Summary of Remote Sensing Hydrology Lab's Research in Parowan Valley, Utah

The Remote Sensing Hydrology Lab - vision

Develop groundwater methods that integrate in-situ data with the wealth of satellite and ground-based geophysical datasets, improving predictive capabilities and enabling groundwater evaluation in data-sparse regions.

The Remote Sensing Hydrology Lab - datasets

In-situ

Satellite

Airborne

Ground-based

My background

- BS in Geology at Brigham Young University (2014)
- PhD in Geophysics at Stanford University (2018)
- Assistant Professor at Missouri University of Science and Technology (2018-2022)
- Assistant Professor at Colorado State University (2022-present)

Central Valley, California
Parowan Valley, Utah
High Plains Aquifer, Kansas
Mississippi Alluvial Aquifer
San Luis Valley, Colorado
Southern Arizona
Victoria
Seattle
WASHINGTON
MONTANA
NORTH DAKOTA
MINNESOTA
Portland
Minneapolis
SOUTH DAKOTA
WISCONSIN
OREGON
IDAHO
WYOMING
Chicago
NEVADA
Denver
United States
ILLINOIS
INDIANA
Sacramento
COLORADO
KANSAS
San Francisco
San Jose
CALIFORNIA
Las Vegas
Nashville
TENNESSEE
Albuquerque
ARKANSAS
Los Angeles
ARIZONA
MISSISSIPPI
San Diego
Phoenix
Dallas
ALABAMA
Tucson
Ciudad Juárez
TEXAS
BAJA CALIFORNIA
SONORA
Austin
Houston
LOUISIANA
CHIHUAHUA
San Antonio
COAHUILA

Why Parowan Valley?

- I’m motivated to study this area because there is an intersection of
  - High-quality data availability
  - Groundwater management priority
  - Compelling science questions
  - Local partnerships

Authors on projects shown here (in addition to myself)

Jiawei Li, PhD student

Katherine Grote, Associate Professor,
Missouri University of Science and Technology

Jim Butler, Senior Scientist, Kansas Geological Survey

Outline of work that has been done to date – contact me for a copy of the papers

- Analysis of key drivers of subsidence in the valley (published)
- Modeling ground deformation with satellite and groundwater level data (published)
- Water budget analysis using satellite, groundwater level, and pumping data (currently under review)
- Geophysical survey of the top ~150 ft of the valley (analysis in progress)

Ryan.G.Smith@colostate.edu

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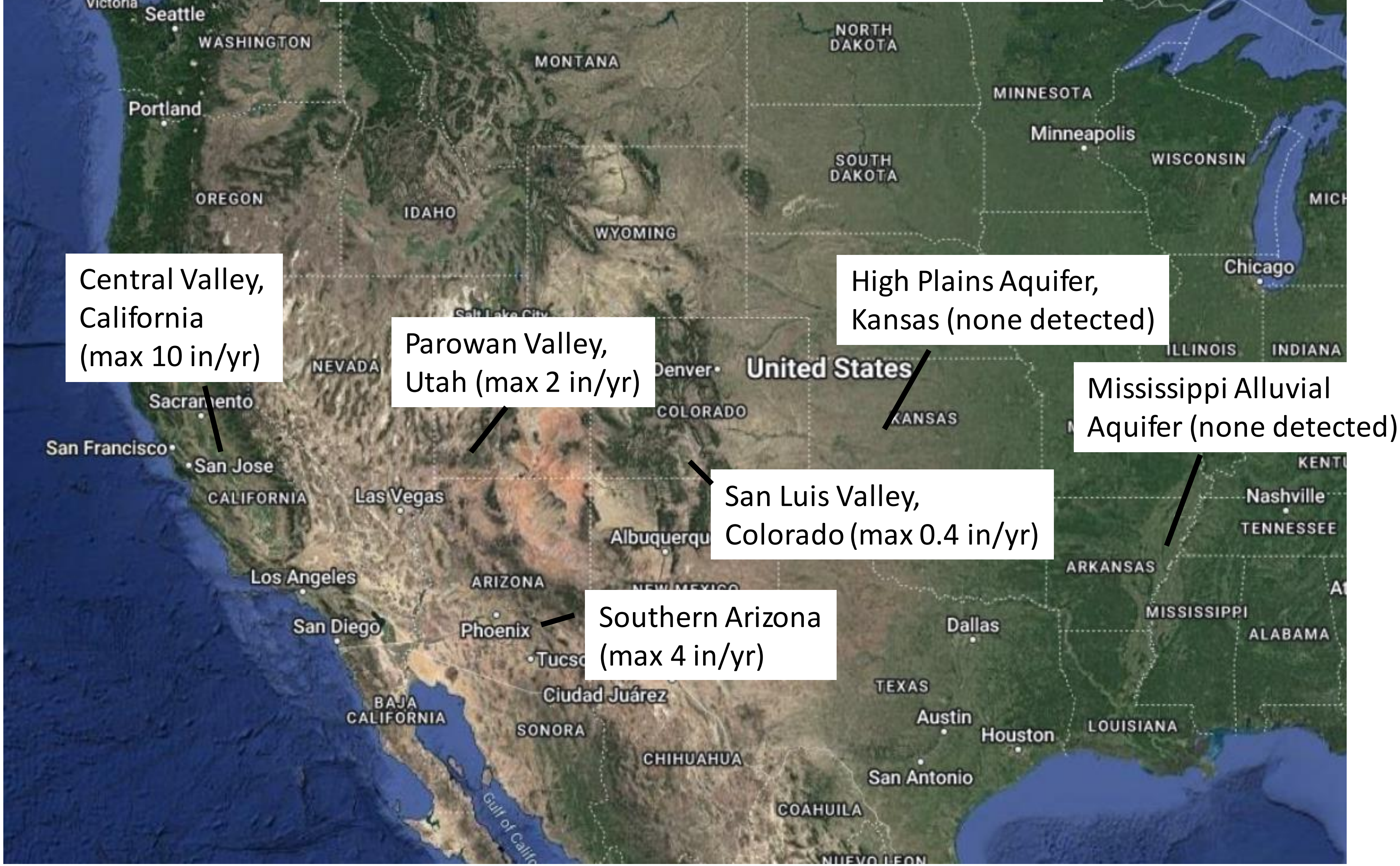
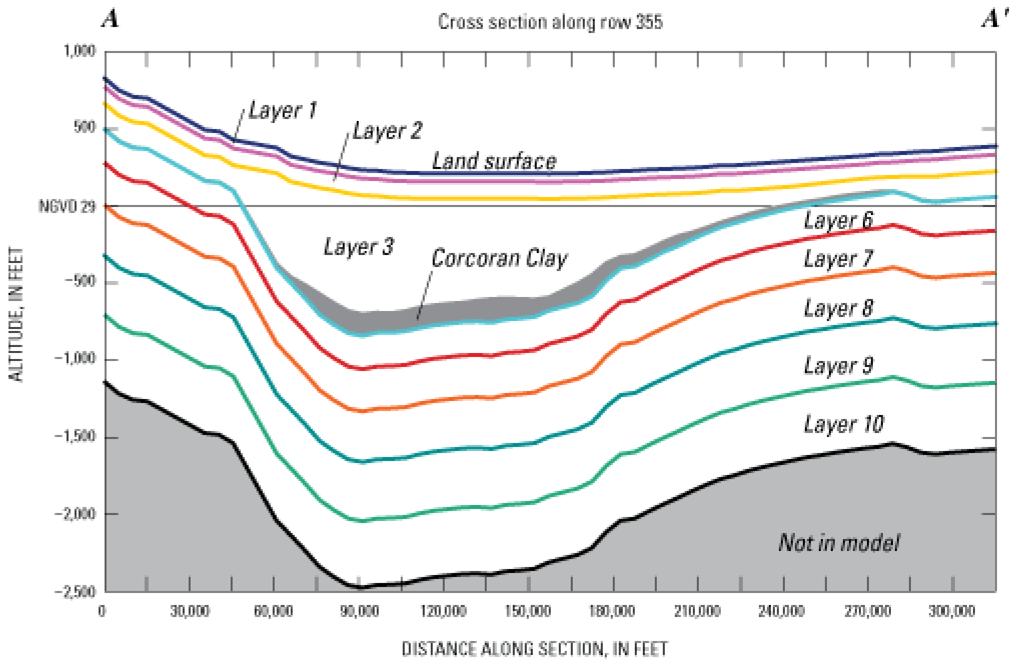
Subsidence rates over other aquifers in the US

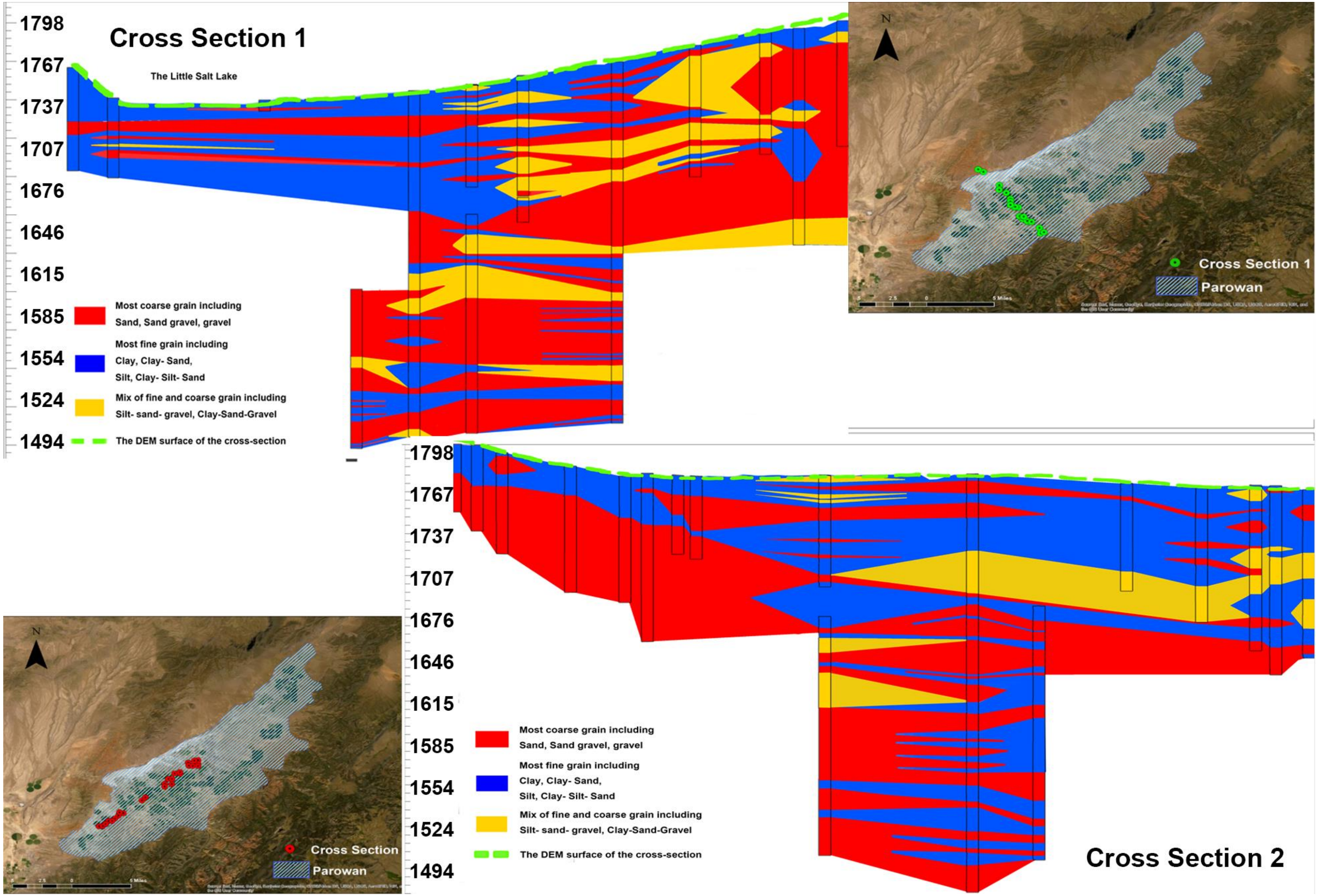


What causes subsidence?

- Three things are needed:
  - Groundwater pumping
  - Significant clay in the aquifer system being pumped
  - Confining unit

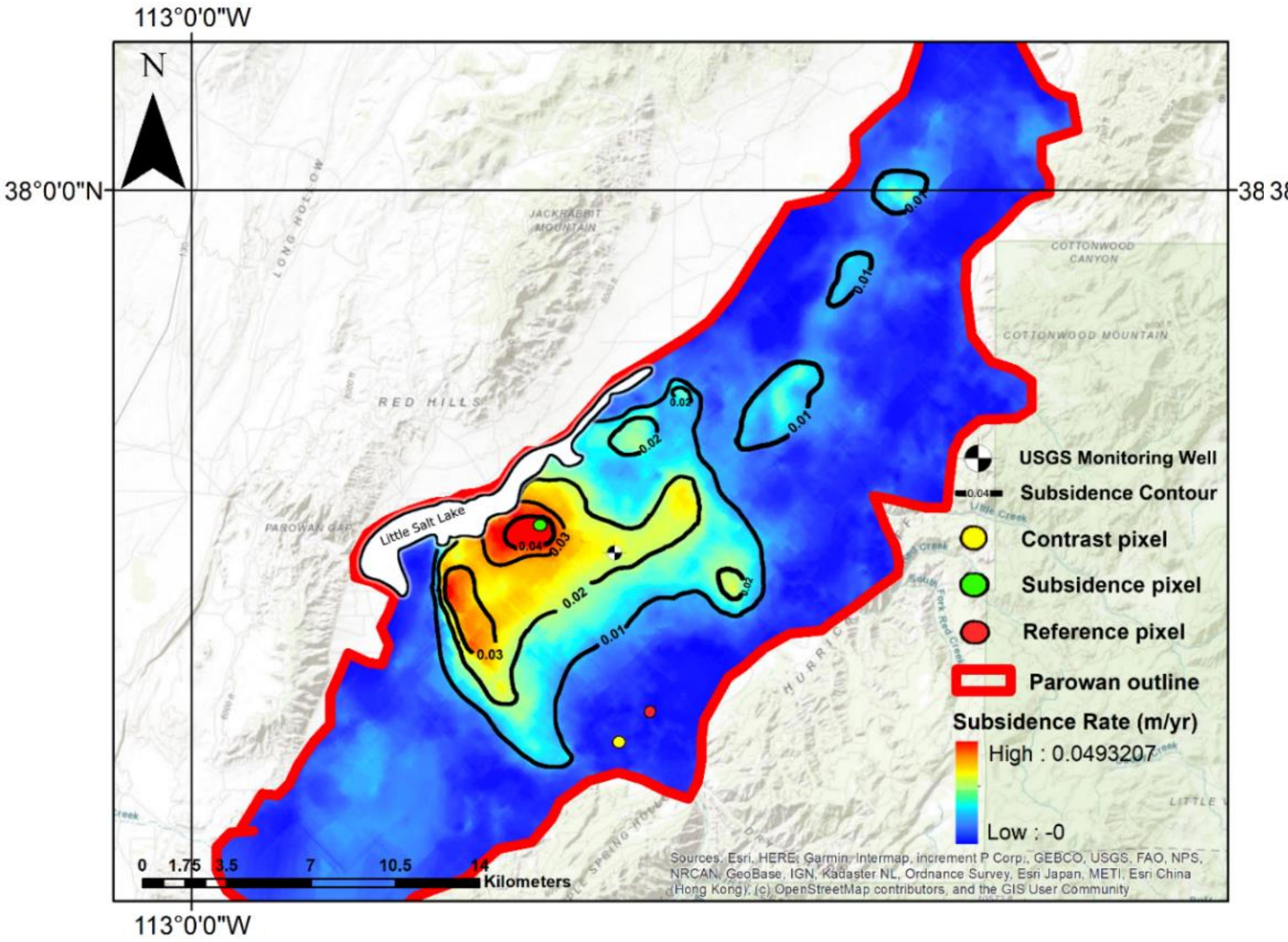
Example in California: the Corcoran Clay confines the deep aquifers, causing pressurization



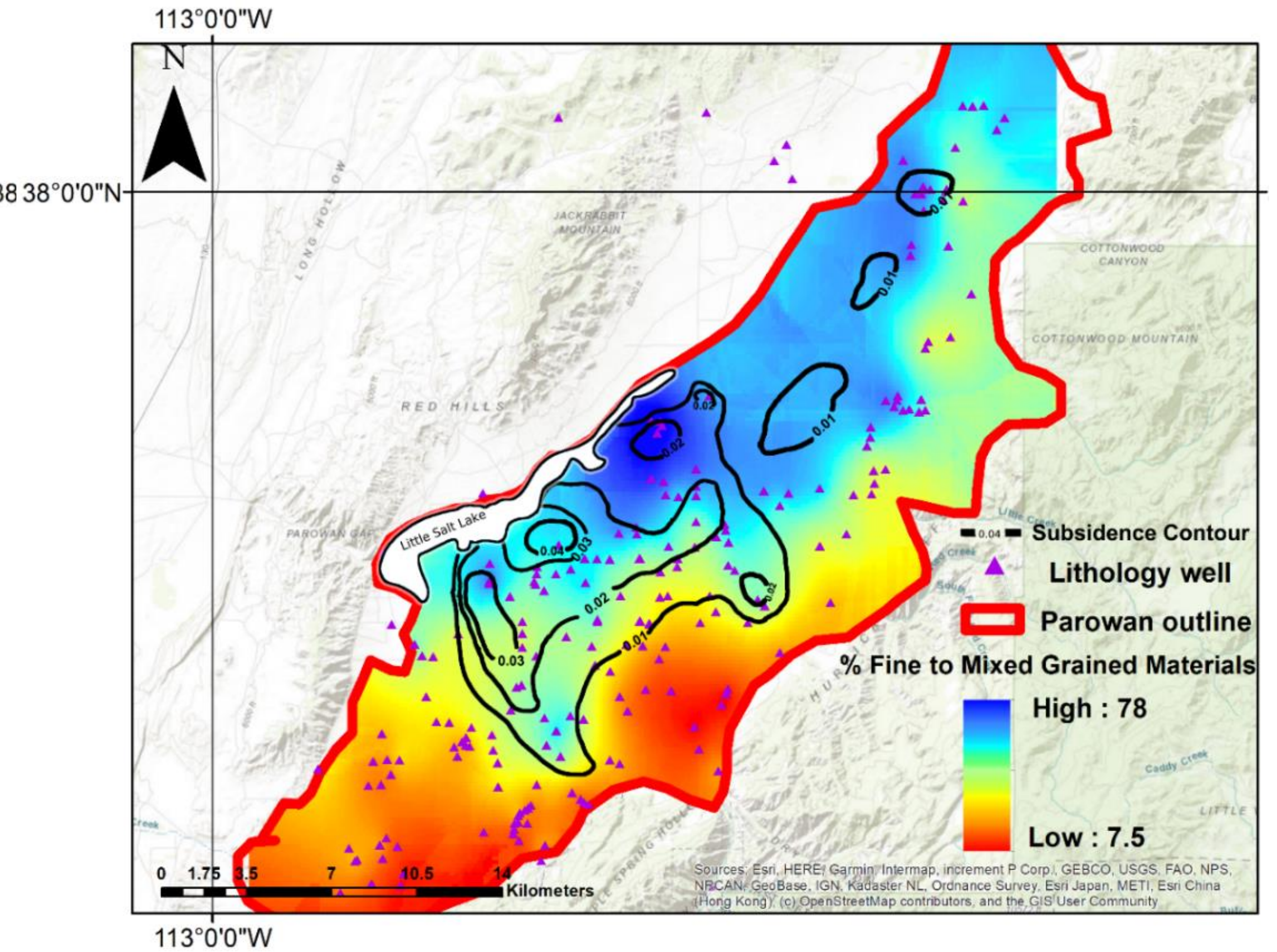


Cross Section 1
The Little Salt Lake
1798
1767
1737
1707
1676
1646
1615
1585
1554
1524
1494
Most coarse grain including
Sand, Sand gravel, gravel
Most fine grain including
Clay, Clay- Sand,
Silt, Clay- Silt- Sand
Mix of fine and coarse grain including
Silt- sand- gravel, Clay-Sand-Gravel
The DEM surface of the cross-section
N
Cross Section 1
Parowan
Cross Section 2
1798
1767
1737
1707
1676
1646
1615
1585
1554
1524
1494
Most coarse grain including
Sand, Sand gravel, gravel
Most fine grain including
Clay, Clay- Sand,
Silt, Clay- Silt- Sand
Mix of fine and coarse grain including
Silt- sand- gravel, Clay-Sand-Gravel
The DEM surface of the cross-section
N
Cross Section
Parowan

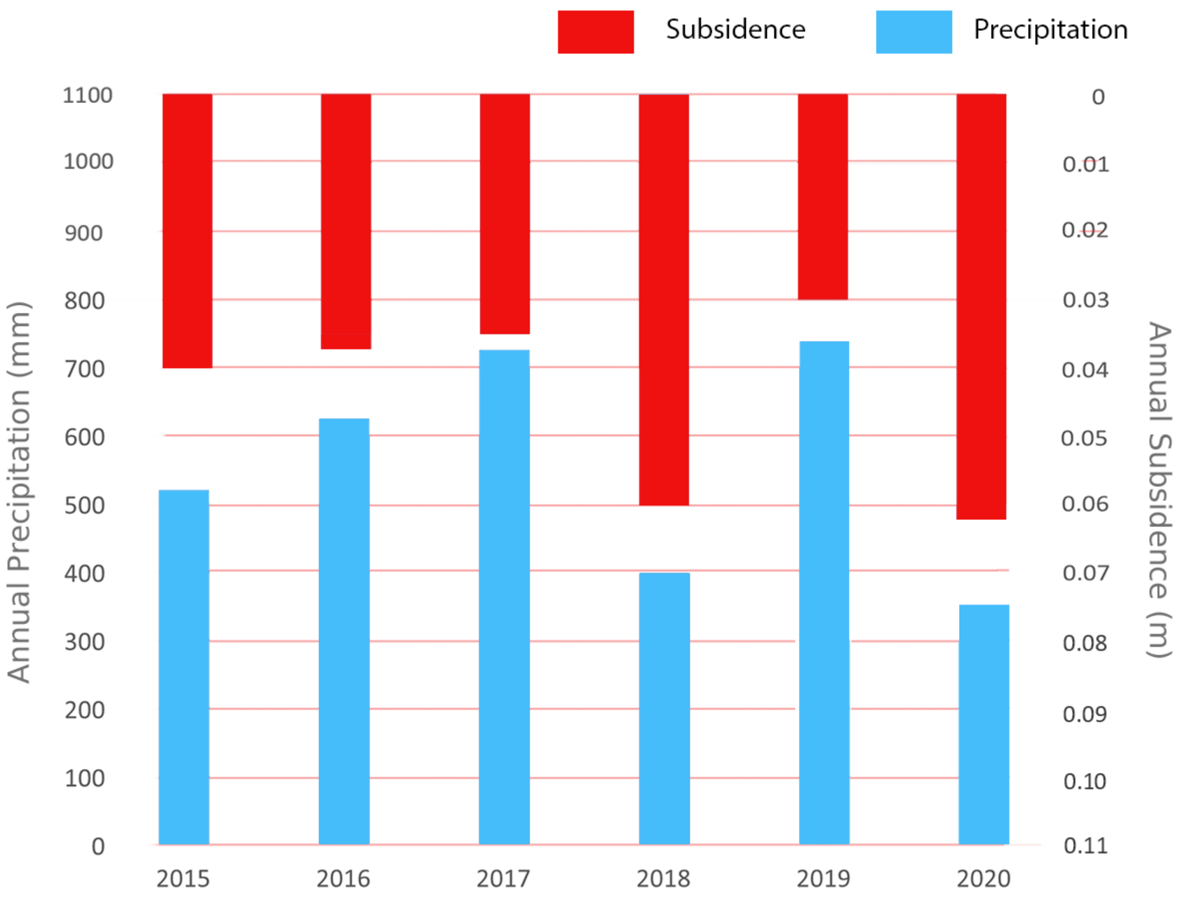
Subsidence rate mapped by satellites



% clay or other fines with subsidence overlain



Yearly subsidence compared with precipitation



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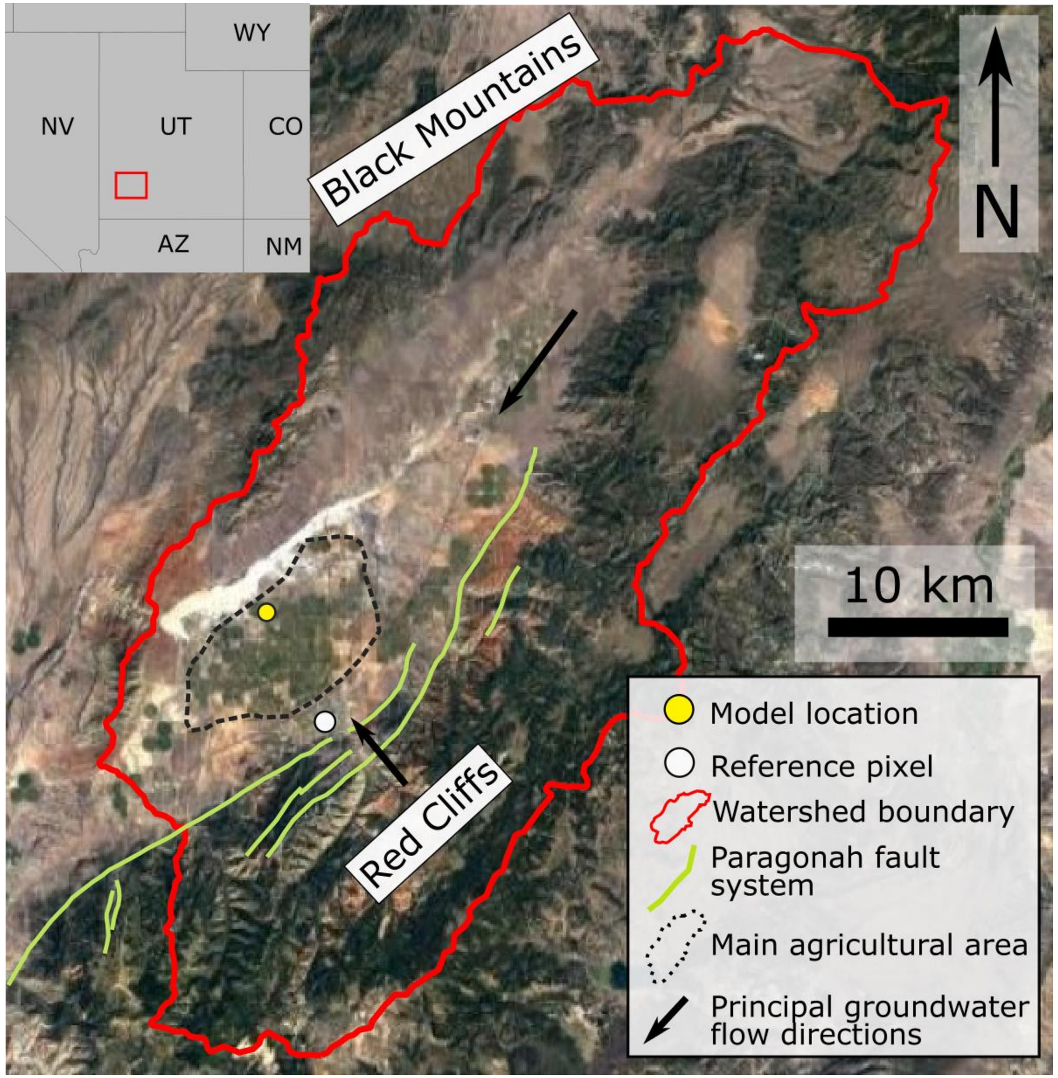
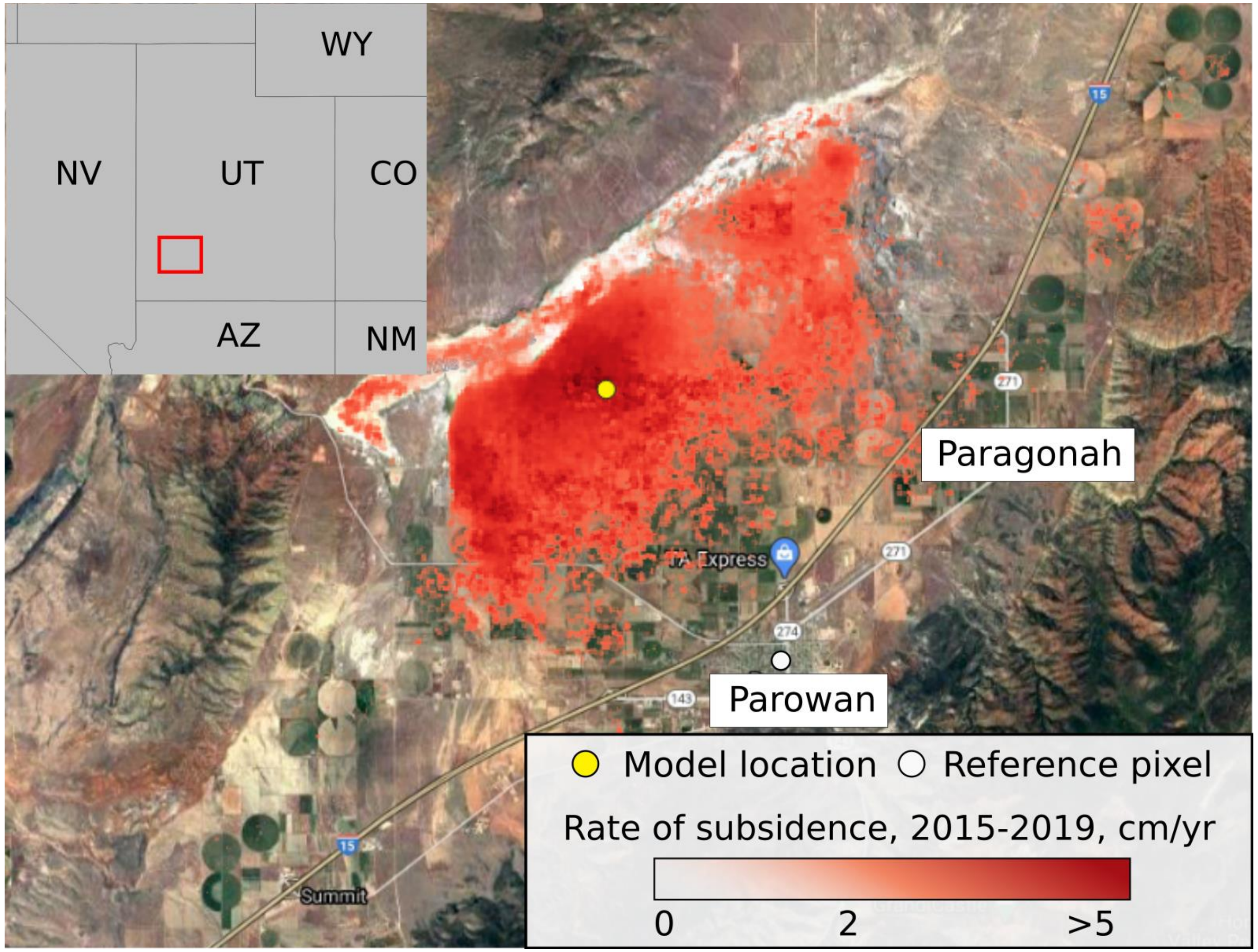
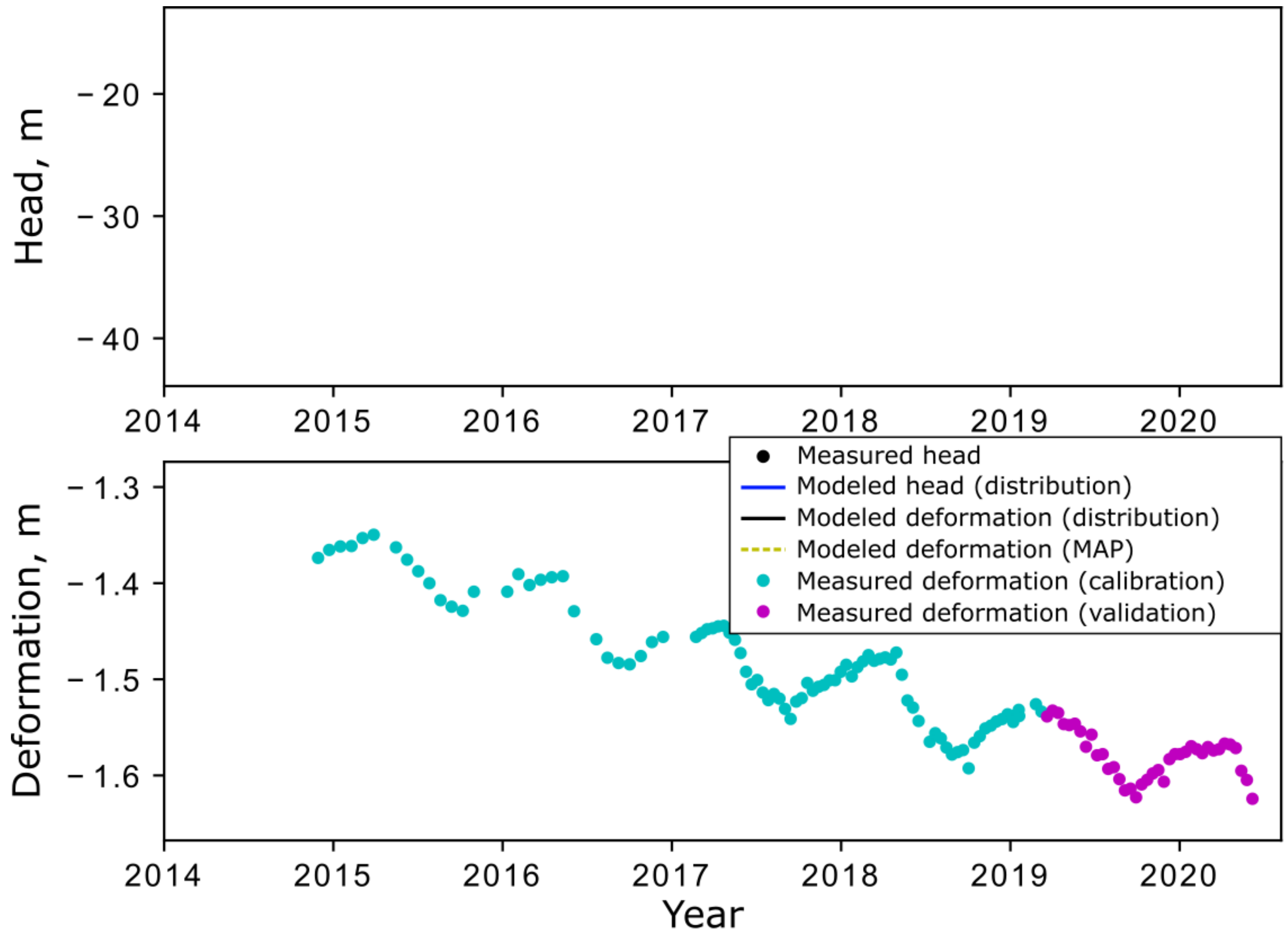
Modeling ground deformation with satellite and groundwater level data (published)



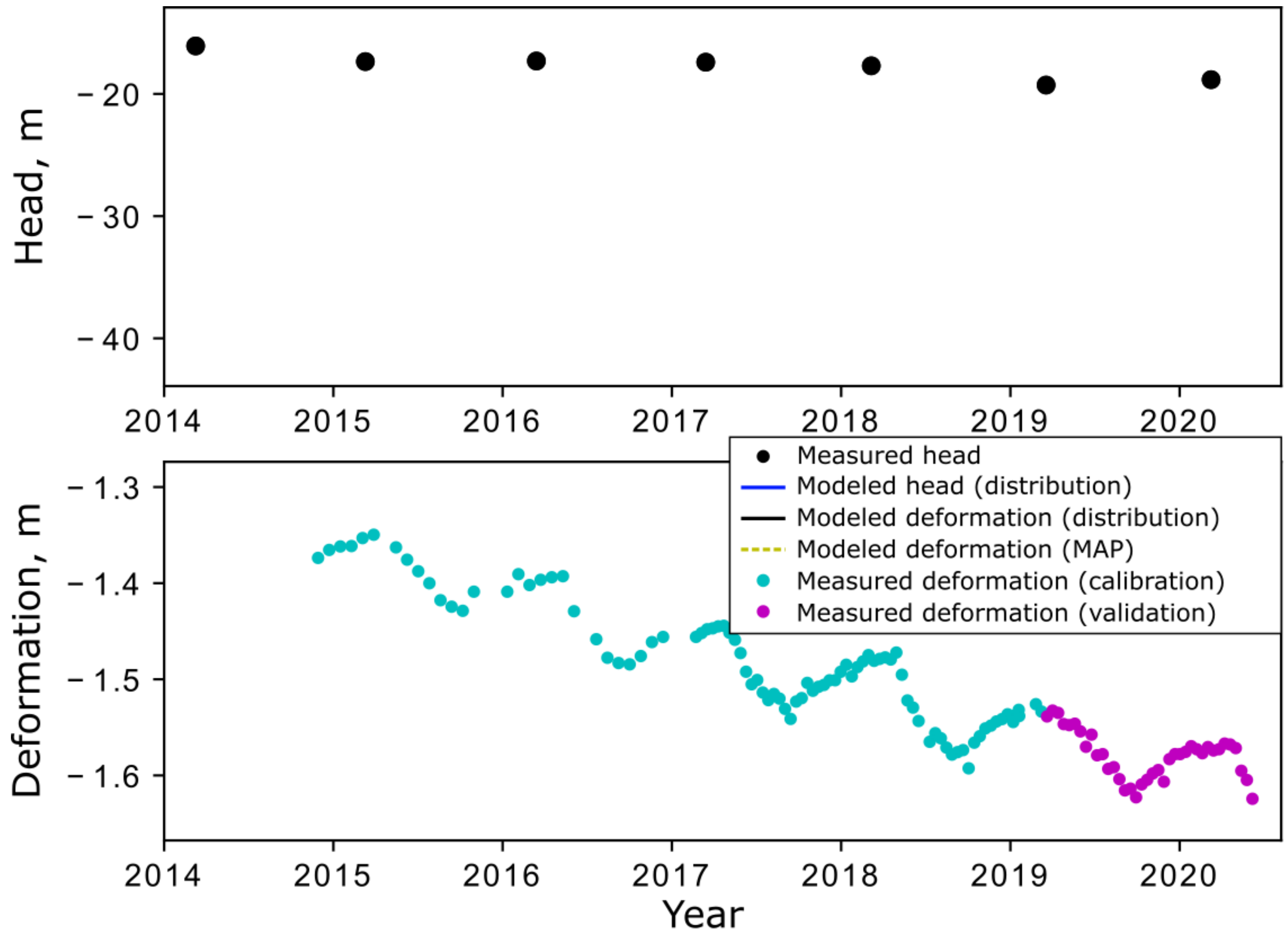
Long-term subsidence rate in the southern part of Parowan Valley



Subsidence and uplift over time at one location

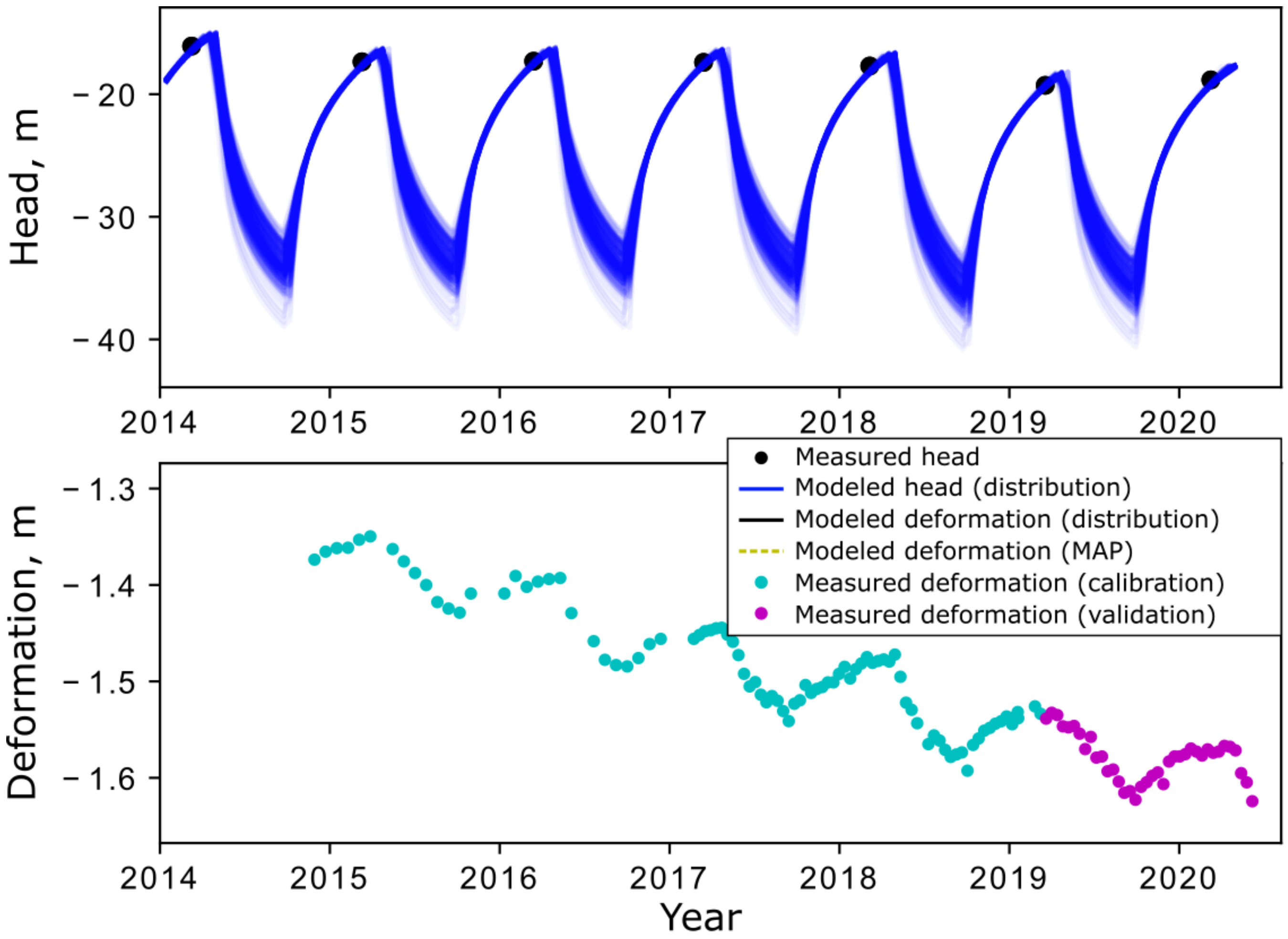


Subsidence and uplift over time at one location is controlled by groundwater levels



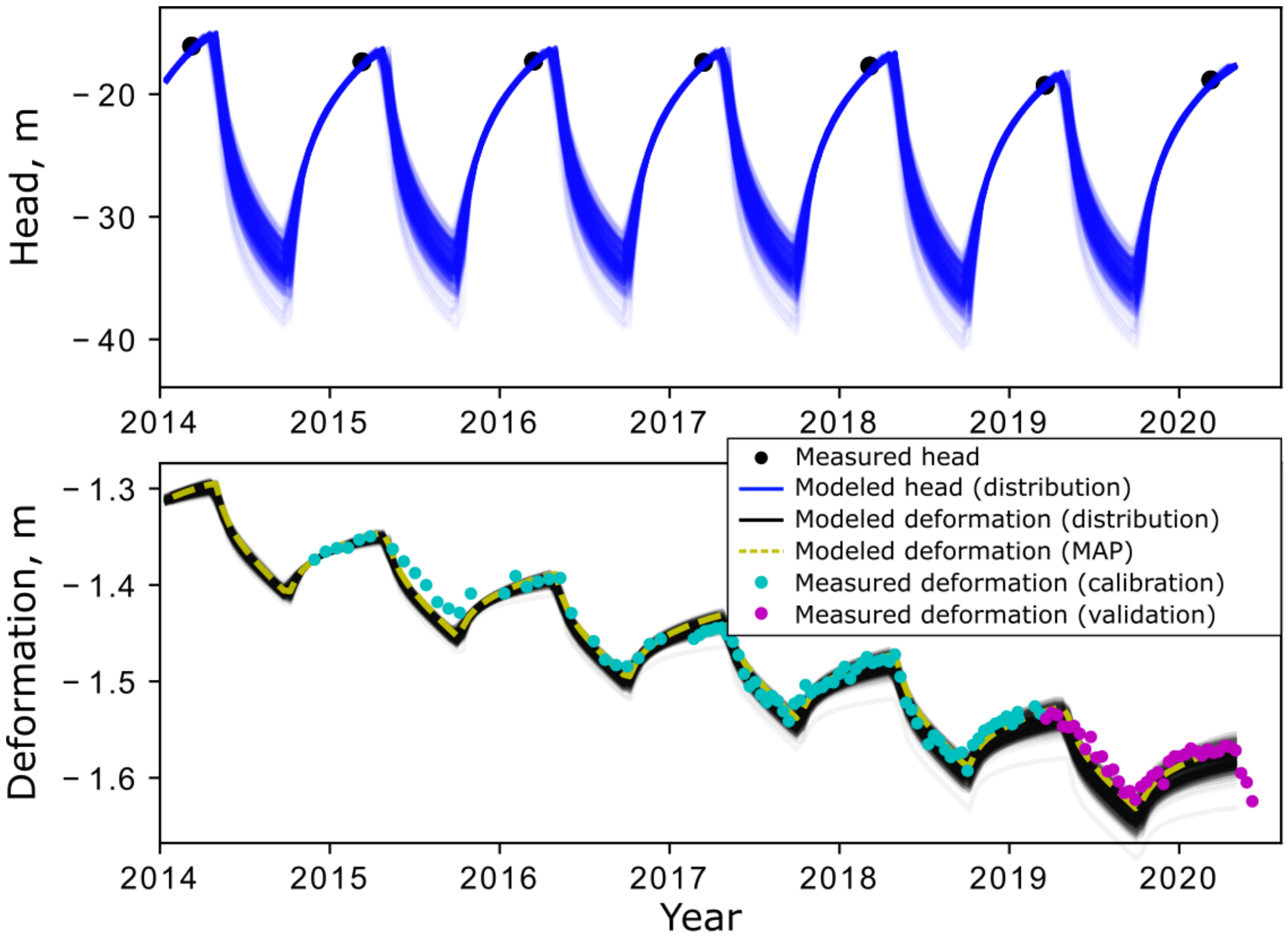
We simulated groundwater levels to model deformation

- This model can predict subsidence based on changes in groundwater level (head)
- The model can also estimate the elastic (recoverable) and inelastic (permanent) portions of subsidence

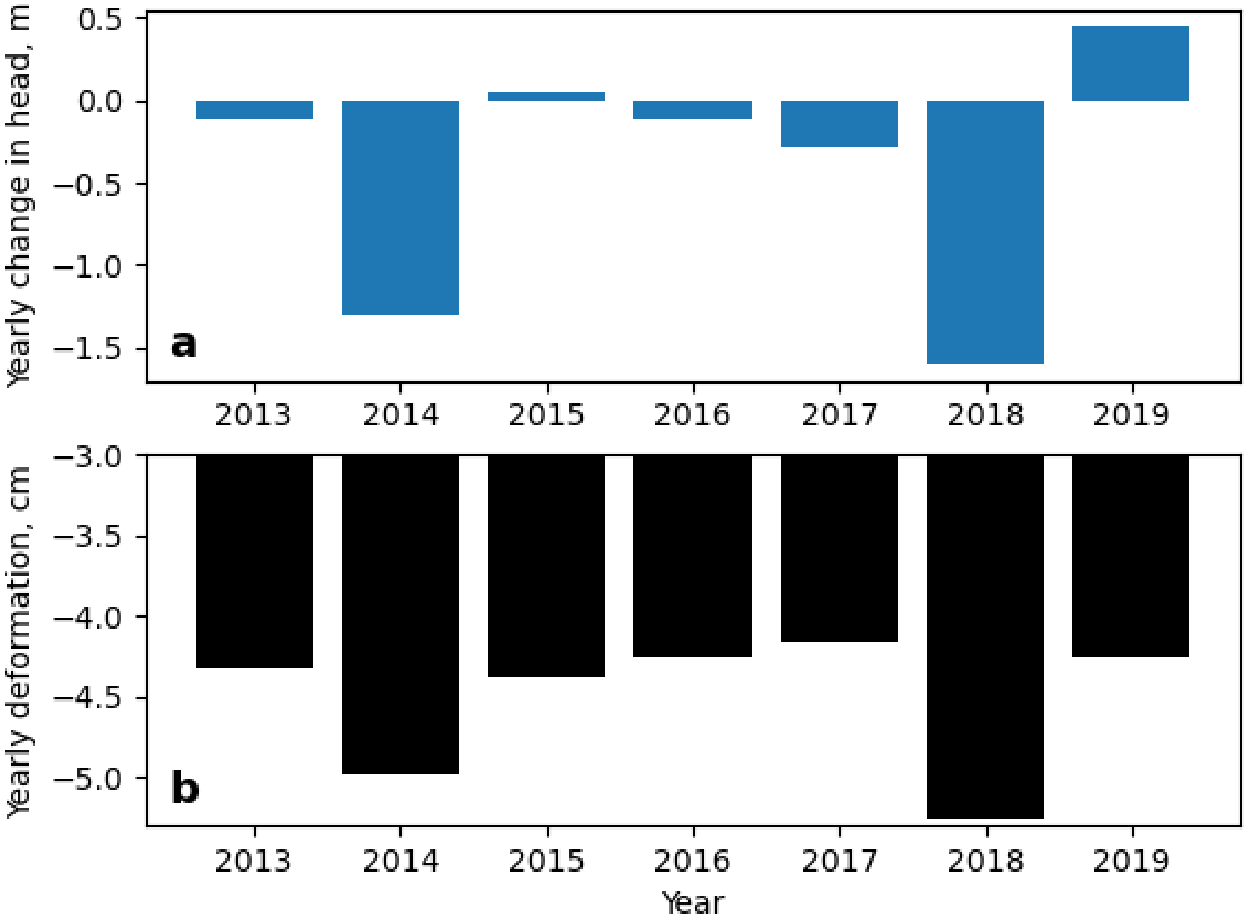


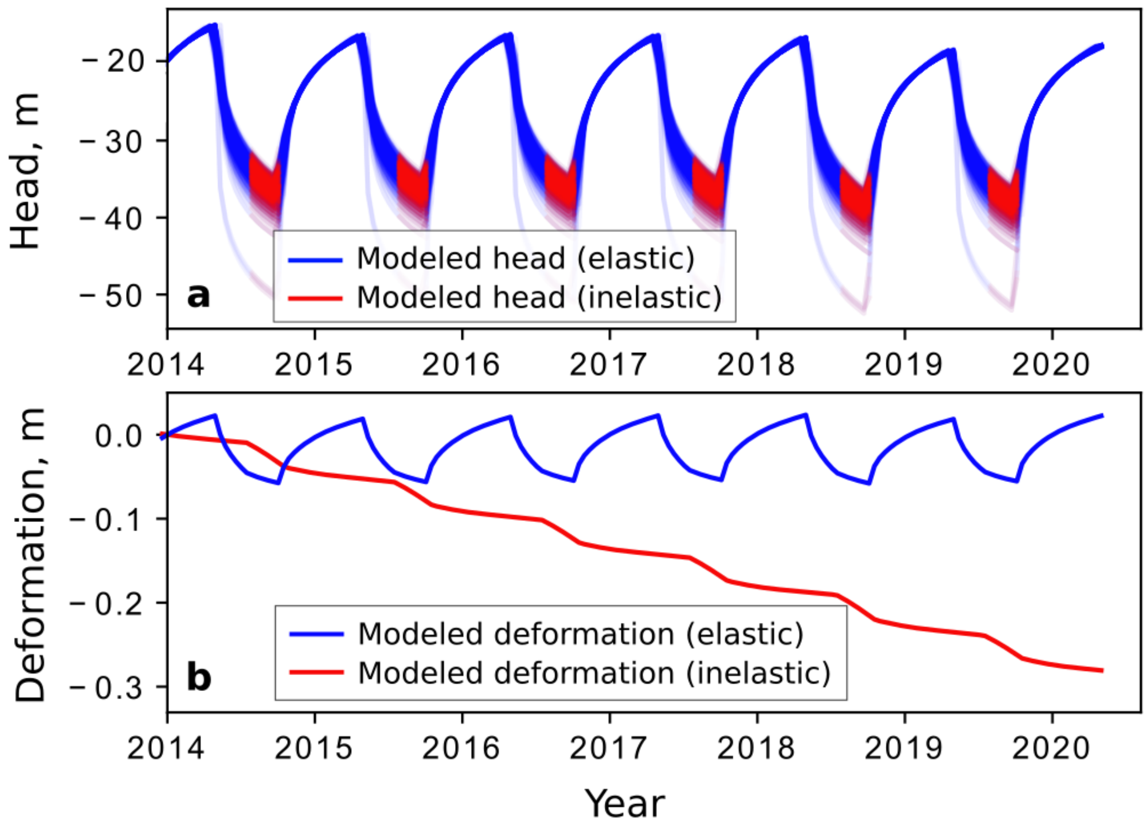
Our model accurately predicts subsidence and rebound

- This model can predict subsidence based on changes in groundwater level (head)
- The model can also estimate the elastic (recoverable) and inelastic (permanent) portions of subsidence



Most of the long-term subsidence is permanent (inelastic)





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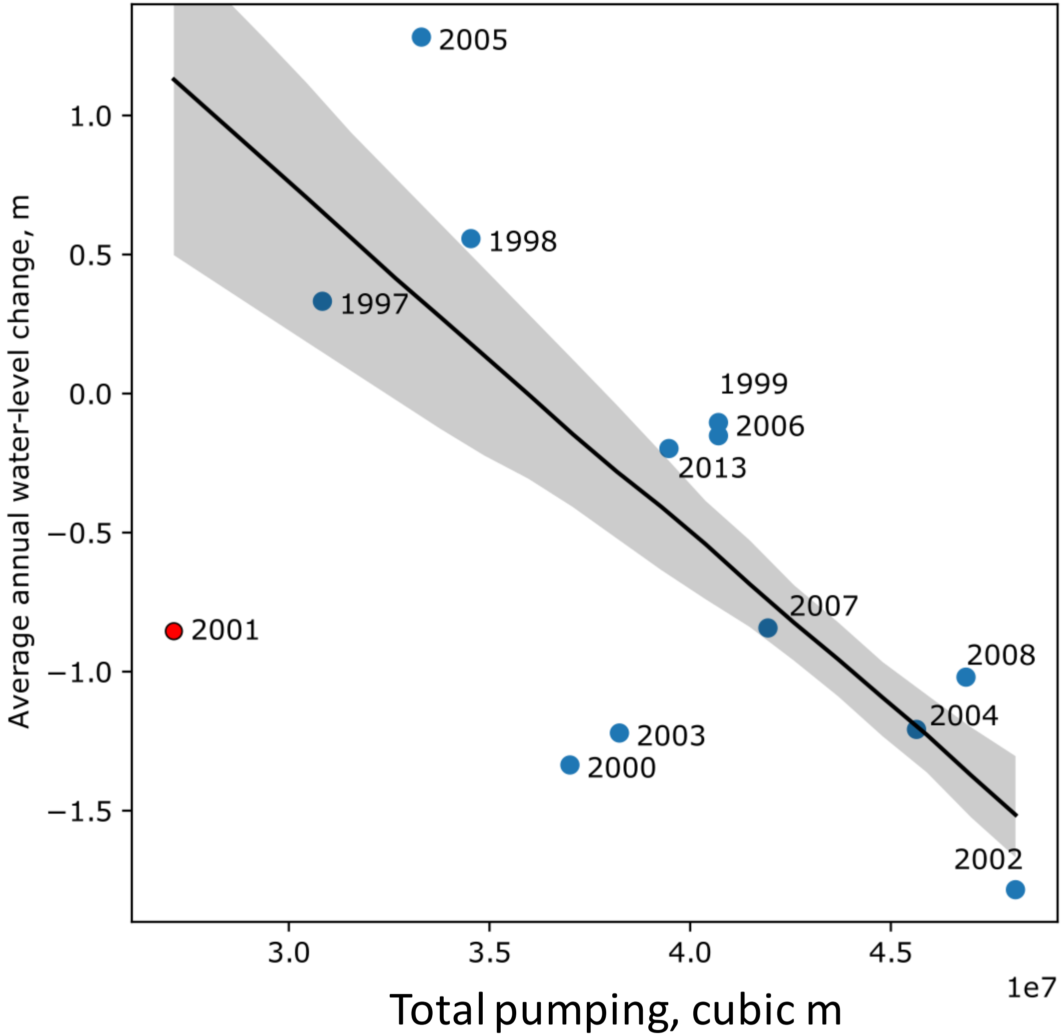
Water budget approach: compare total annual pumping with average annual change in head



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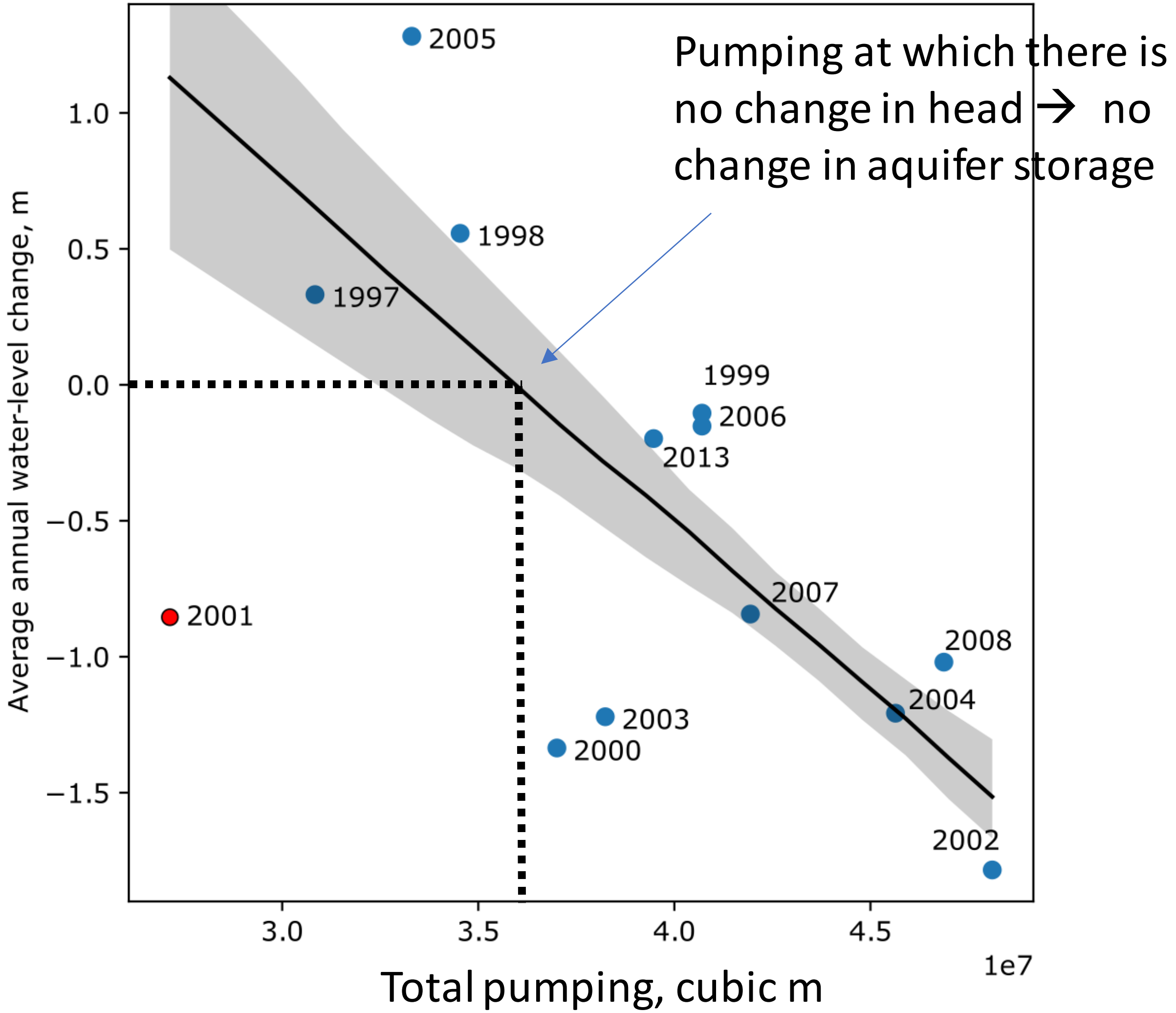
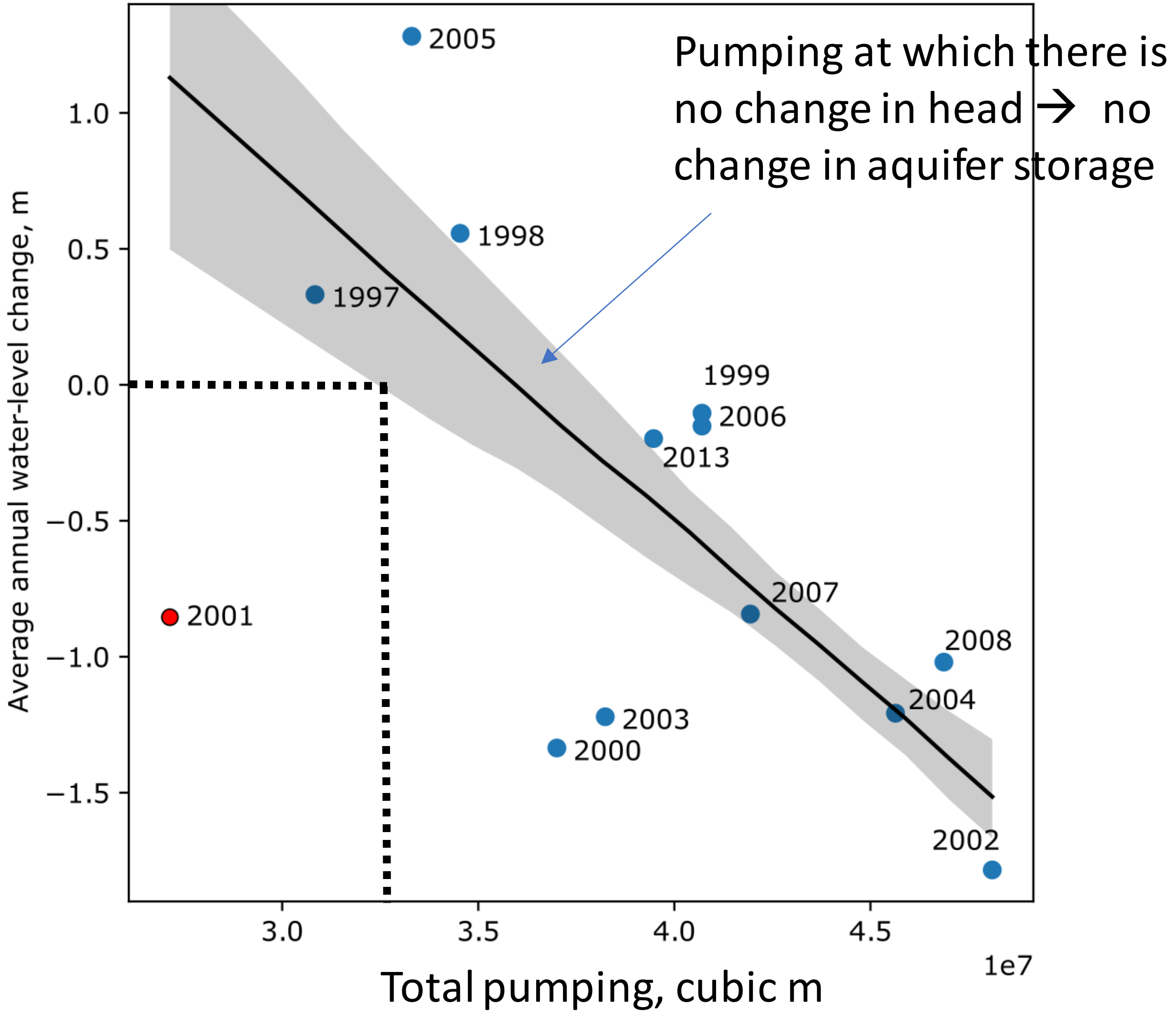


There's some uncertainty in this value!



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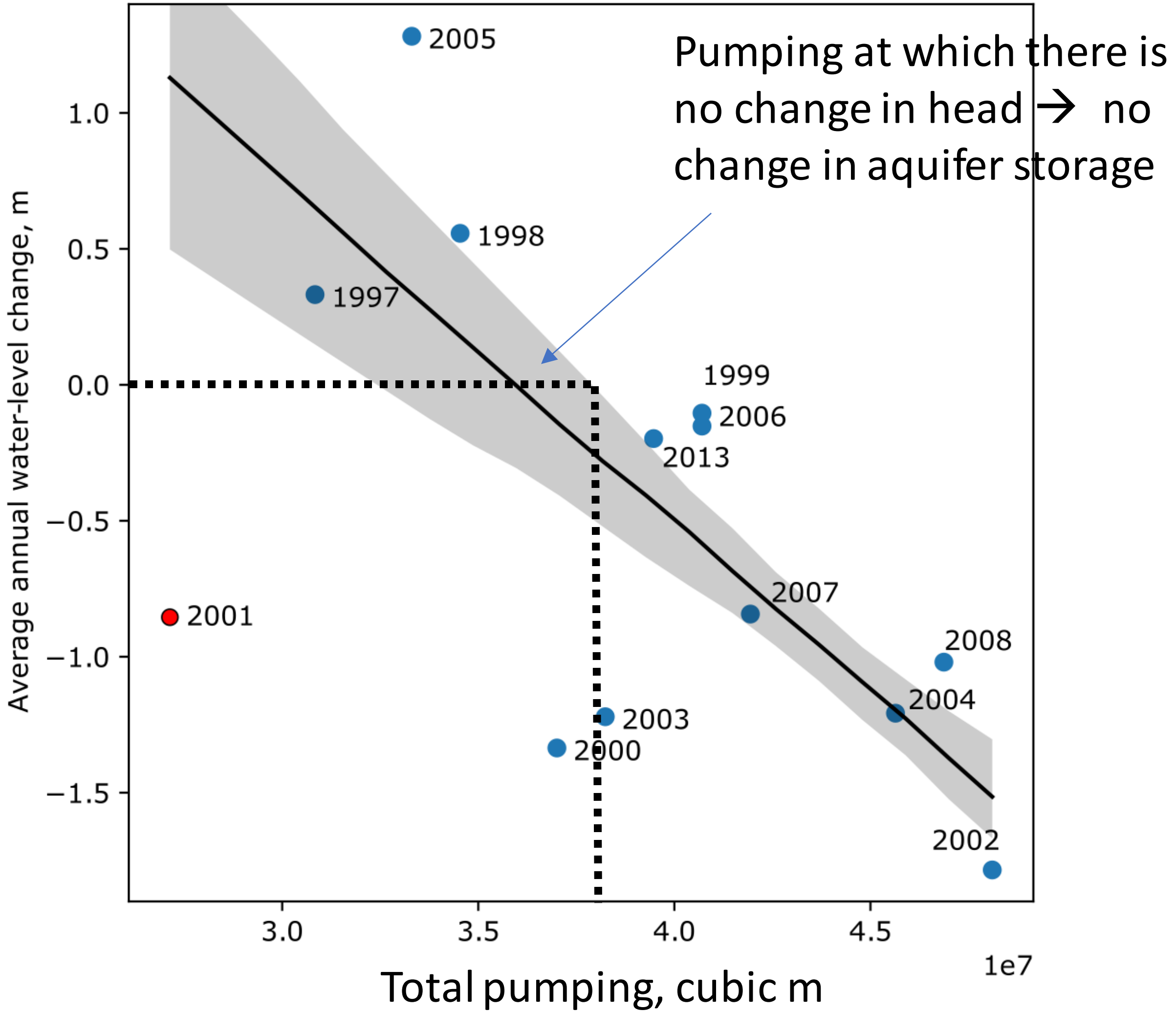
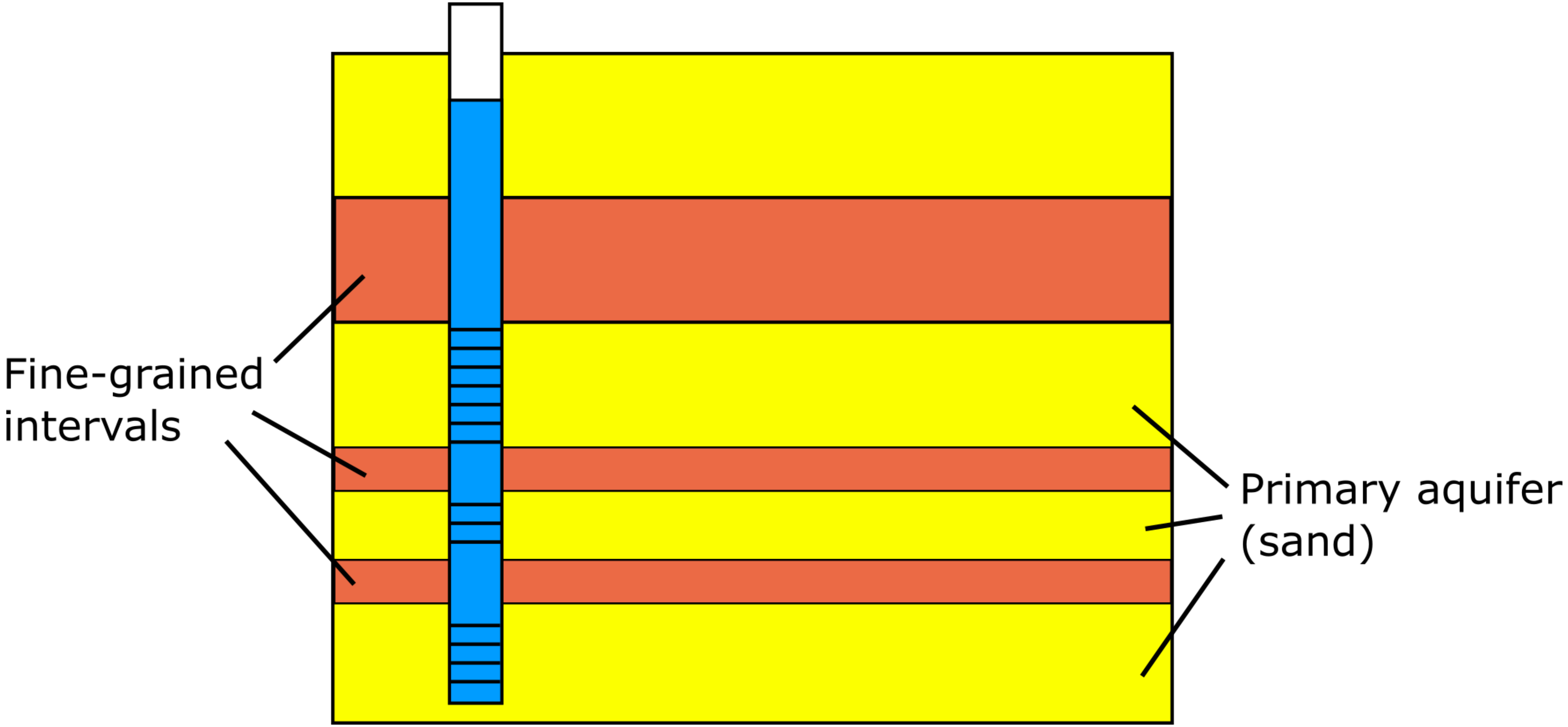
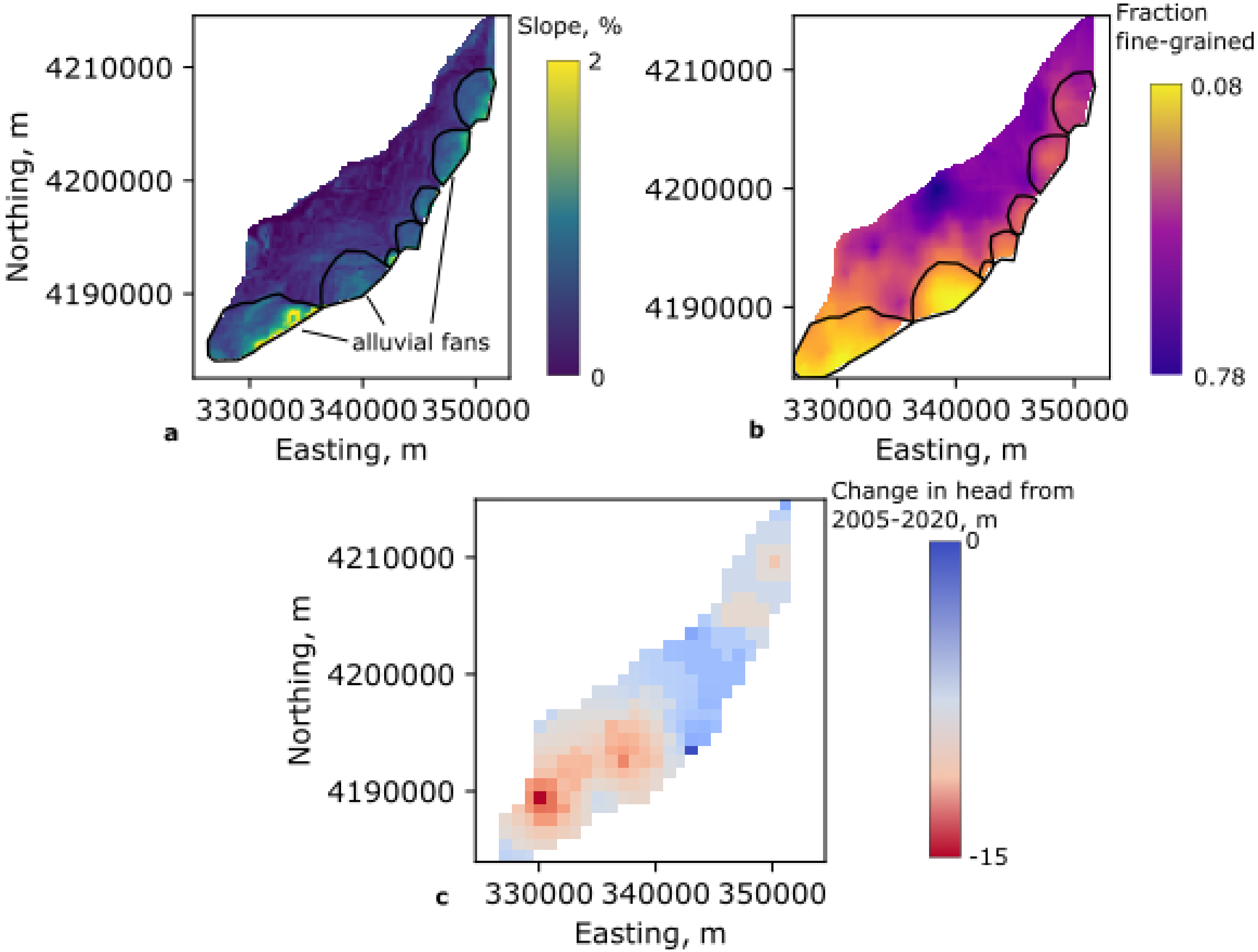


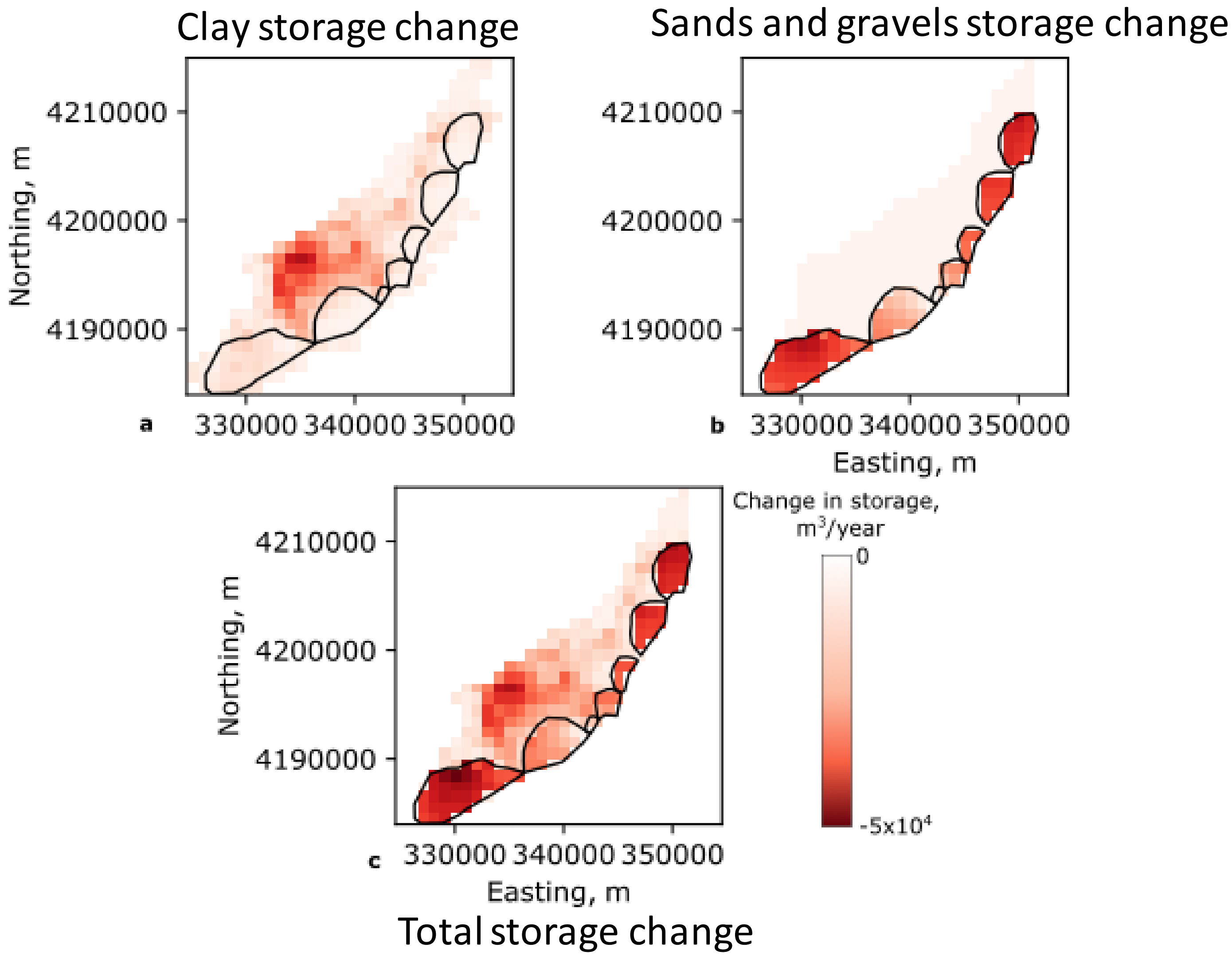
We also know that there is some storage coming into the aquifer from clays that will go away once drawdown stops



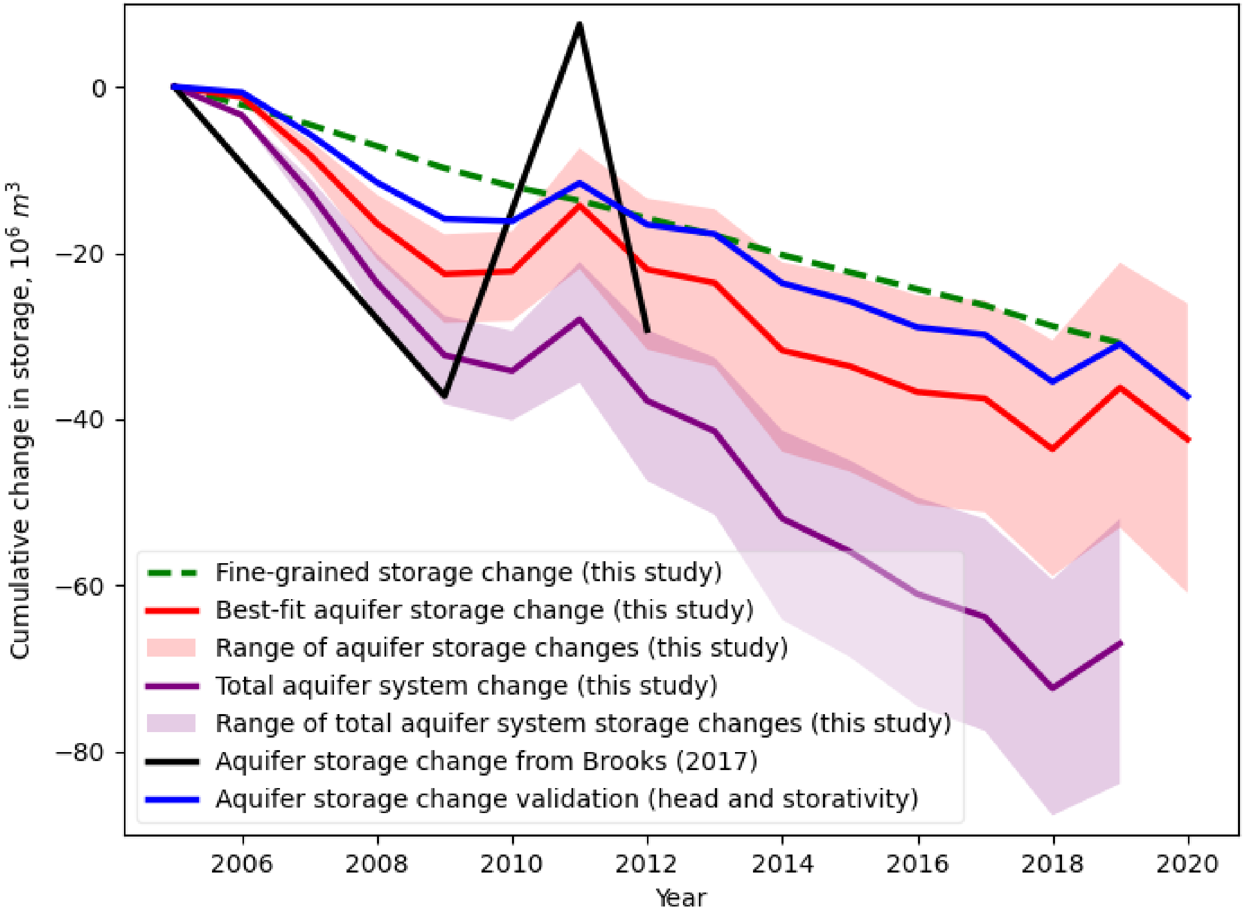
Another approach for storage change: multiply change in head by storativity



We can then estimate storage change in both the aquifer (sands and gravels) and the clays

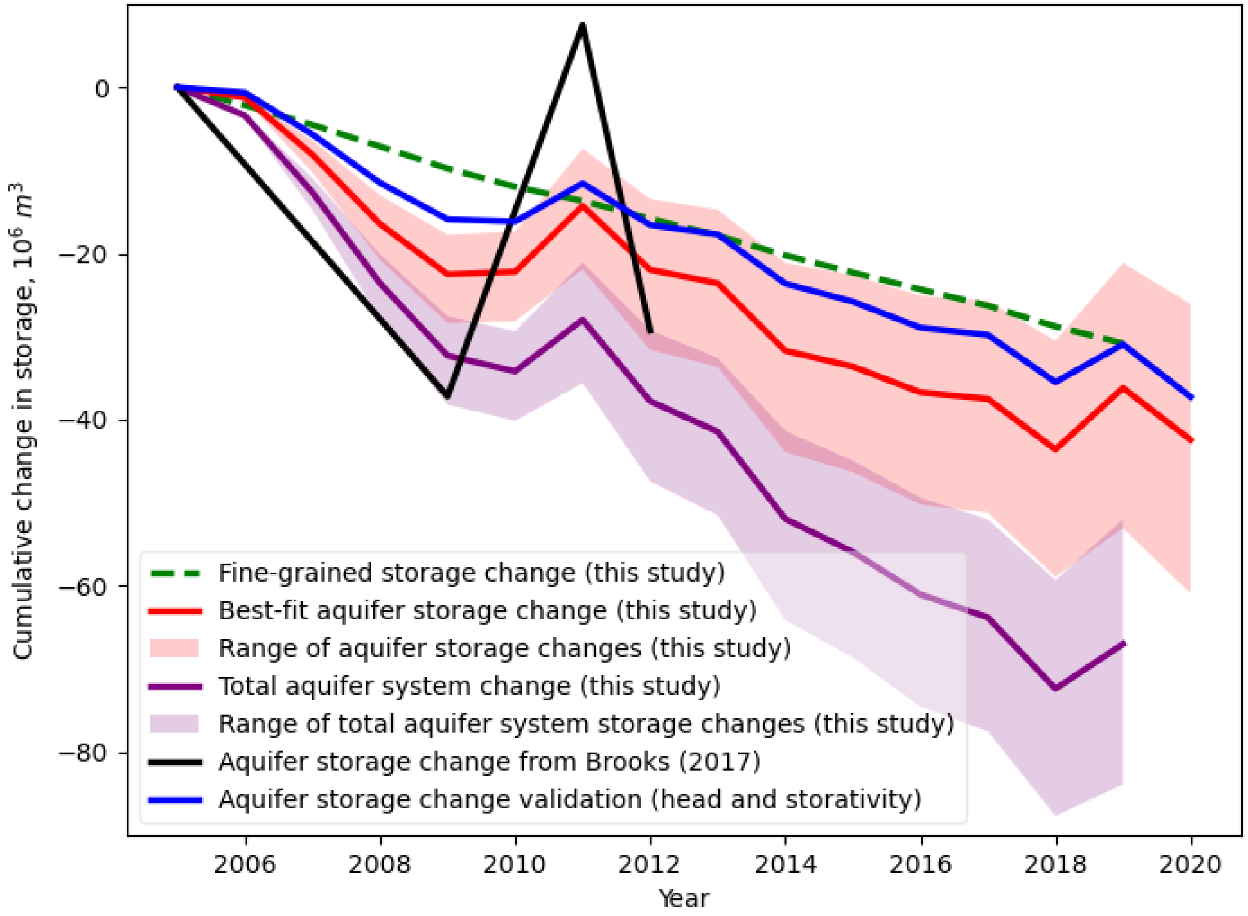


Storage change estimates from this study, compared with USGS groundwater model (Brooks 2017, black line)



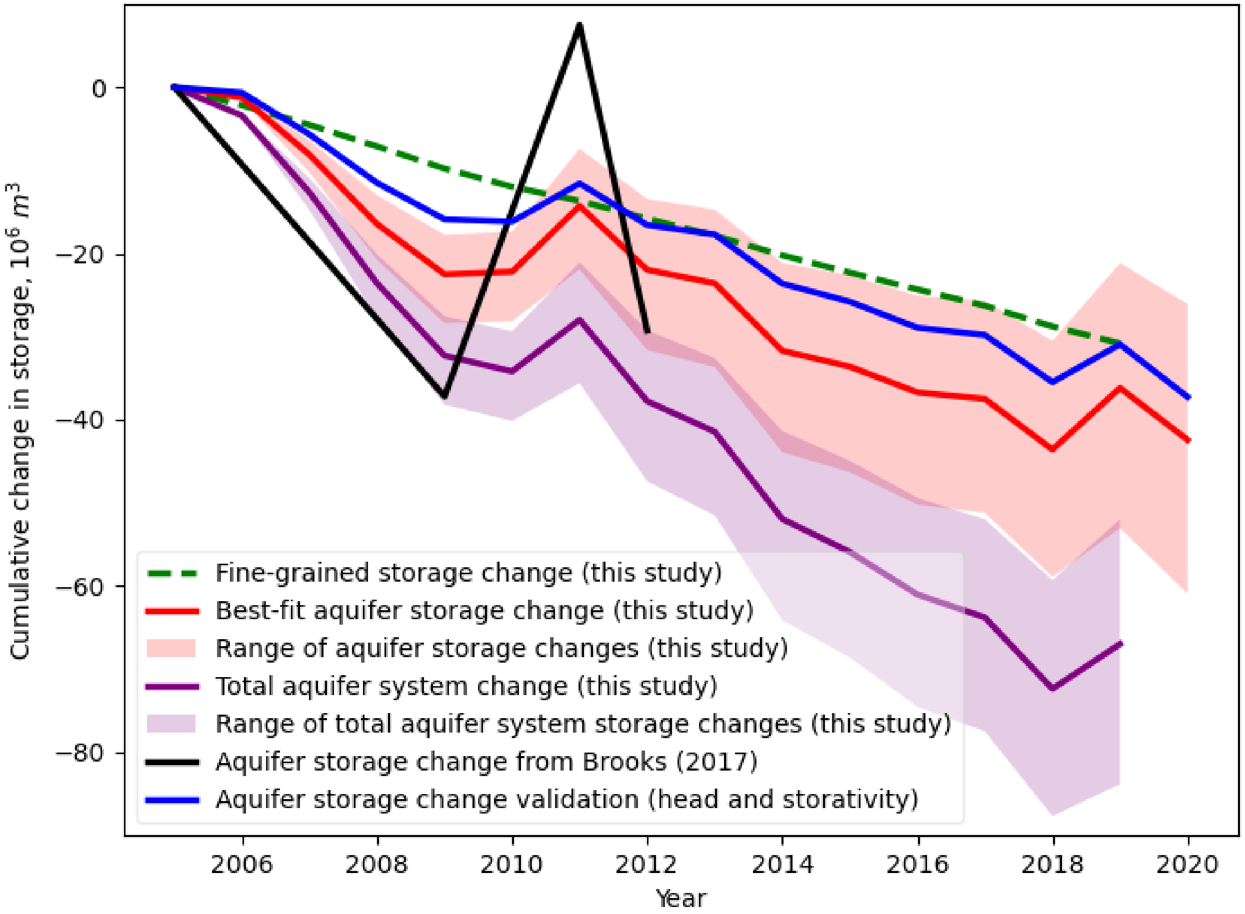
Lots of uncertainty in storage change estimates!

Average annual storage loss, 2005-2012 (acre-feet)				Average annual pumping, 2005-2012 (acre-feet)
Brooks (2017)	Marston (2017)	This study, range (**best estimate**)	Validation, this study	
3,388	10,863	5,493 -3,386 (**4,376**)	1,921	34,125



Lots of uncertainty in storage change estimates!

- Each of these storage change estimates is much lower than that of Marston (2017), who used a water budget approach
- In water budgets, recharge is very difficult to estimate
- Possible explanations for discrepancy:
    - Marston (2017) under-estimated recharge
    - Mountain aquifers are being depleted and considered a source of 'inflow' in our water balance approach



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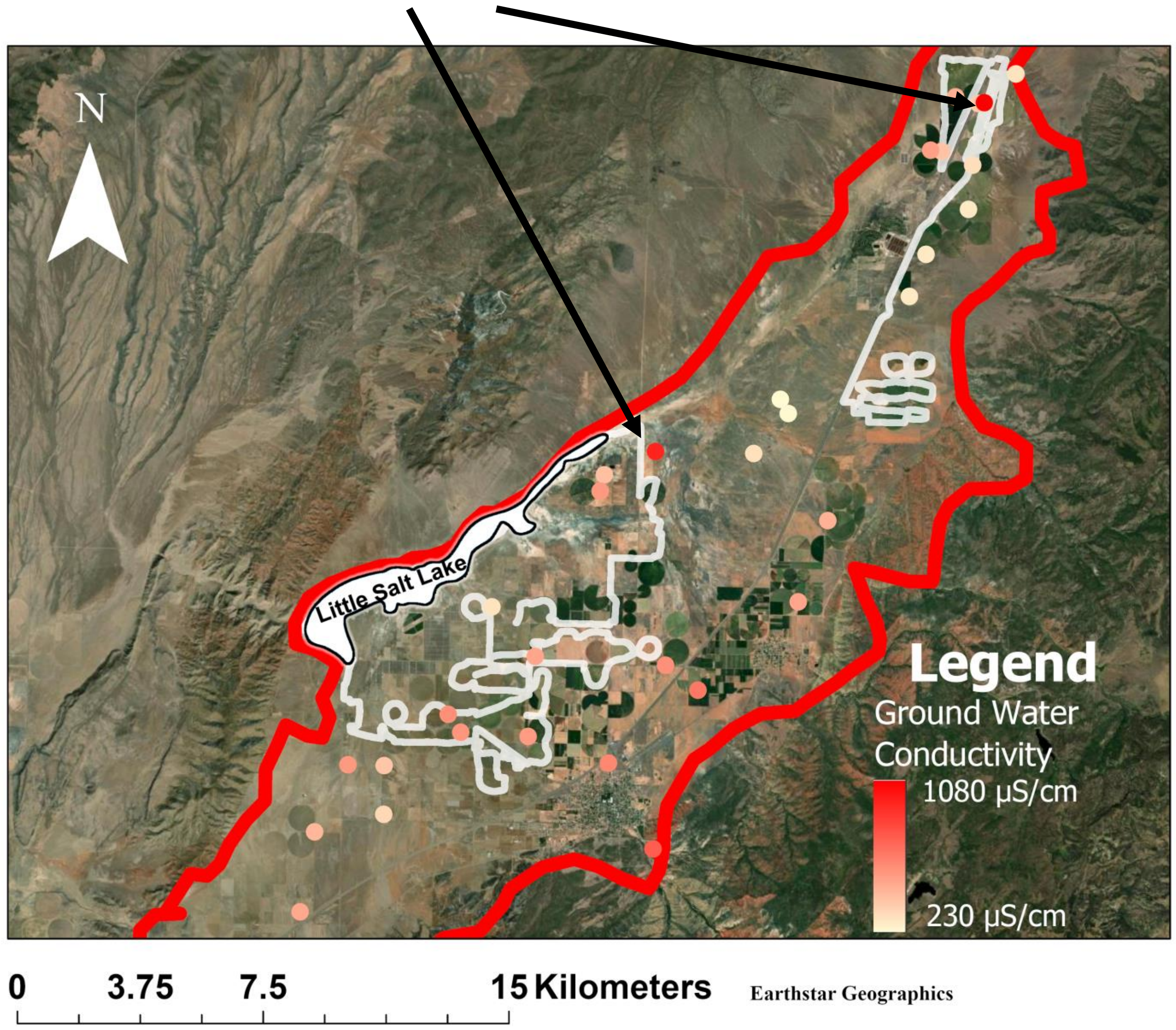
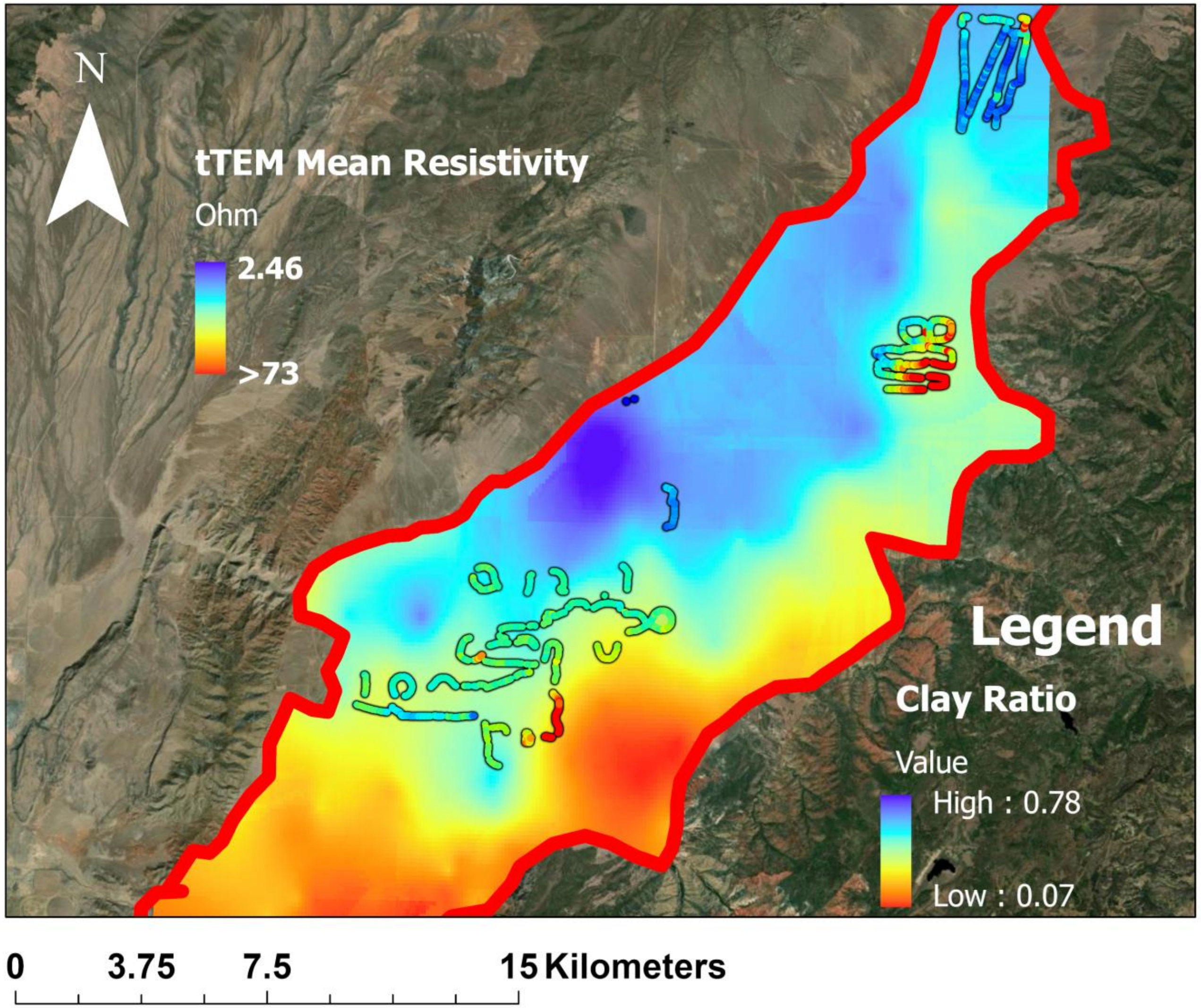
Geophysical survey – thanks so much to the community for helping us do this!

- November 2021
- Conducted with a towed Time-domain ElectroMagnetic system (tTEM)
- Towed behind an ATV at ~8 mph
- Images resistivity from the surface to a depth of ~150 ft
- This can be used to identify aquifers (sands/gravels) and aquitards (clays and other fines) in the subsurface
- Resistivity of common materials
  - Sand: 40-200 ohm m
  - Clay: 5-20 ohm m
  - Freshwater: >6 ohm m
  - Brackish water: 0.6-10 ohm m

It appears that the water conductivity is fairly consistent except for one spot in the north, and one near Little Salt Lake



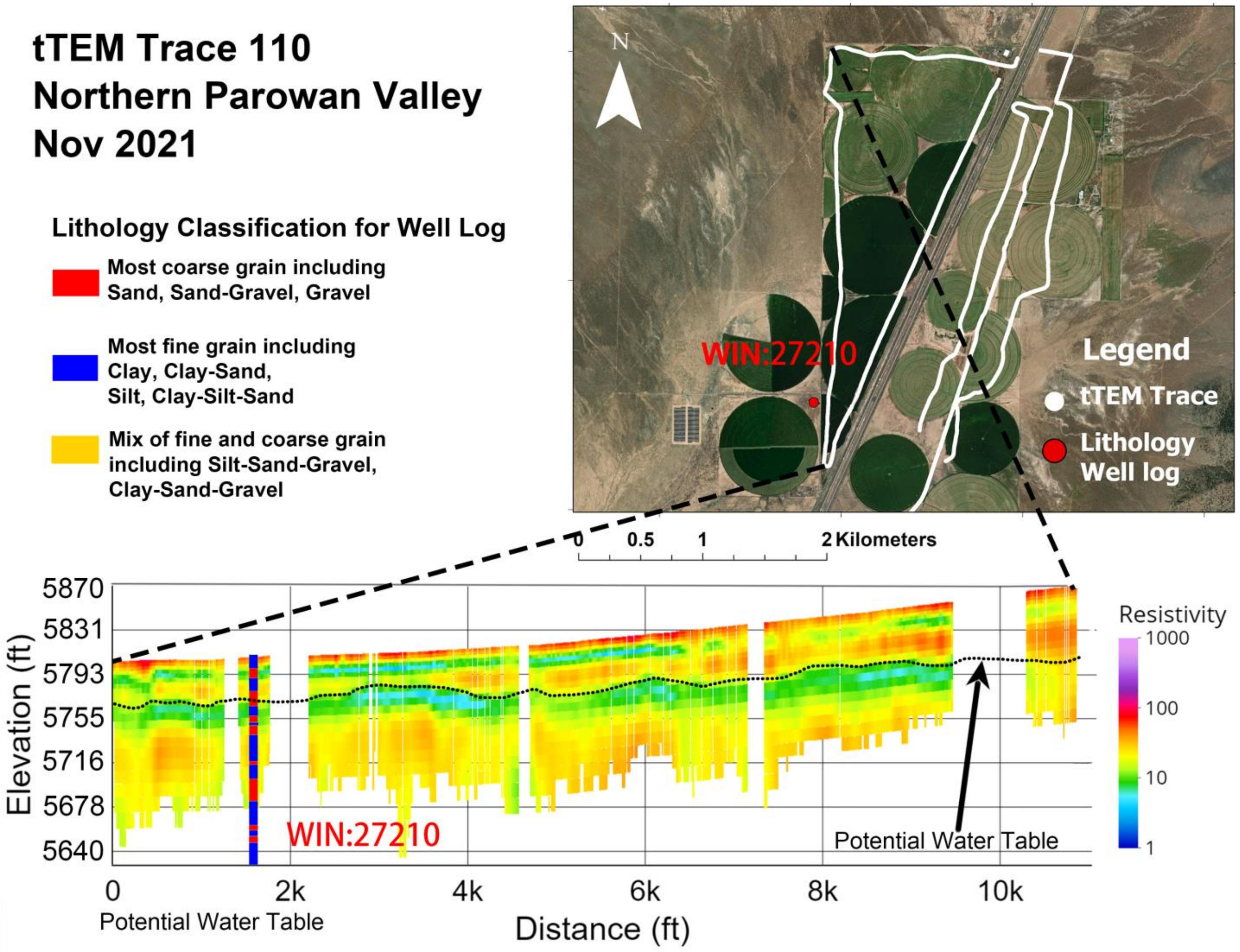
Mean resistivity from tTEM compared with % clay from drillers' logs

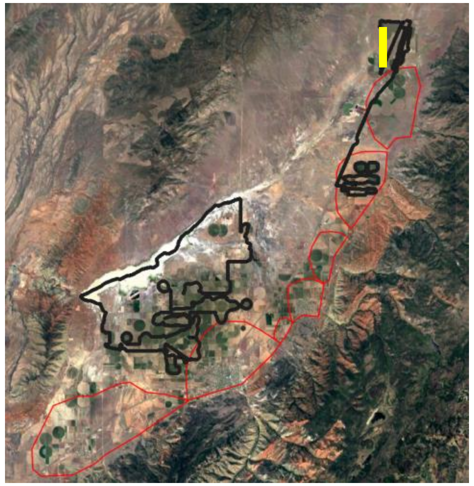


tTEM Trace 110
Northern Parowan Valley
Nov 2021

Lithology Classification for Well Log

- Most coarse grain including Sand, Sand-Gravel, Gravel
- Most fine grain including Clay, Clay-Sand, Silt, Clay-Silt-Sand
- Mix of fine and coarse grain including Silt-Sand-Gravel, Clay-Sand-Gravel

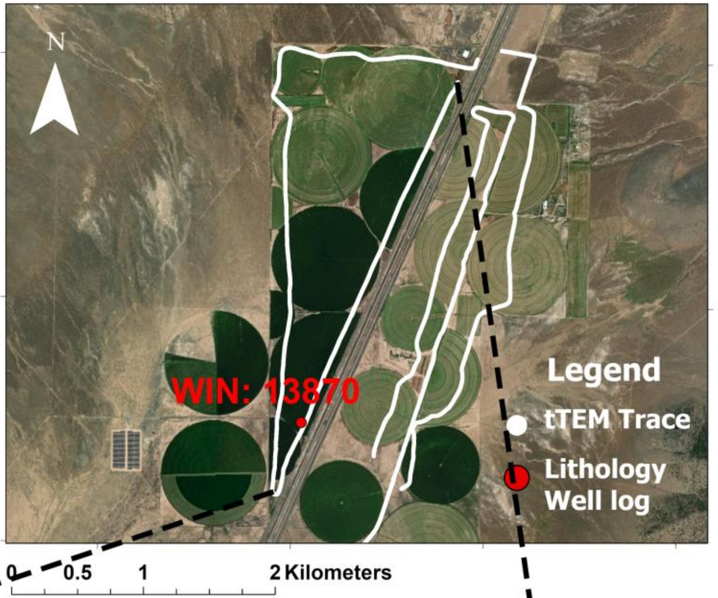


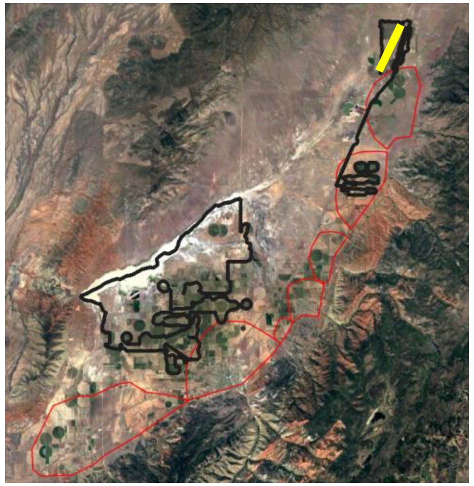


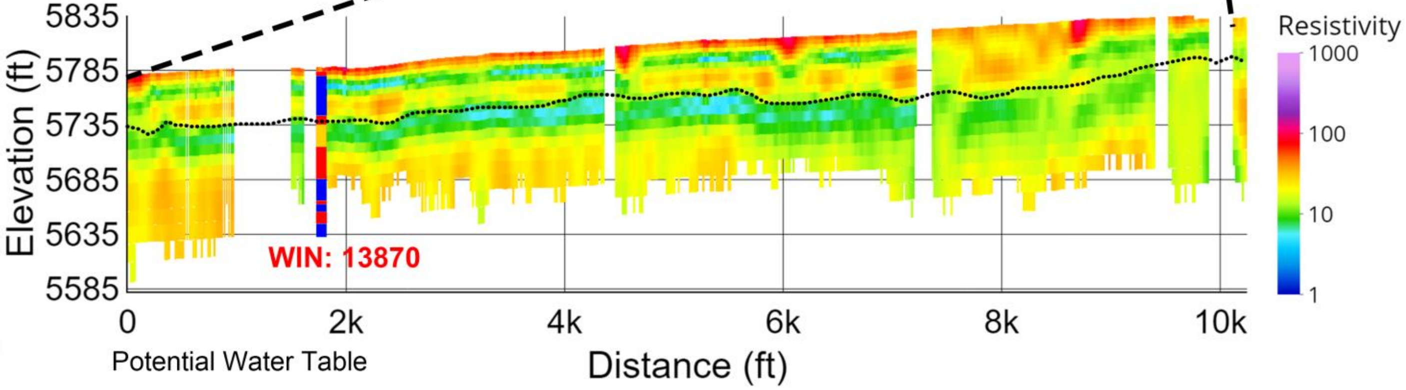
tTEM Trace 100
Northern Parowan Valley
Nov 2021

Lithology Classification for Well Log

- (red) Most coarse grain including Sand, Sand-Gravel, Gravel
- (blue) Most fine grain including Clay, Clay-Sand, Silt, Clay-Silt-Sand
- (yellow) Mix of fine and coarse grain including Silt-Sand-Gravel, Clay-Sand-Gravel



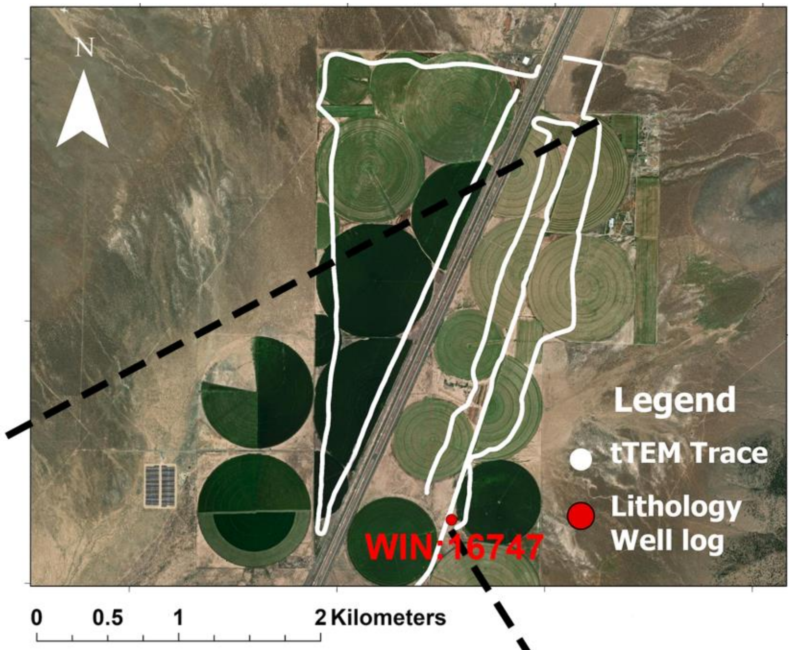


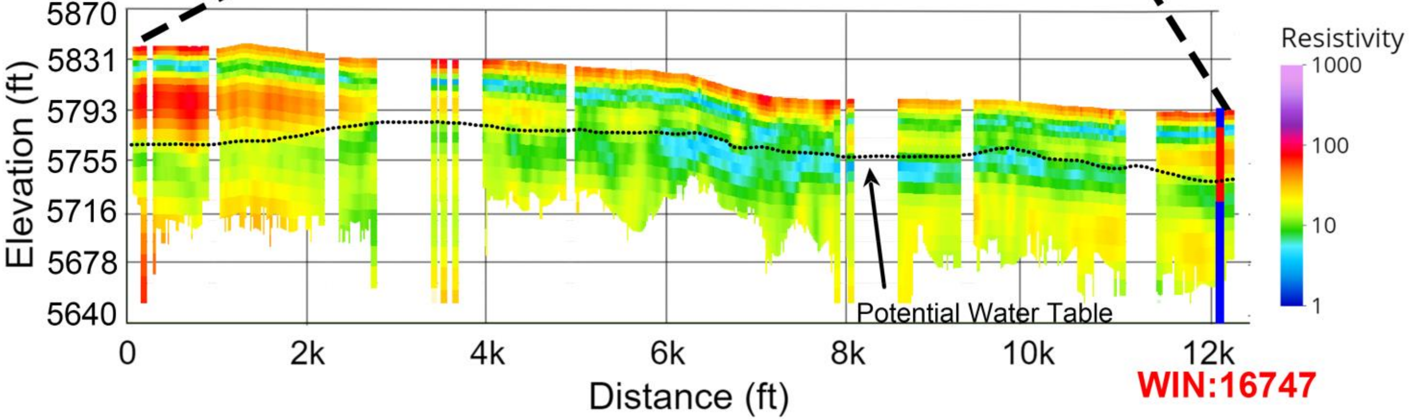


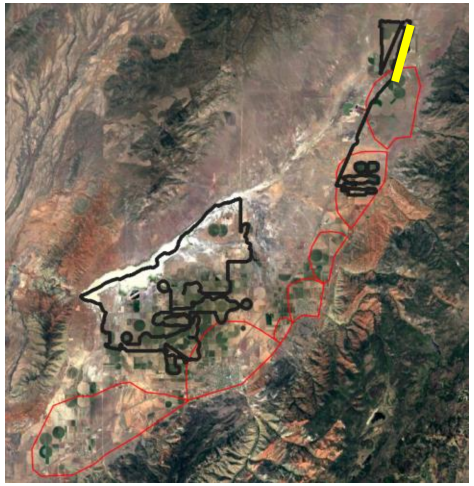
tTEM Trace 120
Northern Parowan Valley
Nov 2021

Lithology Classification for Well Log

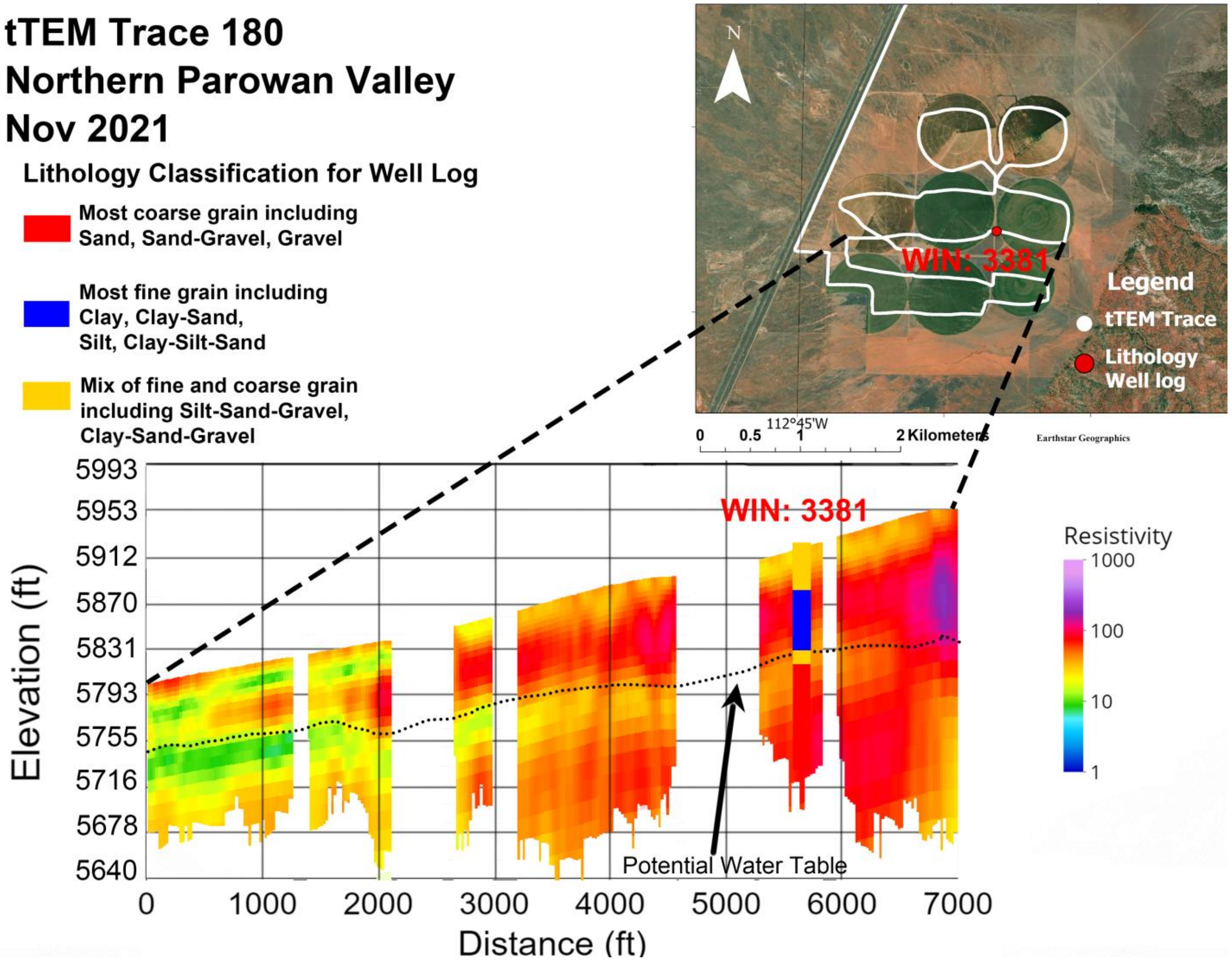
- Most coarse grain including Sand, Sand-Gravel, Gravel
- Most fine grain including Clay, Clay-Sand, Silt, Clay-Silt-Sand
- Mix of fine and coarse grain including Silt-Sand-Gravel, Clay-Sand-Gravel

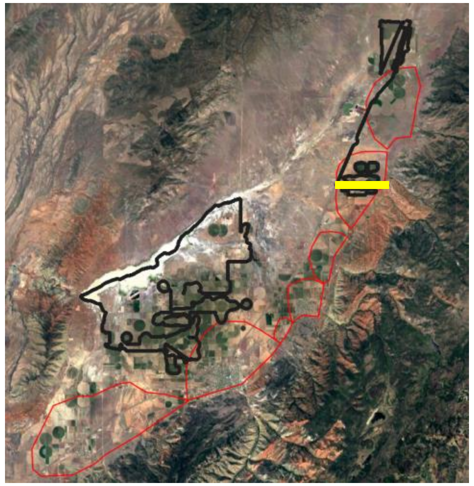






tTEM Trace 180
Northern Parowan Valley
Nov 2021





tTEM Trace 230
Centeral Parowan Valley
Nov 2021

Lithology Classification for Well Log

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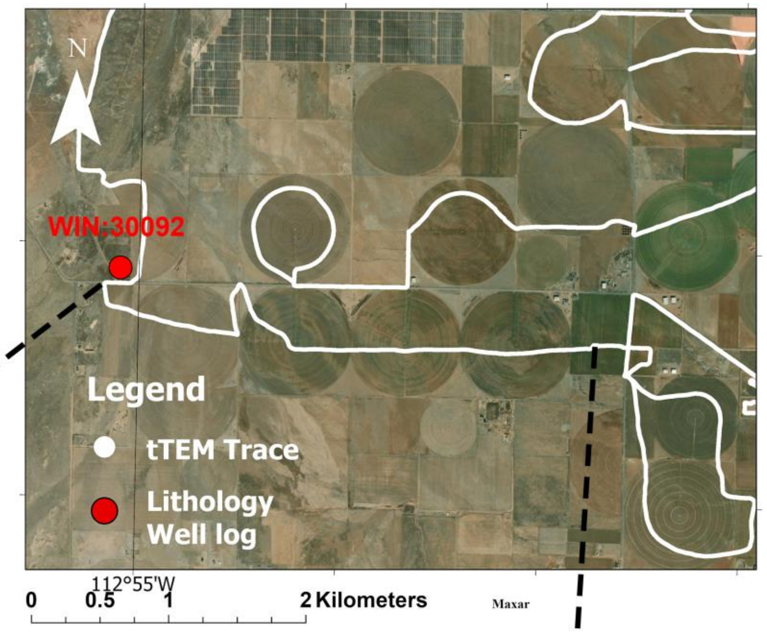
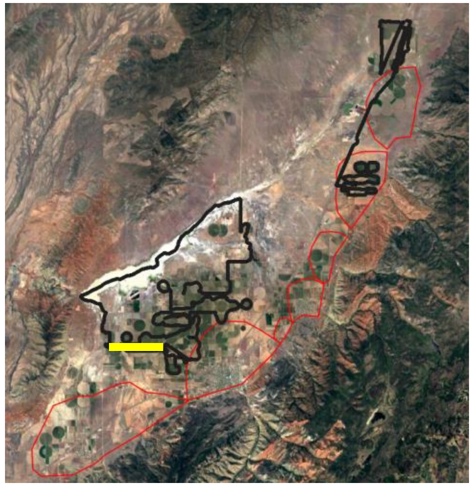
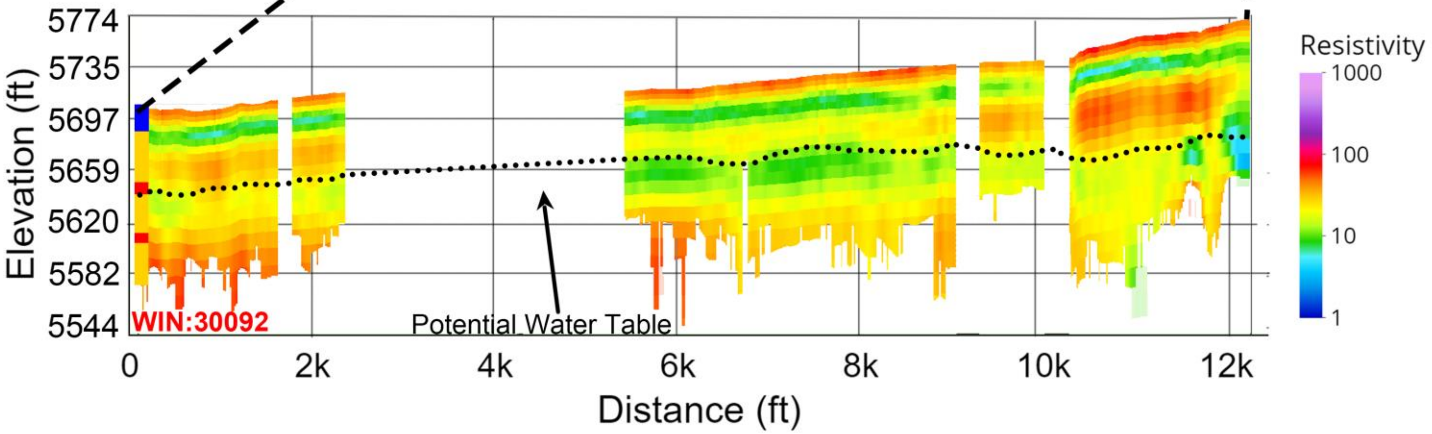
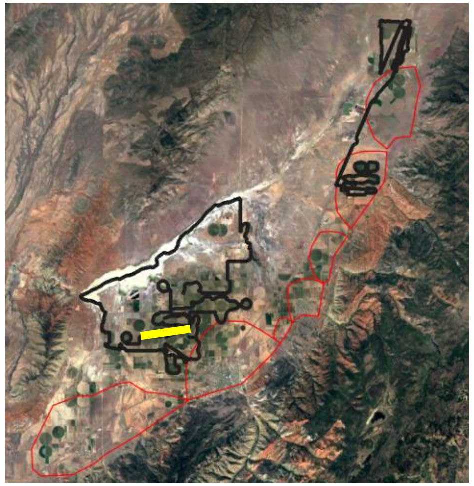
- (yellow) Mix of fine and coarse grain including Silt-Sand-Gravel, Clay-Sand-Gravel









tTEM Trace 300
Centeral Parowan Valley
Nov 2021

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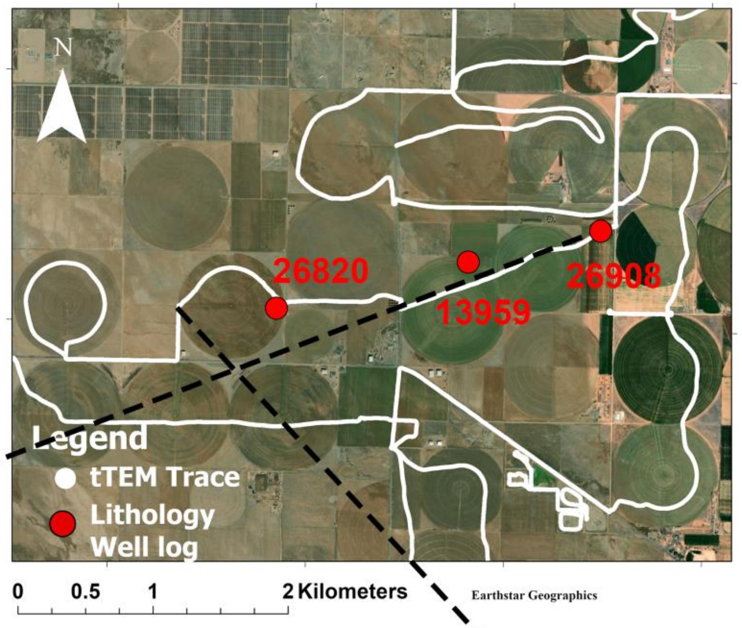

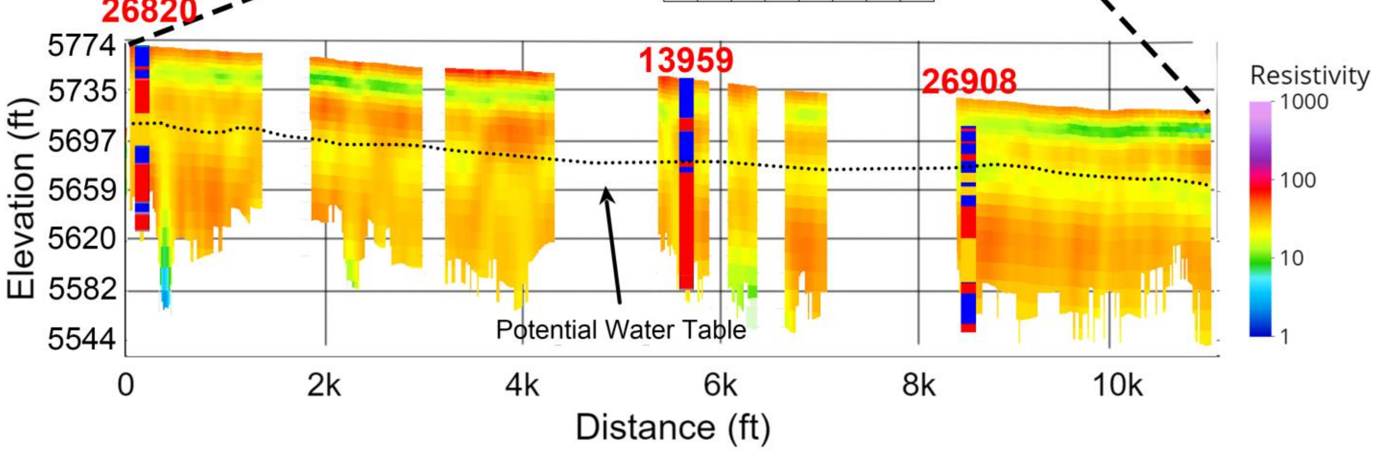

tTEM Trace 270
Centeral Parowan Valley
Nov 2021

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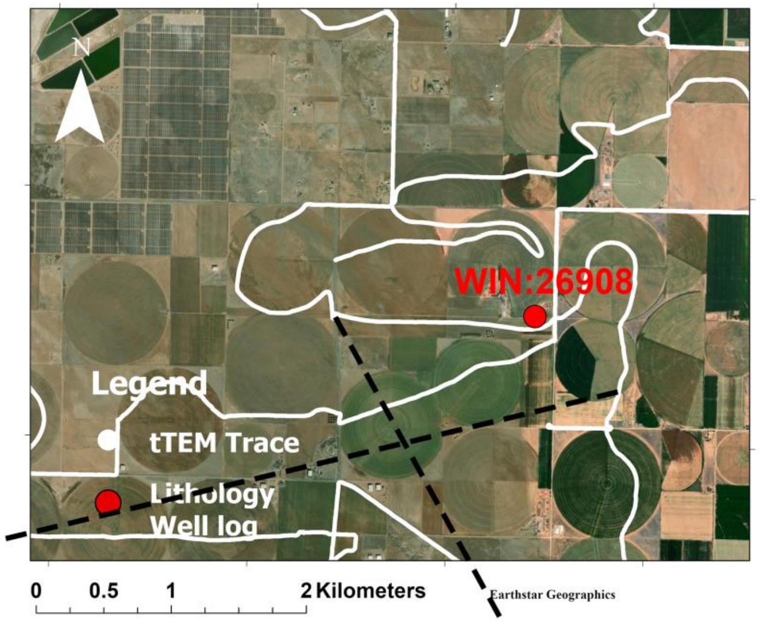

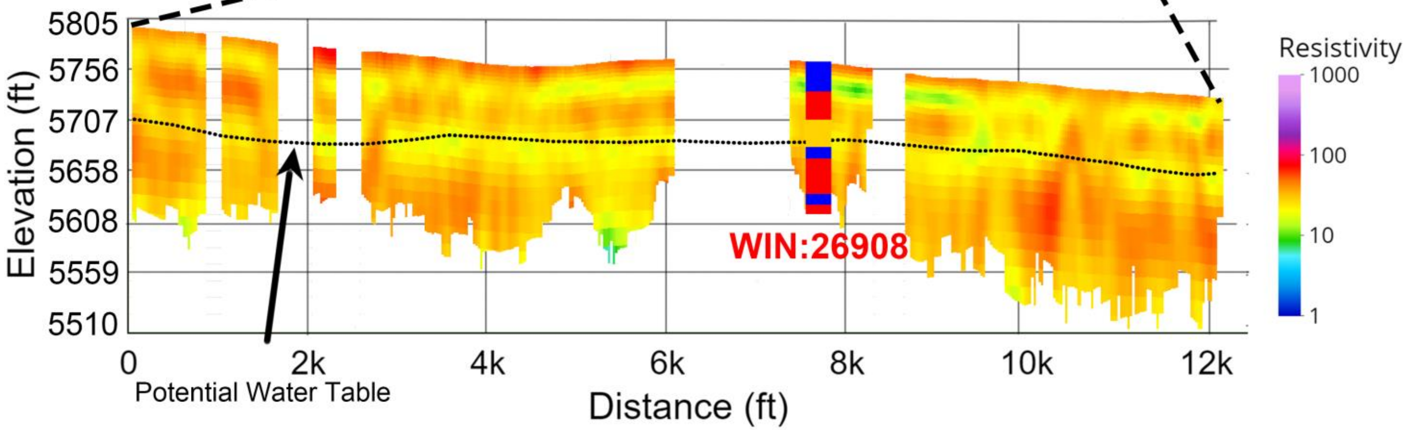

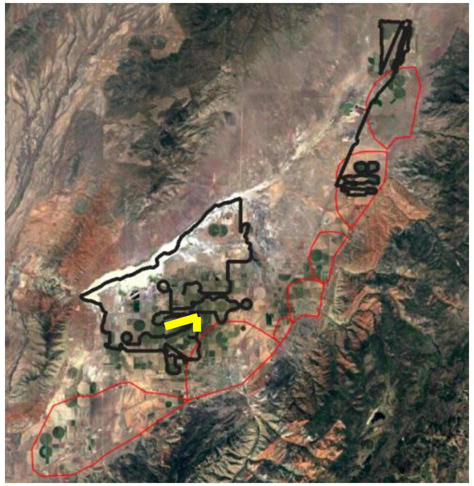

tTEM Trace 290
Centeral Parowan Valley
Nov 2021

Lithology Classification for Well Lo

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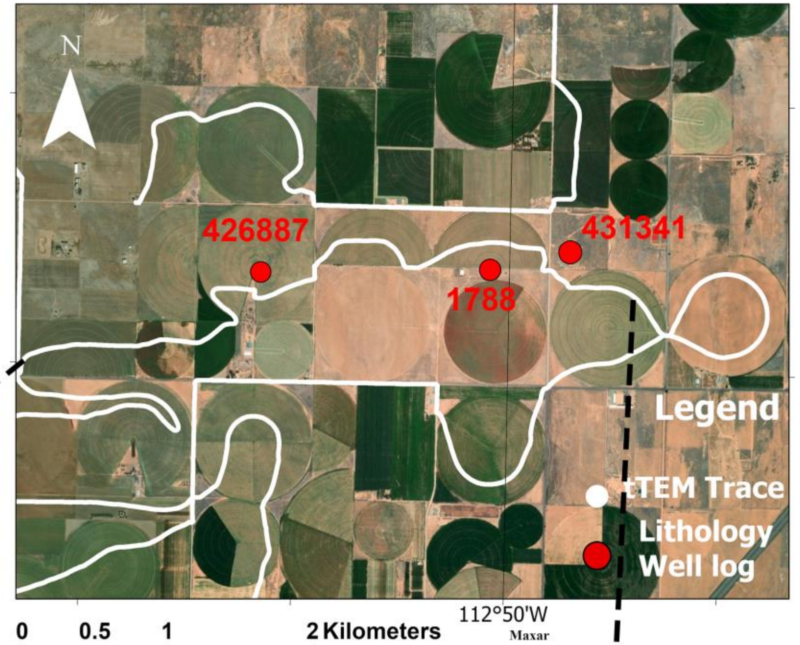

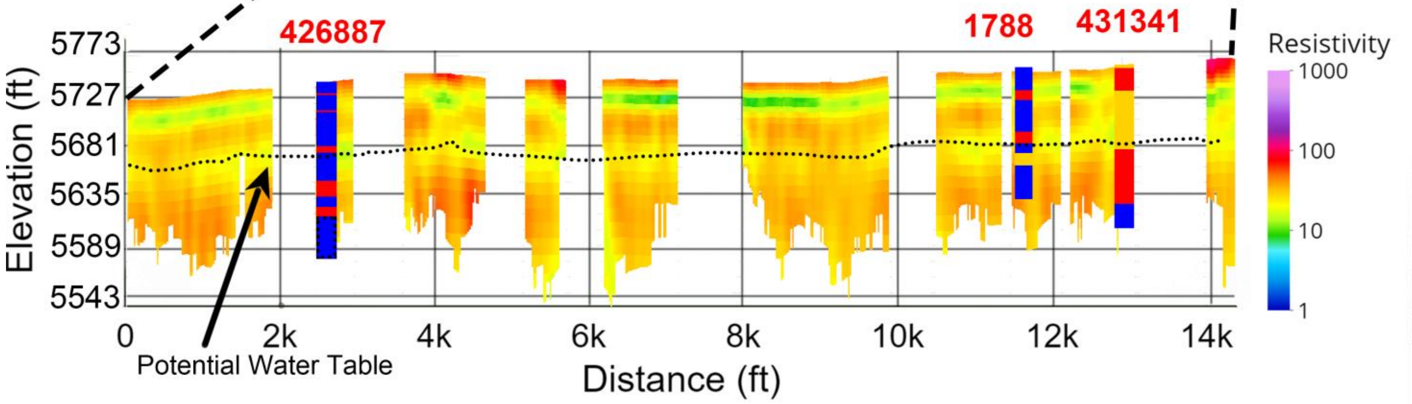

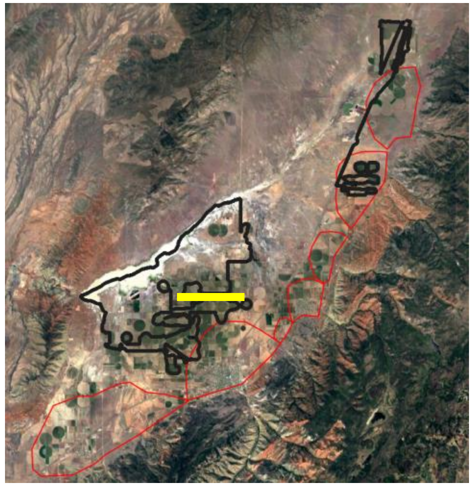

Future tTEM work

- Could be used to identify best locations for managed aquifer recharge
- Could better inform texture (relative amount of sands/clays) of the valley for modeling

Questions?

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www.remote-sensing-hydrology.com