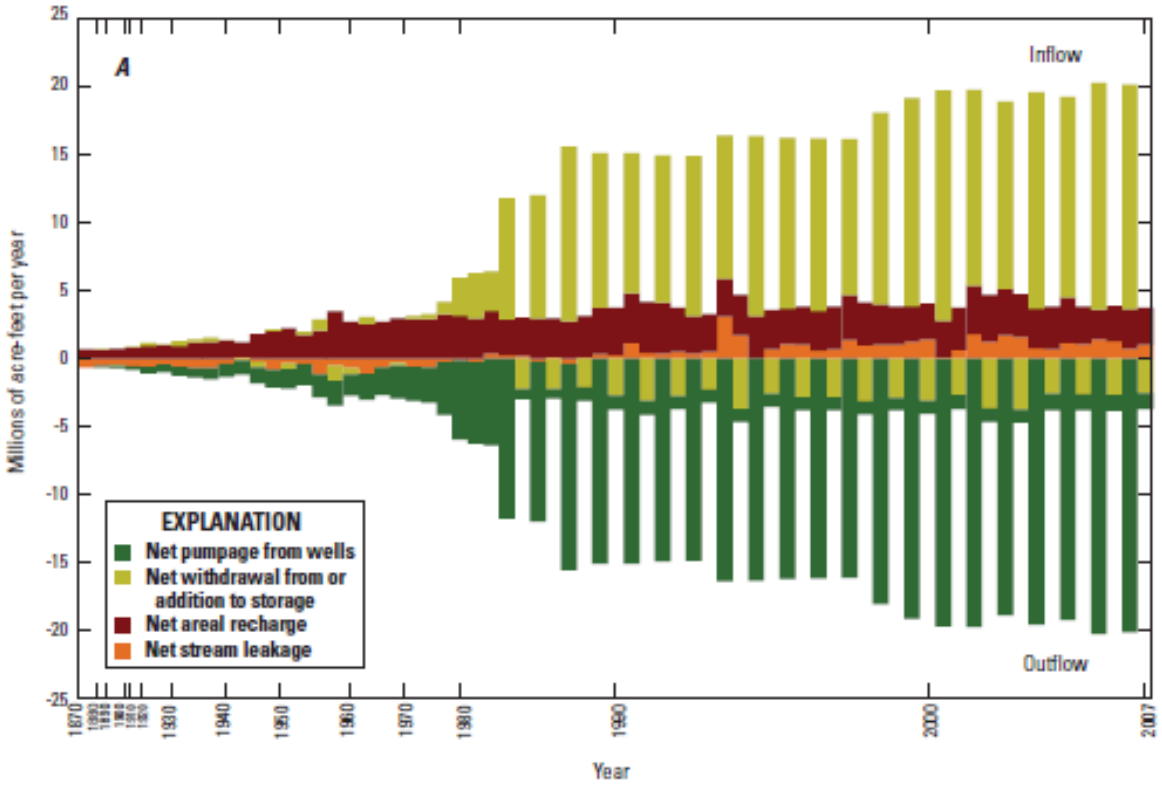
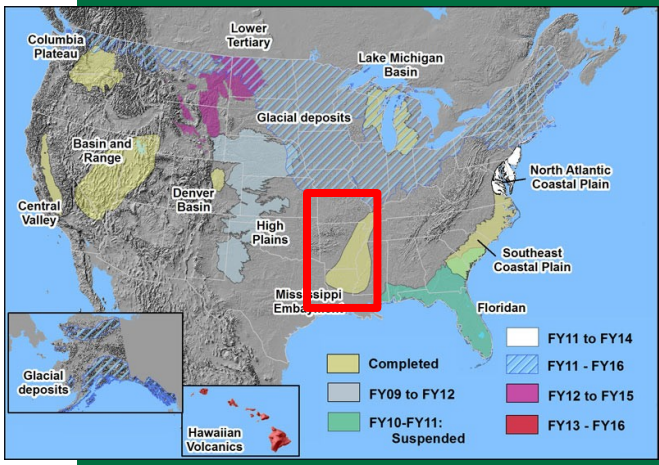


Figure B4. *A*, Estimated change in hydraulic head in upper part of the aquifer system from 1860 to 1961 (modified from Williamson and others, 1989; Bertoldi and others, 1991). *B*, Simulated change in hydraulic head in lower part of the aquifer system from spring 1962 to spring 2003.

Faunt, Chapter B, 2009.

USGS





USGS

Clark, B.R., Hart, R.M., and Gurdak, J.J., 2011, Groundwater availability of the Mississippi embayment: U.S. Geological Survey Professional Paper 1785, 62 p.

Clark and others, 2011

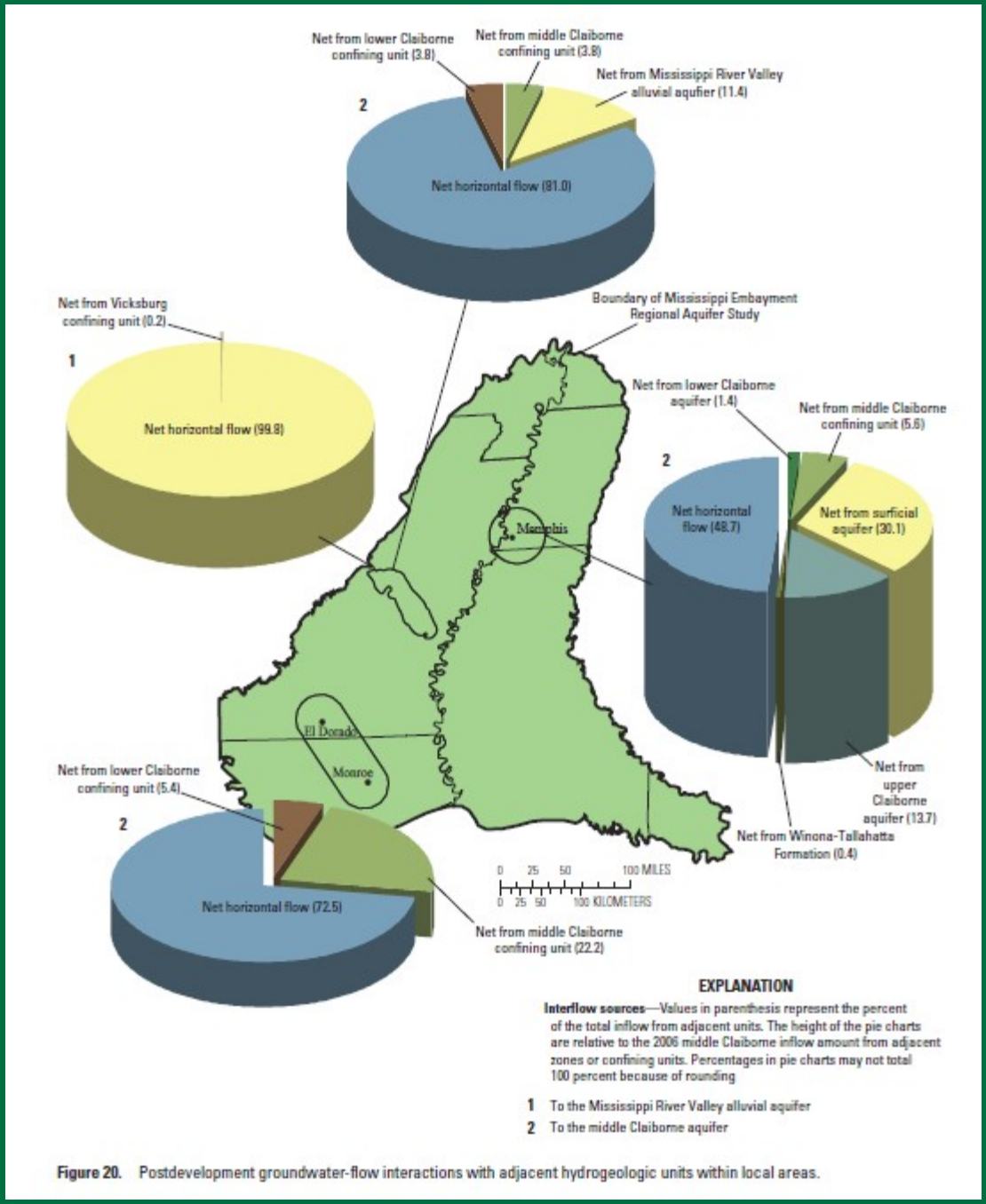


Figure 20. Postdevelopment groundwater-flow interactions with adjacent hydrogeologic units within local areas.

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Drawdown in Mississippi River Alluvial Aquifer in 2007 from Clark and others, 2011

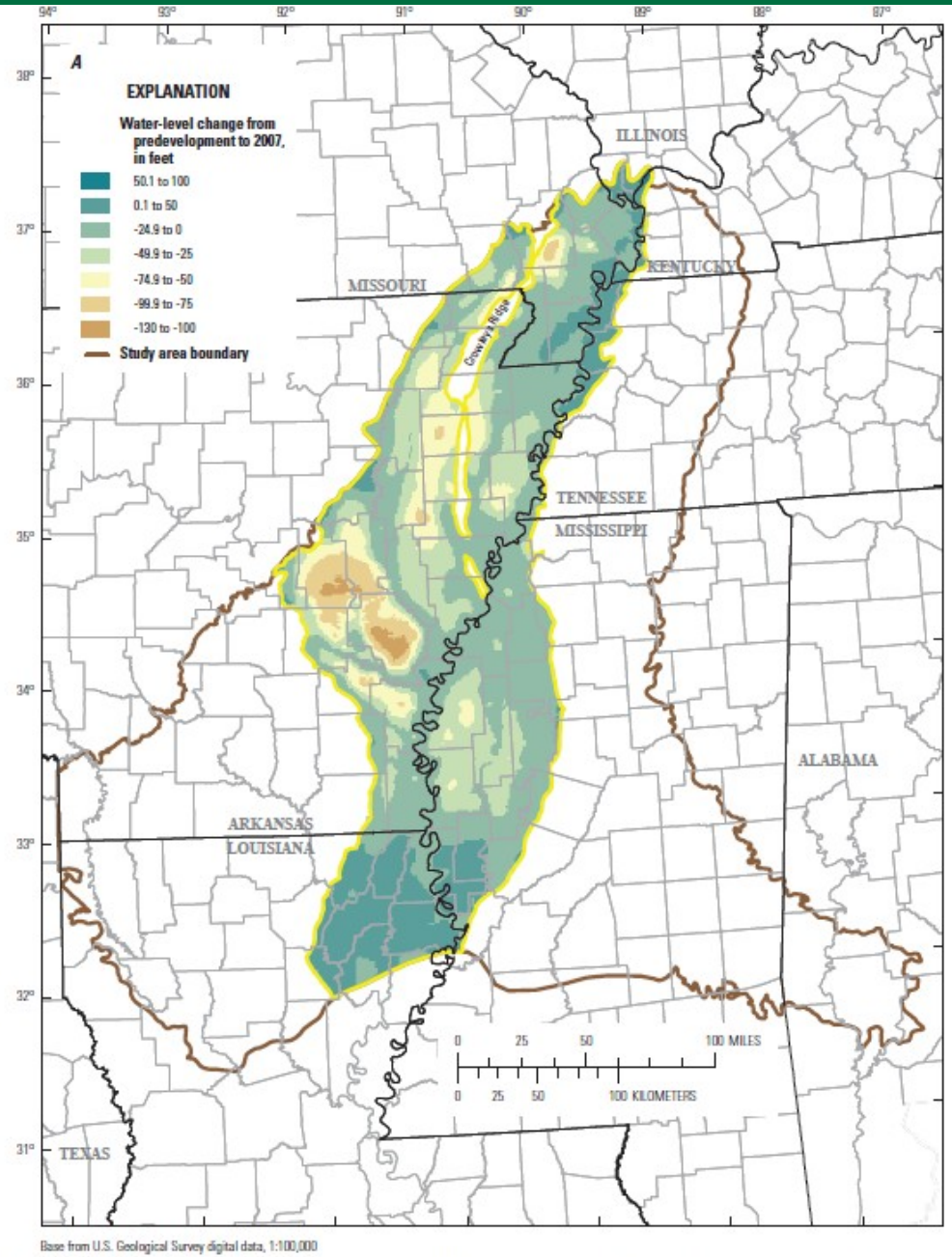

Figure 14. Water-level change from predevelopment to 2007 in the *A*, Mississippi River Valley alluvial aquifer and *B*, the middle Claiborne aquifer.

Water Availability and Use Great Lakes Basin Pilot

- Funded in 2005, five-year project
- Groundwater, surface water, water use
- Develop methods for national program
- Respond to Great Lakes issues including development of the Great Lakes Compact

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Image from NOAA, Great Lakes Environmental Research Laboratory, AVHRR satellite imagery, 1995

Overview

- Great Lakes water availability characterized by regional abundance with potential for local shortages.

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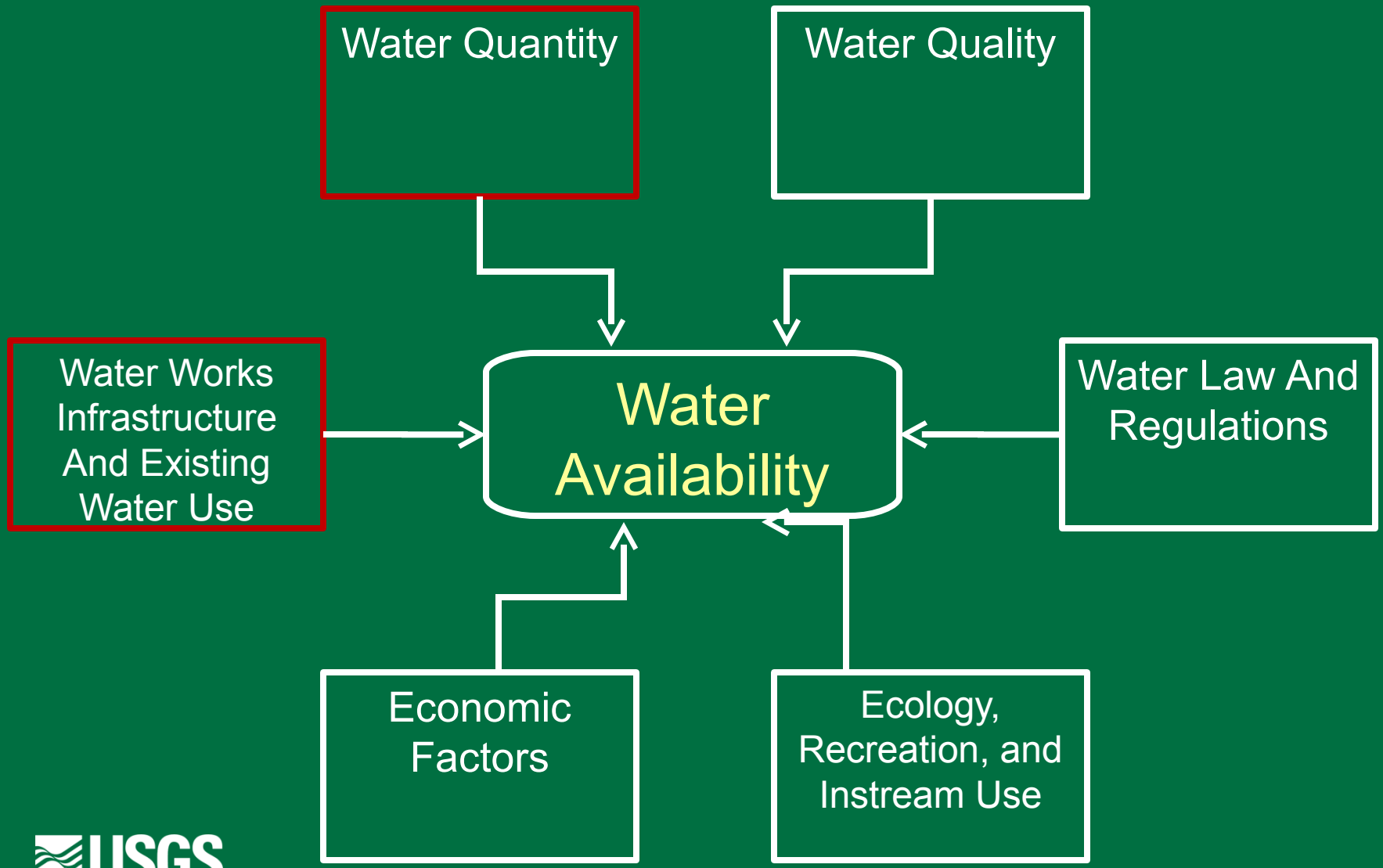
Many Factors Affect Water Availability



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Surface Water Analysis

- What are current streamflows and how have they changed over time?
- How will new withdrawals affect streamflow?

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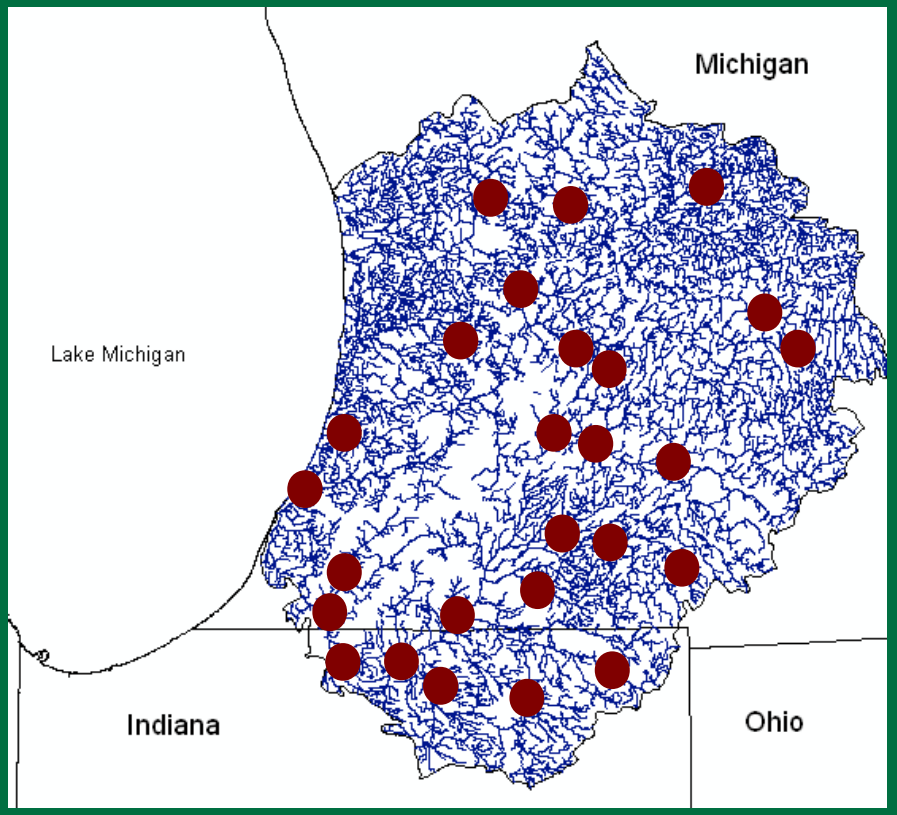
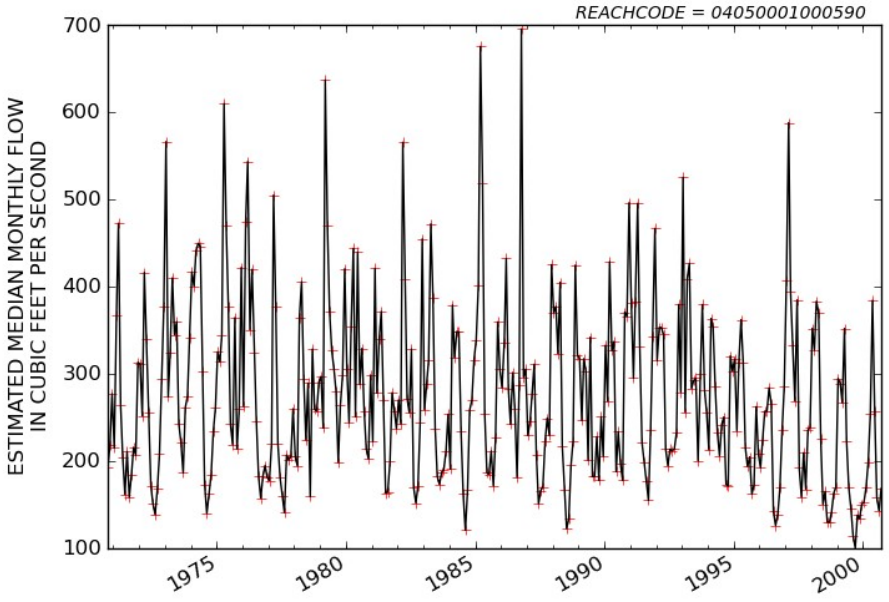
Surface Water Analysis

- Streamgage data are not available everywhere
- Developed a new method to:
  - Estimate streamflow for any stream
  - Integrate water use and streamflow data
  - Account for trends in time



USGS



Result of the new method

Streamgage data

Michigan

Lake Michigan

Illinois

Indiana

Ohio

USGS

Water Use

- How much water is withdrawn and how much water is used in the Great Lakes Basin?
- How does use vary in time and space across the basin?
- Future water availability depends on groundwater, surface water, and current water use

USGS

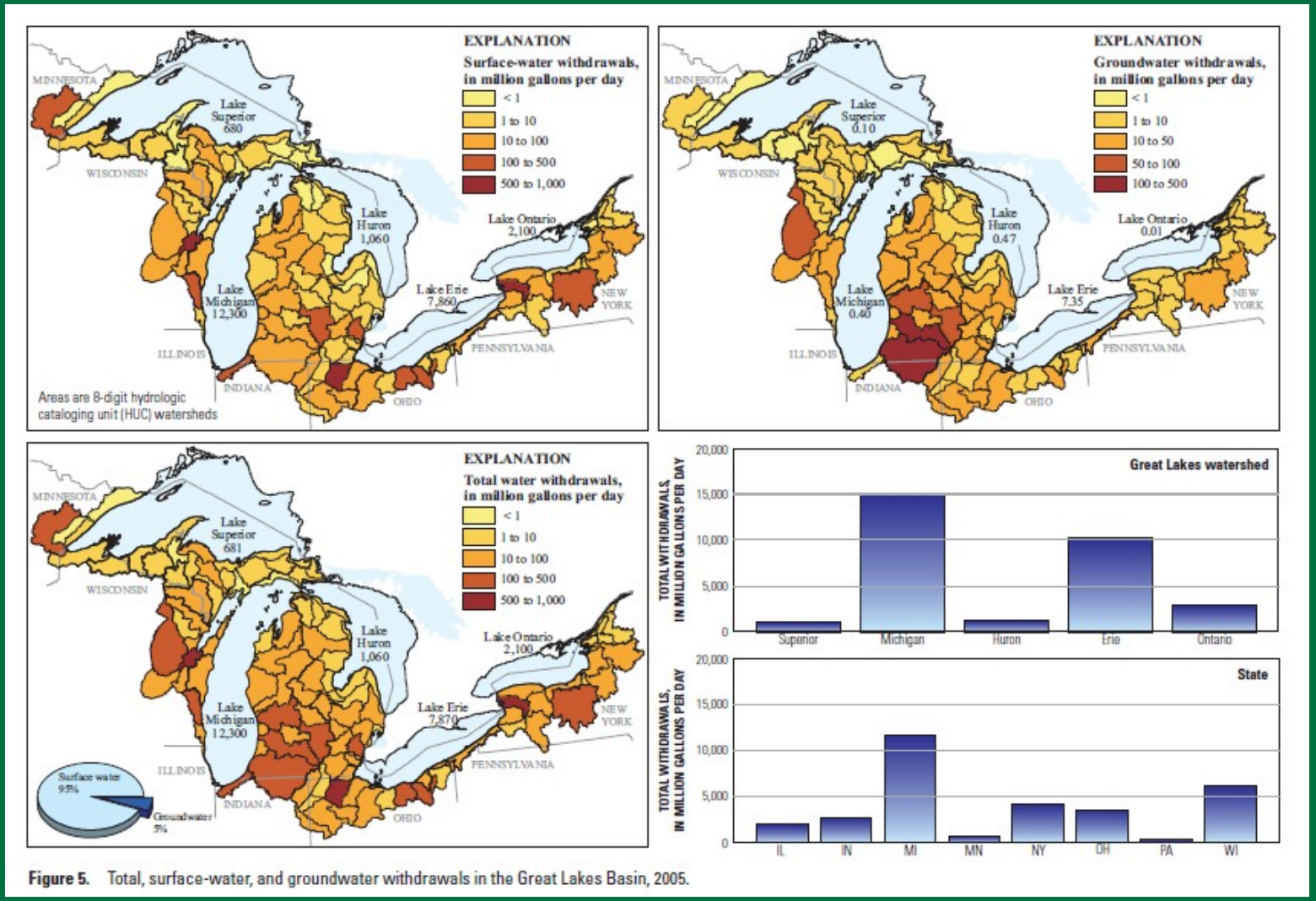
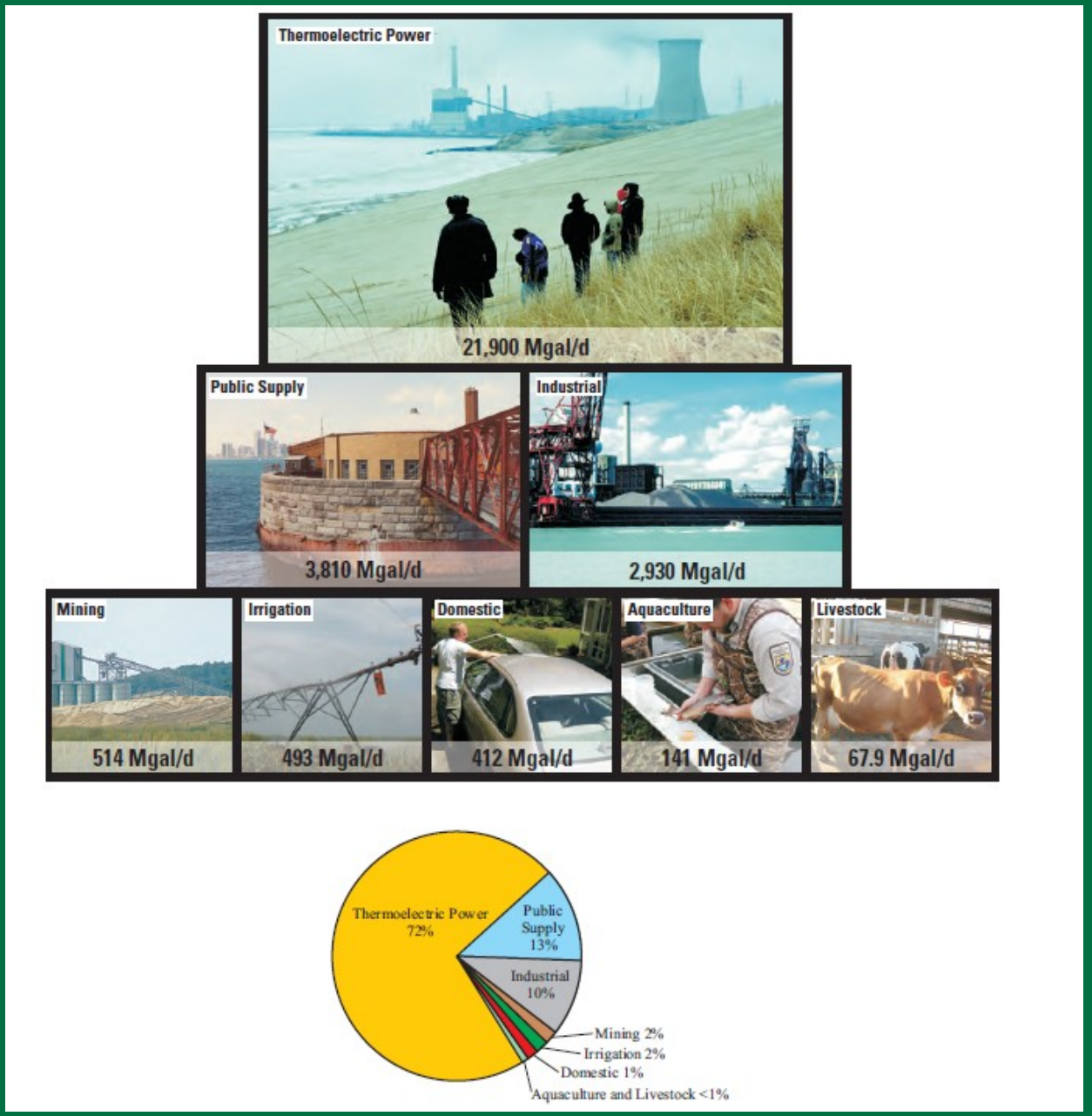


Figure 5. Total, surface-water, and groundwater withdrawals in the Great Lakes Basin, 2005.

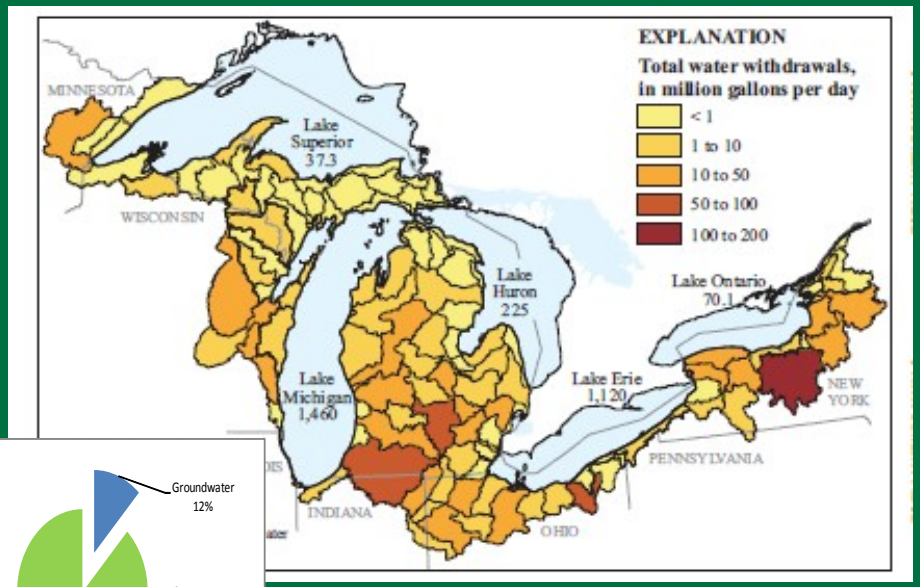
USGS

Mills, P.C., and Sharpe, J.B., 2010, Estimated withdrawals and other elements of water use in the Great Lakes Basin of the United States in 2005: U.S. Geological Survey Scientific Investigations Report 2010–5031, 95 p.

Mills, P.C., and Sharpe, J.B., 2010.



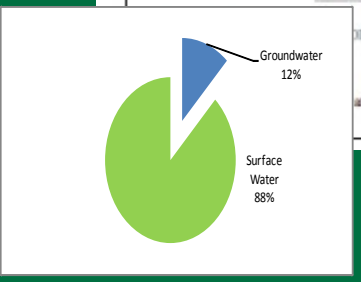
USGS



Public-supply withdrawals

3,800 million gallons per day

17.7 million people

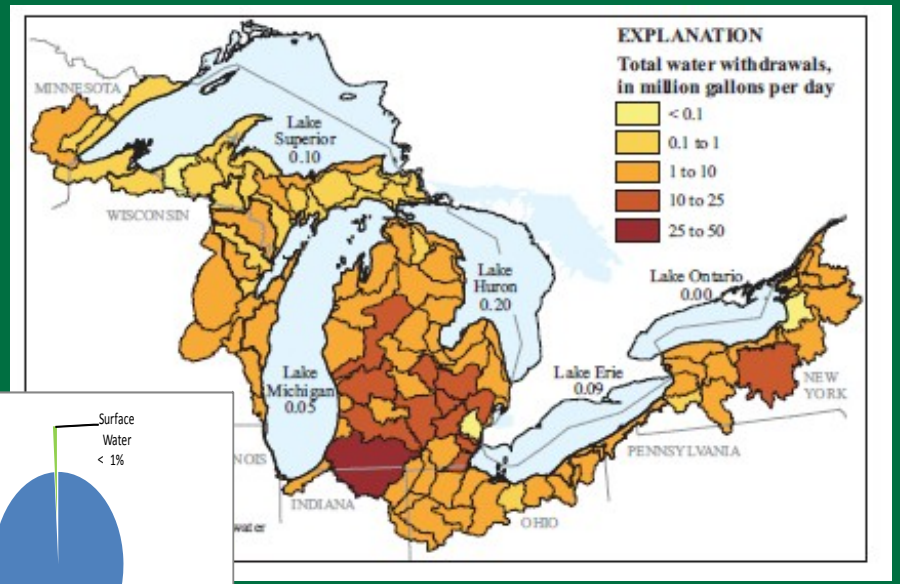


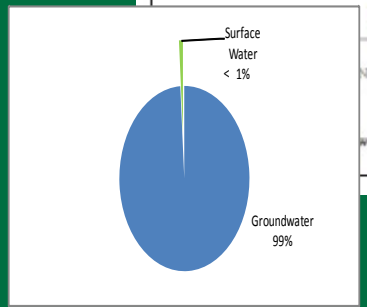
Mills, P.C., and Sharpe, J.B., 2010.

Self-supply domestic withdrawals

410 million gallons per day

5.2 million people





USGS

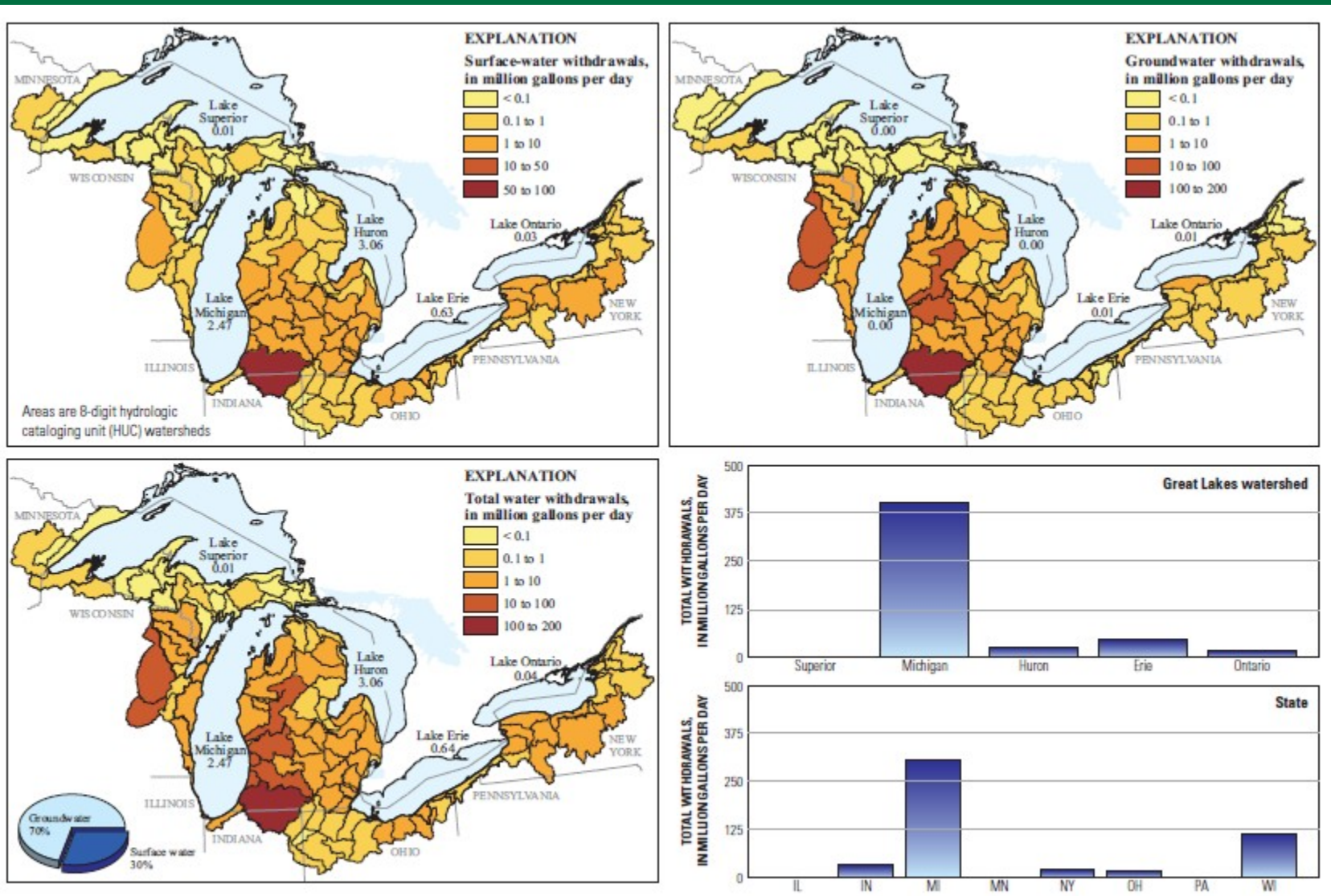


Figure 13. Irrigation withdrawals by source, watershed, and state in the Great Lakes Basin, 2005.

USGS

Mills, P.C., and Sharpe, J.B., 2010.

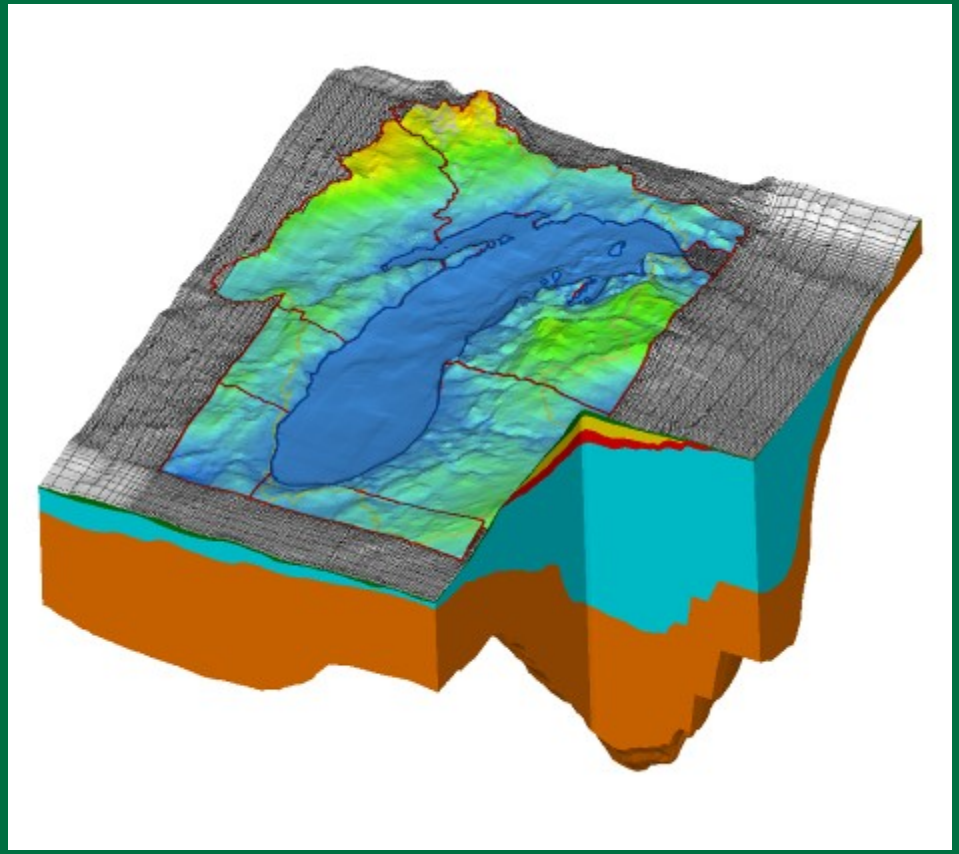
Groundwater availability

- How much groundwater is in storage?
- What are groundwater divides?
- How has development changed groundwater levels and availability?
- What are potential constraints limiting groundwater availability?

USGS

Groundwater flow model

- SEAWAT– density dependent MODFLOW
- 20 layers
- ~ 2 million cells
- 1864-2005 in 1 steady-state and 12 transient stress periods
- Heterogeneous properties



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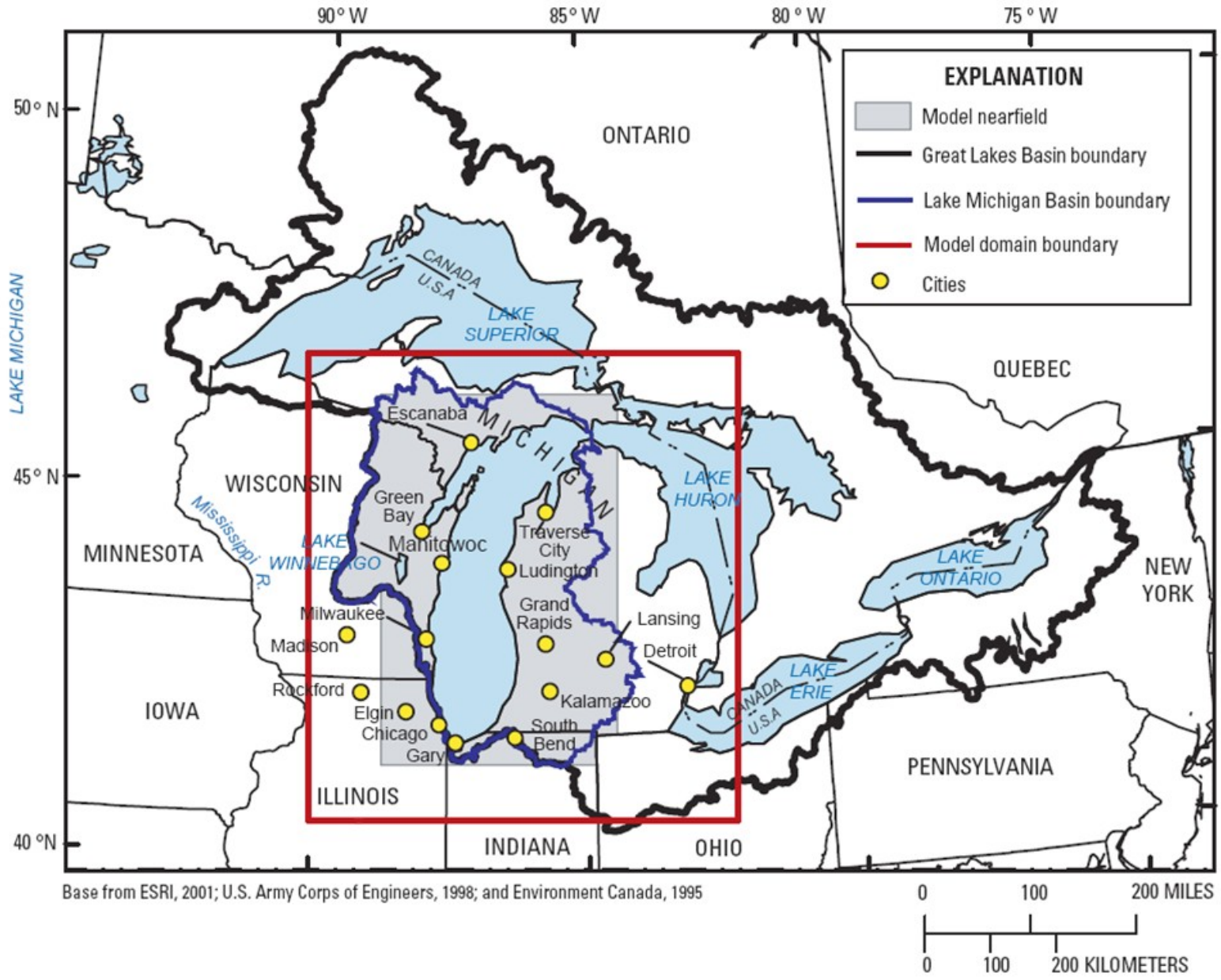
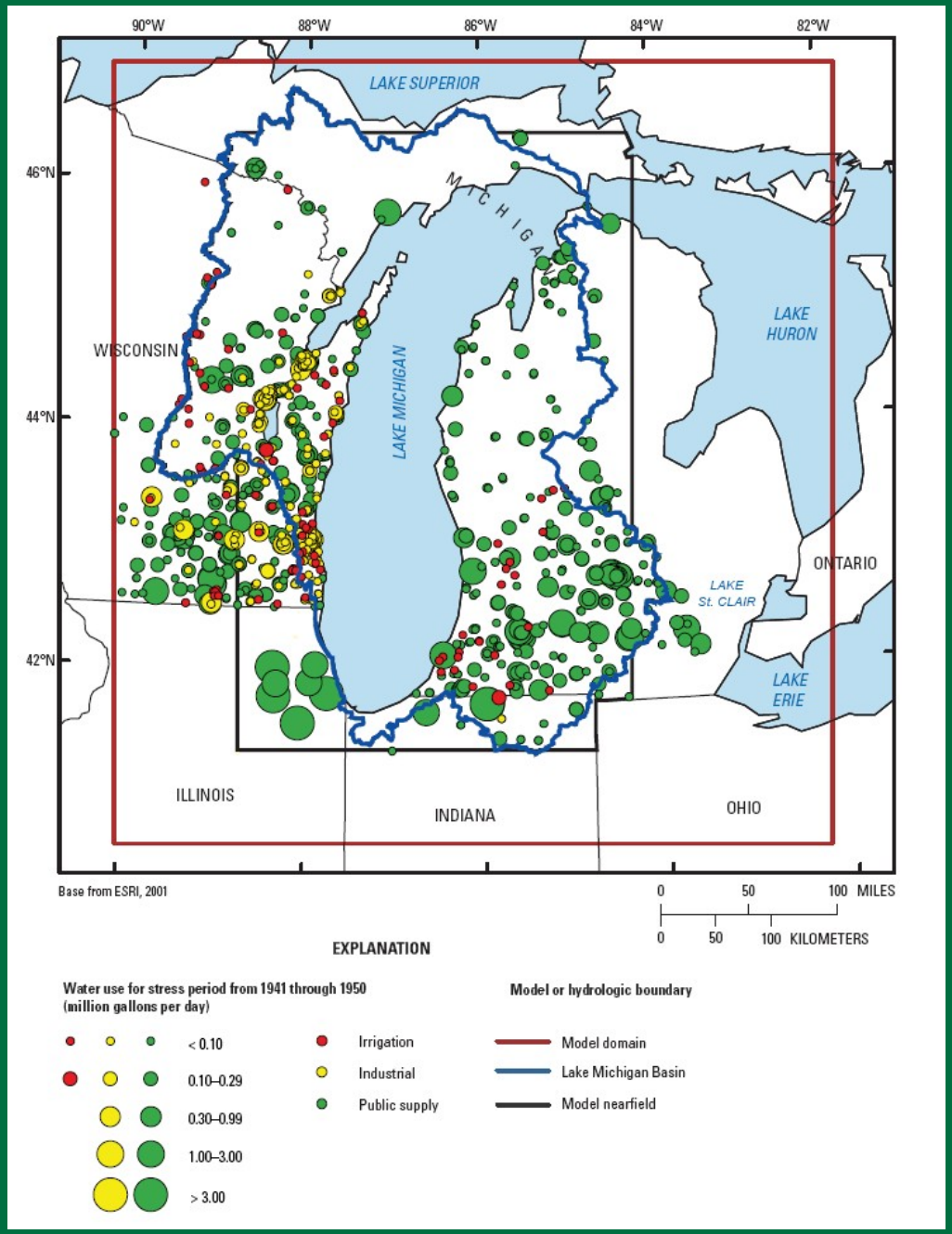

90° W
85° W
80 ° W
75 ° W
50 ° N
45 ° N
40 °N
EXPLANATION
Model nearfield
Great Lakes Basin boundary
Lake Michigan Basin boundary
Model domain boundary
Cities
ONTARIO
QUEBEC
LAKE MICHIGAN
CANADA
U.S.A
LAKE SUPERIOR
LAKE HURON
LAKE ONTARIO
LAKE ERIE
MICHIGAN
WISCONSIN
MINNESOTA
IOWA
ILLINOIS
INDIANA
OHIO
NEW YORK
PENNSYLVANIA
Mississippi R.
LAKE WINNEBAGO
Escanaba
Green Bay
Manitowoc
Traverse City
Ludington
Grand Rapids
Lansing
Detroit
Milwaukee
Madison
Rockford
Elgin
Chicago
Gary
Kalamazoo
South Bend
Base from ESRI, 2001; U.S. Army Corps of Engineers, 1998; and Environment Canada, 1995
0 100 200 MILES
0 100 200 KILOMETERS

Water use, up to 1.1 billion gallons per day;

13,300 wells total across all stress periods

(+ Milwaukee deep tunnel, 270 nodes)



1941-1950

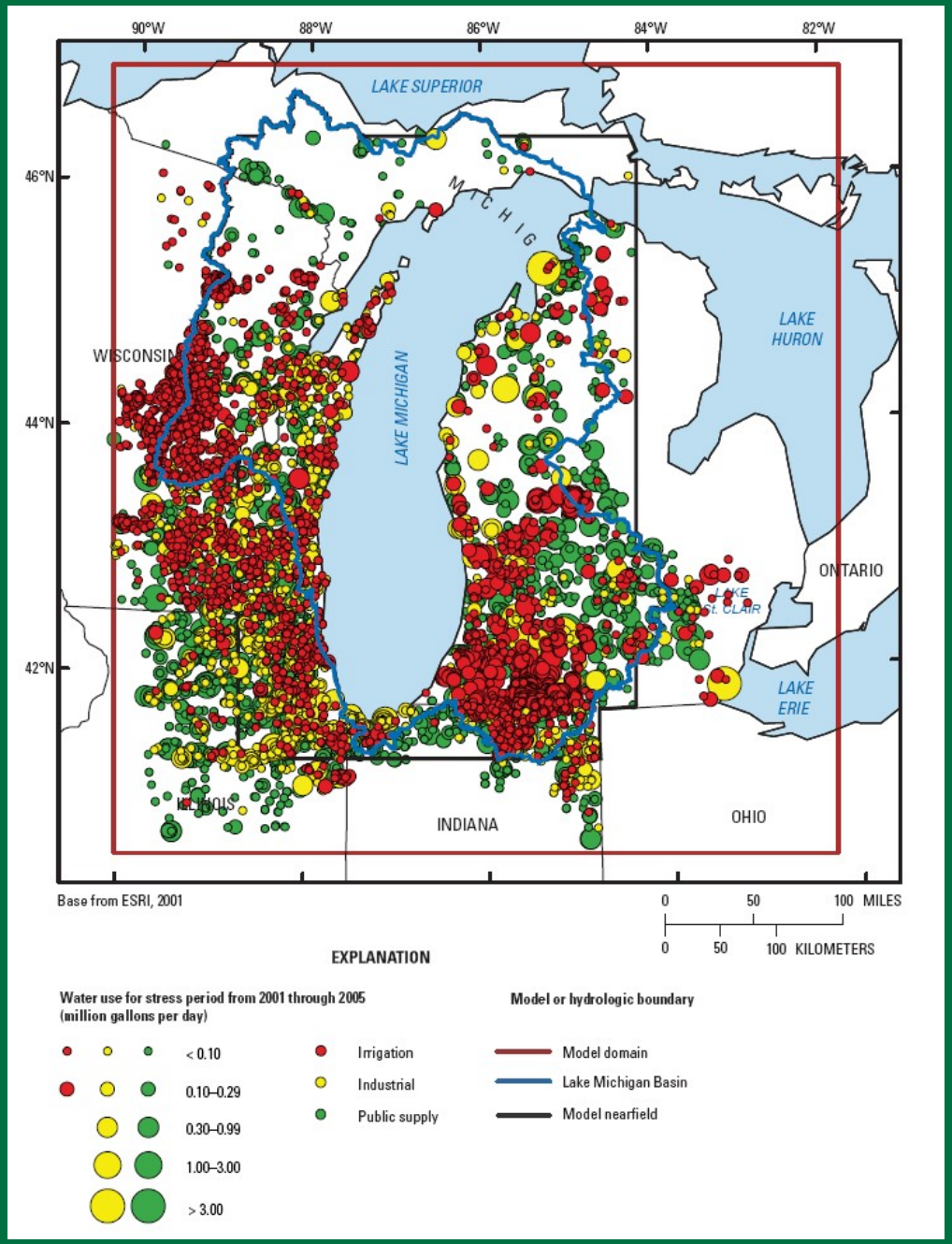
Buchwald, Luukkonen, and Rachol, USGS

USGS

Water use, up to 1.1 billion gallons per day;

13,300 wells total across all stress periods

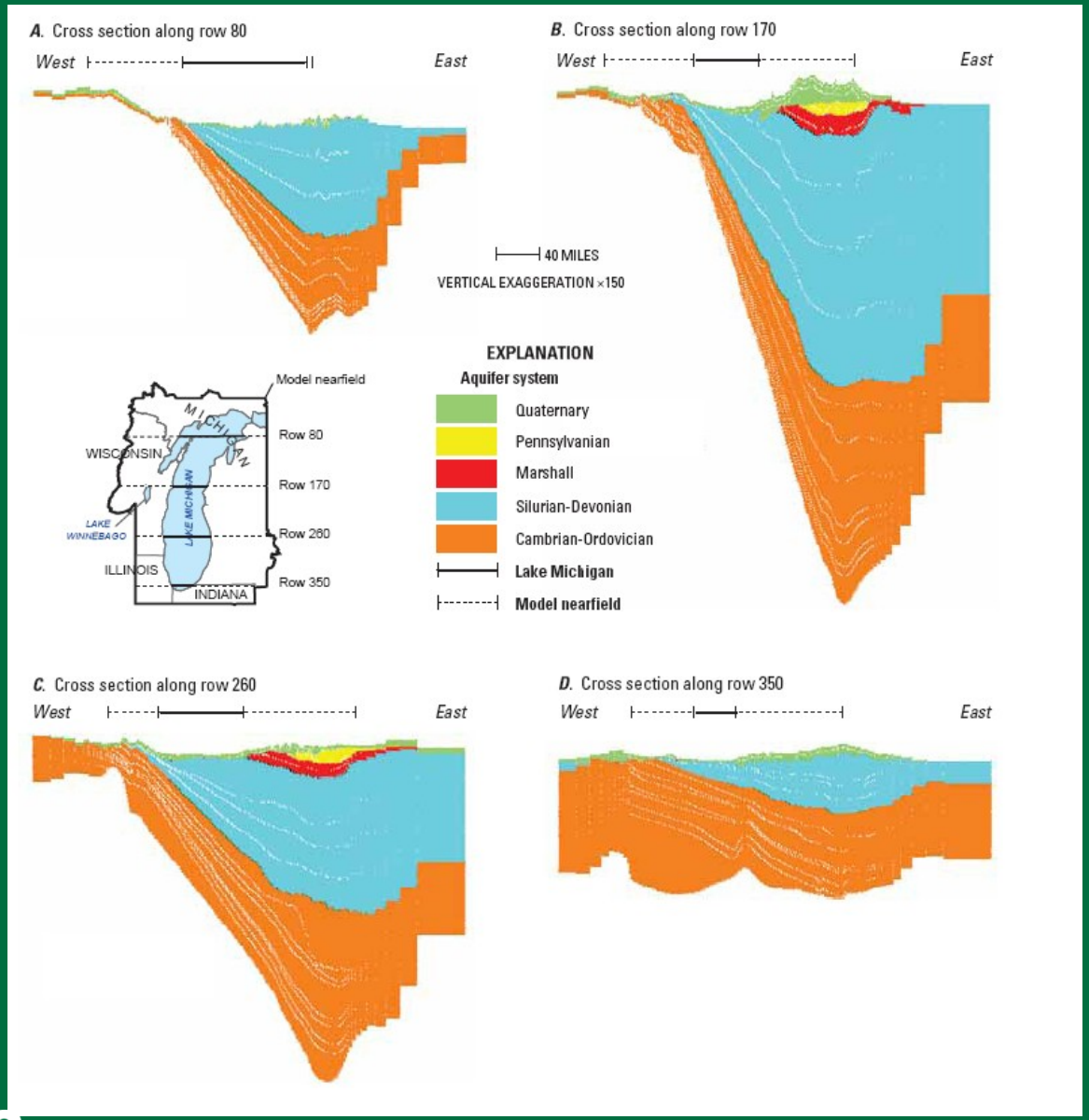
(+ Milwaukee deep tunnel, 270 nodes)



2001-2005

Buchwald, Luukkonen, and Rachol, USGS

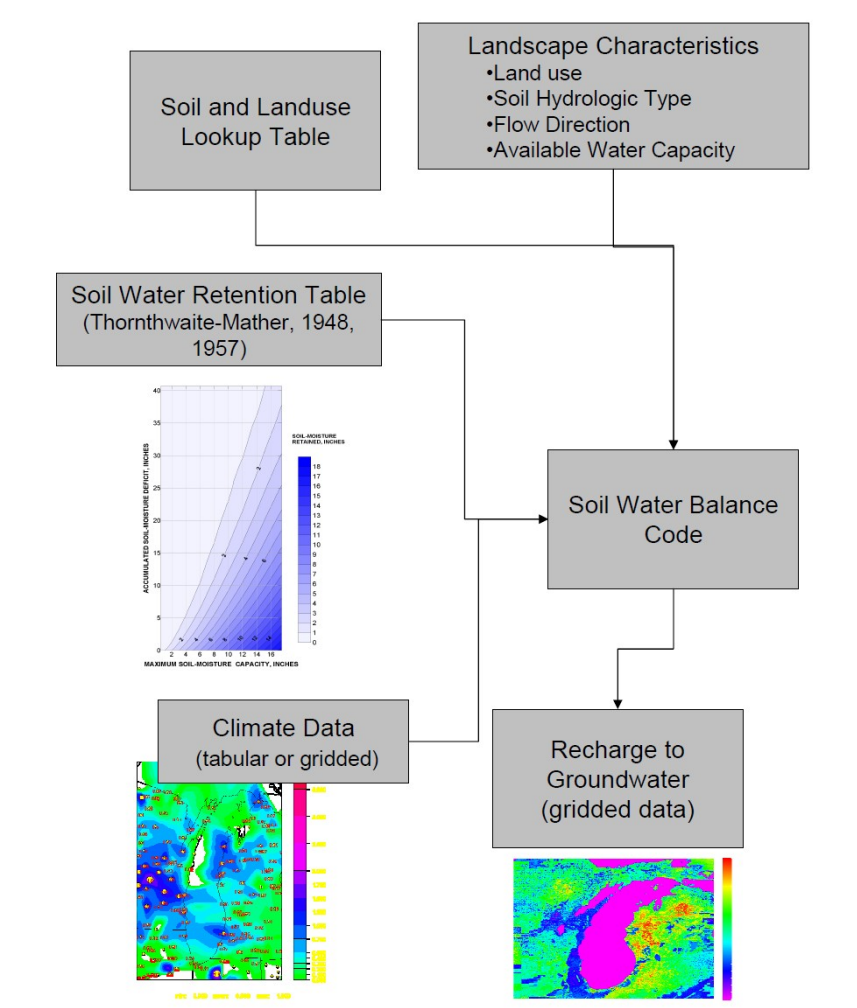
USGS

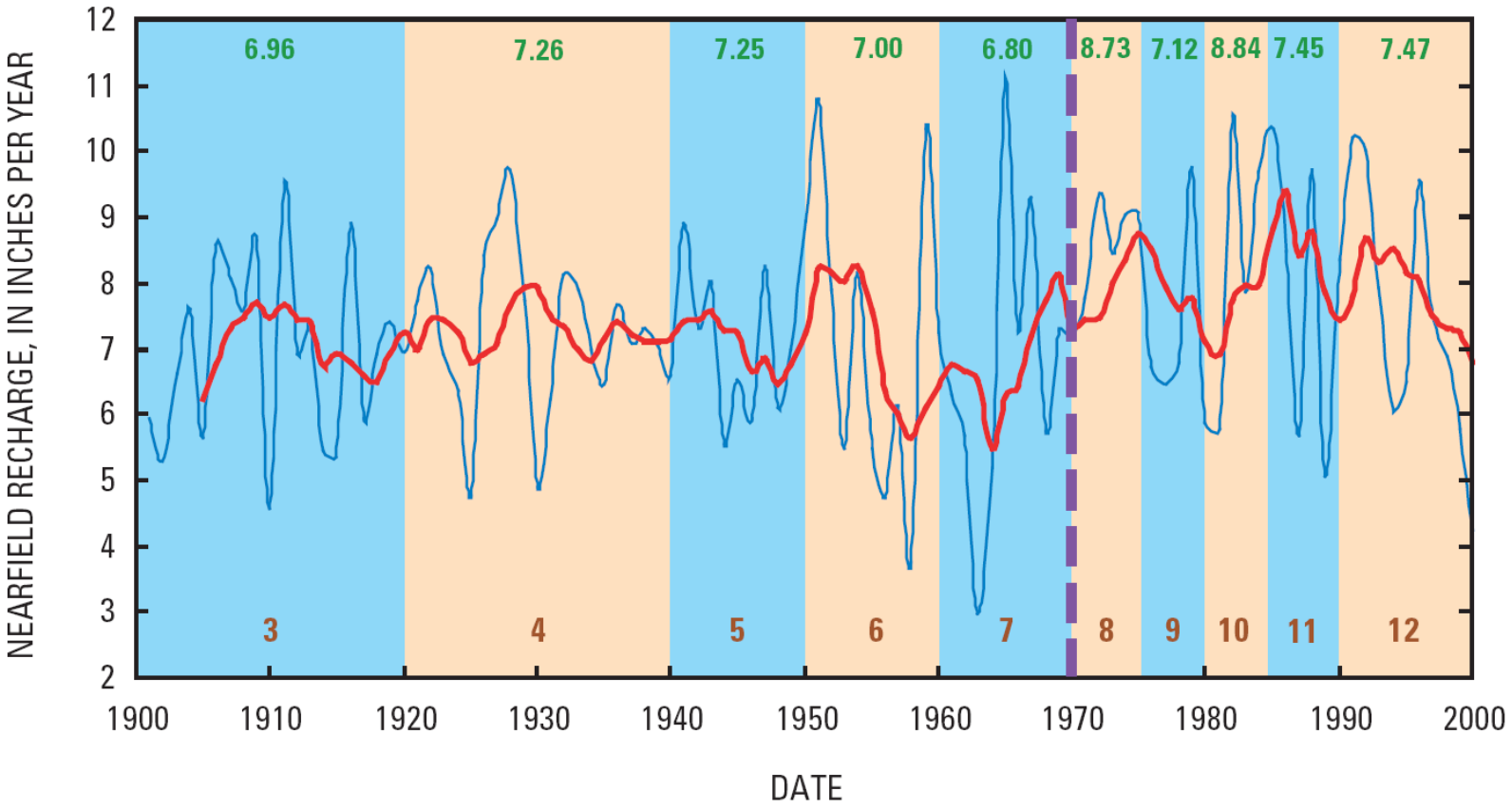

A. Cross section along row 80
West
East
B. Cross section along row 170
West
East
40 MILES
VERTICAL EXAGGERATION ×150
EXPLANATION
Aquifer system
Quaternary
Pennsylvanian
Marshall
Silurian-Devonian
Cambrian-Ordovician
Lake Michigan
Model nearfield
Model nearfield
Row 80
Row 170
Row 260
Row 350
WISCONSIN
MICHIGAN
LAKE MICHIGAN
LAKE WINNEBAGO
ILLINOIS
INDIANA
C. Cross section along row 260
West
East
D. Cross section along row 350
West
East

Recharge

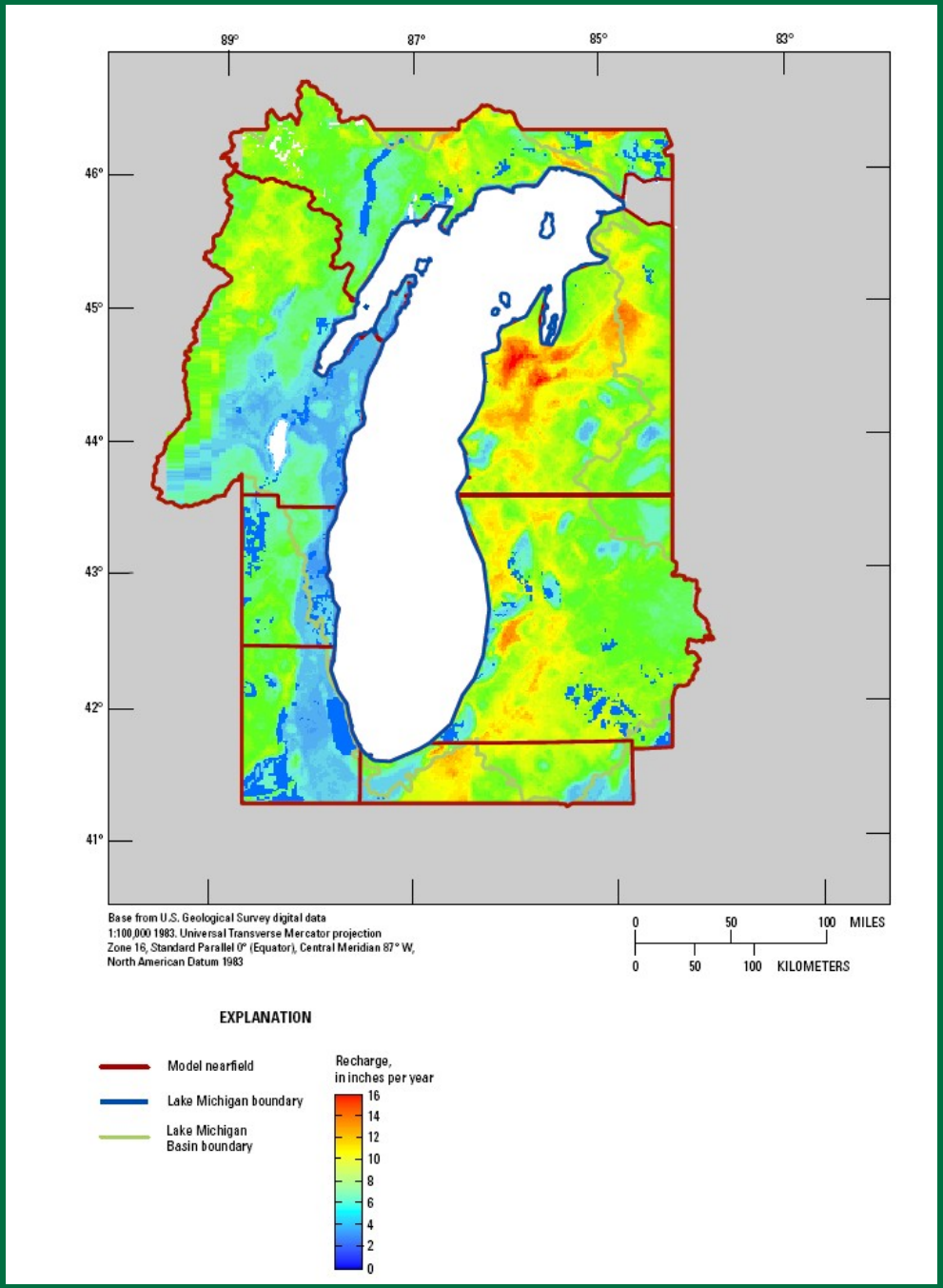
Westenbroek, S.M., Kelson, V.A., Dripps, W.R., Hunt, R.J., and Bradbury,K.R., 2009, SWB—A modified Thornthwaite-Mather Soil-Water Balance code for estimating ground-water recharge: U.S. Geological Survey Techniques and Methods 6-A31, 65 p.

Calibrated to be consistent with baseflow estimates




NEARFIELD RECHARGE, IN INCHES PER YEAR
12
11
10
9
8
7
6
5
4
3
2
6.96
7.26
7.25
7.00
6.80
8.73
7.12
8.84
7.45
7.47
3
4
5
6
7
8
9
10
11
12
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
DATE

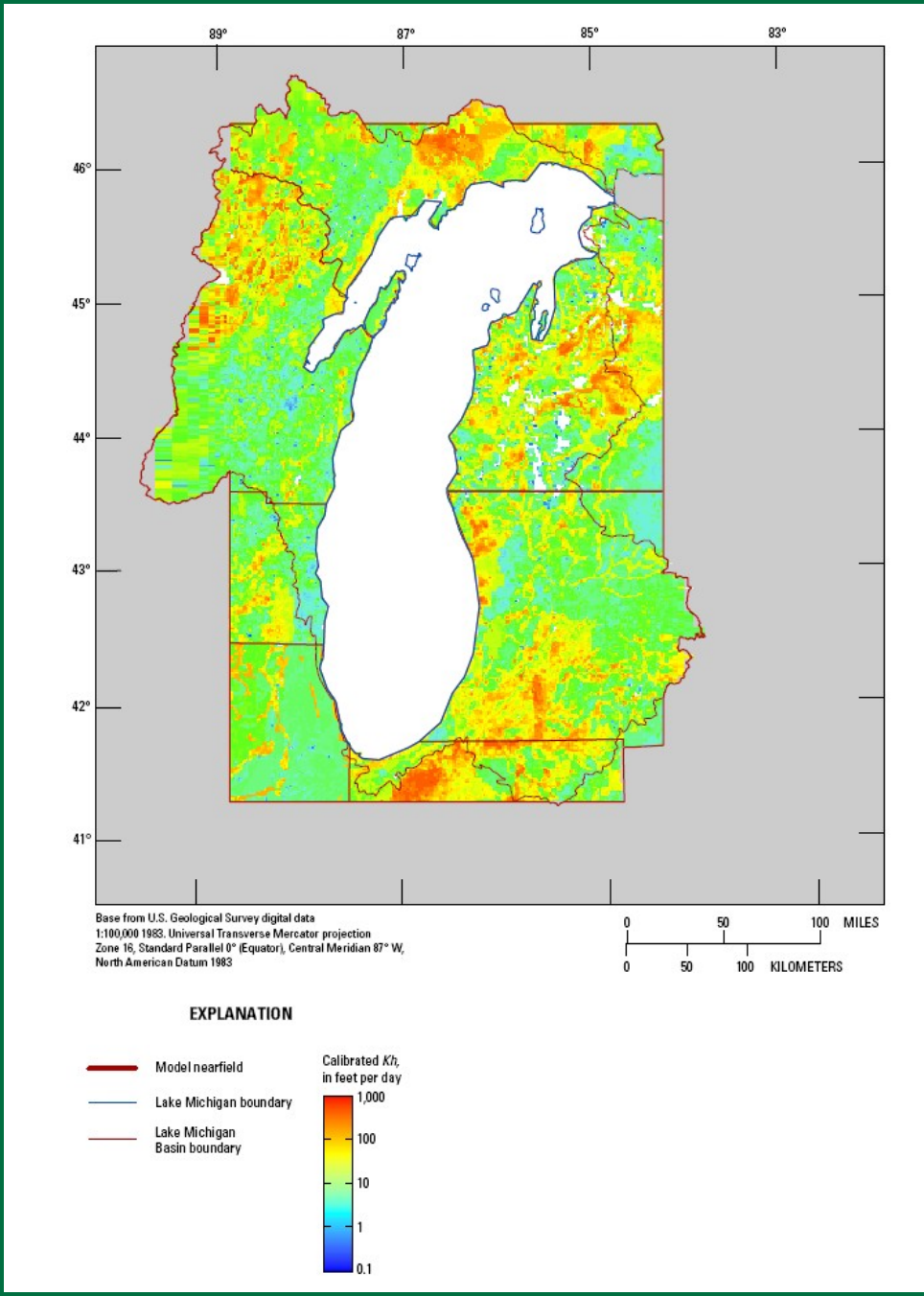
USGS


89°
87°
85°
83°
46°
45°
44°
43°
42°
41°
Base from U.S. Geological Survey digital data
1:100,000 1983, Universal Transverse Mercator projection
Zone 16, Standard Parallel 0° (Equator), Central Meridian 87° W,
North American Datum 1983
0
50
100 MILES
0
50
100 KILOMETERS
EXPLANATION
Model nearfield
Lake Michigan boundary
Lake Michigan
Basin boundary
Recharge,
in inches per year
16
14
12
10
8
6
4
2
0

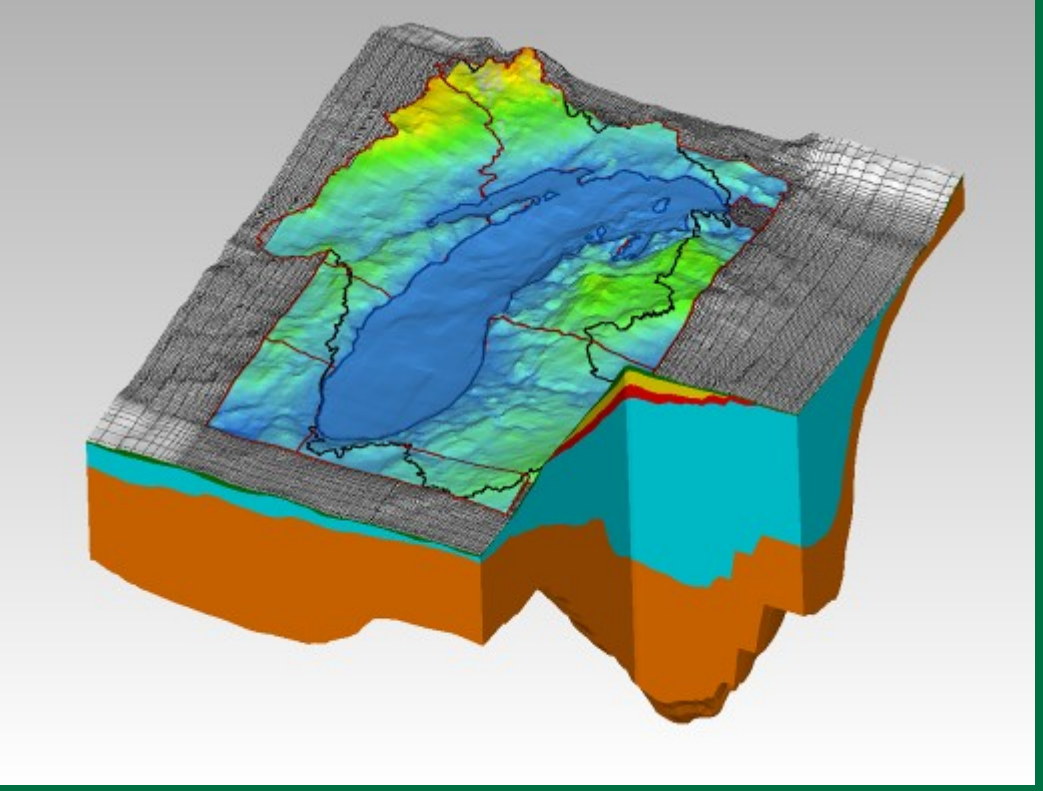
USGS

Properties of glacial deposits

- 3 model layers
- ~ 1200 ft thick
- Water well records and regional geological maps: (Arihood, USGS)



USGS



RESULTS….

- Water levels and drawdown
- Water budgets
- Sources of water to wells
- Indicators of sustainability
- Inset model

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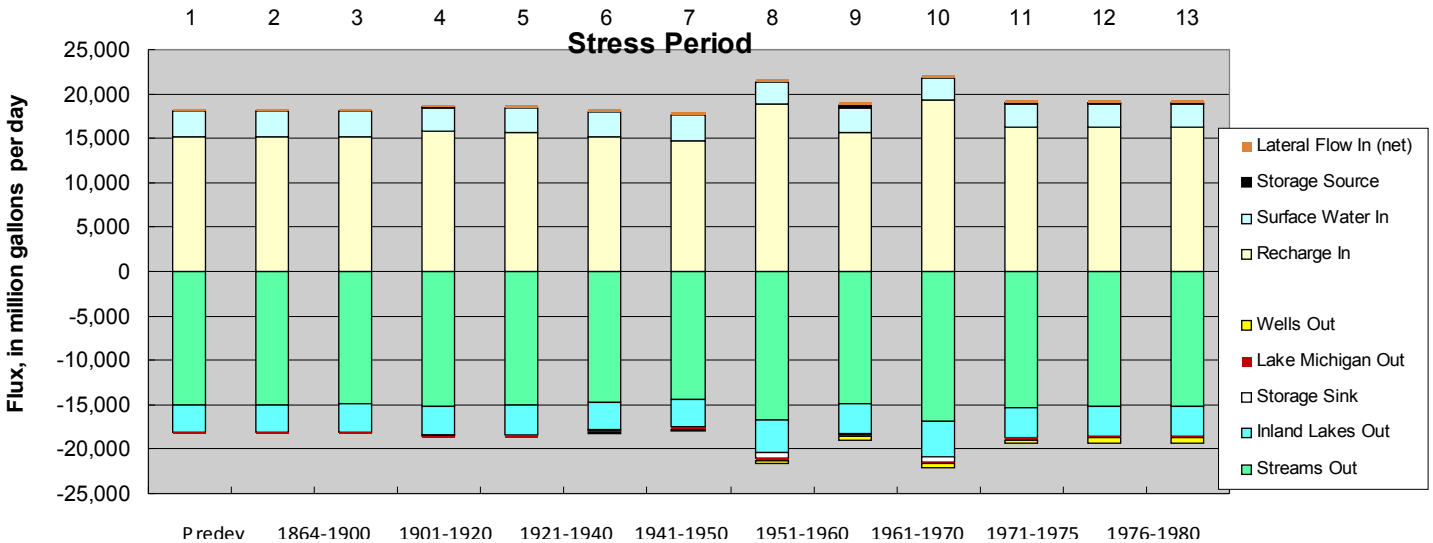
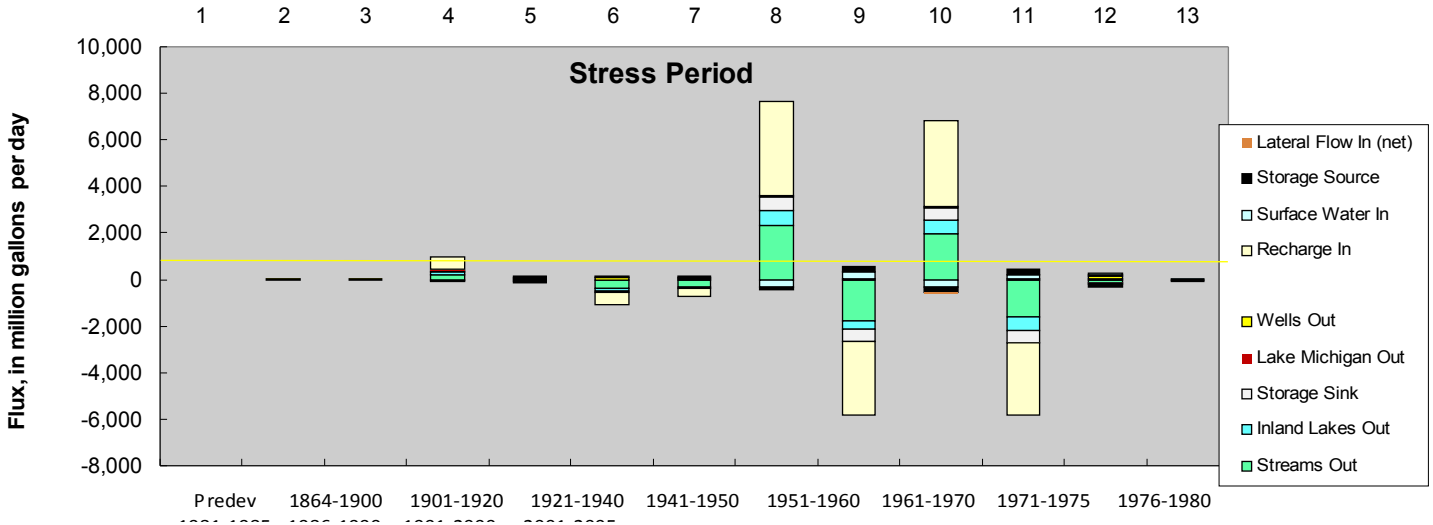
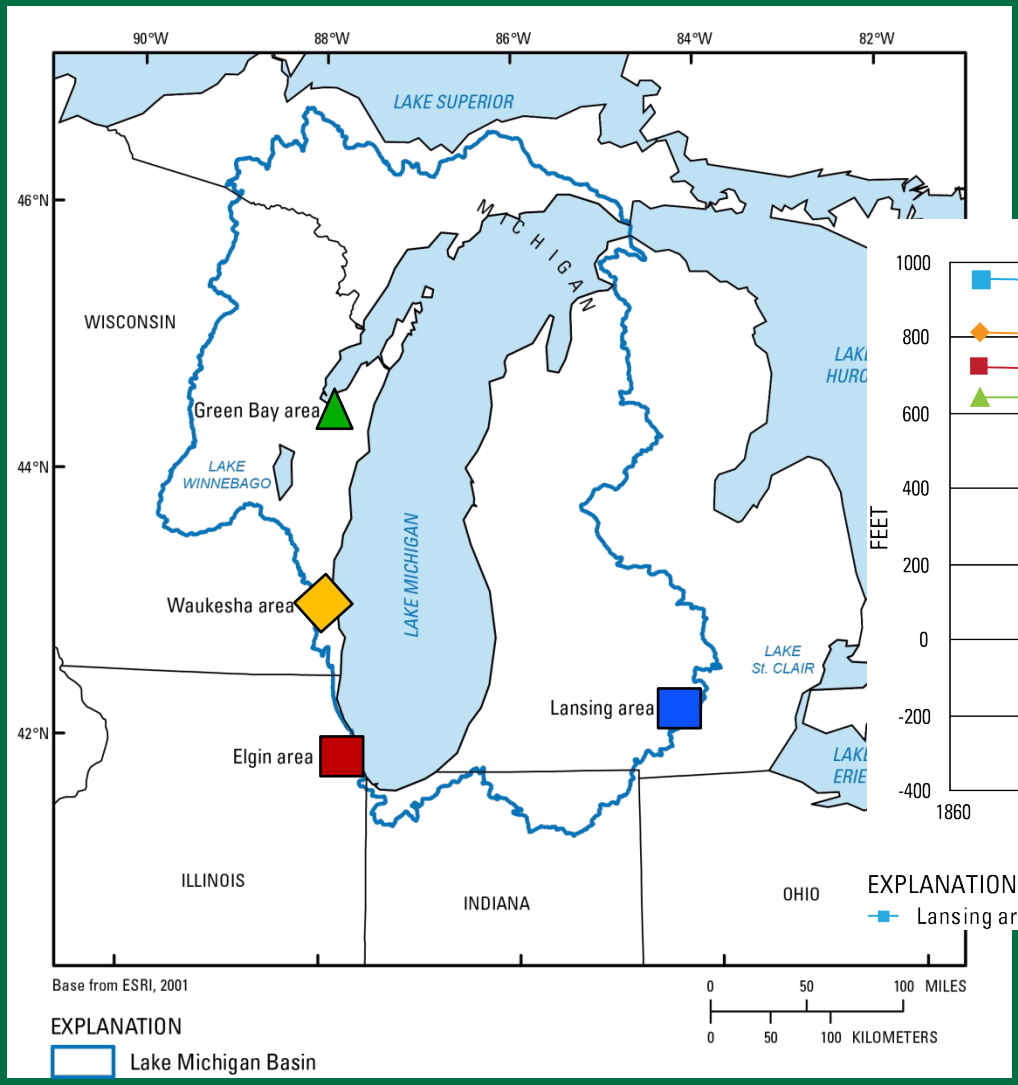
Water Budget by Stress Period for Lake Michigan Basin

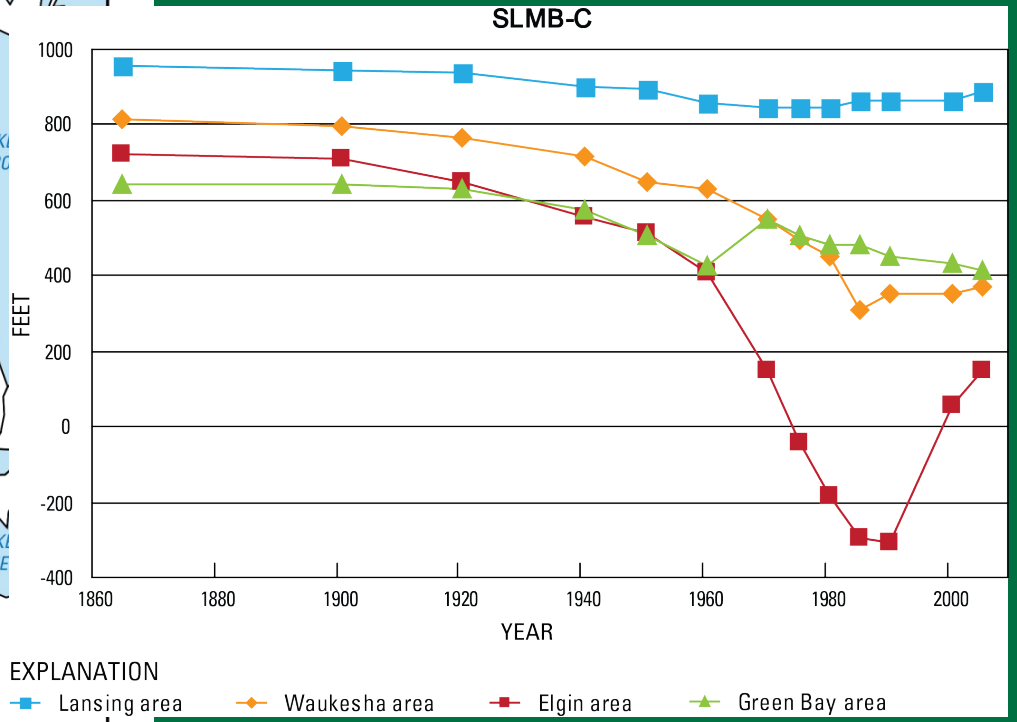


Water Budget Changes from Previous Stress Period for Lake Michigan Basin



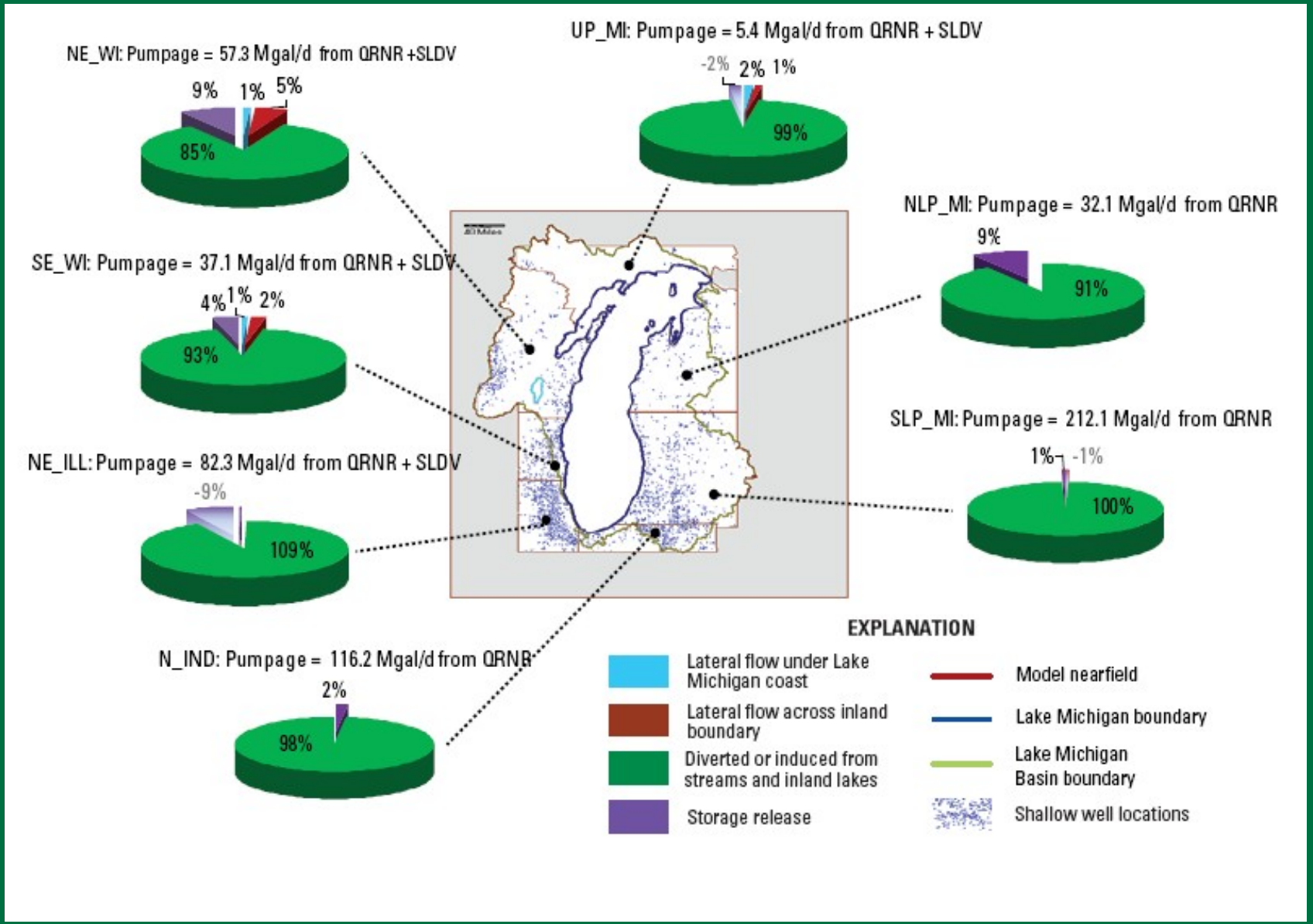
USGS


90°W
88°W
86°W
84°W
82°W
46°N
44°N
42°N
LAKE SUPERIOR
MICHIGAN
WISCONSIN
Green Bay area
LAKE WINNEBAGO
LAKE MICHIGAN
Waukesha area
Lansing area
Elgin area
LAKE St. CLAIR
ILLINOIS
INDIANA
OHIO
Base from ESRI, 2001
0 50 100 MILES
0 50 100 KILOMETERS
EXPLANATION
Lake Michigan Basin

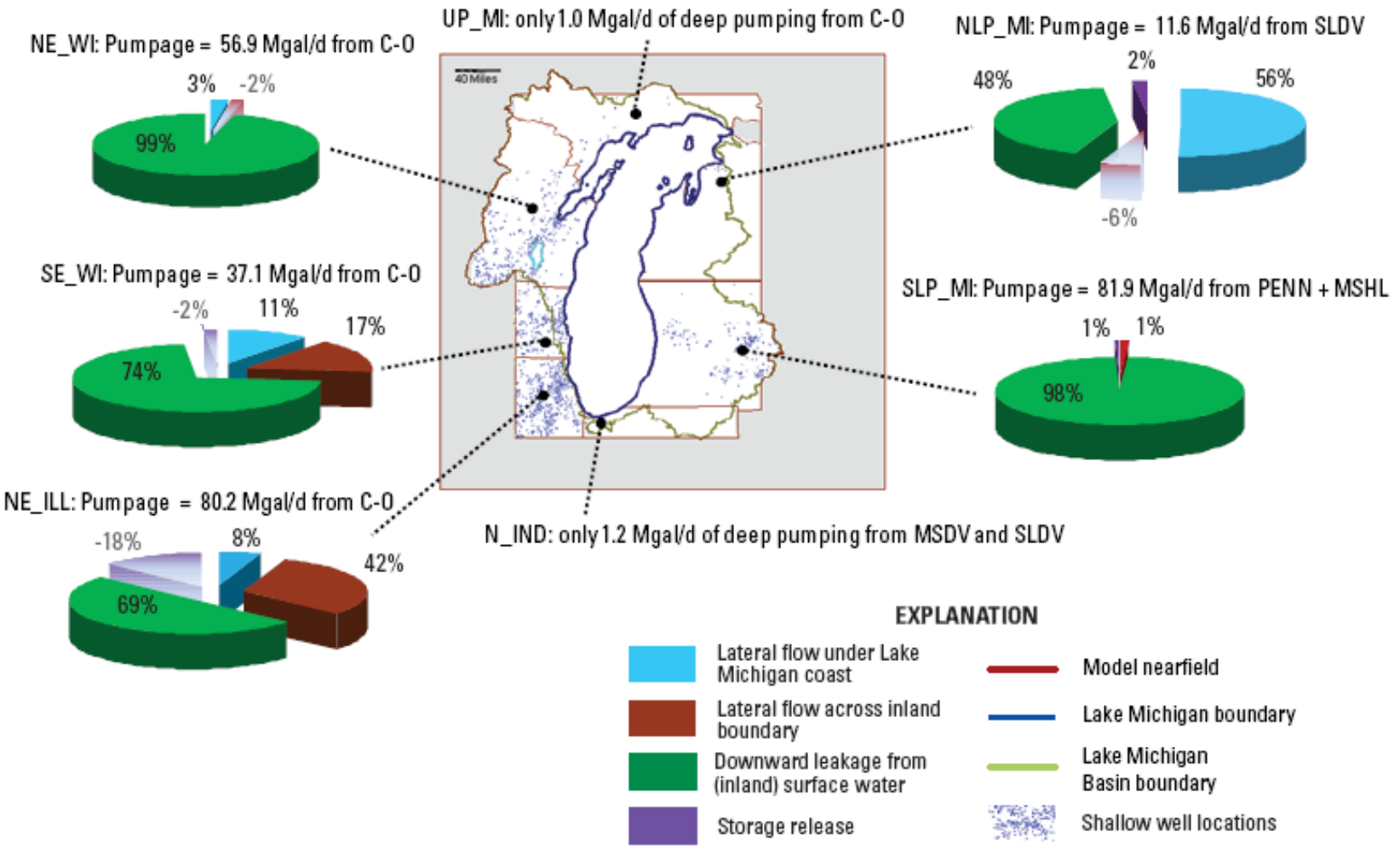

SLMB-C
1000
800
600
400
200
0
-200
-400
FEET
1860
1880
1900
1920
1940
1960
1980
2000
YEAR
EXPLANATION
Lansing area
Waukesha area
Elgin area
Green Bay area

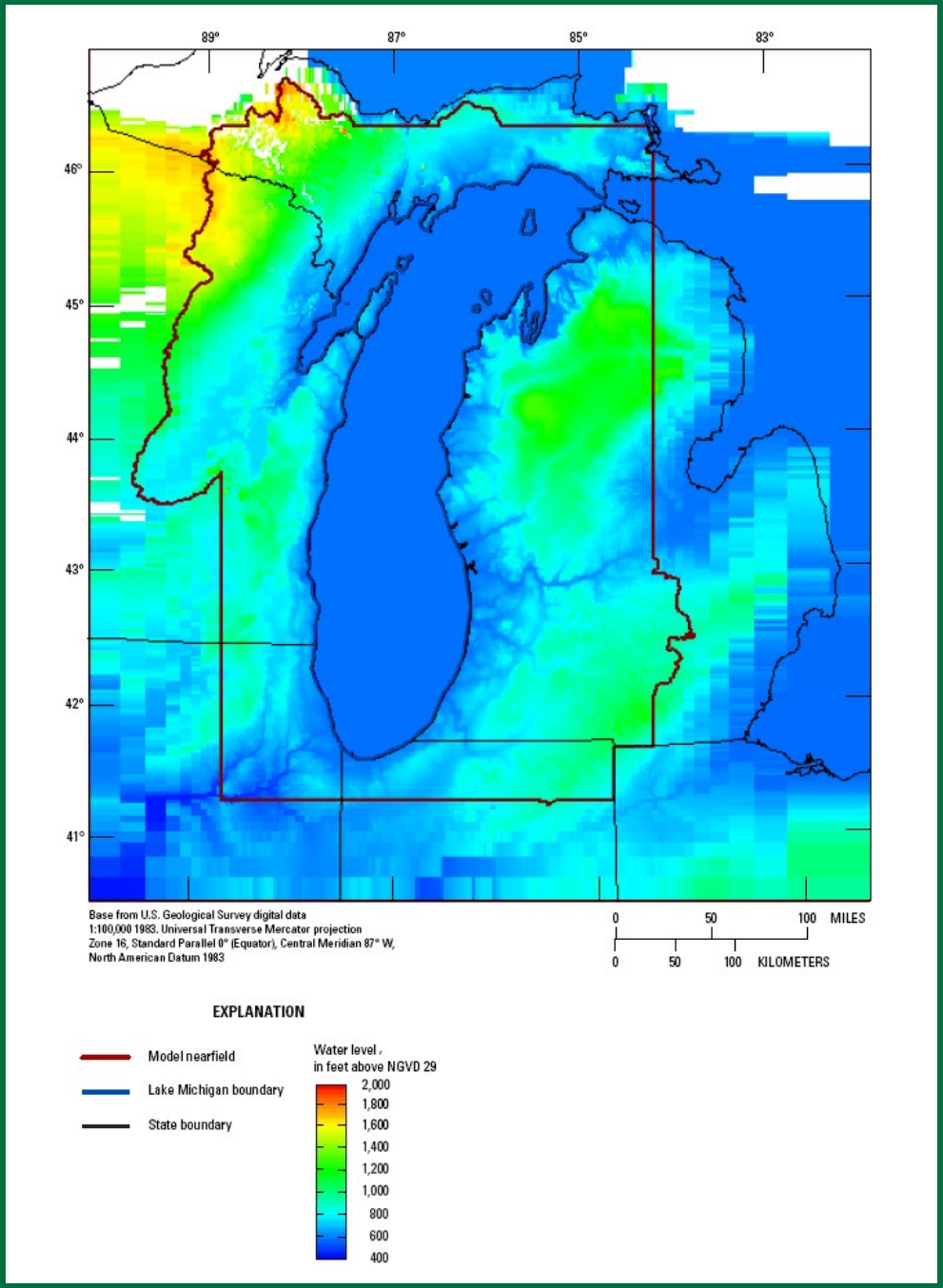
USGS

Source of water to wells, 2005, shallow



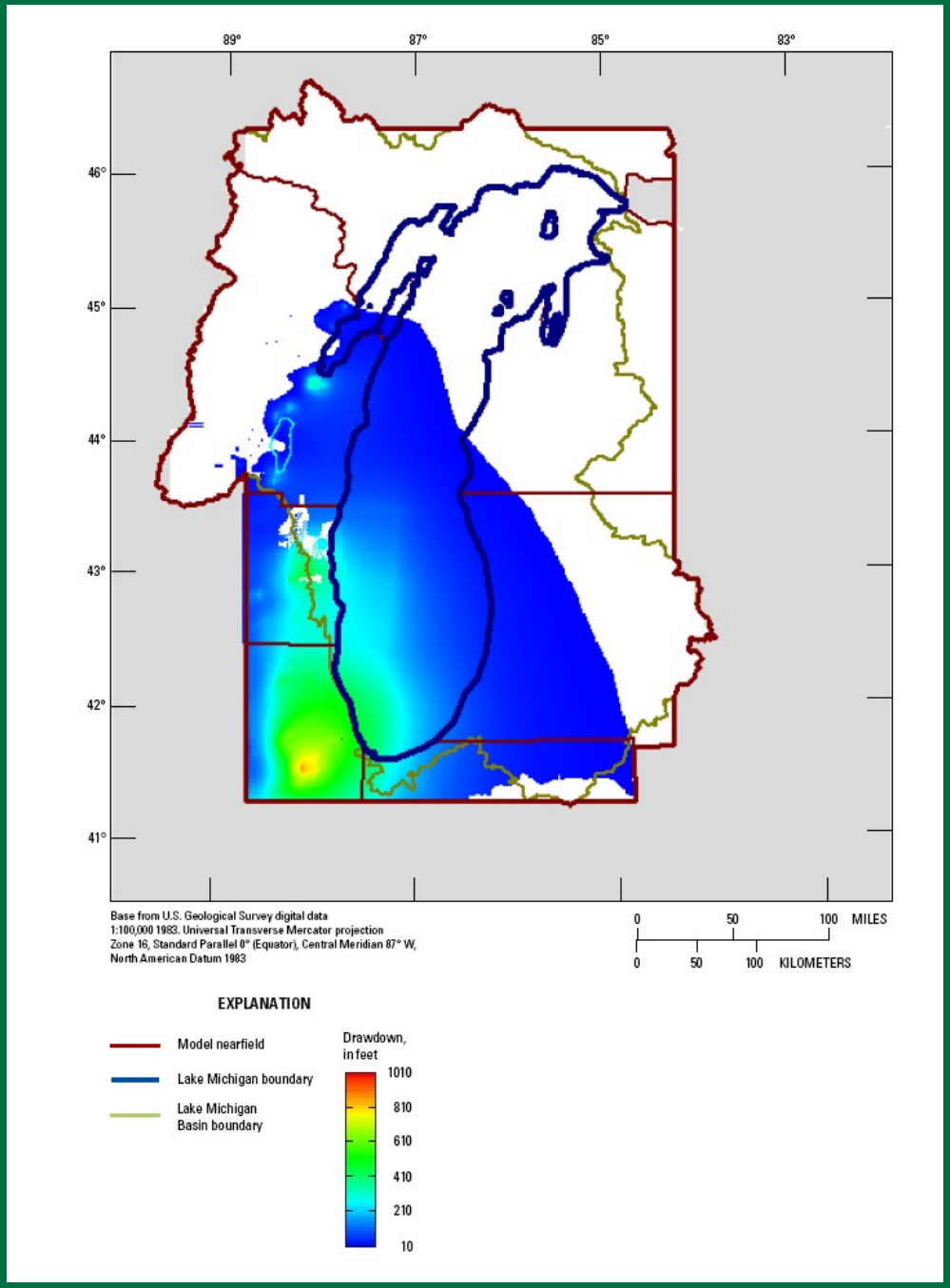
Source of water to wells, 2005, deep





Water Table

USGS



St. Peter drawdown: 1864 - 2005

USGS

Indicators

DEMAND TO SUPPLY RATI0 for a given area at given time=

$$\frac{\text{(Pumping – Injection)t}}{\text{(Sum of natural inflows)t, no pumping}}$$

BASEFLOW REDUCTION INDEX for a given area at given time=

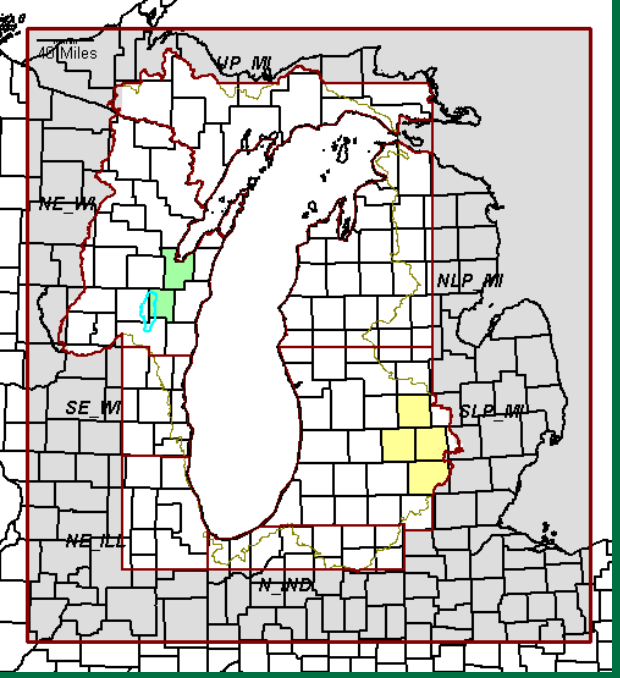
$$\frac{\text{(Net Baseflowt – Net Baseflowt, no pumping)}}{\text{(Net Baseflowt, no pumping)}} \times 100$$

Where net baseflow = SWout - SWin

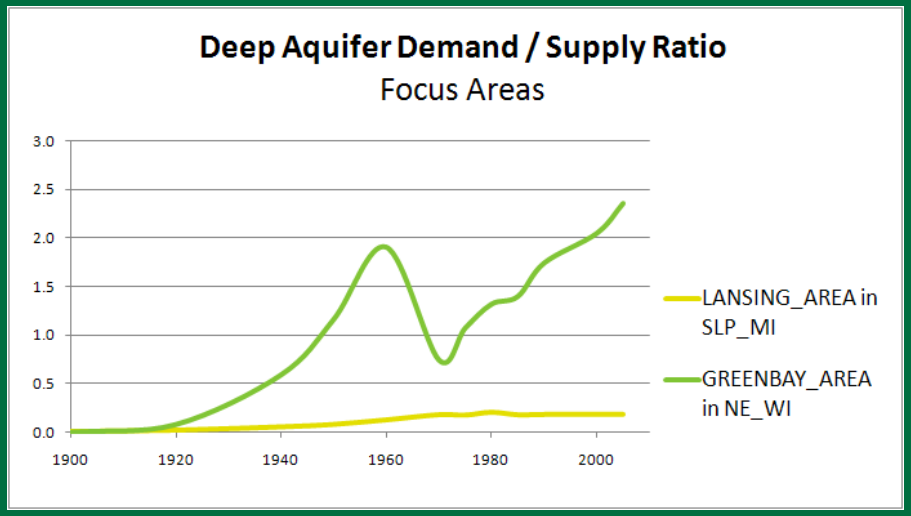
USGS

Weiskel and others, 2007
Cherkauer, 2009
Great Lakes Pilot, 2010

Indicators for Focus Areas



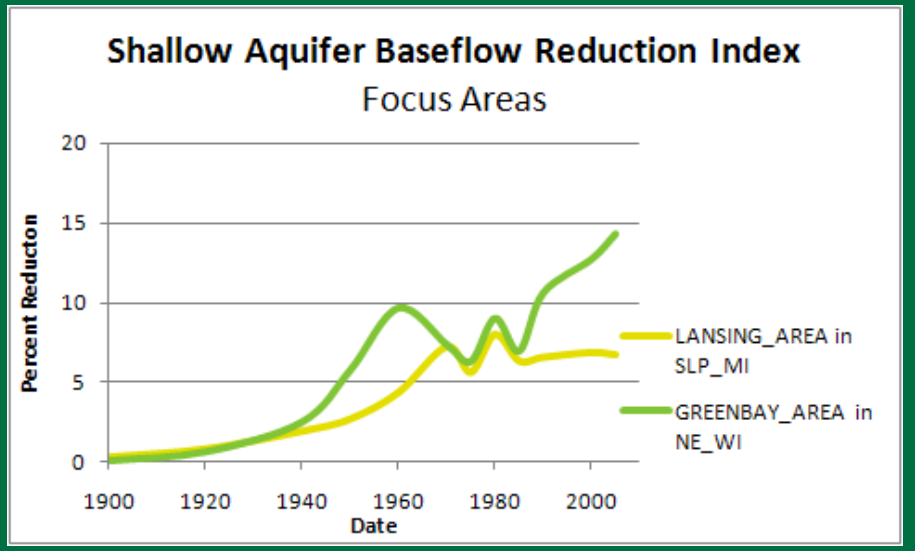
Demand relative to natural supply: *big range*



Focus Areas

- Lansing area in SLP_MI (4 counties)
- Green Bay area in NE_WI (2 counties)

Baseflow Reduction relative to natural flow: *greater than 5%*

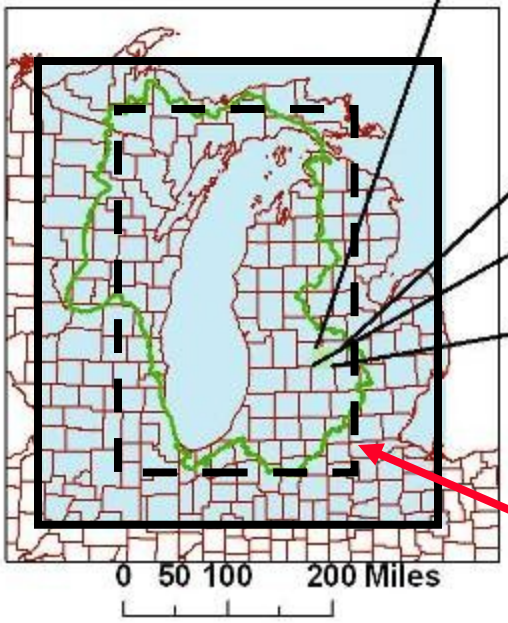


USGS

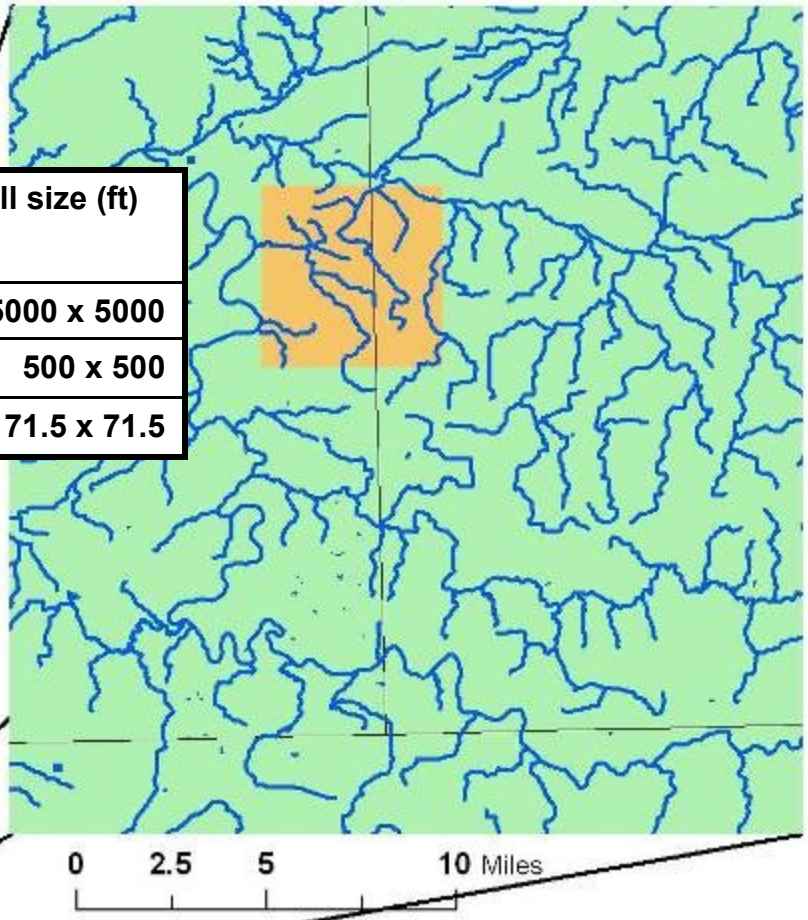
Ground-Water-Flow Model: Regional to Local Scales

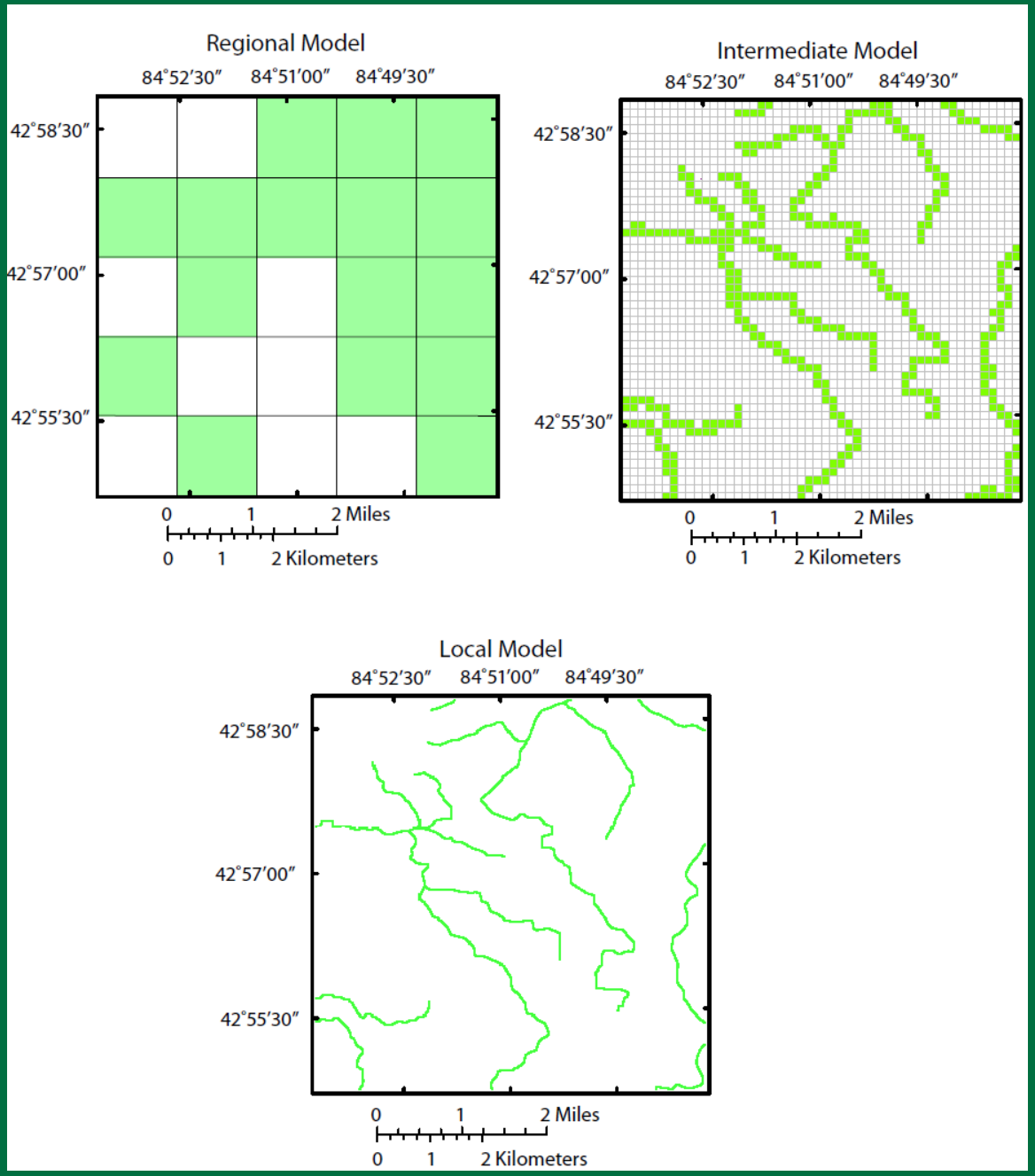
Scale	Area (mi2)	Cells per layer	Cell size (ft)
Regional	180962.6	102051	* 5000 x 5000
Intermediate	453.7	50600	500 x 500
Local	21.6	118336	71.5 x 71.5

* Smallest cells in non-uniform grid

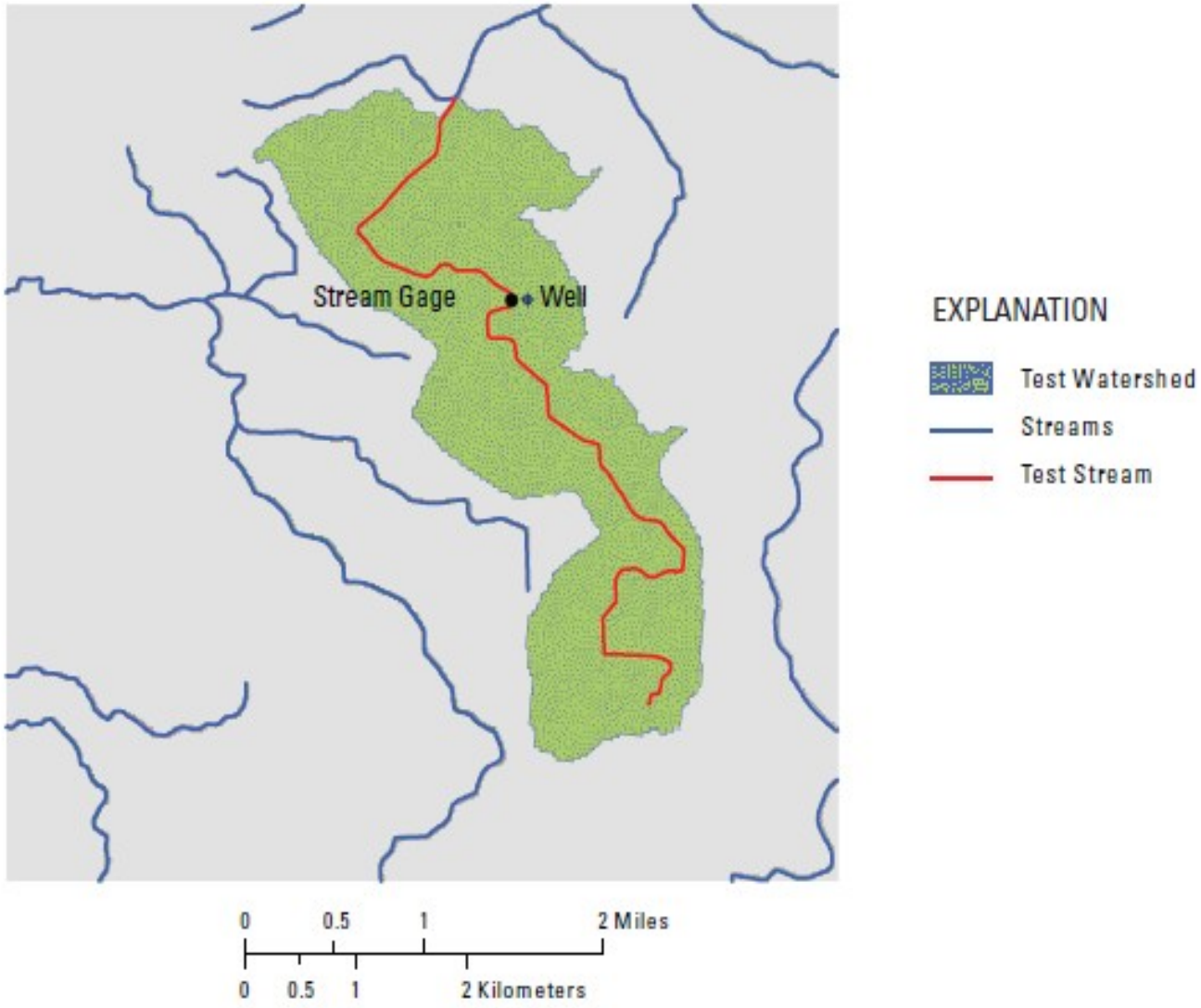


near field



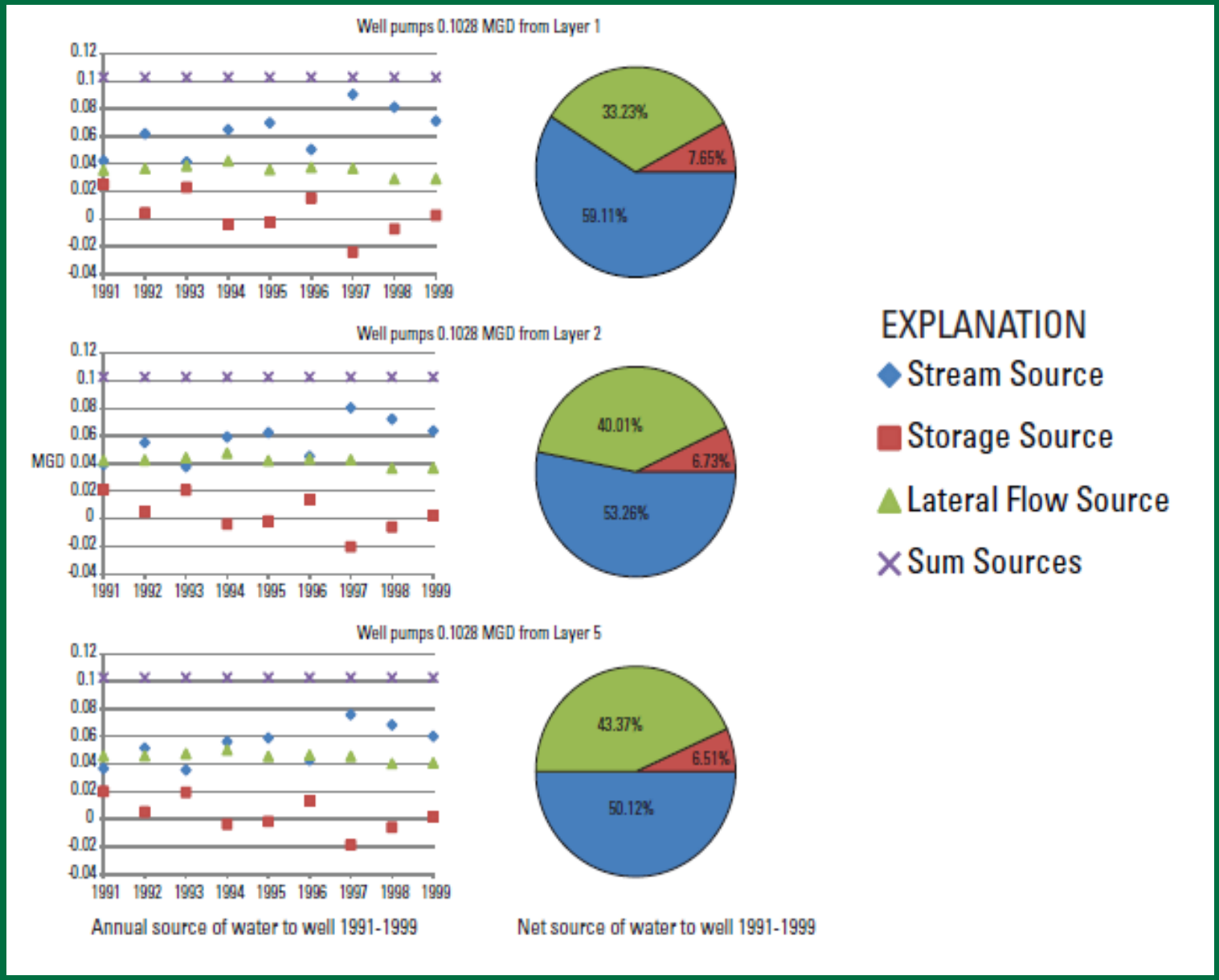

Regional Model
84°52′30″
84°51′00″
84°49′30″
42°58′30″
42°57′00″
42°55′30″
0 1 2 Miles
0 1 2 Kilometers
Intermediate Model
84°52′30″
84°51′00″
84°49′30″
42°58′30″
42°57′00″
42°55′30″
0 1 2 Miles
0 1 2 Kilometers
Local Model
84°52′30″
84°51′00″
84°49′30″
42°58′30″
42°57′00″
42°55′30″
0 1 2 Miles
0 1 2 Kilometers

USGS



USGS

(Hoard, 2010)



USGS

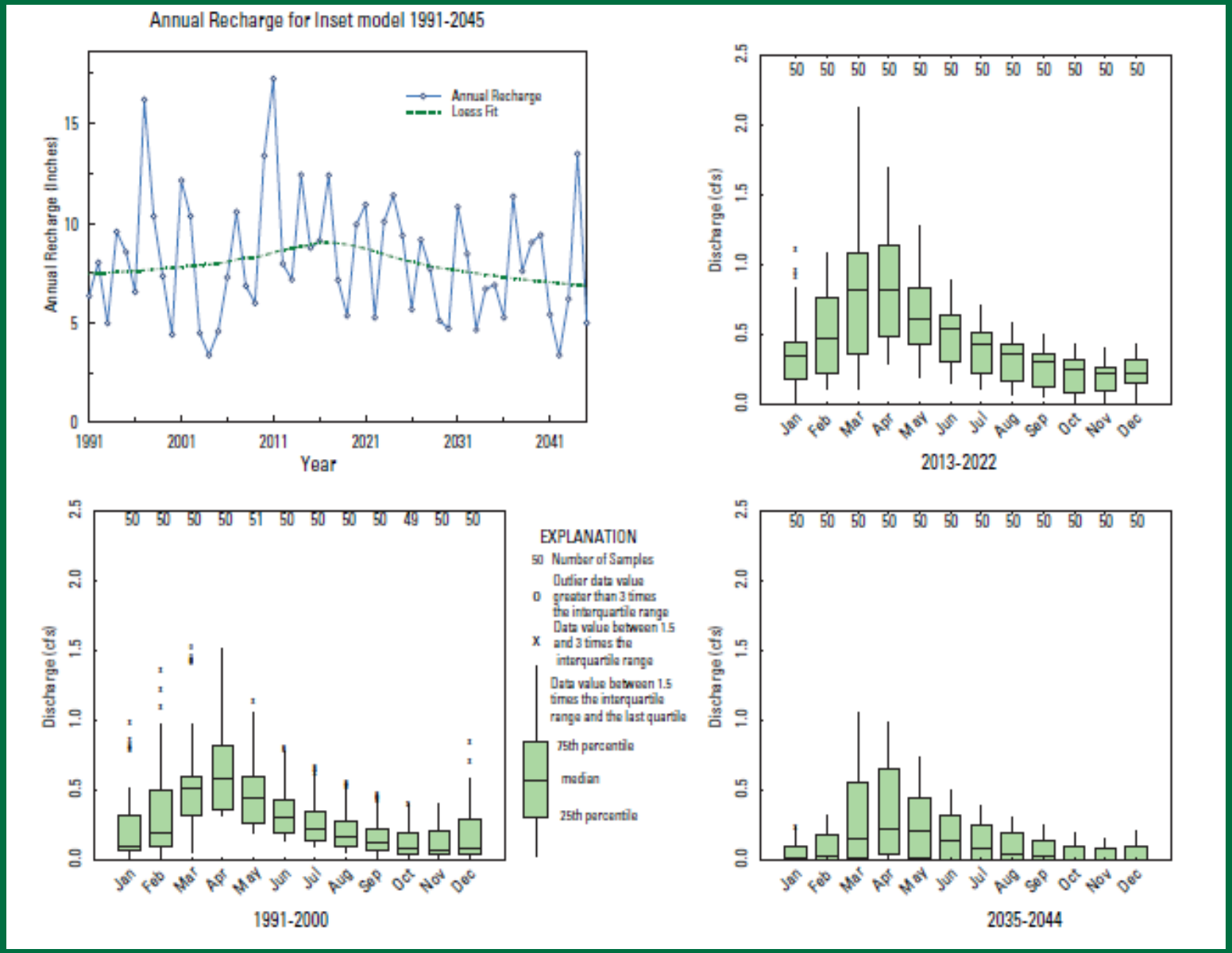
(Hoard, 2010)

Climate variability and change simulation

- Climate input from a downscaled atmosphere-ocean couple general circulation model (Hayoe and others, 2008)
- A1 fi scenario (high global greenhouse gas emission)
- AOGCM input to soil-water-balance model to estimate recharge

- Hayhoe, K., C. Wake, B. Anderson, X.-L. Liang, E. Maurer, J. Zhu, J. Bradbury, A. DeGaetano, A. Stoner and D. Wuebbles. 2008. Regional Climate Change Projections for the Northeast USA: Mitigation and Adaptation Strategies for Global Change, Vol. 13, No. 5-6, p. 425-436

USGS



USGS

(Hoard, 2010)

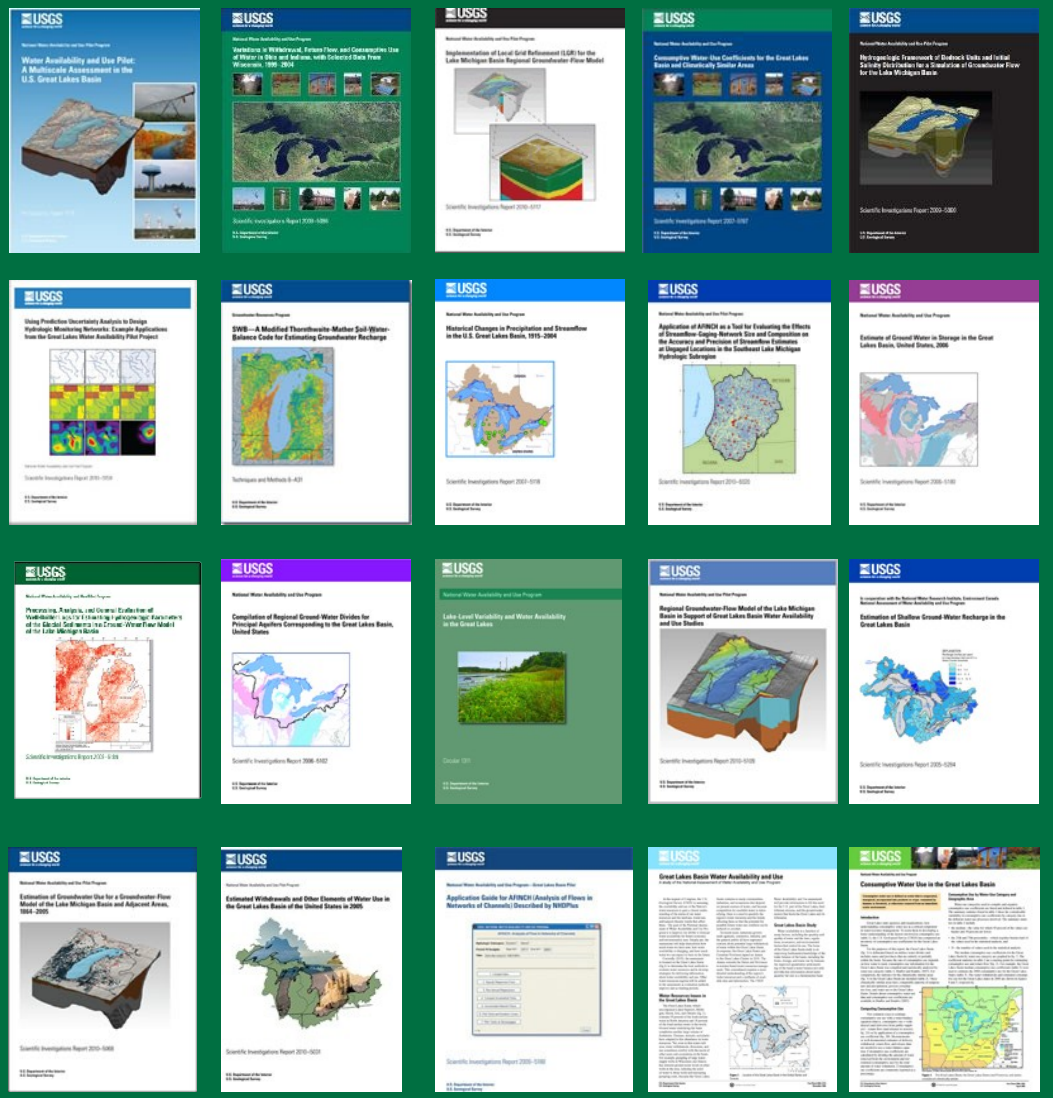
Relation to the Great Lakes Compact

- .. Strengthen the scientific basis for sound water management (Section 1.4)
- Role of groundwater (Section 1.4)
- Water use and development of the required cumulative impact assessment (Section 4.15)
- .. Consider adaptive management principles and approaches recognizing, considering, and providing adjustments for the uncertainties in, and evolution of, science concerning the Basin's water resources, watersheds and ecosystems (Section 4.15)

USGS

Great Lakes Pilot

- Regional abundance does not mean water will always be available where and when it is needed.
- Regional study provides information that local stakeholders can build on to make decisions.



USGS

http://water.usgs.gov/wateravailability/greatlakes/index.html