Using sensitivity analyses to enhance the hydrologic model of a complex volcanic aquifer system to support Sustainable Groundwater Management

Laura Foglia[1,2], Jose Tomas Diaz Casanueva[1], Gerald O'Neill[1], Steffen Mehl[3], Andrew Calderwood[1]

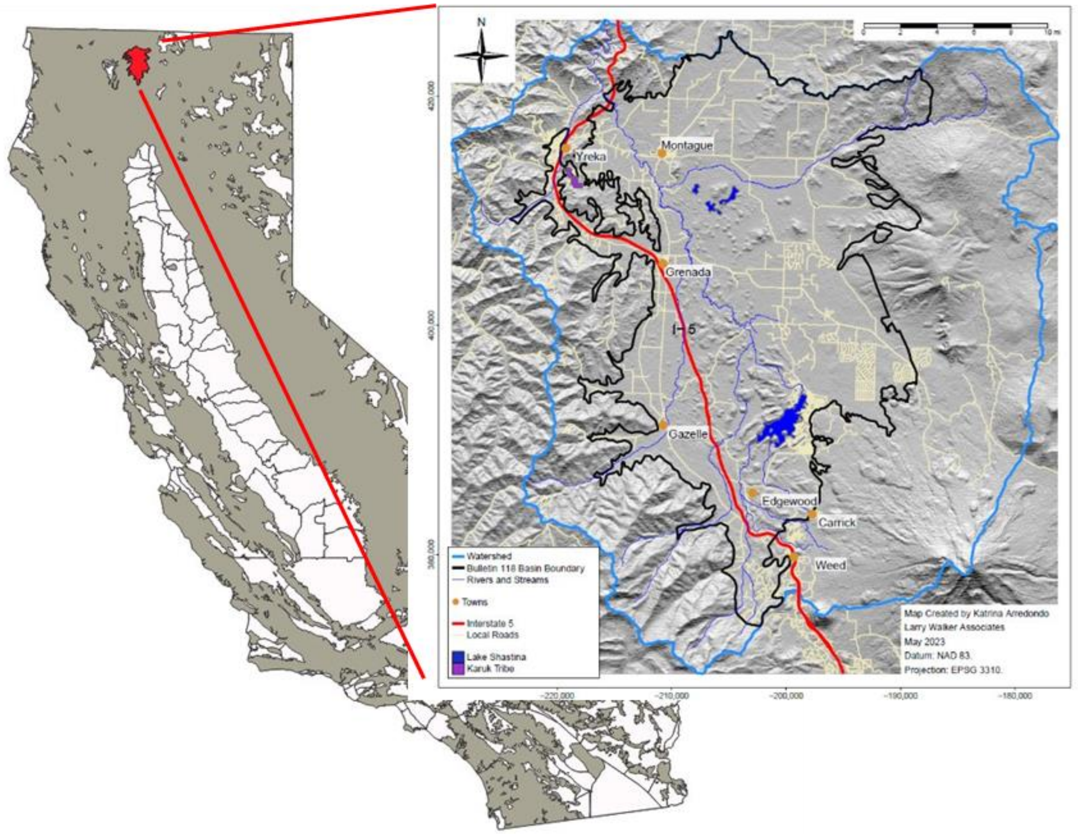
[1] Larry Walker Associates
[2] University of California Davis
[3] California State University Chico

LARRY WALKER ASSOCIATES
science | policy | solutions

The Shasta challenge…

- The summit is not the challenge!!!

Which challenges do we have?

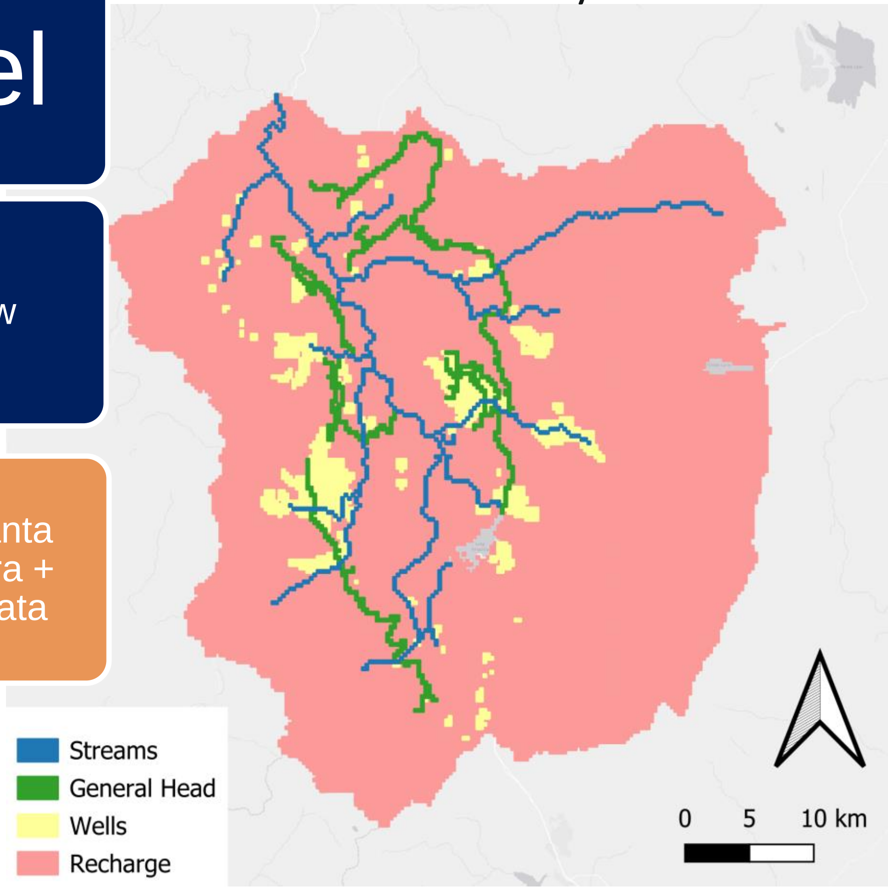


- Many stakeholders with a variety of interests (tribes, farmers, state water board, fisheries)
- Complex volcanic/fractured system interfaced with an alluvial aquifer system
  - This complex geology controls the flow system
- Complex stream/aquifer interactions with springs providing cool baseflow important for fisheries

How does the integrated model work?

Shasta Watershed integrated model					
Geology	Groundwater	Surface Water	Integrated	Agricultural	Snow
Geologic Model	MODFLOW	PRMS	Loosely Coupled	Remote Sensing, now soil water budget tool	UC Santa Barbara + new data

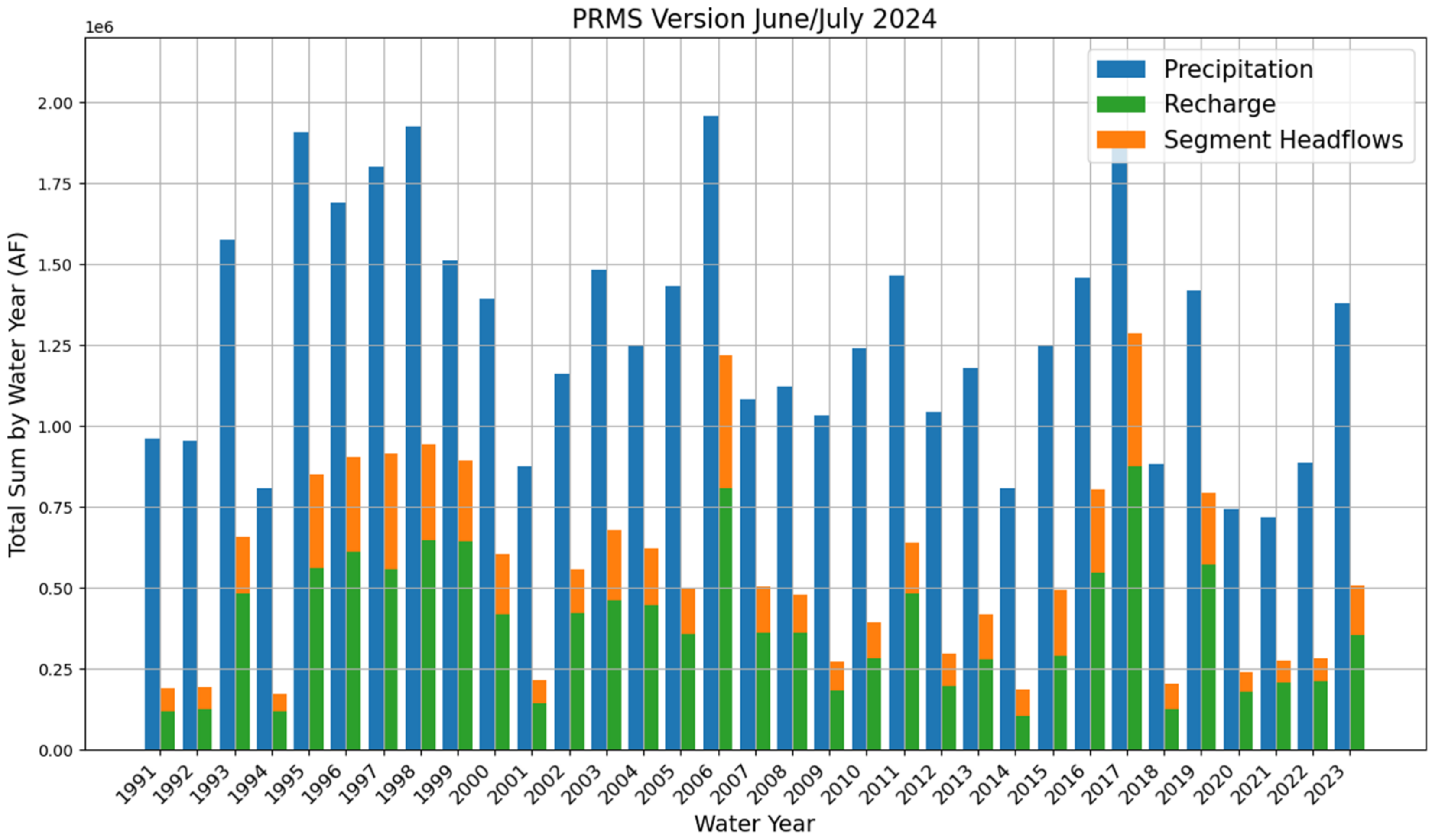
MODFLOW Boundary Conditions



Sensitivity analysis to update initial parameters

- Model improvements
  - New geologic model to better define boundaries with AEM, revised initial parameters based on literature review
  - Improved elevations of wells and reference points with land survey data
  - Manual calibration with DWR CASGEM and continuous data
  - Coming soon… **updated soil water budget model**
- Preliminary sensitivity analysis used to identify parameter ranges of geologic units that can improve model fit

PRMS simulates recharge and streamflow going into the system



How was the geology enhanced?

Figure 7 The WalkTEM unit.

Figure 5 The WalkTEM transmitter cable being positioned.

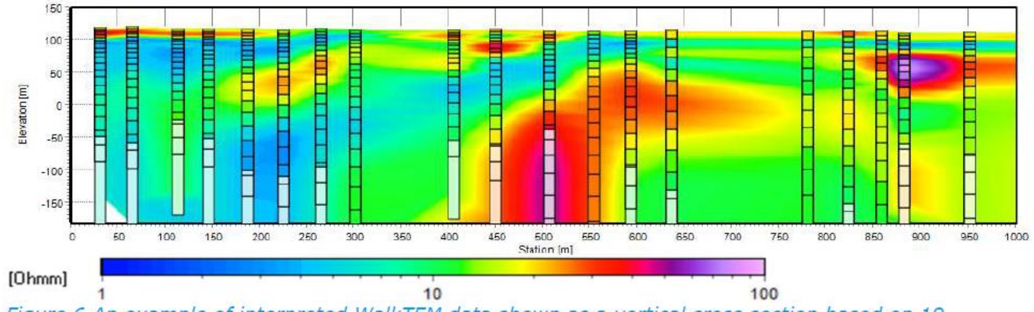
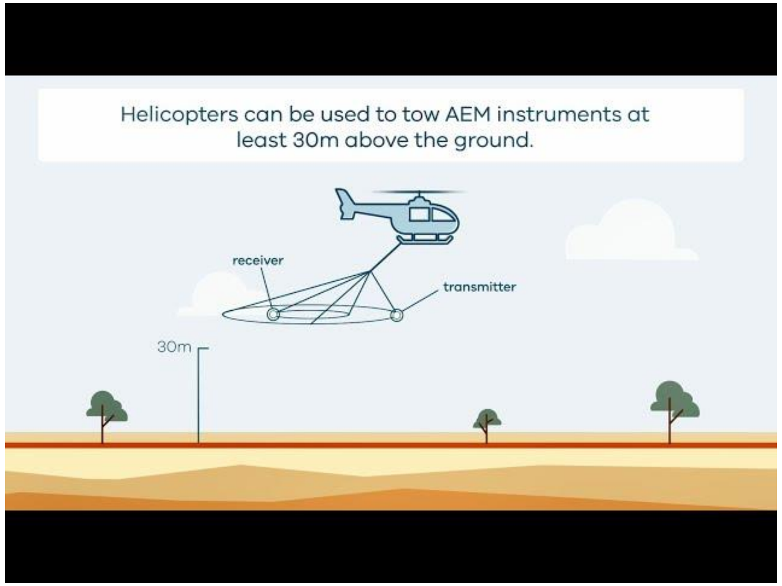
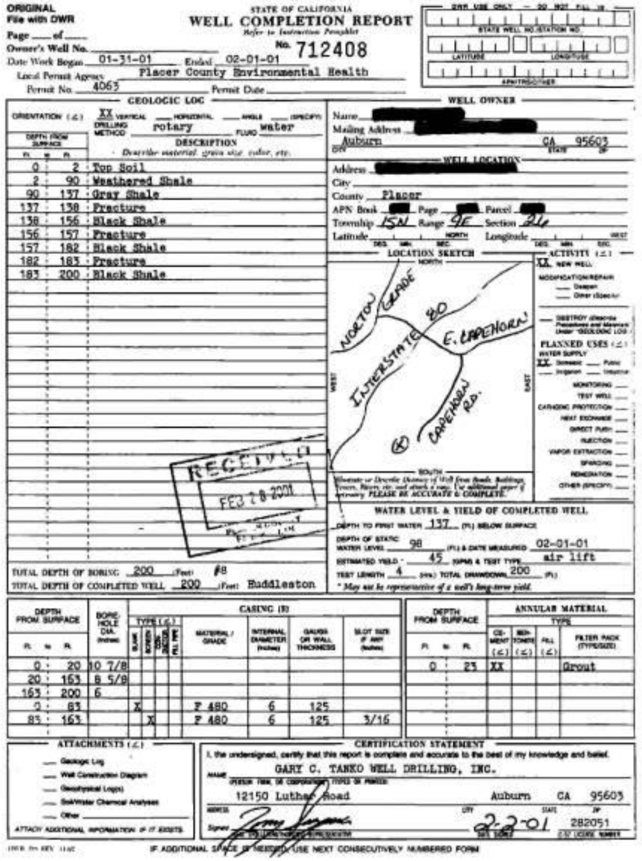


Figure 6 An example of interpreted WalkTEM data shown as a vertical cross section based on 19 WalkTEM soundings measured at a site in the Cuyama river bed, California.





ORIGINAL
File with DWR

STATE OF CALIFORNIA
WELL COMPLETION REPORT
Refer to Instruction Pamphlet

Page ___ of ___
Owner's Well No. ___
No. 712408
Date Work Began 01-31-01 Ended 02-01-01
Local Permit Agency Placer County Environmental Health
Permit No. 4063 Permit Date ___

GEOLOGIC LOG

ORIENTATION XX VERTICAL ___ HORIZONTAL ___ ANGLE ___ (SPECIFY)
DRILLING METHOD rotary FLUID water

Depth from surface (ft. to ft.)		Description
0	2	Top Soil
2	90	Weathered Shale
90	137	Gray Shale
137	138	Fracture
138	156	Black Shale
156	157	Fracture
157	182	Black Shale
182	183	Fracture
183	200	Black Shale

TOTAL DEPTH OF BORING 200 (Feet) #8
TOTAL DEPTH OF COMPLETED WELL 200 (Feet) Huddleston

WELL OWNER
Name [redacted]
Mailing Address [redacted]
Auburn CA 95603

WELL LOCATION
Address [redacted]
City
County Placer
APN Book [redacted] Page [redacted] Parcel [redacted]
Township 15N Range 9E Section 26
Latitude ___ Longitude ___

LOCATION SKETCH
NORTON GRADE
80
E. CAPEHORN
INTERSTATE
CAPEHORN RD.
SOUTH

ACTIVITY
XX NEW WELL
MODIFICATION/REPAIR
PLANNED USES

RECEIVED
FEB 28 2001

WATER LEVEL & YIELD OF COMPLETED WELL
DEPTH TO FIRST WATER 137 (Ft.) BELOW SURFACE
DEPTH OF STATIC WATER LEVEL 98 (Ft.) & DATE MEASURED 02-01-01
ESTIMATED YIELD* 45 (GPM) & TEST TYPE air lift
TEST LENGTH 4 (Hrs.) TOTAL DRAWDOWN 200 (Ft.)
* May not be representative of a well's long-term yield.

CASING (S)

Depth from surface (ft.)	to (ft.)	Bore-hole dia. (inches)	Blank	Screen	Con-ductor	Fill pipe	Material / grade	Internal diameter (inches)	Gauge or wall thickness	Slot size if any (inches)
0	20	10 7/8								
20	163	8 5/8								
163	200	6								
0	83		X				F 480	6	125	
83	163			X			F 480	6	125	3/16

ANNULAR MATERIAL

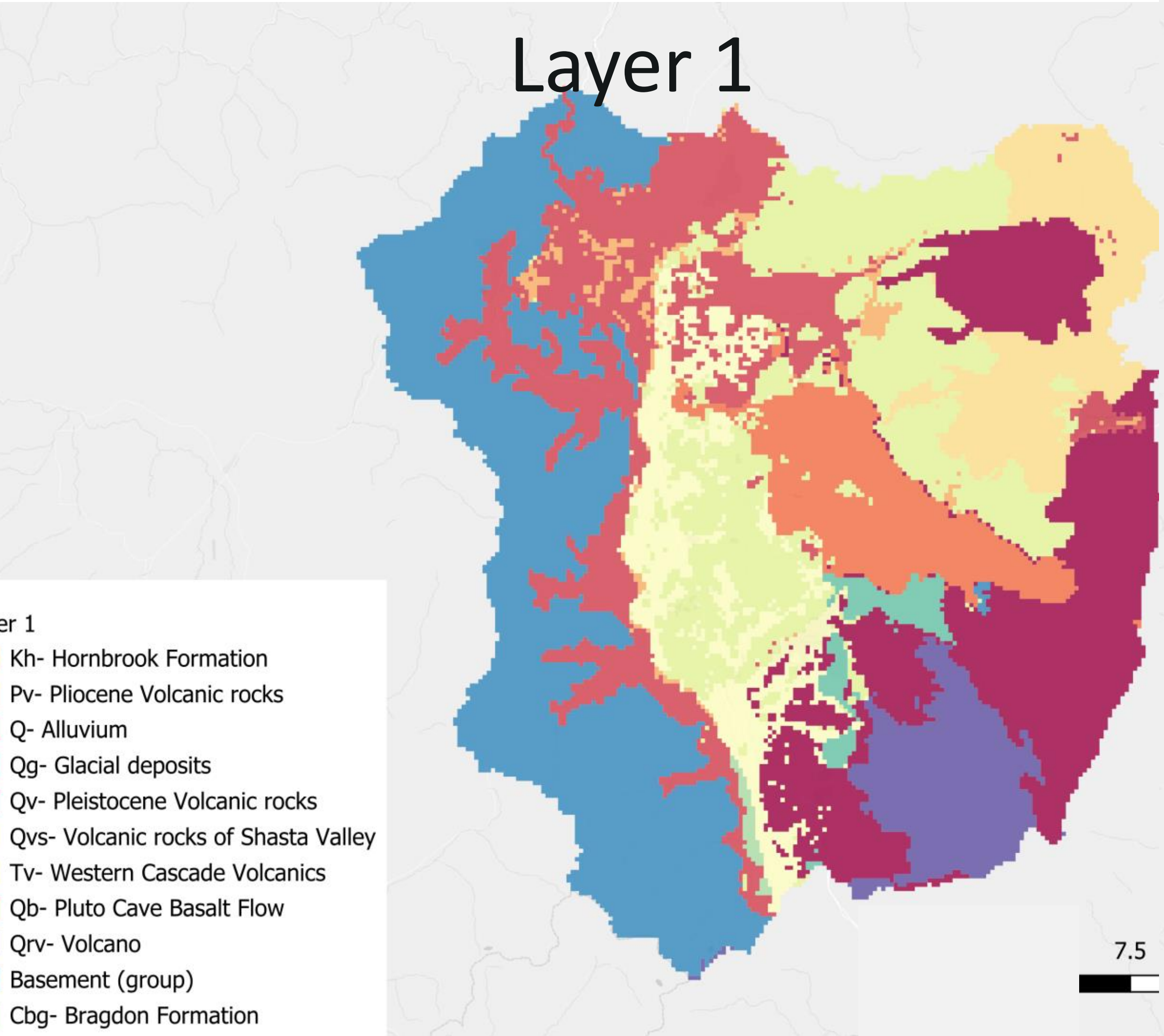
Depth from surface (ft.)	to (ft.)	Cement	Bentonite	Fill	Filter pack (type/size)
0	23	XX			Grout

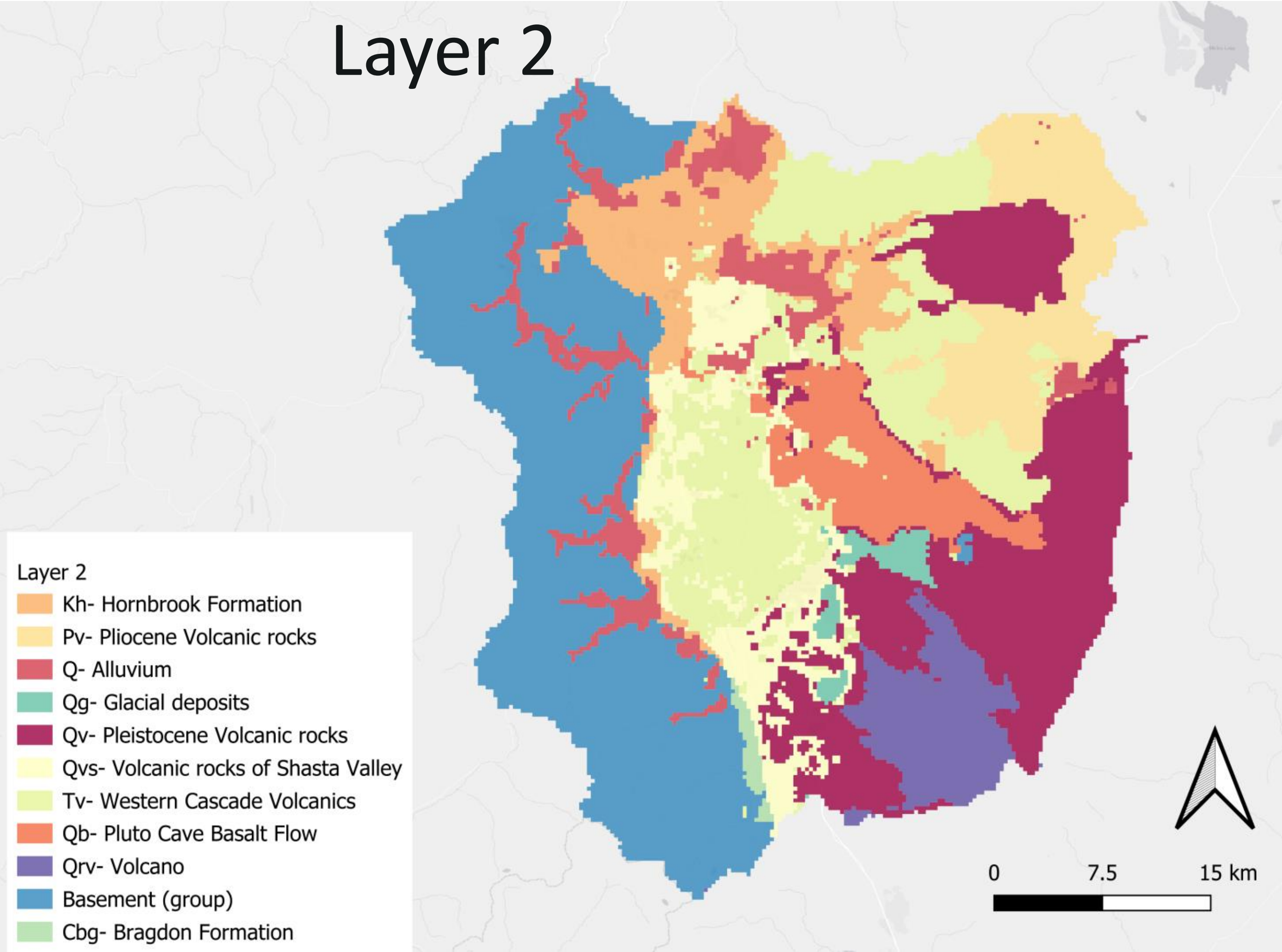
ATTACHMENTS
___ Geologic Log
___ Well Construction Diagram
___ Geophysical Log(s)
___ Soil/Water Chemical Analyses
___ Other ___

CERTIFICATION STATEMENT
I, the undersigned, certify that this report is complete and accurate to the best of my knowledge and belief.
NAME GARY C. TANKO WELL DRILLING, INC.
12150 Luther Road Auburn CA 95603
Signed 2-2-01 282051

IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

New Geologic Units for layer 1&2



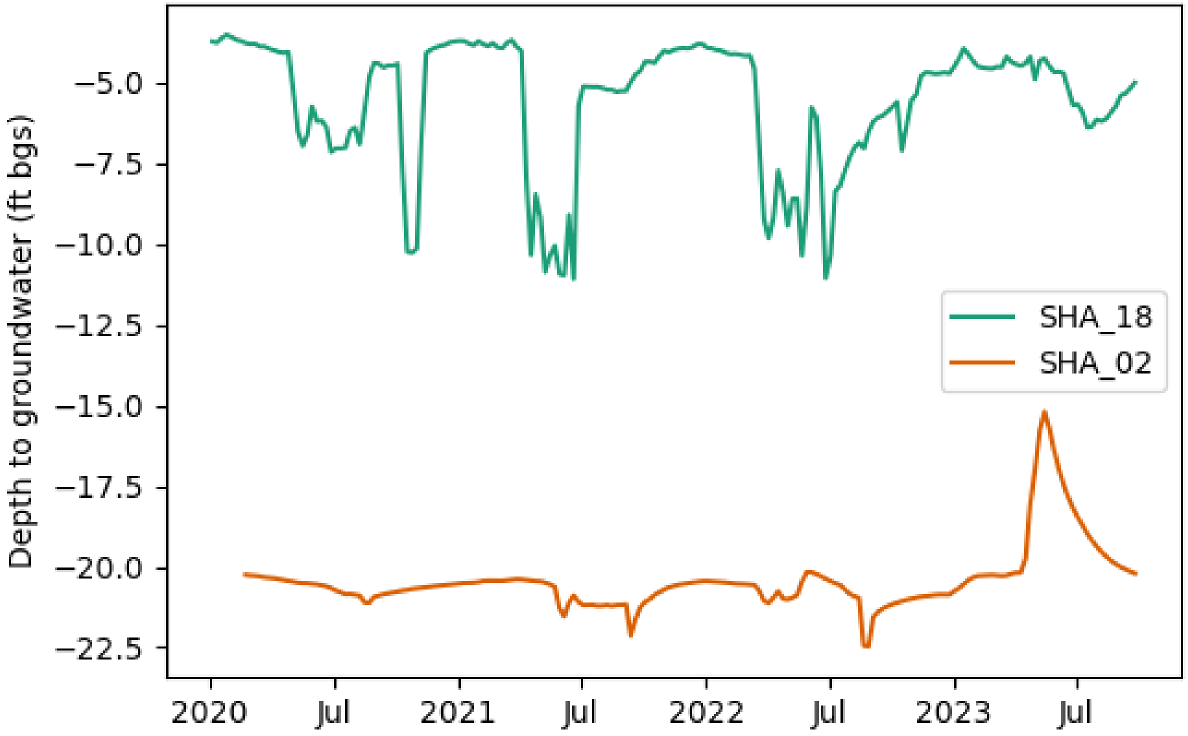


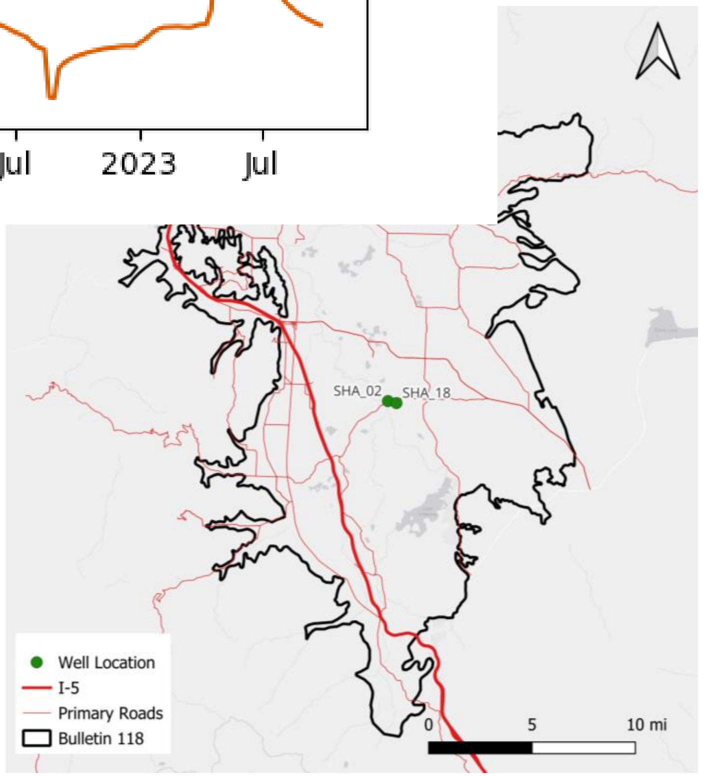
Updated Parameters

Zone	Description	Hydraulic Conductivity (m/d)	Specific Storage (m^{-1})	Specific Yield (-)	Vertical Anisotropy (-)
2	Kh - Hornbrook Formation	12	1×10^{-6}	0.25	10
10	Pv - Pliocene Volcanic Rocks	8.64	1×10^{-6}	0.1	10
12	Q - Alluvium	120	1×10^{-4}	0.2	10
13	Qg - Glacial Deposits	2	1×10^{-6}	0.2	10
15	Qv - Pleistocene Volcanic Rocks	1,000	1×10^{-6}	0.25	10
16	Qvs - Volcanic Rocks of Shasta Valley	3	1×10^{-6}	0.1	10
20	Tv - Western Cascade Volcanics	3	1×10^{-4}	0.2	10
24	Qb - Pluto Cave Basalt Flow	15	1×10^{-4}	0.15	10
27	Qrv - Volcano	1	1×10^{-6}	0.1	10
31	Basement	1.5	1×10^{-6}	0.15	10
32	Cbg - Bragdon Formation	3	1×10^{-5}	0.2	10

Even nearby wells show completely different behavior

- SHA_18 in Qb-Pluto Cave Basalt Flow: Pluto Cave Basalt has a higher head and large seasonal variations
- SHA_02 in Tv-Western Cascade Volcanics: Western Cascade Volcanics exhibit lower heads and dampened dynamics
- Very close proximity to each other but only SHA_18 “sees” the pumping signal

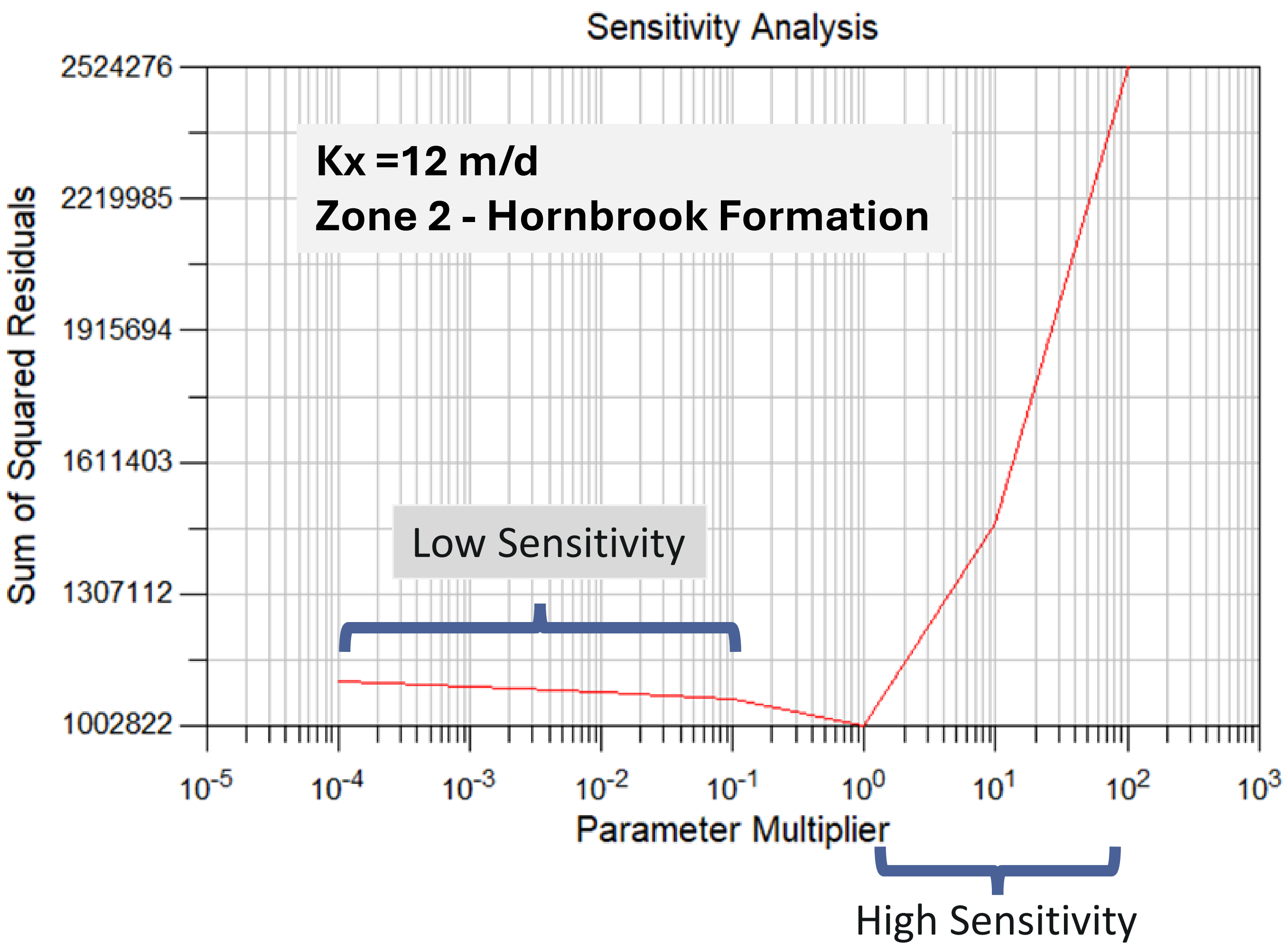




Once all the new data made it to the model… we started with a new sensitivity analysis

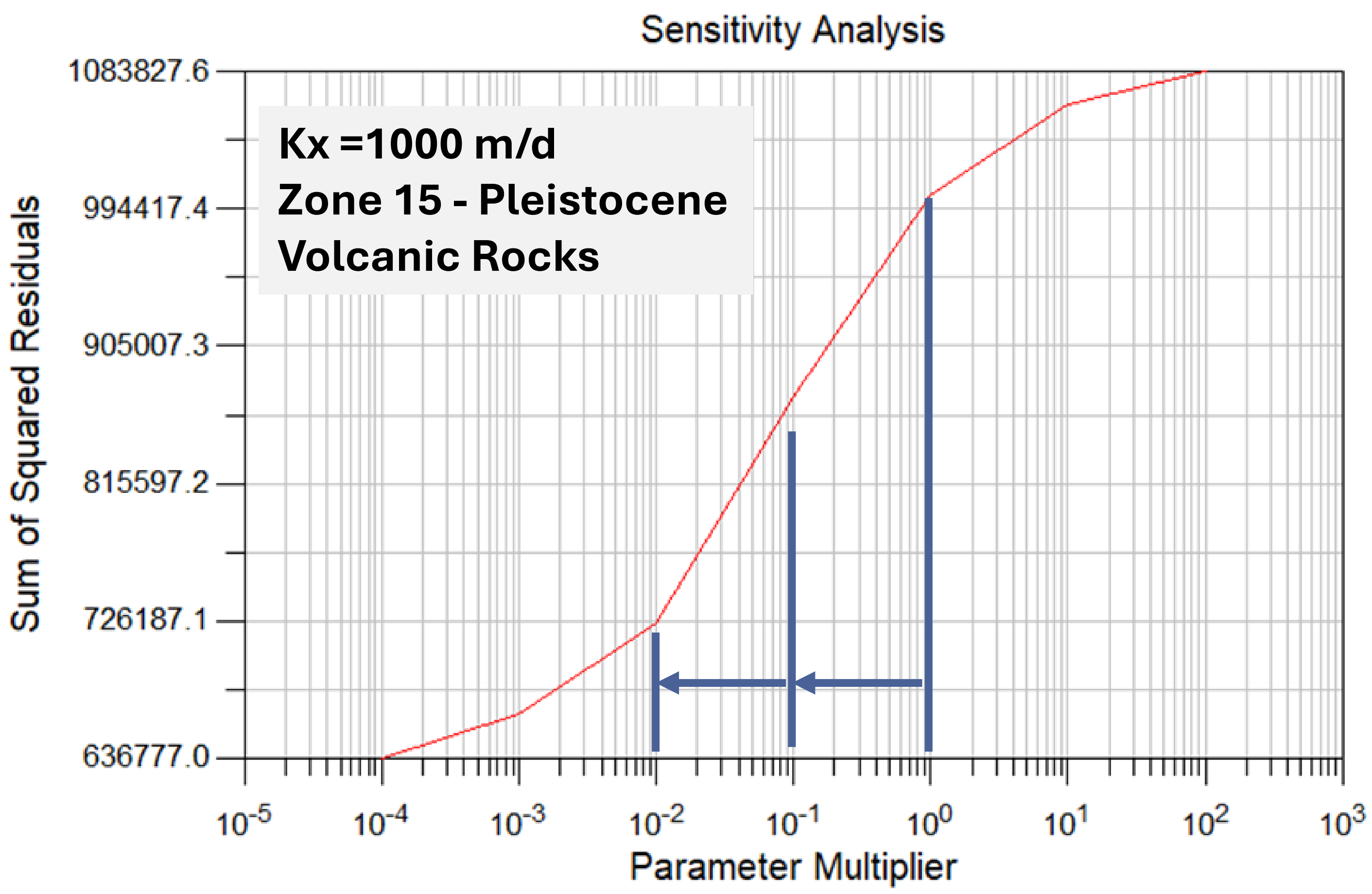
- Parameters included in the sensitivity analysis:
  - for the 12 geologic zones:
    - Hydraulic conductivity
    - Specific yield and specific storage
    - Vertical anisotropy --> this needs special attention
- Observations
  - Groundwater elevation at 78 locations
- To be included in the next sensitivity:
  - Streamflow at 9 streamgages

Identifying ranges of parameter sensitivity



- Each parameter was increased and decreased by multiplying by a range of magnitudes (e.g., 10^{-4} to 10^{2})
- The model sum of squared residuals (SSR) was recorded and plotted against the multiplier
- Large changes in SSR with the multiplier indicate large sensitivity

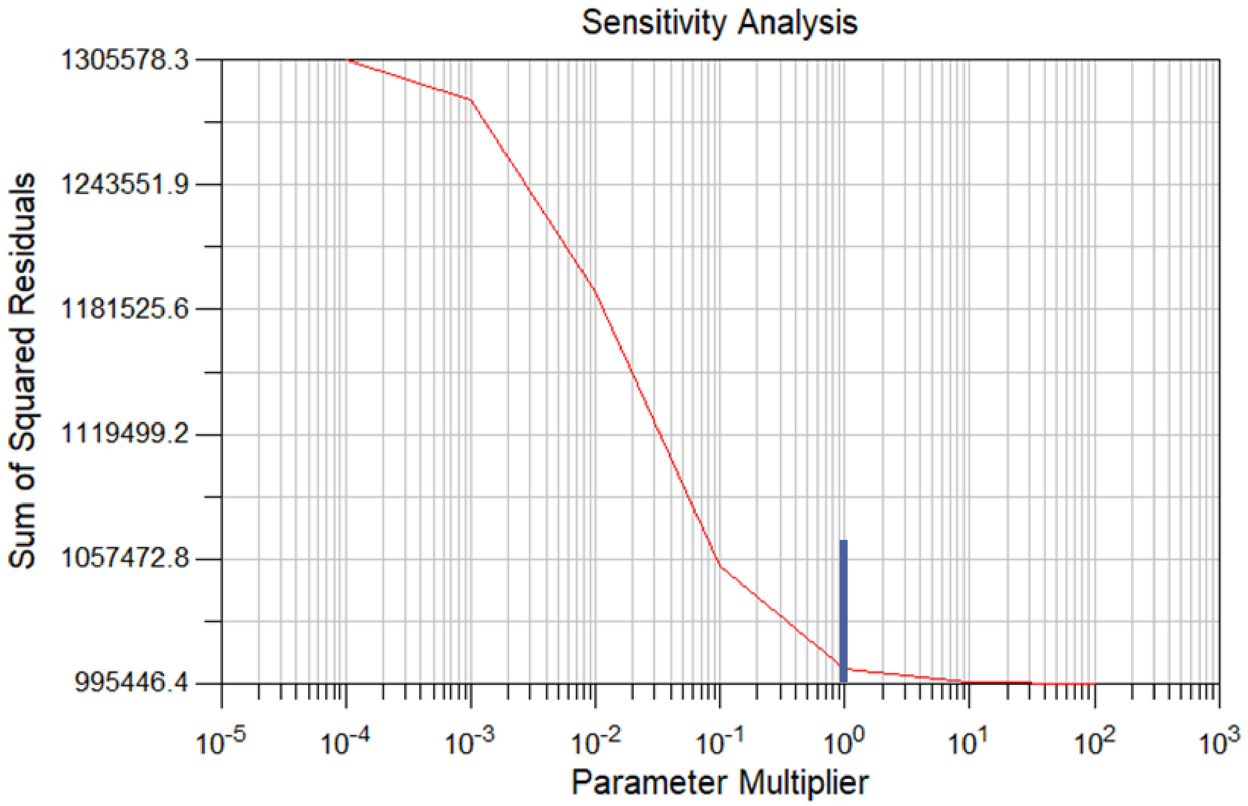
Volcanic rocks sensitivity suggest reducing Kx (m/d) by a factor of 10 to 100



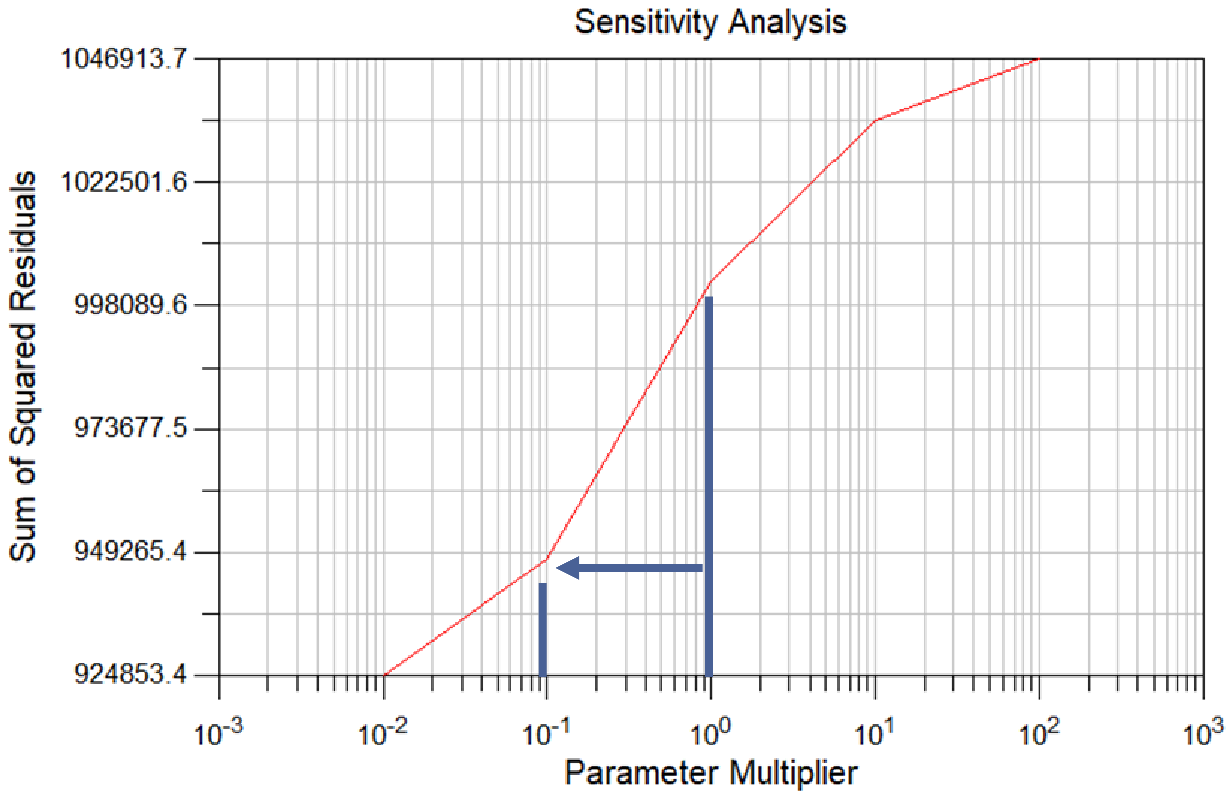
- Next steps:
  - Adjust parameters based on sensitivity results
  - Need to also consider parameter correlation when making adjustments

Maintaining or decreasing Kz (m/d) by a factor of 10 to 100

Kz = 1.2 m/d
Zone 2 – Hornbrook Formation

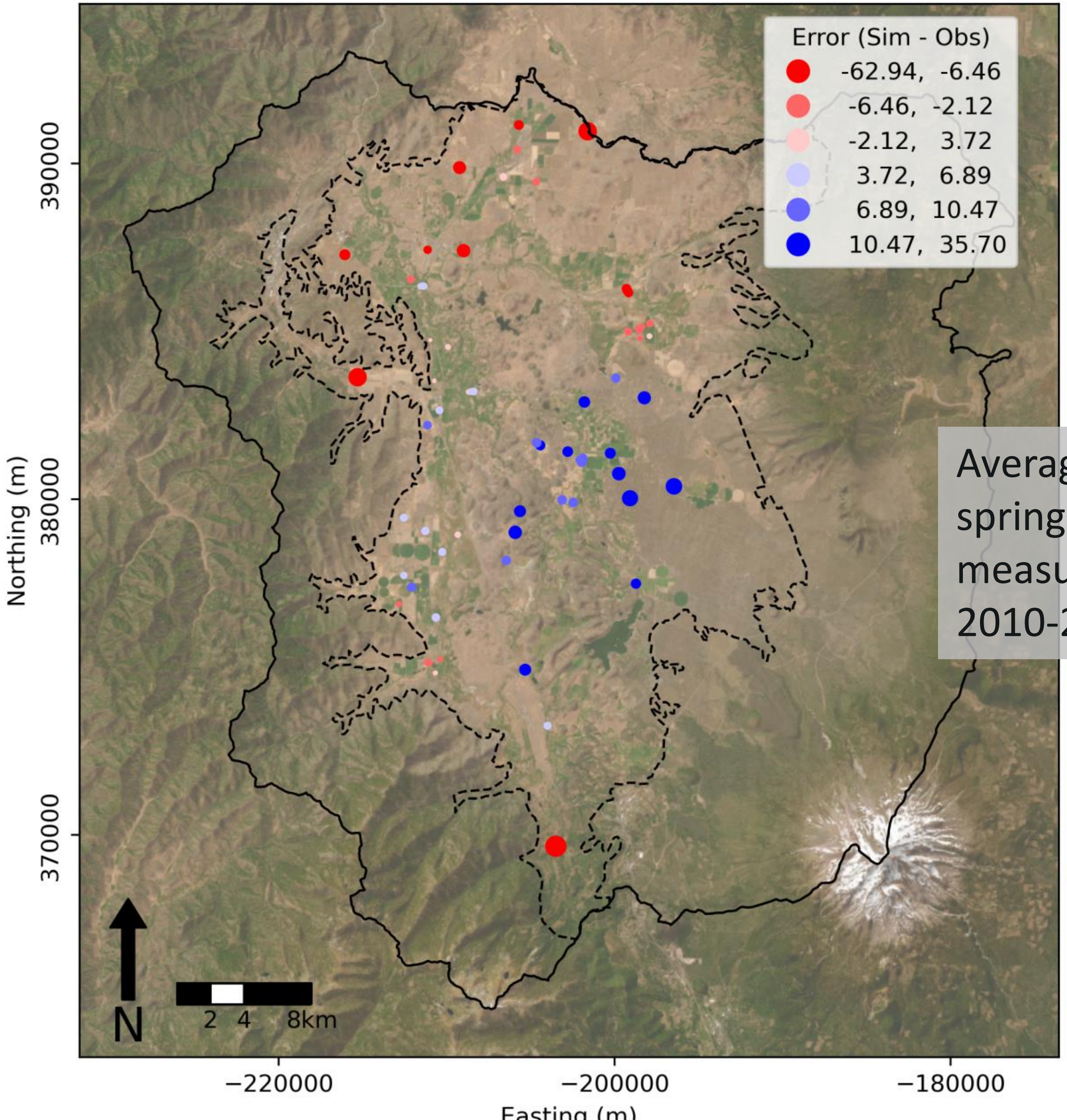


Kz = 0.15 m/d
Zone 31 - Basement complex



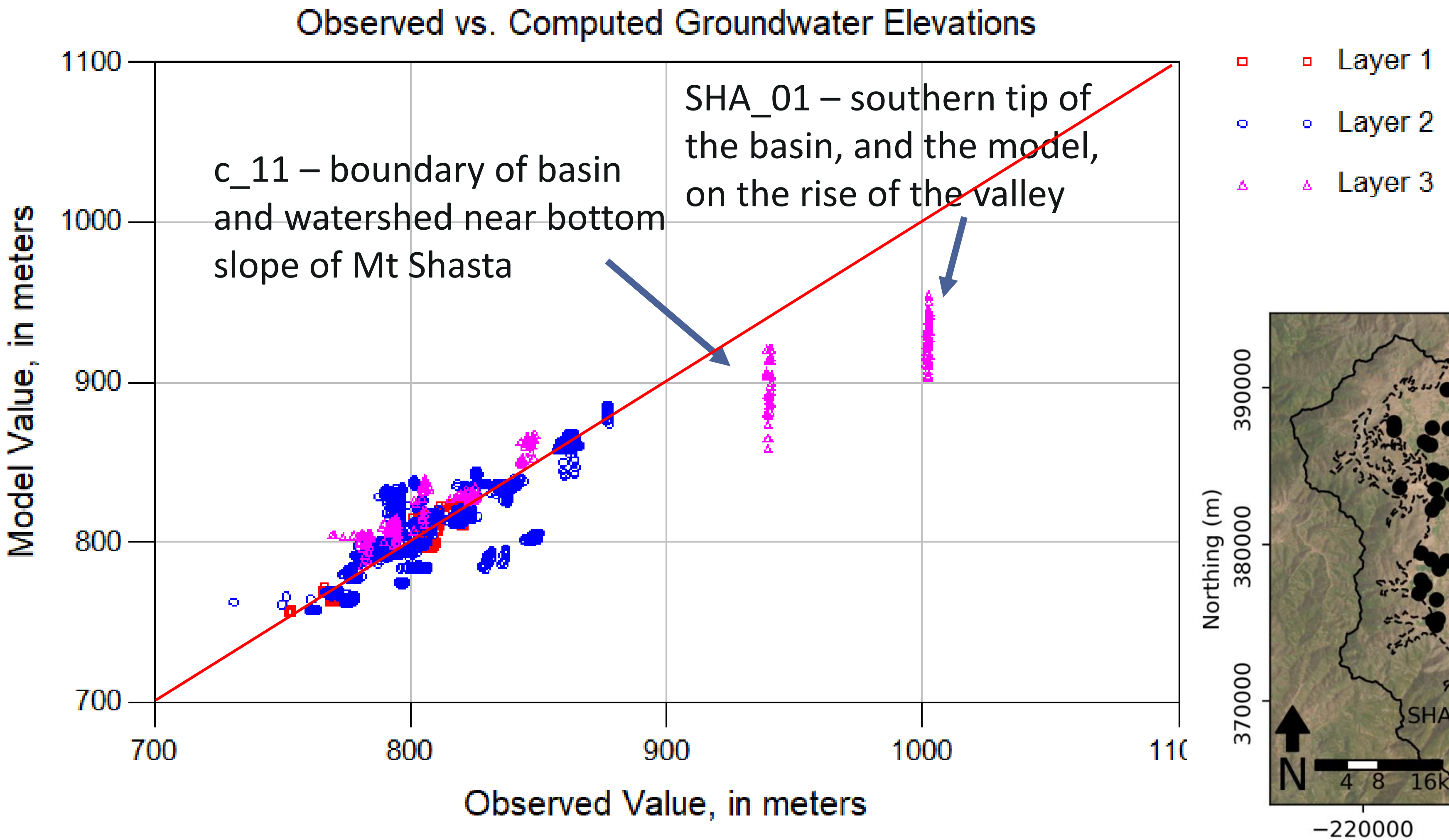
How well does the updated model work?

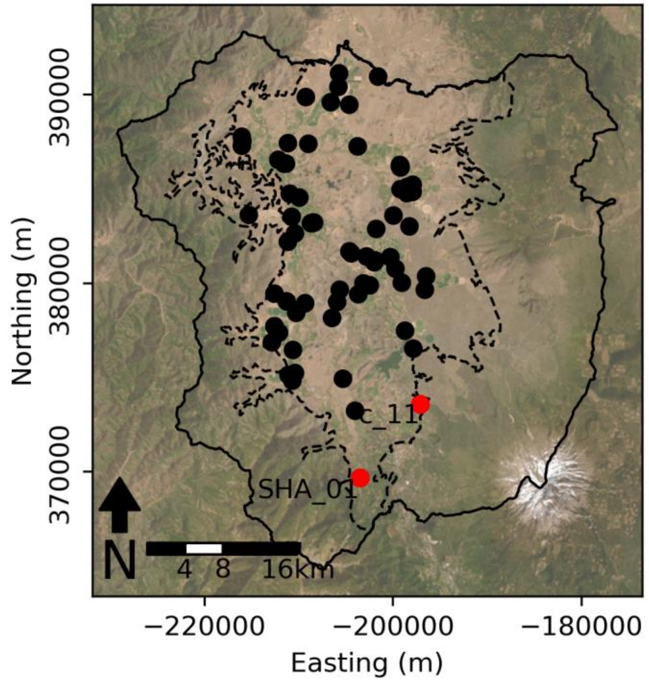
- Geologic units in the west and north generally see matching dynamics and magnitude
- Geologic units in south and central with complex boundaries and uncertain interior features see offsets in magnitude
- Need to work on the inflows...



Average error for spring (March-May) measurements 2010-2024

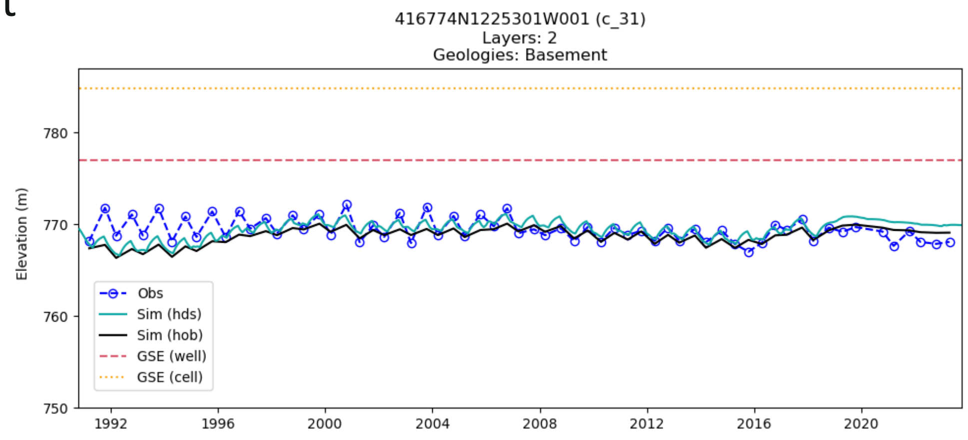
Model fit is aligned along the 1:1 with no apparent bias



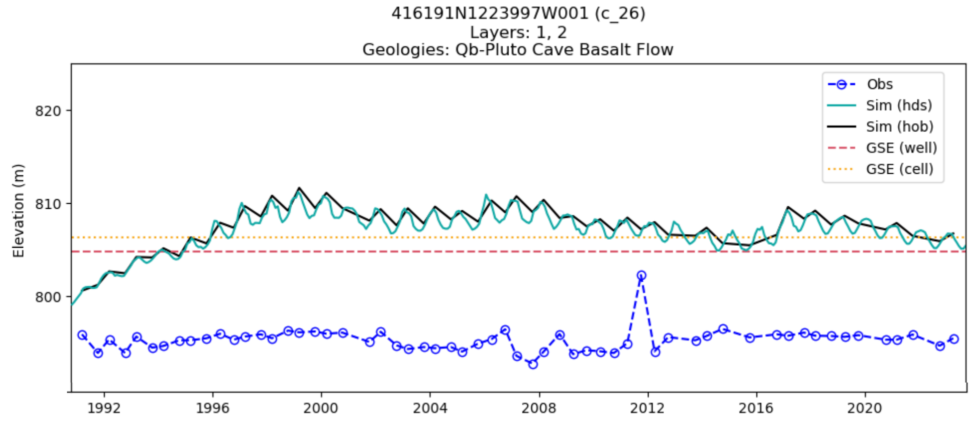


Dynamics beginning to align in west/north, suggests excess water in south/central

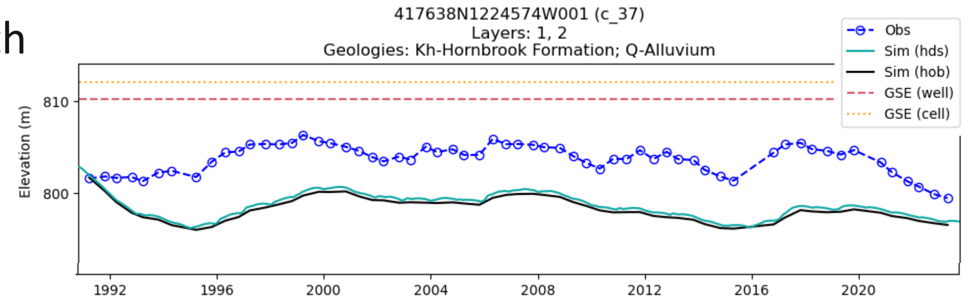
West



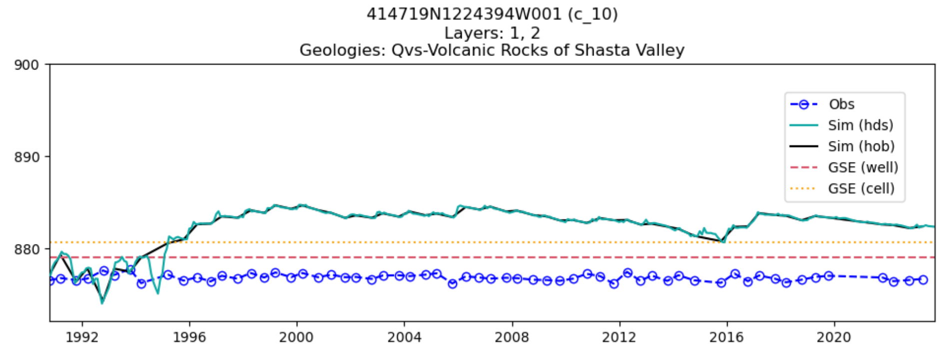
Central



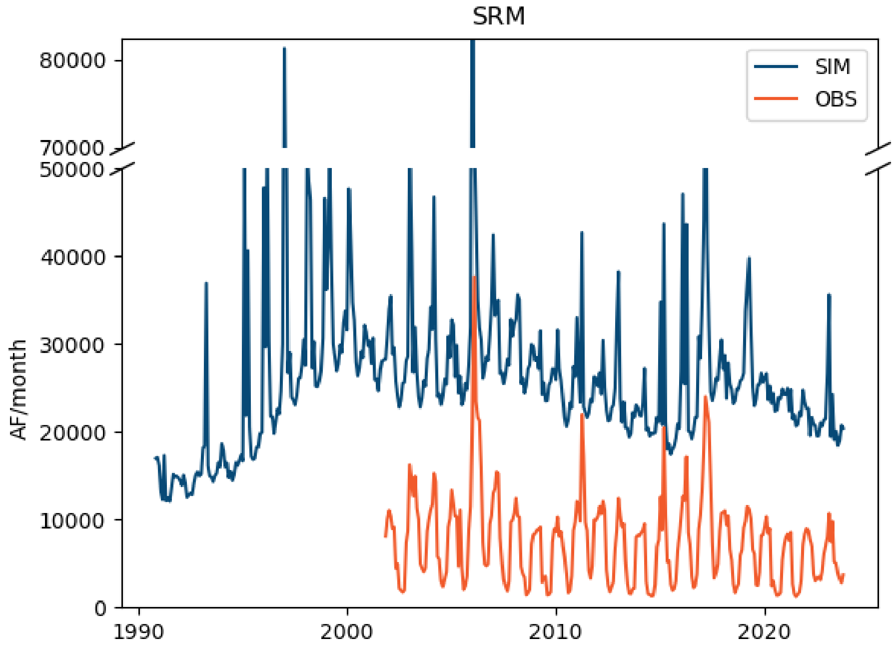
North

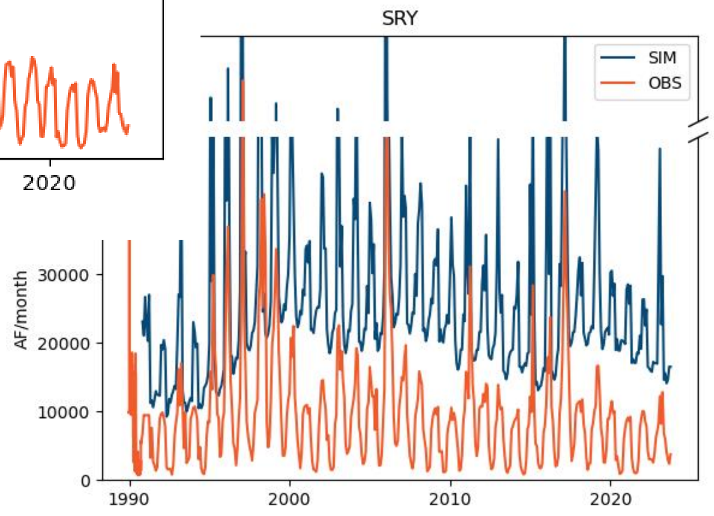


South

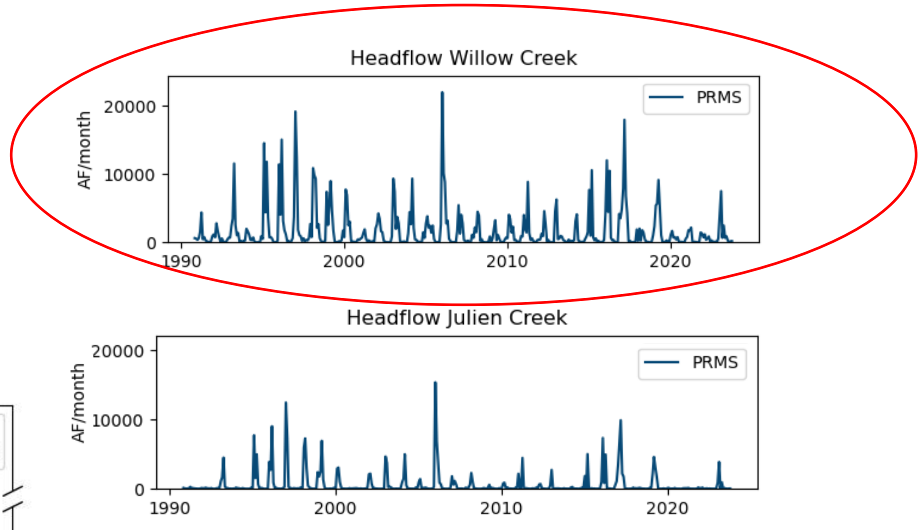


Excess flows are likely a combination of high baseflow from groundwater and excess streamflow from ungauged tributaries





Ungauged tributaries



Next steps

- (1) complete sensitivity analysis, (2) recalibrate model, including PRMS estimated recharge and inflows to streams
- Use model results to better assess interconnected surface water and demonstrate the sustainability of the basin (or what is needed to achieve sustainability!)
- Look at improving the model representation of the fractured aquifer system with alternate hydraulic parameter configurations or packages like the Conduit Flow Process (CFP)

Conclusion

- Relying on a comprehensive set of data, we could compare model results to observations throughout the valley and better evaluate model performance
- Spending time on getting the geology better and understanding the sensitivity of the geology parameters improved the model even before calibration and significantly reduced the computational time
- The model will be used/is being used for management decisions that will have an impact on the entire valley: we need to be as thorough as possible with our modelling assumptions and model calibration

THANK YOU!