Recharge in Nebraska: Research and Results

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*Water Funding Task Force Meeting Presentation 09/06/2013 Grand Island NE

Recharge in Nebraska: Research and Results

Key points:

- ✓ Recharge determines sustainable groundwater pumping rates
- ✓ Statewide patterns mostly understood
- ✓ Impacts of droughts and land-use known locally

- ✗ Predictive capabilities insufficient for management decisions
- ✗ Monitoring-infrastructure lacking

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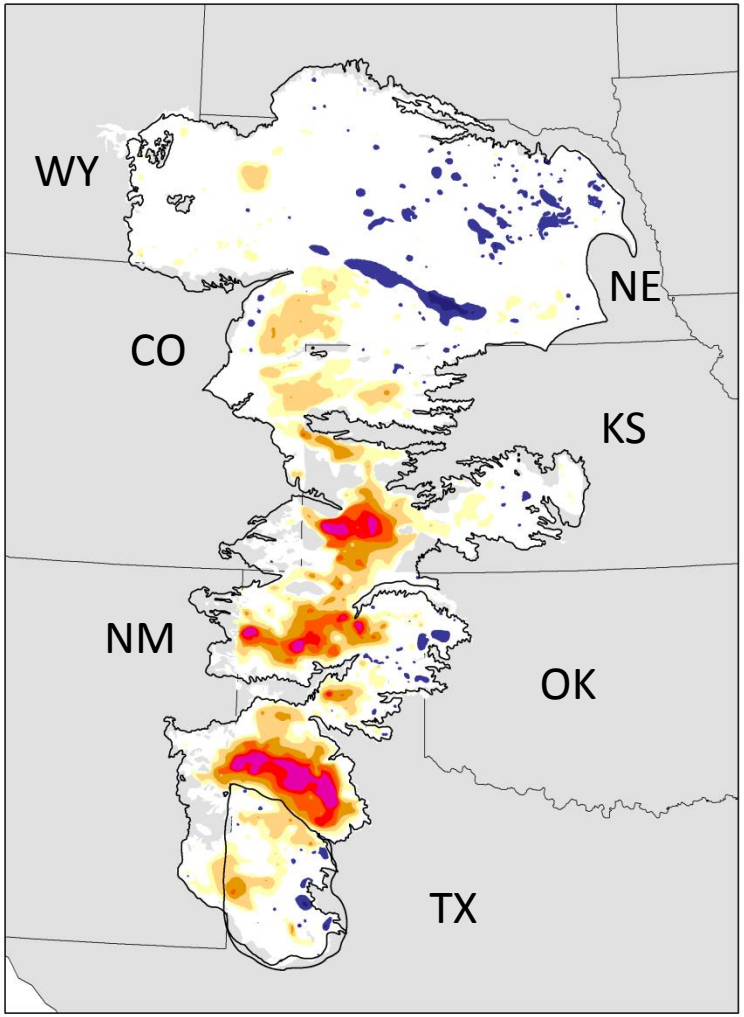
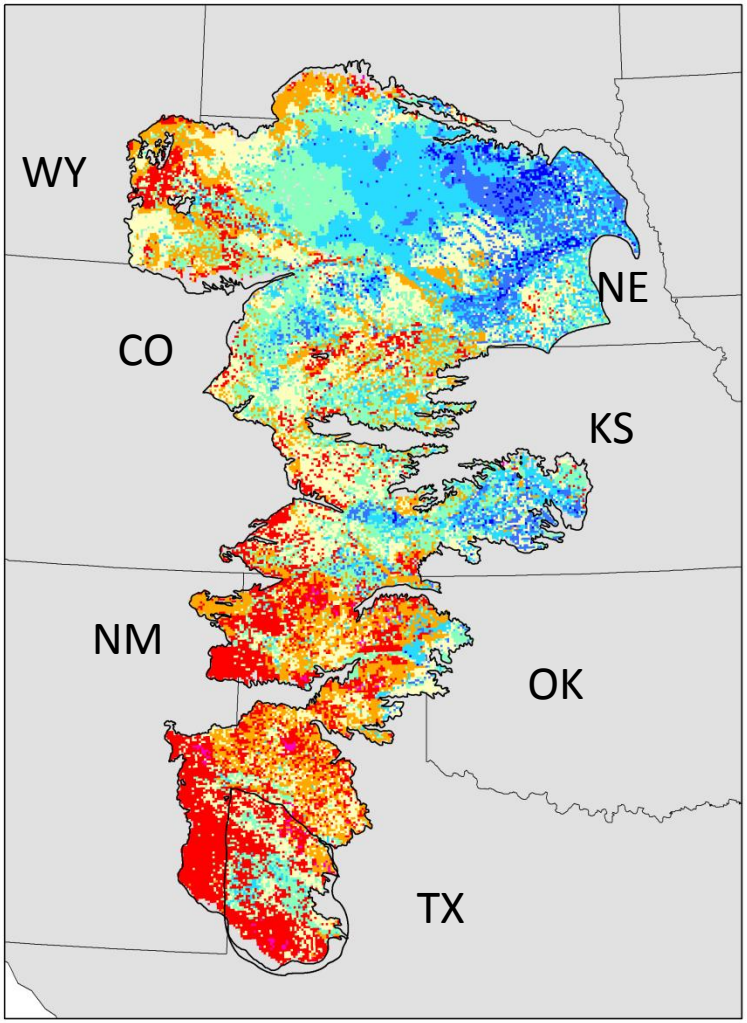
1. Recharge determines sustainable groundwater usage rates

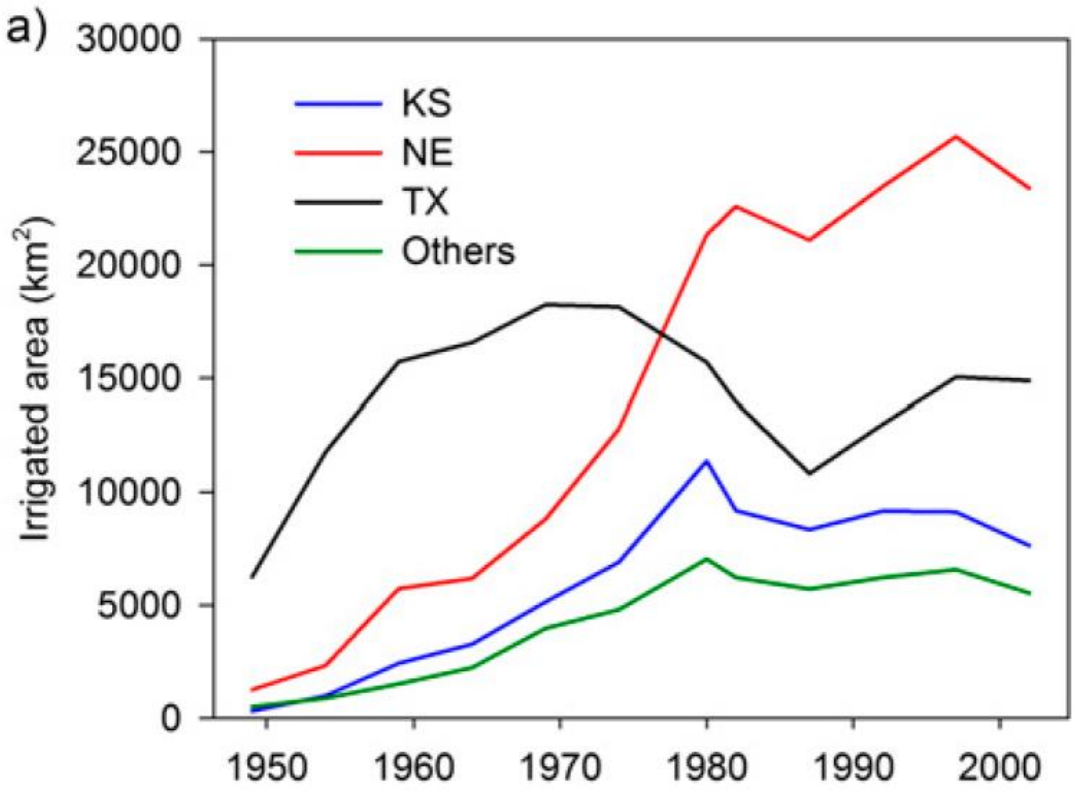


High Plains Water Level Changes,
Pre-development to 2011 (USGS data)



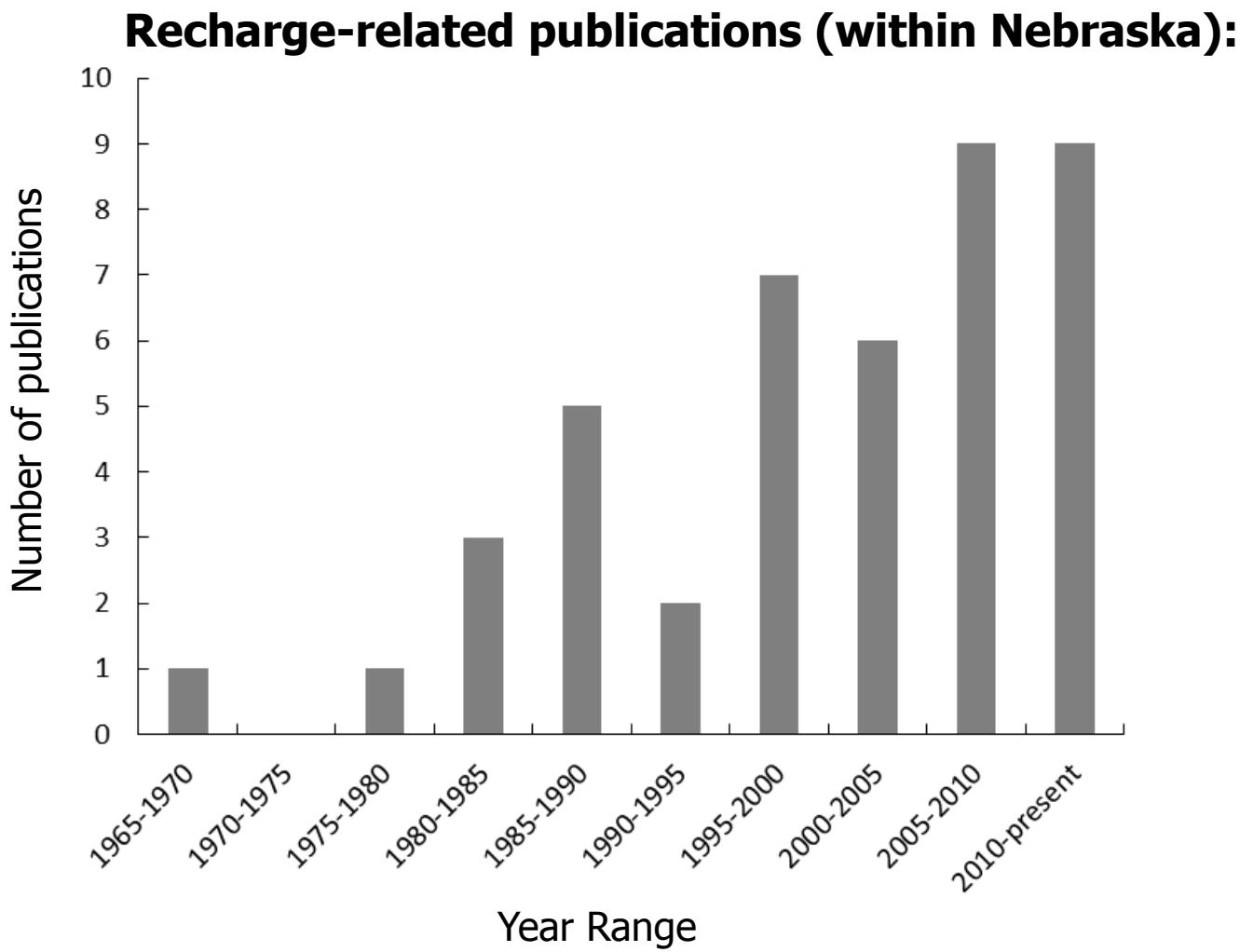
High Plains Recharge Rates (composite data)

1. Recharge determines sustainable groundwater usage rates



From Scanlon et al 2012 (PNAS)

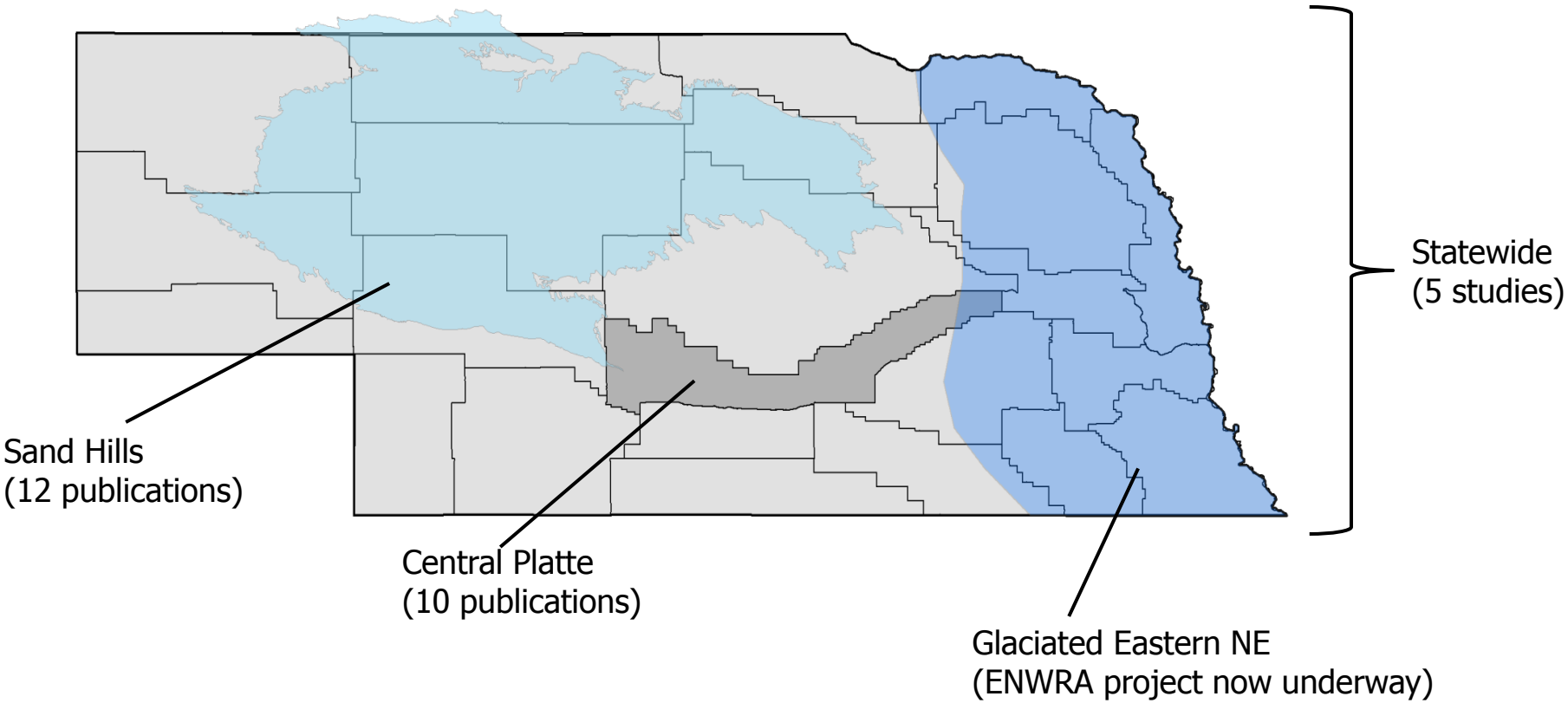
2. Statewide Patterns



*Not including consultant reports and conference presentations
**Source: Google Scholar

2. Statewide Patterns

Areas of focus in Nebraska recharge studies:



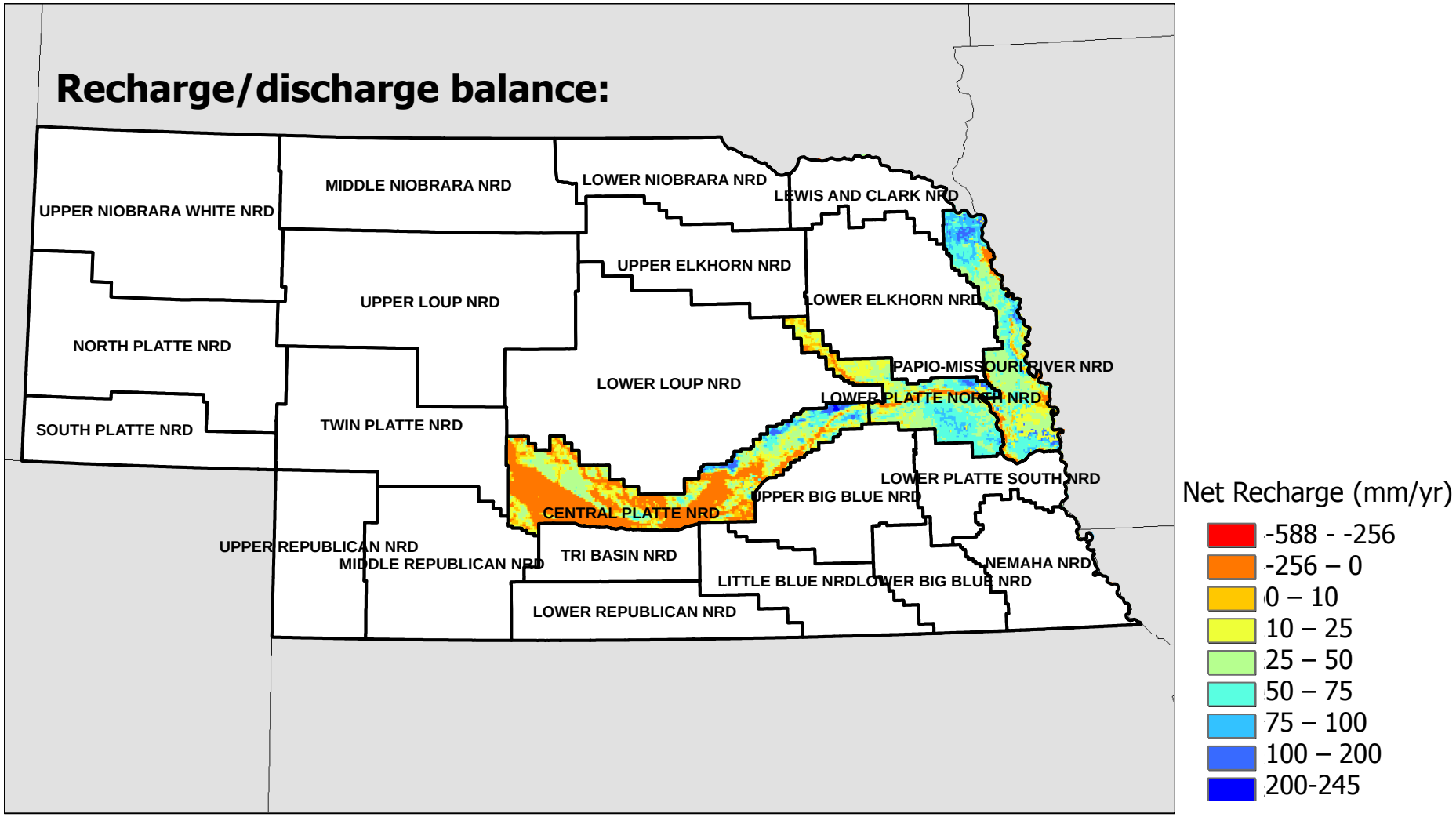
2. Statewide Patterns

Statewide Recharge Maps of Nebraska:

Method	Lead Author
Model (DRASTIC) / remote sensing (MODIS)	J. Szilagyi (UNL)
Groundwater chloride (CMB)	J. Gates (UNL)
Model (SWB)	J. Stanton (USGS)*#
Model (SWAT)	R. Crosbie (CSIRO)*

*Denotes High Plains Aquifer only (excludes Eastern Nebraska)
#Denotes data currently unavailable

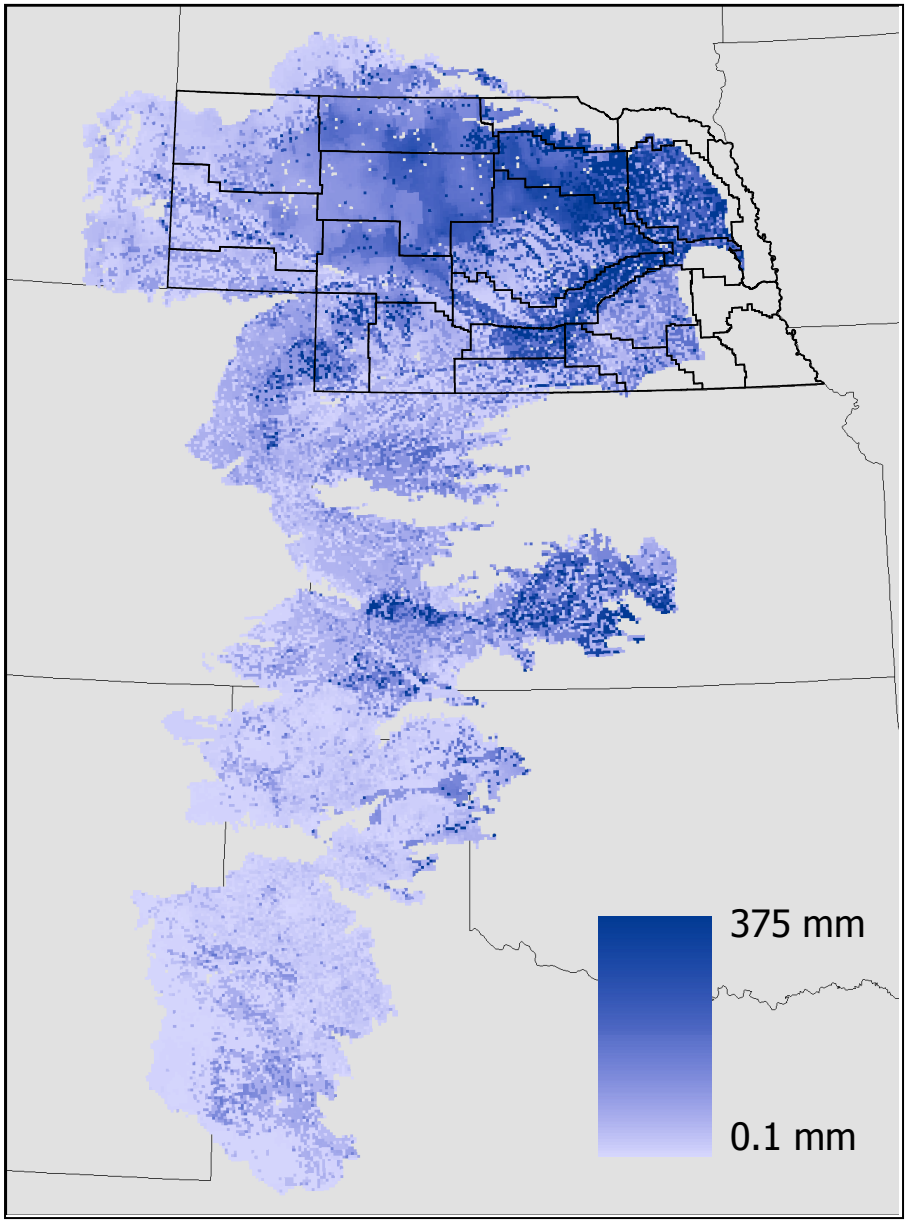
2. Statewide Patterns



Data from Szilagyi and Jozsa, 2012

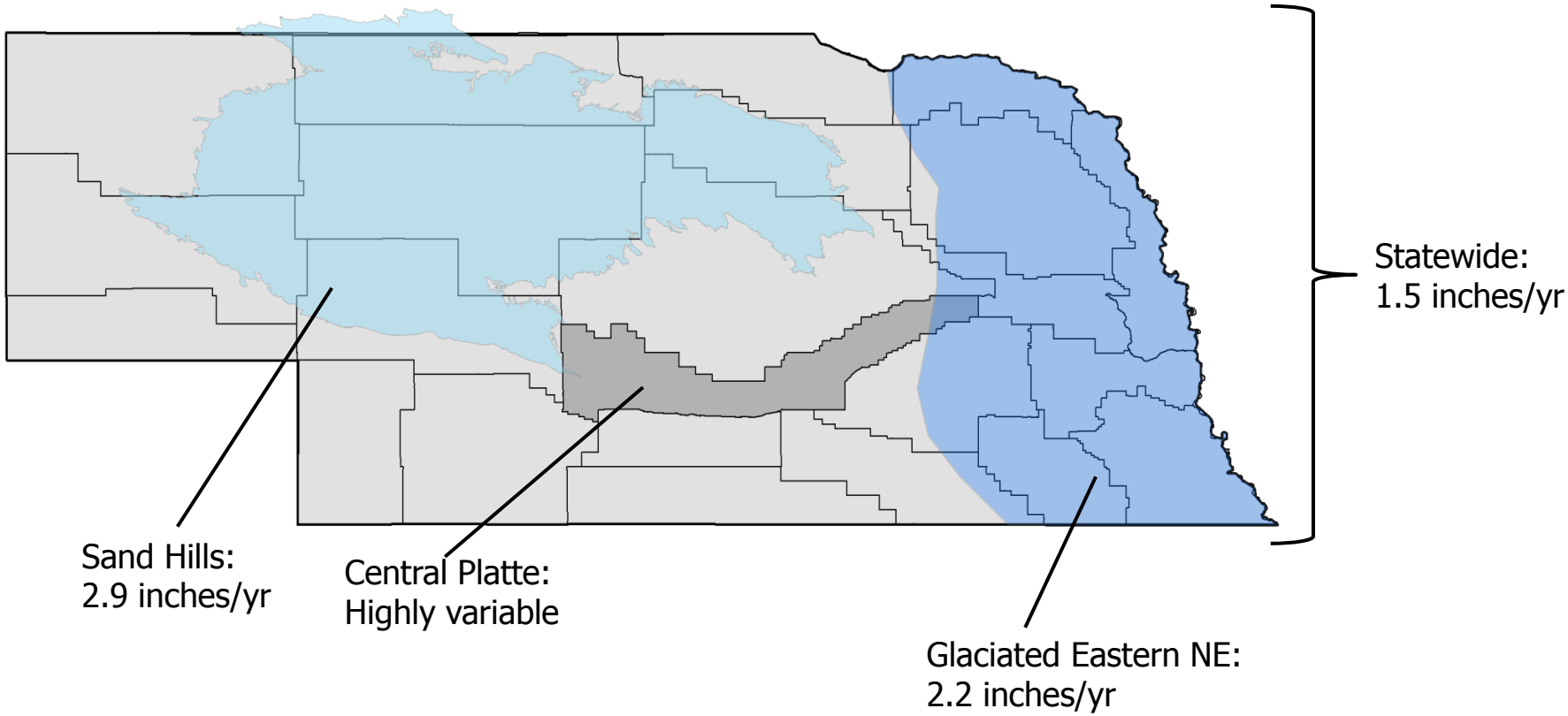
2. Statewide Patterns

Recharge Rates: High Plains Region

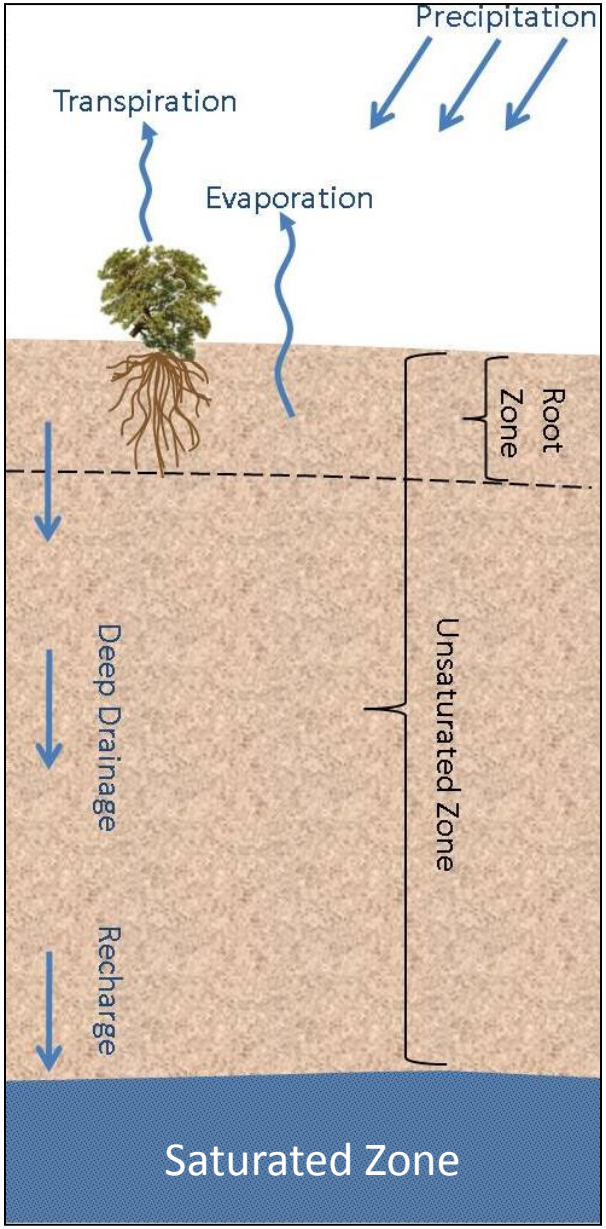


2. Statewide Patterns

Best estimates of long-term averages by region:



3. Impacts of Drought and Land Use



"Anything that can affect soil water can affect groundwater recharge."

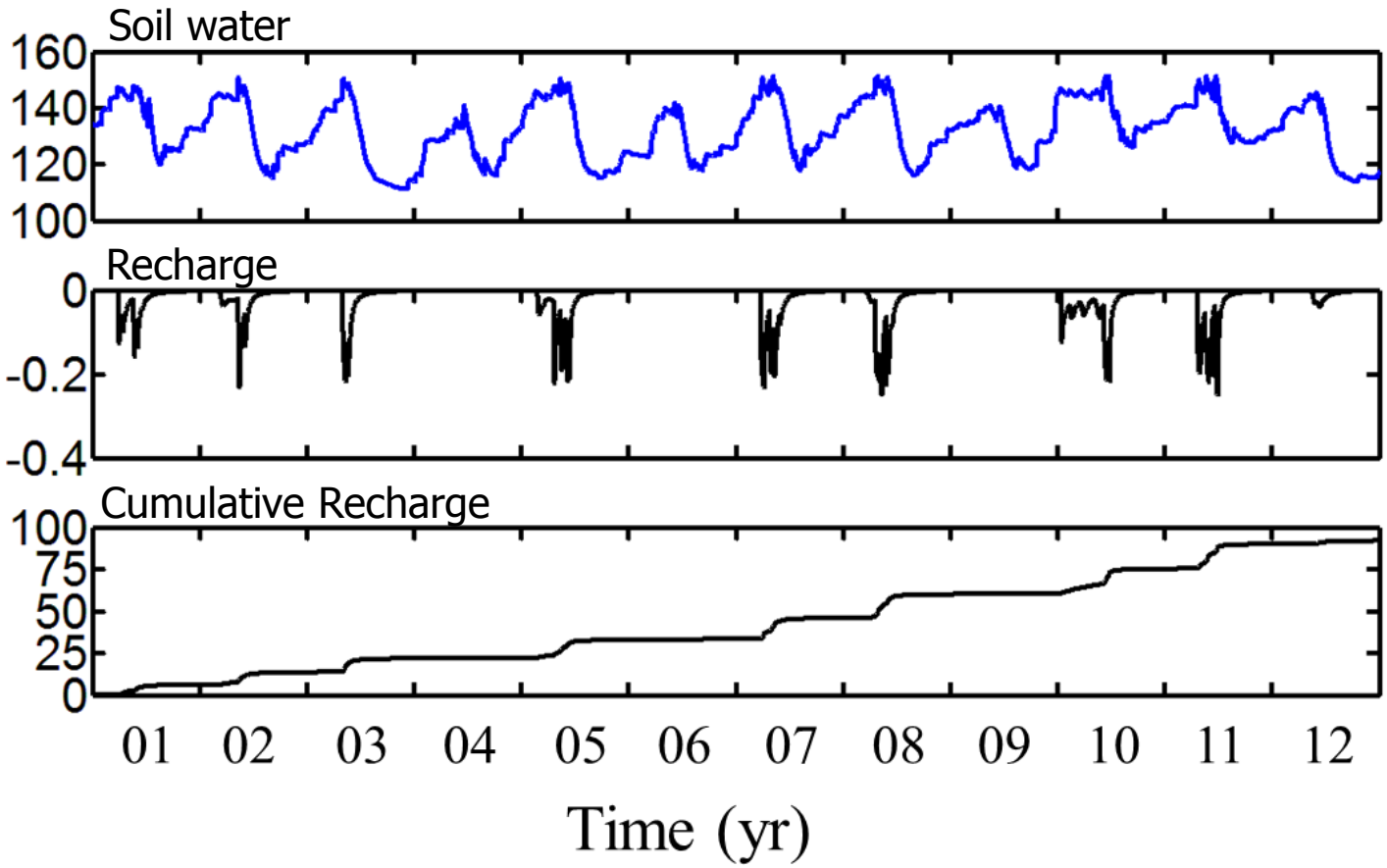
- Land use change
- Climate change
- Drought and dry spells
- Others

3. Impacts of Drought and Land Use

Method	Example Measurement
Coring/analysis	Moisture/chloride
Sensors	Matric tension/drainage
Groundwater chemistry	Tritium/helium

3. Impacts of Drought and Land Use

2012 Drought Impact Example:
Oakland NE (Burt County)
Rainfed Corn Plot – ENWRA Project



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2012 Drought Impact Example:
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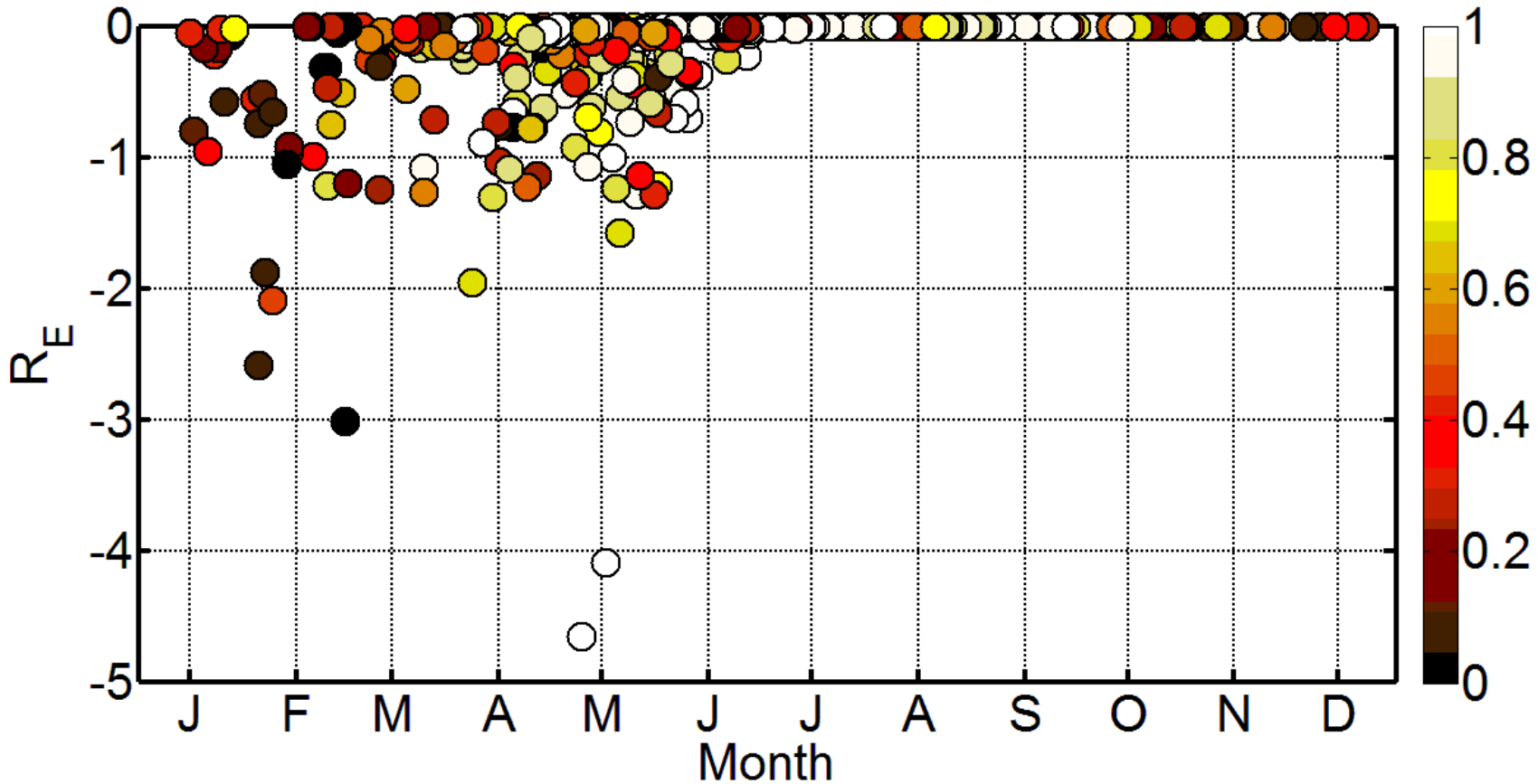
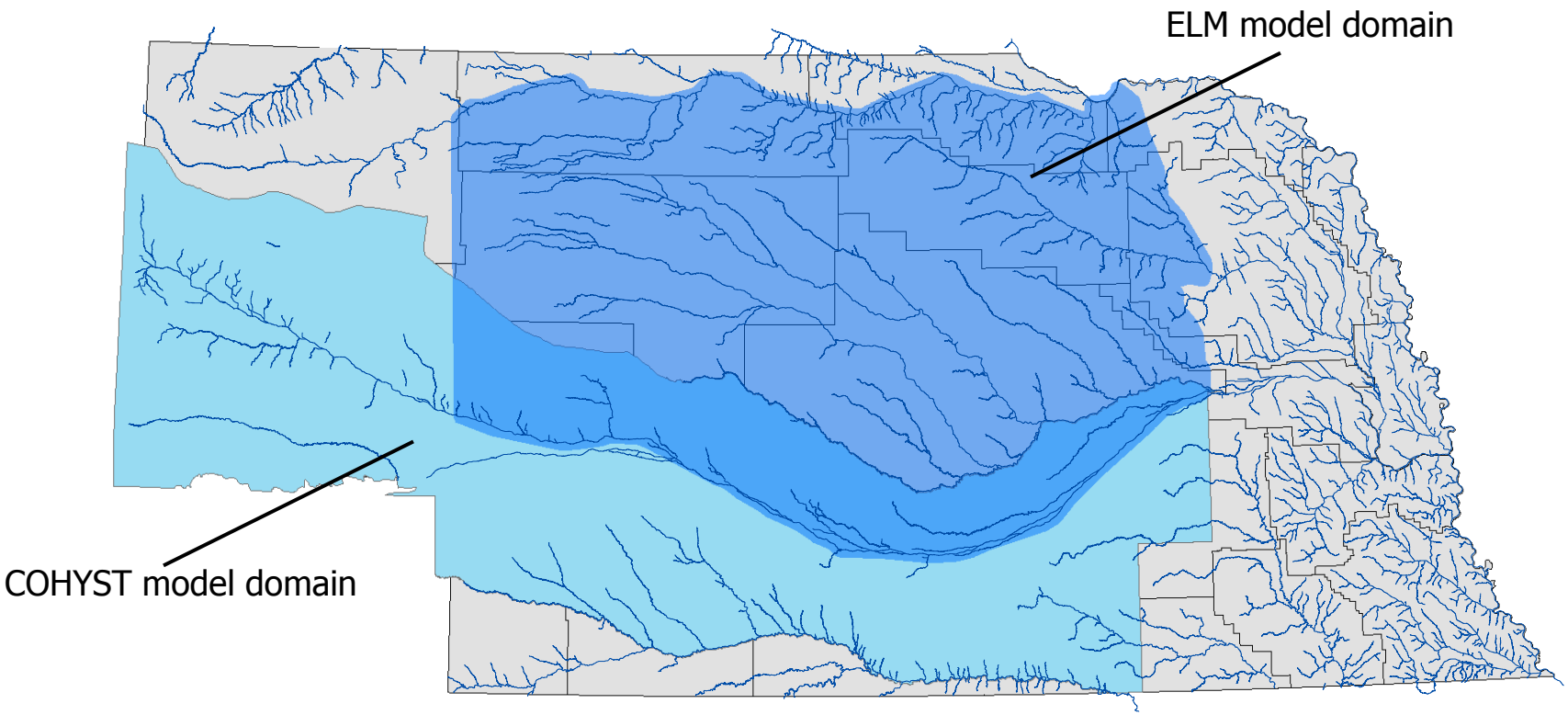


4. Predictive Capabilities

- Different recharge models often do not agree with each other.
- **Groundwater resource models typically "adjust" recharge during calibration to achieve good model fit to well level or stream flow records.**



5. Monitoring Infrastructure

Weather Station

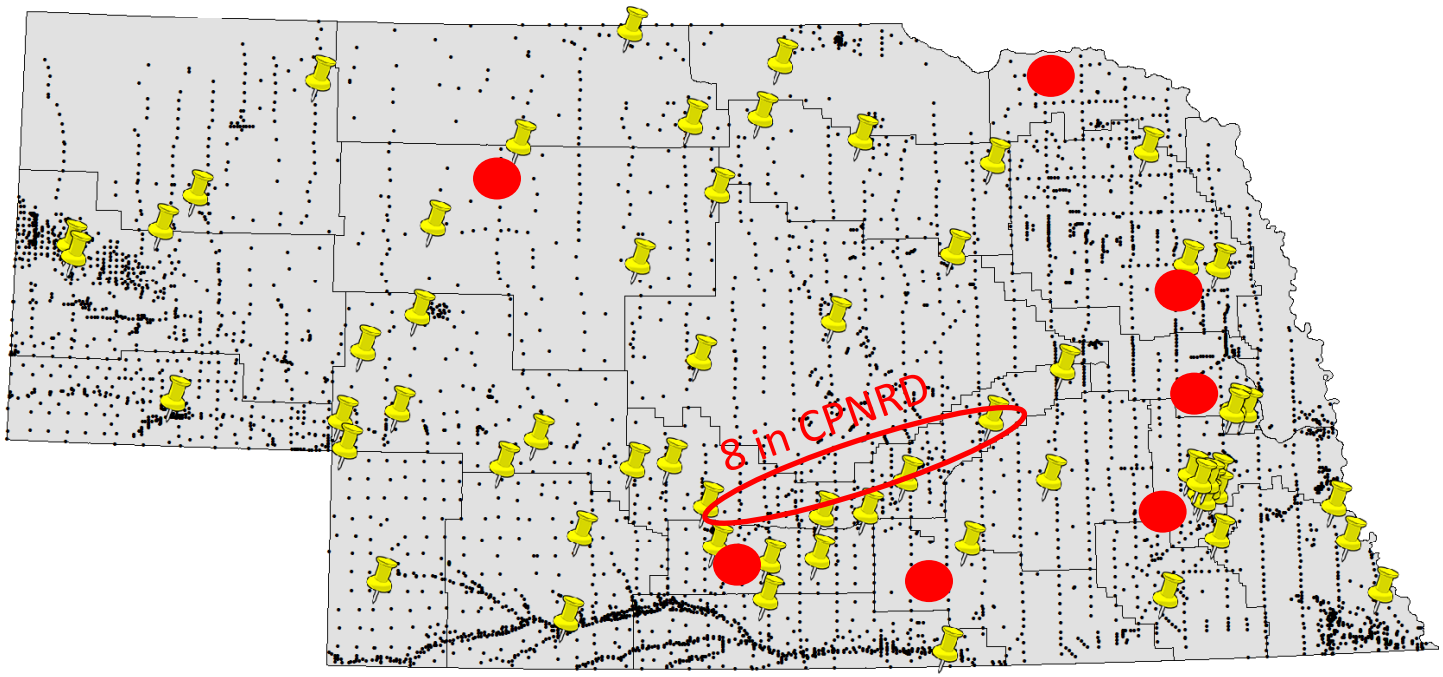
Rain Gauge

Subsurface sensor conduit

ENWRA station near Fordyce NE (Cedar County)

Electronic control/communication

5. Monitoring Infrastructure



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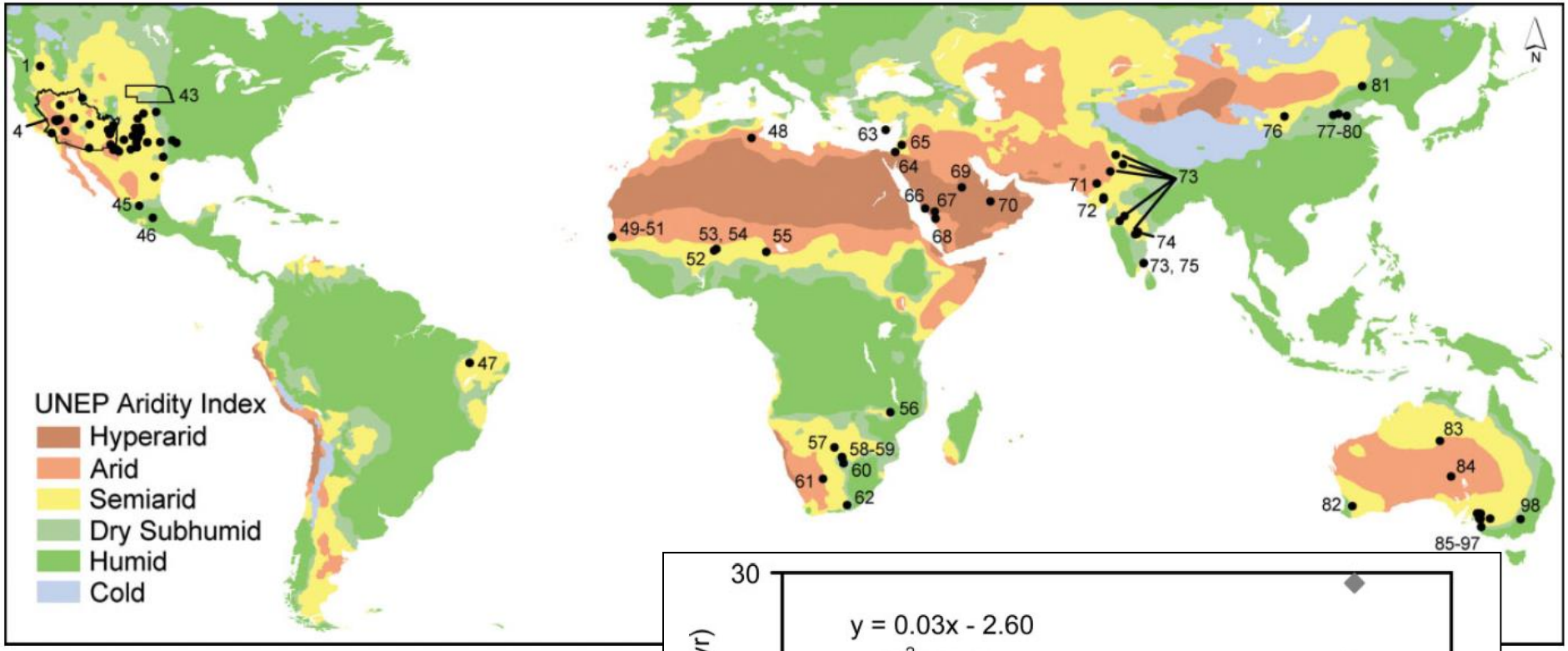
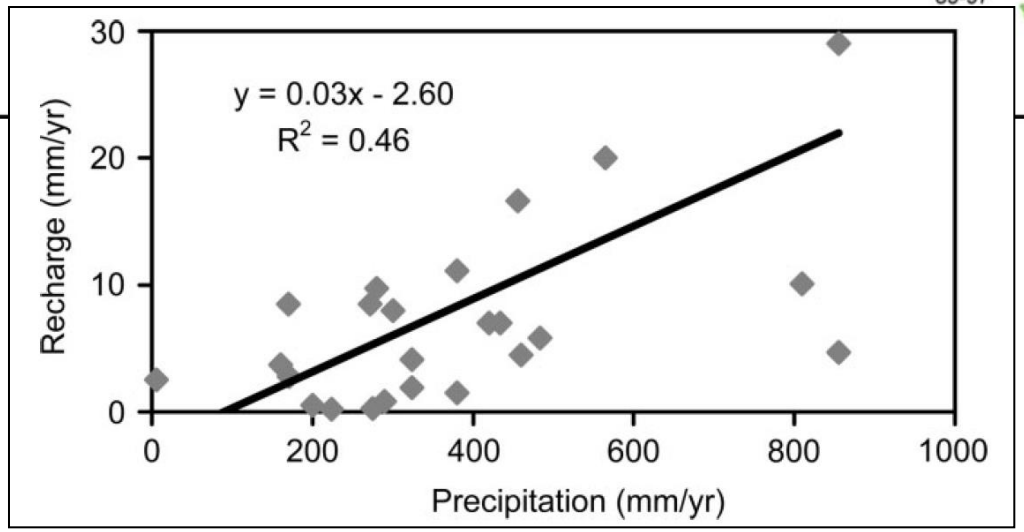
Recharge in the Terrestrial Water Balance:





- Weak correlations between precipitation and recharge globally

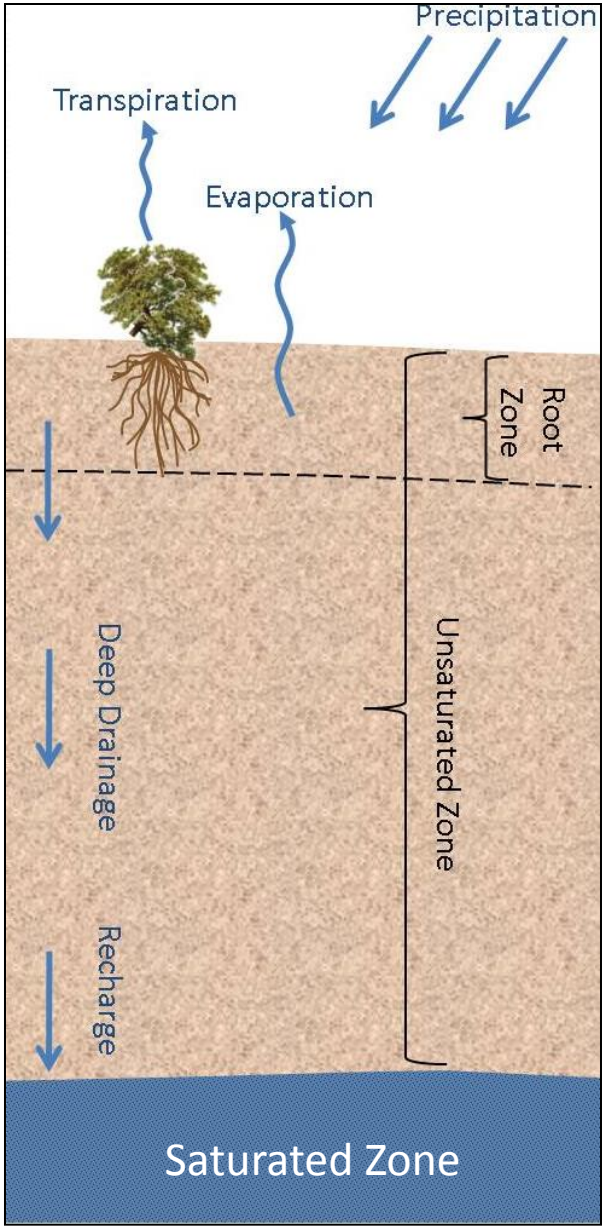
Scanlon BR, Keese KE, Flint A, Flint L, Gaye C, Edmunds WM, Simmers I. 2006. Global synthesis of groundwater recharge in semiarid and arid regions. *Hydrological Processes 20: 3335-70*

Recharge in the Terrestrial Water Balance:

Richards Equation (1D):

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K(\psi_M)\left(\frac{\partial \psi_M}{\partial z} + 1 \right) \right) - S(z,t,\psi_M)$$

- Dynamic boundary conditions
- Highly nonlinear response

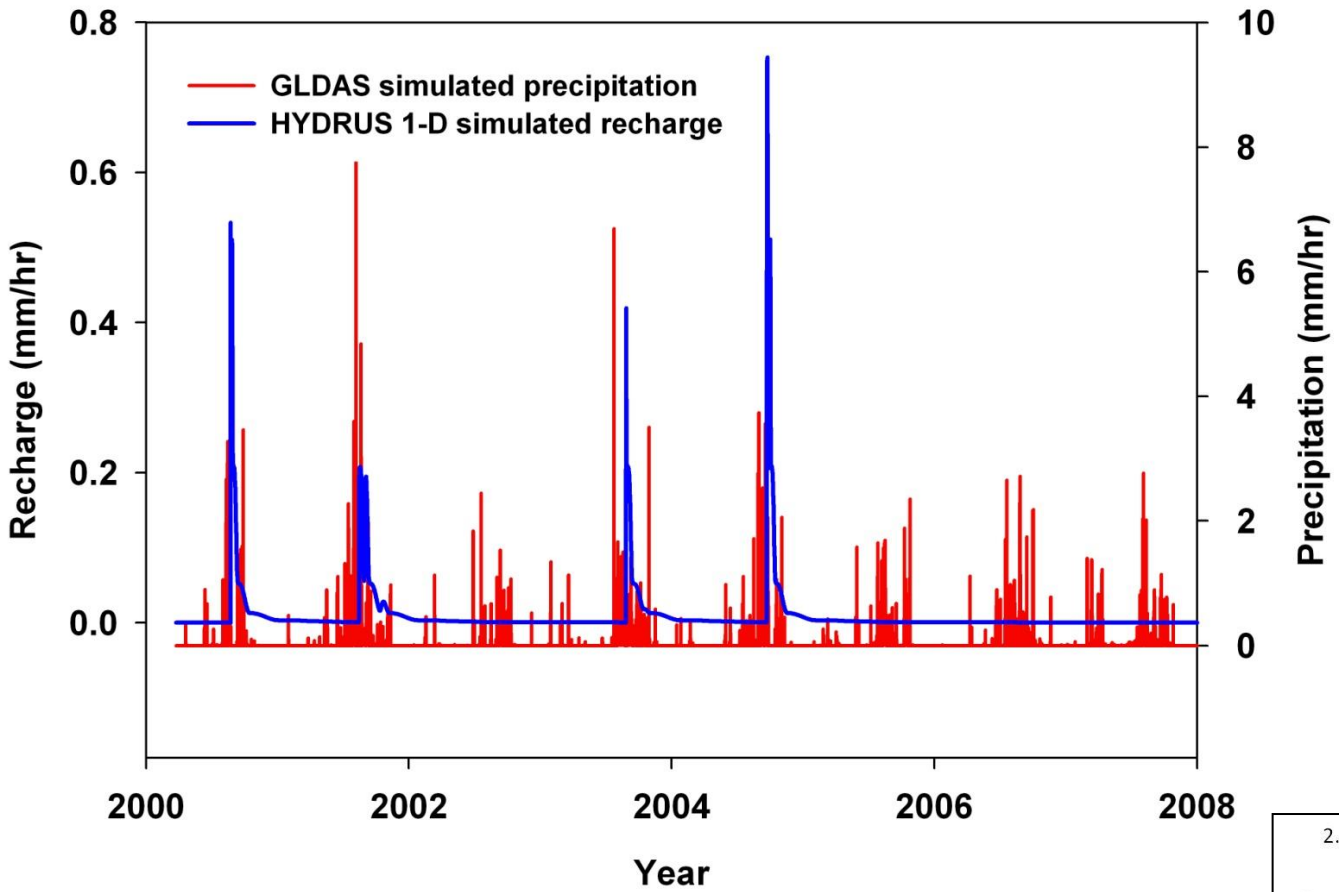


$P(t)\downarrow$, $ET(t)\uparrow$, runoff

$S(t,z,\psi_M)\uparrow$

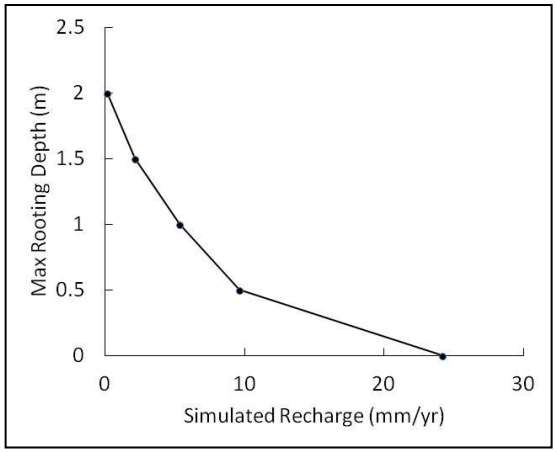
$Q(t,z,\psi_M)$

Model Sensitivity: Thar Desert (India) Example

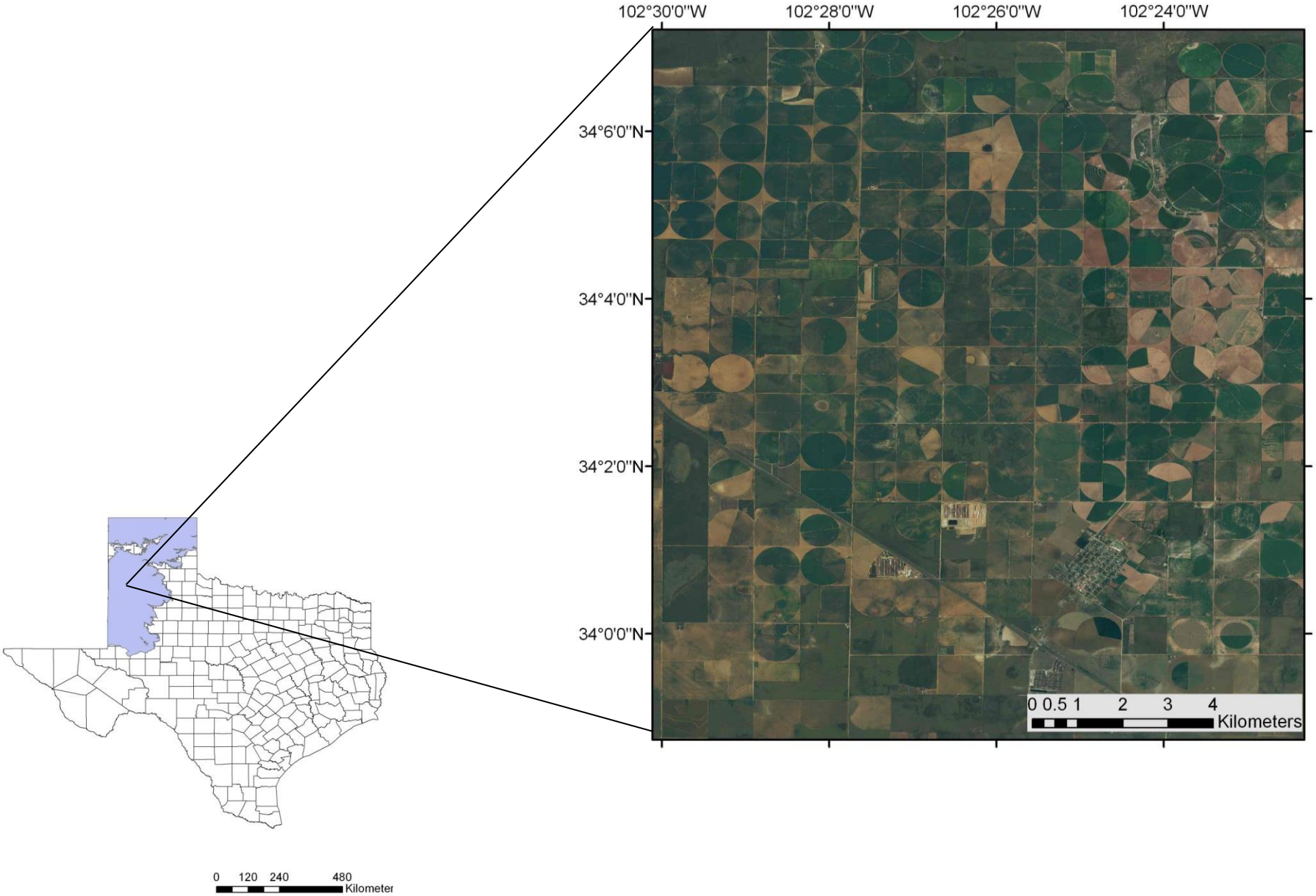


Scanlon B, Mukherjee A, Gates JB, Reedy R, Sinha A. 2010. Groundwater recharge in natural dune systems and agricultural ecosystems in the Thar Desert region, Rajasthan, India. *Hydrogeology Journal 18: 959-72*

Simulation	Max root depth	Recharge (mm/yr)
1	0.0	24.2
2	0.5	9.6
3	1.0	5.3
4	1.5	2.1
5	2.0	0.1



Response to Land Use Change: Southern High Plains



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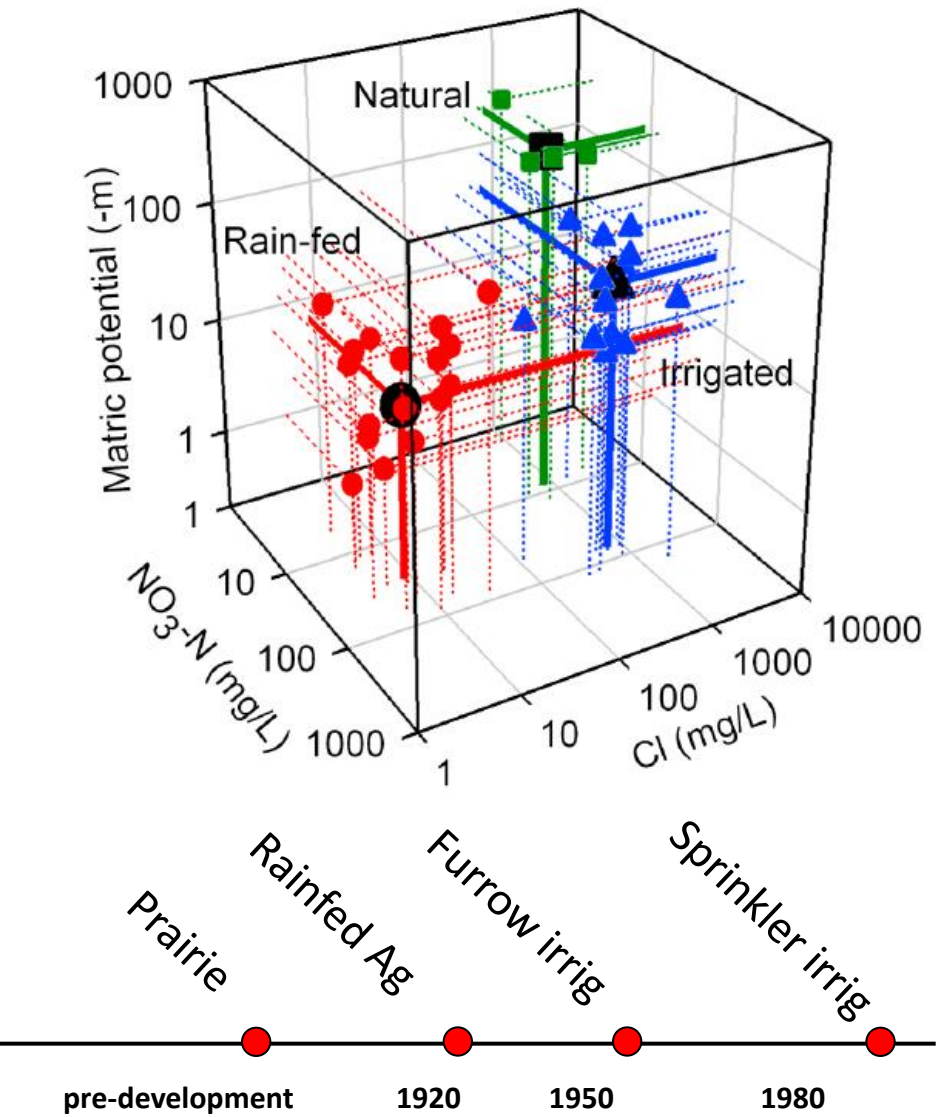
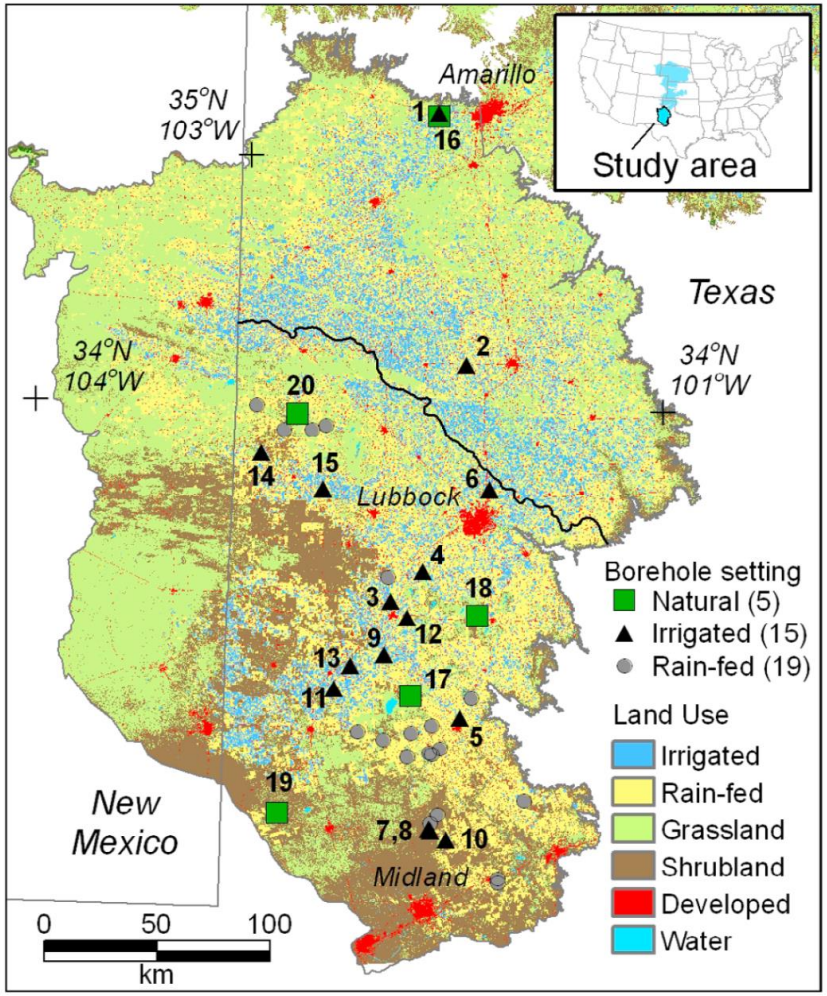




Scanlon BR, Gates JB, Reedy RC, Jackson WA, Bordovsky JP. 2010. Effects of irrigated agroecosystems: 2. Quality of soil water and groundwater in the southern High Plains, Texas. *Water Resour. Res. 46: W09538*

Mass Balance of a Conservative Solute

$$P \cdot C_p = R \cdot C_r$$

Precipitation P [L/T];recharge R [L/T]; C_p and C_r are Cl^- concentrations in rainfall and pore water [M/L^{-3}].

$$t = \frac{1}{P \cdot C_p} \int_0^{z_i} \theta(z) C_r(z) dz$$

Allowing time-variable boundary conditions:

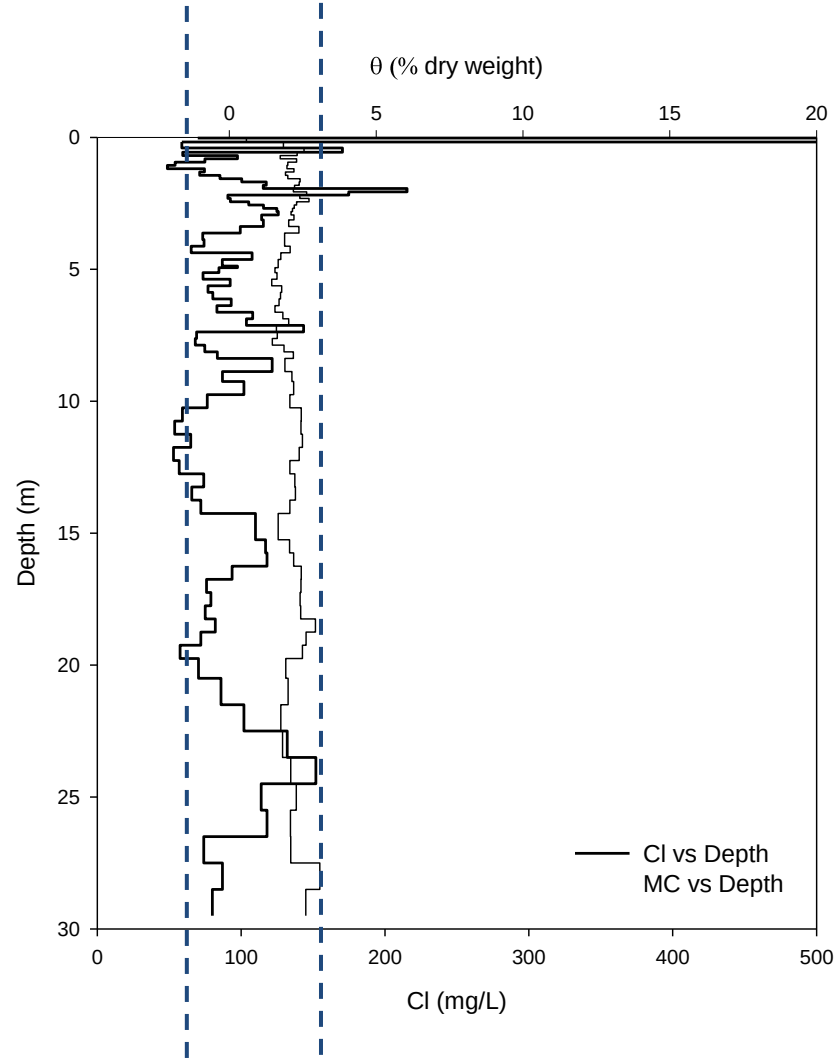
$$q_0(x) \cdot p(t_0(x)) = m_0(t_0(x)) / c^*(x)$$

$c^*(x)$ = Cl concentration [M/L] at depth x

$m_0(t_0(x))$ = chloride mass deposition [$M/L^2/T$] at the time when the parcel of water currently at depth x infiltrated

$p(t_0(x))$ = annual precipitation [L/T] at the time when the parcel of water currently at depth x infiltrated

$q_0(x)$ = partitioning function between rainfall and recharge (unitless).



Gates JB, Edmunds WM, Ma J, Sheppard P. 2008. A 700-year history of groundwater recharge in the drylands of NW China and links to East Asian monsoon variability. *The Holocene 18: 1045-54*

Response to Land Use Change: Southern High Plains

<u>Natural vegetation sites:</u>

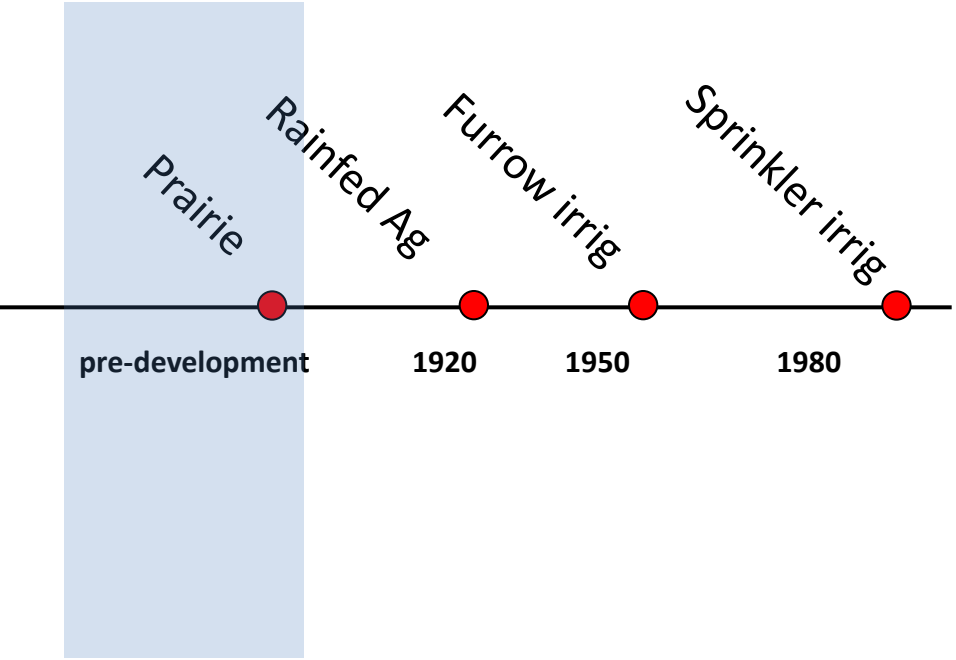
- Root zone Cl accumulation:

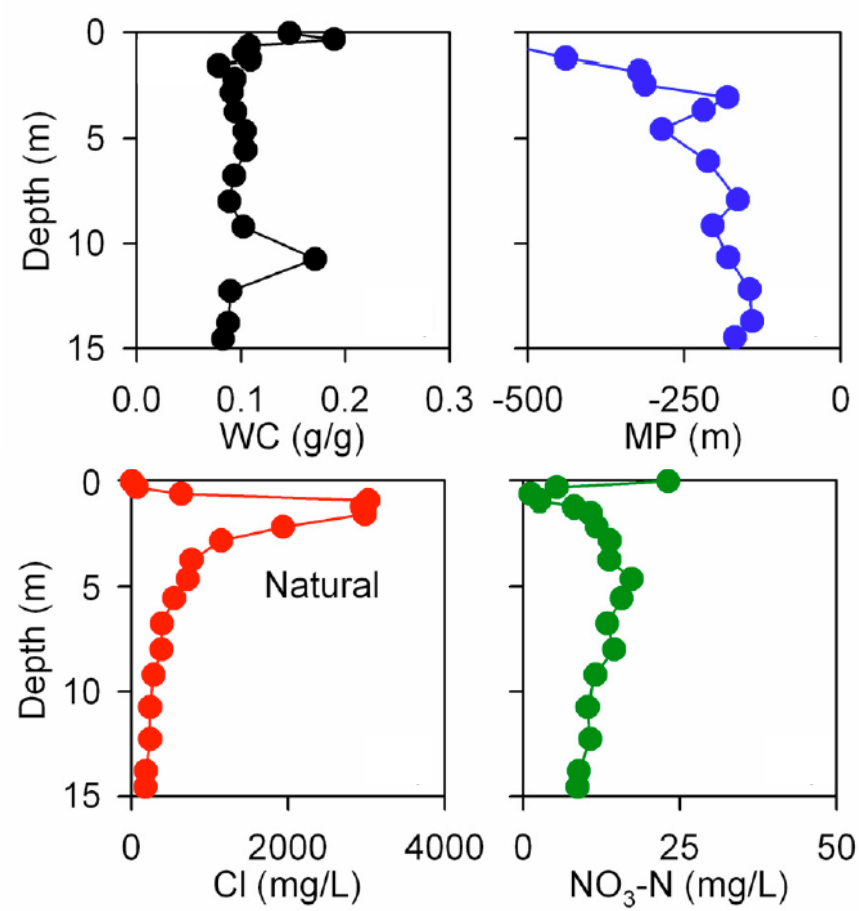
$\sum Cl = 41{,}000$ kg/ha

- Cl deposition ≈ 0.14 kg/ha/yr

$t = \sum Cl / Cl_D = 29{,}000$ years

- ~0 mm/yr drainage flux (Holocene)





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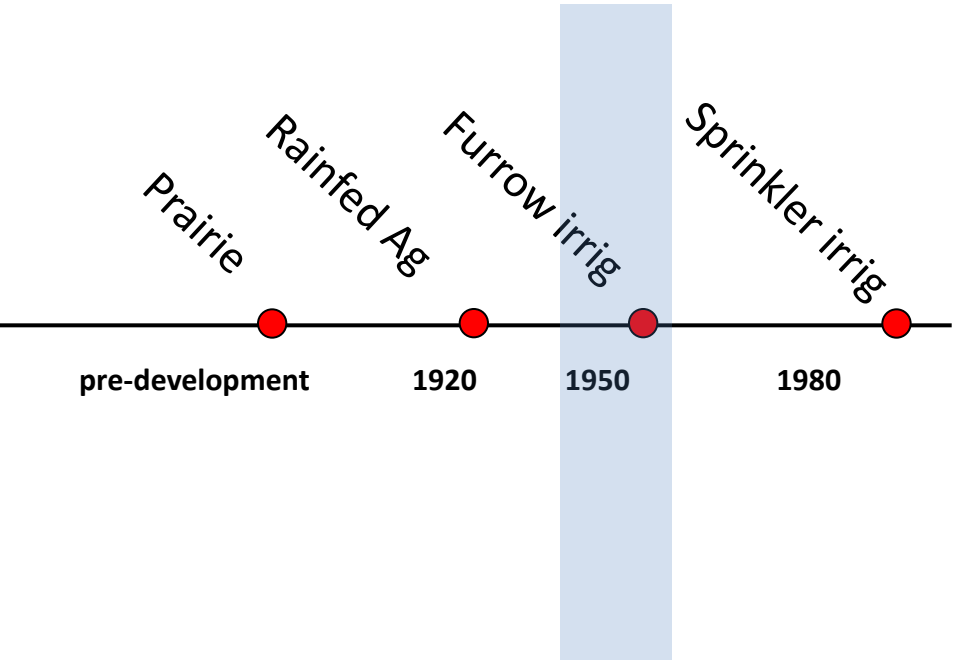
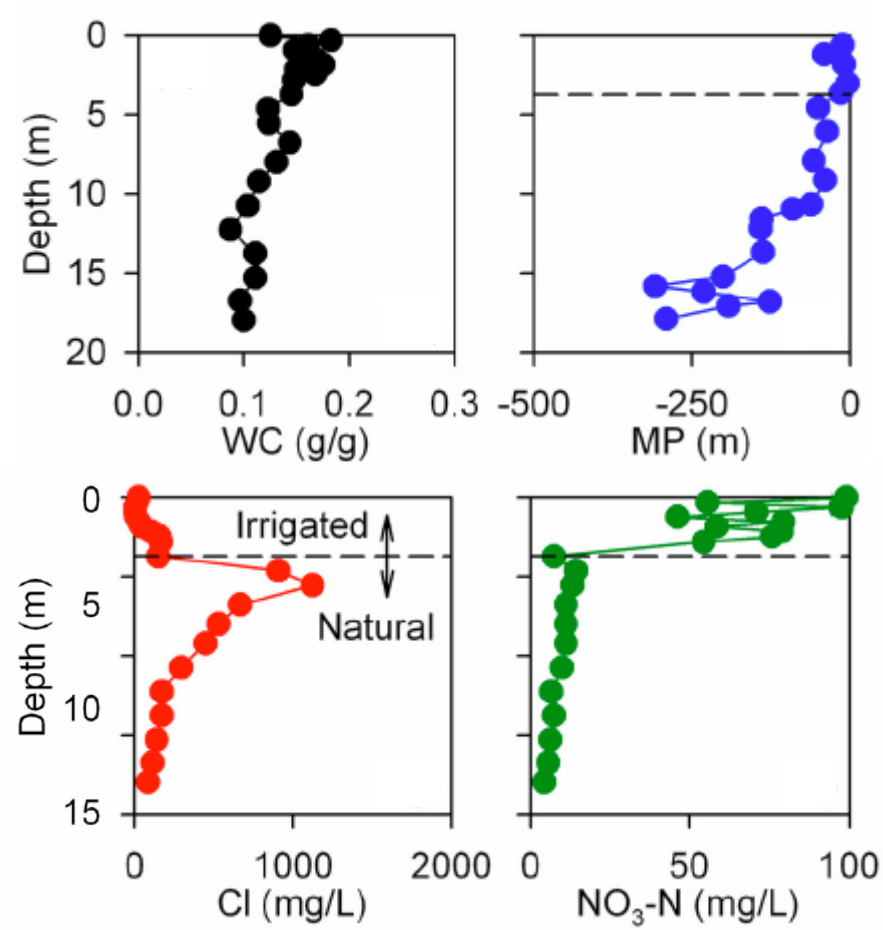
Response to Land Use Change: Southern High Plains

<u>Furrow irrigation sites:</u>

- Displaced Cl accumulations
- Median ~40 mm/yr drainage flux



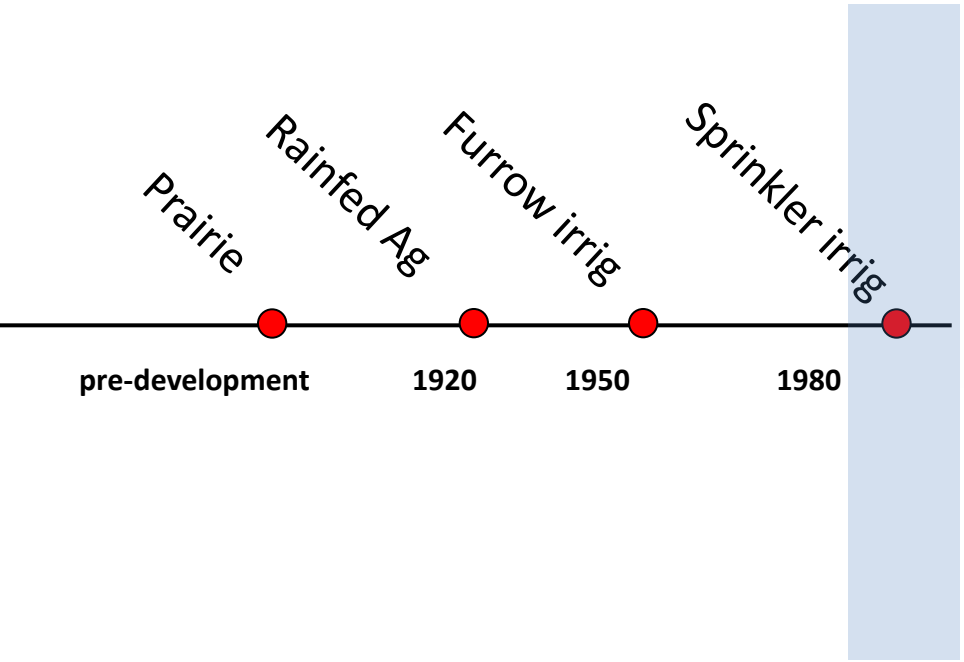


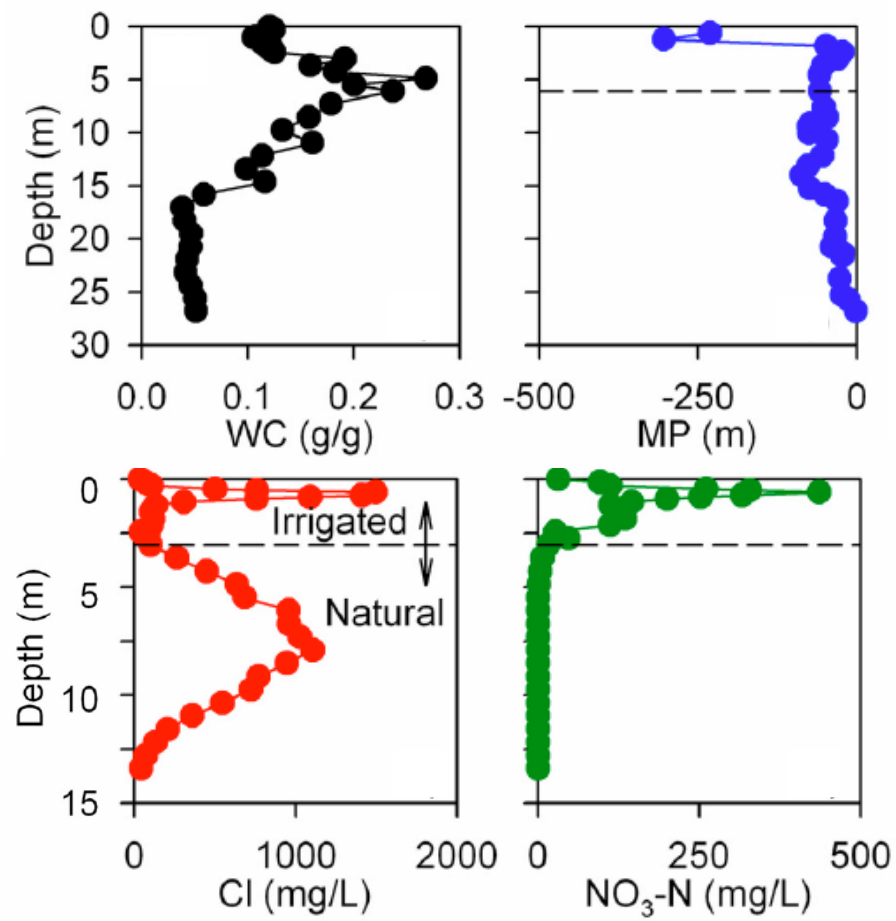
Scanlon BR, Gates JB, Reedy RC, Jackson WA, Bordovsky JP. 2010. Effects of irrigated agroecosystems: 2. Quality of soil water and groundwater in the southern High Plains, Texas. *Water Resour. Res. 46: W09538*

Response to Land Use Change: Southern High Plains

<u>Sprinkler irrigation sites (center pivot):</u>

- New Cl accumulations
- Max root zone concentrations comparable to natural peaks (influence of groundwater salinity)
- Return to ~0 mm/yr drainage conditions





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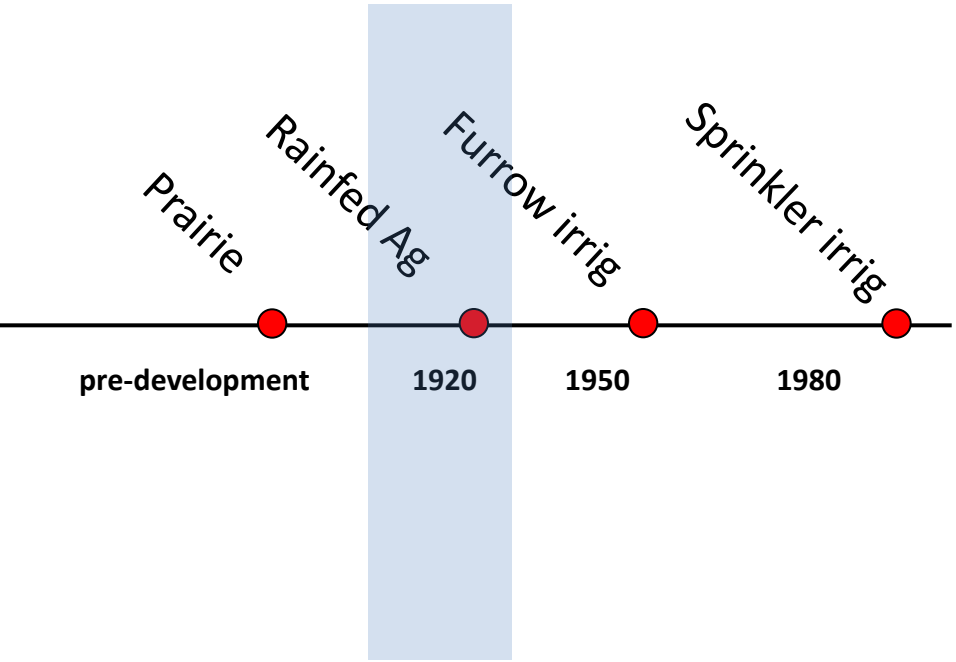
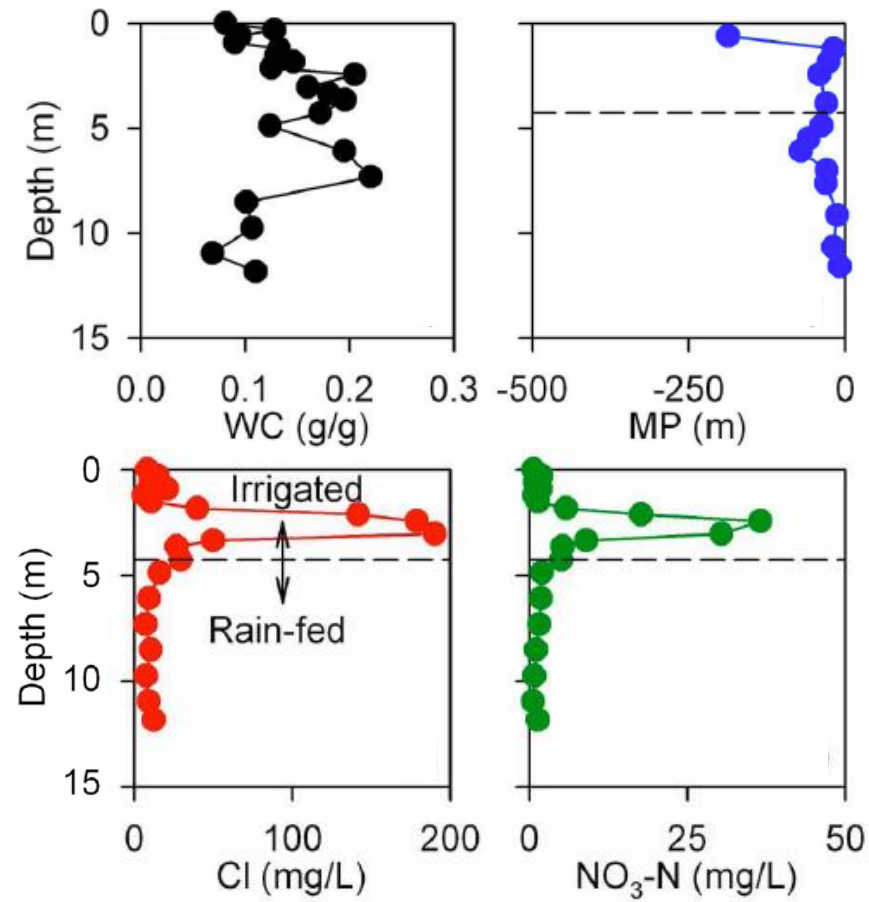
Response to Land Use Change: Southern High Plains

Rain-fed sites:

- Low Cl intervals underlying irrigation intervals
- Natural peak presumably flushed
- Drainage rates comparable to furrow irrigated





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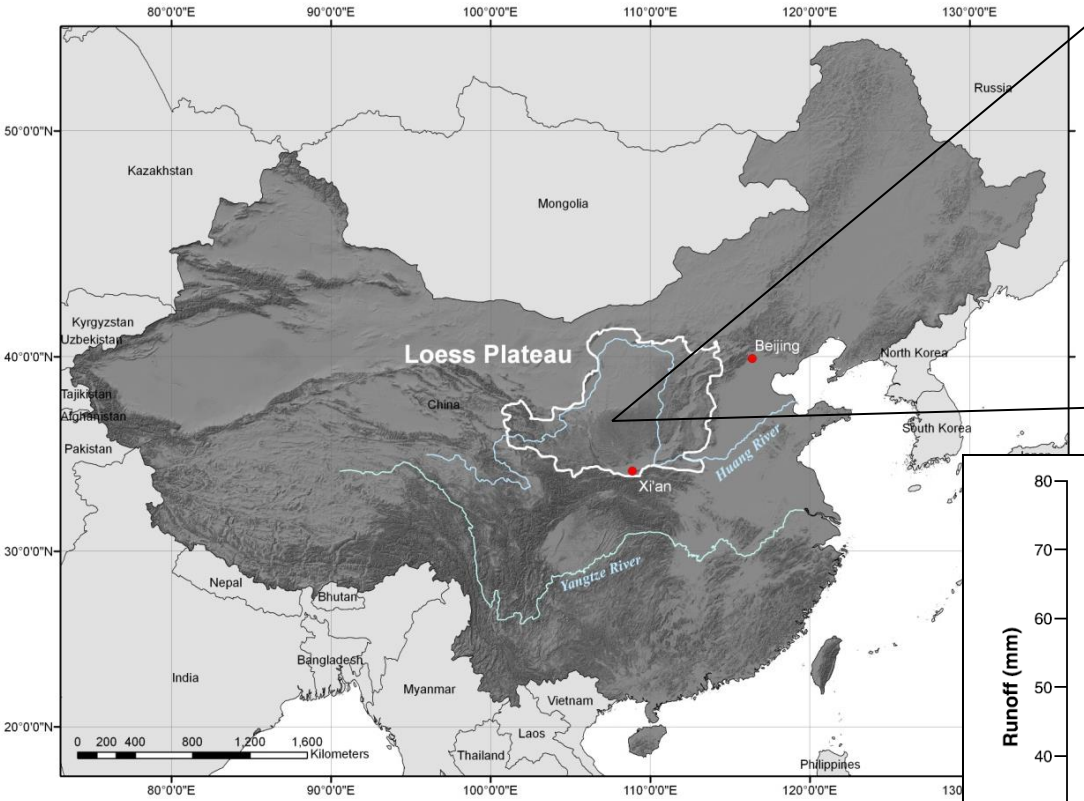
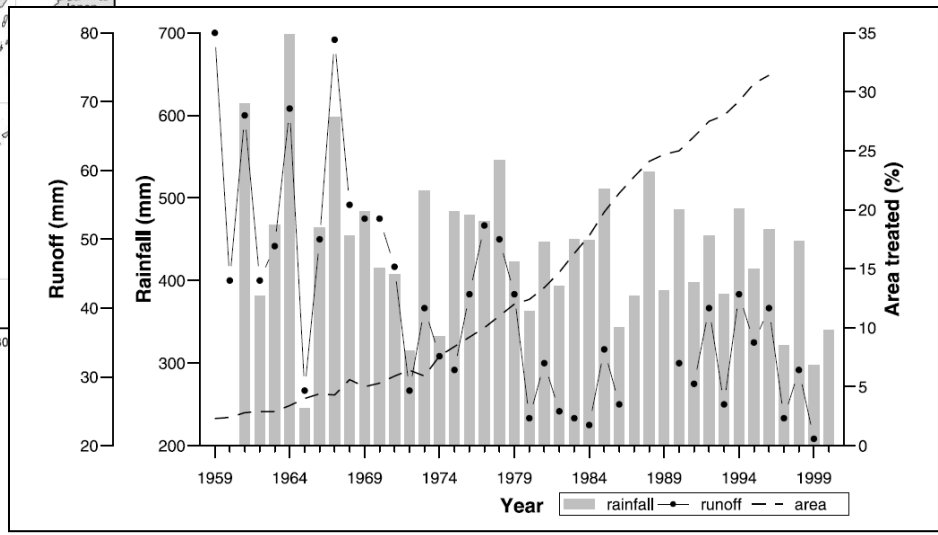
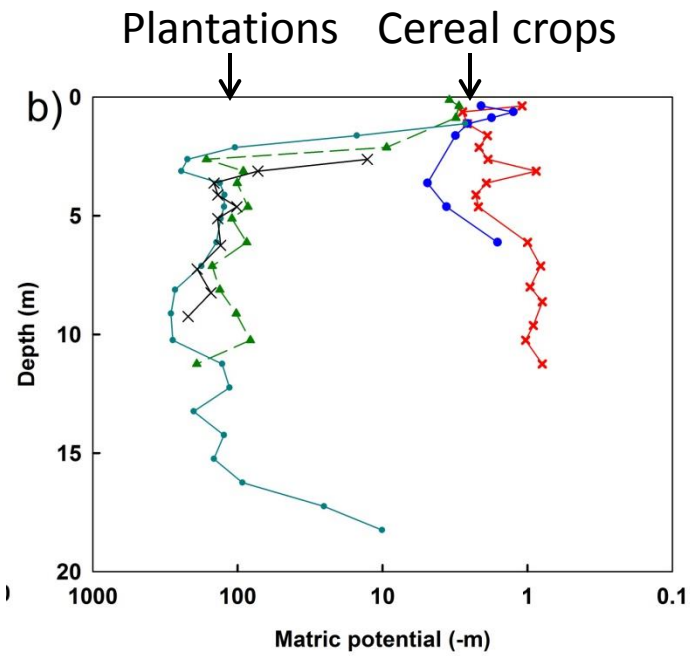
Response to Land Use Change: Loess Plateau, China

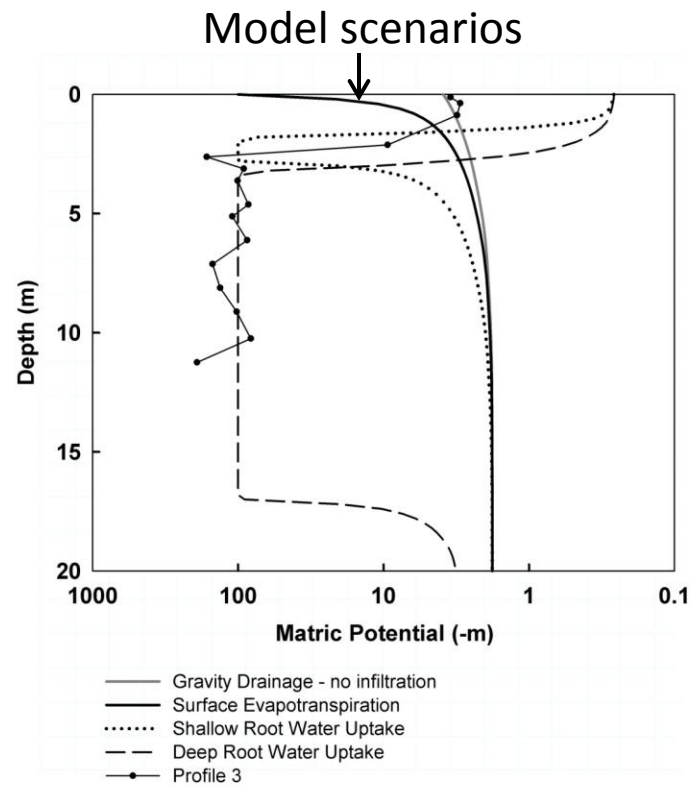


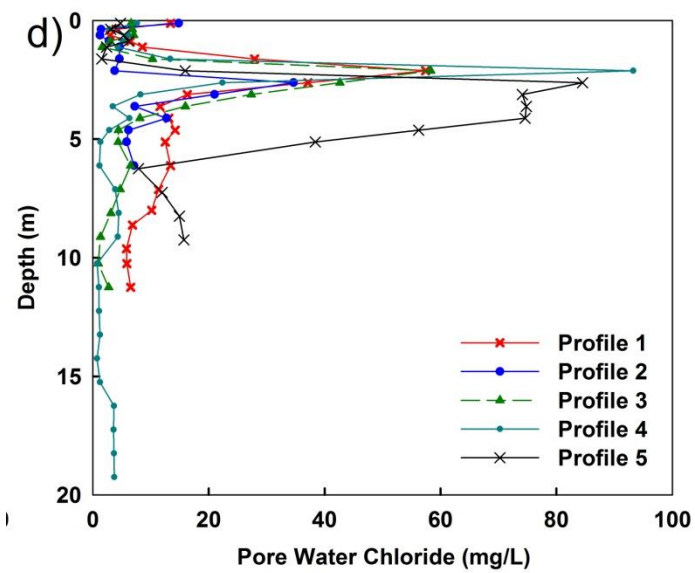


Zhang, X. et al (2008). Responses of streamflow to changes in climate and land use/cover in the Loess Plateau, Water Resour. Res., 44, W00A07

Response to Land Use Change: Loess Plateau, China





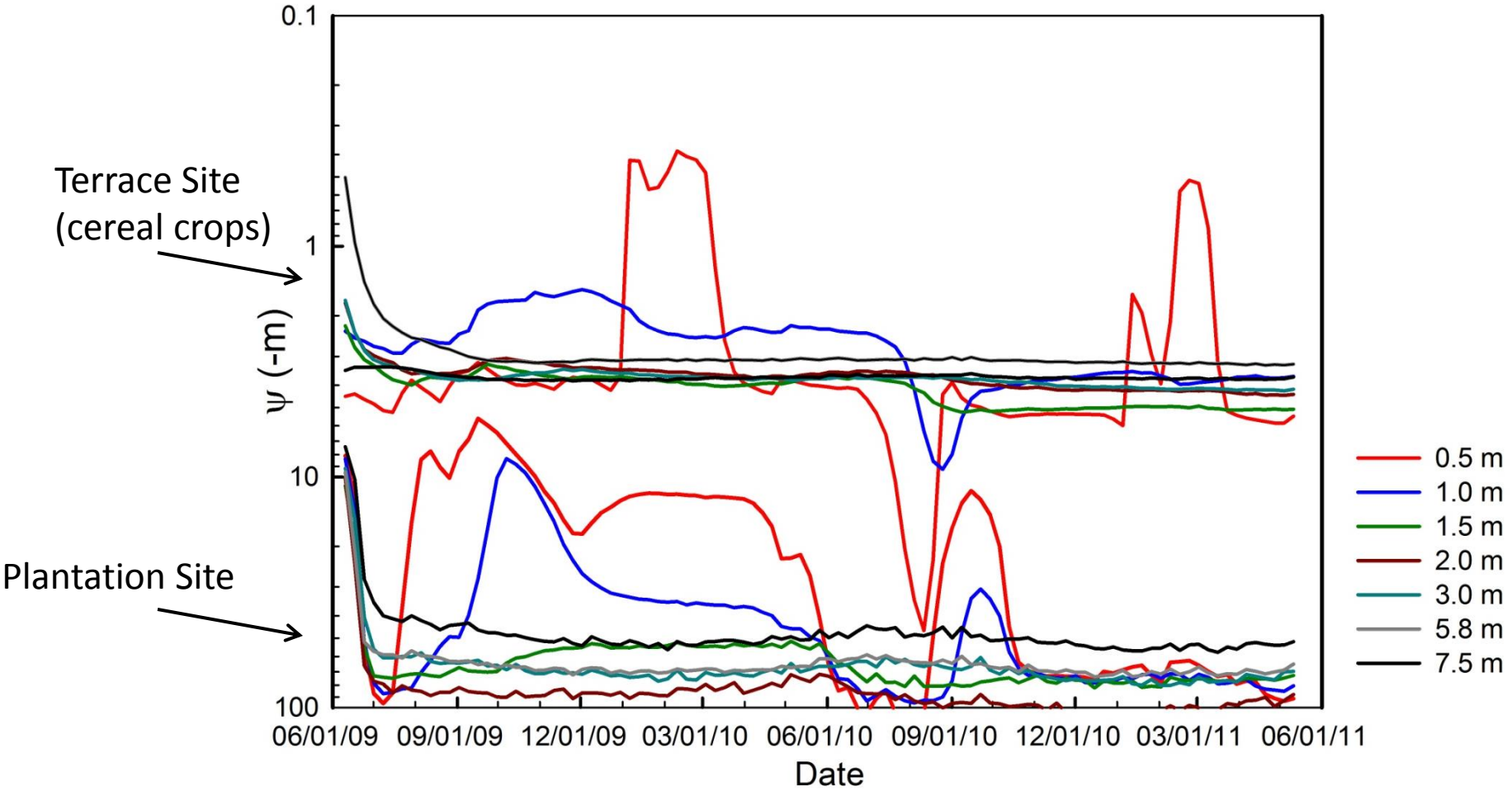


<u>Rain-fed agriculture to tree plantations:</u>

- ~40 mm/yr flux reduced to ~0 mm/yr
- Cl accumulating in root zone
- Low matric potentials

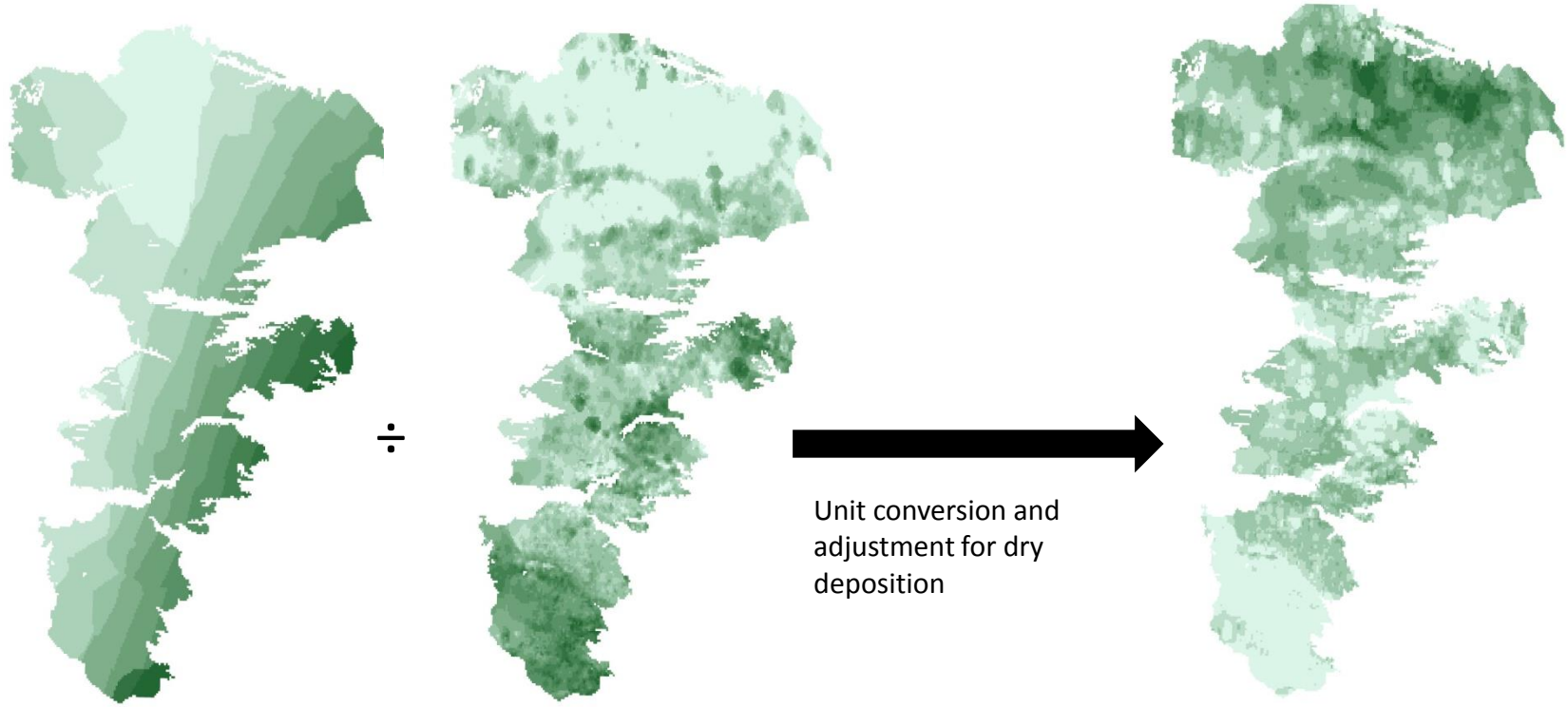
Gates J, Scanlon B, Mu X, Zhang L. 2011. Impacts of soil conservation on groundwater recharge in the semi-arid Loess Plateau, China. *Hydrogeology Journal 19: 865-75*

Response to Land Use Change: Loess Plateau, China



J Gates, unpublished data

Regionalization of tracer methods



Wet deposition (kg/ha) **Groundwater Cl^- (mg/L)** **Recharge (mm/yr)**

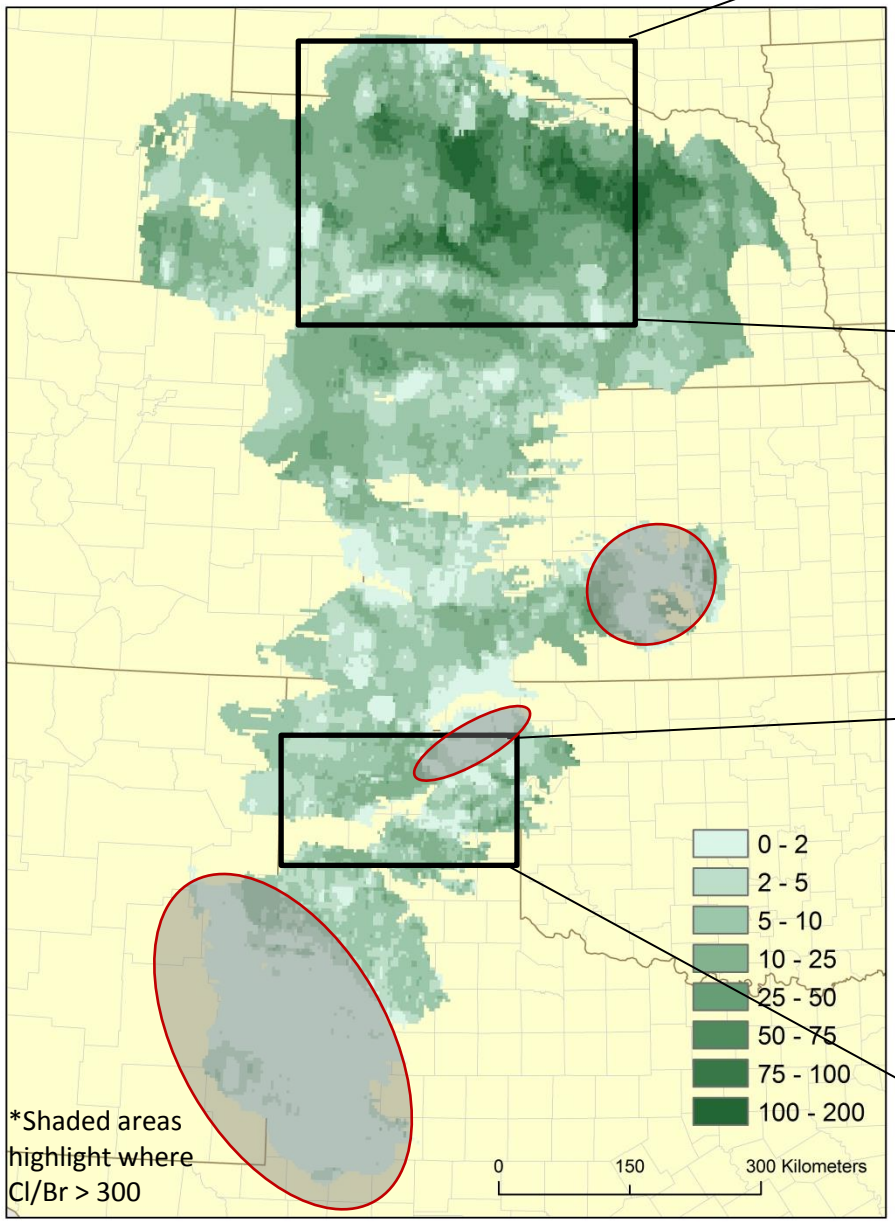
Solute Mass Balance:

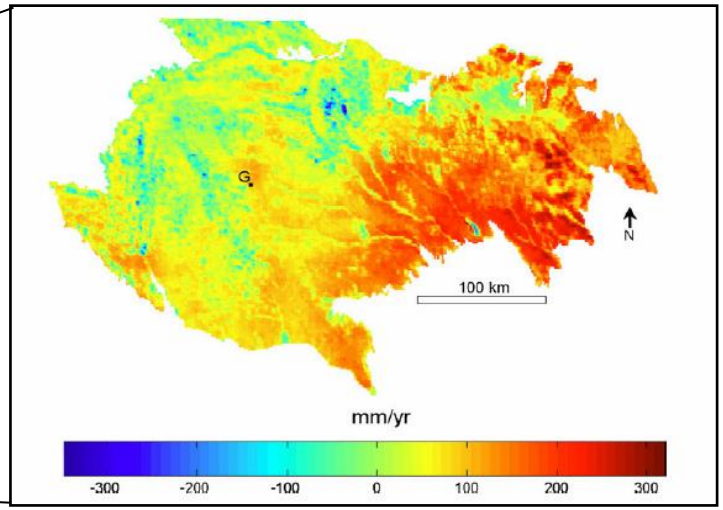
$$\underbrace{P * C_P}_{\text{Mass flux in from precipitation}} = \underbrace{R * C_R}_{\text{Mass flux out from recharge}}$$

Szilagyi J, Zlotnik V, Gates J, Jozsa J. 2011. Mapping mean annual groundwater recharge in the Nebraska Sand Hills, USA. *Hydrogeology Journal 19: 1503-13*

Scanlon BR, Reedy RC, Gates JB, Gowda PH. 2010. Impact of agroecosystems on groundwater resources in the Central High Plains, USA. *Agriculture, Ecosystems & Environment 139: 700-13*

Regionalization of tracer methods





Nebraska Sand Hills:

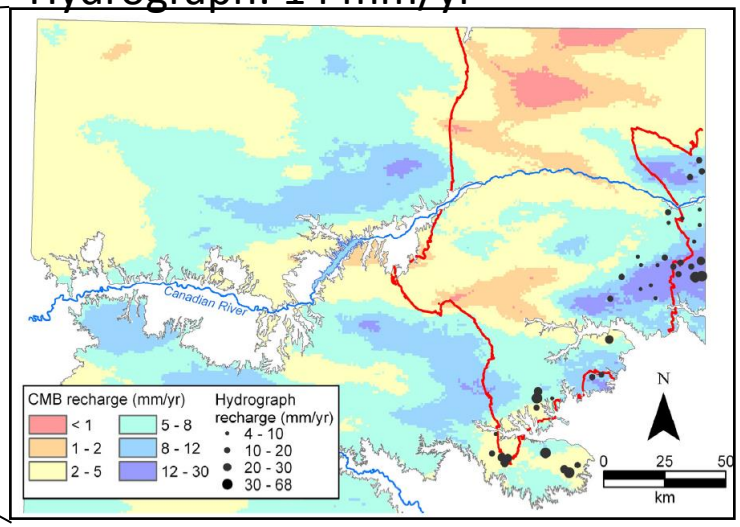
Chloride Balance: 73 mm/yr

MODIS/SWB: 73 mm/yr

Southern Central High Plains:

Chloride Balance: 27 mm/yr

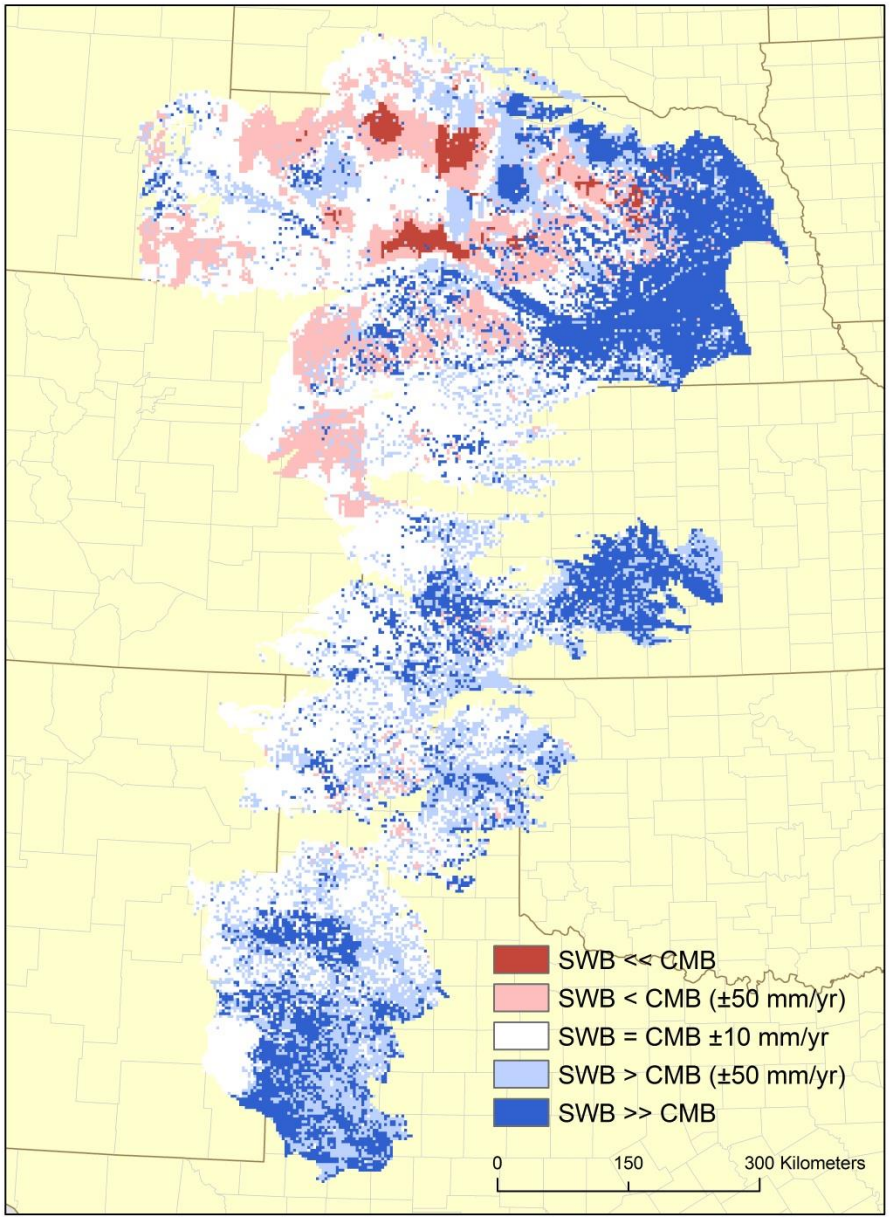
Hydrograph: 14 mm/yr



Regionalization of tracer methods

<u>Model output comparison:</u>

- Soil Water Balance
- Chloride Balance



J Gates, unpublished data
Source of SWB data: Stanton et al (2011) USGS Scientific Investigations Report 2011-5183.