SVIHM 101

Understanding Model Results and Management Scenarios

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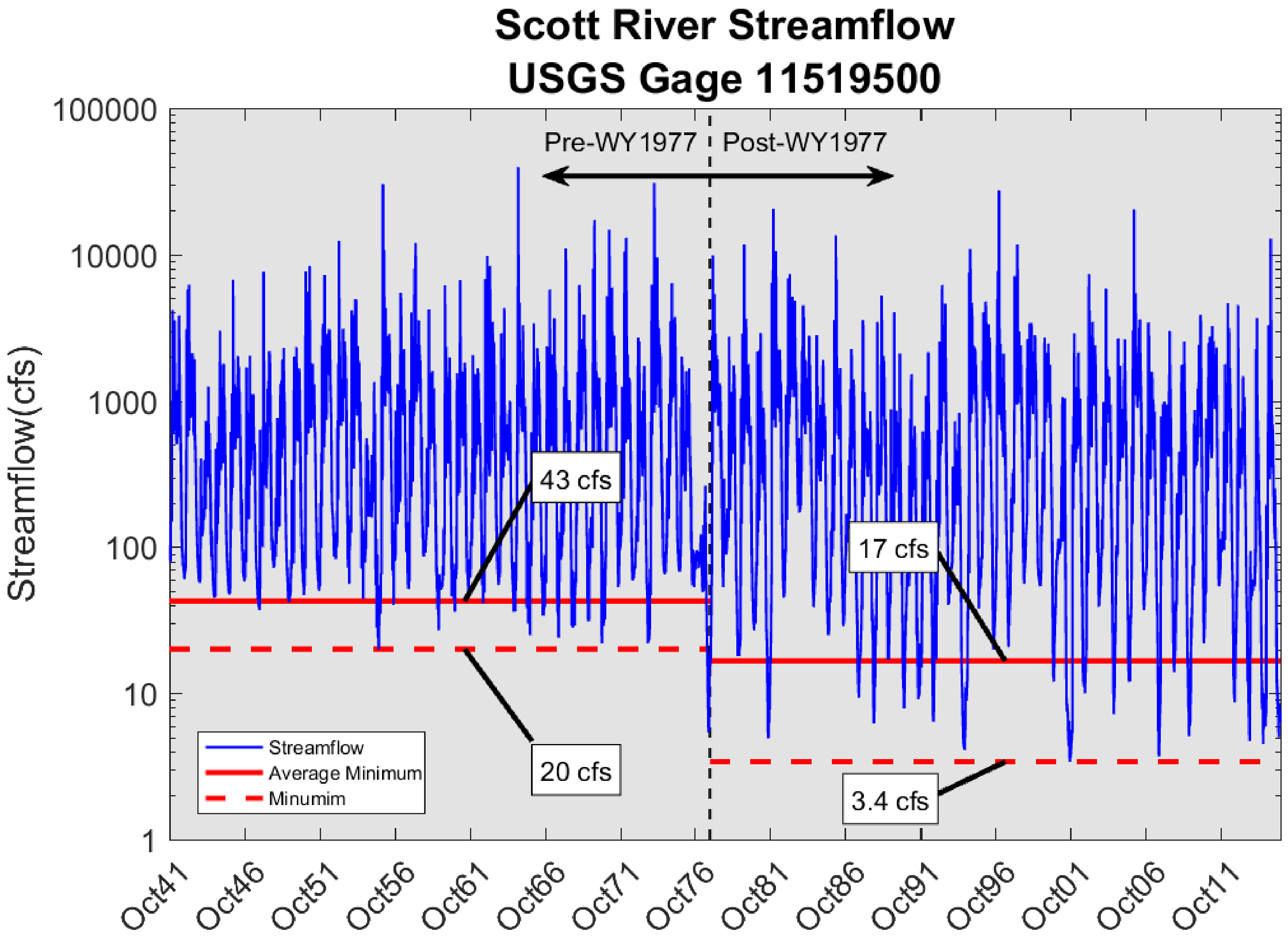
Outline

1. SVIHM basics
2. Guide to reading and interpreting SVIHM results (key graphs)
3. Model scenarios
   - Using SVIHM to ask "What If" questions with model scenarios
   - Using SVIHM to calculate stream depletion
   - Catalog of other scenarios
4. Upcoming SVIHM updates and new data sources

Motivation



Difference in average minimum discharge ~ 6,000 – 9,000 AF

~5.5 – 8 in over 13,000 acres

~Volume of water needed for a 3rd cutting of alfalfa

Motivation

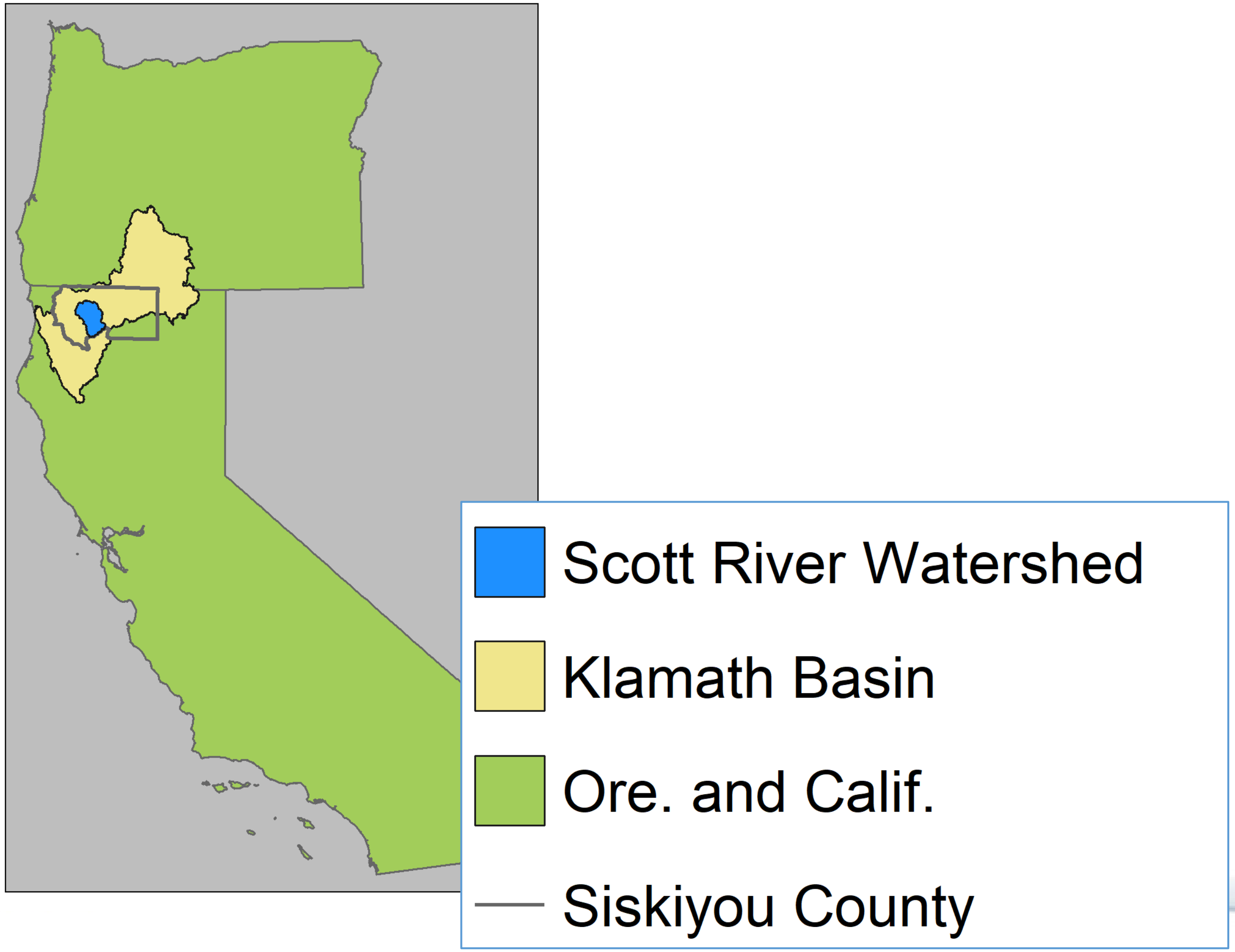
- Unforeseen consequences of move to more efficient irrigation:
  - Increased consumptive use in the valley (+ 50% for alfalfa)
  - Decreased groundwater recharge
  - Increased extractions from the aquifer

  ➢ Greater depletion of streamflow

- **Can we change management strategies in the basin to improve fish habitat while maintaining agricultural production in the valley?**

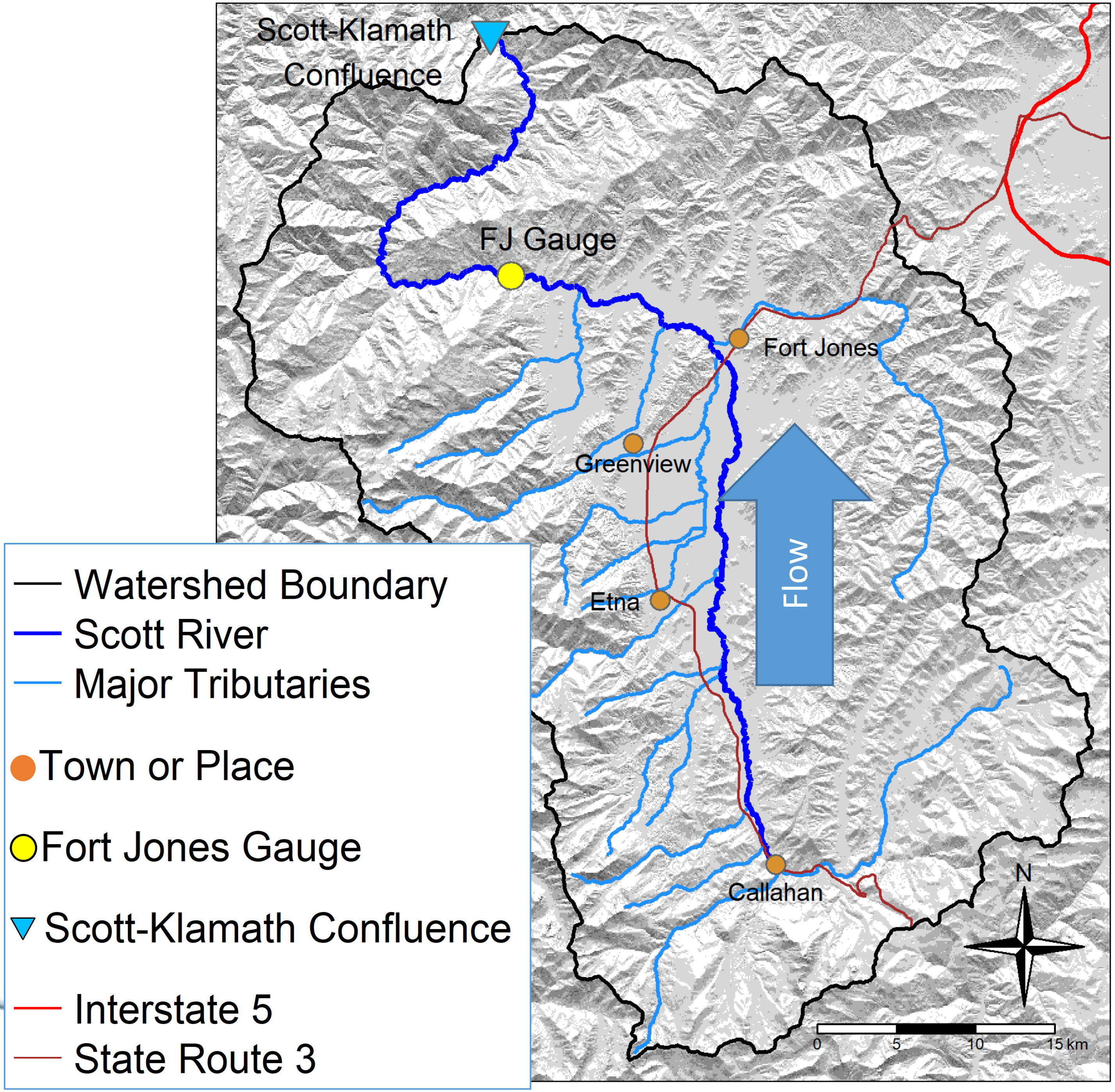
Study Area

- Scott Valley
  - Watershed: 2,100 km2 (800 mi2)
  - Valley: 200 km2 (77 mi2 = 50k ac)

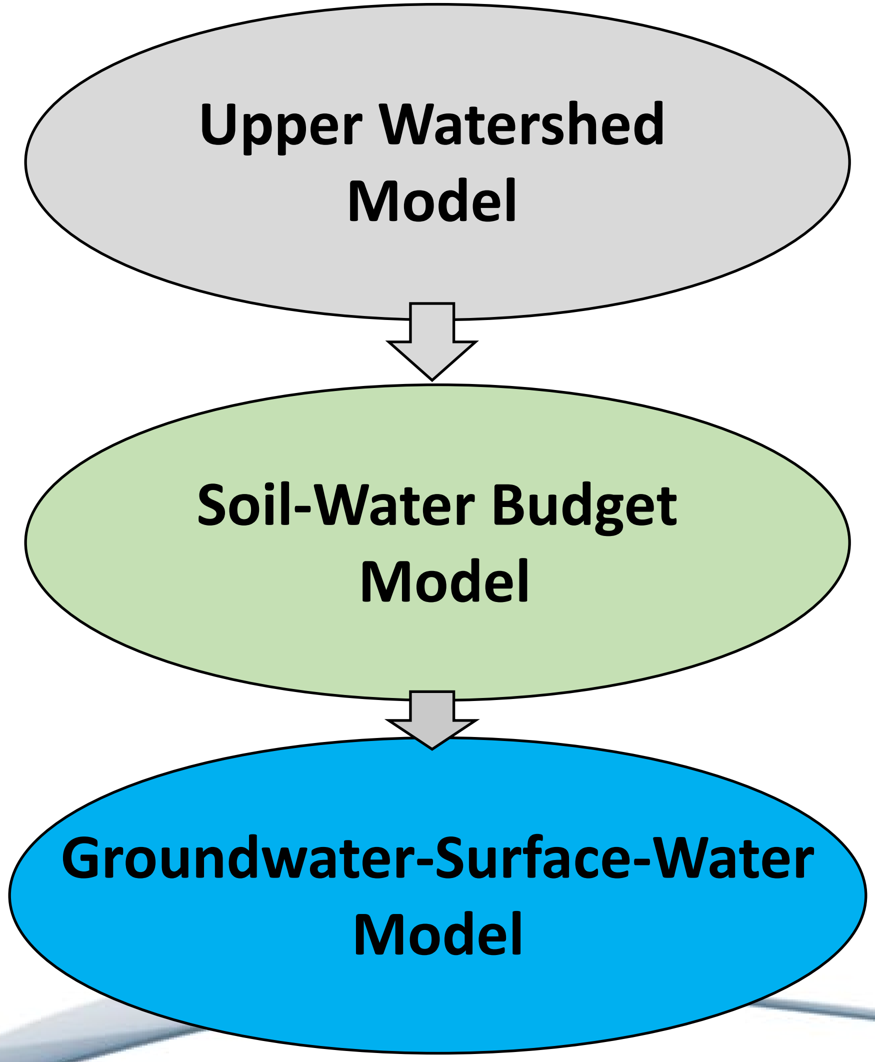


Hydrology

- Scott River flows from south to north
- 12 major tributary streams
- 2 major diversion ditches



Components of SVIHM



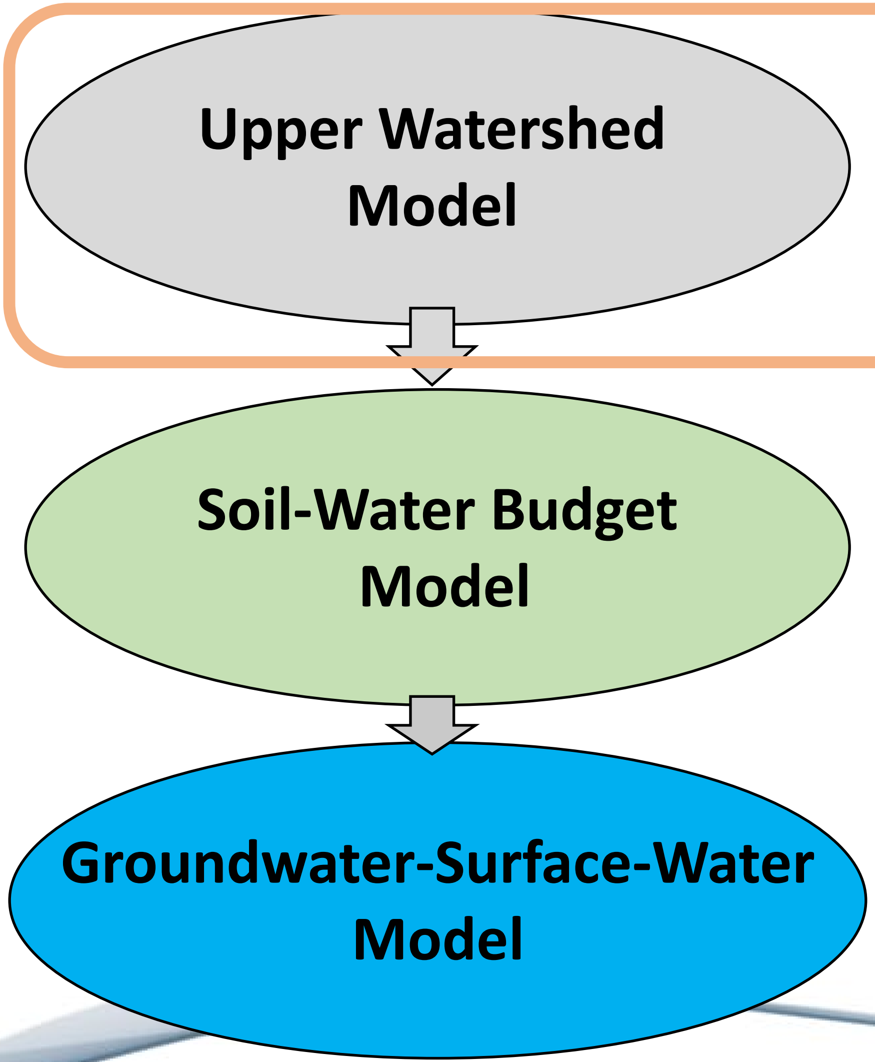
Streamflow entering Scott Valley (Regression model)

Updates Coming Soon!

Recharge and pumping within the valley (Tipping bucket model)

Detailed groundwater levels and streamflow within the valley (MODFLOW model)

Components of SVIHM



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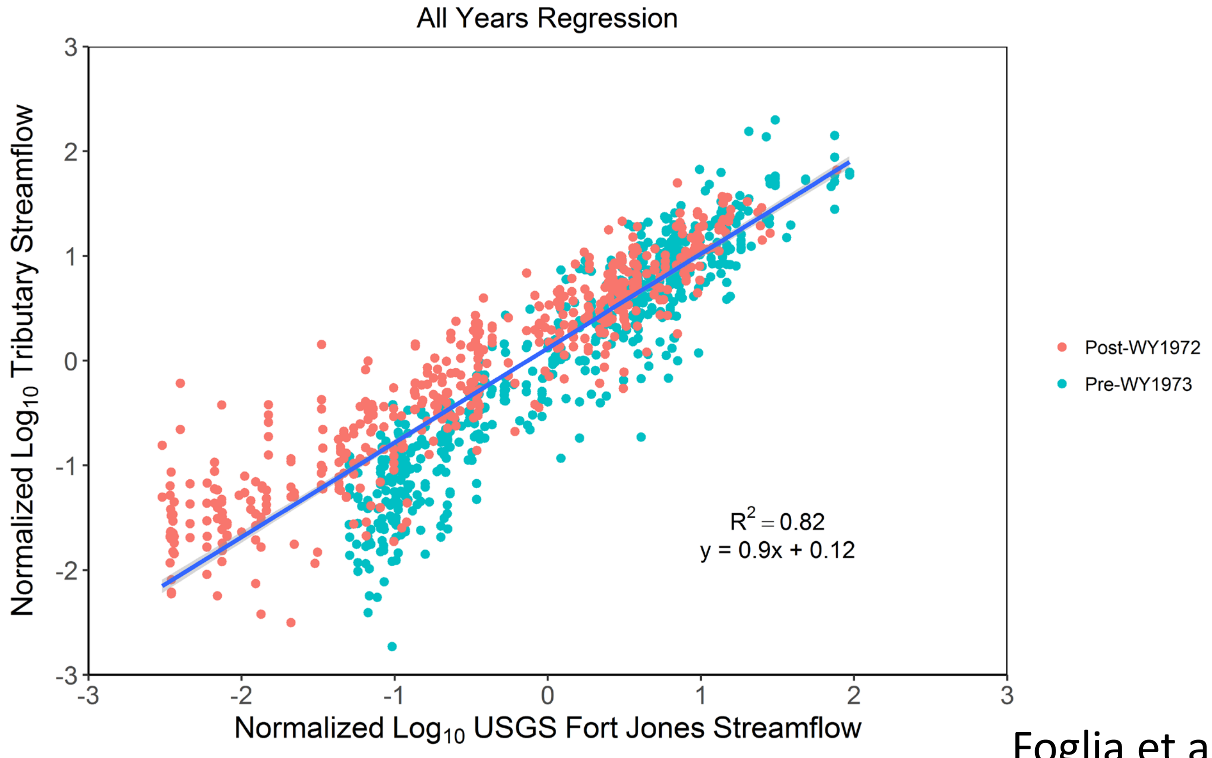
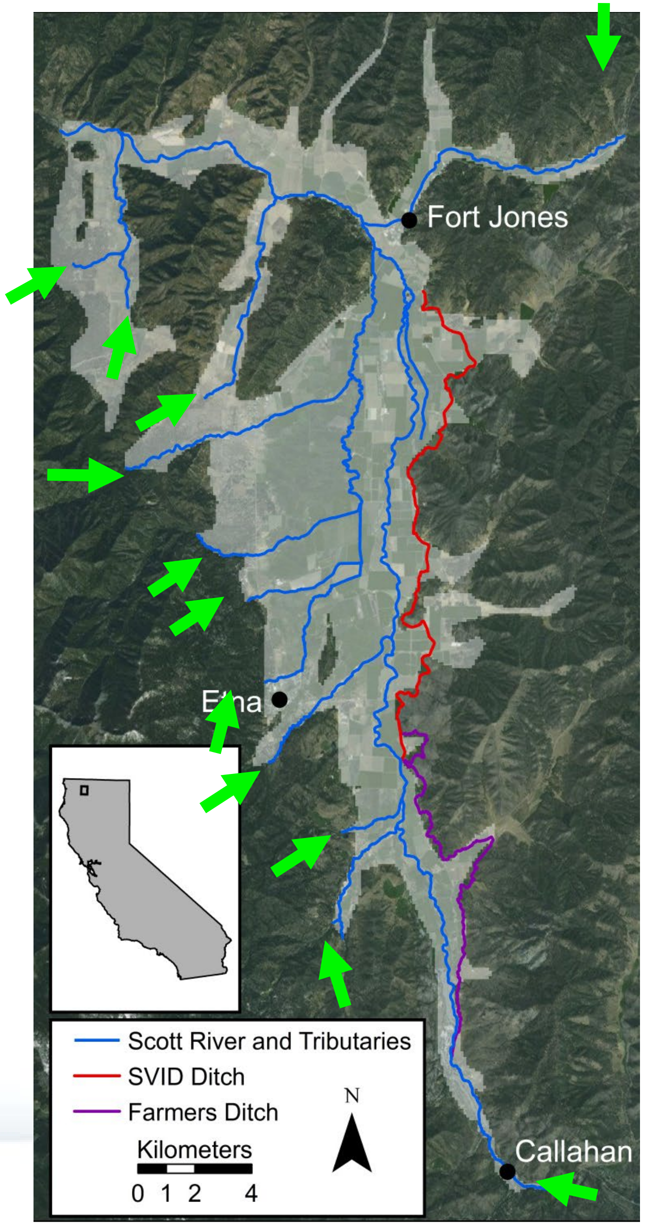
Upper Watershed – Regression Model

$$Norm(x_{i,t}) = \frac{\log_{10}(x_{i,t}) - M[\log_{10}(\boldsymbol{x}_i)]}{SD[\log_{10}(\boldsymbol{x}_i)]}$$



Foglia et al. (2013)



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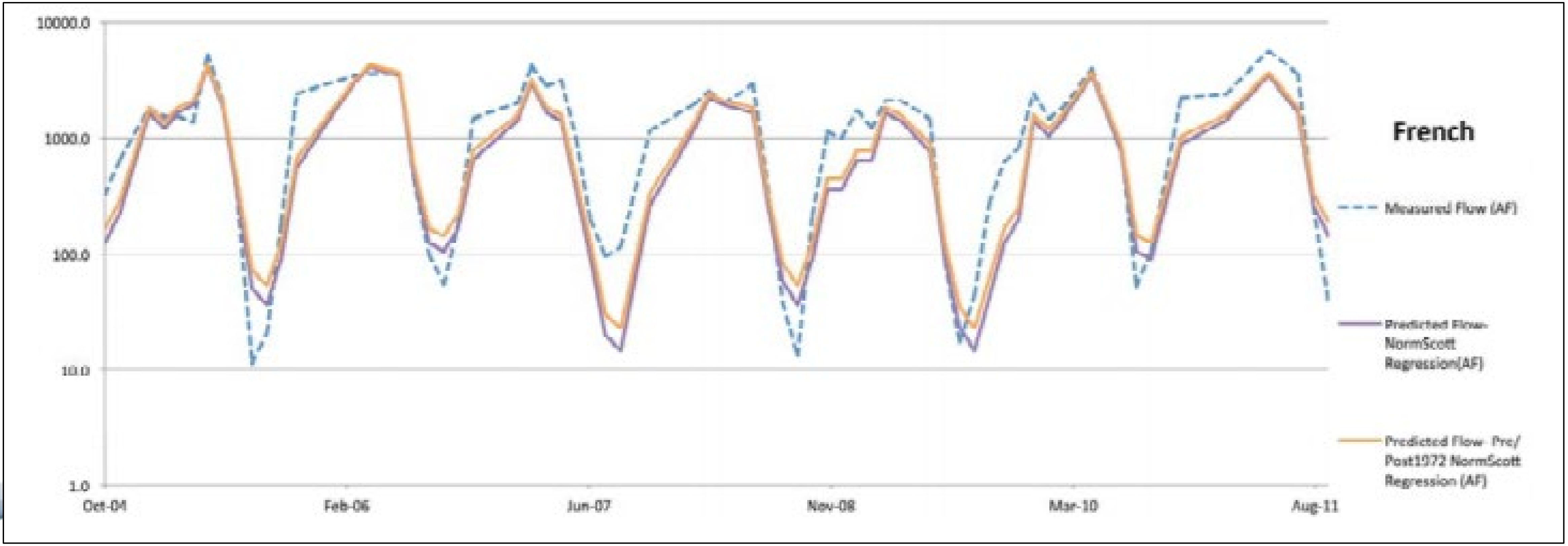

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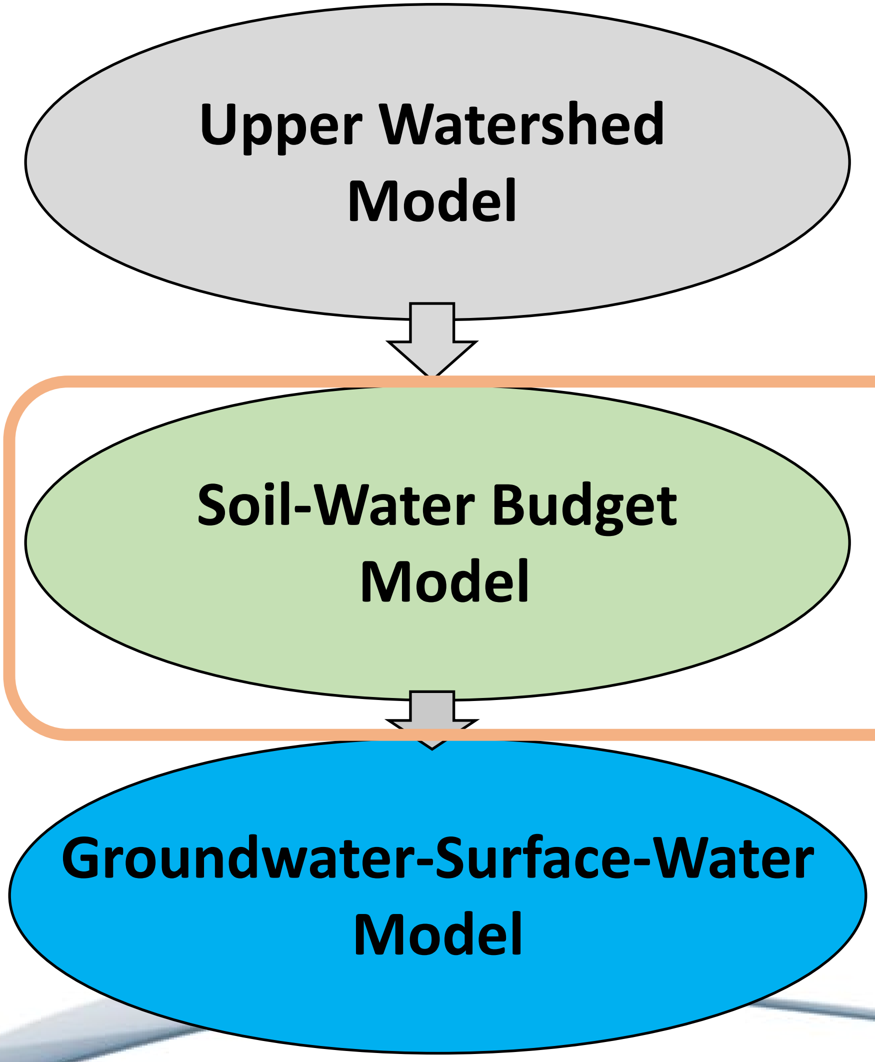

Streamflow entering
Scott Valley
(Regression model)

Recharge and pumping
within the valley
(Tipping bucket model)

Detailed groundwater levels and
streamflow within the valley
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Soil Water Budget Model

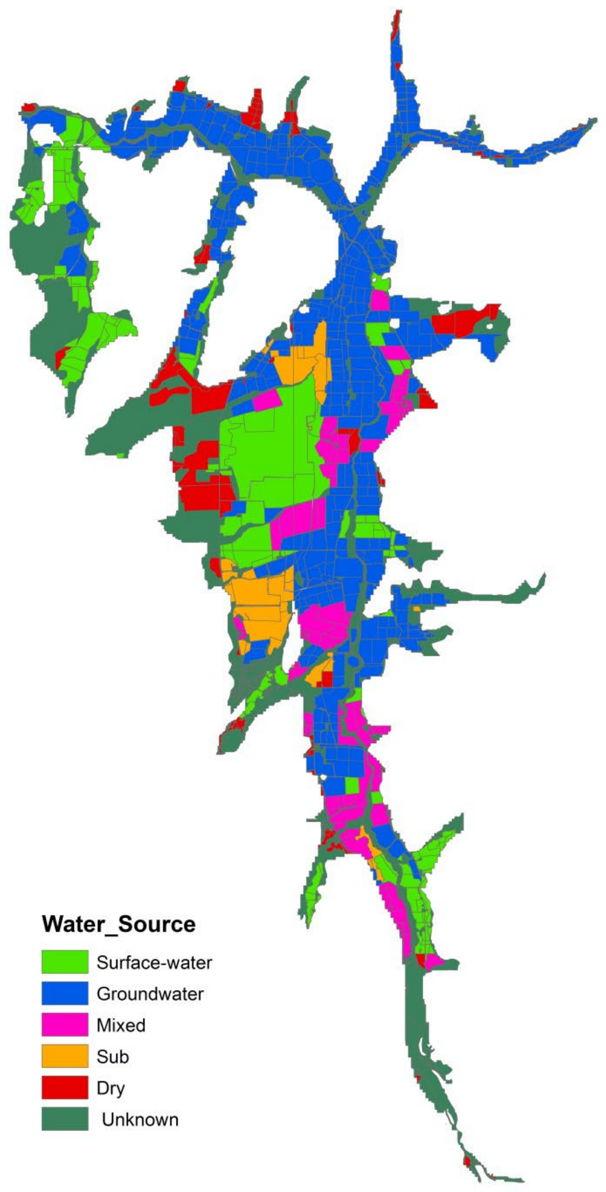
- Calculates daily water fluxes at field-scale (2,119 fields)

Soil Water Budget Model

- Calculates daily water fluxes at field-scale (2,119 fields)
- Input data (text files)

  Landuse
  Soil properties
  Irrigation type
  Water source
  Potential ET
  Crop Coefficient (Kc)
  Rooting depth
  Precipitation
  Streamflow

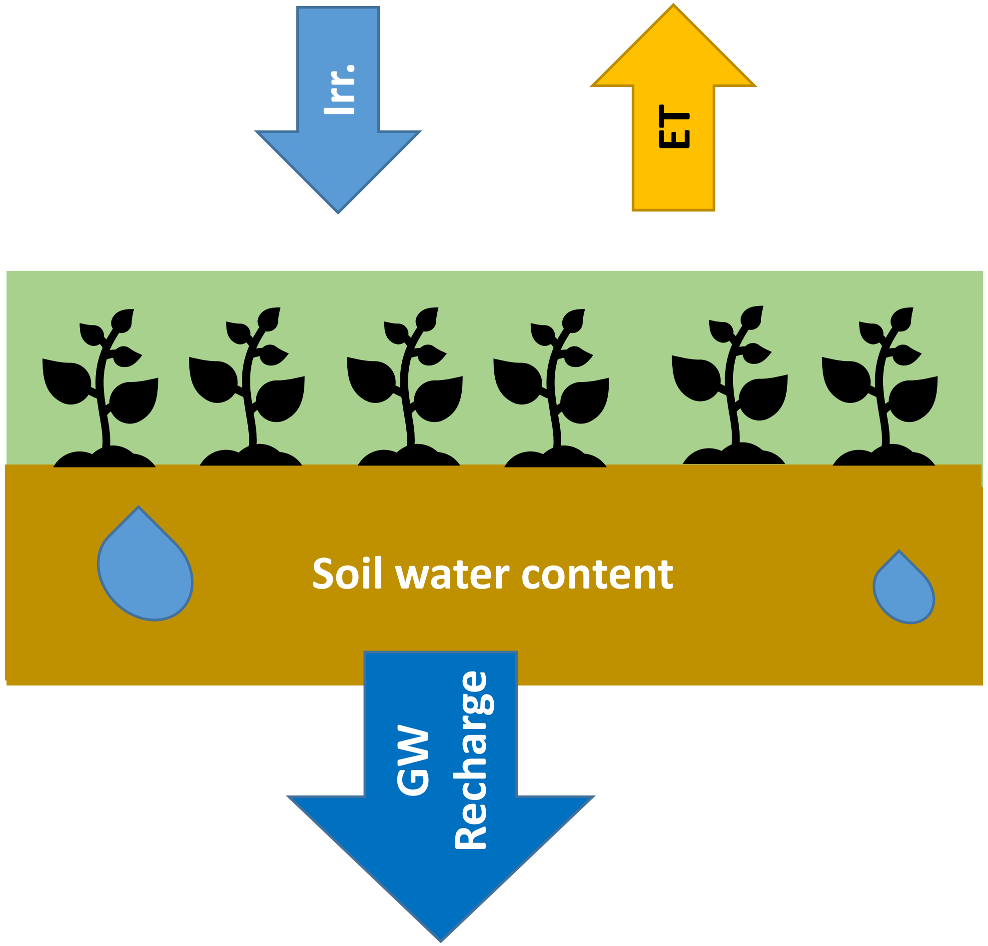
- Estimates pumping in 167 irrigation wells



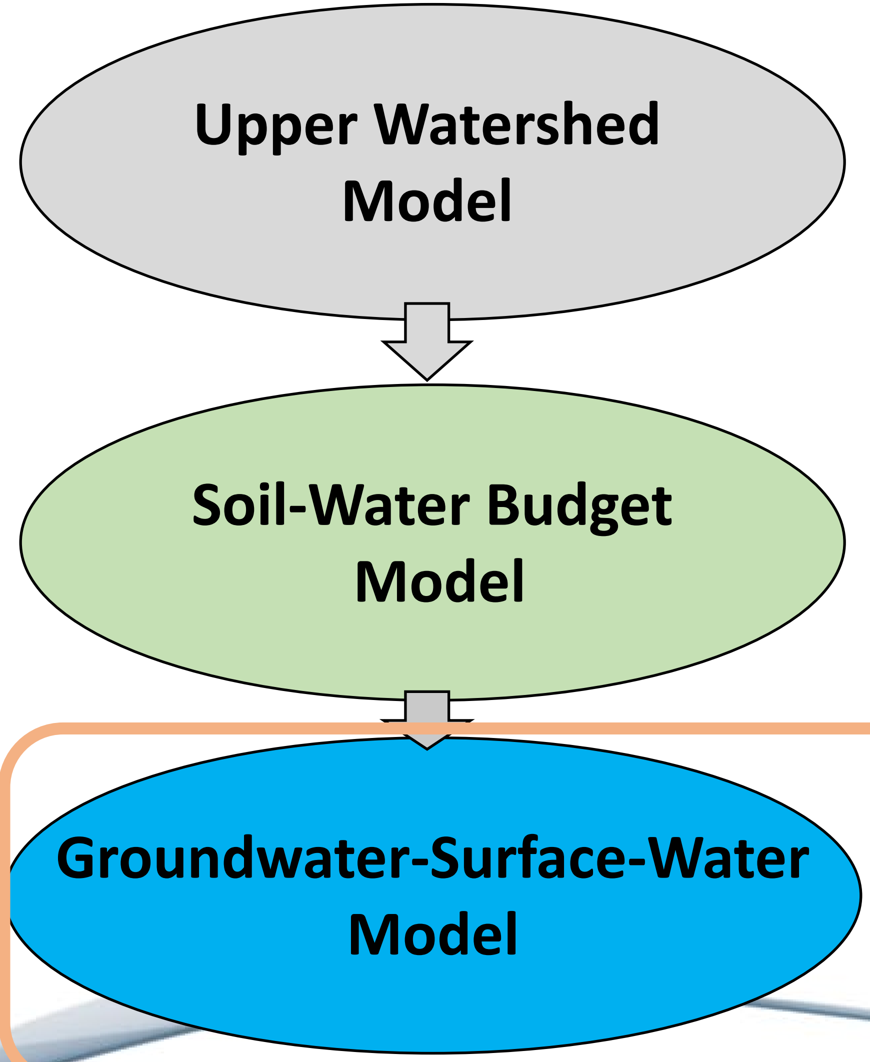
Soil Water Budget Model

- Calculated daily for each field
  - ET
  - Irrigation (from streams and wells)
  - Soil water content
  - Groundwater recharge

- Groundwater recharge and irrigation are summed to monthly values for MODFLOW model



Components of SVIHM



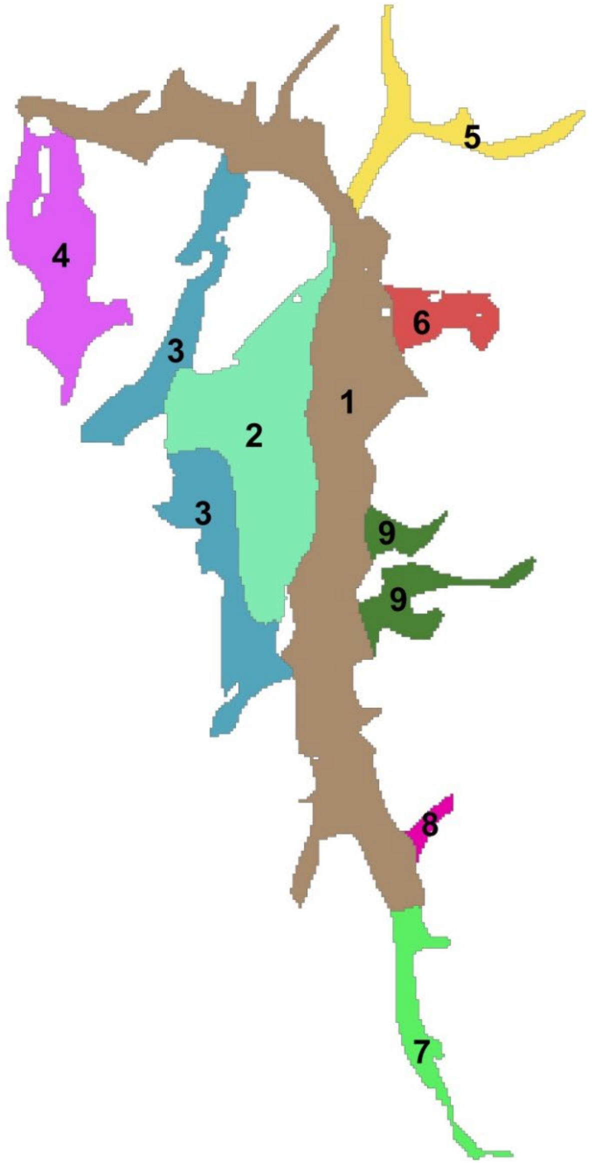
Streamflow entering Scott Valley (Regression model)

Recharge and pumping within the valley (Tipping bucket model)

Detailed groundwater levels and streamflow within the valley (MODFLOW model)

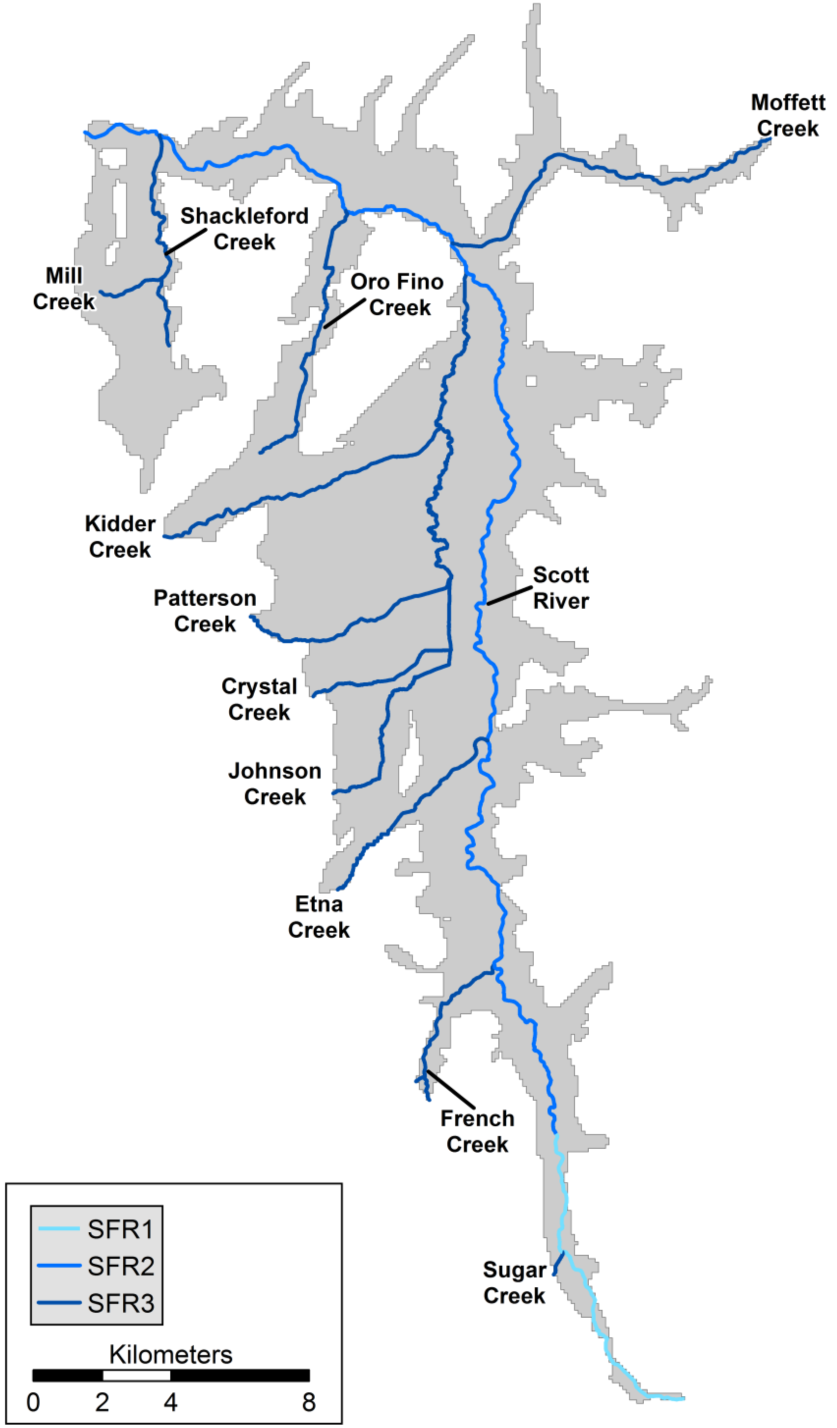
MODFLOW Model

- Aquifer properties:
  - Hydraulic conductivity (vertical/horizontal)
  - Specific yield (storage coefficient)
  - Largely based on zones defined by Mack (1958)



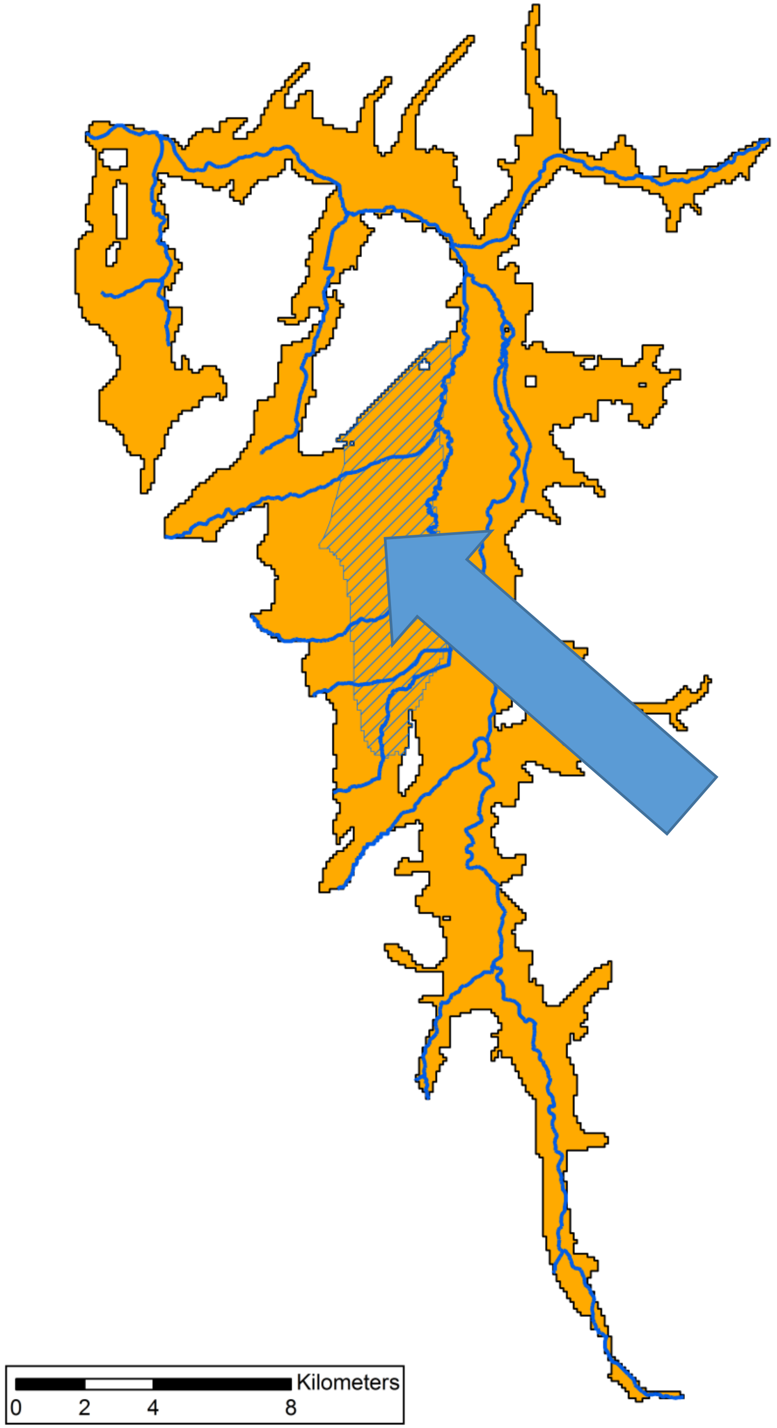
MODFLOW Model

- Streamflow routing package (SFR) used to simulate Scott River and tributaries



MODFLOW Model

- Streamflow routing package (SFR) used to simulate Scott River and tributaries
- Discharge Zone (shallow groundwater)
- Oct 1, 1990 – Sept 30, 2018 simulation period (28 years)
  - Daily timesteps, monthly stress periods



SVIHM Summary

- SVIHM structure:
  1. Streamflow regression model
  2. Soil water budget model
  3. MODFLOW Model

Estimated streamflows →
Field-by-field water demand →
Groundwater-surface water model

- Recharge estimated at the field scale (step 2)

- Groundwater heads, streamflow, and stream-aquifer exchange are solved together (step 3)

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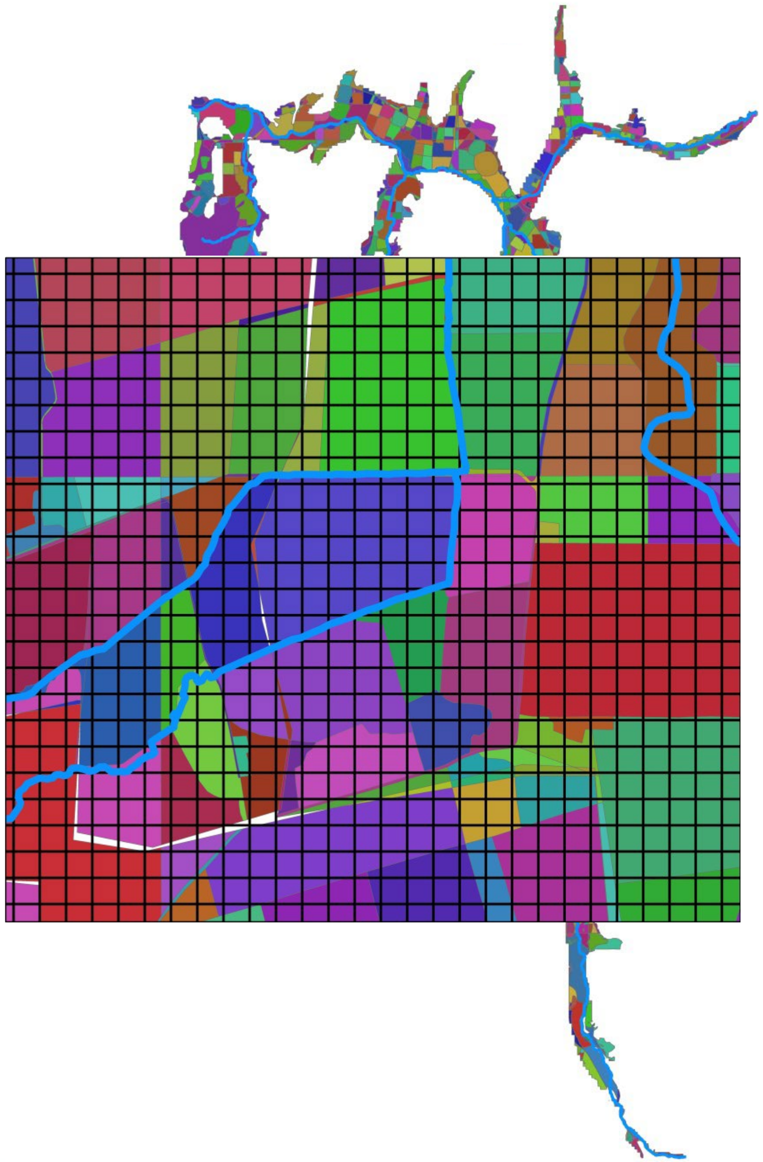
What do SVIHM results look like?

- Data everywhere
  - ~20,000 aquifer cells (100-meter grid)
  - 1,837 stream reaches
  - 336 months in 28-year model period
- Groundwater heads
  - each model cell, in each month
- Stream flows
  - each stream reach, avg. in each month



SVIHM results in space and time

- Groundwater heads
  - Contour map

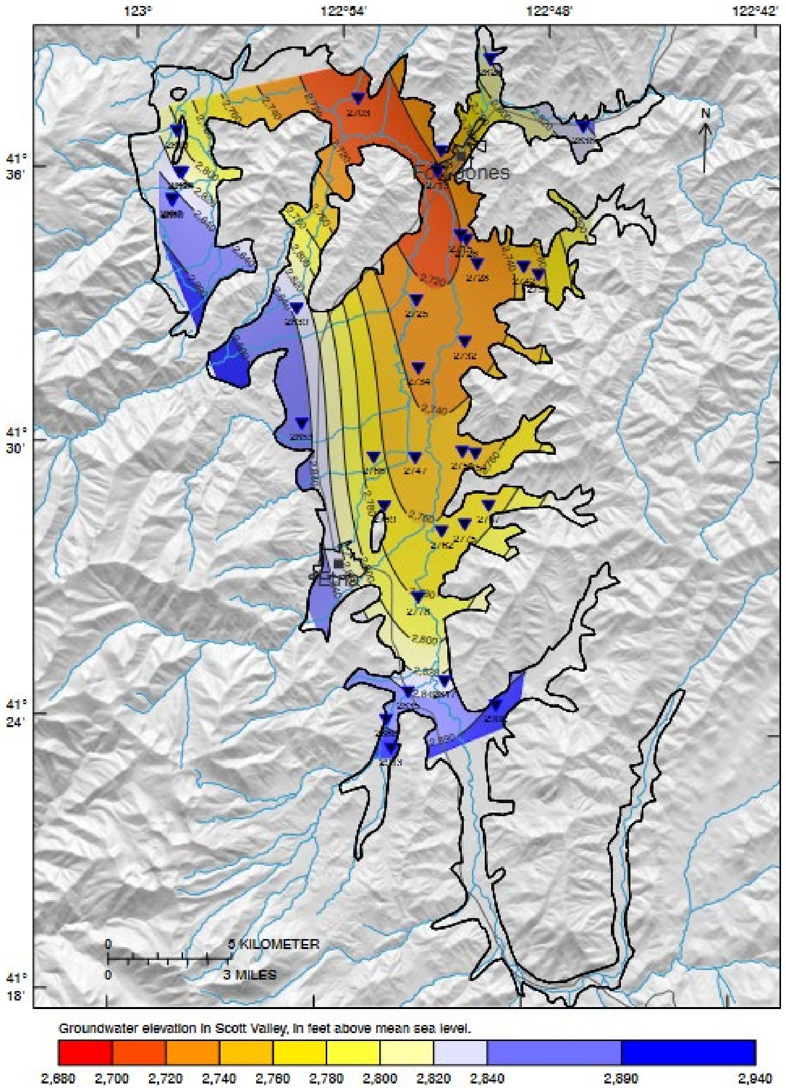


Figure 27: Scott Valley Groundwater Elevations, March 2015.

SVIHM results in space and time

- Groundwater heads
  - Contour map
  - Well hydrograph

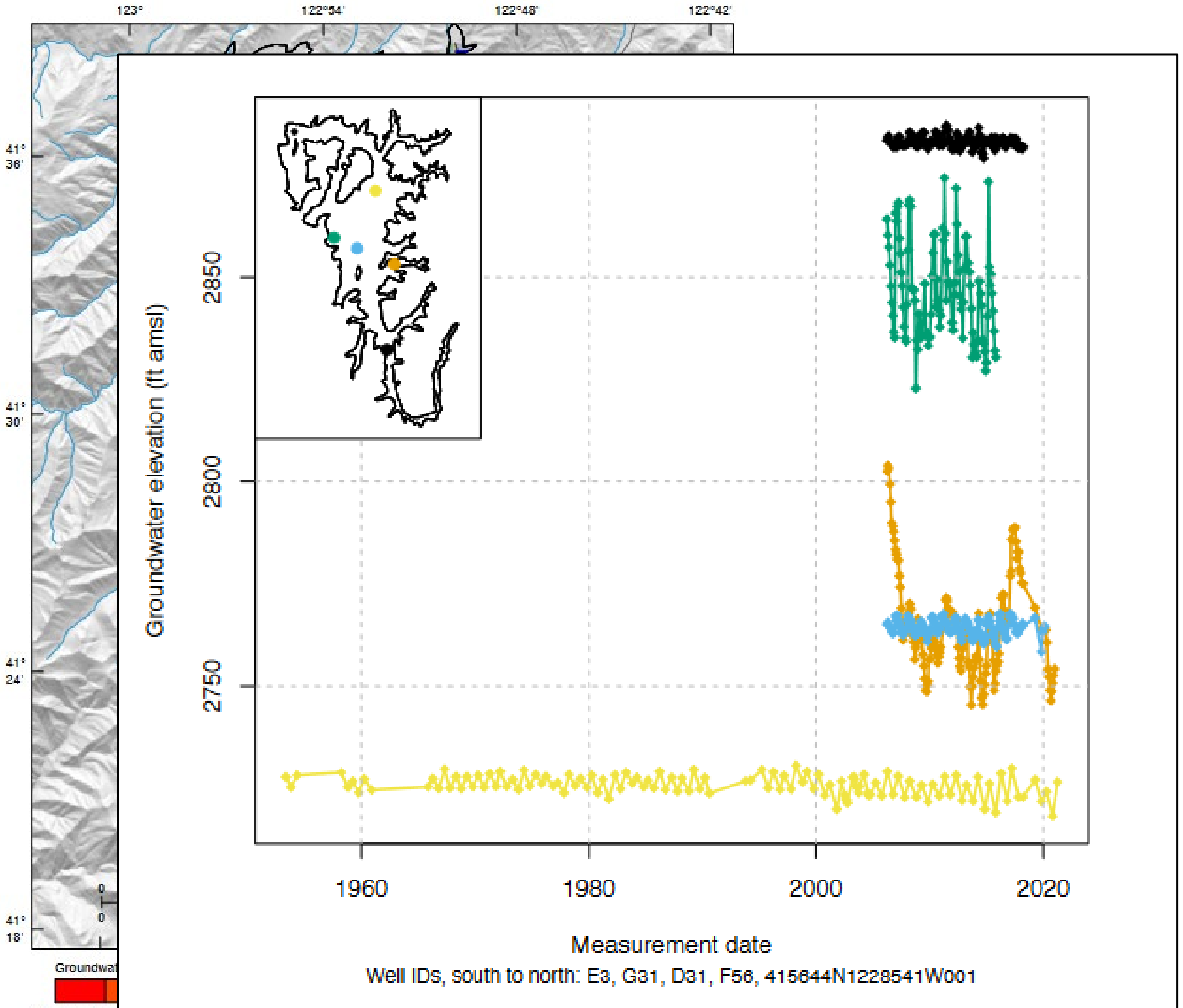
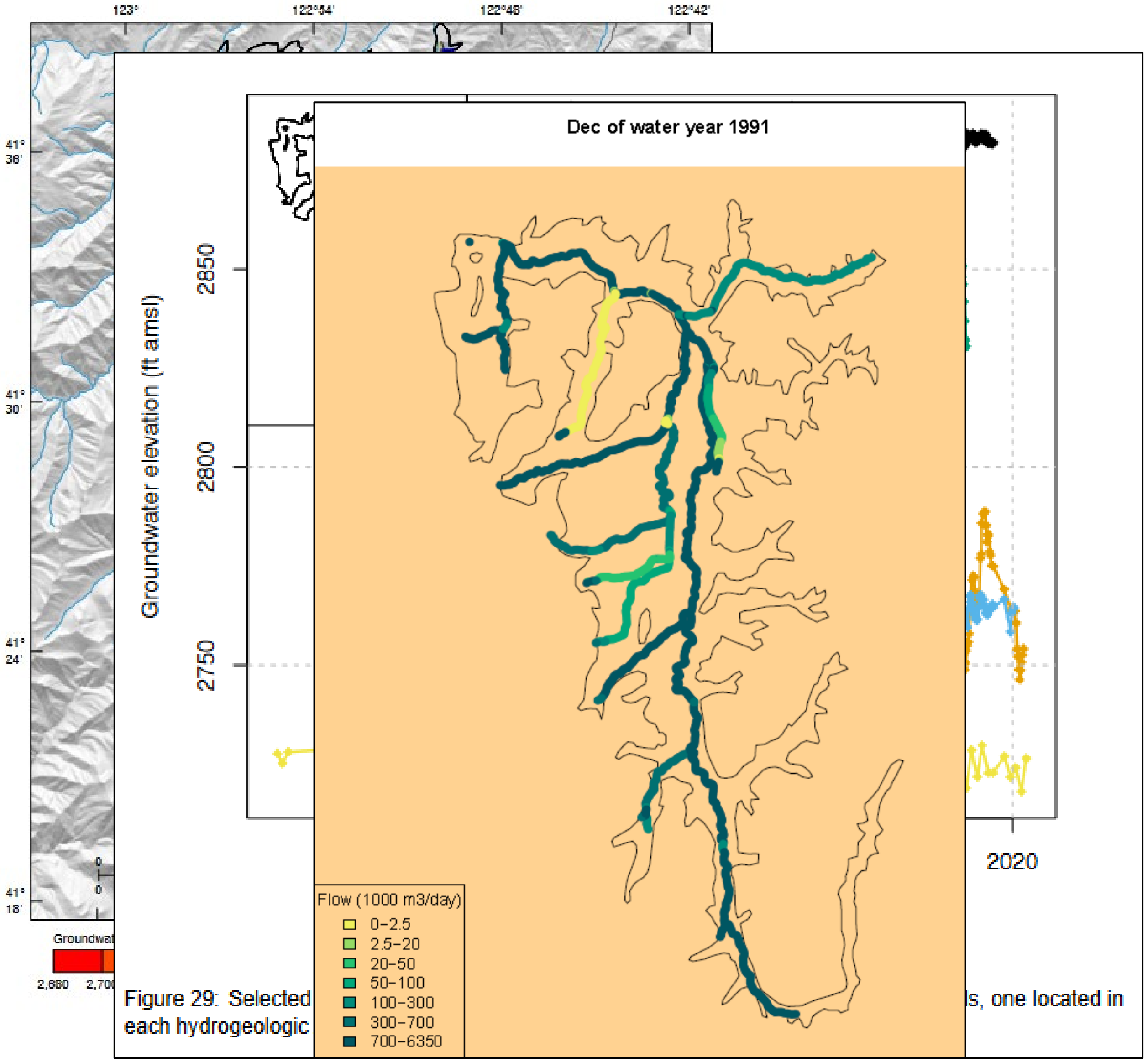


Figure 29: Selected long-term groundwater elevation measurements over time in five wells, one located in each hydrogeologic zone of the Scott River Valley Groundwater Basin.

SVIHM results in space and time

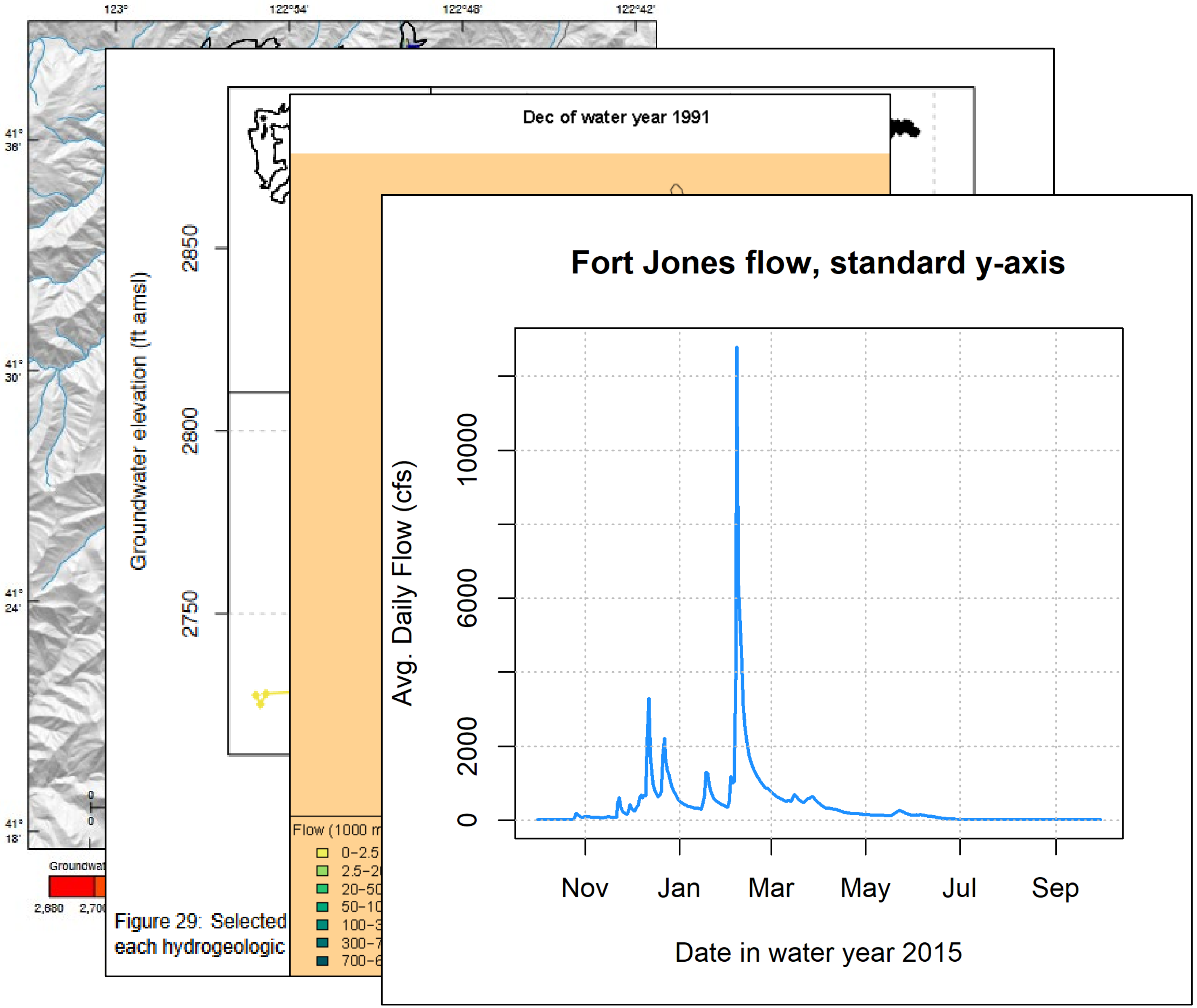
- Groundwater heads
  - Contour map
  - Well hydrograph
- Stream flows
  - Stream connectivity map



SVIHM results in space and time

- Groundwater heads
  - Contour map
  - Well hydrograph

- Stream flows
  - Stream connectivity map
  - River hydrograph



Key graphs from GSP

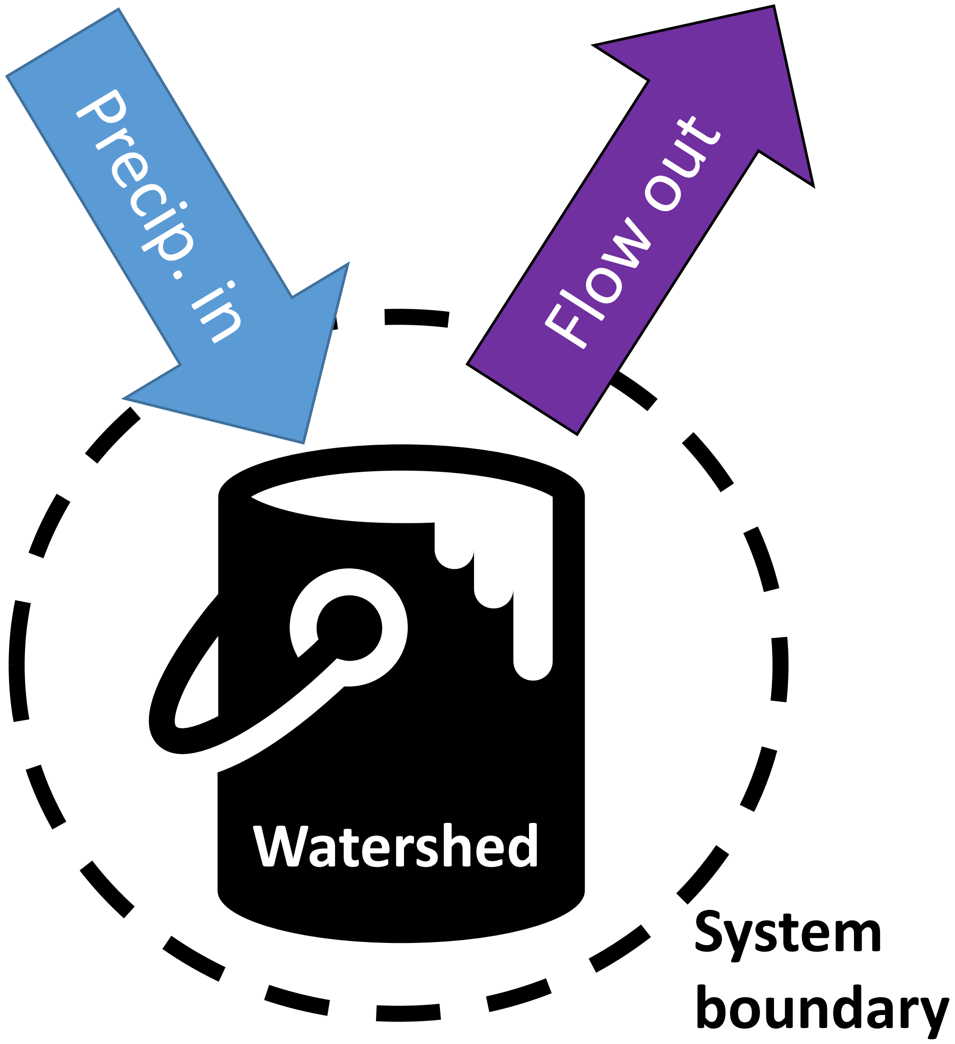
1. Water budget

2. Fort Jones flow

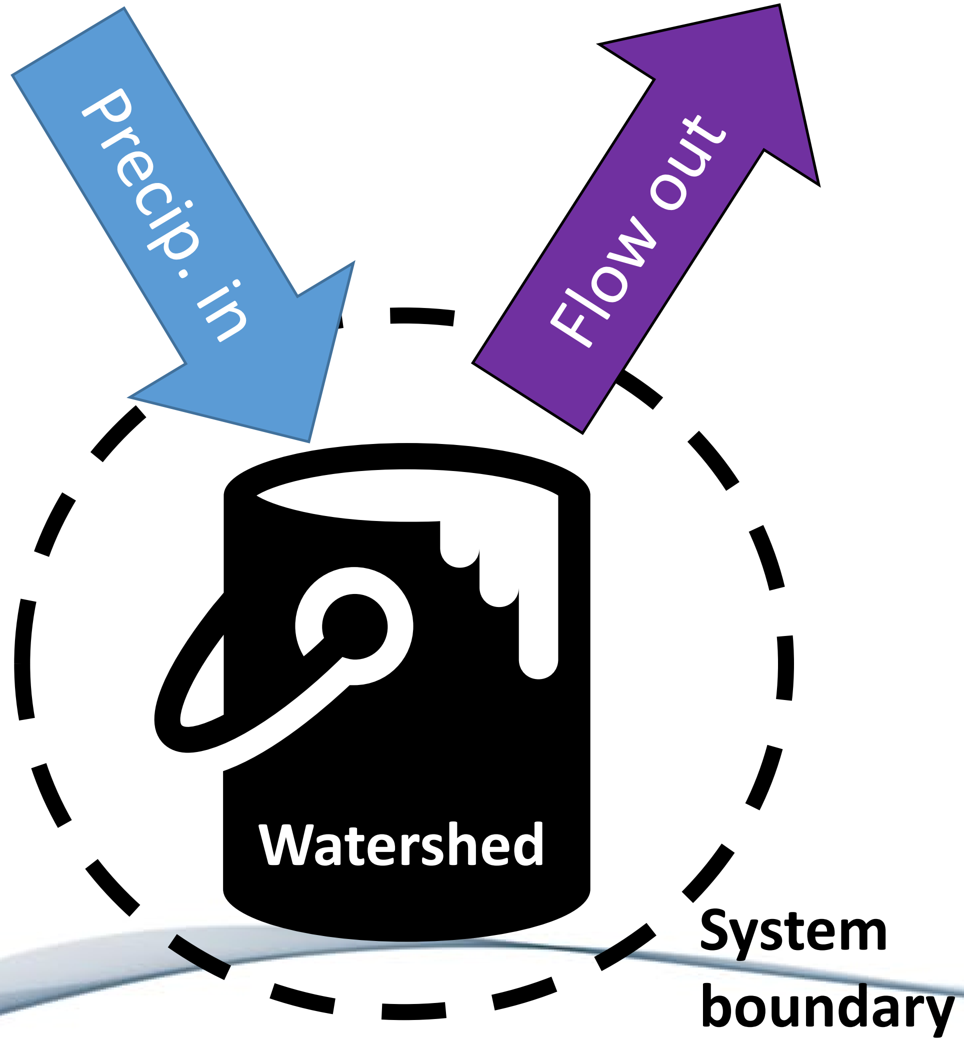
3. Scenario comparisons: **Summaries** of **FJ flow differences**
   a. Percentile Plots
   b. Reconnection Dates
   c. Flow differences by water year type

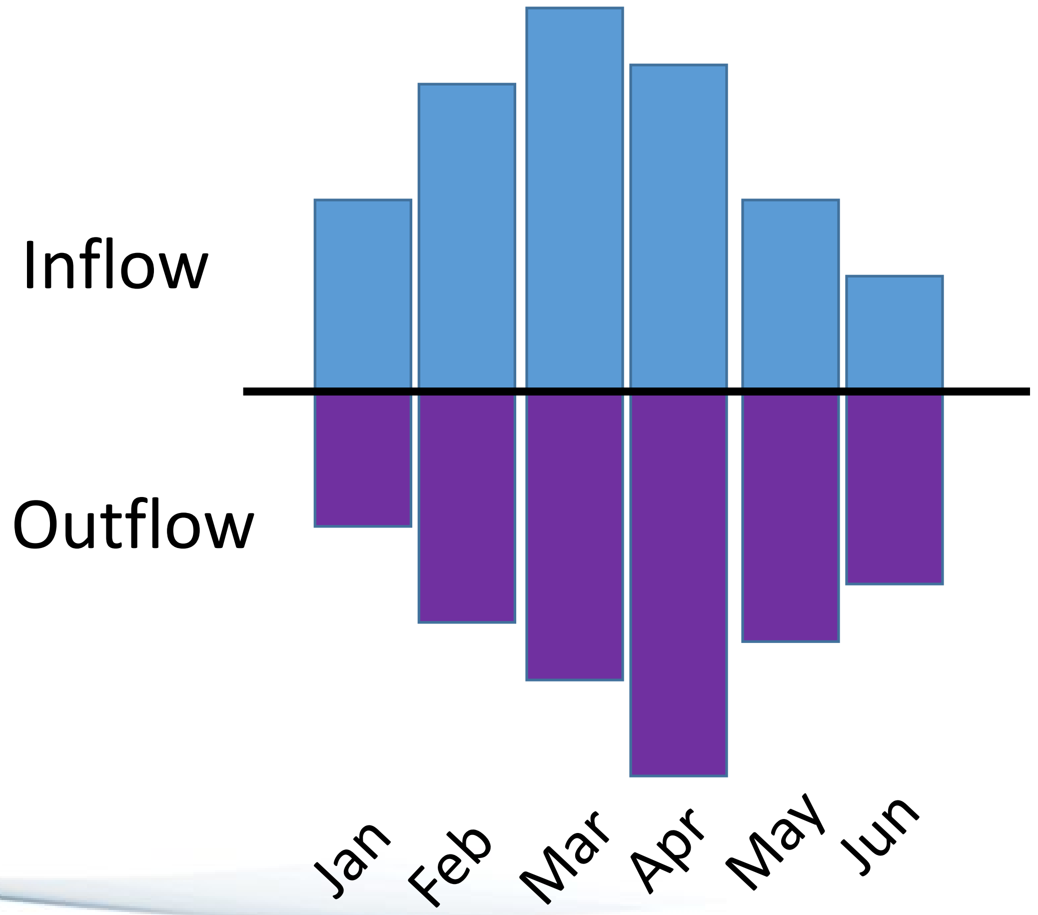
Key graph 1. SVIHM water budget

- Q: What is a water budget?
- **A: Quantifies the flows in/out of a system**
  - Defined by a system boundary
  - Over a certain time span
- Rule of thumb: which arrows cross the boundary?



Key graph 1. SVIHM water budget

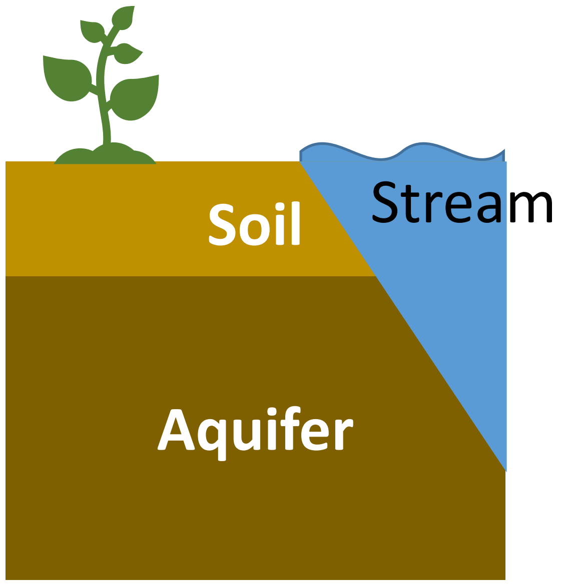




Key graph 1. SVIHM water budget

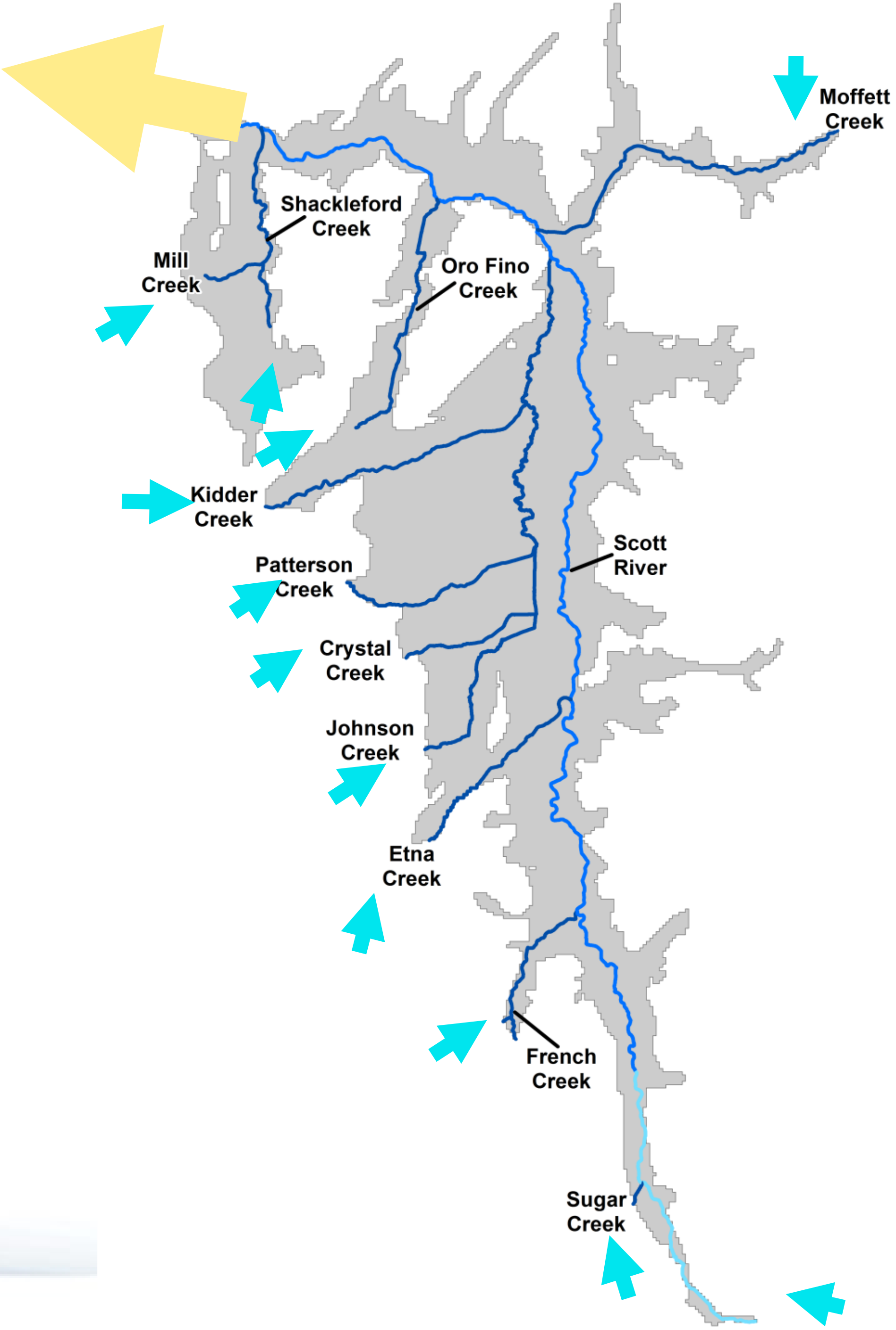
- We calculate water budgets for 3 volumes:

1. Surface water (streams)
2. Soil zone
3. Aquifer



Key graph 1. SVIHM water budget

- Surface water (streams) budget



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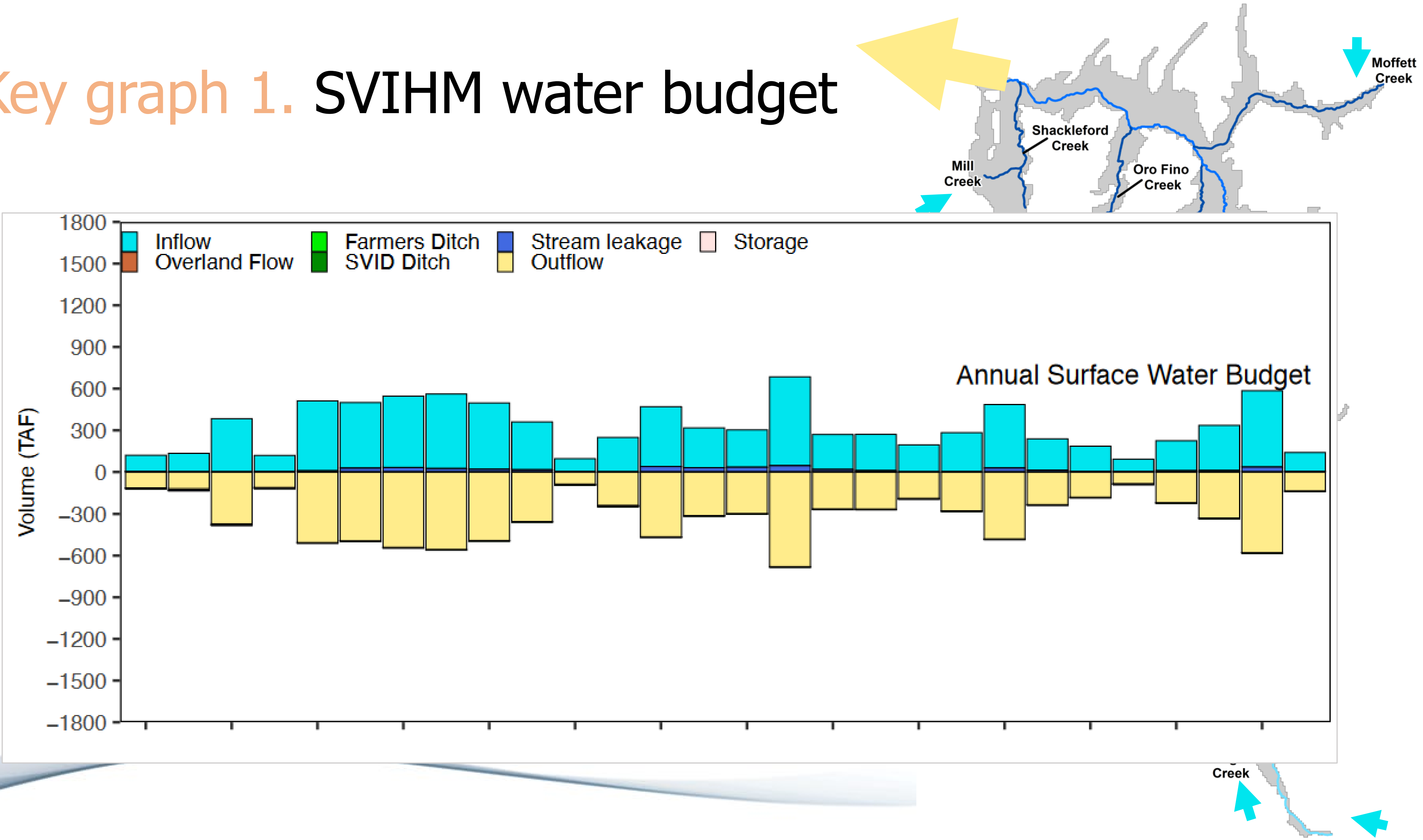
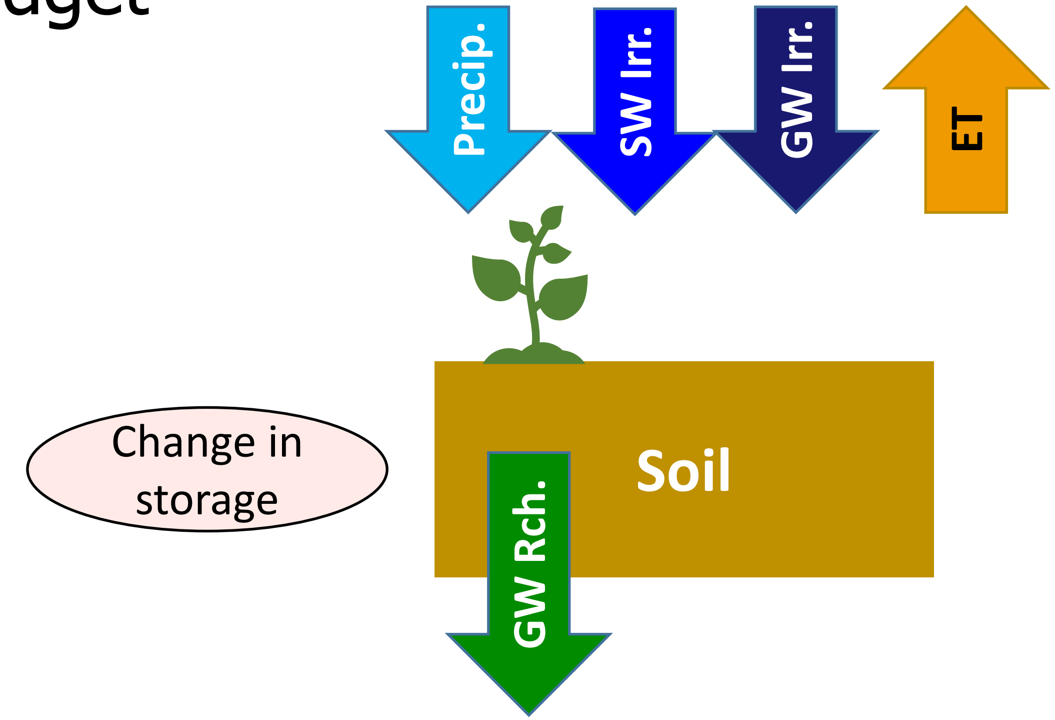


Key graph 1. SVIHM water budget

- Soil zone budget



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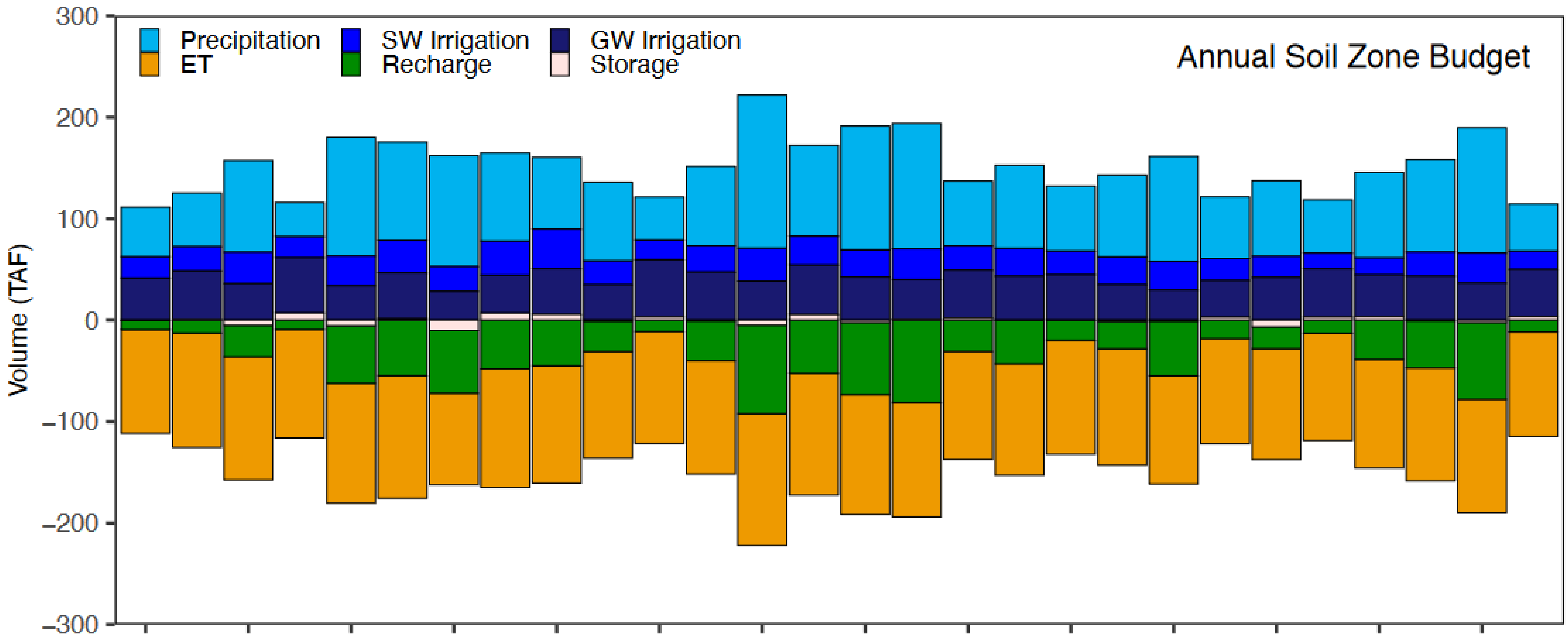
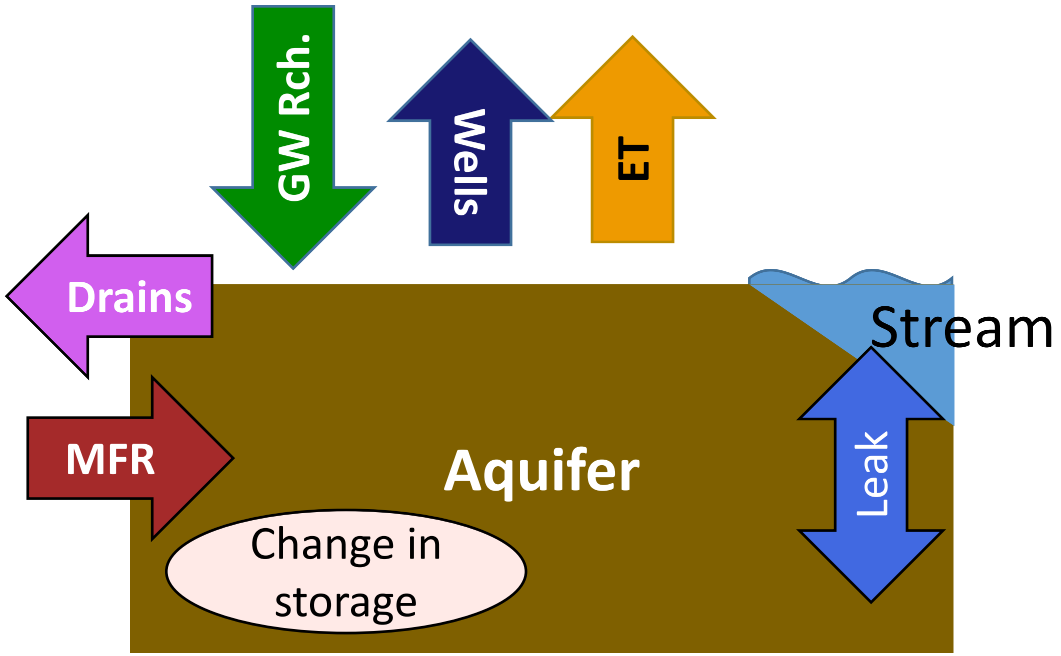


Key graph 1. SVIHM water budget

- Aquifer budget



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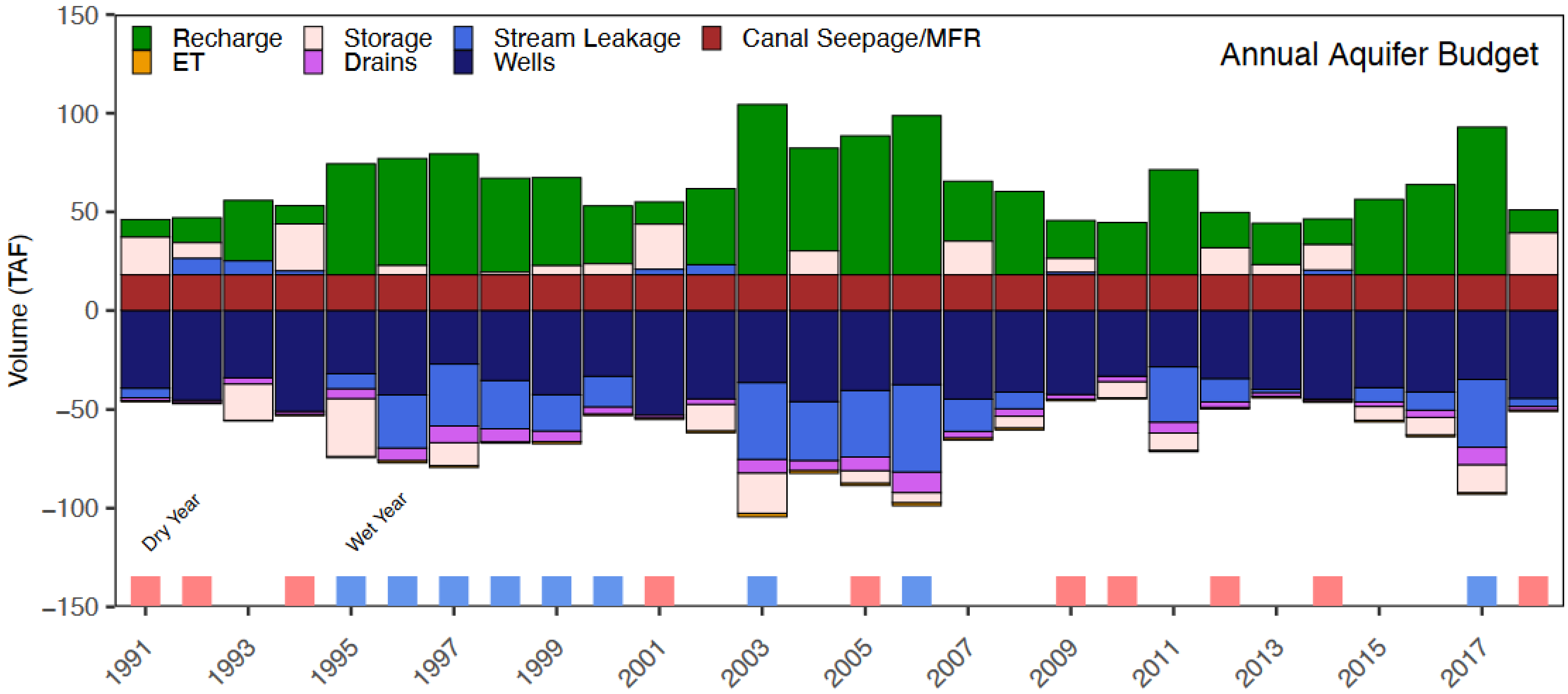


Key graph 1. SVIHM water budget takeaways

- Surface water:
  - Dominated by tributary flow in and FJ flow out
  - Small of surface flow proportion seeps into aquifer as stream leakage
- Soil zone:
  - Annual ET relatively consistent.
  - Irrigation and recharge vary with water year type
- Aquifer:
  - Inflows are mostly recharge from soil and Mountain Front Recharge (MFR)
  - Main outflows: well pumping and discharge to streams
  - Stream leakage: small part of surface water budget, large part of aquifer budget
  - Change in storage fluctuations are relatively larger for aquifer than for soil zone

Key graphs from GSP

1. Water budget

2. Fort Jones flow

3. Scenario comparisons: **Summaries** of **FJ flow differences**
    a. Percentile Plots
    b. Reconnection Dates
    c. Flow differences by water year type

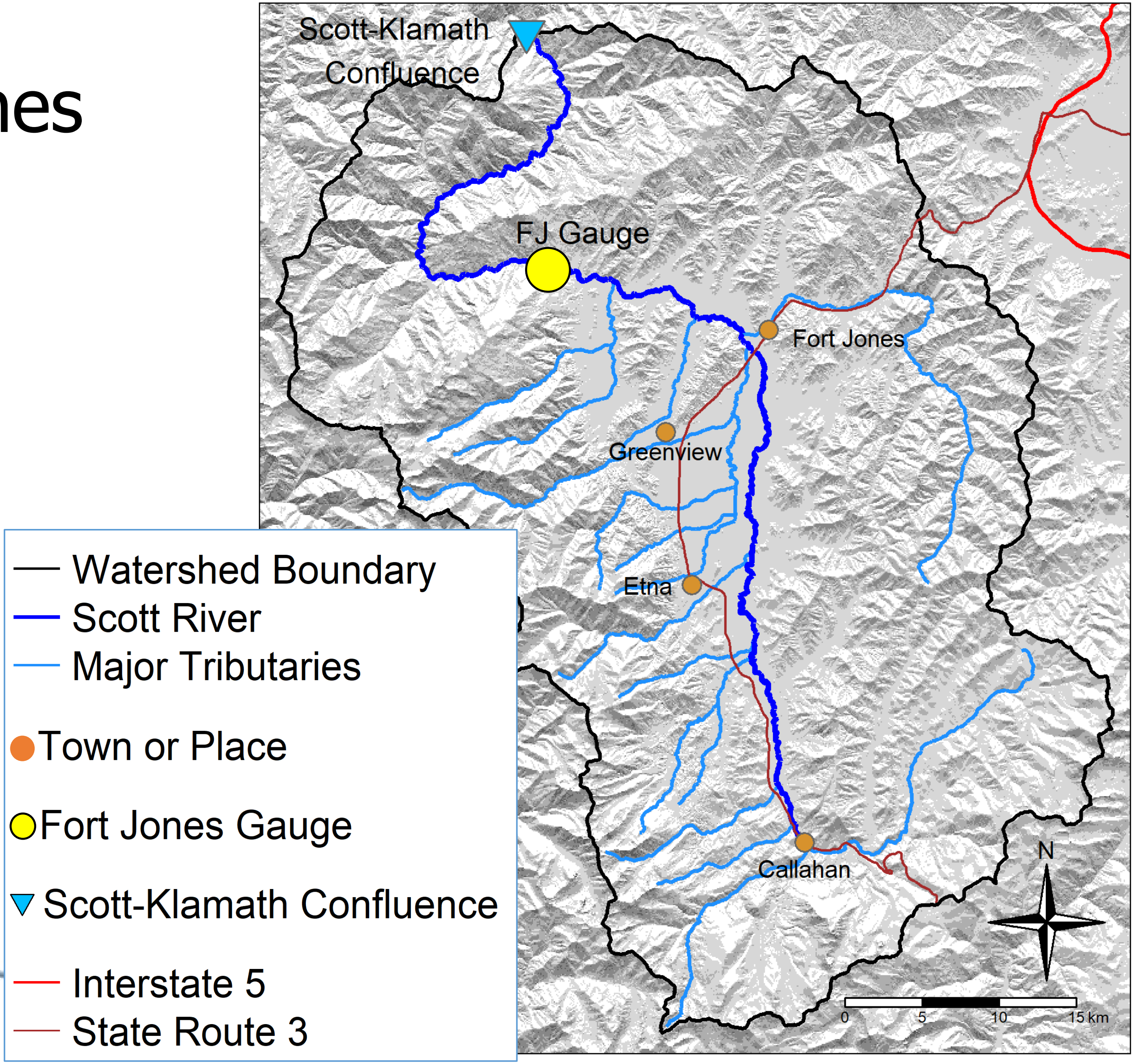
Key graph 2. Fort Jones flow over time

- Features of Key Graph 2
  - Why FJ gauge?
  - Log-y axis exercise
  - Questions you can ask with Key Graph 2
- How to use FJ flow to think about SVIHM scenarios
  - Observed vs. Simulated (historical basecase) FJ flow
  - Basecase vs Scenario FJ flow

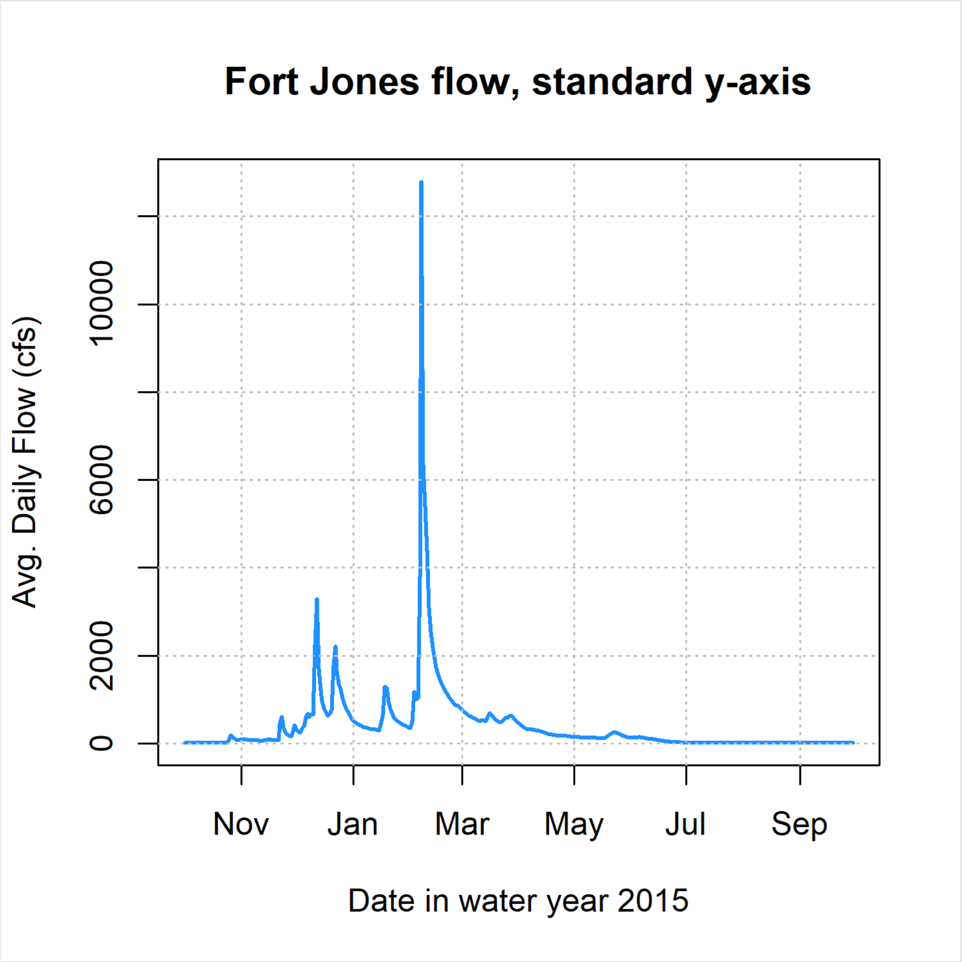
Importance of Fort Jones gauge

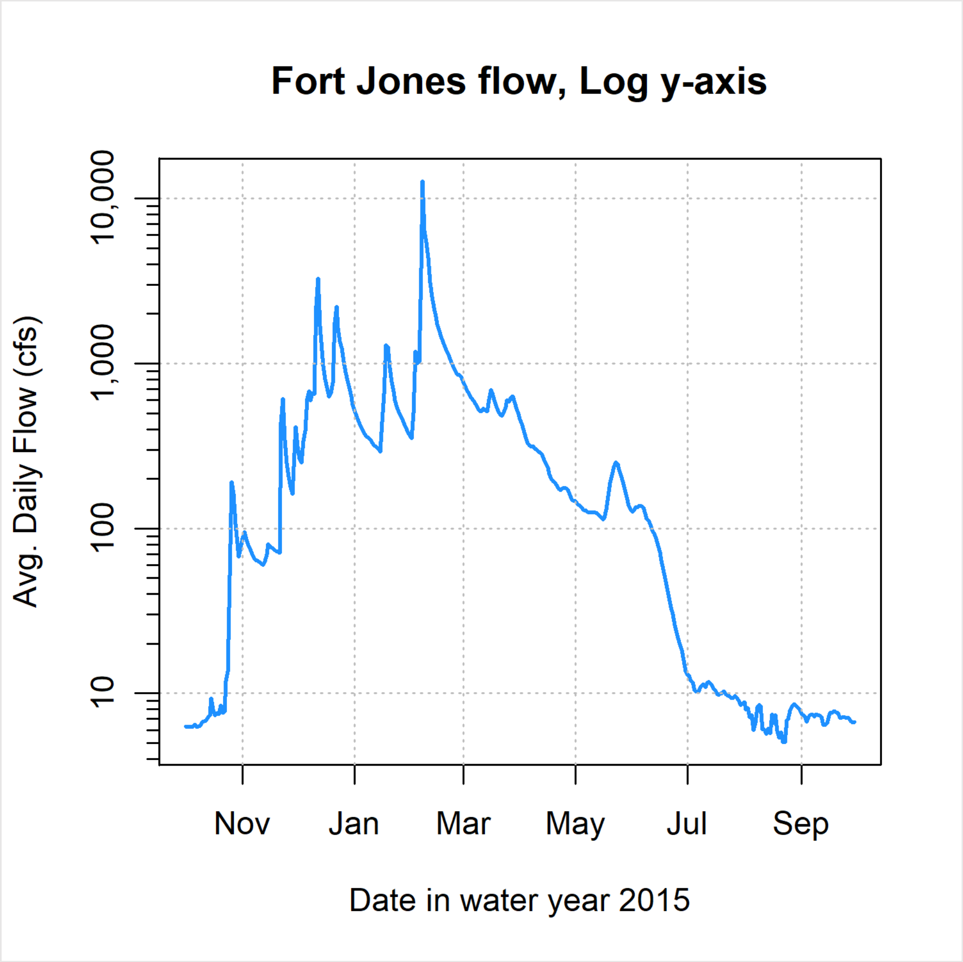
- Long record (80 years)
- Key location
- Used for management
- Can be used for model calibration

- Management impact often summarized as **flow changes at Fort Jones gauge**



Key graph 2. Fort Jones flow – why a log-y axis?





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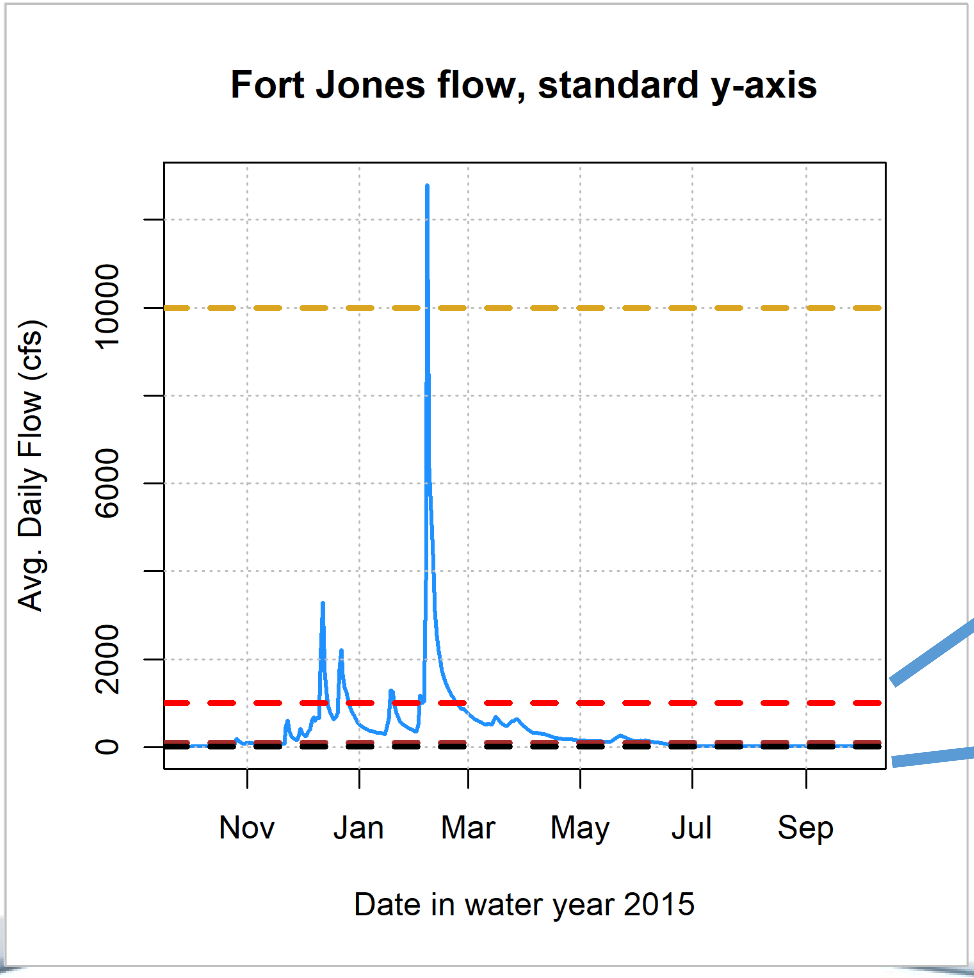
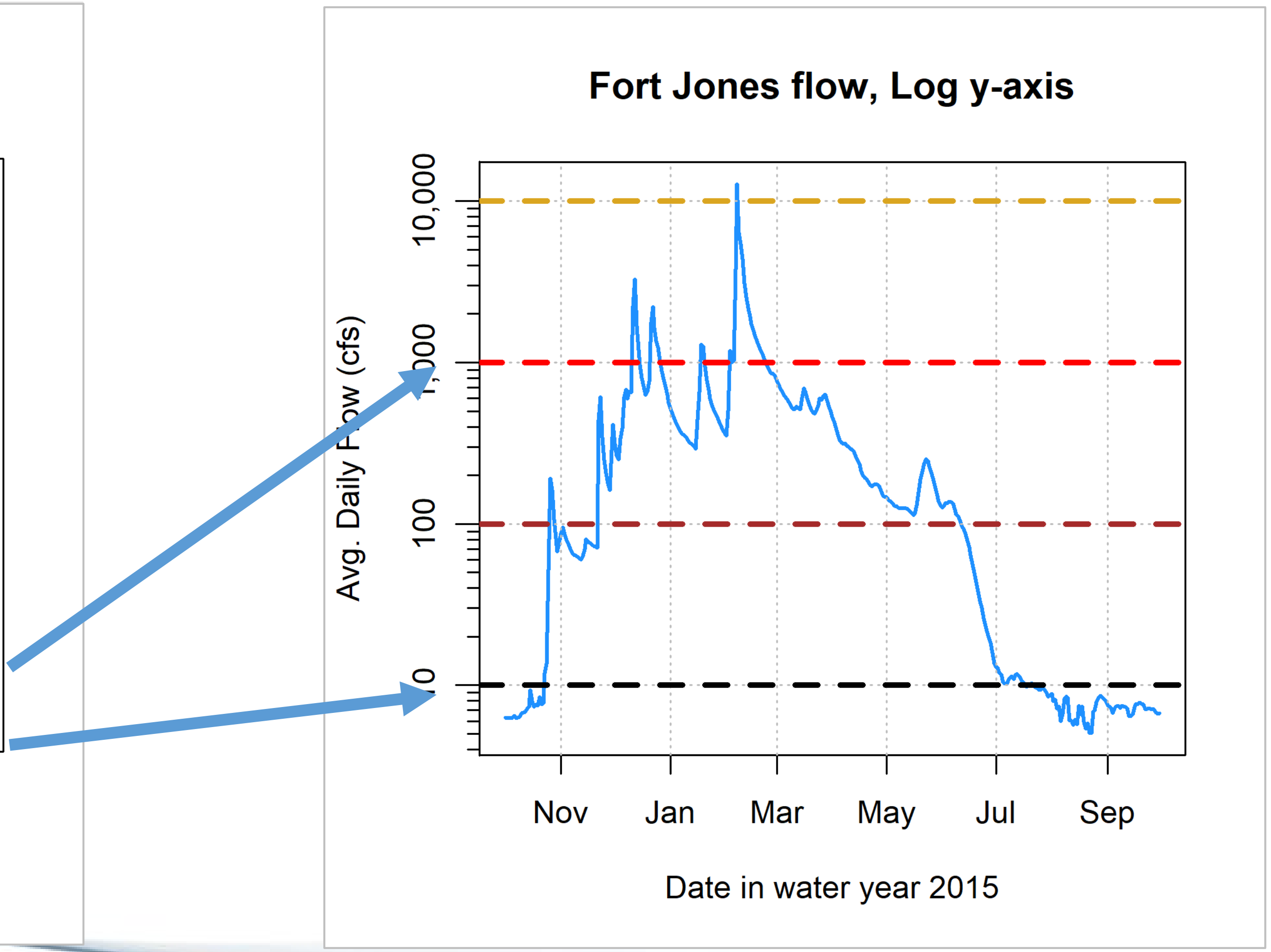
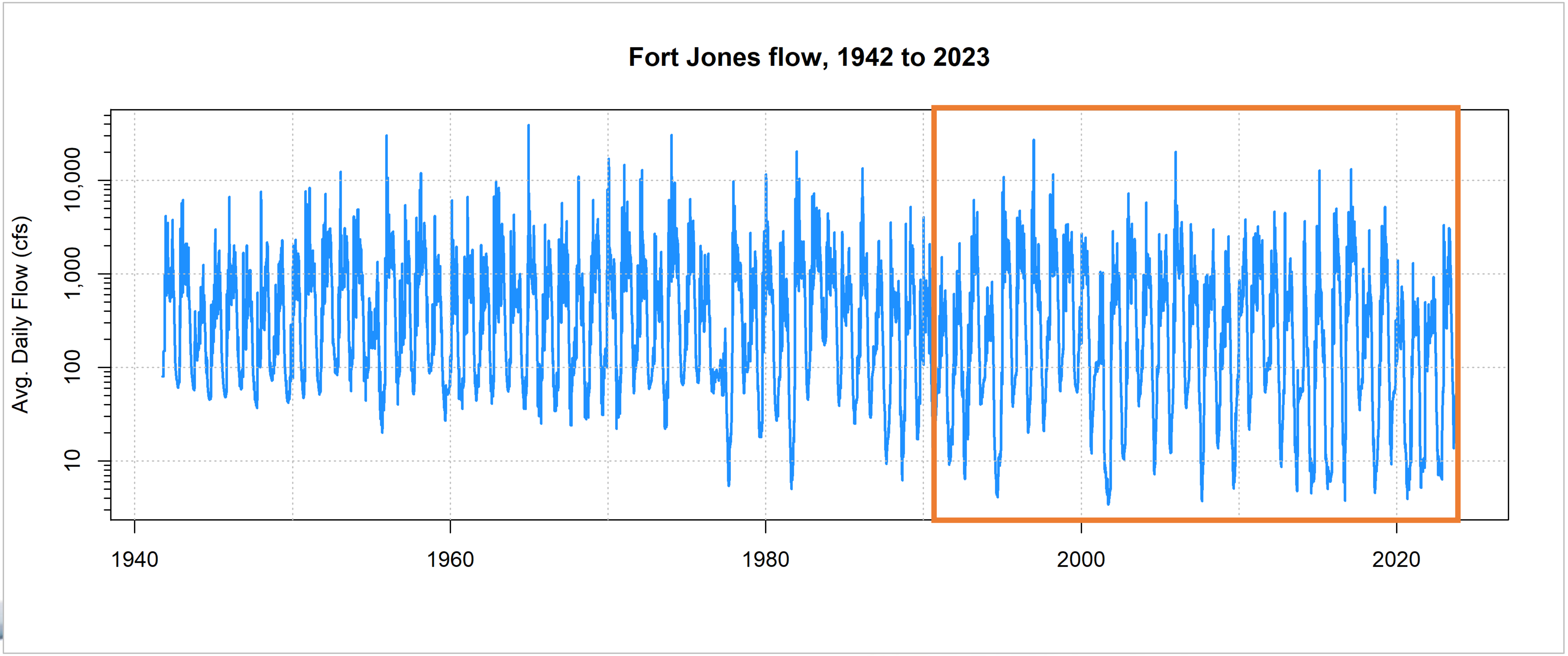


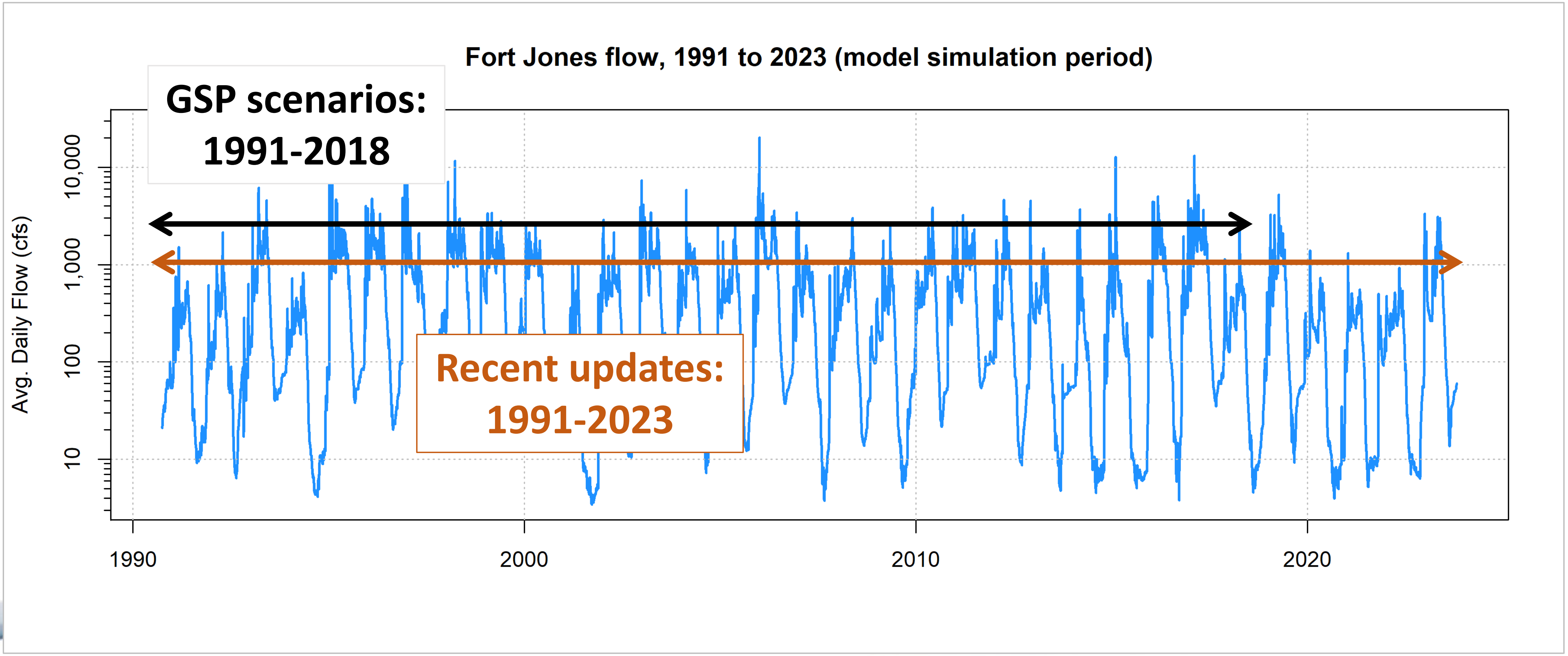


A log-scale axis shows more detail at low flows

Key graph 2. Fort Jones flow: ~80 years of flow observations, ~30 years of simulations in SVIHM



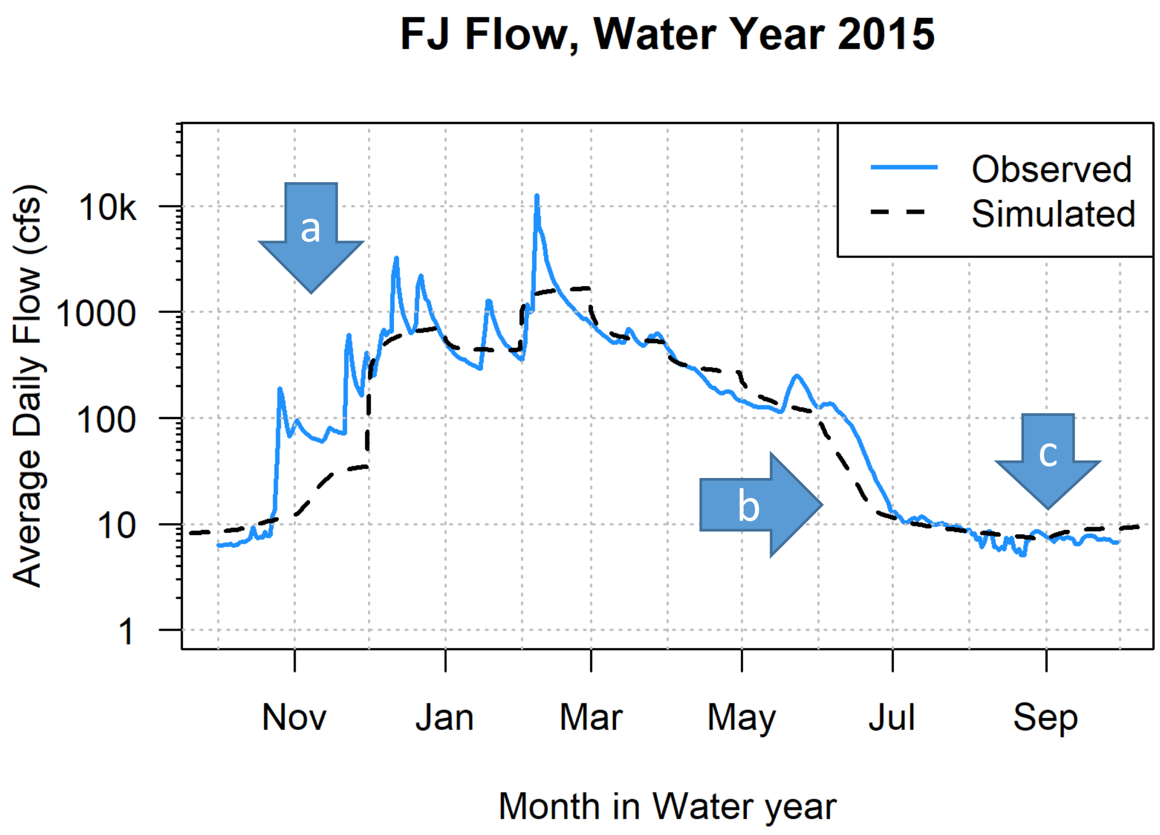
Key graph 2. Fort Jones flow: ~30 years of flow observations to compare to SVIHM simulation



Key graph 2. Fort Jones flow: comparing observations and SVIHM simulation

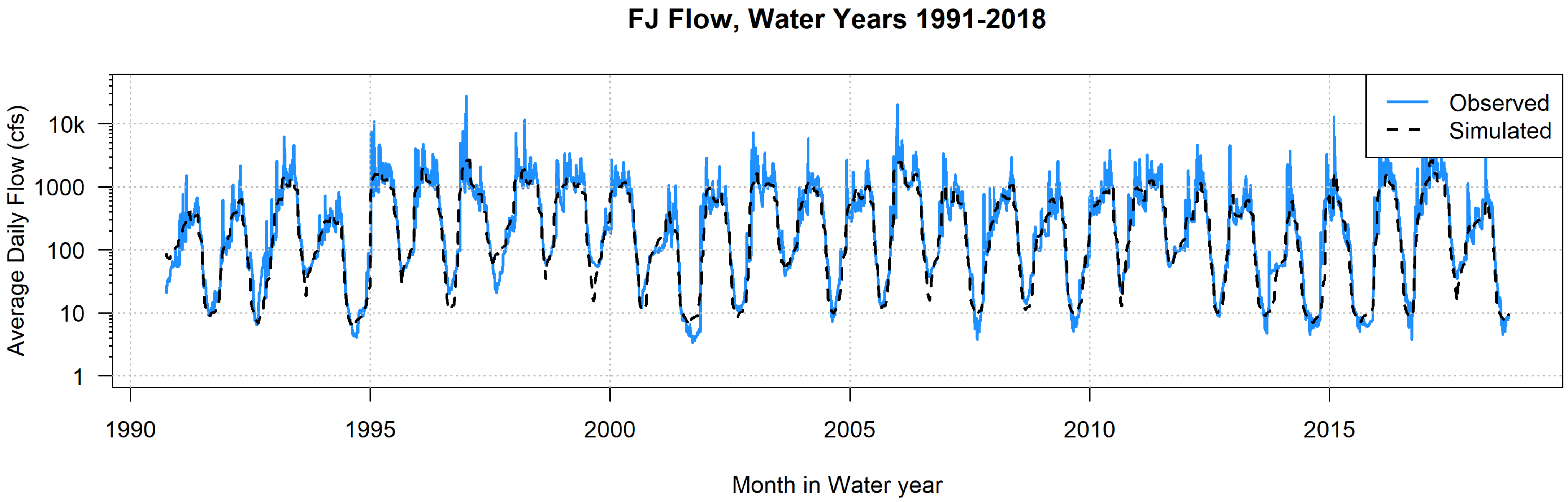
Key graph 2 (1 water year)

- Can see water year type
- Can compare model performance during:
  a) Wet season onset
  b) Spring flow recession
  c) Dry season



Key graph 2. Fort Jones flow

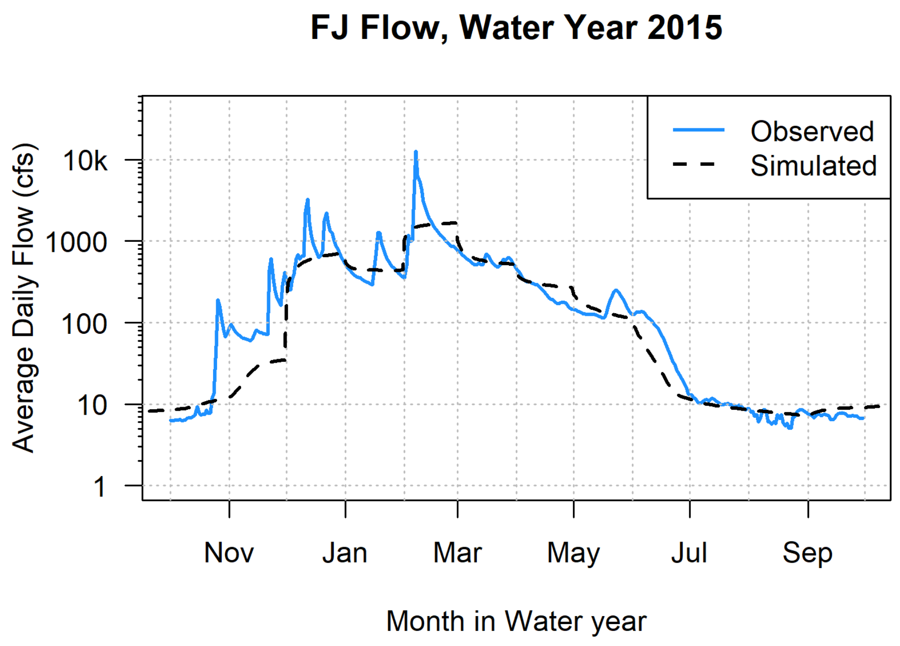
- However, the utility of Key Graph 2 breaks down when looking at >3 water years.



- We need to summarize. (**Key Graphs 3-5**)

Key graph 2. Fort Jones flow
Sim. vs **Obs.** – model performance

- Match between Observed and Simulated is one measure of model performance (i.e. Nash-Sutcliffe Efficiencies)

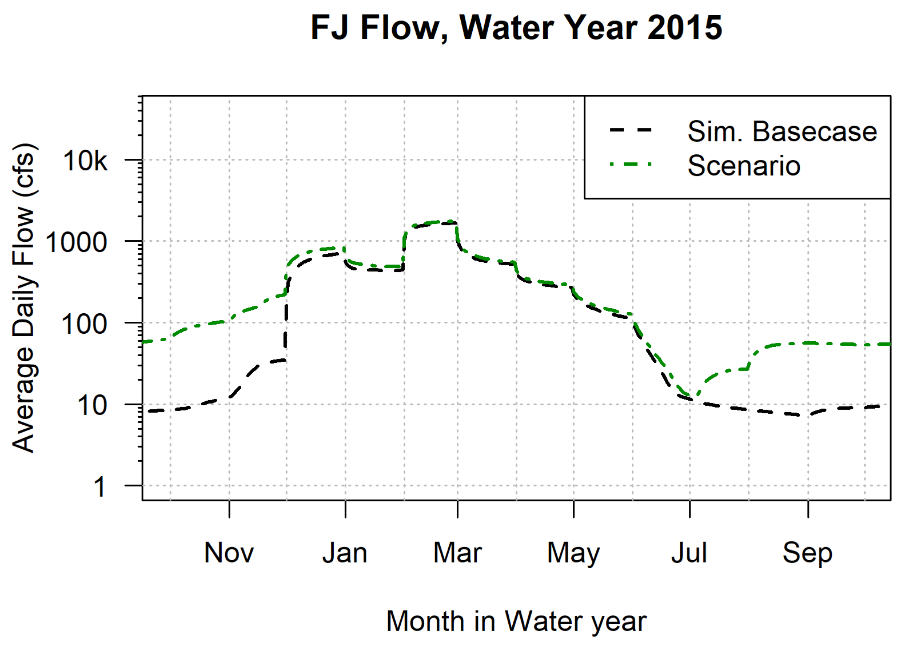


<u>Comparison between:</u>

- **Observed**: what was measured
- **Simulated** Historical Basecase: SVIHM's calibrated estimate of the observed flow

Key graph 2. Fort Jones flow
Basecase vs. **Scenario** – management impact

- Assume basecase is a close estimate of history. Then, what if history/management was different?



<u>Comparison between</u>

- Simulated **Historical Basecase:** SVIHM's calibrated estimate of the observed flow
- Simulated **Scenario**: calibrated estimate of the flow if history were different

Key graph 2. Fort Jones flow: **Basecase** vs. **Scenario** – management impact

Key graph 2 (1 water year)

- Can see water year type
- Can compare management impact during:
  a) Wet season onset
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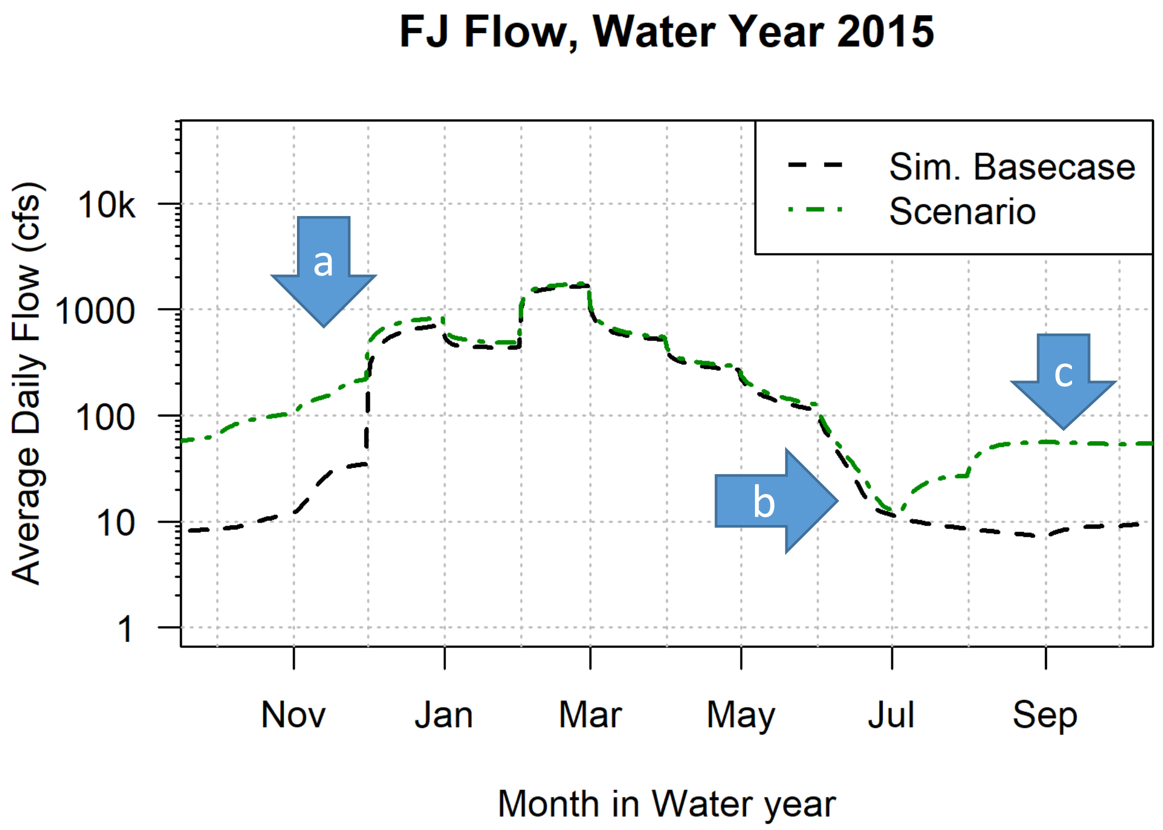

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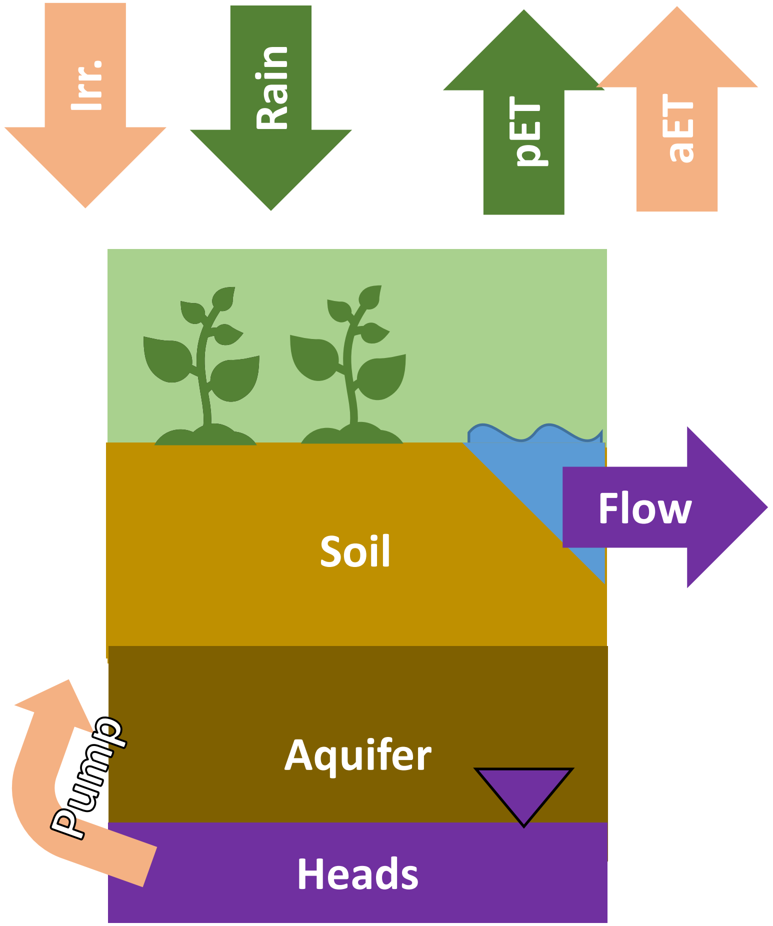
What is a model scenario?

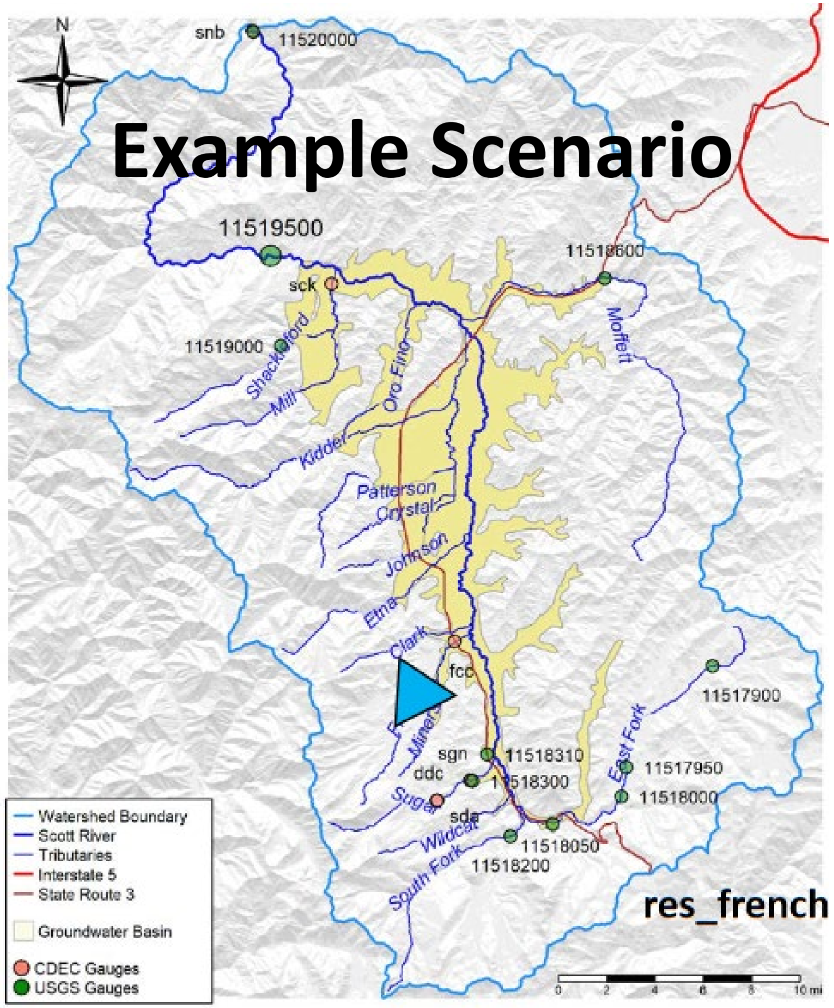
- If history was different, e.g. different **inputs** (weather, land cover, etc)
- … how would that change different **intermediate** calculations (ET, pumping)…
- … and how would that change watershed behavior (**outputs**: heads, flows)?



How to interpret a model scenario

1. Motivating question
2. Simplifying assumptions

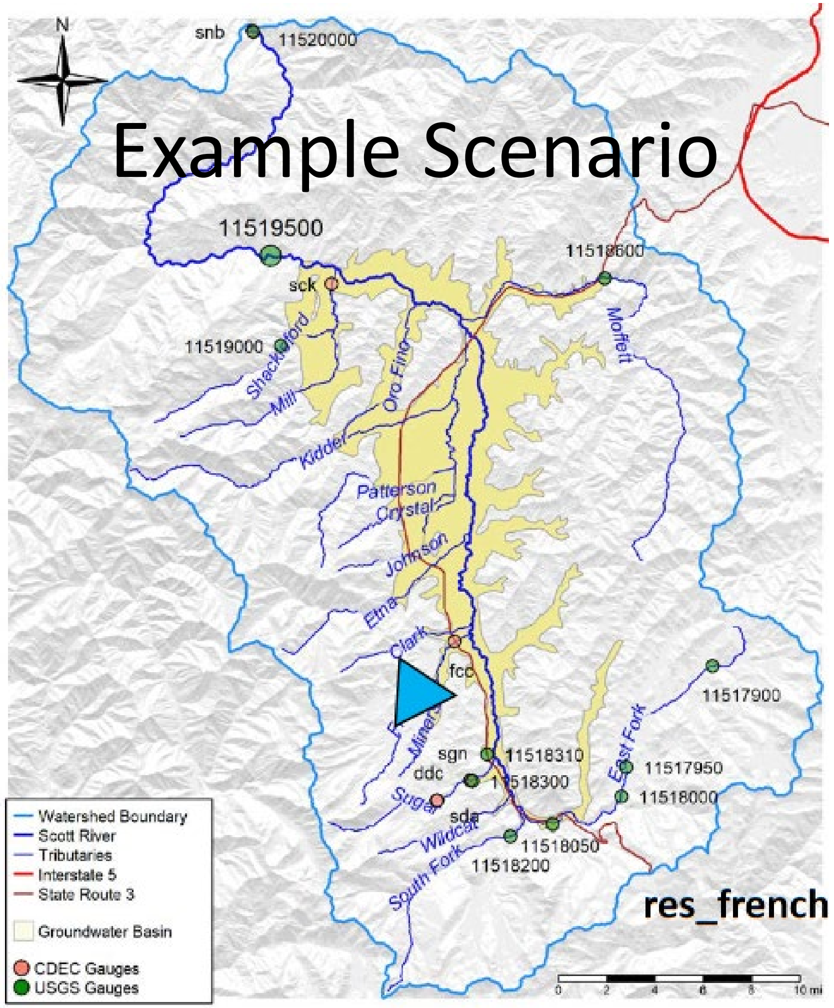
- Motivating question, e.g.:
  - What flow changes would we see…
  - If Scott Valley had a reservoir on French Creek?



Model scenario interpretation

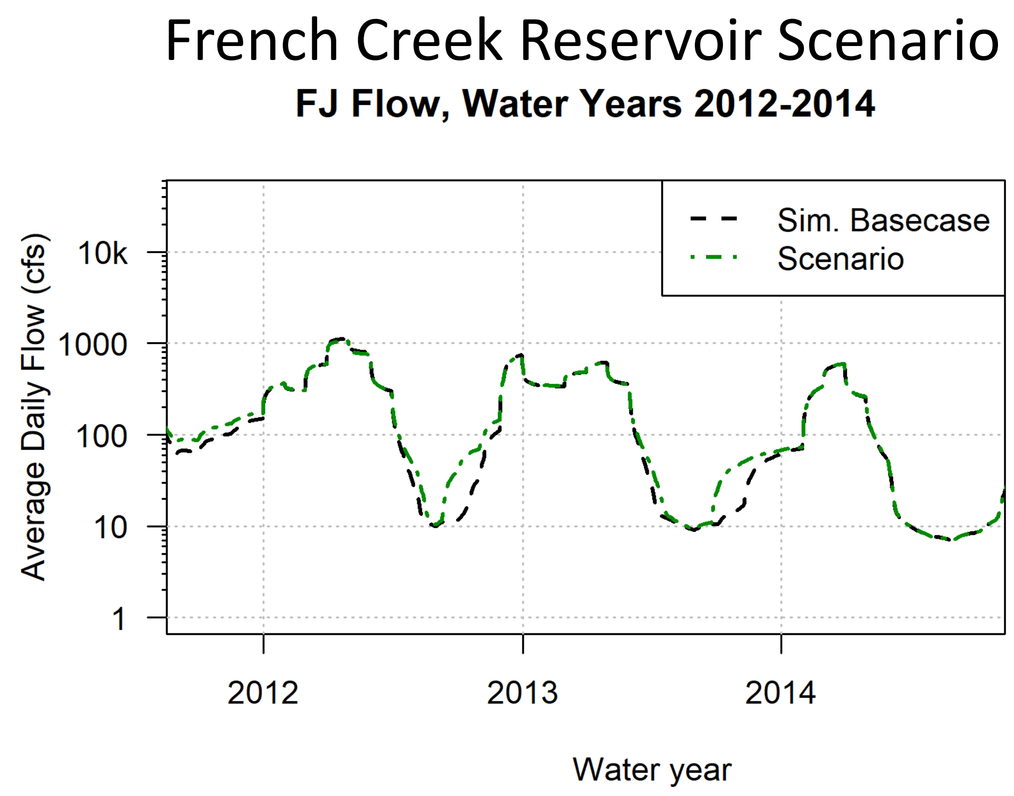
1. Motivating question
2. Simplifying assumptions

- Simplifying assumptions, e.g.:
  - 9 TAF in-line reservoir
  - No feasibility/construction constraints
  - Reservoir outflow is added directly to a tributary's inflow
  - Assume set of reservoir operating rules



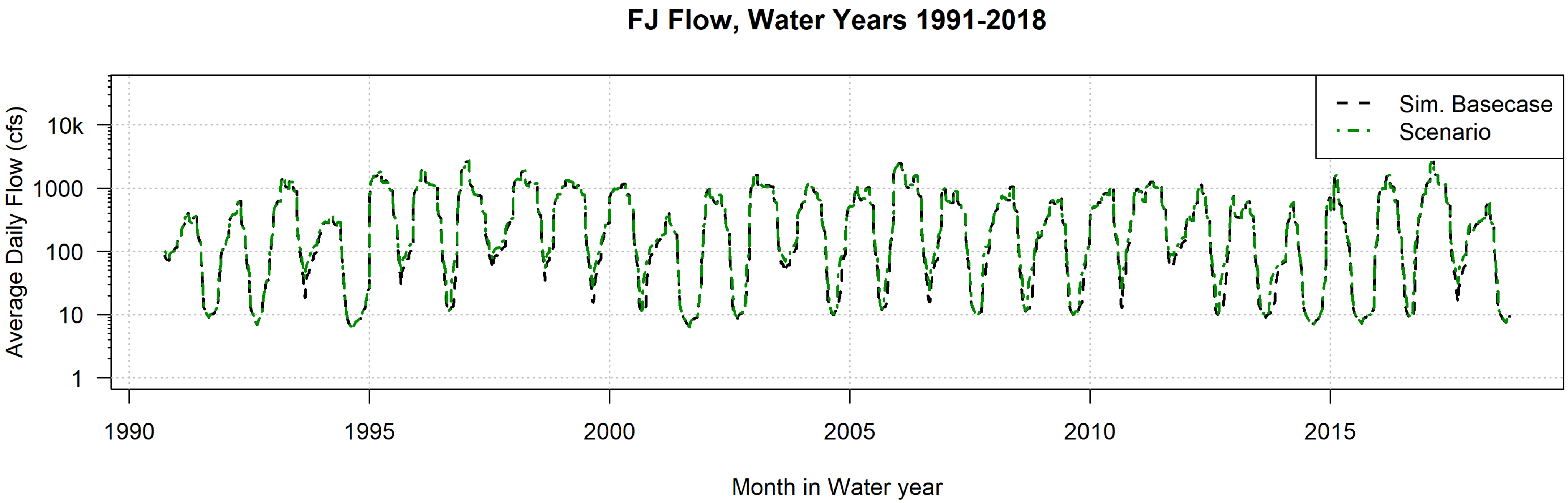
Model scenario interpretation

- Motivating question, e.g.:
  - What flow changes would we observe…
  - If Scott Valley had a reservoir on French Creek?
  - ➢ Most flow differences occur in the at the end of the dry season (with these operating rules)



Model scenario interpretation

- Trying to look at full model period:



- Can't see differences. We need to summarize!

Model scenario summary: key questions

Questions

1. Did flow meet X flow regime? (How much of the time?)
2. Did the scenario improve the timing of fall flows (earlier river reconnection)?
3. Did the scenario improve flows in wet, average, and dry years?

Key graphs

- Percentile Plots
- Reconnection Dates
- Flow diff. by water year type

Key graphs from GSP

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2. Fort Jones flow
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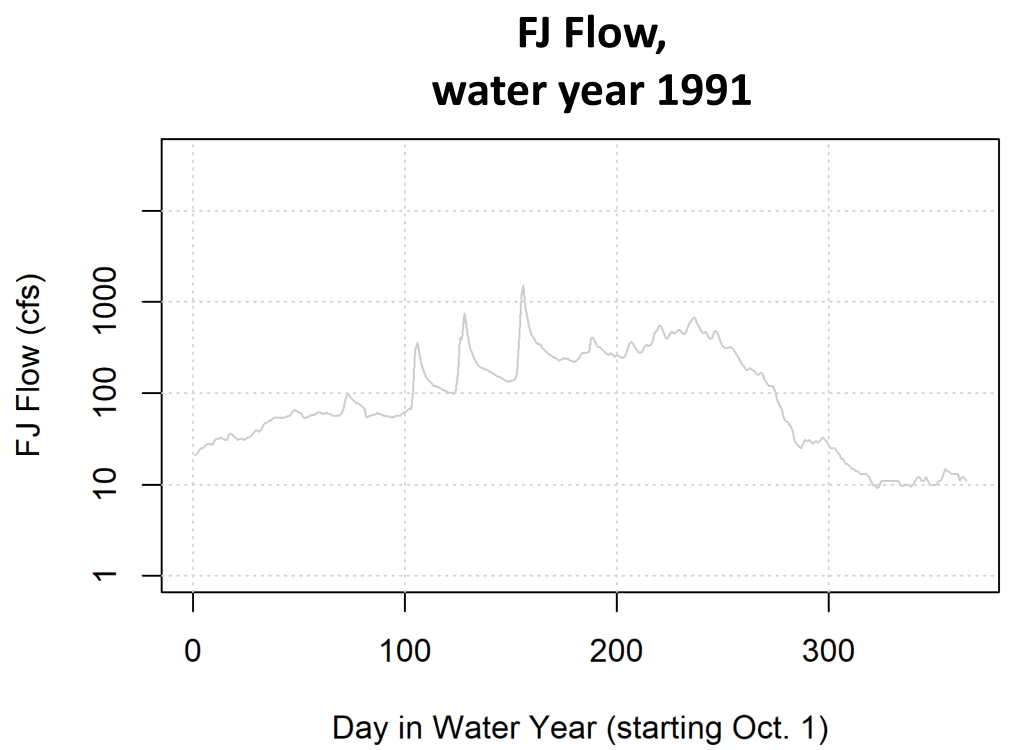
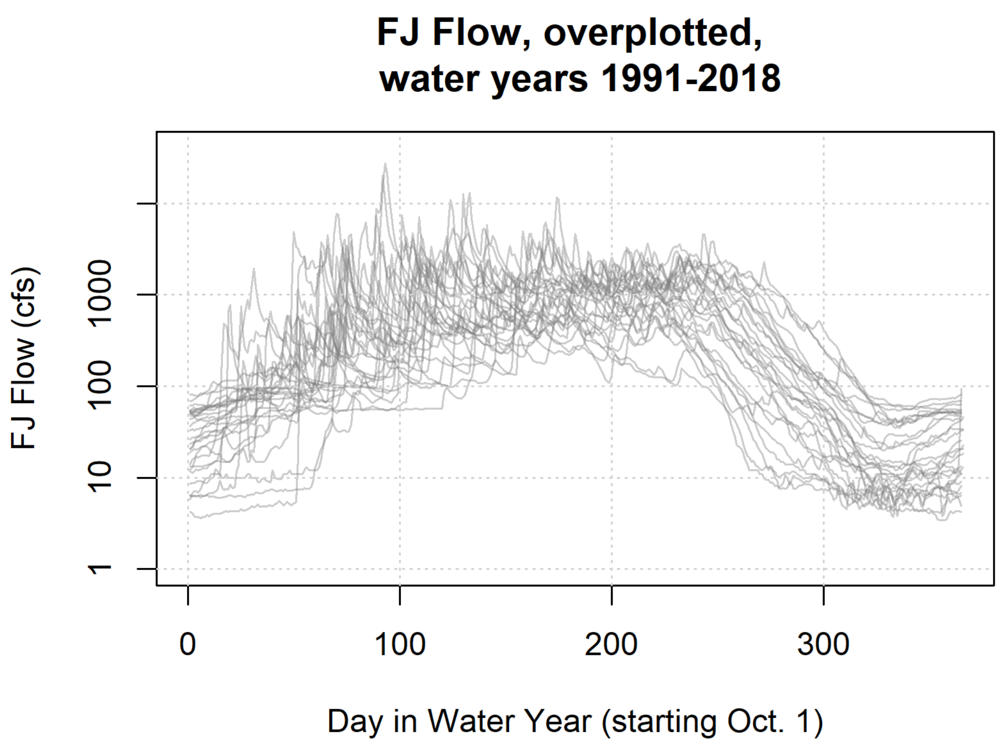
Key graph 3. Percentile plots

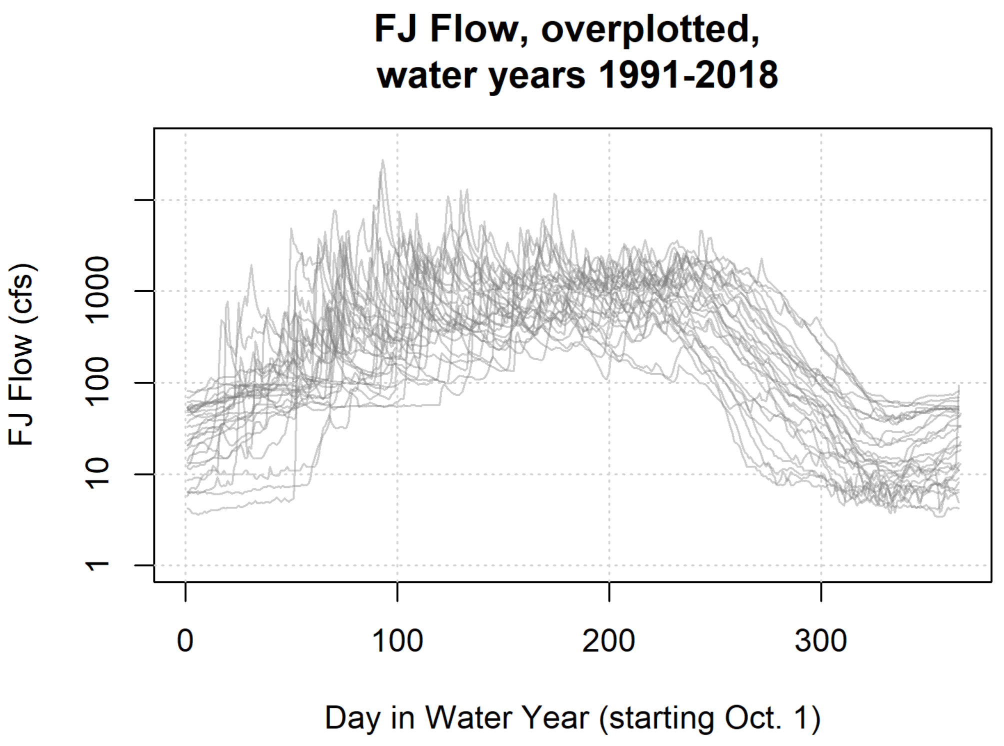
- Did flow meet X flow regime?
  - How much of the time?
  - Did the scenario make a difference?
  - Did scenario flow meet X flow regime more or less than the basecase?

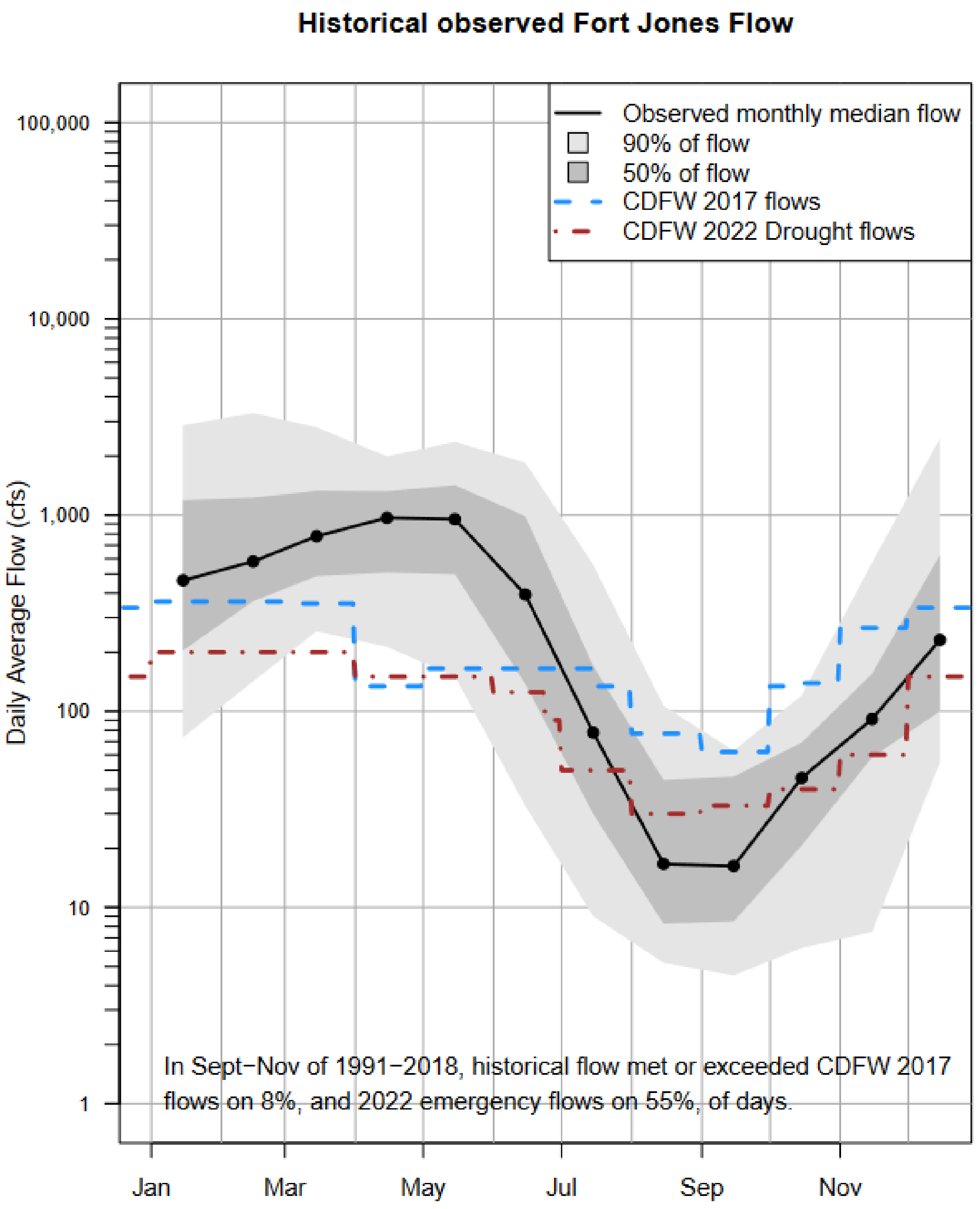
Key graph 3. Percentile plots

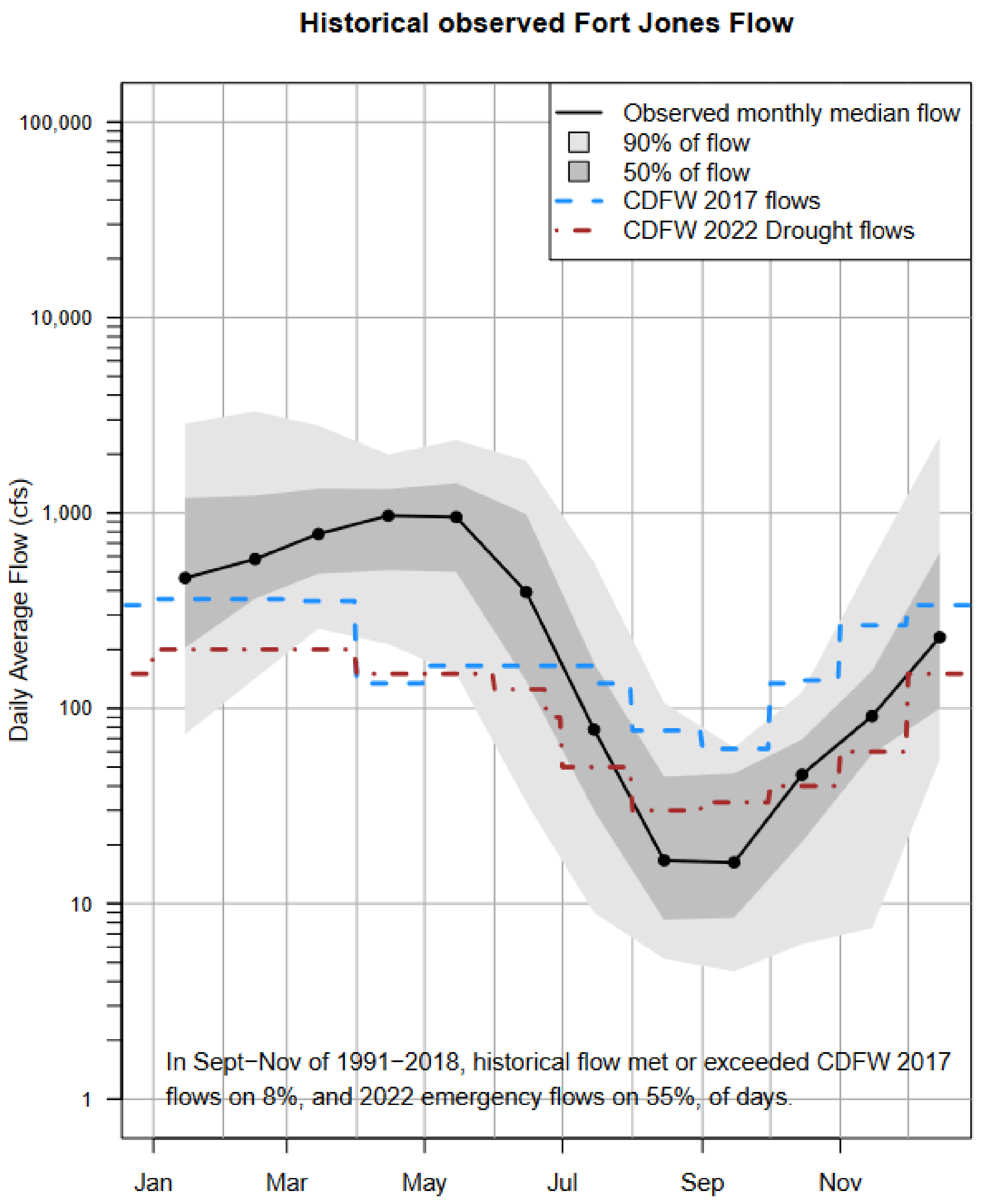


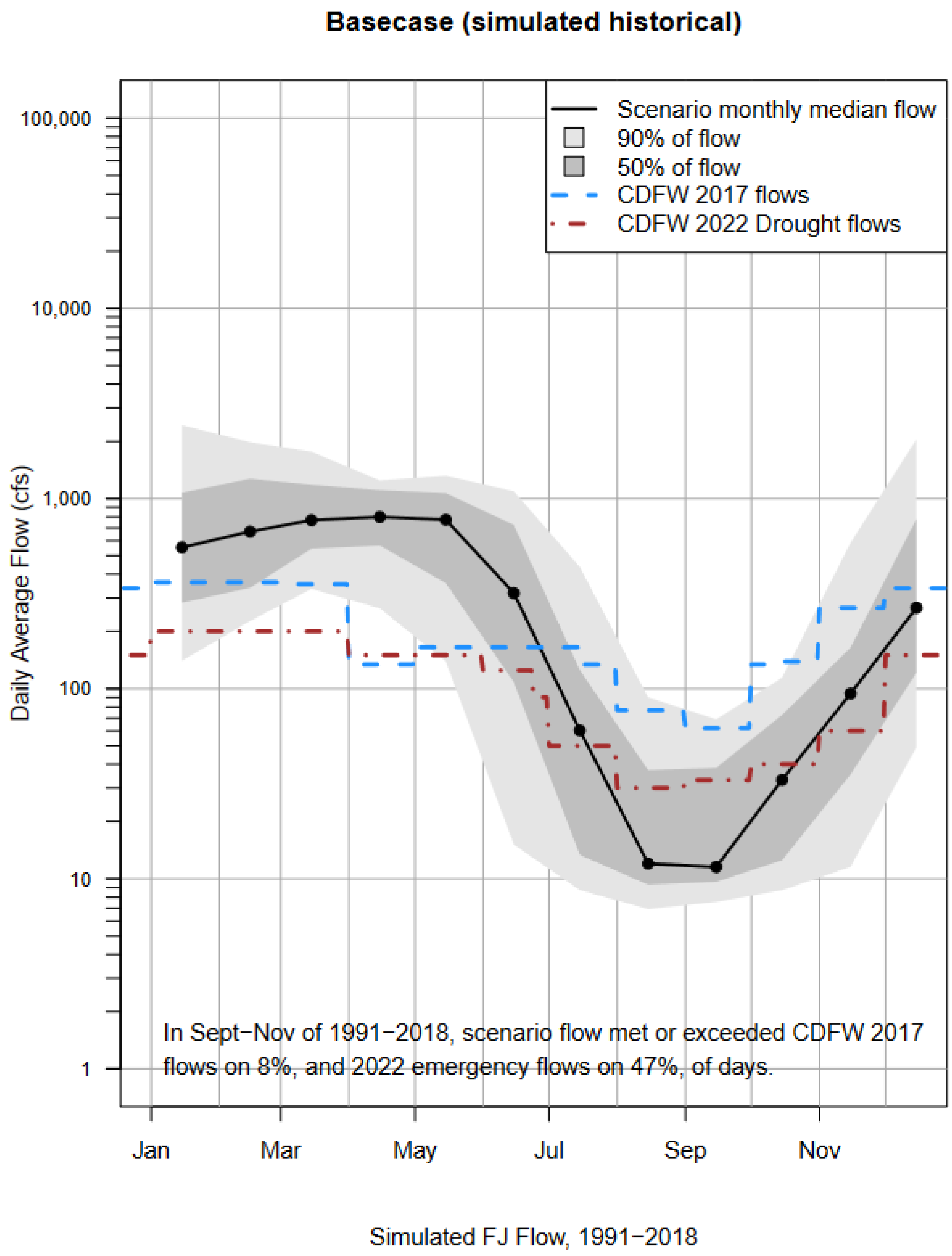


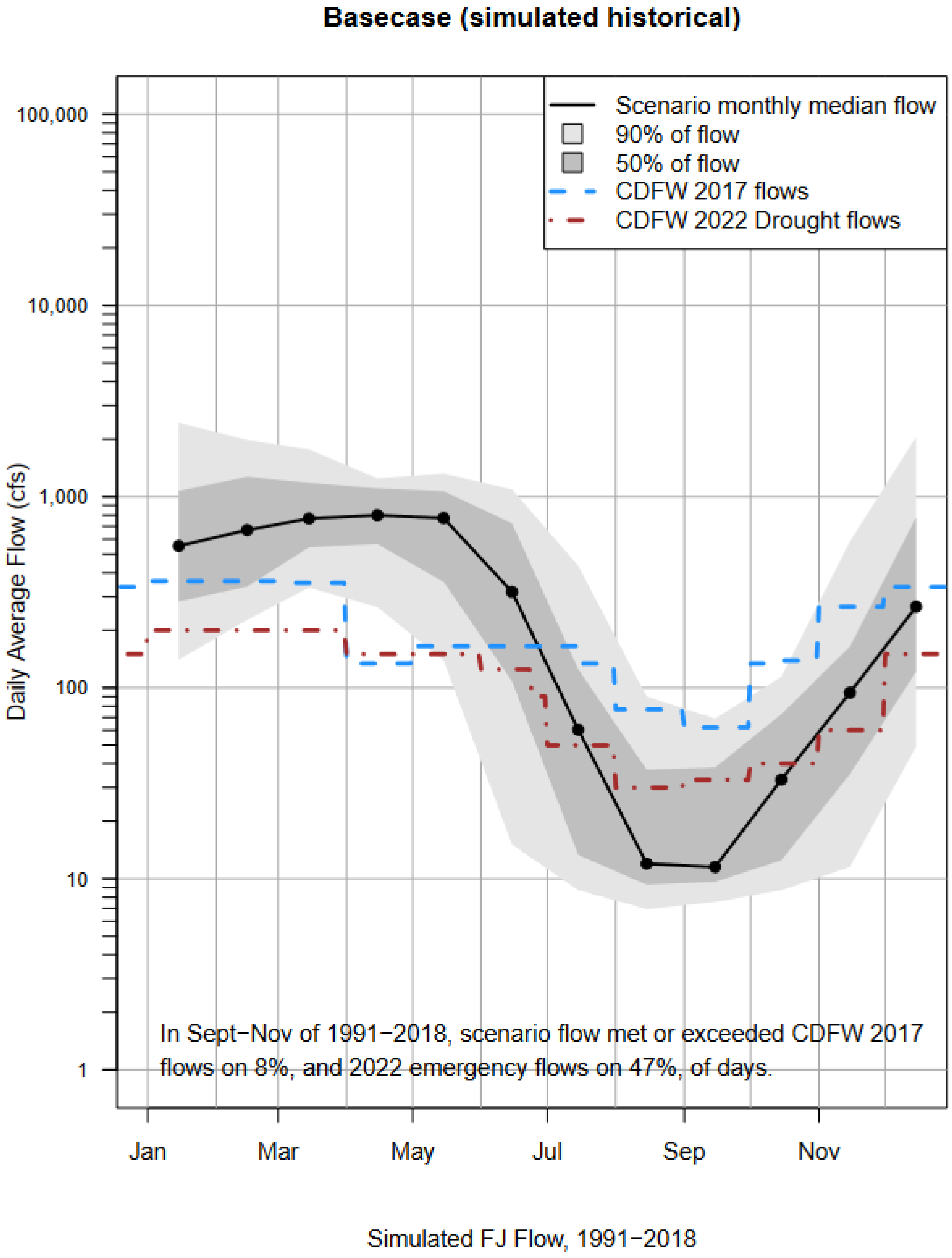
Key graph 3. Percentile plots

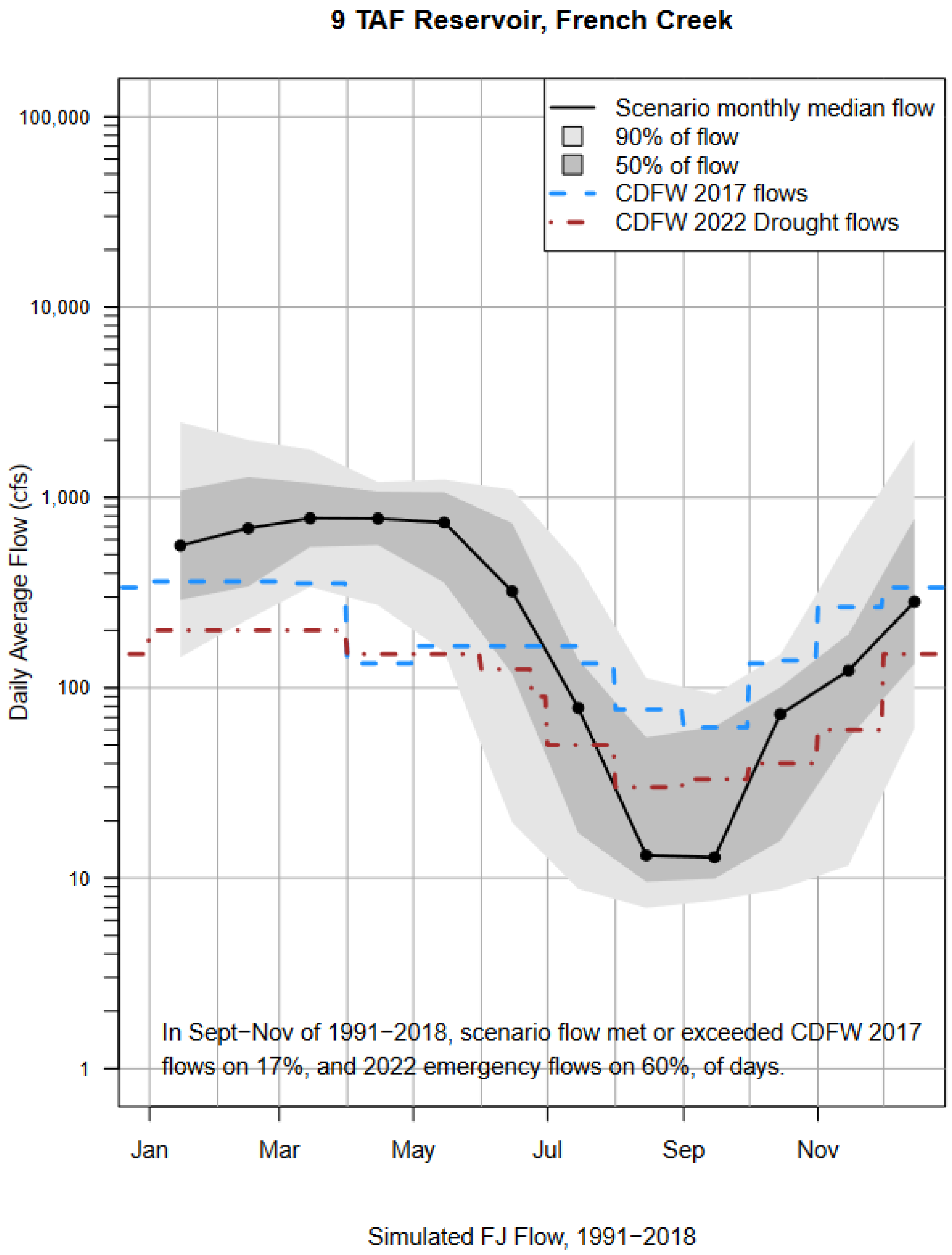





Historical observed Fort Jones Flow
Observed monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, historical flow met or exceeded CDFW 2017 flows on 8%, and 2022 emergency flows on 55%, of days.

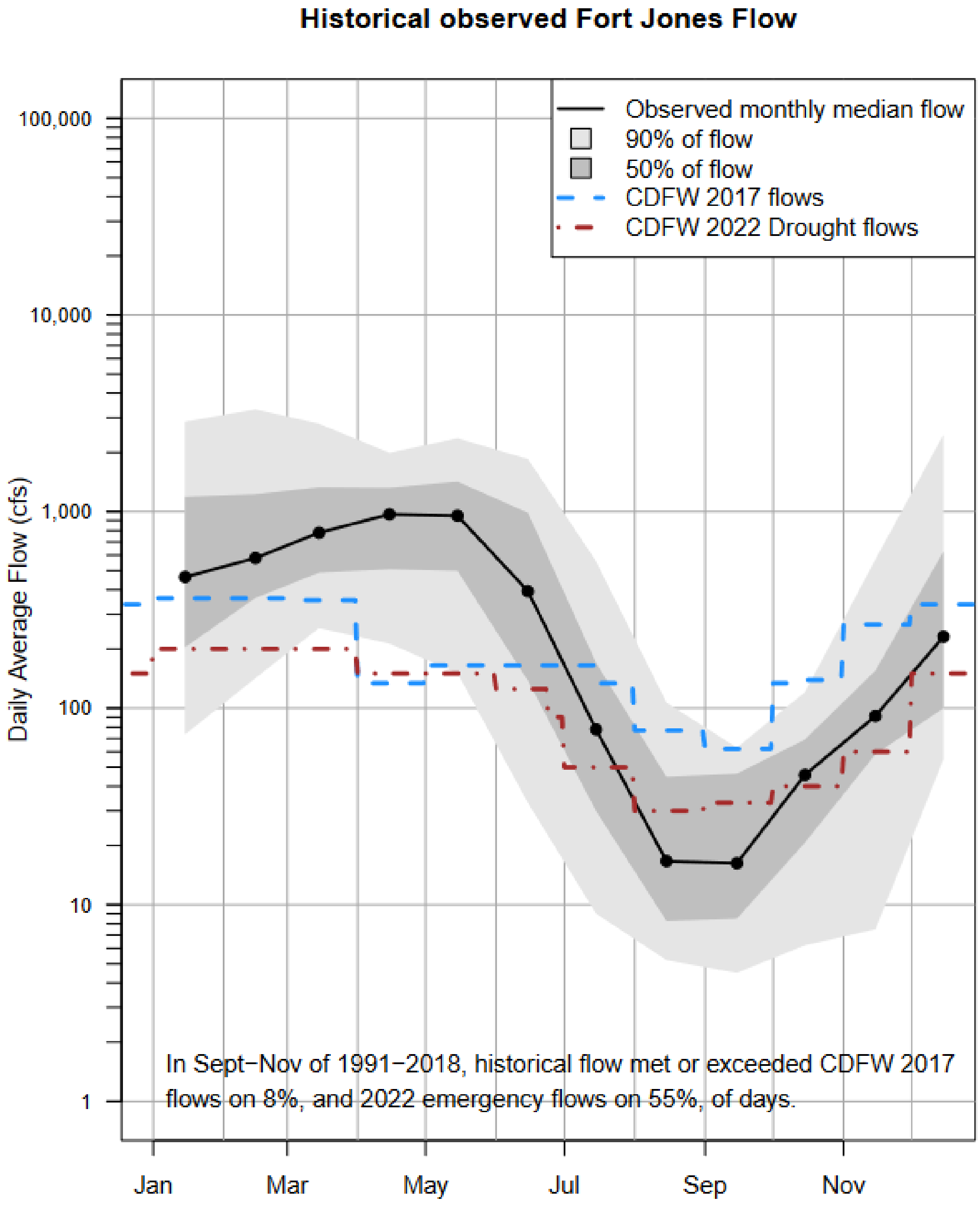

Basecase (simulated historical)
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 8%, and 2022 emergency flows on 47%, of days.
Simulated FJ Flow, 1991−2018


Basecase (simulated historical)
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 8%, and 2022 emergency flows on 47%, of days.
Simulated FJ Flow, 1991−2018


9 TAF Reservoir, French Creek
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 17%, and 2022 emergency flows on 60%, of days.
Simulated FJ Flow, 1991−2018

Key graph 3. Percentile plots

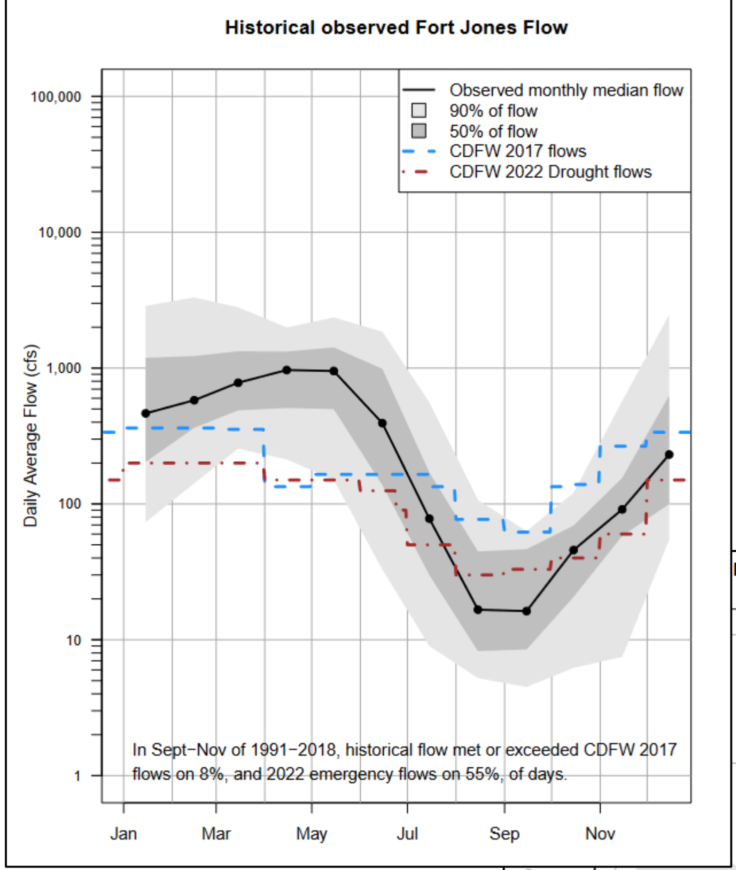
- Does observed flow meet X flow regime?
  - In Aug-Sep, median flow does not meet 2017 or 2022 flow regime
  - Oct-Dec, median flow meets 2022 regime, but 2017 regime is met only in 10%-25% of days

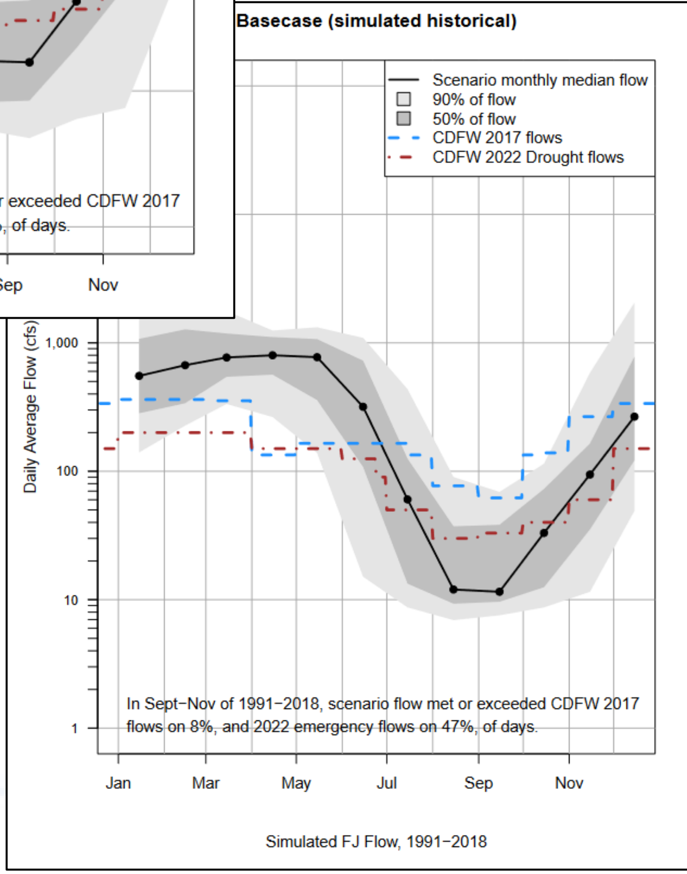


Key graph 3. Percentile plots

- SVIHM underpredicts dry season flow (median flow of 10 cfs to 20 cfs)
- Simulated fall flow increase is slightly steeper than observed

- Both observed and simulated (historical basecase) capture behavior re: two CDFW flow regimes

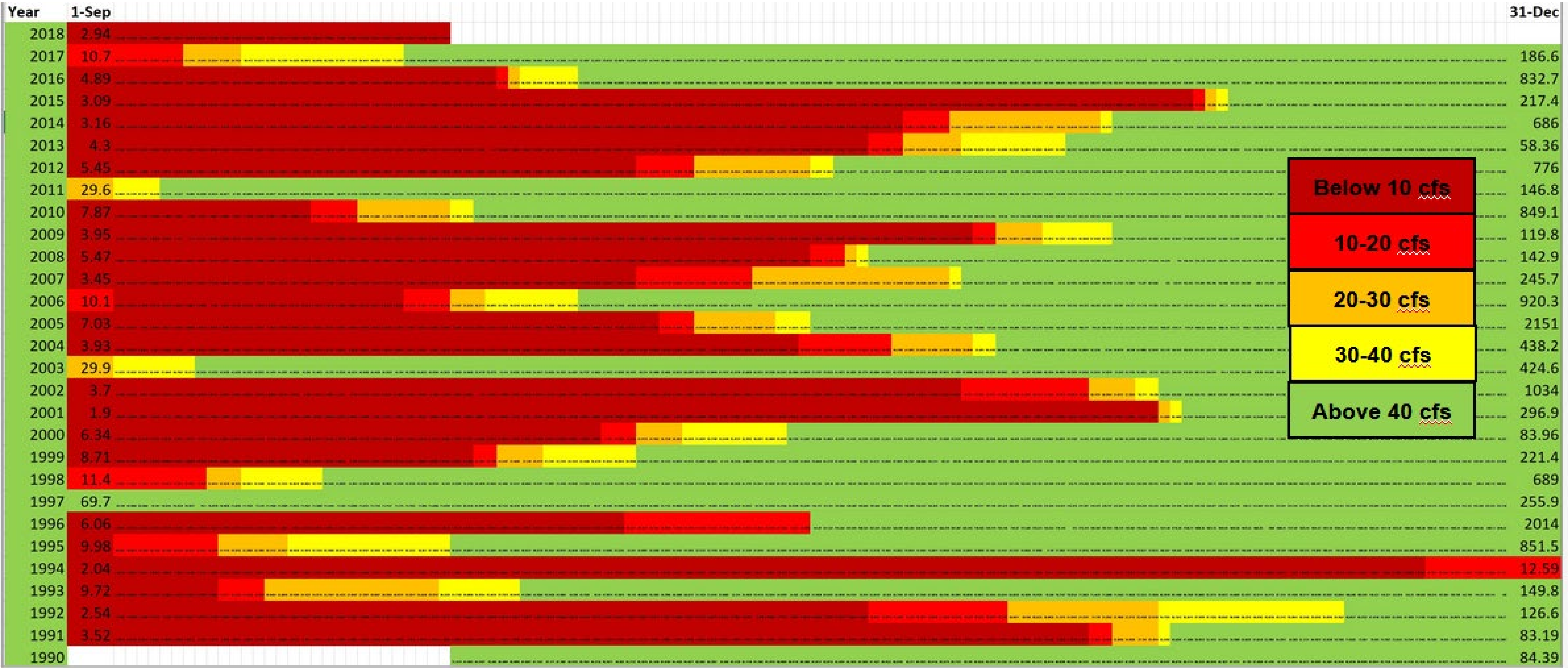




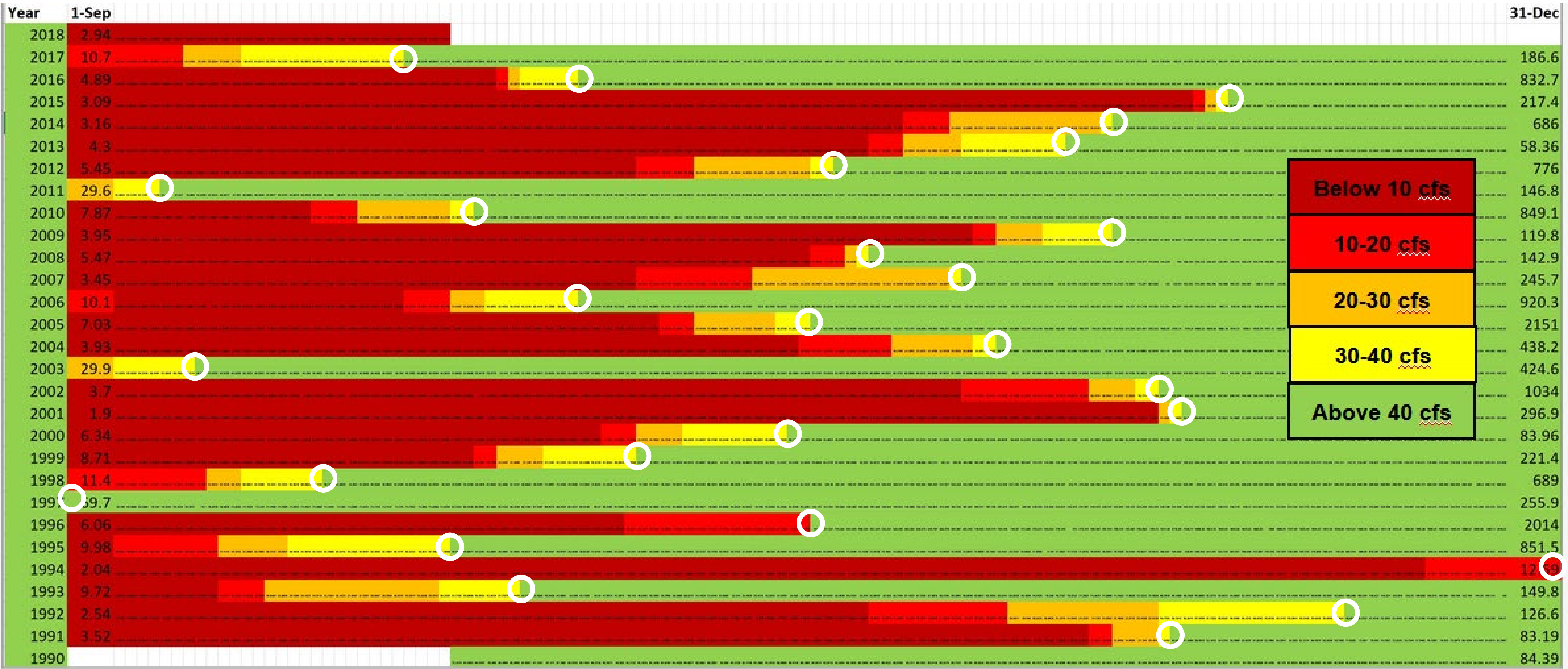
Key graph 4. Reconnection date

- Did the scenario improve the timing of fall flows (earlier river reconnection)?

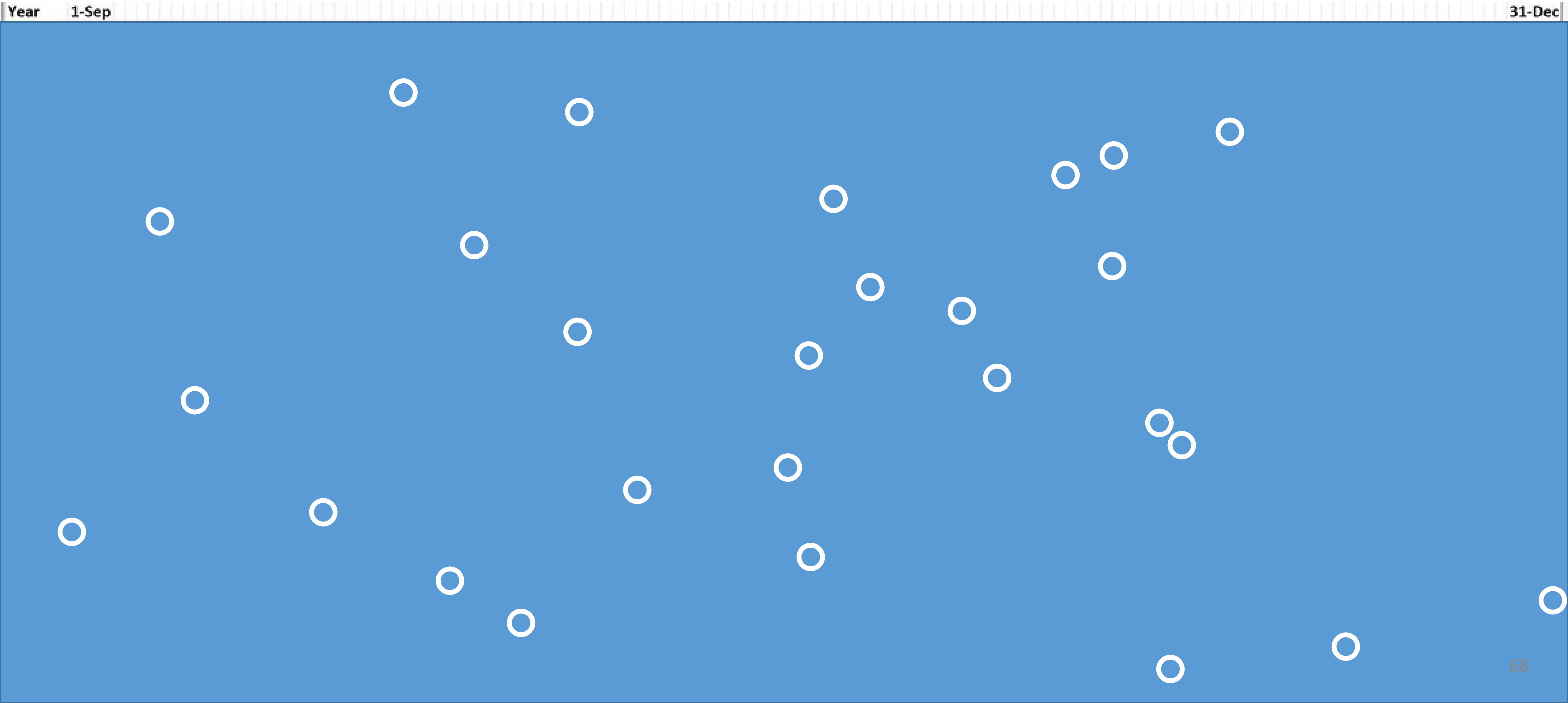
Fall flows timing, 1991-2018



Fall flows timing, 1991-2018



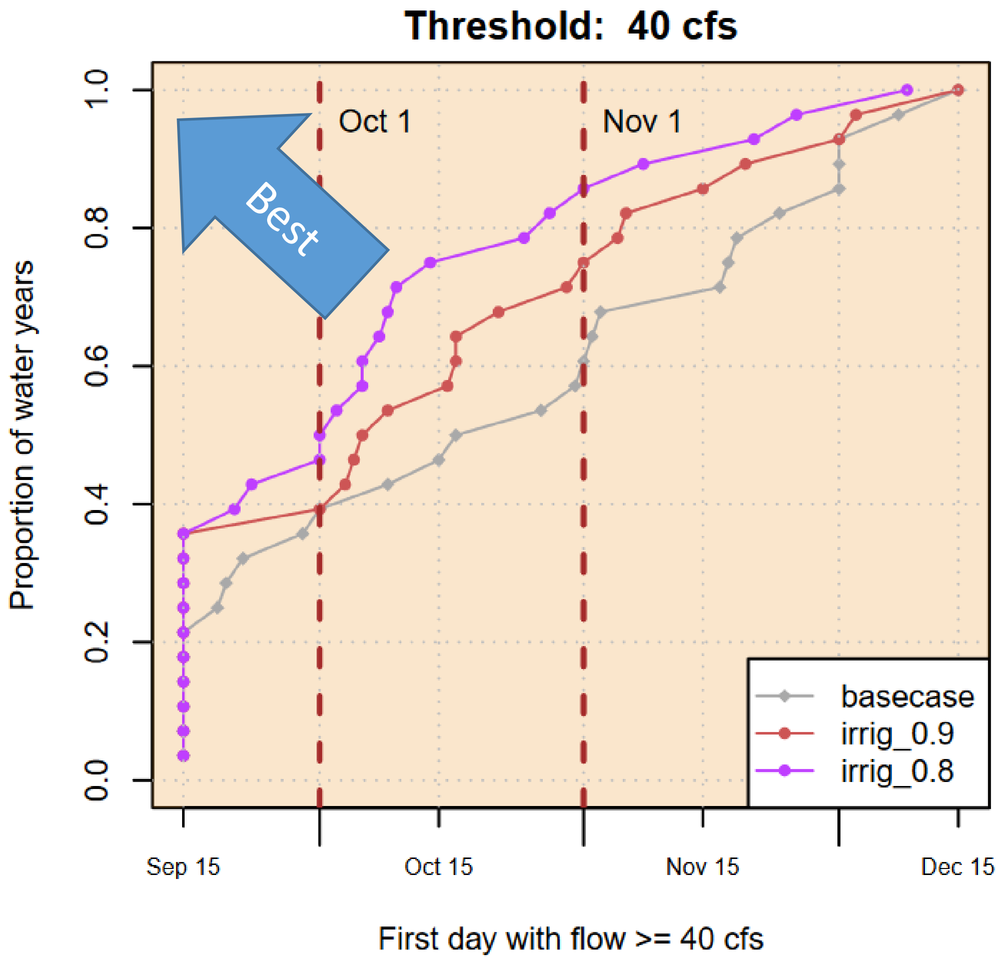
Fall flows timing, 1991-2018



Fall flows timing, 1991-2018 – management impact

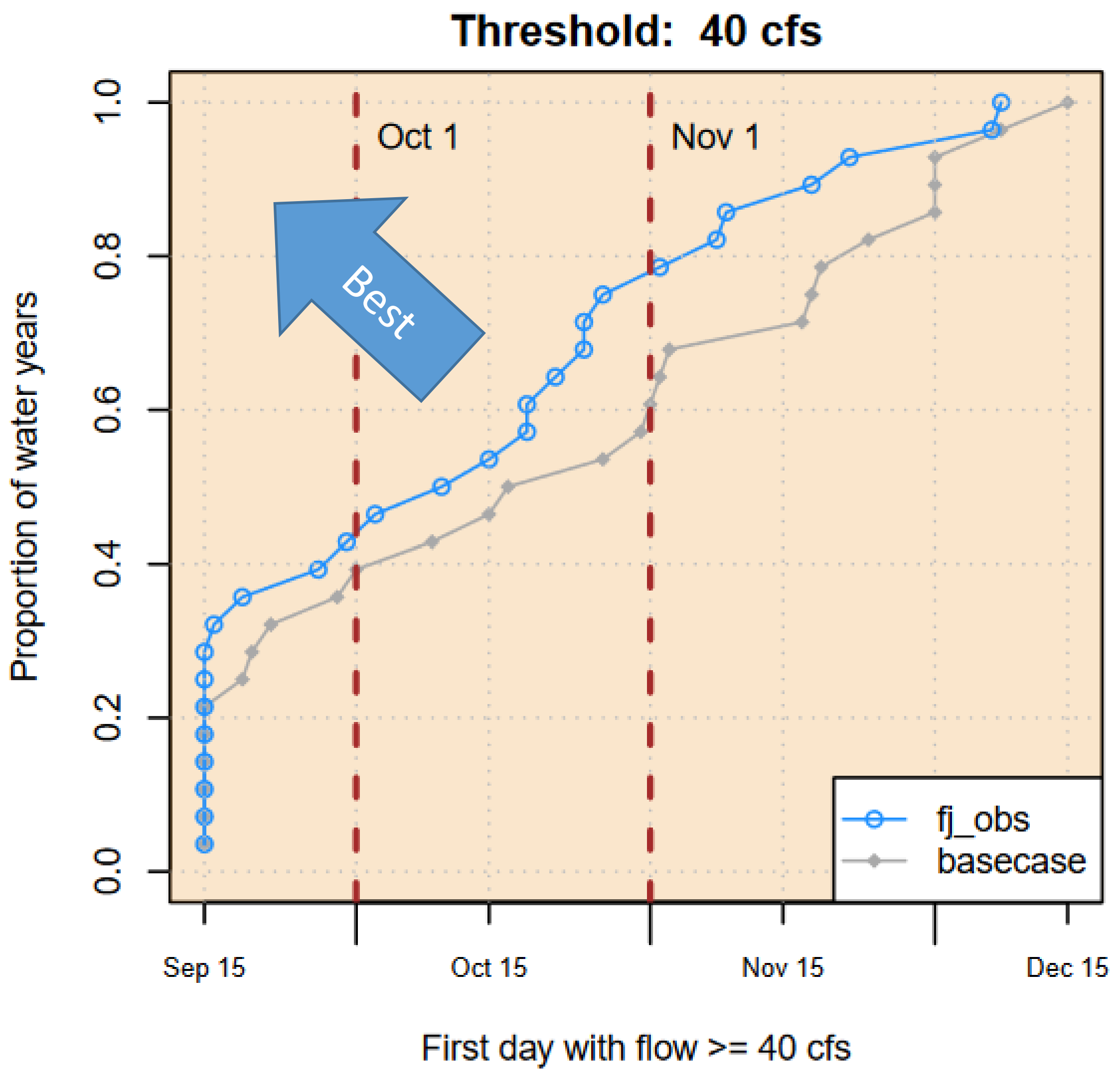
- Did the scenario improve the timing of fall flows (earlier river reconnection)?

- Crops that consume less water (90% or 80% of bascase ET) can improve collective stream reconnection dates



Fall flows timing, 1991-2018 – model performance

- SVIHM historical basecase is more pessimistic about fall flows timing
- In aggregate, in normal water years, reconnects 1-4 weeks later than observed flows



Outline

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Stream depletion

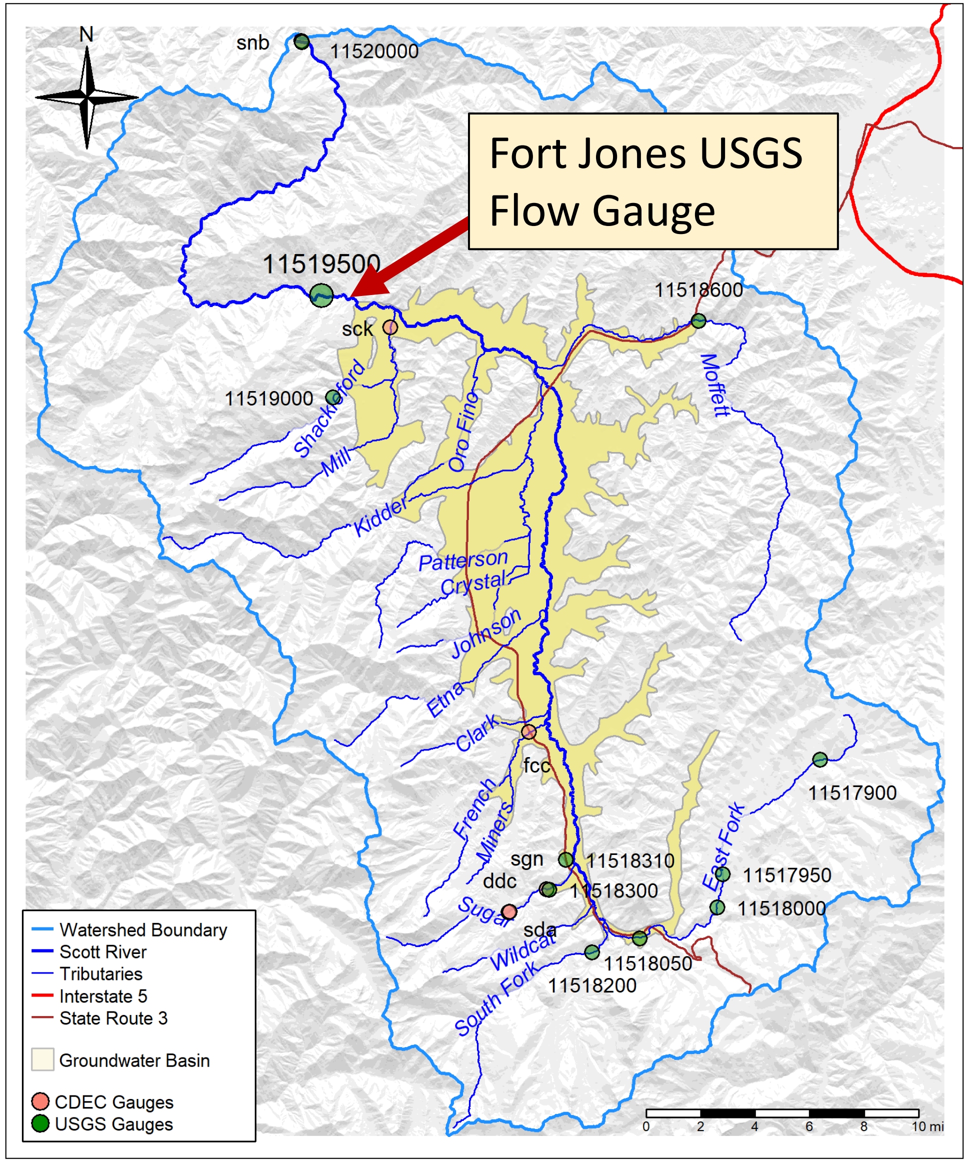
- How much stream depletion has happened?
  - Difficult to measure. Rephrase question:

- How would flow have been higher:
  - If there were no agriculture in Scott Valley?
  - If there were no agricultural pumping in Scott Valley?
  - If there were no ag. pumping in the areas of Scott Valley under SGMA jurisdiction?

Quantifying the SMC

Streamflow Depletion is quantified as:

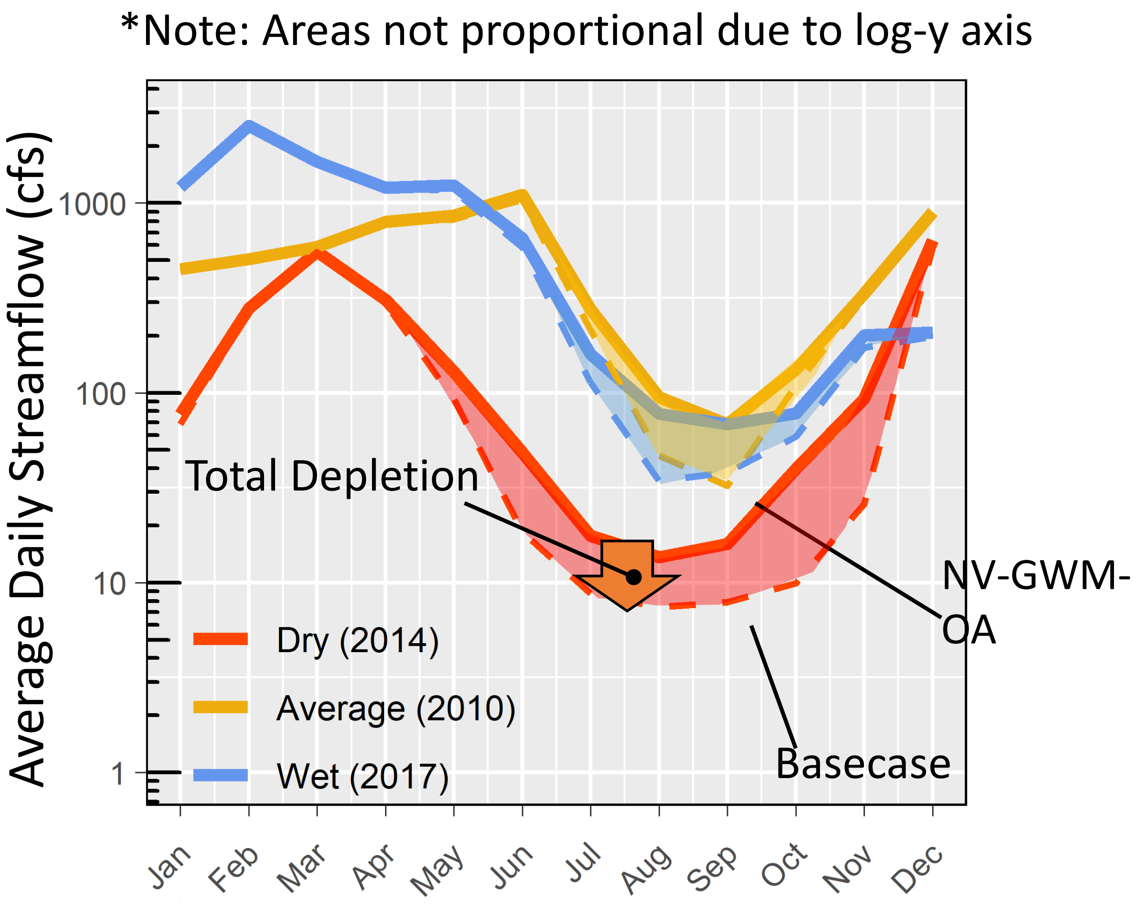
- the **difference in flow** at the Fort Jones Gauge…
- over the model period of 1991-2018…
- between the **Basecase** (simulated historical) conditions and a no-pumping reference scenario.

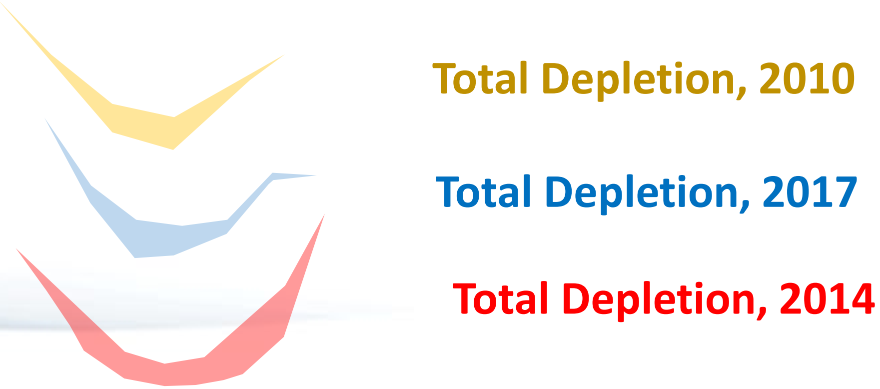


Quantifying the SMC

Total Streamflow Depletion* is quantified as:

- the **difference in flow** at the Fort Jones Gauge…
- over the model period of 1991-2018…
- between the Basecase (estimated historical/current) conditions and the No Pumping** Reference case.





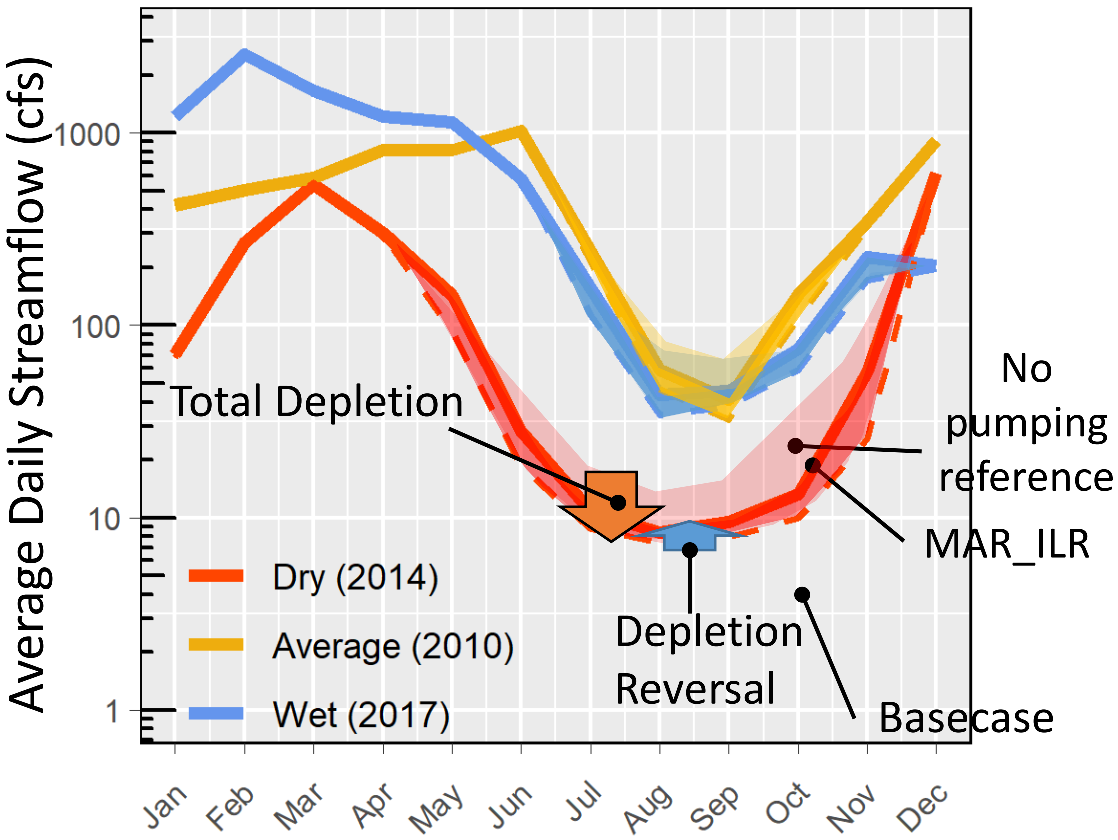
* Due to pumping in SGMA wells

** Also referred to as "Natural Vegetation on GW and Mixed-source fields Outside the Adjudicated Zone", or NV-GWM-OA

Quantifying the SMC

Depletion Reversal is quantified for **each** scenario as the difference between the Basecase (simulated historical & current) conditions and the relevant scenario (for example, MAR+ILR).

*Note: Areas not proportional due to log-y axis



Total Depletion, 2010

Total Depletion, 2017

Total Depletion, 2014

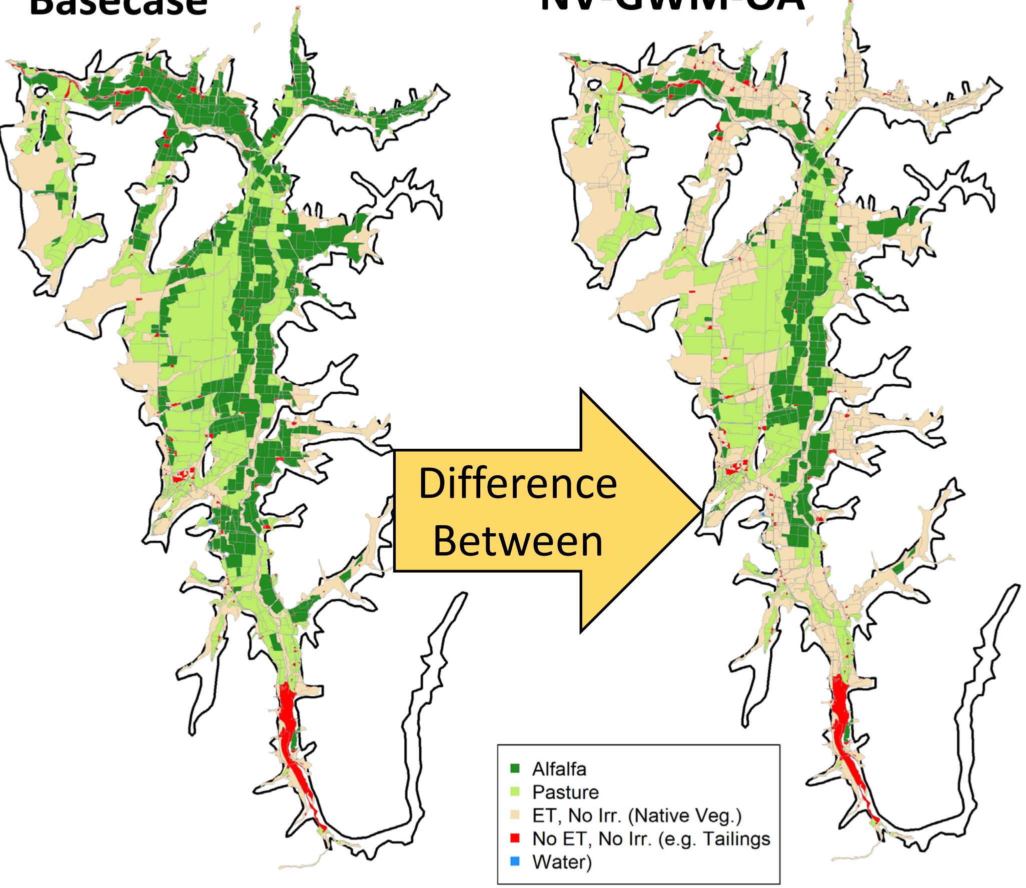
MAR+ILR Depletion Reversal, 2010

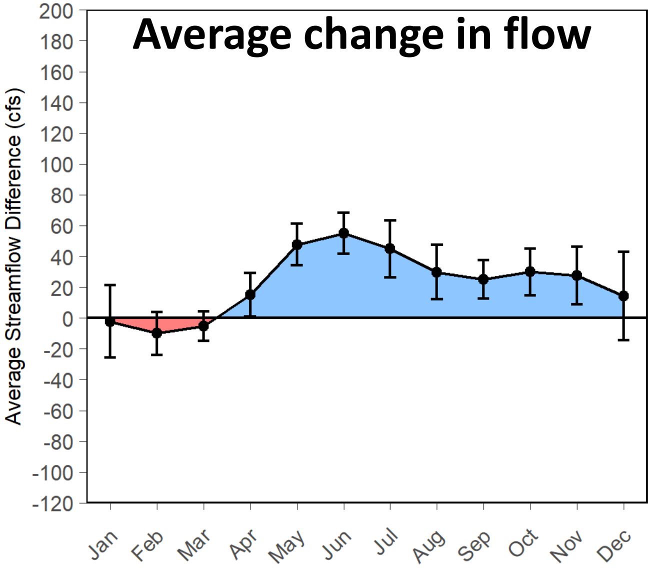
MAR+ILR Depletion Reversal, 2017

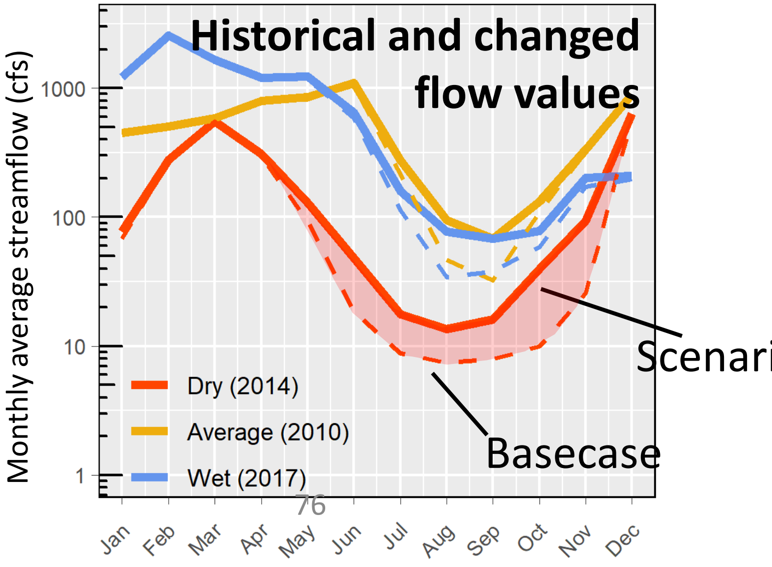
MAR+ILR Depletion Reversal, 2014

Total Depletion: no-pumping reference case maps

Basecase **NV-GWM-OA**



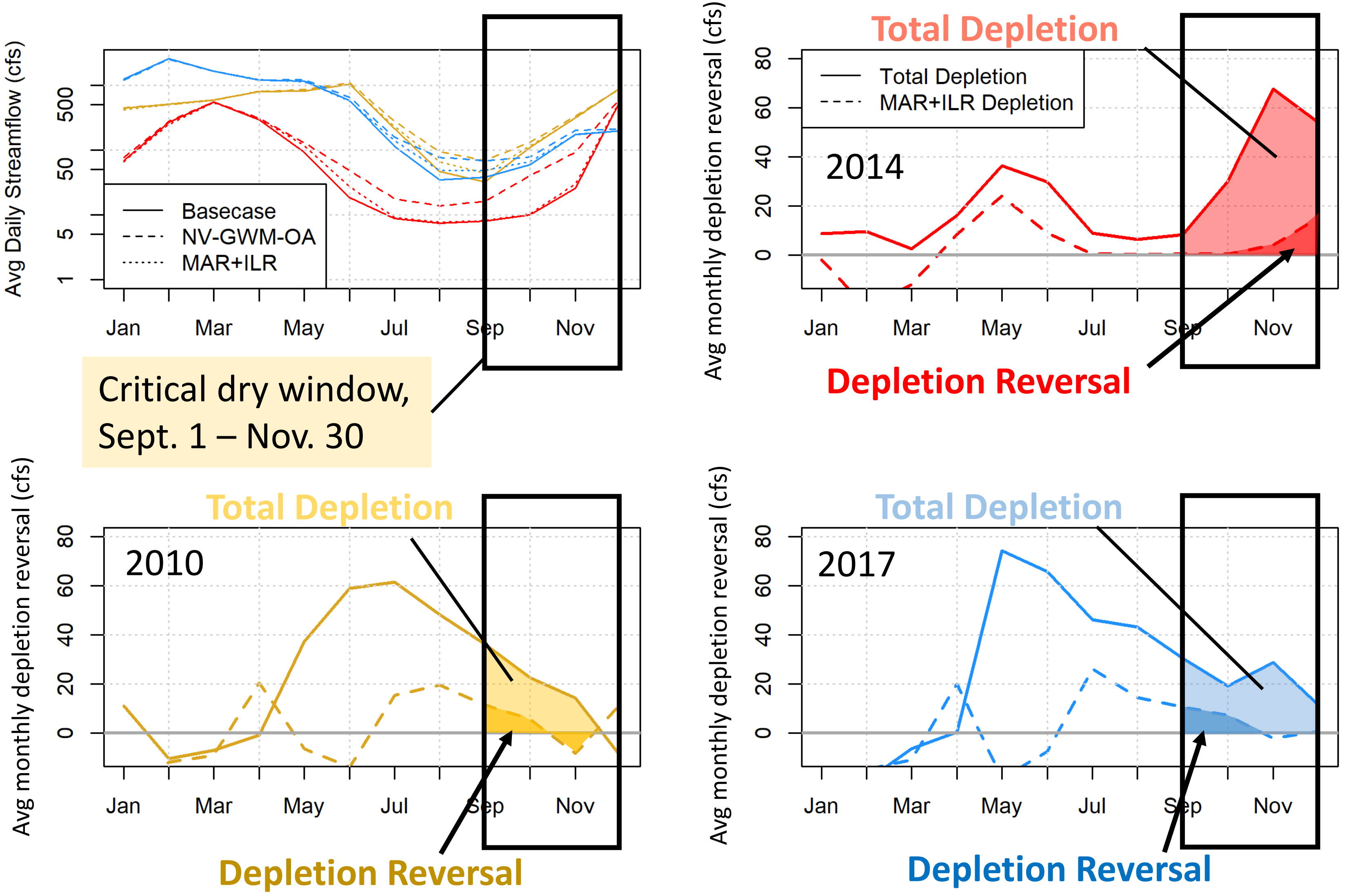




Basecase Landuse

Native Vegetation on *GW and Mixed Water Source Fields* Outside Adjudication

Quantifying Depletion Reversal



To calculate relative depletion reversal, sum the darker areas for each year and divide by the sum of the lighter areas in the Sept-Nov window.

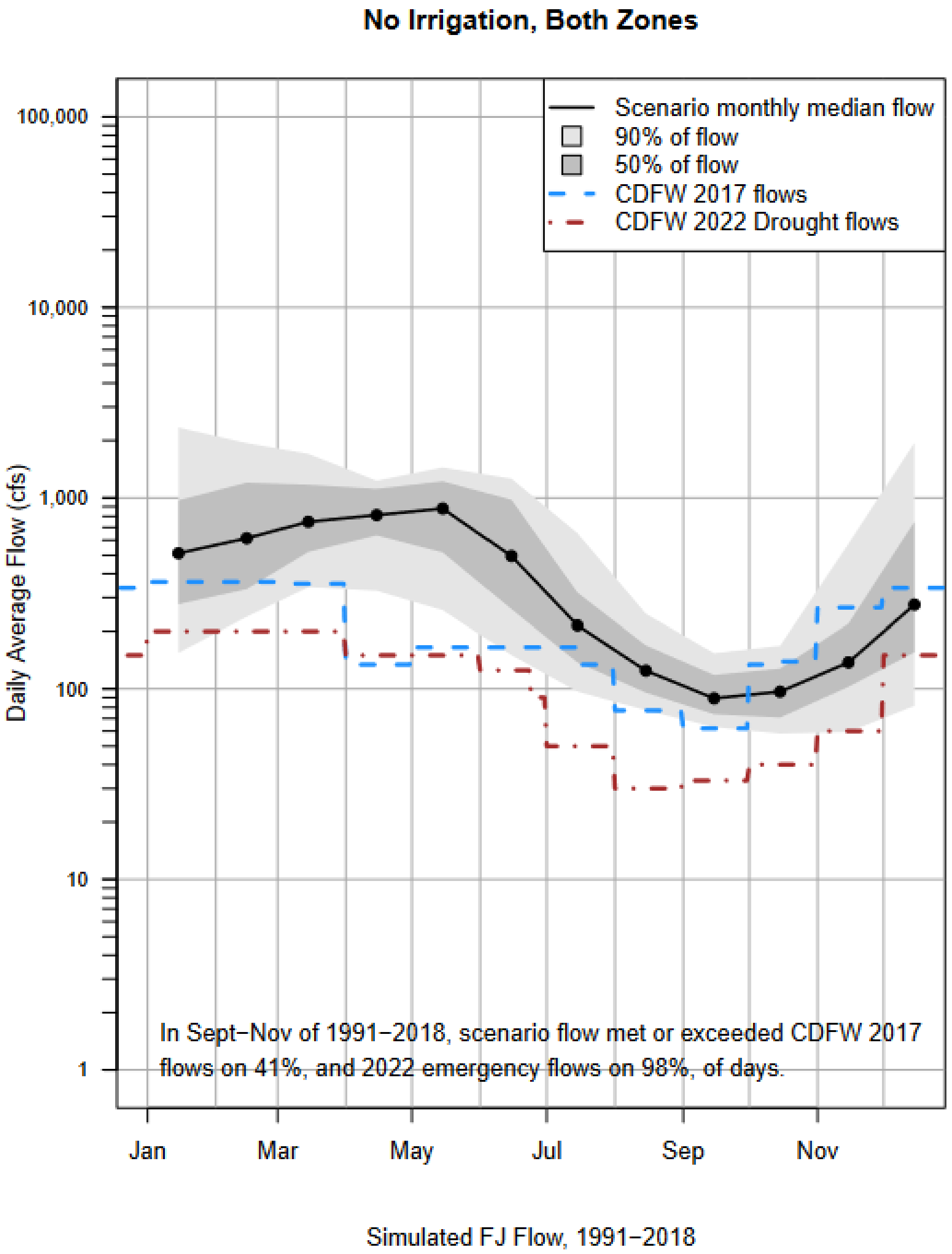
Relative Depletion Reversal for MAR+ILR:

19%

of Total Depletion, Sept.-Nov. for 1991-2018.

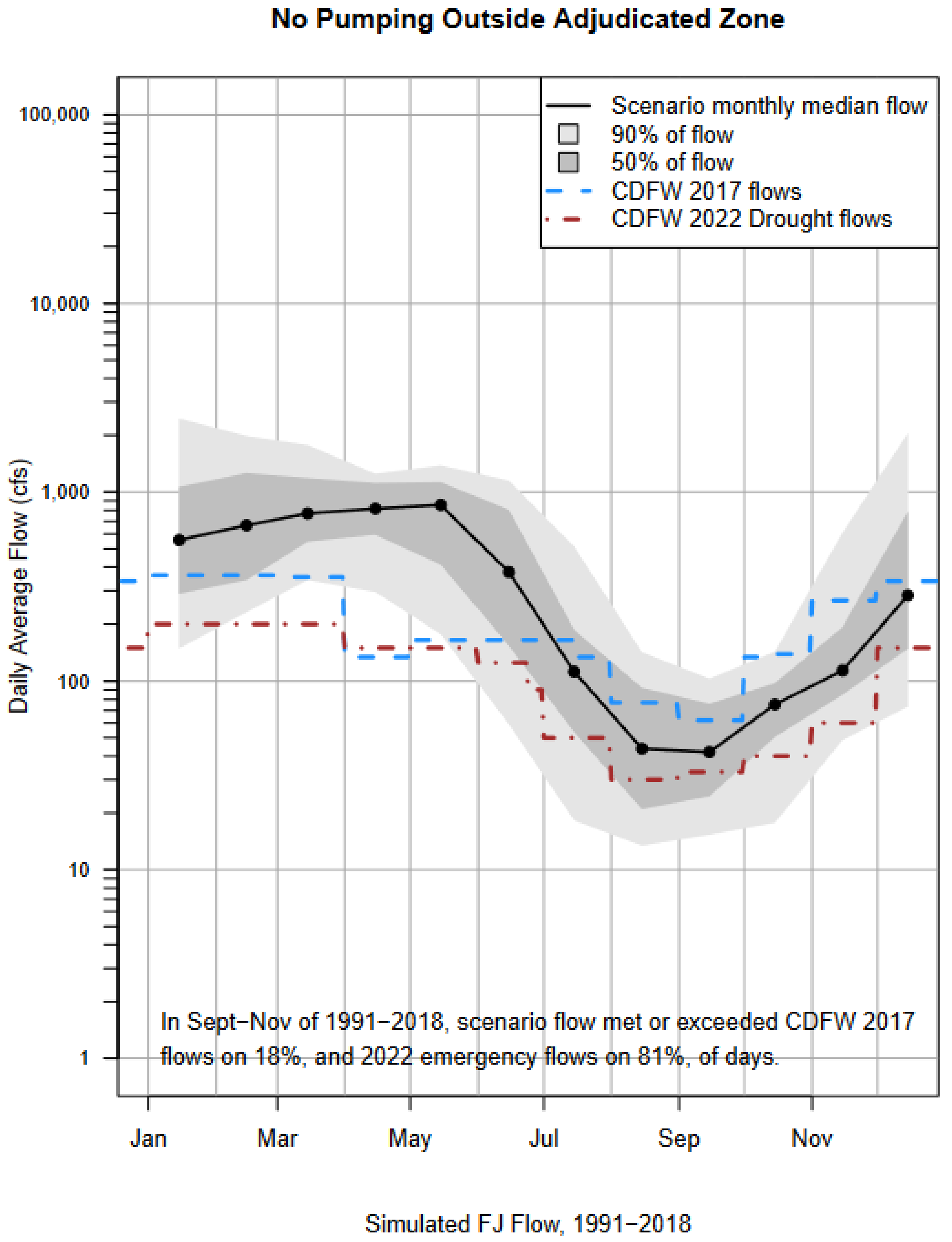
Percentile plots – Stream depletion attribution scenarios

- If all agriculture, 1991-2018, had been replaced by native vegetation,
- Fall flows would nearly always meet the 2022 emergency drought regime,
- And would meet the 2017 CDFW regime on 41% of days.



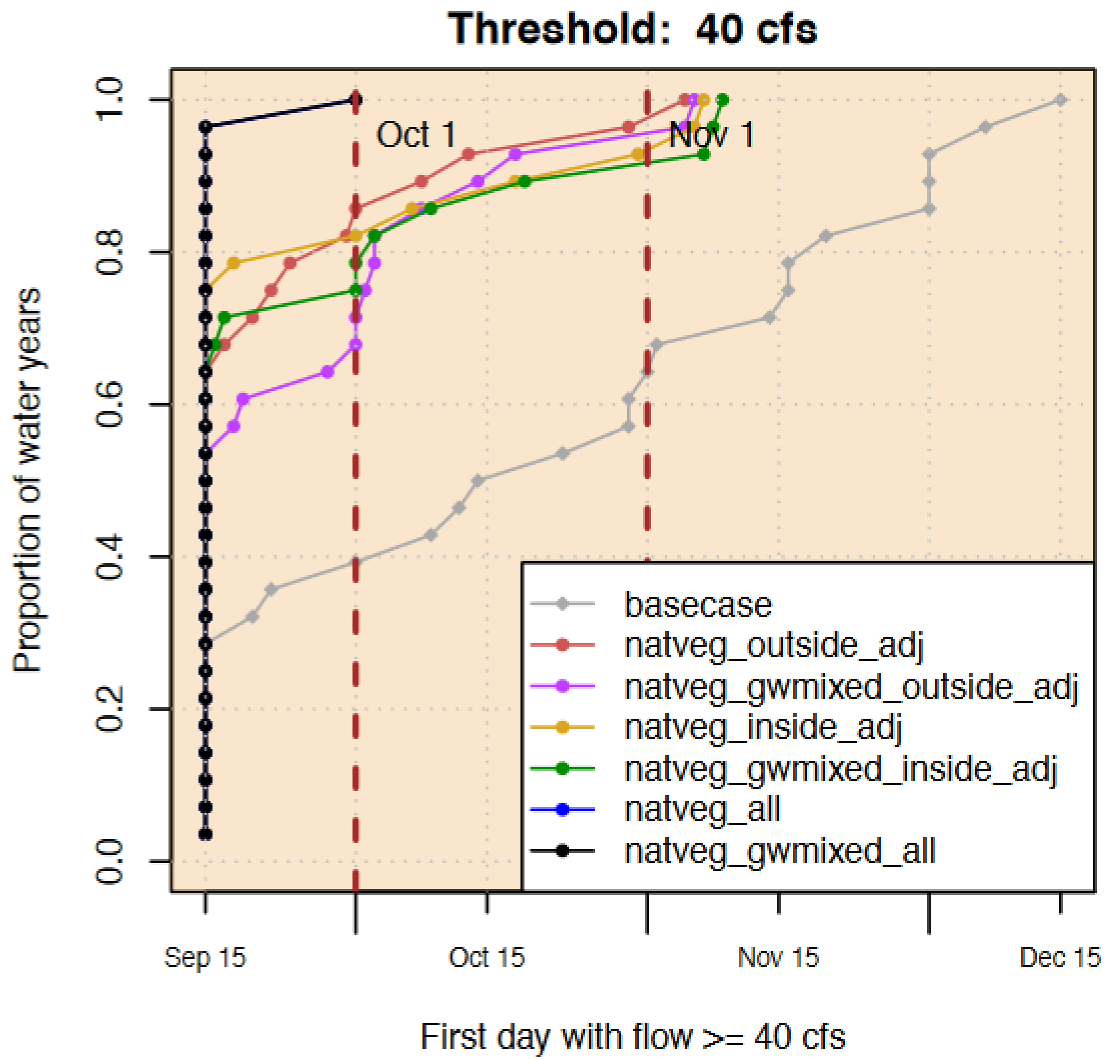
Percentile plots – Stream depletion attribution scenarios

- If pumping in SGMA wells had not occurred, 1991-2018,
- Fall flows would meet the emergency drought regime on 80% of days,
- And would meet the CDFW 2017 flow regime on 18% of days.



Reconnection date – Stream depletion attribution scenarios

- Stream depletion accounts for ~a month of later river reconnection

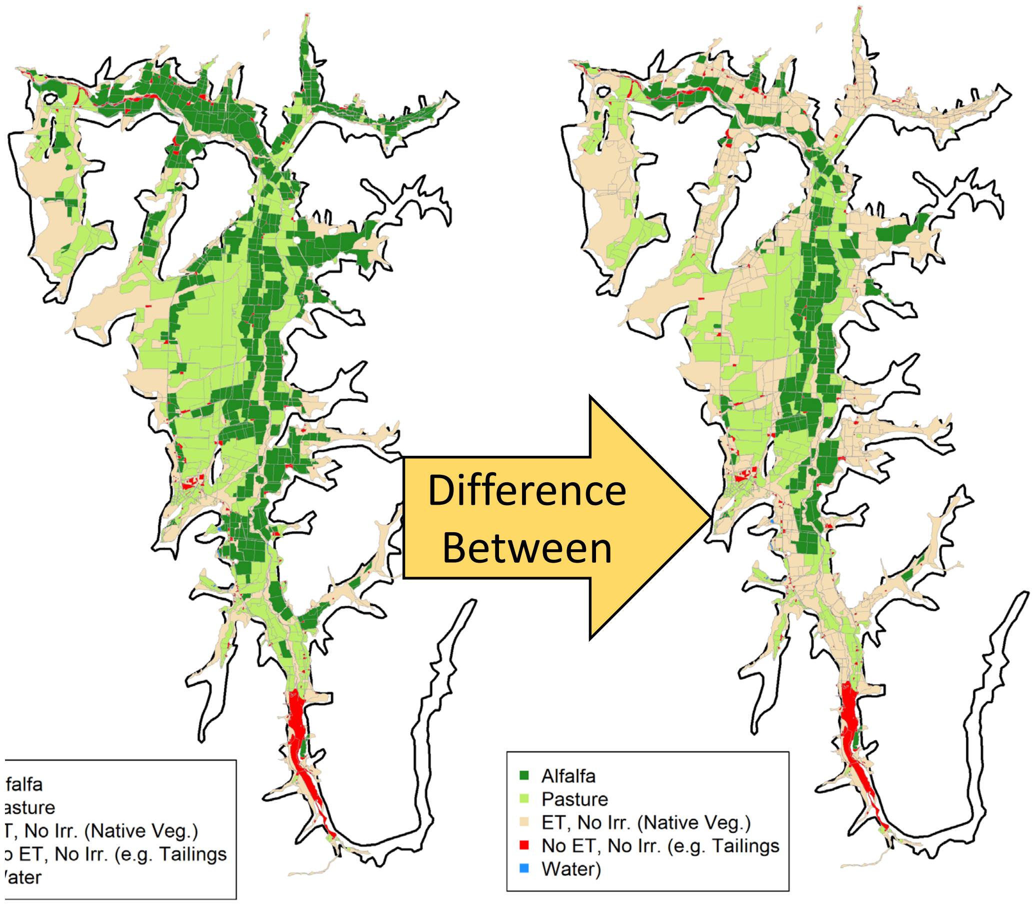


Stream depletion summary

Can use SVIHM to estimate stream depletion due to:

- Pumping in SGMA wells
- All water use (agricultural)

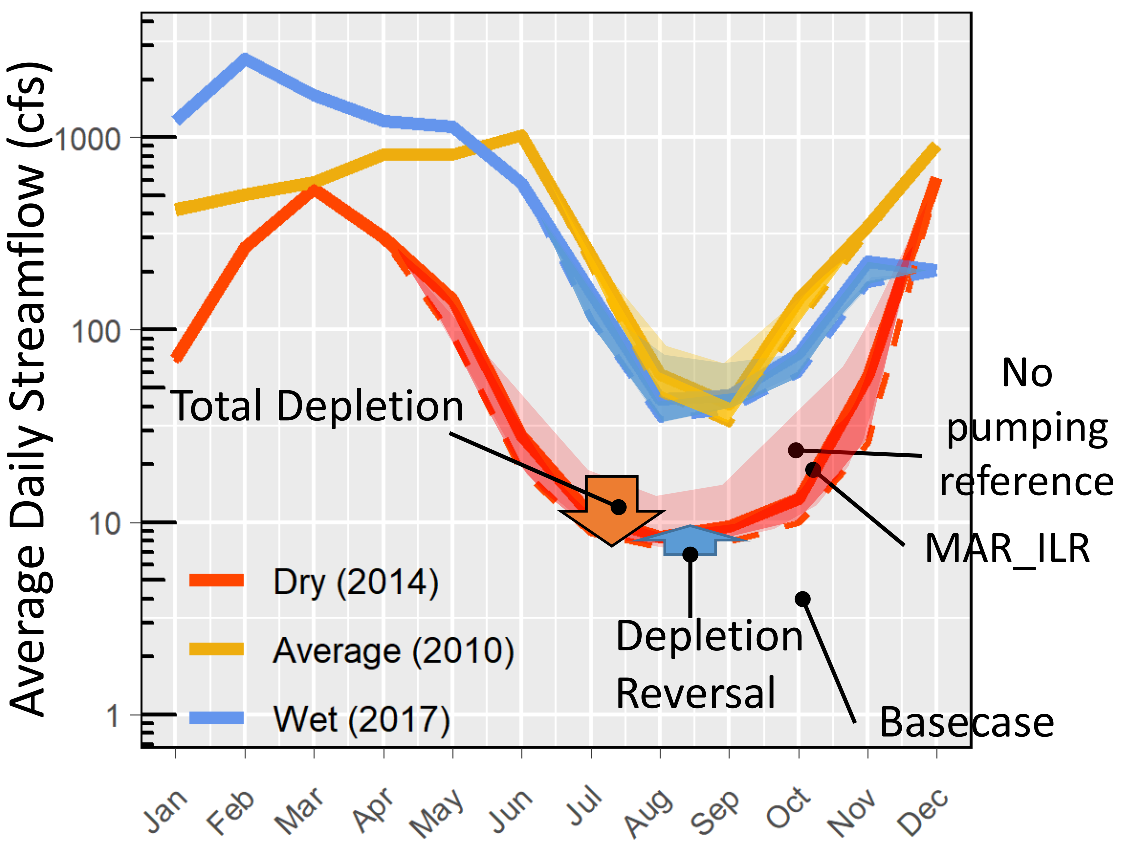
… by simulating unirrigated native vegetation in place of some irrigated ag.



Stream depletion summary

- Need 2 scenarios to calculate stream depletion:
  - Simulated historical basecase
  - No-Pumping Reference Scenario
- To calculate stream depletion **reversal**, need a 3rd scenario
  - Management ACtion

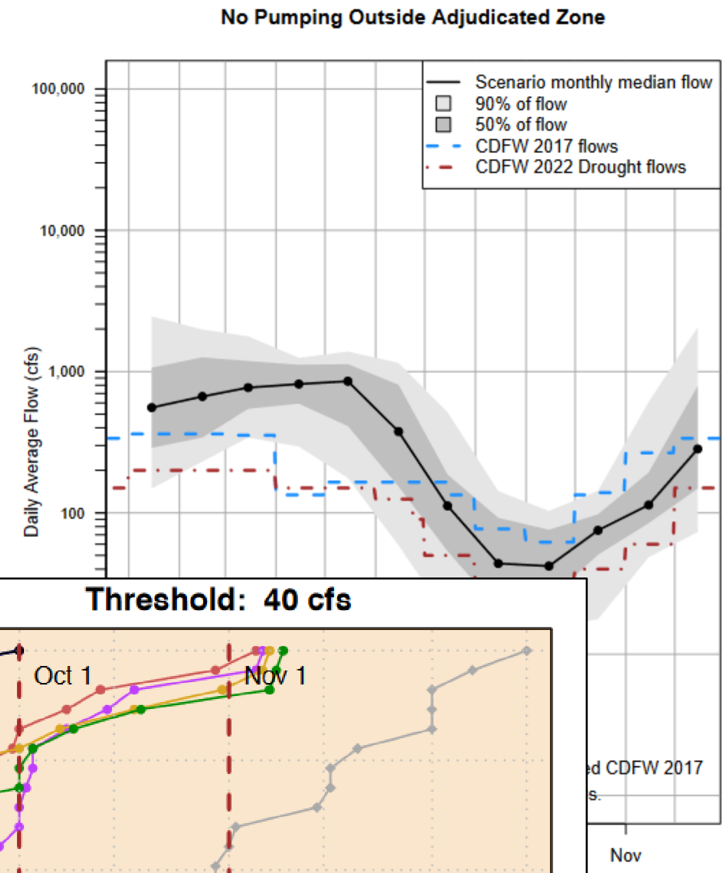
*Note: Areas not proportional due to log-y axis

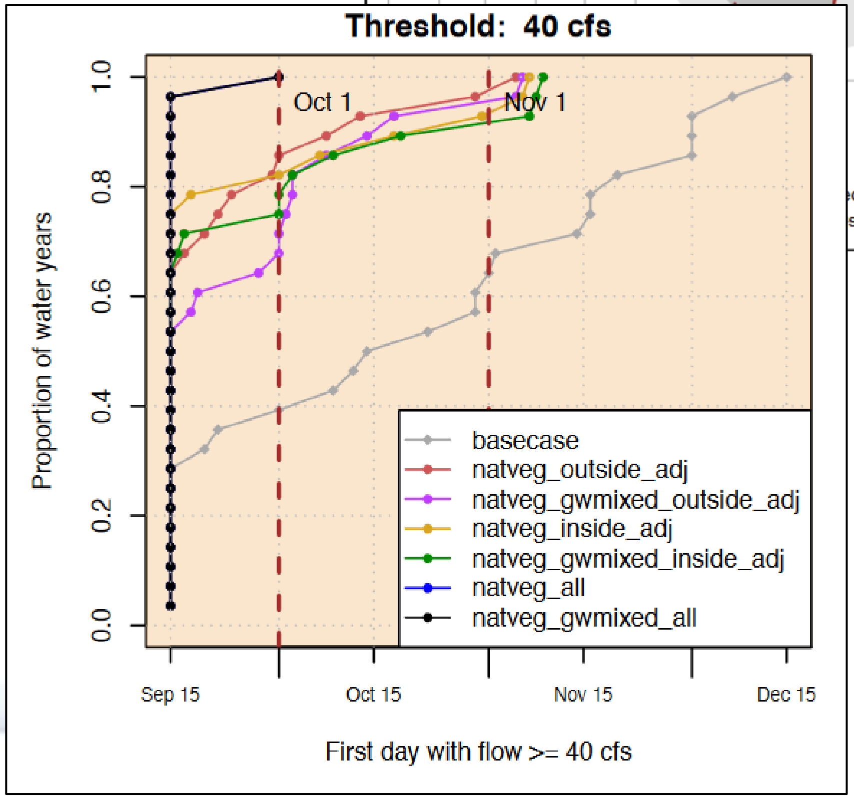


Stream depletion summary

Stream depletion can be summarized in different ways:

- Differences over time (FJ flow hydrograph, one water year)
- Total flow summary (Percentile Plot)
- Flow timing (Reconnection Plots)





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Catalog

- See Appendix 4A of Scott Valley GSP
  - https://www.co.siskiyou.ca.us/naturalresources/page/scott-valley-final-gsp
- Also Appendix to SVIHM-2018 report
  - https://ucanr.edu/sites/groundwater/files/391947.pdf

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SVIHM Updates

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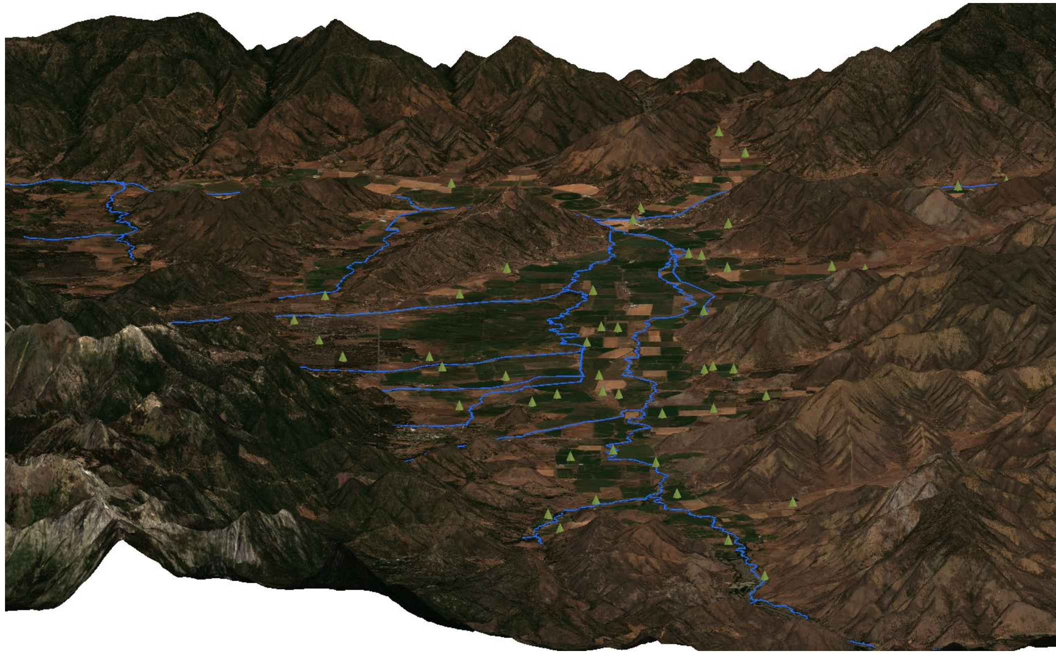
PhD Candidate
Feb. 15, 2024



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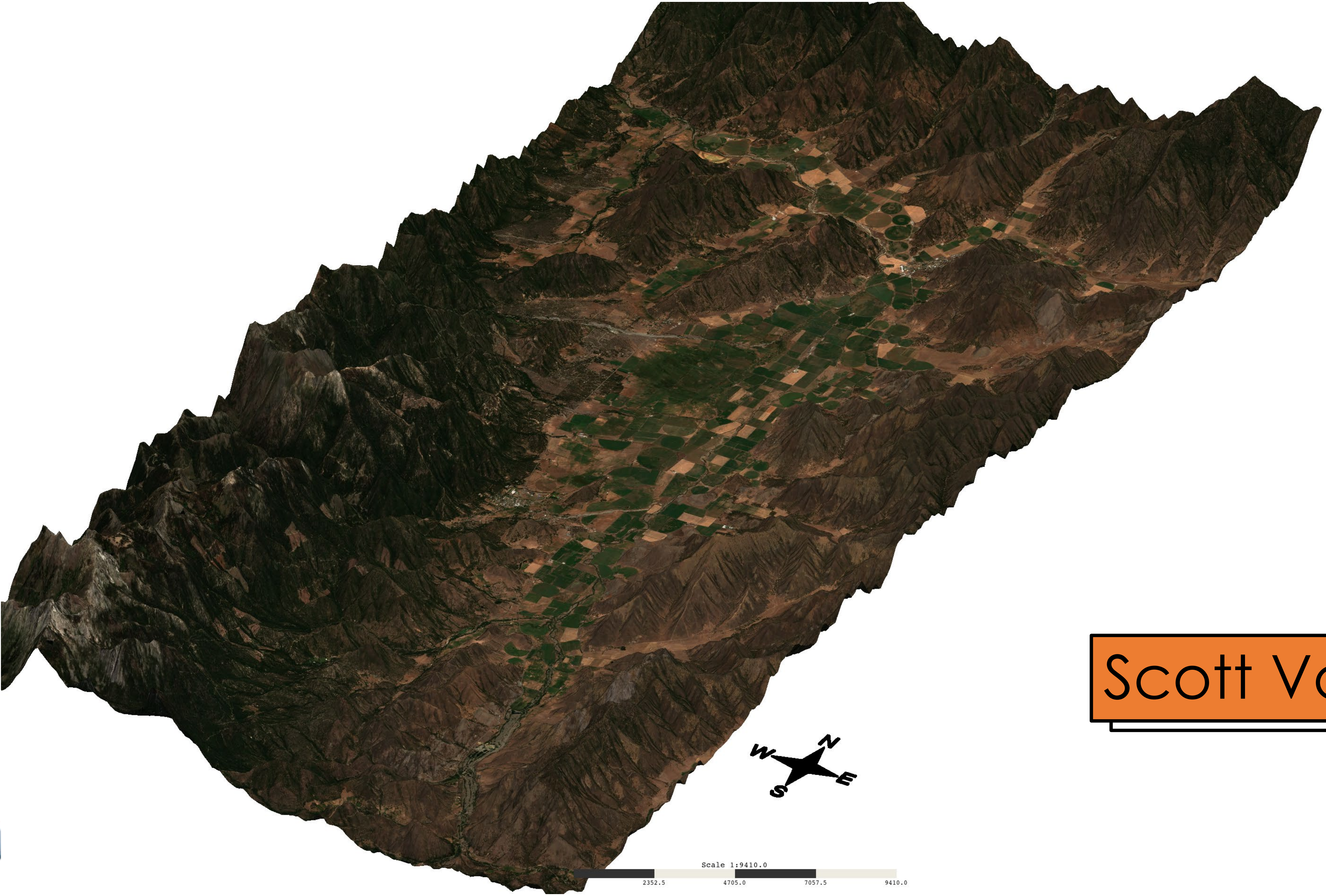
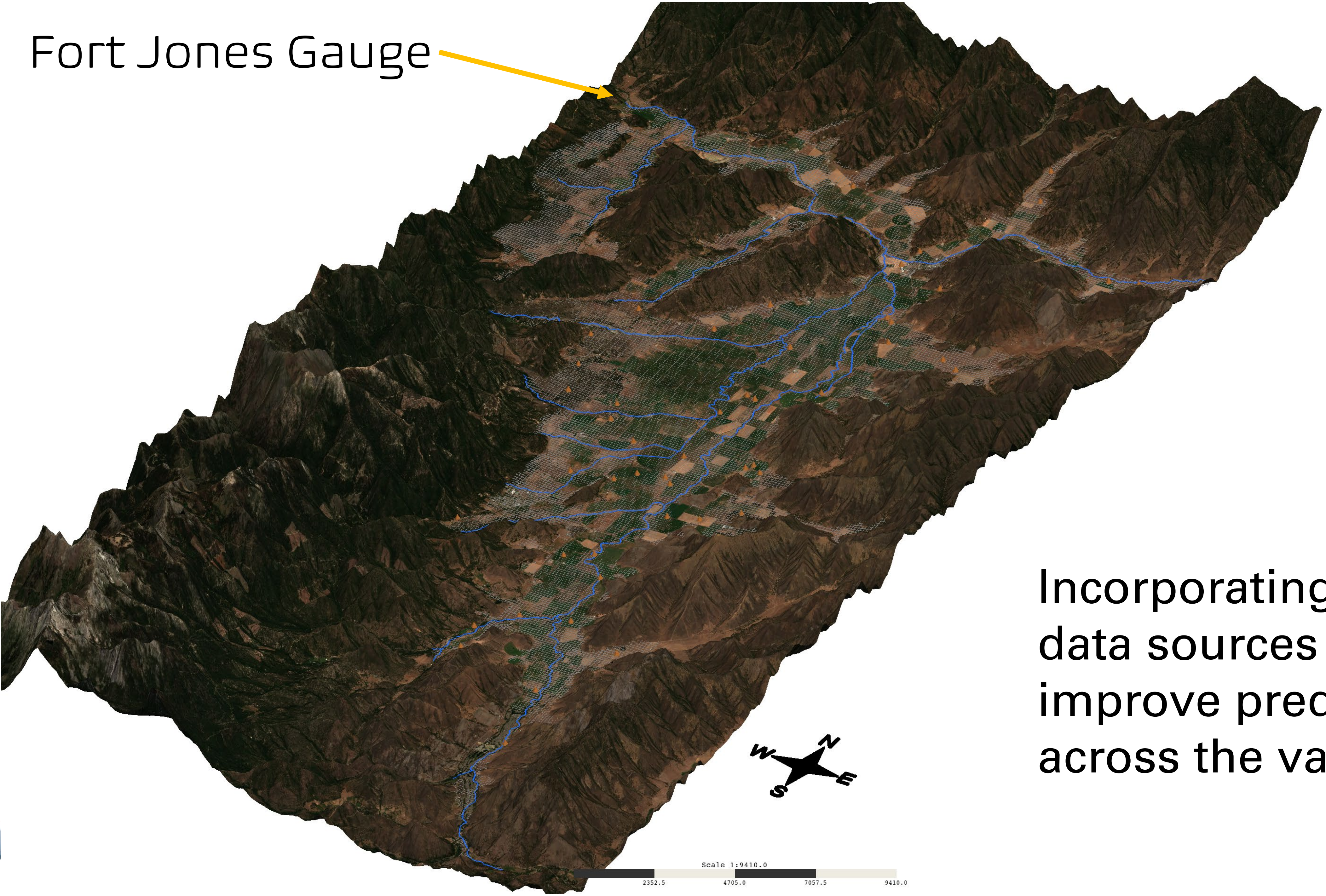
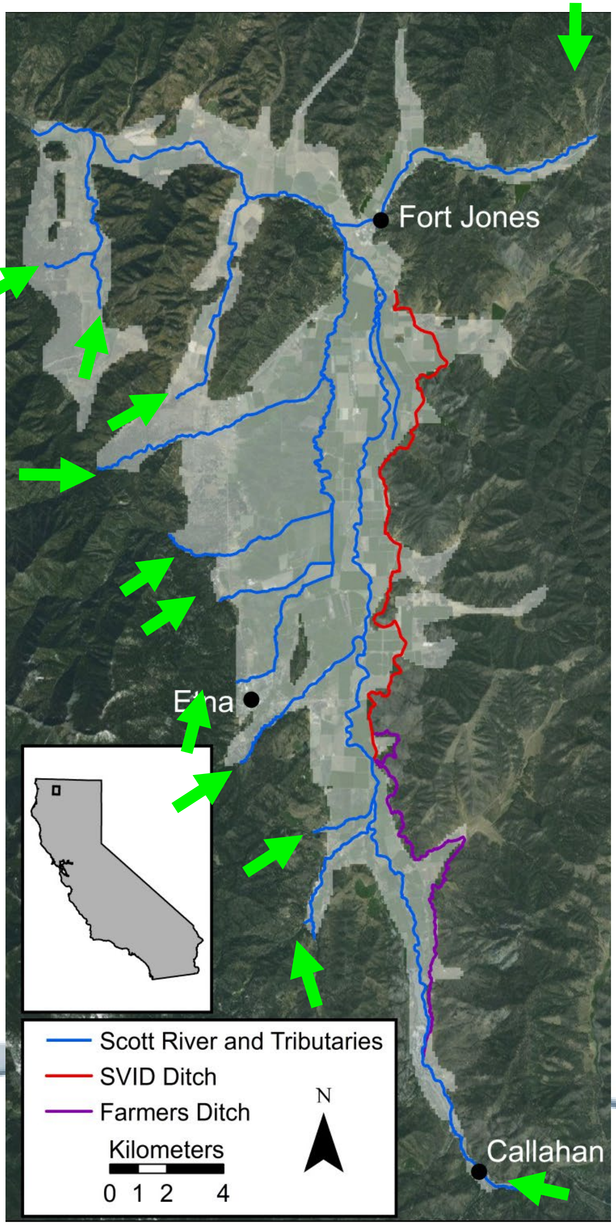
Scott Valley

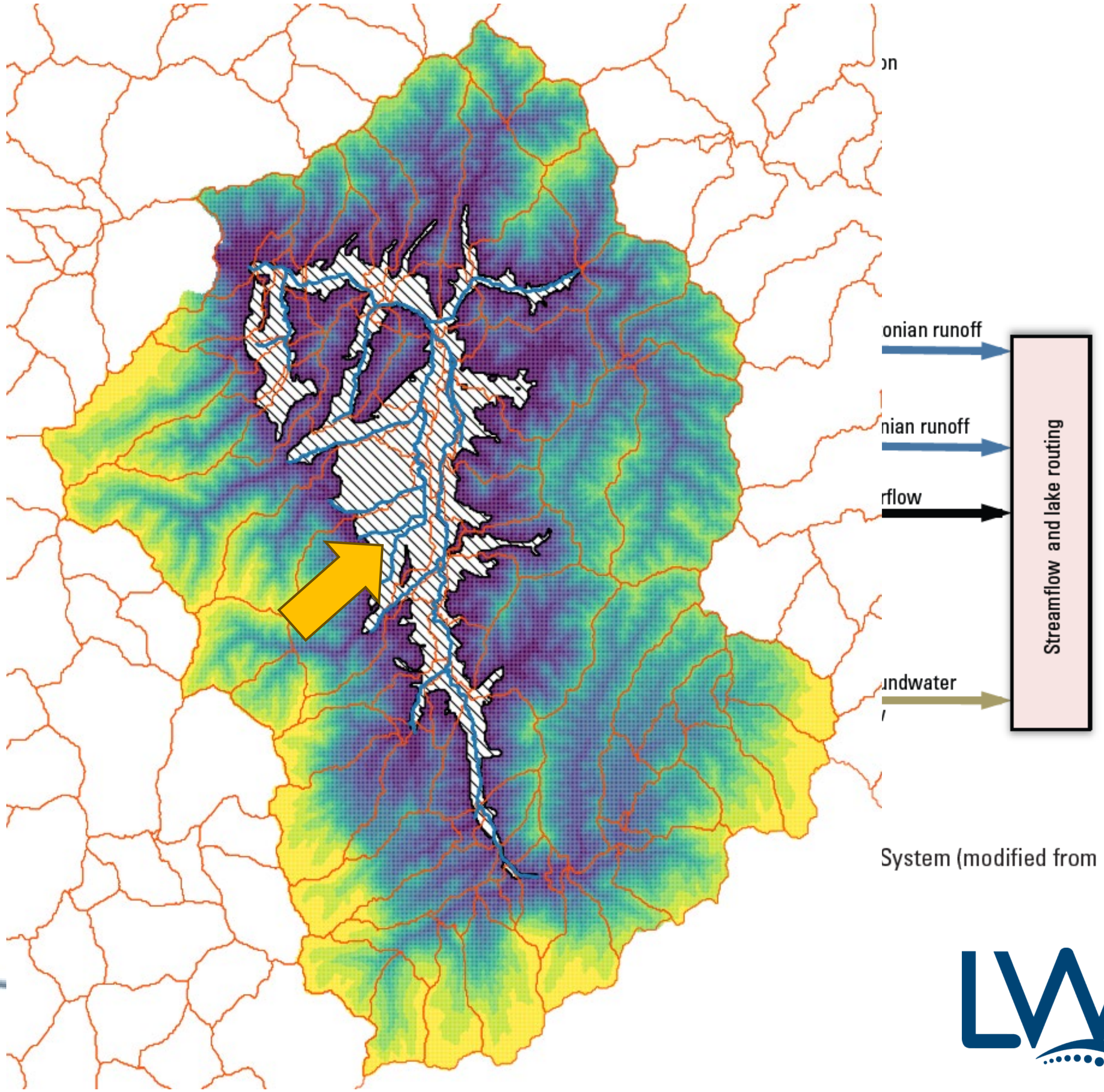




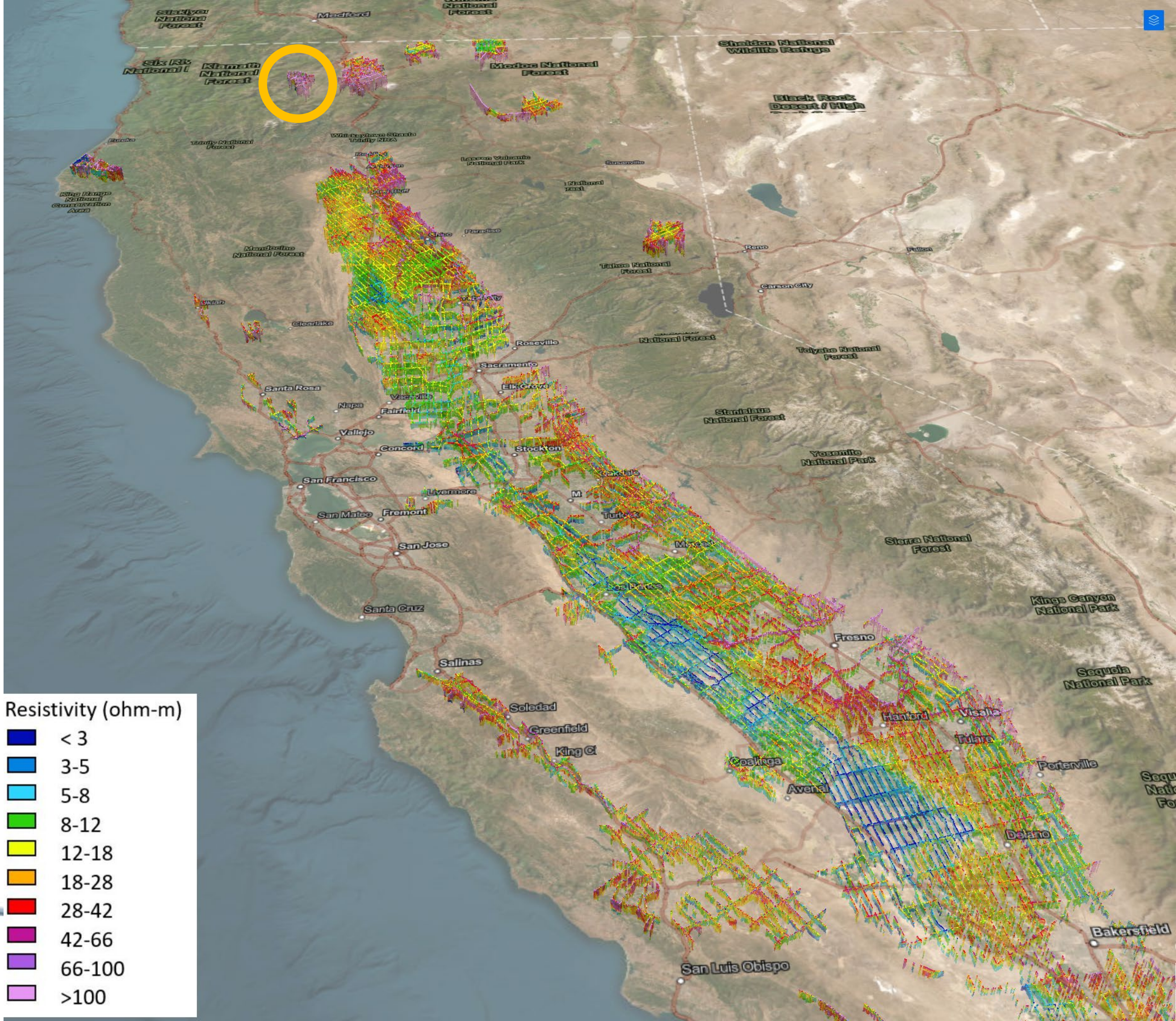
Incorporating new data sources to improve predictions across the valley

Precipitation Routing Modeling System (PRMS)



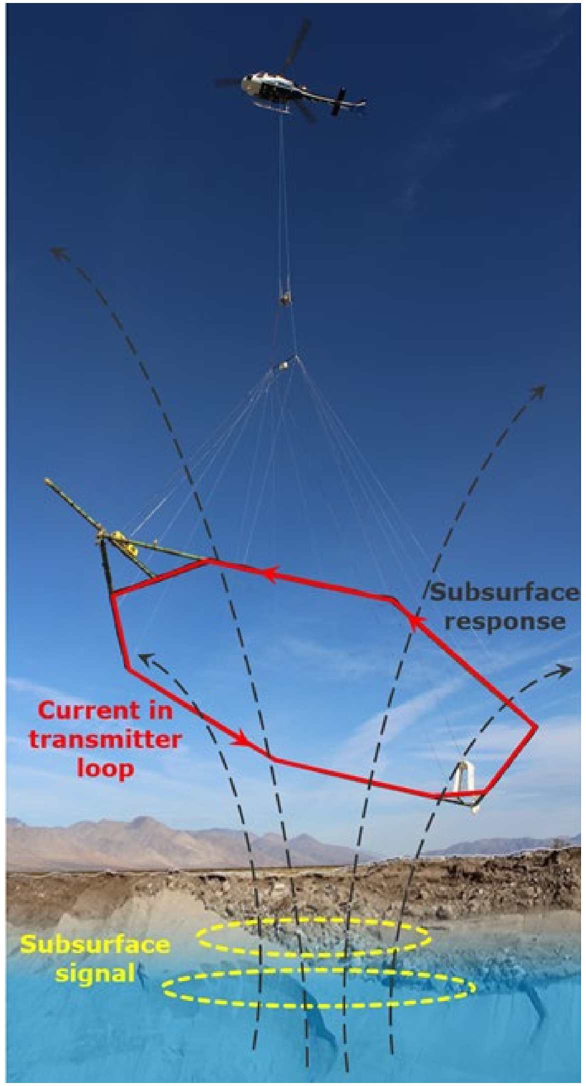


DWR Airborne Electromagnetic (AEM) Survey

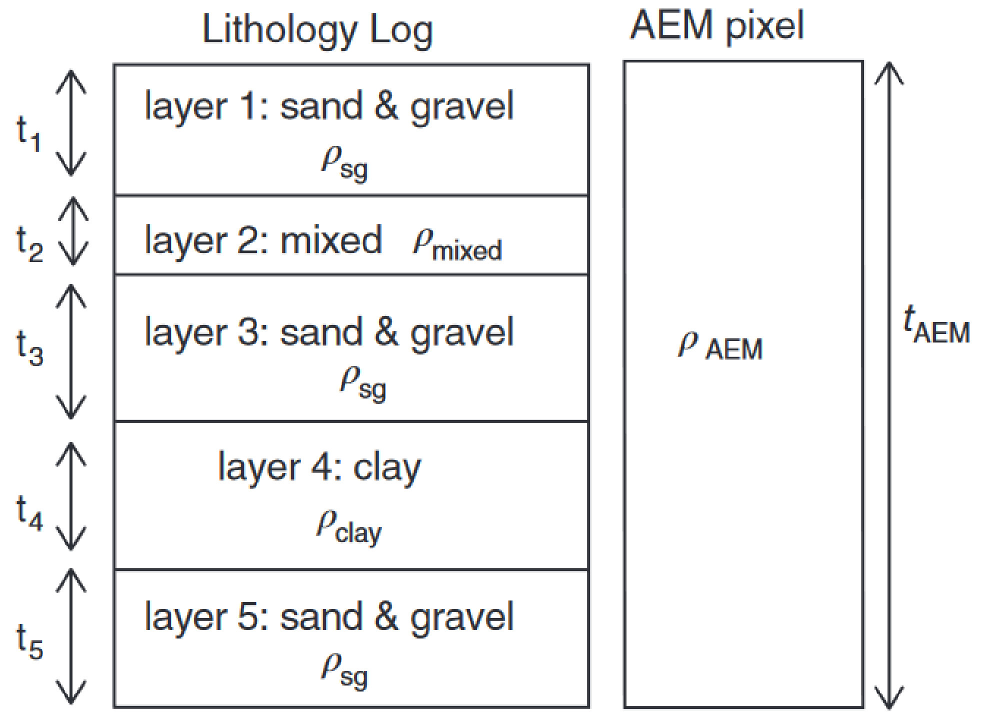


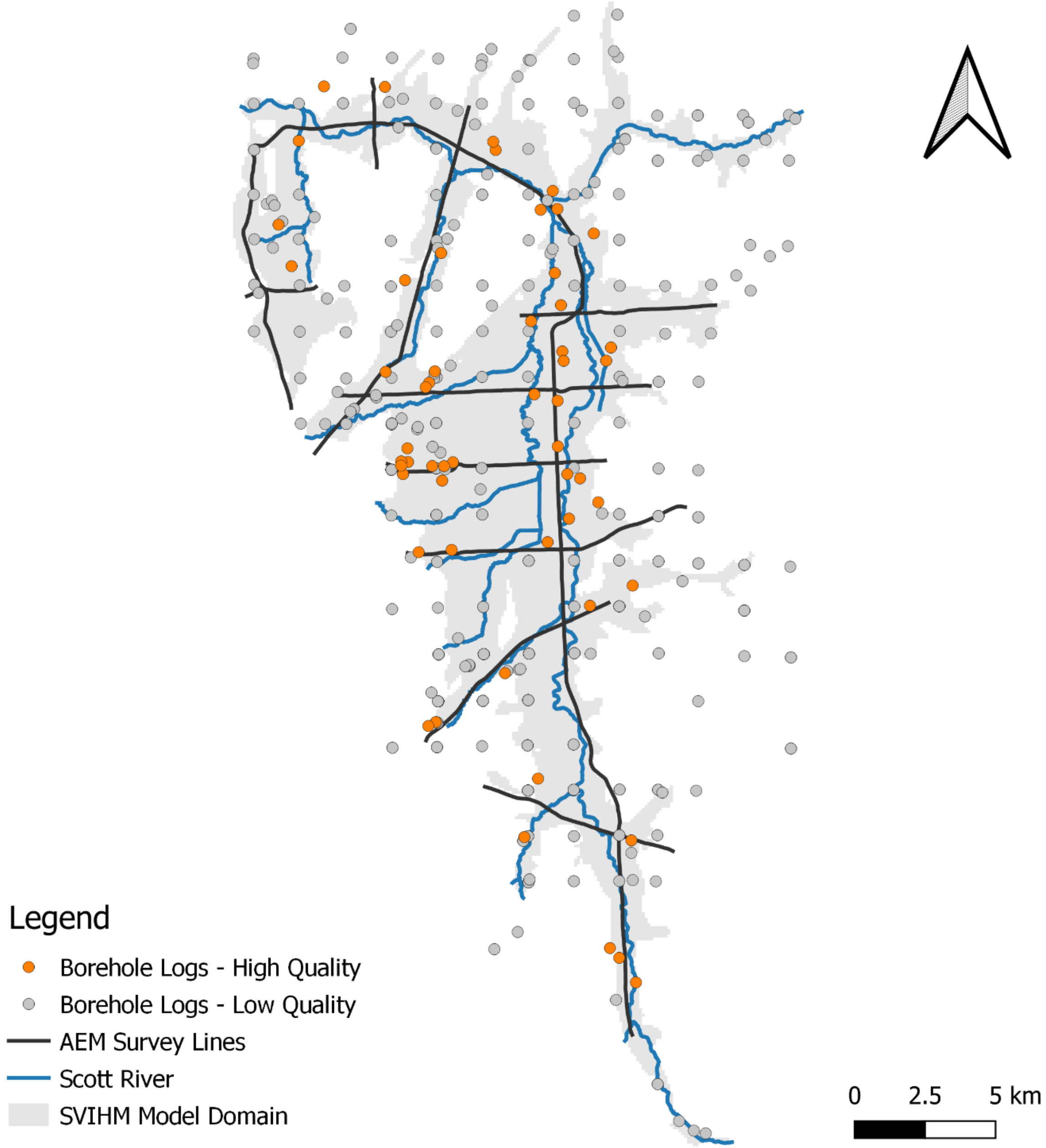
DWR Airborne Electromagnetic (AEM) Survey

- Geophysical method measuring electromagnetic response of subsurface materials
- Response is related to subsurface materials, but also…
  - Water content
  - Salinity/Water quality
- After cleaning, data can be inverted to obtain 2D models of resistivity up to 300 m (1000 ft) deep

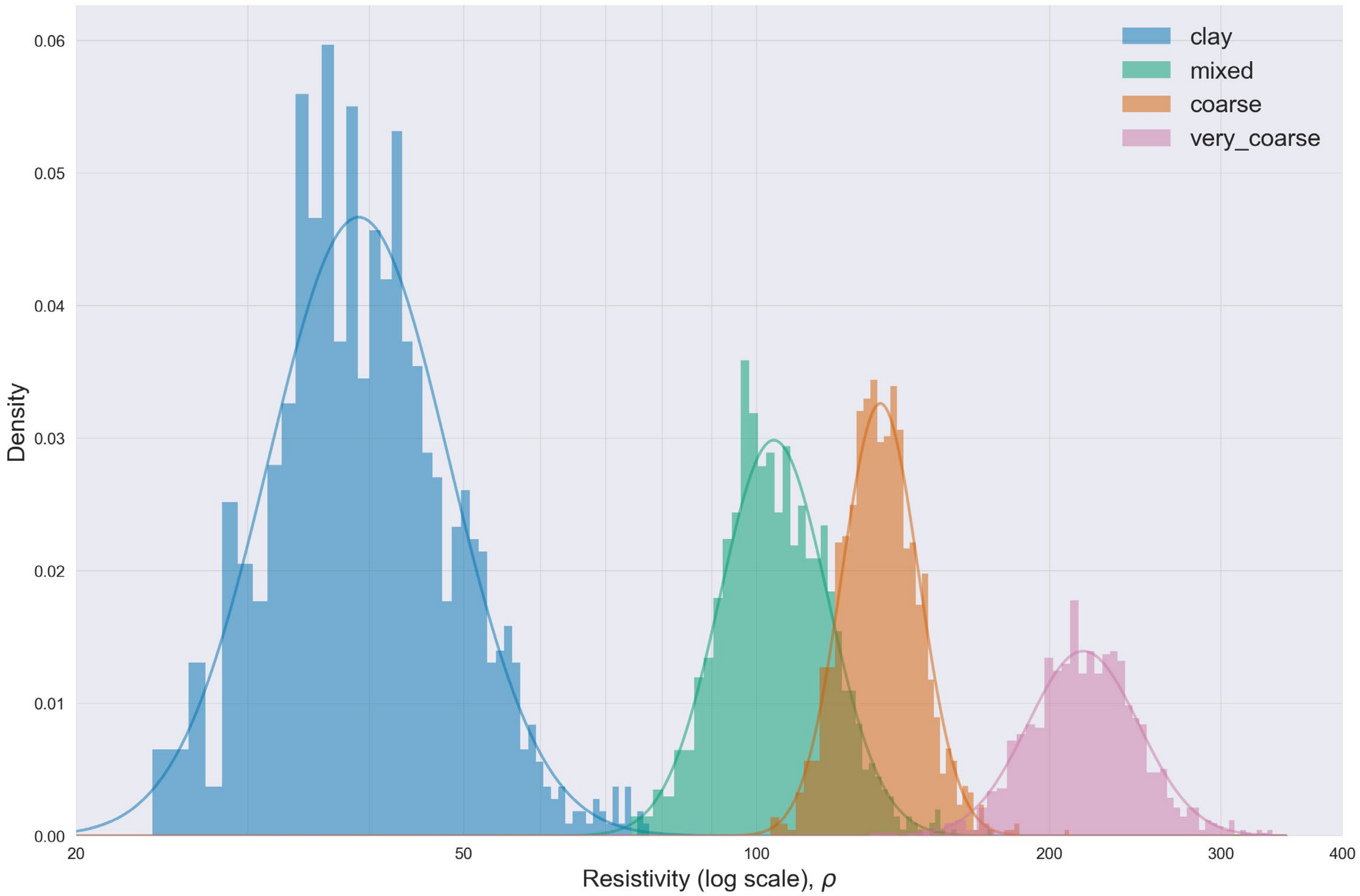


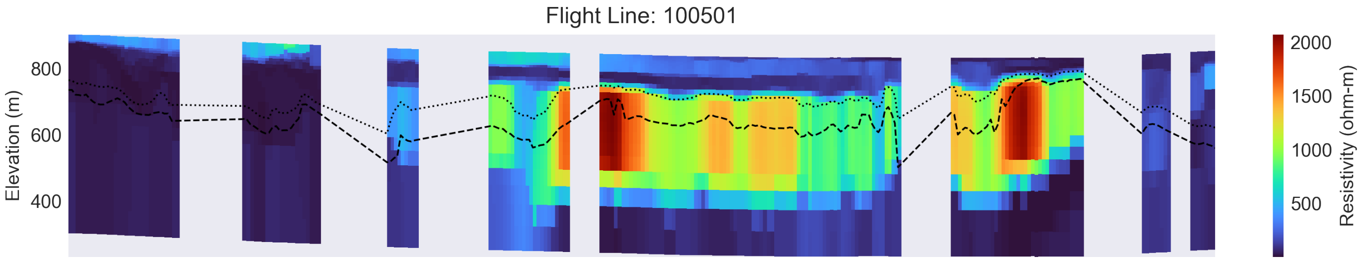
But how do we use AEM survey results in a GW-SW Model??

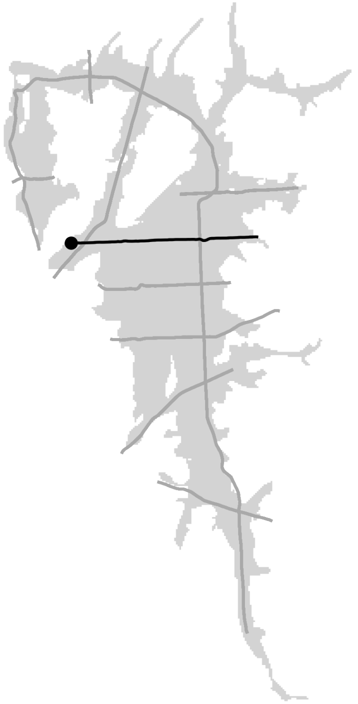


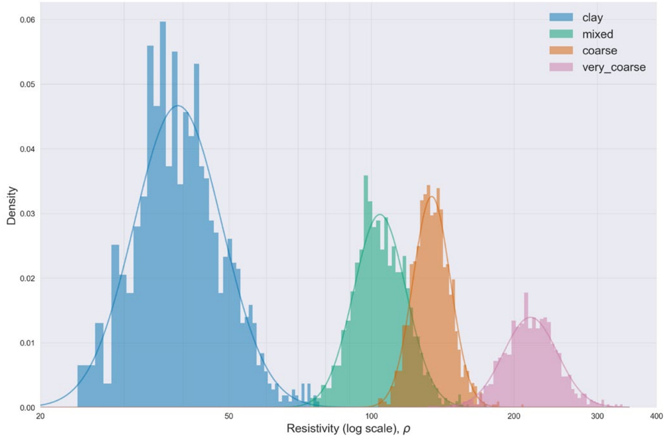


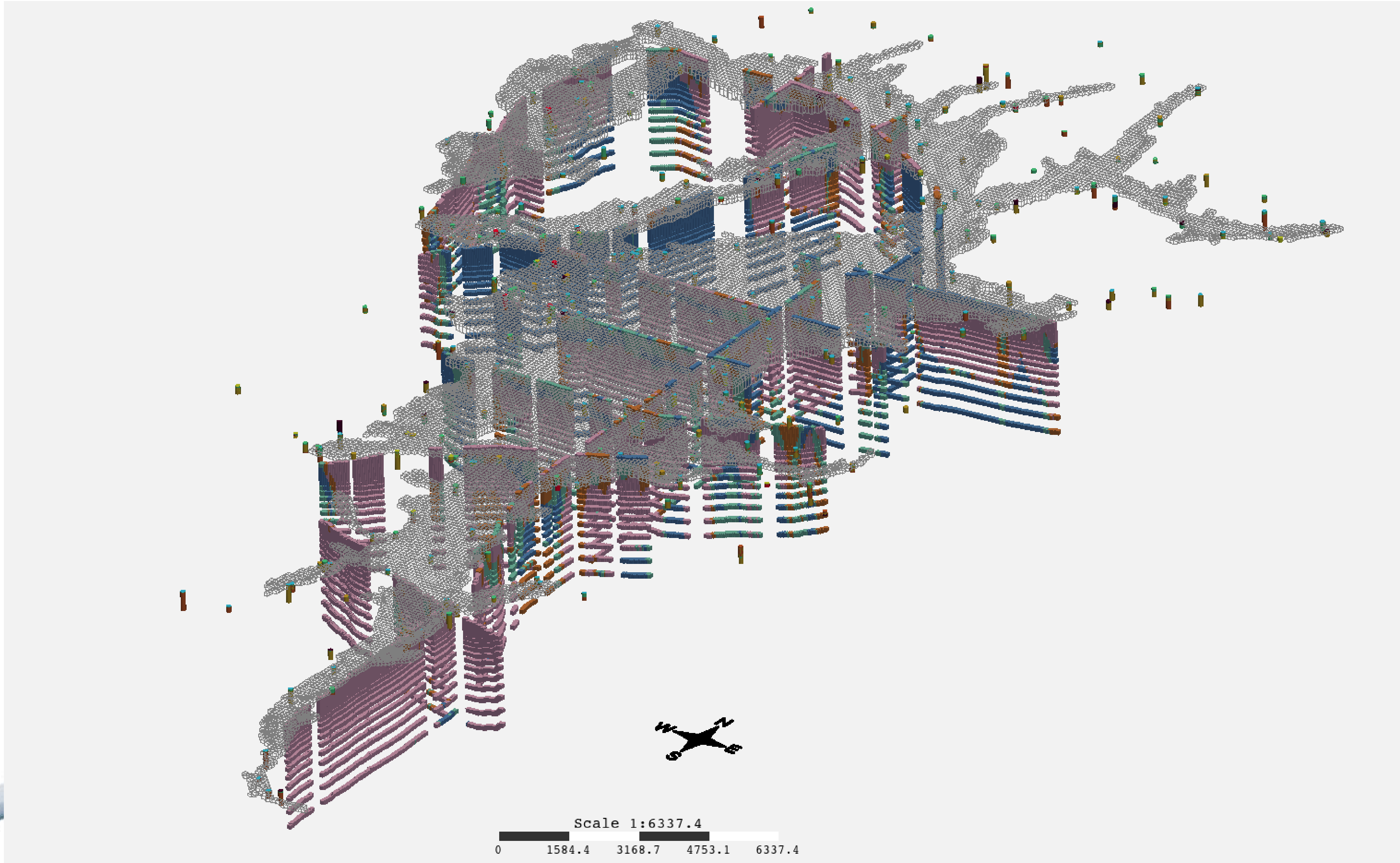
Following Knight et al. (2018)…



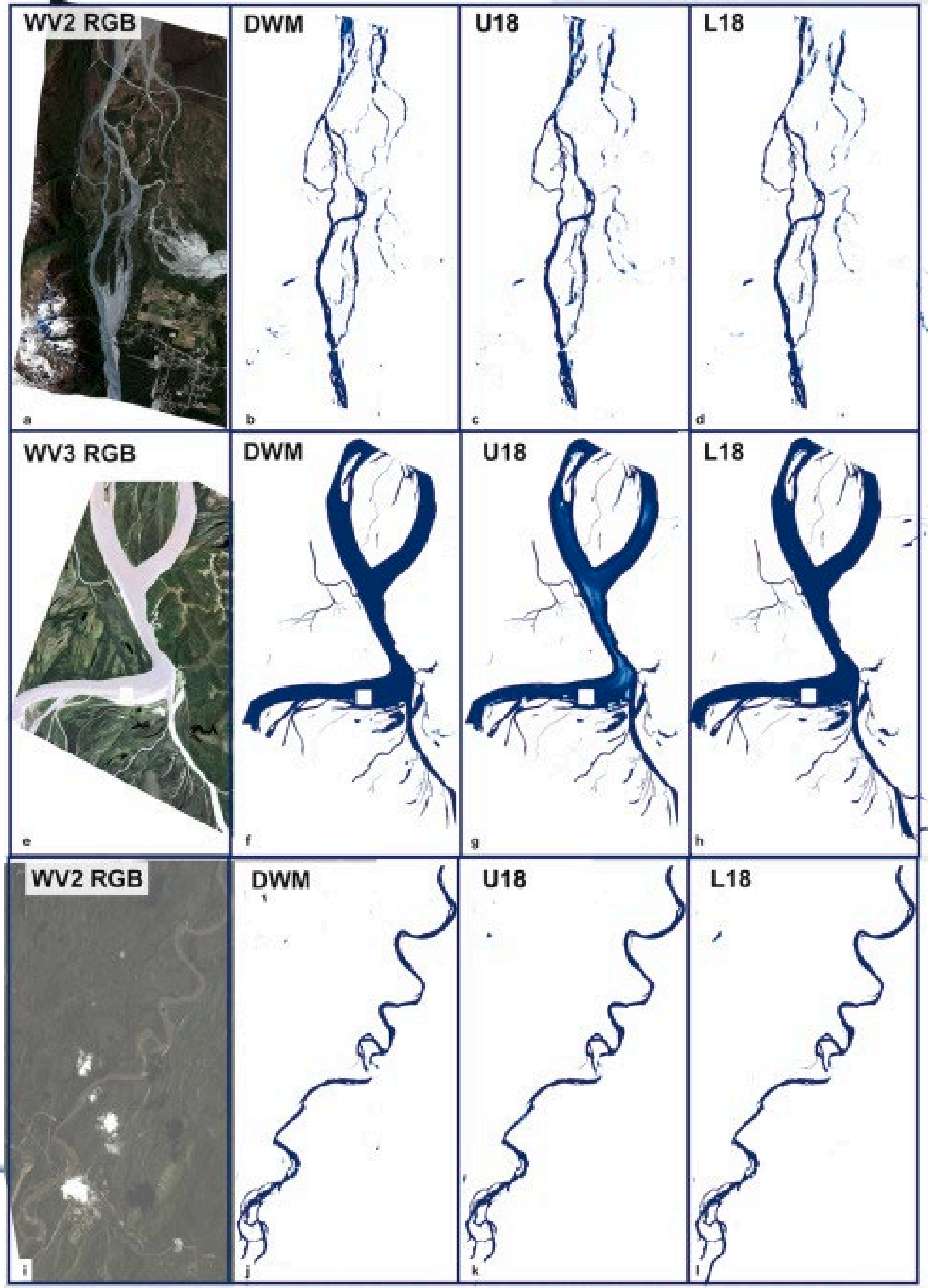

Flight Line: 100501
Elevation (m)
800
600
400
2000
1500
1000
500
Resistivity (ohm-m)



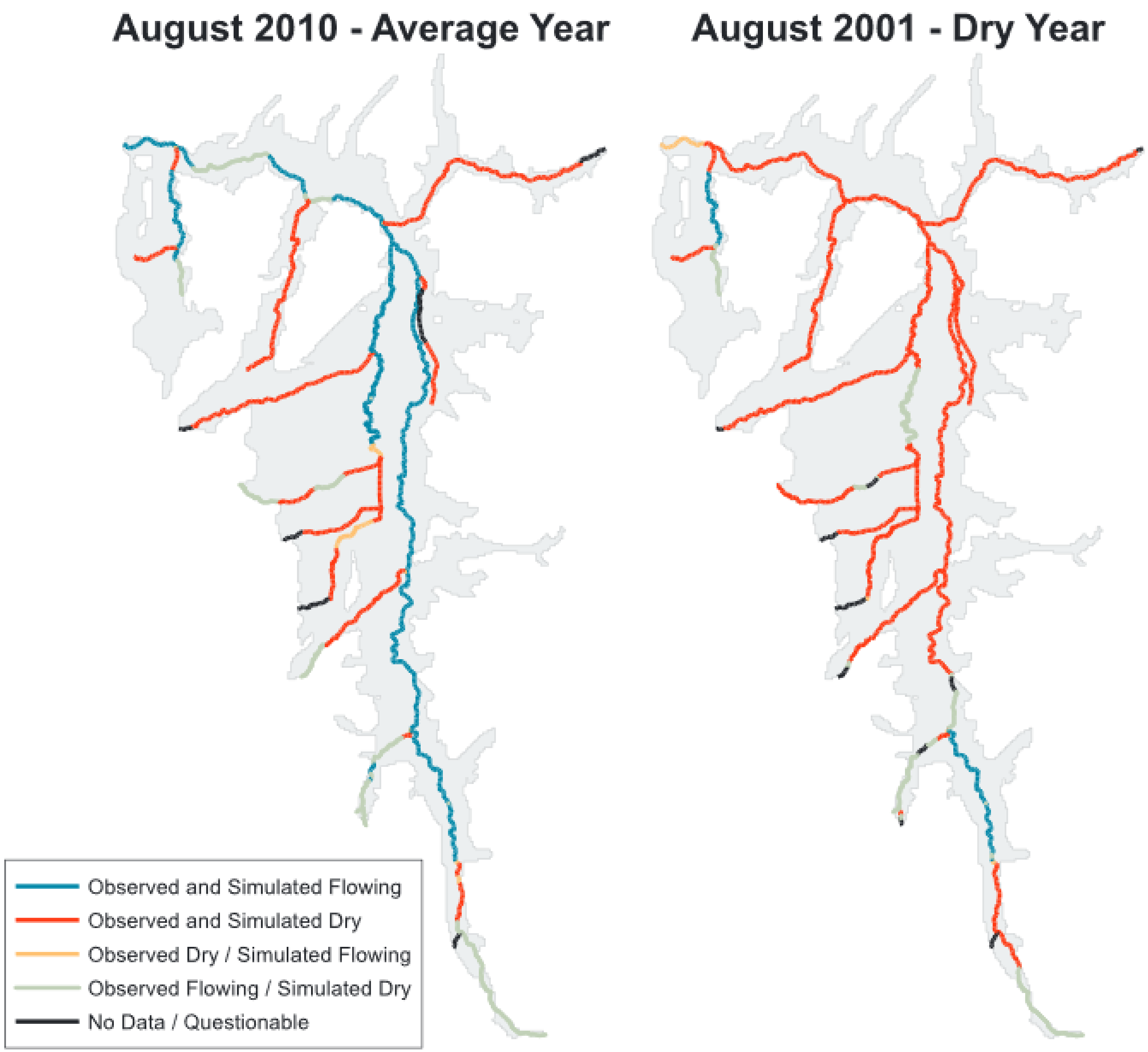

clay
mixed
coarse
very_coarse
Density
0.06
0.05
0.04
0.03
0.02
0.01
0.00
20
50
100
200
300
400
Resistivity (log scale), ρ


W
N
S
E
Scale 1:6337.4
0
1584.4
3168.7
4753.1
6337.4

Remote Sensed Water Presence



From Moortgat et al. (2022)



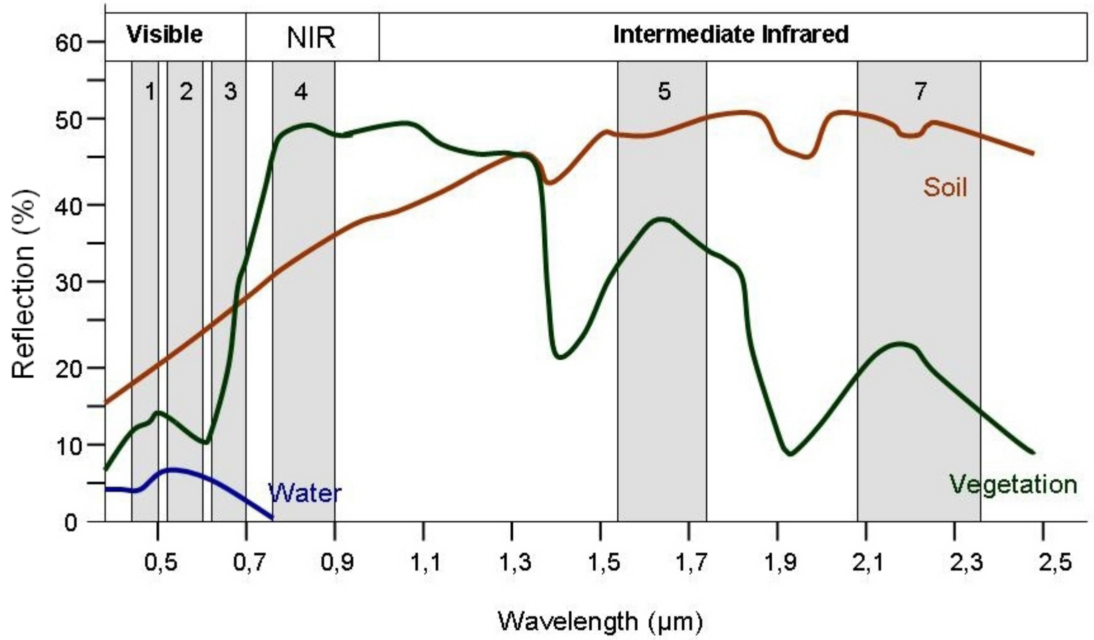
From Tolley et al. (2019)

What can we get from this data?

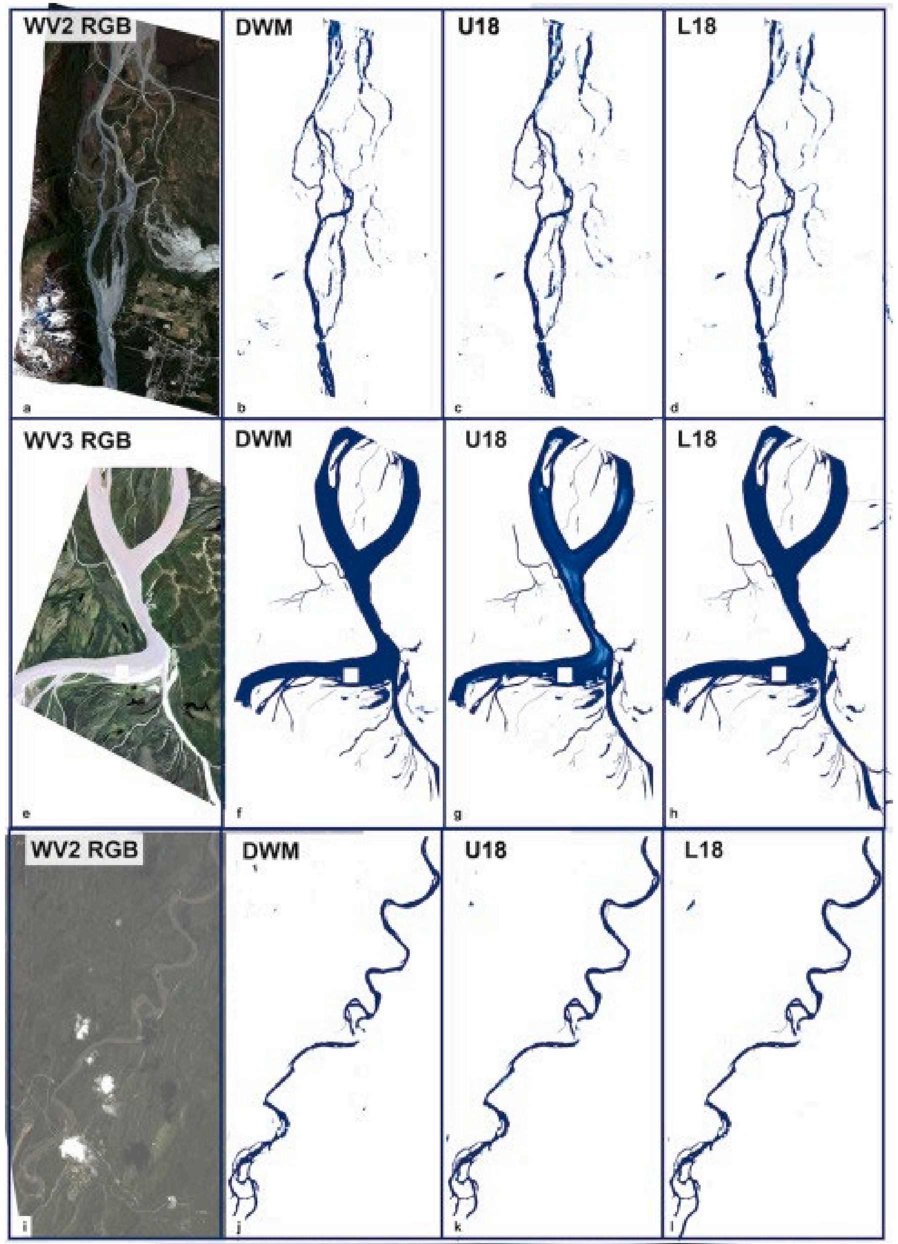
- Embedded in the location & timing of stream disconnection is data about:
  - How much water is in the river
  - The groundwater level in the aquifer below
  - Connection between the stream and aquifer
- Important model capability for running scenarios to see how management actions (like MAR) help keep the stream connected

Remote Sensing Basics

- Satellites orbiting Earth sending photos that contain different parts of the electromagnetic spectrum
- High spatial resolution, frequent return data is available
  - Sentinel-II
  - Planet Data (commercial)
- Proposed method most useful for non-perennial streams



From ESA
Eduspace

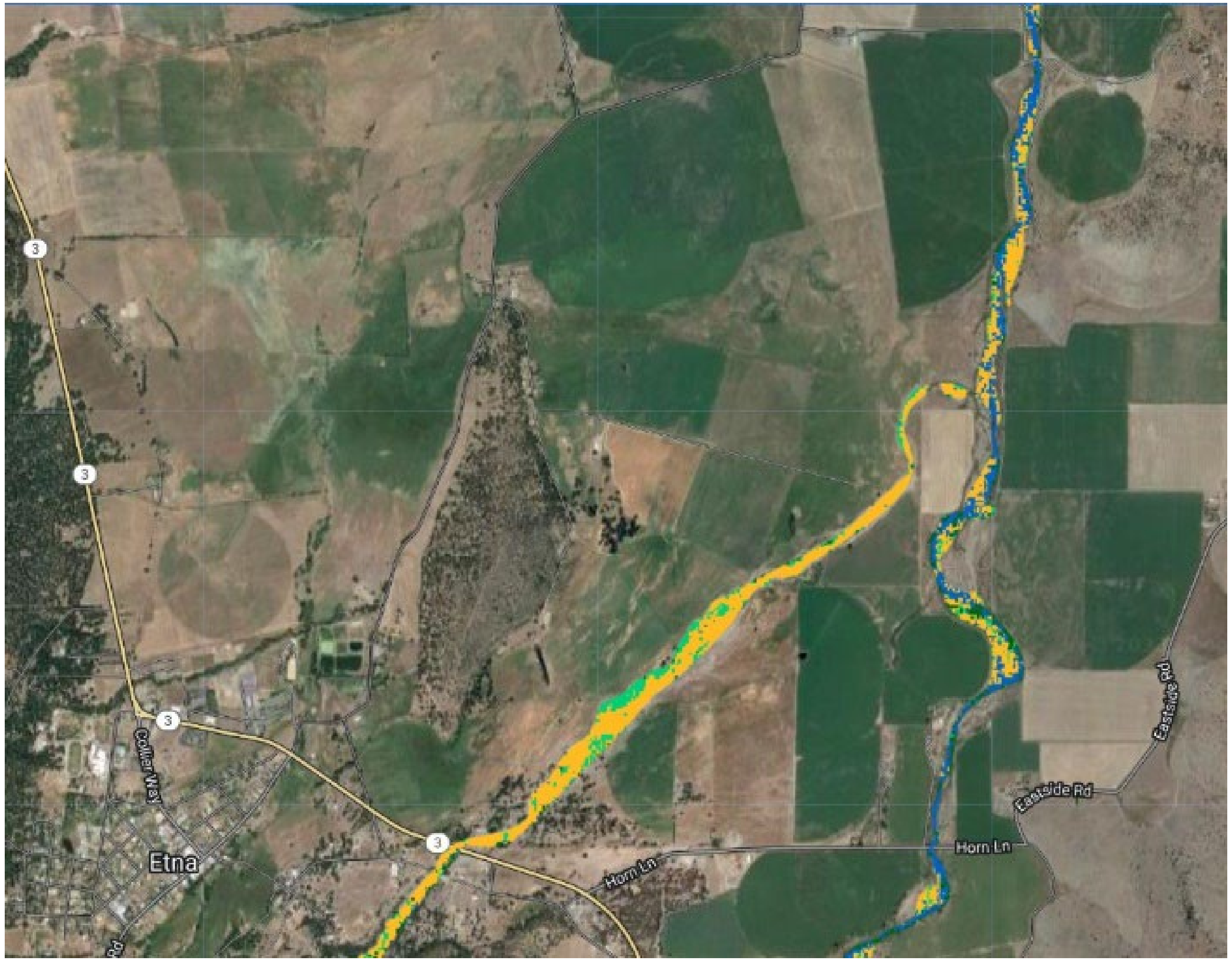


From Moortgat et al. (2022)

Methods

- Normalized Difference Water Index (NDWI) (McFeeters, 1996)
- Modified NDWI (Xu, 2006)
- Augmented NDWI (Rad et al., 2021)
- Machine Learning Methods
  - Random Forest
  - Neural Networks
- Classification models can be trained/evaluated using weekly SV connectivity survey data
  - Predictive error can be estimated by reserving some training data

August 17, 2023



Big thanks to Bekzhon Bekzhonov!

SVIHM Updates

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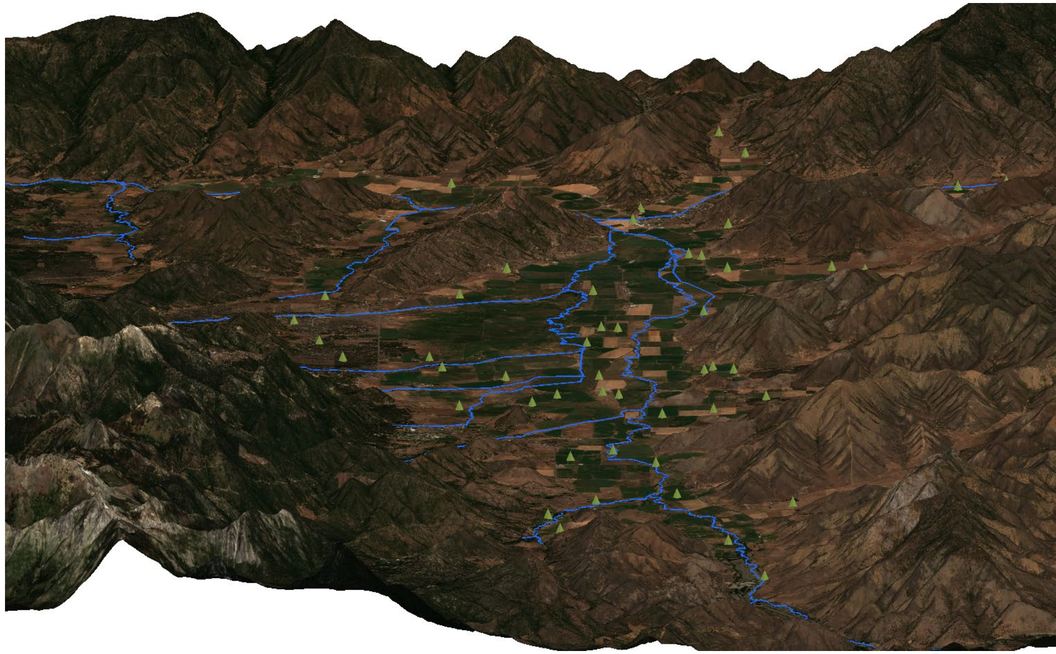

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Questions