ASSESSMENT OF GLDAS 2.2 FOR ESTIMATING GROUNDWATER STORAGE CHANGE IN SEMI-ARID IRRIGATED BASINS

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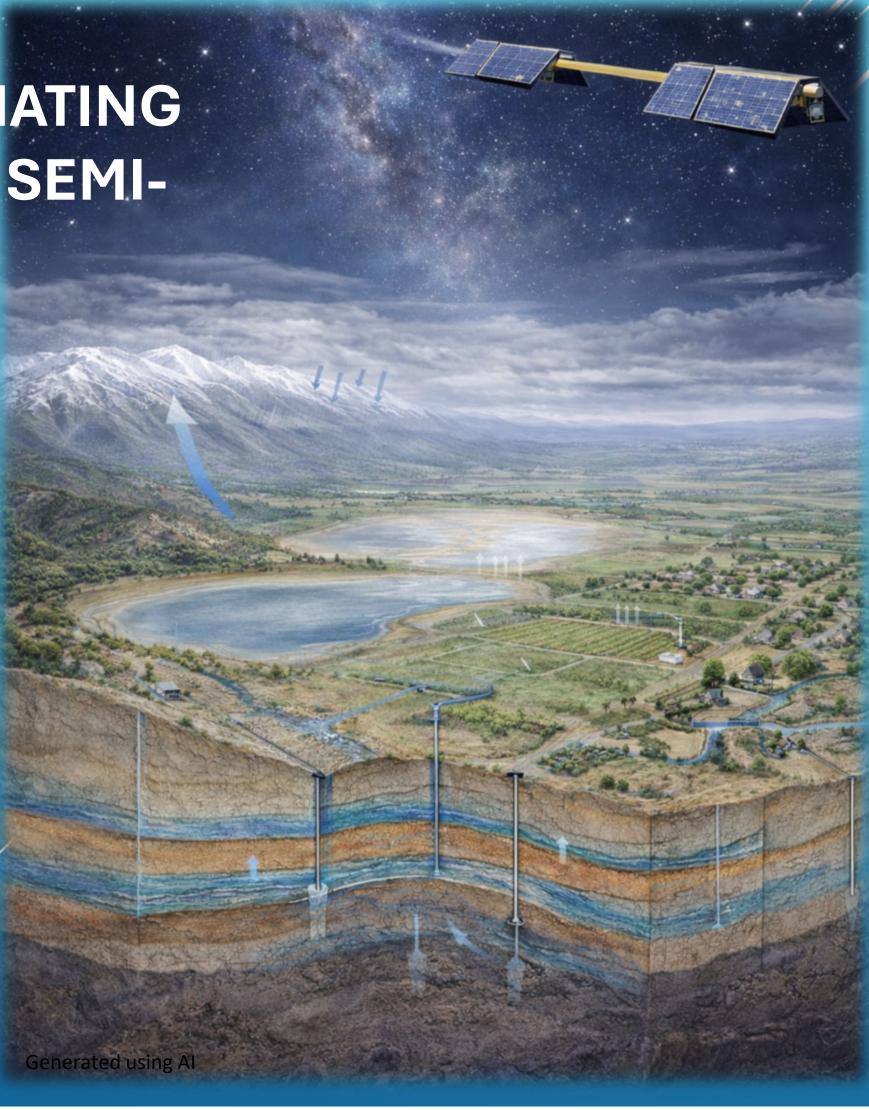
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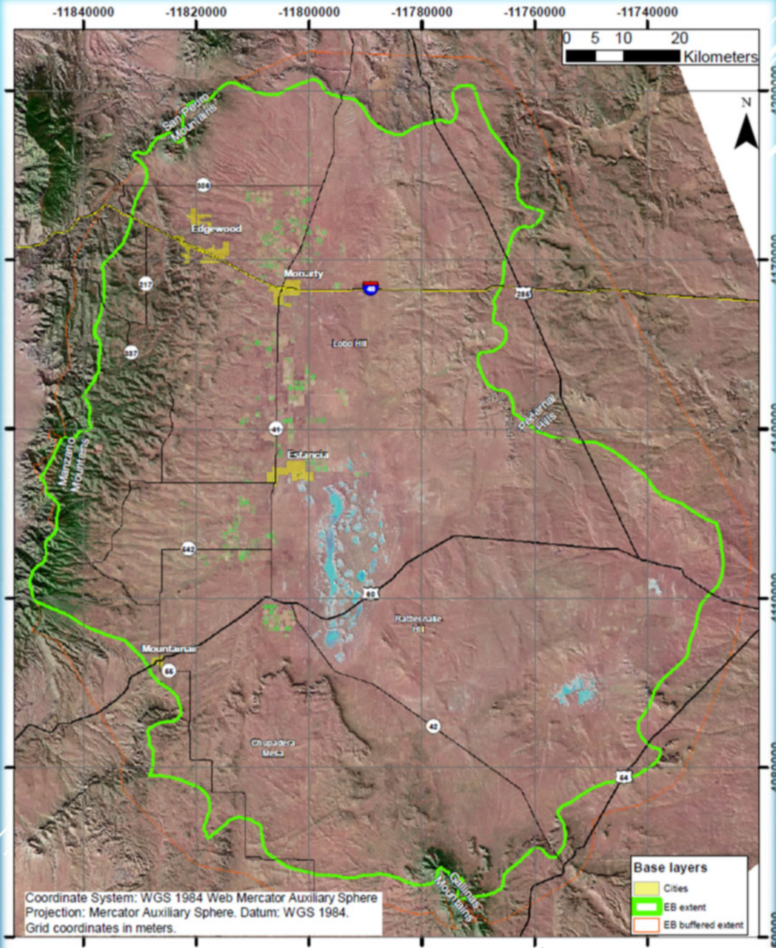
ESTANCIA GROUNDWATER BASIN – CENTRAL NEW MEXICO
~ SEMI-ARID ~ IRRIGATED ~ INTERNALLY DRAINED ~

https://en.wikipedia.org/wiki/User:Matthew.kowal

https://home.nps.gov/sapu/learn/nature/index.htm

Open-file Report - 609, Hydrogeologic Framework of the Estancia Basin, New Mexico, Newton, B. Talon, Cikoski, Colin, and Allen, Bruce, 2020



Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
Projection: Mercator Auxiliary Sphere. Datum: WGS 1984.
Grid coordinates in meters.

Newton, C.T, 2000, OFR– 609 , Hydrogeologic Framework of the Estancia Basin

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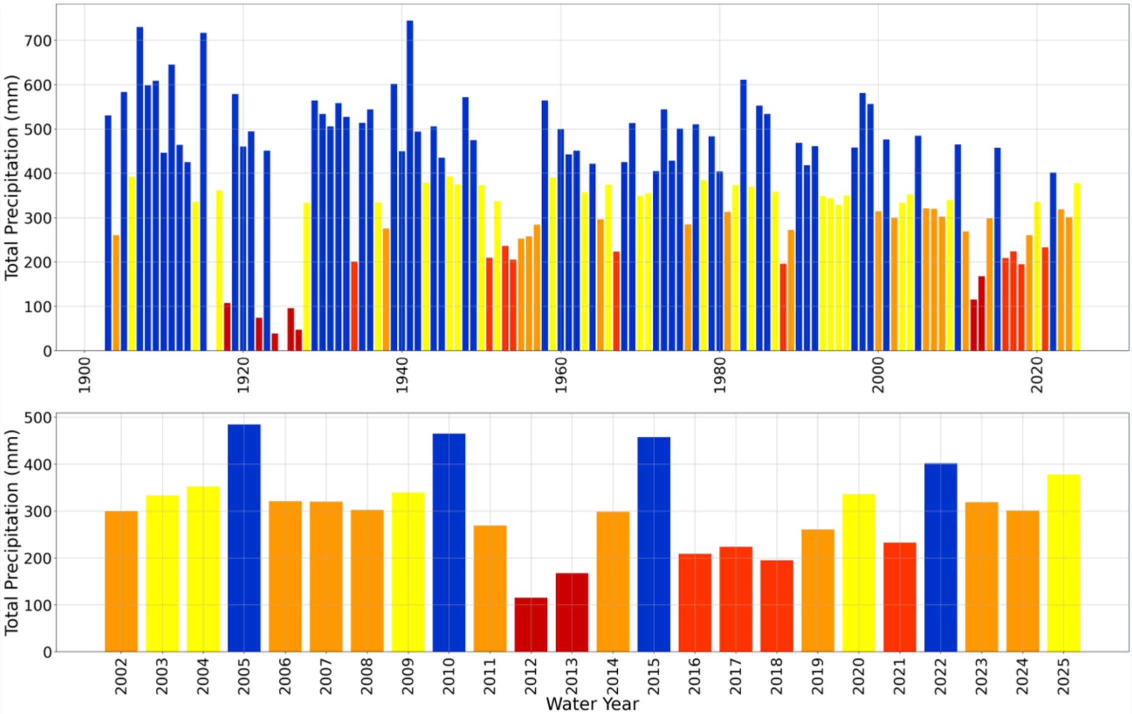
NEW MEXICO AQUIFER MAPPING

GROUNDWATER FLOW, RECHARGE, AND DISCHARGE: CLIMATE DRIVEN PROCESSES

WATER-YEAR PRECIPITATION COLORED BY STANDARDIZED DROUGHT ANOMALY

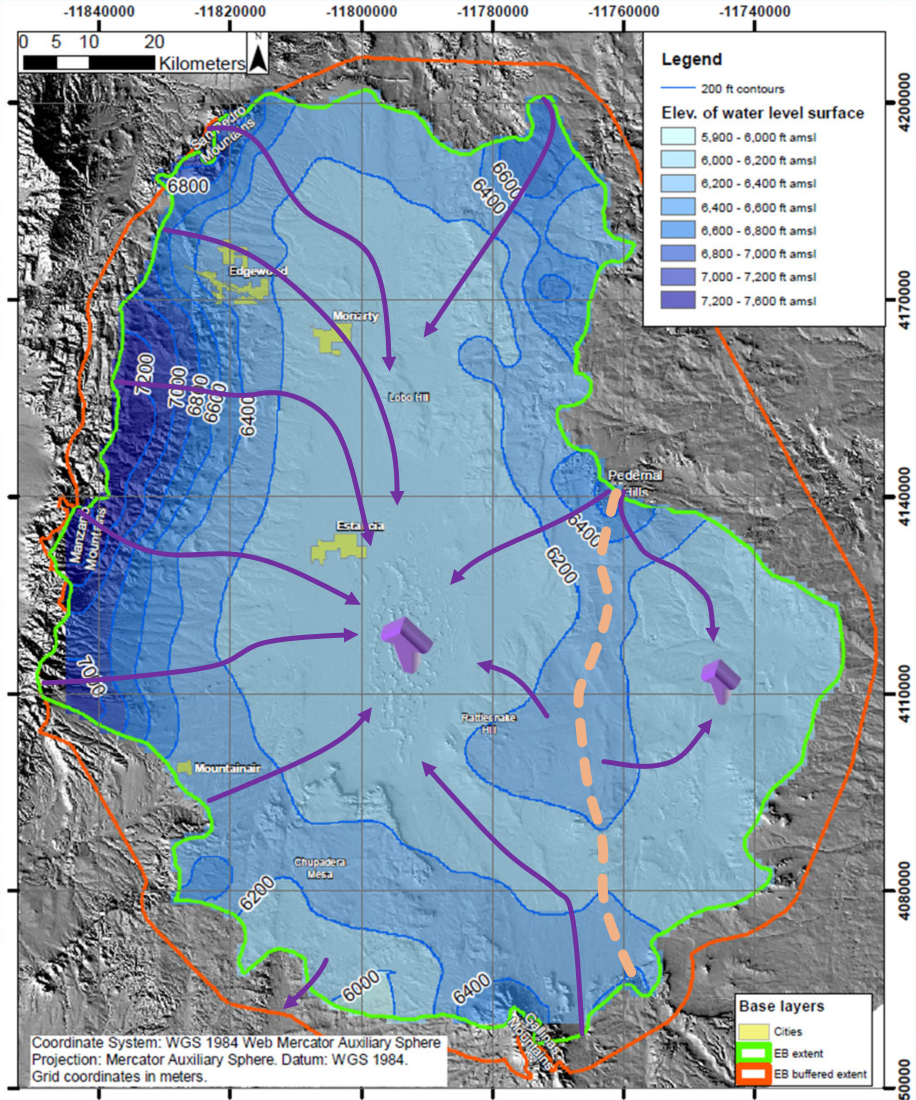


Legend: Standardized Drought Index (SDI)

Color	SDI Range	Interpretation
🟦	SDI > 0.0	Above Average / Wet
🟨	0.0 ≥ SDI > -0.5	Near Normal to Mild Dryness
🟧	-0.5 ≥ SDI > -1.0	Moderate Drought
🟥	-1.0 ≥ SDI > -1.5	Severe Drought
🟥	SDI ≤ -1.5	Extreme Drought

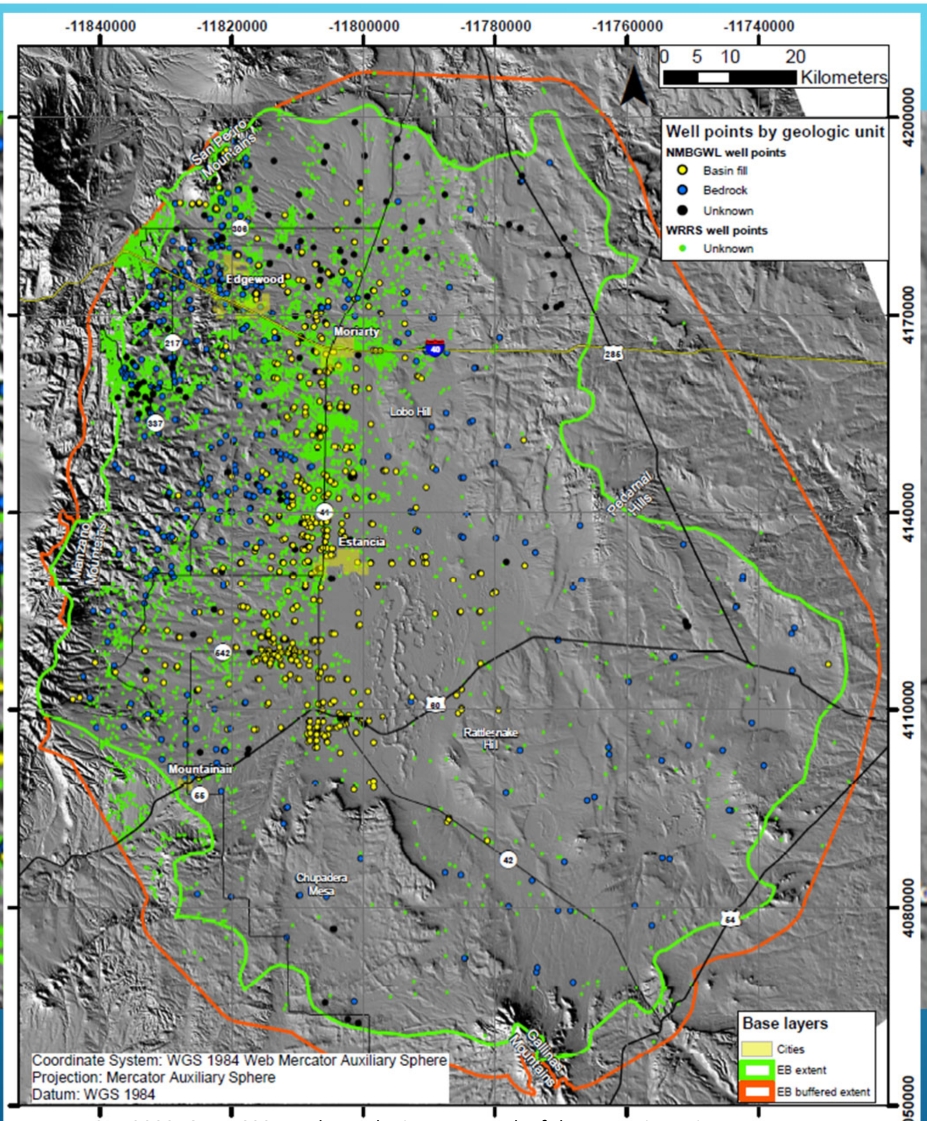
GROUNDWATER POTENTIOMETRIC SURFACE MAP

- -steady-state groundwater flow direction
- -primary, natural, steady-state groundwater discharge
- -Steady-state groundwater divide



Newton, C.T, 2000, OFR– 609 , Hydrogeologic Framework of the Estancia Basin

HYDRO-STRATIGRAPHY AND ANTHROPOGENIC GROUNDWATER DEPLETIONS



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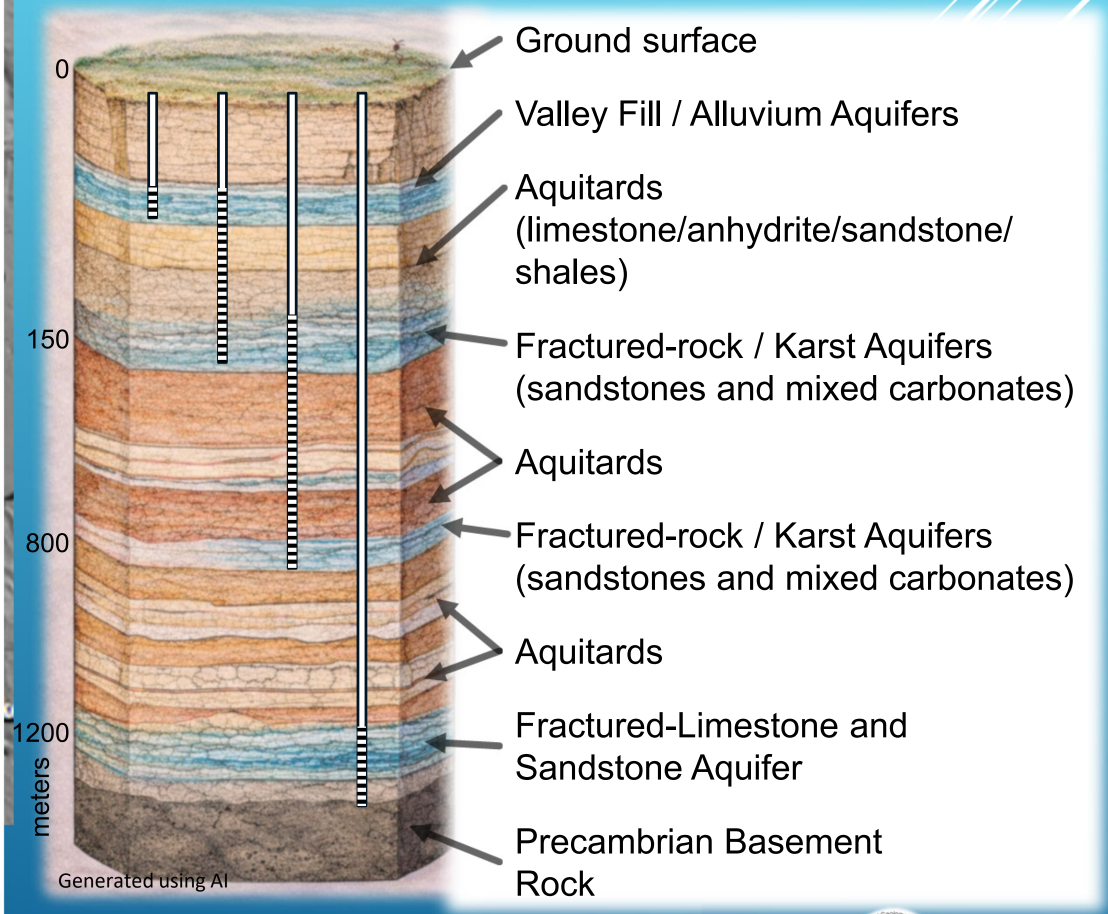


Ground surface

Valley Fill / Alluvium Aquifers

Aquitards (limestone/anhydrite/sandstone/ shales)

Fractured-rock / Karst Aquifers (sandstones and mixed carbonates)

Aquitards

Fractured-rock / Karst Aquifers (sandstones and mixed carbonates)

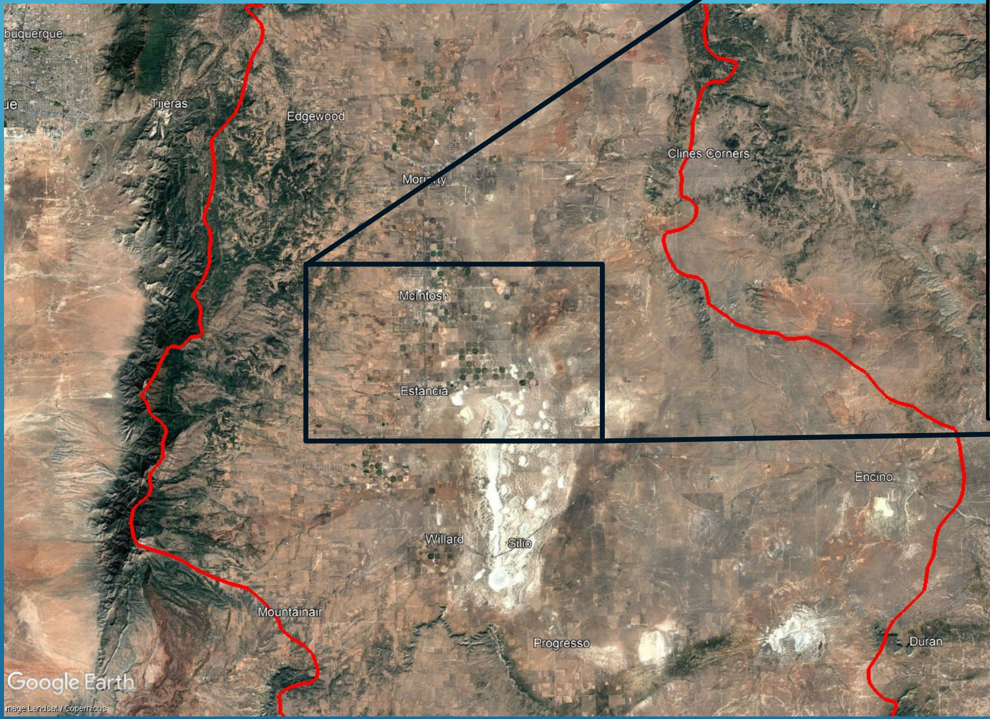
Aquitards

Fractured-Limestone and Sandstone Aquifer

Precambrian Basement Rock

IRRIGATION IN THE ESTANCIA BASIN

- Primary Groundwater Depletion (95%)
- ~ -14 mm Groundwater Storage Change (GWS) per Year since 2022



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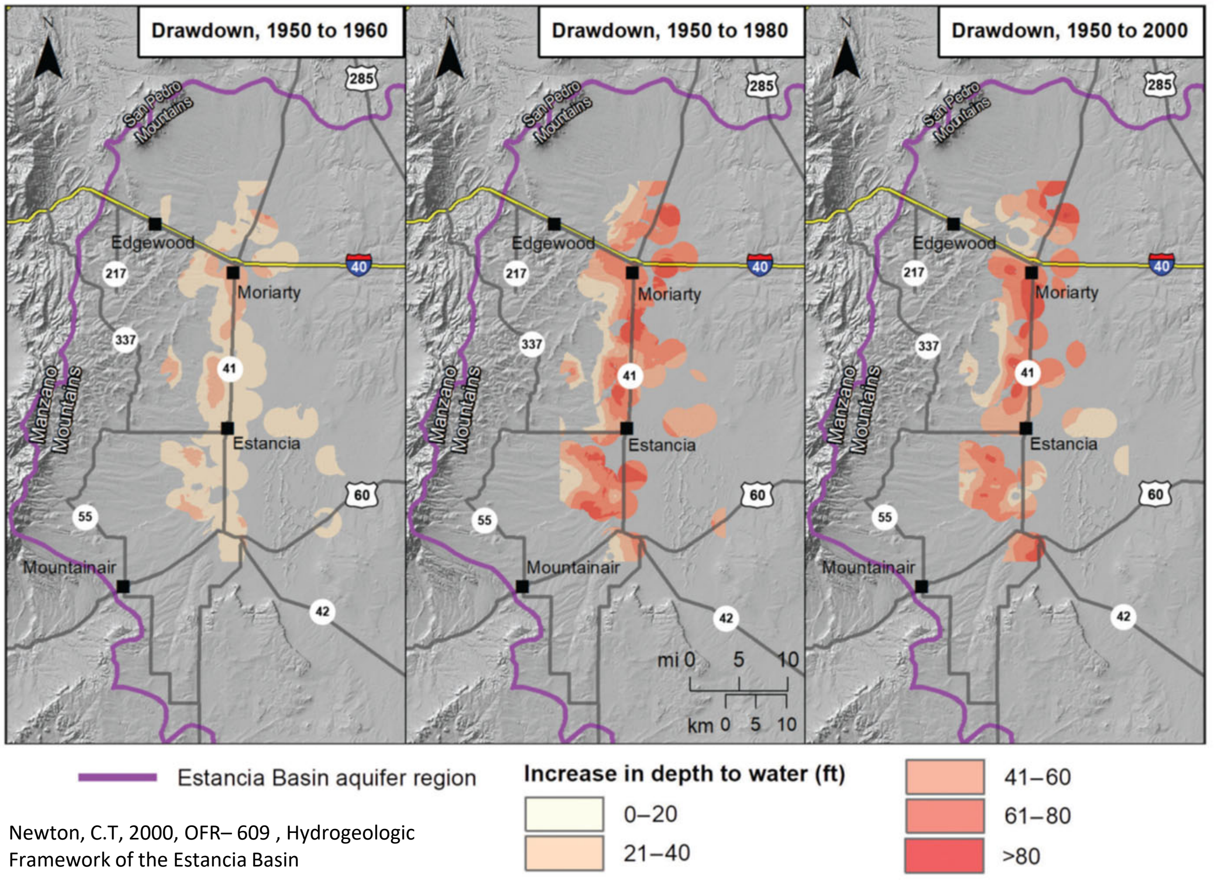
IRRIGATION IN THE ESTANCIA BASIN

~ Groundwater level drawdown in the primary aquifers - 1950 – 2000 ~



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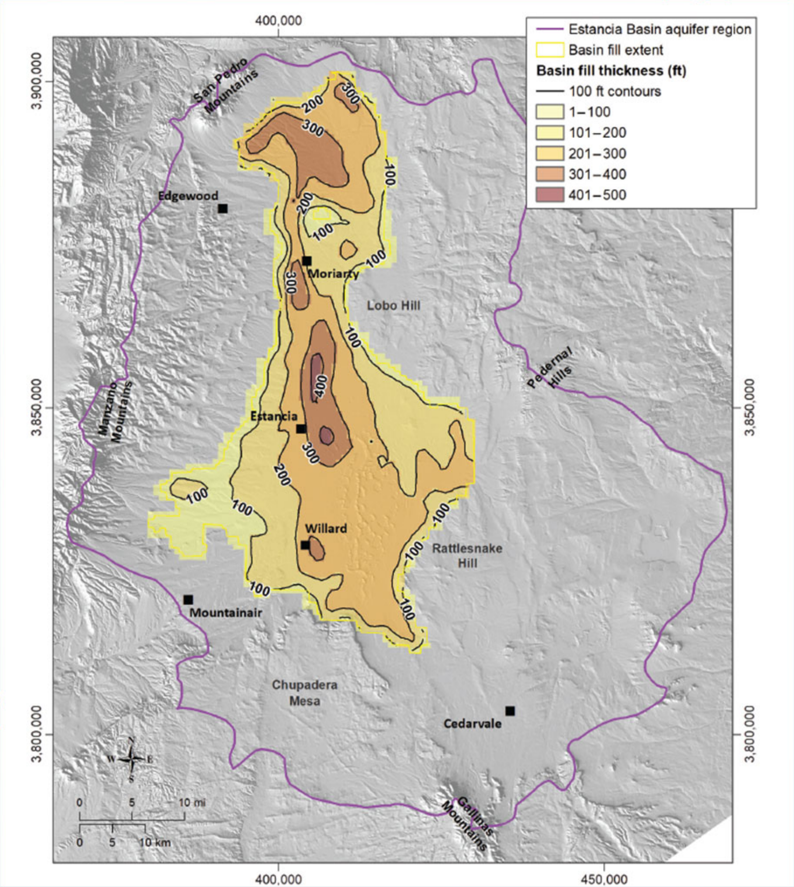

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GROUNDWATER STORAGE MODEL EVALUATION

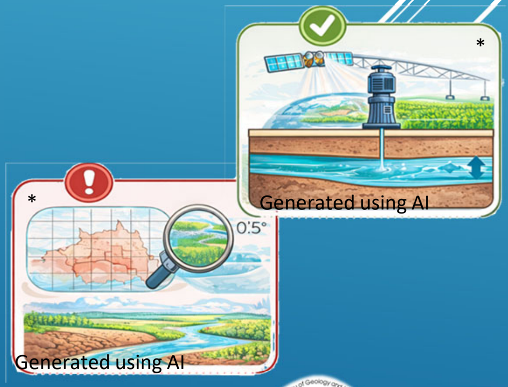
~ GRACE-BASED GROUNDWATER MODELS (WHAT THEY DO WELL / DON'T) ~

LSMs / CLSMs (GLDAS, Noah, CLM, VIC)

- Simulated water balance
- Strengths:
  - capture climate-driven variability
  - Downscaling and parameter specific scaling-factors improve resolution of the GWS estimate
- Limitation: no pumping + weak deep aquifer
- Systematically underestimate

GRACE-derived ΔGWS

- direct observation of total water storage change
- Strength: captures deep aquifer + pumping signal
- Limitation: coarse resolution + depends on model subtraction



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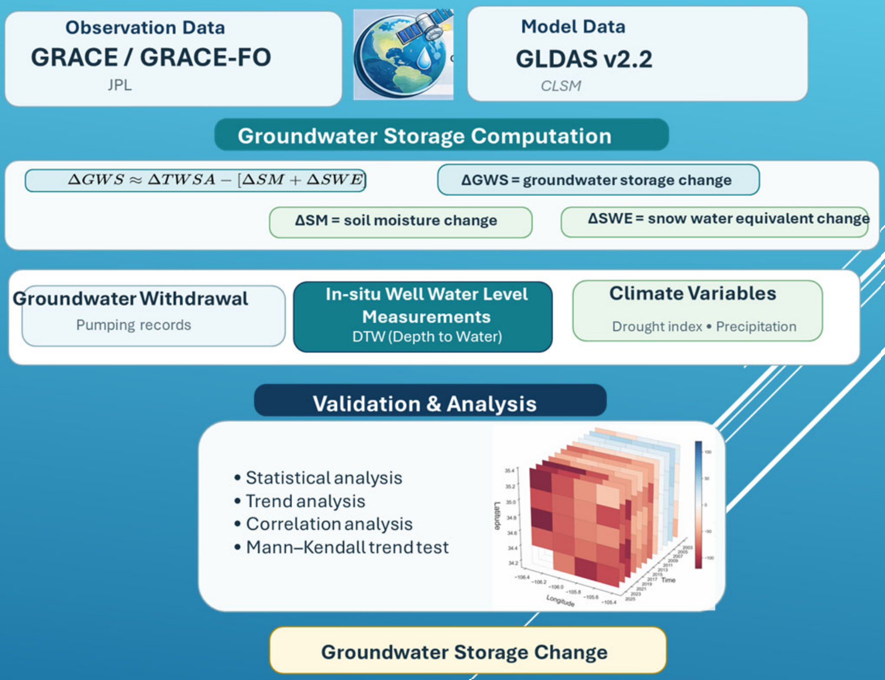
METHODS – DATA AND ANALYTICAL FRAMEWORK

Data Sources:

- *GRACE/GRACE-FO mascon solutions* (JPL): monthly TWS anomalies on 0.5° grid.
- *GLDAS-2.2 CLSM model:* simulated soil moisture, snow, and groundwater.
- *Irrigation withdrawals:* annual consumptive use from state water records.
- *NOAA - National Centers for Environmental Information (NCEI), Global Historical Climatology Network (GHCN), Daily precipitation datasets*
- *Groundwater wells:* water-level records to estimate storage change.

Groundwater Storage Estimation:

- GRACE-based GWS = TWS_anomaly – (GLDAS soil moisture + snow + canopy water).
- GLDAS GWS taken directly from its groundwater layer (derived by subtracting soil moisture from total water storage).
- **Analysis:** Compute monthly anomalies, remove seasonal cycle, fit linear trends (2003–2020) for each dataset.
- **Drivers:** Compare GWS time series to precipitation records and the Palmer Hydrological Drought Index (PHDI). Evaluate correlation with irrigation usage.



Observation Data
GRACE / GRACE-FO
JPL

Model Data
GLDAS v2.2
CLSM

Groundwater Storage Computation

$\Delta GWS \approx \Delta TWSA - [\Delta SM + \Delta SWE]$

ΔGWS = groundwater storage change

ΔSM = soil moisture change

ΔSWE = snow water equivalent change

Groundwater Withdrawal
Pumping records

In-situ Well Water Level Measurements
DTW (Depth to Water)

Climate Variables
Drought index • Precipitation

Validation & Analysis

- Statistical analysis
- Trend analysis
- Correlation analysis
- Mann–Kendall trend test

Groundwater Storage Change

DATA SOURCES – GRACE & GLDAS 2.2 DATASETS

GRACE/GRACE-FO Over New Mexico:

- Nominal resolution:~300–400 km
- Effective resolvable area: ~150,000–300,000 km²
- Independent signals across NM: ~3

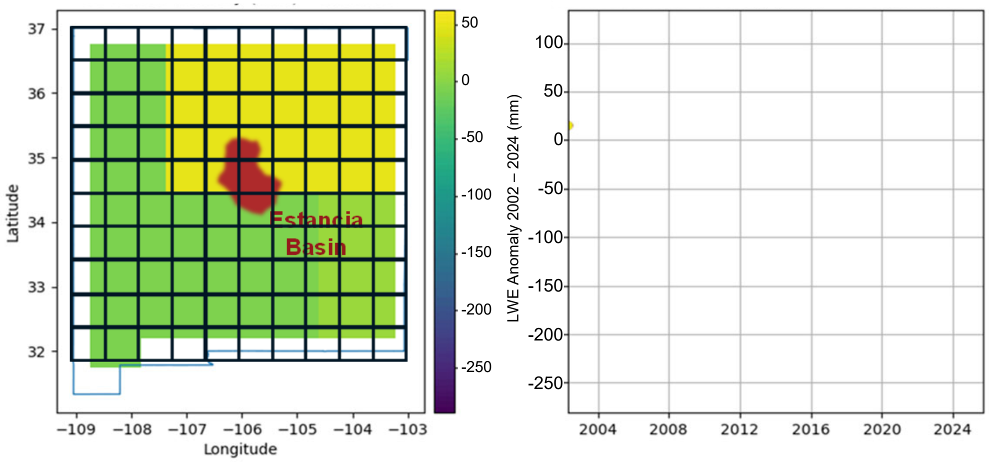
GRACE/GRACE-FO mascon solutions (JPL):

- Monthly TWS anomalies on 0.5° grid (shown)
- Resampled (no added interpolation or transformation)

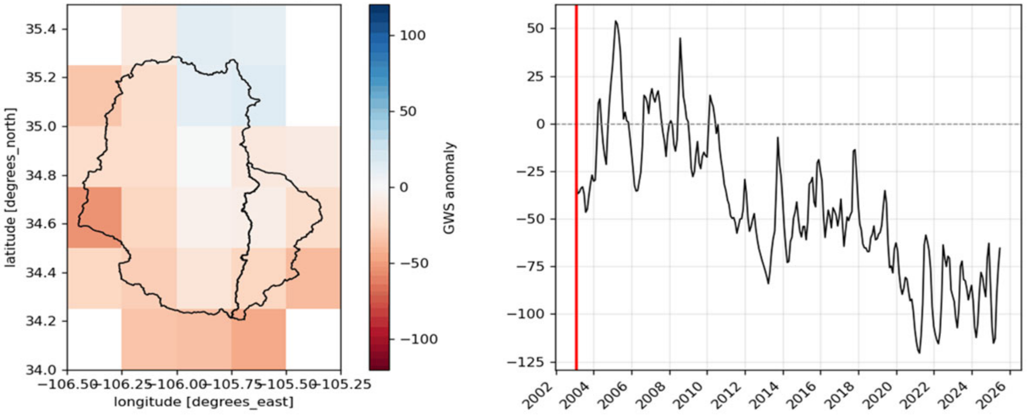
GLDAS 2.2 GWS Over Estancia Basin

- Nominal resolution:~20–30 km
- Effective resolvable area: ~600–650 km²
- Independent signals across EB: ~16
- Downscaling based in other model inputs provides greater resolution.

NM LWE GRACE Anomaly 2002 - 2024



GLDAS 2.2 GWS Anomaly (2004 – 2009 Baseline)



DATA SOURCES: TOTAL PRECIPITATION DATA

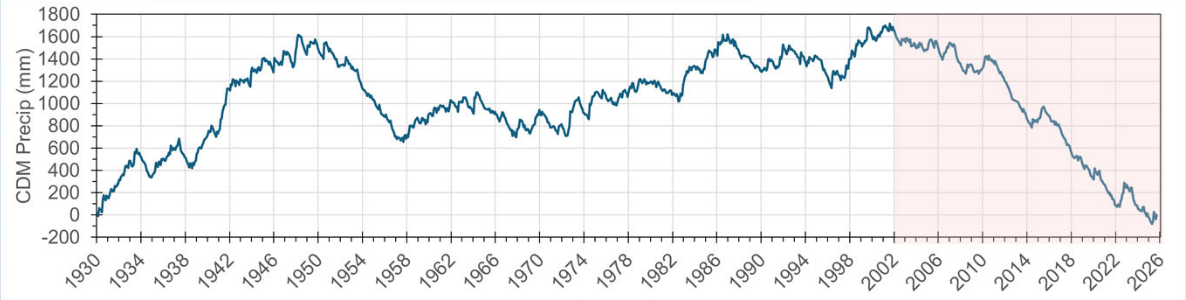
GHCN Dataset Summary

Station coverage (composite basin series):

- Basin precipitation is derived from a multi-station GHCN network
- Station participation varies:
  - variable start - stops
  - record gaps

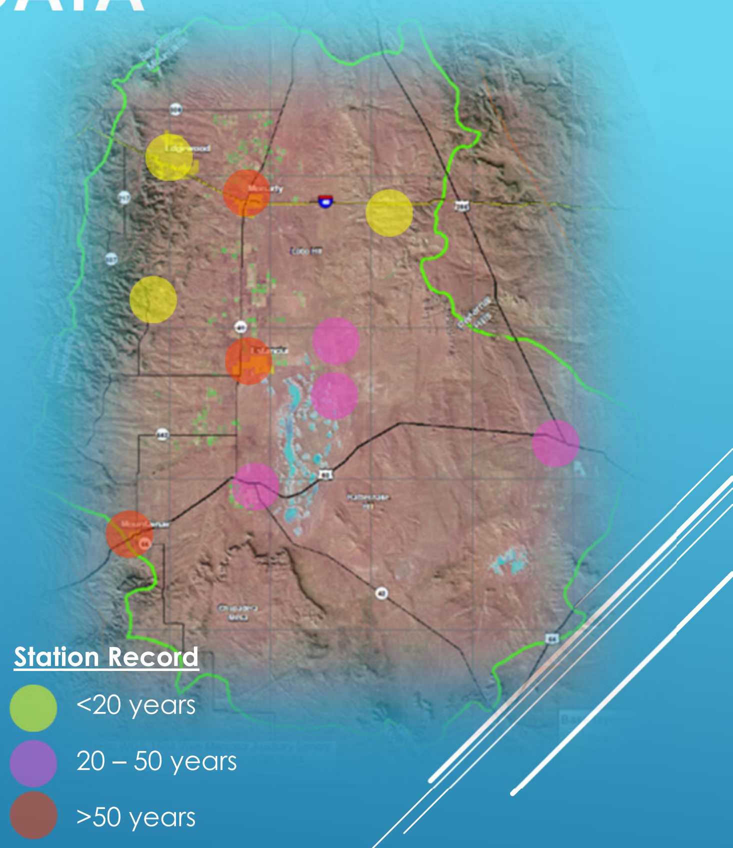
Period of record:

- Data extend from early 20th century (~1900) through present (~2025)
- Basin-average series reflects merged, gap-managed records.



Data characteristics for comparative analysis:

- Water-year totals and long-term monthly totals and means
- Suitable for CDM (cumulative departure from mean) and anomaly analysis
- Provides climate forcing context for GRACE ΔTWS and GLDAS comparisons, capturing multi-decadal drought/wet cycles relevant to groundwater storage trends



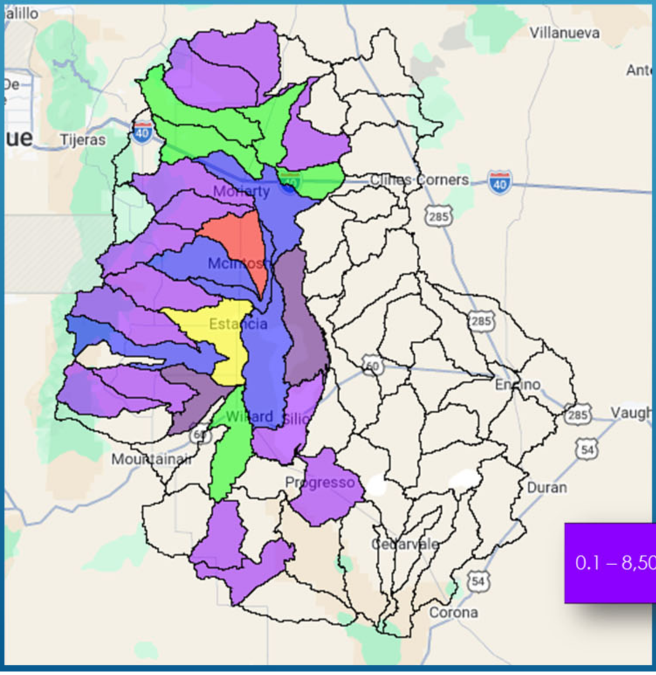
Station Record

- 🟢 <20 years
- 🟣 20 – 50 years
- 🟤 >50 years

NOAA - National Centers for Environmental Information (NCEI), Global Historical Climatology Network (GHCN), Weather Station Locations

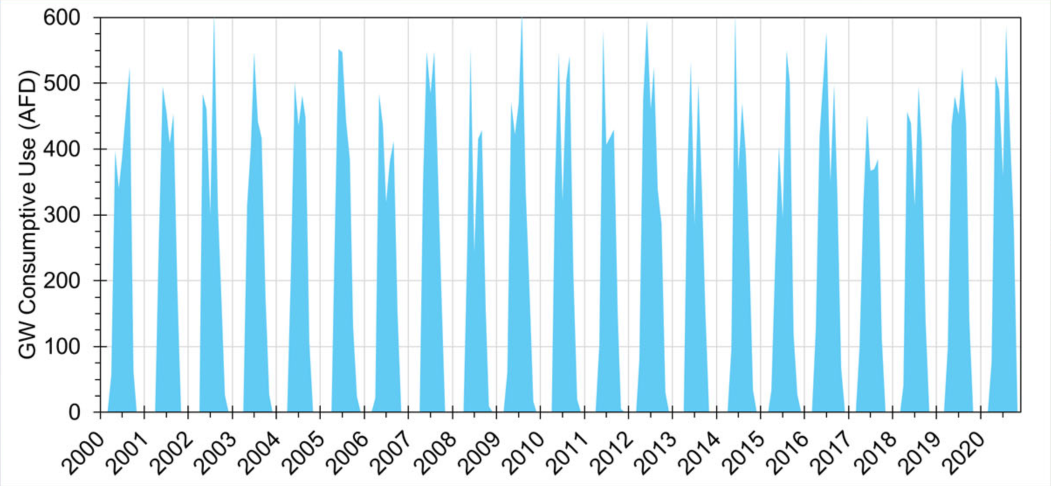
DATA SOURCES: IRRIGATION – CONSUMPTIVE USE ESTIMATES

- USGS Crop Irrigation Consumptive Water-Use Model
  - Satellite ET (30 m → HRU): SSEBop/OpenET ETa over LANID irrigated lands aggregated to NHM HRUs as ET target
  - Inverse irrigation (NHM): Iteratively solves applied water to match ETa via soil-moisture balance
  - CU partitioning (HUC12): Splits ETa into irrigation vs. precipitation → consumptive use, mapped to HUC12
- Irrigation use: High consumptive use (~30–50 million m³/yr) drives groundwater withdrawal.
- Water withdrawals show seasonal peaks (summer irrigation) of depletion, beyond climate alone.



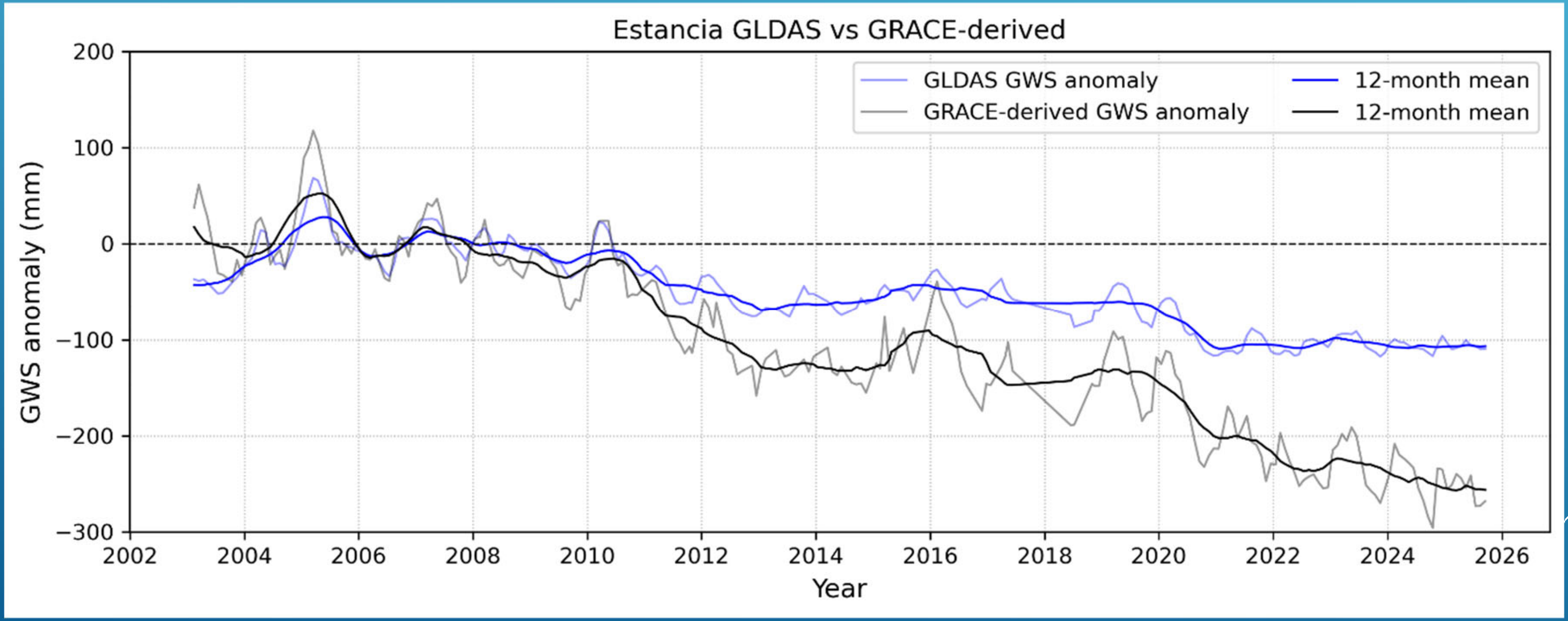
0.1 – 8,500	8,500 – 17,000	17,000 – 25,500	25,500 – 34,000	34,000 – 42,500	42,500 – 51,500	51,500 – 60,000+

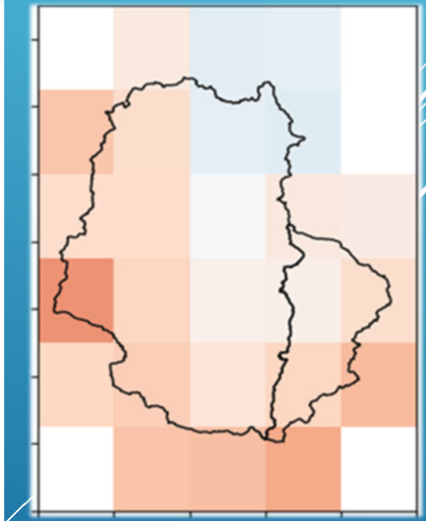
TOTAL GROUNDWATER DEPLETION SINCE 2000 (ACRE-FT)



RESULTS – LONG-TERM GROUNDWATER TRENDS

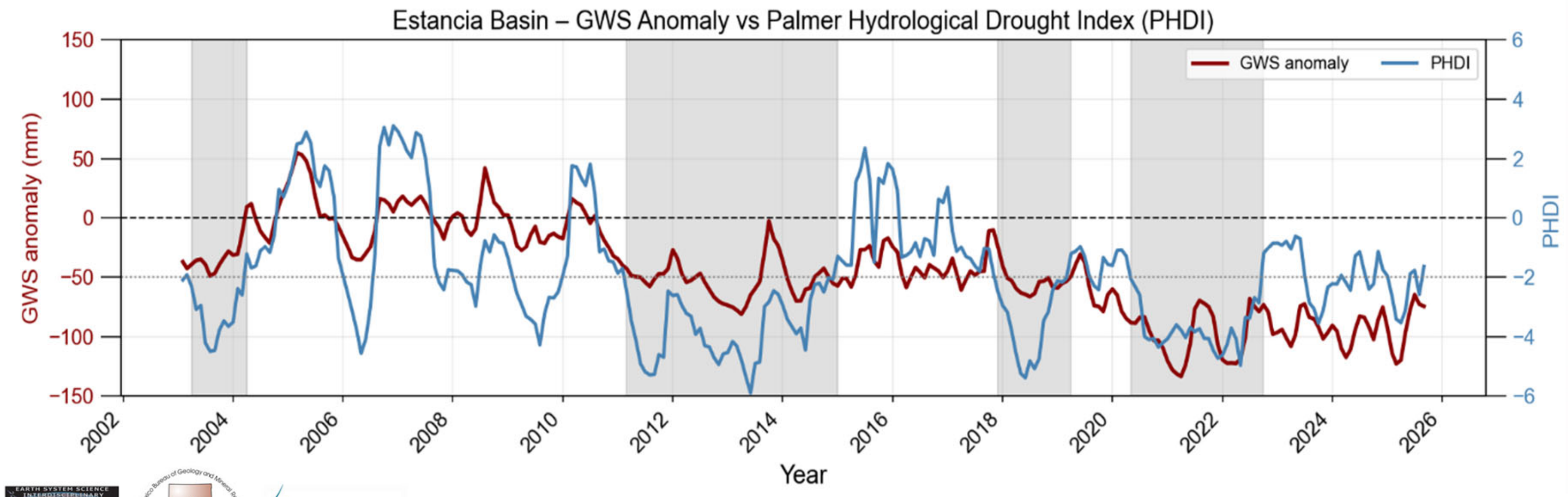
- GRACE-derived and GLDAS2.2 both show declining groundwater storage from 2003–2025.
- GRACE-derived CLSM trend: ~–12.4 mm/yr vs. GLDAS trend: –4.4 mm/yr.
- GRACE's decline is ~3× larger, indicating depletion from pumping.
- GLDAS captures seasonal variability but underestimates magnitude of long-term decline.
- Implication: Water-level declines (from wells) are consistent with the higher GRACE-derived depletion.

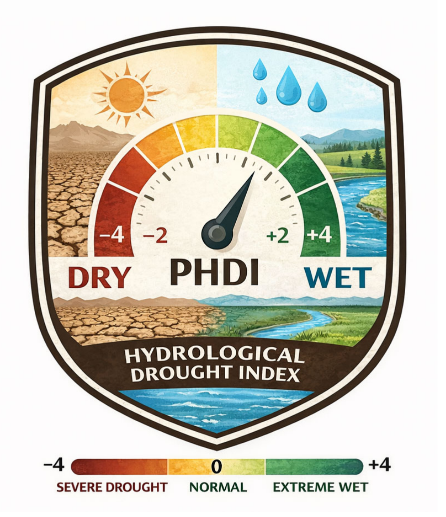




RESULTS – SEASONAL VARIABILITY & CLIMATE DRIVERS

- GWS shows clear seasonal cycles: recharge in wet seasons, drawdown in dry seasons.
- Monthly storage peaks align with precipitation and mountain snowmelt; troughs align with dry summer/fall.
- PHDI correlation: The Palmer Hydrological Drought Index (drier = higher PHDI) closely matches GLDAS GWS anomalies.
- Wet years (e.g. 2008) saw storage rebounds; drought years (2011–2016) saw steeper losses.
- Conclusion: Climate variability strongly modulates intra-annual GWS changes, though long-term trend remains downward.





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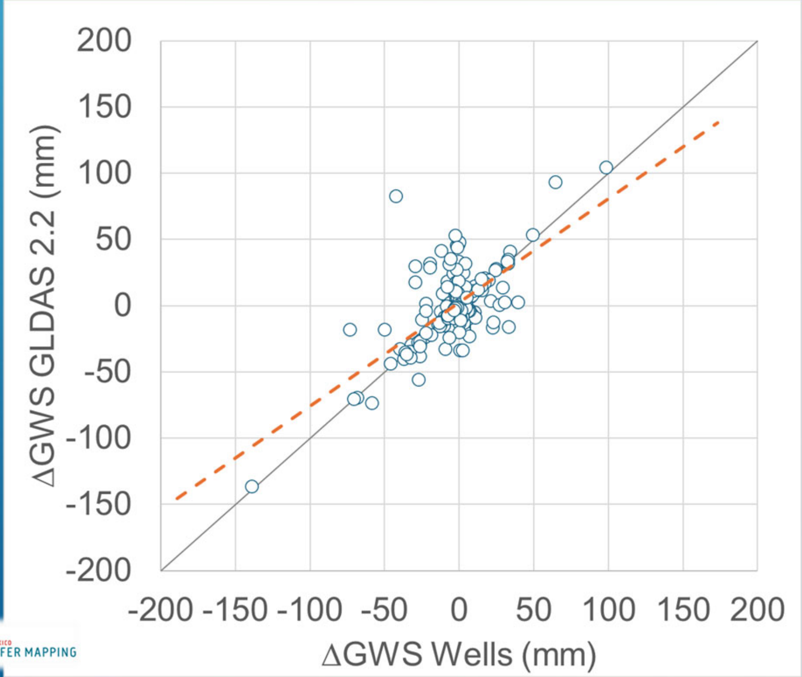
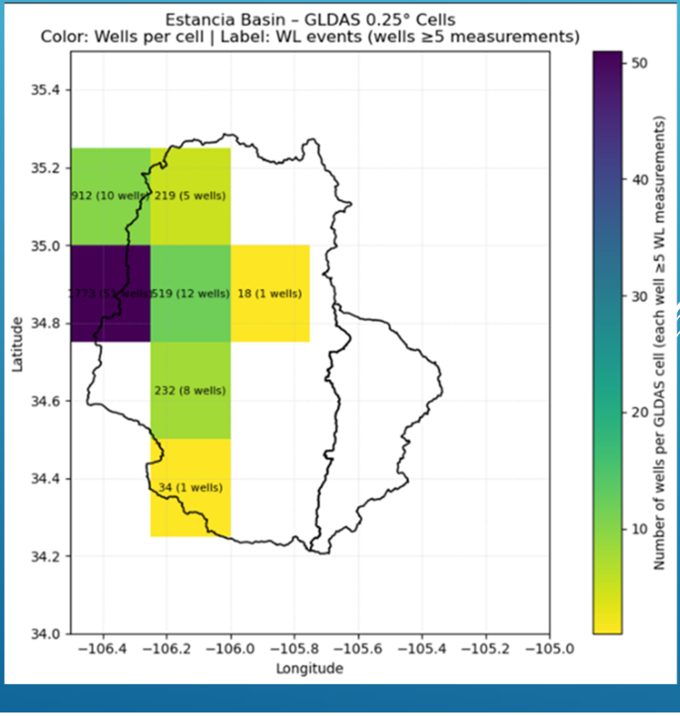
RESULTS – WELL OBSERVATIONS COMPARISON

- Water-level records from **88 wells** were converted to storage change and aggregated.
- Well-based GWS trend also shows long-term decline (consistent with GLDAS 2.2 DGWS) but with local variability.
- Monthly well-derived storage change (bars) vs. GLDAS 2.2 DGWS-based trend line.
- Positive correlation: years of high well depletion correspond to more negative GLDAS 2.2 DGWS anomalies.
- Differences are expected due to scale (wells are point measurements; GLDAS 2.2 DGWS averages large areas).





COMPARING GWS ANALYSIS AND OBSERVATIONS

Persistent decline: GRACE (~−288 mm) >> GLDAS (~−90 mm) → GLDAS underestimates depletion

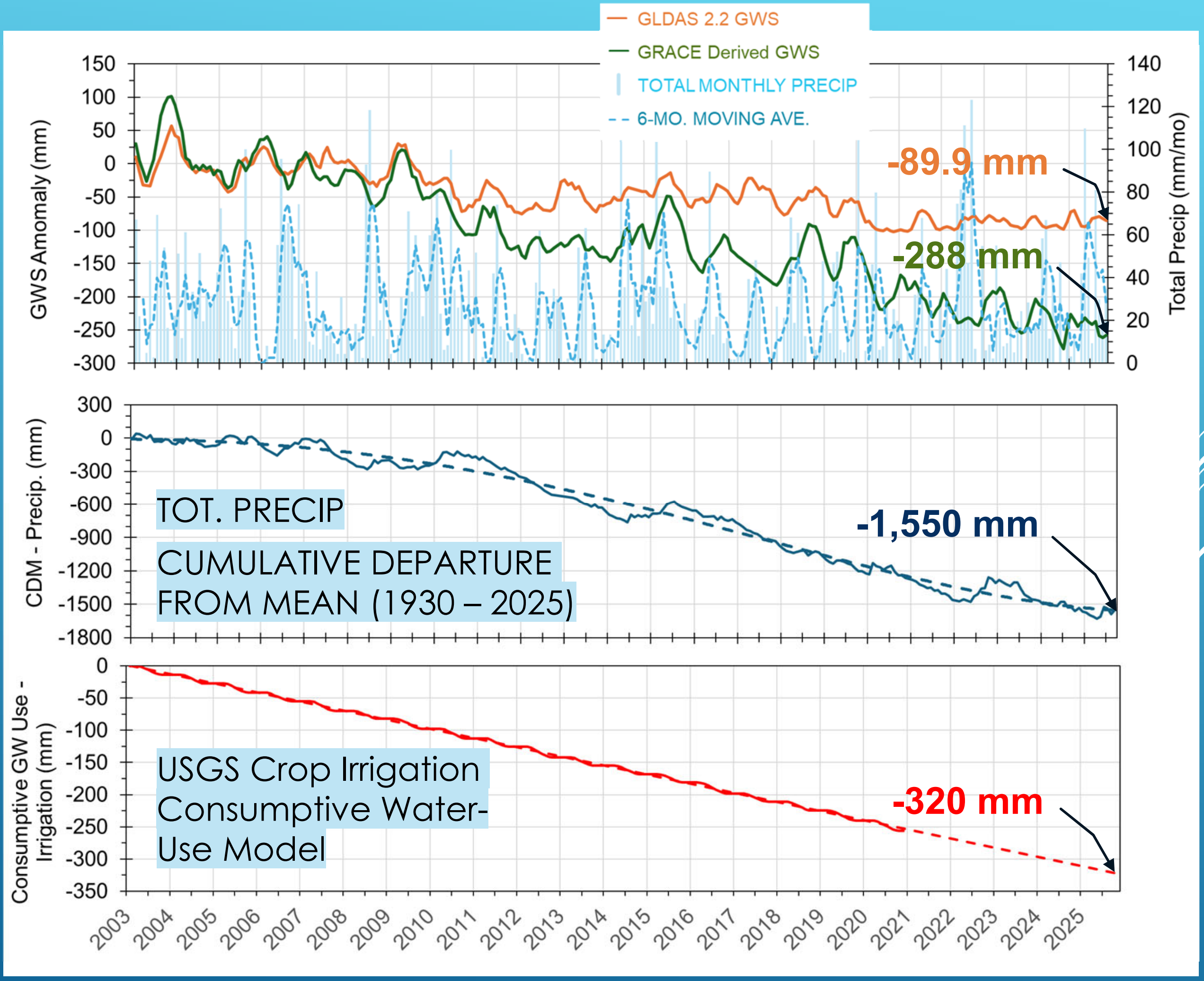
Precip not driving trend: High variability, no sustained decline signal

Chronic deficit: long-term recharge shortfall

Pumping signal: CU ~−320 mm ≈ GRACE decline → irrigation dominant

Model vs reality: GLDAS smooth; GRACE captures larger basin-scale variability

Bottom line: Depletion = pumping + long-term drought, not short-term climate



DISCUSSION: INTERPRETATION AND LIMITATIONS

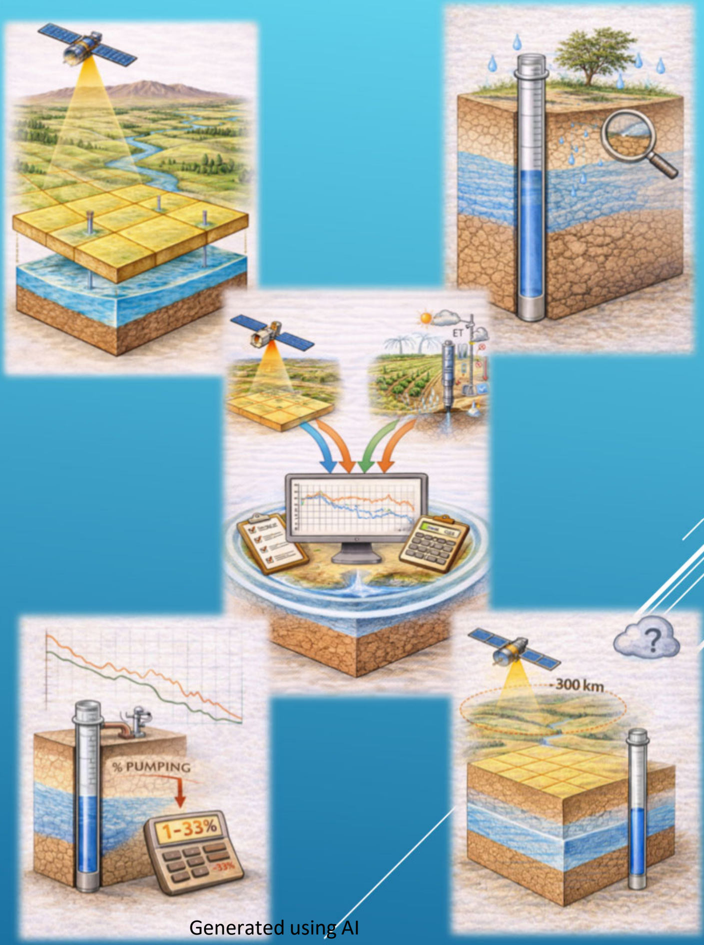
GRACE utility: Effective at capturing basin-scale groundwater trends in data-poor regions (broad agreement with well data).

GLDAS limitations: Does not include pumping in its physics; tends to under-predict declines (hence ~1/3 of GRACE trend).

Hydrogeologic context: Thick vadose zone and localized recharge should smooth and delay GRACE signals compared to water level measurements.

Uncertainties: GRACE has coarse resolution (~300 km); GLDAS soil moisture estimates lack semi-arid basin specificity; well data sparse.

Synergy: Combining datasets compensates for individual gaps, providing robust insight for groundwater assessment.



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CONCLUSIONS AND IMPLICATIONS

Significant depletion: The Estancia Basin has experienced substantial groundwater losses, driven by irrigation pumping and sustained drought.

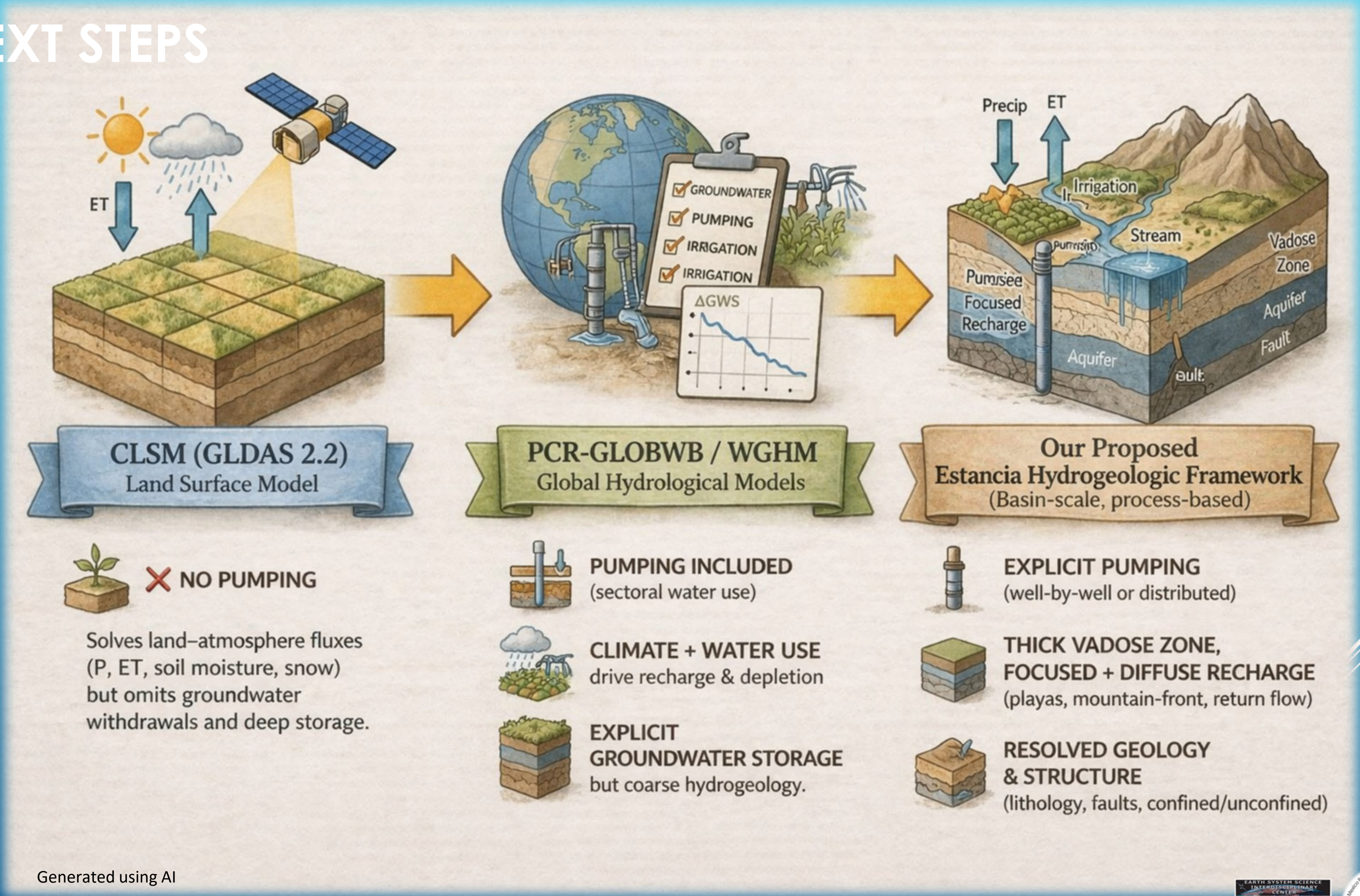
Comparison: GRACE-derived GWS trends exceed GLDAS estimates highlighting the importance of accounting for human withdrawals.

Seasonal vs. Long-term: Seasonal ΔGWS modulates climate.

Validation: Groundwater-level data support the GRACE-observed ΔGWS.

Implications: Integrated satellite-model monitoring can inform management of stressed aquifers; similar methods may be applied to other basins lacking dense monitoring.

NEXT STEPS



CLSM (GLDAS 2.2)
Land Surface Model

✗ NO PUMPING

Solves land–atmosphere fluxes (P, ET, soil moisture, snow) but omits groundwater withdrawals and deep storage.

PCR-GLOBWB / WGHM
Global Hydrological Models

PUMPING INCLUDED
(sectoral water use)

CLIMATE + WATER USE
drive recharge & depletion

EXPLICIT GROUNDWATER STORAGE
but coarse hydrogeology.

Our Proposed
Estancia Hydrogeologic Framework
(Basin-scale, process-based)

EXPLICIT PUMPING
(well-by-well or distributed)

THICK VADOSE ZONE, FOCUSED + DIFFUSE RECHARGE
(playas, mountain-front, return flow)

RESOLVED GEOLOGY & STRUCTURE
(lithology, faults, confined/unconfined)

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