Safe Yield - Principal Aquifer – Indian Wells Valley Groundwater Basin

Todd Kincaid, Ph.D. – GeoHydros, LLC

- Ph.D. – Hydrogeology – University of Wyoming – 1999
- M.S. – Hydrogeology – University of Florida – 1994
- B.S. – Geology – University of Florida – 1991
- 31 years experience in Hydrogeology
- 25 years experience in Hydrogeologic Modeling
- Started and led a company focused on regional and sub-regional scale hydrogeologic modeling – 1999-2021
- Example Projects & ~Level of Effort
  - DOE (Yucca Mt and Nevada National Security Site) - ~8 years
  - DOD (Defense Supply Center Philadelphia) - ~10 years
  - NYC-MTA (East Side Access Project) - ~4 years
  - Florida Geological Survey / Dept. Env. Protection - ~10 years
  - Pennsylvania Dept. Nat. Resources (Bucks County) - ~3 years
  - BP, Conoco Phillips, Exxon, Duke Energy - ~5 years
  - Marina Coast Water District (MPWSP Model Review) ~8 years

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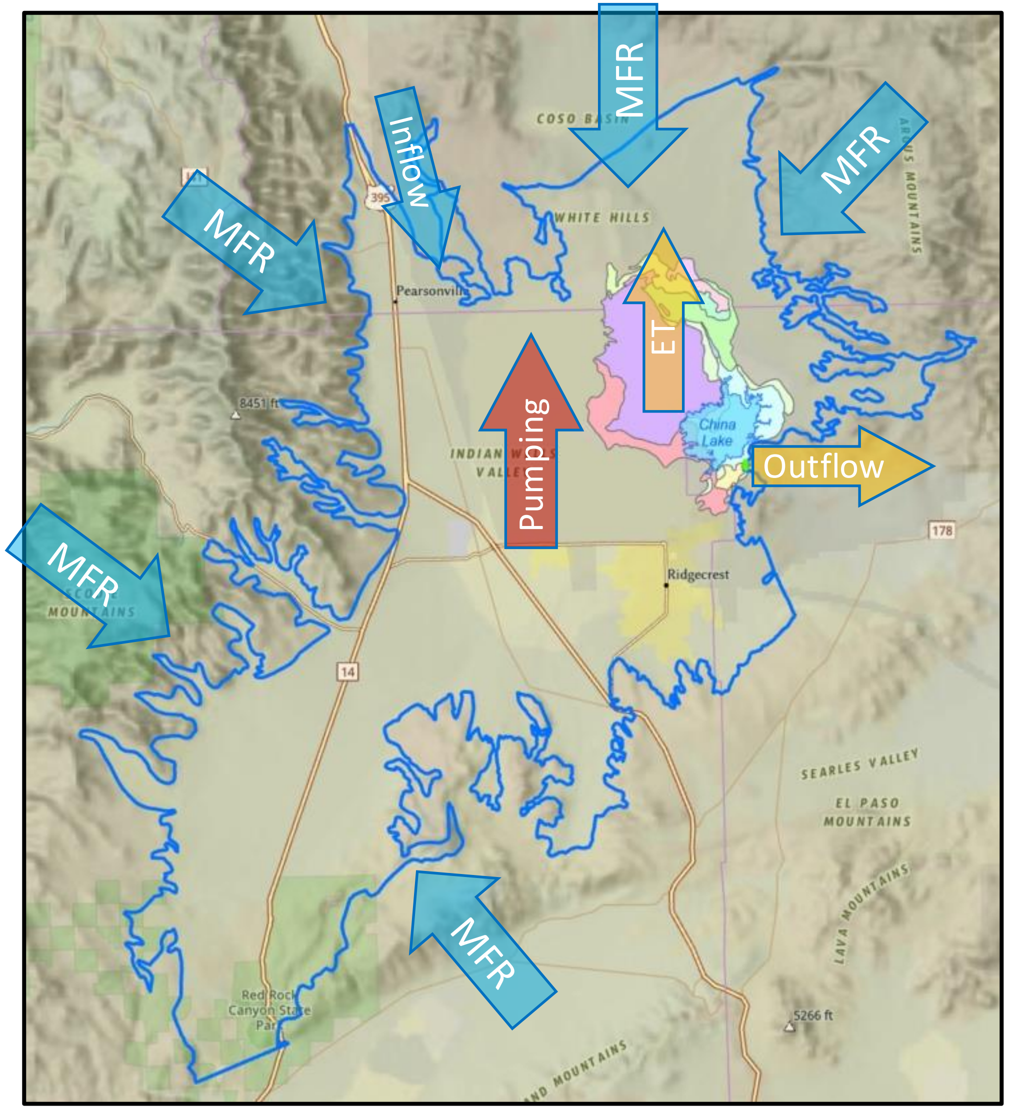
Safe Yield Defined



"Safe yield" describes the condition of a groundwater basin in which the total average annual groundwater extractions are equal to, or less than, the total average annual groundwater inflows, either naturally or artificially.

- Overdraft occurs when total groundwater consumption, which is the sum of natural discharge and groundwater extractions, exceeds total recharge.
- "Safe Yield" should reflect the portion of recharge that can practicably be intercepted by wells, which in the IWVGB is demonstrably less than total recharge.

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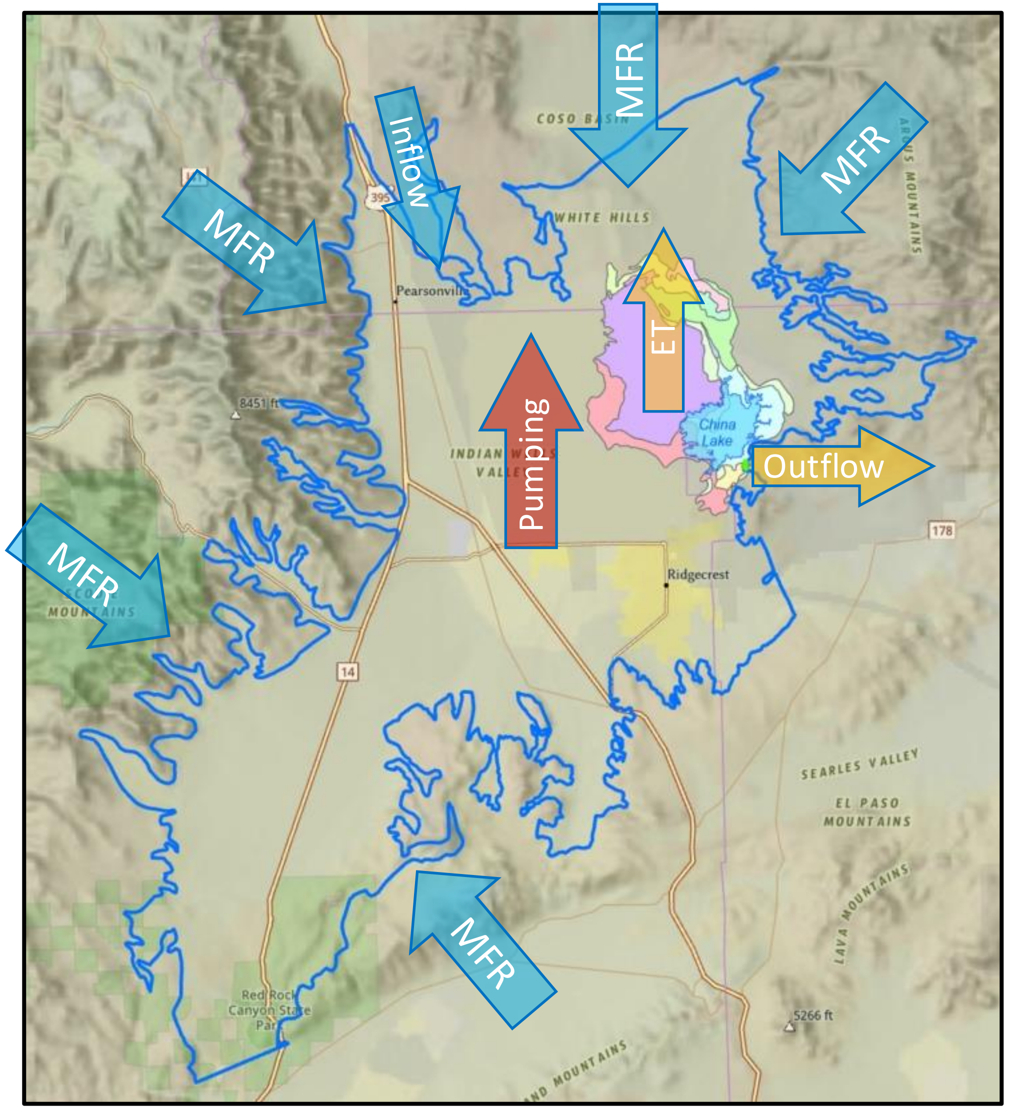
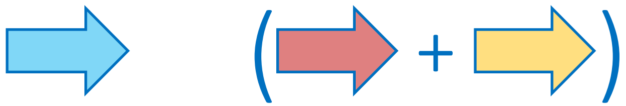
Safe Yield Defined



Safe: Inflows >= Sum of Outflows



- Safe Yield = recharge only if all other outflows are captured or replaced.
- Continued existence of ET from the playas demonstrates that, to-date, pumping has not captured natural discharge.
- "Safe Yield" must therefore be set below total recharge otherwise overdraft will persist and groundwater levels will continue to decline.
- Unless…
  - Pumping is reconfigured to better capture natural discharge; and
  - GDEs are somehow addressed.

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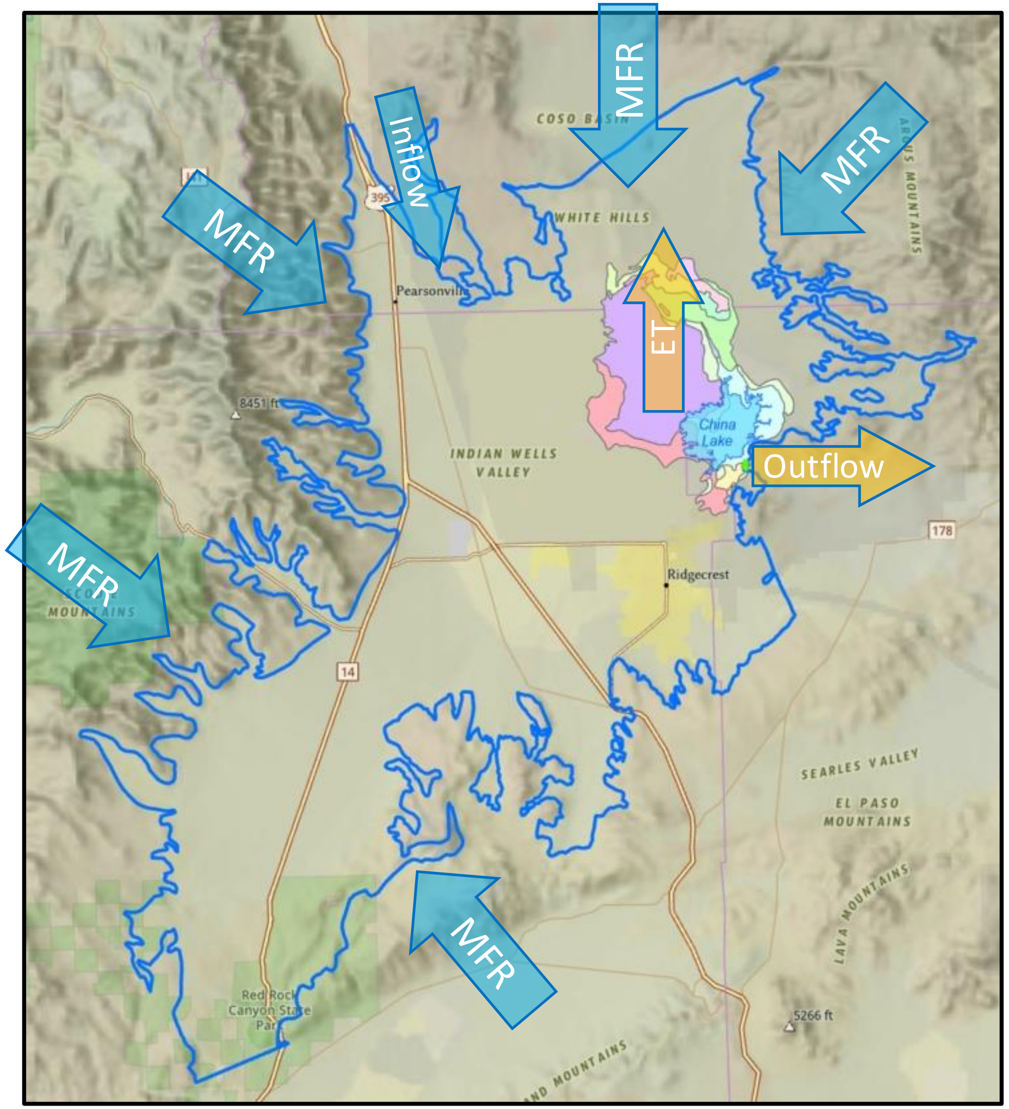
Estimating Recharge from Discharge



Mass Balance

$$Inflows_T + Outflows_T = \delta Storage$$

Assumptions

- Circa 1912, IWVGB was in a steady-state where: *Inflows*$_T$ = *Outflows*$_T$.
- Outflow to Salt Wells Valley was very small such that: *Outflows*$_T$ ~= ET.

Kunkel & Chase (1969) was a detailed study that built and improved on earlier work done in 1912 (Lee, 1913). Detailed mapping of soil and vegetation zones; ET rates per zone from USDA. Concluded ET = 11,000 AFY.

In 2016, DRI (McGraw et. al, 2016) conducted another study of ET: revised soil, vegetation, and geomorphology mapping; ET rates measured in nearby playa basins. And DRI concluded Kunkel & Chase ET rates were likely too high. Thus, DRI concluded total ET/Recharge was less than 11,000 AFY (33%-66% less).

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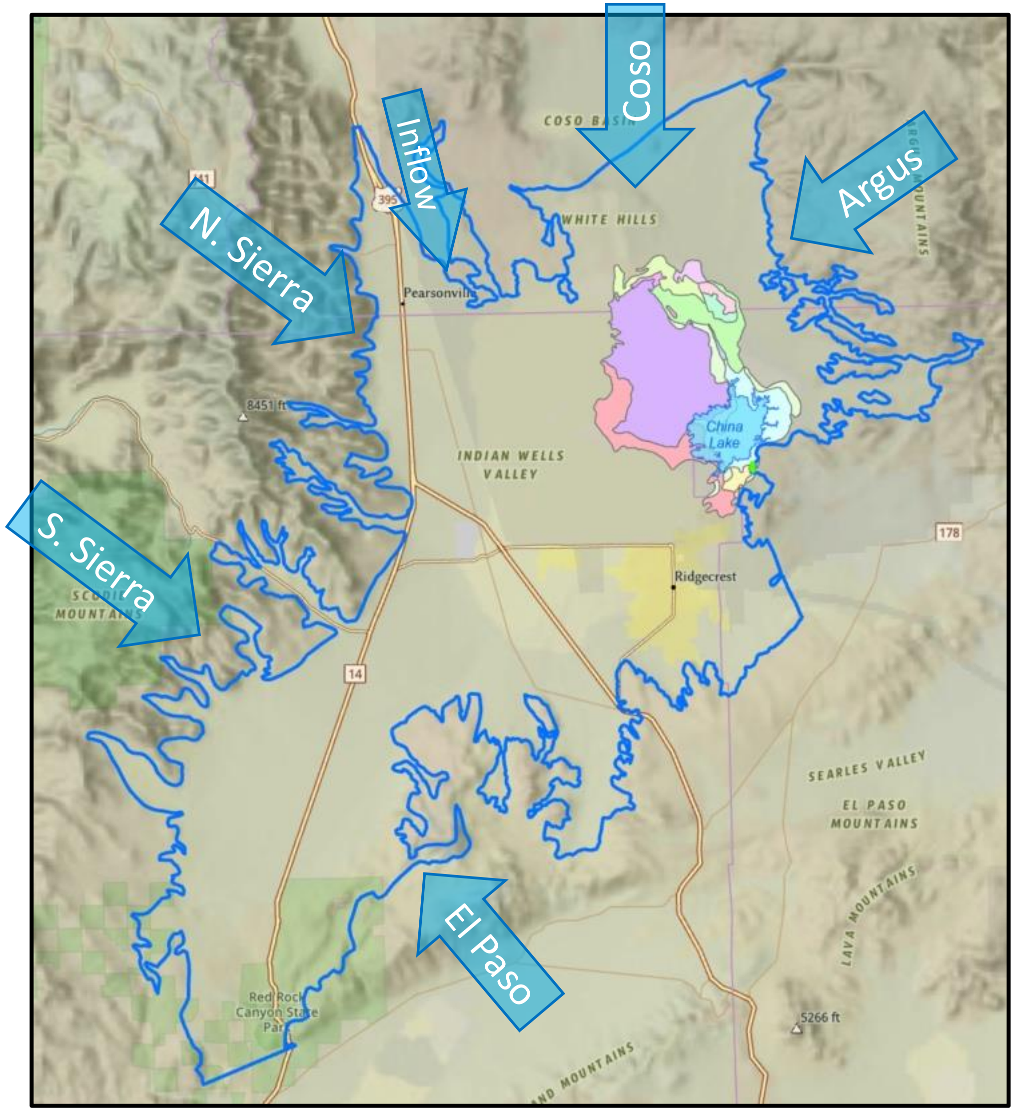
Estimating Recharge from Precipitation



$$\text{Precipitation} = \text{Recharge} + \text{Runoff} + \text{ET}$$

Assumptions

- ET is lower at higher elevations in the surrounding mountains.
- No significant recharge occurs in the playa basins due to ET.
- Recharge is less than or equal to runoff down the mountain streams >> mountain front recharge from disappearing mountain streams.
- Runoff reaching the basin floor is lost to ET.

Researchers generally agree that the majority of recharge, if not all of it, originates as precipitation at elevations above 4,500 feet in the mountain ranges that border the IWVGB:

- Sierra Nevada to the west,
- Coso and Argus ranges to the north and northeast, and
- El Paso Mountains to the south.

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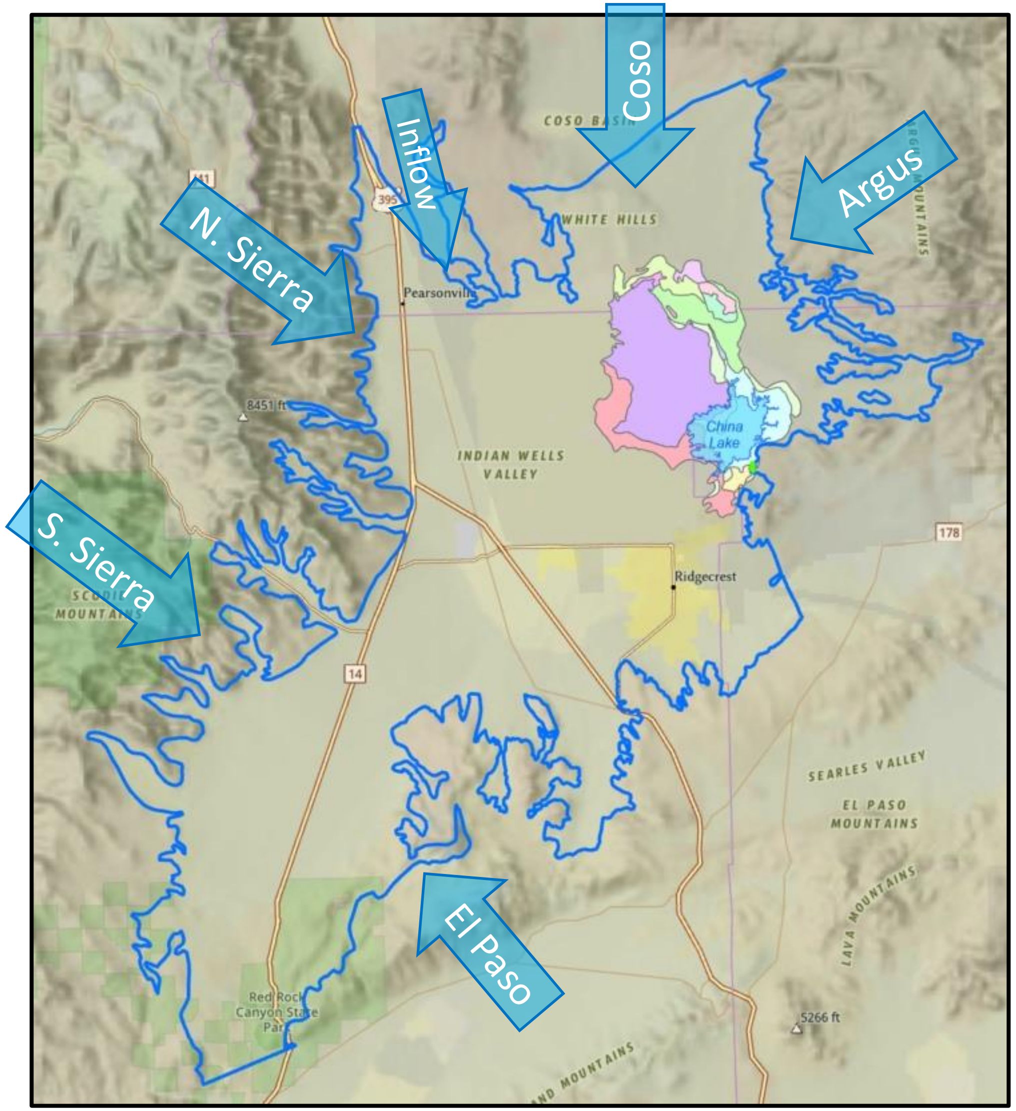
Estimating Recharge from Precipitation



$$\text{Precipitation} = \text{Recharge} + \text{Runoff} + \text{ET}$$

There are clear and well-accepted relationships between recharge from precipitation and the elevation at which it falls. Relationships have been developed and tested in multiple arid mountain settings similar to the IWV.

Estimates of MFR derived from recharge/elevation relationships have typically been refined through numerical modeling.

Estimates of inflow from Rose Valley / Little Lake have also been derived through numerical modeling.

- Bloyd and Robson (1971)
- Berenbrock and Martin (1991)
- Brown & Caldwell (2009)
- DRI (2016 – 2025)

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Total Recharge?

Year	Authors	Acre-Feet/Year					Method
		MFR	Inflow	Total	Min	Max	
1969	Kunkel and Chase	11,000	-	11,000	-	-	Based on study of ET in 1912
1969	Kunkel and Chase	8,000	-	8,000	8,000	15,000	Analytical modeling / Too high
1971	Bloyd and Robson	9,803	45	9,848	-	-	Analytical modeling: recharge/elevation relationship
1973	Dutcher and Moyle	-	-	11,000	-	-	Review ET from Kunkel & Chase
1986	St. Amand	-	-	11,000	-	-	
1989	Bean	9,700	400	10,100	-	-	Review published values
1991	Berenbrock and Martin	9,852	-	9,852	-	-	Disregard WWTF discharge to SA
1993	Watt	9,900	-	9,900	-	-	
1995	Gillespie & Thyne	6,809	952	7,761	7,761	9,061	Est from surface flows (1,300 from LL): Discounted flux calcs
2009	Brown and Caldwell	7,521	1,300	8,821	-	-	Est. via modeling. Started 11,000, reduced for calibration
2010	Epstein et al.	9,300	-	9,300	5,800	12,000	
2014	Todd Engineers	6,440	1,000	7,440	6,040	8,840	Review published values
2016	DRI	5,250	2,400	7,650	-	-	Independent estimates for ET & recharge
2019	USGS	7,938	742	8,680	-	-	Basin Char Model: 1981-2010
2019	USGS	5,379	597	5,976	-	-	Basin Char Model: 2000-2013

Takeaways -

- In 1912, ET was likely the only significant groundwater outflow from the IWVGB.
- Most comprehensive studies: 1969 & 2016 >> independent studies of ET & Recharge.
- Total ET (gw discharge) in 1912 likely less than 11,000 AFY >>> *see DRI, 2016.*
- Estimates of total recharge trending downward in later studies (post 1989).

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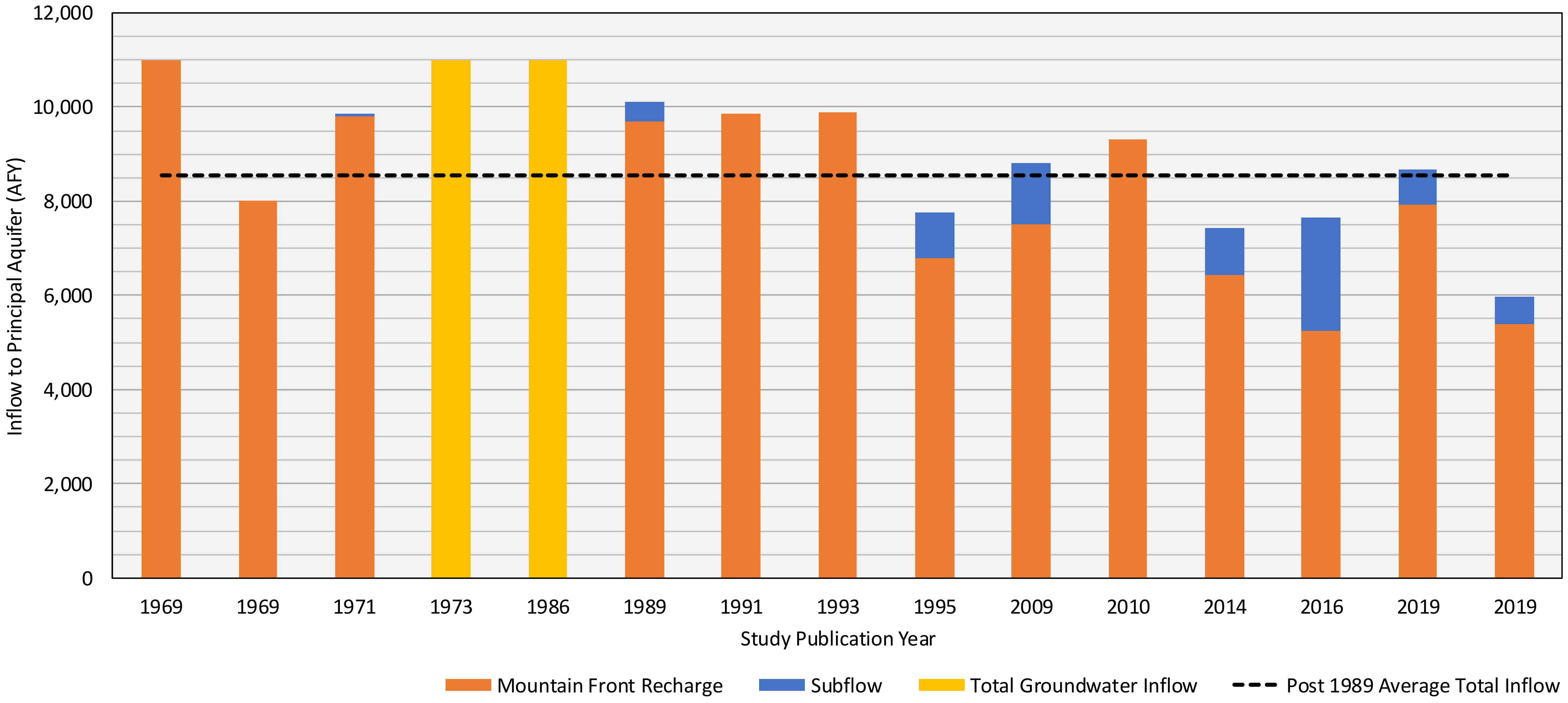
Trend of Studies: Pre-Development Recharge



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Total Recharge & Safe Yield?

Statistic	Acre-Feet/Year				
	MFR	Inflow	Total	Min	Max
Count	13	8	15	4	4
Max	11,000	2,400	11,000	8,000	15,000
Min	5,250	45	5,976	5,800	8,840
Range	5,750	2,355	5,024	2,200	6,160
Average	8,222	930	9,089	6,900	11,225
Standard Deviation	1,865	708	1,500		
Average (1989 - 2019)	**7,809**	**1,056**	**8,548**	**6,534**	**9,967**
Std Dev (1989-2019)	**1,819**	**661**	**1,328**		

Estimated range in MFR

- 1989 Average +/- one standard deviation
- 6,000 to 8,000 AFY

Estimated range in total groundwater inflow

- 1989 Average +/- one standard deviation
- 7,200 to 9,900 AFY

Estimated Safe Yield

- Total estimated groundwater inflow – 15%
- 15% reflects guess as to how much natural discharge will not be captured.
- 6,100 to 8,400 AFY

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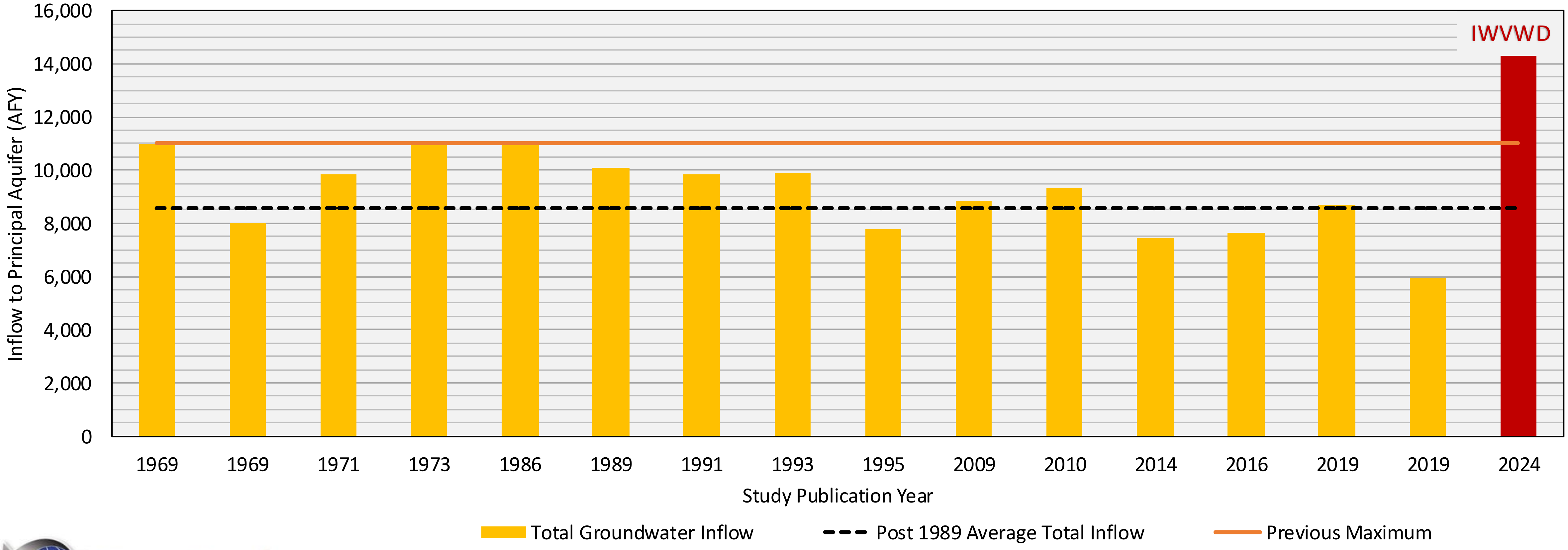
IWVWD Alternative Proposal

- Total recharge to the IWVGB >= 14,300 AFY (safe yield).
- 130% of maximum reasonable previous estimate (11,000 AFY by Kunkel & Chase in 1969).
- 167% of average of post-1989 estimates.
- *Lowest of estimates: 14,300 to 17,000; average = 15,700 (IWVWD-TWG, 2024)*



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IWVWD Alternative Proposal – Requirements

- ET from playa is supplied by direct precipitation & temporal runoff.
  - Counter to assumption described by previous researchers.
  - If not – total recharge would have to be at least 2,000 AFY higher.
  - IWVWD estimates ~2,000 AFY of ET
  - GSP-2025 estimates ~5,500 AFY – based on DRI studies
- Total ET in 1912 must have been >=14,300 AFY
  - 30% higher than estimated in 1969
  - DRI 2016 studies indicated that the 1969 value was likely too high
- Or - Recharge is higher now than it was in 1912
  - most researchers believe that recharge is either the same today as then or has declined
  - expectation is that it will decline due to climate change.
- IWVWD value implies that basin was not in overdraft when it was previously believed to be in overdraft
  - i.e. before total pumping exceeded 14,300 AFY
  - Was pumping increasing faster than the aquifer was equilibrating? No

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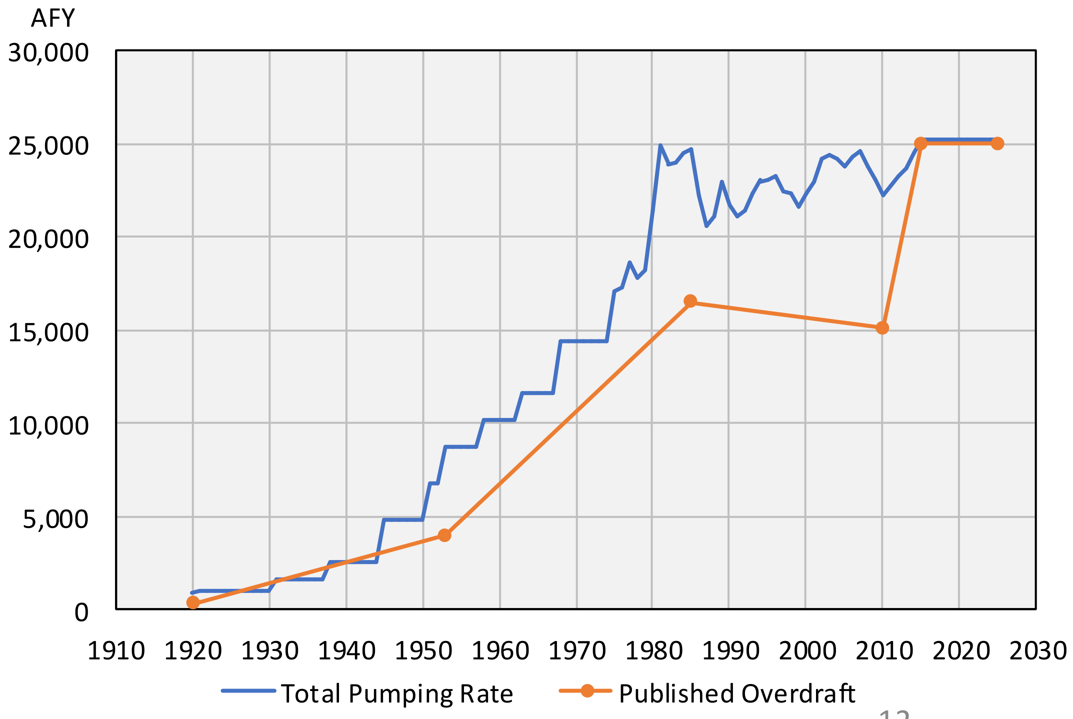
Historically Estimated Overdraft

Year	Total Pumping (AFY)	Reported Overdraft (AFY)	Data Sources (Pumping/ Overdraft)	Period (Years)	Cumulative Storage Loss (acre-feet)	Rate of Change in Storage Loss (AFY/year)
1920	1,000	301	Brown & Caldwell 2009	NA	0[a]	NA
1953	8,726	4,000	Brown & Caldwell 2009 Kunkel & Chase 1969	33	29,748	112
1985	24,739	16,515	Brown & Caldwell 2009 Bean (1989) / Berenbrock & Martin (1991)	32	283,247	391
2010	22,300	15,100	Todd Engineers (2014)	25	384,520	-57
2015	25,285	25,000	Stetson Engineers (2020)	5	101,958	1,980
2025	25,285	25,000	Assumed 2015 Rate Held	10	250,000	0
Estimated Storage Loss over 105 Years (1920 to 2025):					1,049,474	
Average Rate of Increased Storage Loss (AFY per year):						485

Notes

a) Assume no storage loss despite reported value

- Aquifer believed to be in overdraft since nearly the start of pumping.
- Indicates that pumping did not capture natural discharge.
- IWVWD presumes aquifer was not in overdraft until ~1970
- ET should have been declining by an amount ~= to pumping.



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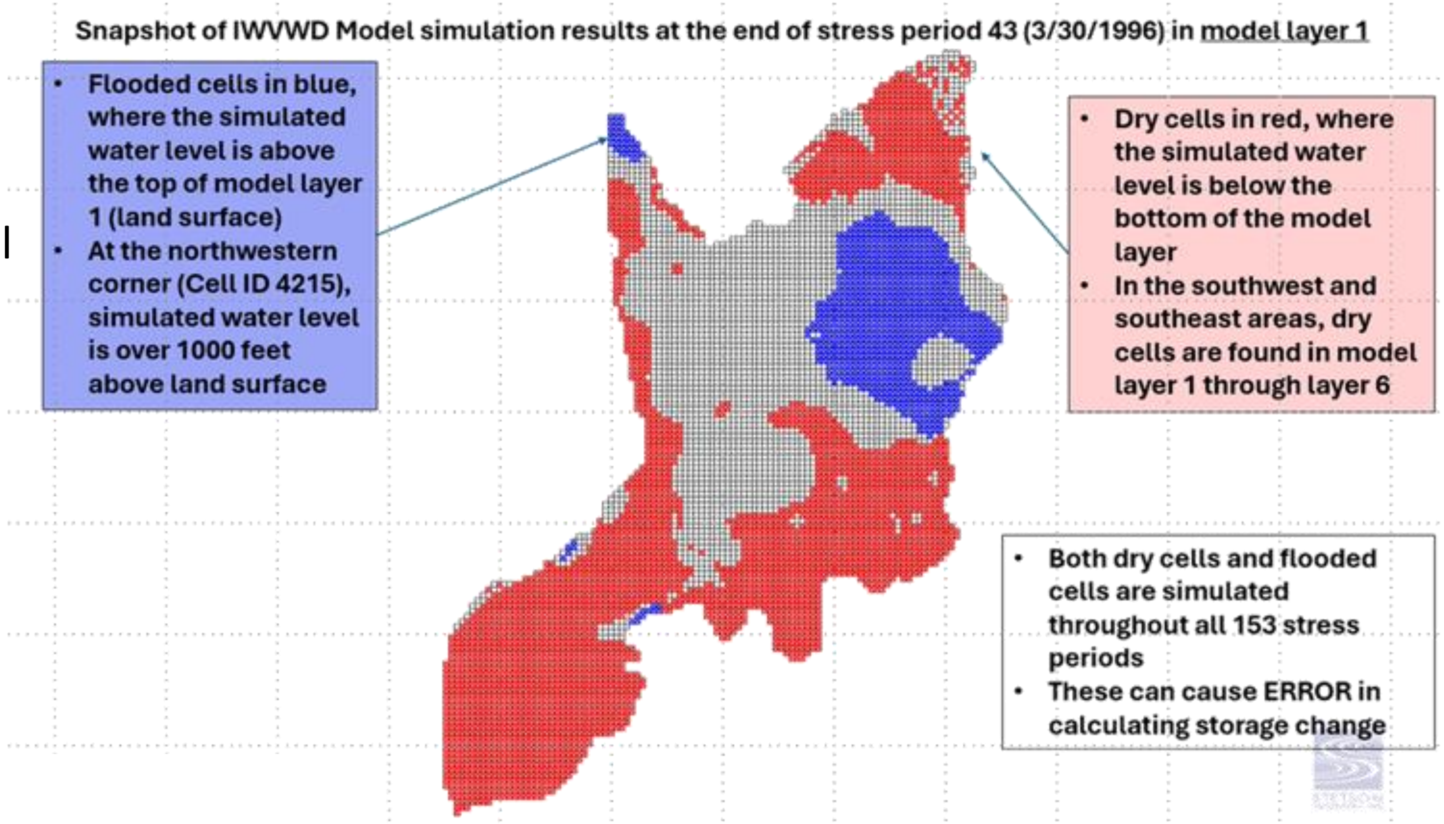
Evaluating IWVWD's Groundwater Model

First Pass Evaluation -- Fails

- Dry Cells
    - Simulated water level below bottom of cell
    - Model stability problem
- Flooded cells lake in playa
    - Simulated water level above land surface
    - Creates lake where no lake exists
    - Creates aquifer storage in the air
- First pass "calibration" should have identified and corrected these problems



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Evaluating IWVWD's Groundwater Model

Correcting Storage

Nearly all of difference in the respective model simulations of storage change can be explained by the magnitude of IWVWD model-simulated storage above the land surface, which doesn't exist

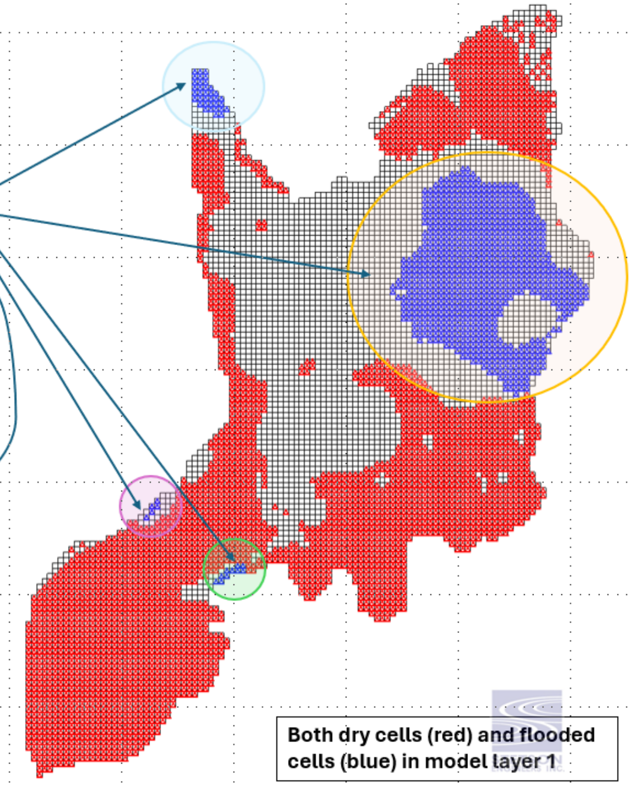
Storage = Area * Specific Yield * (Simulated Water Level – Observed Water Level)

Flooded Area	Number of Flooded Cells (-)	Area of Cell (acres)	Specific Yield (-)	Simulated Water Level[1] (ft amsl)	Observed Water Level[2] (ft amsl)	Calculated Storage (AF)
Rose Valley	36	40	0.086417	3,229.84	2,246.87	122,321
China Lake	842	40	0.11024	2,183.57	2,161.79	80,859
El Paso	8	40	0.086417	2,700.09	2,436.85	7,279
Freeman Canyon	5	40	0.086417	3,018.11	2,697.61	5,539
TOTAL[3]						215,999

*Calculated Storage total may be slightly off due to rounding

STORAGE CHANGE (1/1/1986-1/1/2022)		
IWVWD MODEL	STORAGE IN FLOODED CELL AREA	GSP MODEL
-491,528	215,999	-851,256

1. Simulated water level is averaged over all flooded cells and for all the stress periods in each respective area, as illustrate by representative hydrographs at cell 4215, 8120, 14454 and 17117.
2. Calibration wells at the nearest location are selected. Water level observations are shown by hydrographs for USBR-10-S, TTBK MW-12, IWV-MW-03, and Father Crowley West. Averaged water level observations are listed.
3. Numerous simulated water levels at cells in the surrounding areas are far above observed water levels but still below land surface were not included in the above calculation.



Both dry cells (red) and flooded cells (blue) in model layer 1

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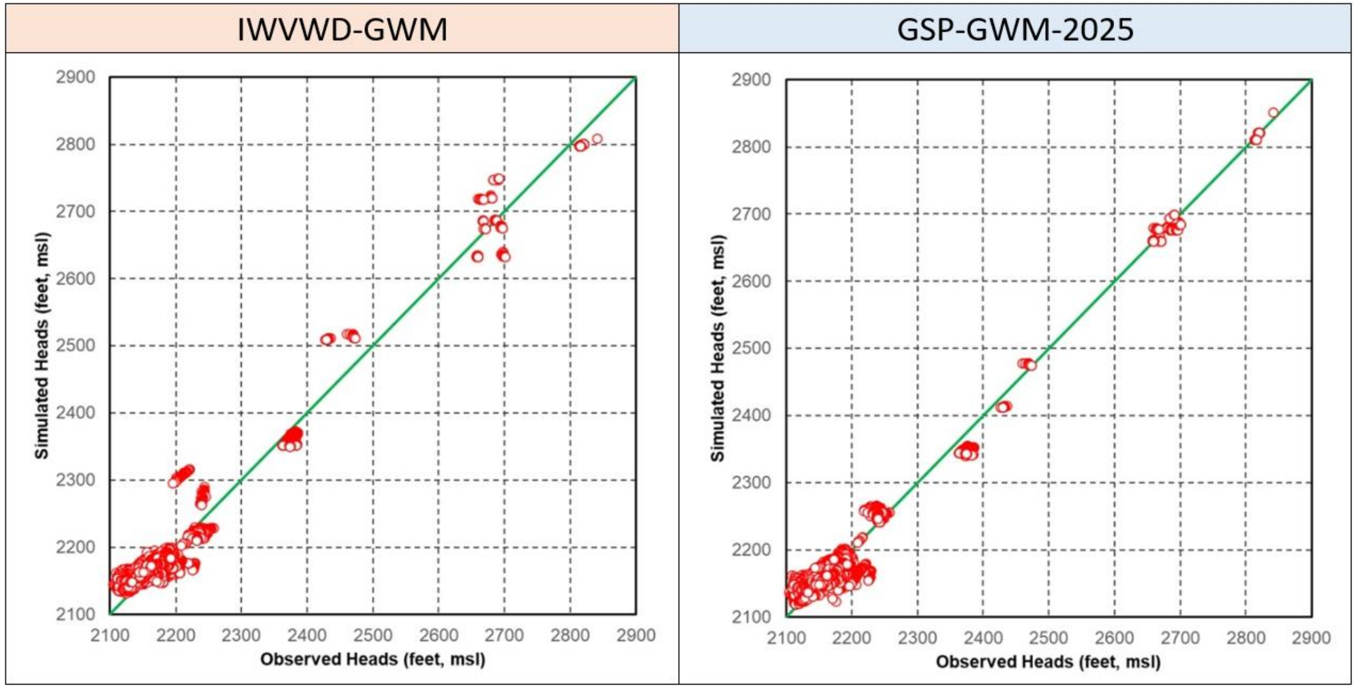
Evaluating IWVWD's Groundwater Model

Bulk Calibration Statistic

- Similar
- GSP-2025 >> A little better

Statistic	IWVWD-GWM	GSP-GWM-2025
Number of Wells	164	164
Number of Observations	6,373	6,373
Max Observed Water Level	2,840.94	2,840.94
Min Observed Water Level	2,104.03	2,104.03
Residual Mean (ft)	-3.43	5.72
Absolute Residual Mean (ft)	14.49	14.05
Residual Std. Deviation (ft)	20.29	17.98
RMS Error (ft)	20.58	18.86
Min. Residual (ft)	-103.46	-53.33
Max. Residual (ft)	68.05	69.89
NRMSE (RMSE/ObsRange)	2.79%	2.56%



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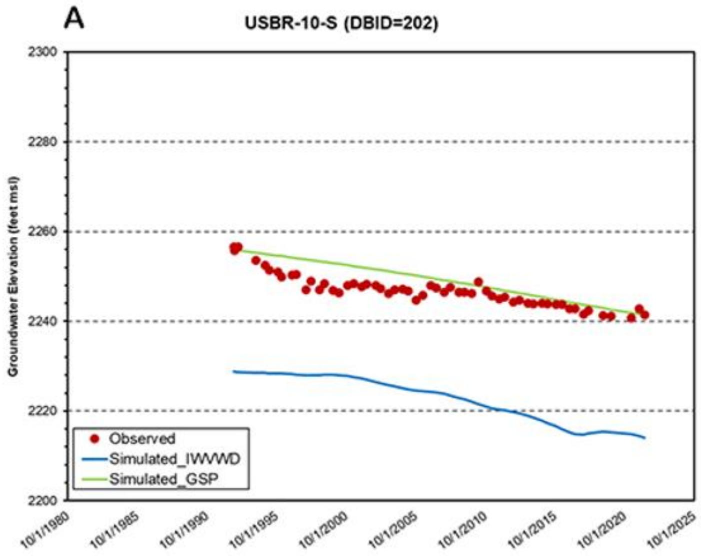
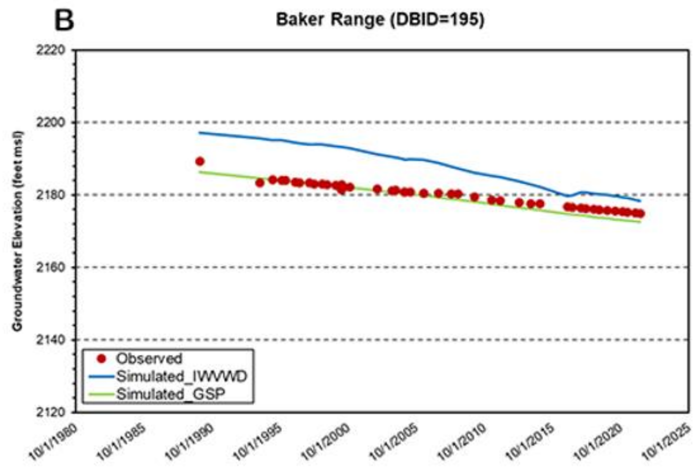
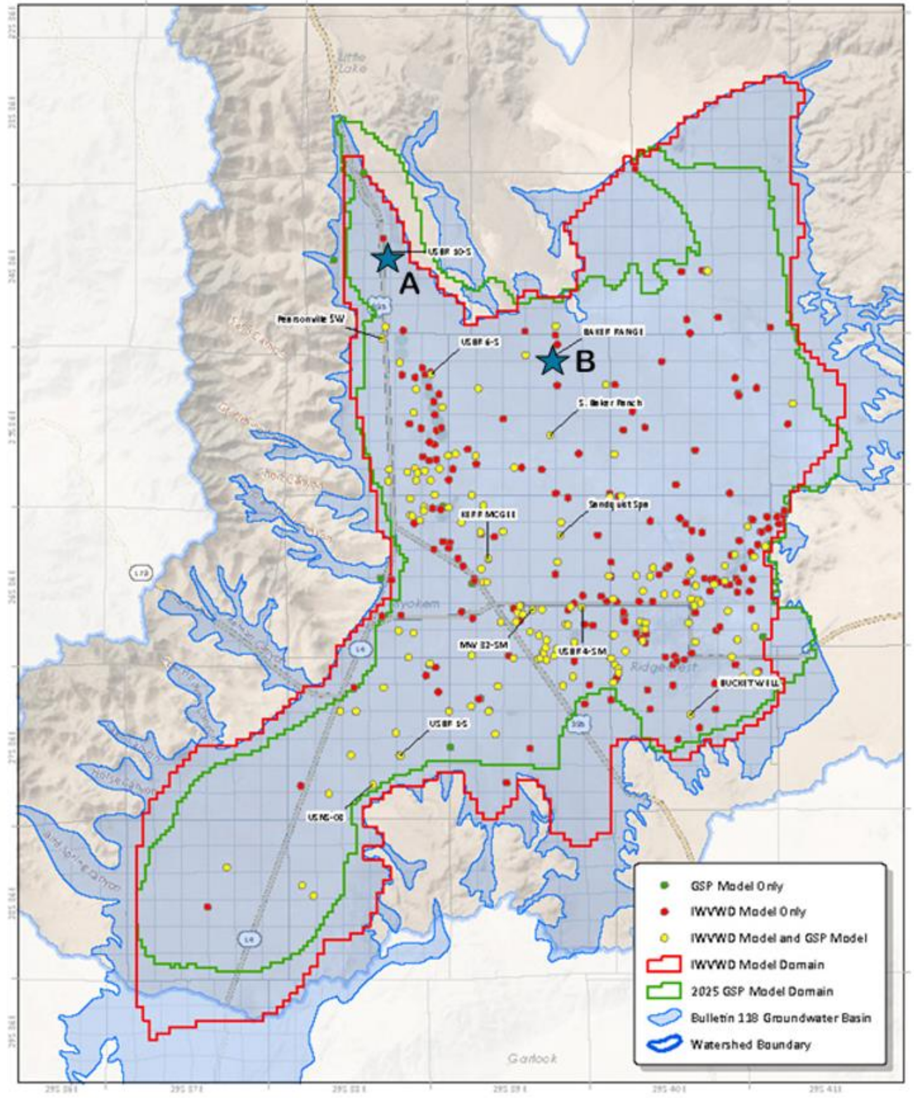
Evaluating IWVWD's Groundwater Model

Well by Well Evaluation

- Green lines are GSP-2025
- Blue lines are IWVWD
- Red dots are measured data
- GSP-2025 >>
  Significantly Better







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Evaluating IWVWD’s Groundwater Model

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- Note evidence of recharge spikes in blue line not observed in data
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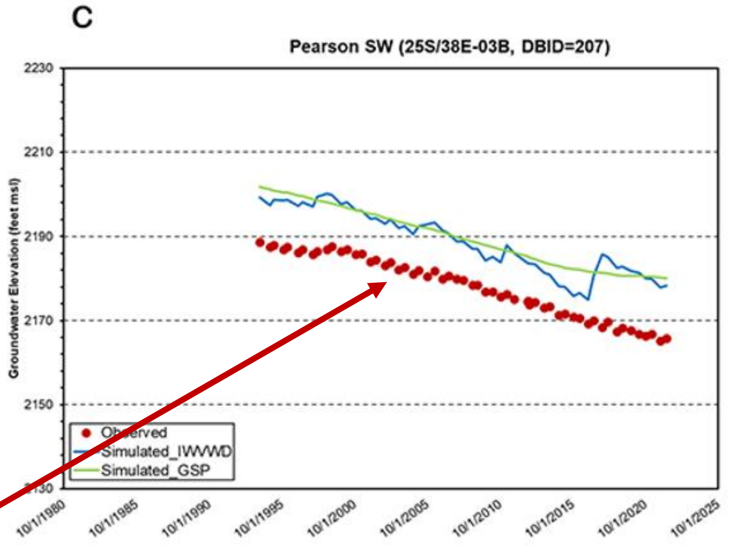

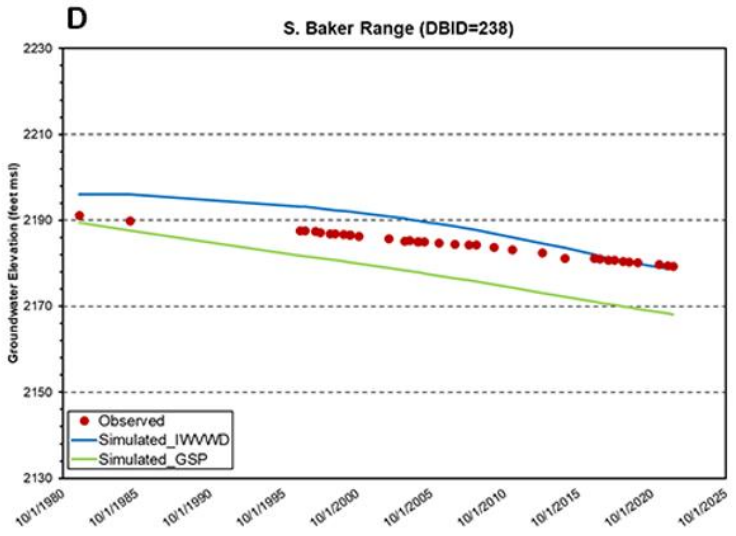

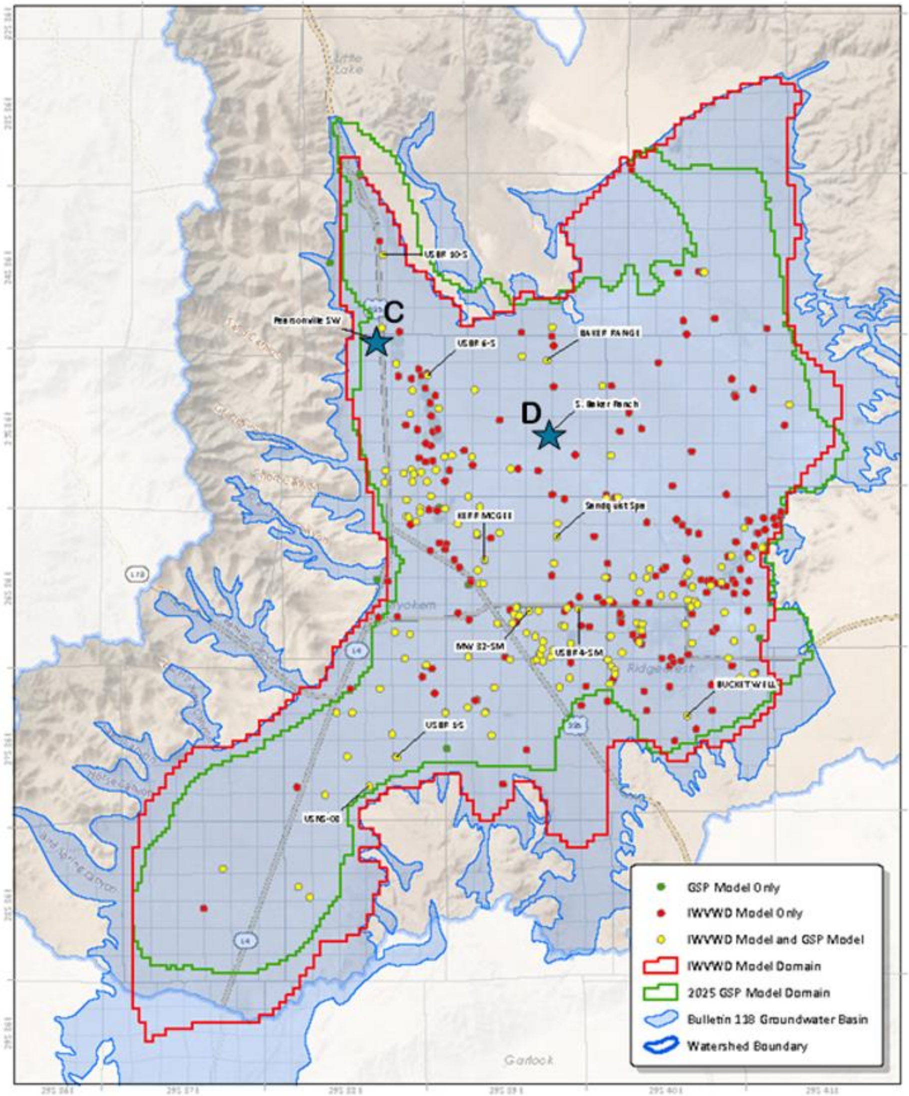

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Evaluating IWVWD's Groundwater Model

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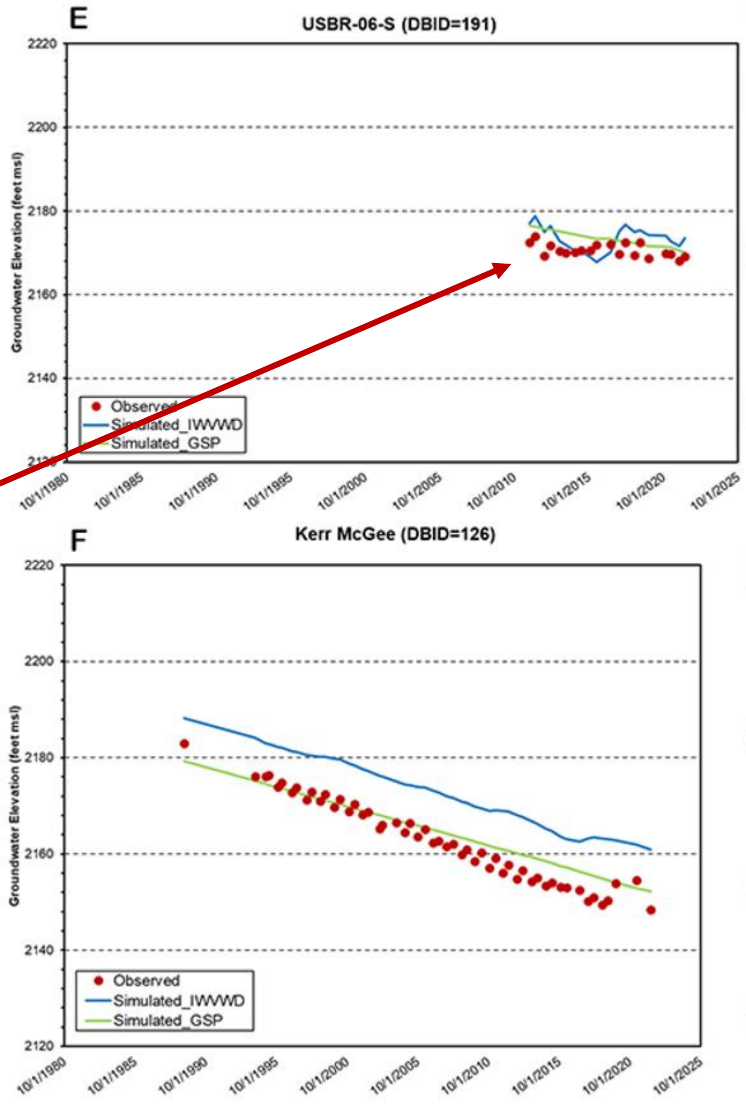

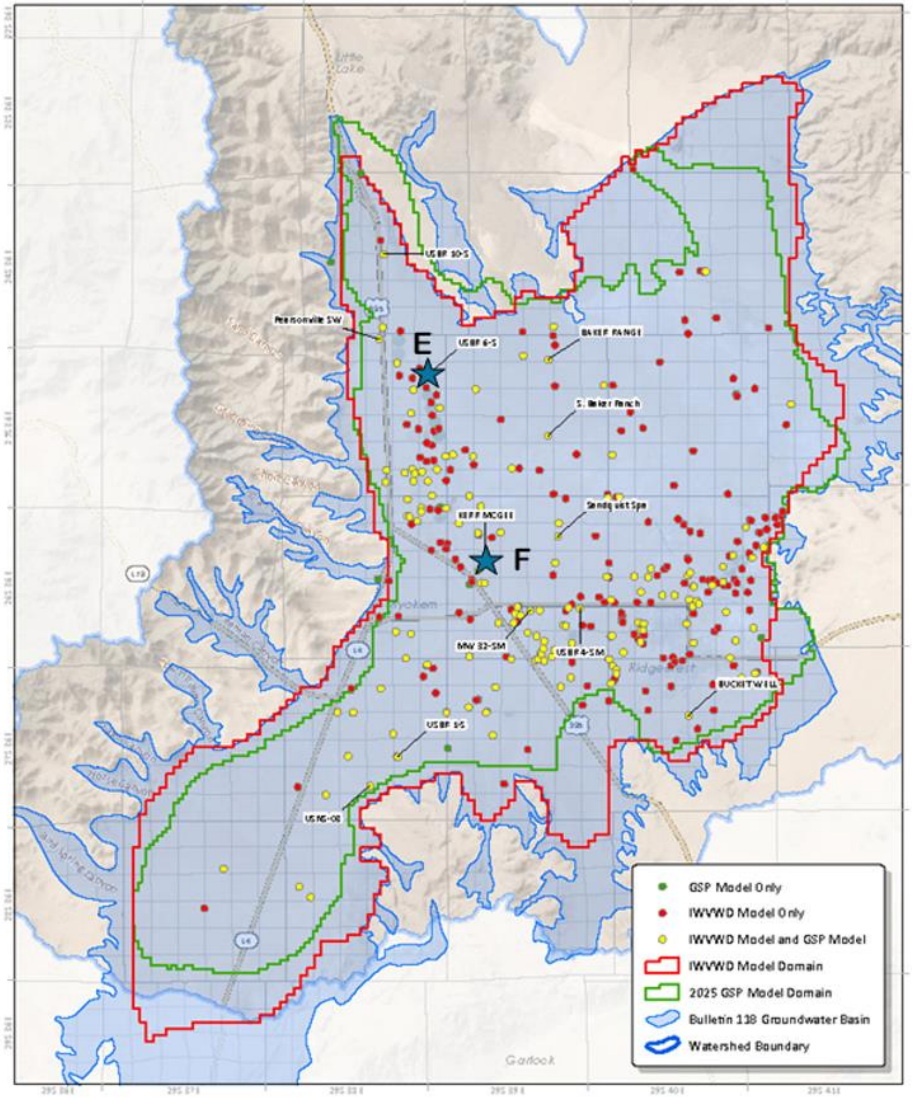

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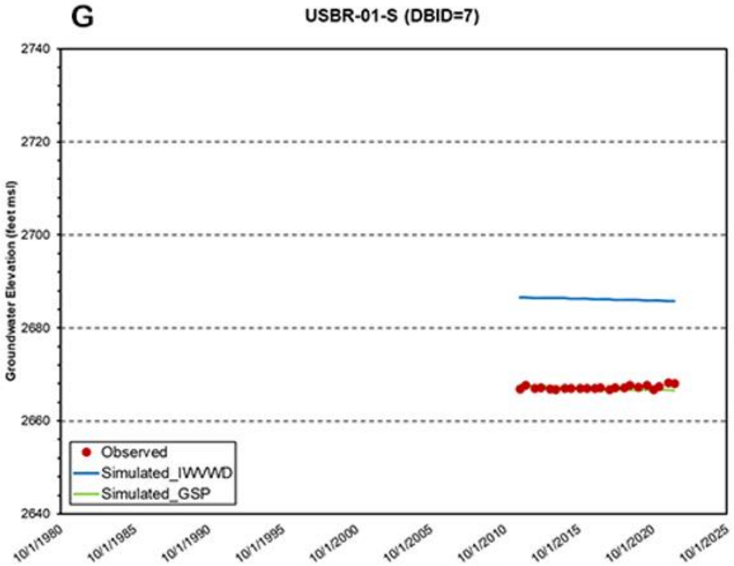

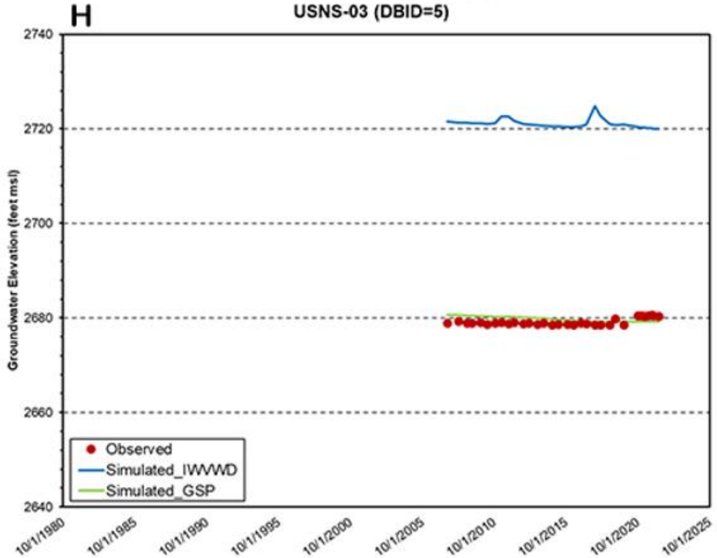

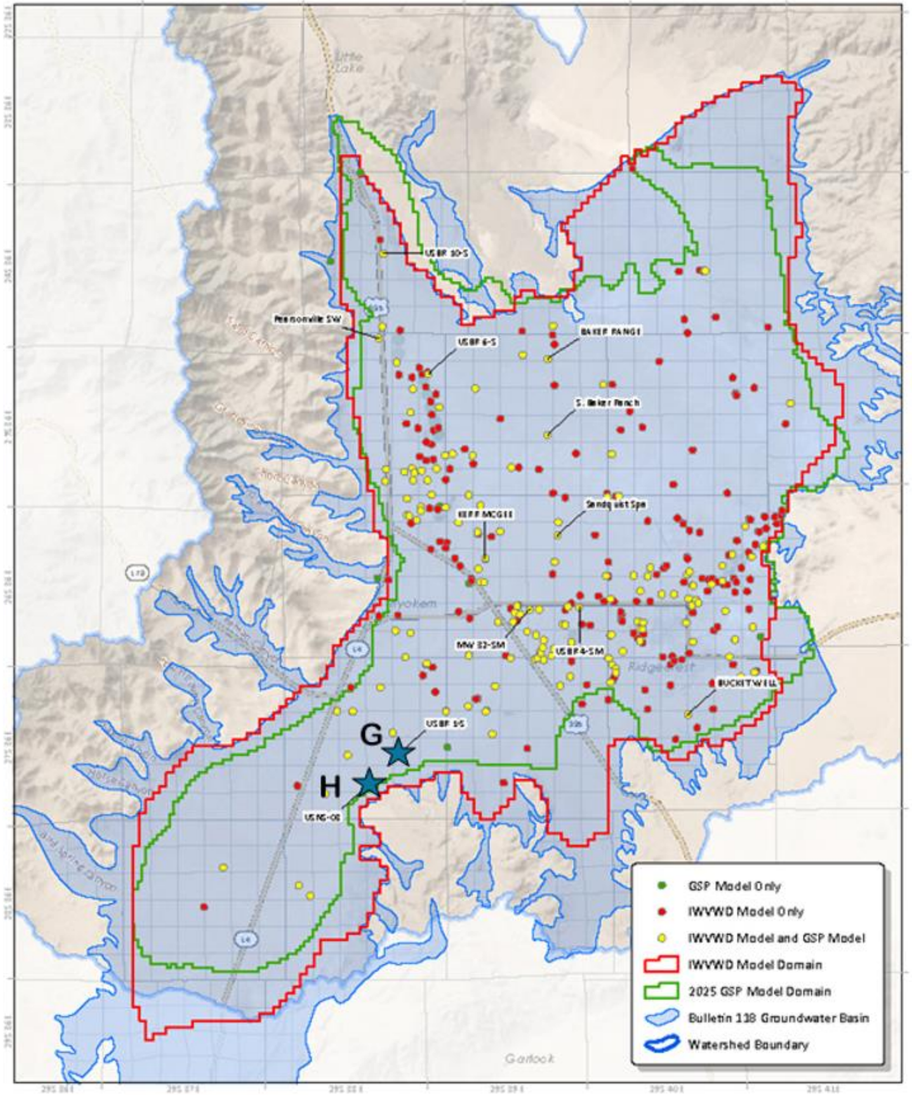

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Conclusions

IWVWD’s new model is not adequately calibrated

- The IWVWD model is not better than the current GSA model.
- IWVWD’s proposition that there is substantially more recharge in the IWVGB is not supported by data or by a more reliable model.
- IWVWD’s proposition that there is substantially less ET from the IWVGB is not supported by data or by a more reliable model.

Safe Yield must be less than total recharge

- Persistence of ET from the playas and upward gradients to the playas demonstrates that pumping has not been able to capture natural discharge
- Safe Yield values that don’t account for the persistence of natural discharge will not be “Safe”
- Consideration of GDEs is needed

Redesigning the distribution of pumping wells will likely increase capture of natural discharge and result in higher Safe Yield

Questions

Thank You!

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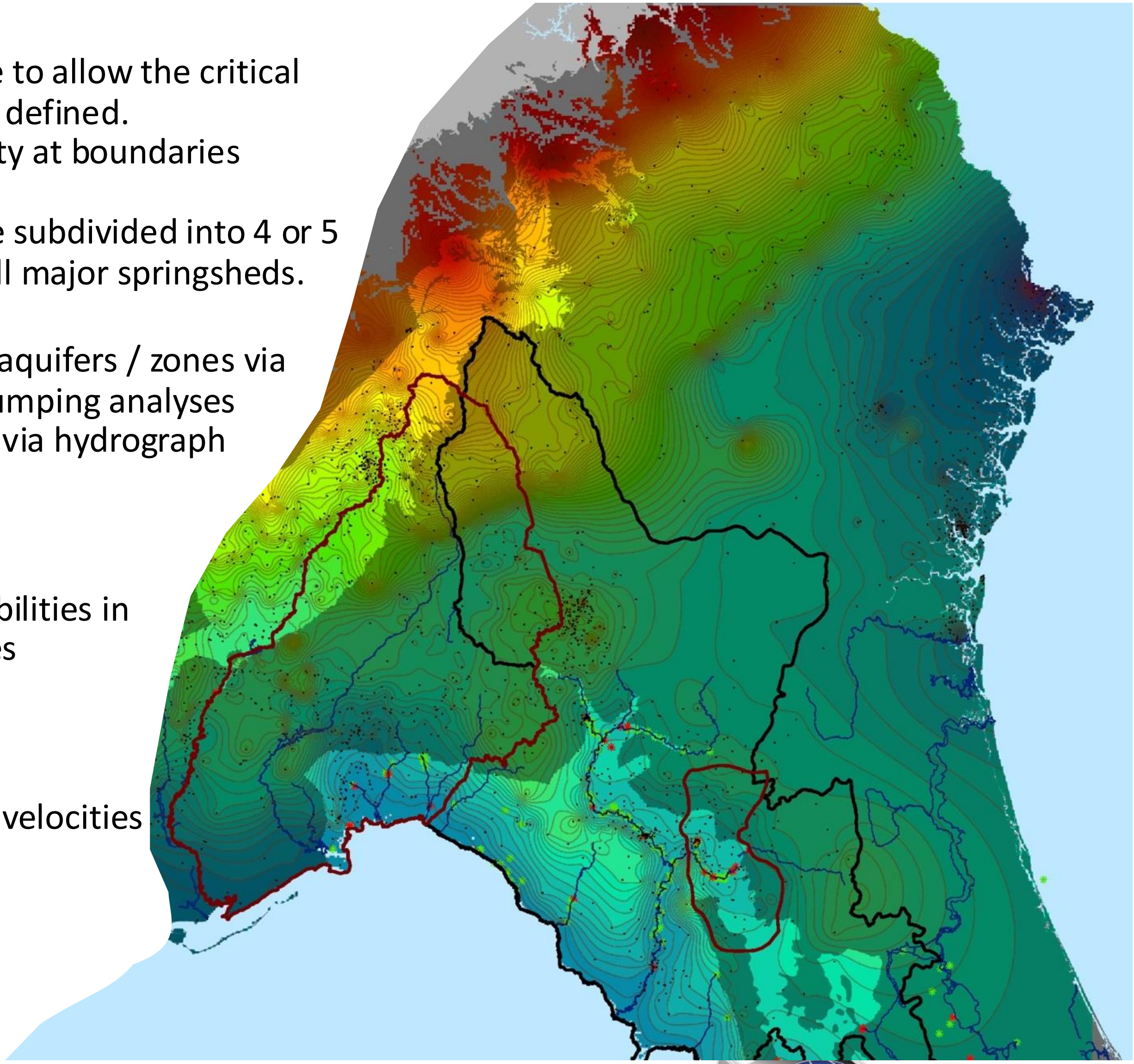
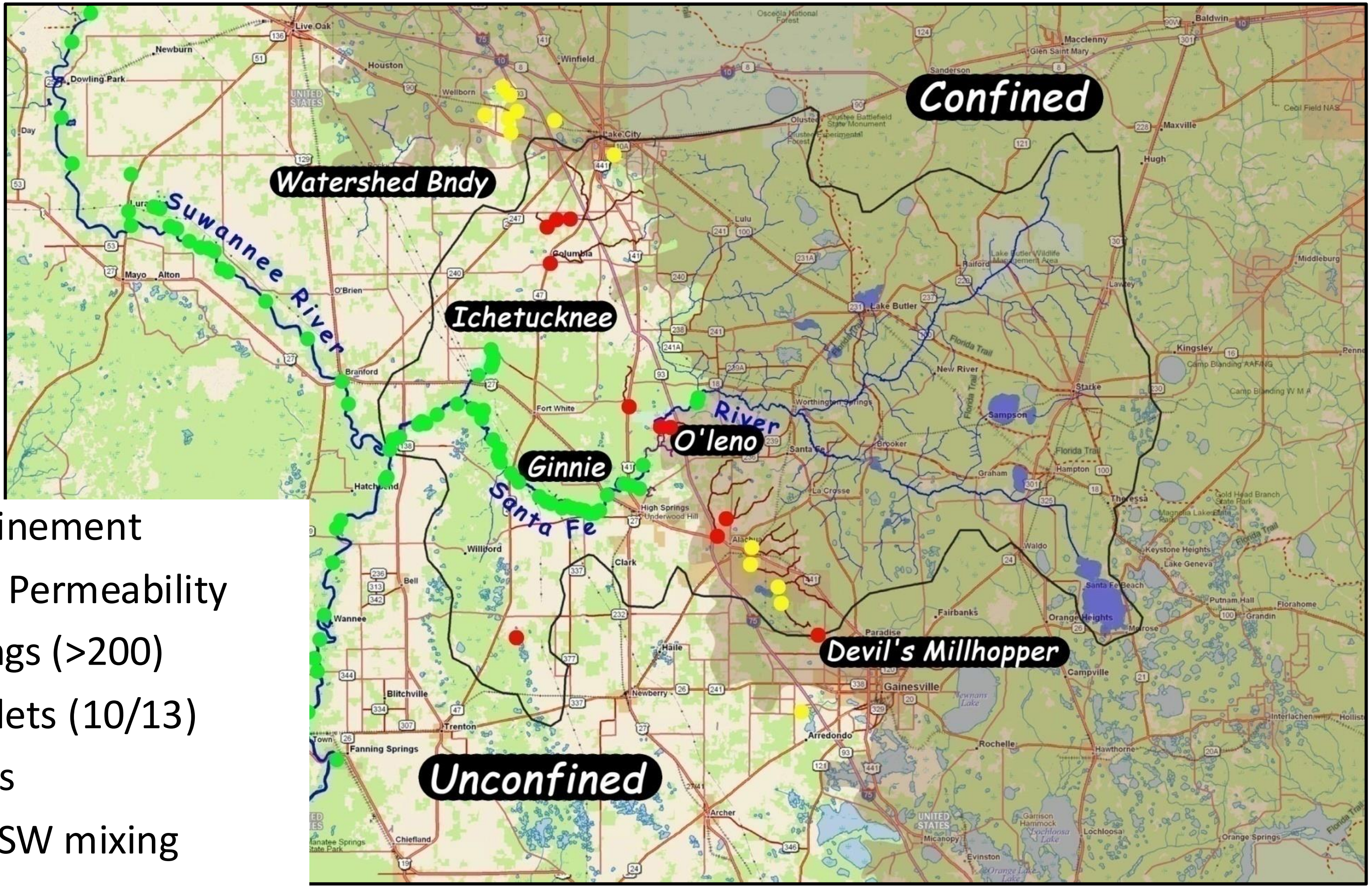
New Approach to Modeling Karst

- Watershed-scale models
  - Need to be sufficiently large to allow the critical springsheds to be internally defined.
  - Design to establish continuity at boundaries between adjacent basins.
  - Florida's Karst Belt would be subdivided into 4 or 5 basin models to delineate all major springsheds.
- Detailed data analysis
  - Delineate vertical extent of aquifers / zones via well completion, head, & pumping analyses
  - Expand calibration datasets via hydrograph analysis & correlation
- Dual-permeability
  - Explicitly define conduits
  - Use realistic matrix permeabilities in geologically defensible zones
- Multiple lines of calibration
  - Heads
  - Spring & river flows
  - Tracer/ hydrograph defined velocities
- Multiple calibration periods
  - High water
  - Low water
  - Possibly transient



Important Hydrogeologic Complexities



- Confinement
- Rock Permeability
- Springs (>200)
- Swallets (10/13)
- Caves
- GW/SW mixing

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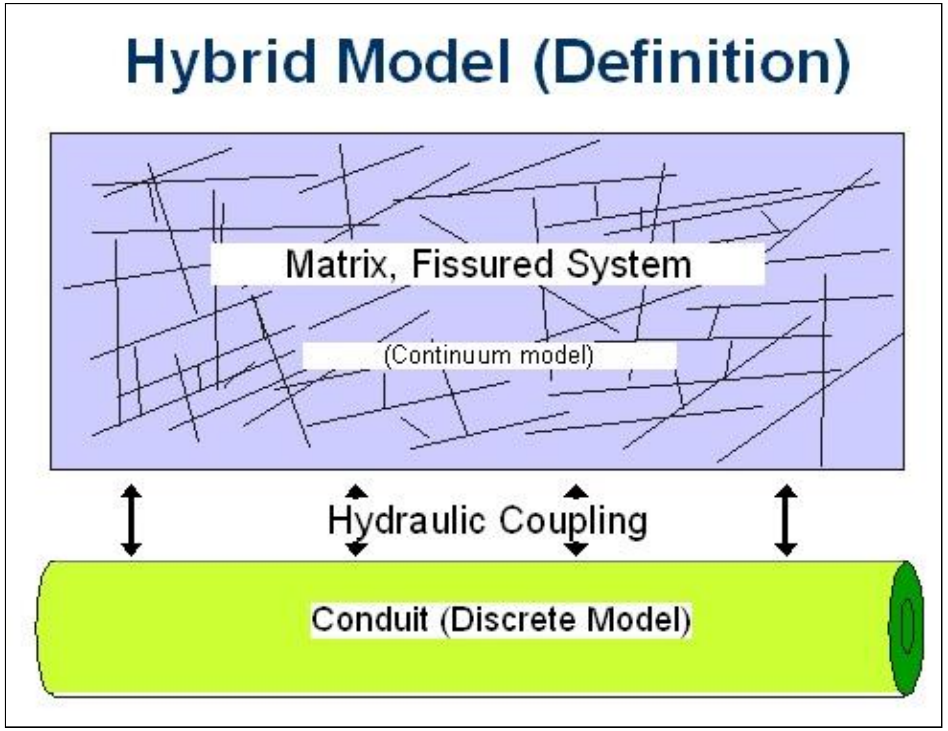
Karst features create the dominant controls on flow

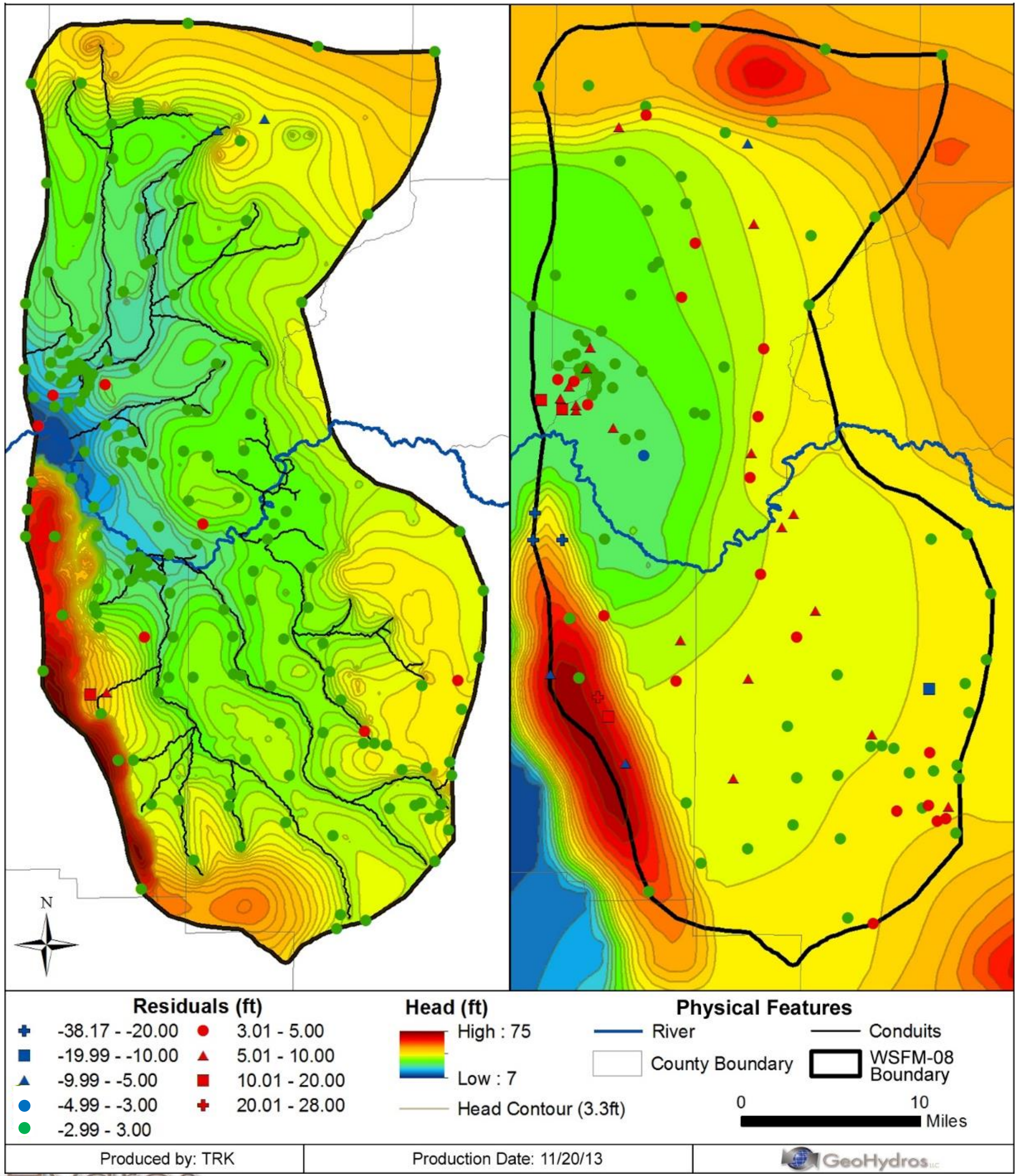
Why FEFLOW?

- Hybrid Model (Dual Permeability)
  - Continuum model for matrix
    porous media > Darcy flow
  - Discrete model for conduits
    Pipe flow
  - Flow can exchange between the two media
- Finite-element formulation
  - Maximum flexibility for geometric design
  - Computational efficiency
    more model runs = higher confidence



DHI WASY

http://www.feflow.info/



Comparison to EPM *Head Calibration*

Hybrid Model

- 176 of 188 wells to < 3.5 feet
- 5 residuals > 5 feet
- 1 > 10 feet
- average abs residual 1.4 feet

EPM - North Florida Model (NFM)

- The NFM-08 matched groundwater levels to less than 5 feet at only 101 of 132 wells in the same domain.
- To less than 3.5 feet at only 80 of the 132 wells.
- Residuals at 9 wells were >10 feet and >20 feet at 5 wells.
- The average absolute residual for wells within the Hybrid Model domain was 4.2 feet.

Conclusions from Florida Example

We proposed a radically new conceptual model for north-central Florida

- Groundwater flow dominated by karst conduits
- Groundwater flow through conduits 3 or more orders of magnitude faster than traditionally believed possible in groundwater systems

Compiled new data

- Cave maps and dye traces that defined the conduits
- Denser groundwater level datasets, i.e. more wells

Identified and used a more appropriate numerical model

Produced a radically better calibration to the totality of observed (known and measured) conditions

Questions

Thank You!

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IWVWD Alternative Proposal – Recharge

Irrigation Return Flow

- Not verified
- Study of travel time through unsaturated zone: ≅122 years
- No mounding in groundwater levels
- No apparent salinity rise
- Evaporation in unsaturated zone
- Returns to shallow aquifer don't benefit principal aquifer

Pipeline Leakage

- Los Angeles Power and Water Department (LAPWD)
  - No right to water
  - Expectation should be that LAWPD will continue to fix leaks as they are discovered
  - See LAPWD website…
- Not verified
  - Leakage estimates are based on reported line losses
  - Assumed to be distributed along line and to result in recharge