Hydrologic Management for the Anthropocene

A Concurrent Session at the 39th Annual Salmonid Restoration Conference held in Santa Cruz, California from April 19 – 22, 2022.

- **Session Coordinator:**
  - David Dralle, Ph.D. *Pacific Southwest Research Station, Forest Service*
  - Tim Baily, *Watershed Research and Training Center*

A climate emergency is upon us. Salmon and their watersheds face extremes in flow and water temperature due to more frequent drought, extreme heat, flooding, wildfire, and reduced snowpack. Novel, science-based strategies are needed to maintain a place for cold water fish in our landscapes. This session is an opportunity to disseminate basic and applied scientific knowledge that will help to advance management practices for the betterment of salmon-supporting watersheds. This is a venue for practitioners from a variety of roles to report on their efforts. Approaches to enhance instream flow, improve water quality, and augment beneficial environmental conditions are encouraged to participate.

Presentations

Slide 4 – **California Senate Bill 19 Stream Gaging Plan**, Valerie Zimmer, *State Water Resources Control Board*

Slide 34 - **An Enhanced Method for Evaluating Large-scale, multi-objective Floodplain Restoration Opportunities**, Luke Tillmann, MS, *cbec eco engineering*

Slide 58 - **Notes from Underground: The Hydrological Underpinnings of Watershed Response to Drought Across California,** David Dralle, PhD, *US Forest Service, Pacific Southwest Research Station*

Slide 84 - **Thermal Stratification of River Pools—Field and Numerical Modeling Study,** Todd H. Buxton, Ph.D., *Bureau of Reclamation*

Slide 108 - **A Decade of Data and Lessons Learned from Restoring a Sierra Meadow Complex,** Barry Hecht, *Balance Hydrologics*

California Department of Conservation

CALIFORNIA DEPARTMENT OF WATER RESOURCES

California Senate Bill 19 Stream Gaging Plan

Salmonid Restoration Federation Conference

Valerie Zimmer and Todd Carlin

April 22, 2022

CALIFORNIA WATER BOARDS
State Water Resources Control Board

California Department of Fish and Wildlife

Core Team

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California Department of Fish and Wildlife

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DWR	– Teresa Connor – Les Grade – Radley Ott
Water Board	– Dan Schultz – Erin Ragazzi – Valerie Zimmer
DFW	– Todd Carlin – Robert Sherrick – Diane Haas
DOC/CGS	– Mike Fuller – Bill Short

StreamGagingPlan@waterboards.ca.gov

Technical Advisory Committee

Entity	**Member**
Association of California Water Agencies – MBK	Marc VanCamp
California State Association of Counties	Catherine Freeman
Central Valley Flood Protection Board	Doug Kennedy
NOAA - California Nevada River Forecast Center	Alan Haynes
Northern California Water Association	David Guy
The Nature Conservancy (TNC)	Kirk Klausmeyer
Trout Unlimited	Mia van Docto
United States Geological Survey - Water Science Center	Mark Dickman
Internet of Water	Peter Colohan
California Water Data Consortium	Tara Moran

Agenda

Is my watershed getting a gage?

What are we doing for SB19?

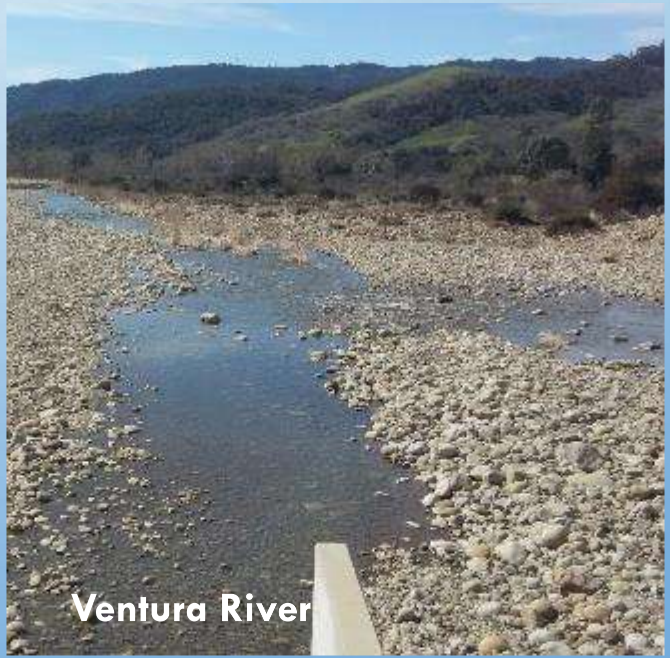
1. Stream Gaging **PLAN**
2. Identify priority watersheds based on Management Criteria
3. Identification of existing gage or gage sites that need upgrades and reactivation.
4. Data Management, Funding, Collaboration, New Technologies, etc.
5. Data Visualization and Tool w/ Internet c

We are NOT installing gages

Management Criteria

Placing or modernizing and reactivating stream gages where lack of data contributes to conflicts in water management

Water Supply
Flood (Public Safety)
Water Quality
Ecosystem
Reference Gages



Gage Inventory

USGS & CDEC only

Primary Source*	Total Gages	Active - HQ	Active - LU	Inactive	Excluded
NWIS	2080	460	174	1133	313
CDEC	442	197	182	34	29
WDL	75	2	6	34	33
Total	2597	**659**	**362**	**1201**	375

Lots of preprocessing!!

Active – High Quality

Active – Limited Use
Eligible for upgrade.

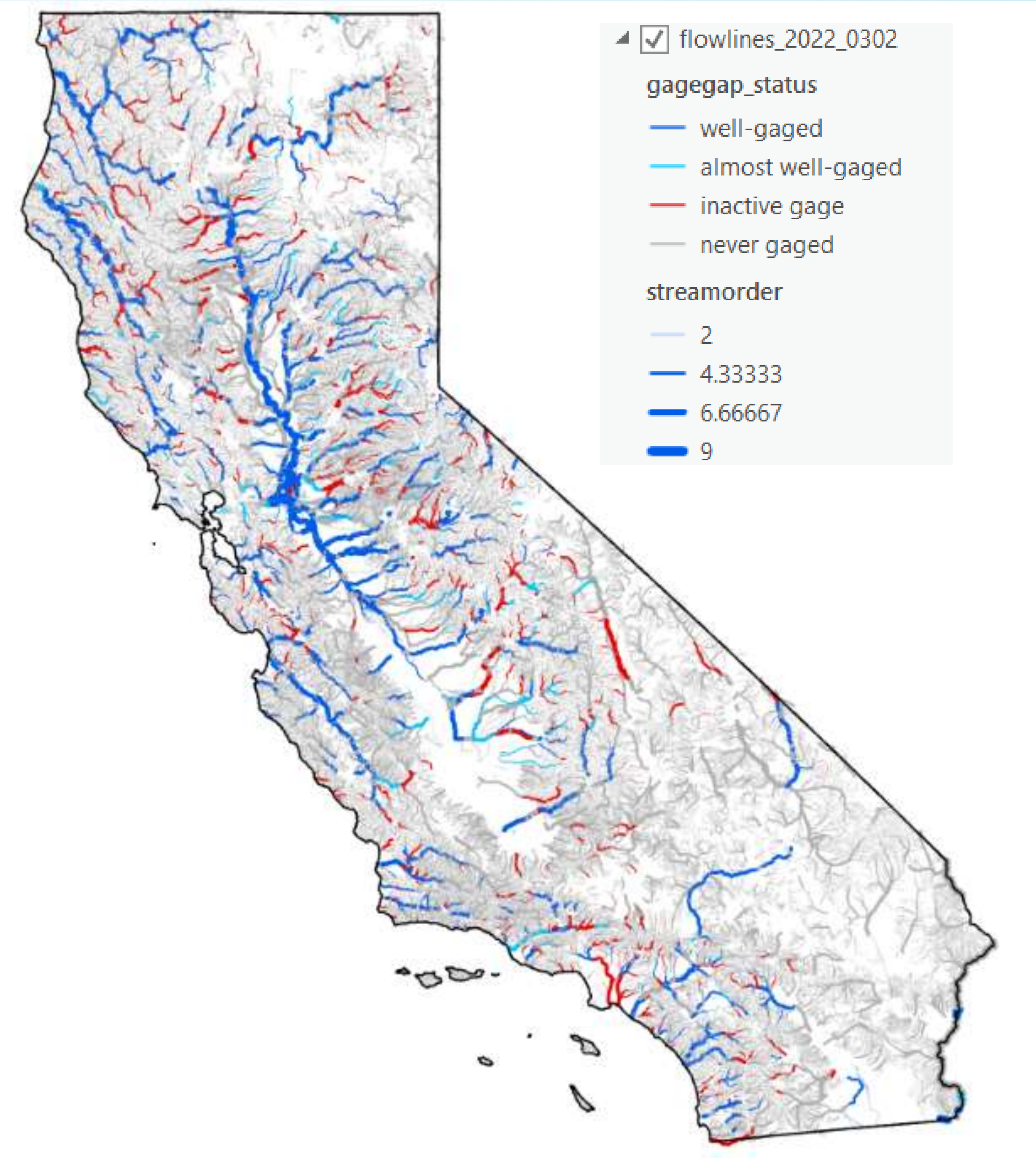
Inactive
Eligible for reactivation.

Exclude
Not classified as active for analysis
not eligible for reactivation or upgrade

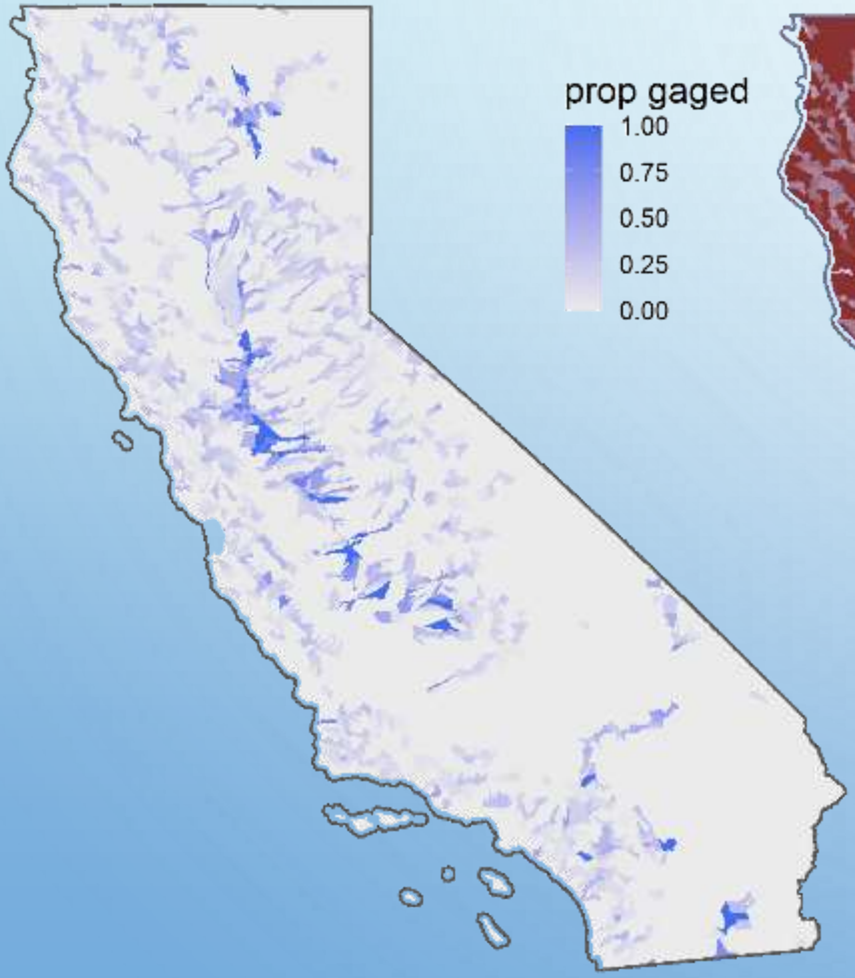
Stream Network Analysis for Gages (SNAG)

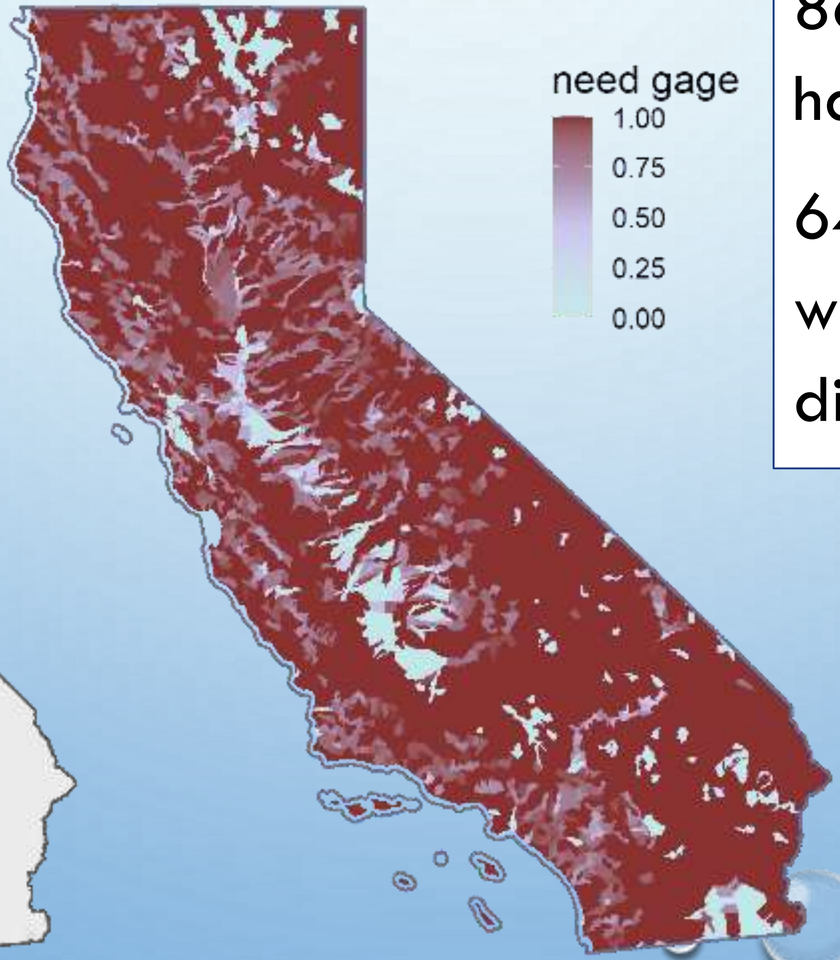
- Based on gage location and watershed area
- Coverage = upstream to 50% and downstream to 150% of gage's watershed area.
- "Well Gaged" = Active – HQ
- "Almost Well Gaged" = Active – LU

R-code gage gap algorithm by
Lucy Andrews and Ted Grantham (UC Berkeley)



Gage Gap Analysis HUC12 Summary

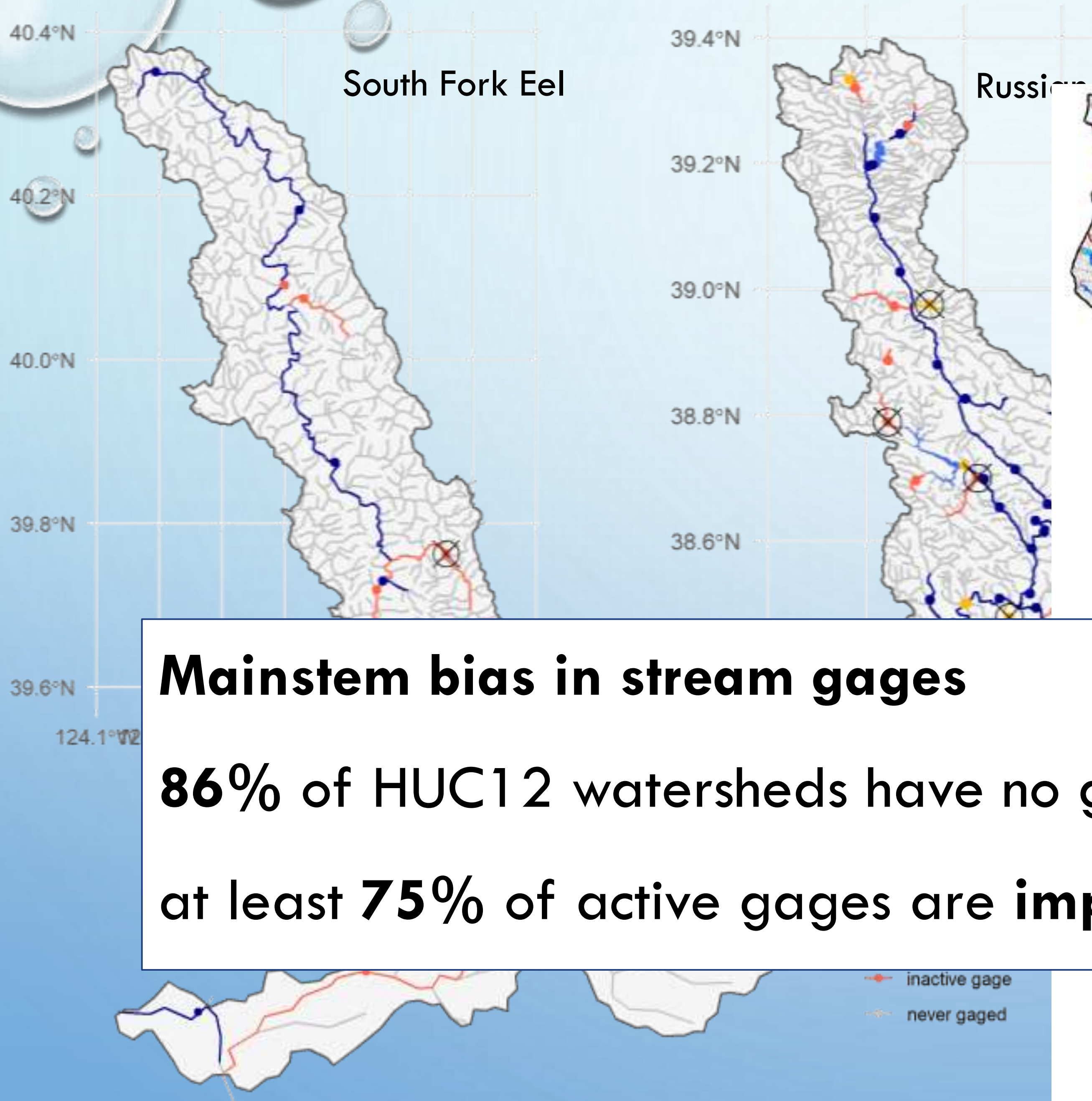


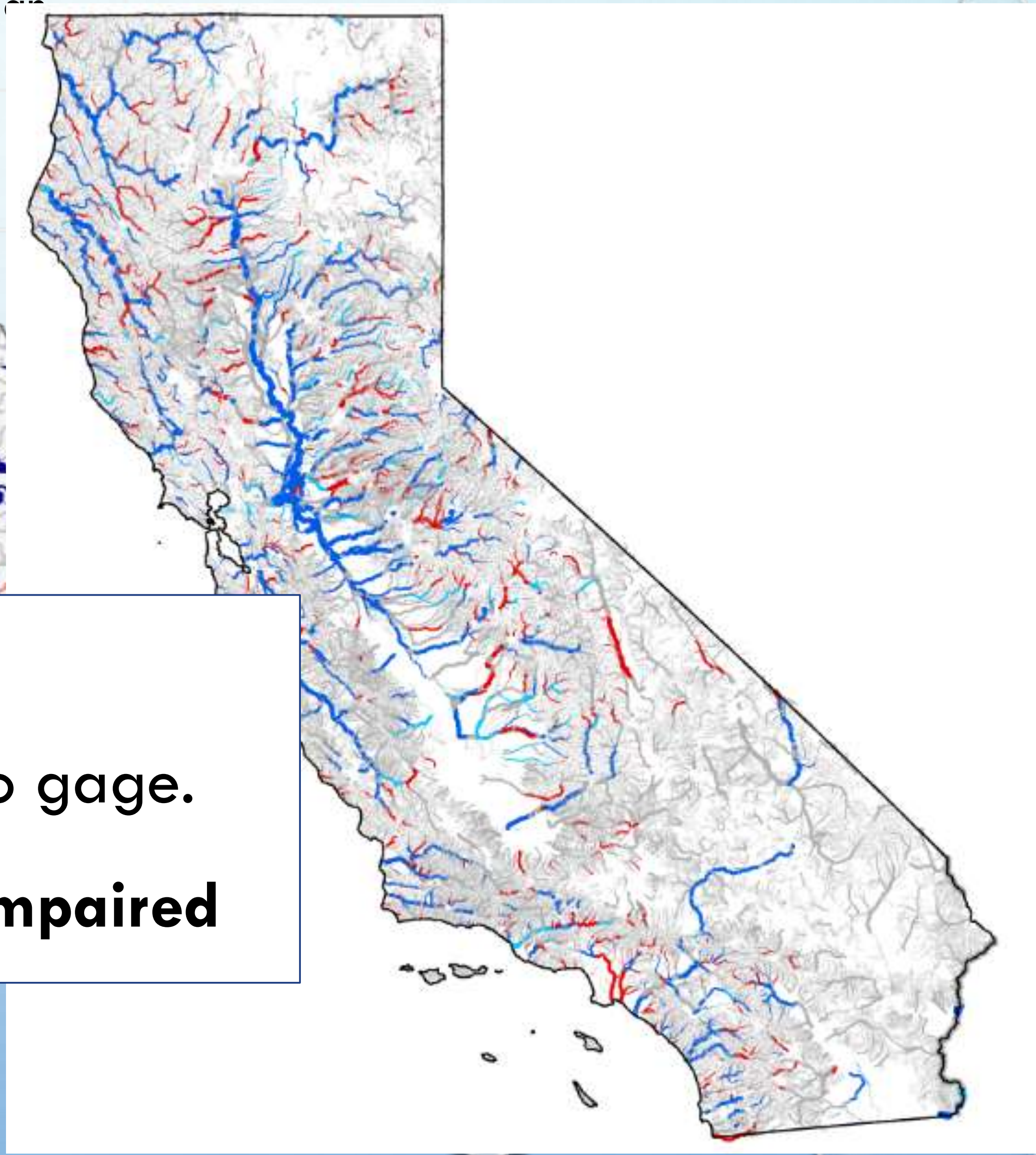


86% of HUC12 watersheds have no gage.

64% of the un-gaged watersheds have surface water diversions.

Gage Gap Results





Mainstem bias in stream gages

86% of HUC12 watersheds have no gage.

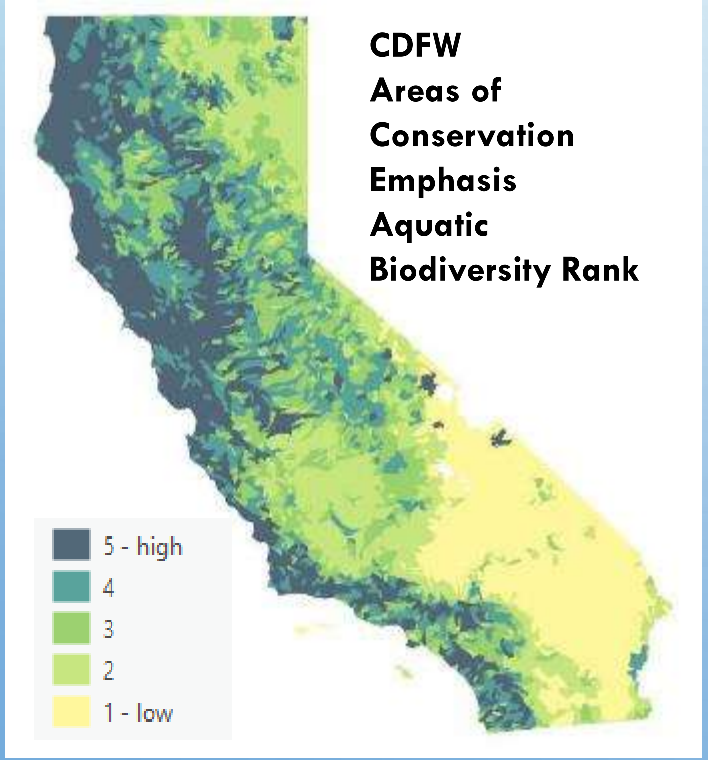
at least **75%** of active gages are **impaired**

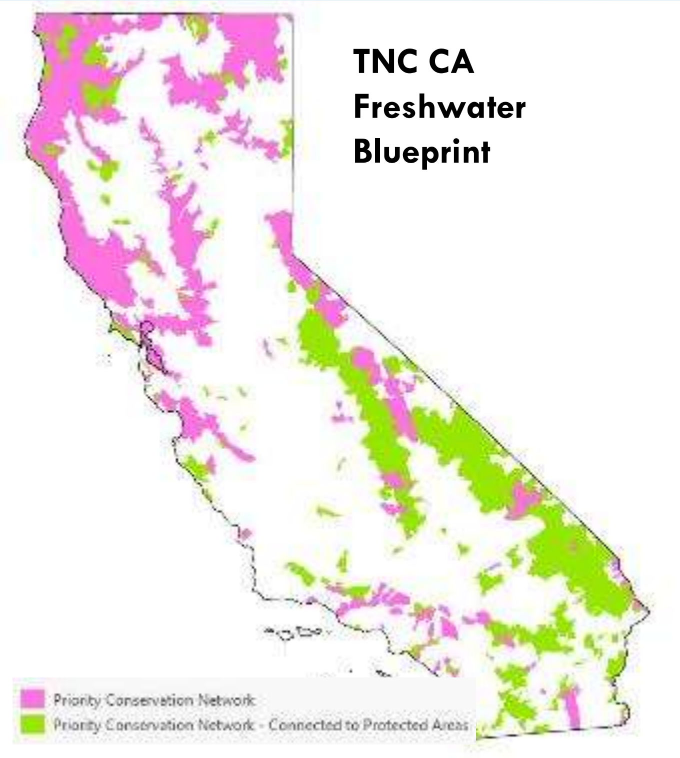
Ecosystem Management Criteria

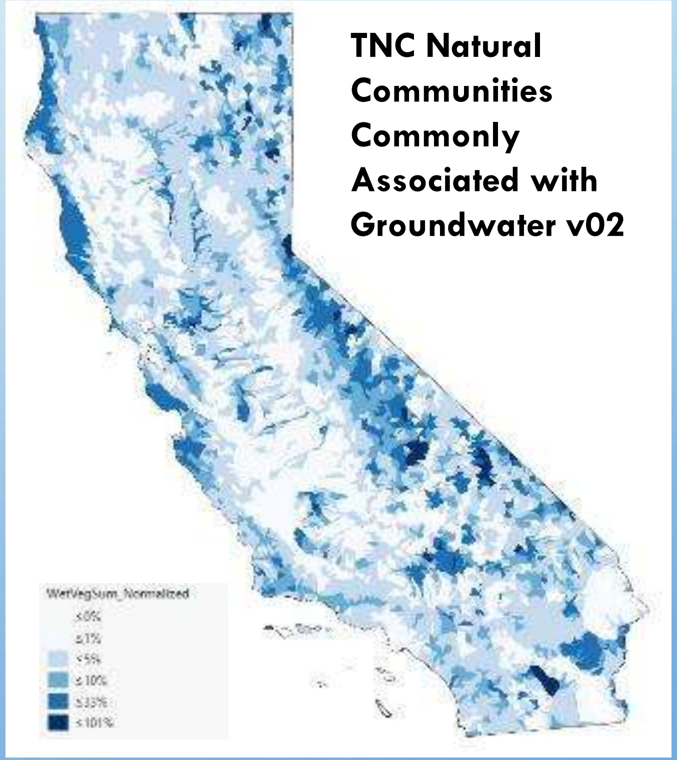
Aquatic Biodiversity: CDFW (2018-2020)

Priority Conservation Network: The Nature Conservancy (2018)

Groundwater Dependent Ecosystems: The Nature Conservancy (2021)

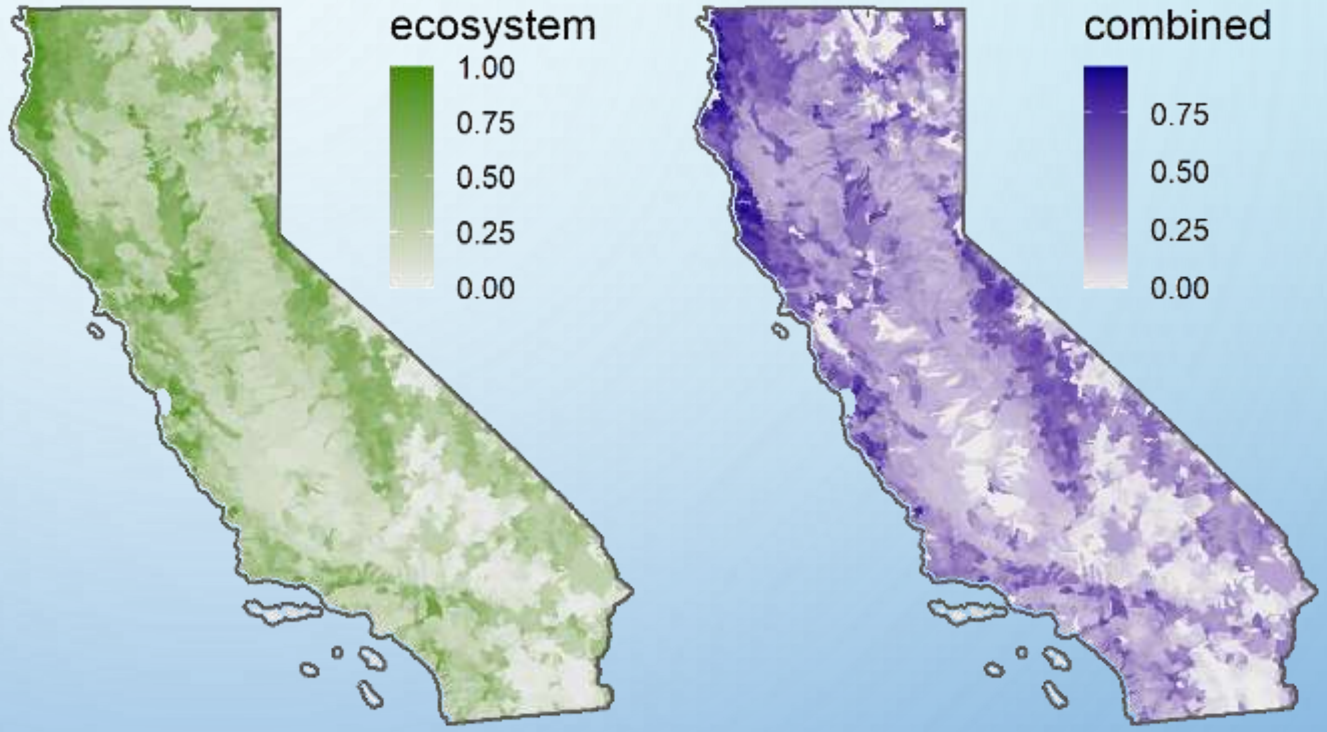






Combining Input Datasets

1. Choose
2. Generate score
3. Weight and add
4. Multiply by gage gap (proportion un-gaged)



$$\sum_{m=1}^{M} dataset\_score_m * weight_m = management\_criteria\_score$$

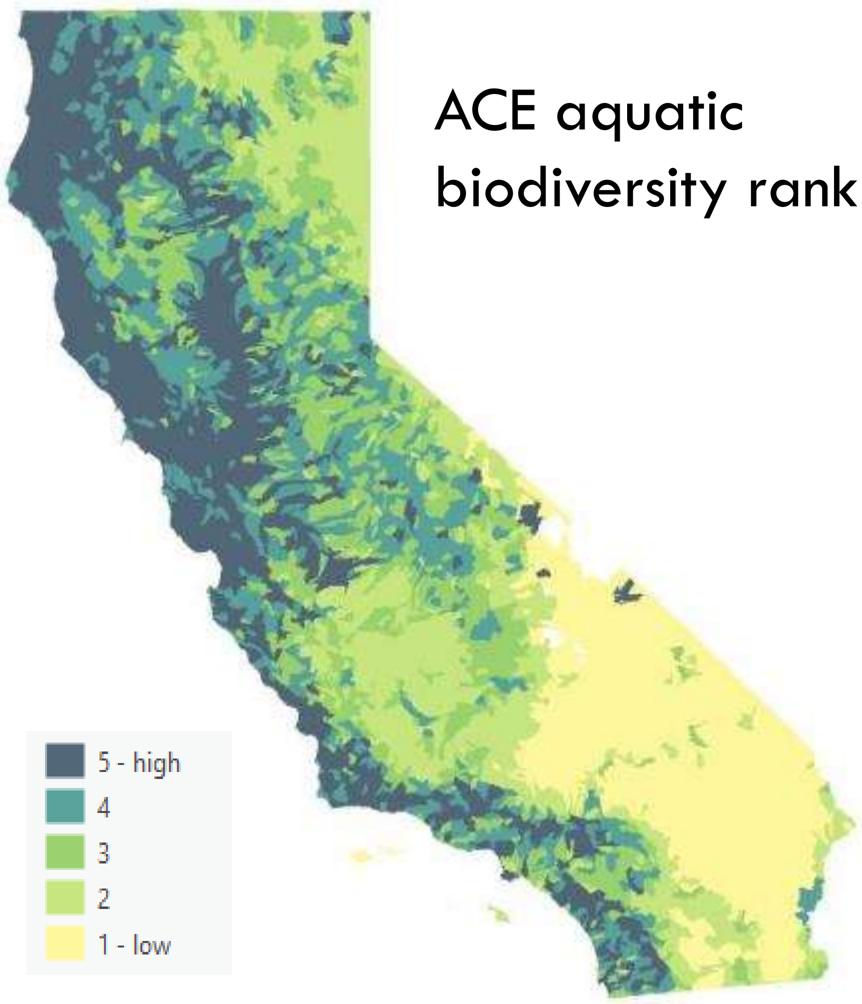
Prioritization Ranking – "Easy"

"Easy" = Datasets with clear priorities and spatial distribution

Even "easy' prioritization can be tricky

- Summarize and Normalizing data:
  - *Pin to stream segments?*
  - *Rank by total area in HUC12?*
  - *Divide by total area?*
- Example: Wetlands

ACE aquatic biodiversity rank

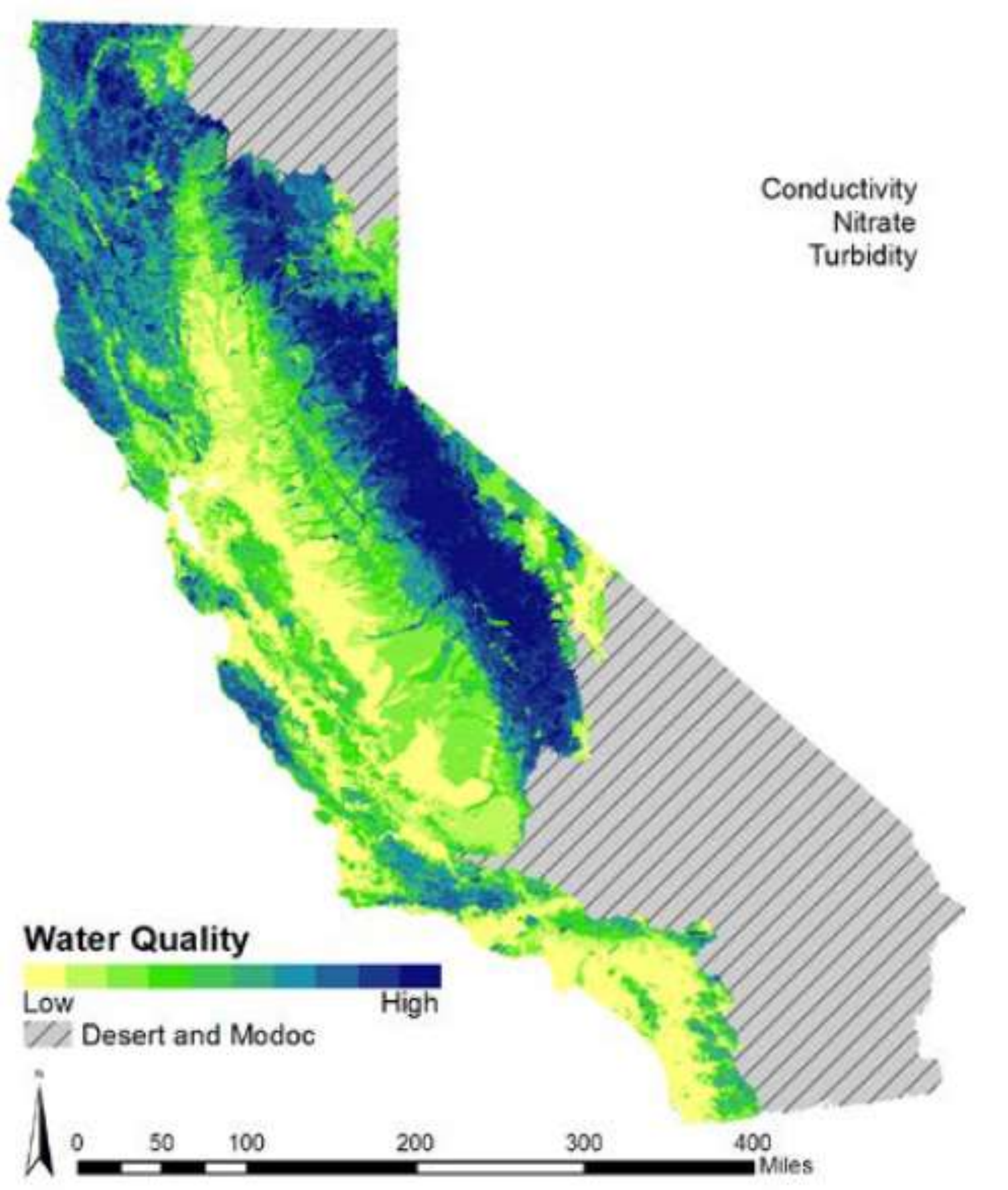


Prioritization Ranking - "Tricky" Water Quality

Where should we put a gage?

Do we prioritize the most impaired areas or the most pristine?

Which parameters to select?

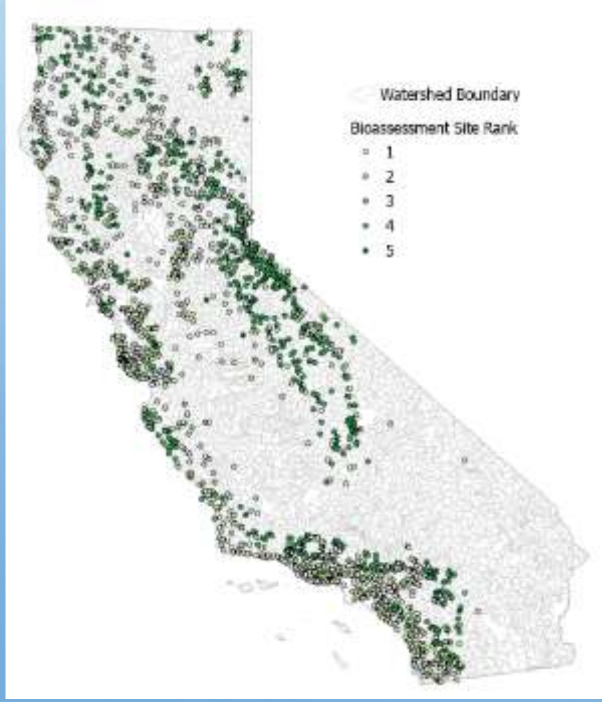


Water Quality Management Criteria

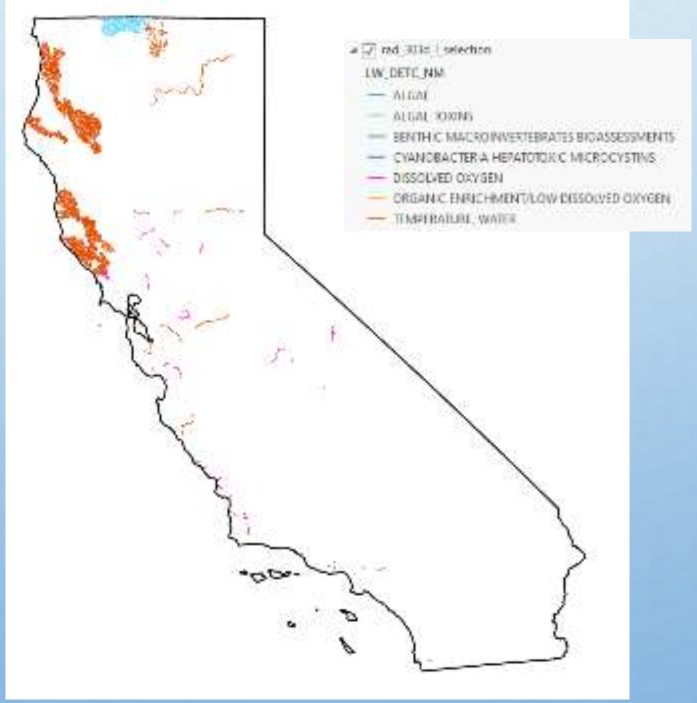
Water Quality Monitoring *locations:* as priorities for flow gaging

excluding issues that are not directly caused by streamflow (e.g. concentration and dilution are indirect)

Bioassessment Monitoring Sites



303d Listed Temperature and Dissolved Oxygen



Water Quality Monitoring

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Surface W

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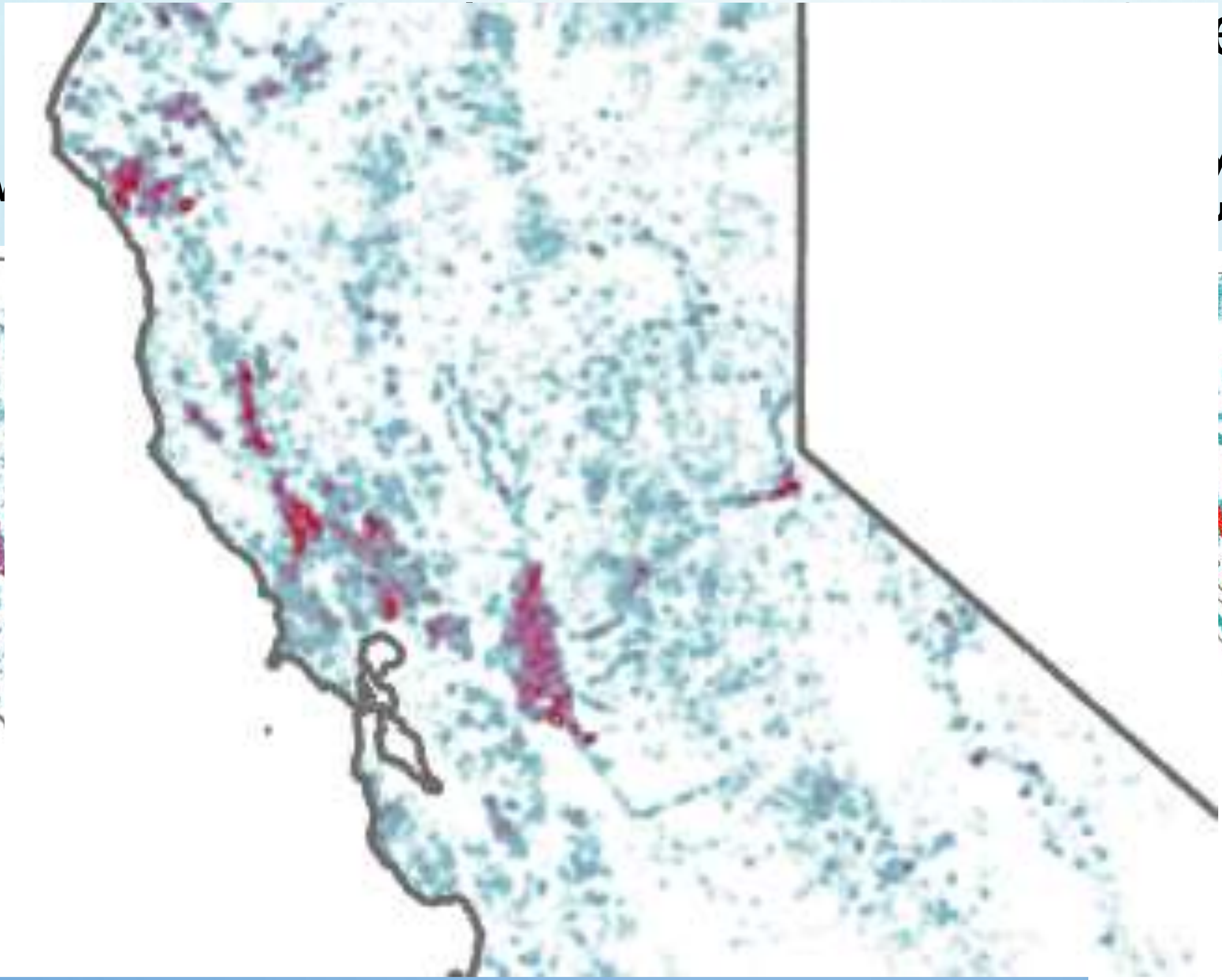
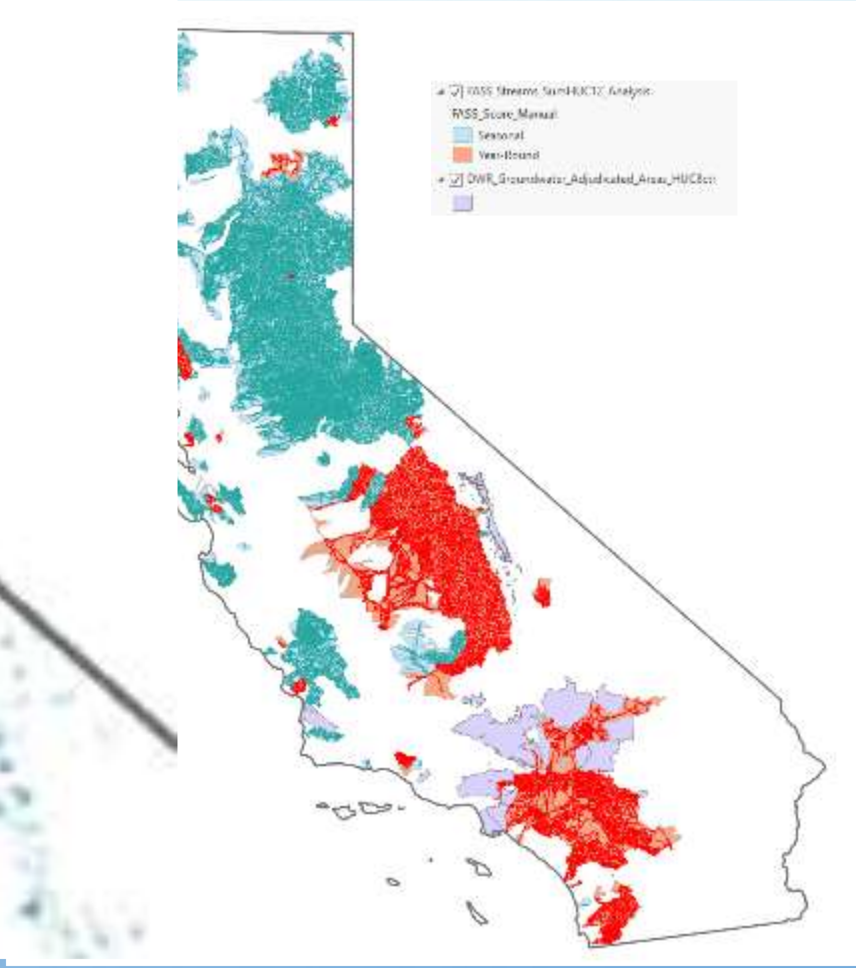
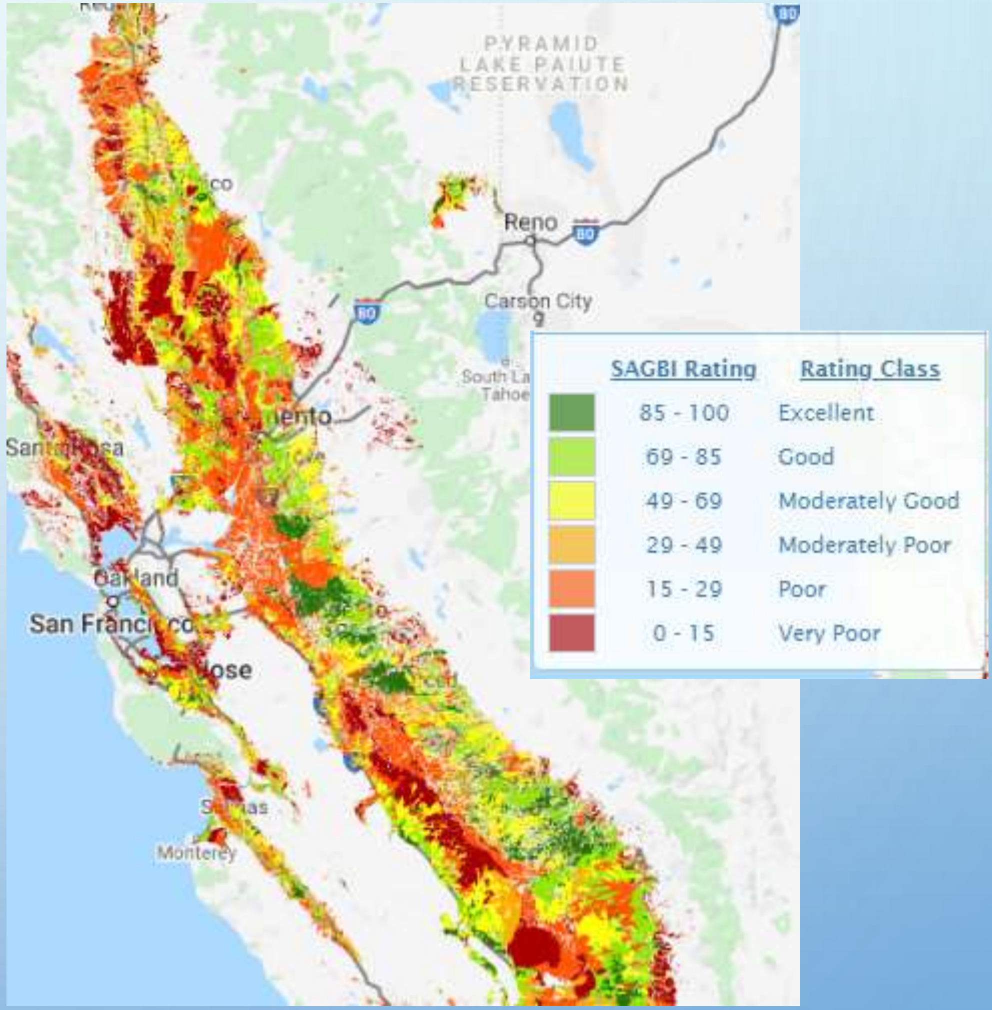




Prioritization Ranking – “Tricky”

Flood Managed Aquifer Recharge (FloodMAR)

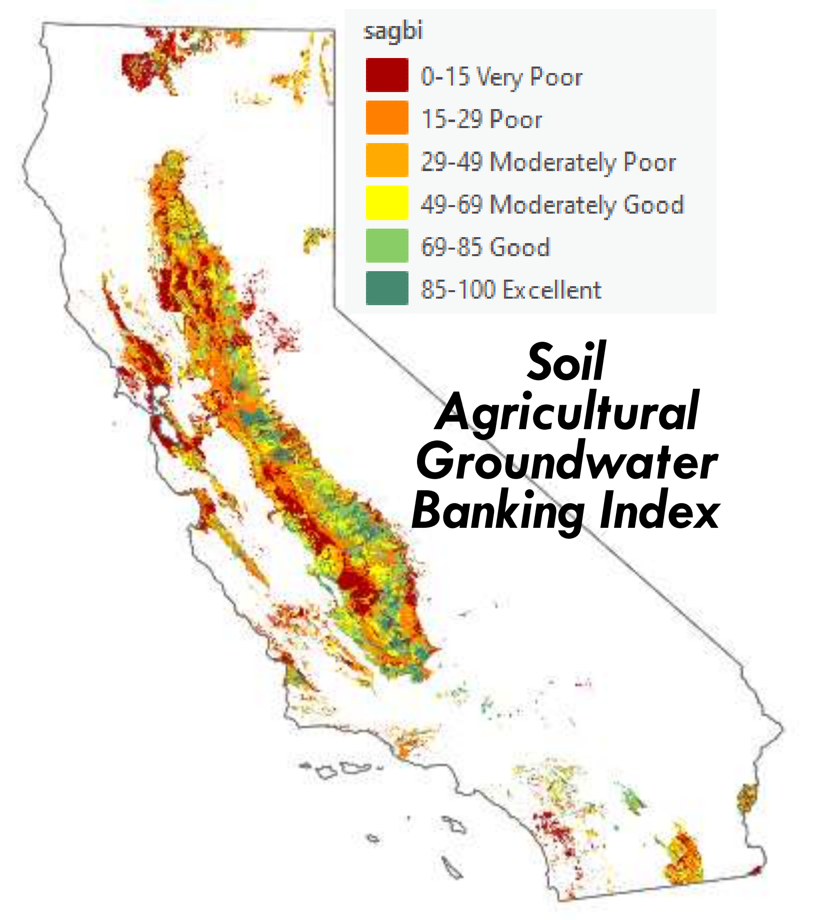
What if the best place for a gage is upstream of the data layer? Where, exactly?

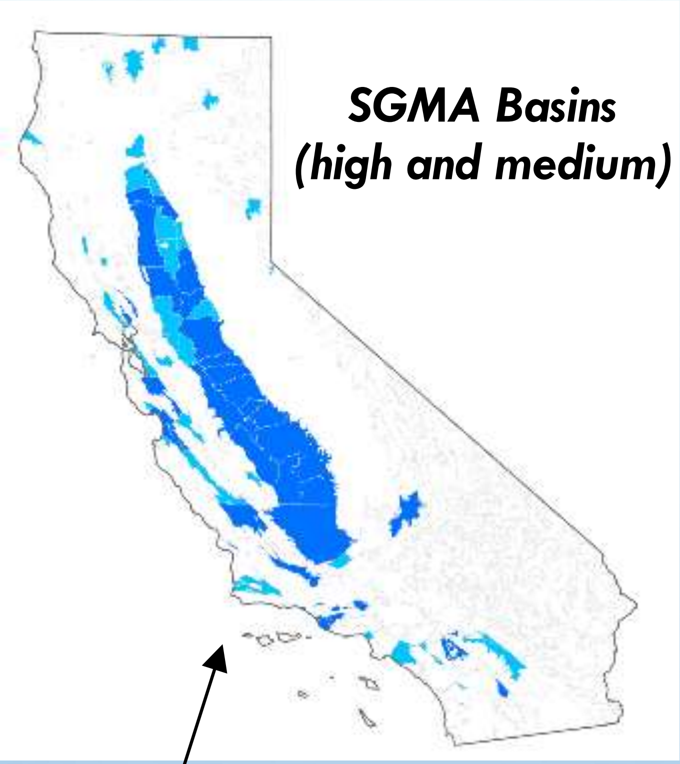


https://casoilresource.lawr.ucdavis.edu/sagbi/

Soil Agriculture Groundwater Banking Index

Water Supply Layers: Groundwater





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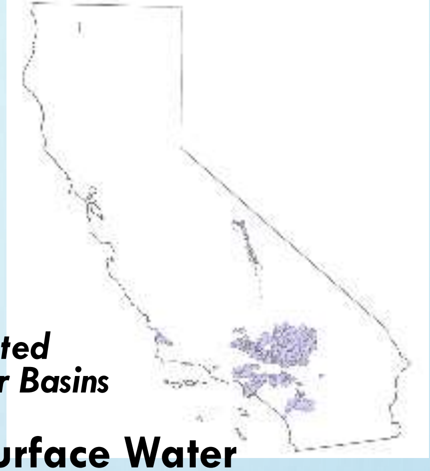
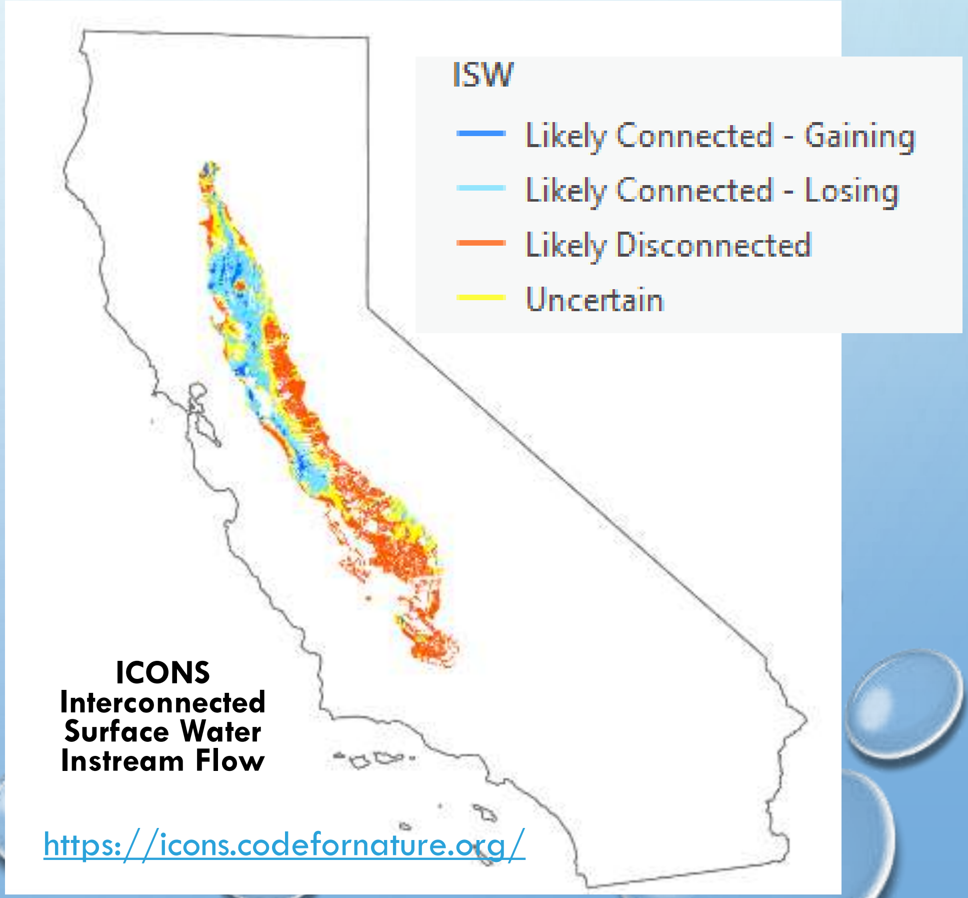


ICONS Interconnected Surface Water

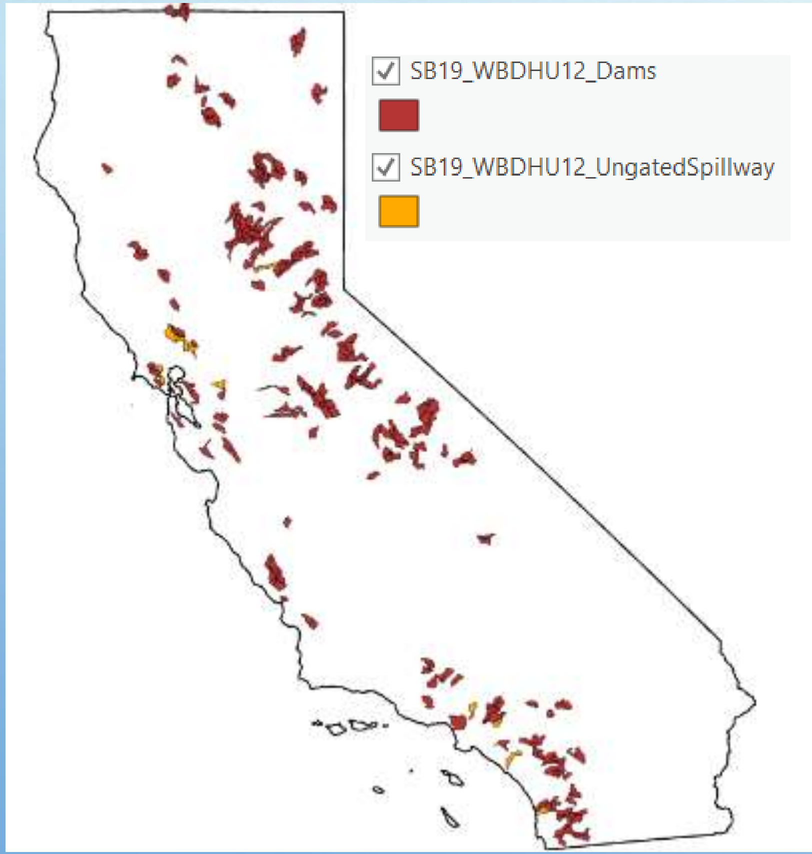


Groundwater

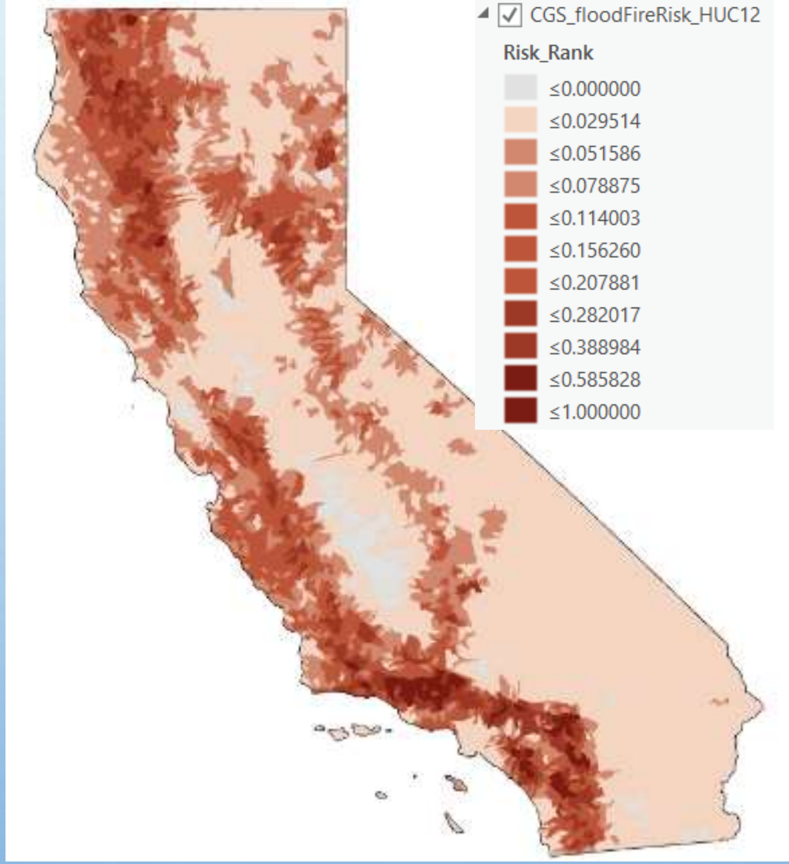
Only if a surface water gage is useful!

Flood (Public Safety) Management Criteria

Ungated Spillways,
Upstream Unmonitored Dams



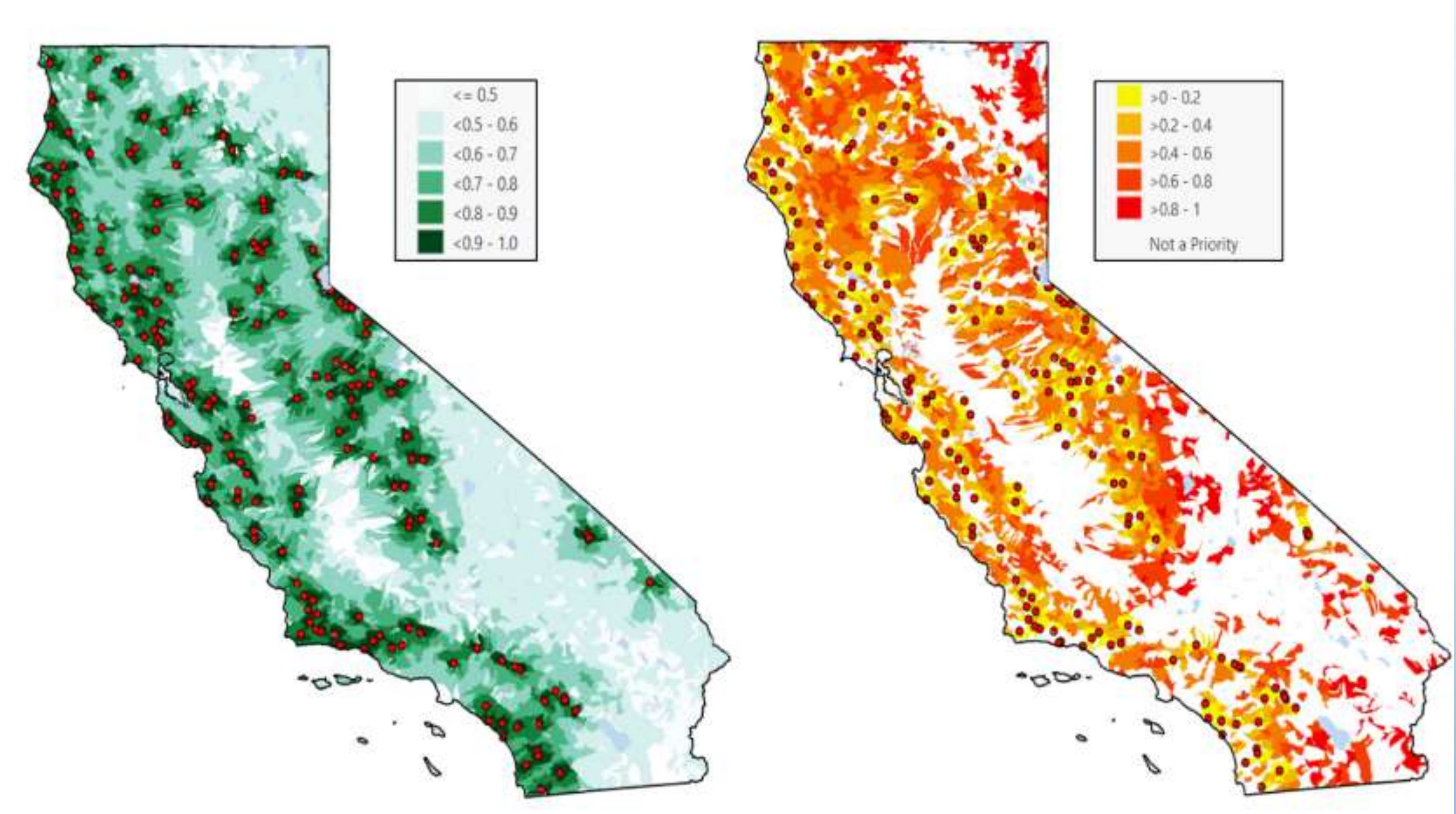
CGS Fire and Landslide
Sedimentation Risk



upstream of FIRO projects

Lake Oroville
(Feather)
New Bullards Bar
(Yuba)

Reference Gages (180) – Gage Pairing



Gage Pairing Factors

1. Distance (50%)
2. Hydrology (20%)
3. Flow Direction (20%)
4. Drainage Area (10%)

Watershed Reference Potential

requires at least one stream segment that:

- 25 km^2 drainage area
- < 15% drainage above dams (e.g. relatively unimpaired by diversions
- Classified as a stream or river (not artificial)

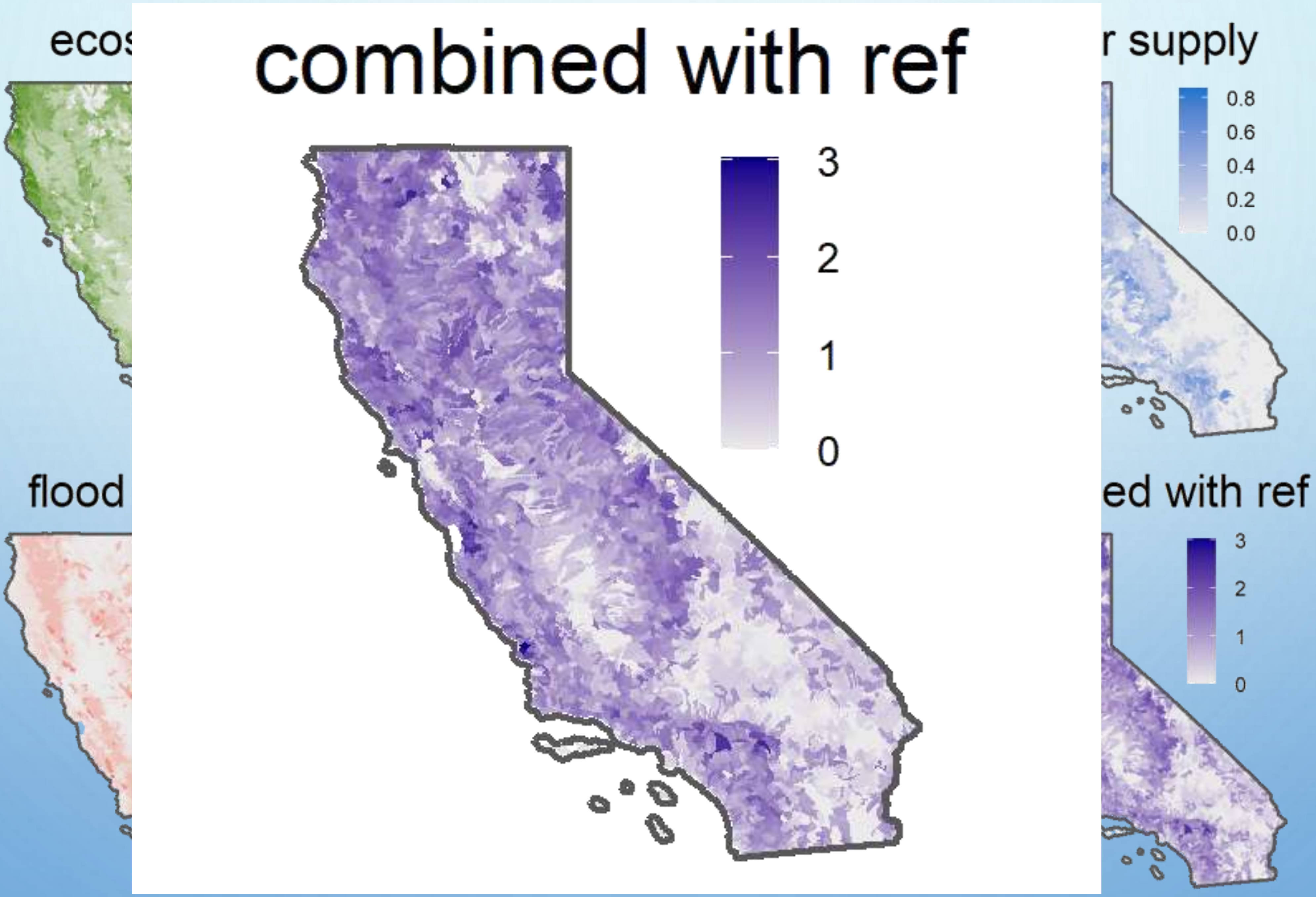
Reference Gages Overview

Definition: Reference-quality gages have low anthropogenic impairment and are used to estimate the natural flow in nearby stream systems.

- Reference gage watersheds must be **relatively unimpaired.**
- Reference gages need to be **well-distributed spatially and cover the full range of hydrologic, climate, and local weather conditions.**

Reference gages support water supply and flood modeling, county planning, forecasting, ecosystem assessment, etc.

US EPA (201
Health,
https://mywo
ds/assessmen


combined with ref
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flood
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2
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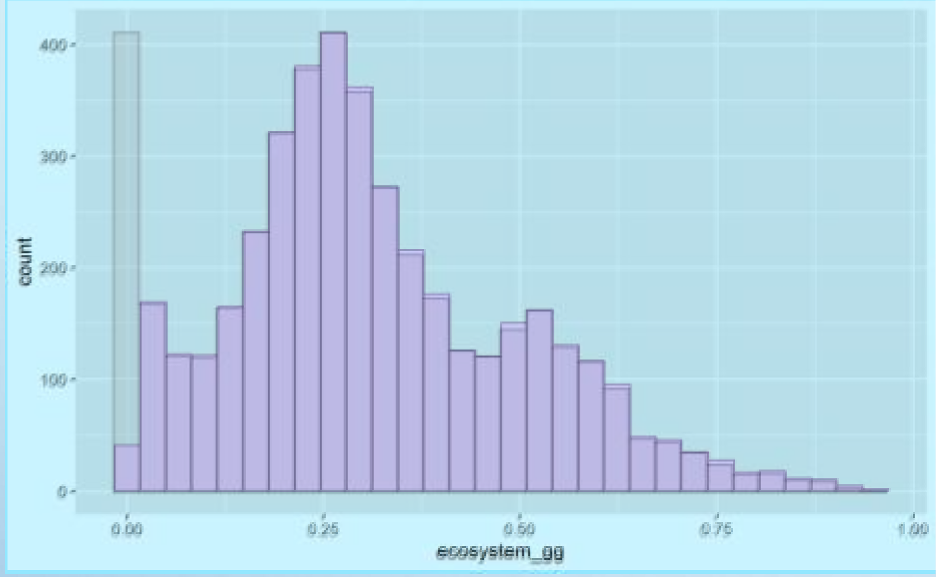
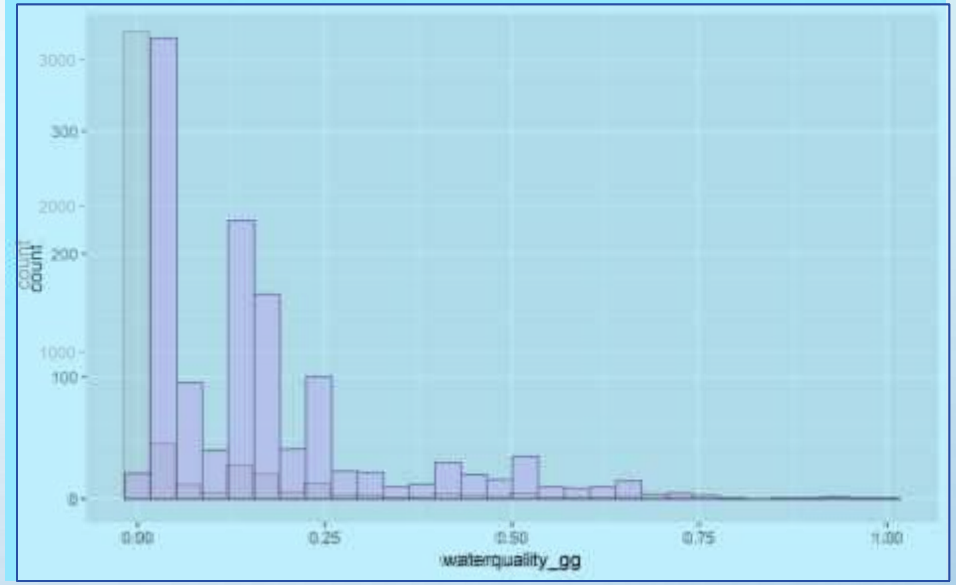
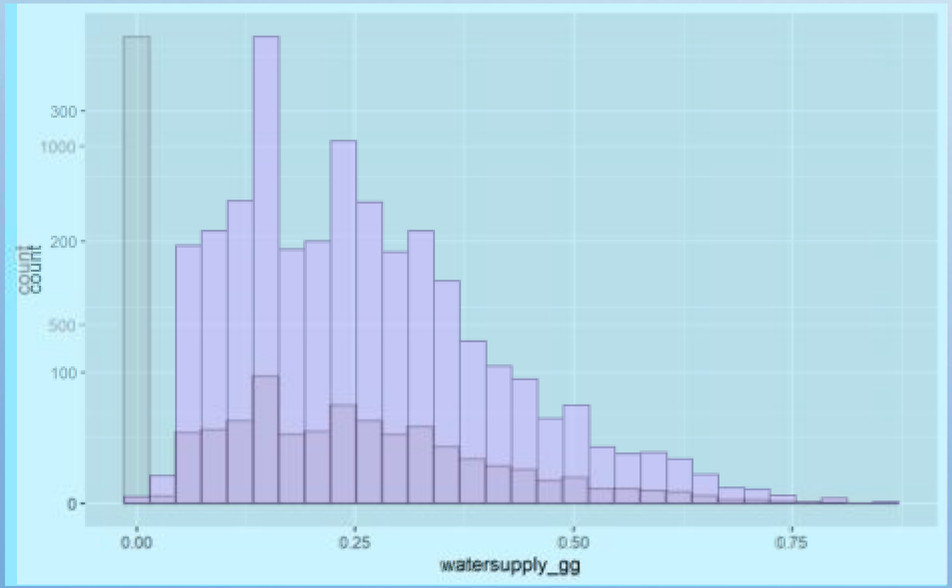
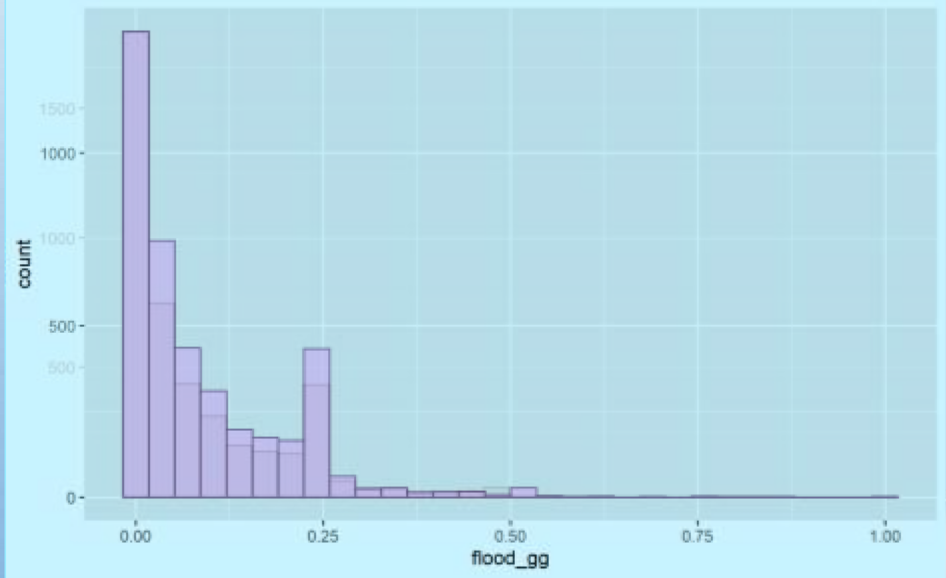
0

Data Combination Challenges (Data Shape)



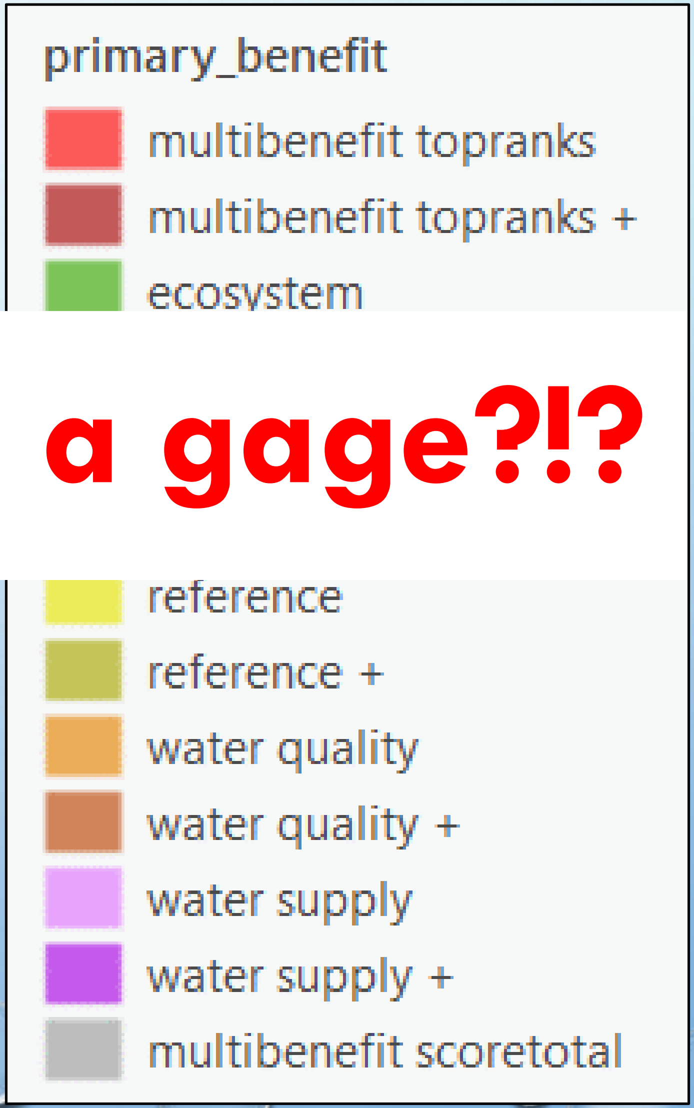




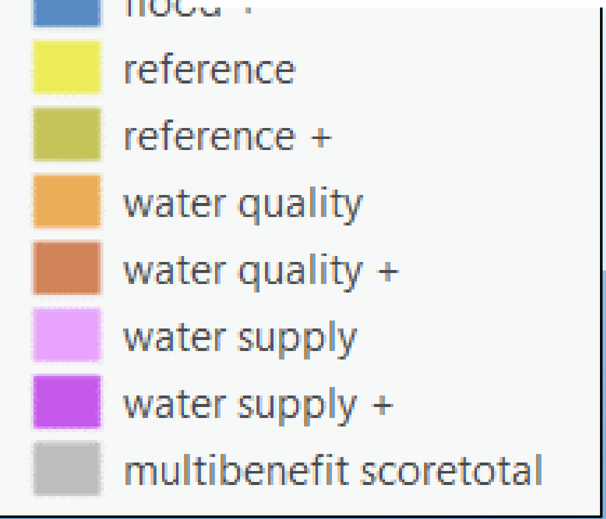


Priority Watershed Results
Top 200 in each category

Is my watershed getting a gage?!?



This analysis does not include every consideration and does not supercede local knowledge!



Priority Watershed Results – Central California

Data Management Issues and Objectives

Stream gage data in California are collected by dozens of different entities for various purposes

- variable quality
- no standardized quality control and quality assurance processes
- no standardized data formats or metadata
- not accessible on a public database
- **small project/limited resources data is very useful and should be supported and shared**

Results – Top 200 by Management Category

Tier	Tier Category	HUC12 Watersheds	Reactivation Gages	Upgrade Gages	New Gages
1	High - MultiBenefit	73	17	1	56
	High – Single Benefit	413	67	10	346
	CNRFC and FIRO	30	*NA*	*NA*	30
2	Medium	435	49	9	386
3	Gages only - High	*NA*	28	28	*NA*
	Recommended	**516**	**161**	**48**	**432**
	Total Count	4469	901	203	4469

Summary

84% of CA watersheds are un-gaged.

Gages that exist tend to be on mainstems and impaired.

1000 gages in operation, 1200-2000+ gages have been deactivated

Datasets are complicated – select, summarize, and combine

Data doesn't always point to necessary gage site

Small project gage data should be supported

WRAP UP

- **DRAFT DOCUMENT RELEASED NEXT WEEK**
- **Website – google “stream gaging sb19”**
- **GIS visualization**
- **Questions?**

StreamGagingPlan@waterboards.ca.gov

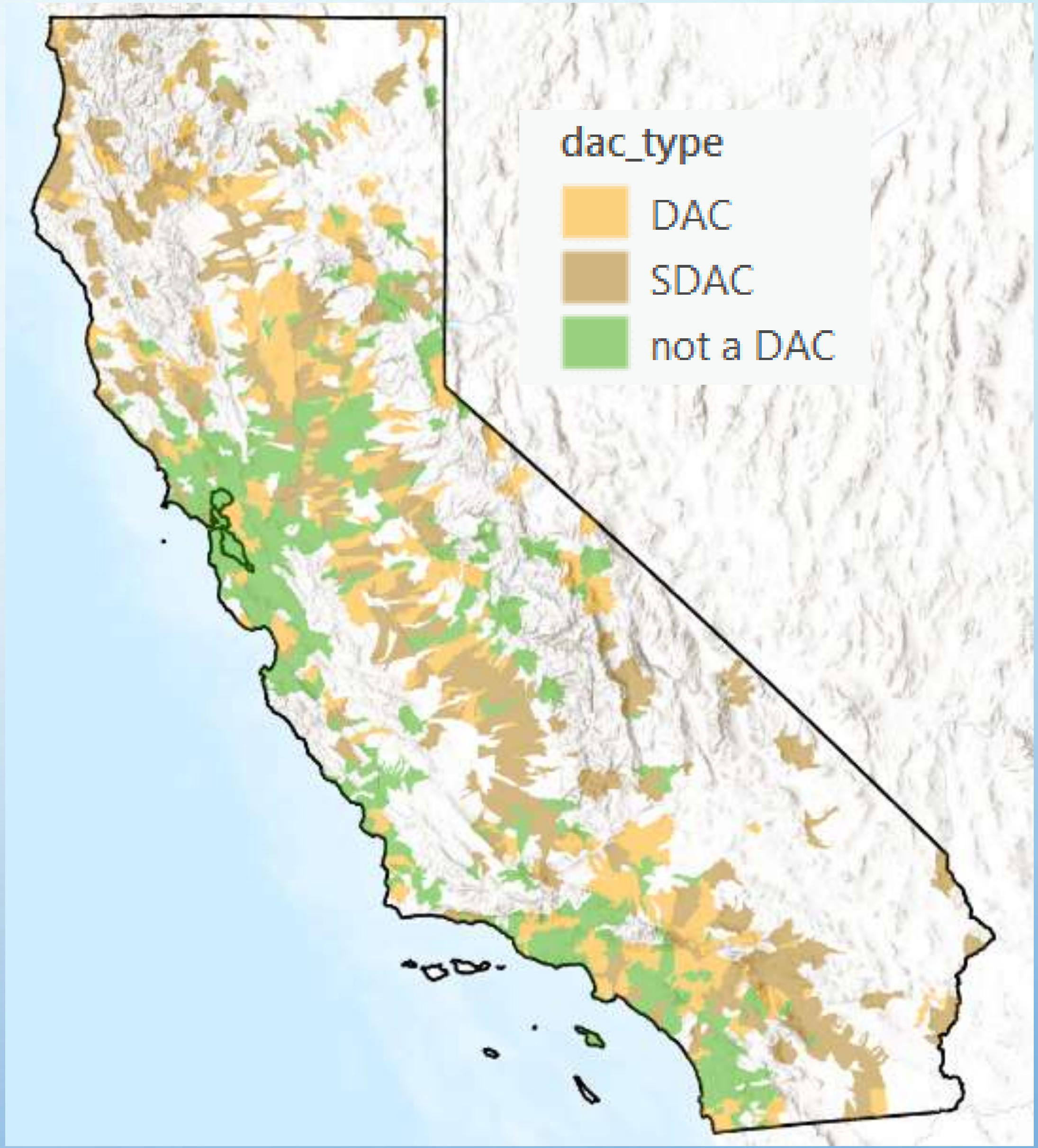
Underrepresented Communities

Community Present	Priority HUC12	All HUC12
Severely Disadvantaged	149	621
Disadvantaged	141	463
Community with No Data	1	1
Community not a DAC	177	612
No Census Communities	453	2,772
Total DAC	290	1,084
Total HUC12	921	4,469
Percent DAC	**31%**	**24%**

DAC (disadvantaged community)

< 80% median income is a DAC

< 60% median income is severe (SDAC)



DAC Mapping Tool   Designed to assist with responsibilities related to IRWM, SGMA, and the CA Water Plan

https://gis.water.ca.gov/app/dacs/

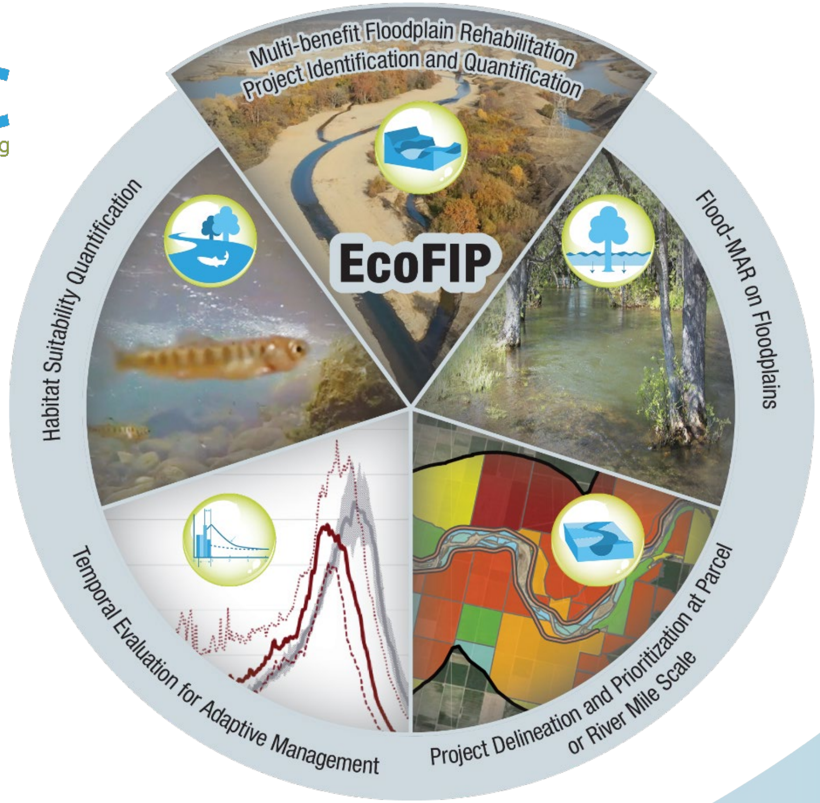
EcoFIP:

An Enhanced Method for Evaluating Large-scale, multi-objective Floodplain Restoration Opportunities

Luke Tillmann, Michael Founds, Chris Bowles, Caitlin Barnes
cbec eco engineering

Jeremy Thomas, Tapash Das
Jacobs

Lori Clamurro-Chew, David Martasian, Jenny Marr
California Department of Water Resources



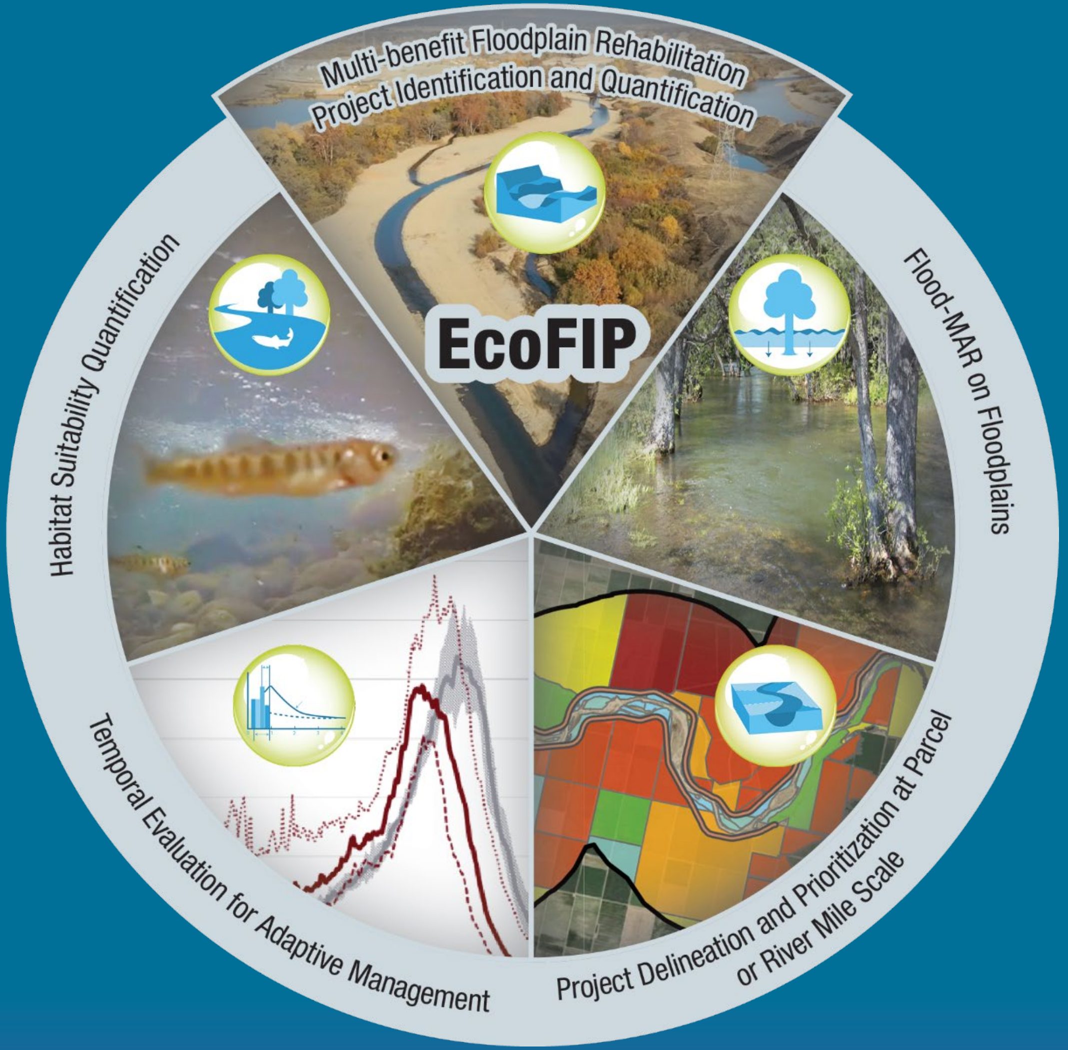
Pilot Study Motivation

Need systematic approach to evaluate multi-benefit floodplain projects at the landscape scale:

- Salmonid Habitat Suitability
- Managed Aquifer Recharge (MAR)
- *(Flood risk reduction)*

Ability to consider:

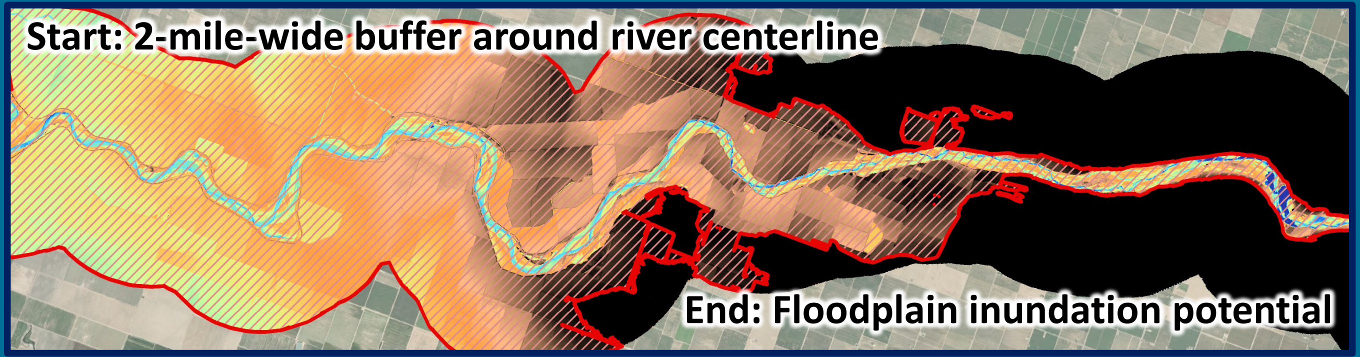
- Climate Resilience
- Future management scenarios

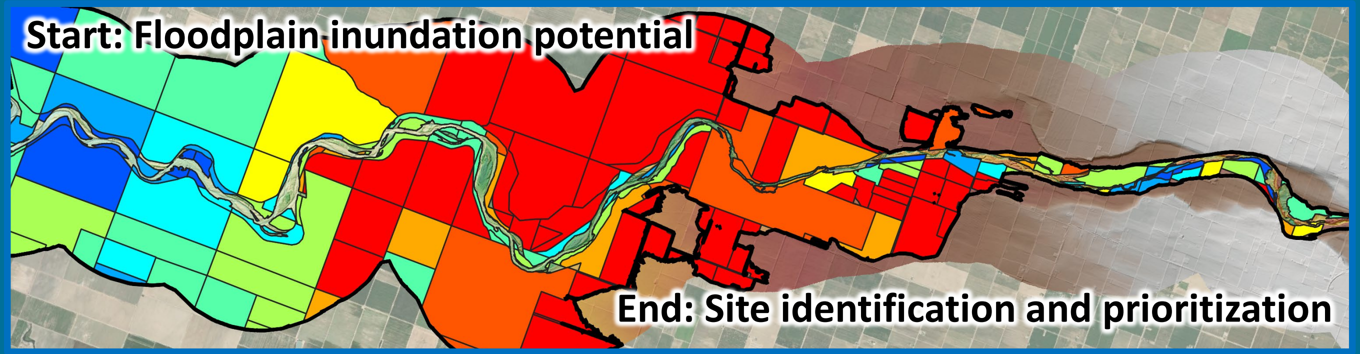


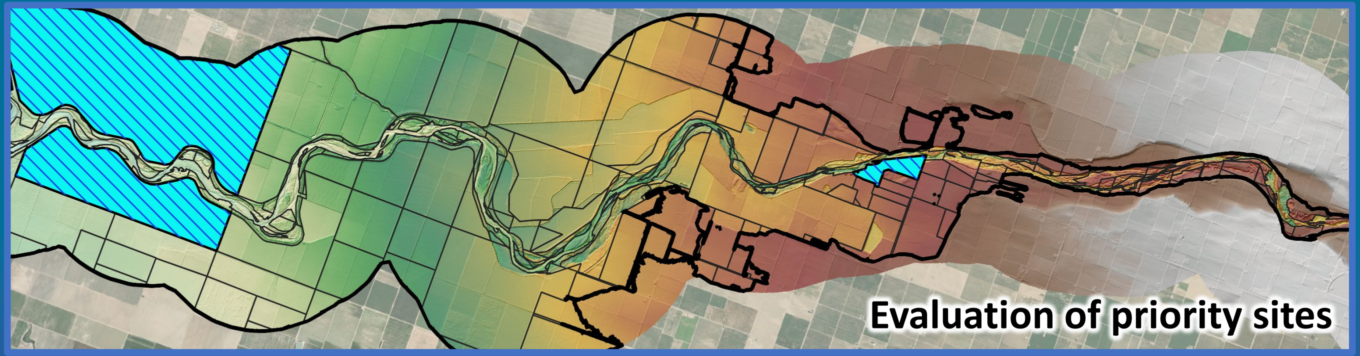
EcoFIP Method

Analysis Dimensions

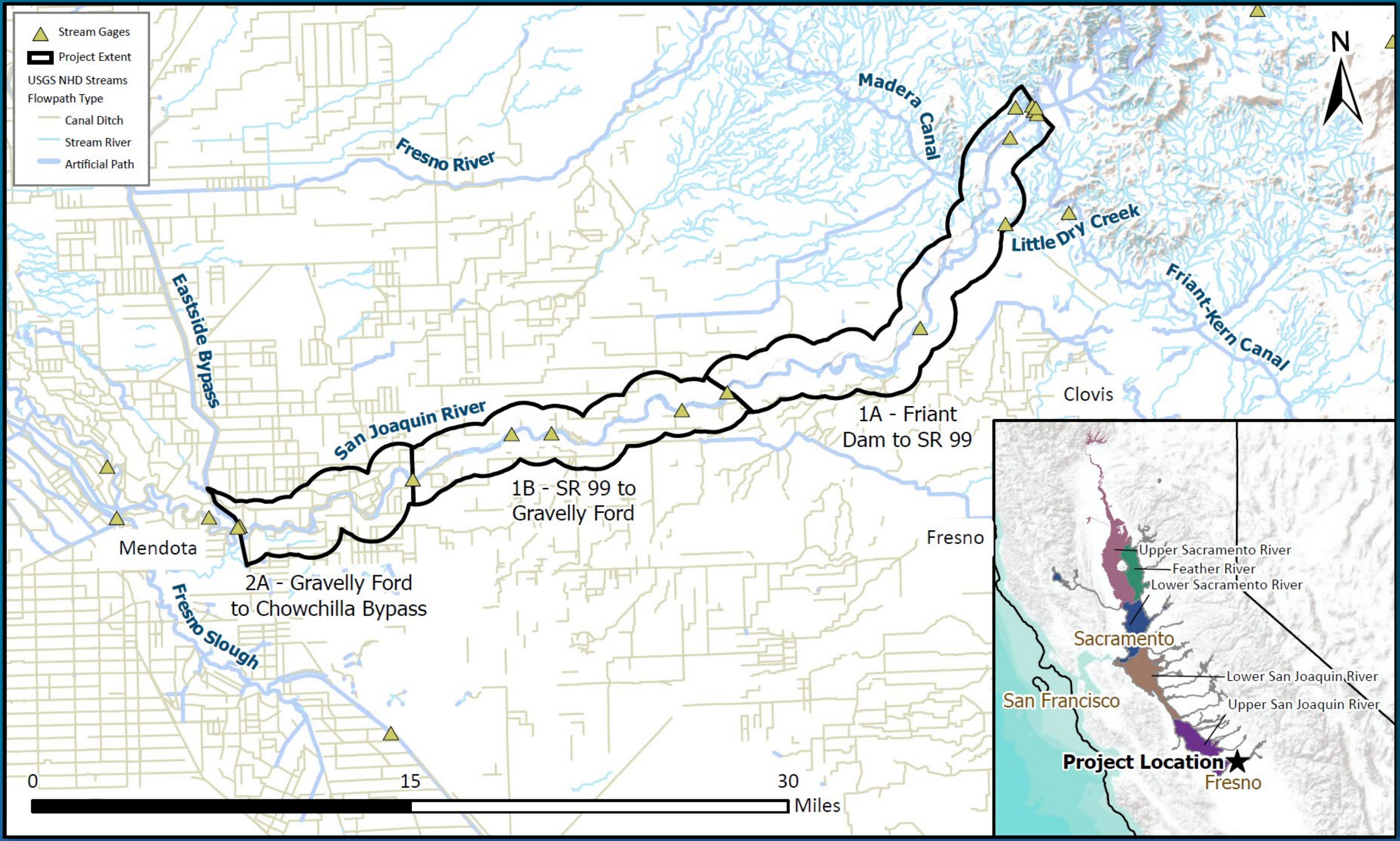
Tier	Temporal	Spatial
Tier 1: *Large-scale inundation potential*	*Individual flows*	*River reach*
Tier 2: *Multi-objective Site Identification and Prioritization*	*WY-based accumulated stats (simplified)*	*Boundaries (parcels, river miles)*
Tier 3: *Site Evaluation*	*WY-based accumulated stats (advanced)*	*Pixel / site*



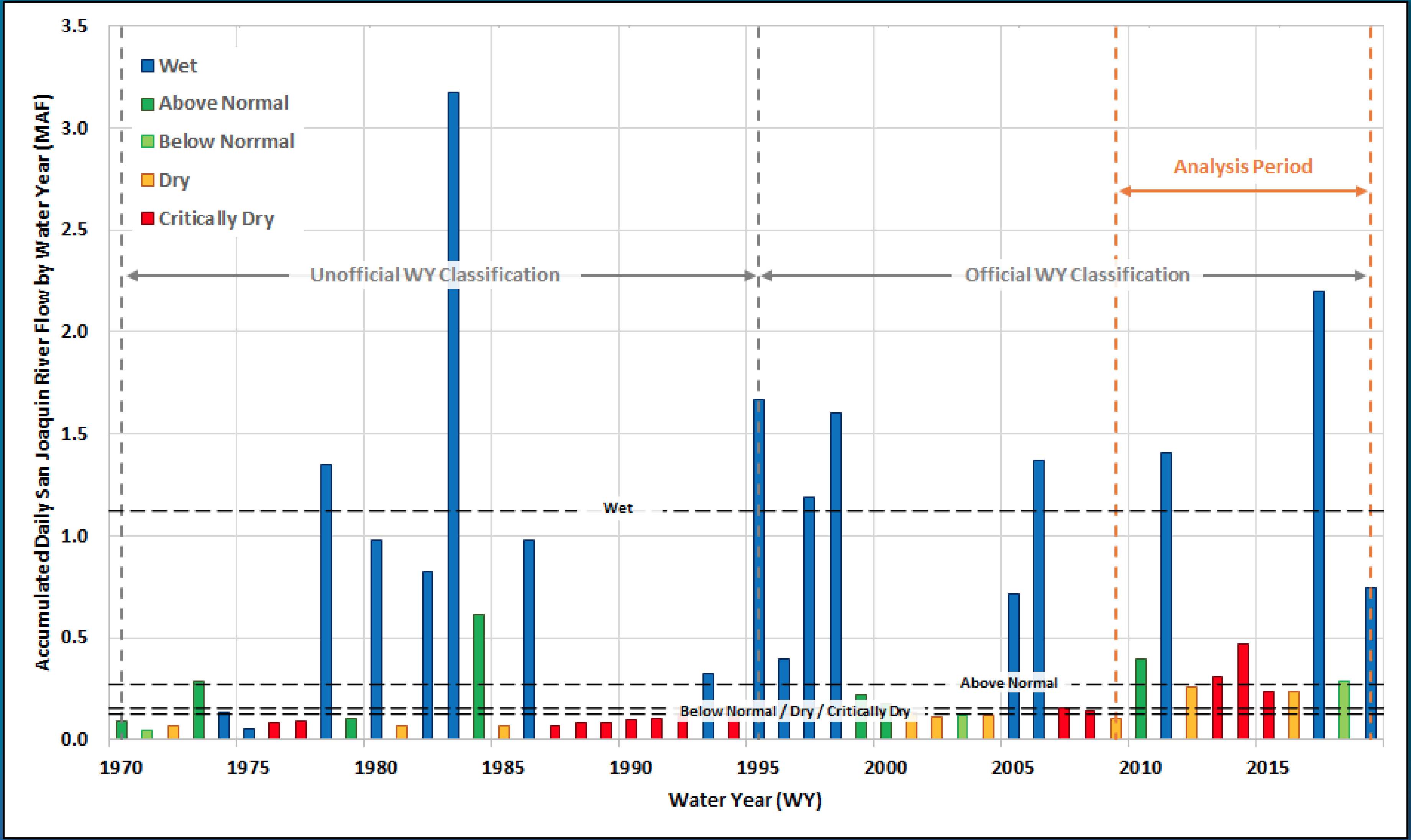




Pilot Study Reach

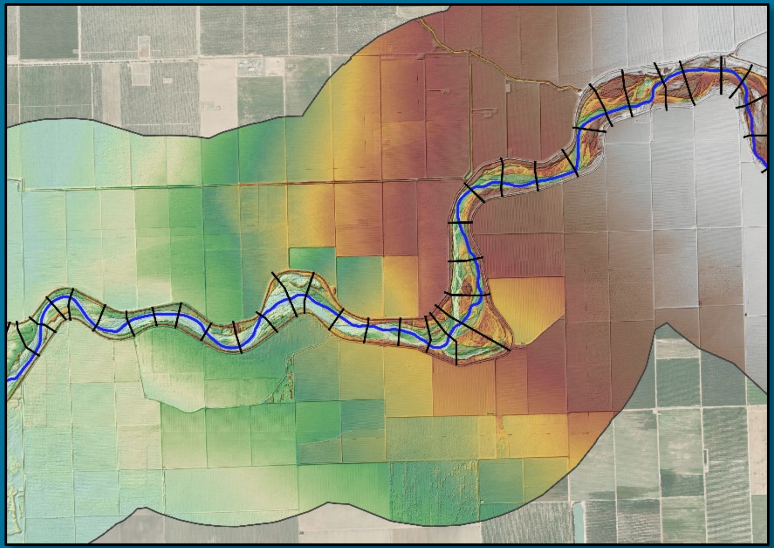


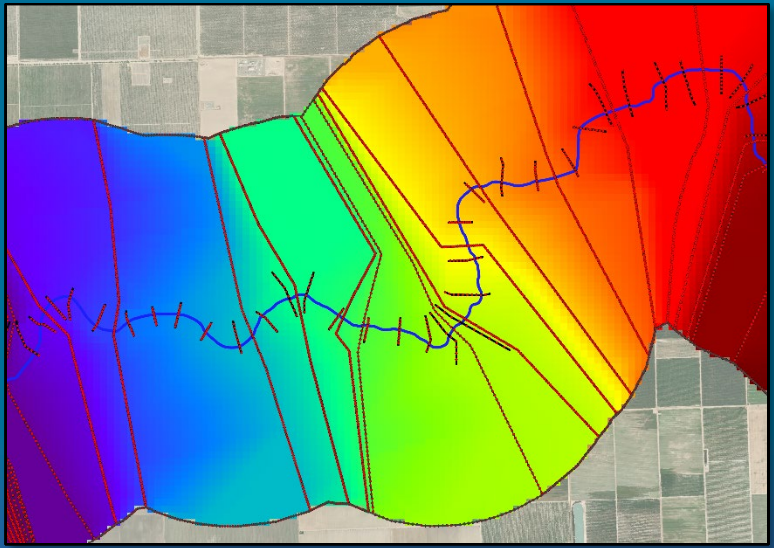
Hydrologic Period of Interest



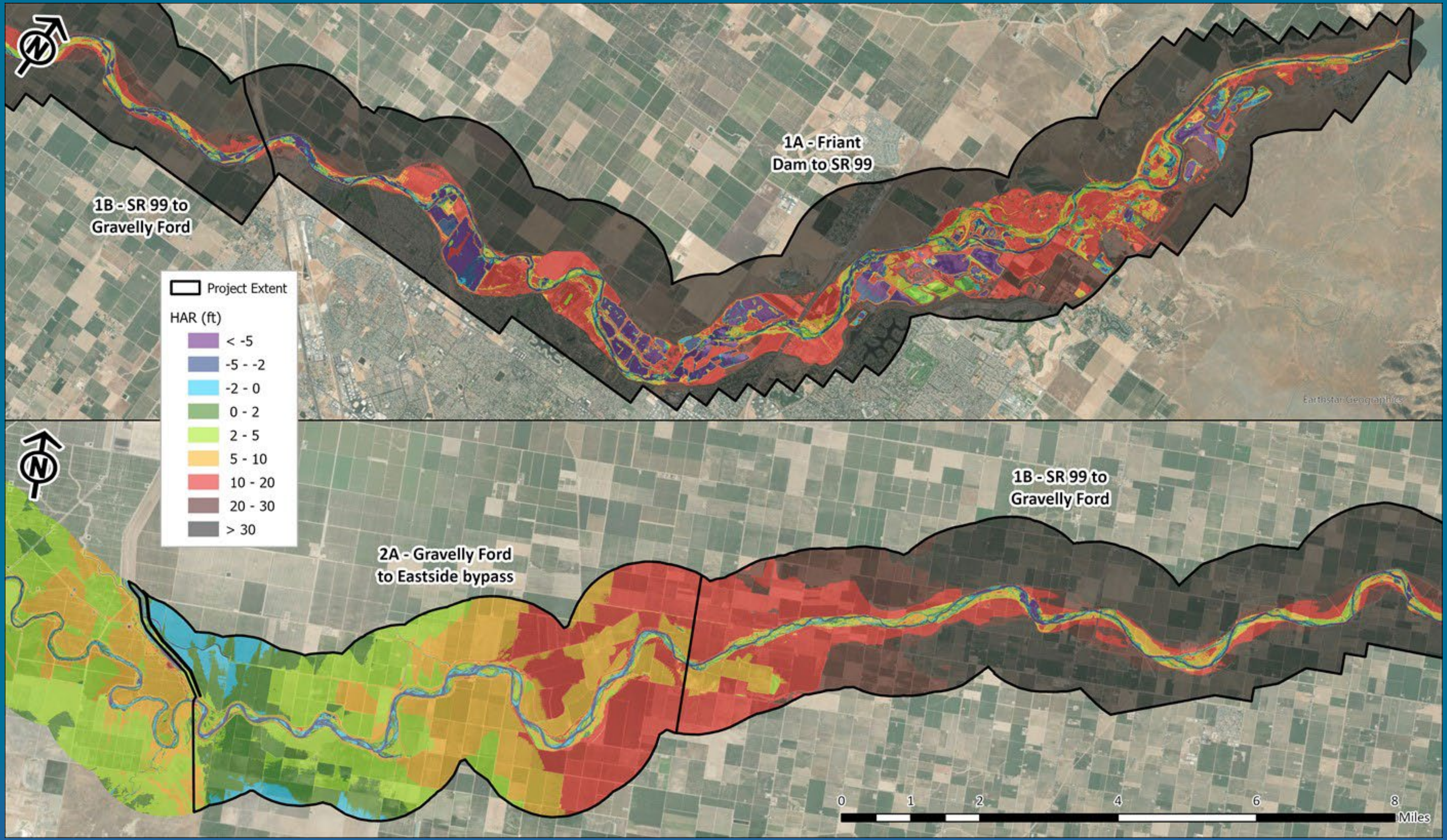
cbec eco engineering | Jacobs

Tier 1: Large-scale Inundation Potential

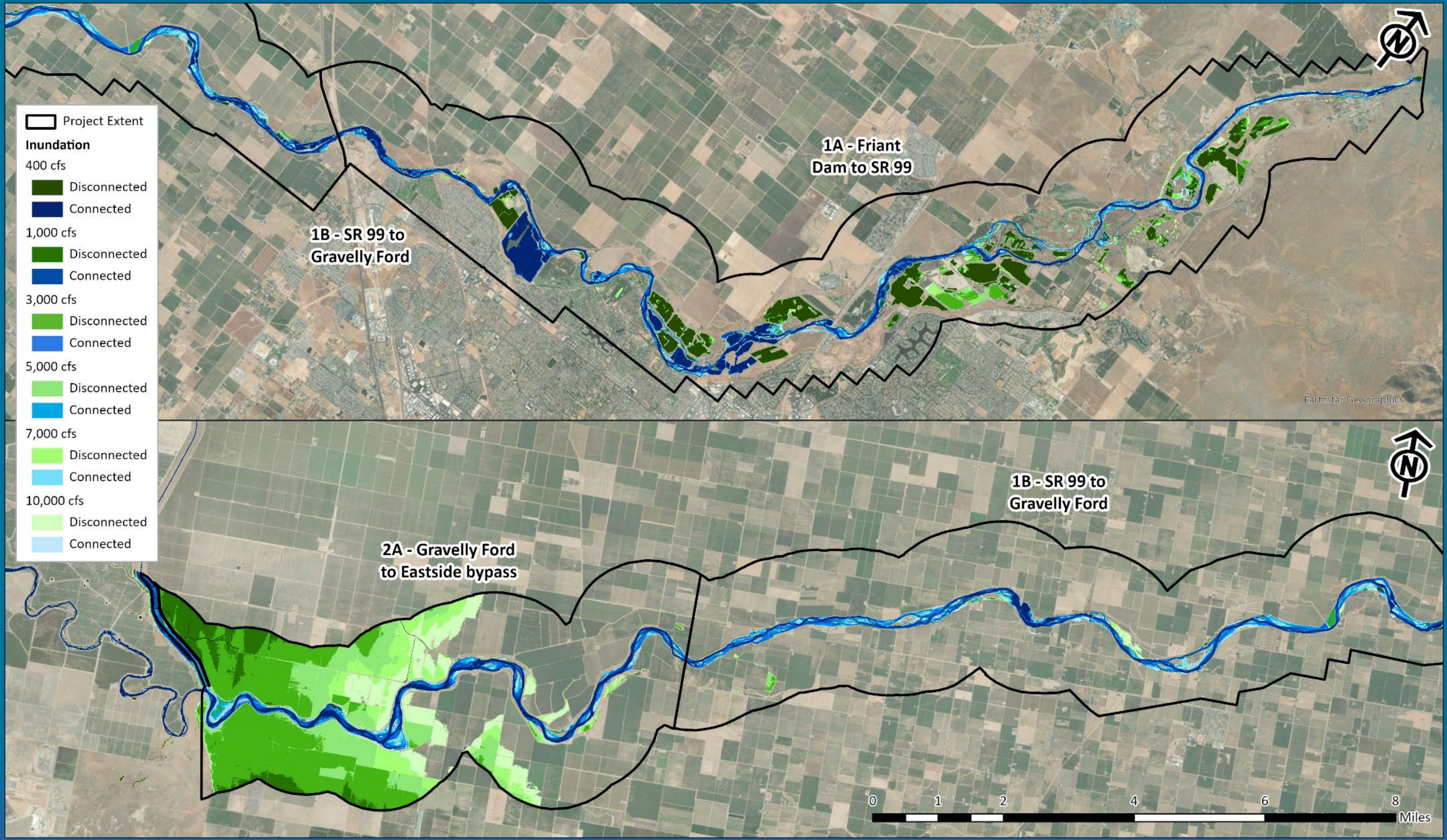




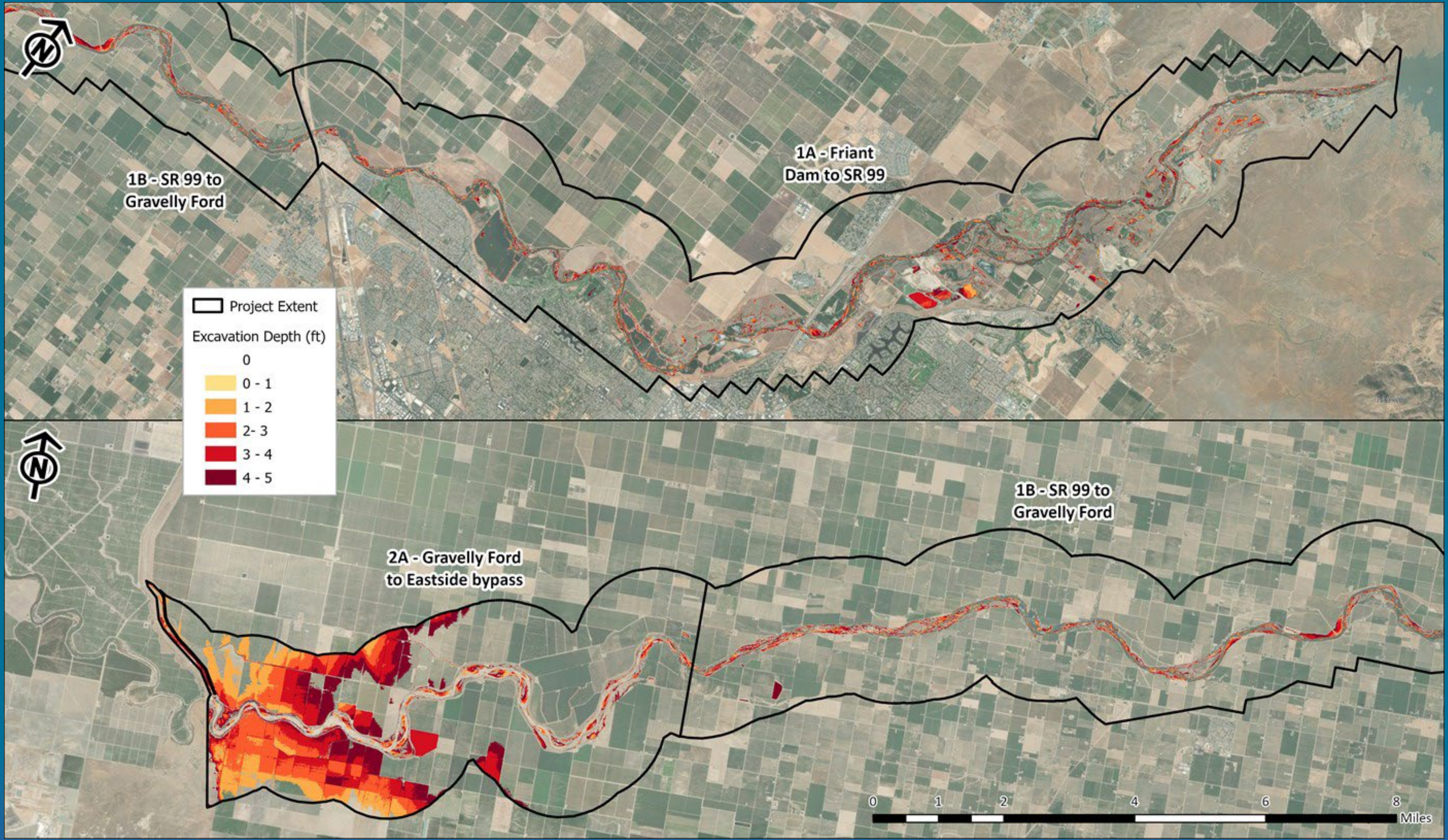
Tier 1: Height Above River (HAR)



Tier 1: Floodplain Inundation

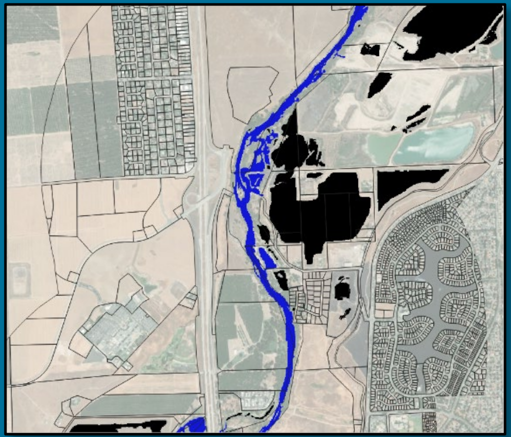


Tier 1: Grading potential

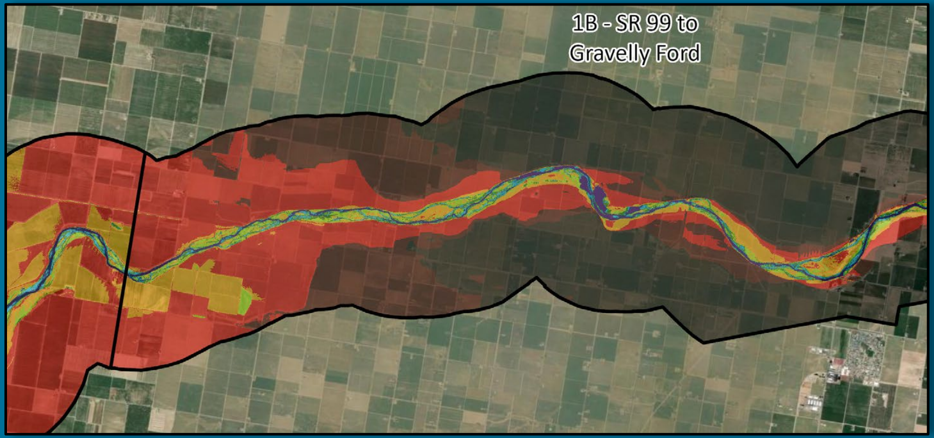


Tier 2: Multi-objective Site Identification and Prioritization

Areas of connected baseflow removed



Areas of high ground removed

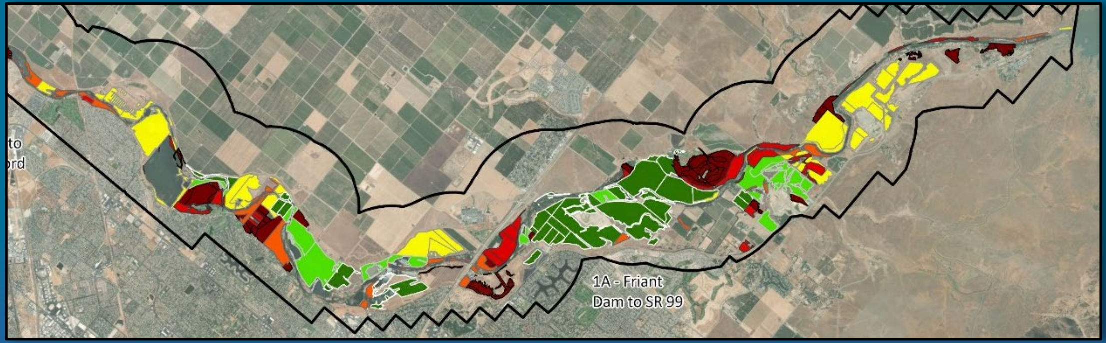


Small areas removed

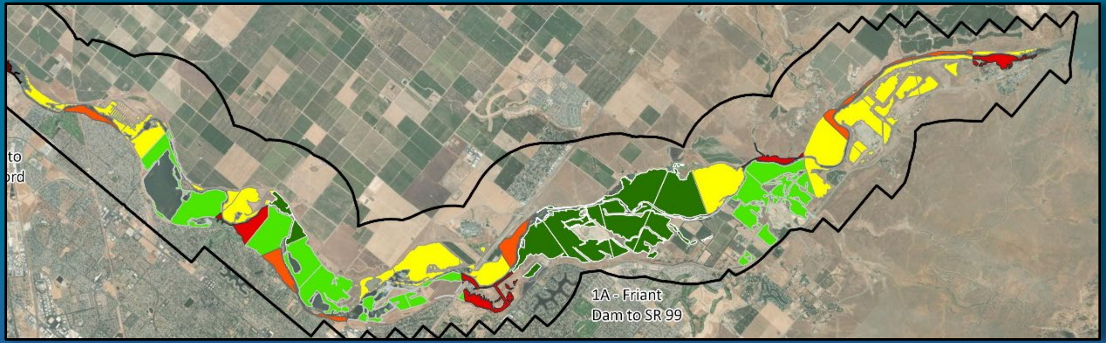
* from Tier 1

Floodplain Analysis Units

Parcel scale



River mile scale

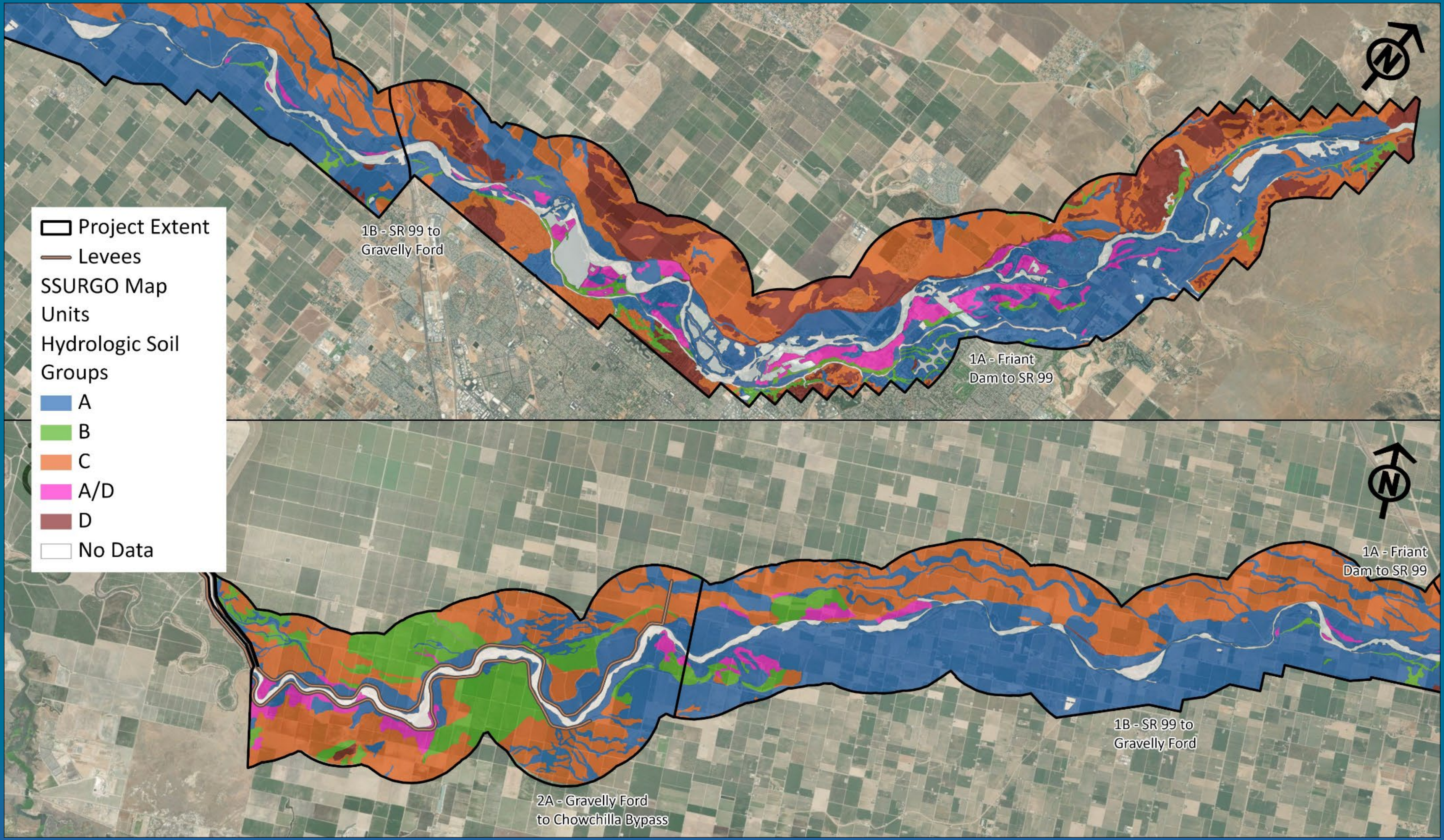


Tier 2: Flow vs. Area Curves

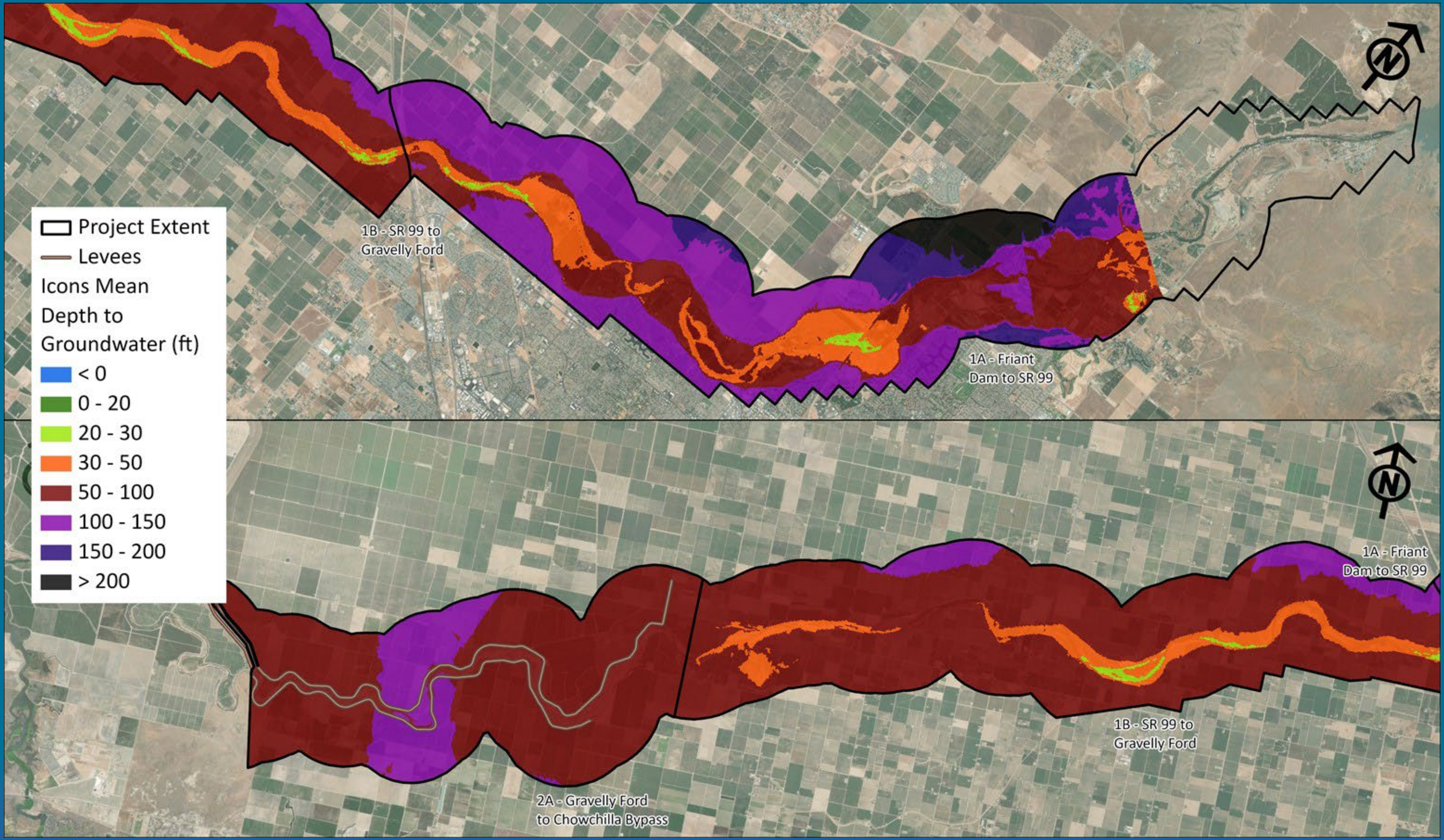
- Flow vs. Inundated Area
- Flow vs. Weighted Usable Area (WUA)

Used to simulate long-term hydrologic records with the tool without the need for long hydraulic model simulations as inputs

Tier 2: Recharge – Hydrologic Soil Groups

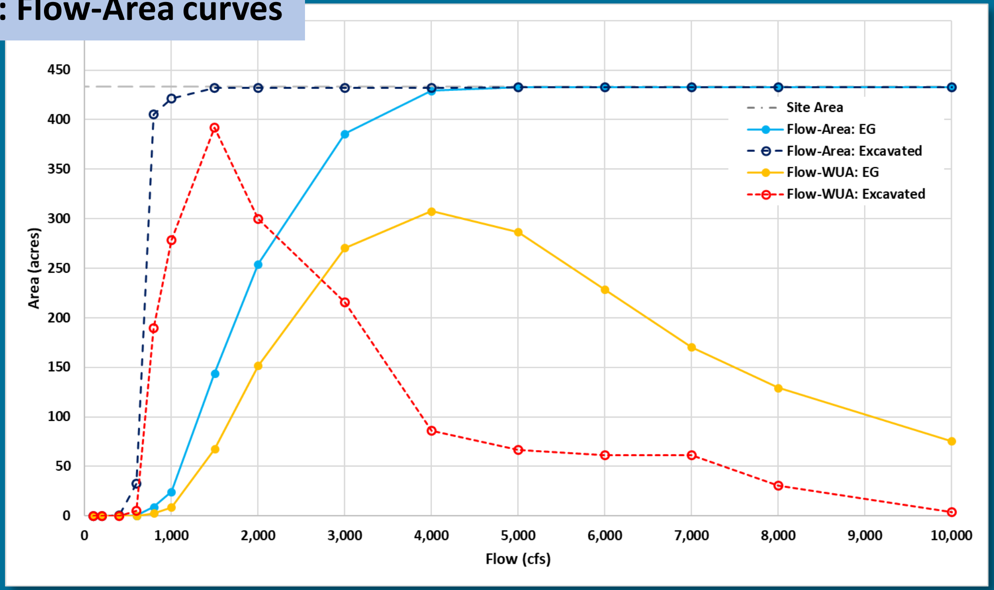


Tier 2: Recharge – Depth to Groundwater

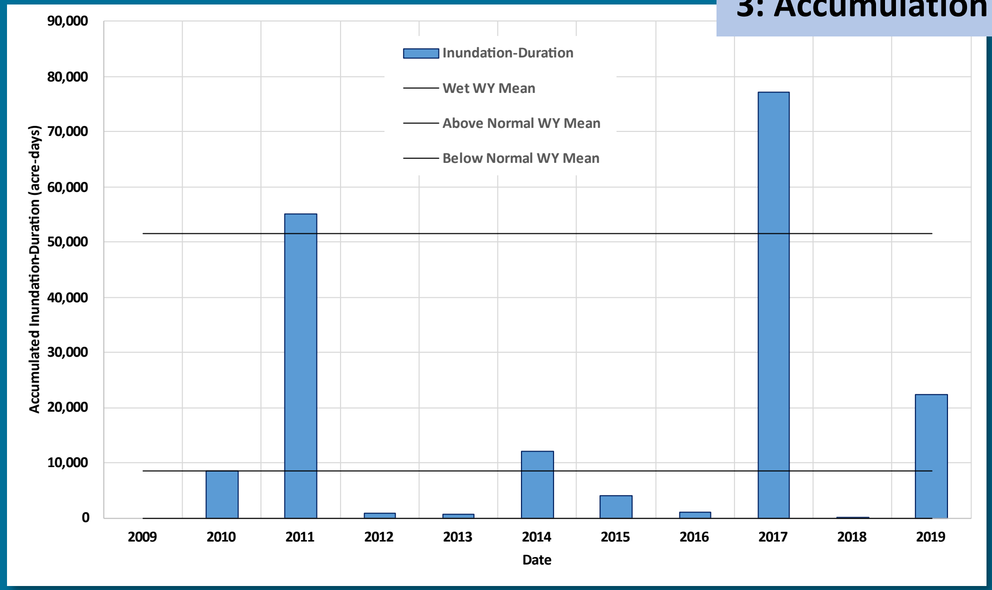


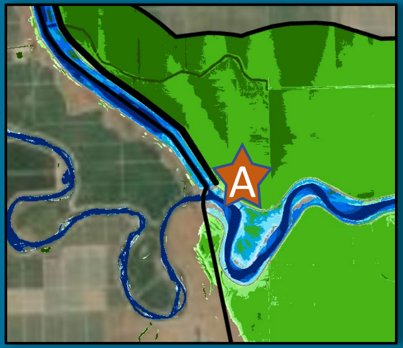
Tier 2: Acre-Day Statistics

1: Flow-Area curves



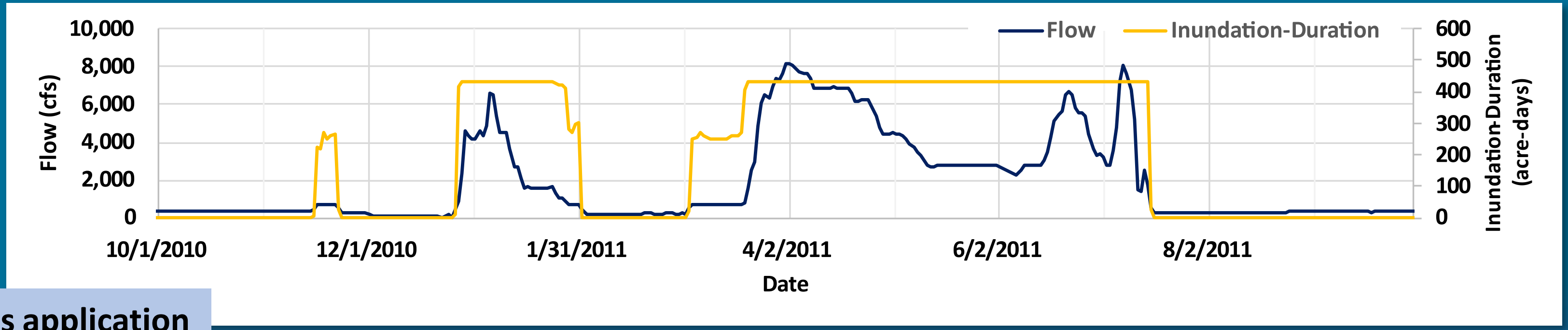
3: Accumulation





WY Summary		
WY	WY Type	acre-days
2009	BN	-
2010	AN	8,463
2011	W	55,060
2012	D	895
2013	C	665
2014	C	12,114
2015	C	3,993
2016	D	1,082
2017	W	77,162
2018	BN	10
2019	W	22,436

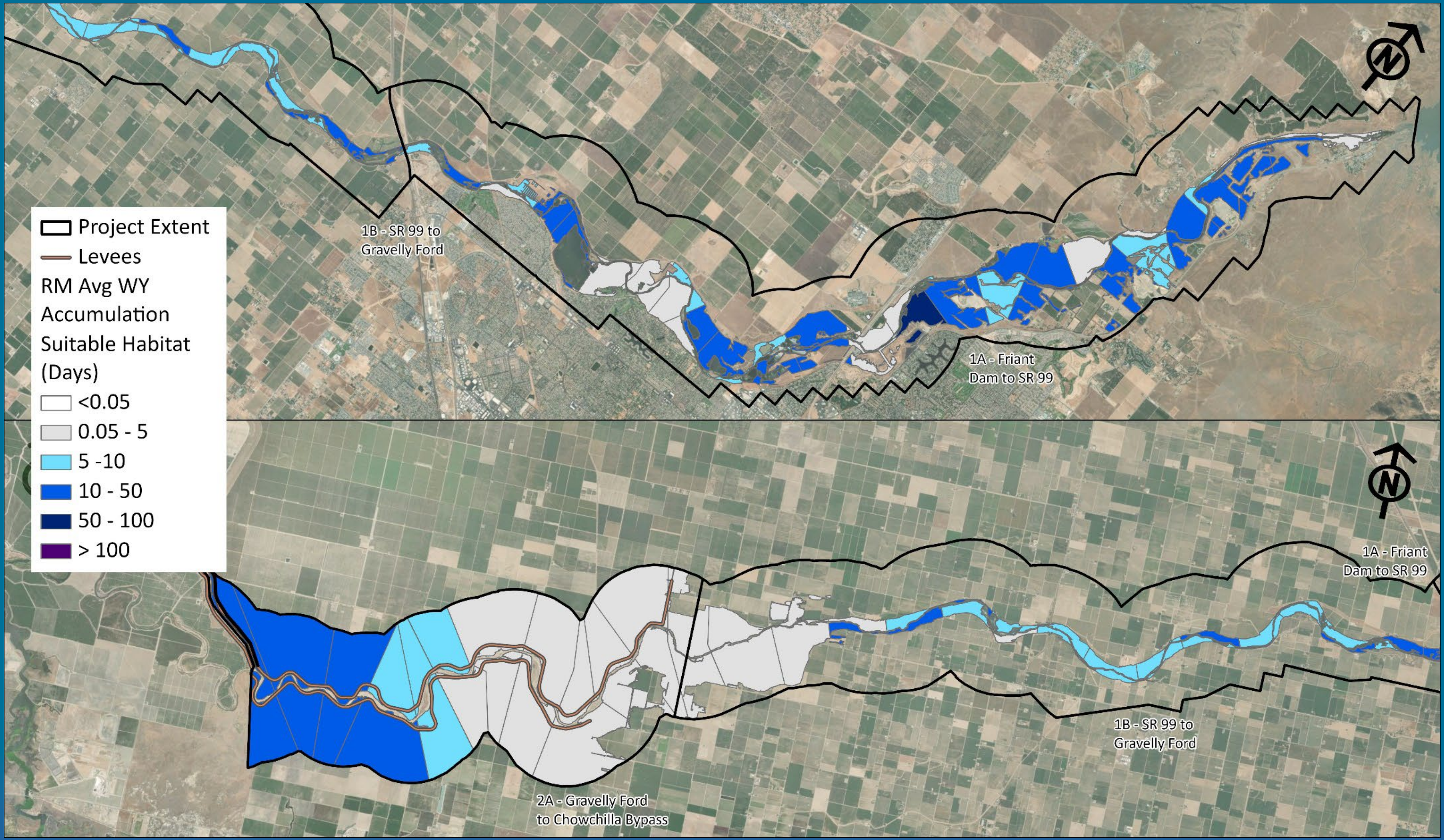
WY Class Summary	
Class	mean acre-days
W	51,553
AN	8,463
BN	5
D	989
C	5,590



2: Timeseries application

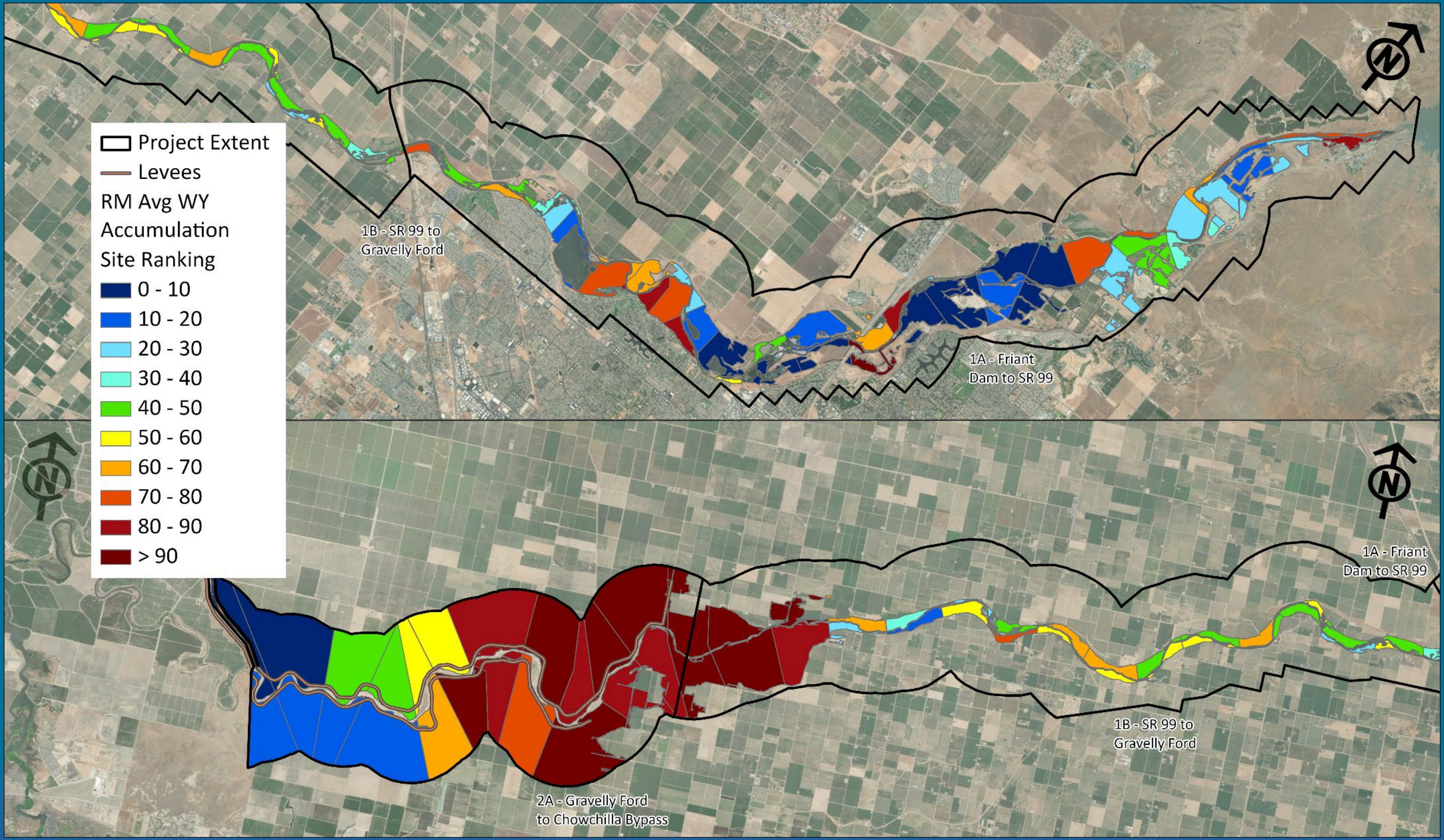
* Timeseries generated for inundated area, WUA, and recharge volume

Tier 2: Results – WUA



Tier 2: Results – Recharge

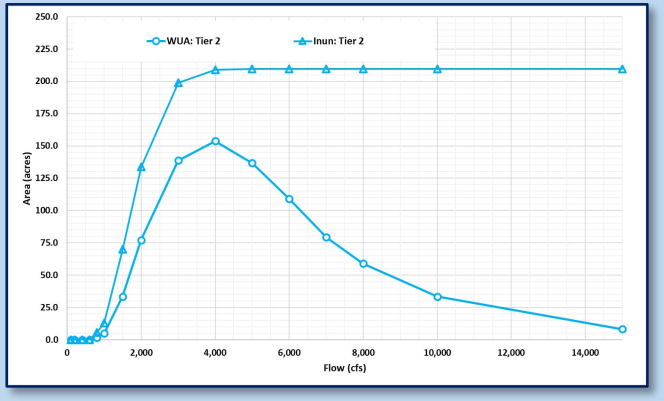
Tier 2: Results – Ranking



Tier 2 vs. Tier 3: Inundation and WUA

Tier 2

- Flow-area curves from steady state flows



- Habitat suitability based on:
  - Depth
  - Velocity
  - Season

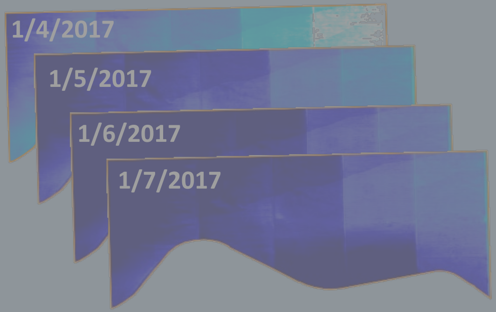
- Boundary-based results (e.g., parcel)

Computationally Fast

Tier 3

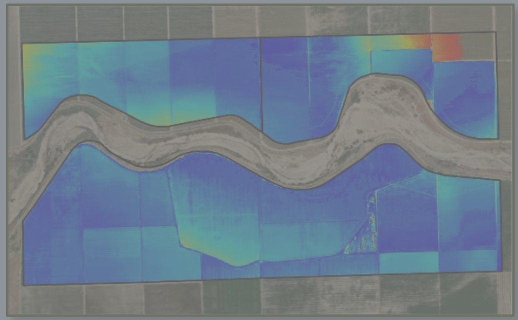
- Daily synthetic timeseries of depth, velocity

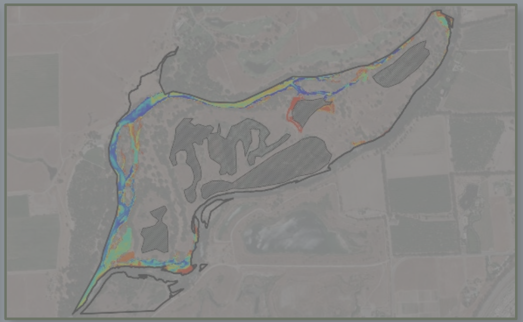
- Habitat suitability based on:
  - Depth
  - Velocity
  - Season
  - Connectivity
  - Duration



- Pixel-based results

Computationally Intensive

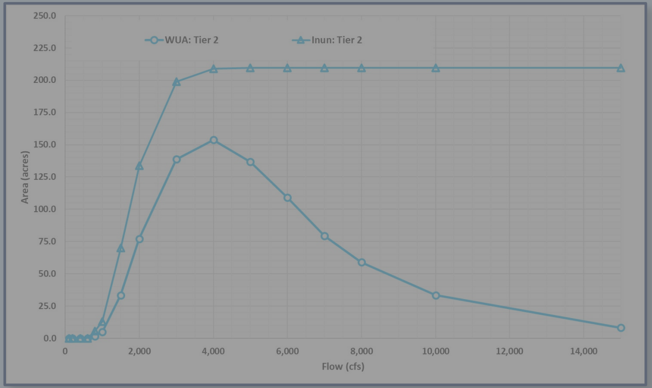




Tier 2 vs. Tier 3: Inundation and WUA

Tier 2

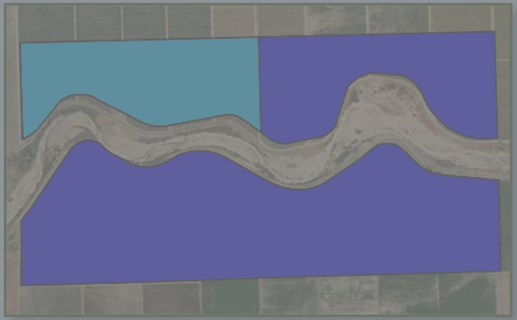
- Flow-area curves from steady state flows



- Habitat suitability based on:
  - Depth
  - Velocity
  - Season

- Boundary-based results (e.g., parcel)

Computationally Fast



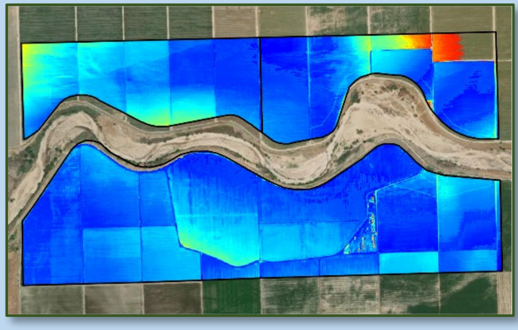
Tier 3

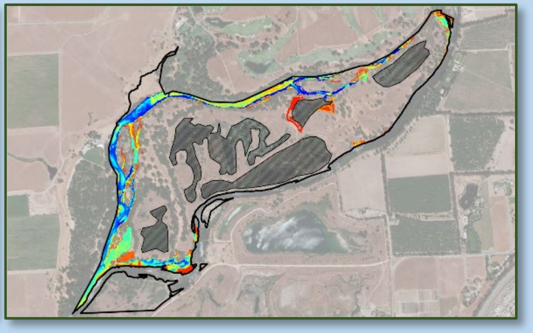
- Daily synthetic timeseries of depth, velocity

- Habitat suitability based on:
  - Depth
  - Velocity
  - Season
  - Connectivity
  - Duration

- Pixel-based results

Computationally Intensive

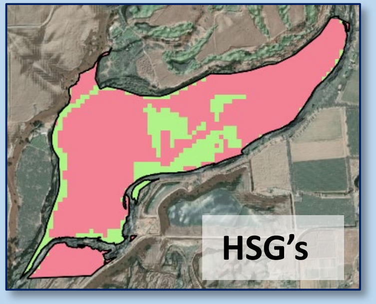




Tier 2 vs. Tier 3: Recharge methods

Tier 2

- Infiltration rates based on HSG's
- Max recharge volume limited by WY capacity
- Site-averaged recharge rates applied to interpolated inundation timeseries



Avg. Recharge Rate:

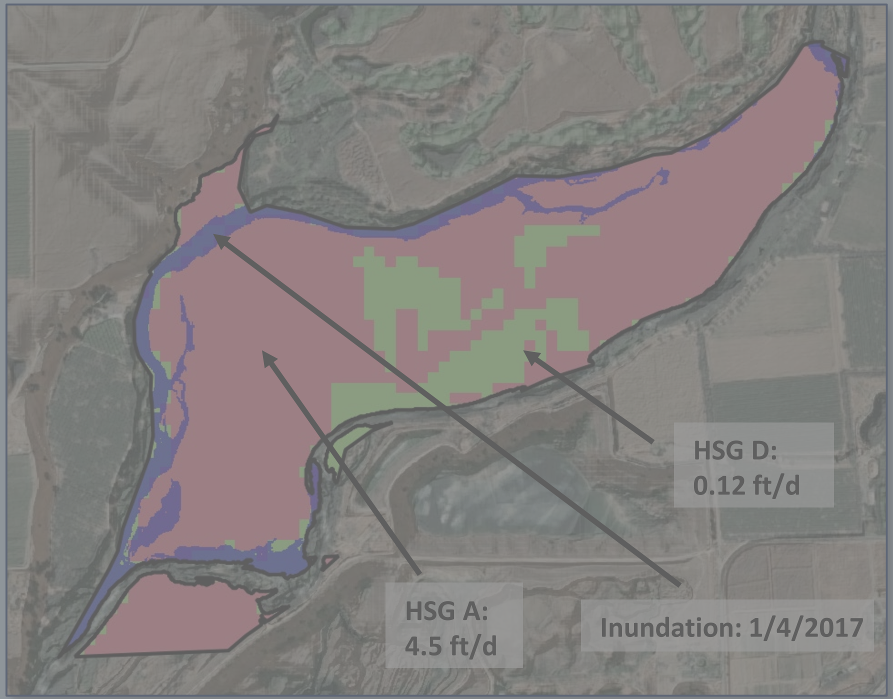
3.6 ft/day

Inundated area timeseries

Recharge timeseries

Tier 3

- Infiltration rates based on HSG's
- Max recharge volume limited by WY capacity
- Spatially-explicit inundation and infiltration



Tier 2 vs. Tier 3: Recharge methods

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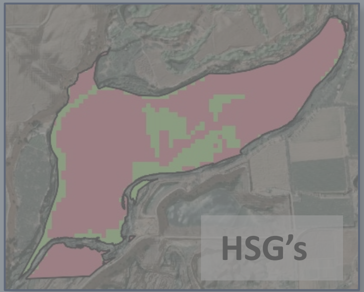


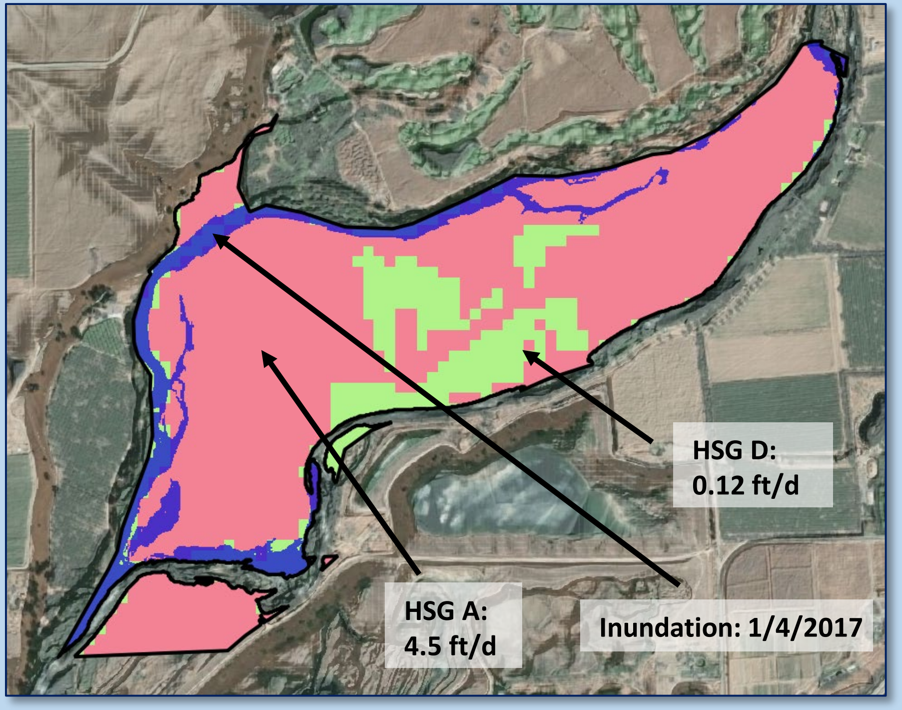
→ Avg. Recharge Rate: 3.6 ft/day

↓

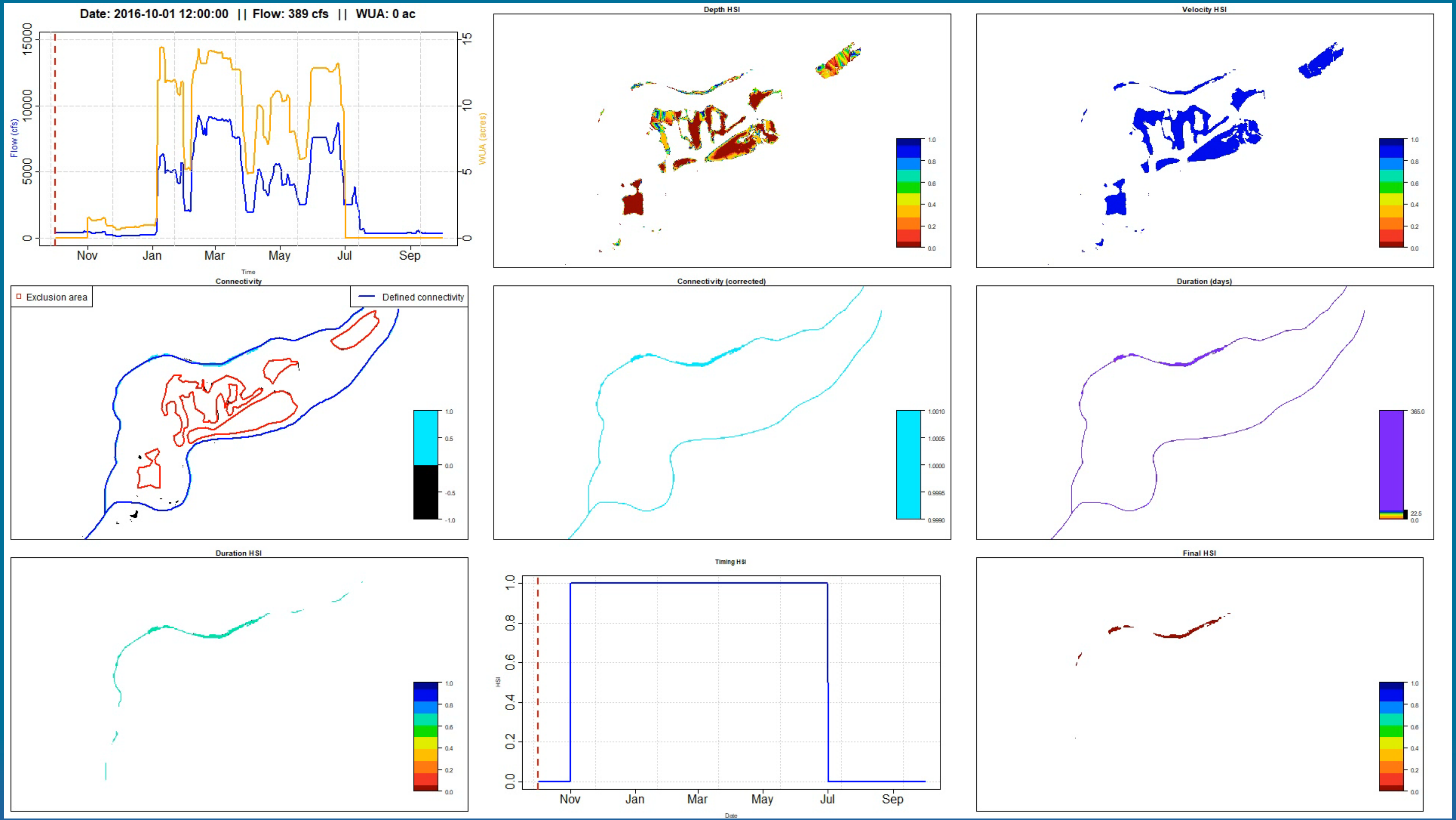
Inundated area timeseries → Recharge timeseries

Tier 3

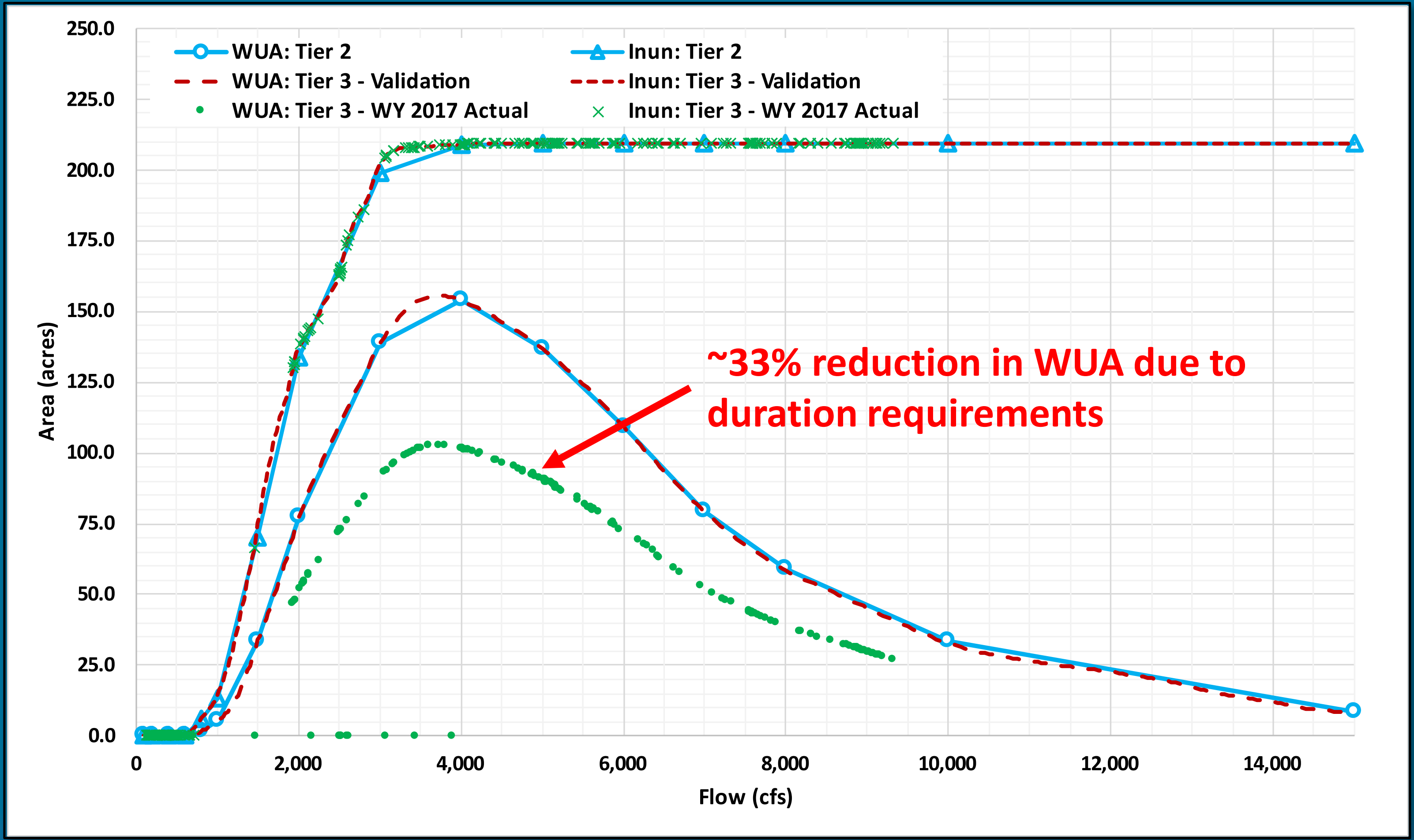
- Infiltration rates based on HSG's
- Max recharge volume limited by WY capacity
- Spatially-explicit inundation and infiltration



Tier 3: Animation



Tier 2 vs. Tier 3: Results summary



- Tier 3 is overall more conservative, data-intensive, and judgement-driven but provides more accurate estimates of inundation, habitat, and recharge.
- Tier 2 is a highly useful precursor to Tier 3 for its broad application and site prioritization framework, especially given that Tier 3 would be prohibitive to apply at-scale.
- Tier 3 is spatially-explicit and allows for a much broader array of post-processing applications beyond what is currently included in the EcoFIP methodology.

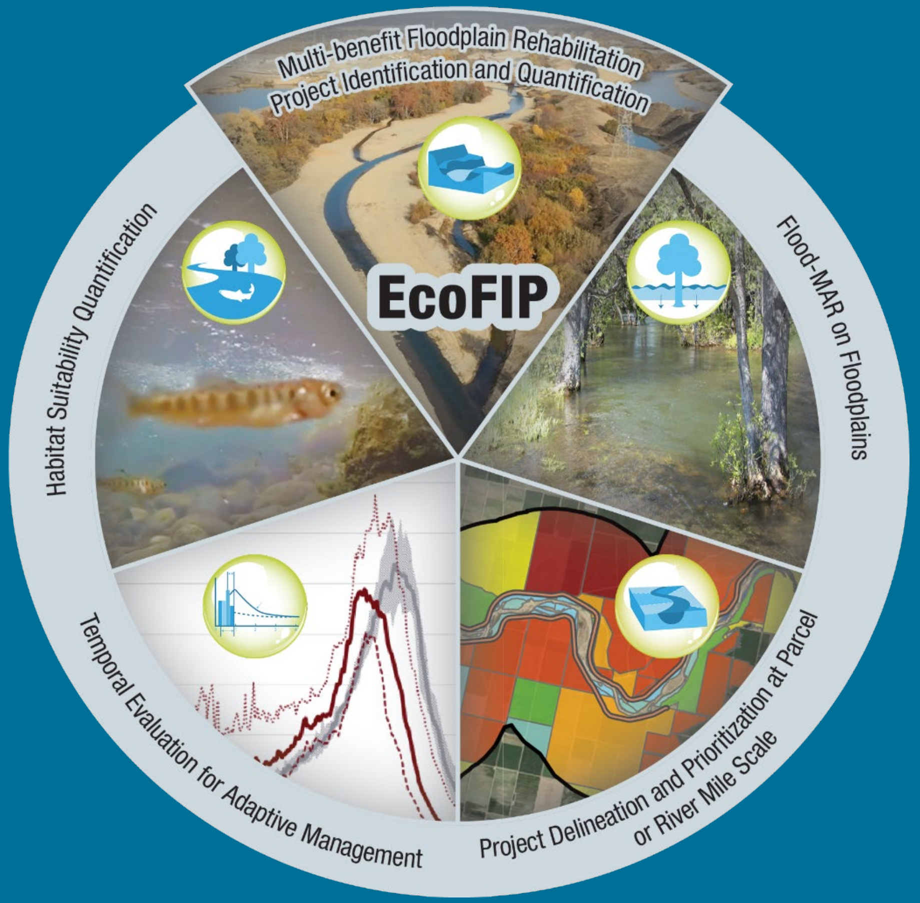
Discussion and Next Steps

Next Steps - Methods

- Technology - Incorporation of Airborne Electromagnetic (AEM) surveys into subsurface characterization
- Fate of Groundwater – Use groundwater models to better characterize fate of recharged water and amount of subsurface storage at the site scale
- Support additional target species, ecosystem processes, or geomorphic processes within EcoFIP

Next Steps - Application

- Evaluate alternative management (e.g., FIRO)
- Evaluate future climate scenarios
- Development of restoration concepts for highly ranked sites
- Broader application of this approach to other systems



Please reach out with any questions!

- Luke Tillmann (cbec) – l.tillmann@cbecoeng.com
- Michael Founds (cbec) – m.founds@cbecoeng.com

Notes from underground: The hydrological underpinnings of drought response across California forests

David Dralle

US Forest Service, Pacific Southwest Research Station

with





Dana A Lapides[1,3] Daniella M Rempe[2] W. Jesse Hahm[3] Erica McCormick[2] John Whiting[1]

1- Pacific Southwest Research Station, US Forest Service
2-University of Texas, Austin, TX, USA
3-Simon Fraser University, Burnaby, BC, Canada

Widespread, devastating, and unpredictable (?) forest mortality

The New York Times

CALIFORNIA TODAY

California Today: 100 Million Dead Trees Prompt Fears of Giant Wildfires

Trends in
Ecology & Evolution

2 March 2021

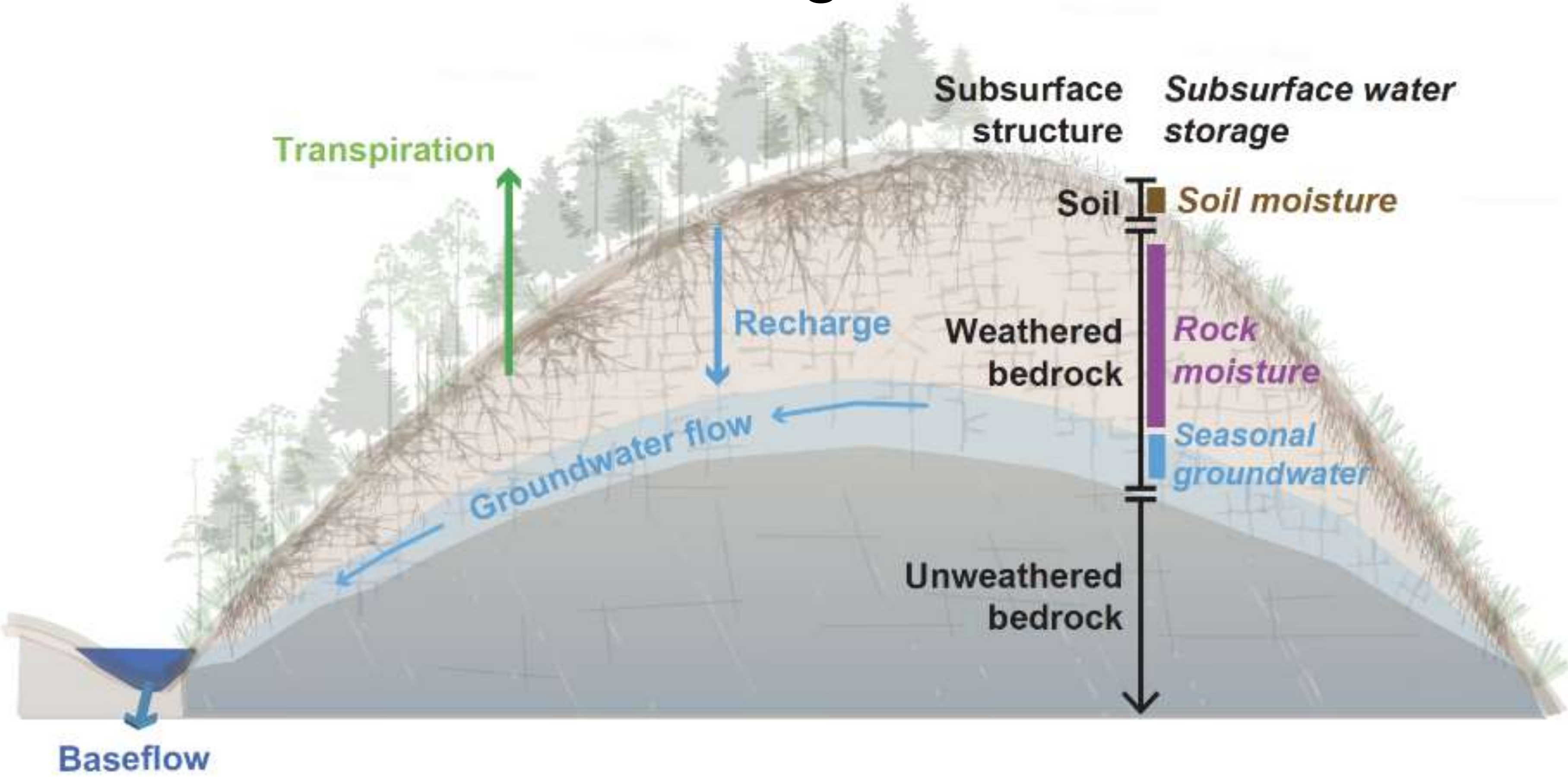
Review

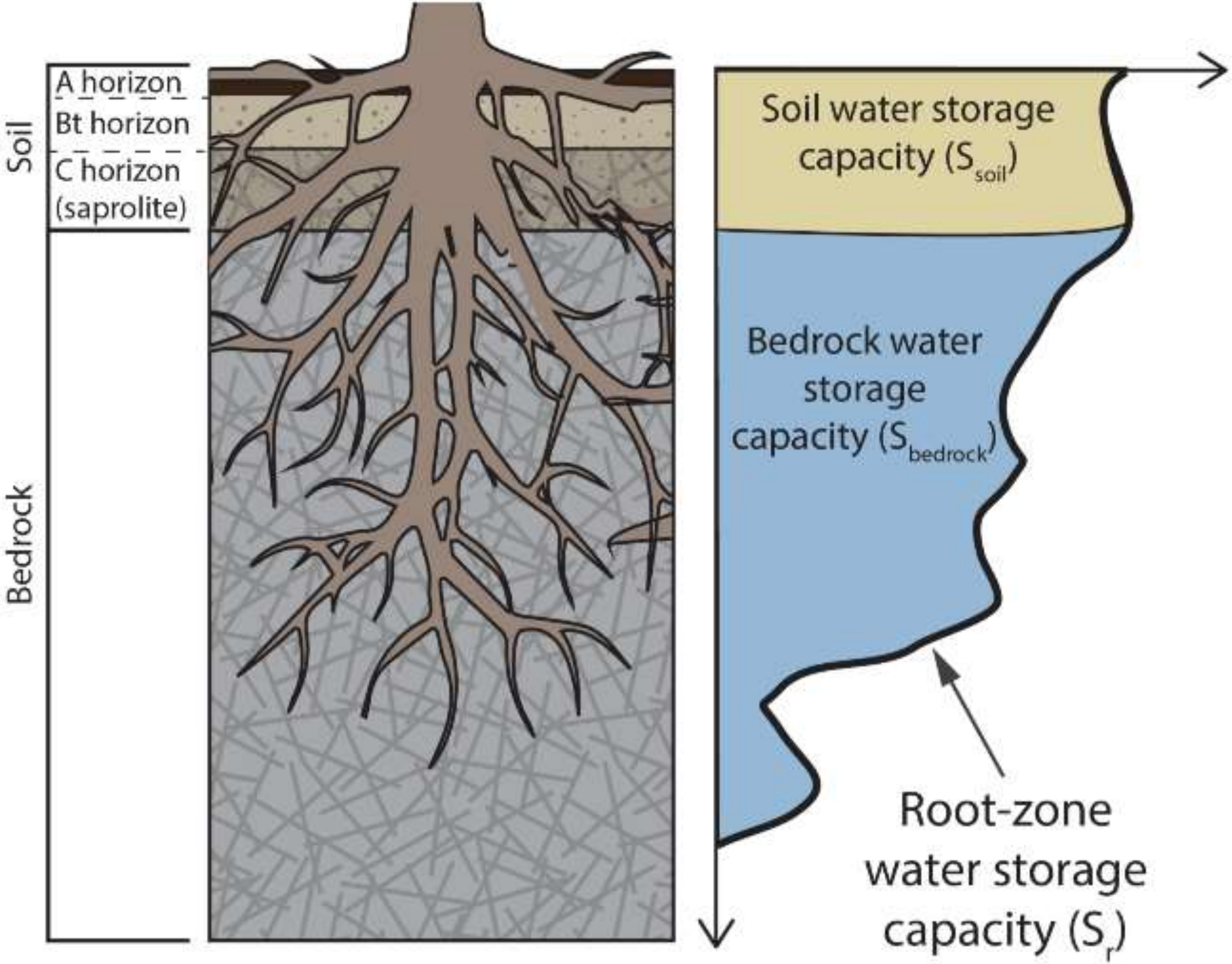
Why is Tree Drought Mortality so Hard to Predict?

Anna T. Trugman,[1,6,*] Leander D.L. Anderegg,[2,3,6,*] William R.L. Anderegg,[4]
Adrian J. Das,[5] and Nathan L. Stephenson[5]

Drought mortality has wide-ranging ramifications from environmental conservation to climate change mitigation efforts. Thus far, mortality prediction efforts using physiology alone have found limited success.

Subsurface water storage





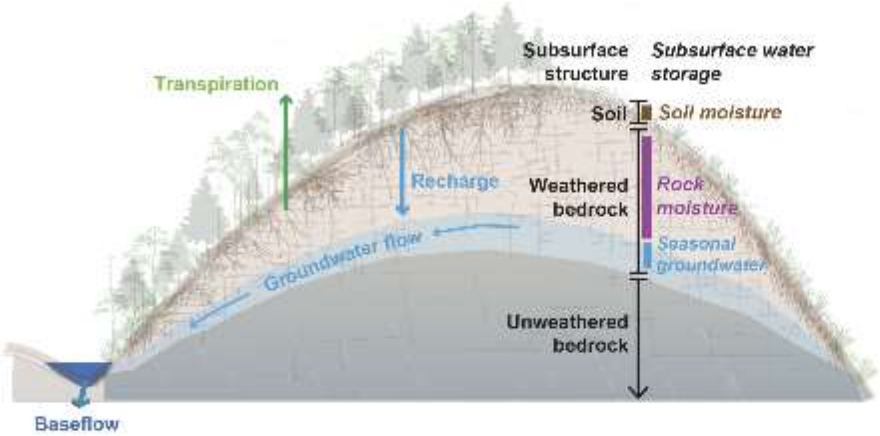
McCormick et al, 2021

≈

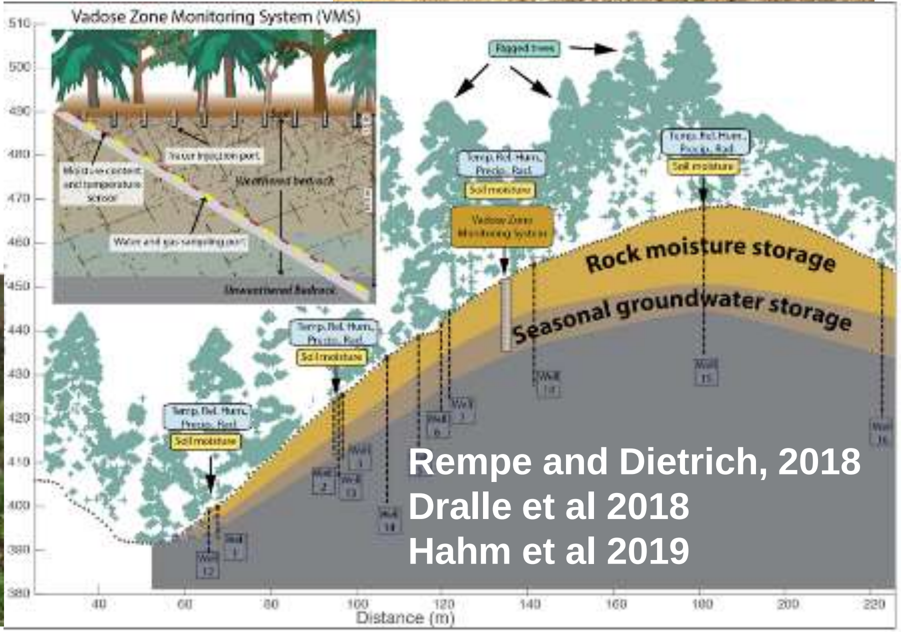
Wisdom of the sponge

Evaporation fully dries the wet sponge

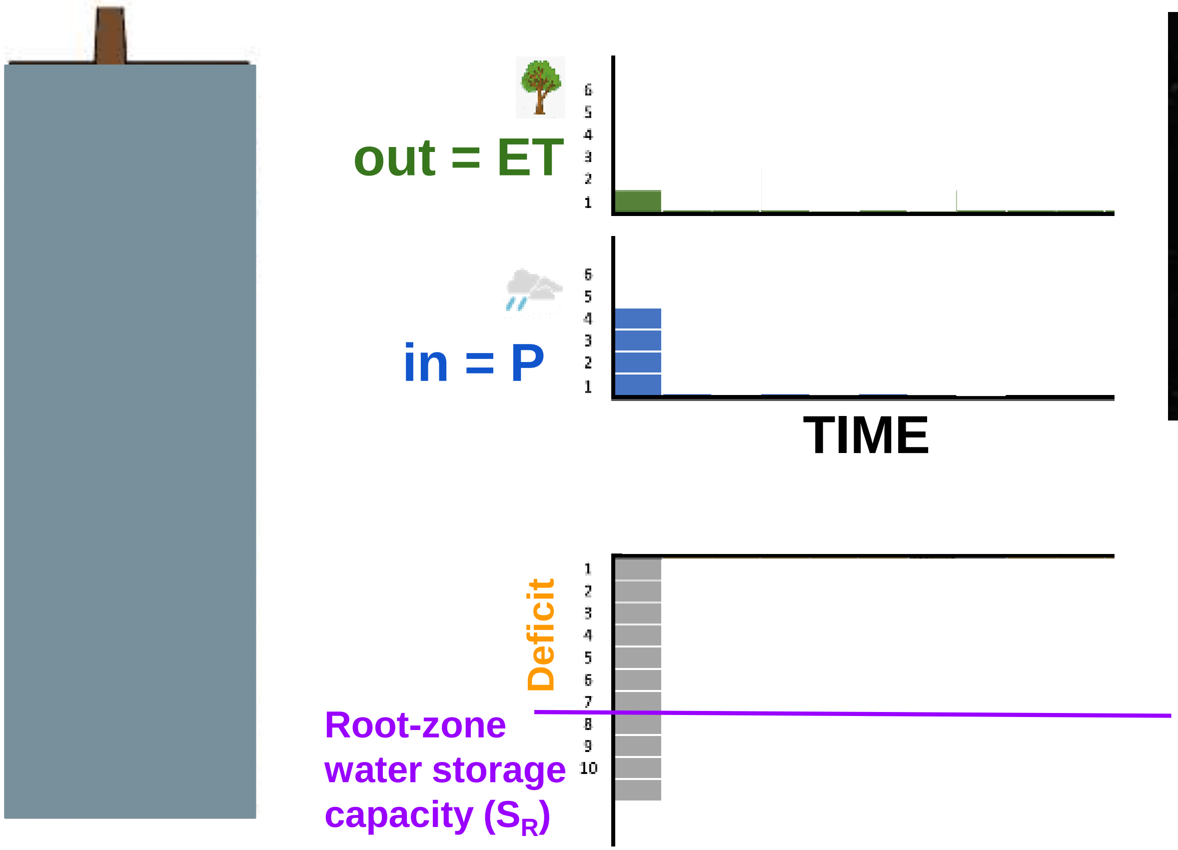
Wet sponge drips excess water, and stays wet



Observing the sponge



Rempe and Dietrich, 2018
Dralle et al 2018
Hahm et al 2019



How big?

&

How dry?

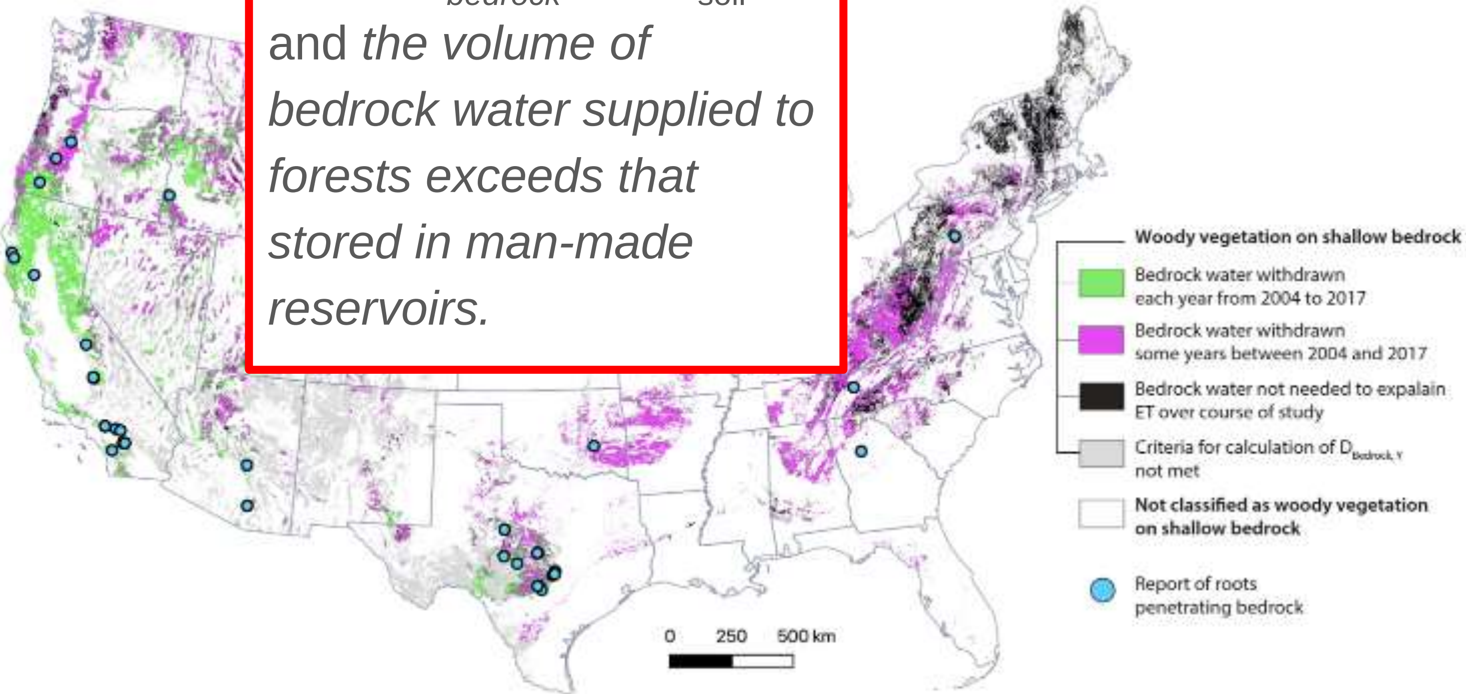
Dralle et al (2021), HESS or Wang-Erlandsson et al (2016), HESS

Forests in the American West are commonly rooted into weathered bedrock mantled by thin soils

Widespread use of bedrock water by woody plants across the continental U.S.

$$S_r = S_{bedrock} + S_{soil}$$

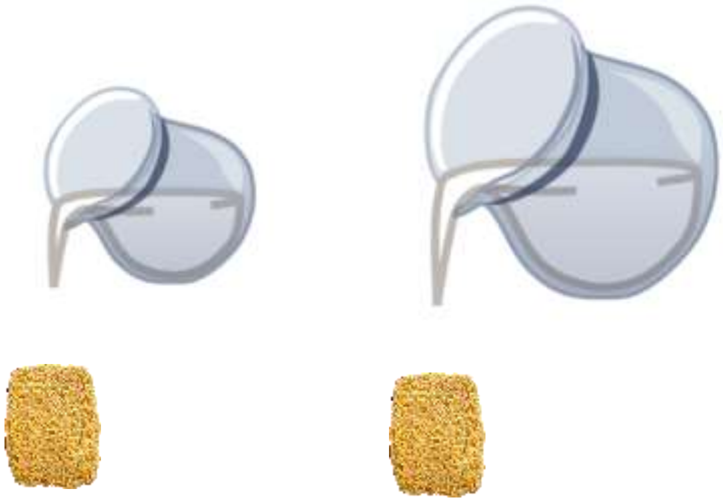
In CA, $S_{bedrock} \gg S_{soil}$ and *the volume of bedrock water supplied to forests exceeds that stored in man-made reservoirs.*



McCormick, Dralle, et al, Nature, 2021

Storage capacity limited

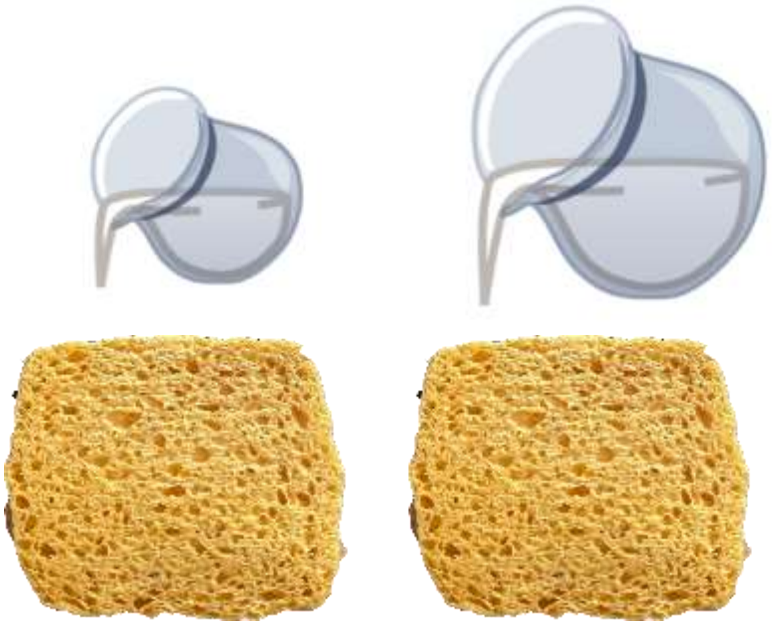
Dry winter | Wet winter



$$\frac{Storage\ capacity}{Average\ precip} < 1$$

Precipitation limited

Dry winter | Wet winter



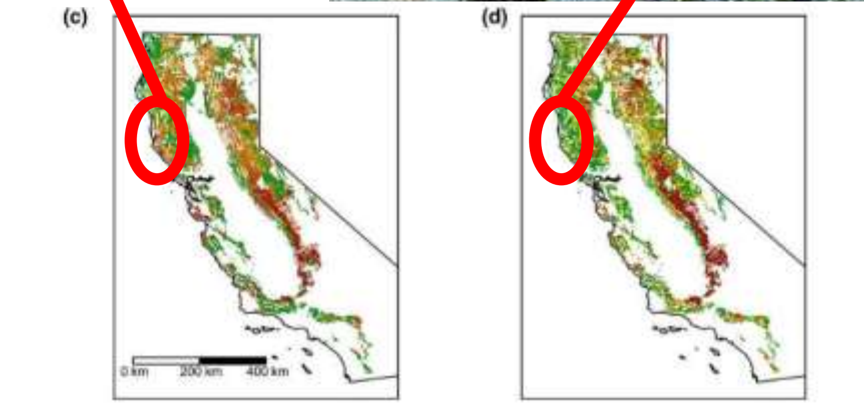
$$\frac{Storage\ capacity}{Average\ precip} > 1$$

Hahm and Dralle et al (2019), GRL

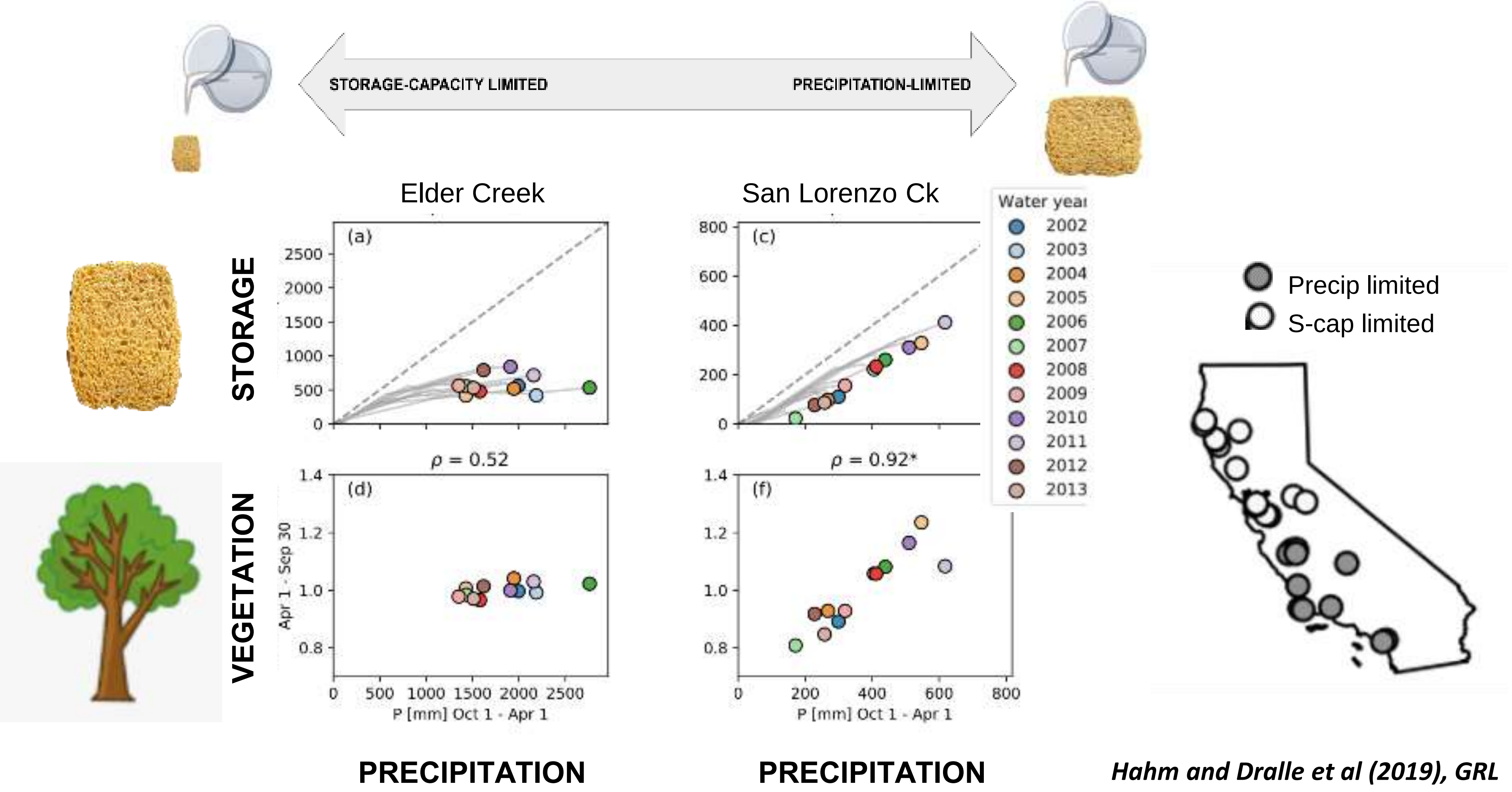
High predicted mortality

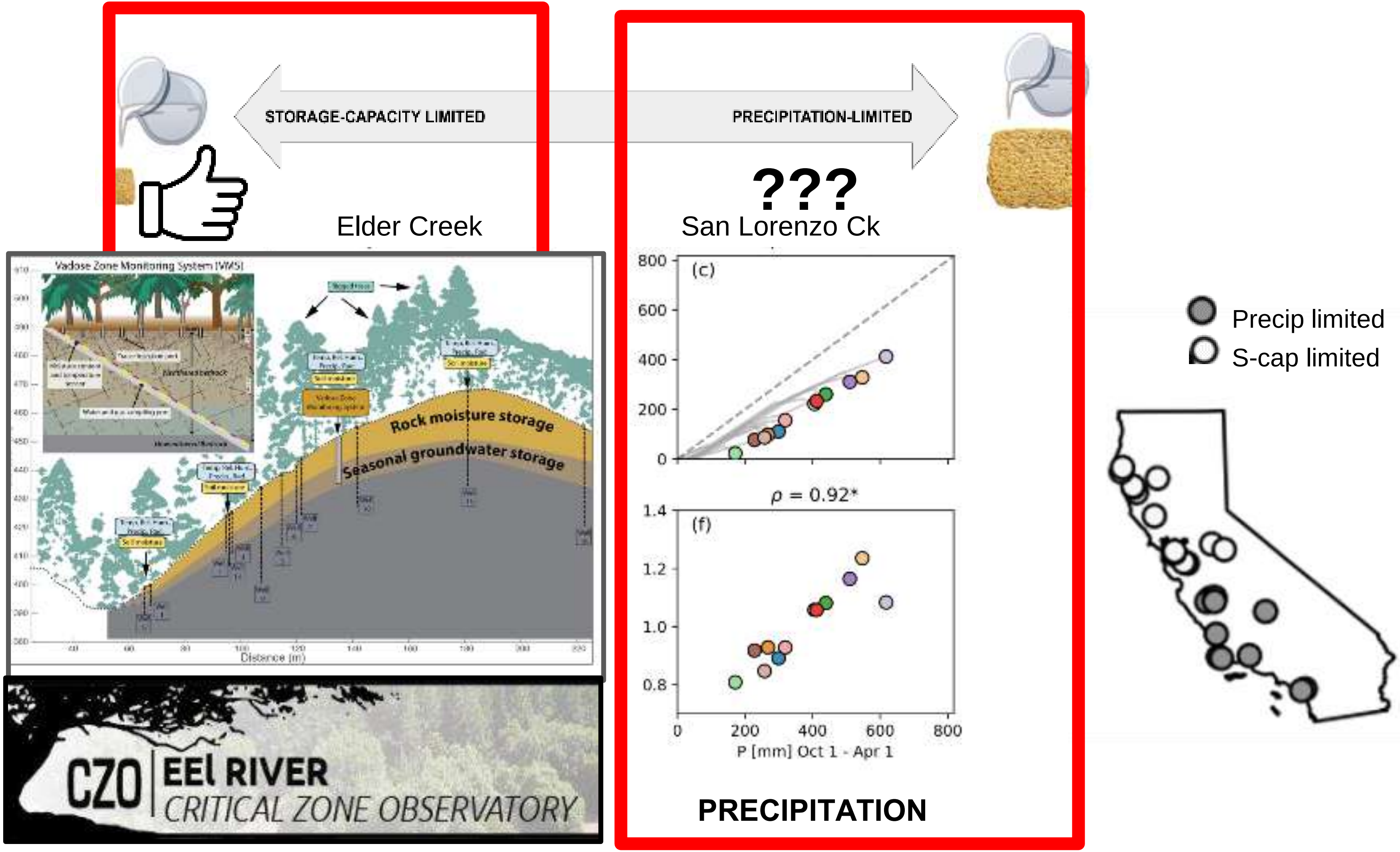
Low measured mortality

Young et al, 2017



Biogeography of drought not fully explained by decreased precip or increased temperature

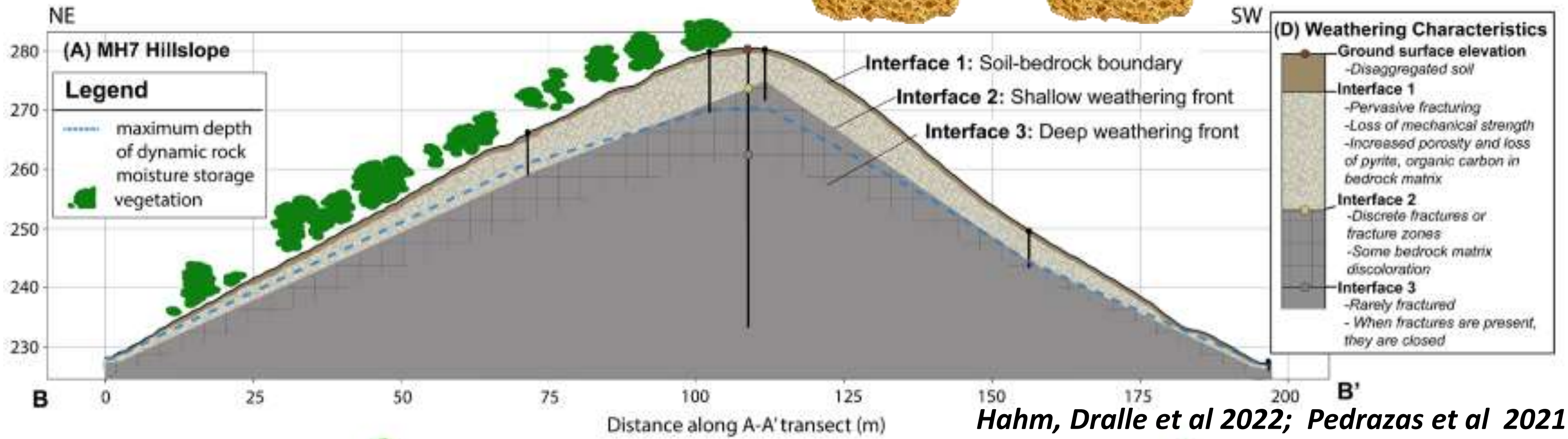

STORAGE-CAPACITY LIMITED
PRECIPITATION-LIMITED
Elder Creek
San Lorenzo Ck
STORAGE
VEGETATION
(a)
(c)
(d)
(f)
ρ = 0.52
ρ = 0.92*
Apr 1 - Sep 30
P [mm] Oct 1 - Apr 1
P [mm] Oct 1 - Apr 1
Water year
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Precip limited
S-cap limited
PRECIPITATION
PRECIPITATION
Hahm and Dralle et al (2019), GRL



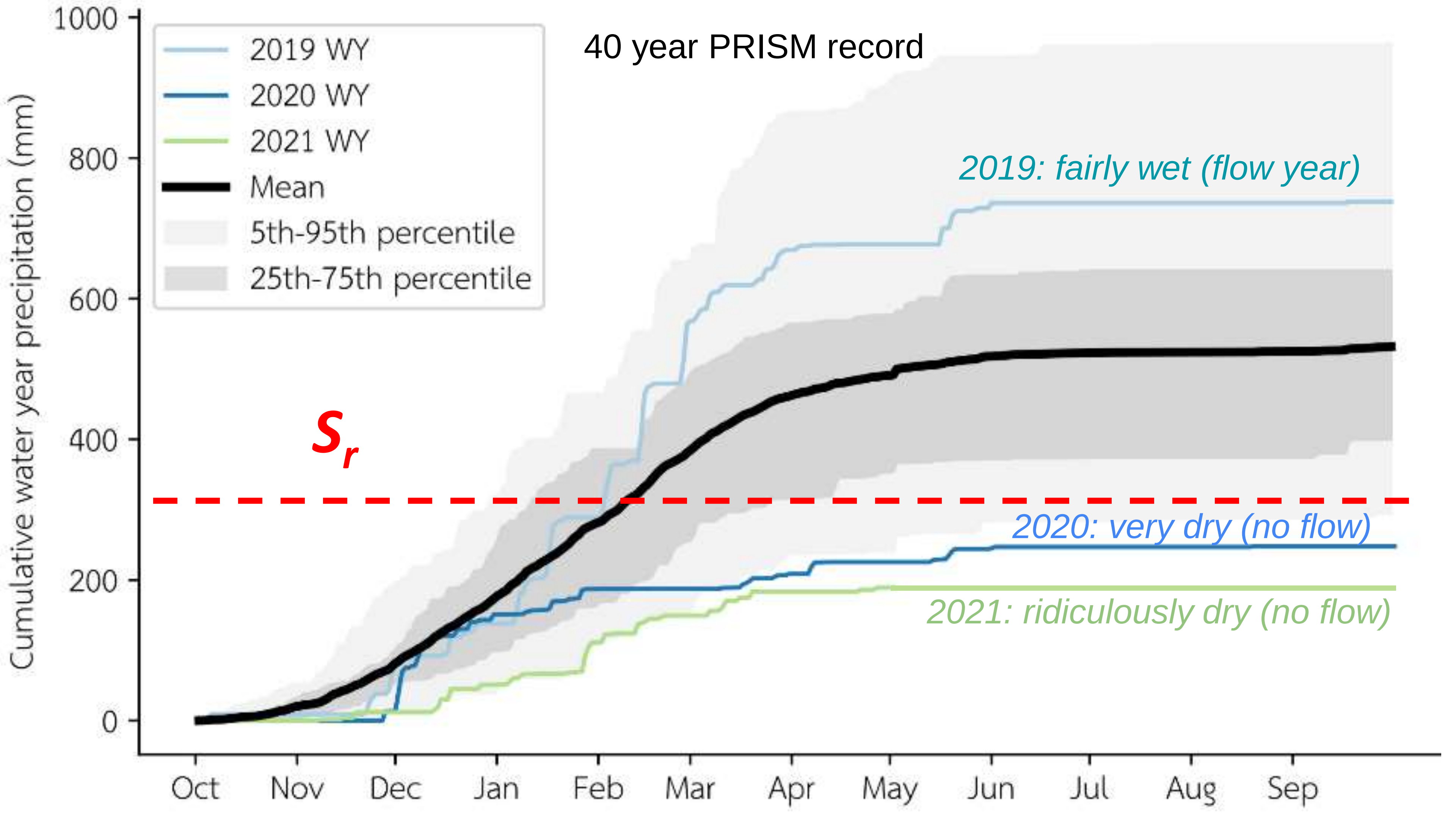
STORAGE-CAPACITY LIMITED
PRECIPITATION-LIMITED
???
Elder Creek
San Lorenzo Ck
Vadose Zone Monitoring System (VMS)
Rock moisture storage
Seasonal groundwater storage
Distance (m)
CZO EEL RIVER
CRITICAL ZONE OBSERVATORY
(c)
800
600
400
200
0
ρ = 0.92*
(f)
1.4
1.2
1.0
0.8
0 200 400 600 800
P [mm] Oct 1 - Apr 1
PRECIPITATION
Precip limited
S-cap limited

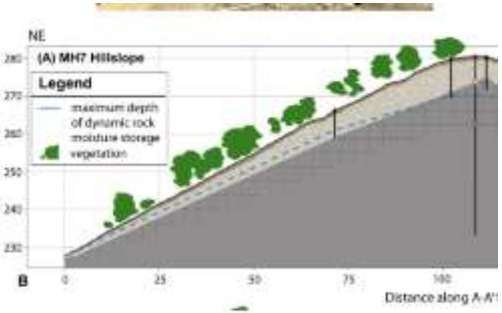
Rancho Venada

$$\frac{Storage\ capacity}{Average\ precip} > 1$$

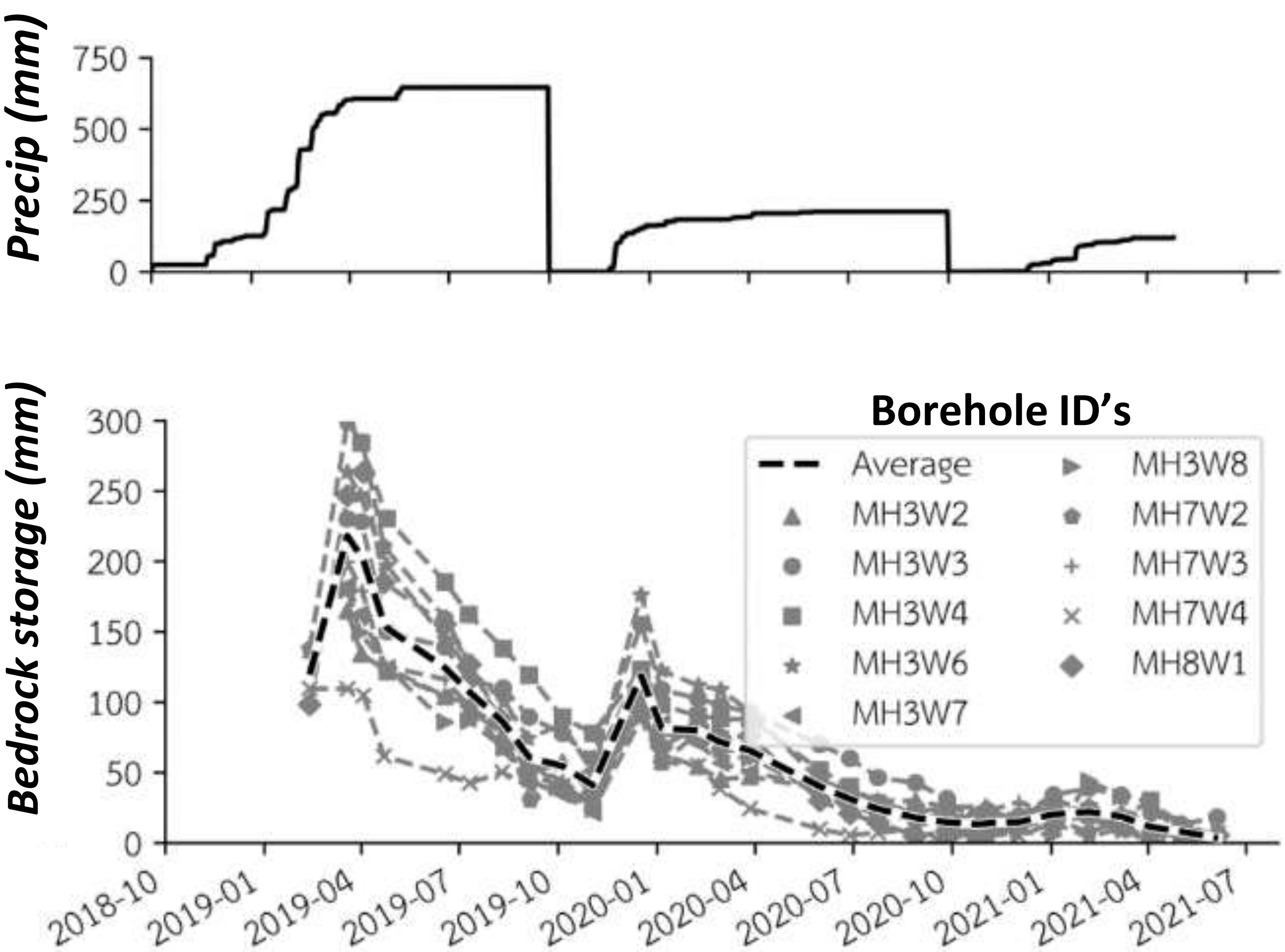


Hahm, Dralle et al 2022; Pedrazas et al 2021


40 year PRISM record
2019 WY
2020 WY
2021 WY
Mean
5th-95th percentile
25th-75th percentile
2019: fairly wet (flow year)
2020: very dry (no flow)
2021: ridiculously dry (no flow)
S_r
Cumulative water year precipitation (mm)
1000
800
600
400
200
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep



NE
(A) MH7 Hillslope
Legend
maximum depth of dynamic rock moisture storage
vegetation
B
Distance along A-A'



Precip (mm)
750
500
250
0
Borehole ID's
Bedrock storage (mm)
300
250
200
150
100
50
0
Average
MH3W2
MH3W3
MH3W4
MH3W6
MH3W7
MH3W8
MH7W2
MH7W3
MH7W4
MH8W1
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
2021-04
2021-07

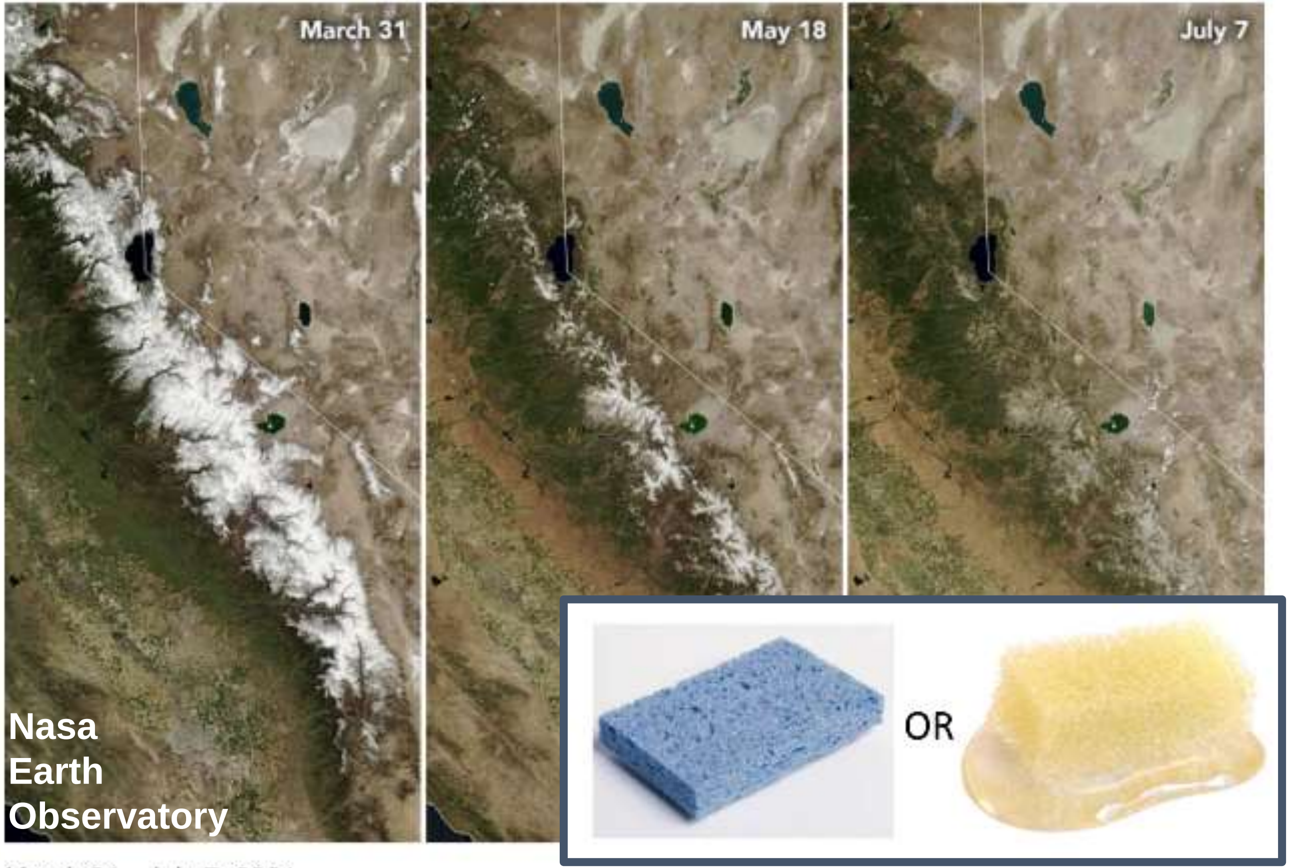
2020

2021

The Case of California's Missing Streamflow

"We have 100 years of data saying if you have this much snow, you would expect this much runoff," de Guzman said. "But that fell apart this year."

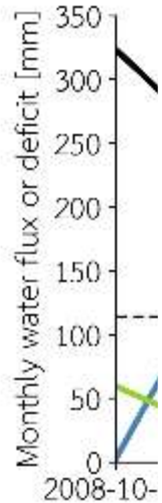
Sean de Guzman, chief of snow surveys and water supply forecasting, CA DWR



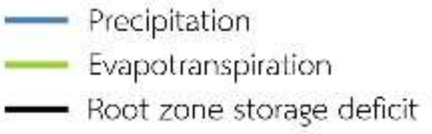
March 31 - July 7, 2021

https://www.mercurynews.com/2021/06/23/where-did-sierra-snow-go-this-spring-not-into-california-rivers-and-water-supplies/

“Real time” deficit calculations

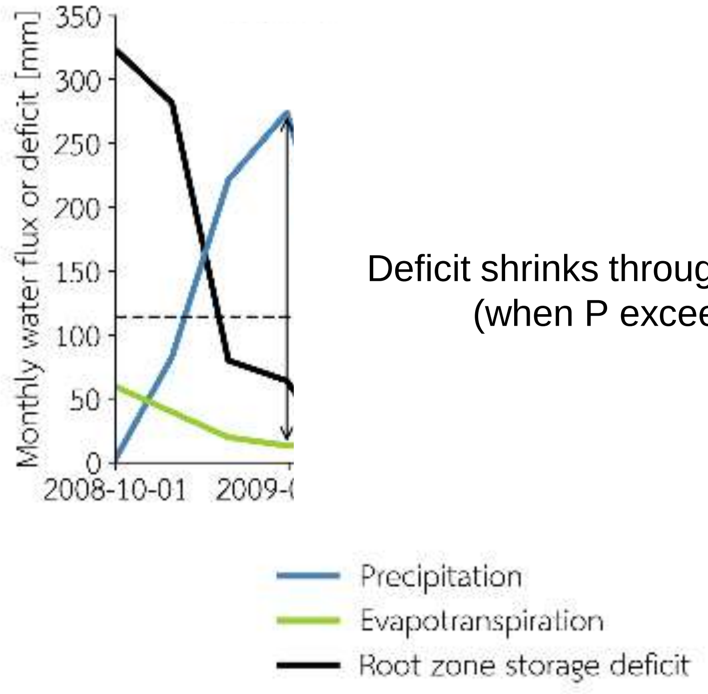


Deficit is large at onset of wet season.



Wang-Erlandsson, Lan, et al. "Global root zone storage capacity from satellite-based evaporation." *Hydrology and Earth System Sciences* 20.4 (2016): 1459-1481.
Dralle, David N., et al. "Accounting for snow in the estimation of root zone water storage capacity from precipitation and evapotranspiration fluxes." *Hydrology and Earth System Sciences* 25.5 (2021): 2861-2867.

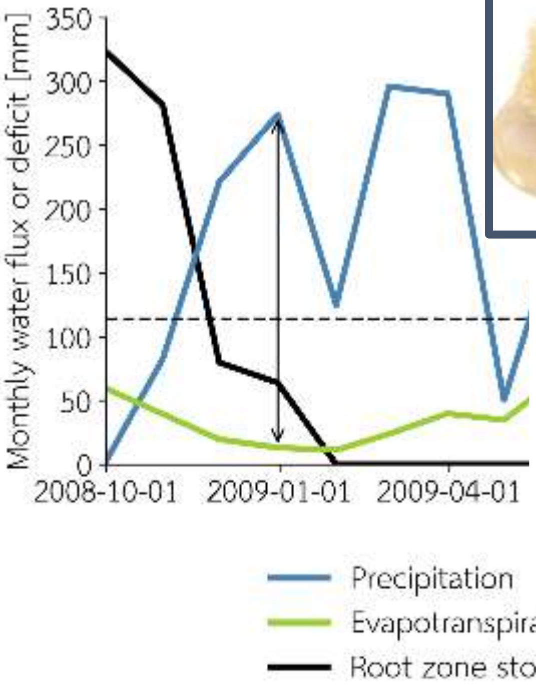
“Real time” deficit calculations



Deficit shrinks through wet season
(when P exceeds ET)

Wang-Erlandsson, Lan, et al. "Global root zone storage capacity from satellite-based evaporation." *Hydrology and Earth System Sciences* 20.4 (2016): 1459-1481.
Dralle, David N., et al. "Accounting for snow in the estimation of root zone water storage capacity from precipitation and evapotranspiration fluxes." *Hydrology and Earth System Sciences* 25.5 (2021): 2861-2867.

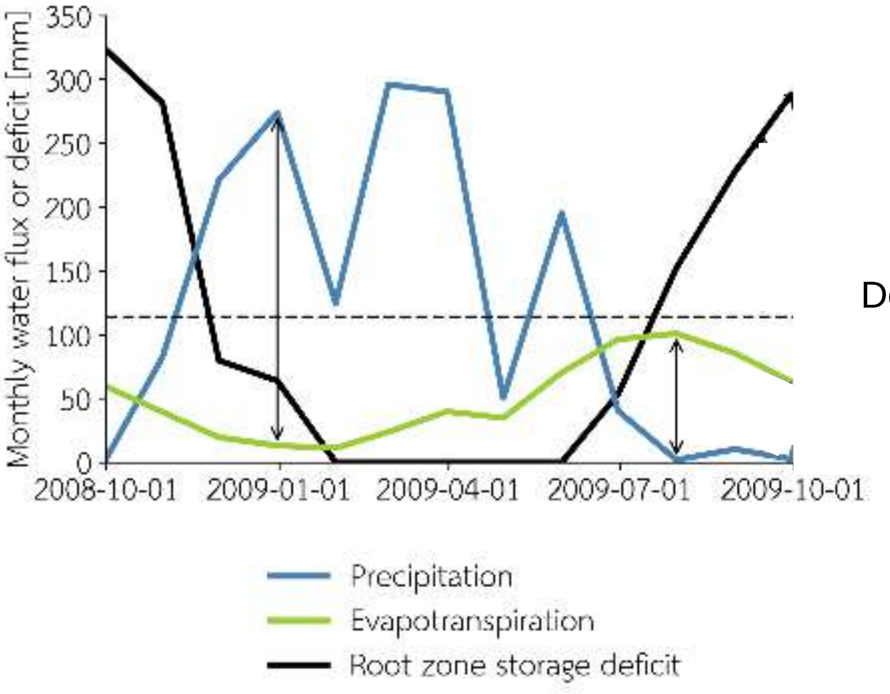
“Real time” deficit calculations



Deficit is 0 when storage is fully replenished

Wang-Erlandsson, Lan, et al. "Global root zone storage capacity from satellite-based evaporation." *Hydrology and Earth System Sciences* 20.4 (2016): 1459-1481.
Dralle, David N., et al. "Accounting for snow in the estimation of root zone water storage capacity from precipitation and evapotranspiration fluxes." *Hydrology and Earth System Sciences* 25.5 (2021): 2861-2867.

“Real time” deficit calculations

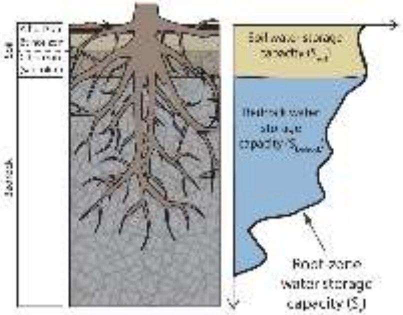


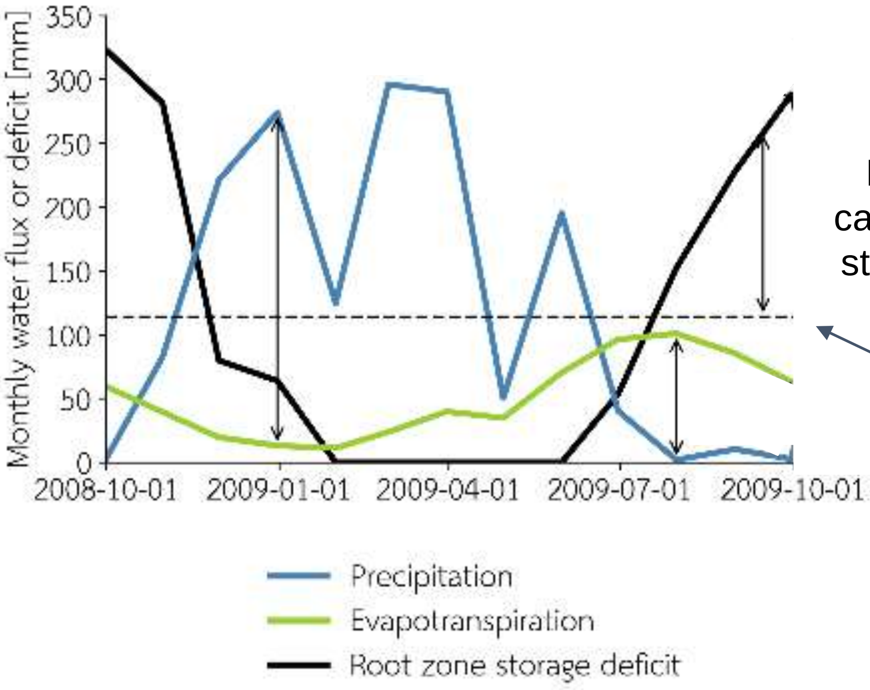
Deficit grows in dry season (when ET exceeds P)

Wang-Erlandsson, Lan, et al. "Global root zone storage capacity from satellite-based evaporation." *Hydrology and Earth System Sciences* 20.4 (2016): 1459-1481.

Dralle, David N., et al. "Accounting for snow in the estimation of root zone water storage capacity from precipitation and evapotranspiration fluxes." *Hydrology and Earth System Sciences* 25.5 (2021): 2861-2867.

“Real time” deficit calculations



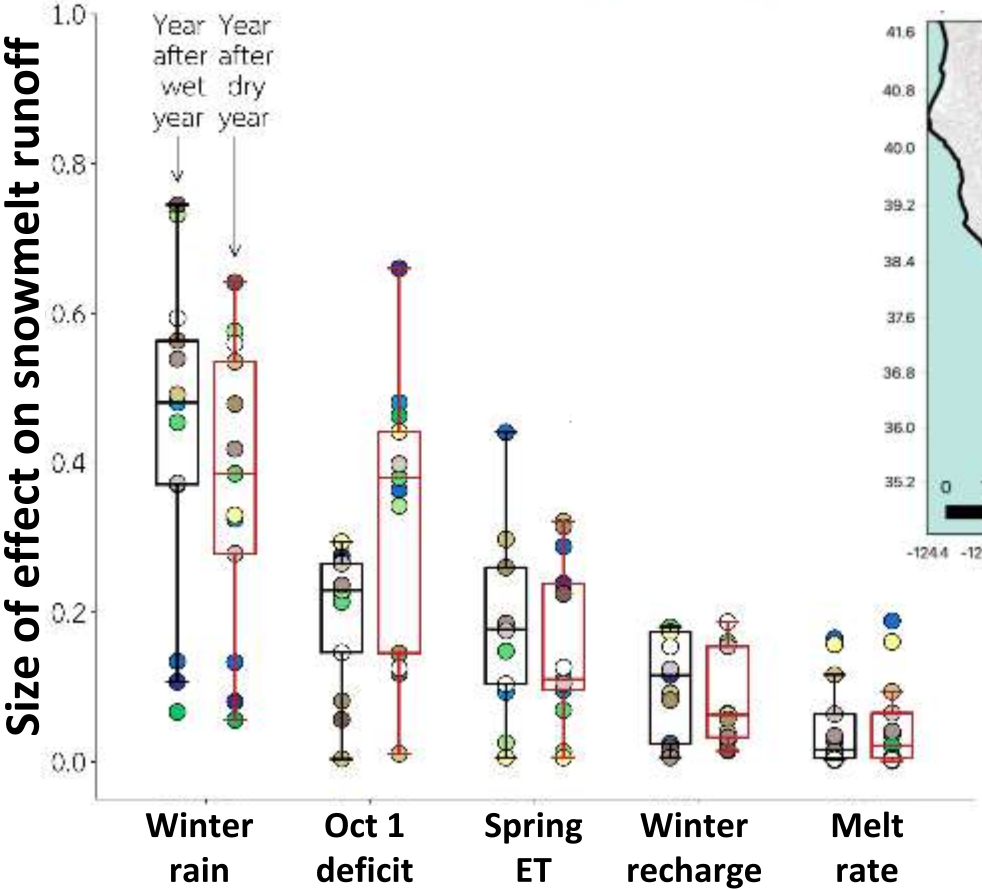


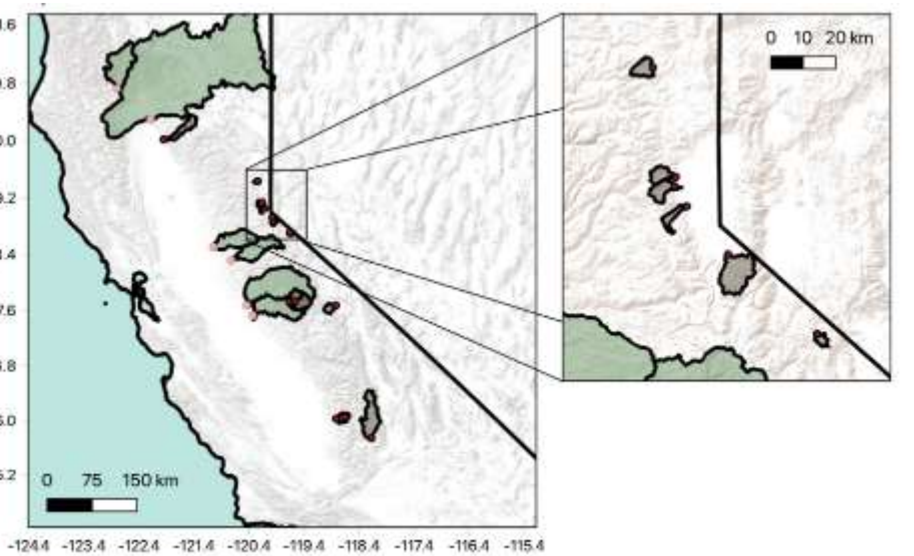
Deficit exceeds soil water capacity—must include water stored in weathered bedrock

Soil water capacity

McCormick, Erica L., et al. "Widespread woody plant use of water stored in bedrock." *Nature* 597.7875 (2021): 225-229.

Deep (below soil) storage deficits explain "missing" runoff following drought





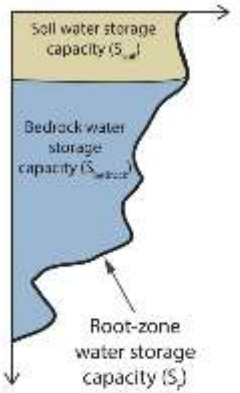
Lapides et al, in review

Preprint: https://eartharxiv.org/repository/view/3142/

Take homes

Root-zone storage deficits are a powerful organizing framework for understanding and predicting stream and tree response to drought

≈



Soil AND bedrock water storage are required to explain deficit magnitudes

Half the forest is underground; we need to dig deeper and peer inside hillslopes to understand the future of forest water resources

Dawson et al, 2020

THANKS!

Please feel free to email thoughts/questions:

david.dralle@usda.gov

Thermal stratification in river pools – Field and numerical modeling study

Todd H. Buxton[1], Yong G. Lai[2], Nicholas A. Som[3,4], Eric Peterson[1], Ben Abban[2]

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[2]Technical Service Center, U.S. Bureau of Reclamation, Denver, CO
[3]U.S. Fish and Wildlife Service, Arcata Field Office, Arcata, CA
[4]California Polytechnic University, Humboldt, Arcata, CA

Field assistance

Jeanne McSloy, Kevin Held, Oliver Rogers, James Lee, Brandt Gutermuth (TRRP), Ken Lindke (CDFW), Kyle DeJuilio, Jon Guczek, Chris Lasdoki (Yurok Tribe)

- Motivation for study

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- Study objectives
  1. Document field conditions that form or destroy thermal stratification in river pools.
  2. Identify the relative importance of variables affecting stratification.
  3. Validate a 3D model (U^2RANS) for predicting critical flows for stratification.

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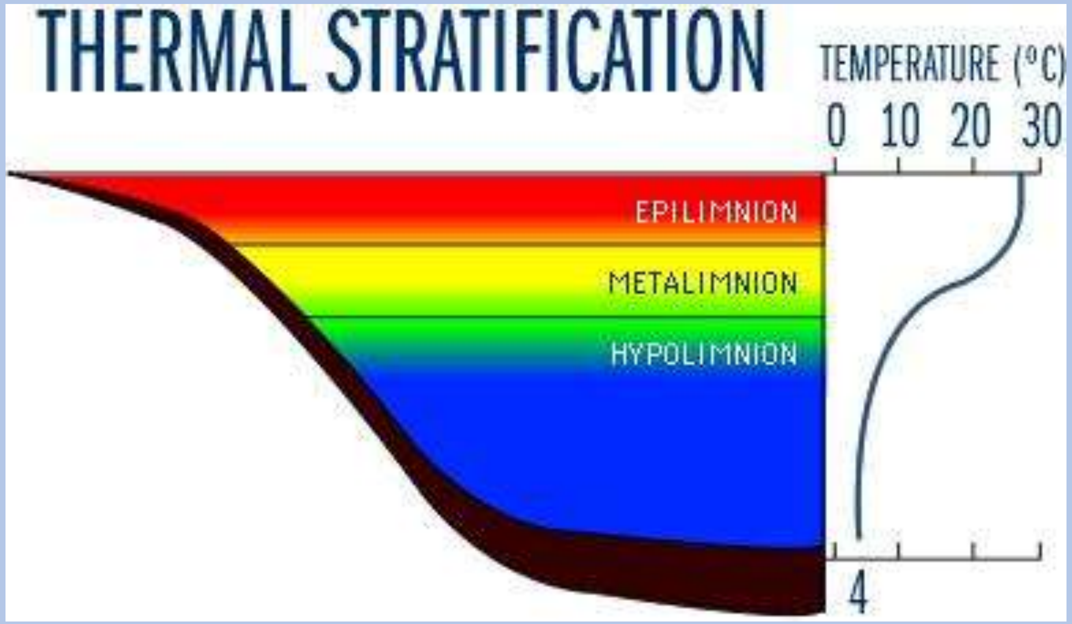

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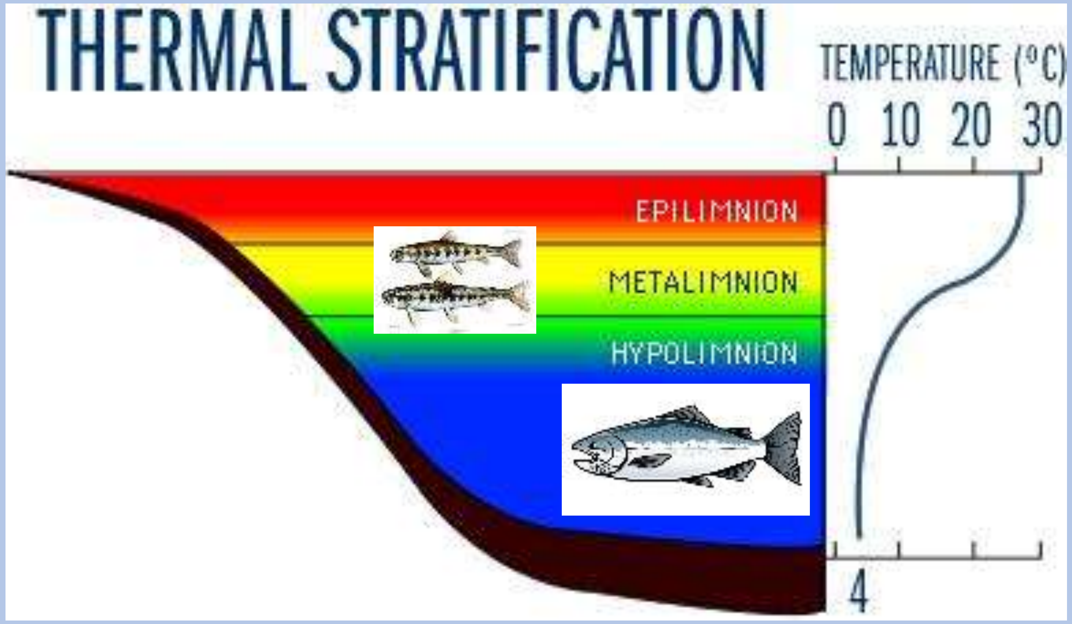

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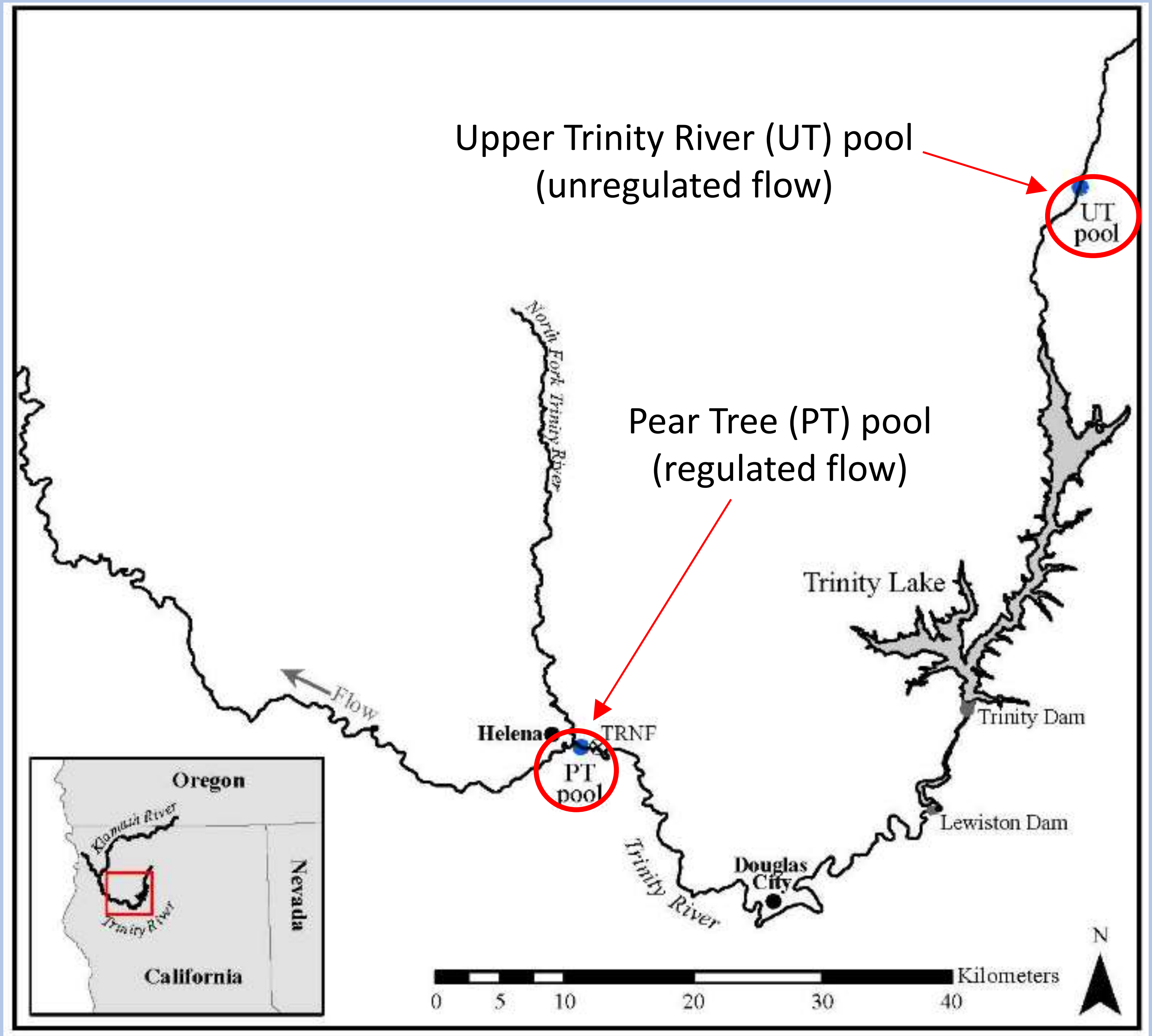
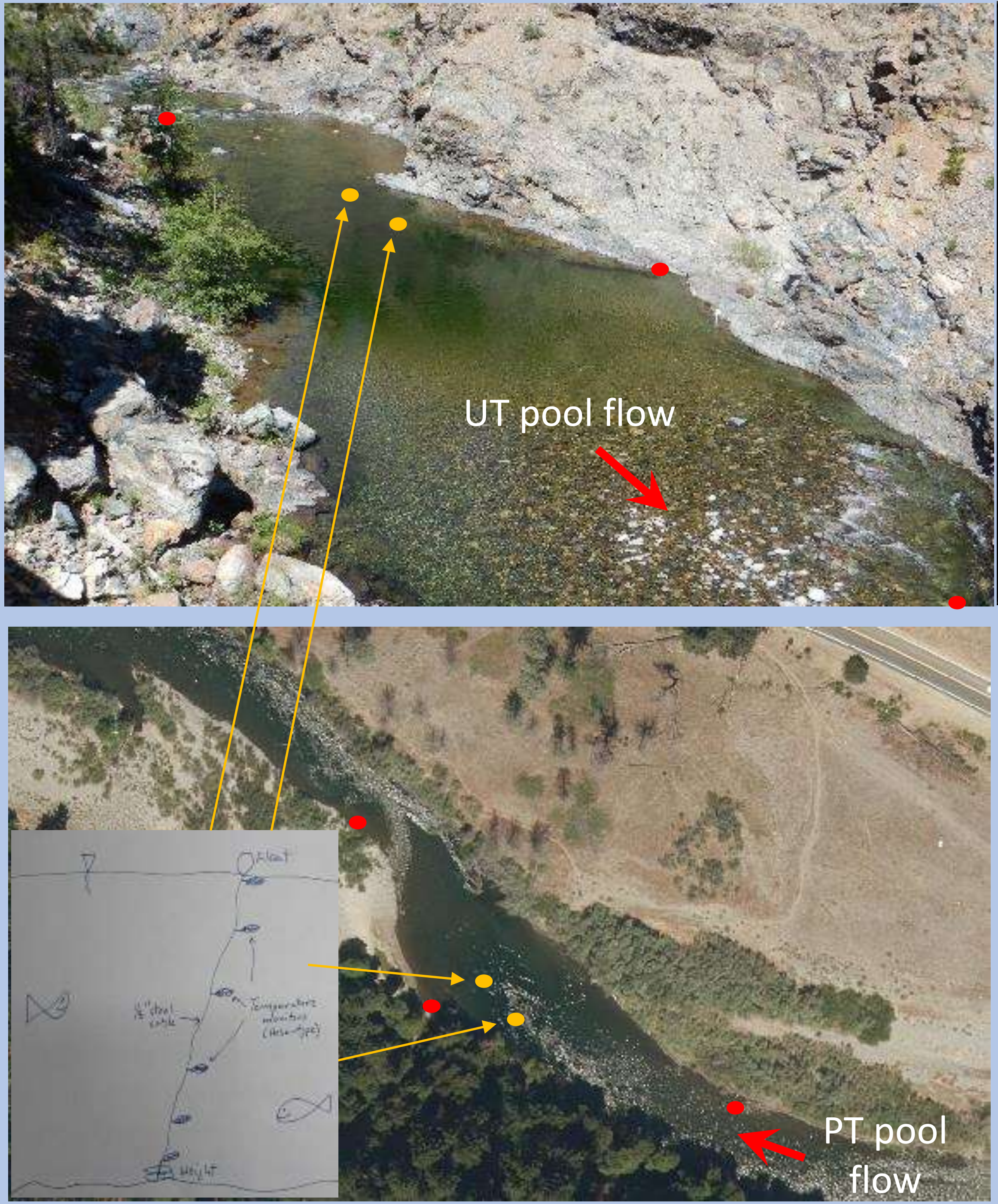
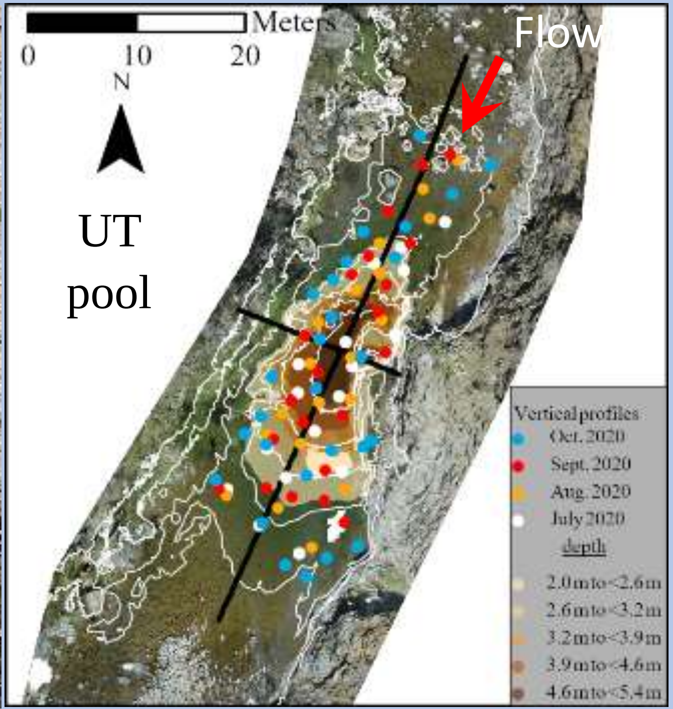
- What is thermal stratification? Arrangement of water temperatures in a thermocline - warm water at the surface, colder water deep.
- Why is stratification important? Enables species to access a wide range of water temperatures.
- Requirements for stratification in river pools:
    - Low discharge to prevent thermal mixing
    - Large pool to disperse fluid momentum
    - Deep water to attenuate solar radiation
    - Water temperatures that diverge in space <u>or</u> time
- Cold water sources = hyporheic or spring, <u>overnight discharge</u>
- Warm water source = <u>solar heated water in daytime</u>

Study pools


Upper Trinity River (UT) pool
(unregulated flow)
UT
pool
Pear Tree (PT) pool
(regulated flow)
North Fork Trinity River
Trinity Lake
Flow
Helena
TRNF
PT
pool
Trinity Dam
Lewiston Dam
Douglas
City
Trinity River
Oregon
Klamath River
Nevada
Trinity River
California
Kilometers
0
5
10
20
30
40
N

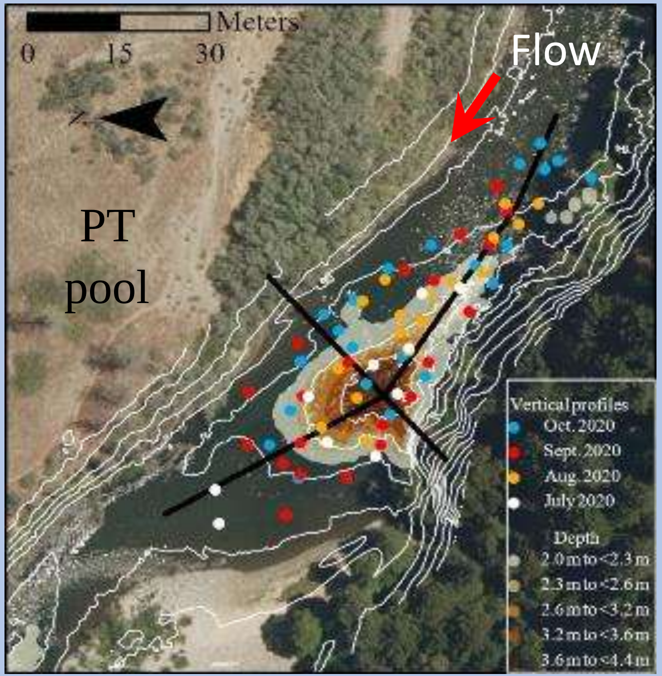




Upper Trinity River (UT) pool

Summer baseflow 0.5 m^3/s
Max depth at baseflow 5.1 m
Surface area ≥2 m depth 193 m^2

Study period 6/10 to 11/22/2020

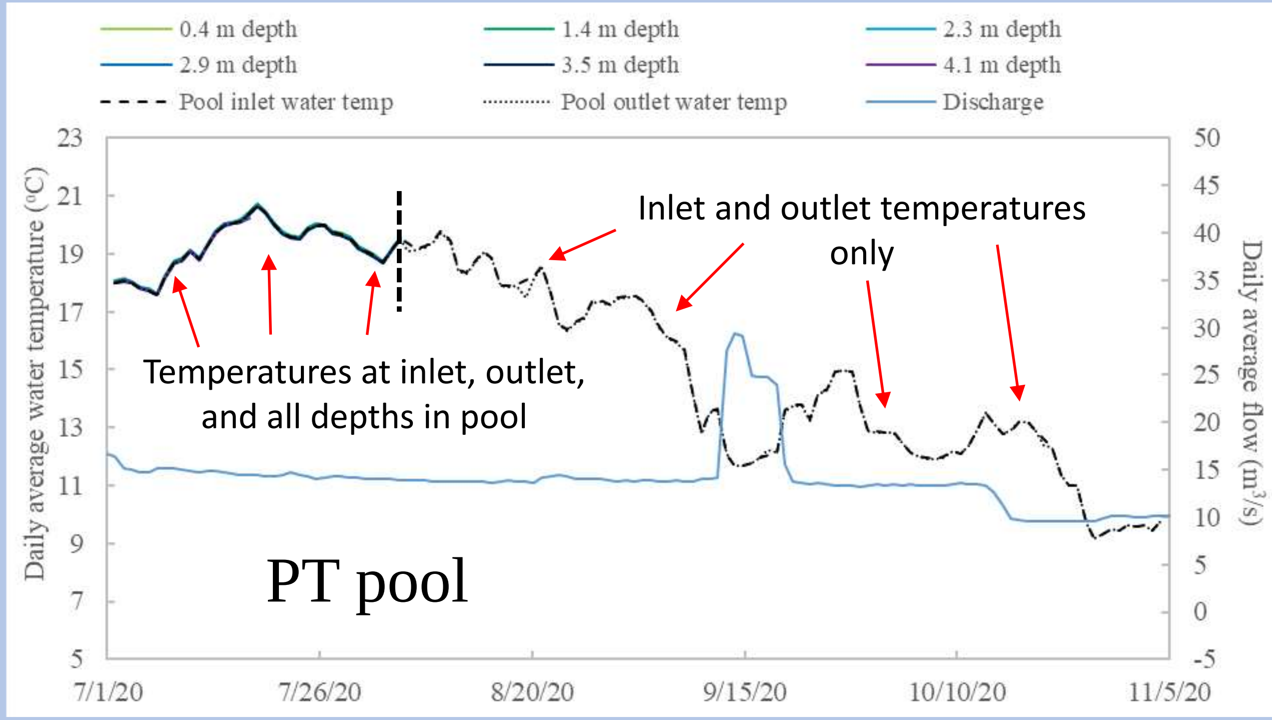


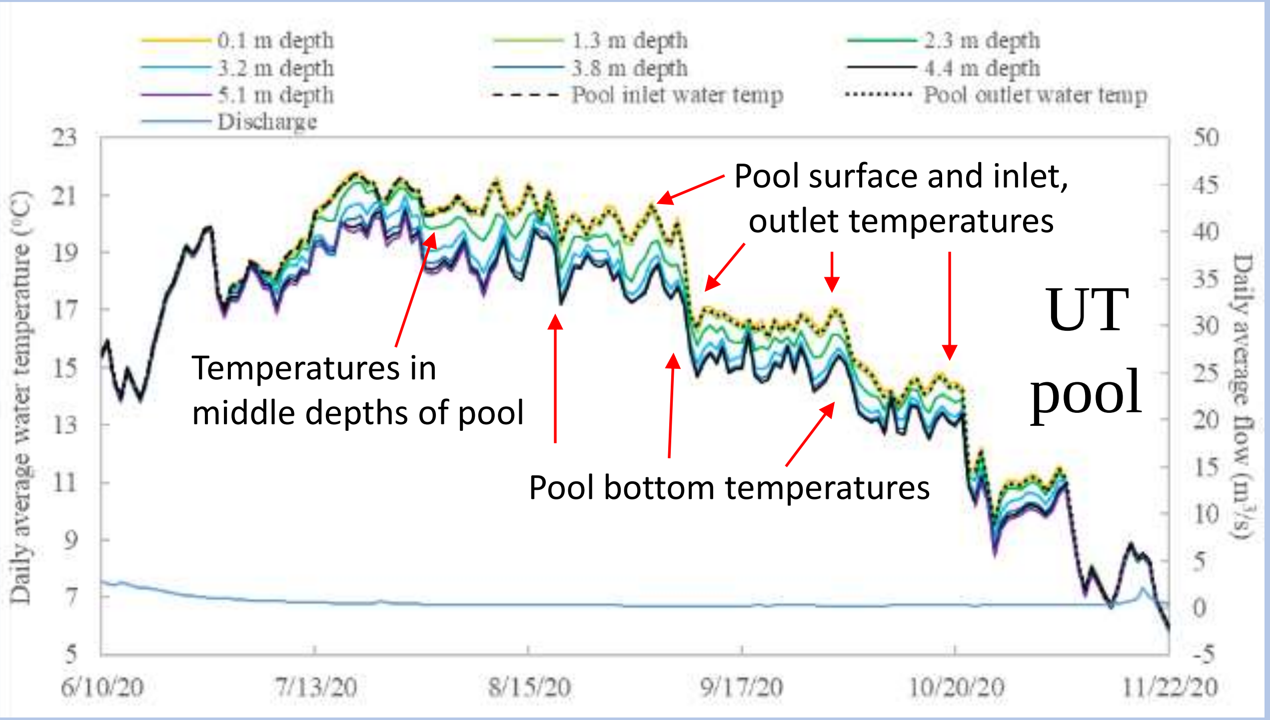
Pear Tree (PT) pool

Summer baseflow 14.2 m^3/s
Max depth at baseflow 4.4 m
Surface area ≥2 m depth 505 m^2

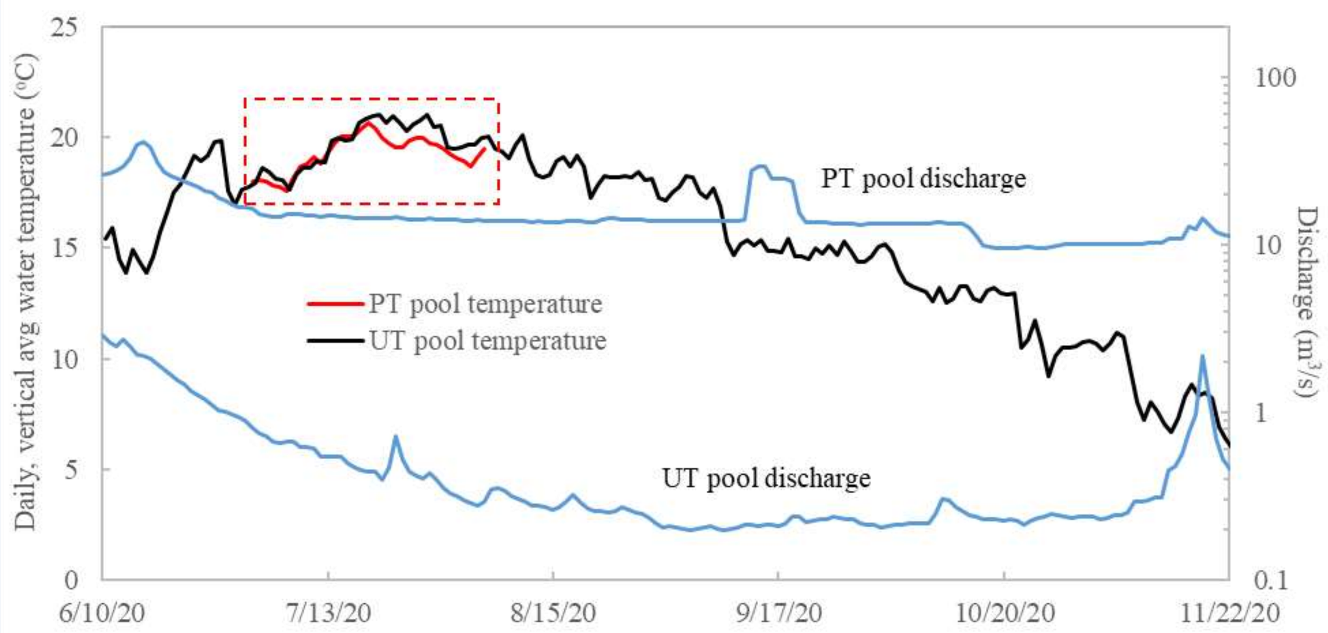
Surface area ≥2 m deep water in PT pool 2.6x larger than UT pool

Study period 7/1 to 11/5/2020.
except stringers 7/1-8/5 (stolen)

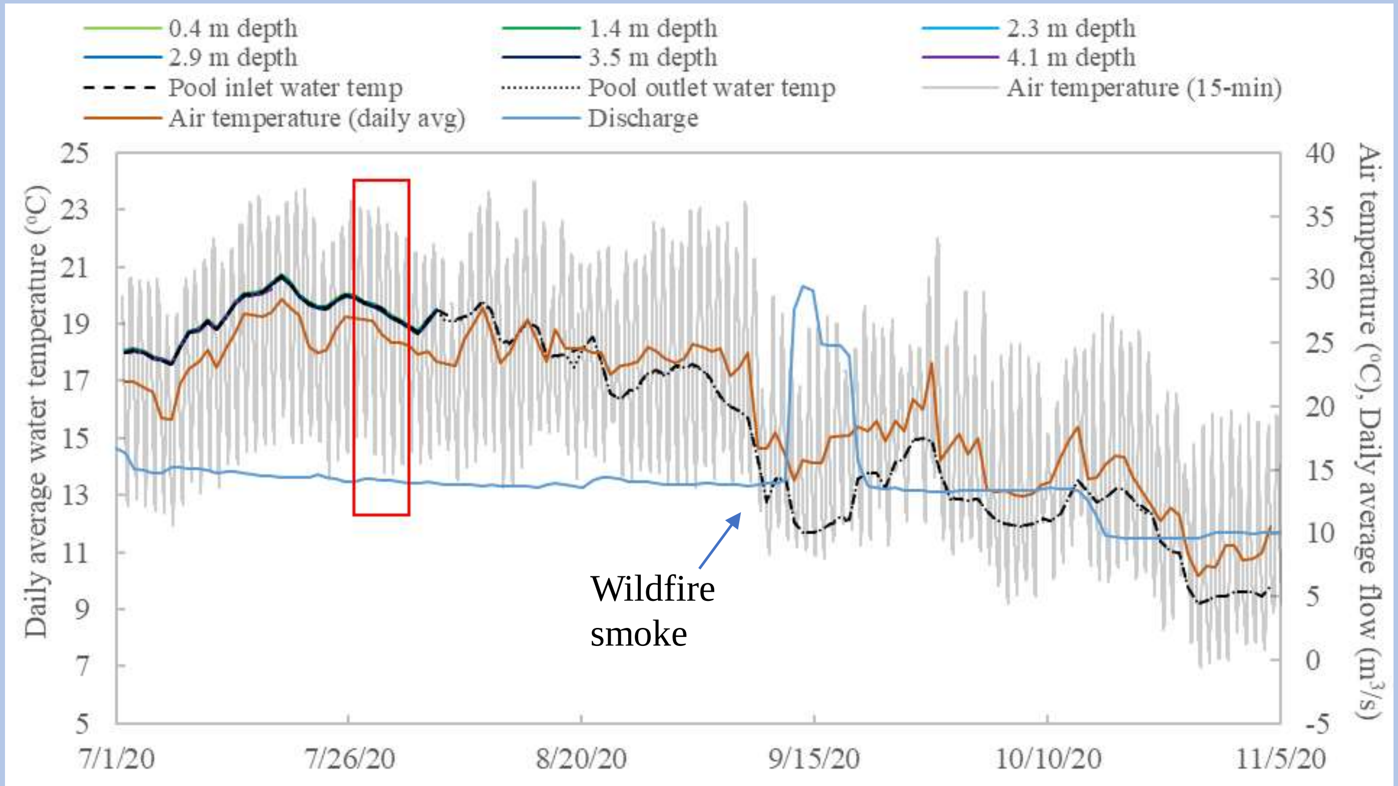


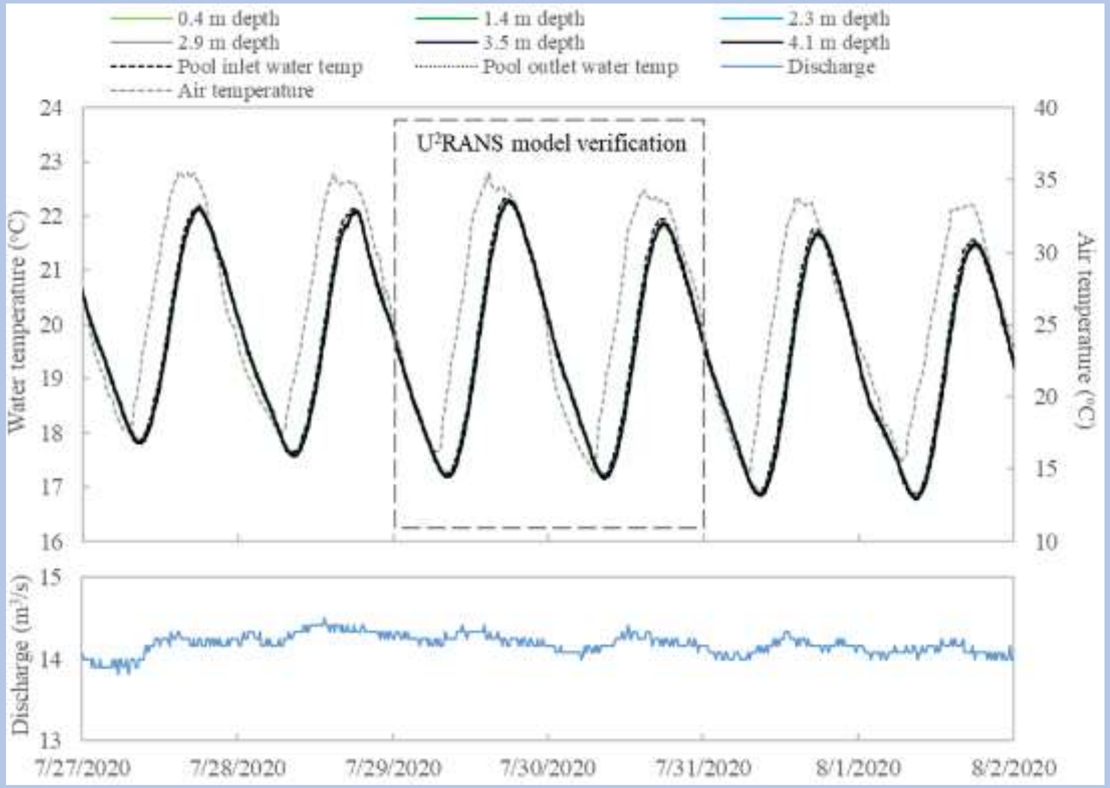


PT and UT pool results



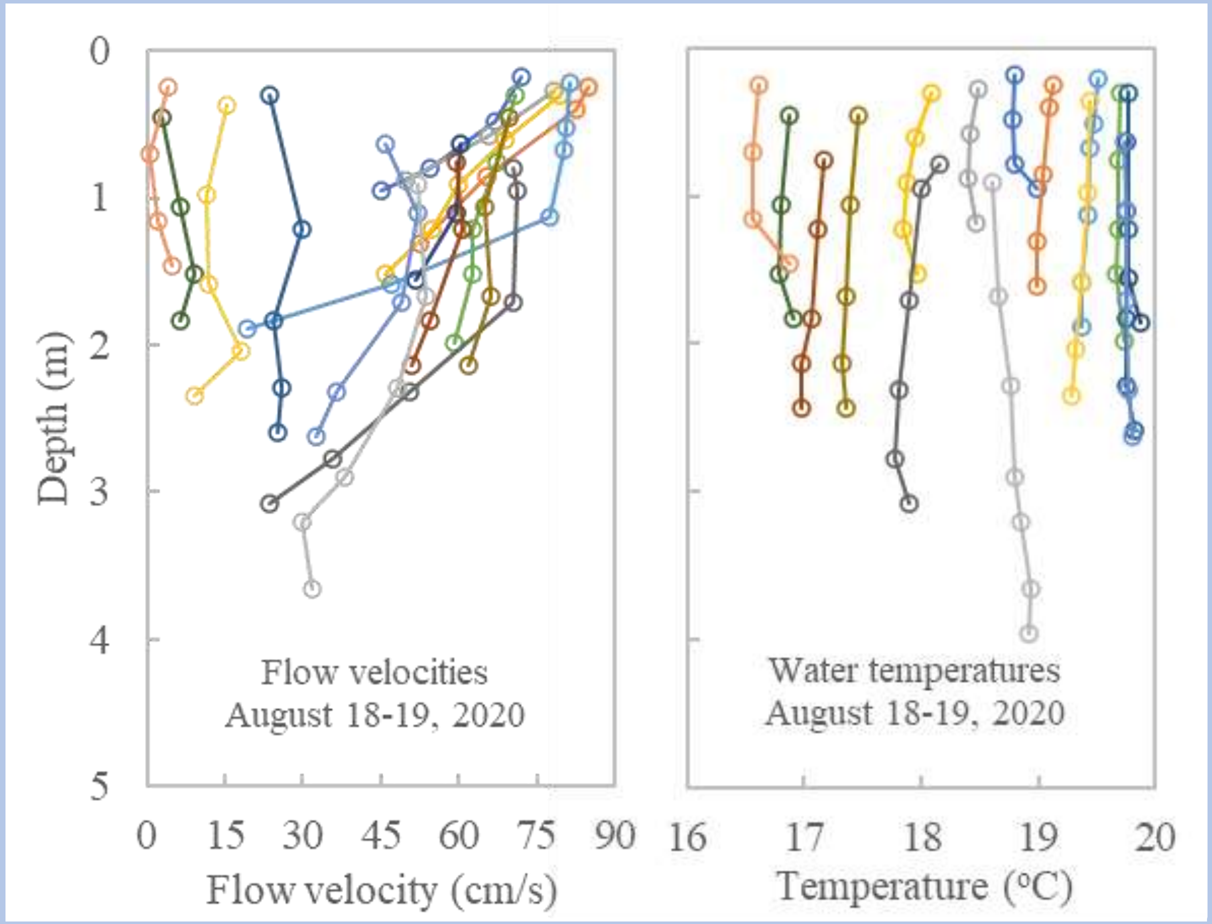
PT pool results

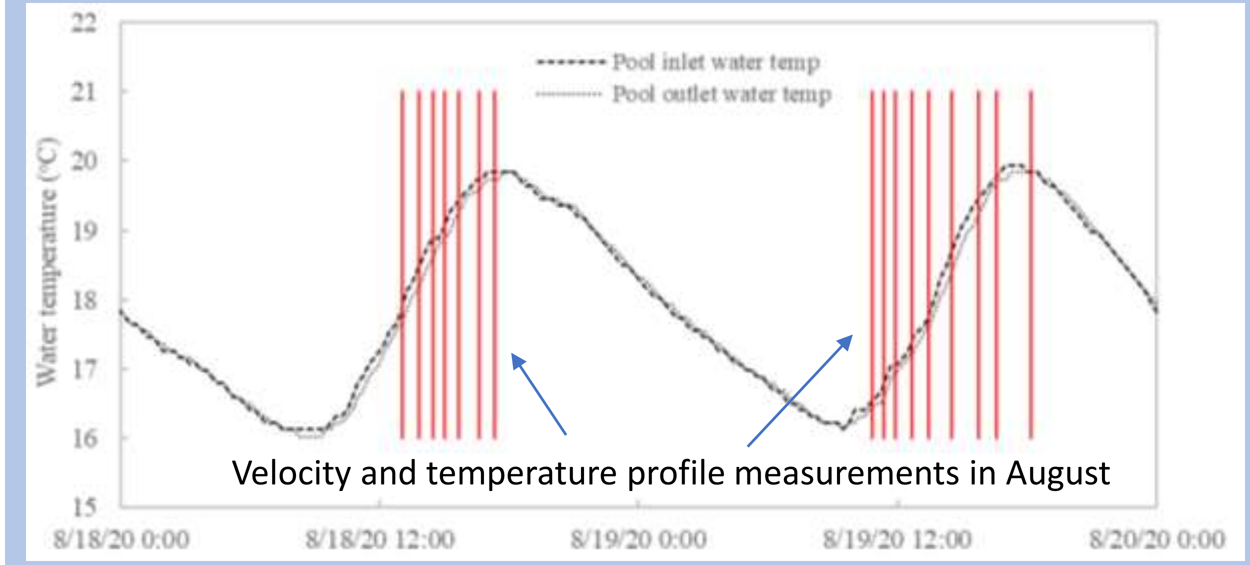




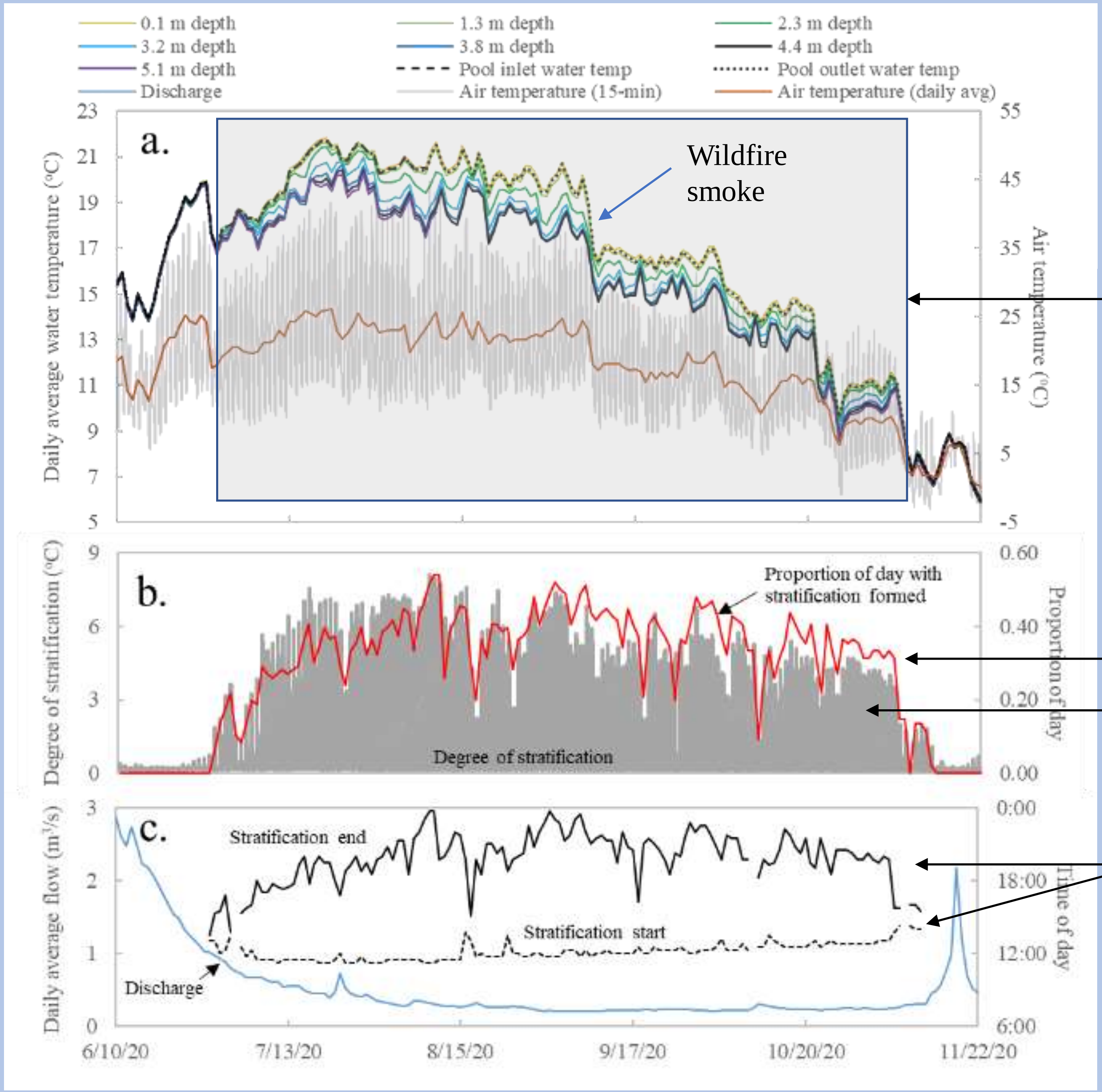
PT pool results

Vertical velocity and temperature profiles



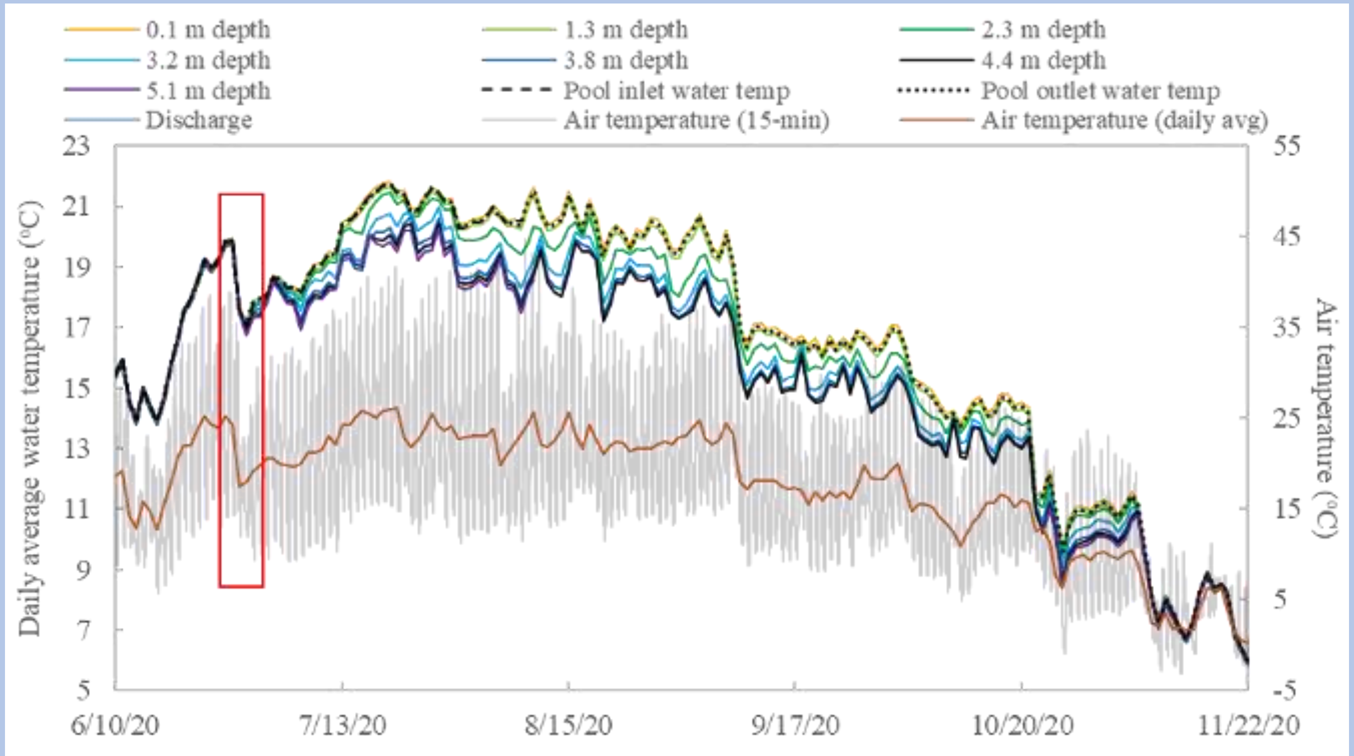


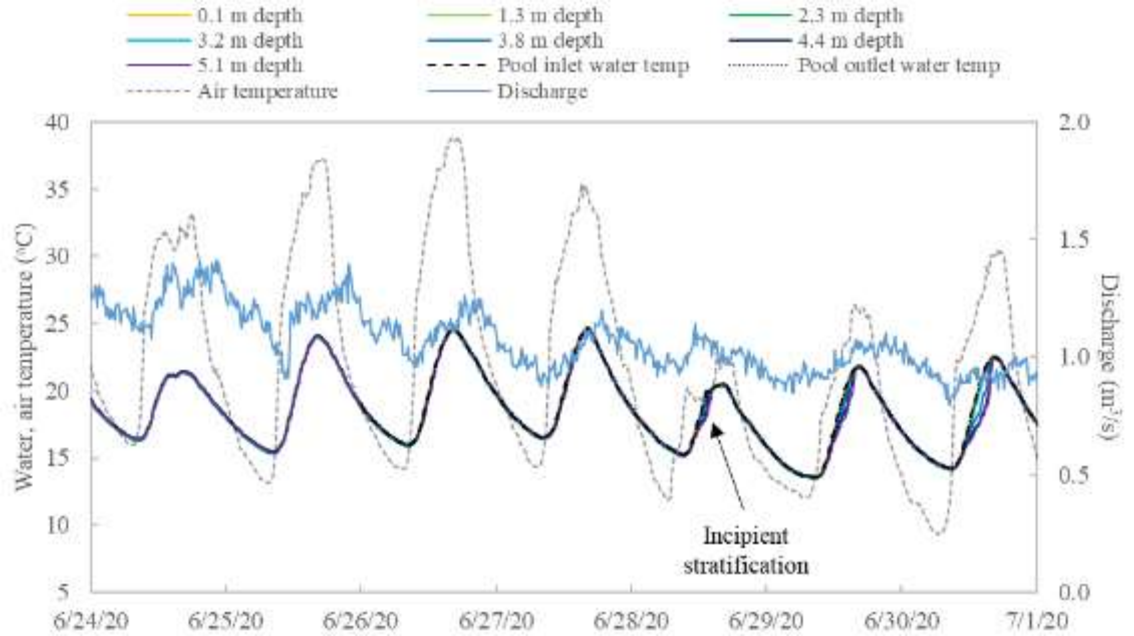
UT pool results



- Pool stratified daily from June 28-November 11
- Avg, max daily period with stratification 8, 13 hrs
- Degree of stratification up to 8.1 ^{o}C
- Stratification formed between 11 am and 2 pm, destroyed between 1 pm and 1130 pm

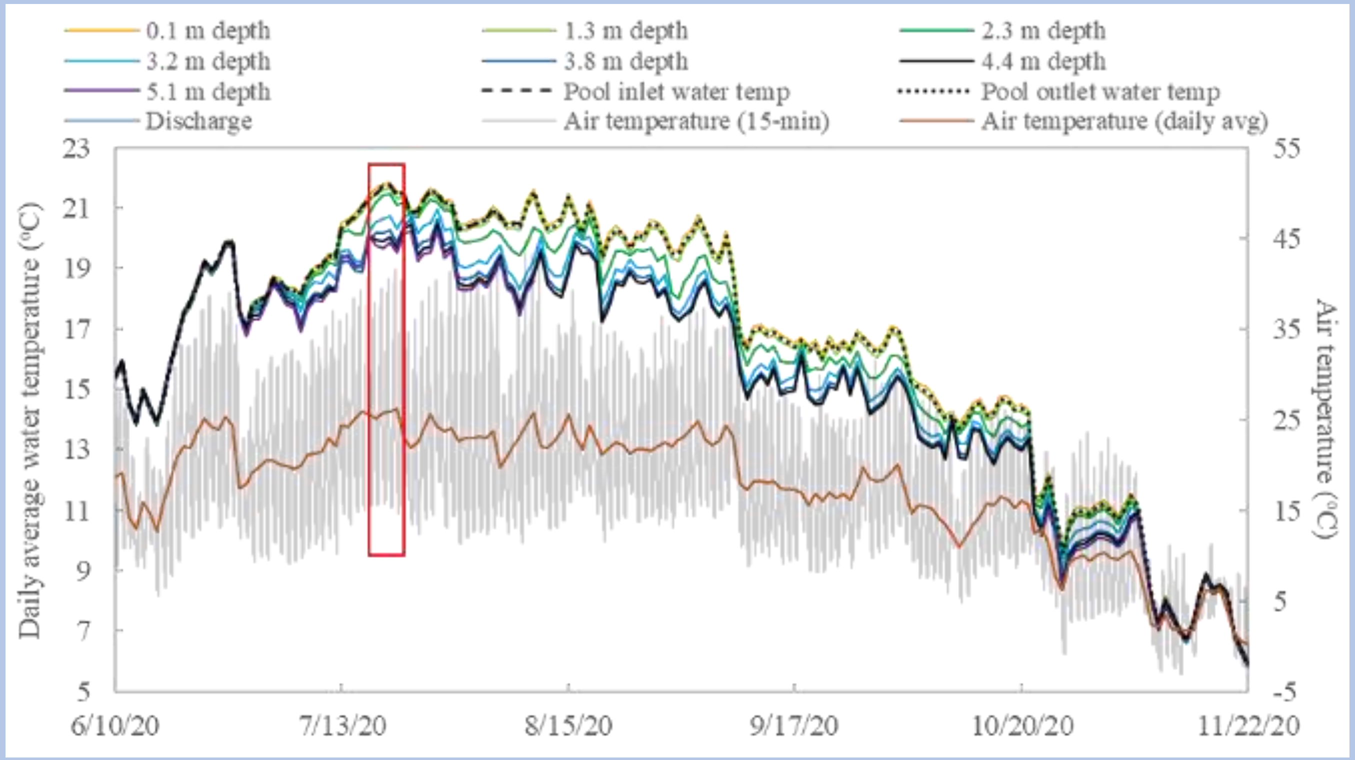
UT pool results

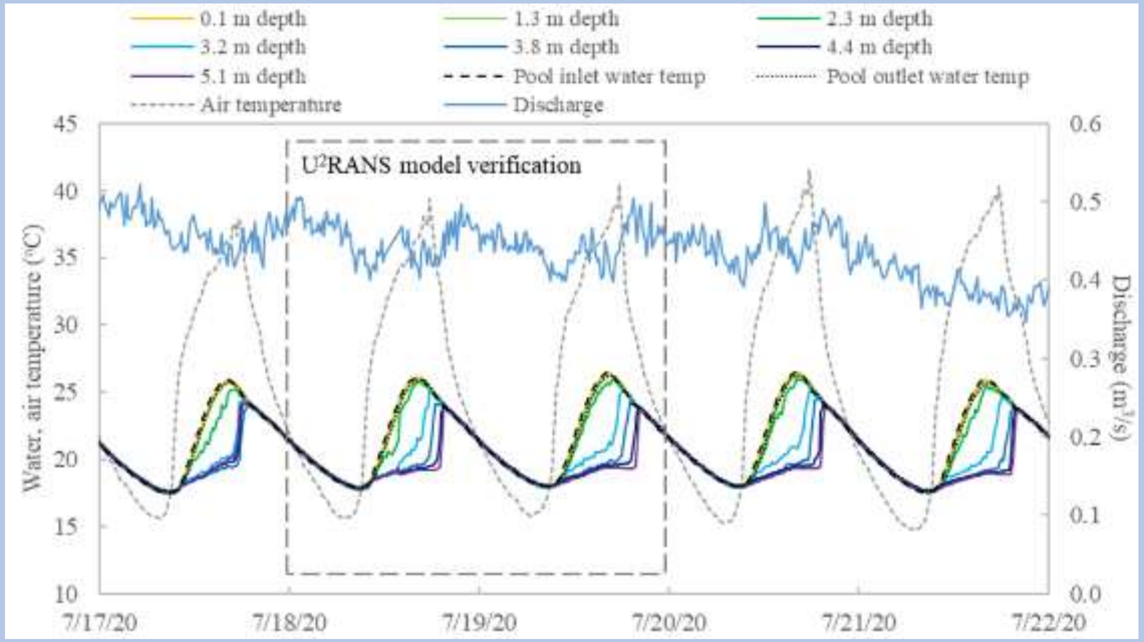




Stratification formed at 1.01 m^3/s on June 28

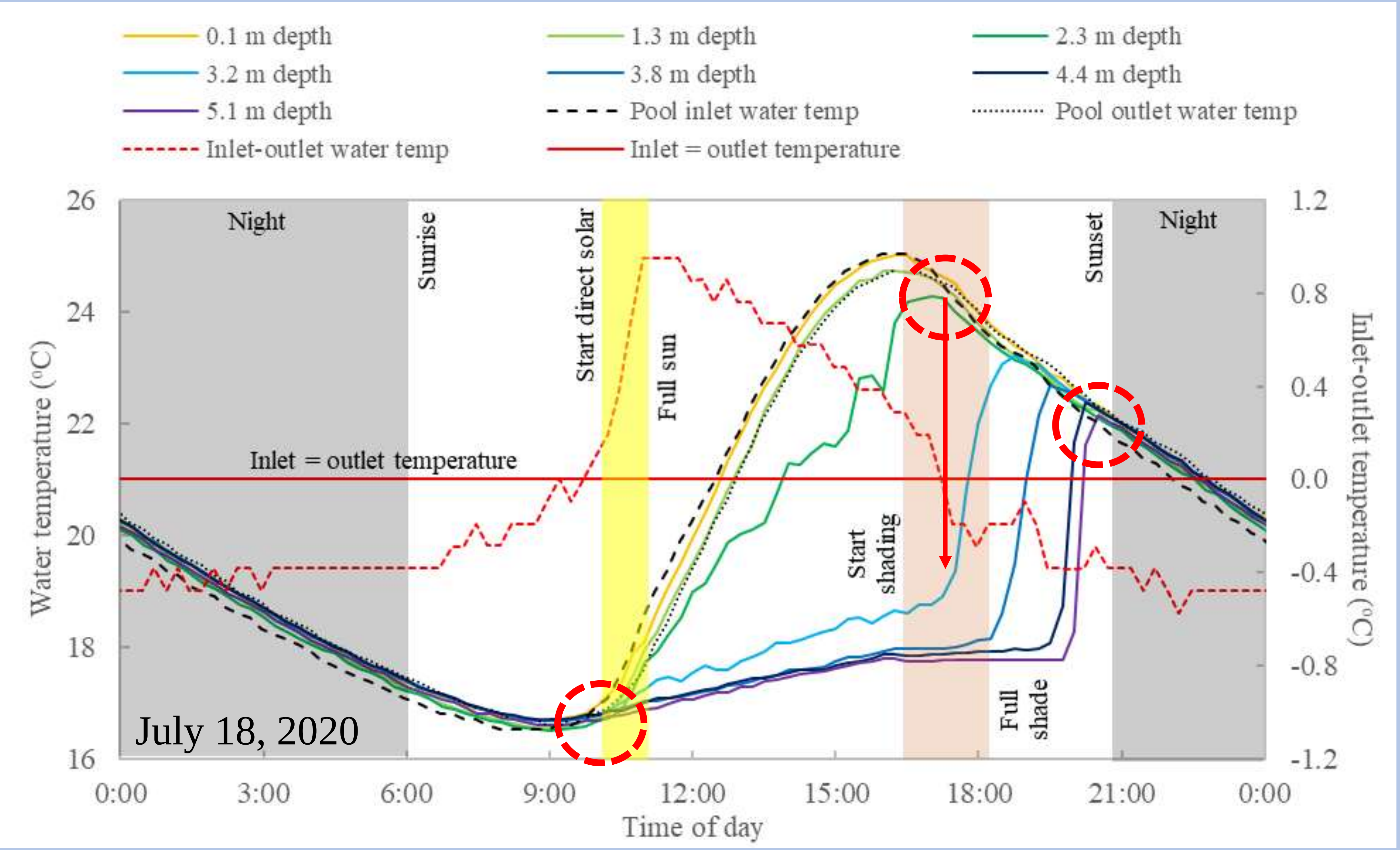
UT pool results





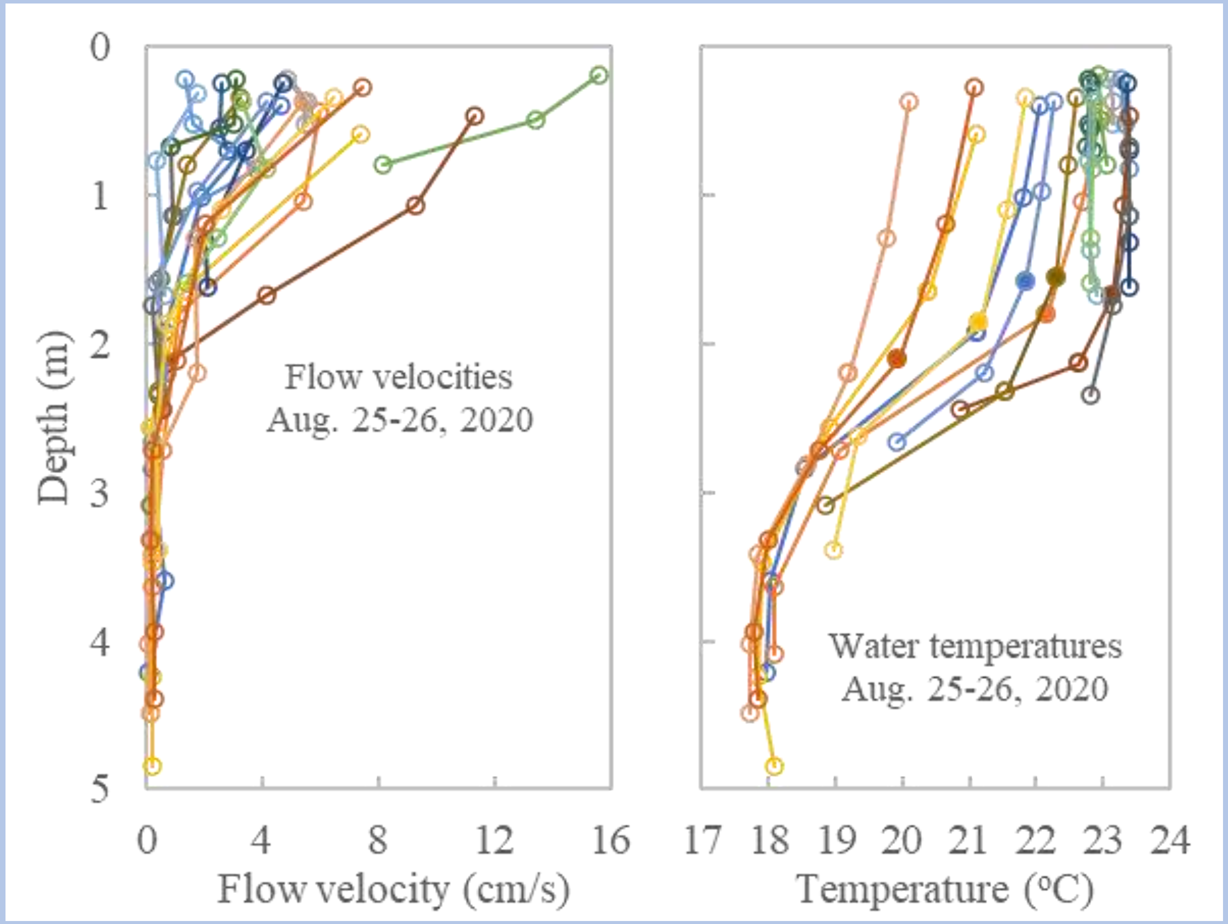
Diurnal cycle of stratification formation and destruction

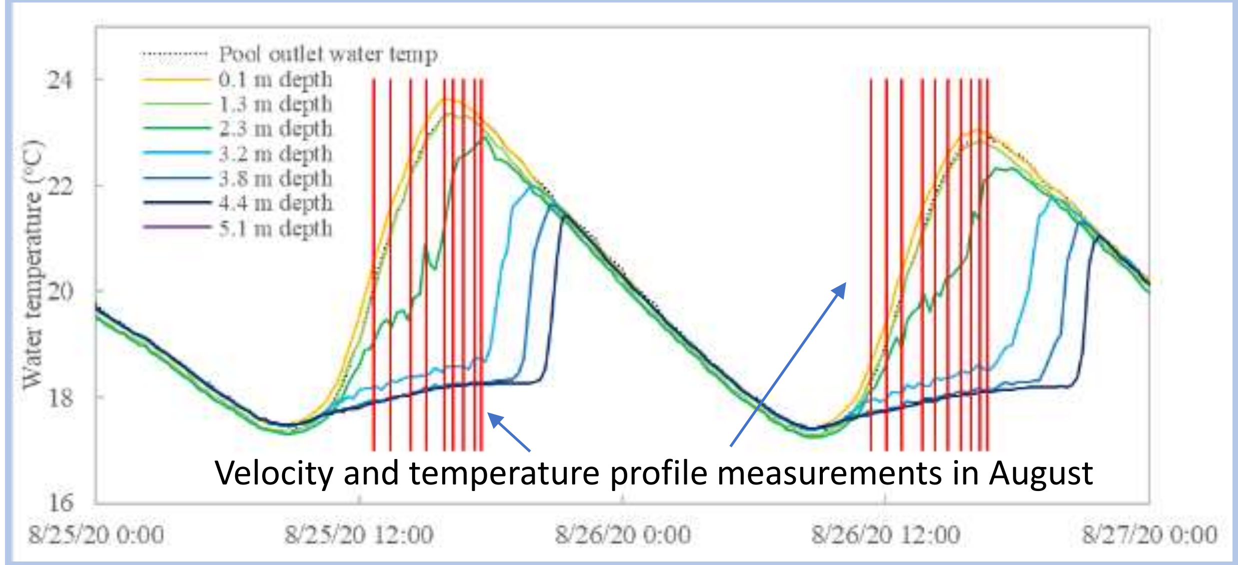
UT pool results



UT pool results

Vertical velocity and temperature profiles





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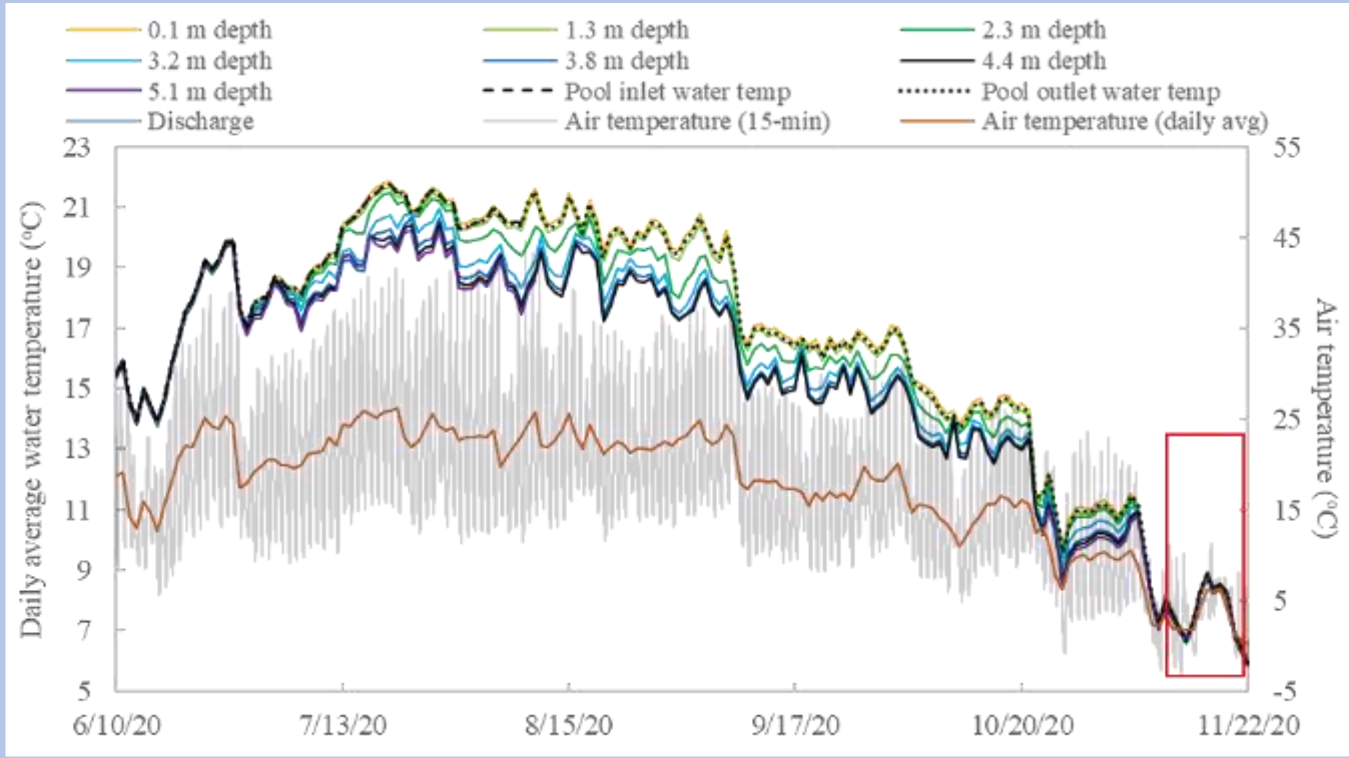
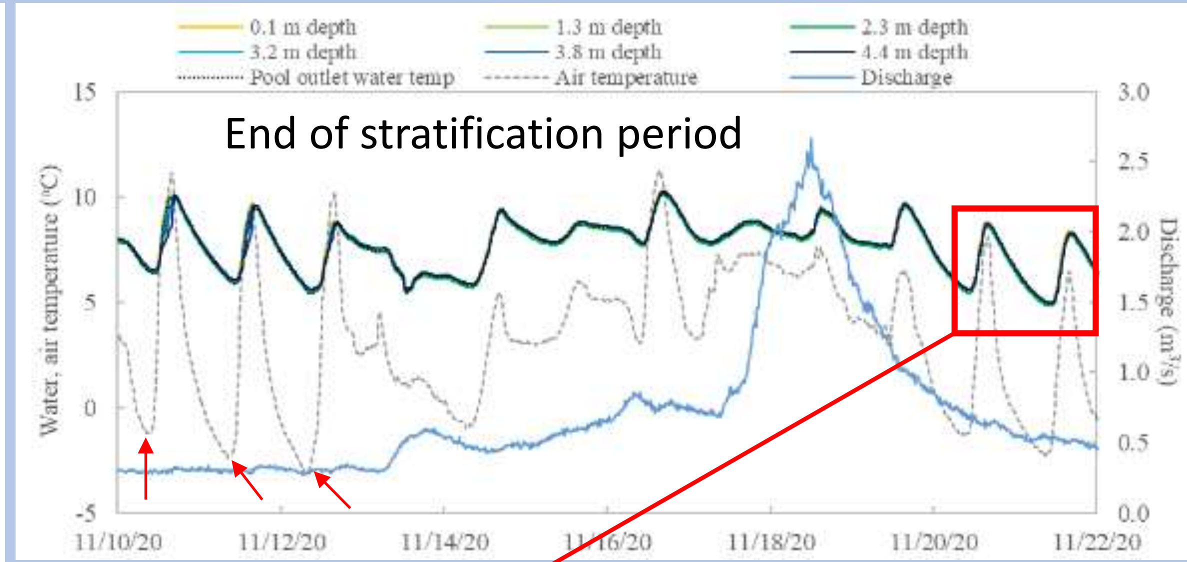
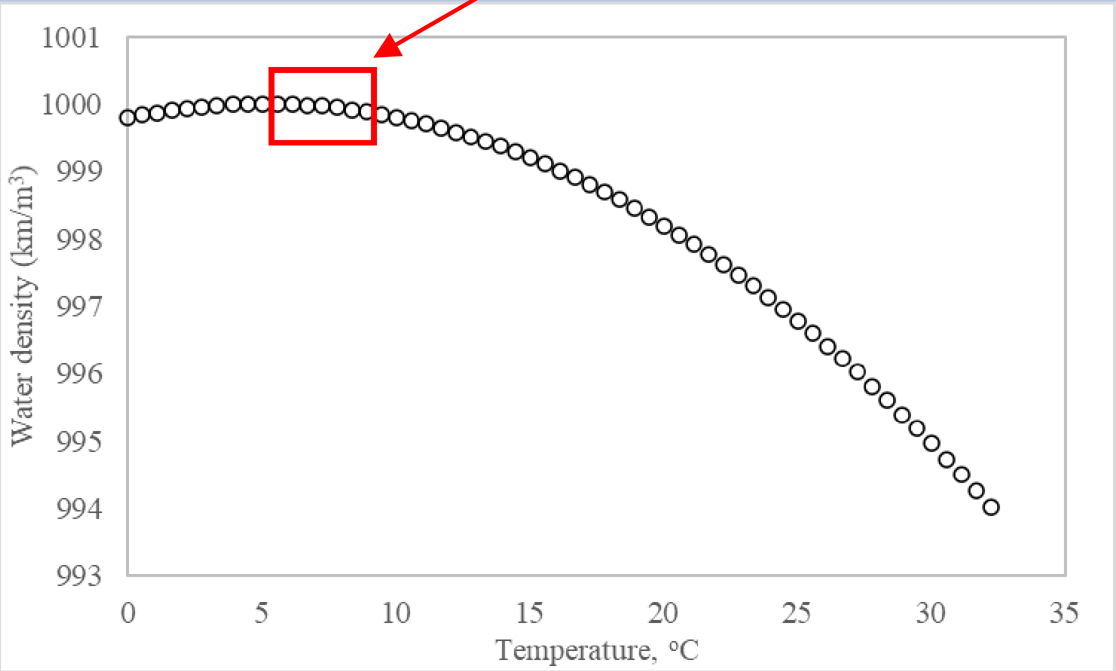






Numerical modeling

- 3D CFD model U²RANS (Unstructured, Unsteady Reynolds-Averaged Navier-Stokes) solves equations for the mass, momentum, and energy conservation laws. Energy conservation equation:

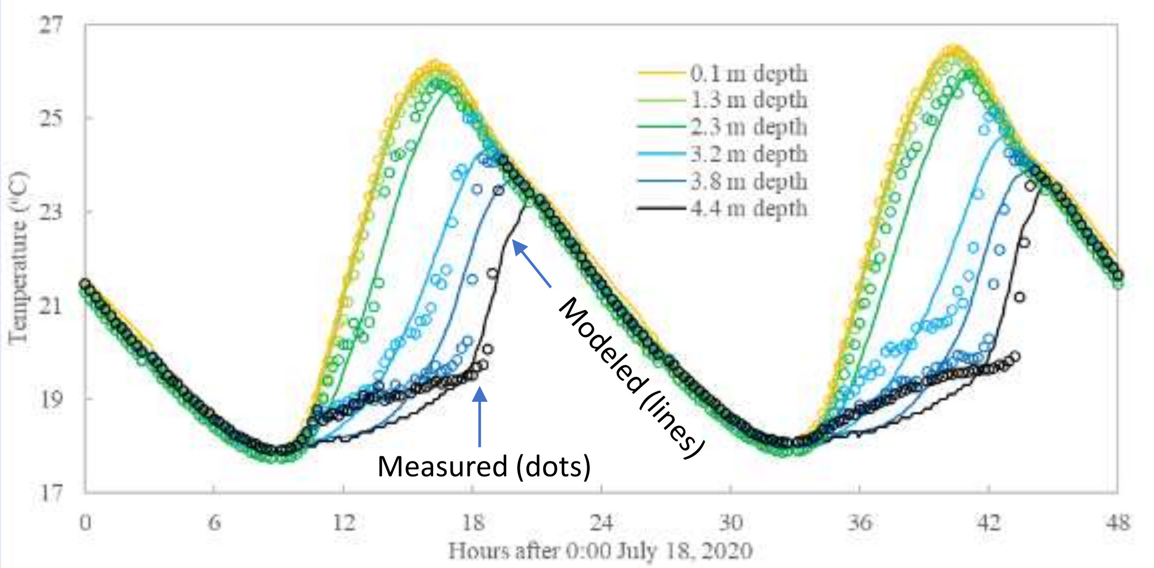
$$\frac{\partial T}{\partial t}+\frac{\partial (U_j T)}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\alpha\frac{\partial T}{\partial x_j}-\overline{T' u_j}\right)+\frac{q_s}{\rho C_P}$$

  where t is time and field measured variables T and T' as daily mean and change in water temperature at the pool inlet, U_j and u_j are j^{th} components of the mean and fluctuating velocities in the pool, α is fluid thermal diffusivity, ρ is water density.

- Governing equations solved in unstructured 3D mesh with cells in arbitrary shapes that conform to terrain. UT pool mesh = 152k cells, PT pool mesh = 230k cells.
- Model parameterized with field data and ran in 1 s timestep for verification. Additional runs to estimate critical discharges for stratification and explore drivers of stratification.

Numerical modeling – verification

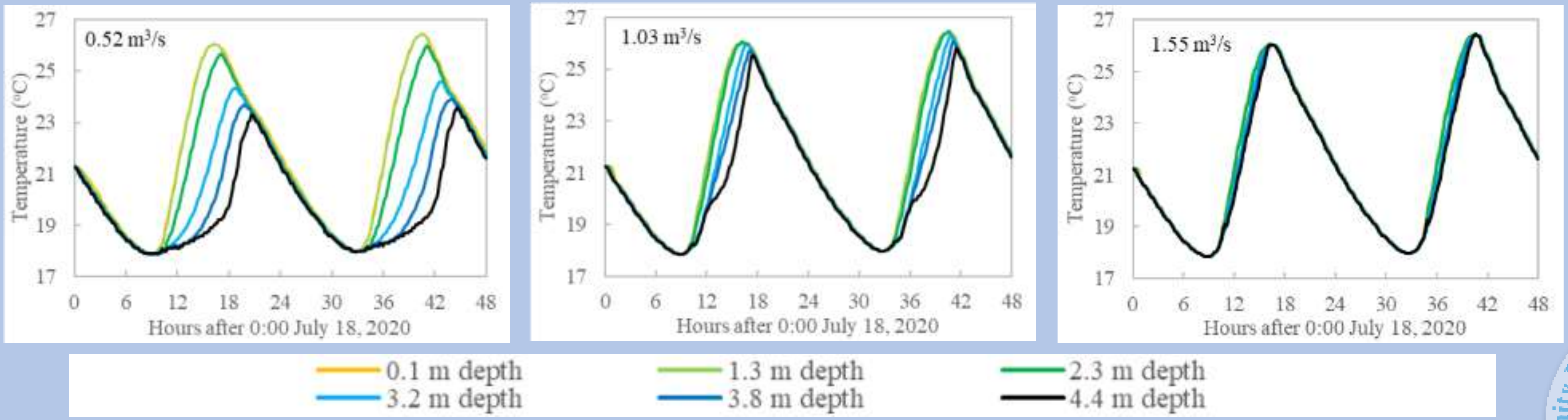
- UT pool: predictions within 0.5 °C of observed temperatures 85% of the time. Model error ≤1.8 °C when stratification initiates. Model predicted the observed diurnal cycle of stratification formation and destruction.



- PT pool: model predicted isotherms as observed in the field – temperature differences between simulated and observed profiles ≤0.25 °C.

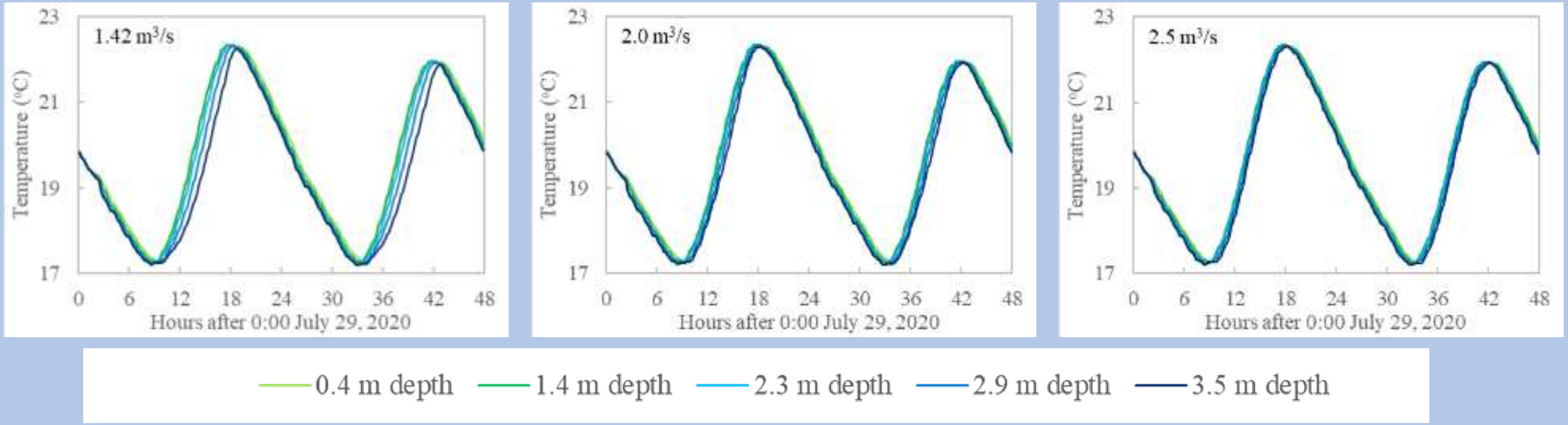
Numerical modeling – critical discharge prediction

- UT pool: Model runs at 0.52, 1.03, and 1.55 m^3/s estimate critical discharge for stratification ~1.0 m^3/s, agrees with observed discharge that formed stratification on June 28.



Numerical modeling – critical discharge prediction

- PT pool: Model runs at 1.4, 2.0, and 2.5 m^3/s estimate stratification initiates at around 2.0 m^3/s.

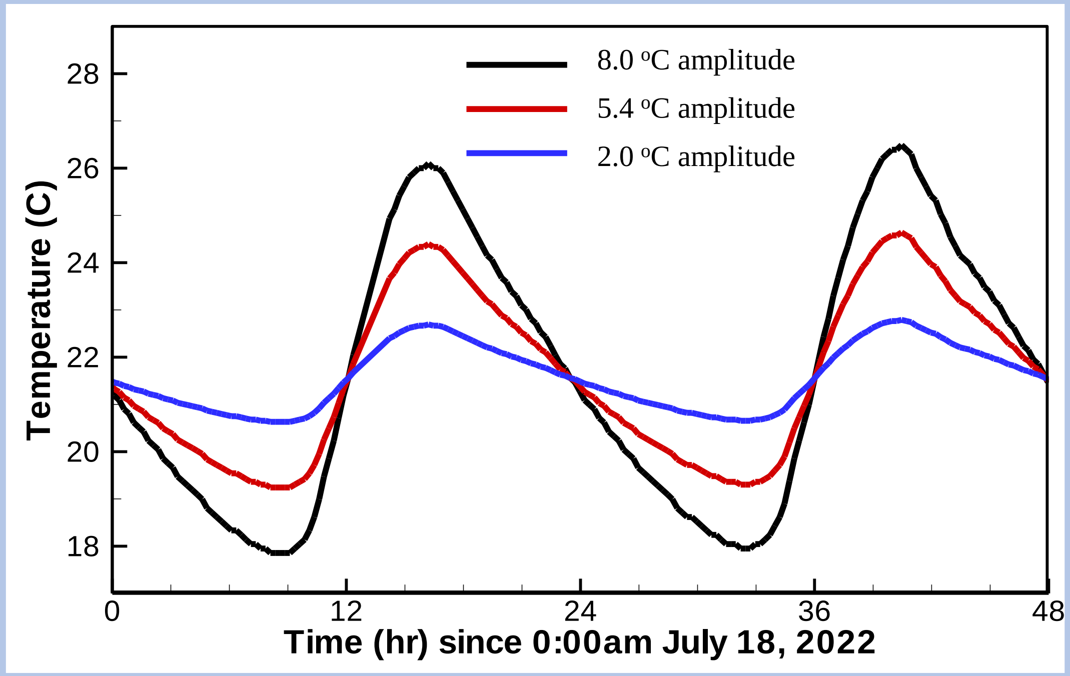


- Higher critical discharge for stratification at PT pool reflects its larger pool size for dispersing inlet flow velocities – thermal mixing is relatively low at higher flows than at UT pool.

Trinity River Restoration Program
Restore • Adapt • Improve

Numerical modeling – strength of stratification

- Model runs at UT pool with discharge (0.52 m^3/s) and average inlet water temperature constant (21.6 ^oC), vary amplitude of diurnal change in water temperature from 8, 5.4, and 2.0 ^oC.



- Predicted maximum degrees of stratification respectively 7.0, 4.5, 1.6 ^oC indicates stratification stronger and temperature diversity greater in pools subjected to wider variations in inlet water temperature at sub-critical flows.

Summary

- Unnaturally high, regulated summer baseflow on the Trinity River generates spatially uniform temperatures in pools. This prevents juvenile salmonids from preferentially accessing temperatures to maximize growth.
- Stratification was ≤8.1 ^{o}C at UT pool, yet daily, vertical average temperatures equaled those at PT pool. This suggests that lowering dam releases to stratify pools will provide both juvenile rearing and adult holding habitat with much less water than is currently released in summer.
- At sub-critical flows, cold water delivered at night is stored in pool bottoms by day making stratified pools a thermal sink in day and thermal source at night, which helps regulate downstream water temperatures.
- Thermal stratification requires sub-critical flows, divergent temperatures, and sufficiently warm water. Lacking any of these and stratification will not form.
- Stratification can be accurately modeled with U^{2}RANS. The model solves the mass, momentum, and energy conservation laws and is universally applicable.

Additional information…questions?

- Next steps: 1) Apply U^{2}RANS on 14 additional pools between PT pool and Lewiston Dam to further evaluate critical discharges for thermal stratification; 2) Evaluate effect of critical flows on hydraulic geometry, flow temperatures, and species requirements in summer in habitats outside of pools; 3) Recommend lowering summer baseflow releases from Lewiston Dam?
- Current study being published here:

  Buxton T.H., Lai Y.G., Som N.A., Peterson E., Abban B. (*in author review*), The mechanics of thermal stratification in river pools. Ecological Engineering.
- U^{2}RANS developed by Lai et al (2003) and modified by Lai et al. (2022):

  Lai, Y.G., Weber, L.J., Patel, V.C., 2003. Non-hydrostatic three-dimensional method for hydraulic flow simulation - Part I: Formulation and verification. J. Hydraulic Engineering, ASCE 129, 196–205.

  Lai Y.G., Buxton T.H., Abban B., 2022. 3D CFD Modeling of river pool stratification characteristics, World Environmental & Water Resources Congress, June 5-8, 2022, Atlanta, Georgia.

A Decade of Data and Lessons Learned from Restoring a Sierra Meadow Complex

David Shaw, PG, Balance Hydrologics
Beth???, Truckee River Watershed Council
Other?

Balance Hydrologics

22 April 2022

Presentation Outline

01 Groundwater development and edge-of-range fish

02 The Santa Margarita streams

03 Accretion surveys

04 Five metrics

01 Groundwater and edge-of-range fish species


02
The Santa Margarita Streams

aa. The flow

bb. The aaquifer

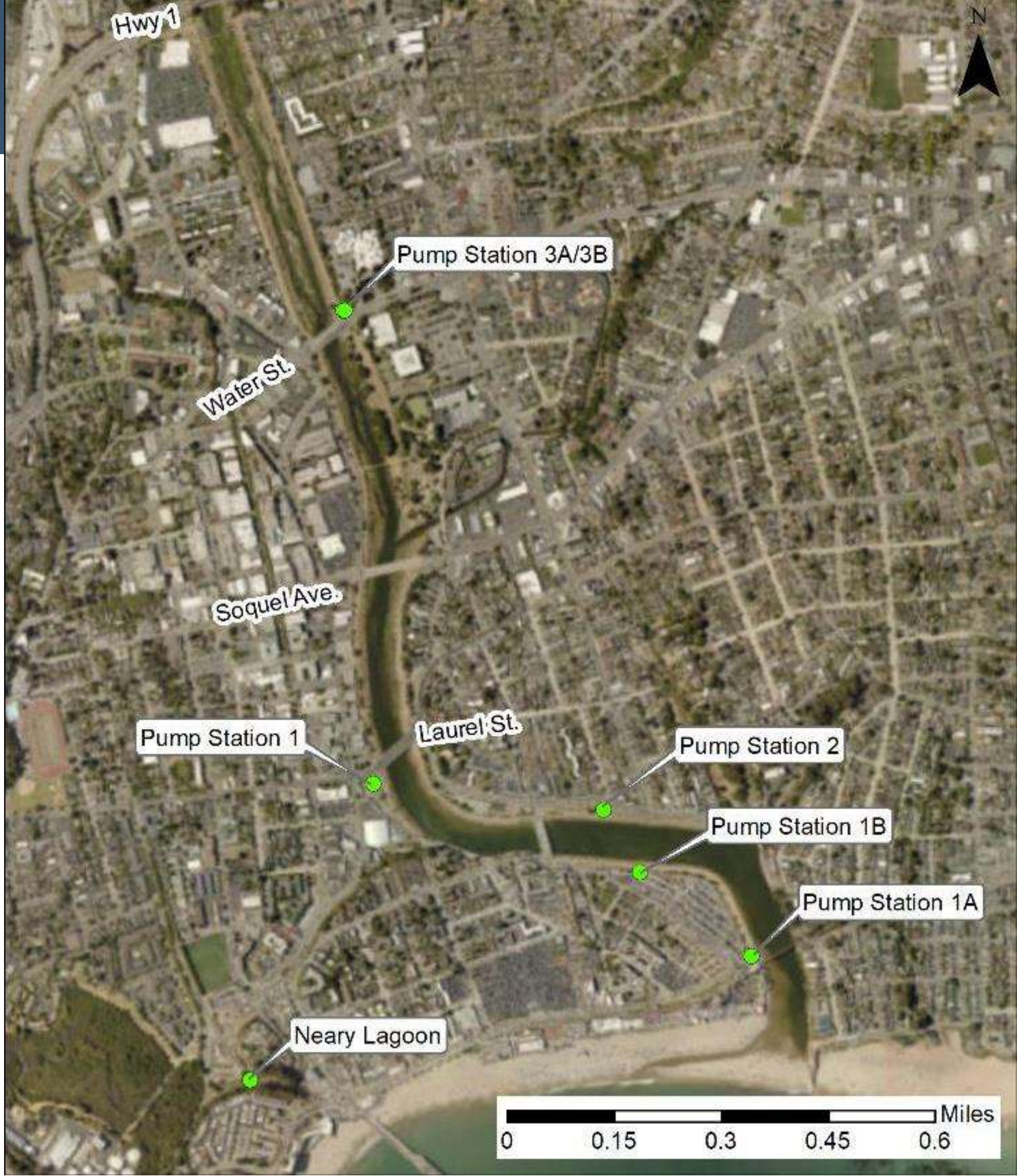
cc. The watershed

dd. The sediment The

Full Page Image

Slide with Image & Text

- You should probably pull together a few slides of our approach to have ready if need be



Slide with Image & Text

- Vertically open system without significant partings

- Simple recharge system

Metric #1 Summer streamflow

- Summer Streamflow
  - Habitat connection: Stream **is** the habitat for salmonids and other key fish species; supports riparian habitat, which holds banks together and provides shade,
    - Measurements: Double-precision streamflow discharge measurements
    - At locations where bedrock focuses flow
    - At locations averaging about 0.5 miles apart
    - Measurements worked up within a day or two, and repeated if unsatisfactory

"Double-Precision Streamflow Measurements"

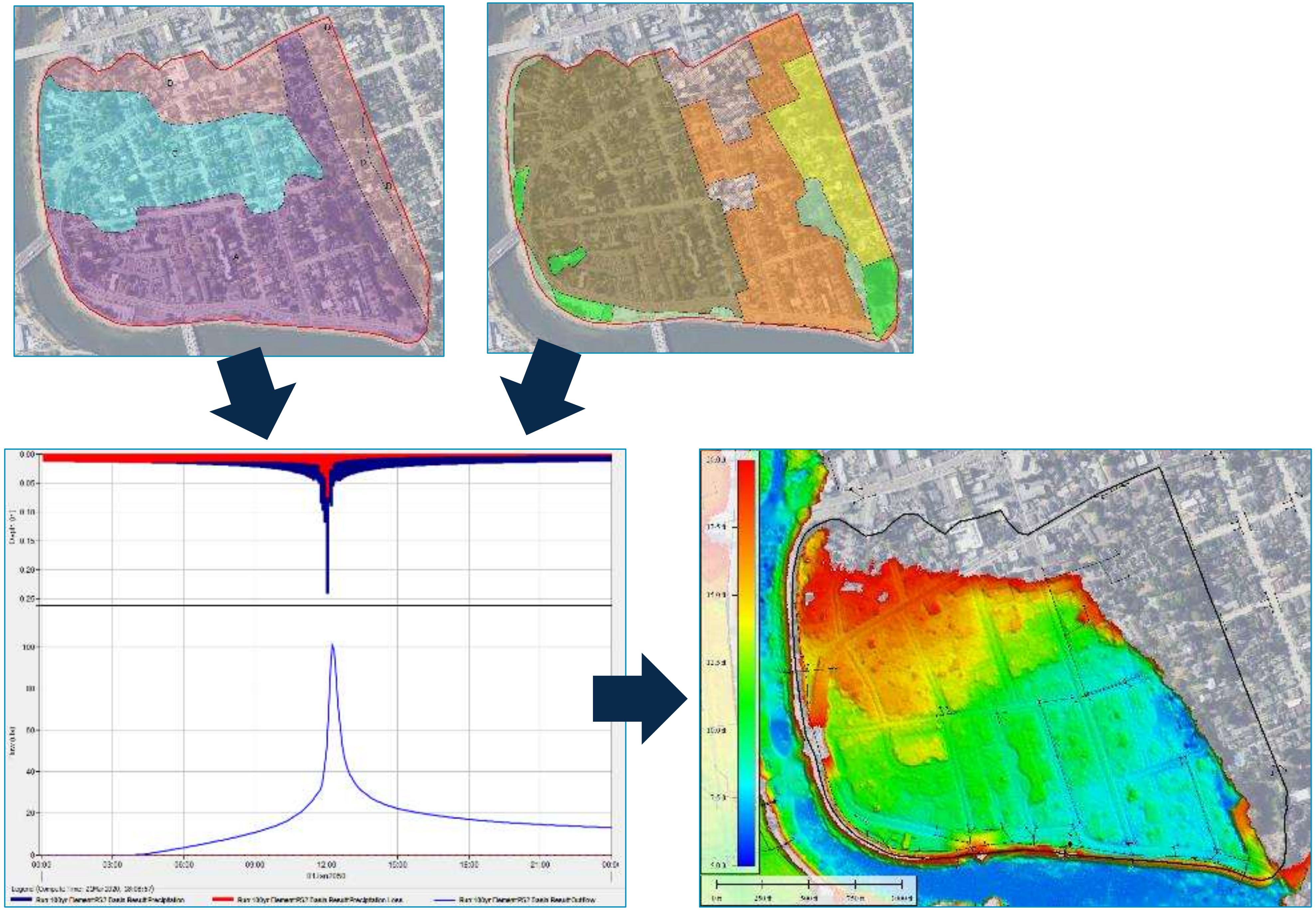
- ***Purposes***:
- Remind staff that the accretion survey is a special application, and that they are allowed/expected to think
- Refresh habits of monitoring staff, such that a default Q measurement does not become acceptable.

- ***Specific departures from norms:***
- ***At least 30 verticals per discharge measurement, with no one vertical incorporating > 5% of flow***
- ***No debris jams affecting low-flow cusrrents within 100 feet upstream***
- ***No twigs in water or willows dangling into the flow within 30 feet***
- ***Reasonably straight channel with uniform and/or slightly converging flow***
- ***Bedrock or hardpans on bed forcing flow to surface.***
- ***Measurement worked up within 48 hours of being made.***
- ***Conformance:***

- ***12 % of measurements were repeated***
- ***98% of measurementshowed more flow than upstream neighbor, and slightly less flow than downstream neihbo.s were slightly***

Slide with text and series of images

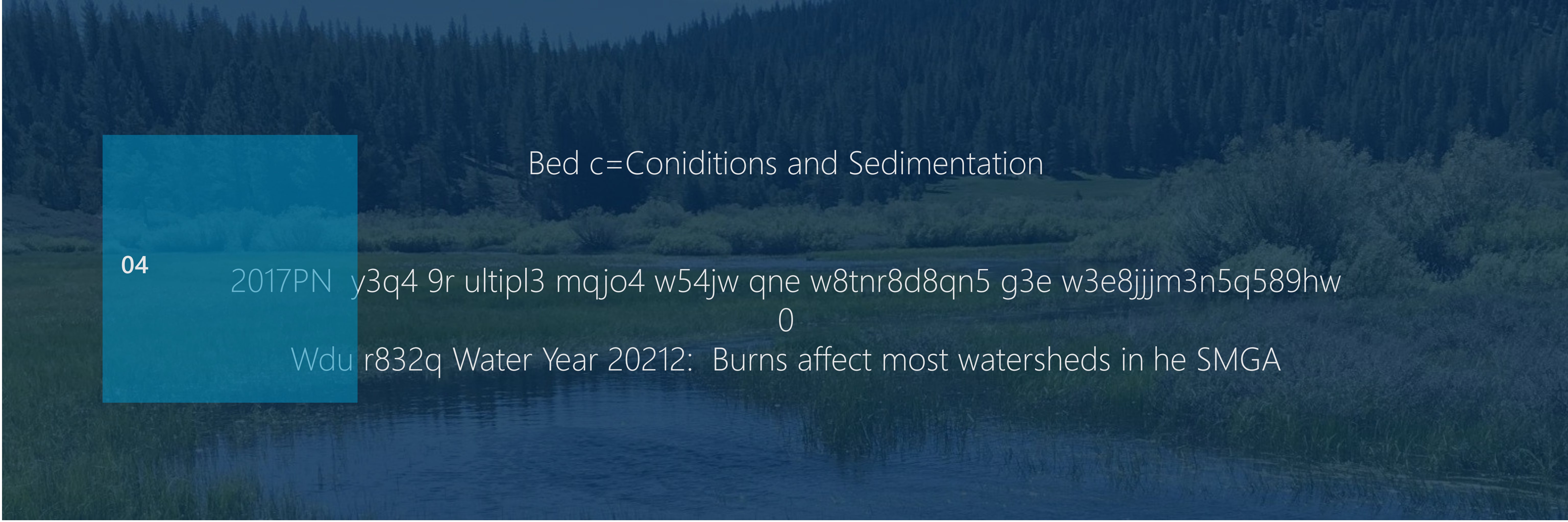
- HEC-HMS and EPA SWMM
- Why EPA SWMM?
    - Open source, public software
    - Simplifies FEMA's technical review
    - Approach offers cost saving to City



Thank you!

Our Partners

Balance Hydrologics
12020 Donner Pass Rd, Truckee, CA 96161
800 Bancroft Way, Suite 101, Berkeley, CA 94710
224 Walnut Avenue, Suite E, Santa Cruz, CA 950600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Wdu r832q Water Year 20212: Burns affect most watersheds in he SMGA

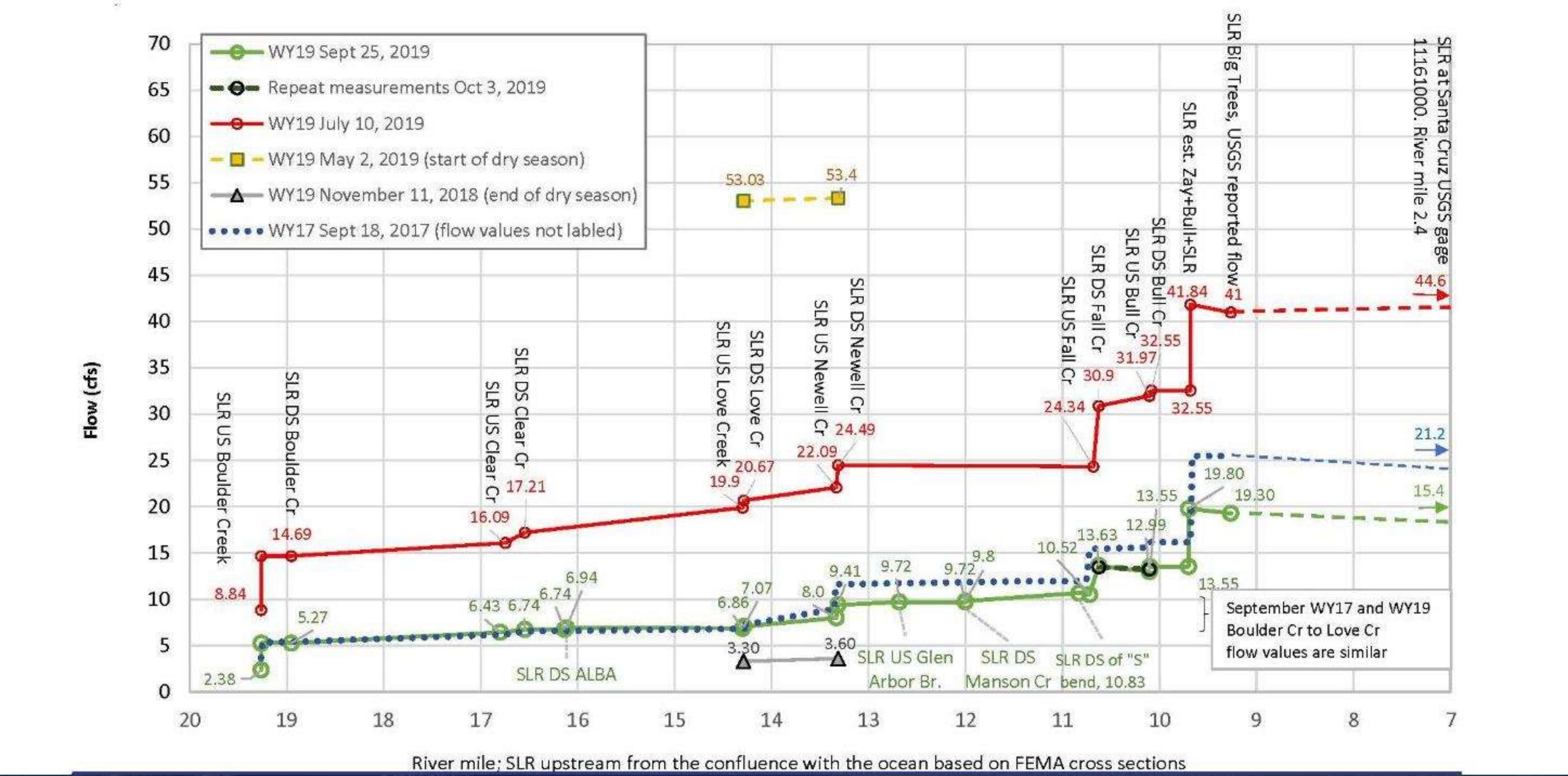
Double-Precision Streamflow Measurements

1. Purposes

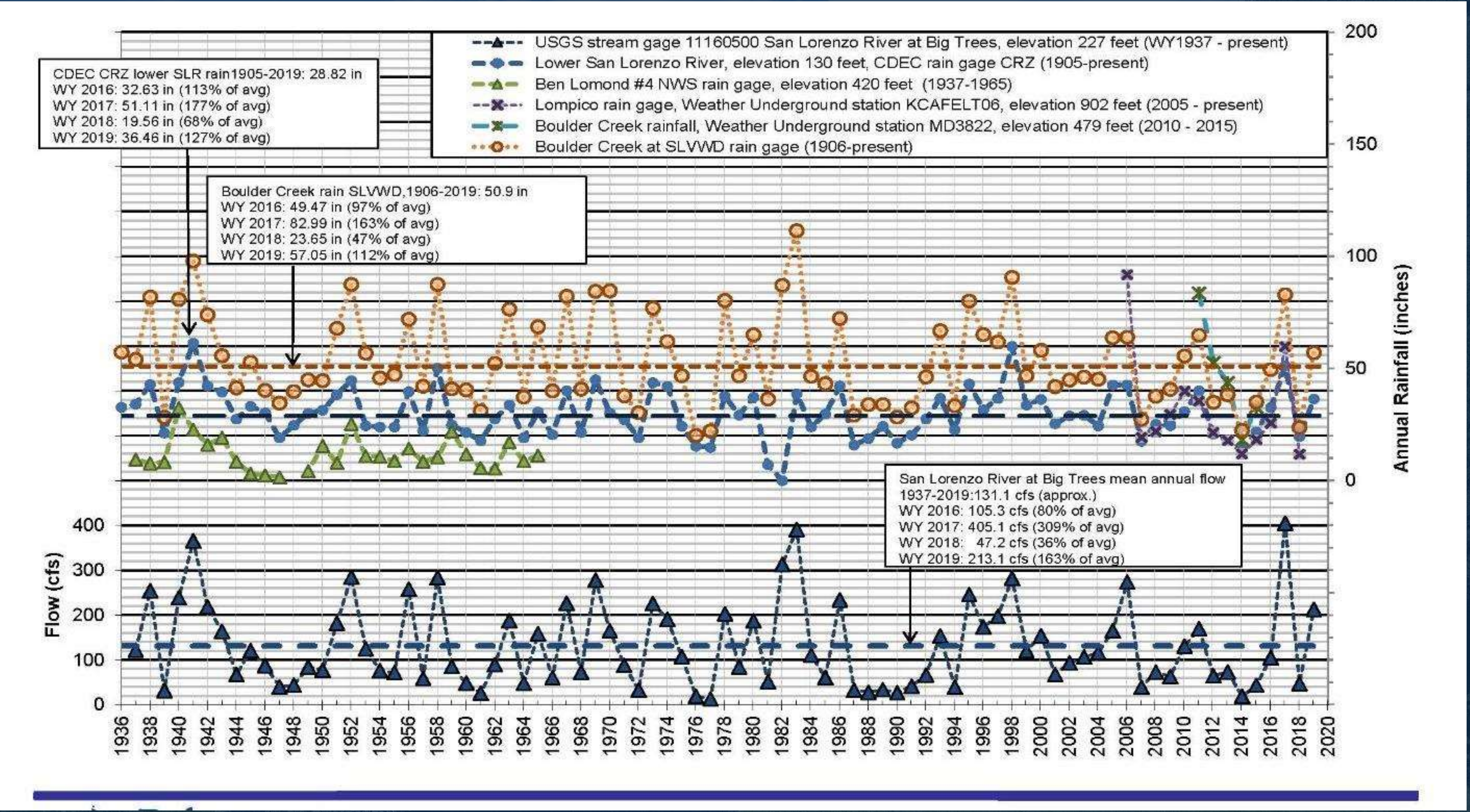
a. Signal to hydrographer that special care is warranted, and that they are encouraged to think

Purposes is to quantify small differences in flow, rather than simply measure flow to a default standard

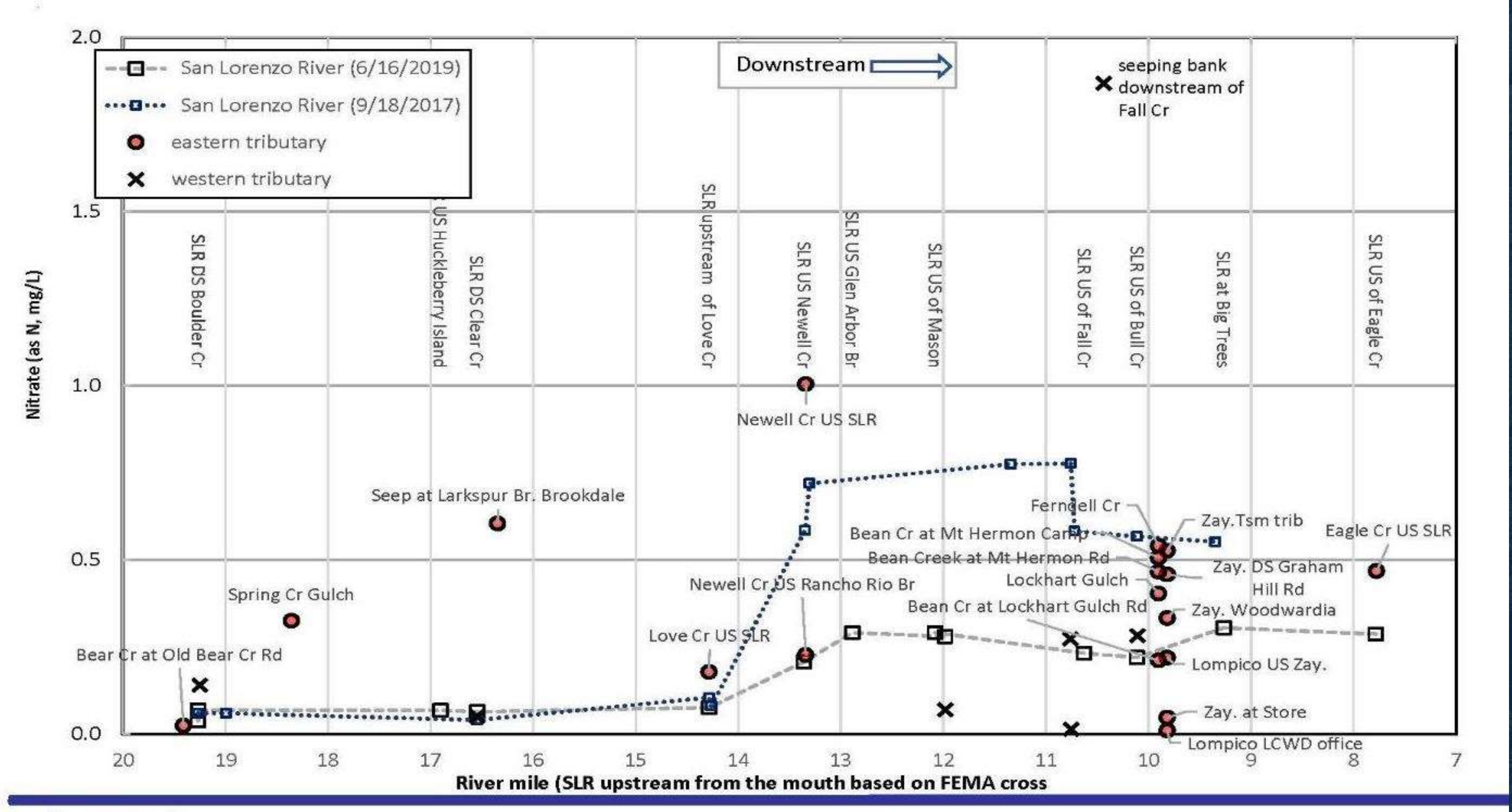
1.



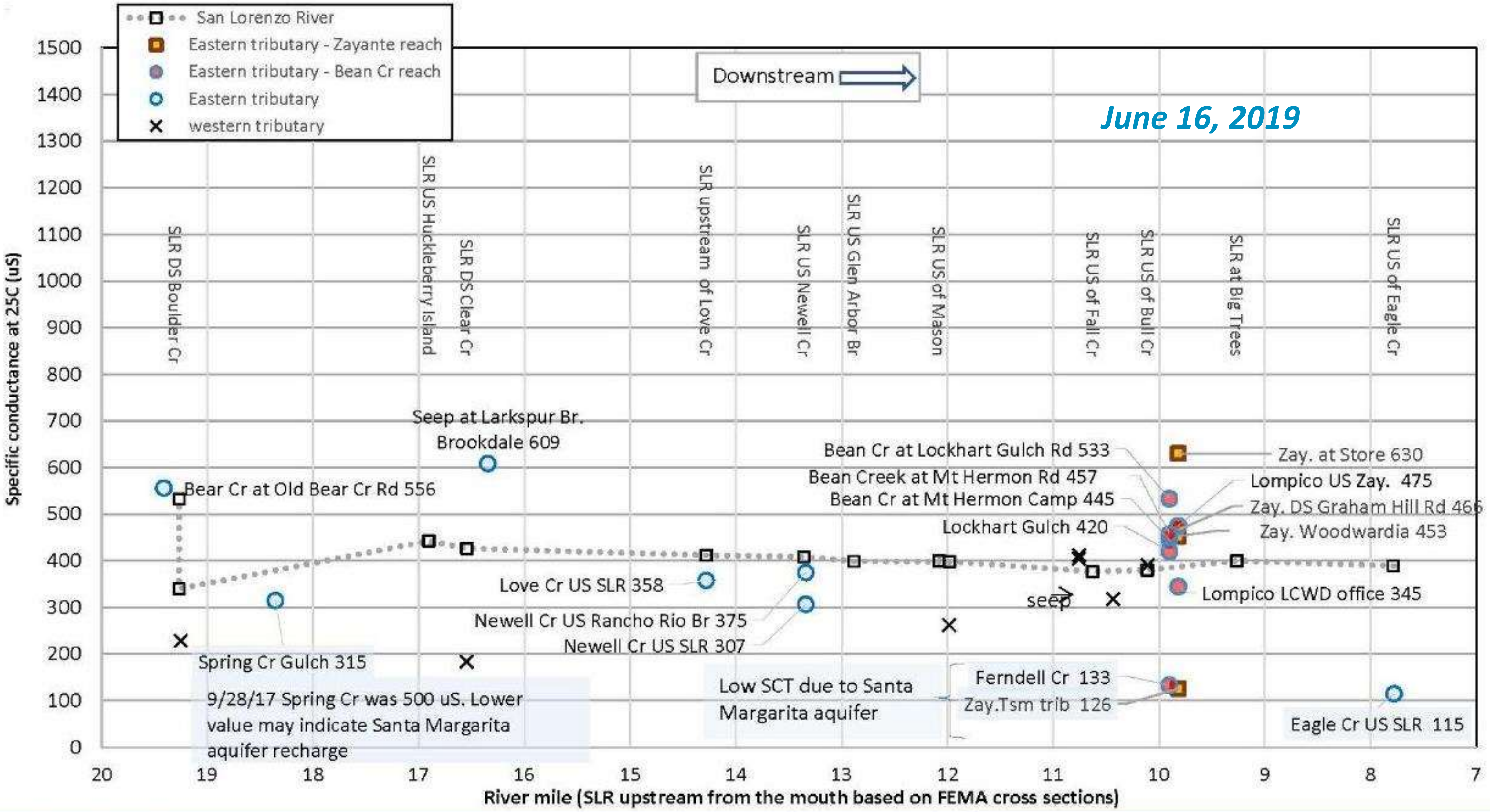
Increasing flow with distance downstream



Historical rainfall and streamflows



Longitudinal influx of nitrate from Santa Margarita groundwaters



Longitudinal influx salts from Santa Margarita groundwaters

Acknowledgments

Conceptualizing

Barry Hecht

John Ricker

Project management

Chelsea Neill

Field adaptation, calibration and rigor

Jason Parke

Transformation to SGMA GSP

Sierra Ryan,

John Ricker

Chelsea Neill

Selection of variables used in a balanced baseline of monitoring variables draws on work by John Ricker and Barry Hecht beginning in 1977, then refined by the project team into a coherent package capable of being implemented through the Sustainable Groundwater management Act (SGMA) and earlier habitat protection efforts. It "took a village" of motivated colleagues and residents to make this presentation possible.