Groundwater Management Policy Evaluation with a Spatial-Dynamic Hydro-Economic Modeling Framework

Presented by Aaron Hrozencik

Dr. Dale Manning

Dr. Jordan Suter

Dr. Chris Goemans

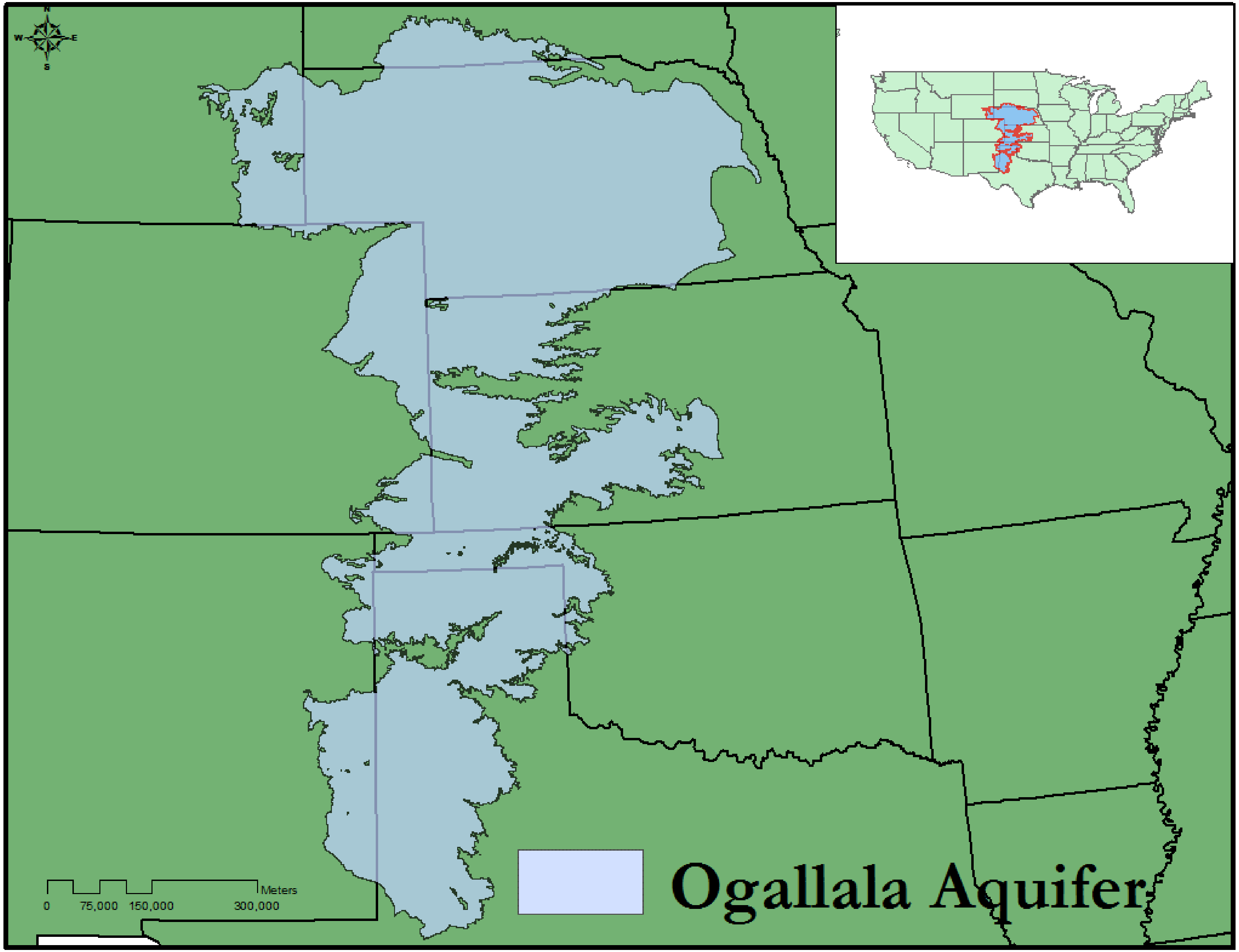
Dr. Ryan Bailey

Colorado State University

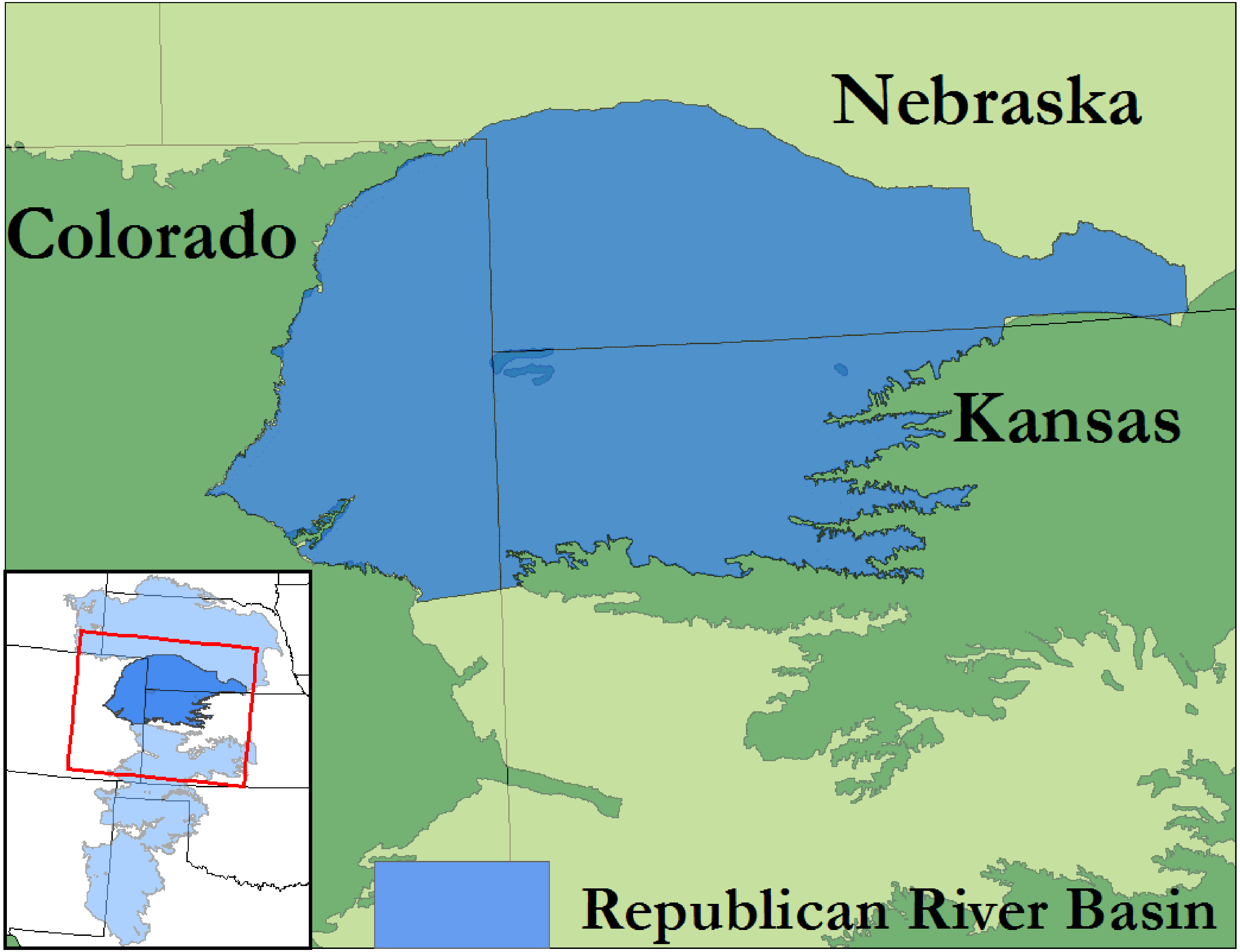
Motivation

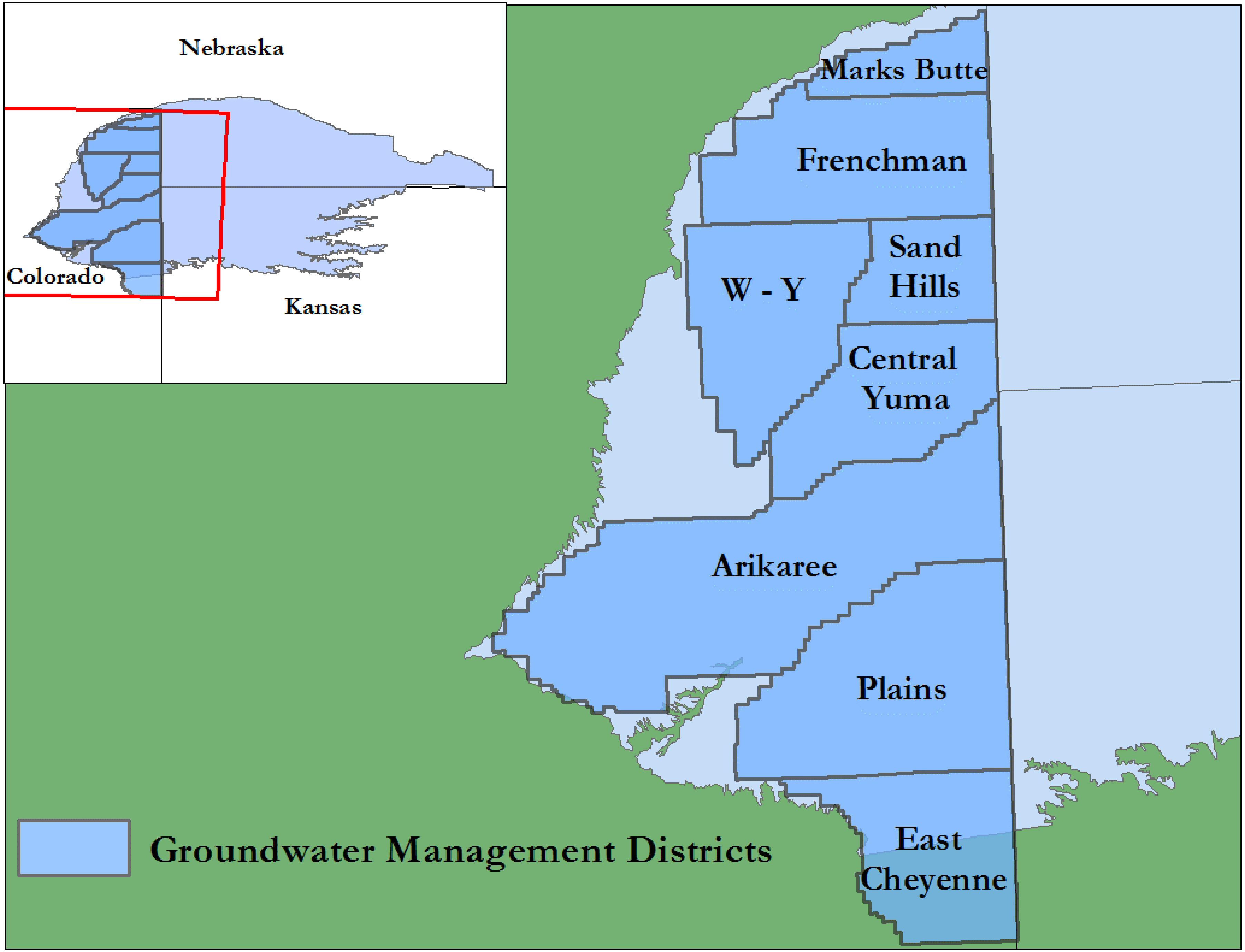
Challenges associated with managing spatial and temporal dynamics in common pool resources

- Fisheries
- Ecosystem Biodiversity
- Wildlife



N
W
E
S
Meters
0
75,000
150,000
300,000
Ogallala Aquifer


Nebraska
Colorado
Kansas
Republican River Basin


Nebraska
Colorado
Kansas
Marks Butte
Frenchman
Sand Hills
W - Y
Central Yuma
Arikaree
Plains
East Cheyenne
Groundwater Management Districts

Research Question:

What is the value of spatially differentiated policies to reach common groundwater conservation goals?

Contribution to literature

- Nested governance, spatially explicit policies

Dietz, Ostrom & Stern, 2003; Sanchirico & Wilen, 2005; Edwards, 2016

- Economic literature assessing gains to groundwater management

Gisser & Sanchez, 1980; Feinerman & Knapp, 1983; Brill & Burness, 1994; Rubio & Casino, 2001

- Economics of spatially explicit groundwater utilizing insights from hydrology

Saak and Peterson, 2007; Brozovic et al., 2010; Pfeiffer and Lin, 2012; Guilfoos et al., 2013, Foster et al., 2014

Groundwater Terminology

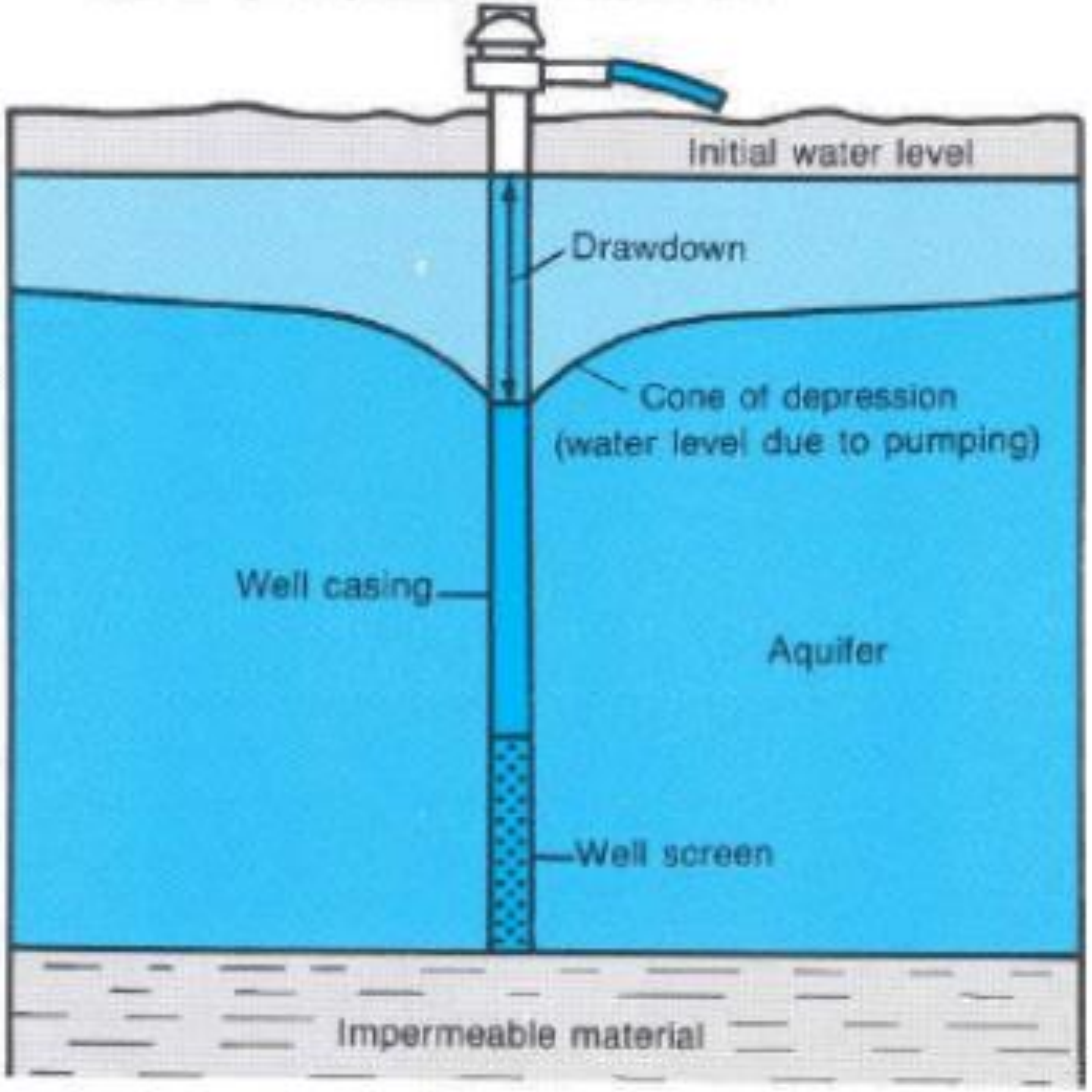
Saturated thickness –

vertical distance of aquifer permeated by water

Hydraulic conductivity – potential velocity of lateral groundwater

Well capacity (yield) –

max flow rate that a well can sustain over a period of time (gallons per minute)



Microeconomic Foundations

Assumes inter-seasonal myopic behavior (Foster et al. 2014)

Stage 1: Planting Decision

$$\max_{A_{ij}} E\left[\sum_{j=1}^{J} p_j A_{ij} f_j\left(w_{ij}; c_{it}, \theta_{it}, \phi_i, \sum_{j=1}^{J} A_{ij}\right) - A_{ij} r_{Aj} - A_{ij} w_{ij} r_w\right]$$

Stage 2: Groundwater Pumping Decision

$$\max_{w_{ij}} \left[\sum_{j\in R} p_j \bar{A}_{ij} f_j\left(w_{ij}; c_{it}, \widehat{\theta_{it}}, \phi_i, \bar{A}_{ij}\right) - A_{ij} w_{ij} r_w\right]$$

Microeconomic Foundations: Policy Options

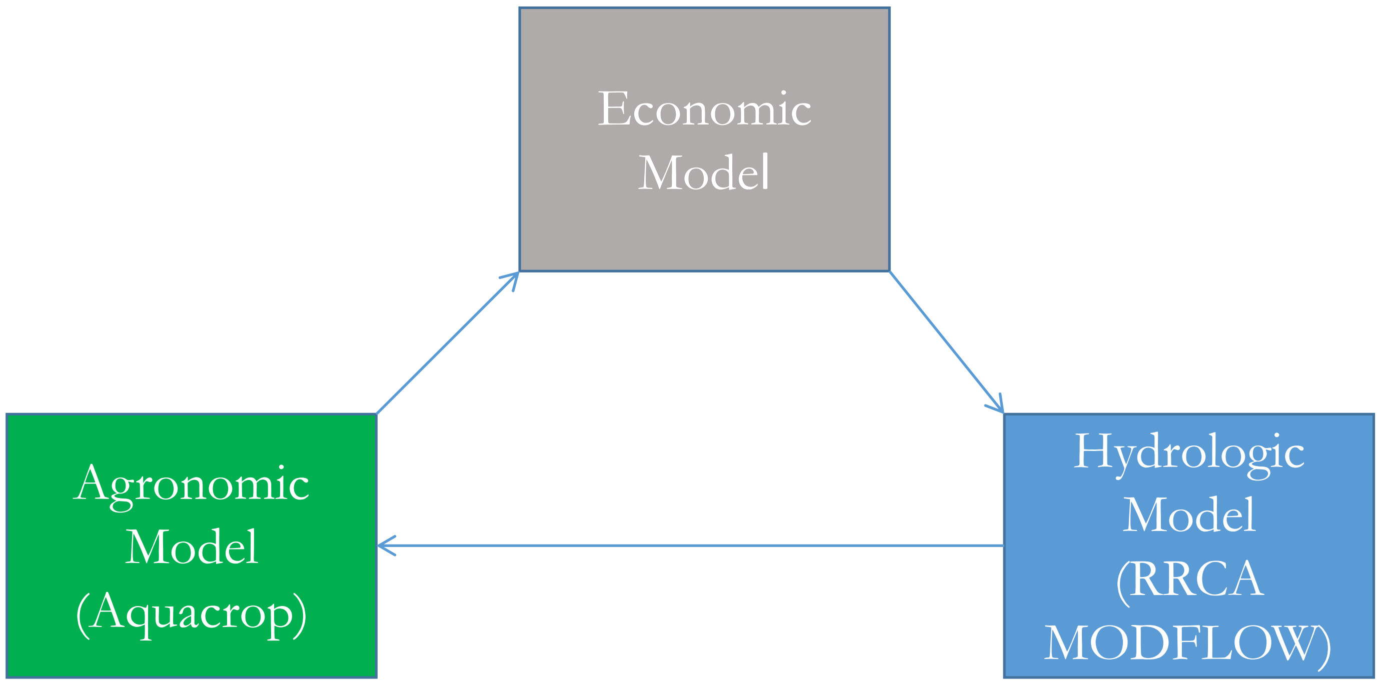
Stage 1:

$$\max_{A_{ij}} E\left[\sum_{j=1}^{J} p_j A_{ij} f_j\left(w_{ij}; c_{it}, \theta_{it}, \phi_i, A_{ij}\right) - A_{ij}(r_{Aj}+\boxed{\tau_A}) - A_{ij}w_{ij}(r_w+\boxed{\tau_w})\right]$$

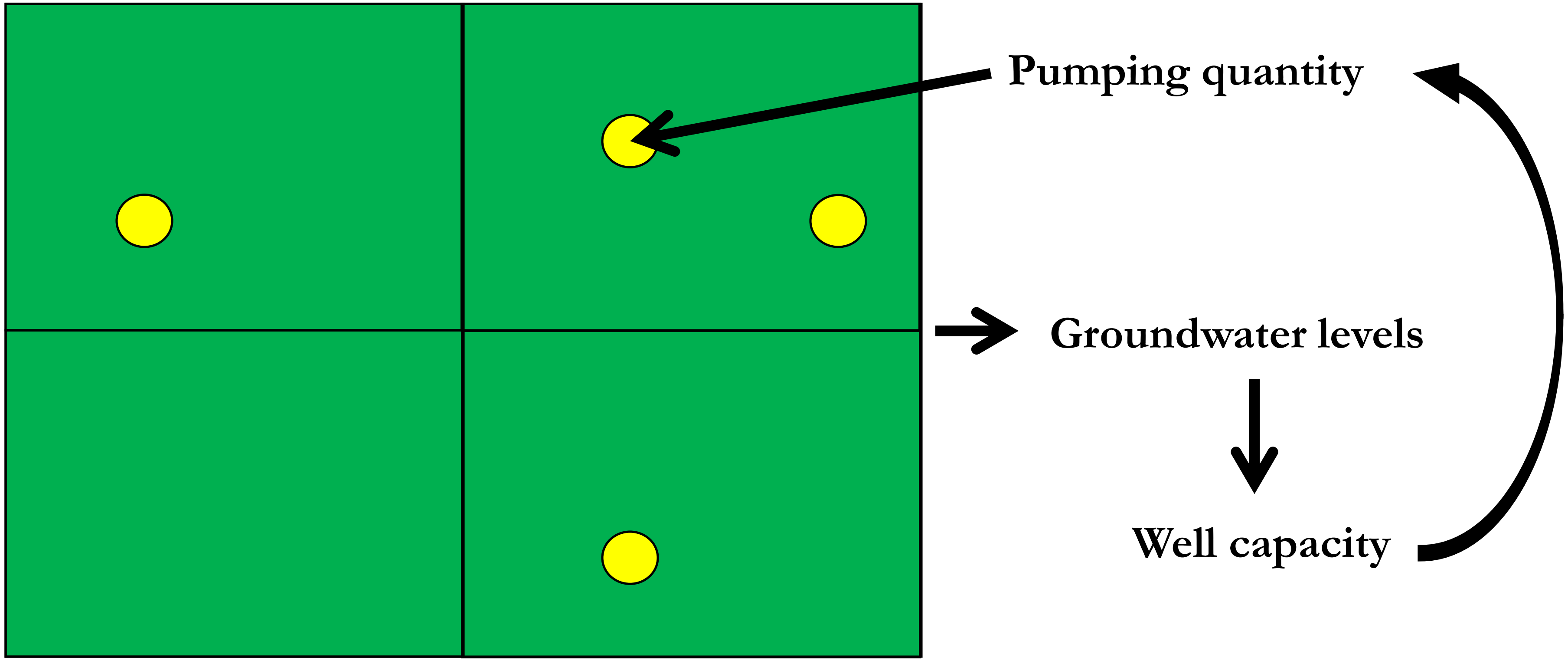
$$\text{subject to } \boxed{\sum_{j=1}^{J} w_{ij} \leq \overline{W}}$$

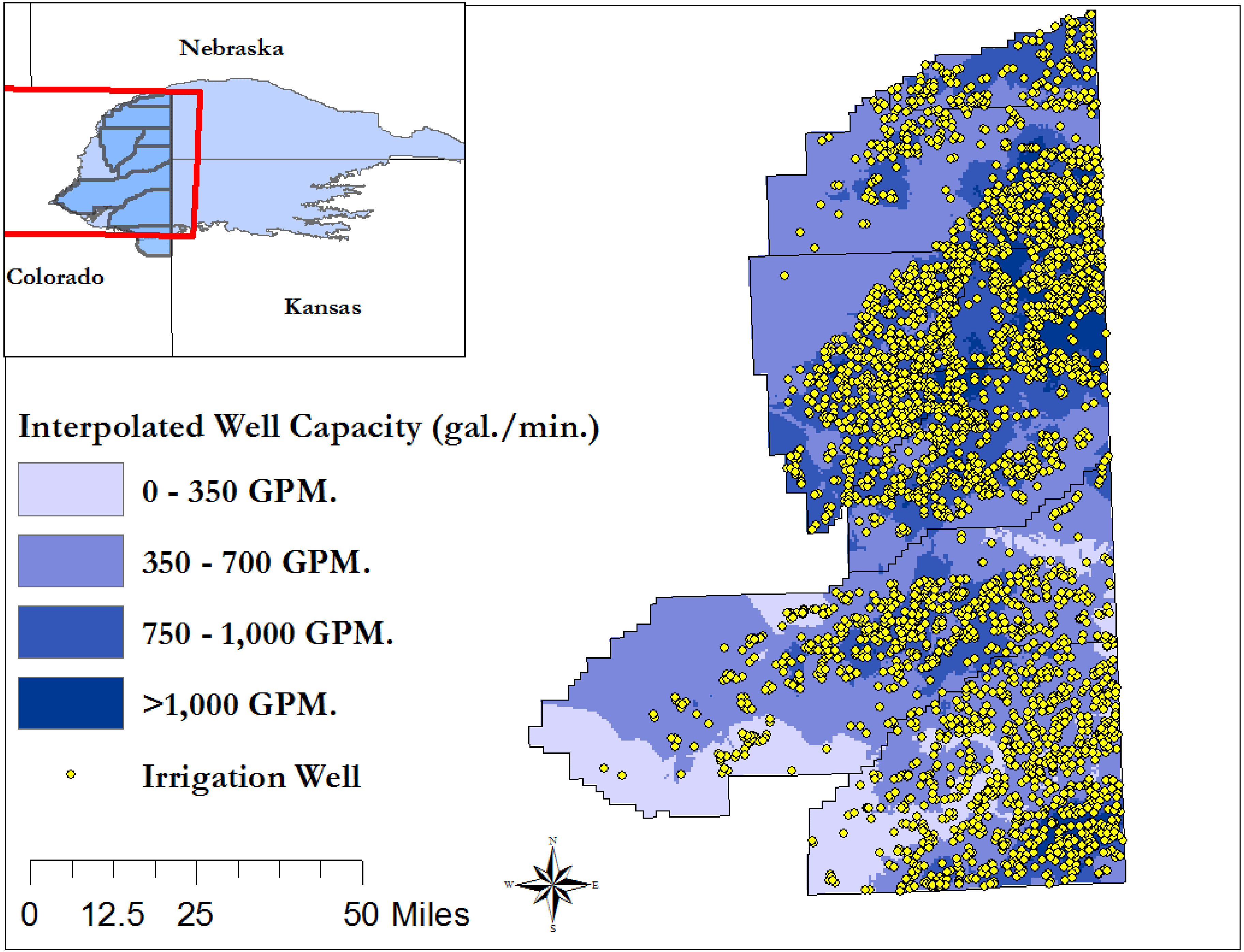
- Planting Tax
- Pumping Tax
- Quota

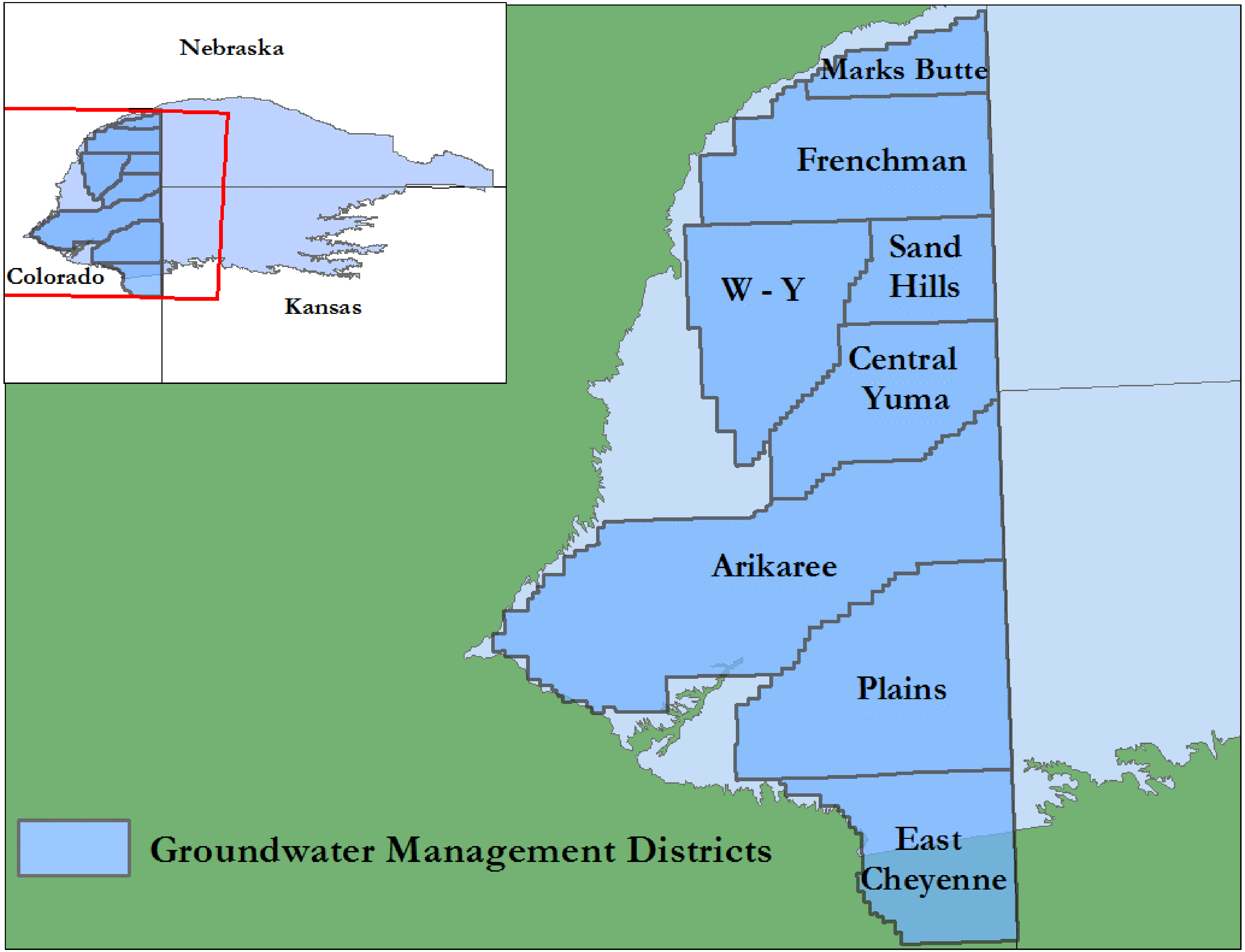
Hydro-Economic Model



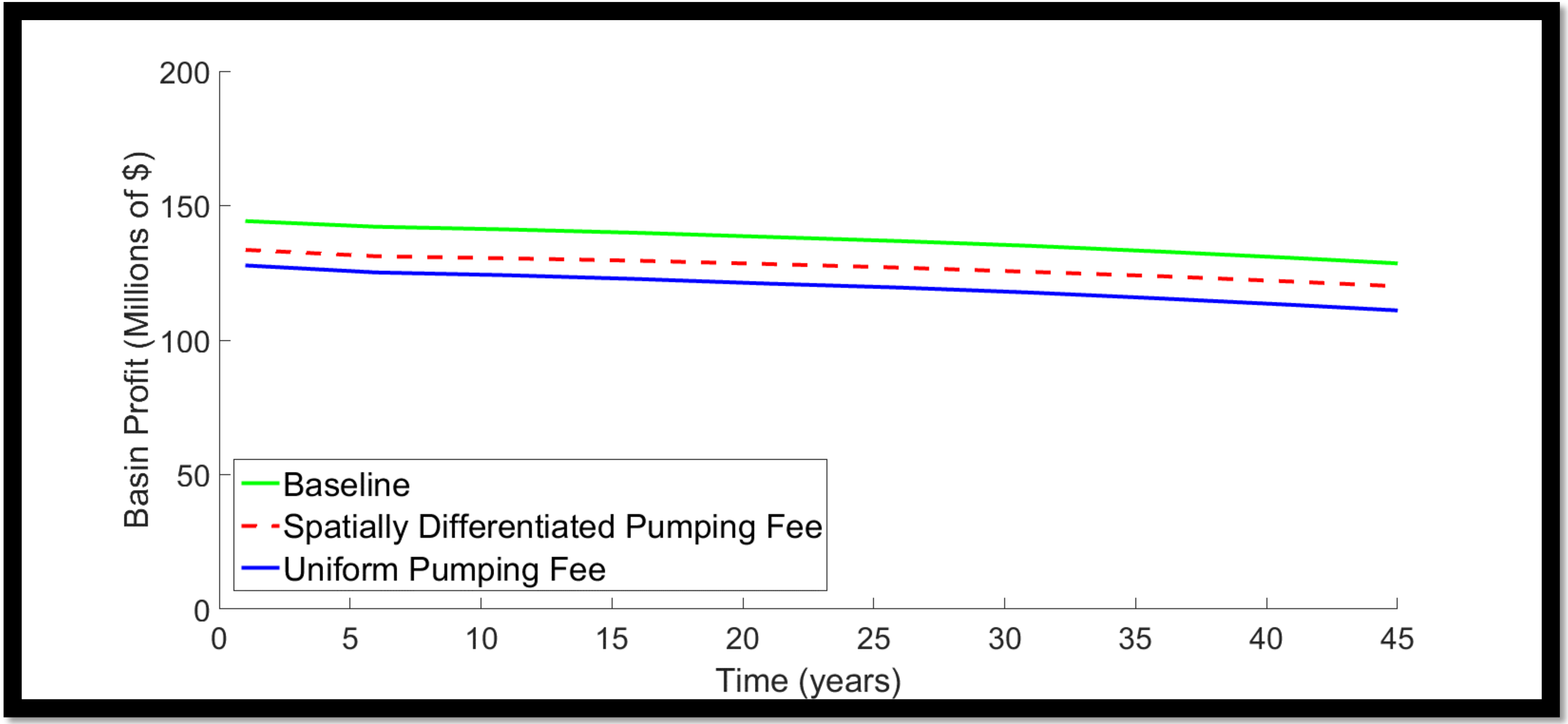
Dynamic Linking



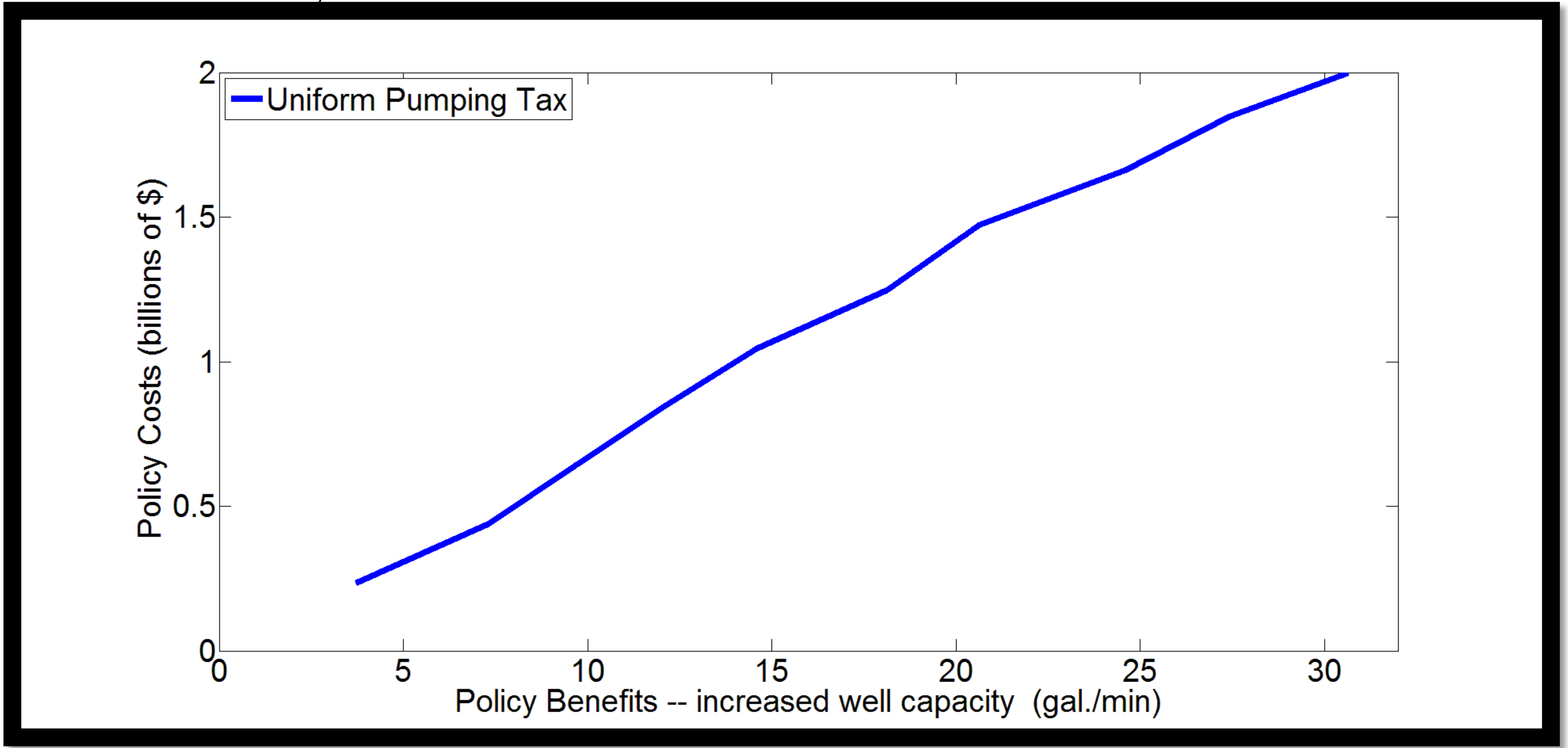

Nebraska
Colorado
Kansas
Interpolated Well Capacity (gal./min.)
0 - 350 GPM.
350 - 700 GPM.
750 - 1,000 GPM.
>1,000 GPM.
Irrigation Well
0
12.5
25
50 Miles
N
W
E
S


Nebraska
Colorado
Kansas
Marks Butte
Frenchman
W - Y
Sand Hills
Central Yuma
Arikaree
Plains
East Cheyenne
Groundwater Management Districts

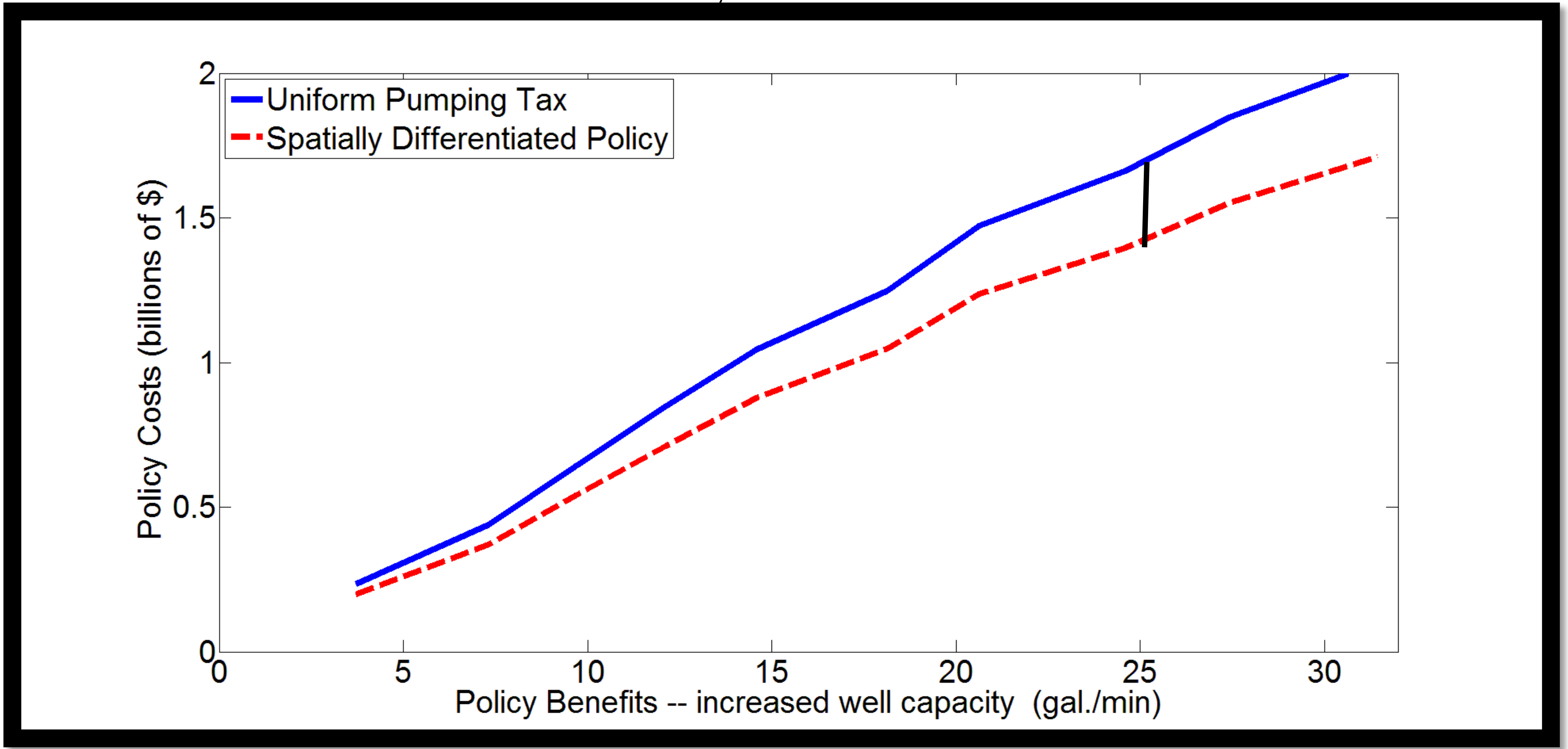
Results: Profit Path for 25% Reduction in Groundwater Pumping



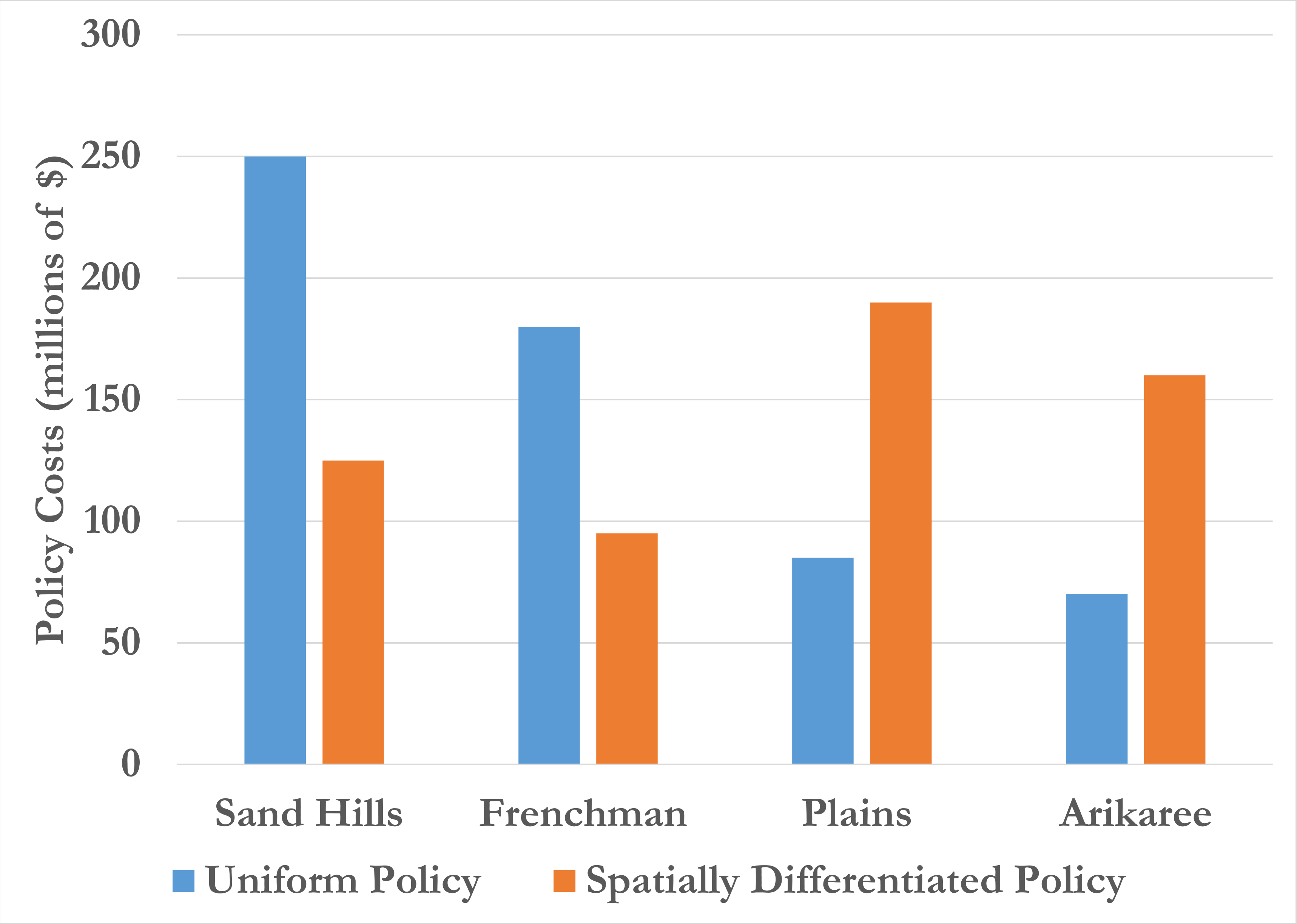
Results: Uniform Policy Costs and Benefits after 50 years



Results: Spatially Differentiated Policy Costs and Benefits after 50 years



GWMD Results



Discussion

How do results inform management strategies for spatially dynamic common pool resources?

- Hydraulic conductivity and initial average well capacity define which GWMDs are targeted in spatially differentiated policy

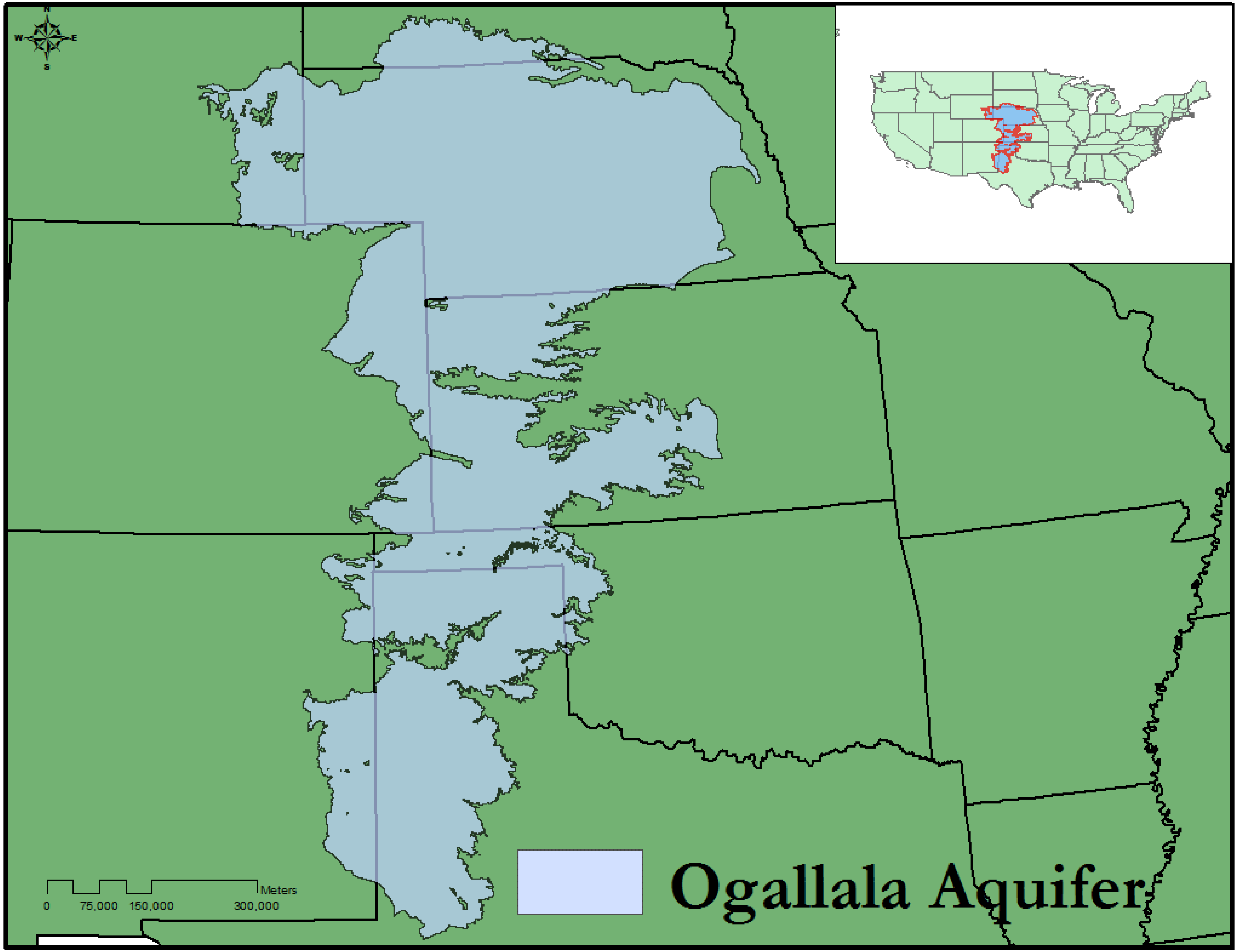
- Incentives and disincentives for cooperation among GWMDs

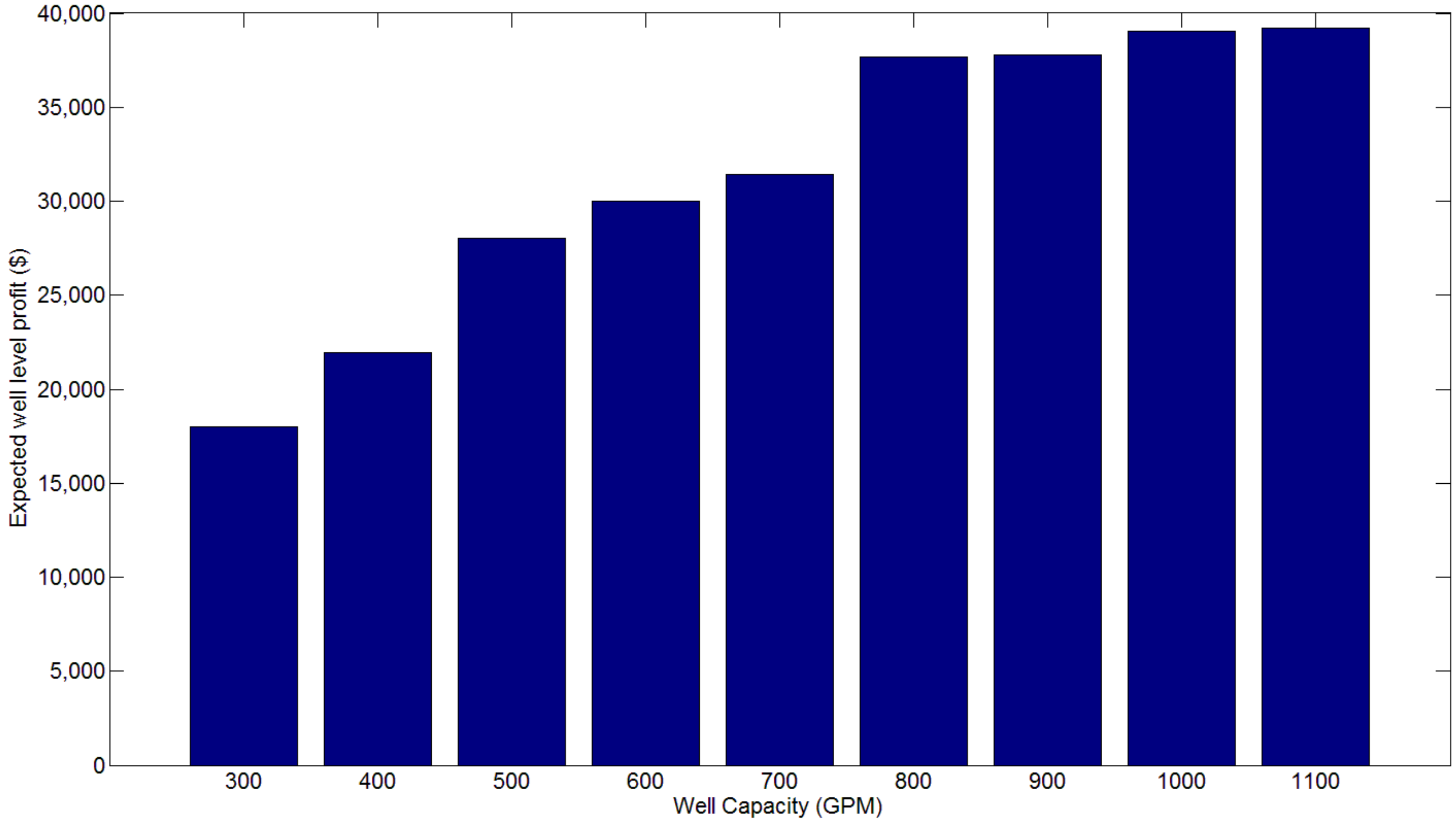
Future Work

- Distributional impacts of spatially differentiated policies.
- Utilize survey instrument to elicit groundwater user preferences over management policies.
- Efficiency of voting mechanisms in groundwater management policy selection.

Questions?

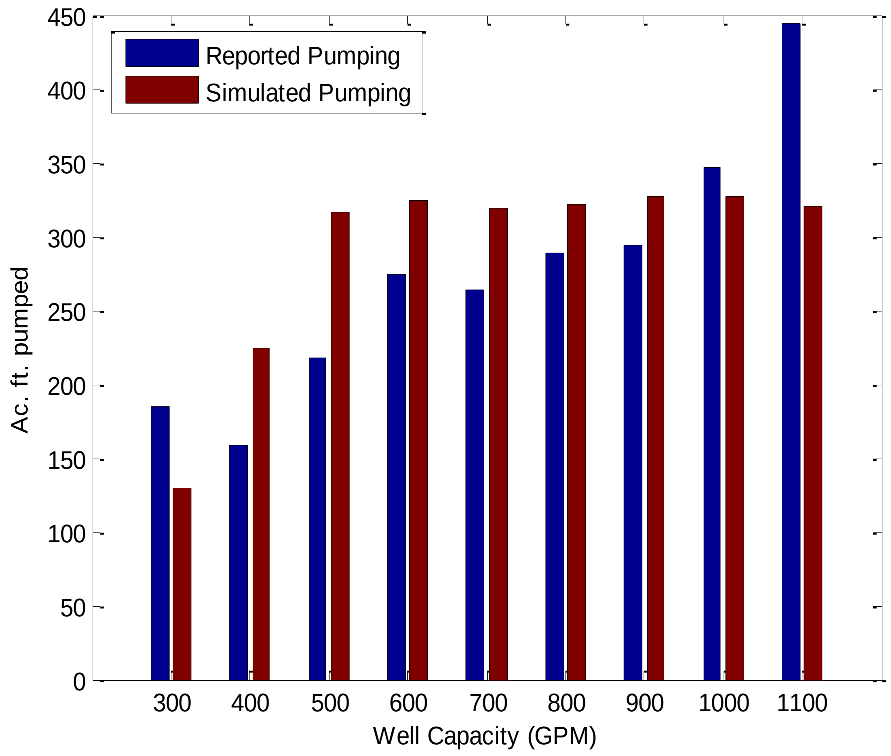
- Appendix


N
W
E
S
0
75,000
150,000
300,000
Meters
Ogallala Aquifer

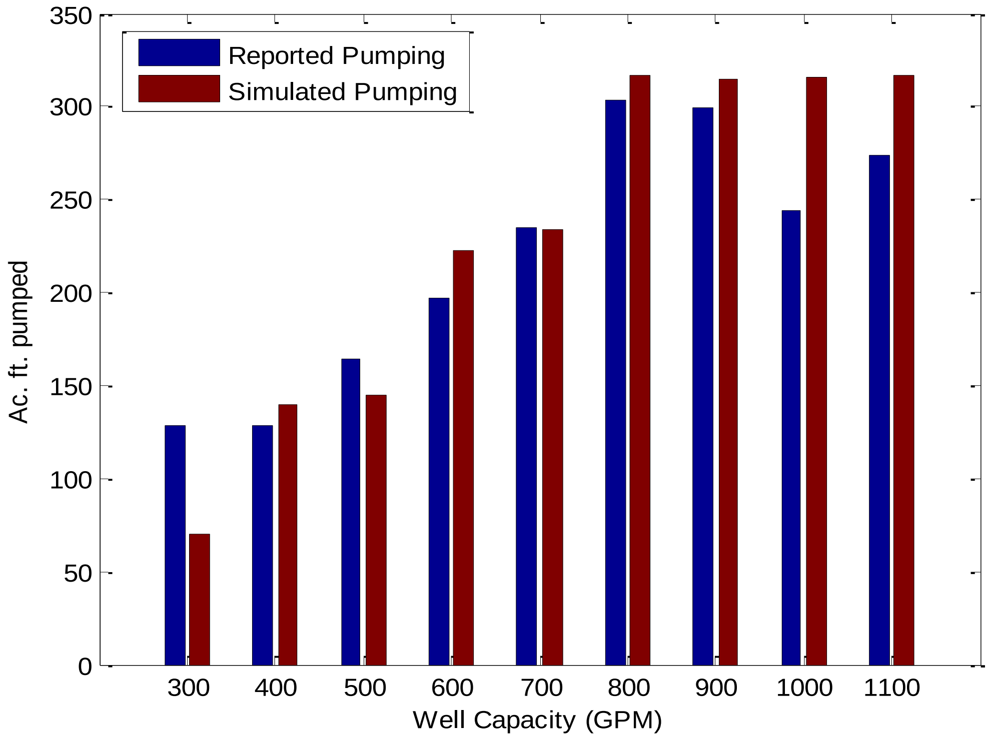


Expected well level profit ($)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
300
400
500
600
700
800
900
1000
1100
Well Capacity (GPM)

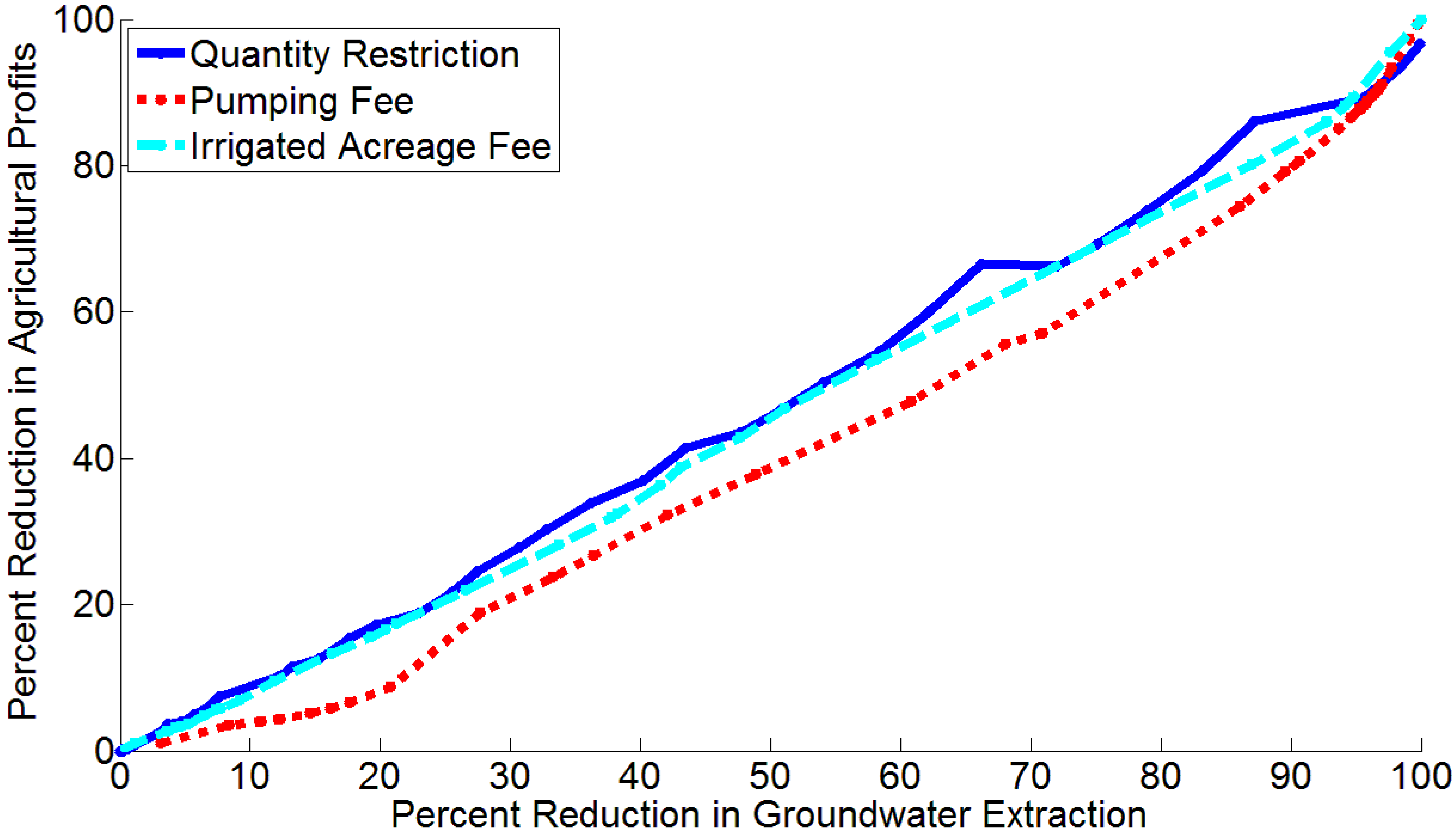
Pumping by well capacity bins



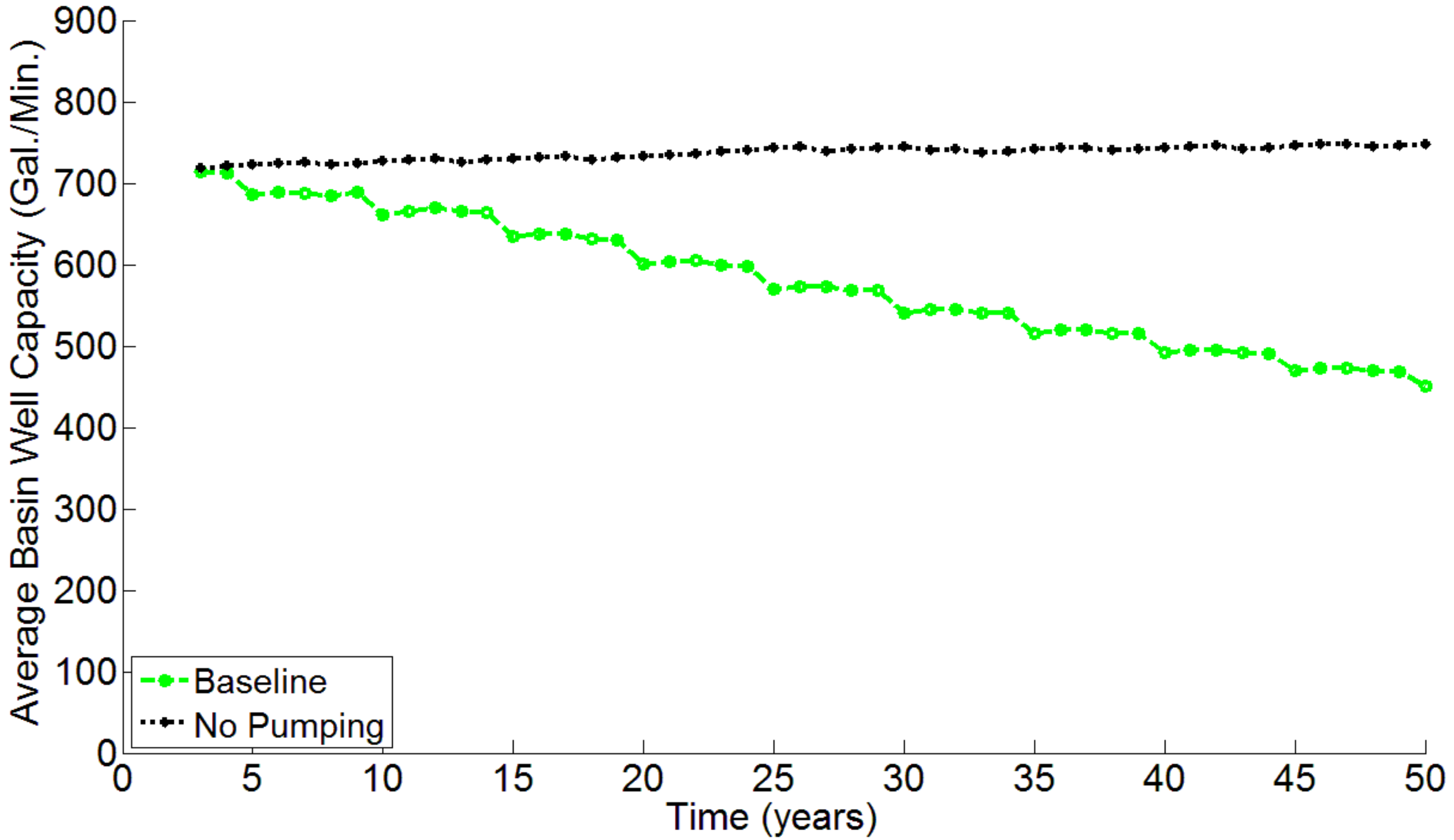
Sandy Soil in North Region



Sandy Soil in South Region



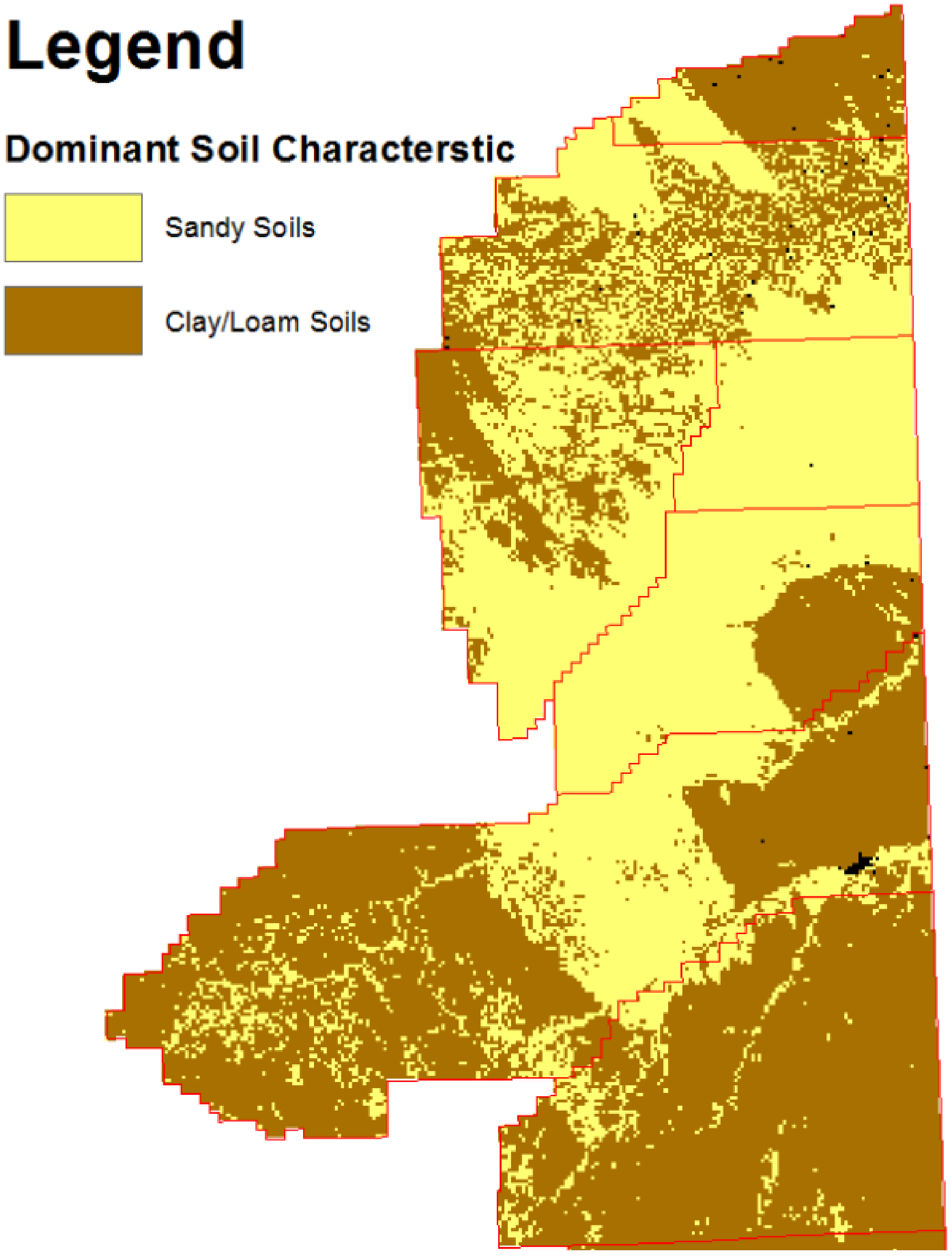
Quantity Restriction
Pumping Fee
Irrigated Acreage Fee
Percent Reduction in Agricultural Profits
Percent Reduction in Groundwater Extraction
0
20
40
60
80
100
0
10
20
30
40
50
60
70
80
90
100


Average Basin Well Capacity (Gal./Min.)
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
45
50
Time (years)
Baseline
No Pumping

Agronomic Model (AquaCrop)

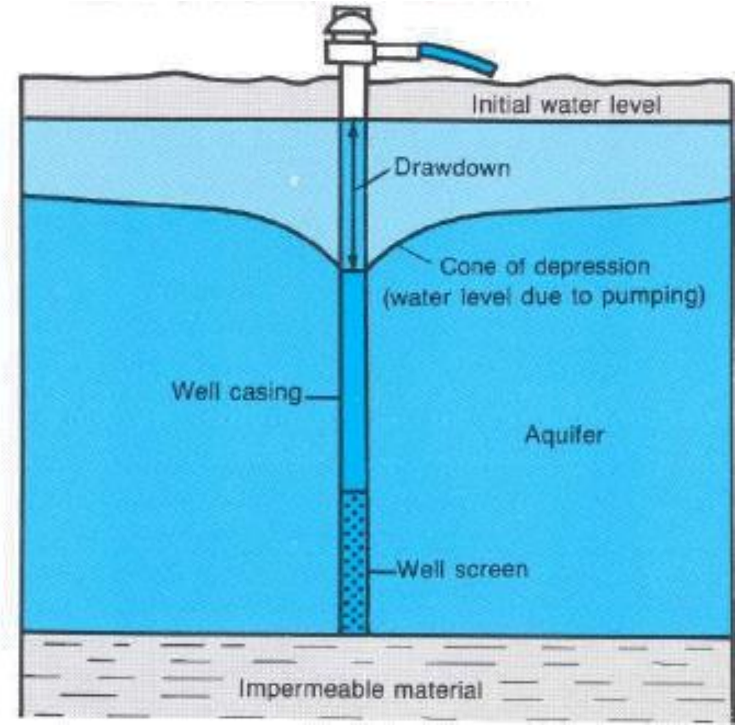
Generates water-crop yield production functions for heterogeneous groundwater users accounting for variation in:

- **Soil Type**
- **Climate Zone**
- **Weather Realization**
- **Well Capactiy**



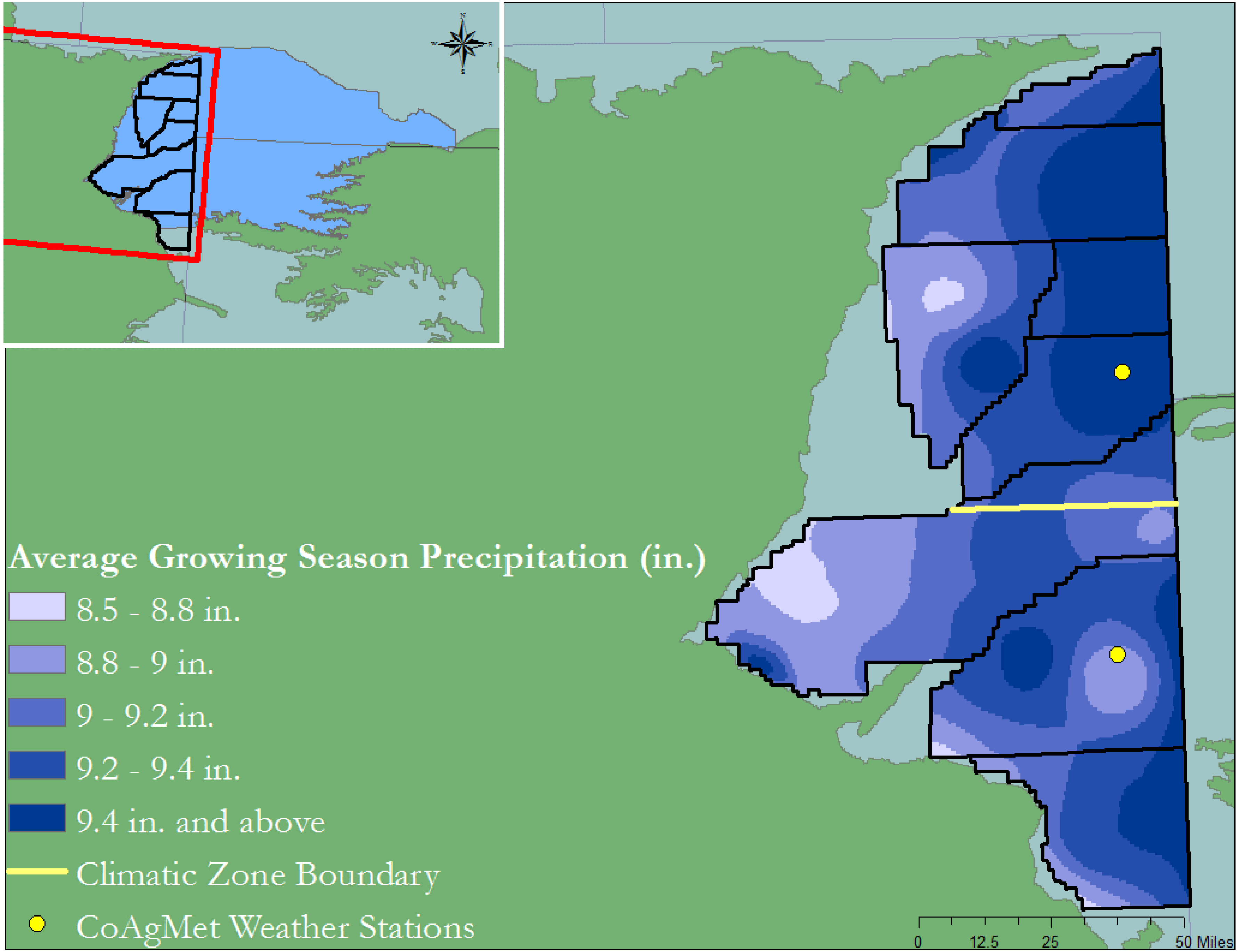
Well Capacity

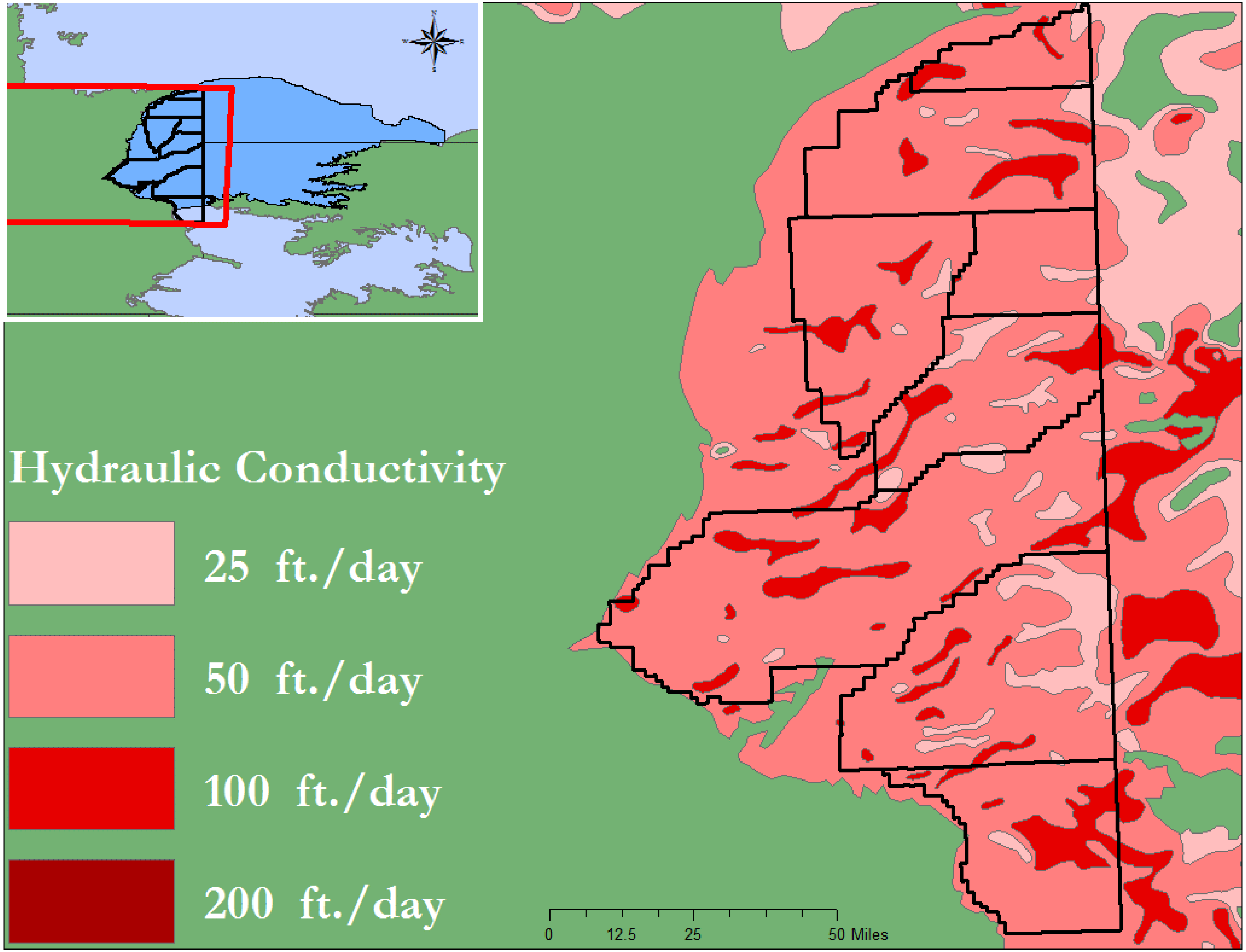
- Maximum flow rate (gpm) that can be sustained over a period of time

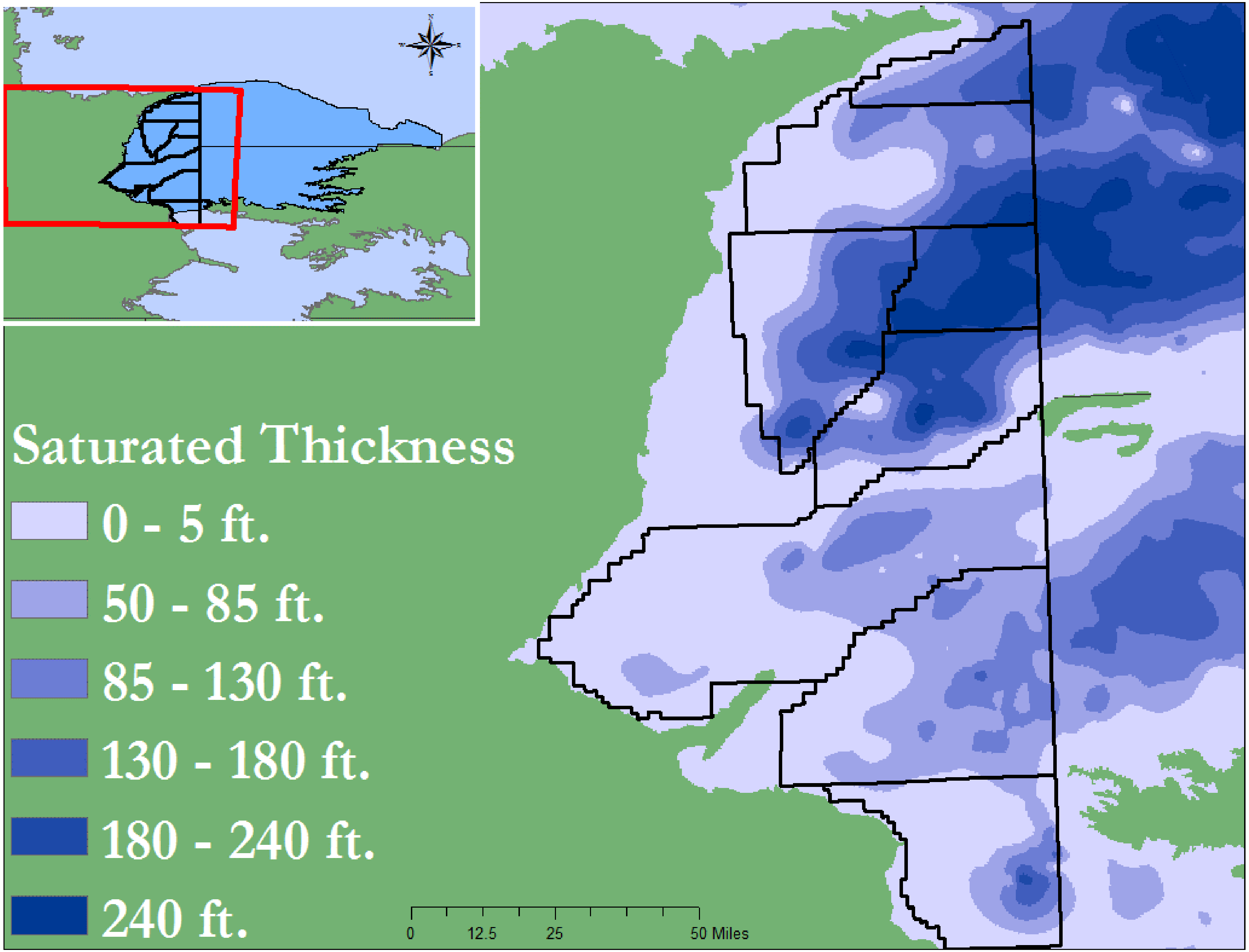


Return

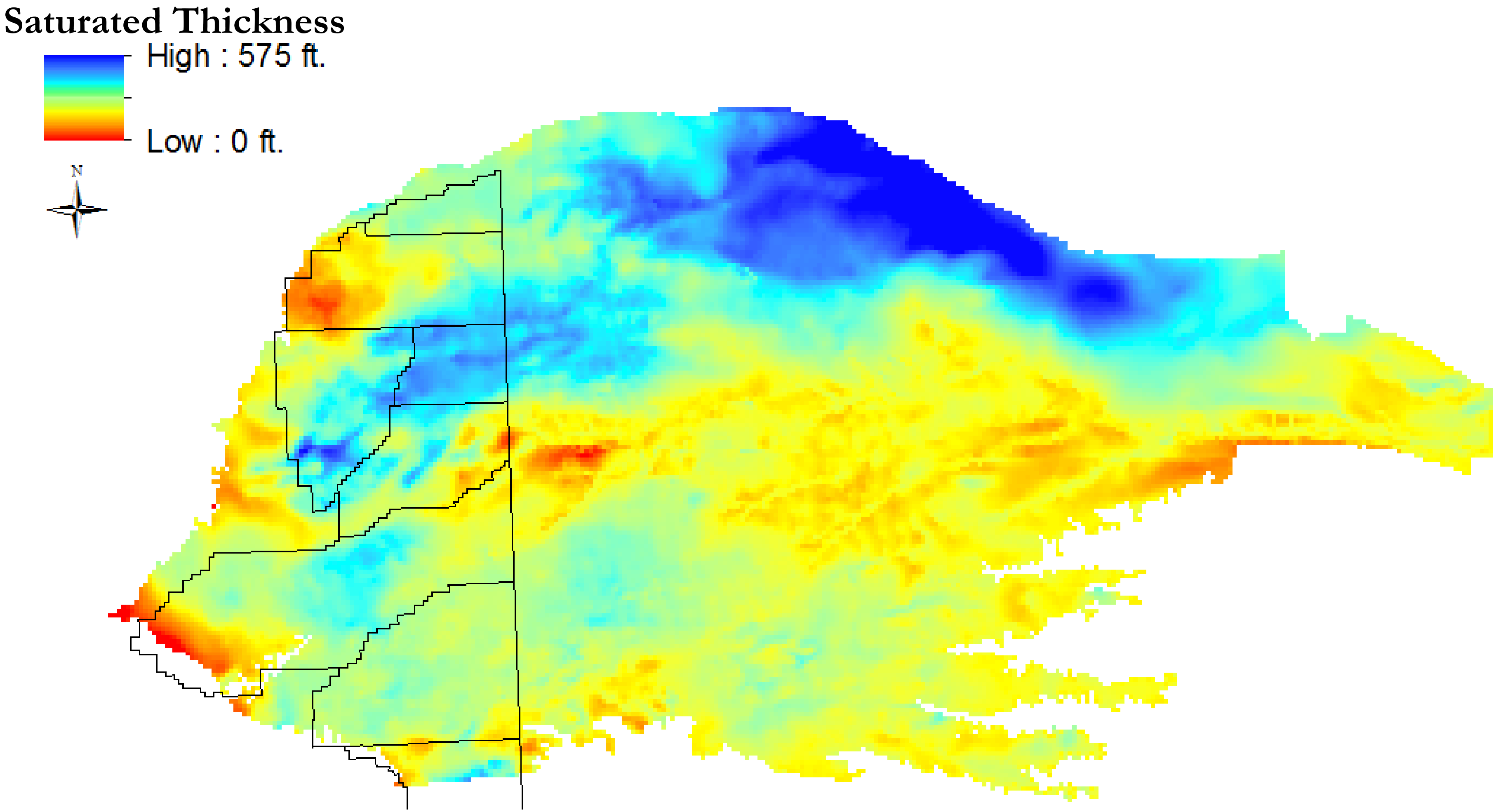
Source: United States Geological Survey


Average Growing Season Precipitation (in.)
8.5 - 8.8 in.
8.8 - 9 in.
9 - 9.2 in.
9.2 - 9.4 in.
9.4 in. and above
Climatic Zone Boundary
CoAgMet Weather Stations
0
12.5
25
50 Miles


Hydraulic Conductivity
25 ft./day
50 ft./day
100 ft./day
200 ft./day
0
12.5
25
50 Miles


Saturated Thickness
0 - 5 ft.
50 - 85 ft.
85 - 130 ft.
130 - 180 ft.
180 - 240 ft.
240 ft.
0
12.5
25
50 Miles

The Case for Spatially Differentiated Policies



Microeconomic Foundations: Policy Options

Stage 1:

$$\max_{A_{ij}} E\left[\sum_{j=1}^{J} p_j A_{ij} f_j\left(w_{ij}; c_{it}, \theta_{it}, \phi_i, A_{ij}\right) - A_{ij}(r_{Aj} + \boxed{\tau_A}) - A_{ij} w_{ij}(r_w + \boxed{\tau_w})\right]$$

subject to $\boxed{\sum_{j=1}^{J} w_{ij} \leq \overline{W}}$

- Planting Tax
- Pumping Tax
- Quota

Three management policies to address over-pumping of aquifer

- Qty restrict
- Uniform pumping tax
- Irrigated acreage fee

Table of policy type and levels

- What do the spatially differentiated policies look like?
- How did we characterize the heterogeneity of the spatial externality of pumping across GWMDs to inform the creation of the spatially differentiated policies