Integrated Hydrologic Model Development and Evaluation (for Non-Modelers)

Douglas (Gus) Tolley, Ph.D.

Daniel B. Stephens & Associates, Inc.

GRA Cast, November 20th 2019

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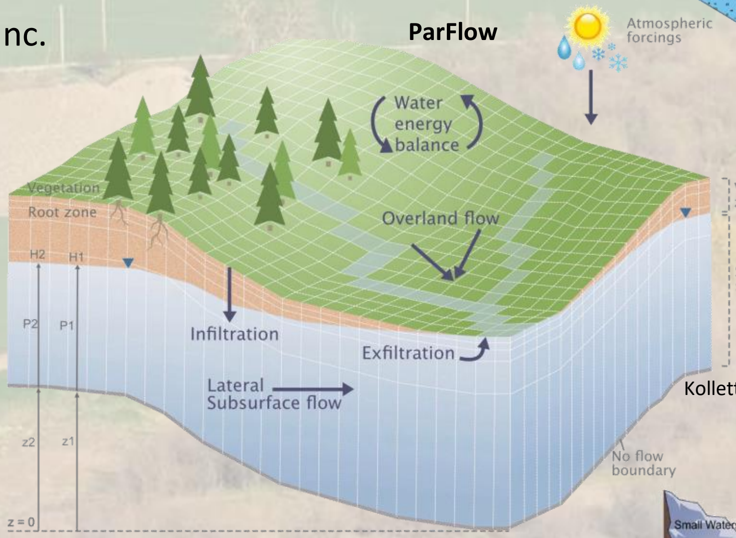
Hydrologic Sciences Graduate Group

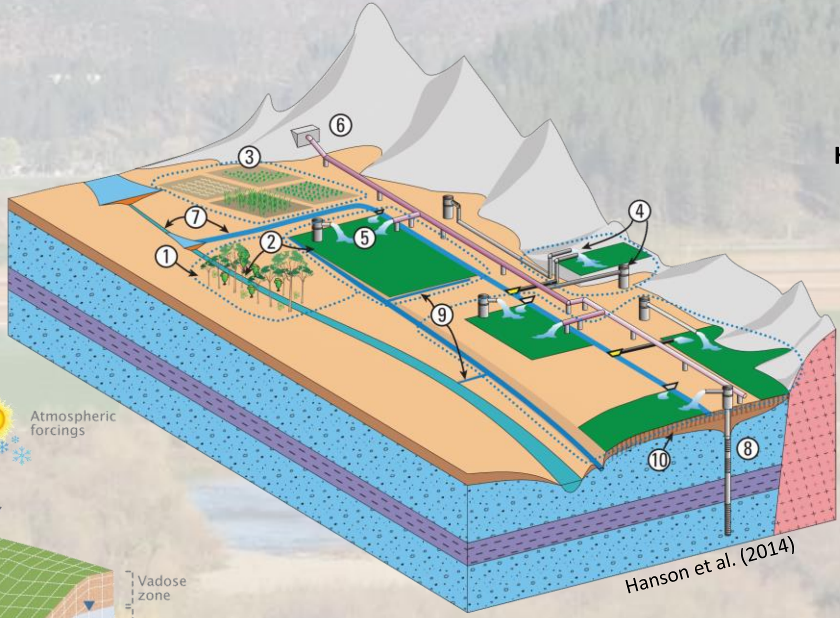
Water Boards

Groundwater Resources Association of California

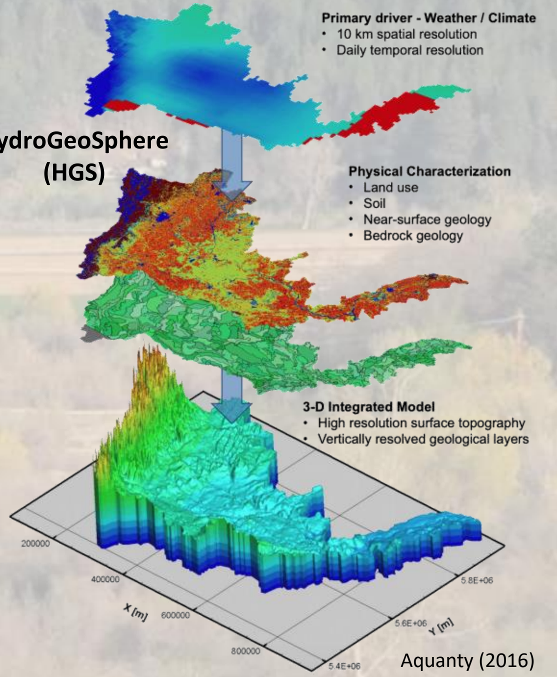


ParFlow

Kollett & Maxwell (2006)

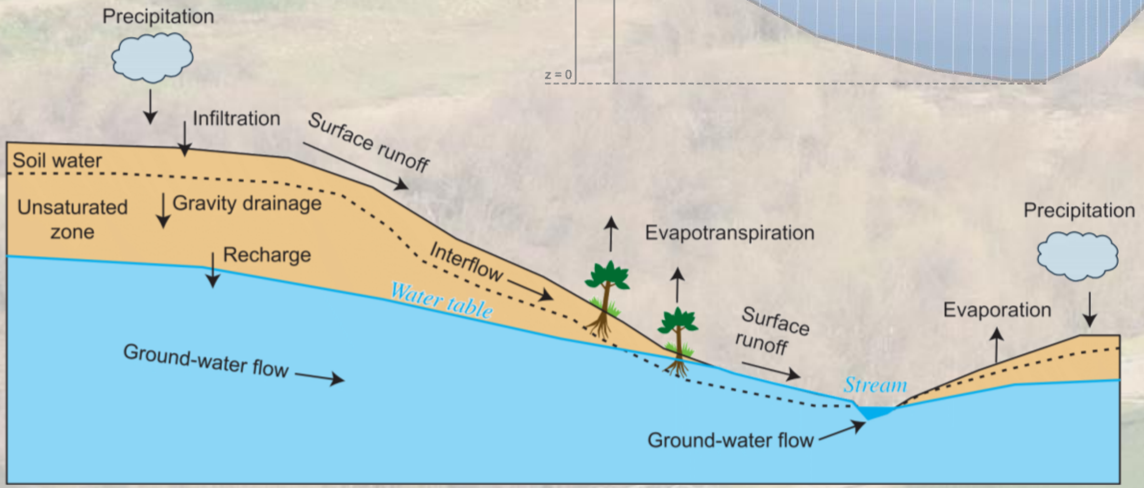


One-Water Hydrologic Flow Model (OWHM)



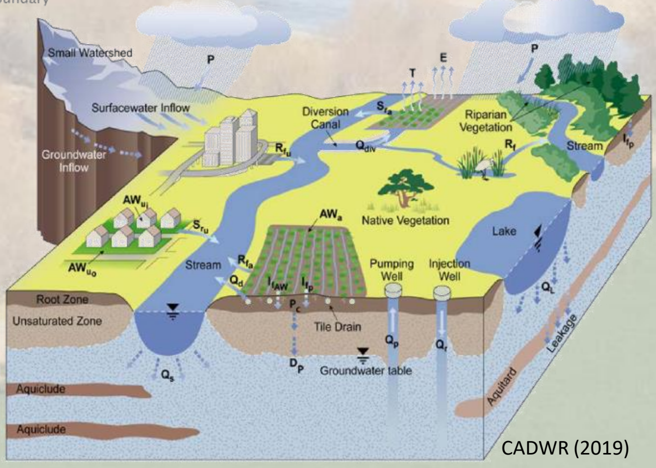
HydroGeoSphere (HGS)

Aquanty (2016)



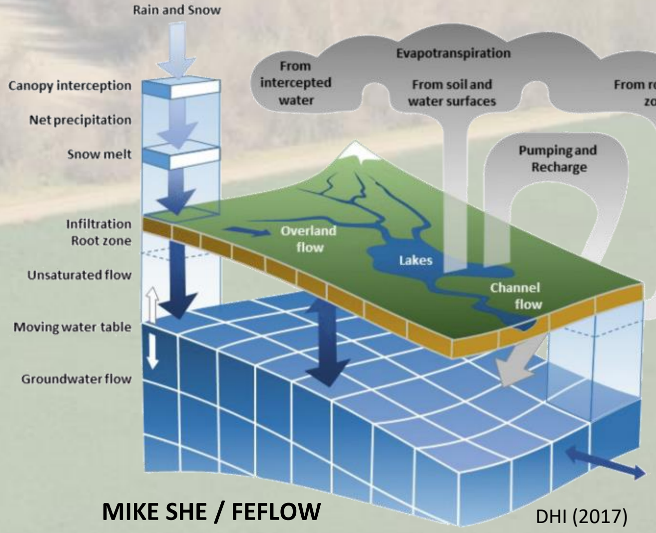
Groundwater and Surface Water Flow (GSFLOW)

Markstrom et al. (2008)



CADWR (2019)

Integrated Water Flow Model (IWFM)



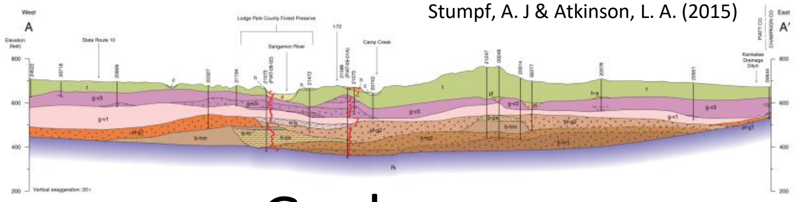
MIKE SHE / FEFLOW

DHI (2017)

Photo: Thomas Harter

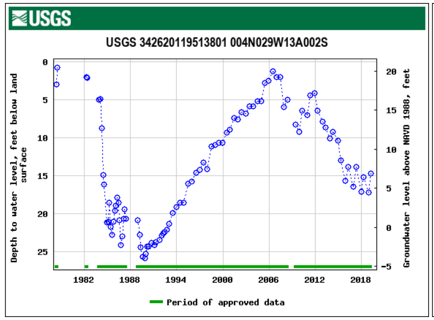
Models can be repositories of lots of different types of information.

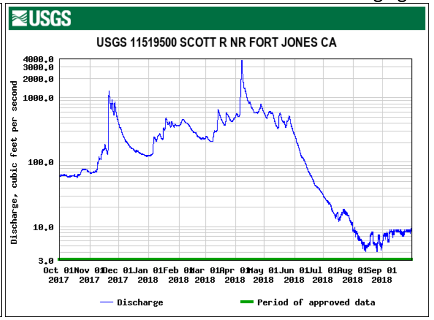
Stumpf, A. J & Atkinson, L. A. (2015)



Geology

nwis.waterdata.usgs.gov





Monitoring Data

commons.wikimedia.org

Expert Judgement

Hydrologic Model

Hydrology

fws.gov

Climate

eo.ucar.edu

Land Use

Google Earth

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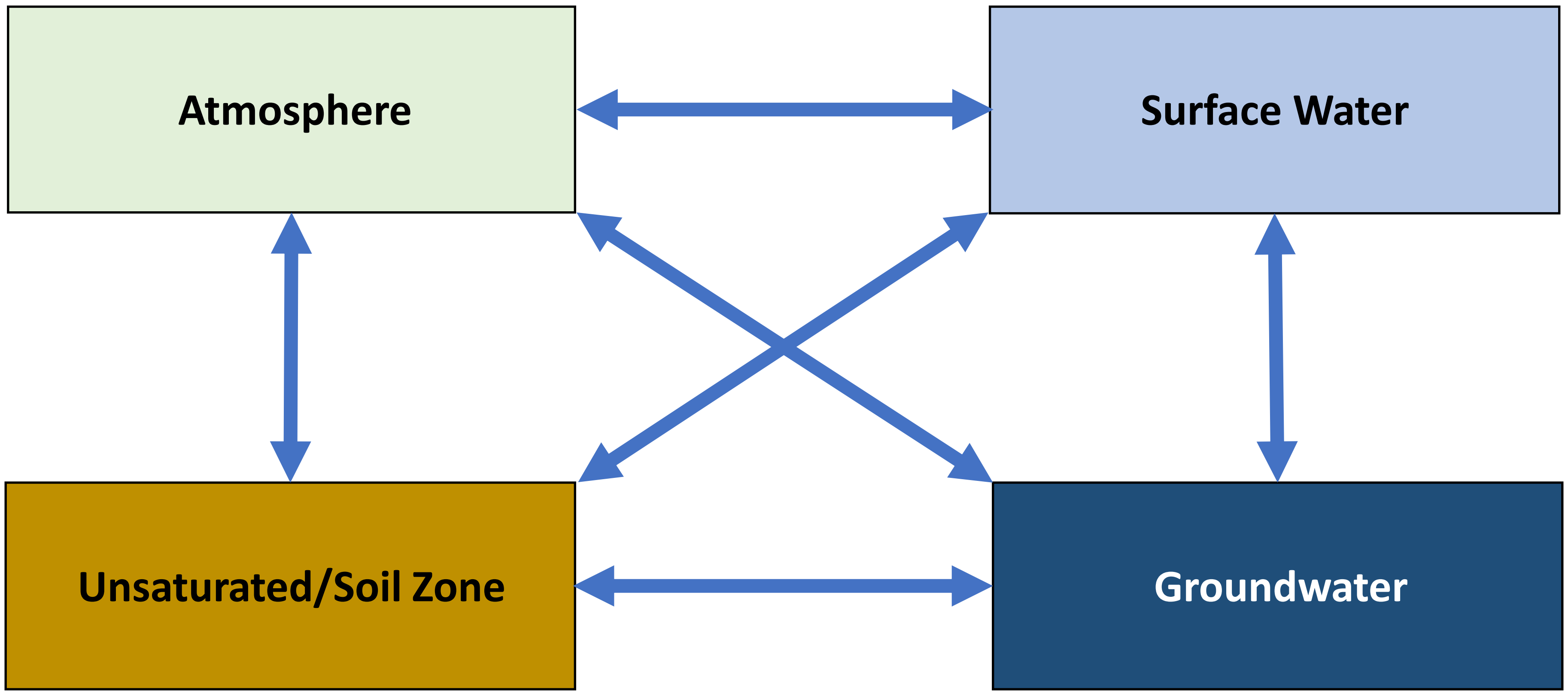
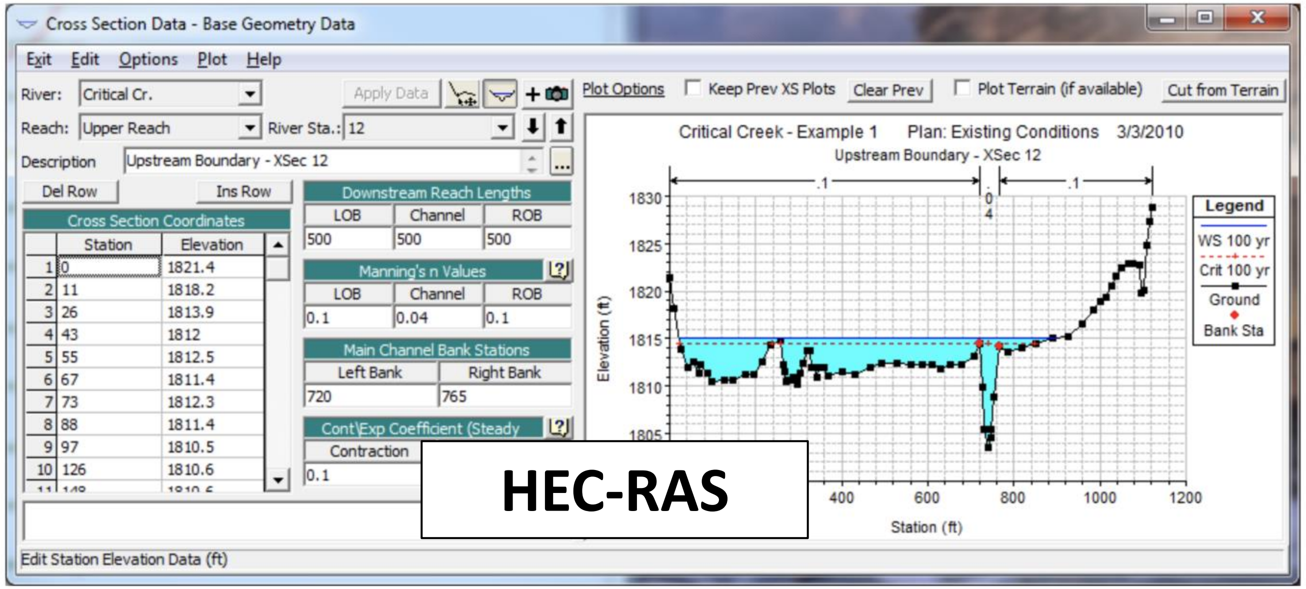
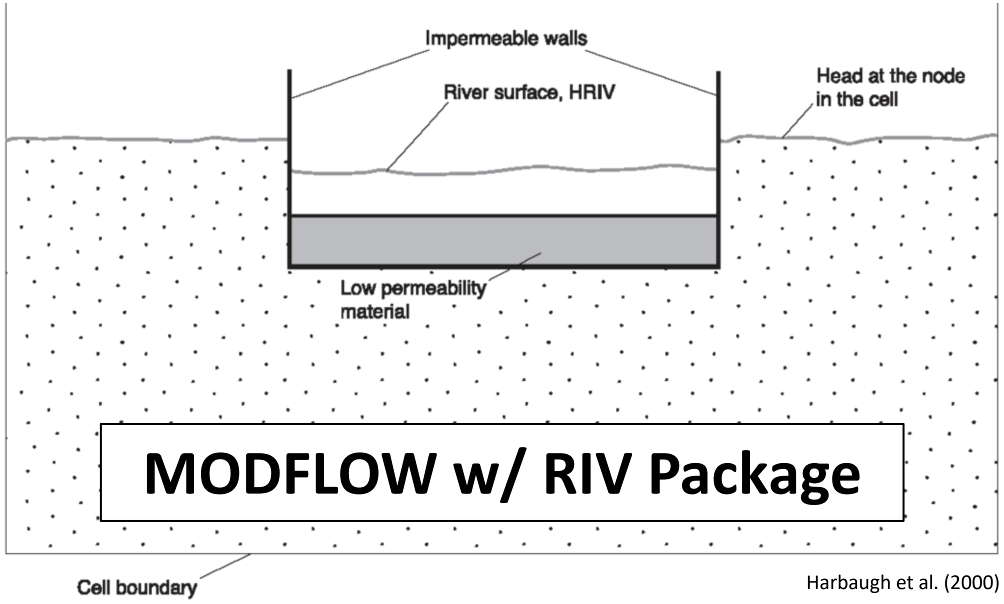
The hydrologic system of can be broadly classified into four subsystems.



Generally only one subsystem is simulated, with various methods for accounting for fluxes from other subsystems.



USACE (2016)



Harbaugh et al. (2000)

"The stage of the groundwater reservoir is assumed to be independent of the interflow from the river…"

"RIV does not simulate surface-water flow in the river – only the river/aquifer seepage."

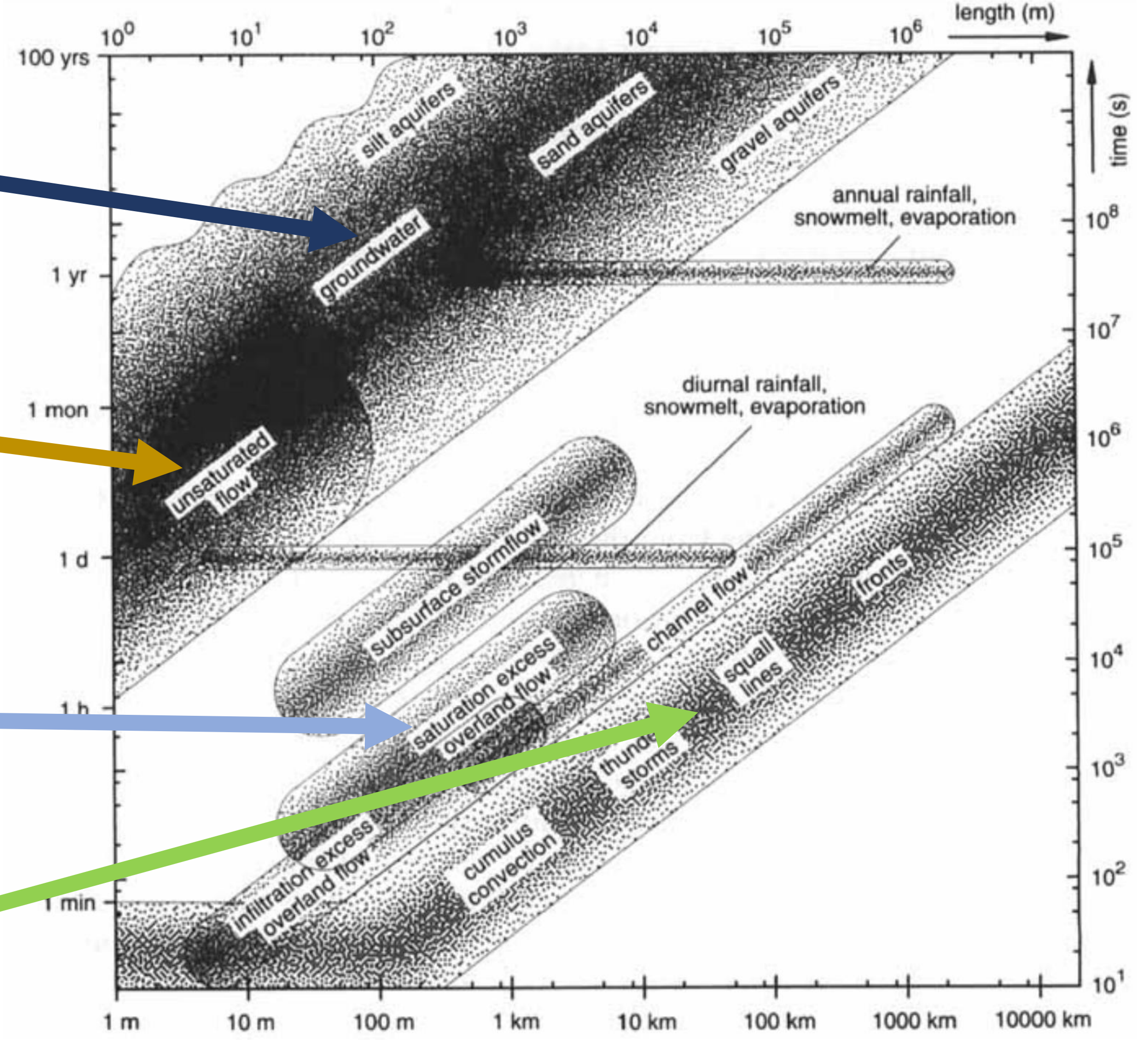
Hydrologic subsystems can have have length and time scales that vary over orders of magnitude.

Groundwater

Unsaturated/Soil Zone

Surface Water

Atmosphere



Time

Blöschl & Sivapalan (1995)

Length

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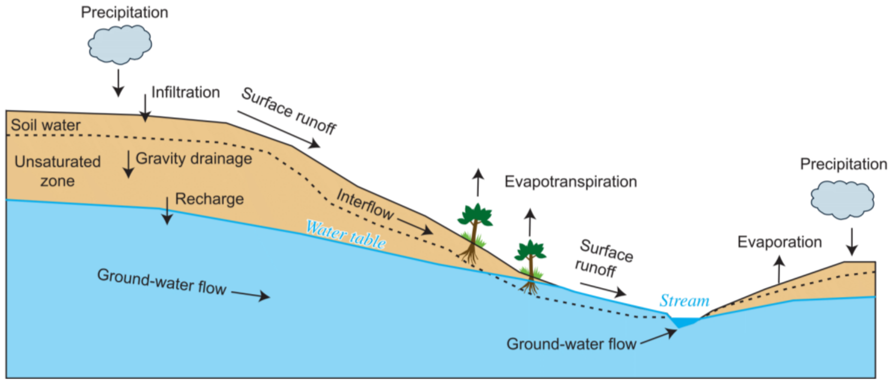
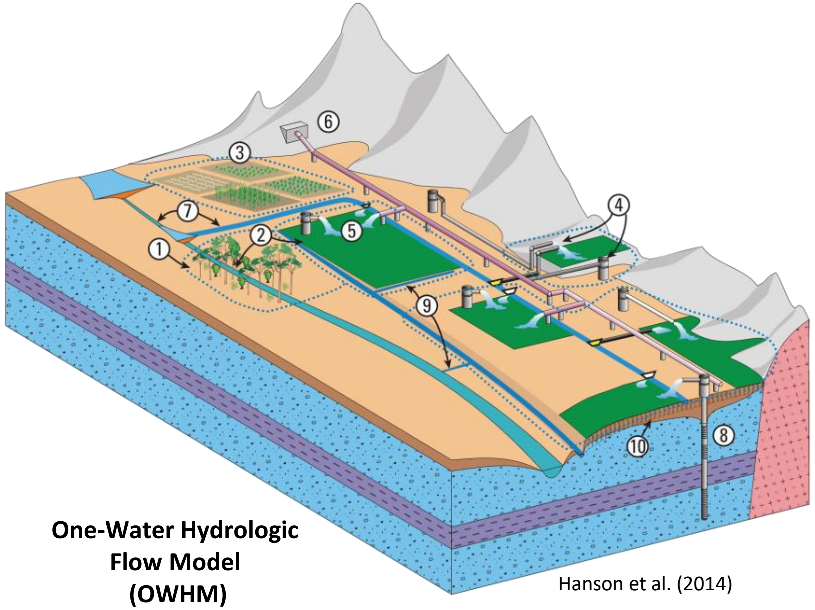
Integrated hydrologic models simulate two or more linked subsystems.

Surface-Water and Groundwater



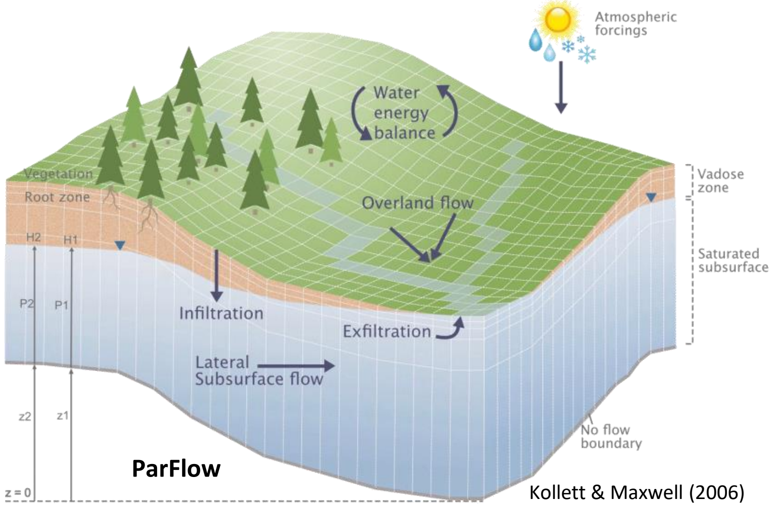
Groundwater and Surface Water Flow (GSFLOW) Markstrom et al. (2008)

Agriculture, Surface-Water, and Groundwater



One-Water Hydrologic Flow Model (OWHM) Hanson et al. (2014)

Climate, Soil Zone, Surface-Water, and Groundwater



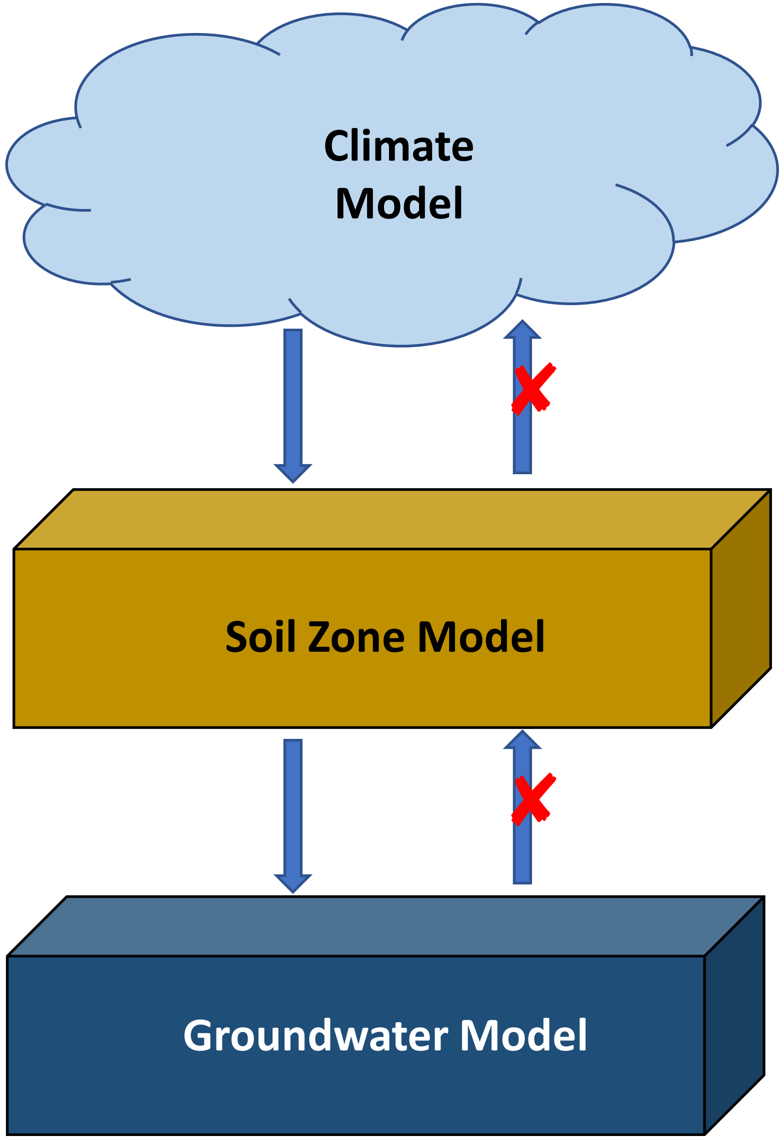
ParFlow Kollett & Maxwell (2006)

Weakly coupled models pass water from one subsystem to another, but only in one direction.

(Relatively) Simple, cheap, and easy!

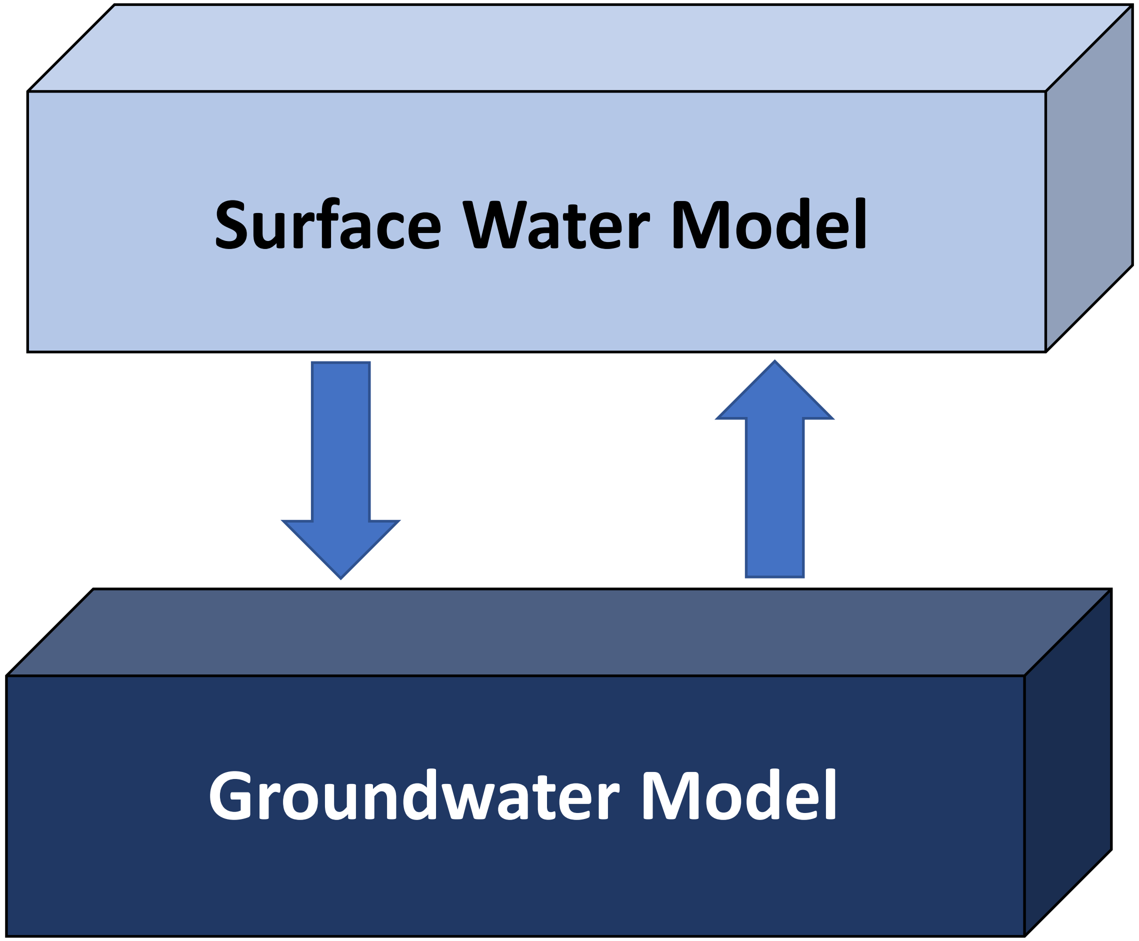
But…

…potentially miss important feedbacks



"Cascading" models

Iteratively coupled models solve each subsystem independently, and water is passed back and forth every timestep.



Increased complexity!

…and computational cost

…and nonlinearity

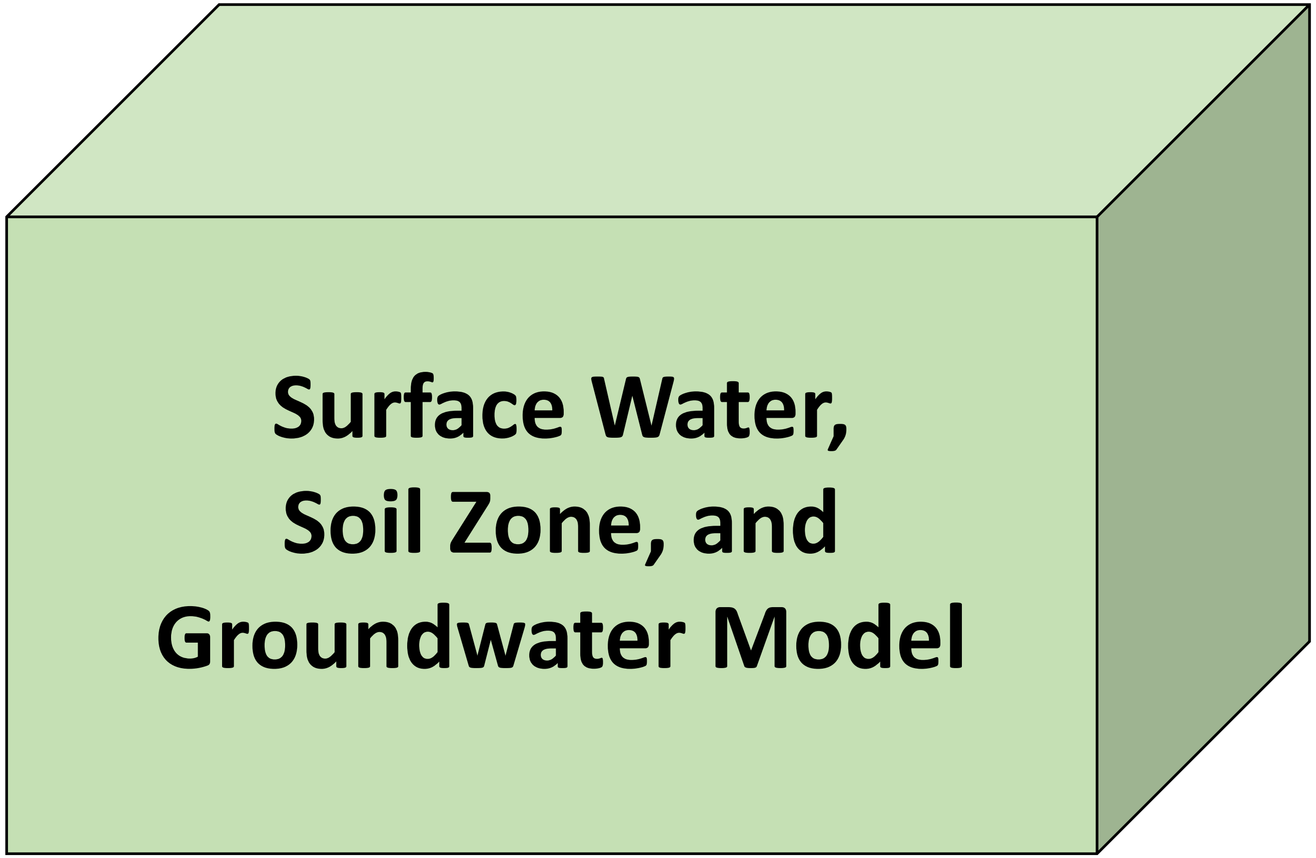
Fully coupled models solve all subsystems simultaneously using a single system of equations.

Detailed representation of physical processes!

But…

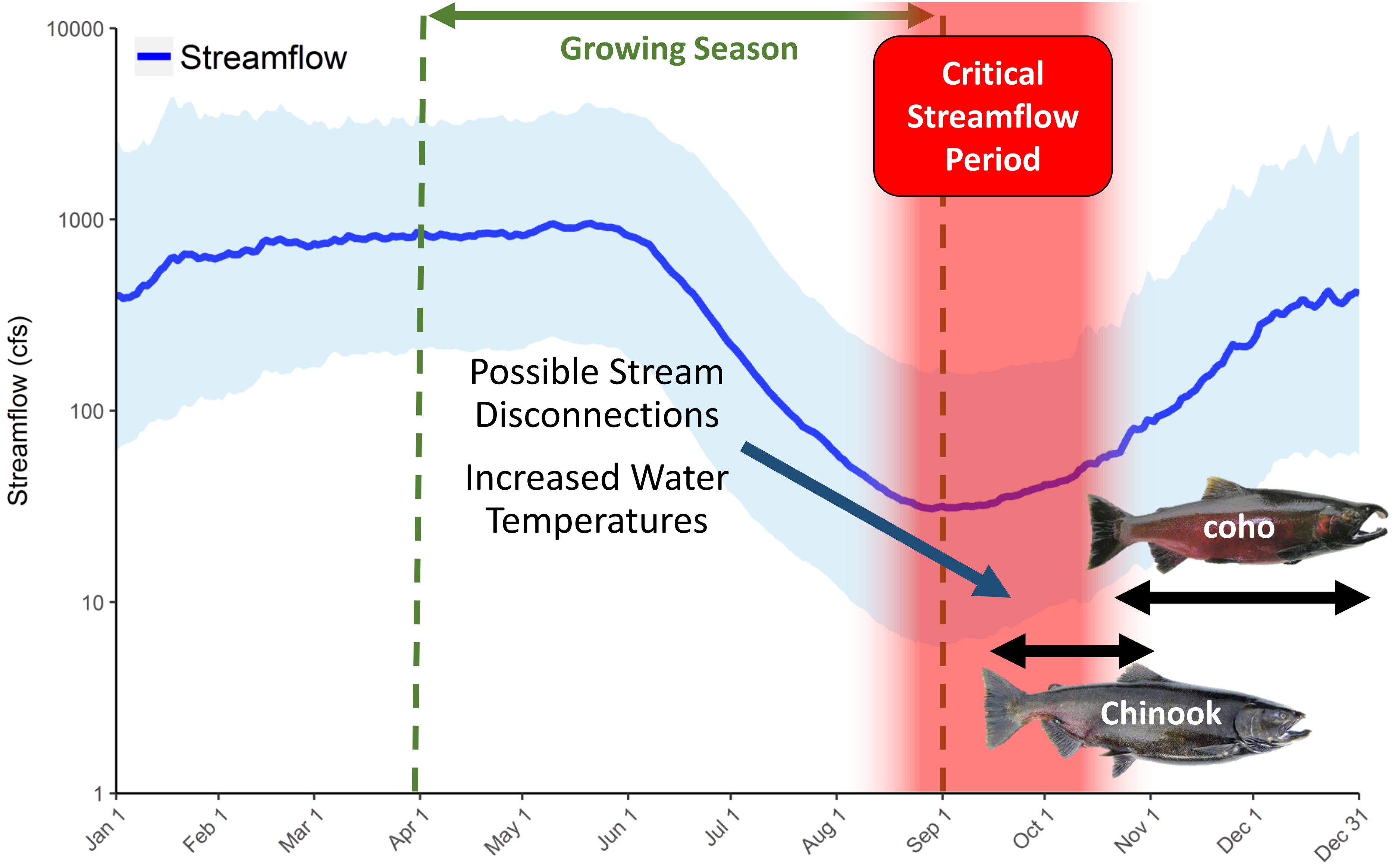
…computationally very expensive

…high degree of parameterization



Model development and evaluation should be centered around the question(s) being asked.

Late-summer streamflow is the primary concern in the Scott Valley.



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The Scott Valley Integrated Hydrologic Model (SVIHM) is the combination of three models and two types of coupling.

Upper Watershed Model

Streamflow entering Scott Valley (regression model)

Soil-Water Budget Model (SWBM)

Recharge and pumping within the valley (tipping bucket model)

Groundwater-Surface-Water Model

Detailed groundwater levels and streamflow (MODFLOW model)

Weakly Coupled

Iteratively Coupled

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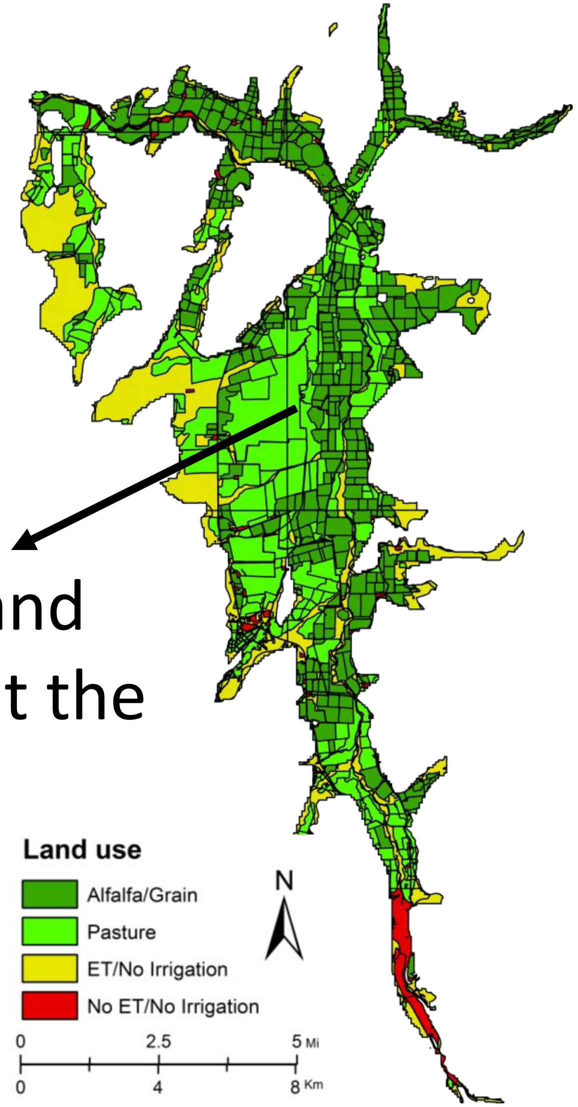
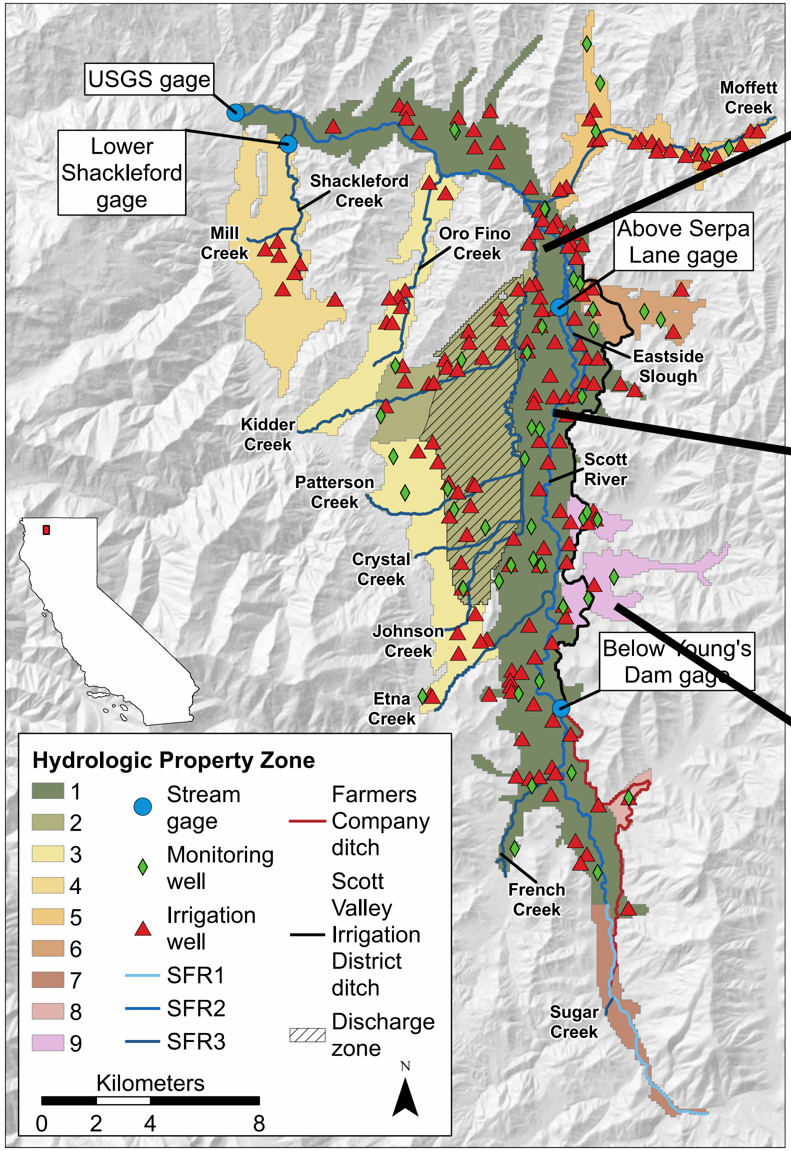
Building the model is often the easier part of model development.



Pumping and recharge at the field scale



100 m resolution

Streamflow Routing Package (SFR)

Monthly stress periods with daily timestep

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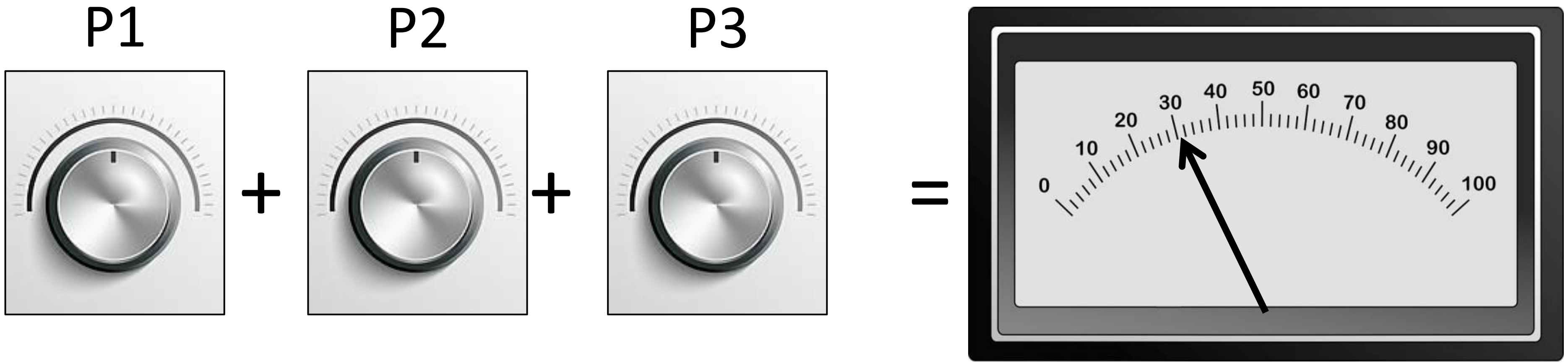
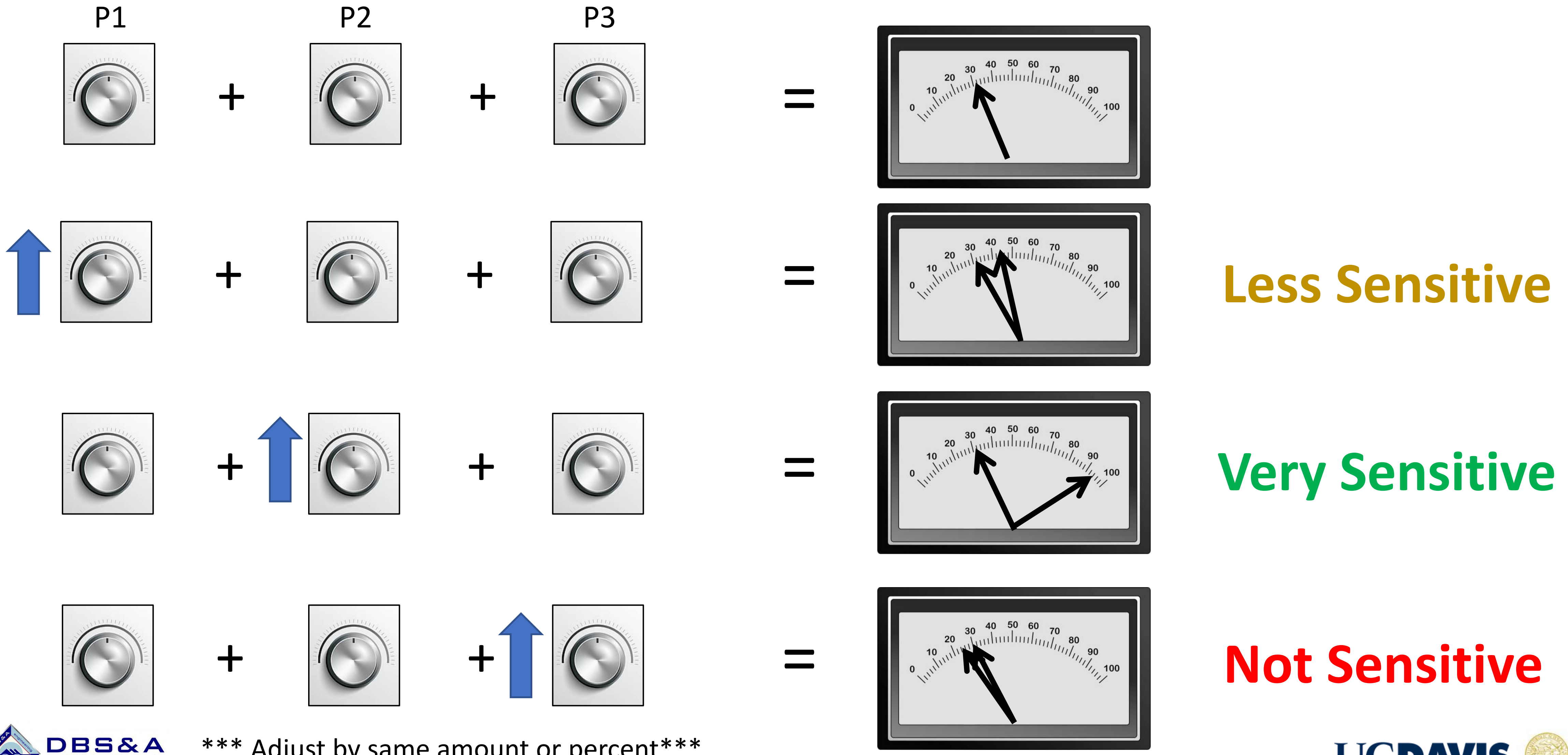
Sensitivity analysis and calibration are where modelers often spend most of their time.



Simple “black box” model

Parameters (model input) that change model outputs when perturbed are considered sensitive.



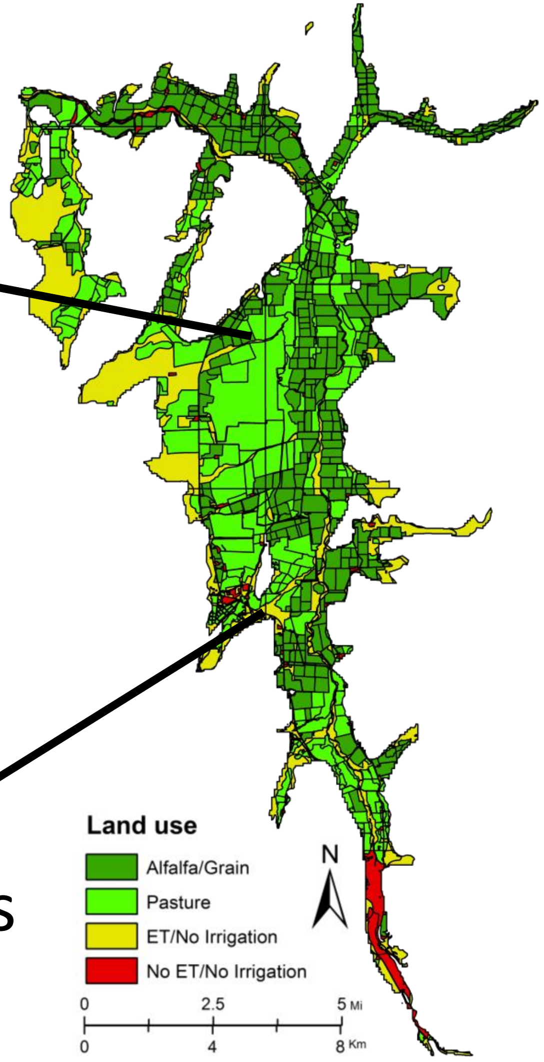
*** Adjust by same amount or percent***

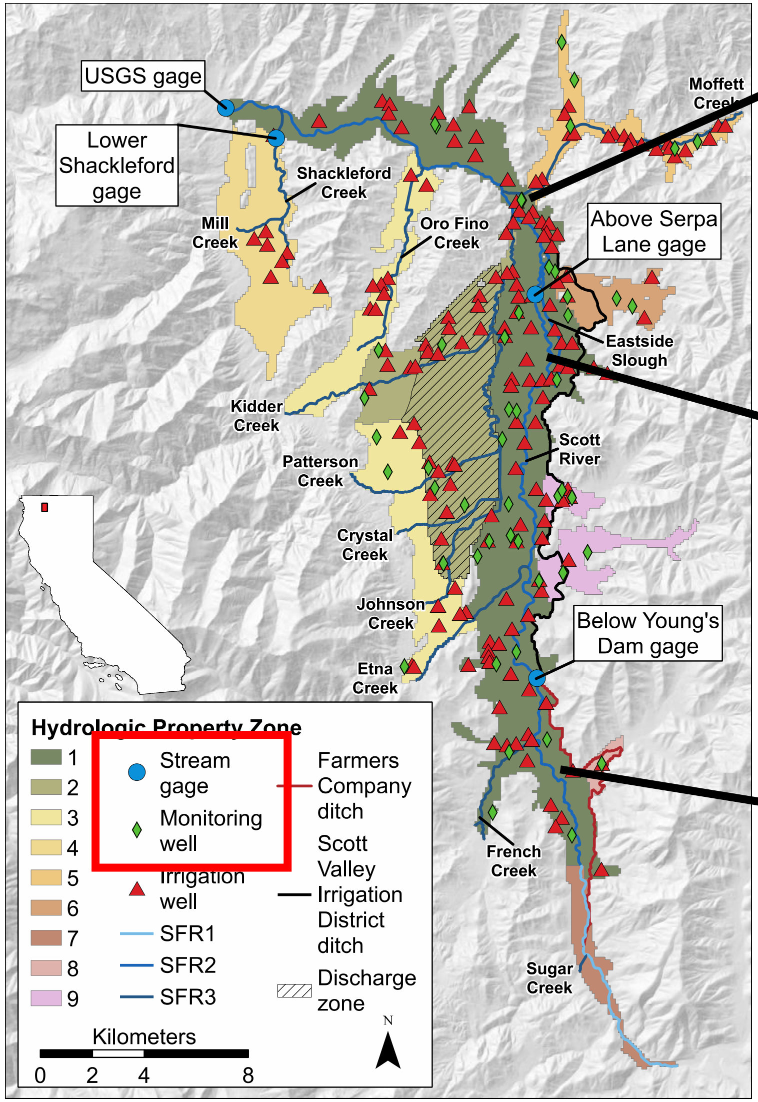
Relatively simple integrated models can have a large number of parameters that need to be evaluated.

Crop parameters

NP = 63

Field Parameters





Aquifer parameters

Stream parameters

Non-field recharge parameters

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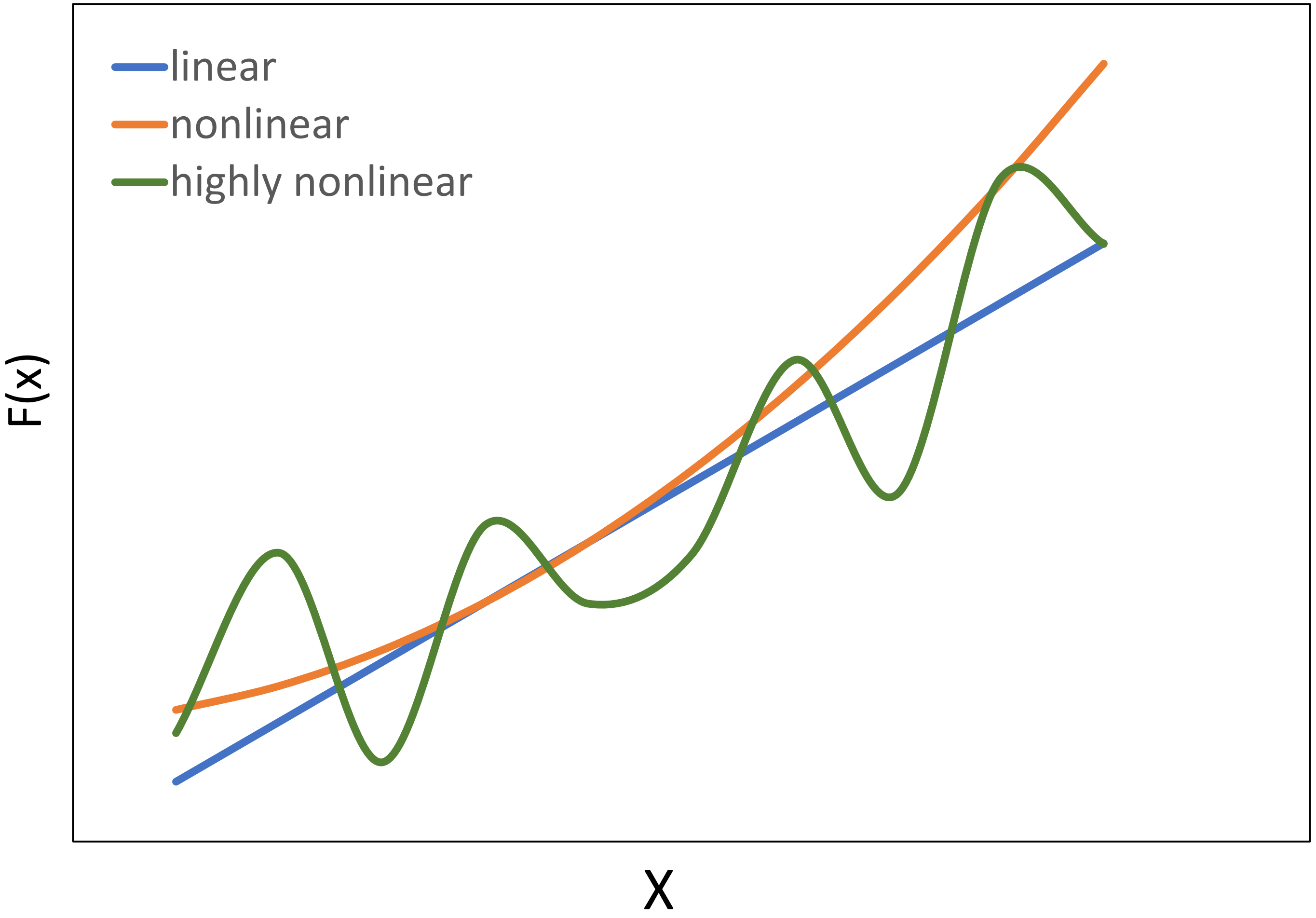
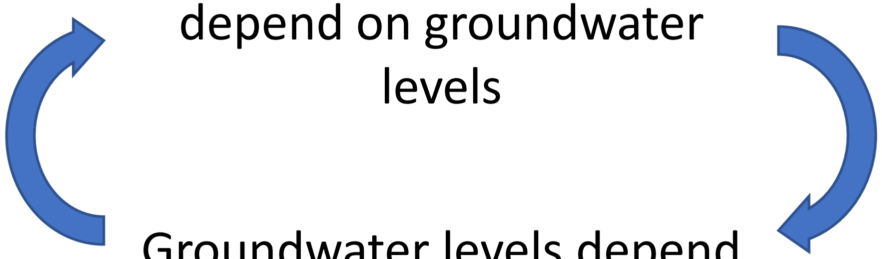
Integrated groundwater-surface-water models tend to have a high degree of nonlinearity.

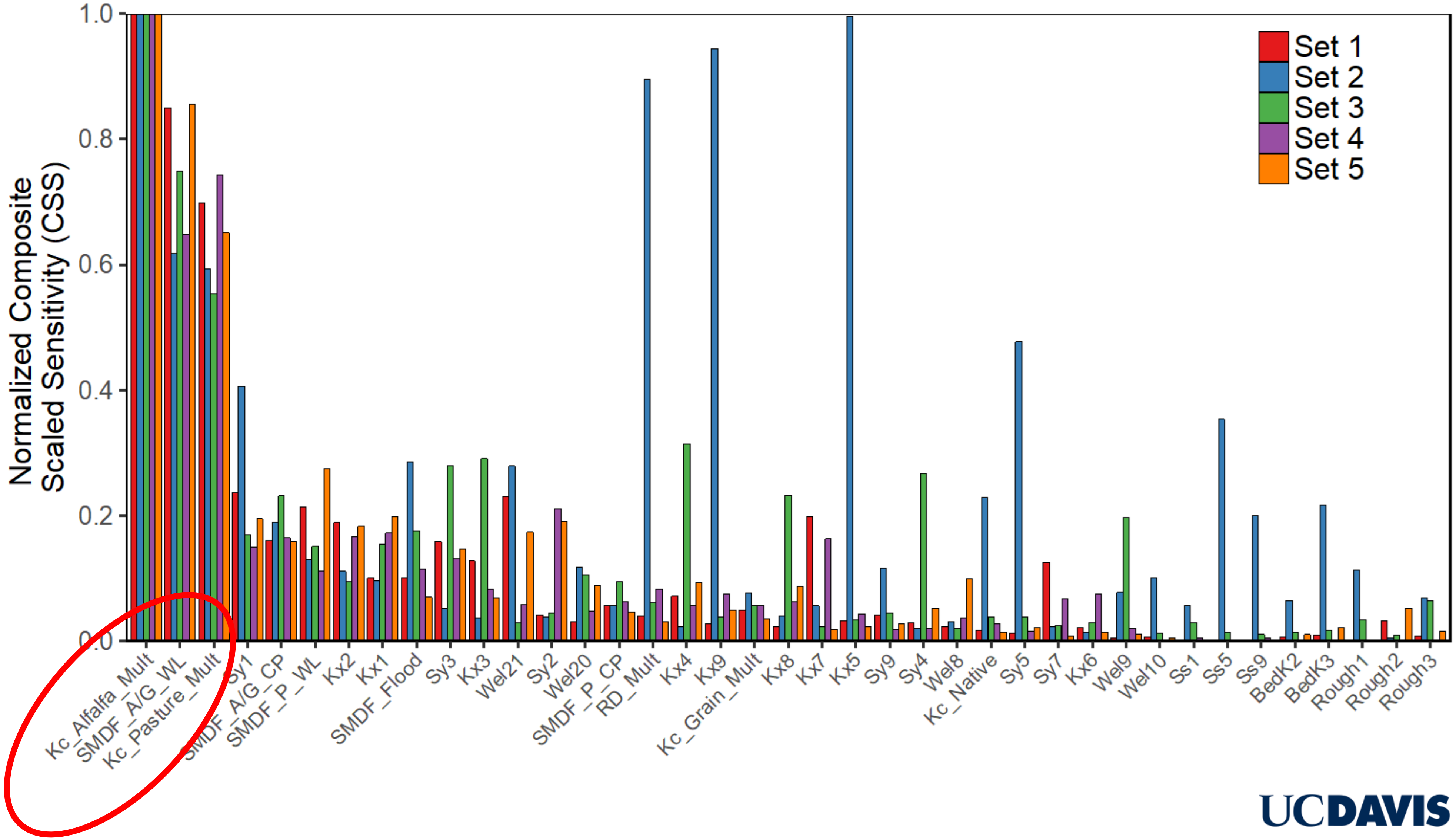


Streamflow and depth depend on groundwater levels

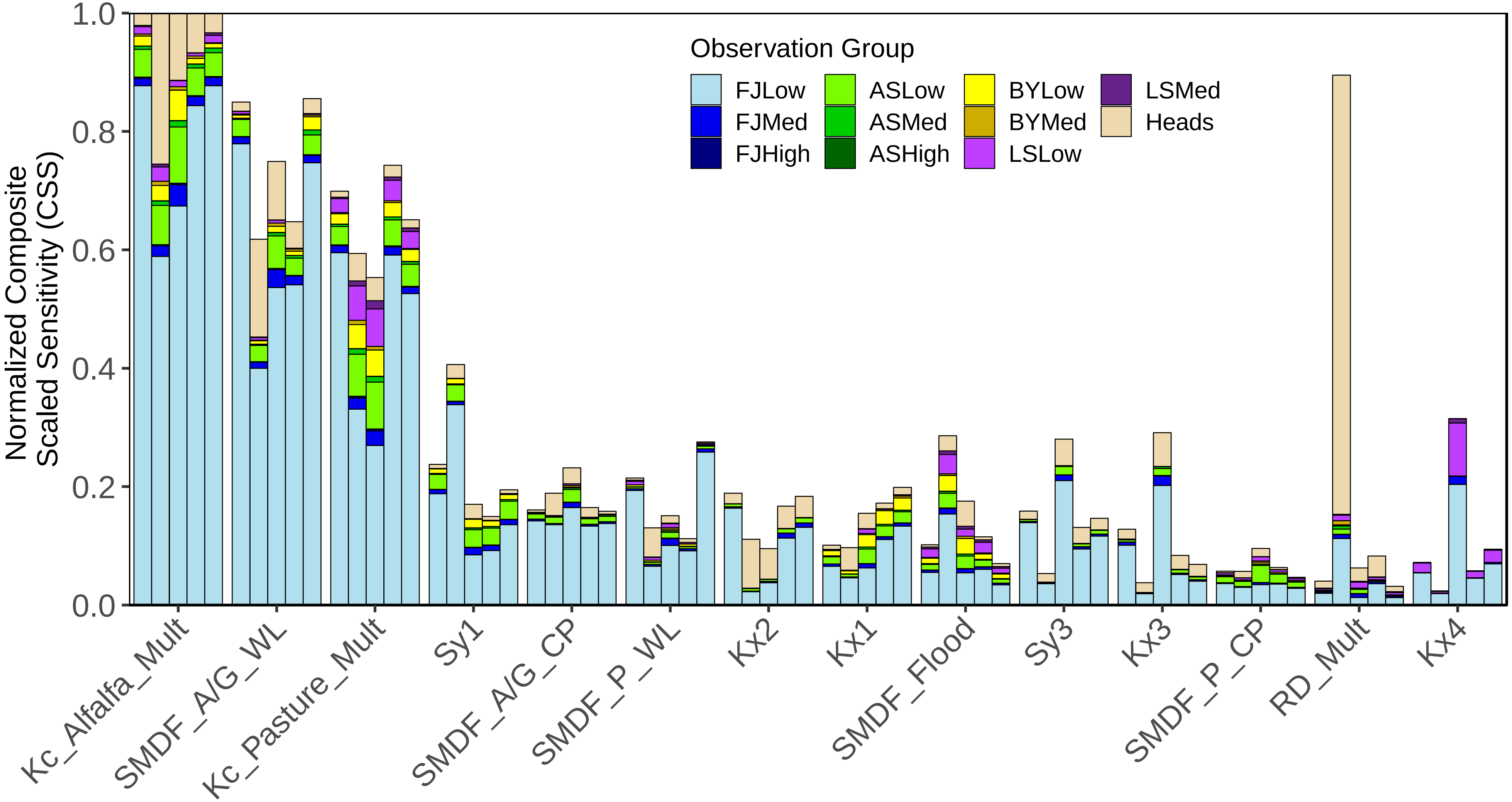


Groundwater levels depend on streamflow and depth

Soil-Water Budget Model (SWBM) parameters are most sensitive in SVIHM.



Low flow (<100 cfs) observations contribute the most information about SVIHM parameters.



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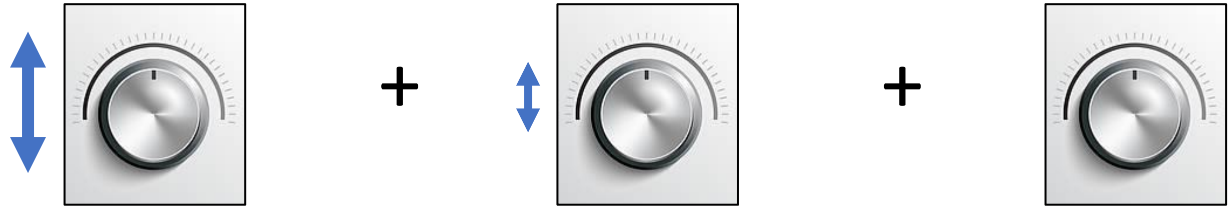
5 Minute Question Break

Coming Up

Model Calibration
Uncertainty Analysis
Integrated Hydrologic Model Applications

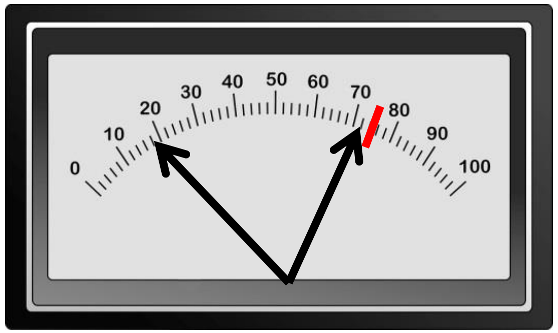
Values of model parameters are often poorly known early in model development, and are estimated using available data.

P1 P2 P3



+ +

=



Observed Value = 75

Simulated Value = 72

“Inverse” modeling

“SVIHM parameters”

Model results that do not agree with observations can identify problems with your conceptual model.

Initial Results
(WY 1991-2011)

Landuse	pET	aET	Applied Water	SW Irrigation	GW Pumping	GW Recharge
	In/yr					
Alfalfa	42.0	40.1	33.1	4.1	29.0	14.6
Grain	16.2	16.1	14.1	2.1	11.9	18.4
Pasture	40.0	33.9	29.7	20.8	9.0	17.2
ET/NoIrr	11.2	10.8	0.0	0.0	0.0	10.8
noET/noIrr	0.0	0.0	0.0	0.0	0.0	21.5

Foglia et al. (2013a)

Alfalfa ~ 14,000 acres
(~50% of irrigated land in Scott Valley)

Scott Valley Three Year Alfalfa Study (2012-2014)

2012	Field 1	Field 2	Field 3
aET	30.8	28.9	28.7
Rain + Irrig.	**18.9**	**21.7**	**22.3**
2013	**Field 1**	**Field 2**	**Field 4**
aET	32.8	30.4	35.4
Rain + Irrig.	**32.3**	**27.0**	**28.5**
2014	**Field 1**	**Field 2**	**Field 4**
aET	32.9	28.0	29.1
Rain + Irrig.	**29.5**	**26.1**	**22.5**

Orloff et al. (2017)

Average aET ~ 31 in/yr

Average Rain + GW Irrigation ~ 26 in/yr

Where is the additional ~5 in/yr of water coming from?

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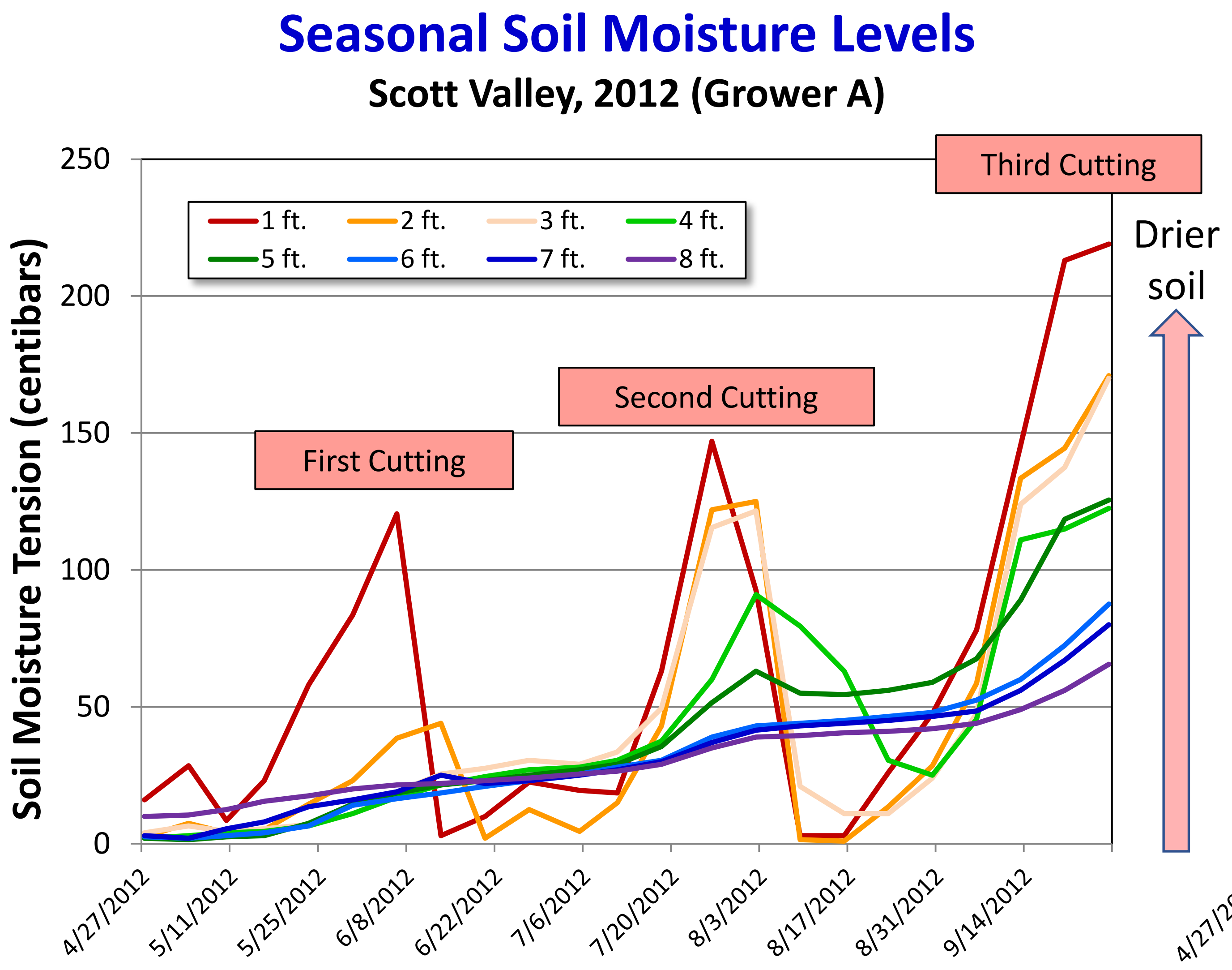
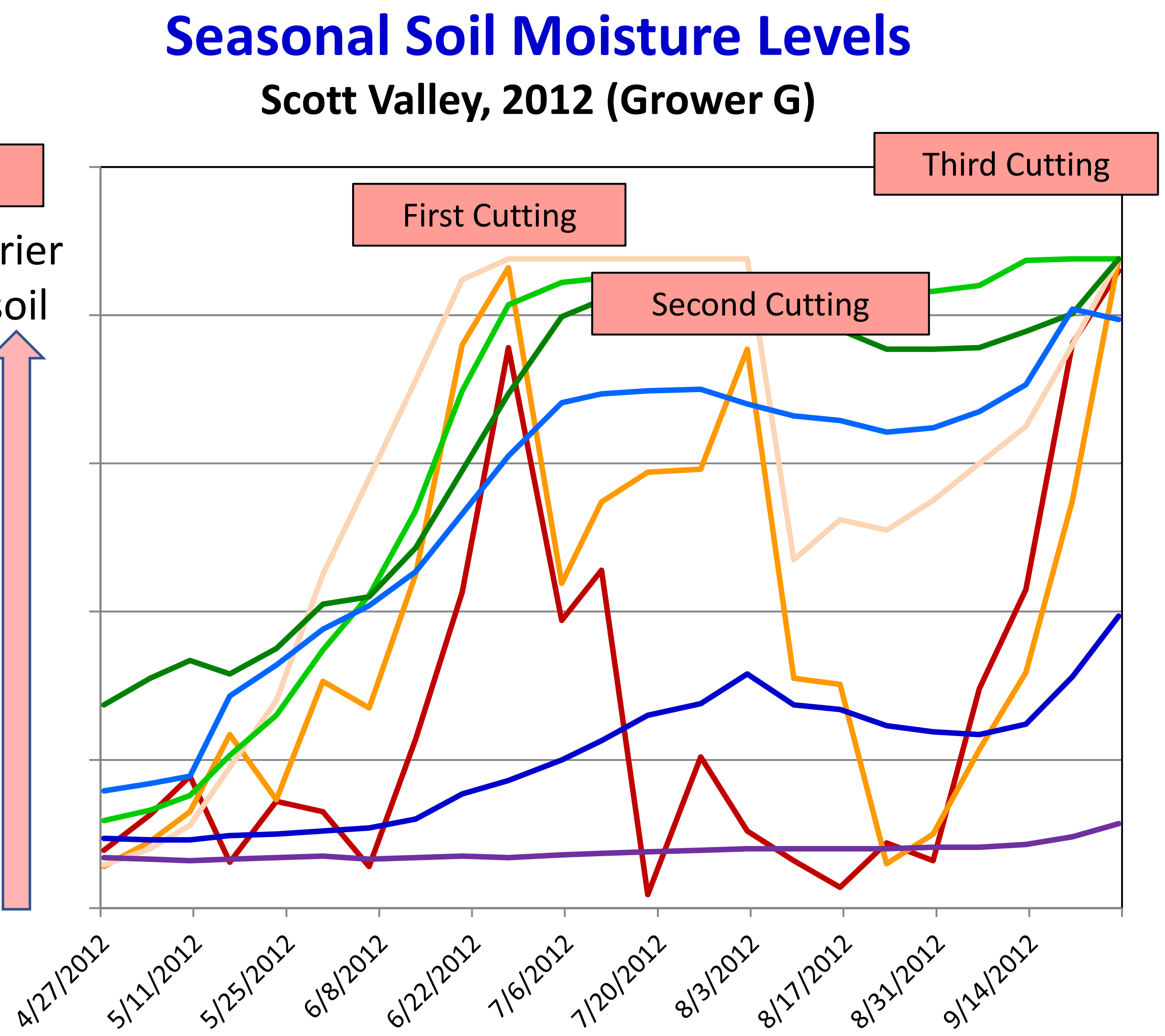
Soil moisture profiles of alfalfa fields continuously dry out during the growing season which limits groundwater recharge.





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Incorporating deficit irrigation on alfalfa fields improves agreement between simulated values and observations.

Landuse	pET	aET	Applied Water	SW Irrigation	GW Pumping	GW Recharge
	In/yr					
Alfalfa	42.0	40.1	33.1	4.1	29.0	14.6
Grain	16.2	16.1	14.1	2.1	11.9	18.4
Pasture	40.0	33.9	29.7	20.8	9.0	17.2
ET/NoIrr	11.2	10.8	0.0	0.0	0.0	10.8
noET/noIrr	0.0	0.0	0.0	0.0	0.0	21.5

Foglia et al. (2013a)

Calibrated Results (WY 1991-2011)

Landuse	pET	aET	Applied Water	SW Irrigation	GW Pumping	GW Recharge
	In/yr					
Alfalfa	39.2	36.8	21.5	2.8	18.7	6.3
Grain	16.1	16.1	10.3	1.6	8.7	10.6
Pasture	38.2	34.8	26.0	20.5	5.5	11.6
ET/NoIrr	14.0	11.0	0.0	0.0	0.0	10.8
noET/noIrr	0.0	0.0	0.0	0.0	0.0	21.6

Foglia et al. (2018)

Scott Valley Three Year Alfalfa Study (2012-2014)

2012	Field 1	Field 2	Field 3
aET	30.8	28.9	28.7
Rain + Irrig.	18.9	21.7	22.3
2013	**Field 1**	**Field 2**	**Field 4**
aET	32.8	30.4	35.4
Rain + Irrig.	32.3	27.0	28.5
2014	[illegible]	[illegible]	[illegible]
aET	[illegible]	[illegible]	[illegible]
Rain + Irrig.	29.5	26.1	22.5

Average GW Irrigation ~ 21 in/yr

Orloff et al. (2017)

35% reduction in GW irrigation

57% reduction in GW recharge

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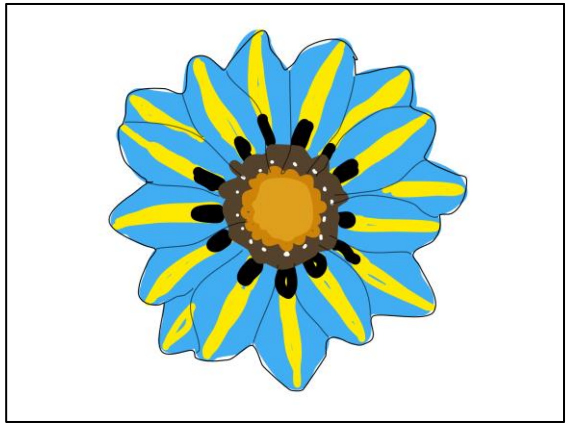
Numerical models will never match the real-world perfectly, so we look for models that are “good enough” to answer our key questions.

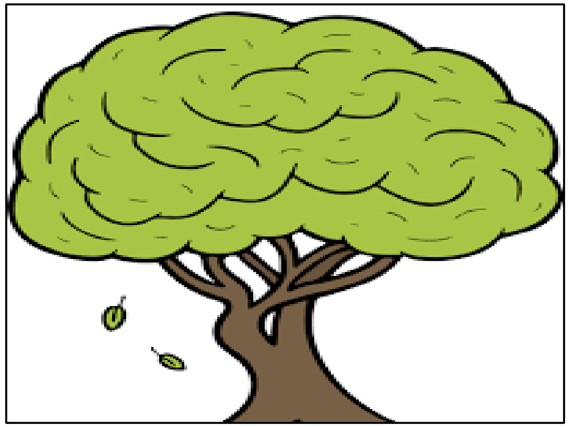
Real World

Great Model



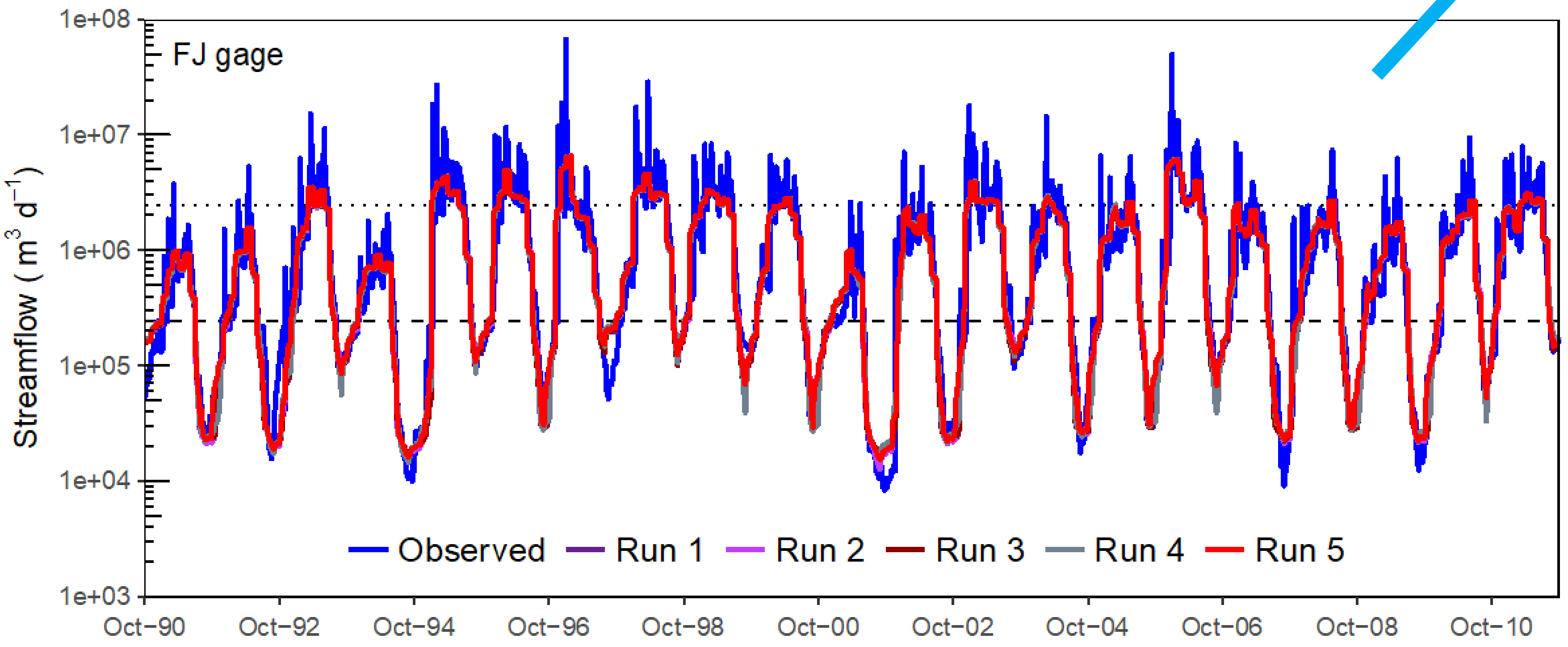
Poor Model

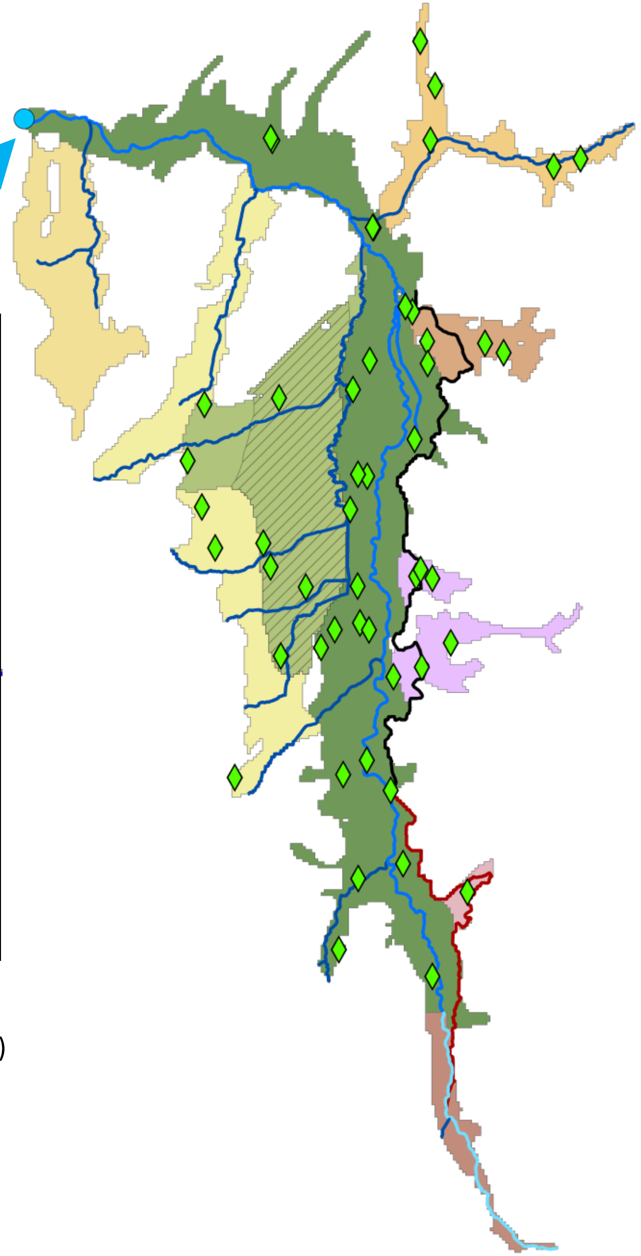
Good Model



Bad Model

Simulated streamflow and groundwater elevations in SVIHM show strong agreement with observations.





Tolley et al. (2019)

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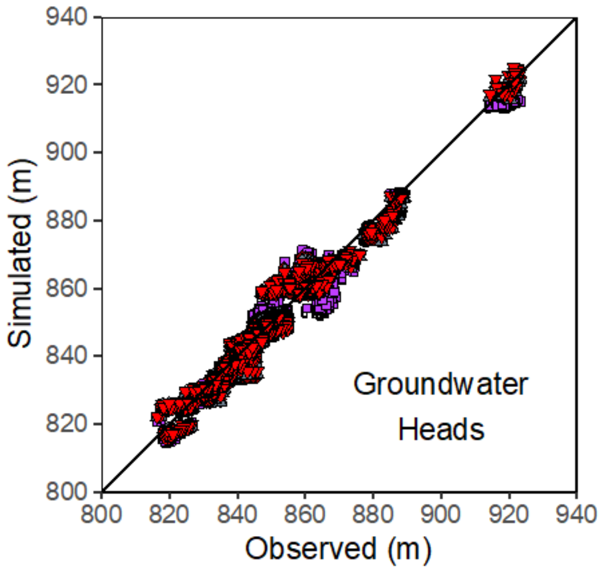
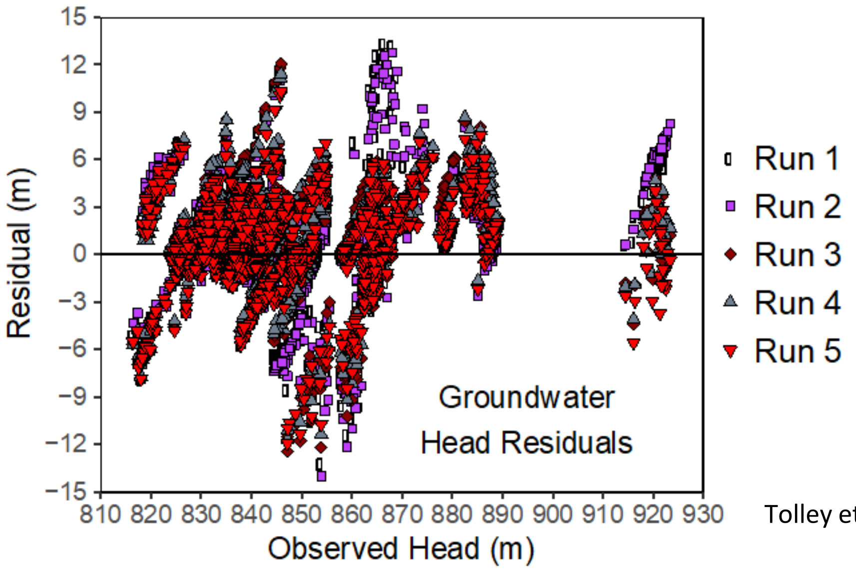
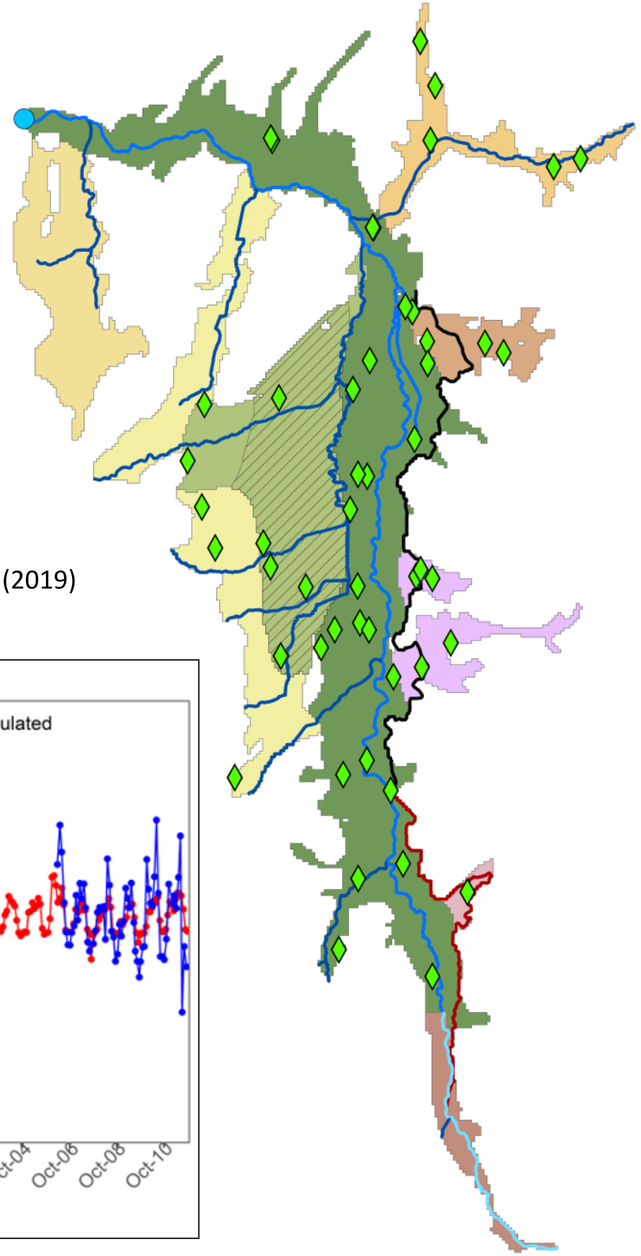
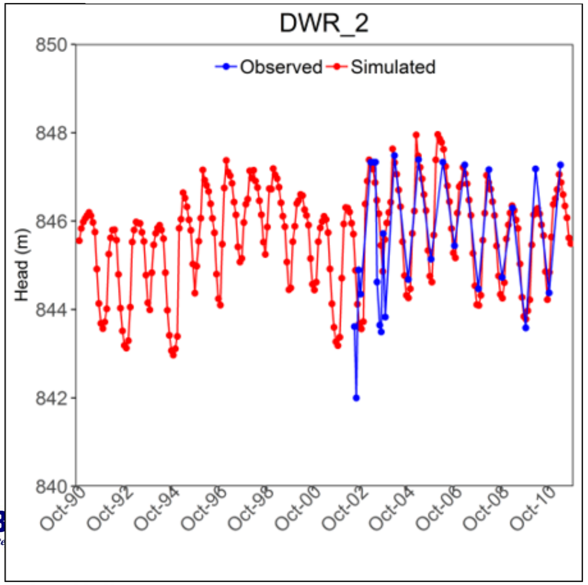
Simulated streamflow and groundwater elevations in SVIHM show strong agreement with observations.

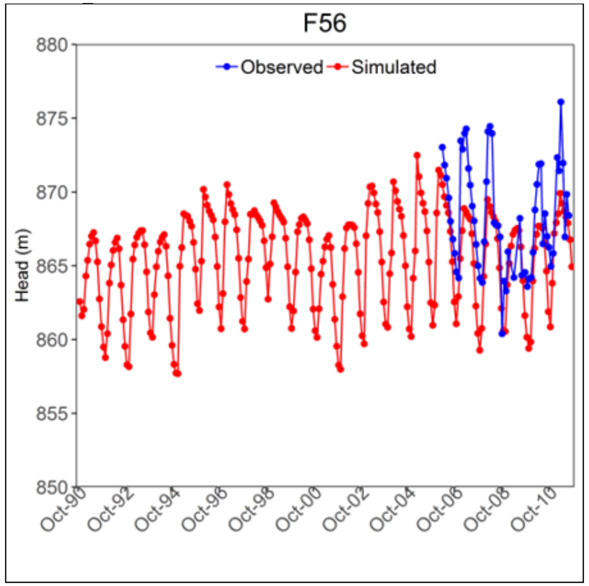


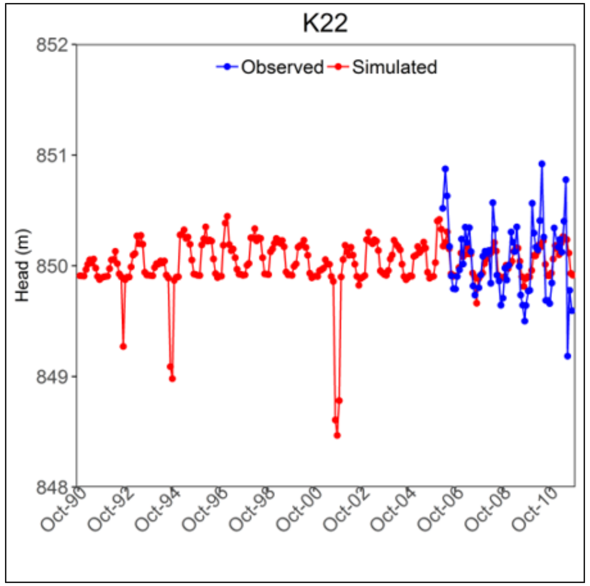


Tolley et al. (2019)







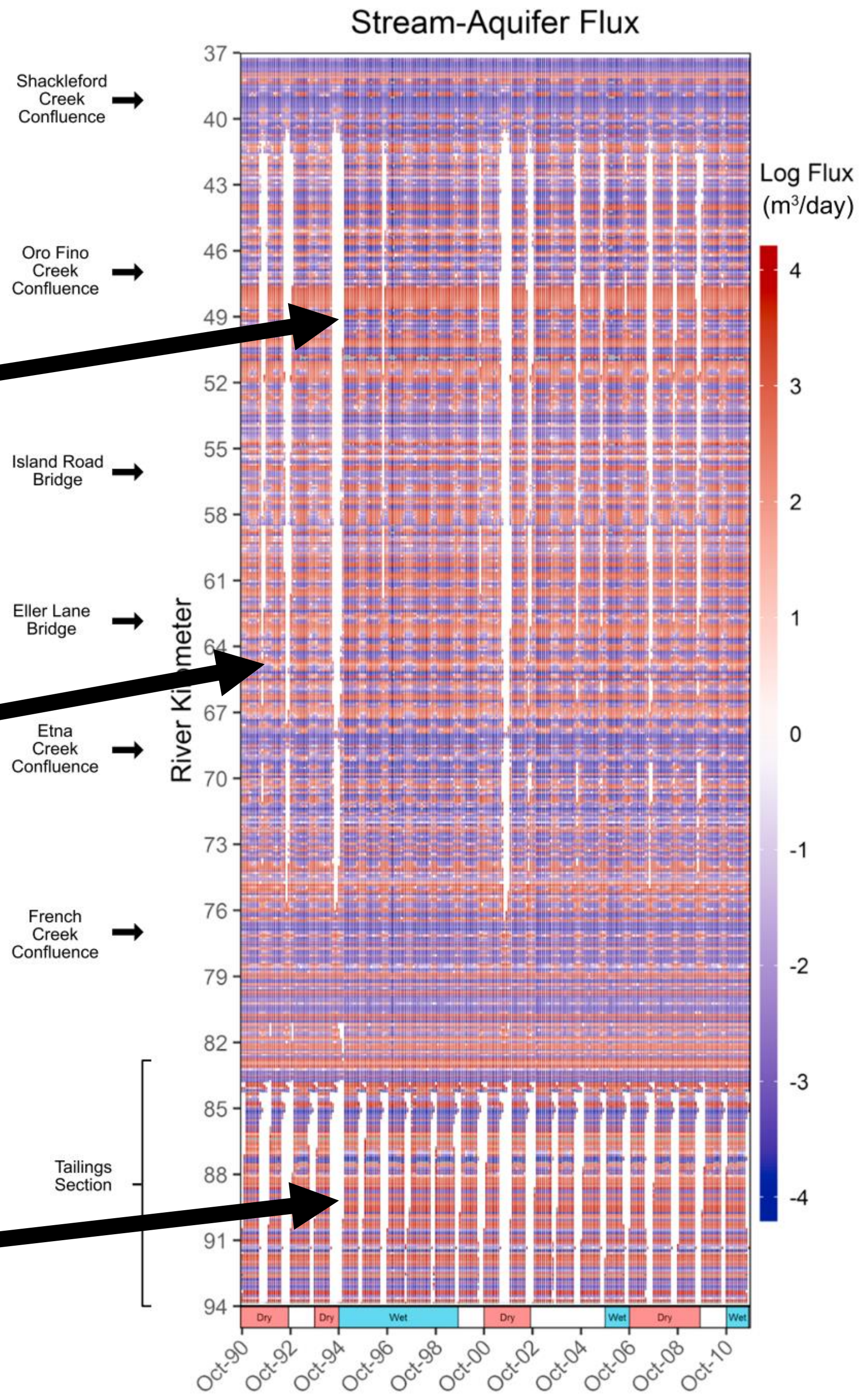


Well-calibrated models can provide a lot of information about system behavior.

Dry sections are consistent spatially but vary in length/duration

Model appears to capture a large degree of hyporheic exchange

Legacy mine tailings section goes dry every year regardless of water year type



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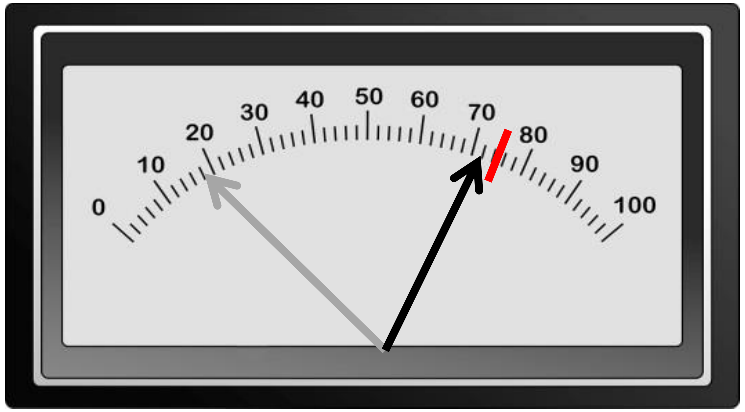
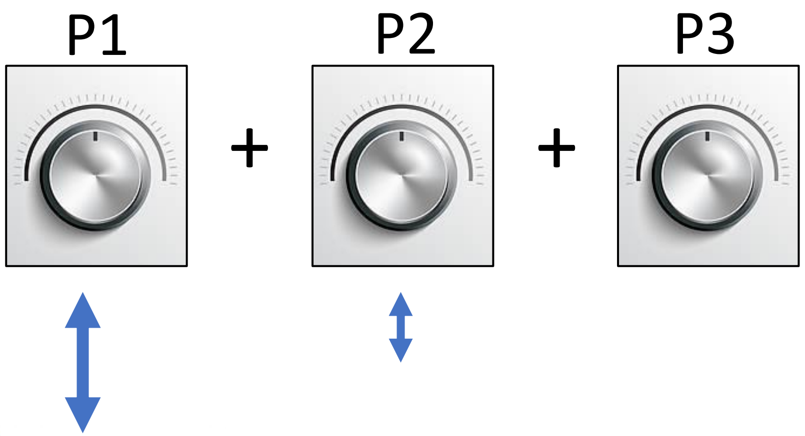
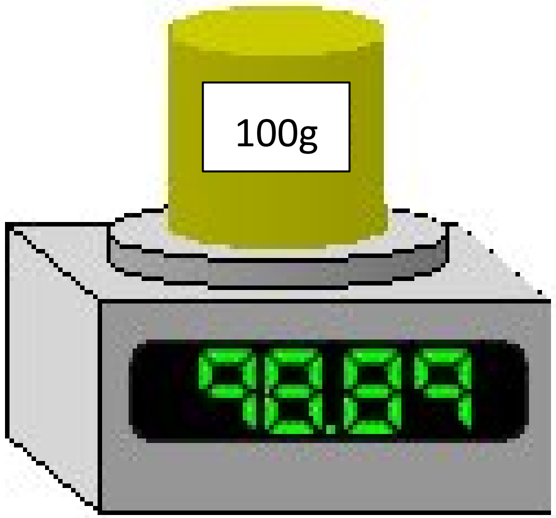
Uncertainty analysis is an important but often overlooked step during model evaluation.



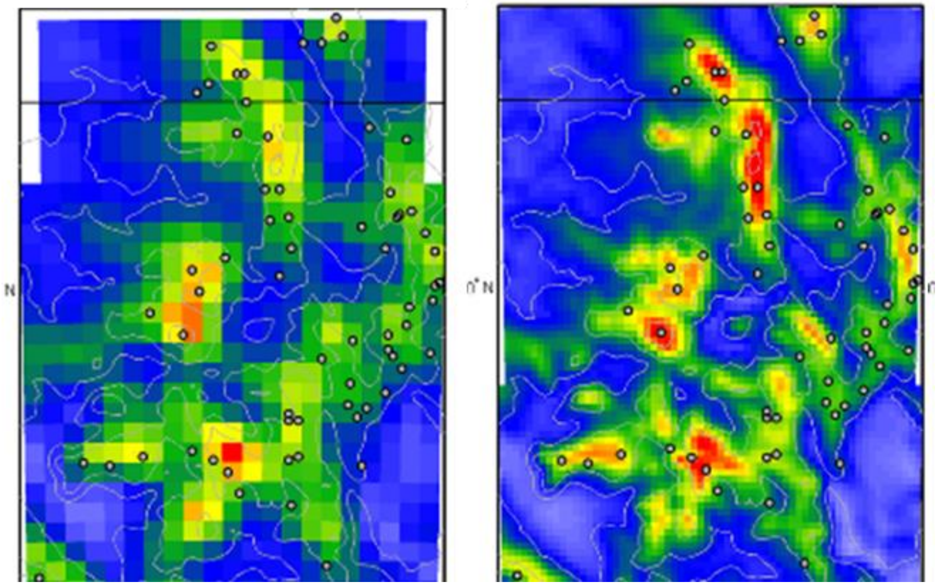
Measured Value = 75

Simulated Value = 72





Observation error

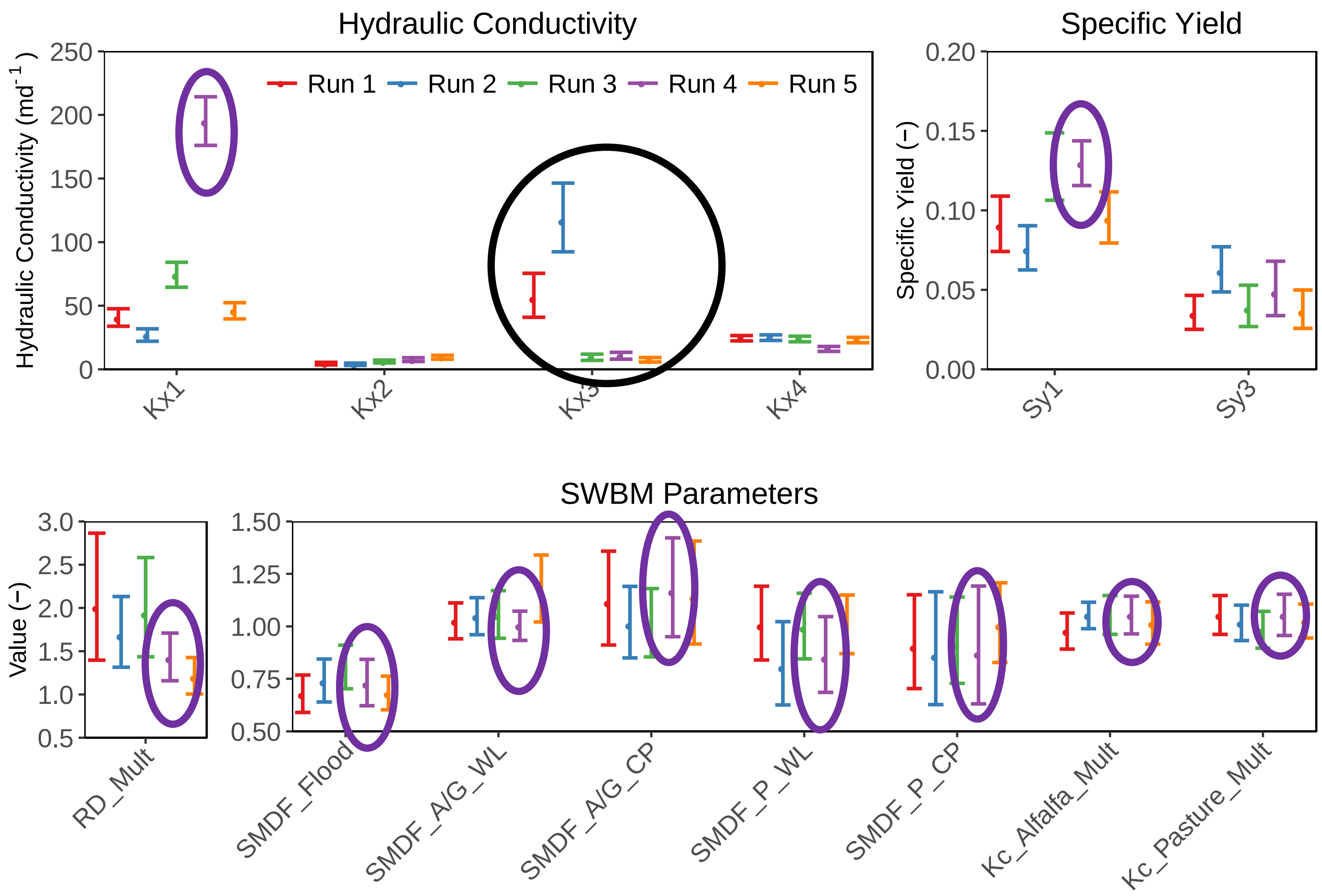


ral.ucar.edu

Structural error

There are many ways to evaluate model parameter uncertainty.

Linear 95% confidence intervals calculated by UCODE

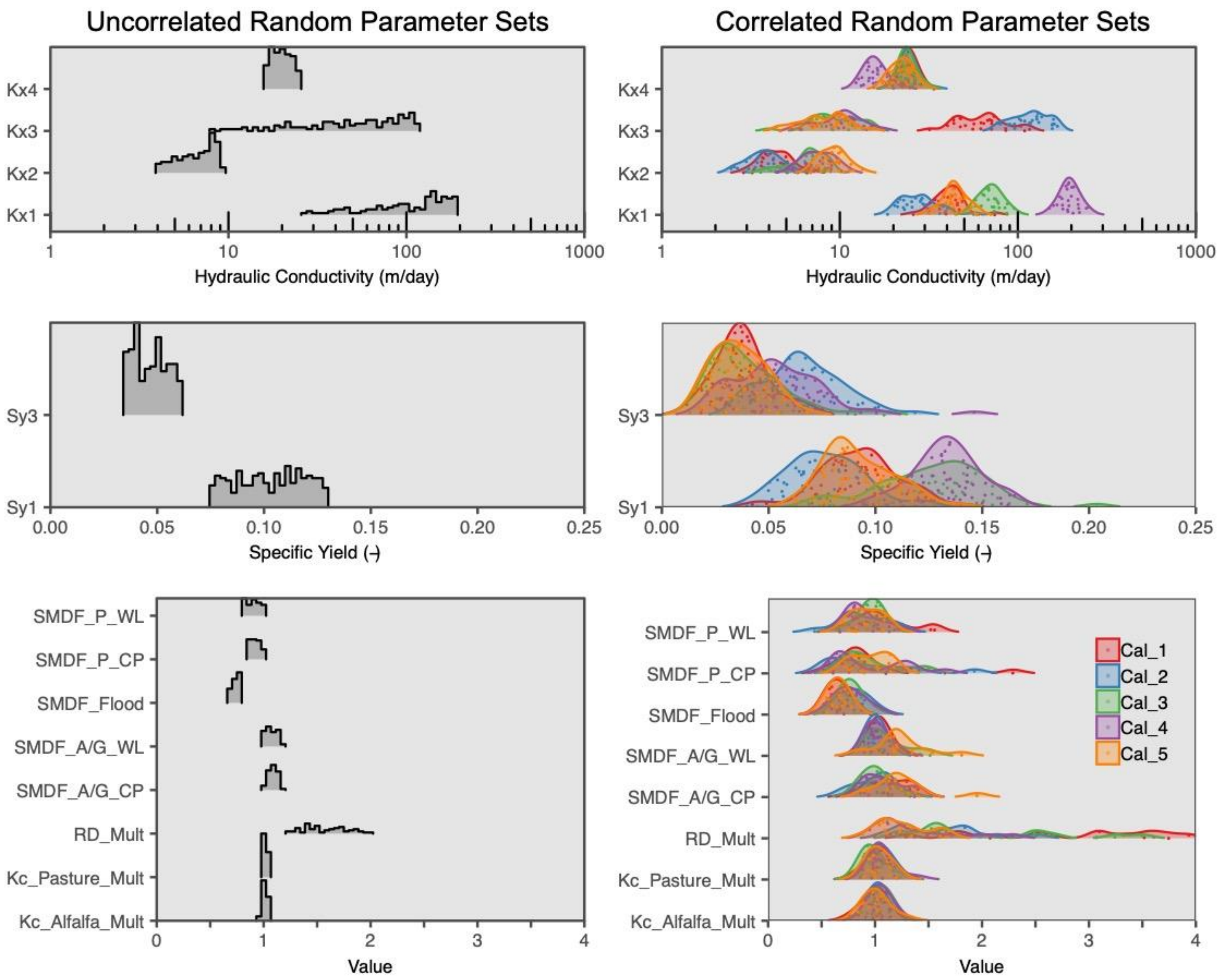


Uncertainty within a single calibration

Uncertainty across calibrations

Tolley et al. (2019)

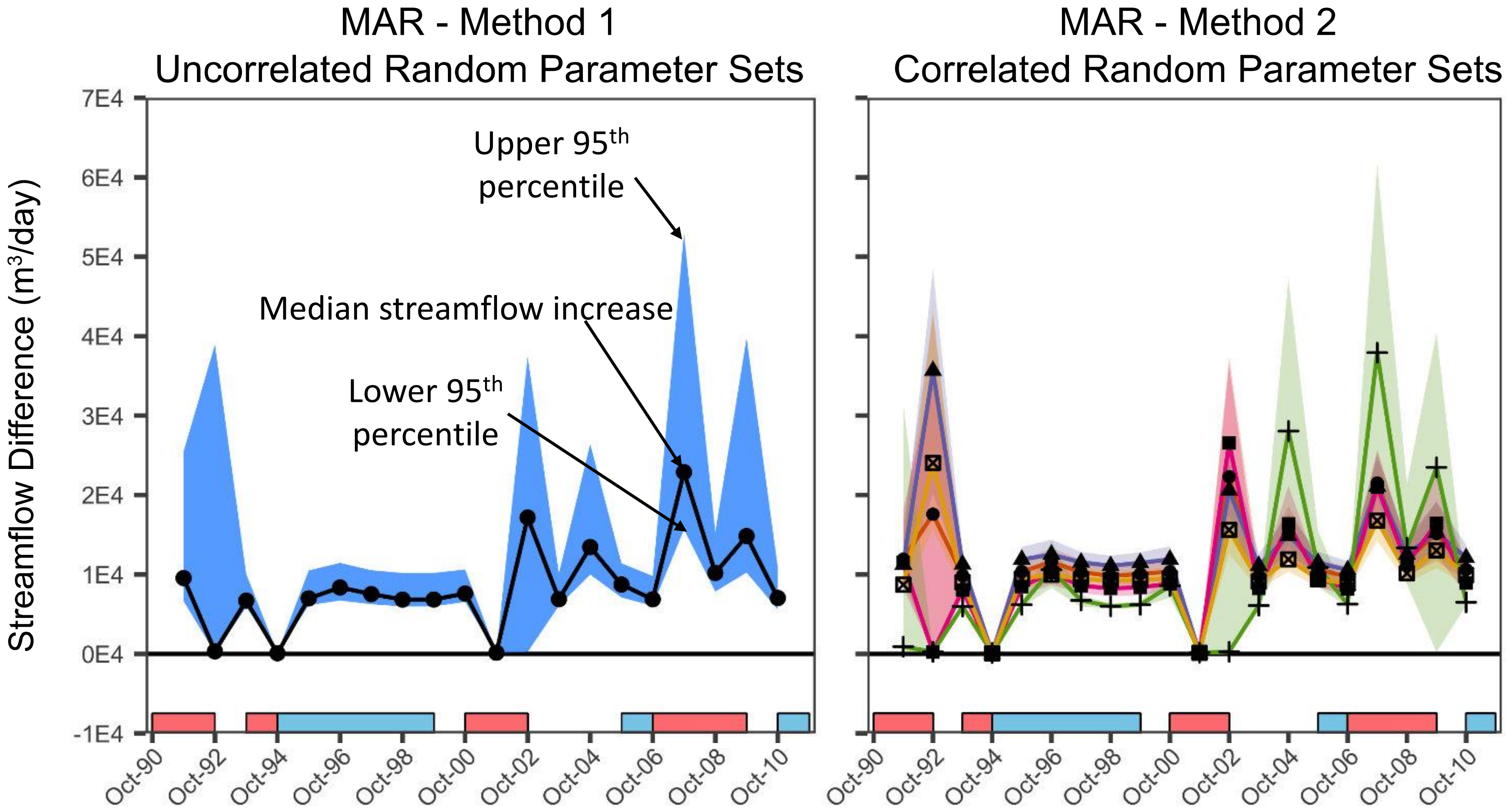
There are many ways to evaluate model parameter uncertainty.



Distributions of possible model parameter values

Tolley et al. (in preparation)

Model(er)s can provide a range of predicted values that incorporate uncertainty about parameters, model structure.

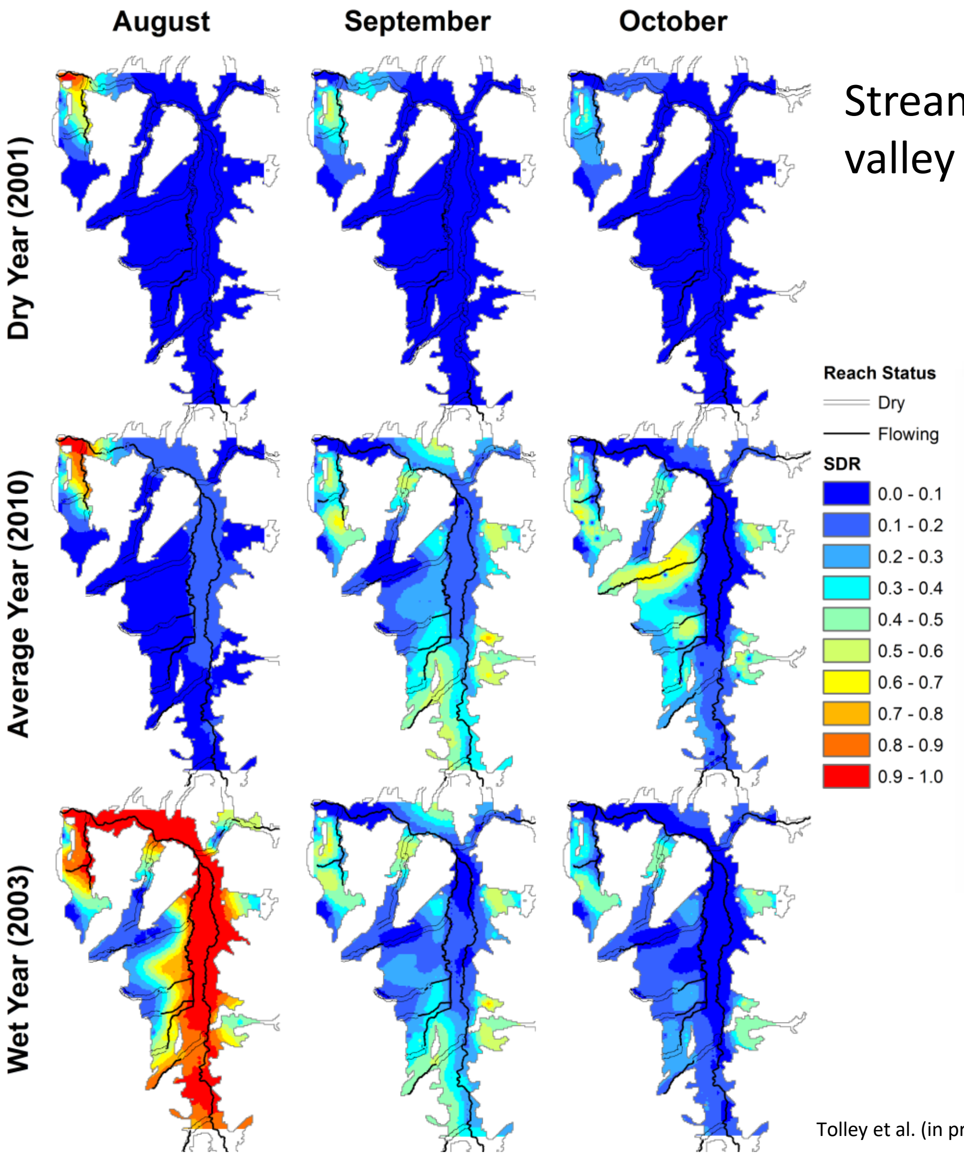


Managed Aquifer Recharge (MAR) from Jan-Mar

October streamflow differences

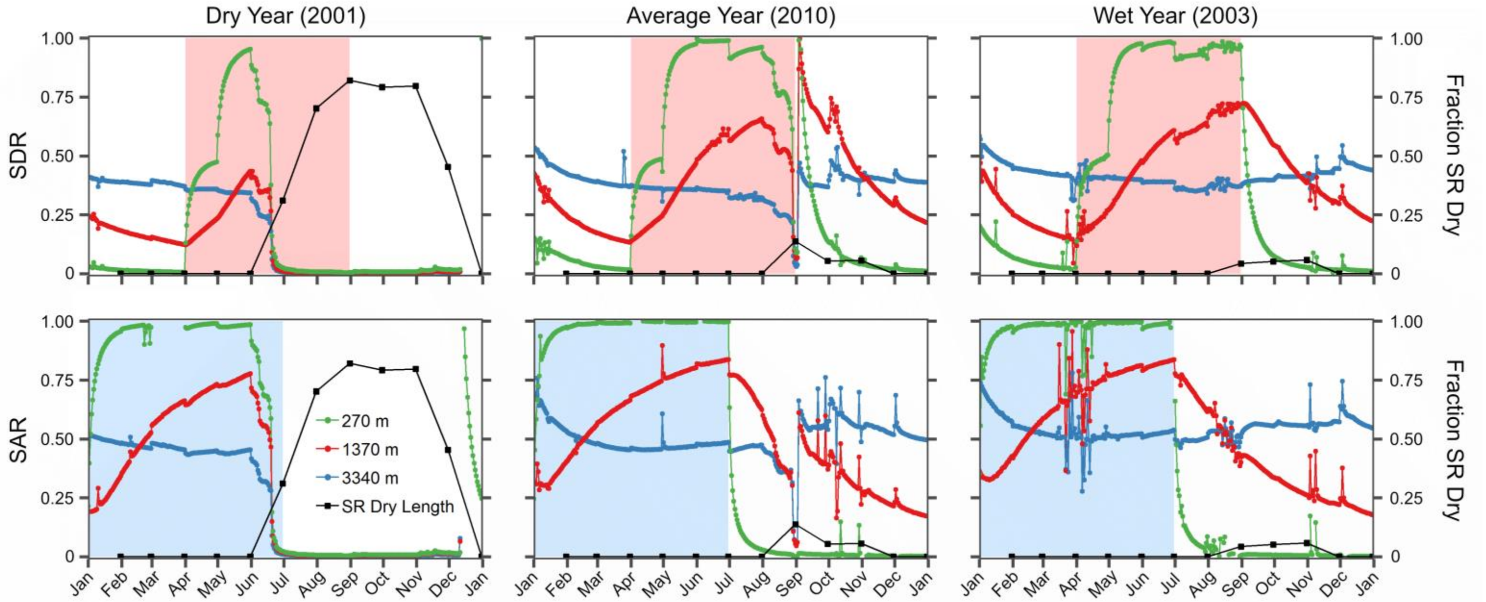
Tolley et al. (in preparation)

Weakly coupled integrated models (e.g., SVIHM) can properly and efficiently reproduce observed groundwater-surface-water interactions.



Tolley et al. (in preparation)

Streamflow depletion at valley outlet (USGS gage)

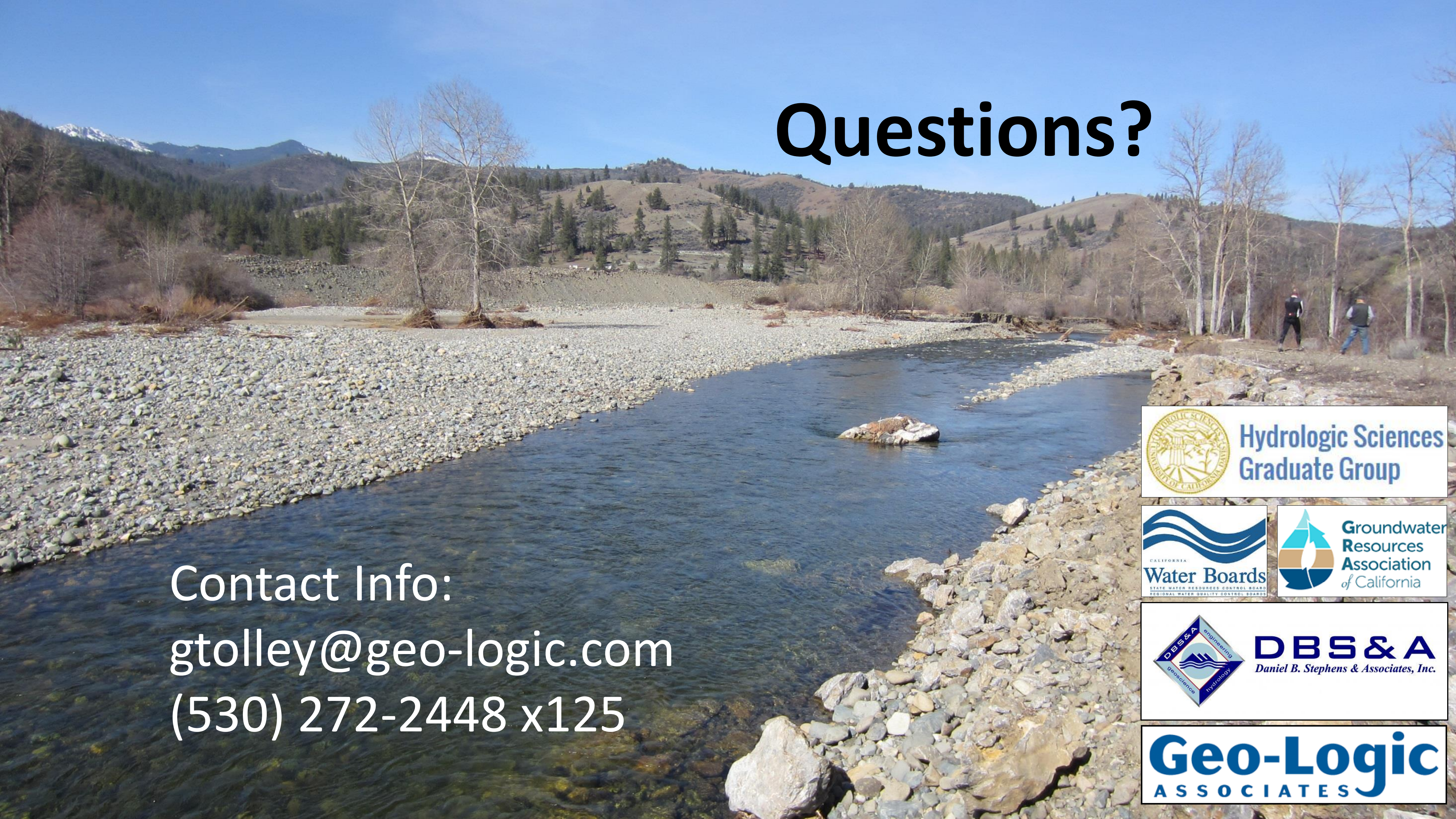


Tolley et al. (in preparation)

Streamflow depletion/accretion at valley outlet (USGS gage)

Project Contributors

- Professor Thomas Harter
- Professor Laura Foglia
- Bryan McFadin and the NCRWQCB
- Steve Orloff
- Ryan Hines
- Jakob Neumann
- Siskiyou County Resources Conservation District
- Scott Valley Groundwater Advisory Committee
- Scott Valley Stakeholders



Questions?

Contact Info:
gtolley@geo-logic.com
(530) 272-2448 x125

Hydrologic Sciences Graduate Group

California Water Boards
State Water Resources Control Board
Regional Water Quality Control Boards

Groundwater Resources Association of California

DBS&A
Daniel B. Stephens & Associates, Inc.

Geo-Logic Associates

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