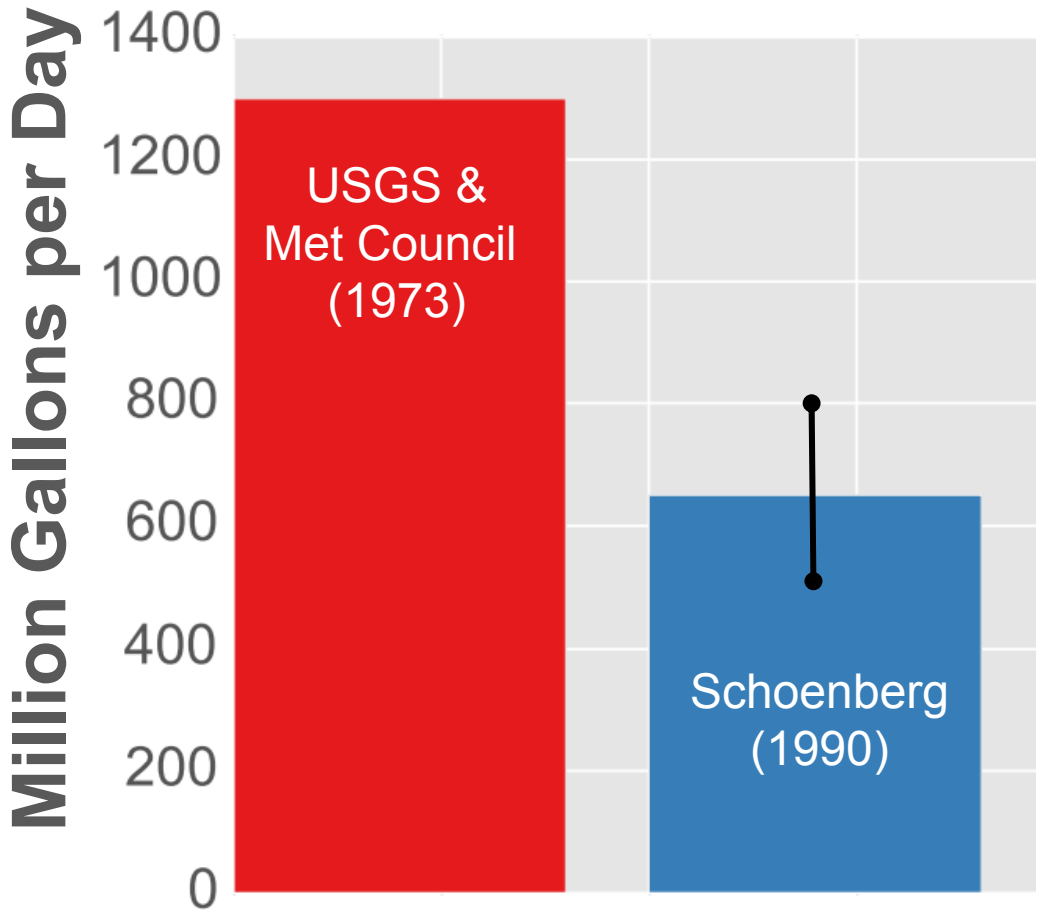
# Connecting sustainability metrics and groundwater pumping with optimization modeling

April 2015


# How much water do we have?

- 1,300 MGD (USGS, 1973)
- 500 to 800 MGD (Schoenberg, 1990)




BARR METROPOLITAN COUNCIL

# Region-Wide Optimization Results

- 7 County Optimized Pumping Rate:  400-500 MGD
  - Low end of past estimate range
  - Definition of sustainability changes over time

BARR METROPOLITAN COUNCIL

# Process

- Review Statutes
- Stakeholder input
  - Department of Natural Resources
  - Communities
- Run optimization
- Review
- Repeat

METROPOLITAN COUNCIL

# Modeling Sustainability
# Surface water Connections

- Flux: water flowing in and out of aquifer system
- Fens
  - No more than 1’ of drawdown allowed
- Trout Streams and vulnerable lakes
  - No more than 10% change in flux between surface water and groundwater
- Mississippi River
  - No more than 25% change in flux between surface water and groundwater
- All other surface water bodies
  - No more than 15% change in flux between surface water and groundwater

BARR METROPOLITAN COUNCIL

# Modeling Sustainability Human Health

- Special Well and Boring Construction Areas
  - Plume flow direction restricted to +/- 10 degrees from baseline conditions

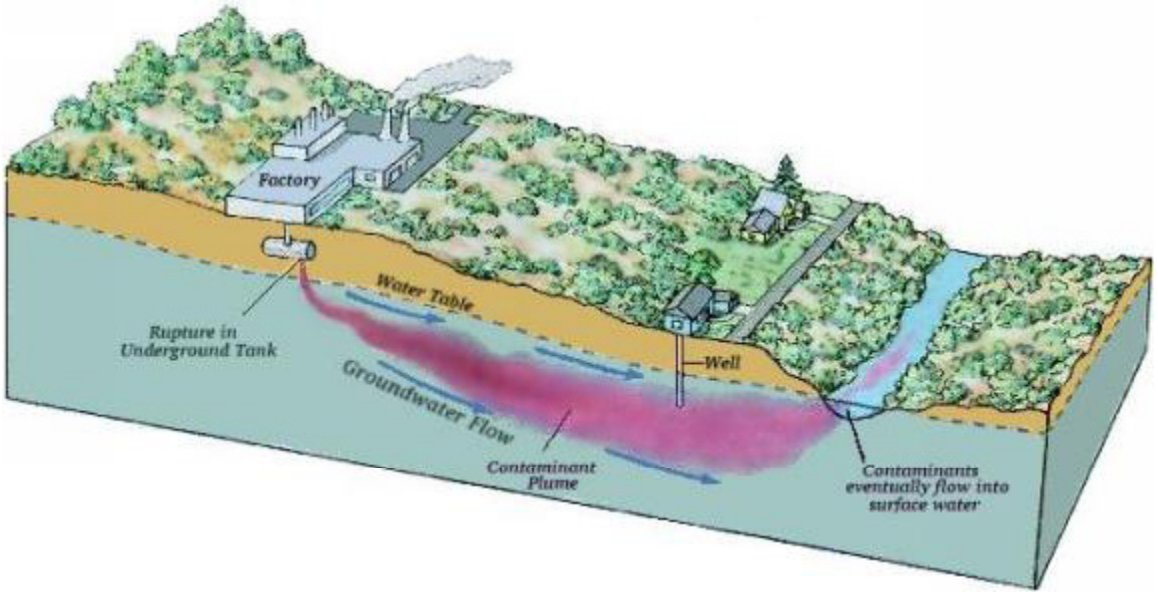
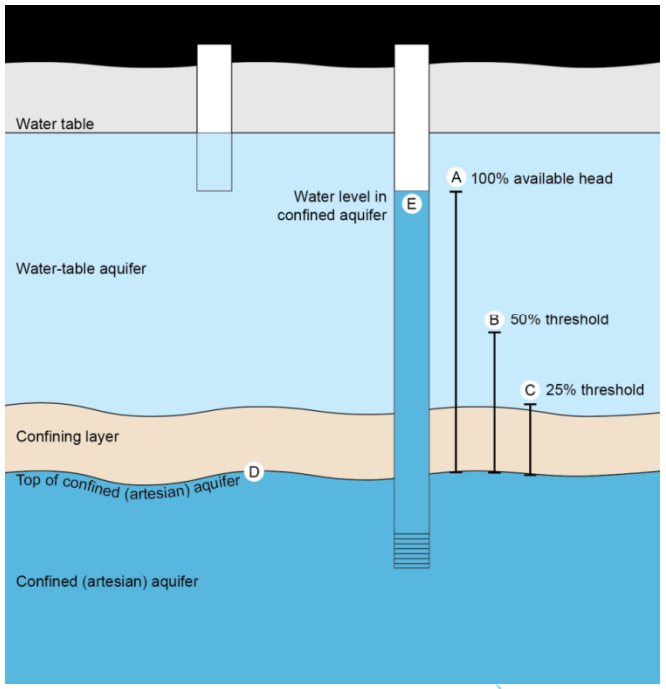



Figure courtesy of Chico State

BARR METROPOLITAN COUNCIL

# Modeling Sustainability
# Aquifer Safe Yield

- Confined Aquifer water levels, excluding Mt. Simon
  - Pumping cannot cause aquifer levels to decline below the 50% threshold
- Mt. Simon Aquifer levels
  - No more than 1’ of drawdown from baseline pumping levels allowed
- Unconfined Aquifer levels
  - Represented by surface-water constraints

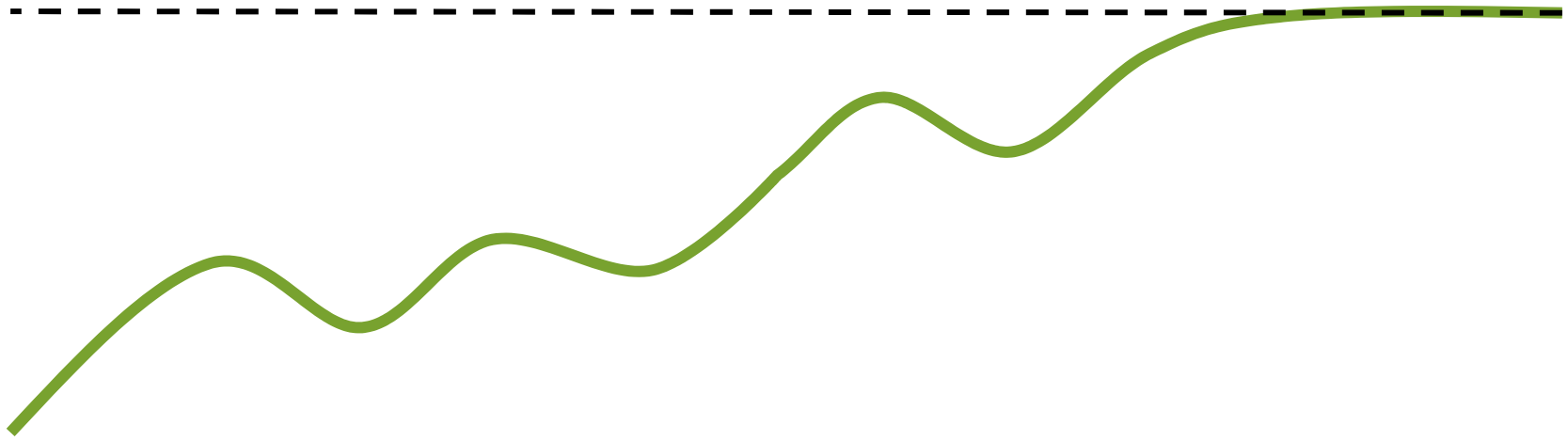



BARR

METROPOLITAN COUNCIL

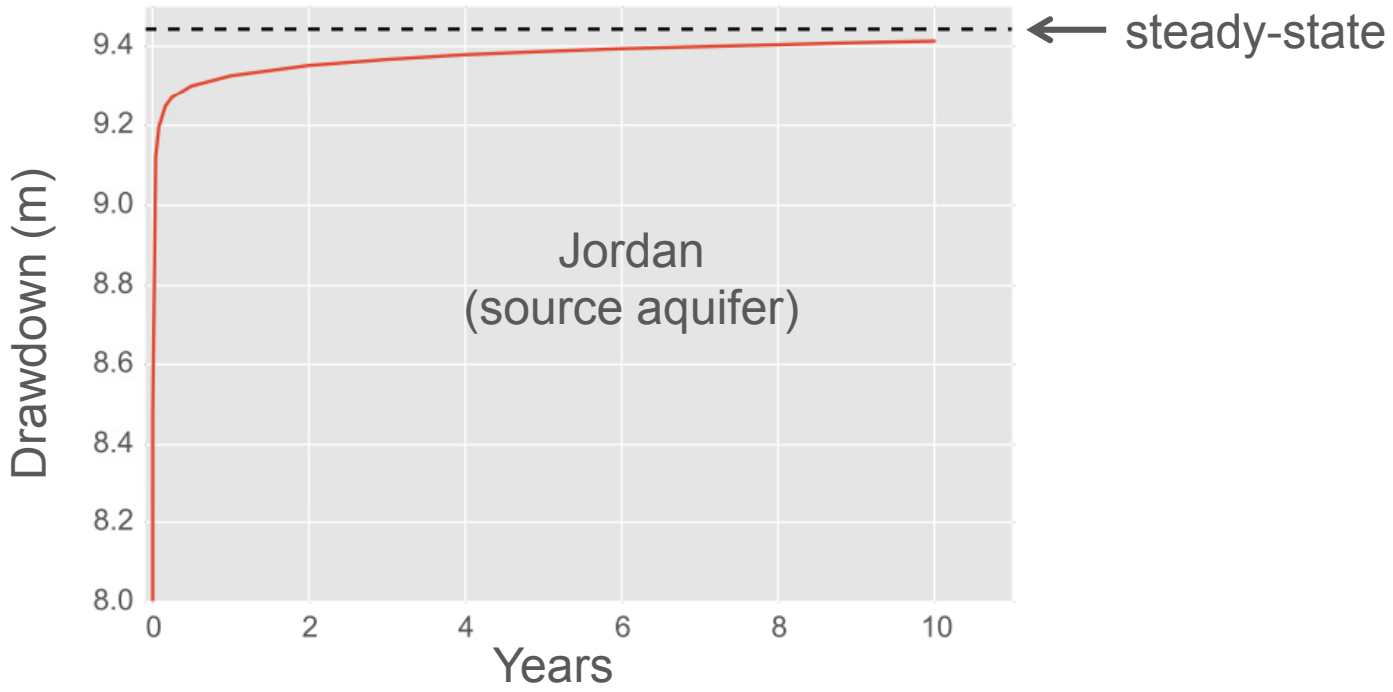
# What is Pumping Optimization?

- Distribute pumping to maximize total groundwater withdrawals while not exceeding pre-determined threshold  (sustainability constraints)



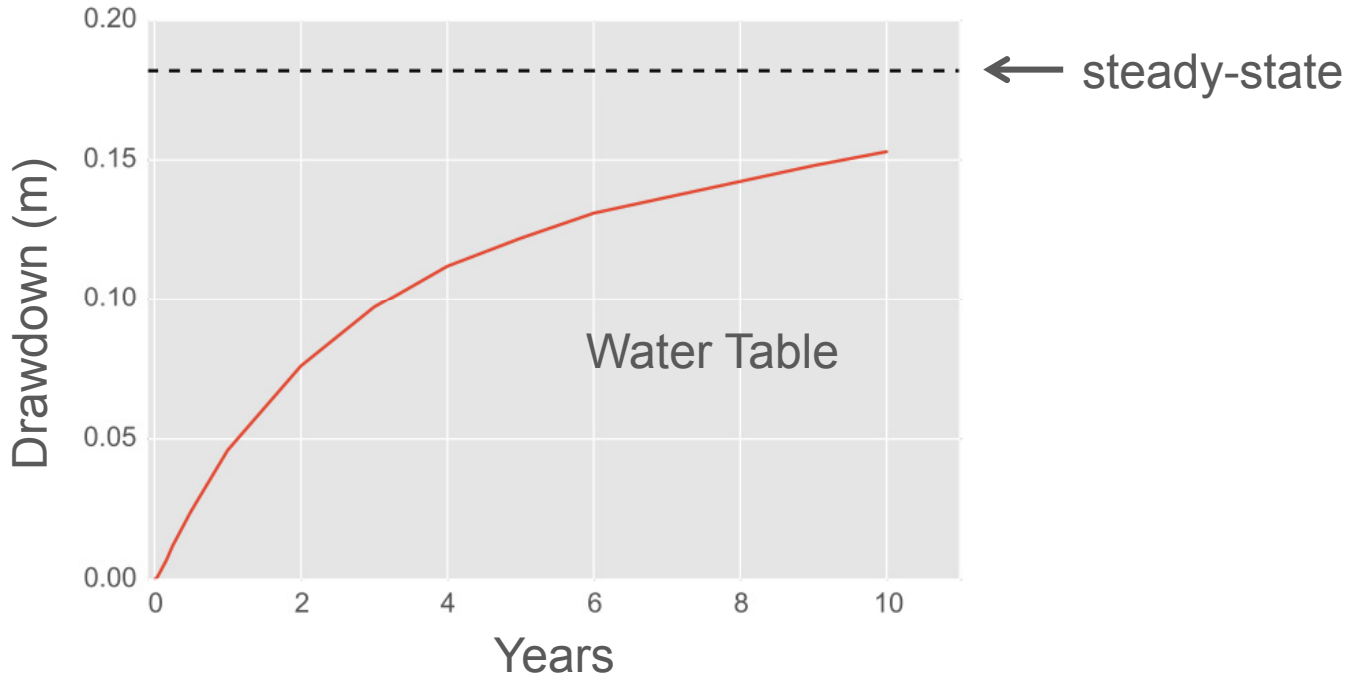
# Why?

- Planning tool
  - Areas of concern and areas of little concern
- Complex geospatial relationships
- Time lag to full impacts makes reliance on monitoring a reactive strategy; modeling is a proactive strategy



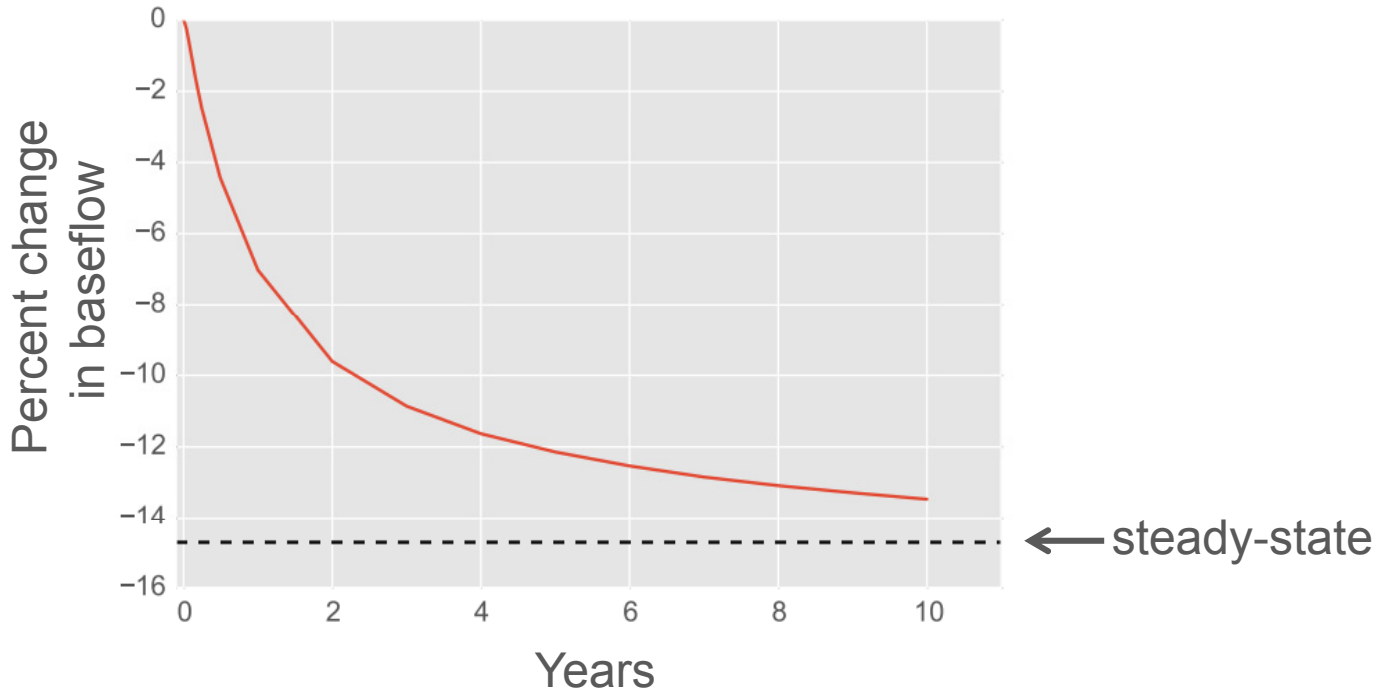
# Why?

- Planning tool
  - Areas of concern and areas of little concern
- Complex geospatial relationships
- Time lag to full impacts makes reliance on monitoring a reactive strategy; modeling is a proactive strategy



# Why?

- Planning tool
  - Areas of concern and areas of little concern
- Complex geospatial relationships
- Time lag to full impacts makes reliance on monitoring a reactive strategy; modeling is a proactive strategy

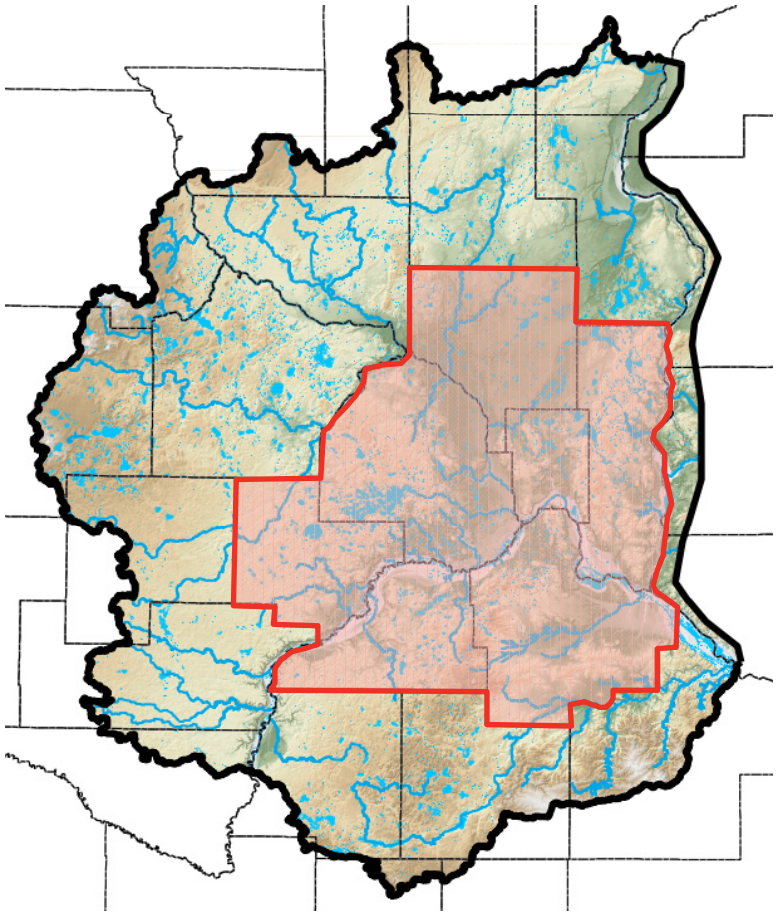


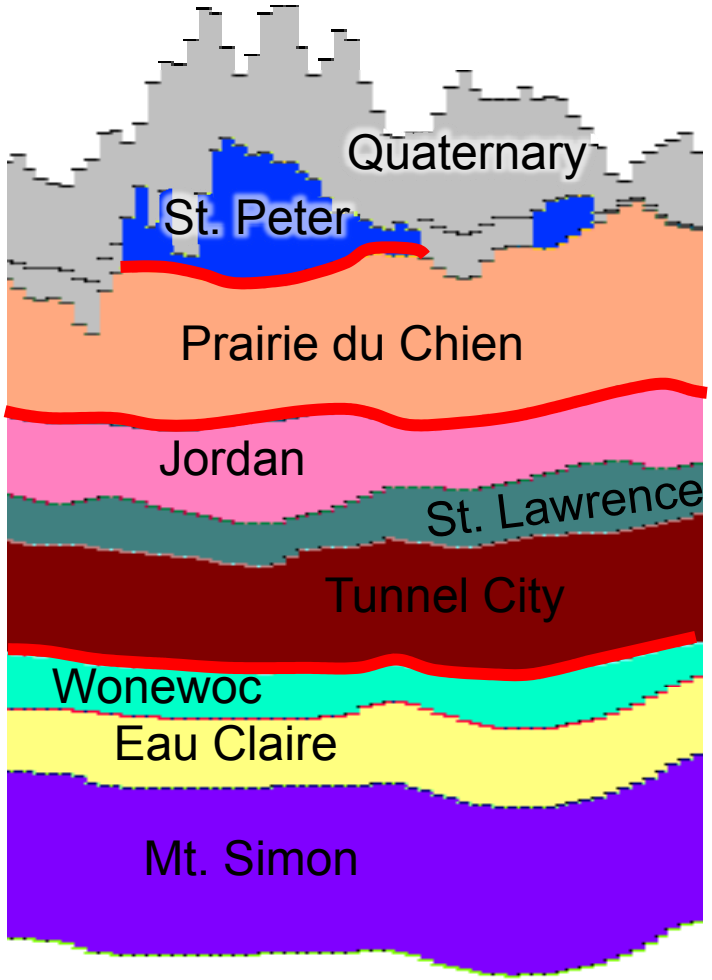
# Estimating Metro-Wide Sustainable Pumping Maximum

- Custom version of USGS Groundwater Management (GWM-VI) pumping optimization code with Metro Model 3
- Only pumping of existing permitted wells in 7-County Metro are were allowed to vary (wells in Mt. Simon-Hinckley remained constant)
- Steady-state simulation

# Metro Model 3

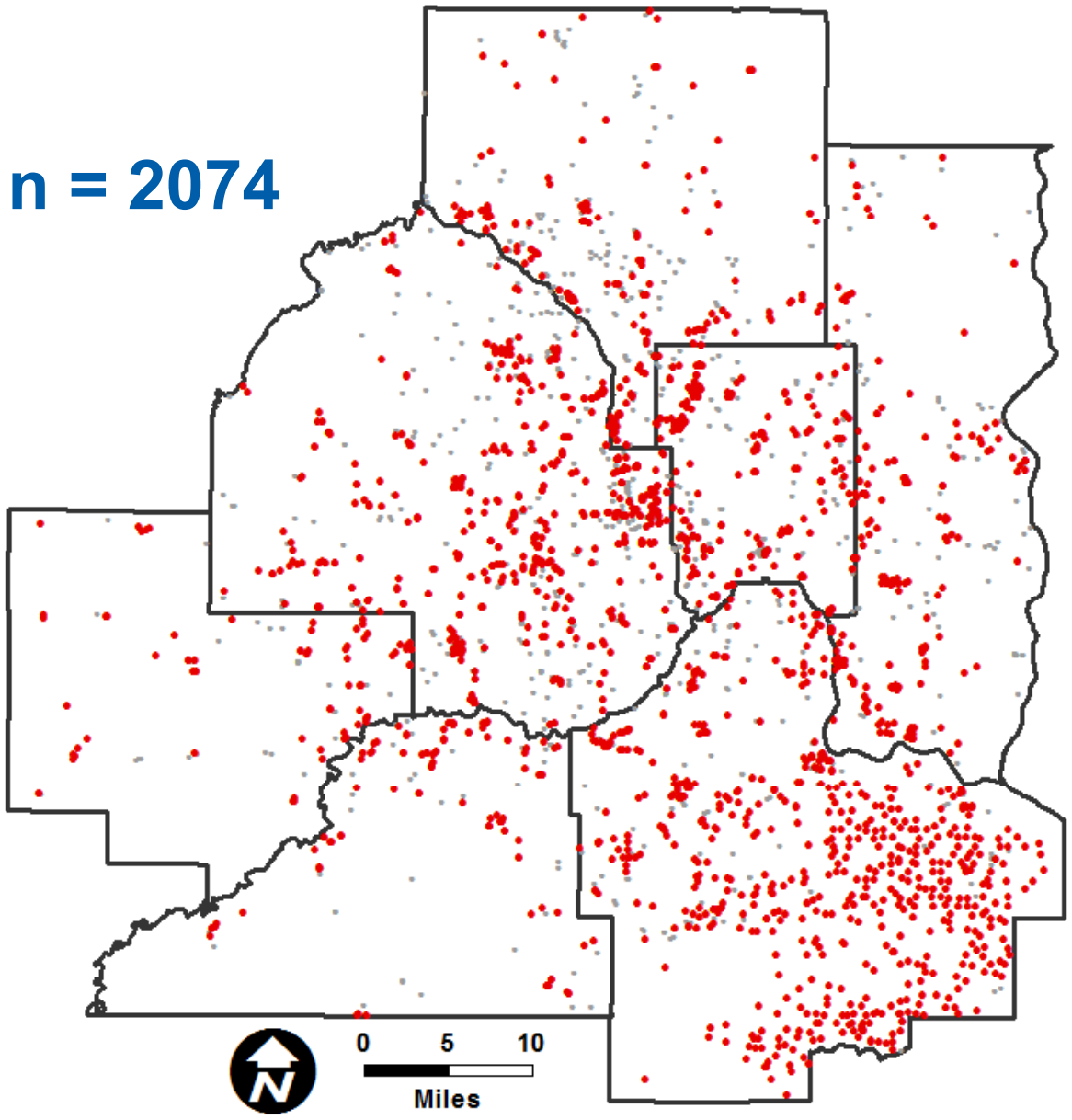
- Completed spring of 2014
- Covers 11-country metro
- All major aquifer and aquitards





# Wells

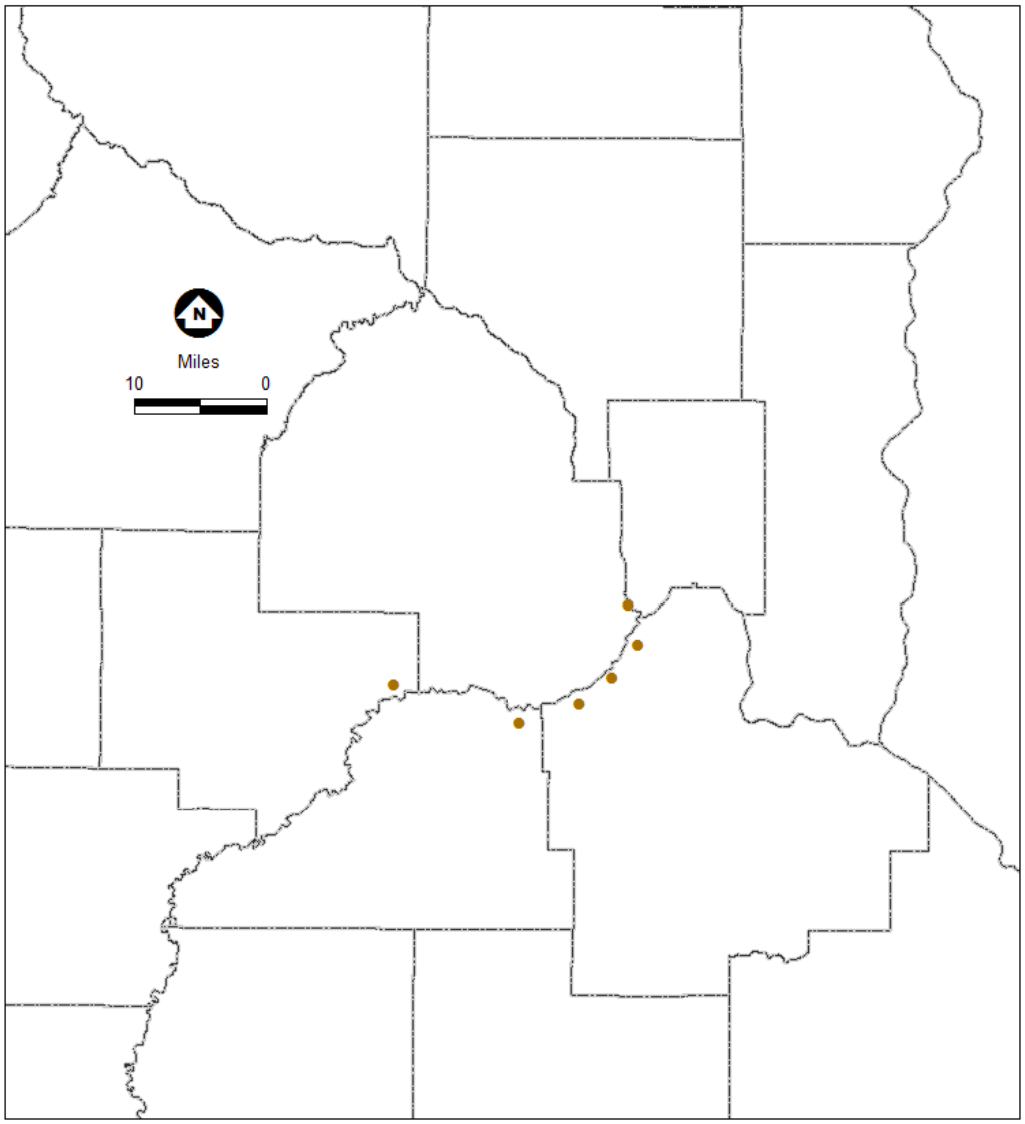
| Use Class |
| --- |
| Municipal |
| Private waterworks |
| Commercial and Institutional |
| Fire protection |
| Power generation |
| Institutions |
| Agricultural processing |
| Pulp and paper processing |
| Petroleum-chemical |
| Metal processing |
| Non-metallic processing |
| Industrial processing |
| Quarry dewatering |
| Sand/gravel pit dewatering |
| Dewatering |
| Pollution containment |
| Sewage treatment |
| Non-crop irrigation |
| Major crop irrigation |



# Constraints

| Constraint Type | | Threshold | Number |
|---|---|---|---|
| Drawdown from available head for confined bedrock aquifers above the Mt. Simon-Hinckley | Head | 50% | 2955 |
| Drawdown in the Mt. Simon-Hinckley aquifer | | 1 foot | 1897 |
| Drawdown at Calcareous fens | | 1 foot | 6 |
| Change in net baseflow to trout streams | Flux | -10% | 13 reaches |
| Change in net baseflow to other river reaches | | -15% | 67 reaches |
| Change in net baseflow to the Mississippi River | | -25% | 12 reaches |
| Change in net groundwater flux for high and outstanding biodiversity | | -15% | 108 areas |
| Change in net groundwater flux to potentially vulnerable lakes with wide littoral zone | | -10% | 68 |
| Change in net groundwater flux for remaining lakes at grouped by Township | | -15% | 103 |
| Change in flow directions at site of groundwater contamination | Direction | 10 degrees | 8 |
| **Total** | | | **5237** |

# Constraints – Head

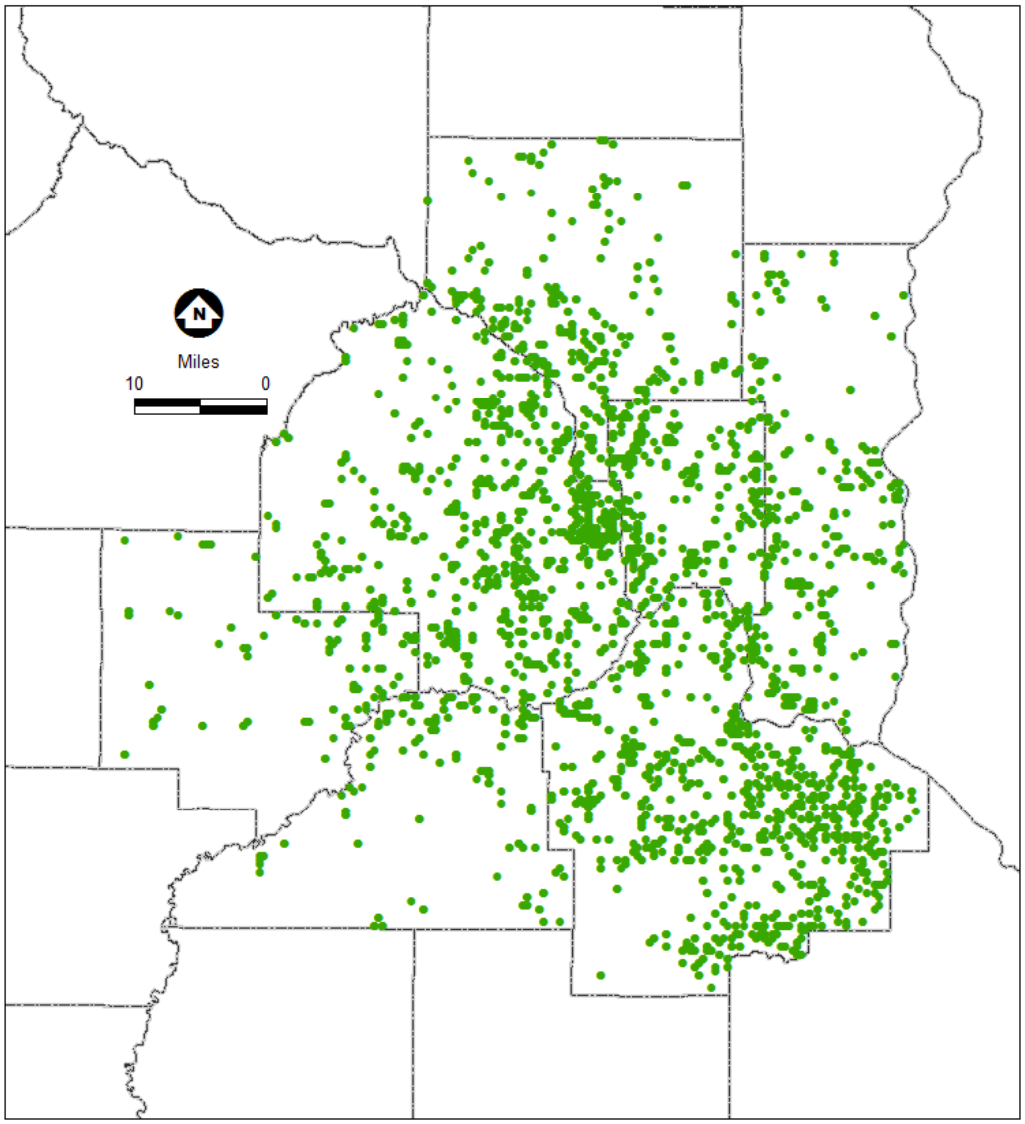



## Fens

Threshold:
1 ft. drawdown

Count:
6

# Constraints – Head

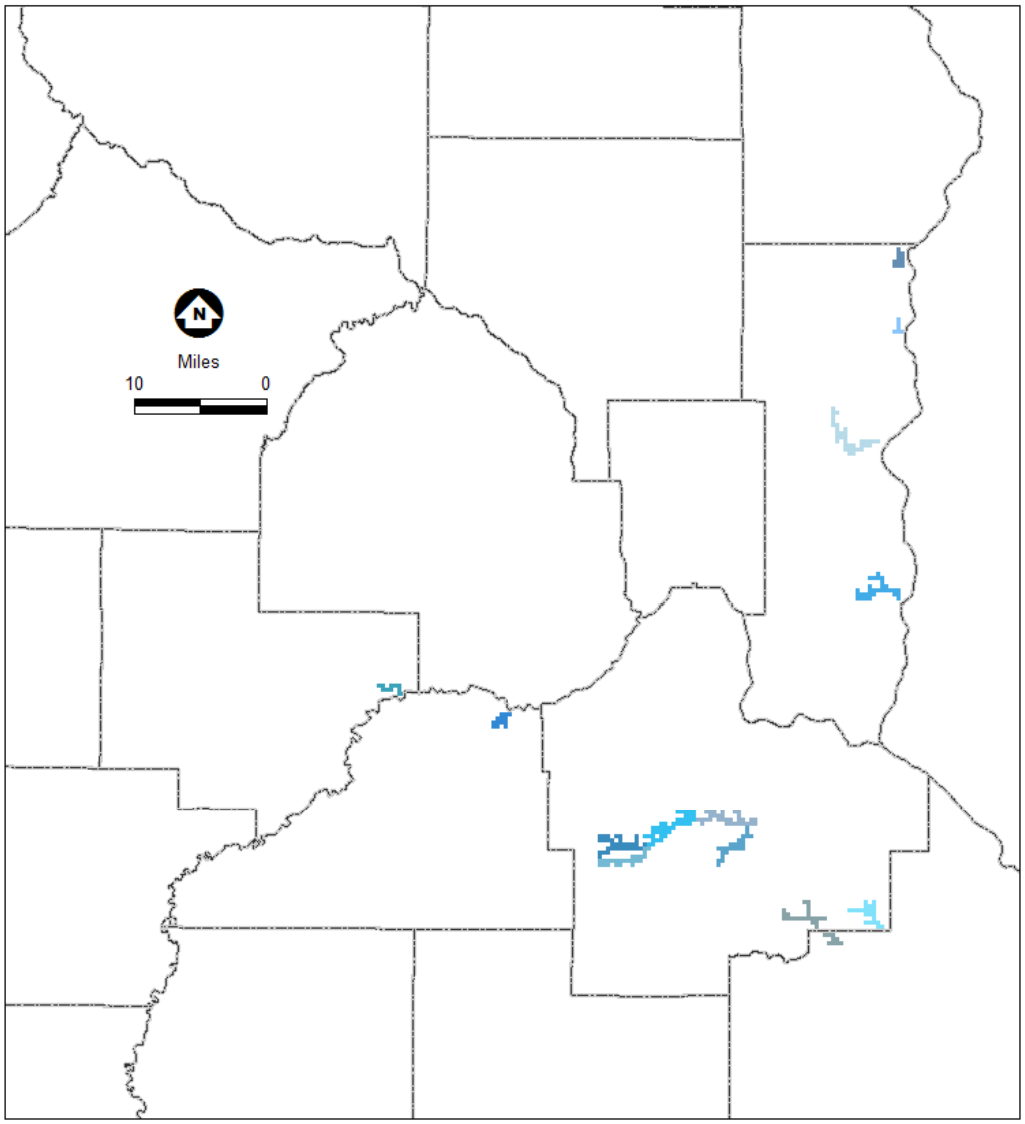



## Safe yield

Threshold:
50% “Available Head”
1 ft. drawdown in Mt. Simon

Count:
2955 – Available Head
1897 – Mt. Simon

# Constraints – Flux

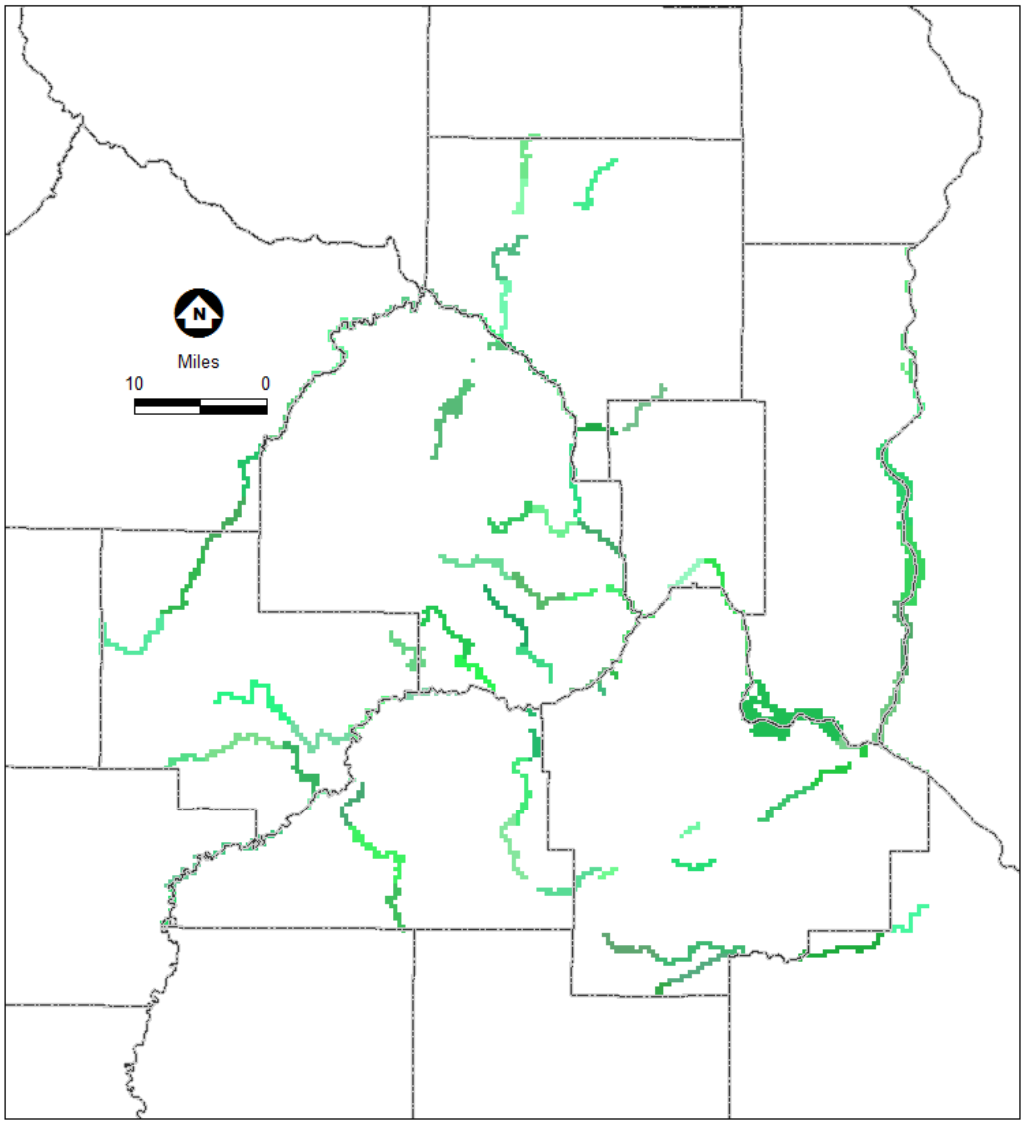



## Trout Streams

Threshold:
-10% change in baseflow

Count:
13 Reaches

# Constraints – Flux

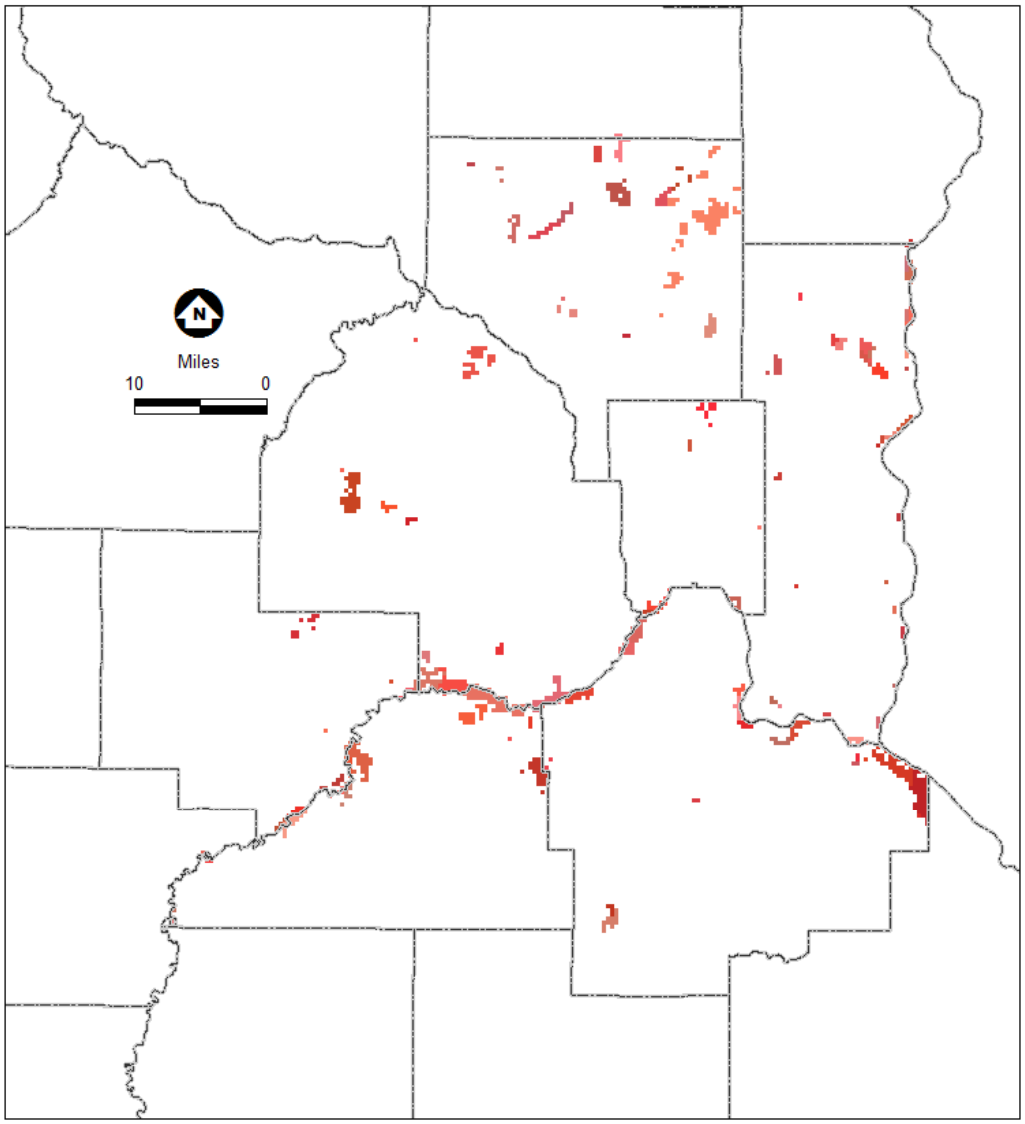



## River Reaches

Threshold:
-15% change in baseflow
-25% change for Mississippi

Count:
67 reaches
12 Mississippi reaches

# Constraints – Flux



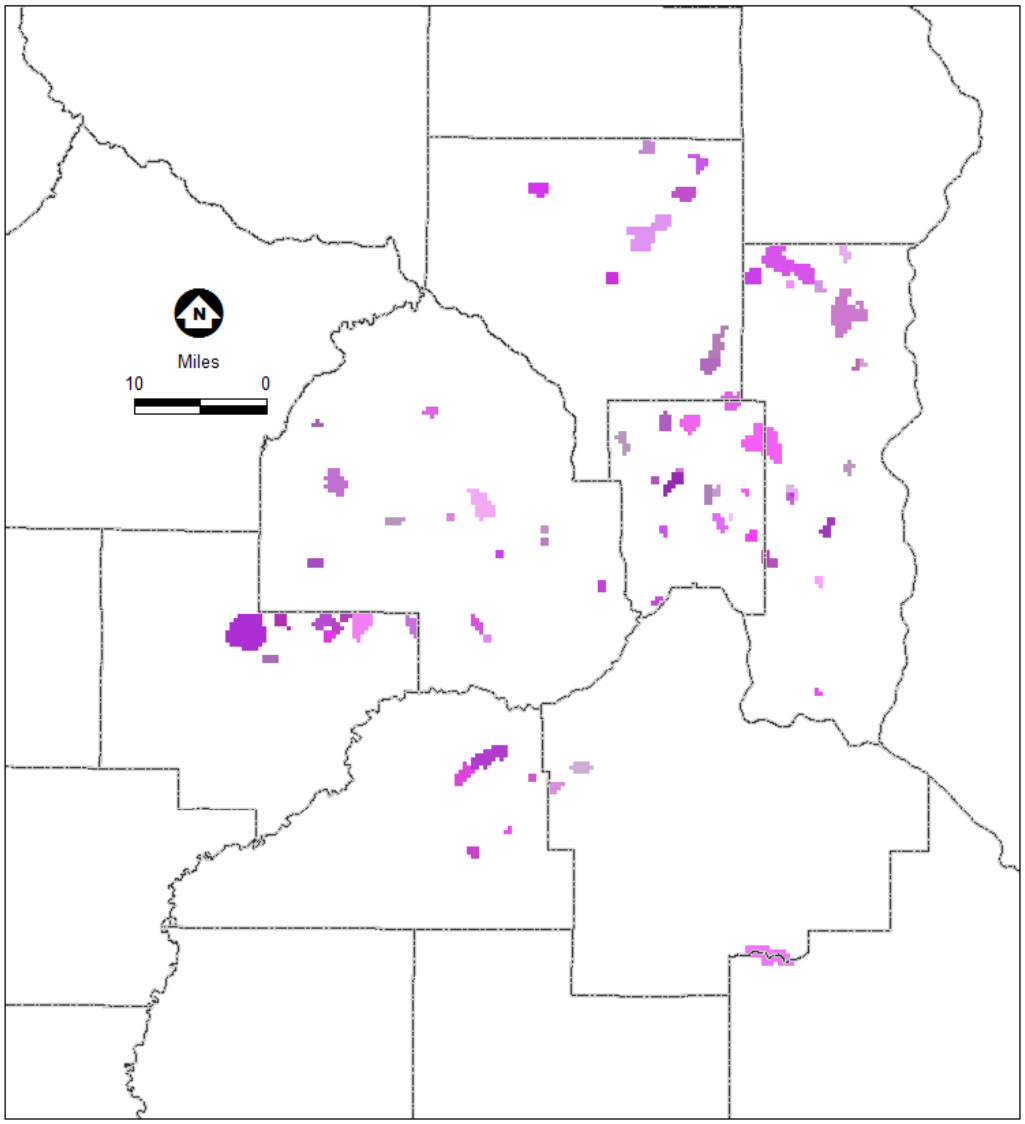

**Sites of high and outstanding biodiversity**

Threshold:
-15% change in flux

Count:
108 areas

Areas defined by Minnesota County Biological Survey (2013)

# Constraints – Flux



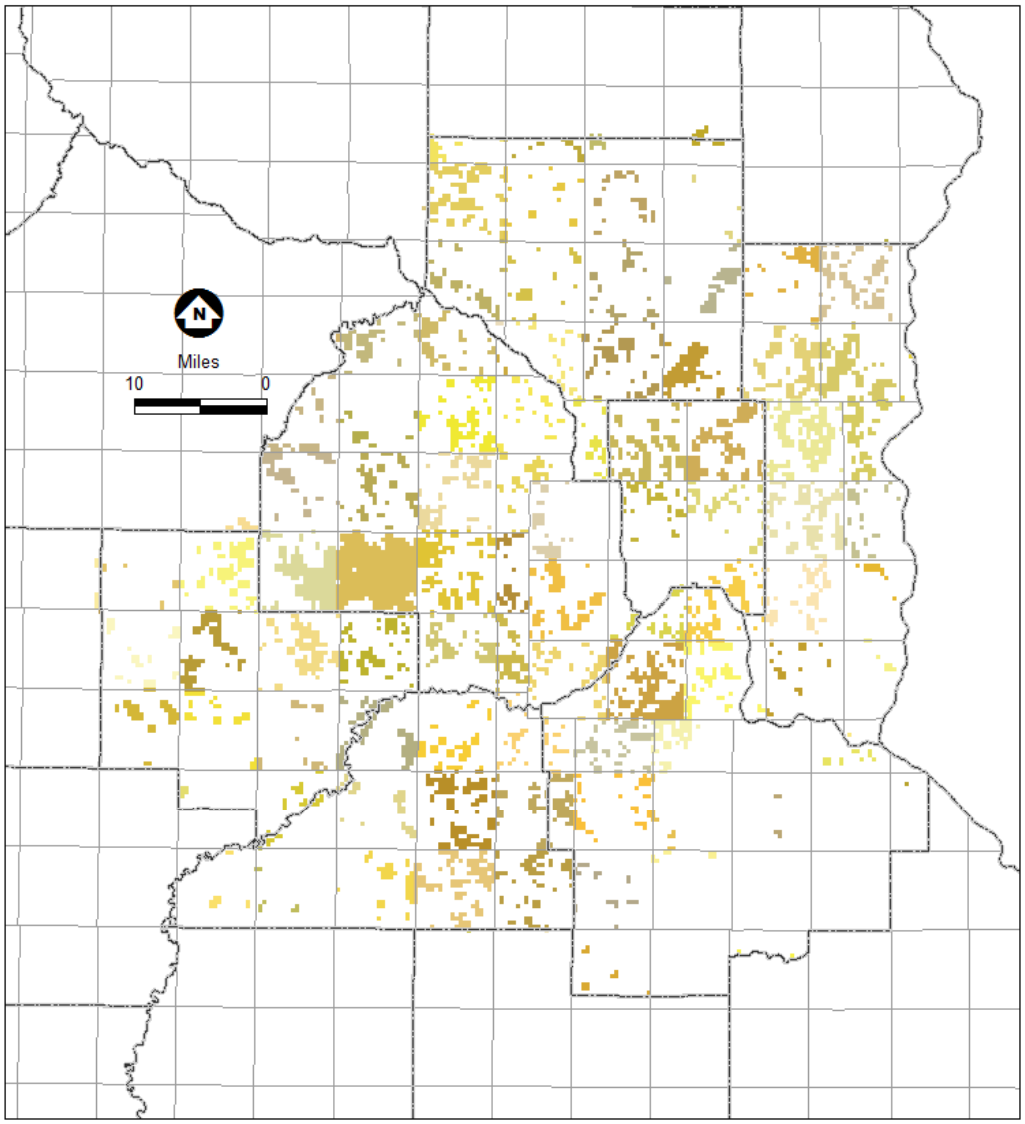

**Basins potentially vulnerable to pumping with wide littoral zone**

Threshold:
-10% change in flux

Count:
68 basins

Vulnerability defined by Barr (2010)

# Constraints – Flux




## Remaining lakes

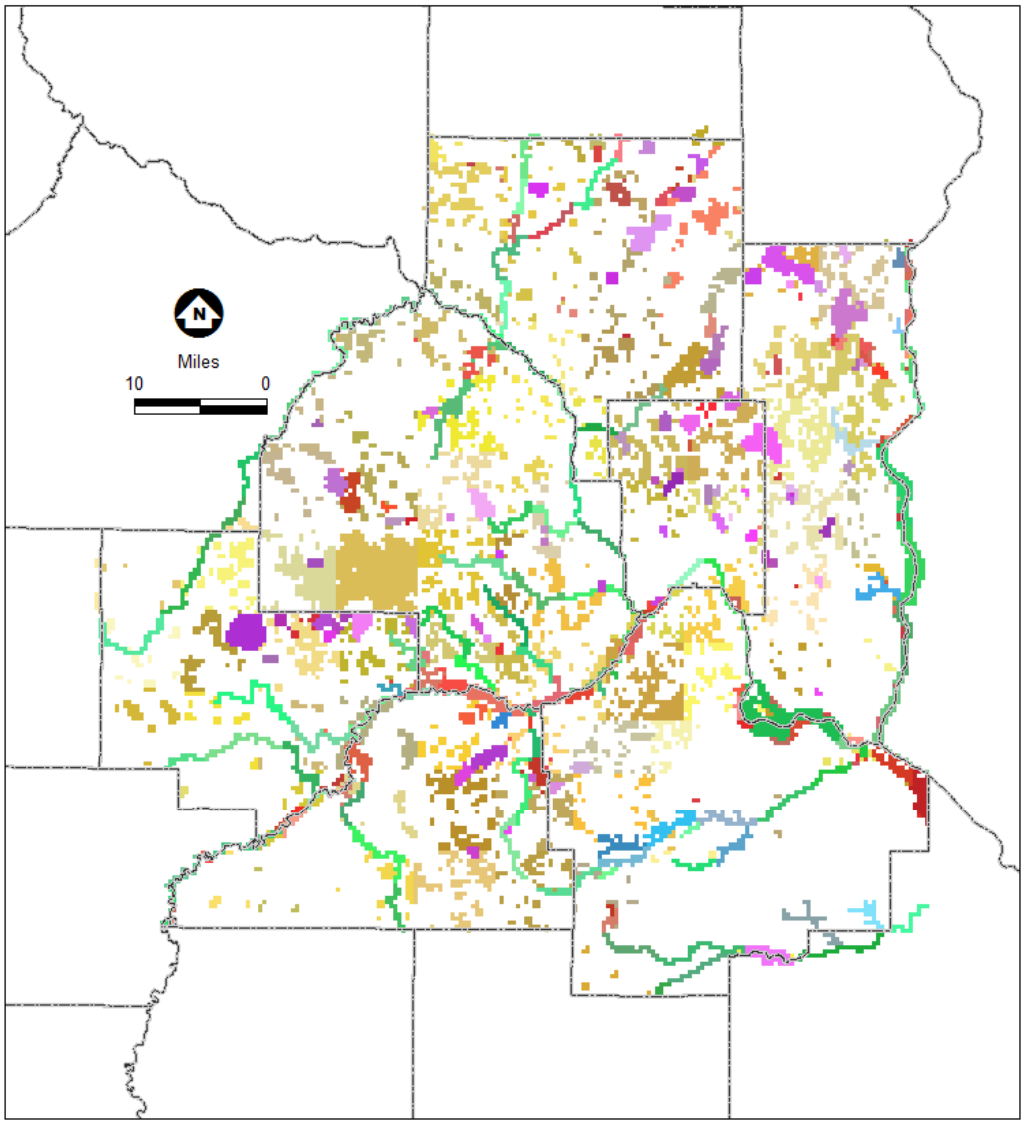
Threshold:
-15% change in flux
grouped at township scales

Count:
103 areas

Areas defined by Minnesota County Biological Survey (2013)

.lyr

# Constraints – Flux

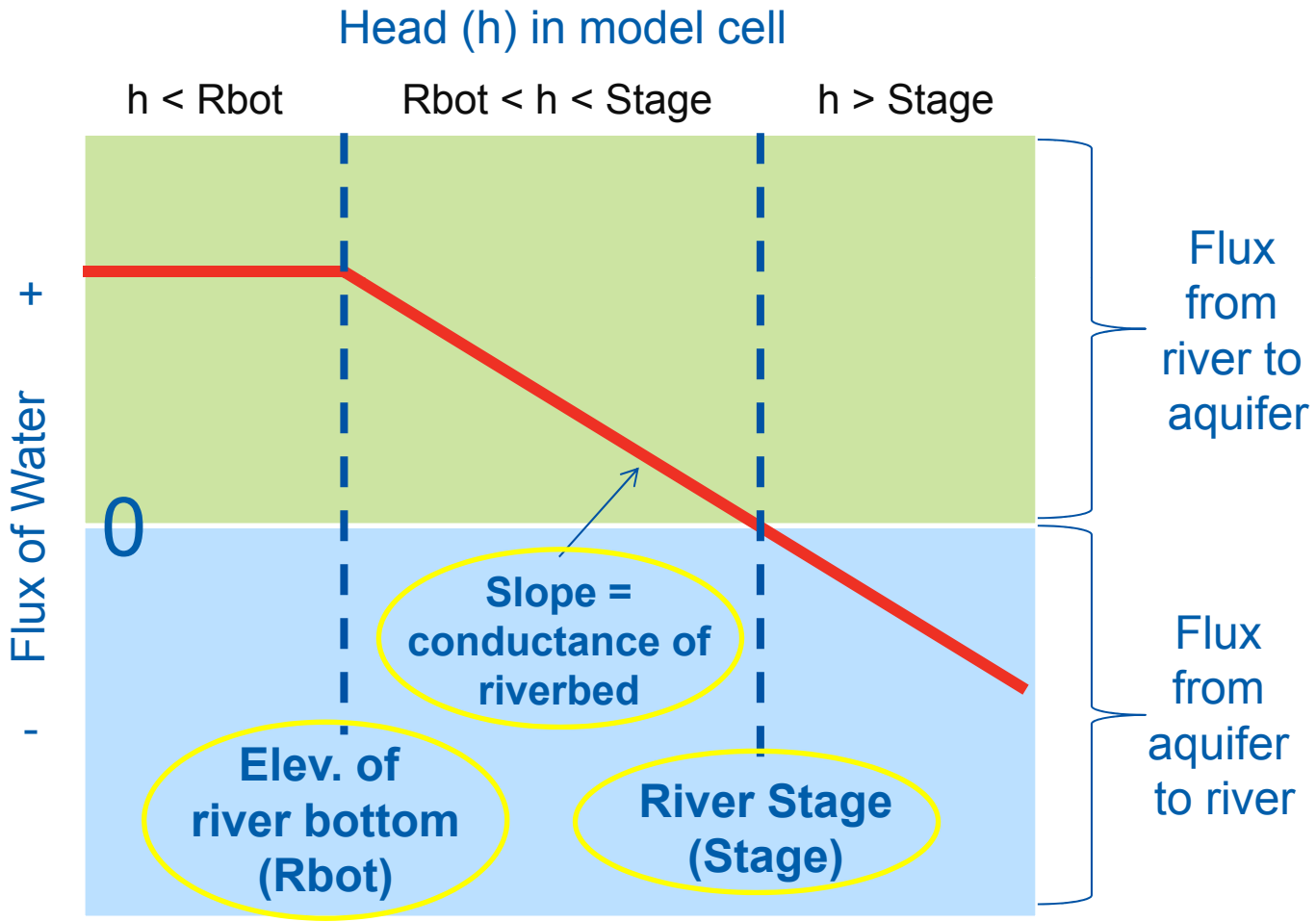



## 371 Flux Constraints

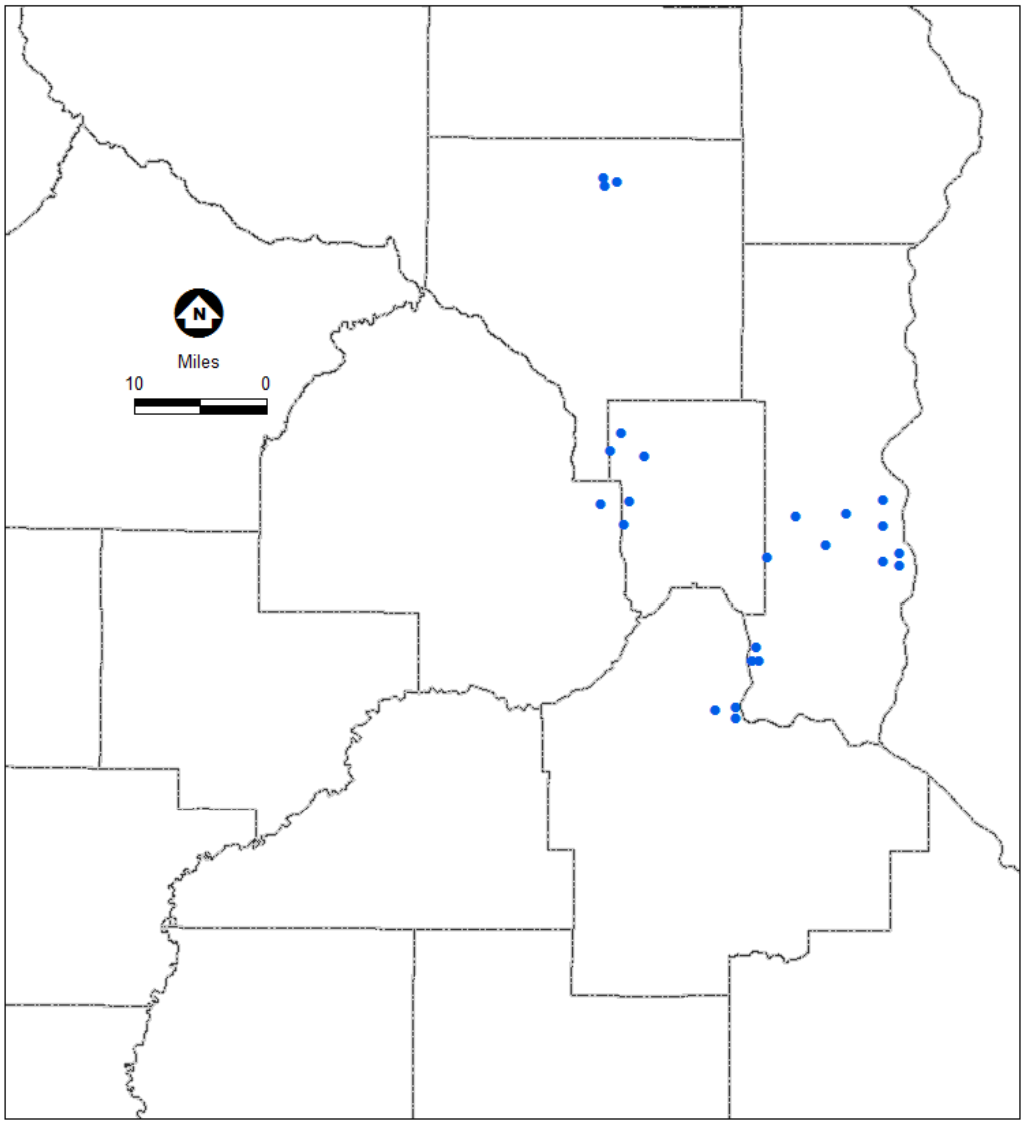
- Biodiversity Area
- Stream/River
- Trout Stream
- Twp. Rng. Group
- Vulnerable Basin

# Why not ½ acre foot (6 inch drawdown) for lakes?

- Requires fully coupled groundwater-surface water model
- Lakes in Metro Model 3 simulated with River Package cells (stage is fixed).

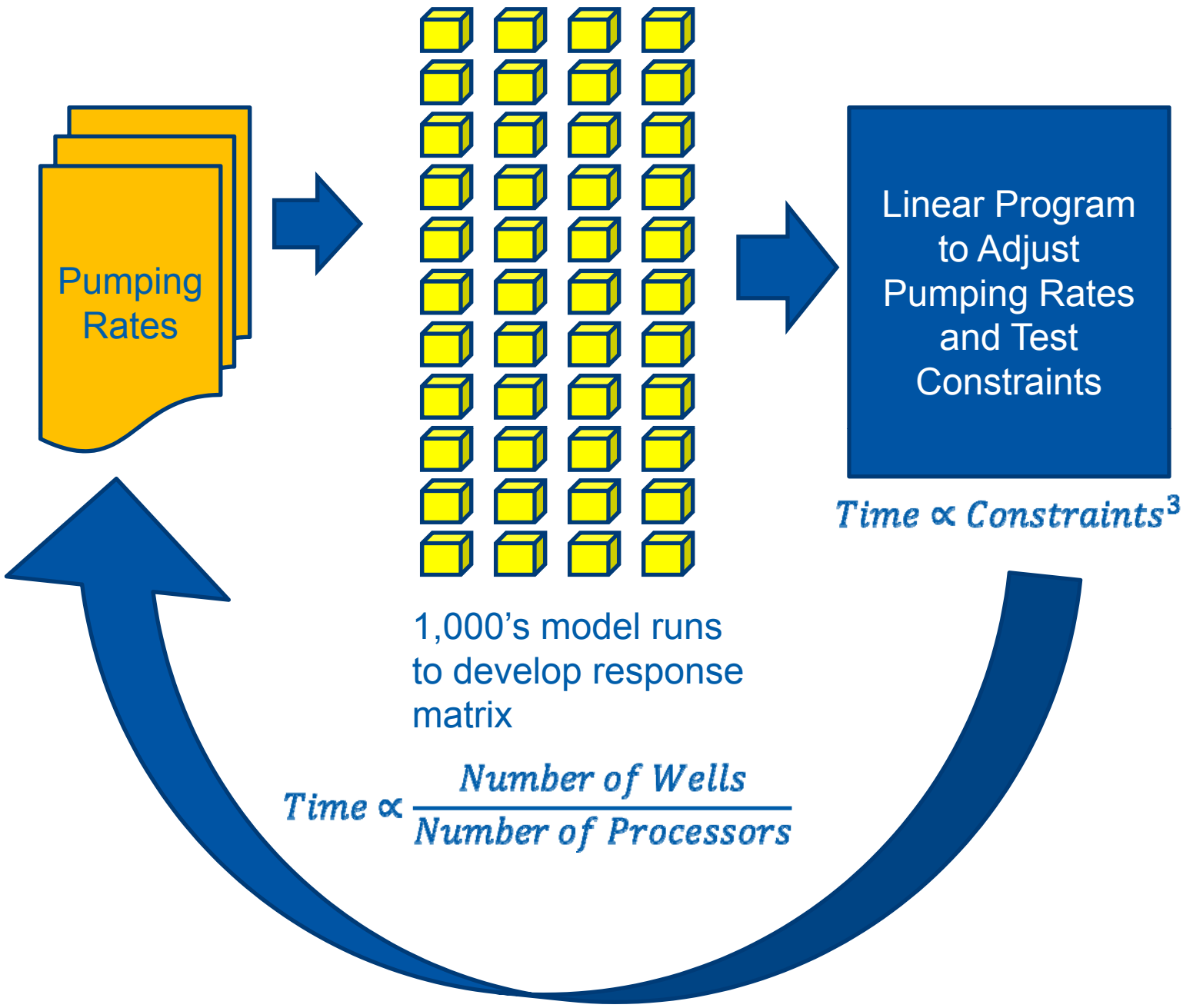


# Constraints – Flow Direction

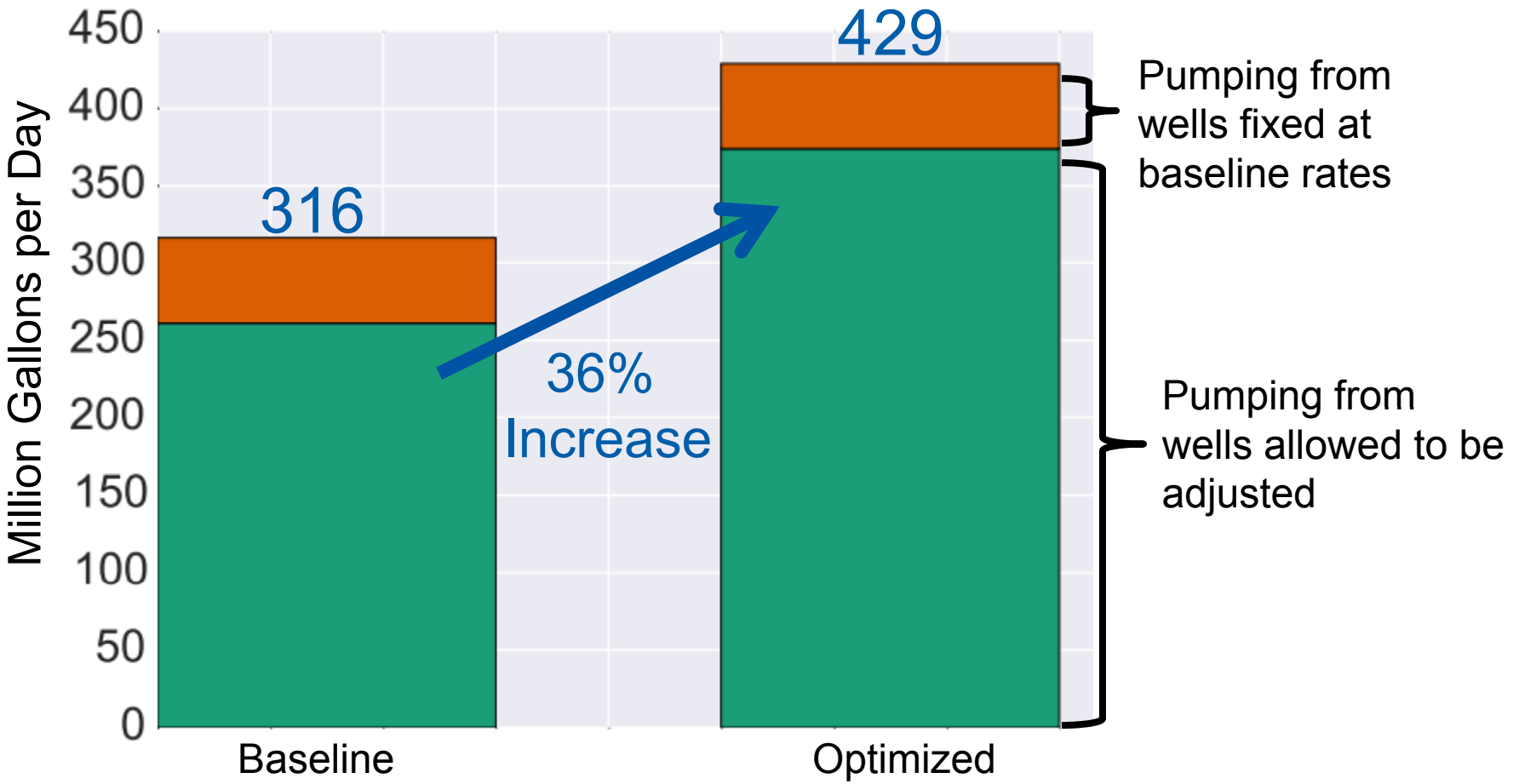



Threshold:
10° change in direction

Count:
8

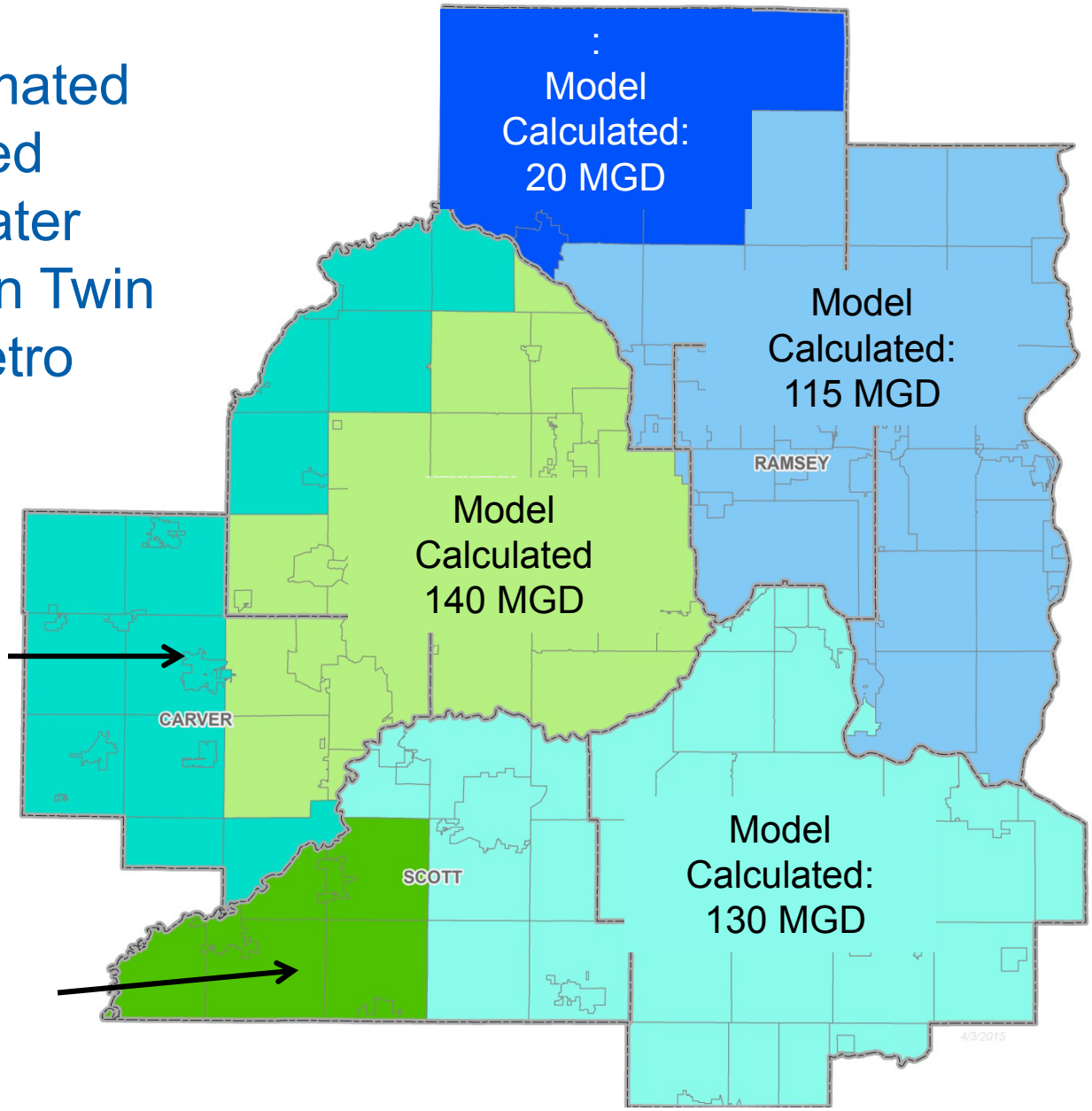

Pumping Rates
Linear Program to Adjust Pumping Rates and Test Constraints
$Time \propto Constraints^3$
1,000's model runs to develop response matrix
$Time \propto \frac{Number\ of\ Wells}{Number\ of\ Processors}$

# Region-Wide Optimization Results

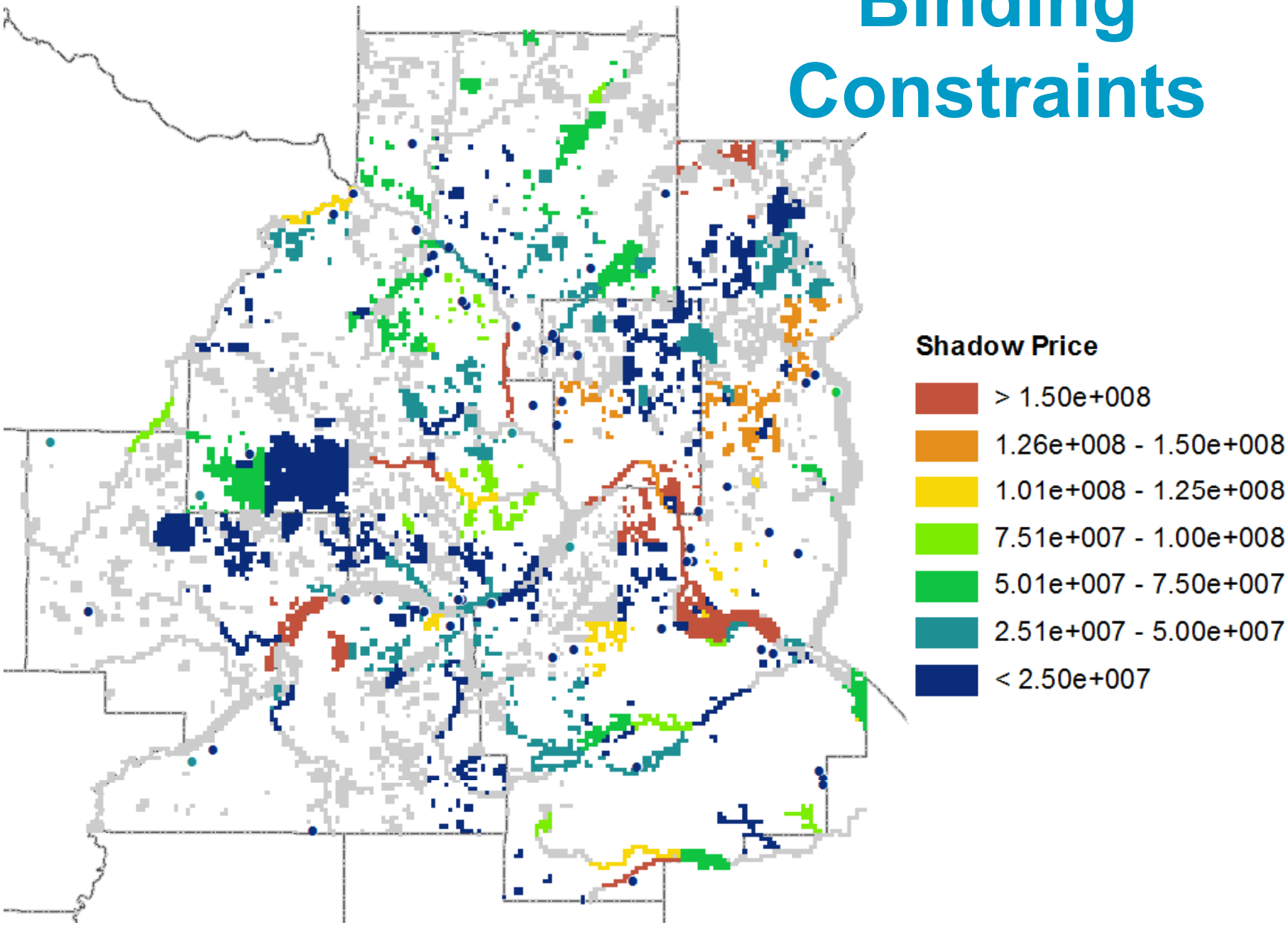



* Does not include surface water withdrawals

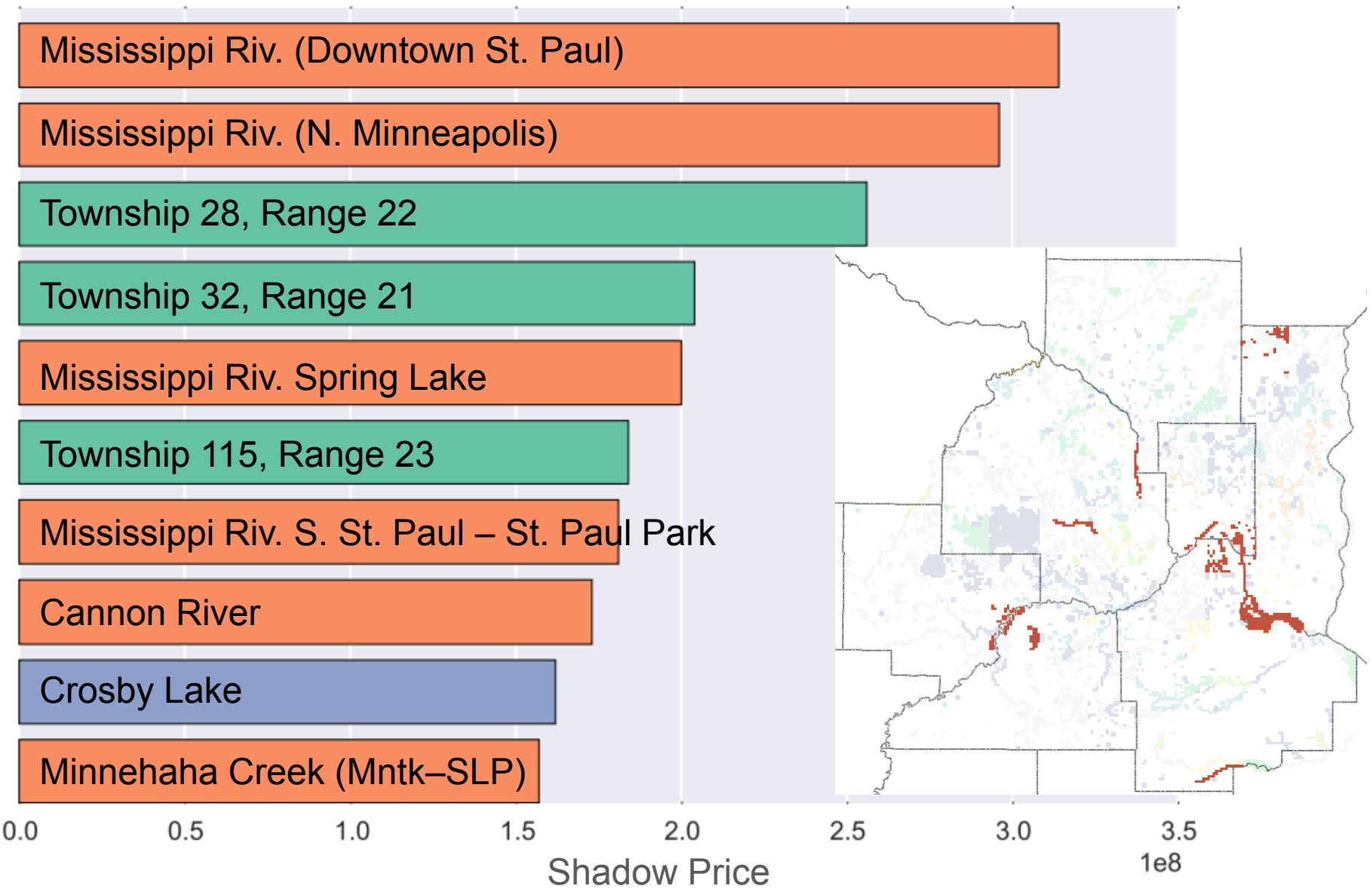
# Model estimated optimized groundwater distribution in Twin Cities Metro



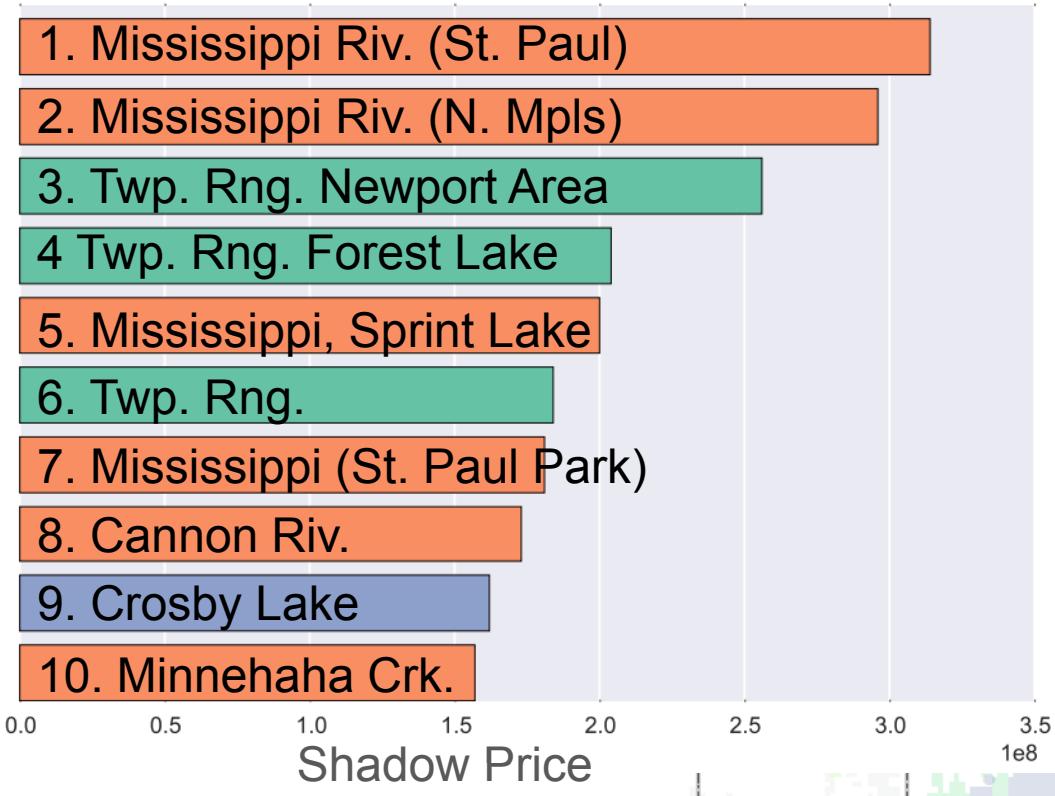
# Binding Constraints

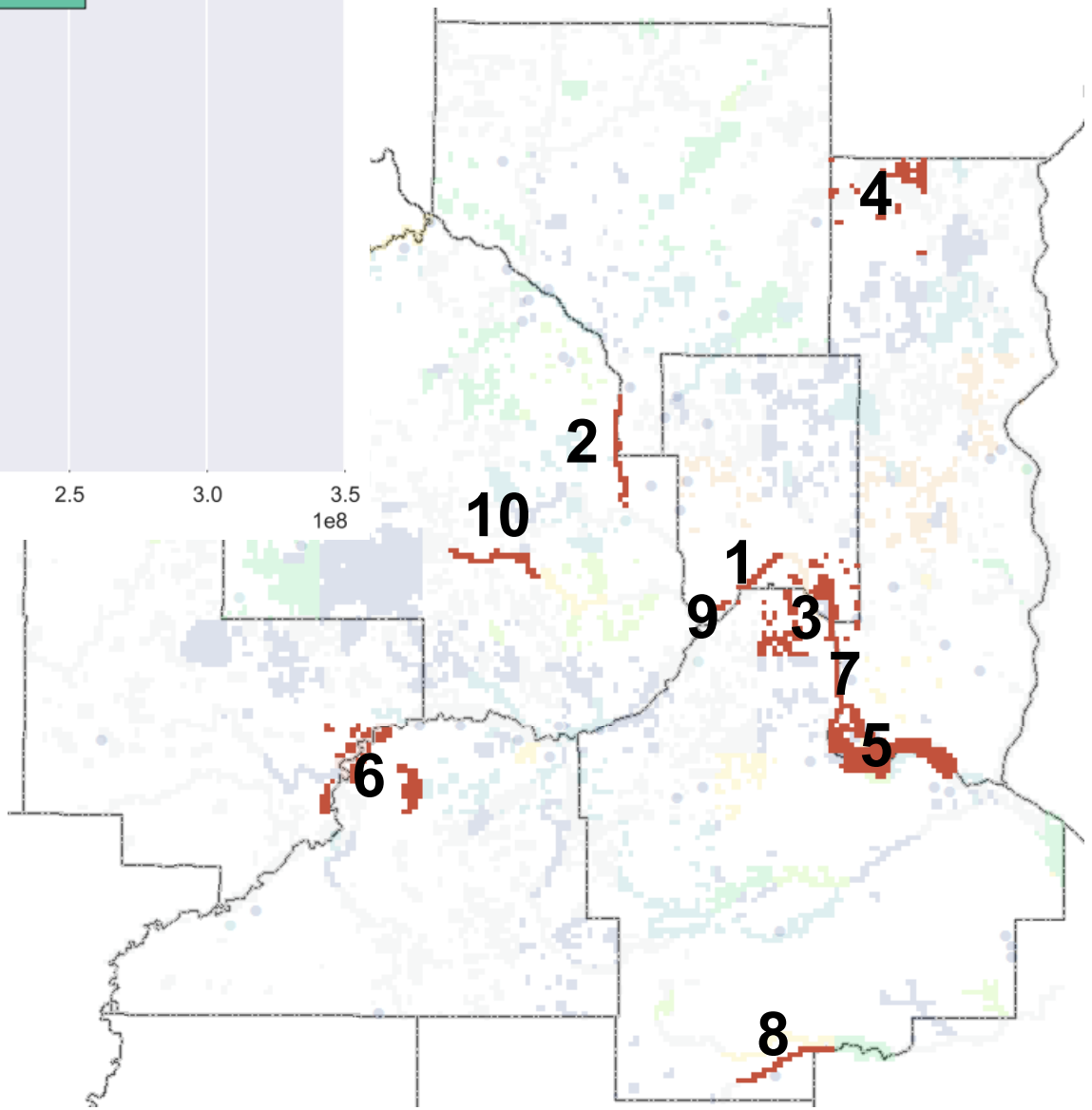


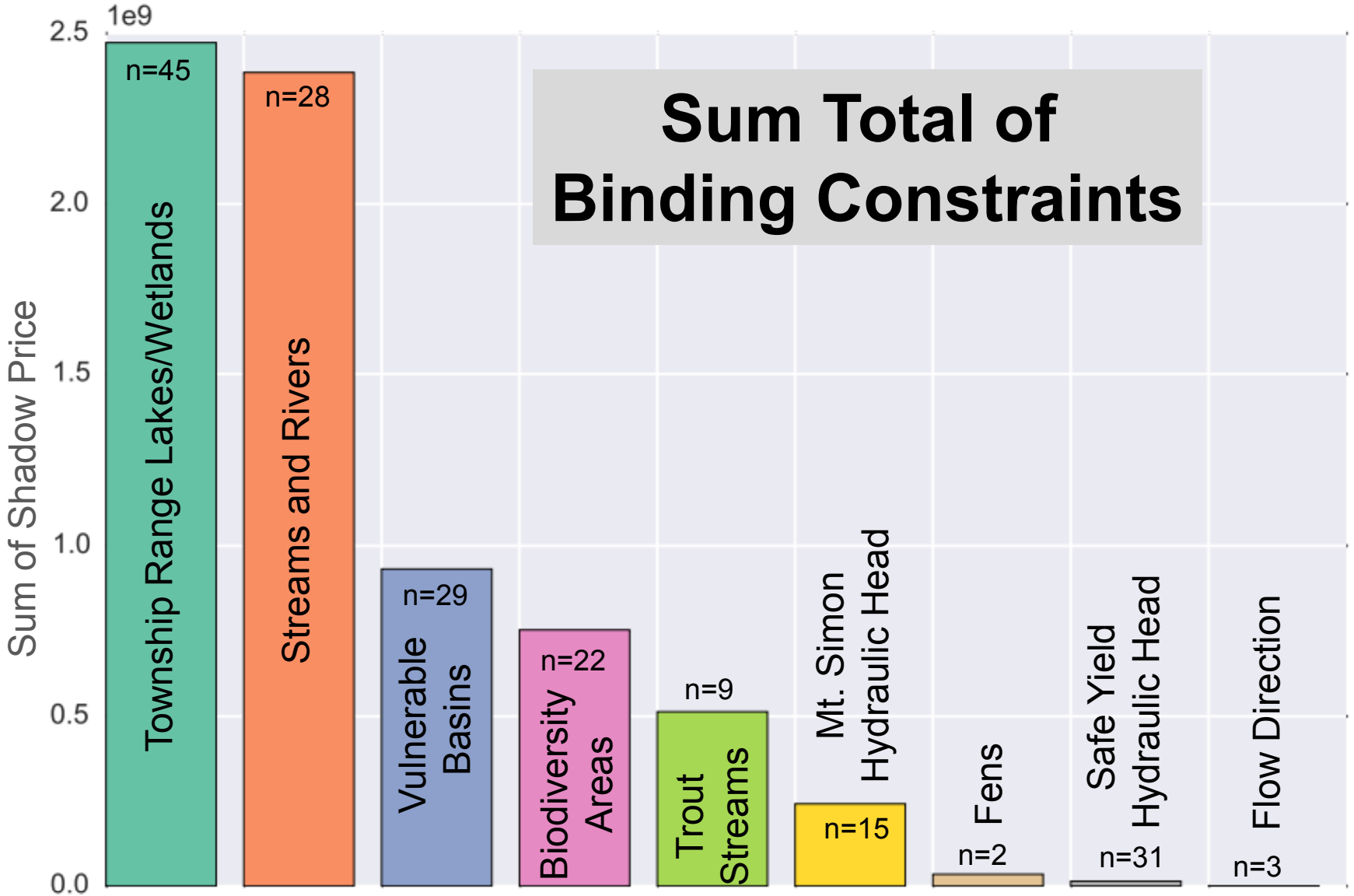
# Binding Constraints

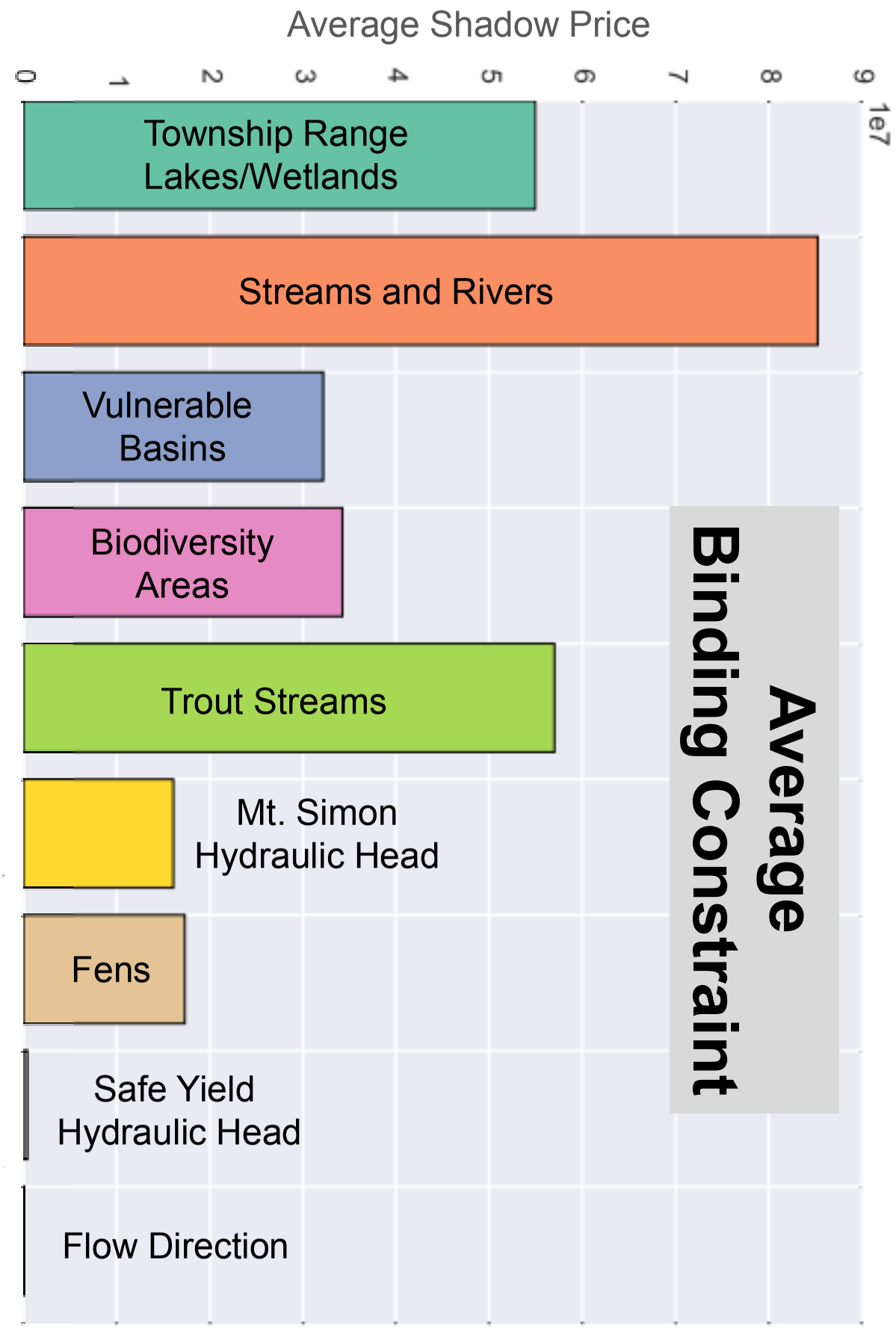


# Binding Constraints

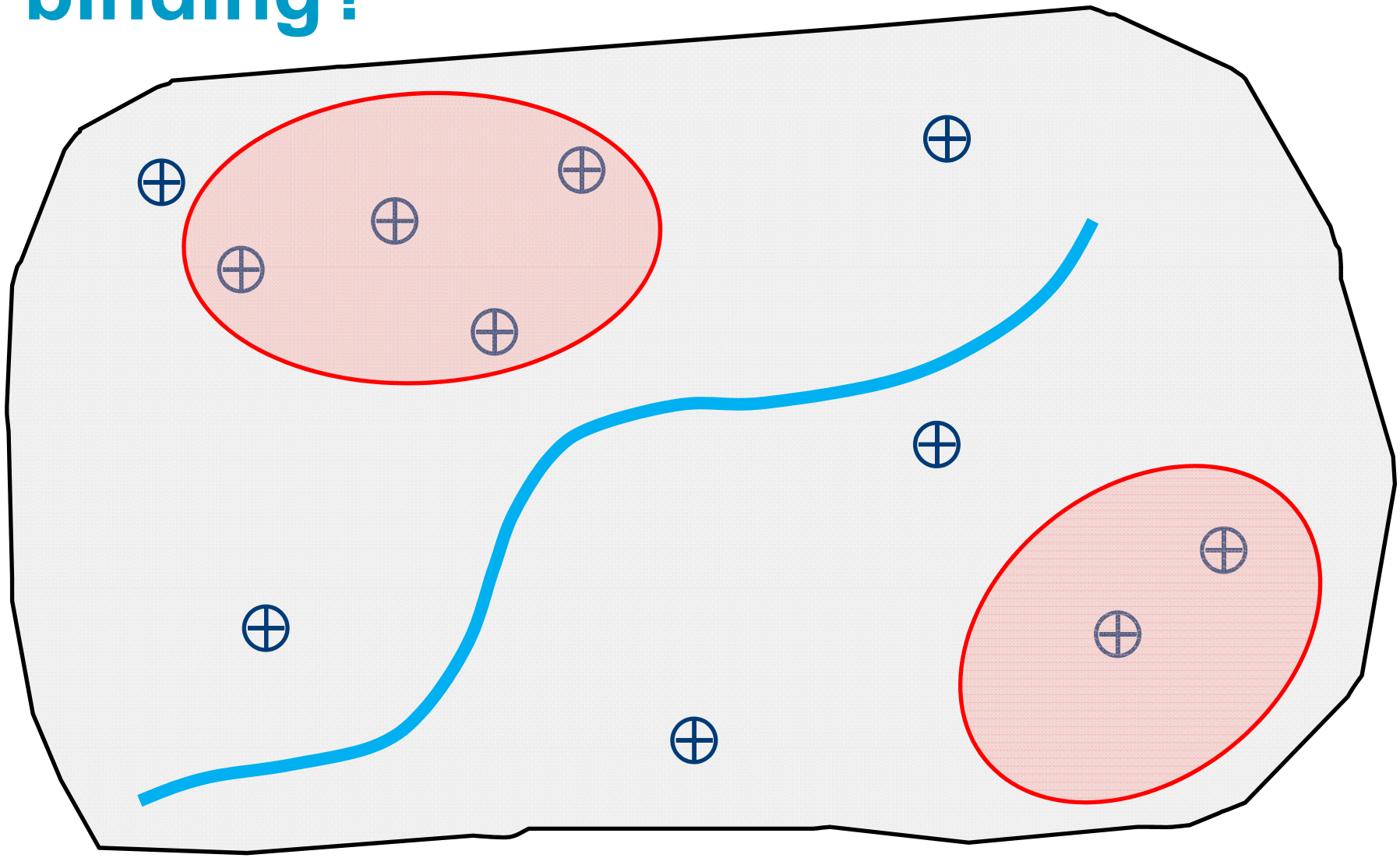



Sum Total of Binding Constraints
Sum of Shadow Price
1e9
2.5
2.0
1.5
1.0
0.5
0.0
Township Range Lakes/Wetlands
n=45
Streams and Rivers
n=28
Vulnerable Basins
n=29
Biodiversity Areas
n=22
Trout Streams
n=9
Mt. Simon Hydraulic Head
n=15
Fens
n=2
Safe Yield Hydraulic Head
n=31
Flow Direction
n=3

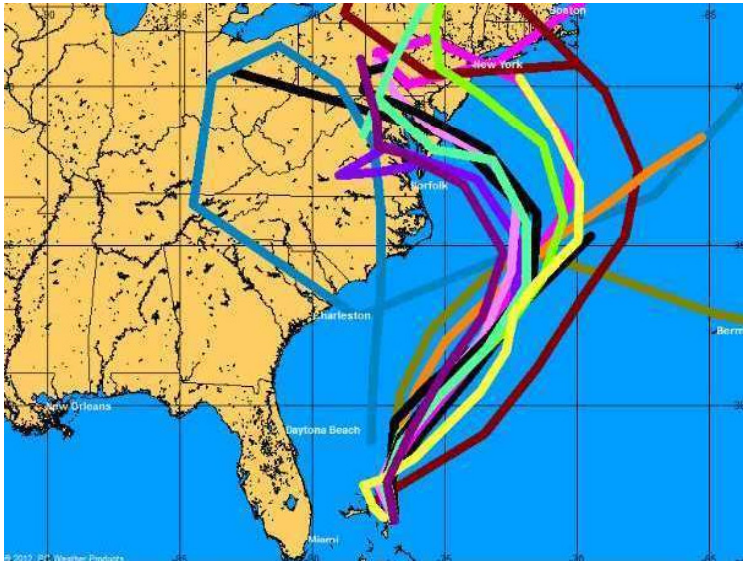

Average Shadow Price
0
1
2
3
4
5
6
7
8
9
1e7
Township Range
Lakes/Wetlands
Streams and Rivers
Vulnerable
Basins
Biodiversity
Areas
Trout Streams
Mt. Simon
Hydraulic Head
Fens
Safe Yield
Hydraulic Head
Flow Direction
Average
Binding Constraint

# Why are flux constraints more binding?



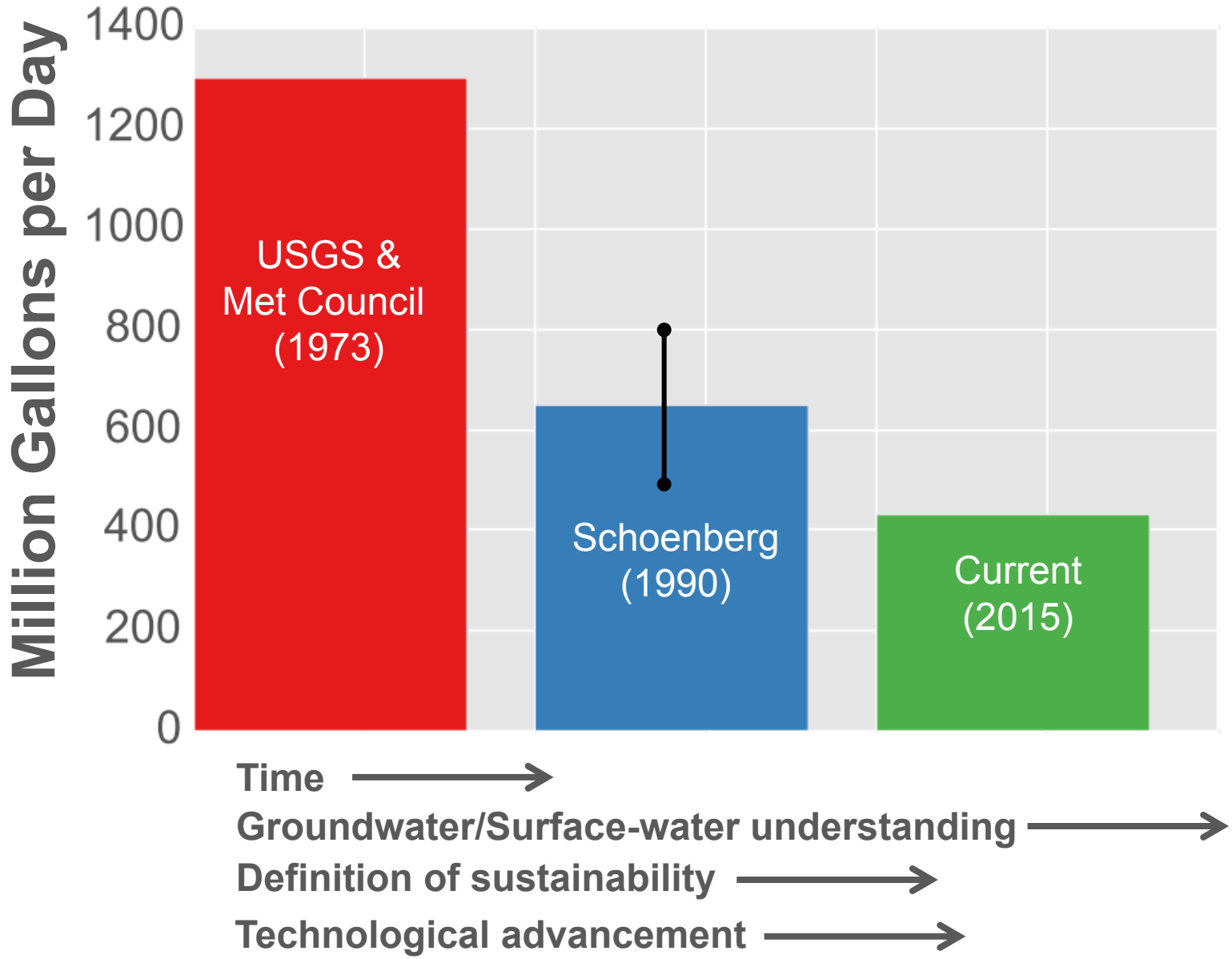
# Sources of uncertainty

- Non-unique solution
- Lake levels are not included directly (requires more detailed model)
- Changing constraints can have very large effect (especially base flow constraints of Mississippi River)
- Model parameter uncertainty
- Limited pumping to existing well infrastructure
- Well operational constraints not considered




PCWeather Products, Inc.

# Sustainable Pumping




Centennial, CO

# GWM-VI and MODFLOW