Impacts of Land Use on Water Resources in the High Plains using Satellite and Ground-based Data

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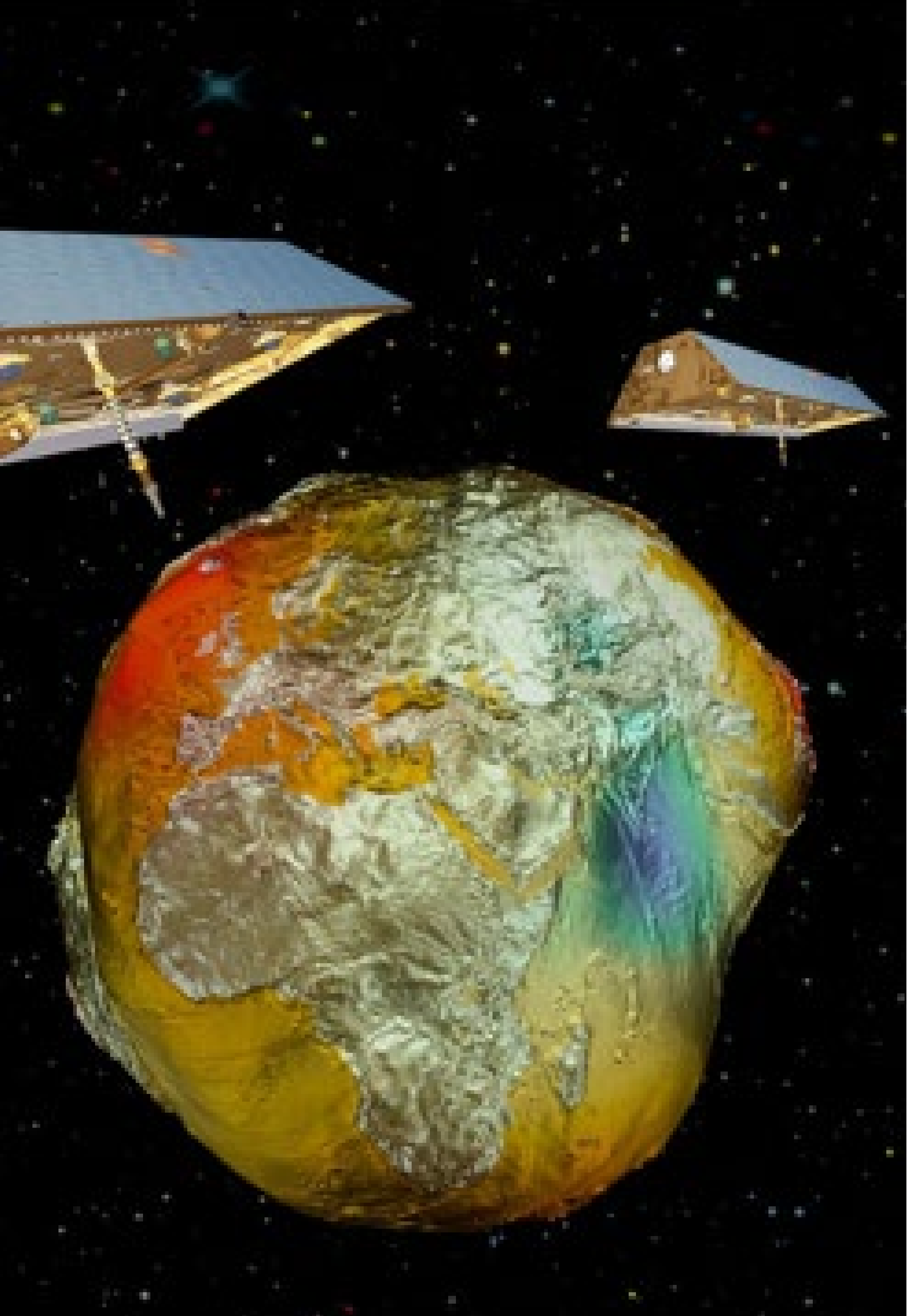
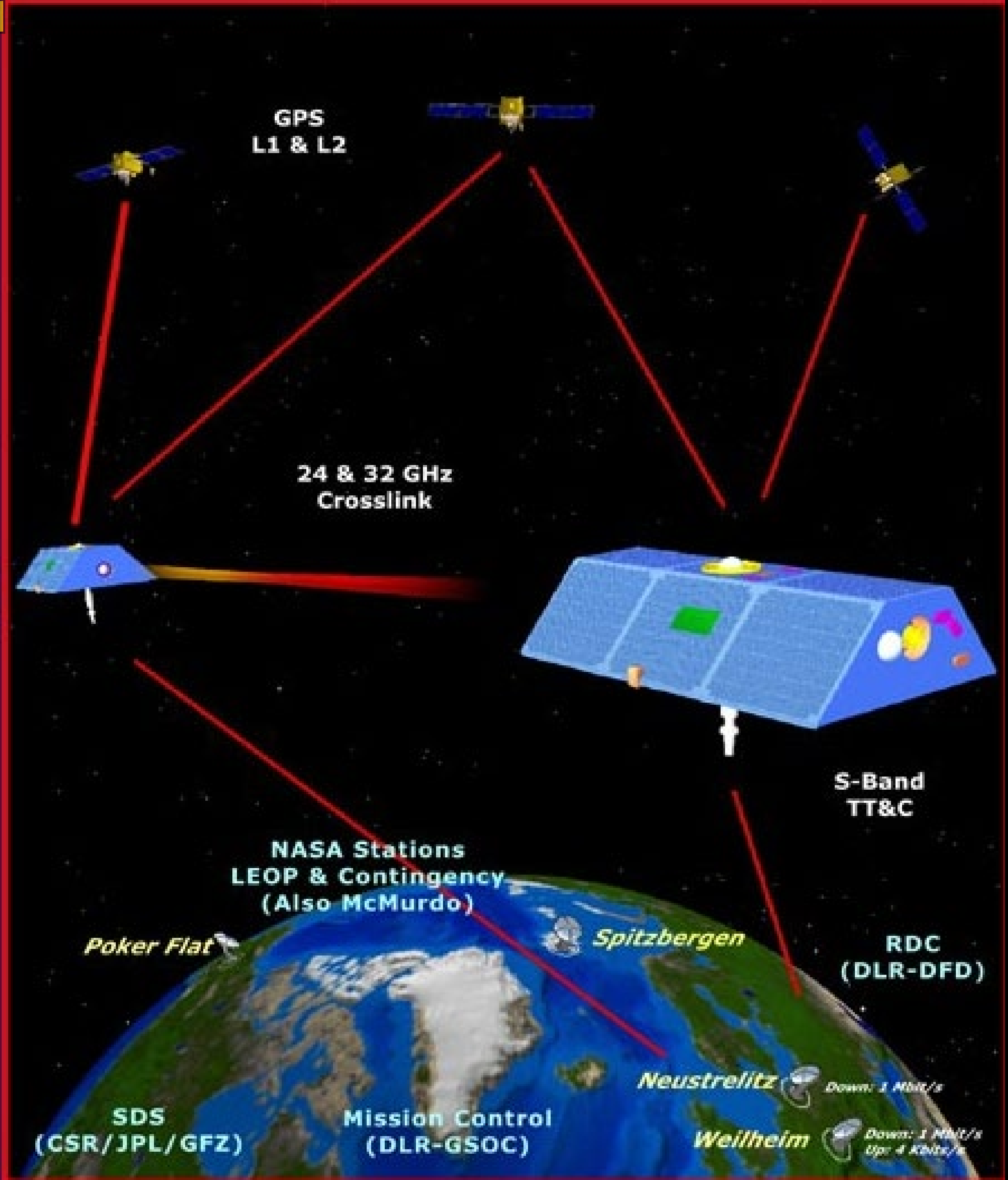


Outline

- GRACE water storage monitoring
- Global land use change
- Land use change impacts on groundwater in the High Plains:
  - Playas
  - Rangeland
  - Rainfed cropland
  - Irrigated cropland



GRACE

Gravity Recovery and Climate Experiment

GRACE: March 2002 – 2017 (low solar activity)
GRACE Follow-On: 2018 →

500 km above land surface controls resolution of GRACE data
Resolution: ~350 km, ~120,000 km^2

Satellites 220 km apart

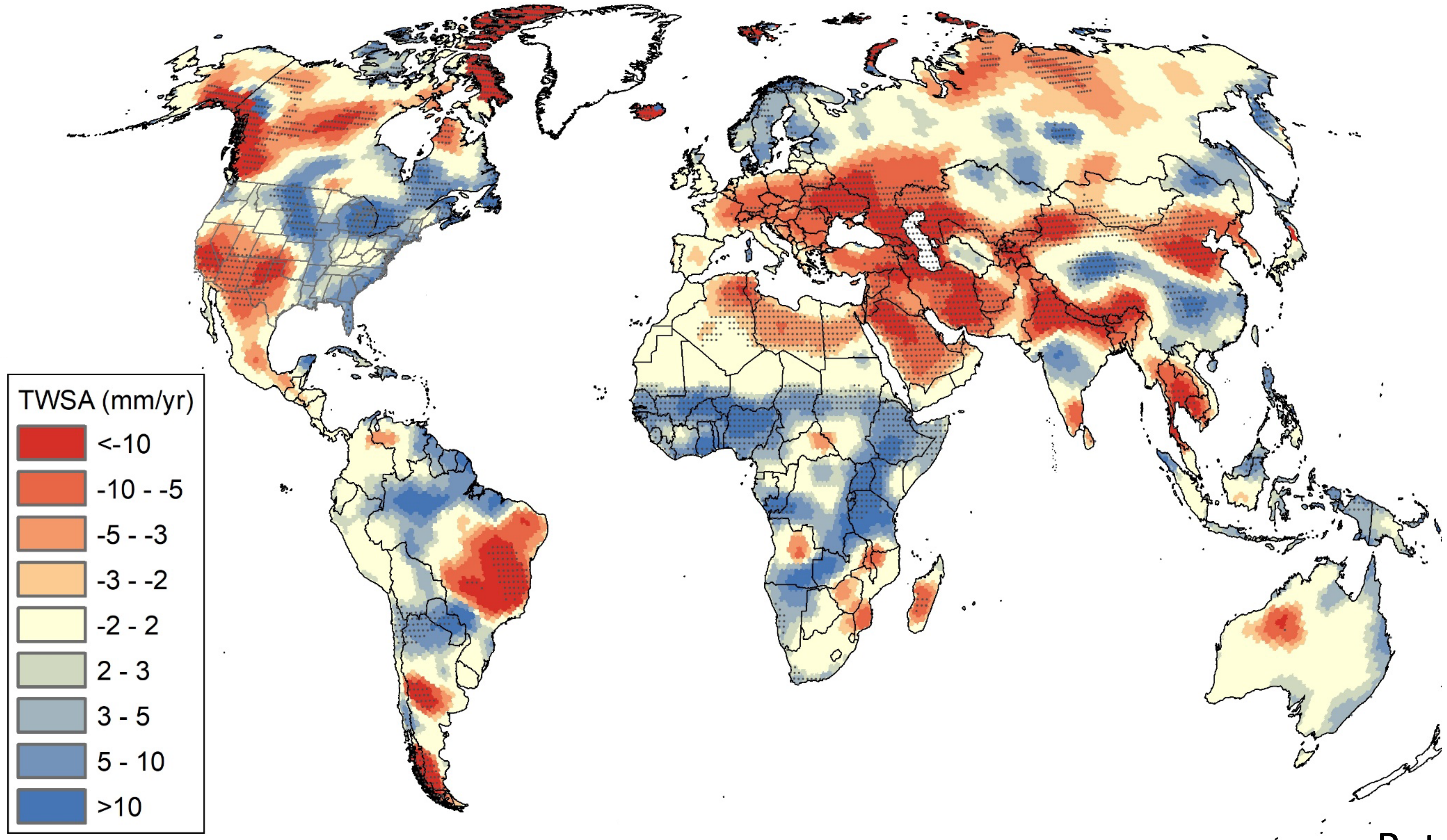
Monthly data
1 gigaton mass change = 1 km^3 of water

Terrestrial water storage (TWS) change

Essential climate variable in
Global Climate Observing System

http://grace.jpl.nasa.gov/mission/gravity-101/

GRACE Total Water Storage Anomalies (04/2002 – 09/2021)



Rateb et al., 2022

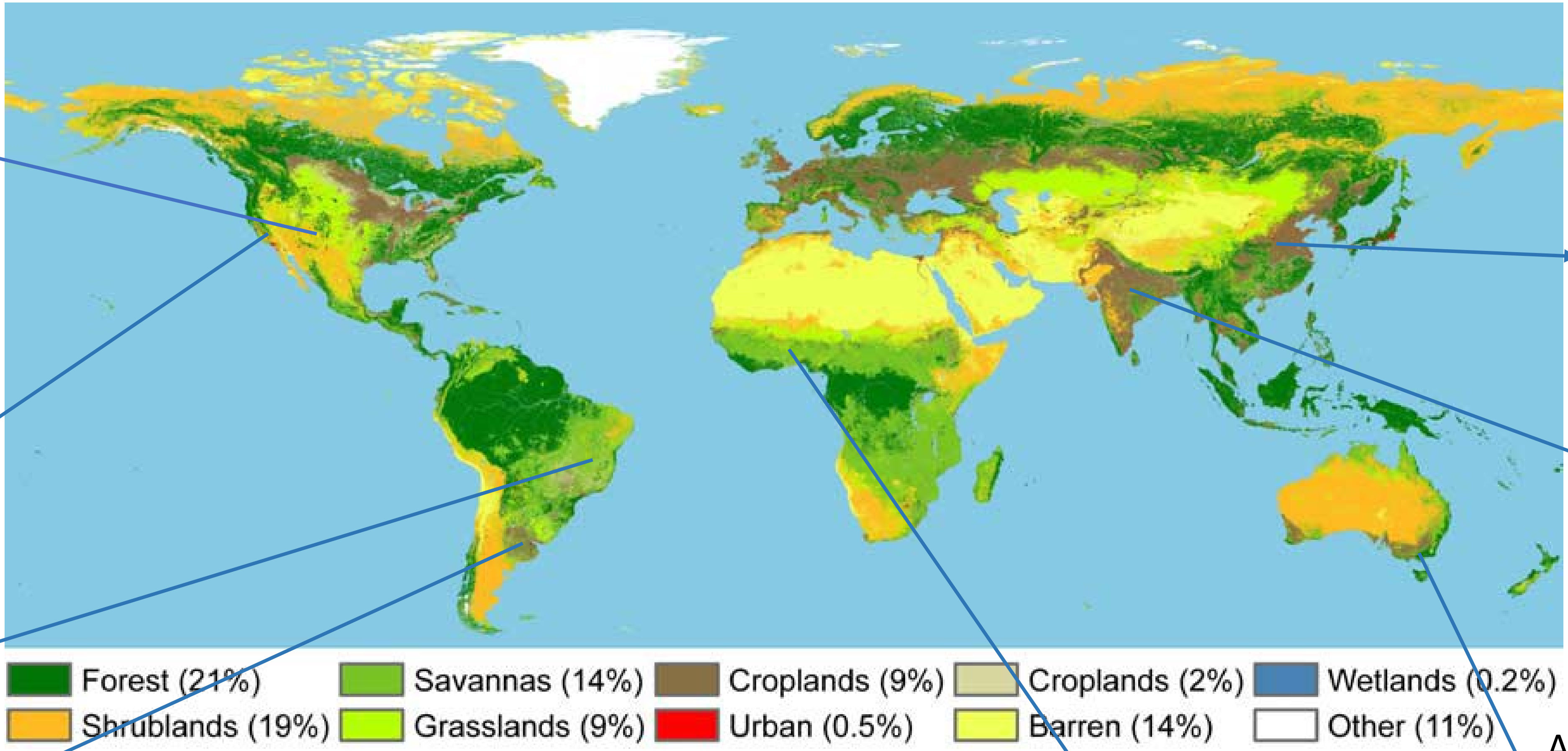
Global Land Use

High Plains
Rainfed + GW
Irrigation

Central Valley
SW & GW
irrigation

Brazil
Agriculture
inc. recharge

Argentina
Rainfed
agriculture
flooding



N China Plain
Irrigation
GW depletion

NW India
Irrig: SW
inc. rech
GW deplete
aquifers

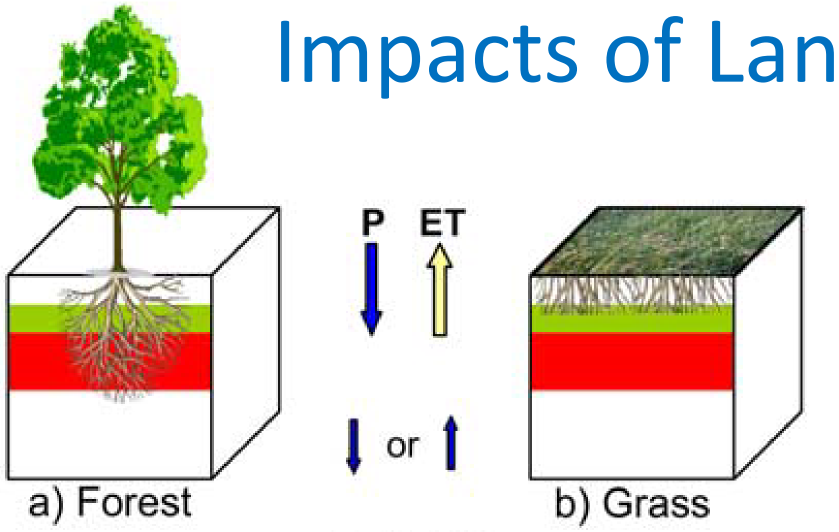
W Africa
Agriculture
Inc. recharge
Ponds, salinity

Australia
Rainfed
Agriculture
inc. recharge
dryland salinity

Natural vegetation: no recharge
Rainfed croplands: increased recharge
Irrigated agriculture: surface water or groundwater

Scanlon et al., WRR, 2007

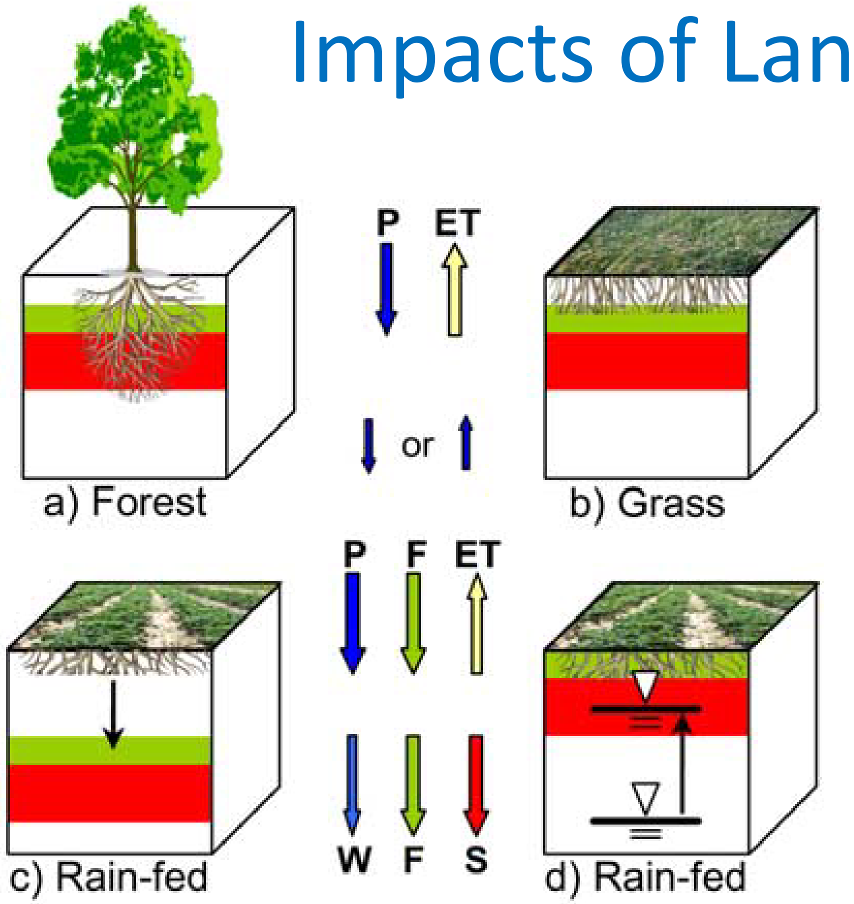
Impacts of Land Use on Groundwater Resources



Native Vegetation:

Semiarid regions: no recharge

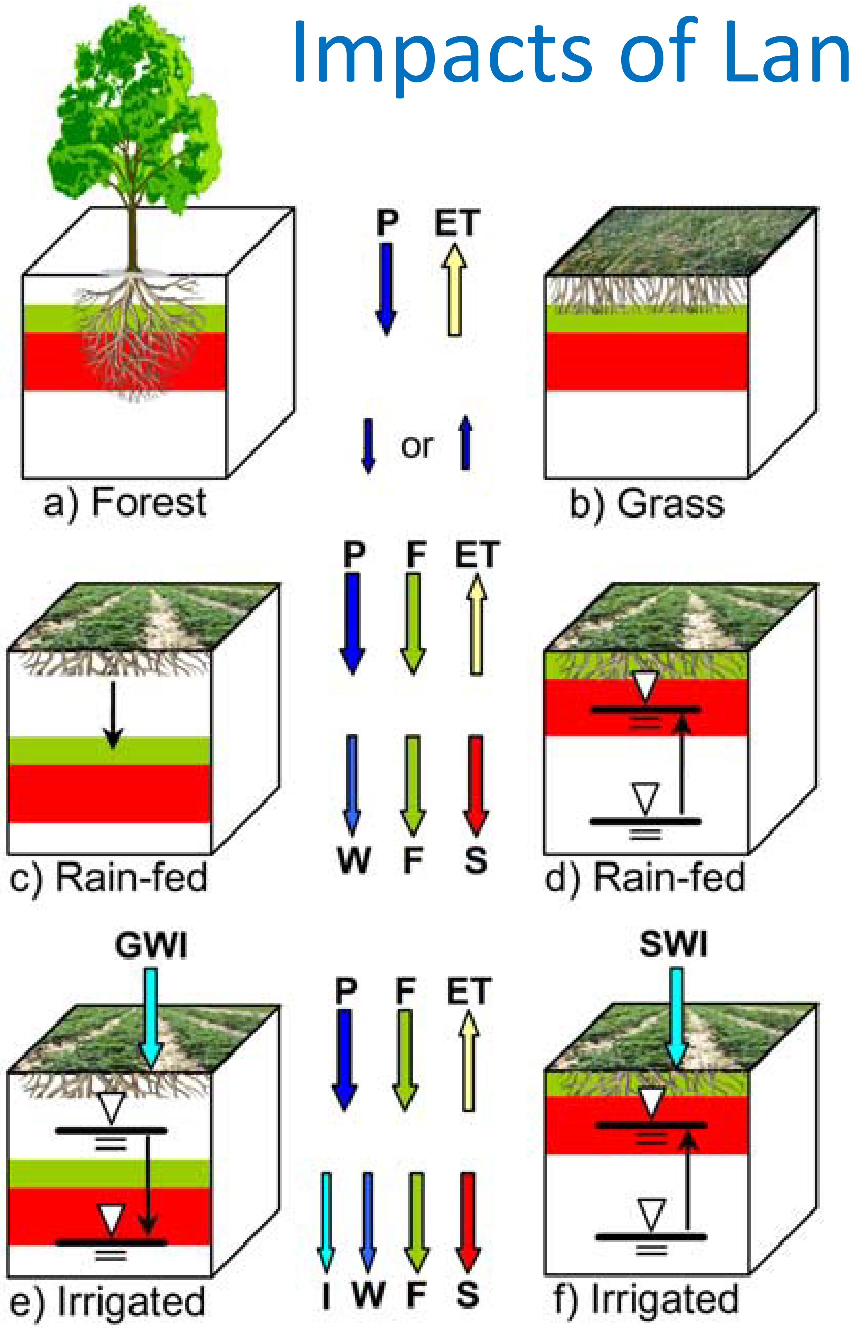
Impacts of Land Use on Groundwater Resources



Native Vegetation:
Semiarid regions: no recharge

Conversion of native vegetation to cropland
Increase GW recharge, raise water tables
Can cause dryland salinity

Impacts of Land Use on Groundwater Resources

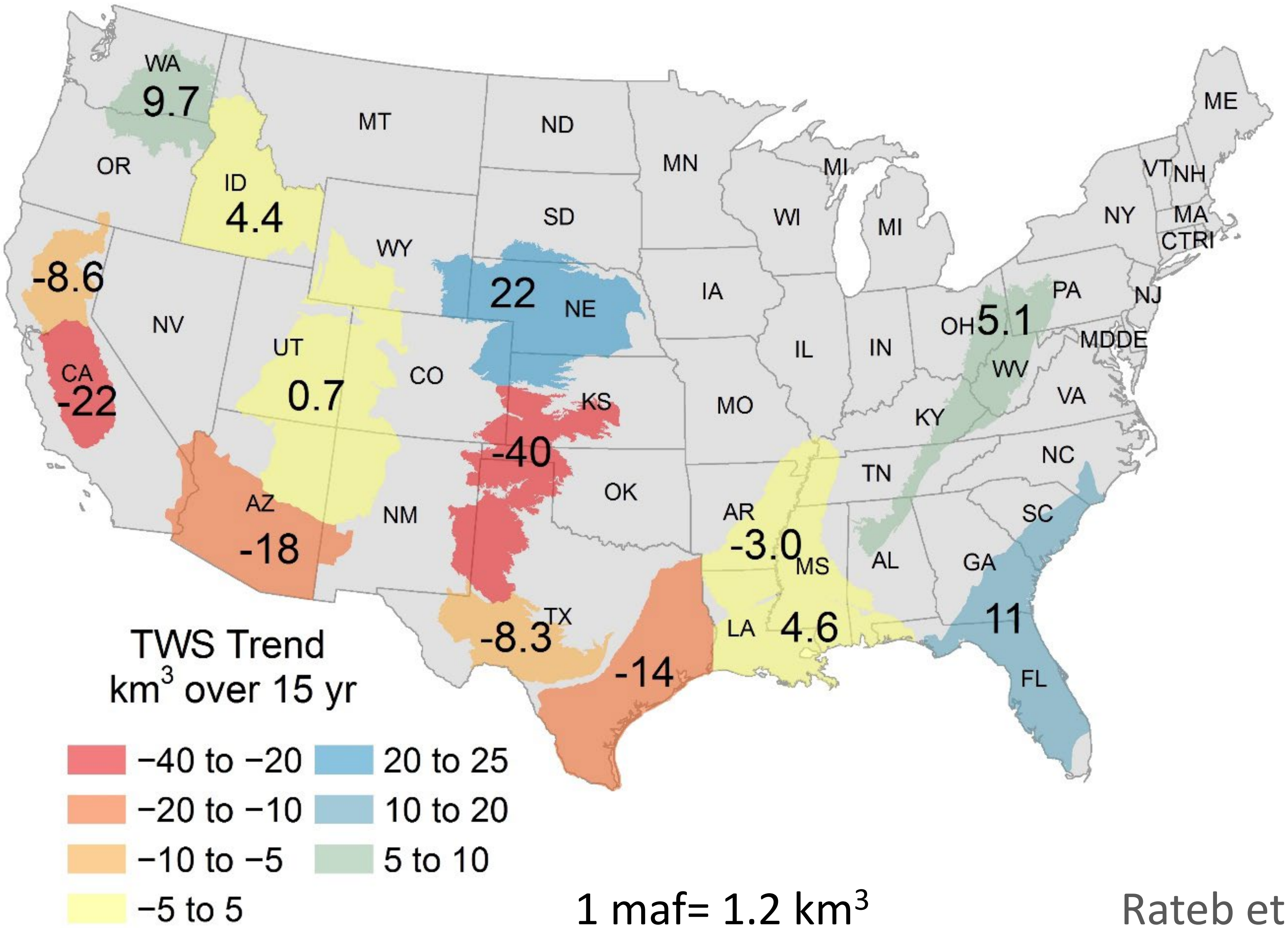


Native Vegetation:
Semiarid regions: no recharge

Conversion of native vegetation to cropland
Increase GW recharge, raise water tables
Can cause dryland salinity

Irrigation:
GW irrigation: deplete aquifers
SW irrigation, raise GW, salinization

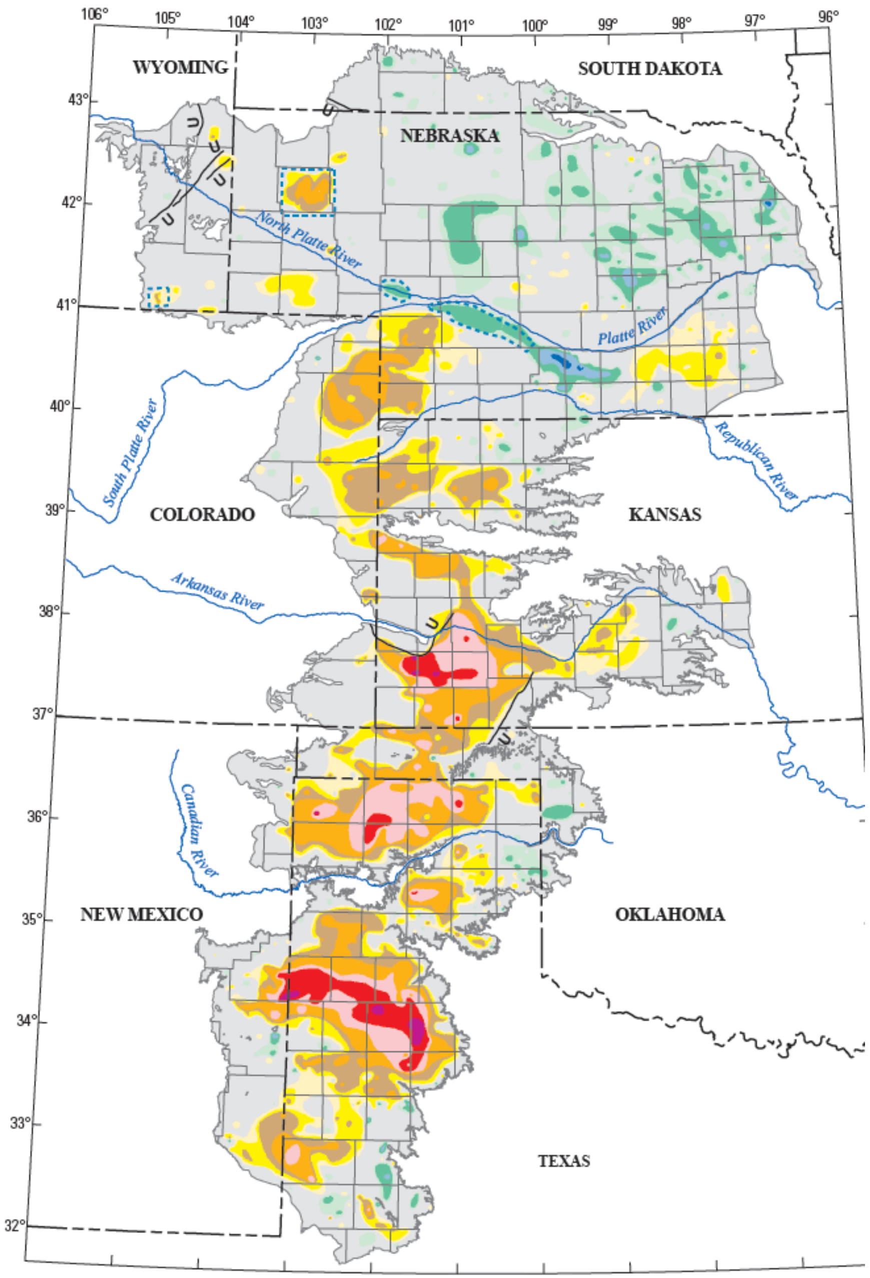
GRACE Total Water Storage Trends in the U.S. (2002 – 2017)



1 maf= 1.2 km^3

Rateb et al., WRR, 2021

Groundwater Level Changes Predevelopment (< 1950) to 2019



Declines

- ≥200 ft
- 150 to 200
- 100 to 150
- 50 to 100
- 25 to 50
- 10 to 25
- 5 - 10

No change

- -5 to 5

Rises

- 5 –to 10
- 10 to 25
- 25 to 50
- 50 to 100

~8,300 wells

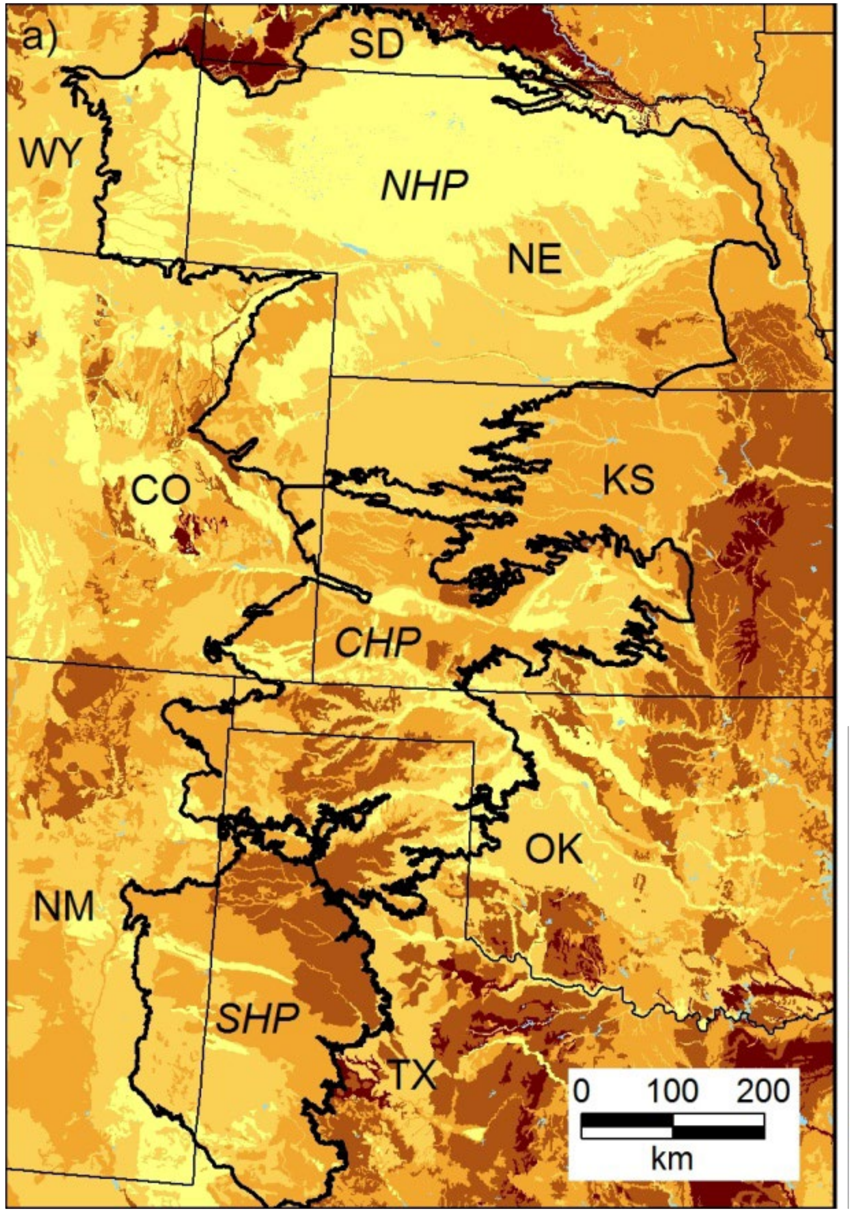
Rise ~ 40 ft to decline ~ 200 ft

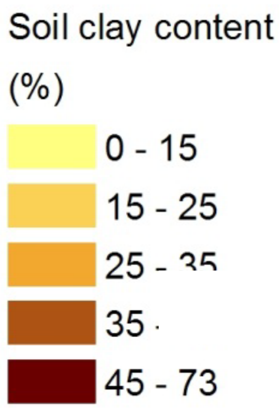
Average decline: 17 ft

Decline Texas: 44 ft

McGuire and Strauch, 2024

Clay Content in High Plains

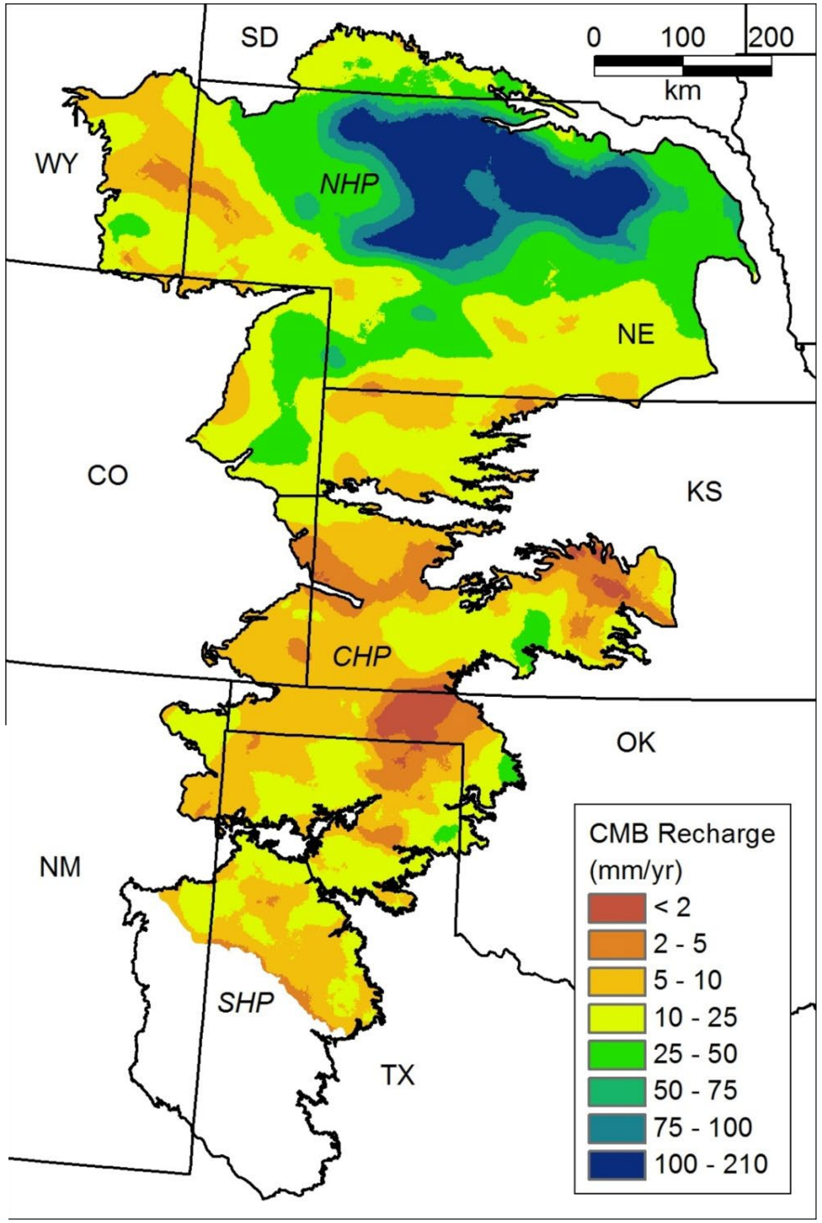




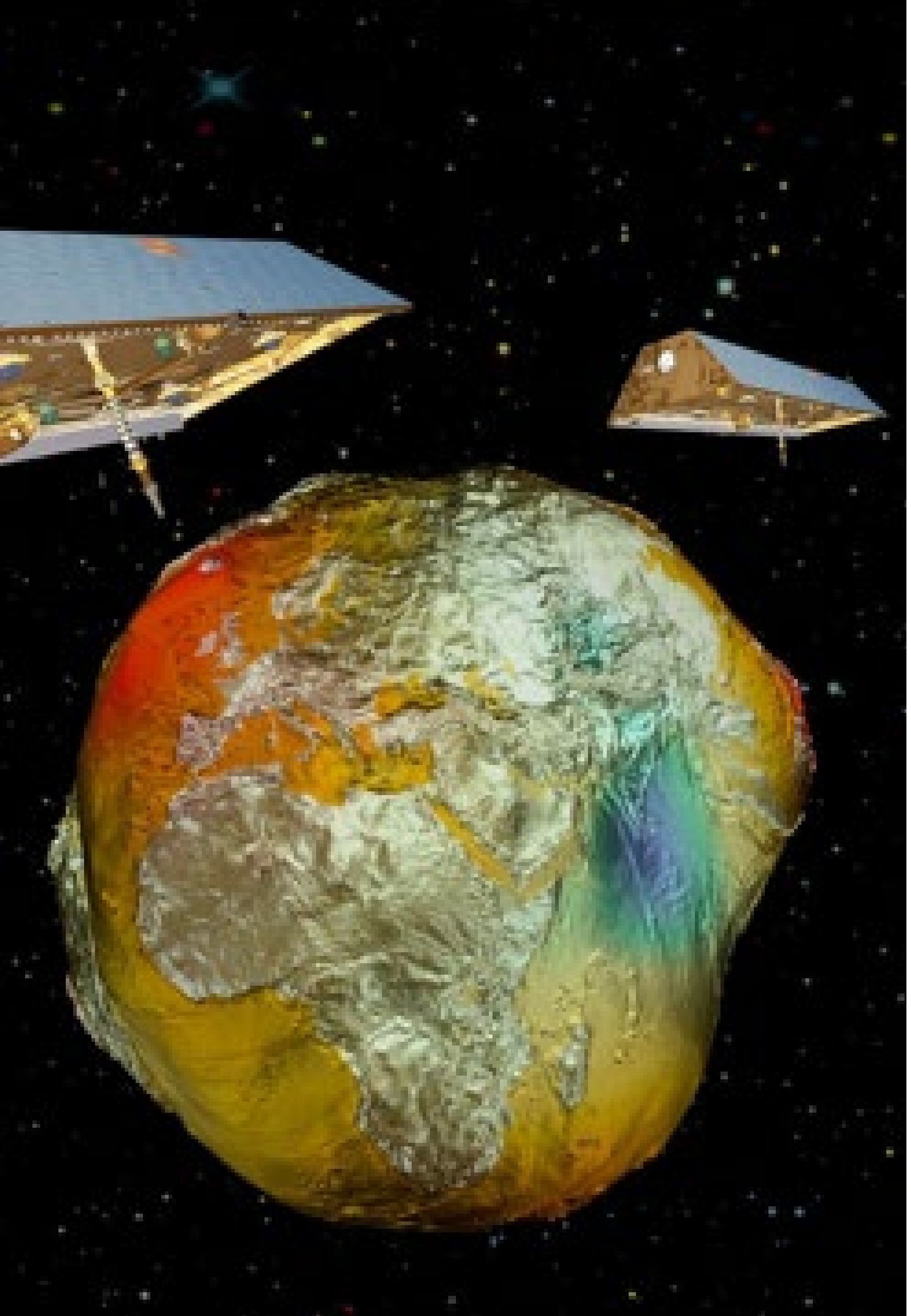
Groundwater Recharge Rate (chloride)

$$R = \frac{P \times ClP}{Cl_{GW}}$$

P = Precipitation
Cl_P: Cl in precip.
Cl_{GW}: Cl in GW



Scanlon et al., PNAS, 2012



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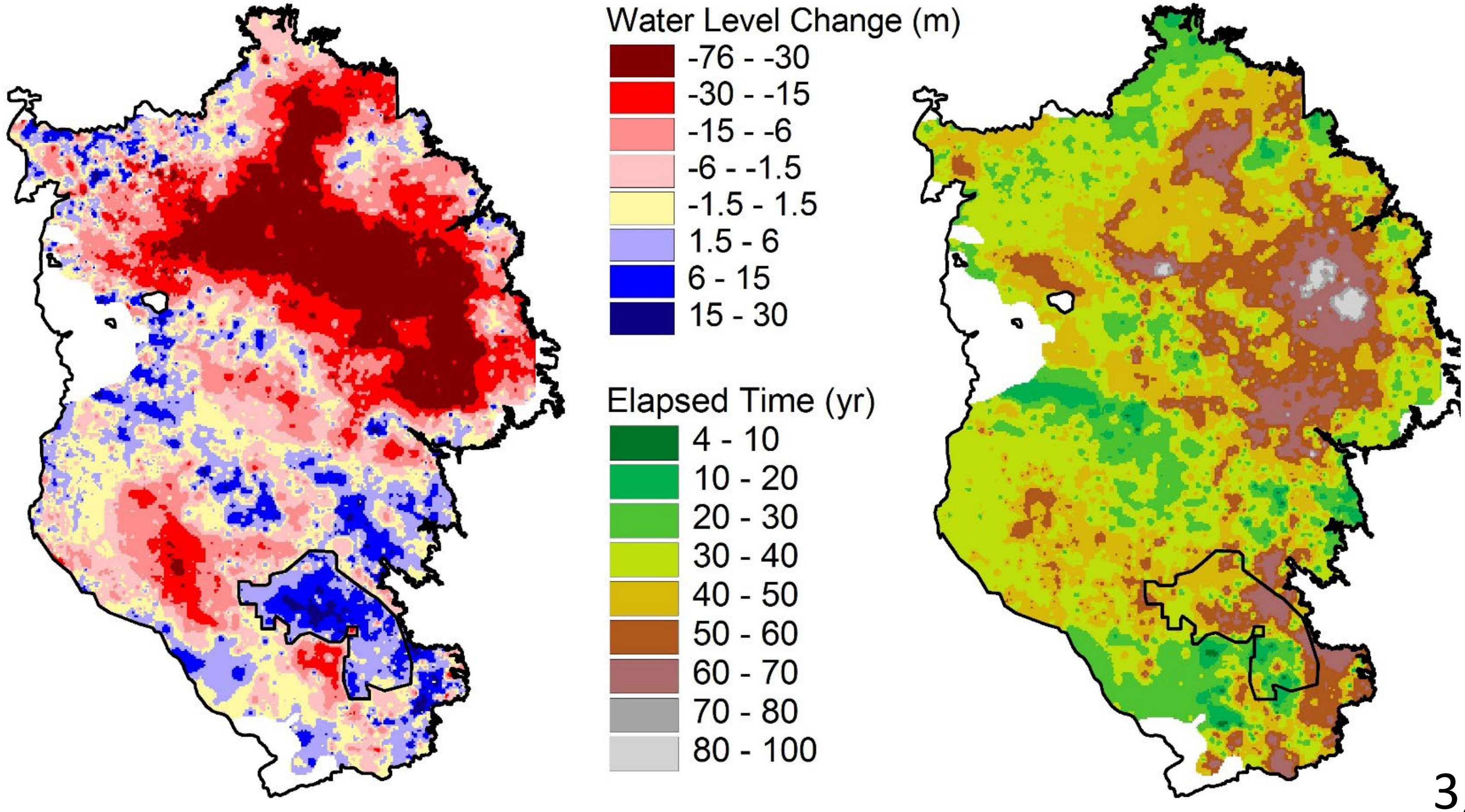
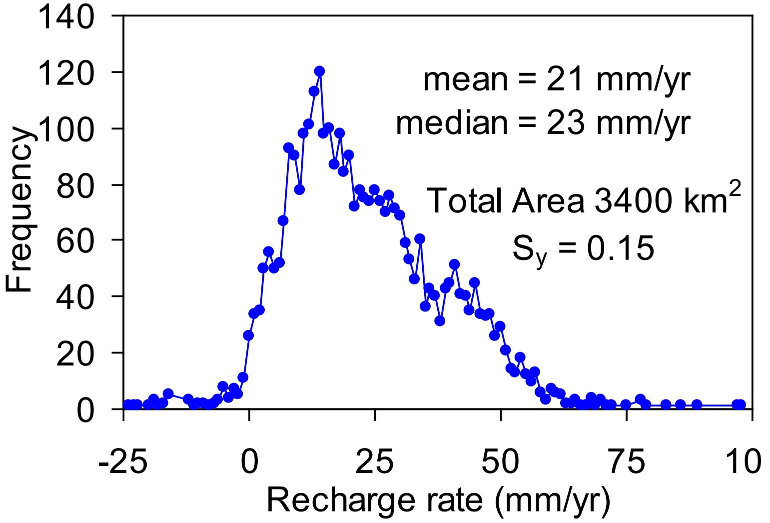
Recharge Estimation from Water Level Rises in Rainfed Agriculture





3,400 km^2 area

Average recharge ~ 1 inch/yr

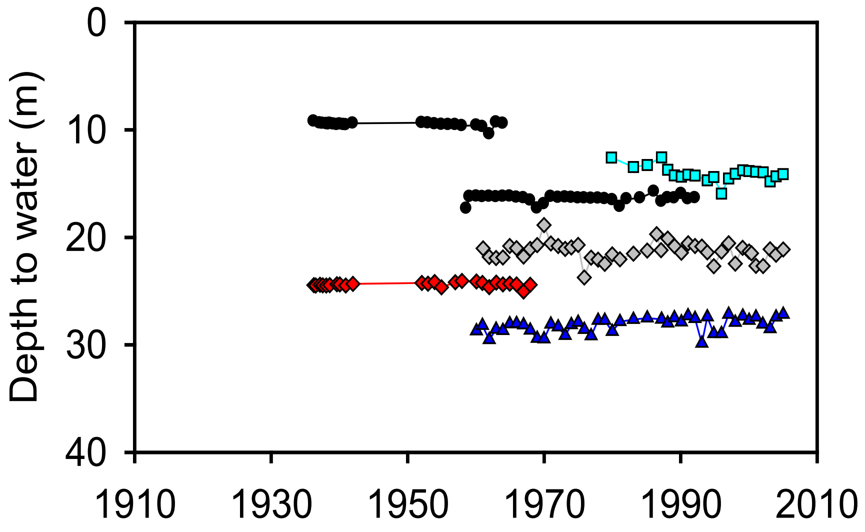
Recharge =

Specific Yield $\Delta h/\Delta t$

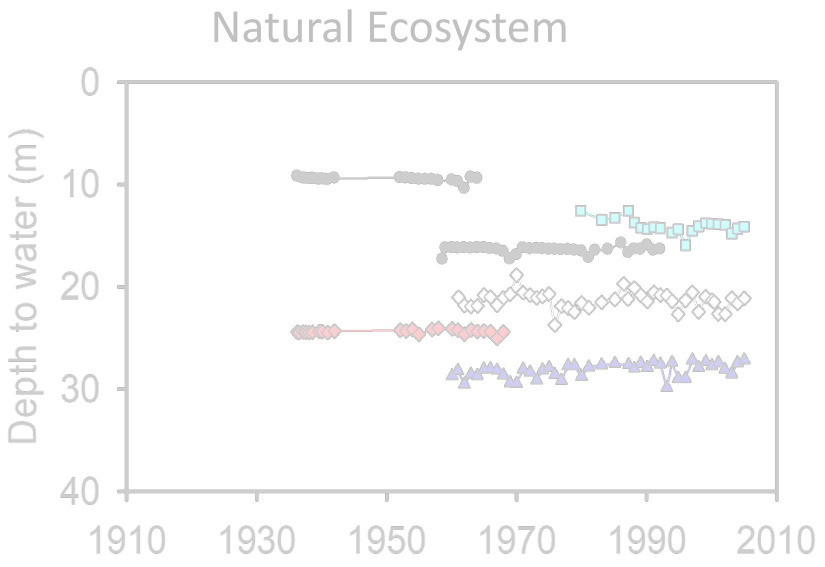
Scanlon et al., GCB, 2005

Natural Ecosystems

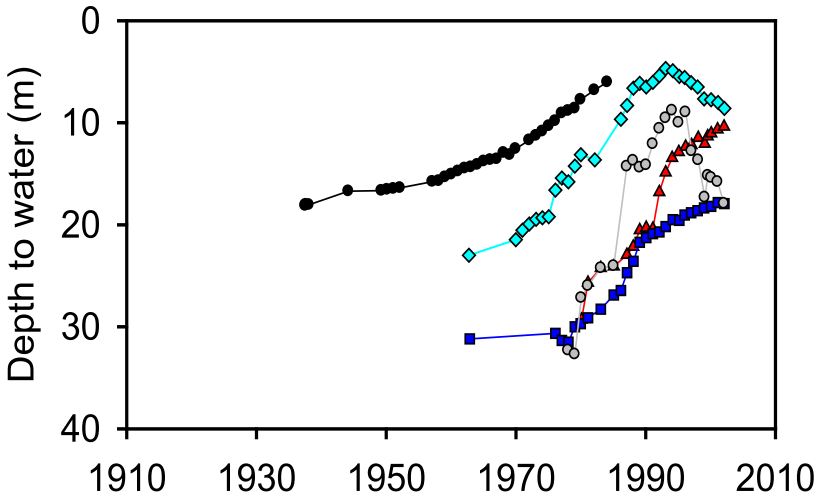
Impacts of Land-Use Changes on Groundwater Levels



No recharge

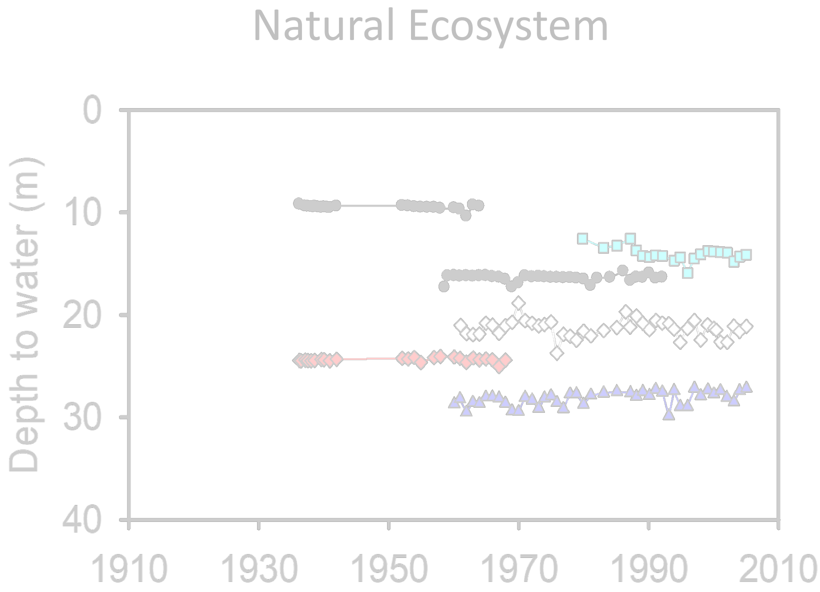


Rainfed Agriculture

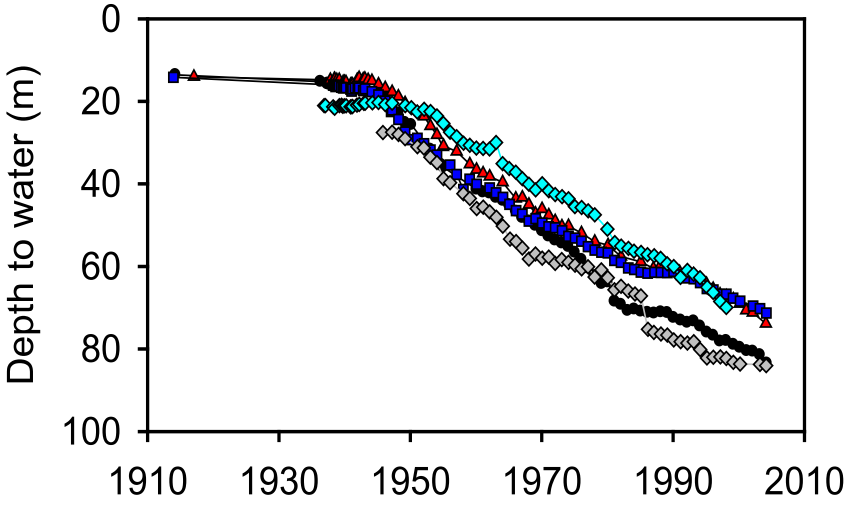


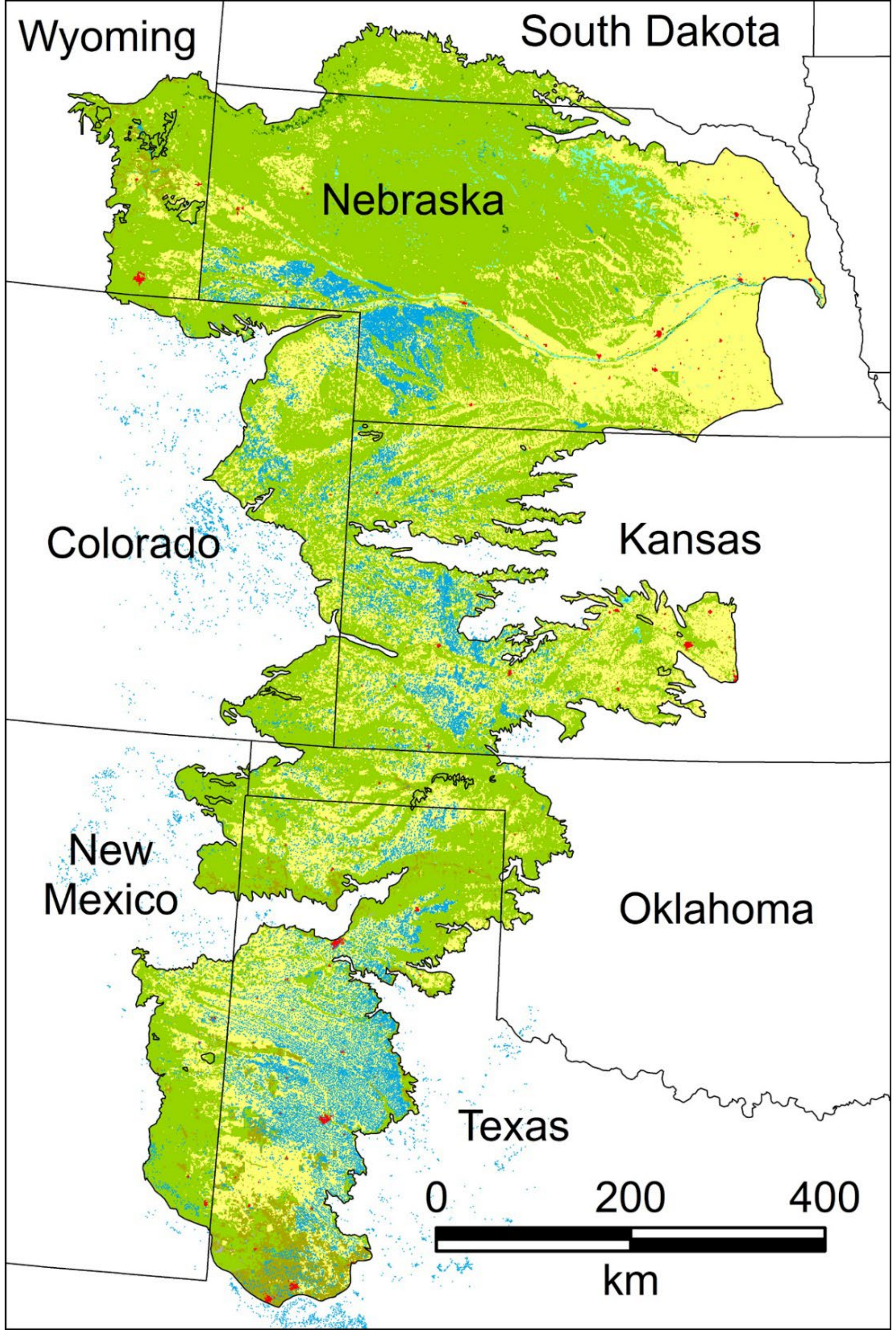
Increasing recharge

Impacts of Land-Use Changes on Groundwater Levels



Irrigated Agriculture





Playa Distribution

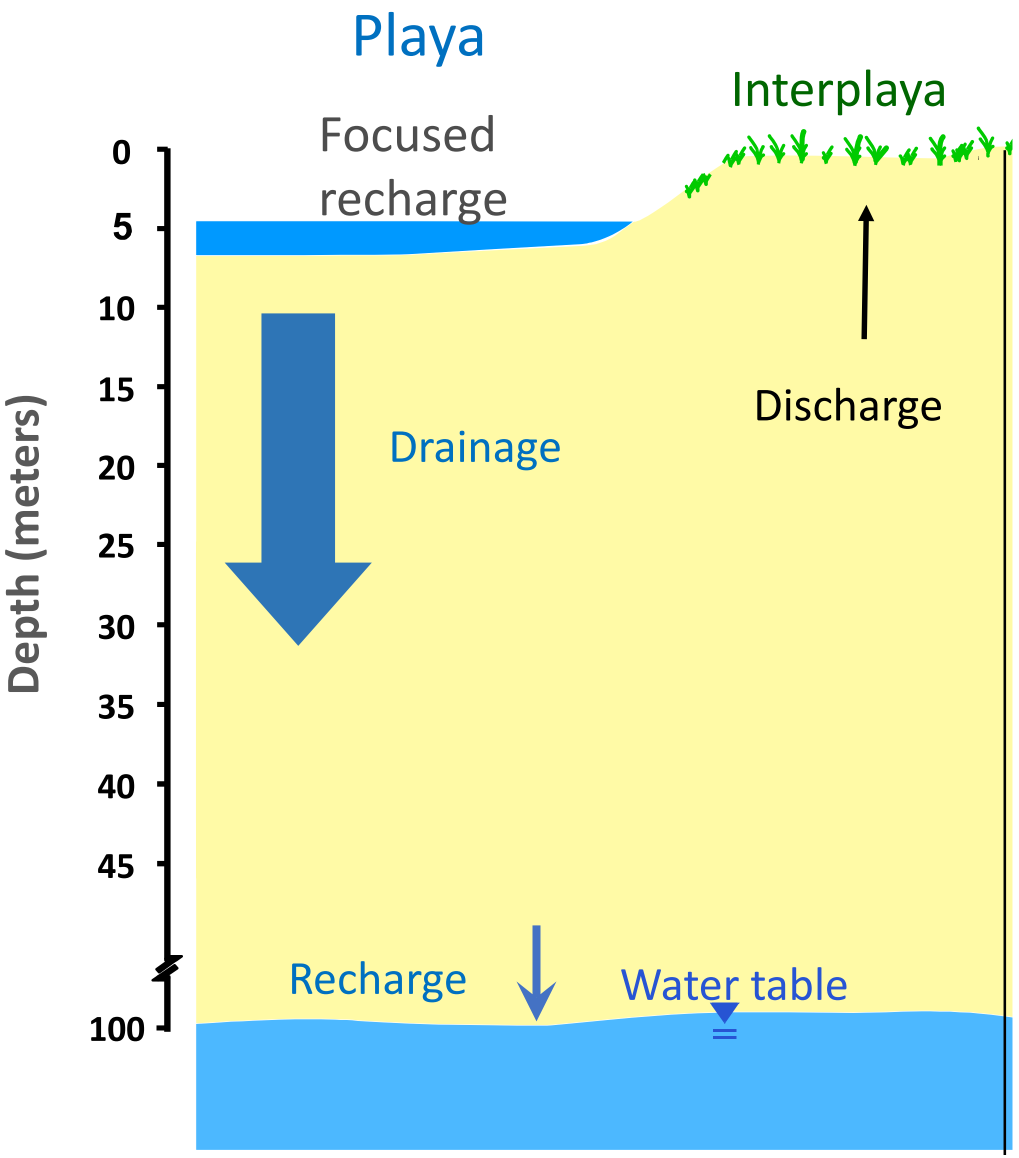
High Plains ~ 50,000 playas

Southern High Plains: ~ 16,000 playas

Playas occupy ~2% of land surface

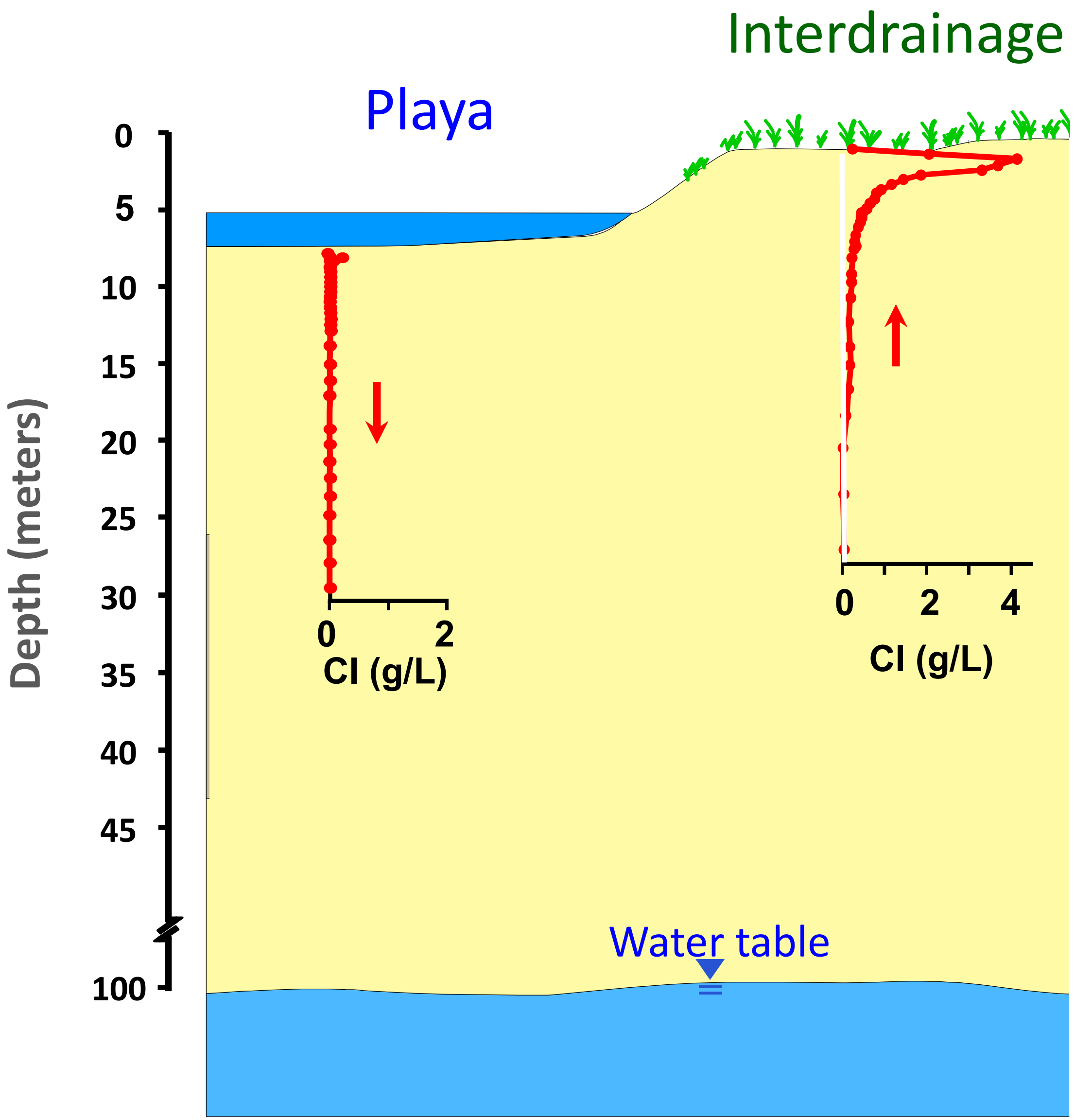
Have evaluated enhanced recharge

Are playas evaporation ponds or recharge features?



Wood and Sanford, 1995; GW
Scanlon and Goldsmith, 1997, WRR

Chloride as a Qualitative Indicator of Water Movement



Chloride from precipitation

Chloride in soil water is inversely related to water flux

low Cl --- high water flux

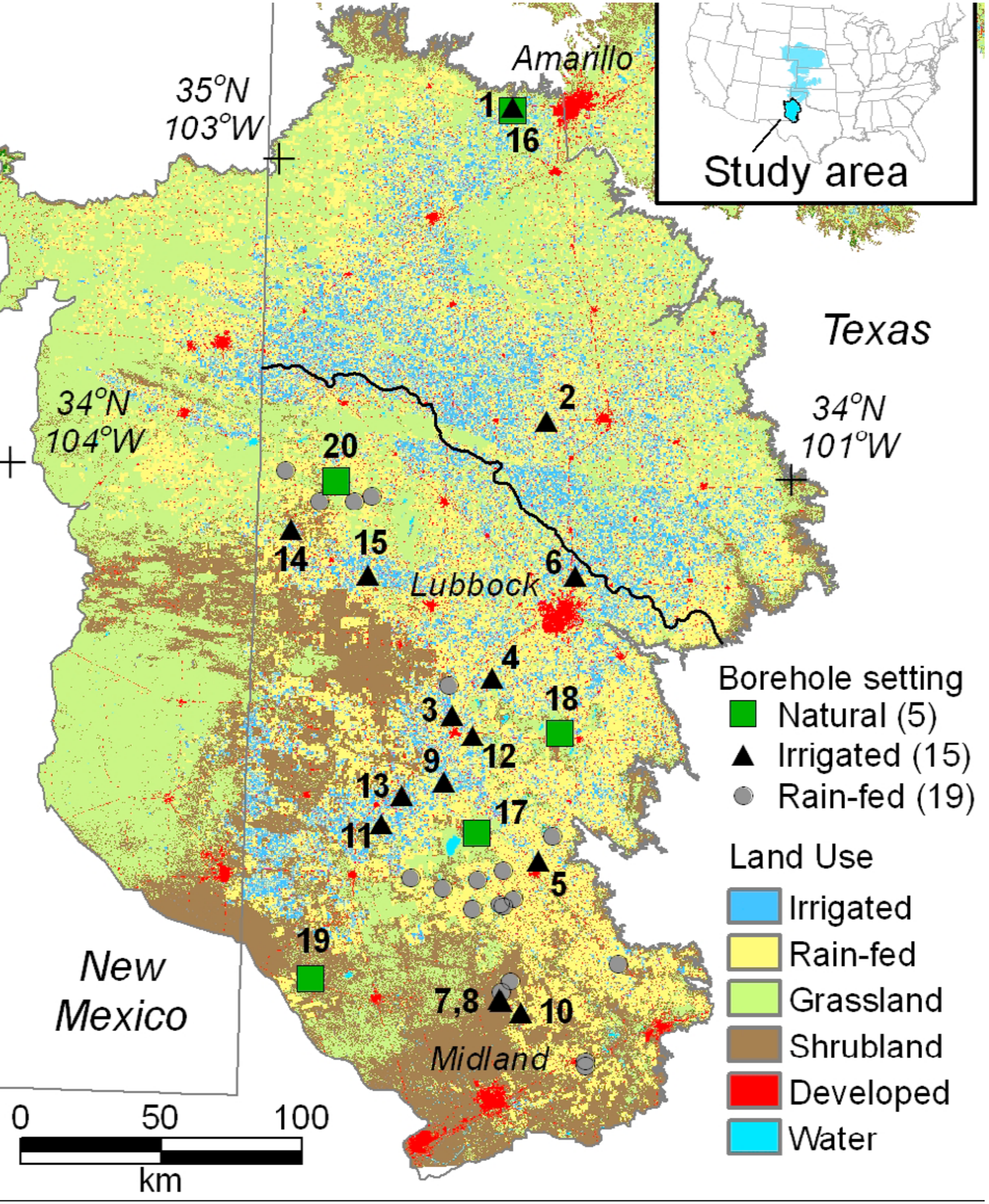
high Cl --- low water flux

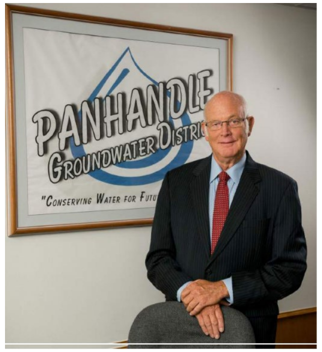
Plants exclude Cl during evapotranspiration

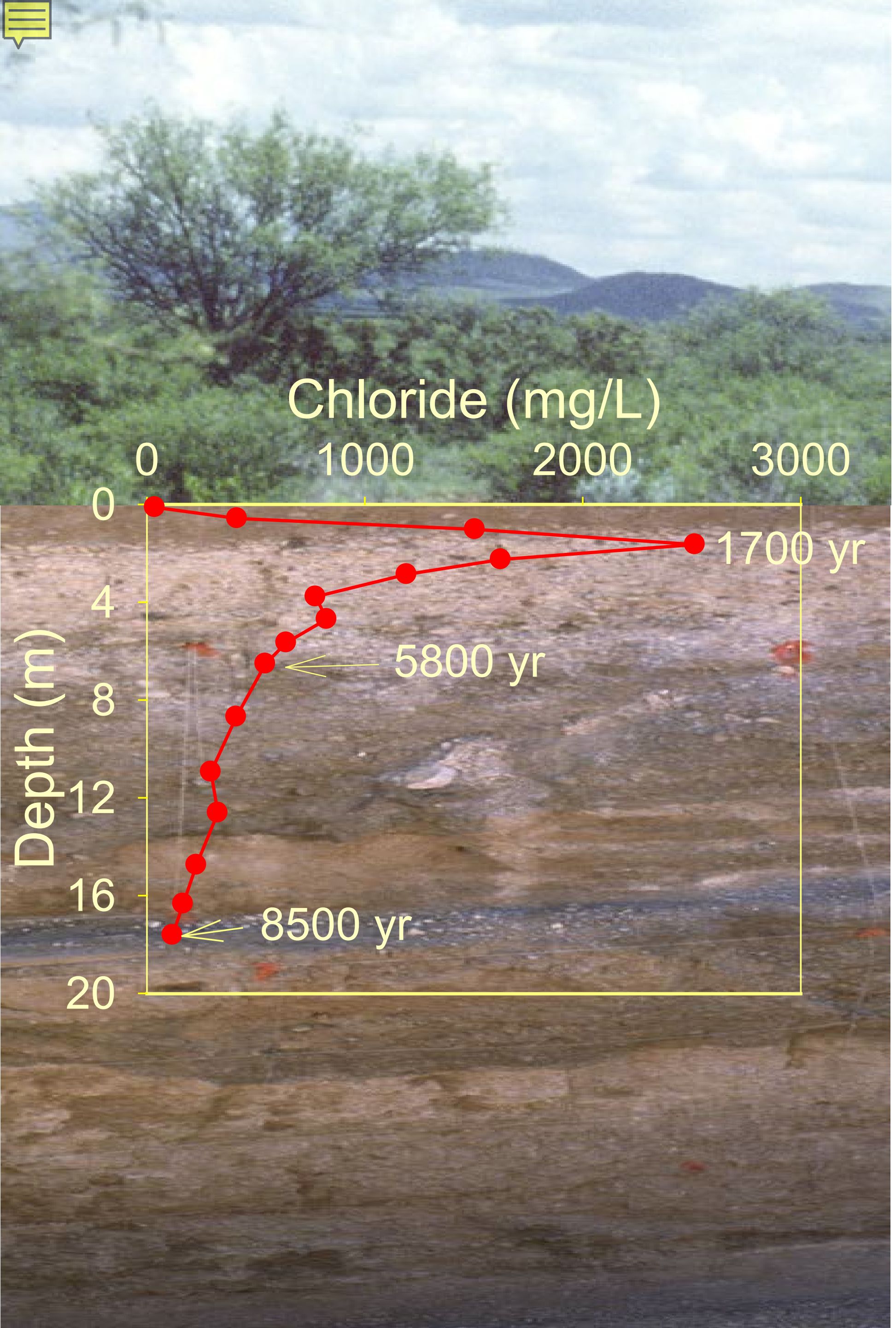
Playas

Scanlon and Goldsmith, 1997, WRR

Drilling and Soil Sampling







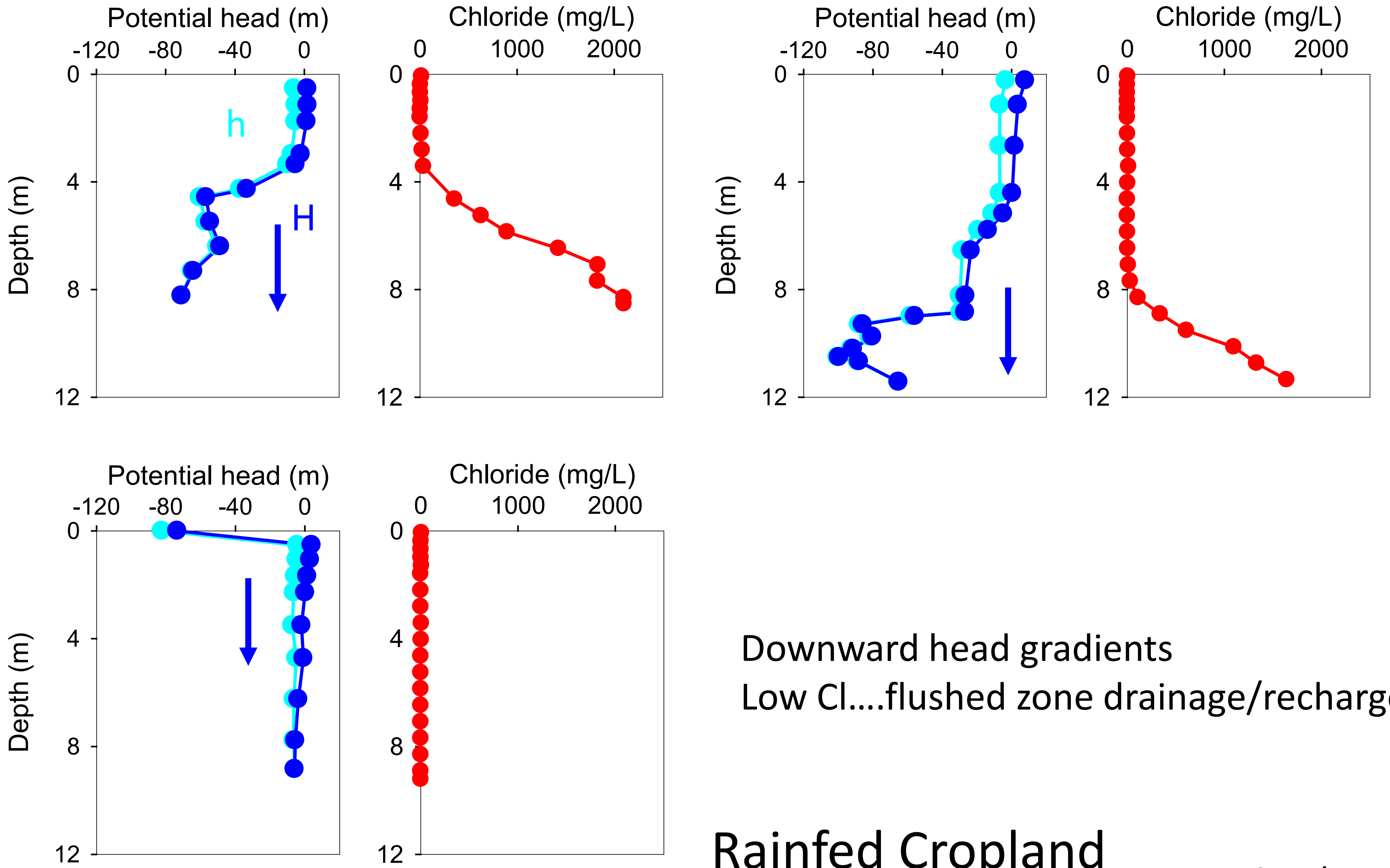
No Recharge under Rangeland

Vegetation removes all of the water from the soil and leaves chloride behind.

We can estimate the age of the water based on the amount of chloride in the soil water and estimates of chloride levels in rainfall and rainfall amount

Rangeland

Rainfed Agriculture

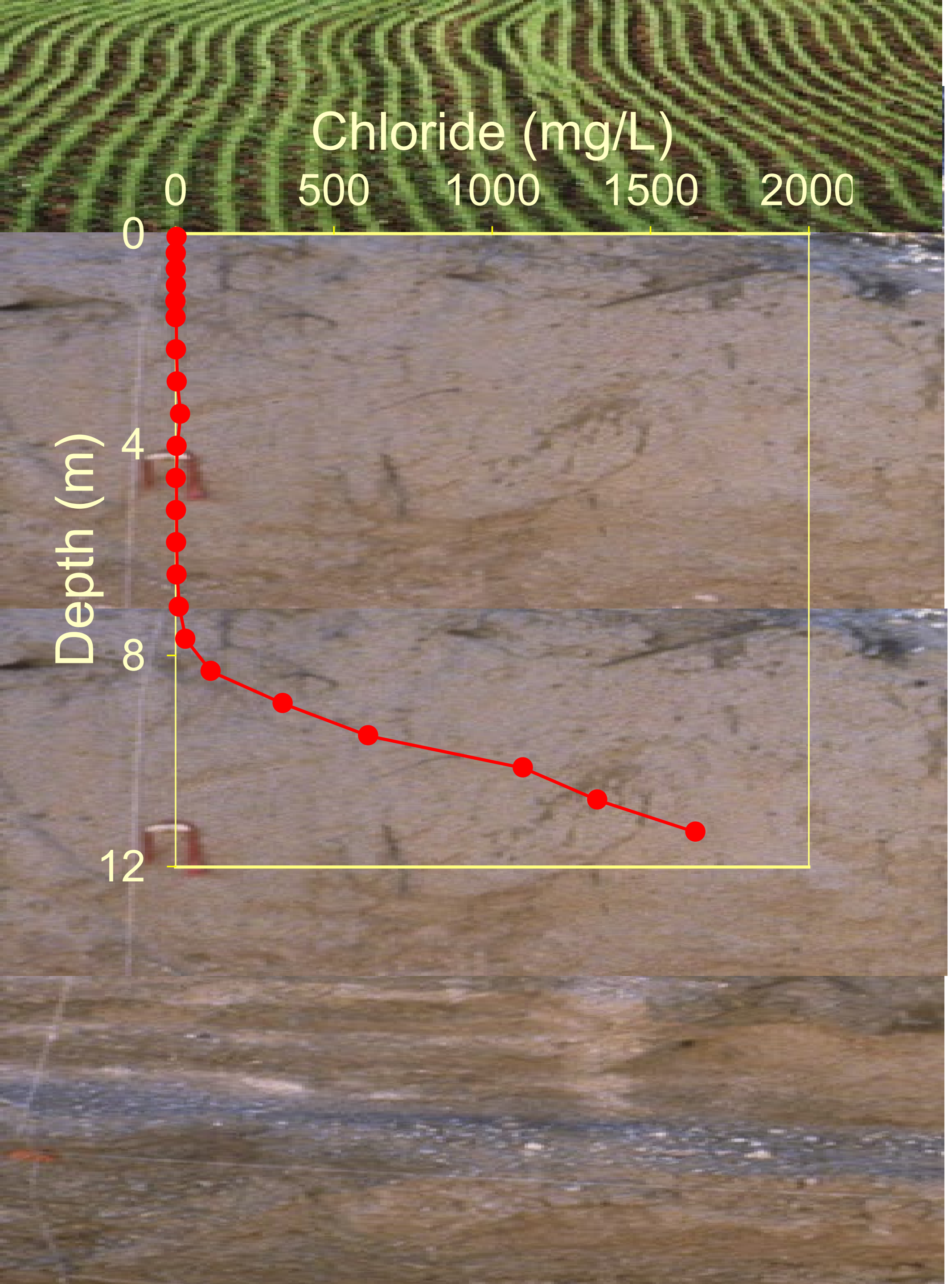


Downward head gradients
Low Cl….flushed zone drainage/recharge

Rainfed Cropland

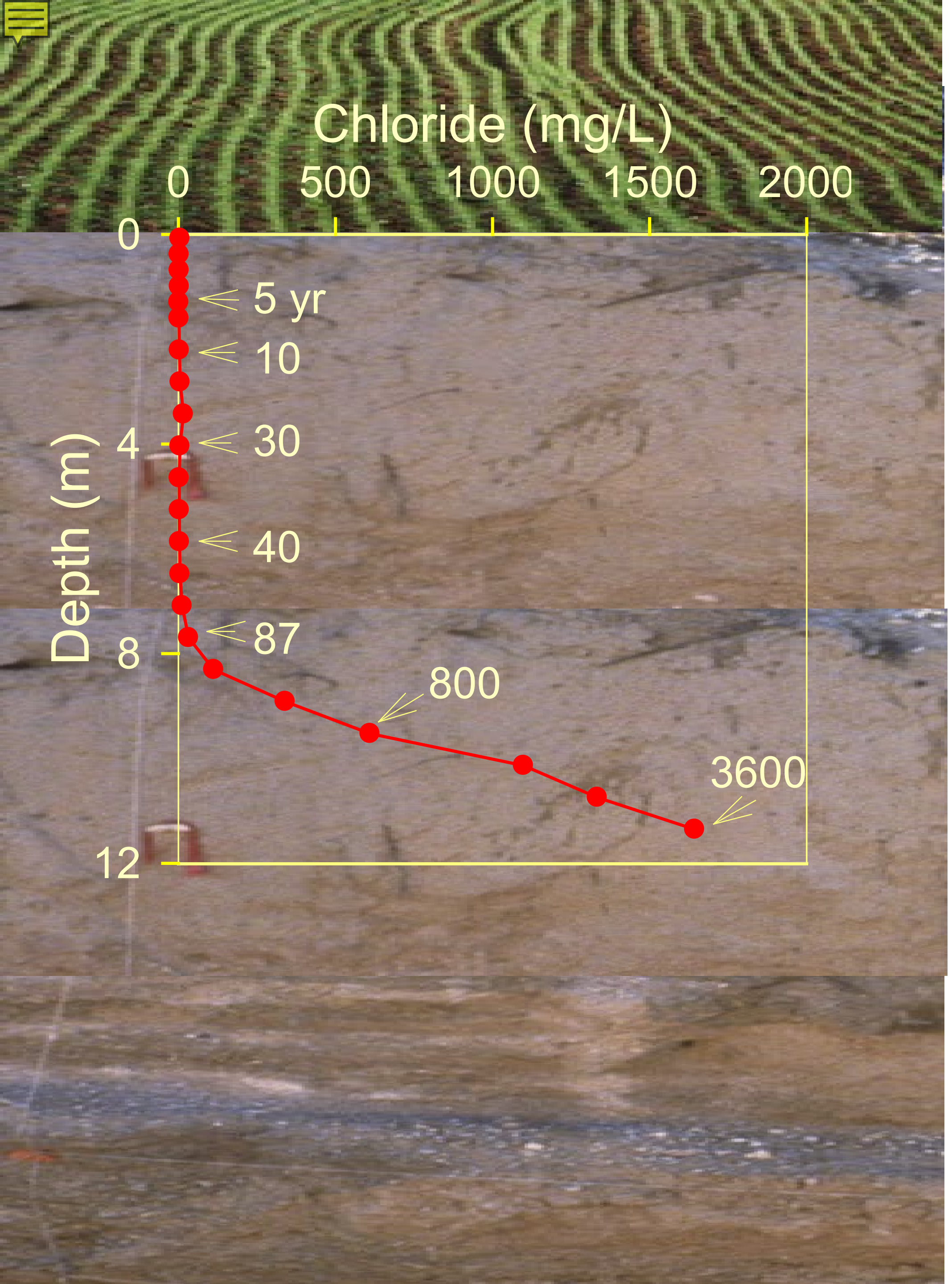
Scanlon et al., WRR, 2007

Chloride Profile beneath Rainfed Agriculture



Rainfed Cropland

Scanlon et al., 2007, WRR



Quantitative Chloride Mass Balance (CMB)

$$\text{Age}=\frac{\textit{mass of chloride}}{\textit{chloride input}}$$

$$t = \frac{\int_0^z \theta Cl_{uz} dz}{P \times Clp}$$

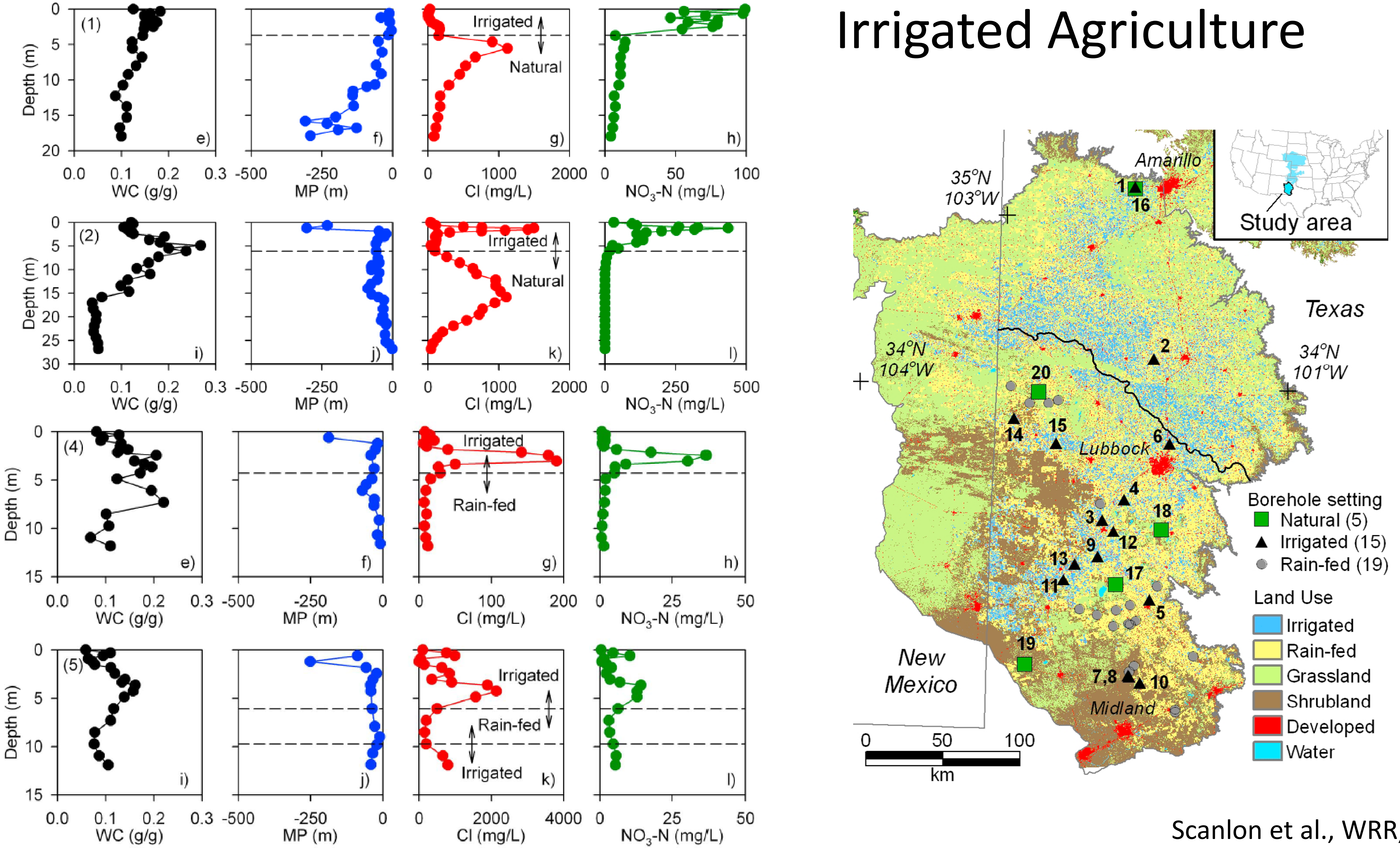
Precipitation = 450 mm/yr

Cl_p = 0.3 mg/L

Rainfed Cropland

Scanlon et al., 2007, WRR

Irrigated Agriculture

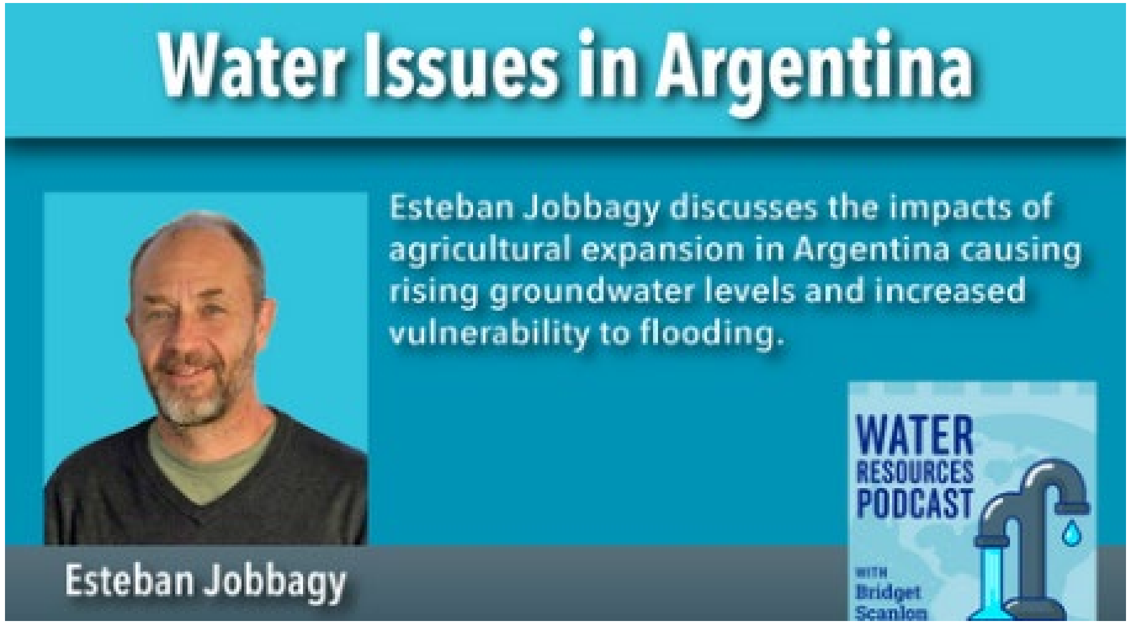


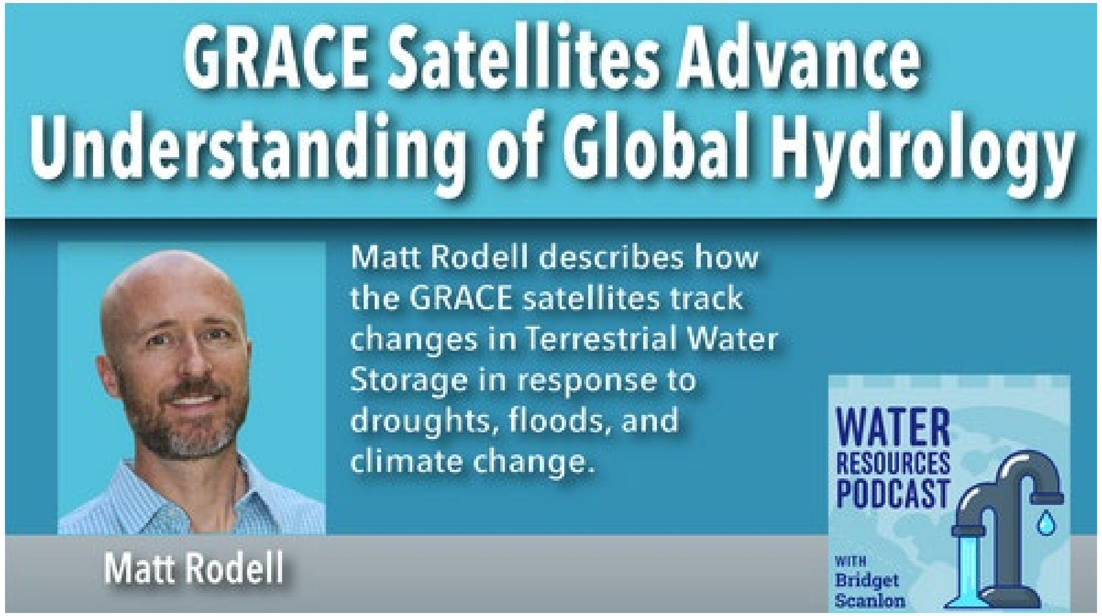
Scanlon et al., WRR, 2010

Summary of Relation between Land Use and Recharge

- Natural ecosystems:
  - Playa focused recharge
  - Long-term (≤ 10,000 yr) drying in interplaya settings
- Rainfed Agriculture
  - Increased drainage/recharge
  - ~ 20 ft increase in WT over 3,400 km^2 area in southern HP = recharge rate of ~1 inch/yr
- Irrigated agriculture: increase in salts (~ 1000 – 2000 mg/L Cl, increase in nitrates

Water Resources Podcast (https://wrp.beg.utexas.edu/)





Youtube: https://www.youtube.com/channel/UCkx8IwI9pNzDA_KEpHyA2vw?app=desktop
Spotify: https://open.spotify.com/show/3zWl6ERJeAxpkMfnChIsW9
Apple: https://podcasts.apple.com/us/podcast/the-water-resources-podcast/id1670449955

Summary

- **GRACE satellites:** global picture of water storage changes, depletion mostly in irrigated areas
- **Land use change** has a large impact on water resources globally
  - **Native vegetation**, semiarid regions, no recharge
  - **Rainfed agriculture:** increased recharge, dryland salinity, flooding
  - **Irrigation** impacts depend on source: GW irrigation deplete aquifers, SW irrigation recharge aquifers
- Need to understand impacts of land use change on water resources to better manage water resources

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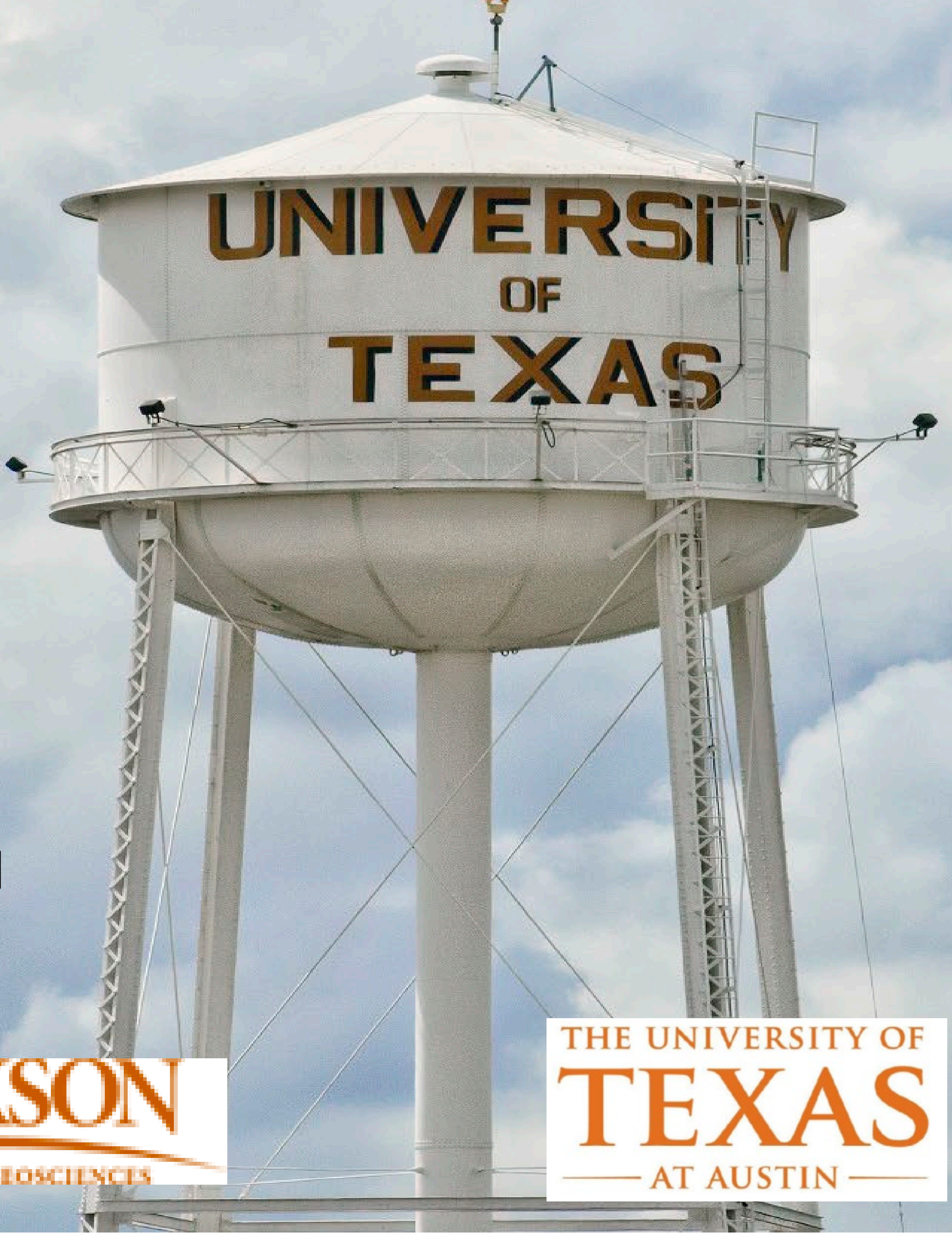

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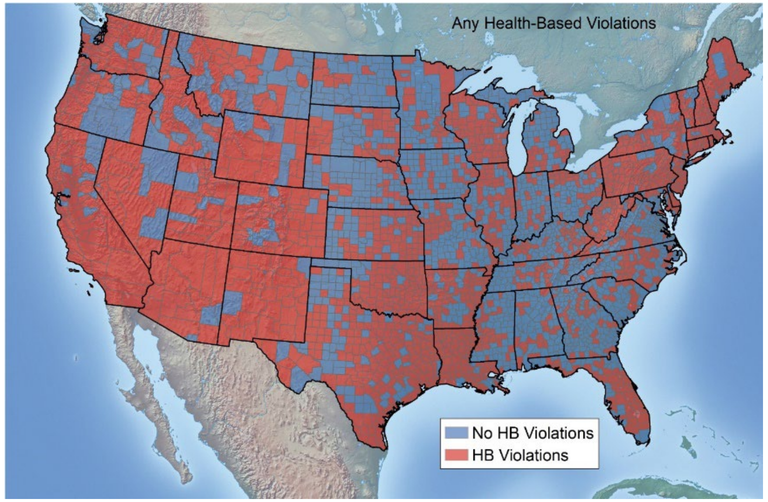
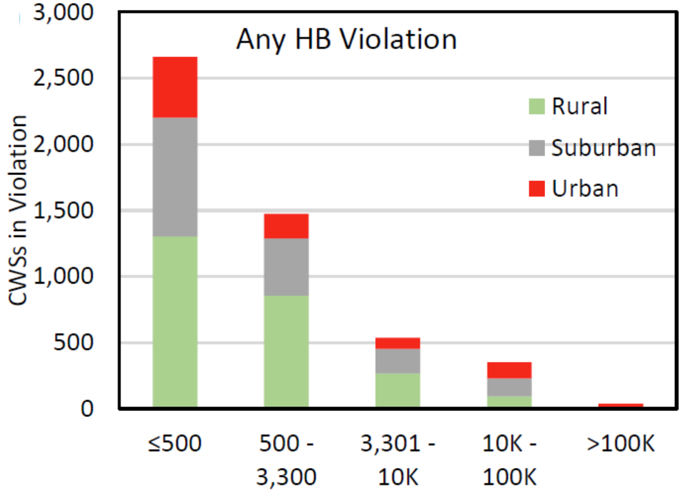
TEXAS
AT AUSTIN

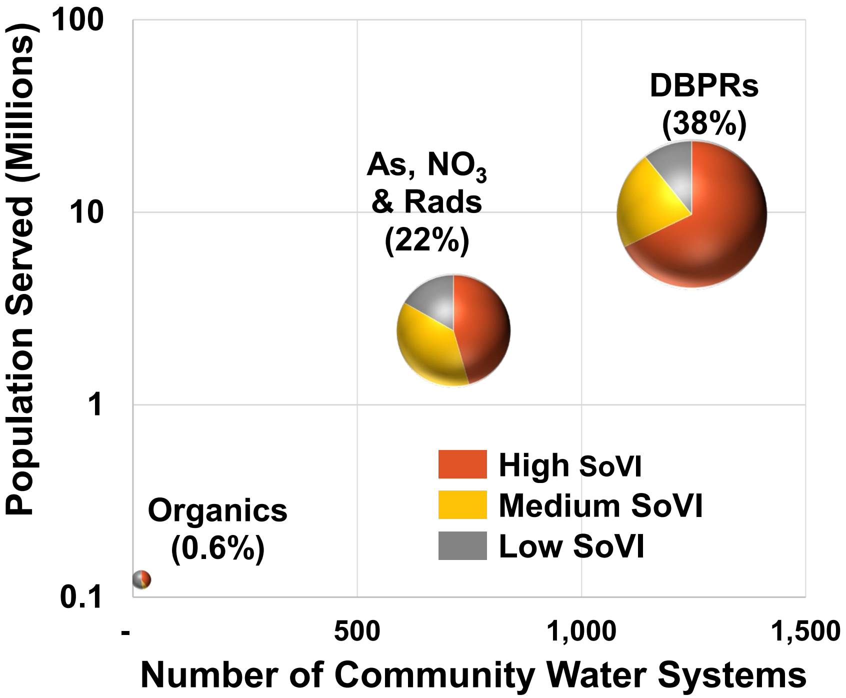
Water Quality: Community Water Systems (2018 – 2020)



Counties with any health-based (HB violation (2018 – 2020)

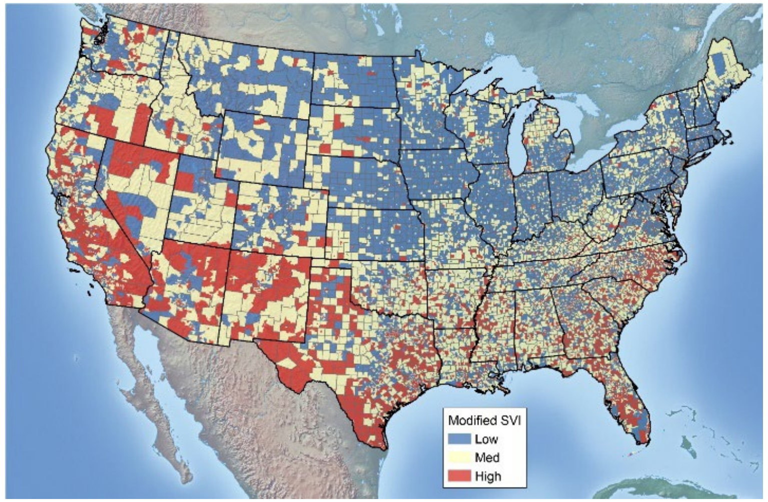
1 in 10 people were exposed to a health-based violation





Causes of health-based violations

Health-based violations mostly in **small systems** in **rural areas**

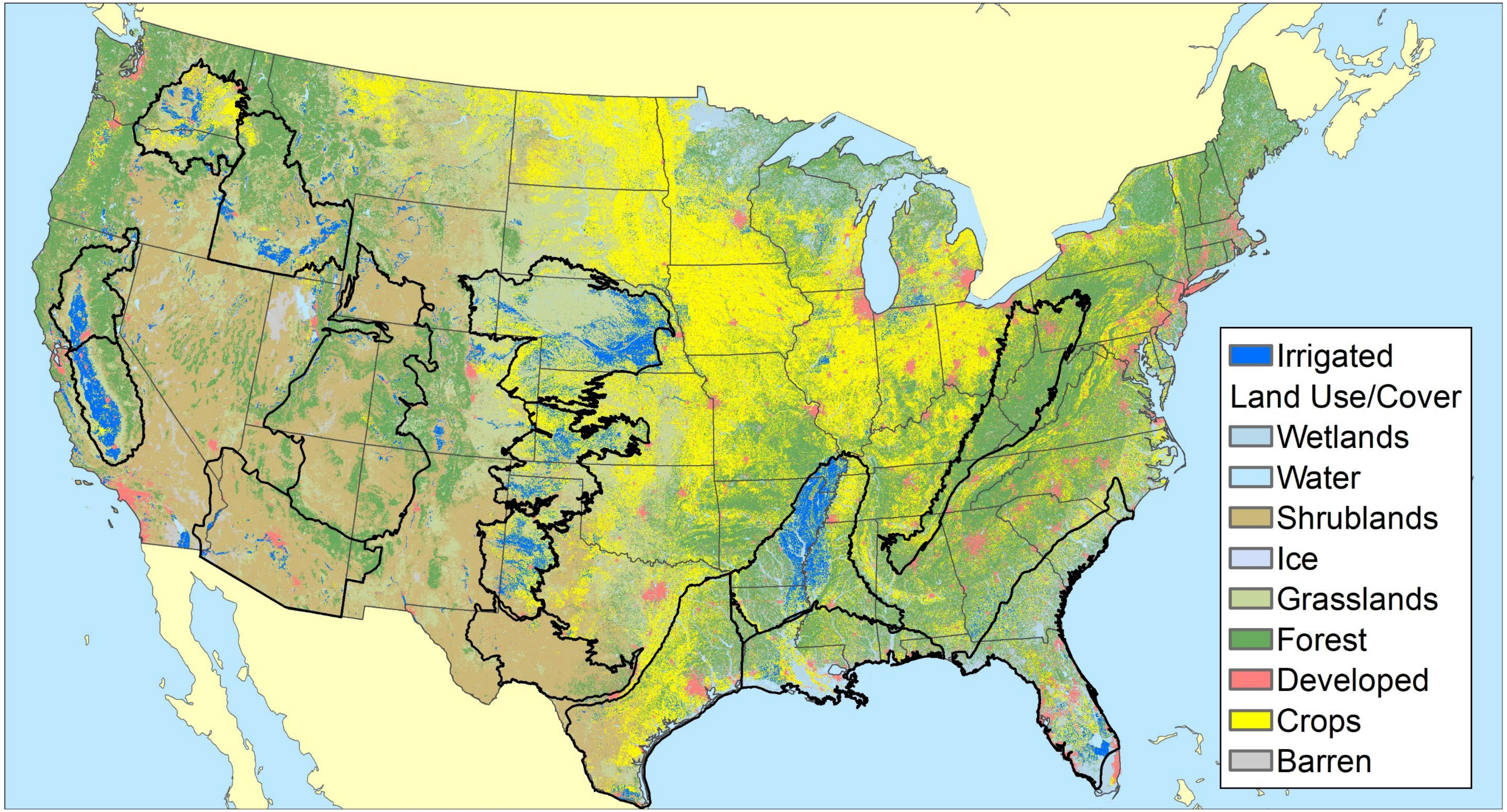


Modified Social Vulnerability Index (SVI)

Socioeconomics, race & language, demographics & housing

Scanlon et al., ERL, 2023

Landcover (NLCD)



Groundwater and Surface Water

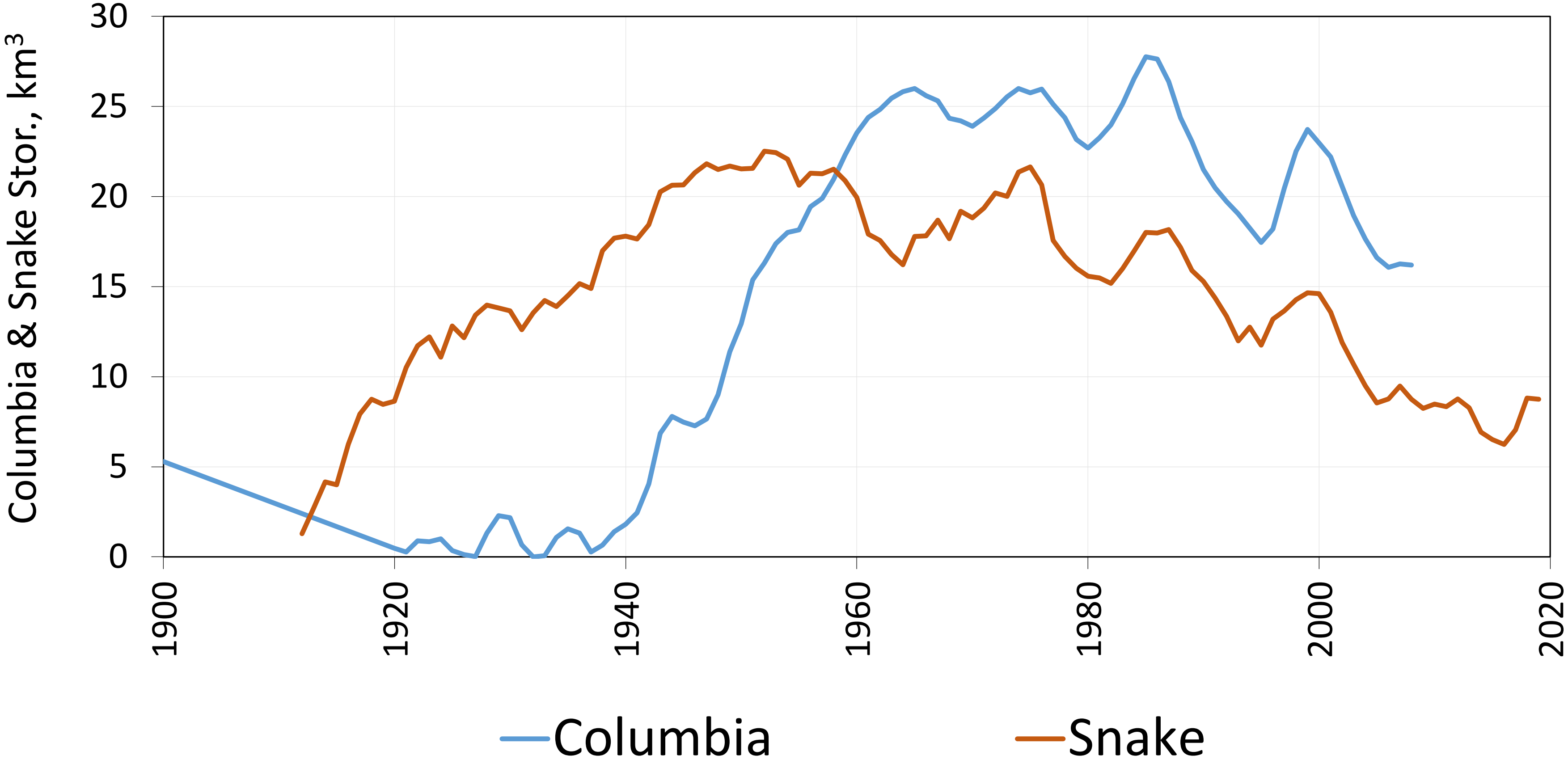
- Groundwater (GW) and surface water (SW) are strongly linked:
  - **85% of GW withdrawals** sourced from **SW** capture and reduced ET
  - Remaining **15%** derived from **aquifer depletion**

Results based on analysis of GW level and modeling data in the US (Konikow et al., 2013)

Comparison of global model (PCR-GLOBWB) that includes/excludes capture (de Graaf et al., 2017)

Recent study Central Valley California, GW pumping, 20% from aquifer storage, remaining 80% from stream leakage and inefficient irrigation (Faunt et al., 2024).

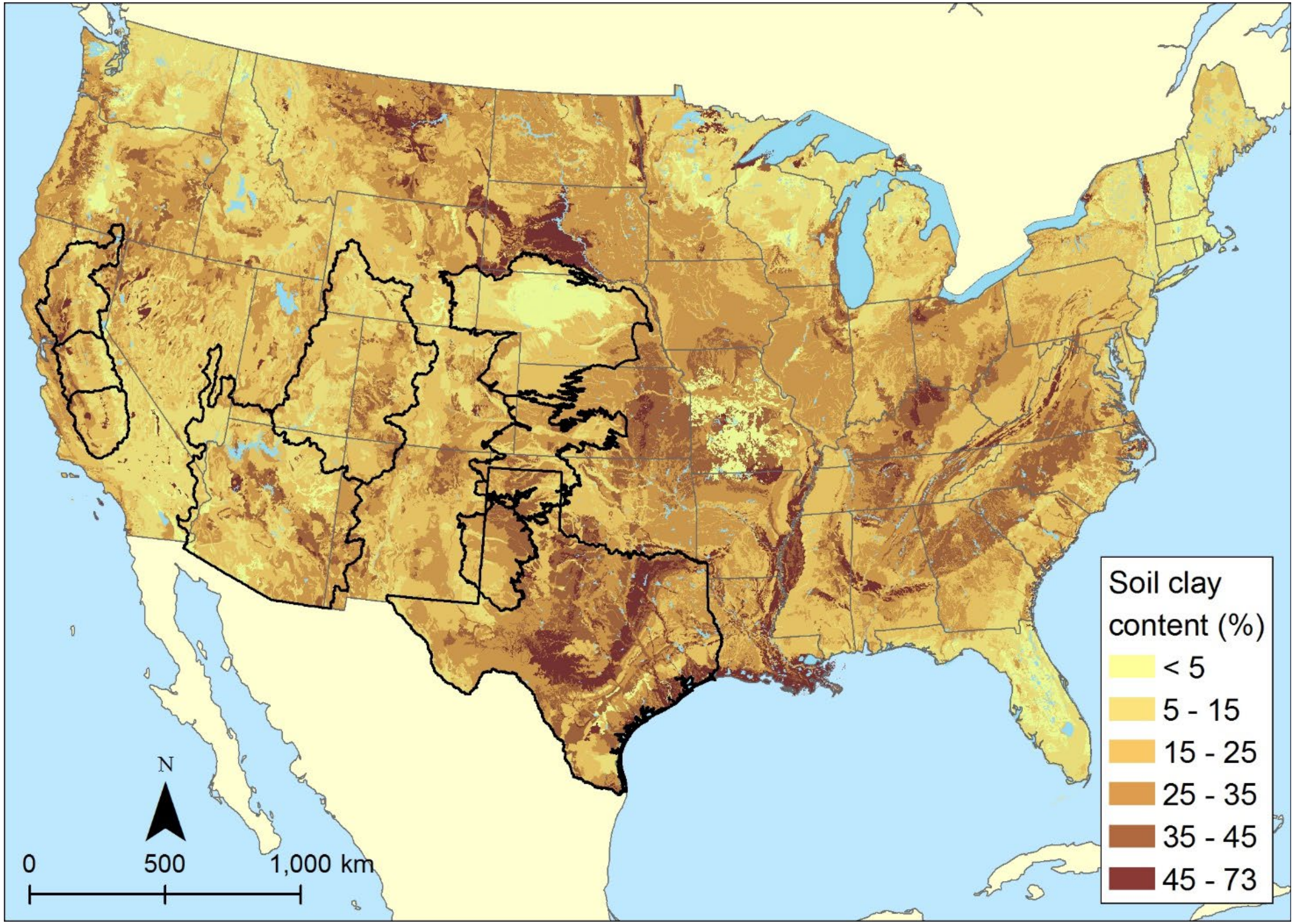
Long-term Trends in Groundwater Storage



Increases in GW storage attributed to surface water irrigation
Columbia and Snake River Basins, NW US

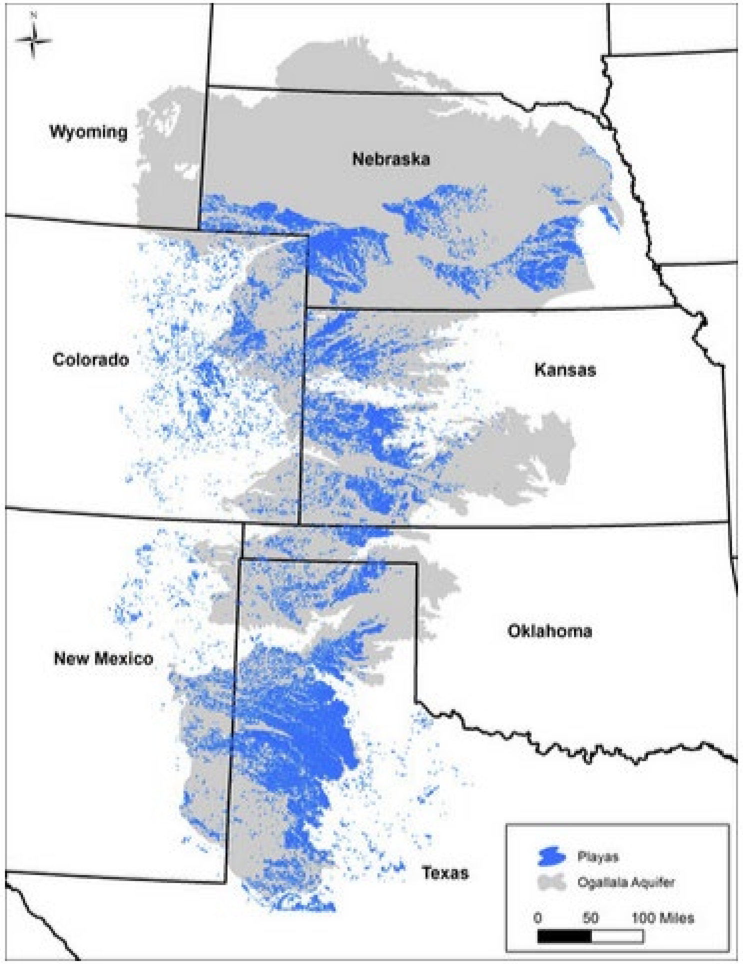
Scanlon et al., 2022

STATSGO Soil Map: Clay Content



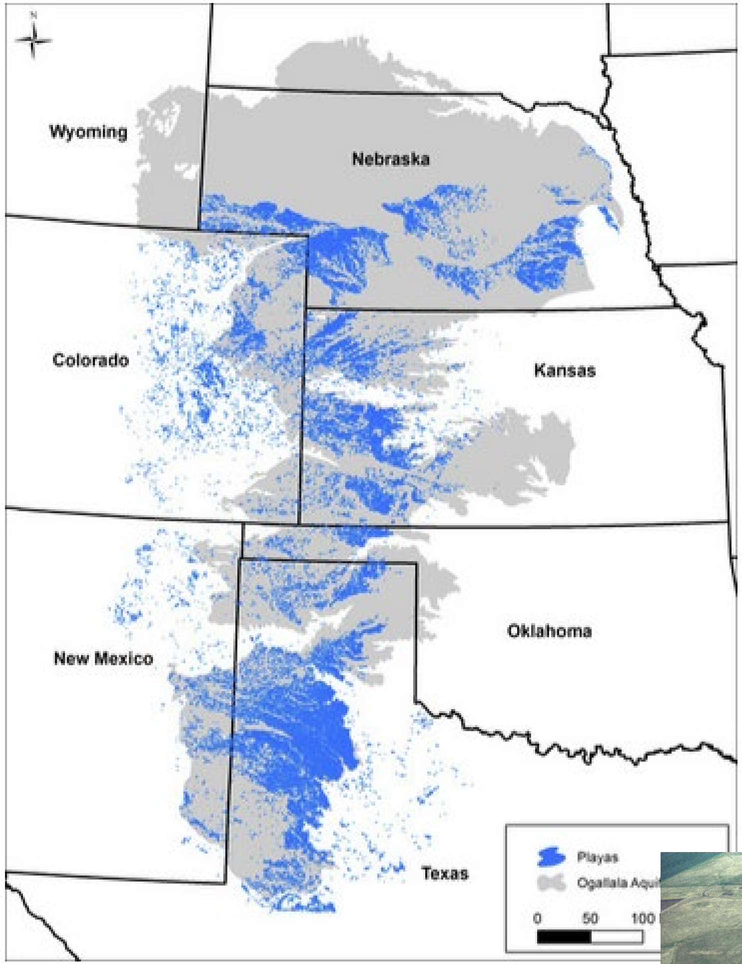
Stream Network: NHD Plus

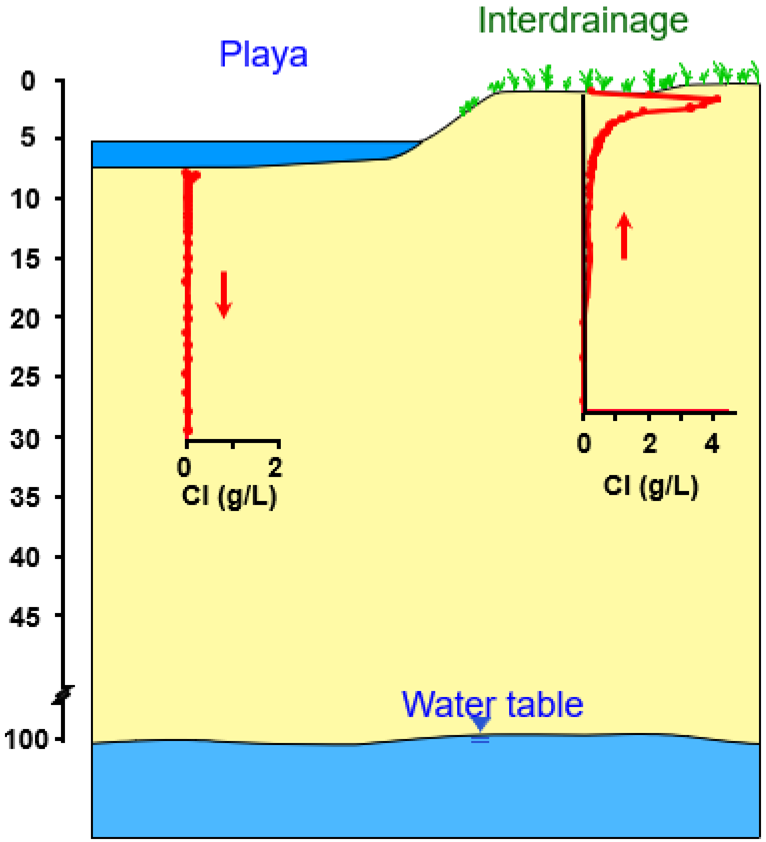
Playas



Playas: endorheic basins
~ 23,000 plays in Texas High Plains
< 2% of land area

Playas: endorheic basins, recharge





23,000 playas Texas High Plains
2% of land area

Chloride in soil water is inversely related to water flux

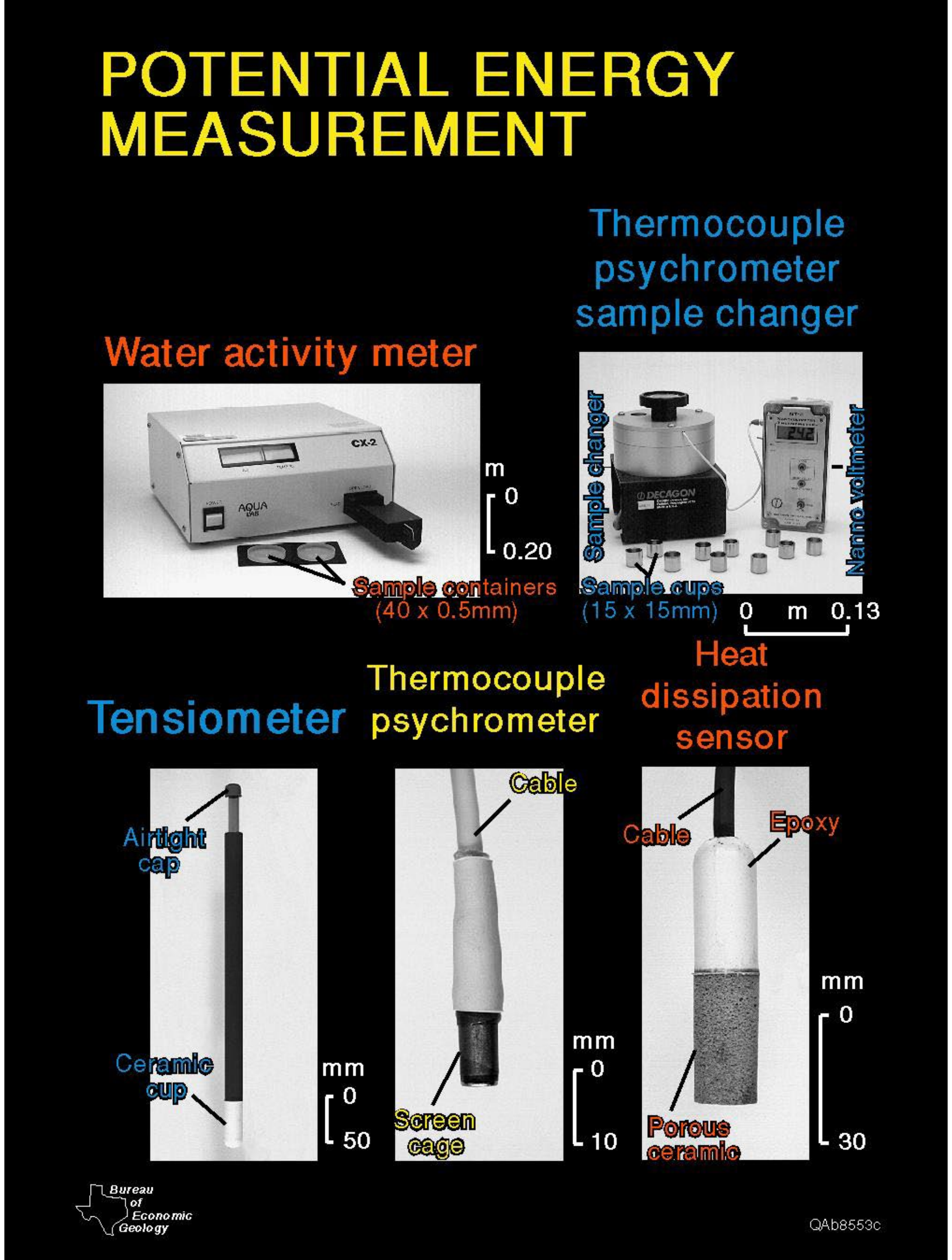
low Cl --- high water flux

high Cl --- low water flux

Plants exclude Cl during ET

Scanlon et al., WRR, 1997

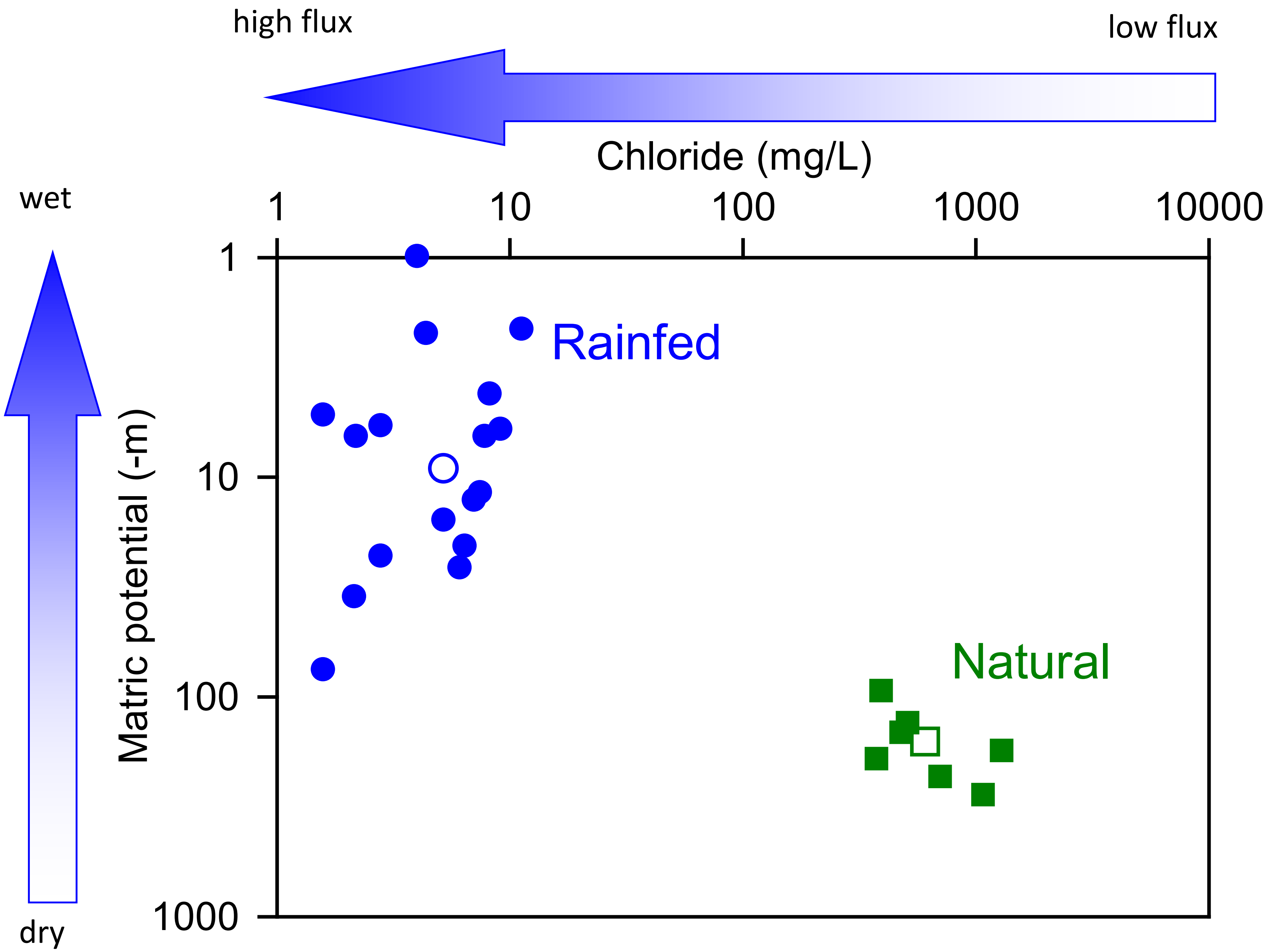
Impacts of Land Use Change on Water Resources


POTENTIAL ENERGY MEASUREMENT
Thermocouple psychrometer sample changer
Water activity meter
CX-2
AQUA LAB
m
0
0.20
Sample containers (40 x 0.5mm)
Sample changer
DECAGON
Nanno voltmeter
Sample cups (15 x 15mm)
0 m 0.13
Tensiometer
Thermocouple psychrometer
Heat dissipation sensor
Airtight cap
Ceramic cup
mm
0
50
Cable
Screen cage
mm
0
10
Cable
Epoxy
Porous ceramic
mm
0
30
Bureau of Economic Geology
QAb8553c

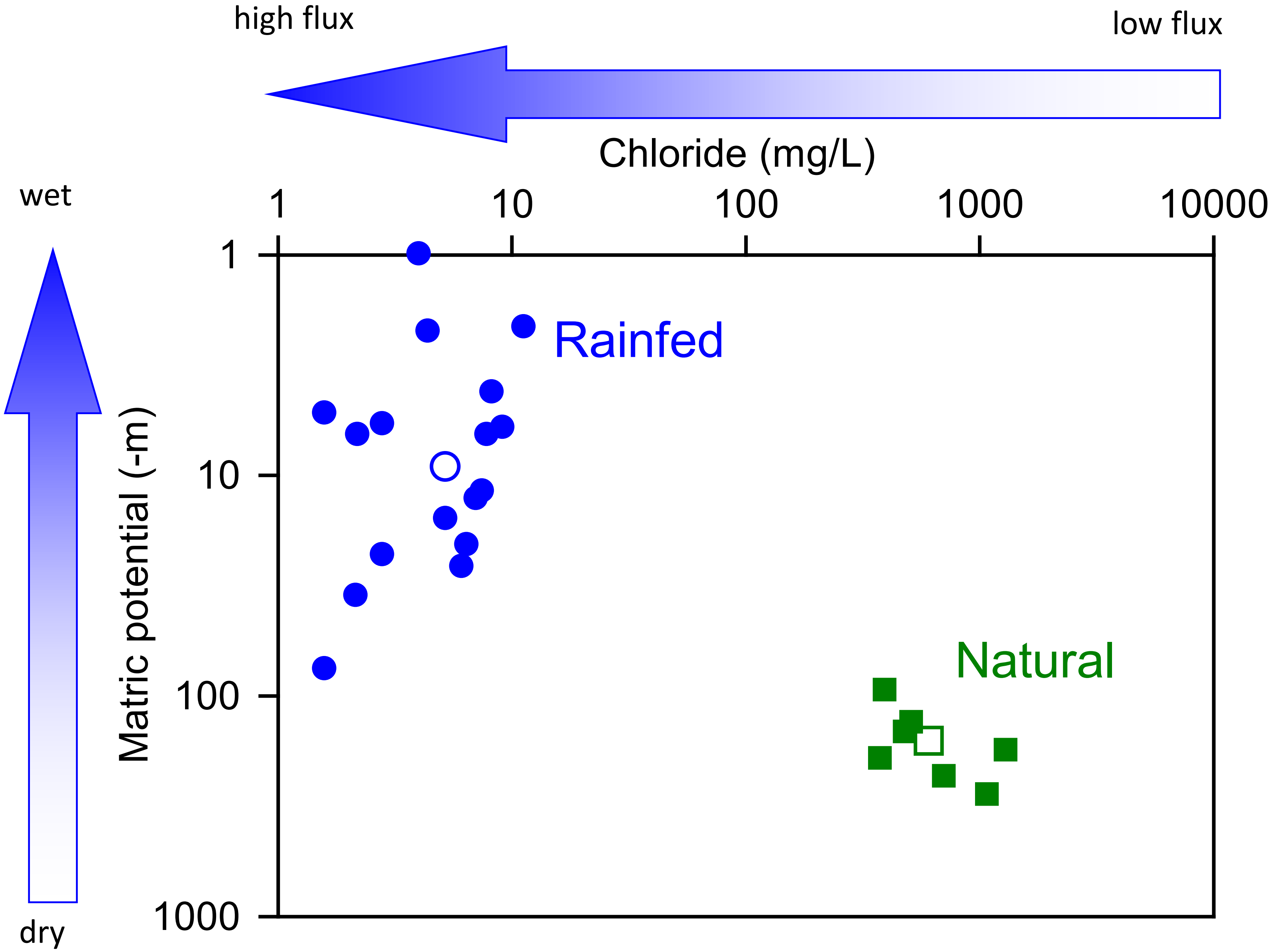
Groundwater Recharge In a Desert Environment

The Southwestern United States

James E. Hogan, Fred M. Phillips
and Bridget R. Scanlon
Editors

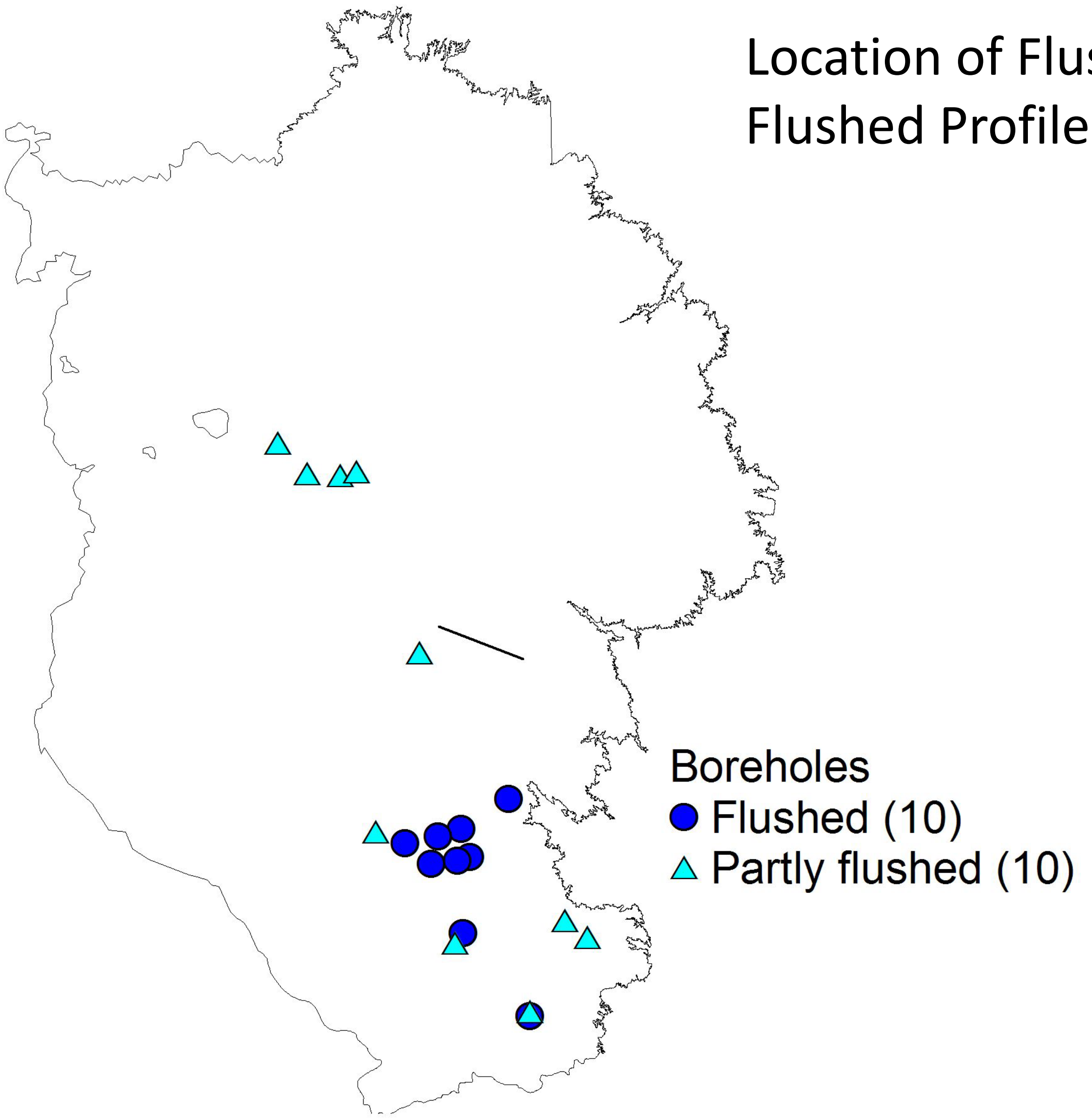


Scanlon et al., 2005, GCB



Scanlon et al., 2005, GCB

Location of Flushed and Partly Flushed Profiles



Causes of Differences in Recharge beneath Natural and Agricultural Ecosystems

- Perennial natural vegetation versus annual crops
- Cropland in southern High Plains is fallow from late November to early June
- Roots in perennial native vegetation are much deeper than those in cropland and can remove episodic deep drainage

Rainfed Agriculture

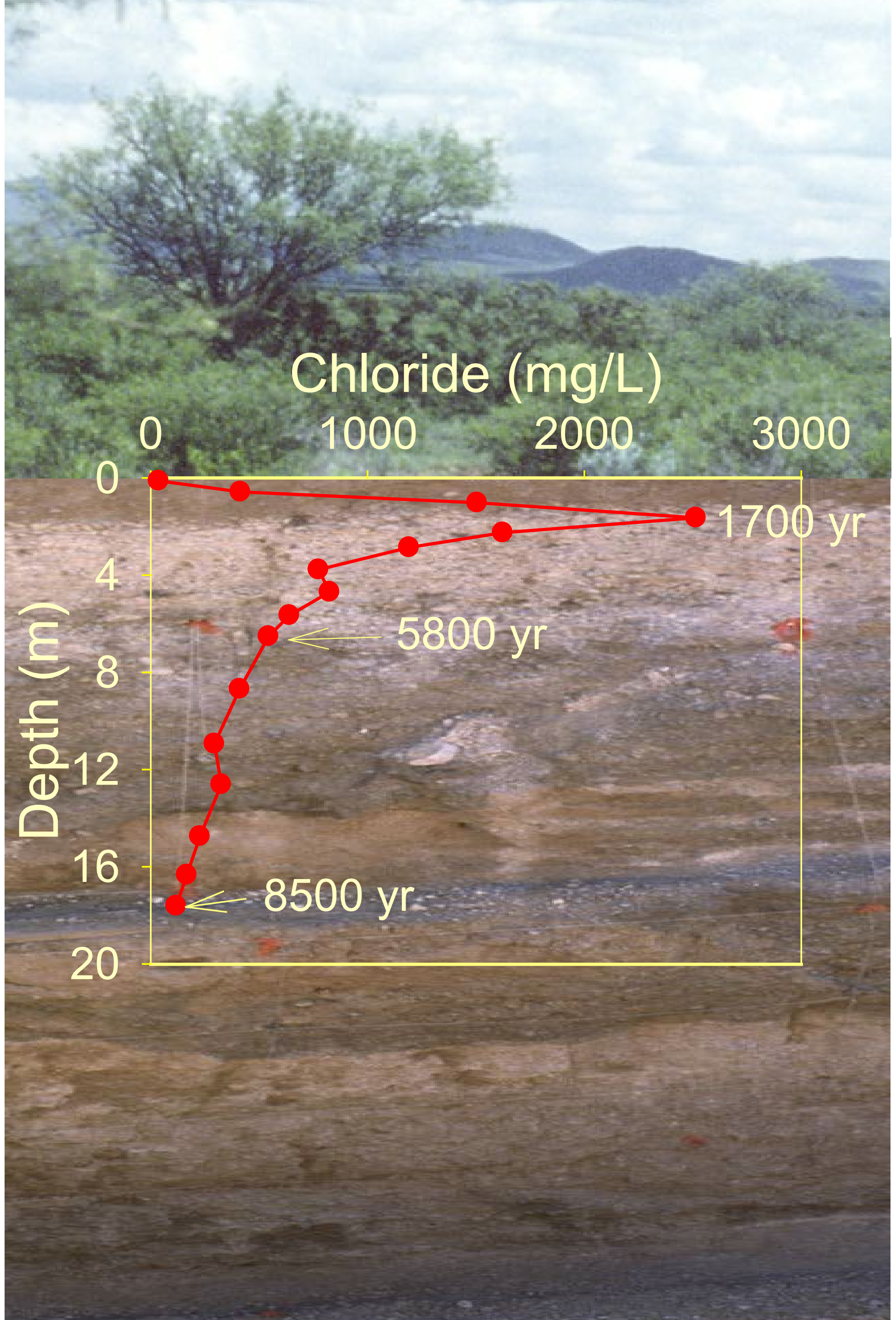
- Groundwater-level rises: mean recharge 24 mm/yr over 3,400 km^2 area = 5% of precipitation
- UZ profiles, varying levels of flushing, log normal distribution of recharge, mean 33 mm/yr
- Time lag between drainage and recharge ~ 60 yr
- Under new equilibrium conditions, volumetric recharge rate would be increased by up to a factor of 8 relative to pre-agricultural recharge rates.
- Mobilization of salts…chloride and sulfate
- Salt mobilization would increase groundwater TDS by up to 1.7 to 2.5 times depending on saturated thickness.

Sustainable Water Resources Management

- Integrate land and water resources management (Blue Revolution, Ian Calder)
- Decrease dependence on irrigated agriculture
- Drop sectoral divisions between irrigated and rainfed agriculture (Comprehensive Assessment of Water Management in Agriculture)
  - Rainwater harvesting and supplemental irrigation in rainfed areas
  - Irrigation shift from semiarid to more humid settings
- Increase productivity of rainfed agriculture (more crop per drop, reduce evaporation, runoff, and drainage; decrease fallow periods)

Sustainable Water Resources Management
Southern High Plains

- Reduce irrigated agriculture
- Irrigated agriculture → rainfed agriculture
- Rotate rainfed agriculture with irrigated agriculture when groundwater levels rise near the land surface
- Convert natural ecosystems to rainfed agriculture
- Deep ploughing of rainfed systems to further increase recharge



Chloride for Age Dating
Soil Pore Water

$$Age = \frac{mass\ of\ chloride}{chloride\ \ input}$$

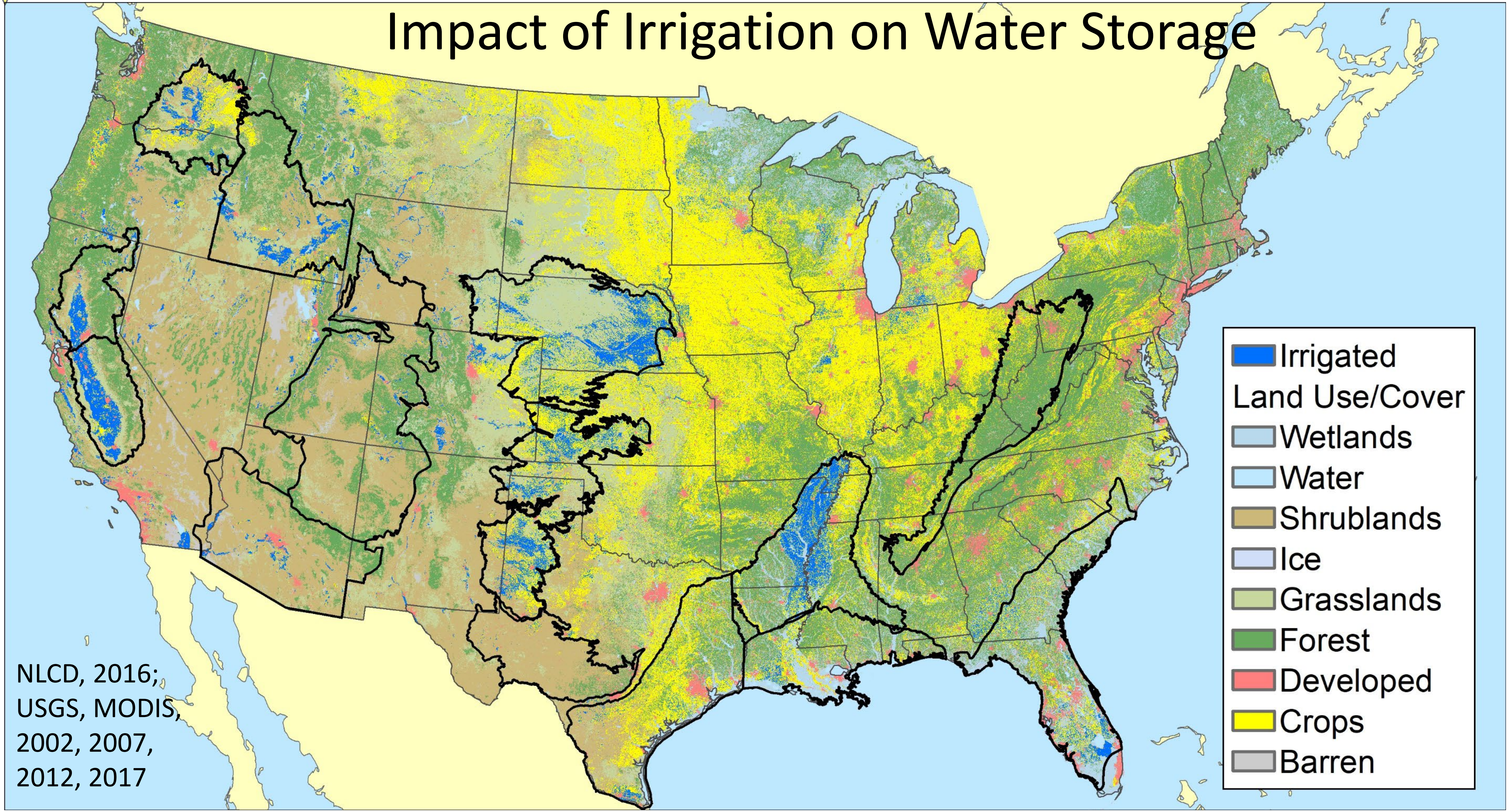
$$t = \frac{\int_0^z \theta Cl_{uz} dz}{P \times Cl_p}$$

P = 500 mm/yr

Cl_p = 0.3 mg/L

Cl_p from National Atmospheric Deposition Program (NADP)

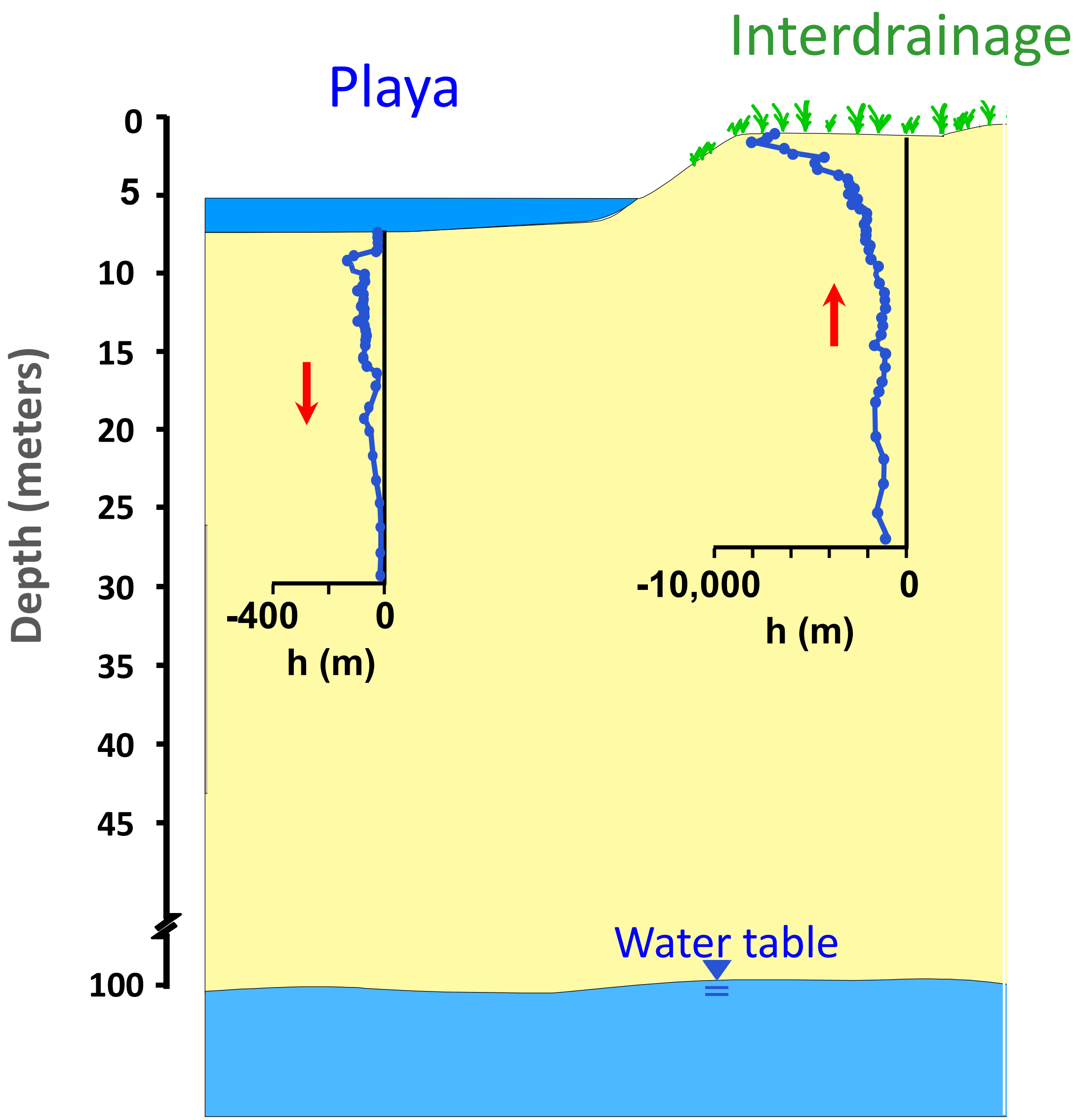
Impact of Irrigation on Water Storage



NLCD, 2016;
USGS, MODIS,
2002, 2007,
2012, 2017


CRC

Flow Directions Determined from Potential Head Data

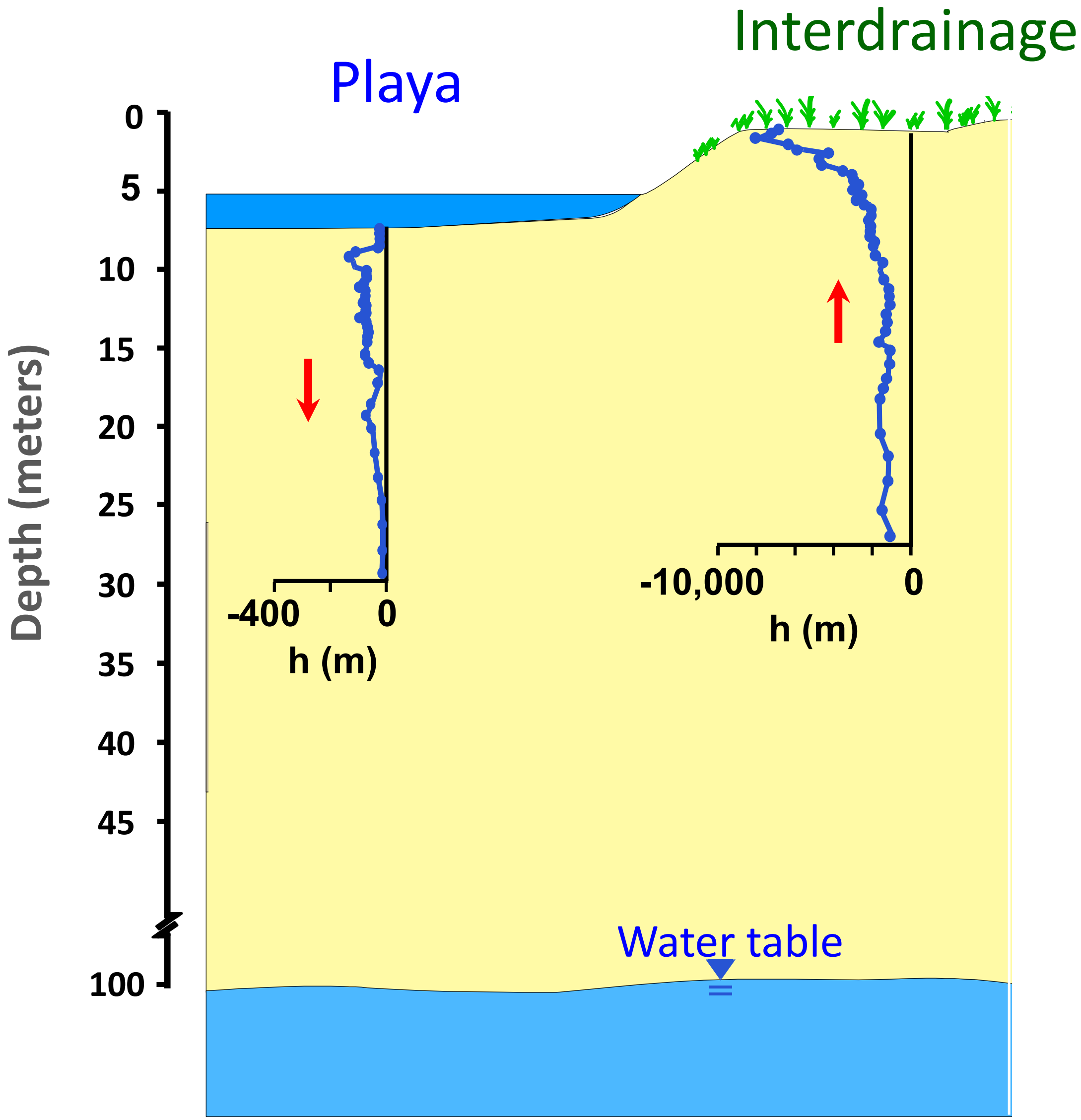


h: matric potential head

Scanlon and Goldsmith, 1997, WRR

Playas

Flow Directions Determined from Potential Head Data



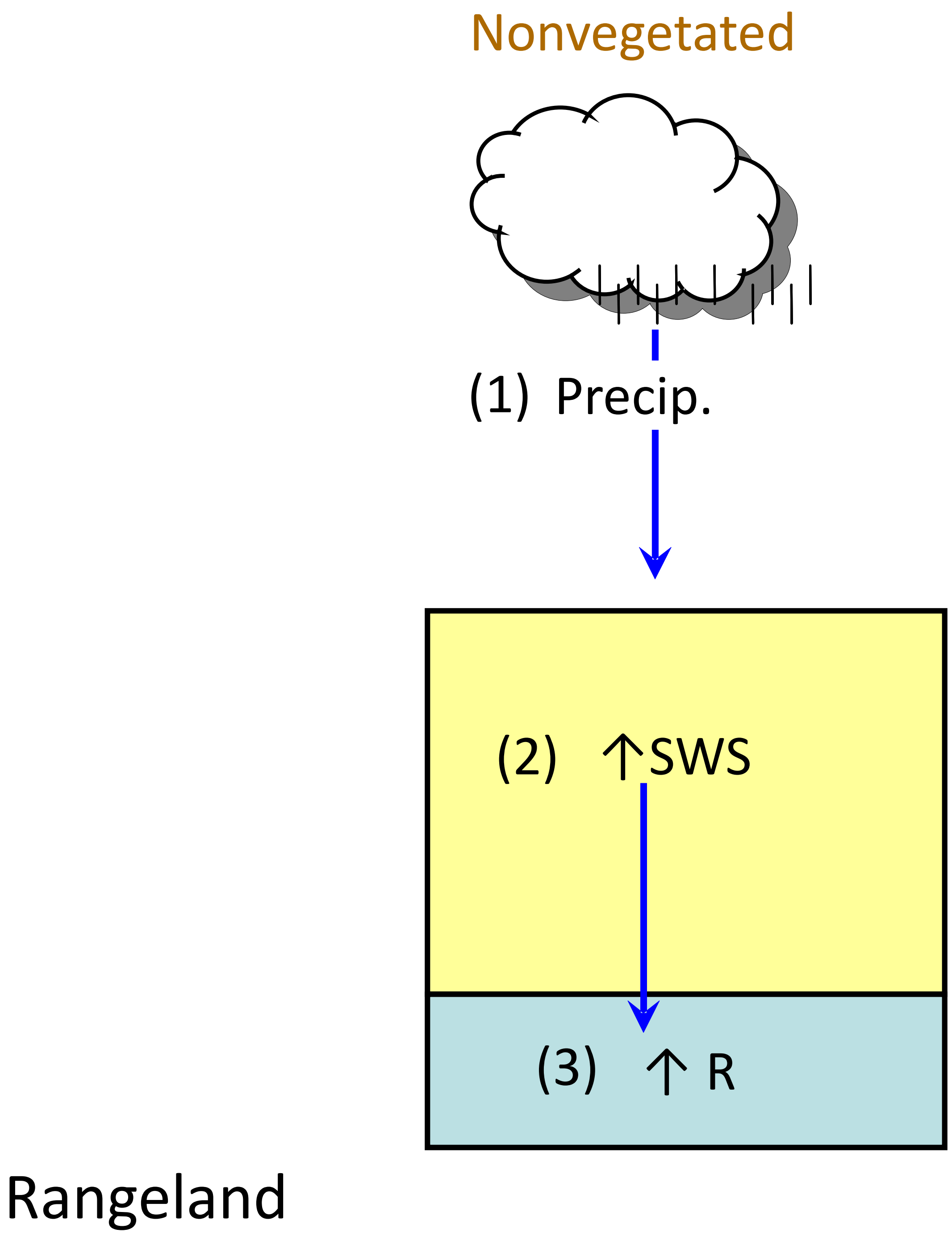
h: matric potential head

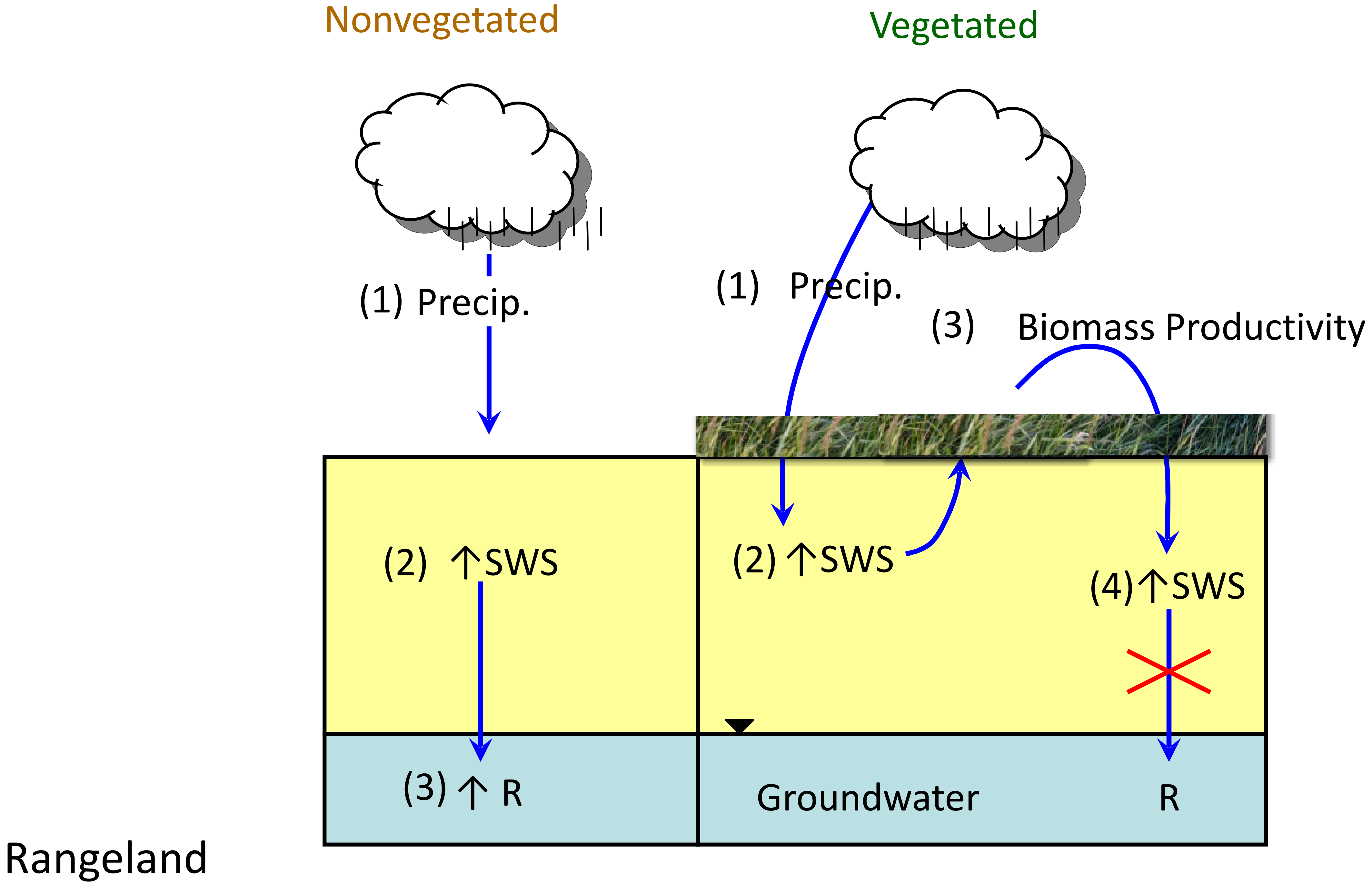
WP-4 Dew Point Potentiameter
(0 to -30,000 m; ± 10 m)

Heat Dissipation Sensor
(0.1 to -35,000 m; ± 1 m)

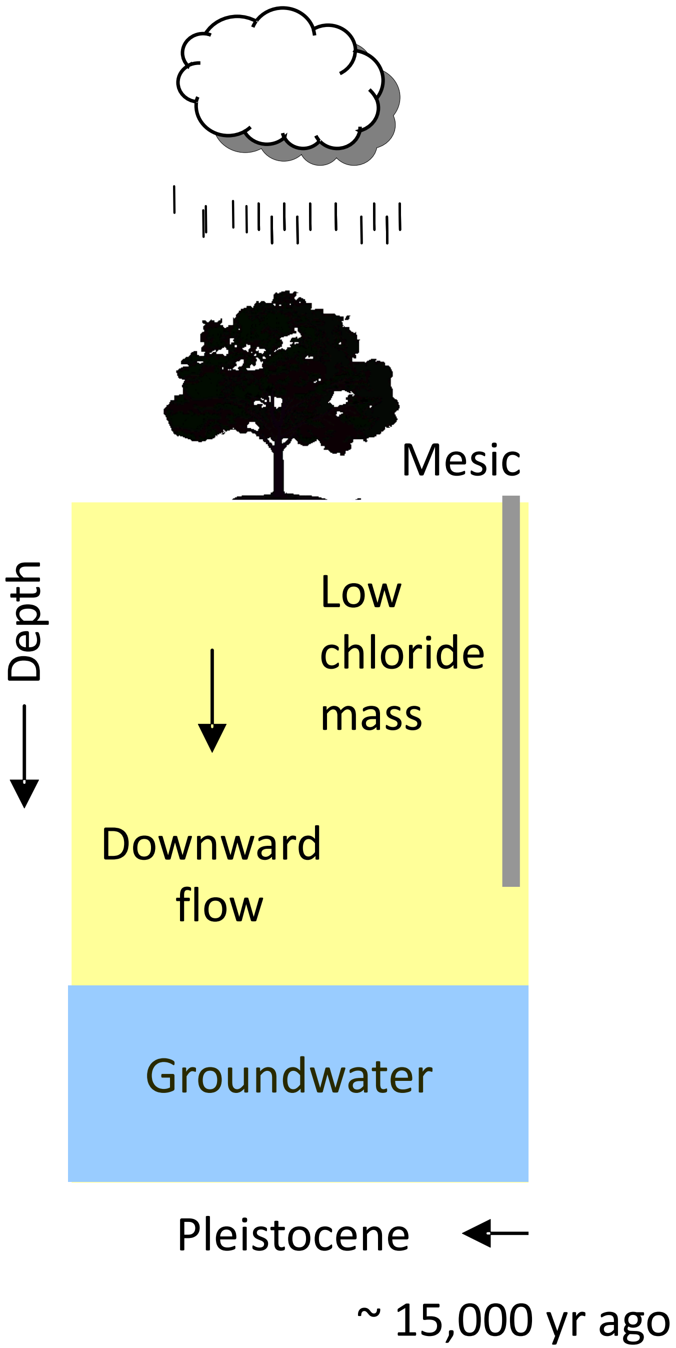
QAd2331Bx

Playas

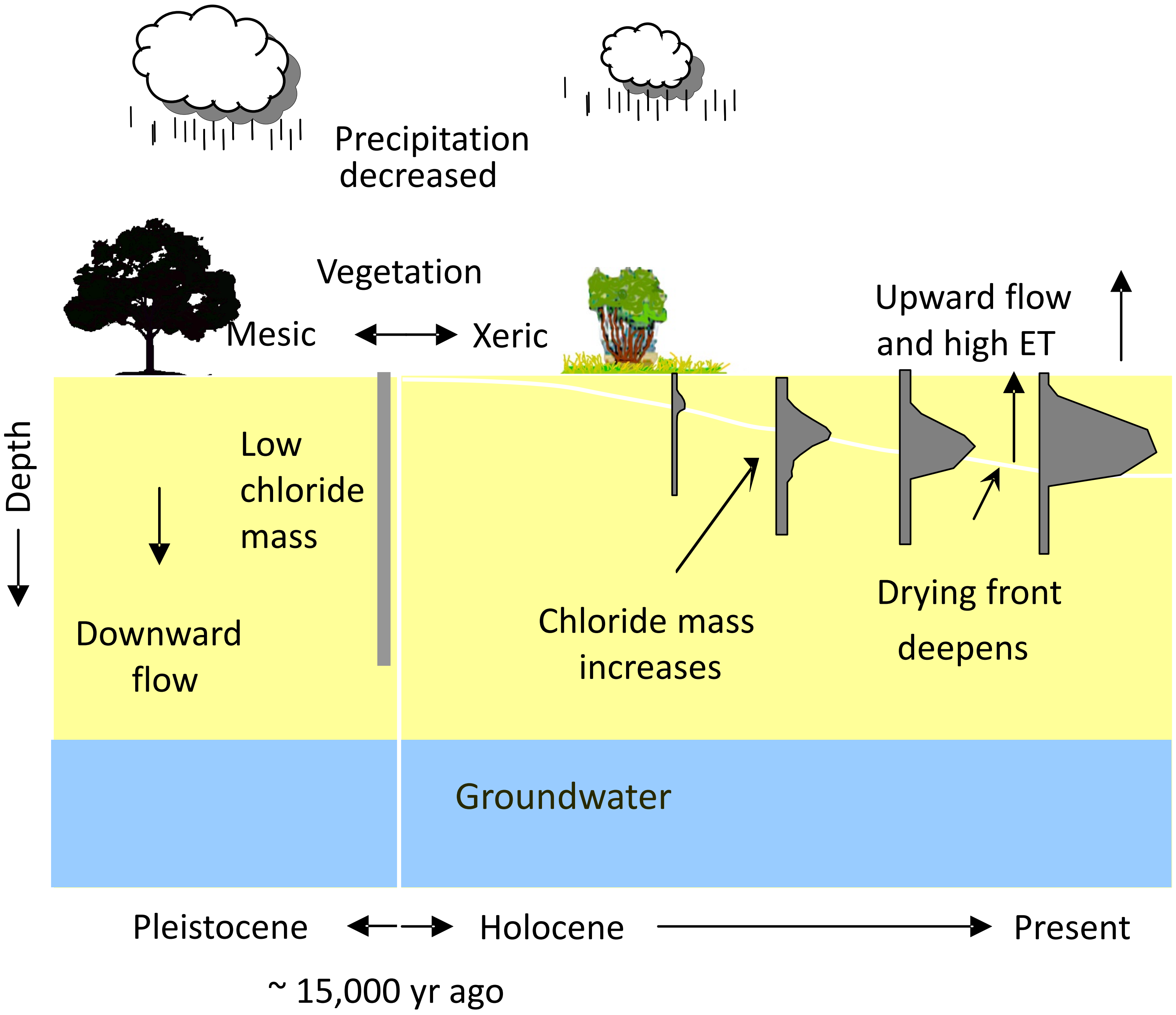

Nonvegetated
(1) Precip.
(2) ↑SWS
(3) ↑ R
Rangeland



Nonvegetated
Vegetated
(1) Precip.
(1) Precip.
(3) Biomass Productivity
(2) ↑SWS
(2) ↑SWS
(4)↑SWS
(3) ↑ R
Groundwater
R
Rangeland

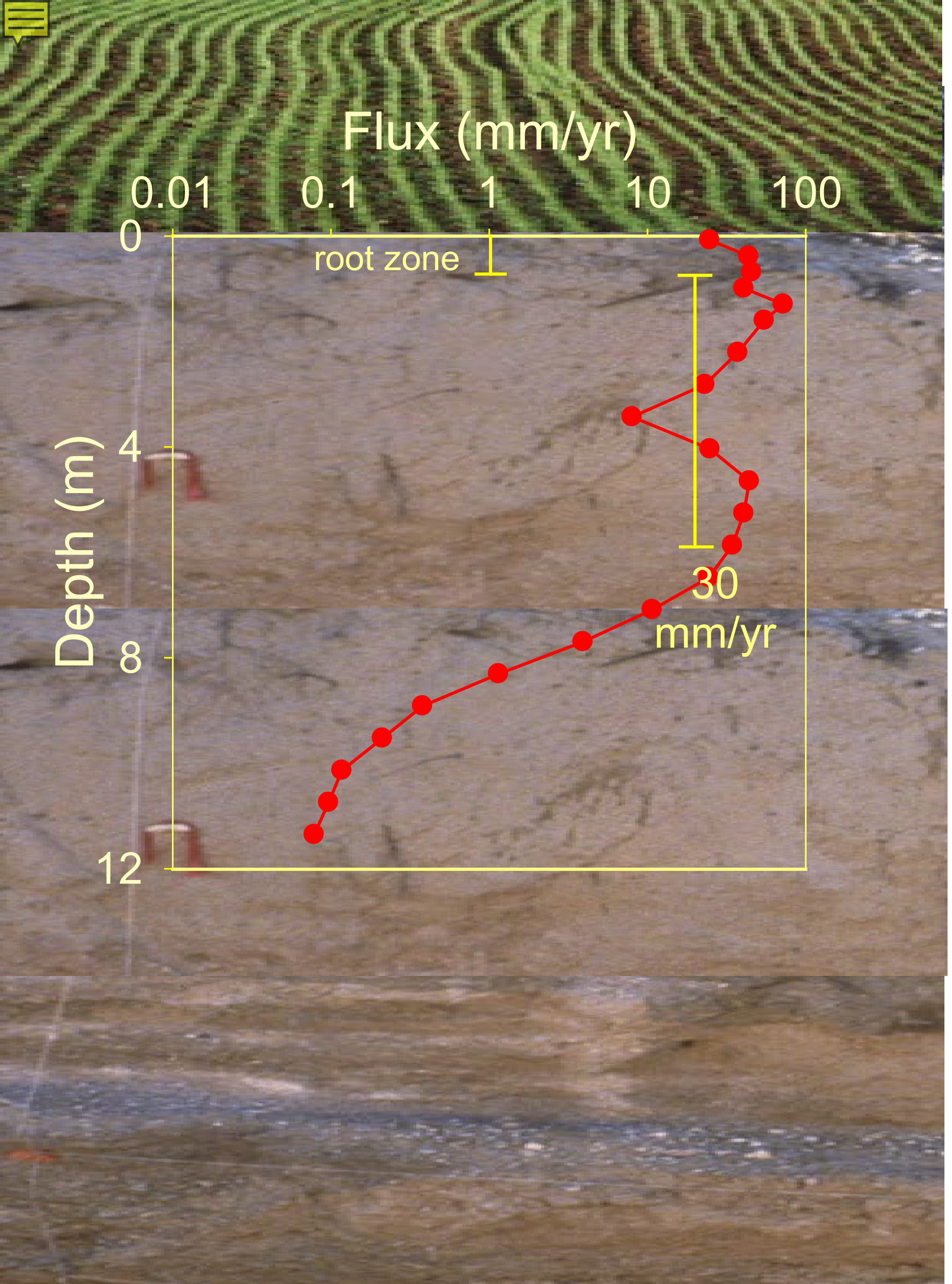

Mesic
Depth
Low
chloride
mass
Downward
flow
Groundwater
Pleistocene
~ 15,000 yr ago

Rangeland


Precipitation
decreased
Vegetation
Mesic
Xeric
Upward flow
and high ET
Depth
Low
chloride
mass
Downward
flow
Chloride mass
increases
Drying front
deepens
Groundwater
Pleistocene
Holocene
Present
~ 15,000 yr ago

Rangeland

Quantitative Chloride Mass Balance (CMB)



$$\text{Age} = \frac{\textit{mass of chloride}}{\textit{chloride input}}$$

$$t = \frac{\int_0^z \theta Cl_{uz} dz}{P \times Clp}$$

Drainage/recharge
19 profiles
Median = ~ 1 inch/yr
= ~5% of rainfall

Rainfed Cropland

Relationship between Drought and Total Water Storage Variability