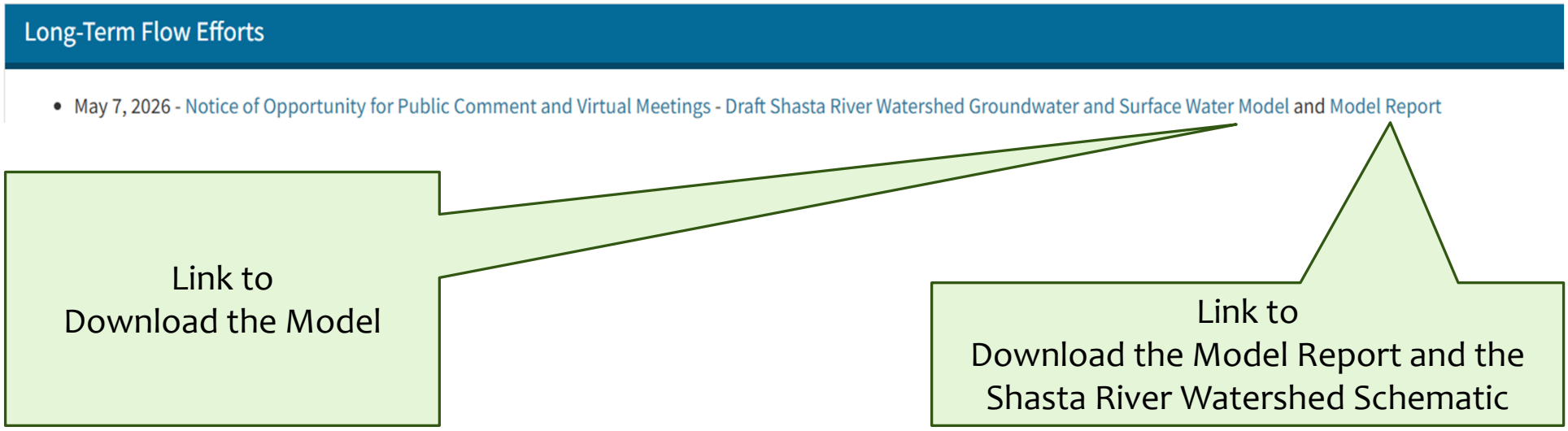
A few notes before the presentation

- The Shasta surface water-groundwater model and model report posted on the Water Board webpage currently include results for only two scenarios: the **Base Case Scenario** and the **Unimpaired Flow Scenario**
- Additional scenarios will be evaluated after verification of the model and confirmation that the model is **sufficiently calibrated and robust** to produce reliable results
- **Your comments** represent an important step in the verification and improvement of the model
- After public comments are received and addressed, the model report will undergo a **CalEPA external peer review process**
  - More information is available at: https://www.waterboards.ca.gov/resources/peer_review/
- This Shasta surface water-groundwater model serves as the foundation for two additional watershed-wide tools for the Shasta watershed: a **Water Temperature Tool** and a **Water Allocation Tool**

A few notes before the presentation

- Folders and files related to the Shasta surface water–groundwater model are posted at: https://www.waterboards.ca.gov/drought/scott_shasta_rivers/

- Please check out the Long-Term Flow Efforts section.



Integrated Surface Water and Groundwater Modeling of the Shasta River Watershed

Presented By:

John Riverson, Paradigm/Ulteig
Vivek Bedekar, SSP&A
May 28, 2026

PARADIGM
AN ULTEIG COMPANY

S.S. Papadopulos & Associates, Inc.
Environmental & Water Resource Consultants

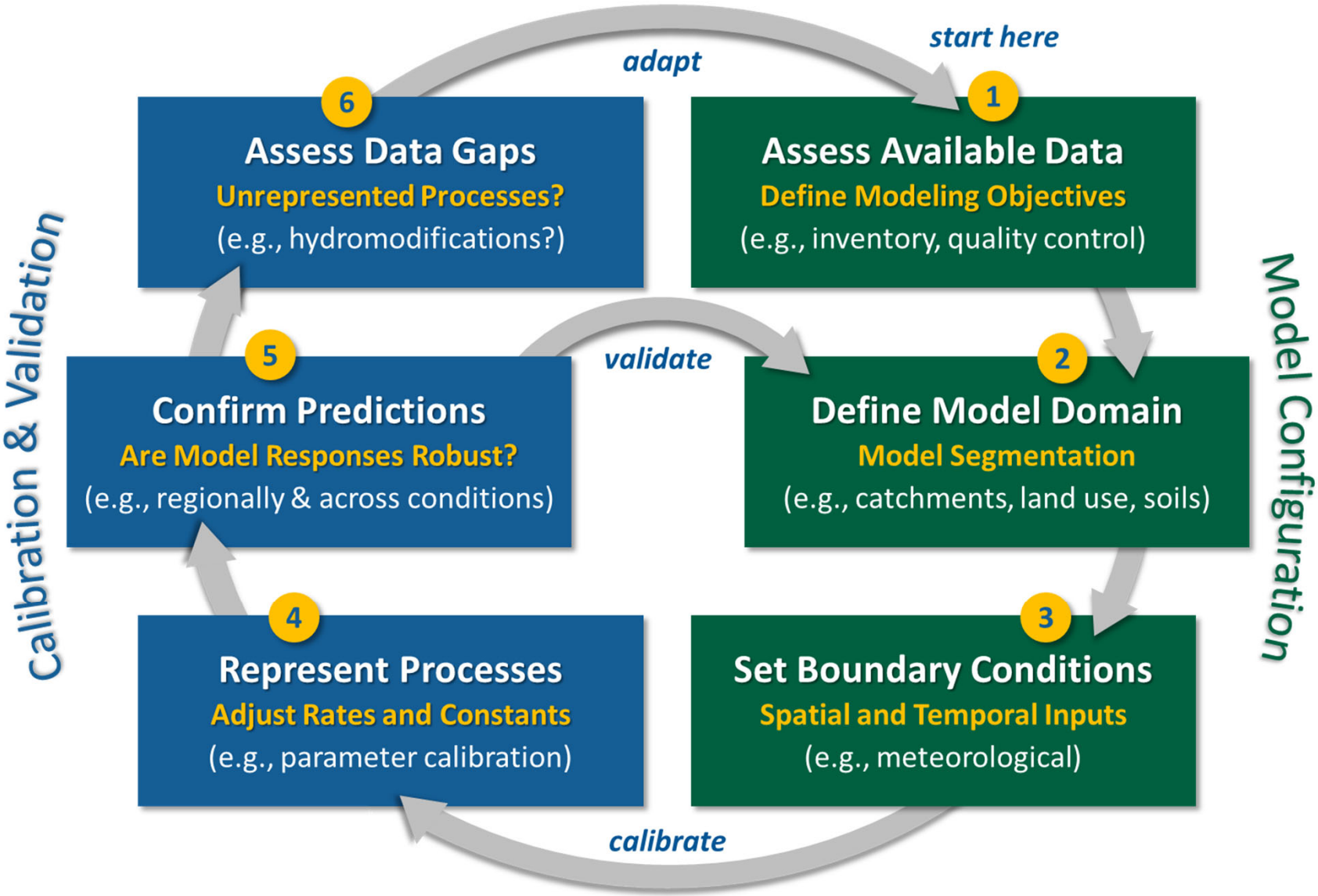
California Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

Study Objectives

- Management Objectives (2014 CA Water Action Plan)
  - More reliable water supplies
  - Restoration of important species and habitat
  - Create a more resilient, sustainably managed water resources system

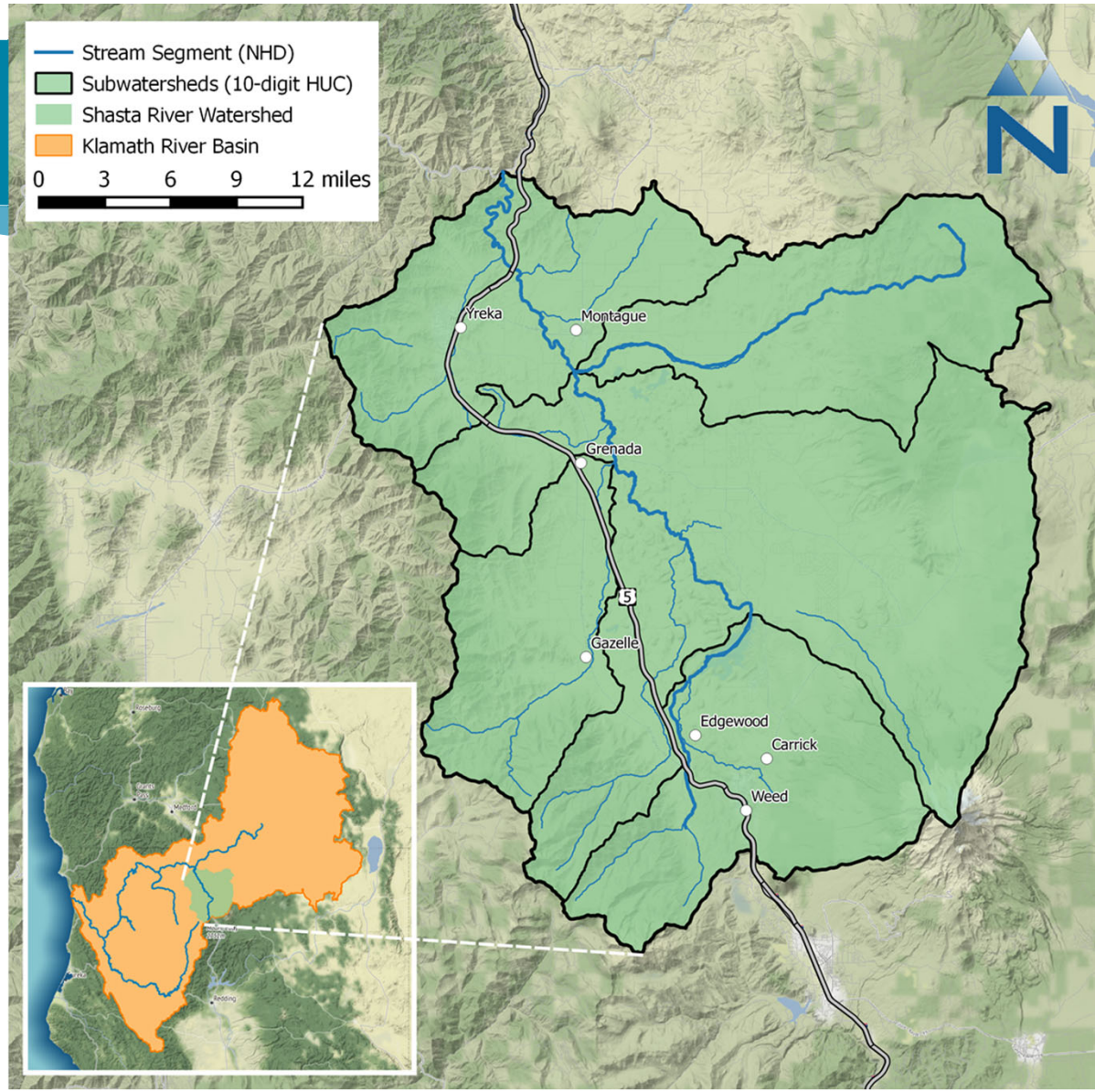
- Desired Modeling Outcomes:
  - Incorporate high-resolution data inputs
  - Quantify existing-condition instream flows
  - Estimate unimpaired streamflow
  - Estimate water availability at un-gaged locations and times
  - Model alternative water management scenarios

Environmental Flows


start here
1
Assess Available Data
Define Modeling Objectives
(e.g., inventory, quality control)
2
Define Model Domain
Model Segmentation
(e.g., catchments, land use, soils)
3
Set Boundary Conditions
Spatial and Temporal Inputs
(e.g., meteorological)
4
Represent Processes
Adjust Rates and Constants
(e.g., parameter calibration)
5
Confirm Predictions
Are Model Responses Robust?
(e.g., regionally & across conditions)
6
Assess Data Gaps
Unrepresented Processes?
(e.g., hydromodifications?)
calibrate
validate
adapt
Model Configuration
Calibration & Validation

Shasta River Watershed

- Drains 794 mi^2
- Flows north to Klamath River
- Originates as snowmelt from southern portion
- Geology/Topography
  - East: Younger Volcanic
  - West: Older Metamorphic
  - Low-gradient floor
  - Surrounding mountains
- Water diversion:
  - Agriculture
  - Municipal supply
  - Recreation
  - 227 cfs (SW Irrigation demand)




Stream Segment (NHD)
Subwatersheds (10-digit HUC)
Shasta River Watershed
Klamath River Basin
0 3 6 9 12 miles
N
Parks Creek, Upstream of Confluence to Shasta River

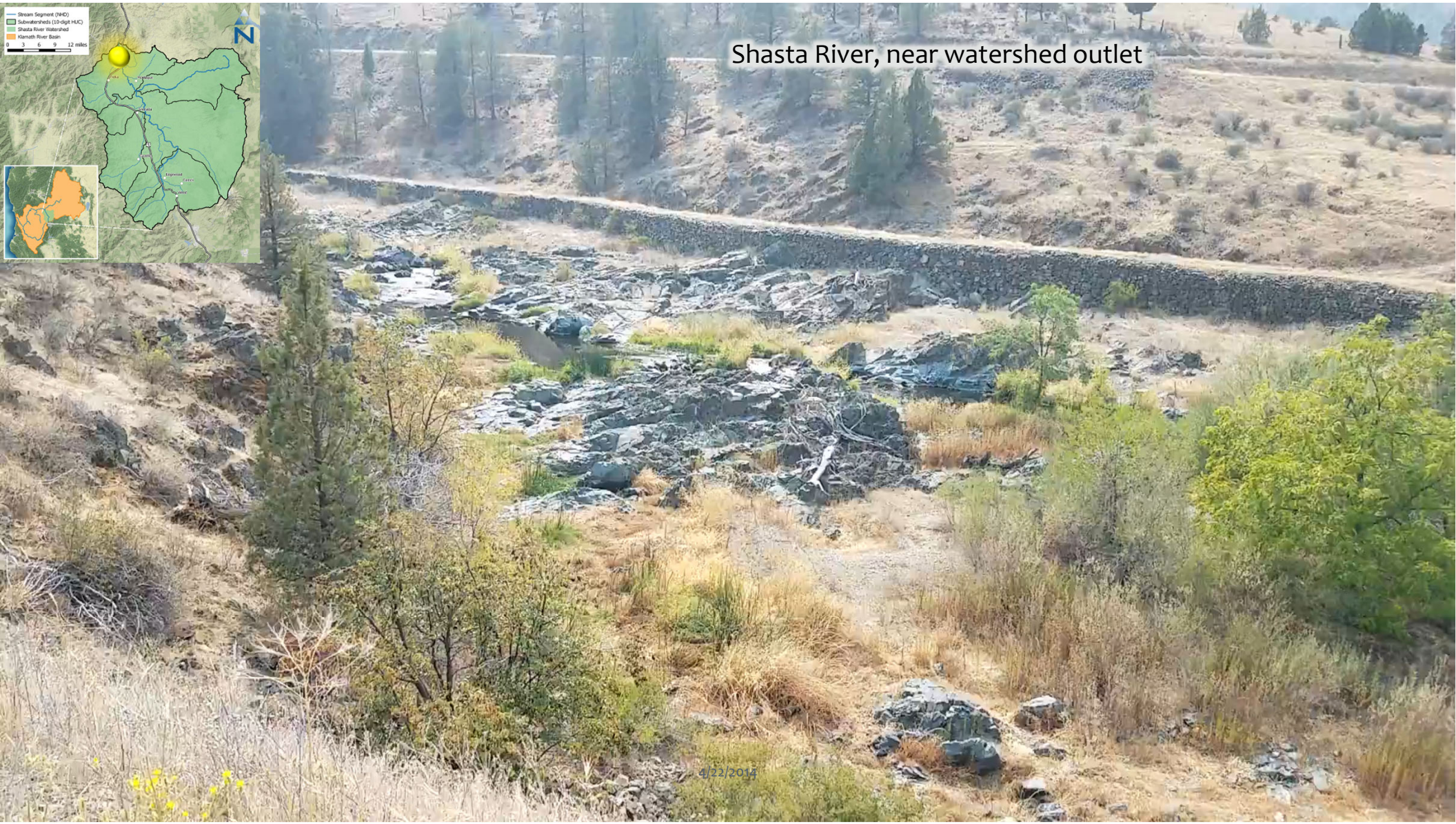

Stream Segment (NHD)
Subwatersheds (10-digit HUC)
Shasta River Watershed
Klamath River Basin
0 3 6 9 12 miles
N
Confluence of Parks Creek and Shasta River


Big Springs Complex
Stream Segment (NHD)
Subwatersheds (10-digit HUC)
Shasta River Watershed
Klamath River Basin
0 3 6 9 12 miles
N

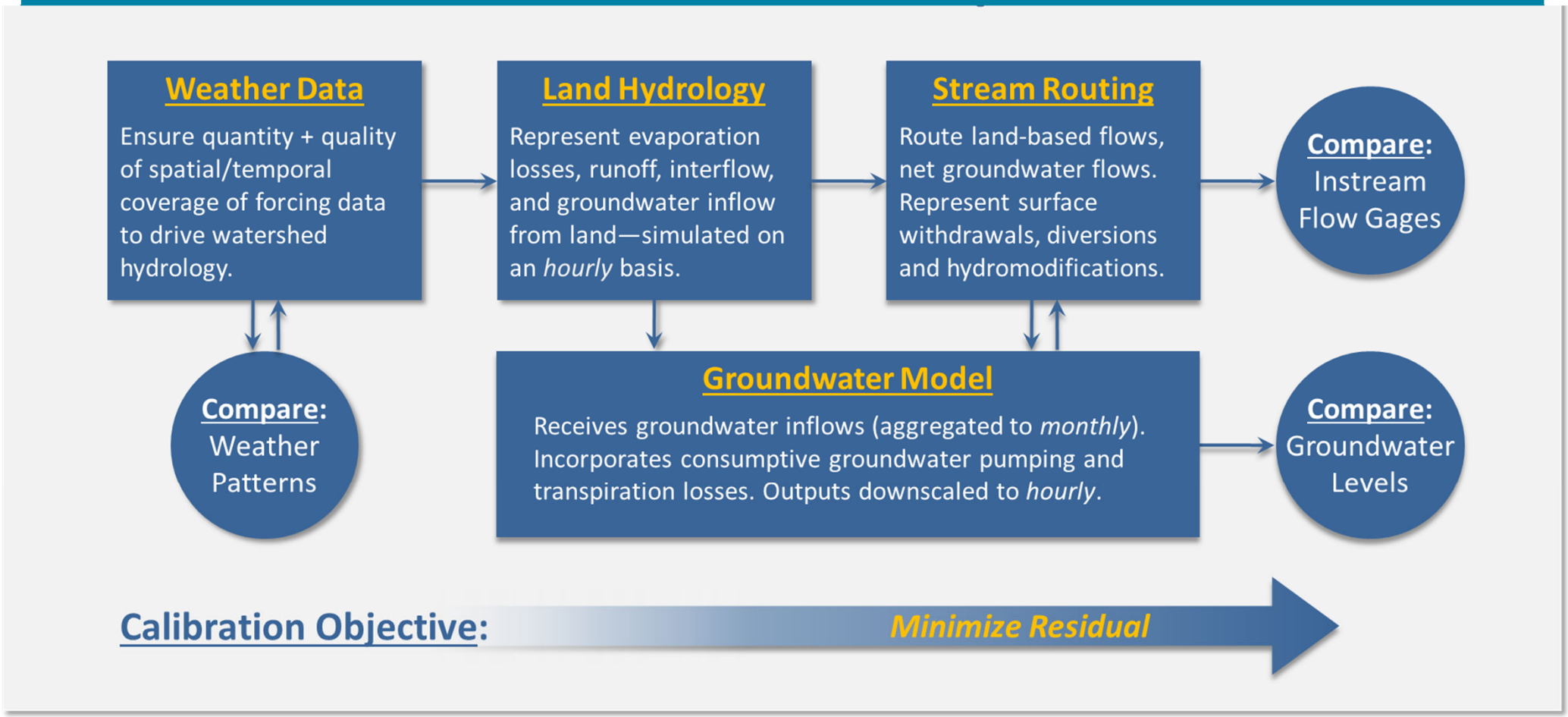

Stream Segment (NHD)
Subwatersheds (10-digit HUC)
Shasta River Watershed
Klamath River Basin
0 3 6 9 12 miles
N
Little Springs


Stream Segment (NHD)
Subwatersheds (10-digit HUC)
Shasta River Watershed
Klamath River Basin
0 3 6 9 12 miles
N
Shasta River, Below Big Springs Confluence

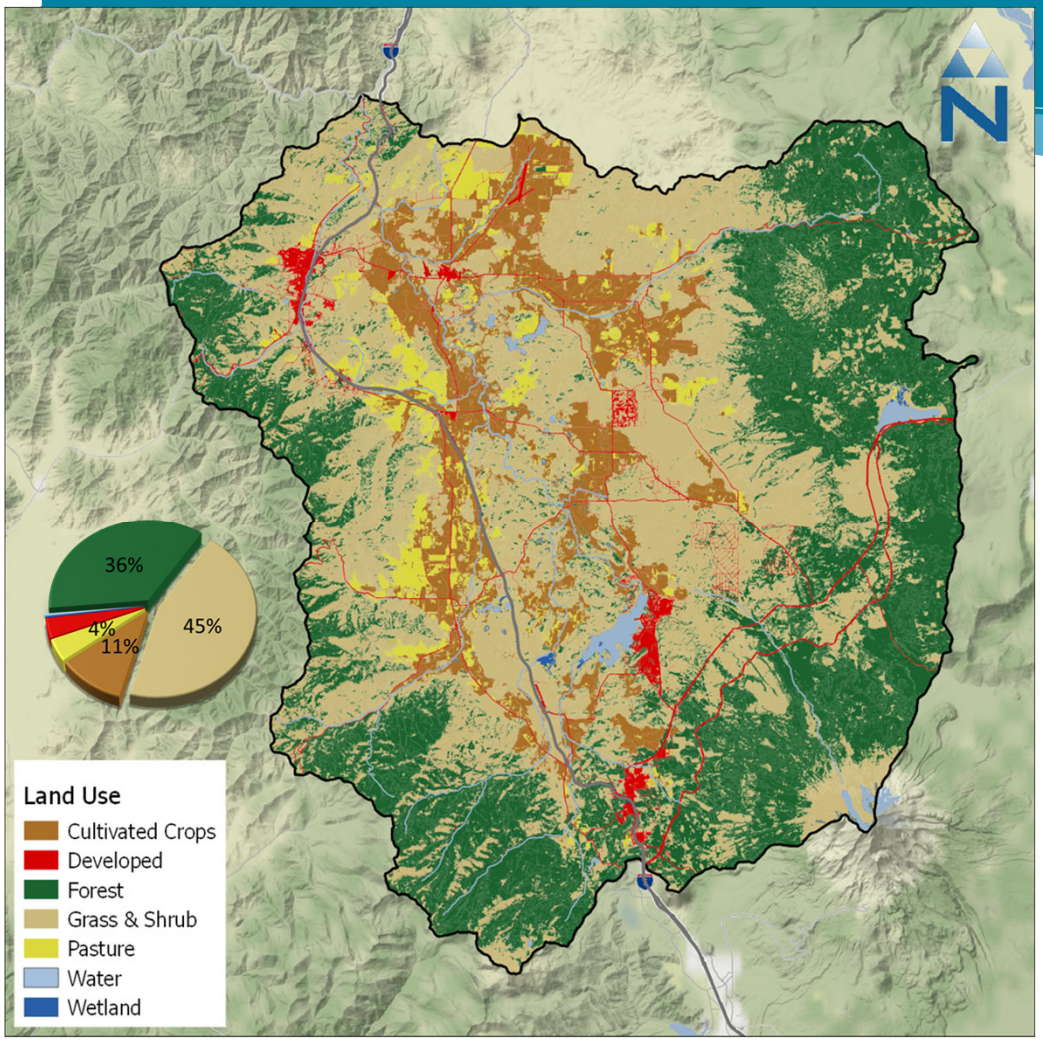

Stream Segment (NHD)
Subwatersheds (10-digit HUC)
Shasta River Watershed
Klamath River Basin
0 3 6 9 12 miles
N
Shasta River, Near Montague


Stream Segment (NHD)
Subwatersheds (10-digit HUC)
Shasta River Watershed
Klamath River Basin
0 3 6 9 12 miles
Shasta River, near watershed outlet
4/22/2014

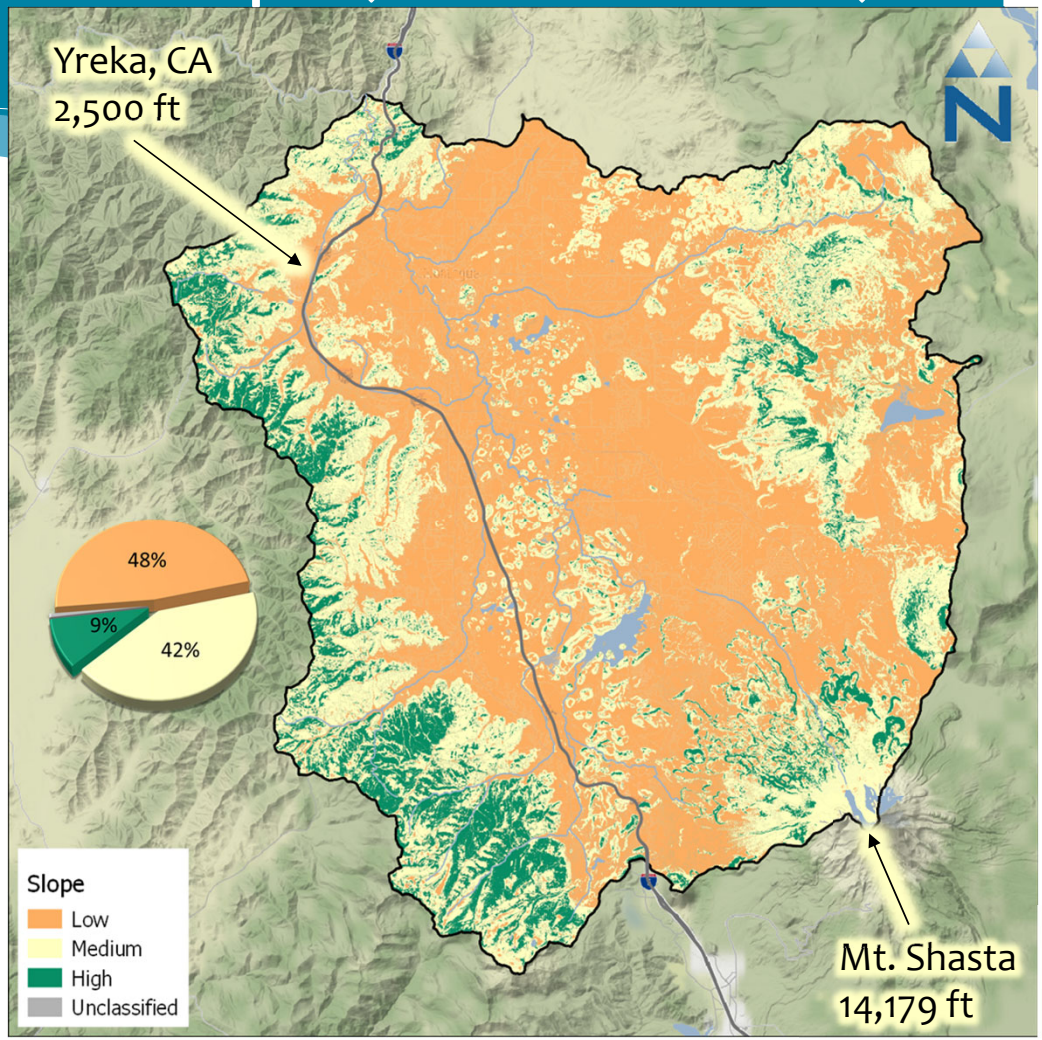
Integrated Modeling Approach



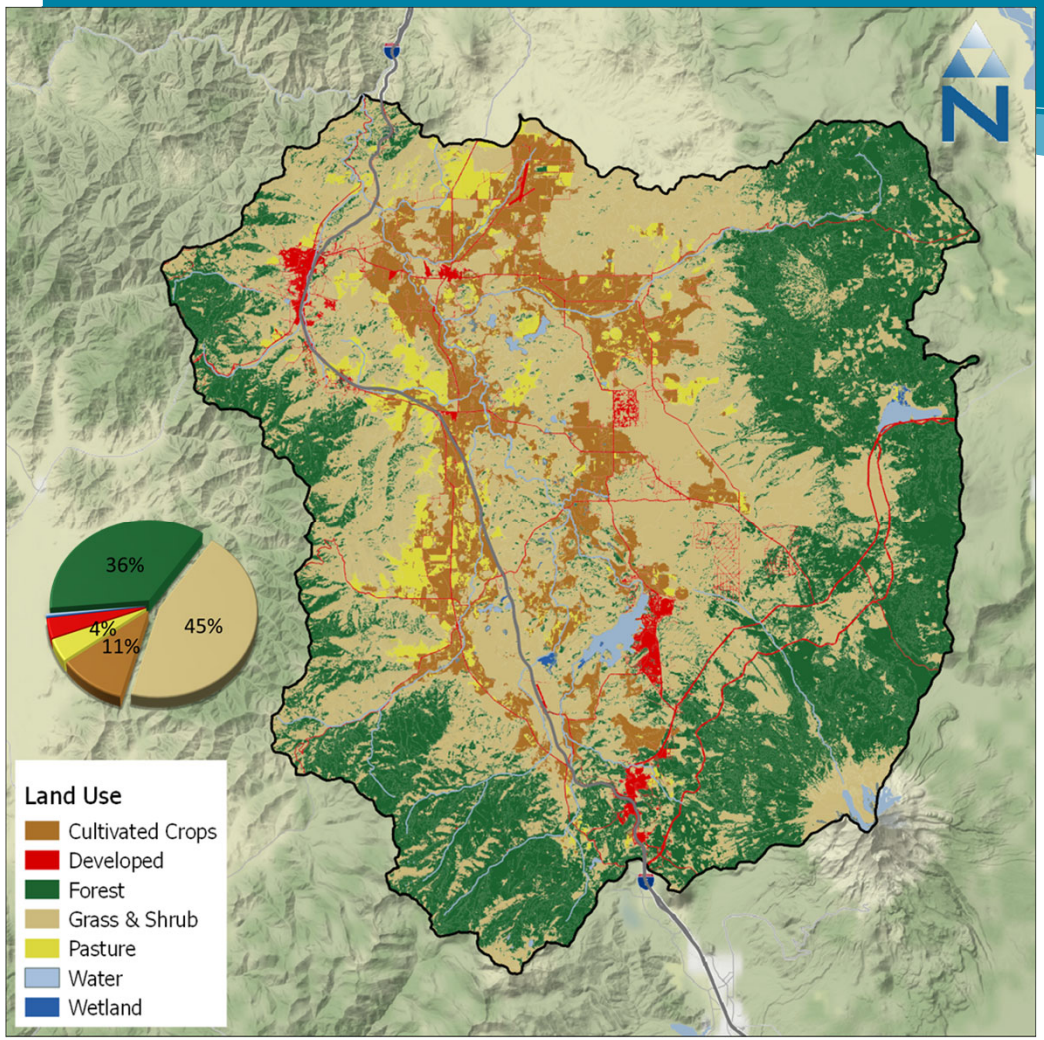
Land Use/Land Cover



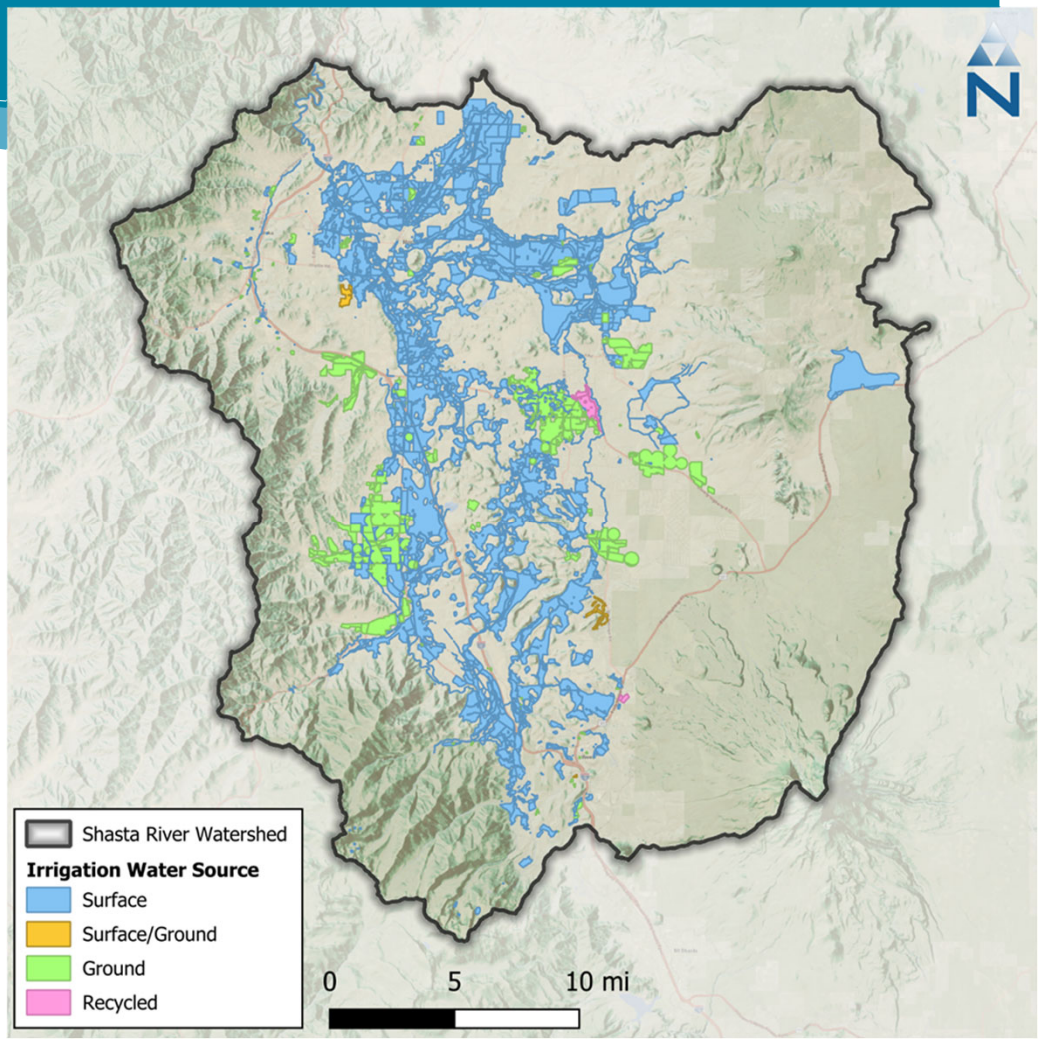
Slope (from Elevation)



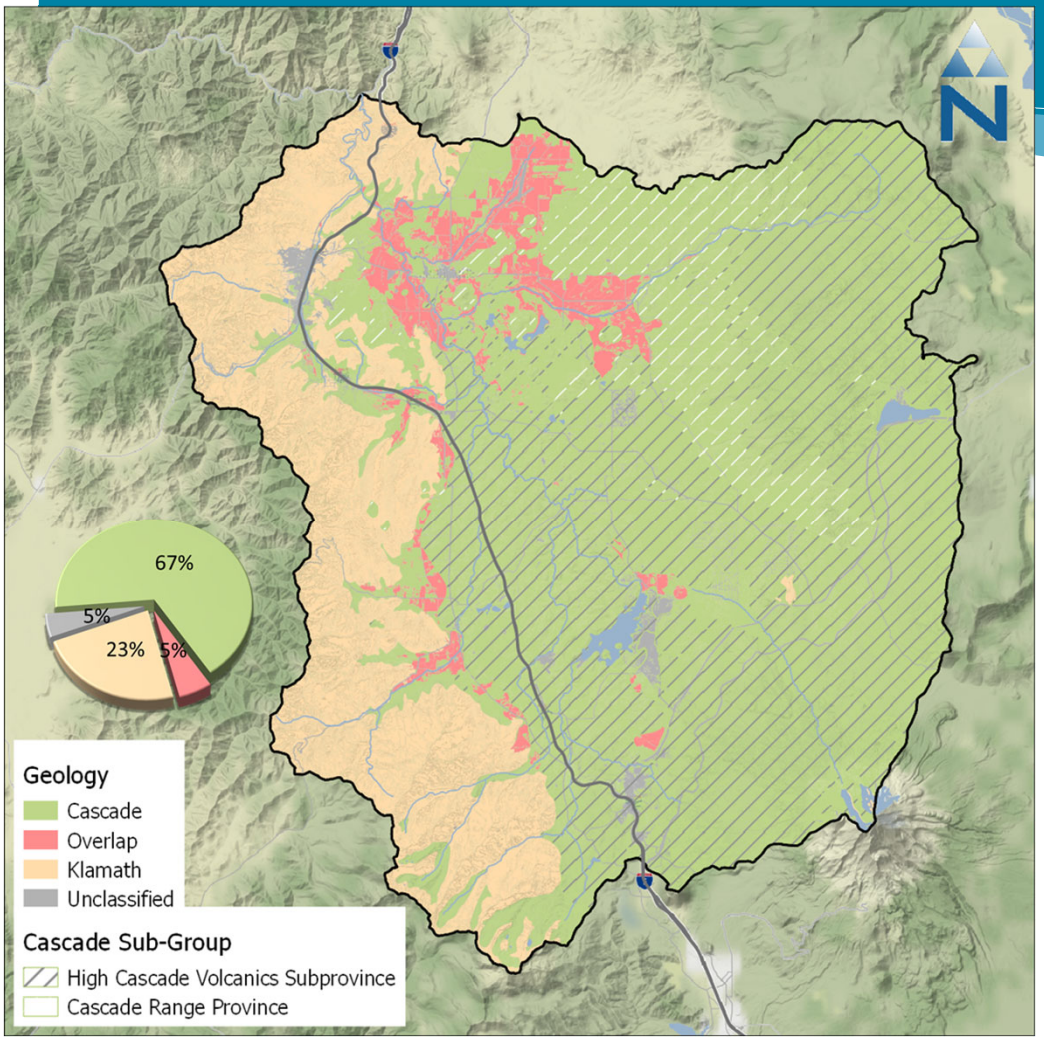
Land Use/Land Cover



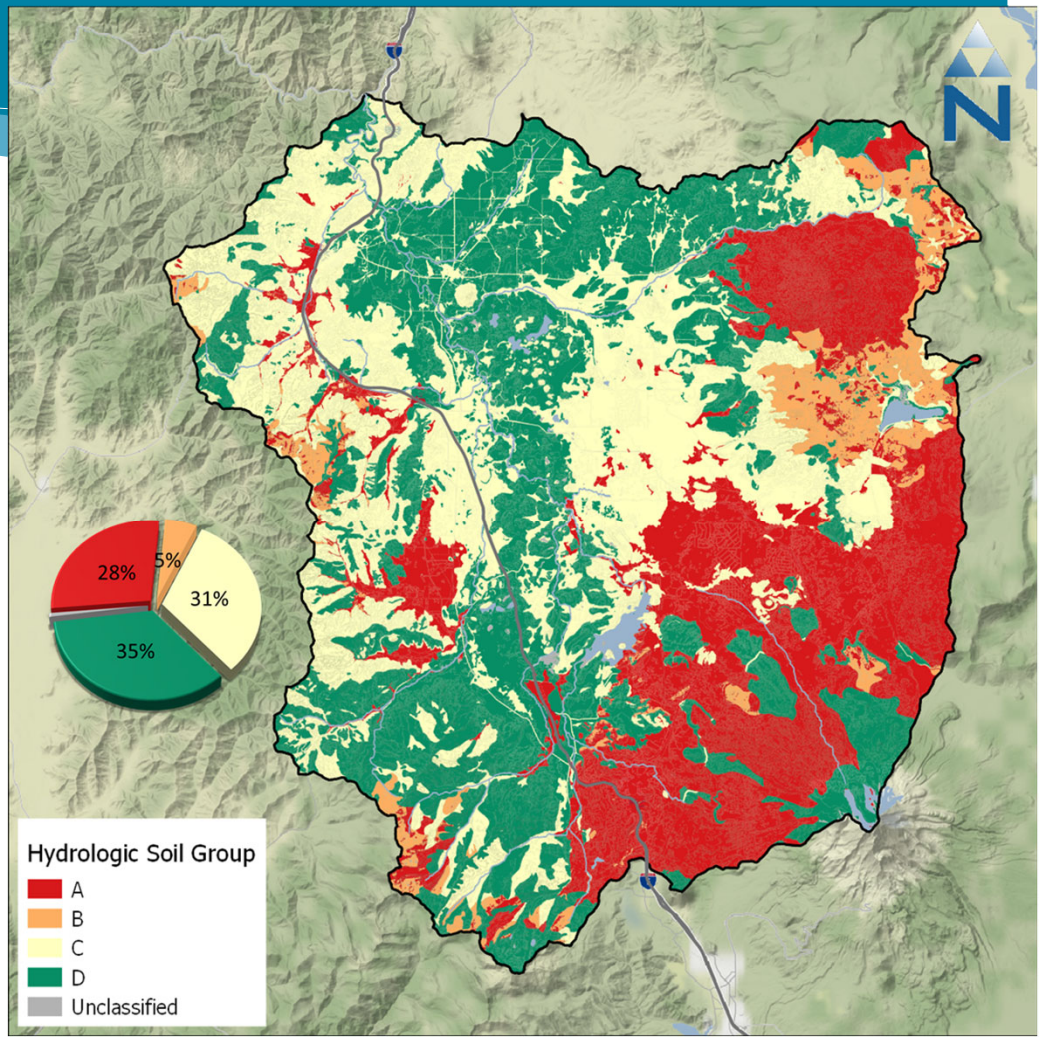
Irrigation Area/Water Source



Geology



Hydrologic Soils Group



Hydrologic Response Units (HRUs)

- Basic building blocks of the model
- Unique combinations of landuse, soil group, slope, and geology (selected based on dominant combinations).

LUC	Total Area	Soil Group (% Landuse Area)				Slope (% Landuse Area)			Geology (% Landuse Area)		
		A	B	C	D	0-15	15-35	>35	Cascade	Overlap	Klamath
		1	2	3	4	1	2	3	1	2	3
Forest	36.0%	40.6%	15.6%	21.6%	22.2%	16.8%	57.0%	26.2%	65.7%	5.9%	28.4%
Grass_Shrub	44.8%	17.1%	5.9%	35.2%	41.8%	50.9%	31.2%	18.0%	59.3%	13.7%	27.0%
Ag_Crop	10.5%	9.4%	2.7%	44.8%	43.1%	99.8%	0.2%	0.0%	49.2%	50.1%	0.7%
Ag_Pasture	4.3%	17.5%	4.6%	43.4%	34.6%	87.5%	11.6%	0.9%	32.6%	49.5%	17.9%
Developed	3.7%	35.2%	10.7%	33.6%	20.6%	91.2%	6.1%	2.7%	53.1%	35.2%	11.7%
Wetland	0.3%	19.2%	0.4%	13.8%	66.6%	93.4%	5.7%	0.9%	33.6%	65.7%	0.7%
Water	0.4%	45.5%	1.6%	22.6%	30.3%	81.4%	0.0%	18.6%	34.3%	54.5%	11.1%

Meteorological Conditions

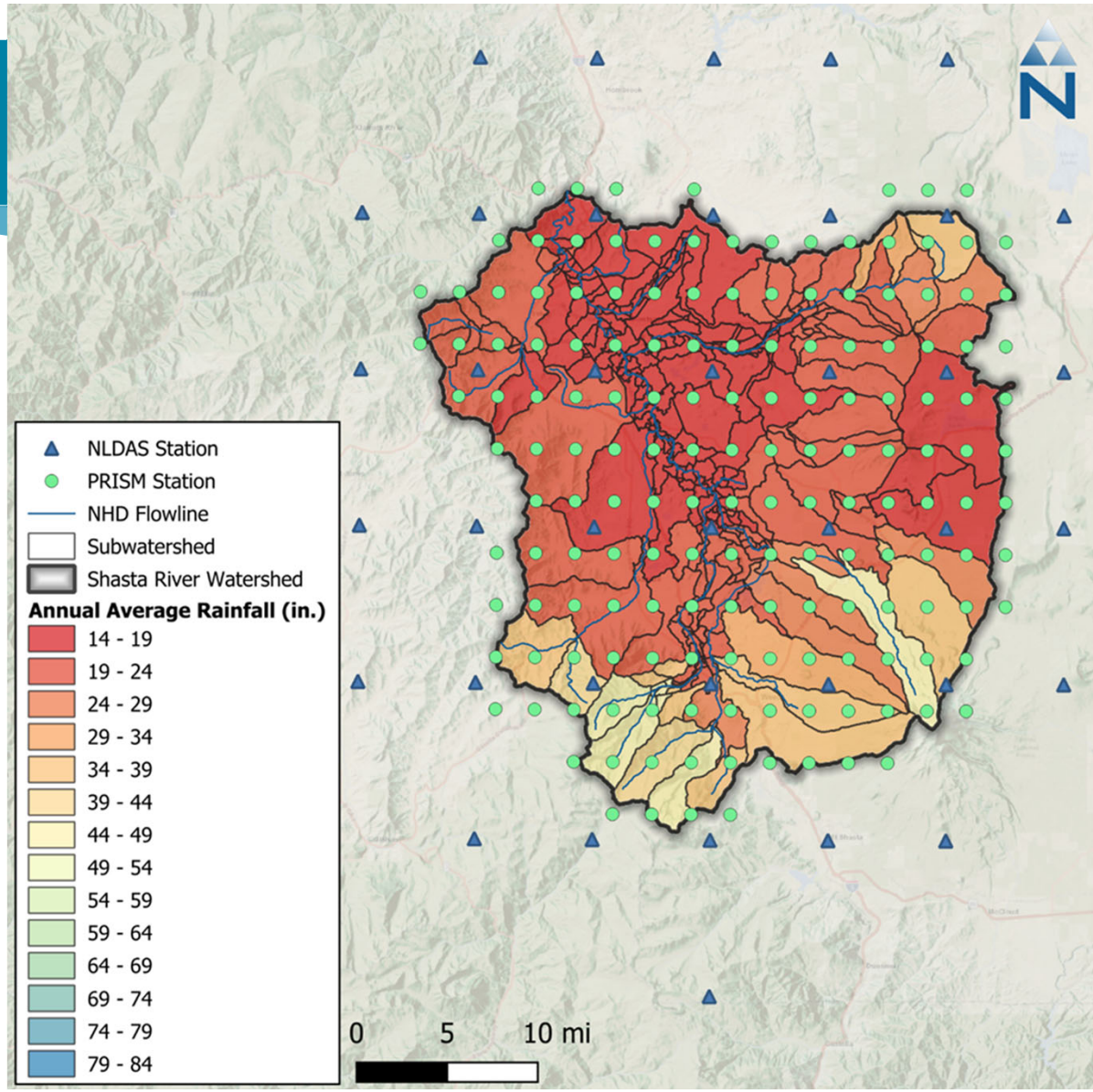
PRISM (4-km)

- Monthly Rainfall

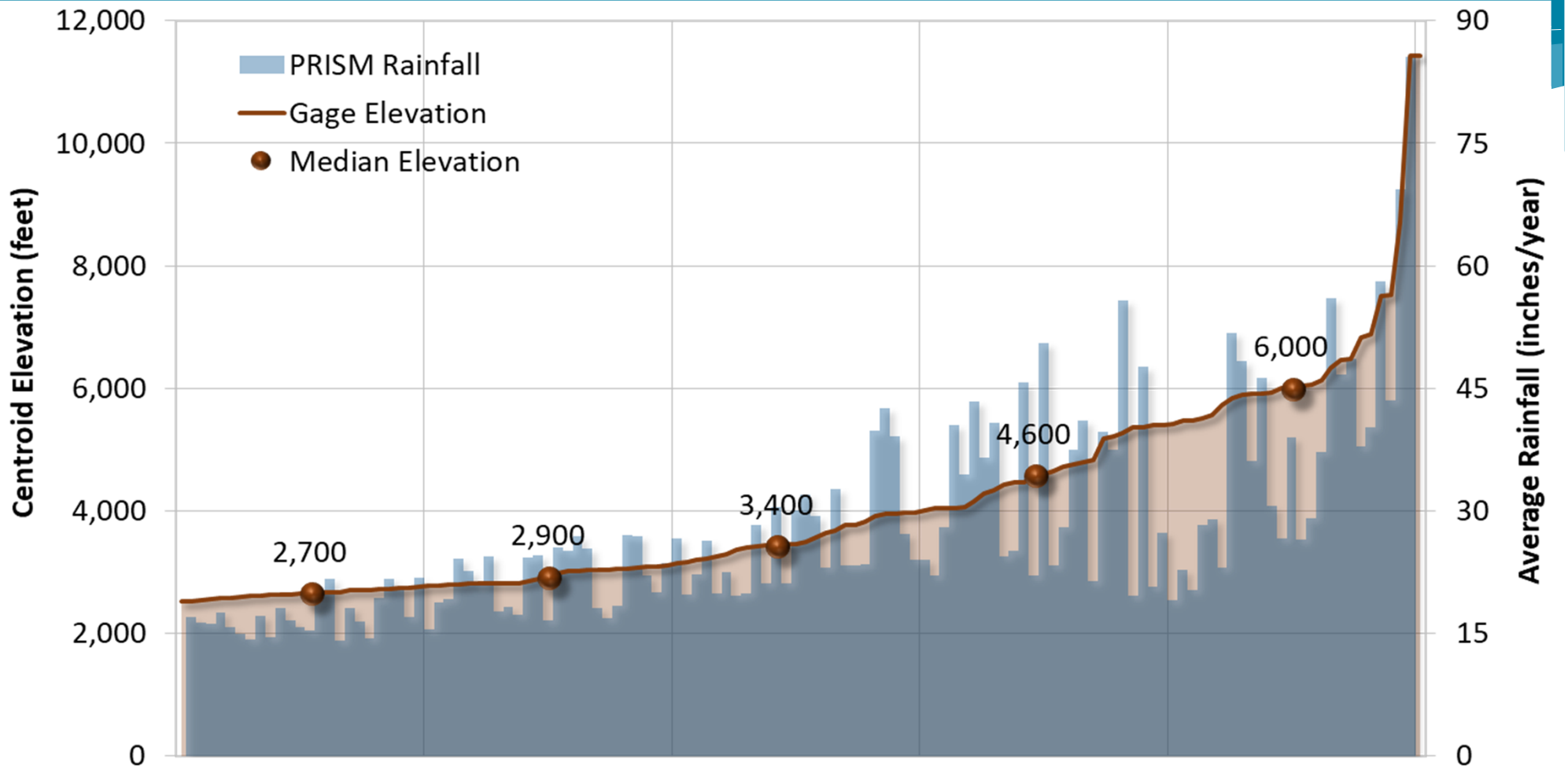
NLDAS (8-mile):

- Hourly Precipitation
- Potential Evapotranspiration
- Air temperature
- Wind Speed
- Solar Radiation
- Dewpoint temperature

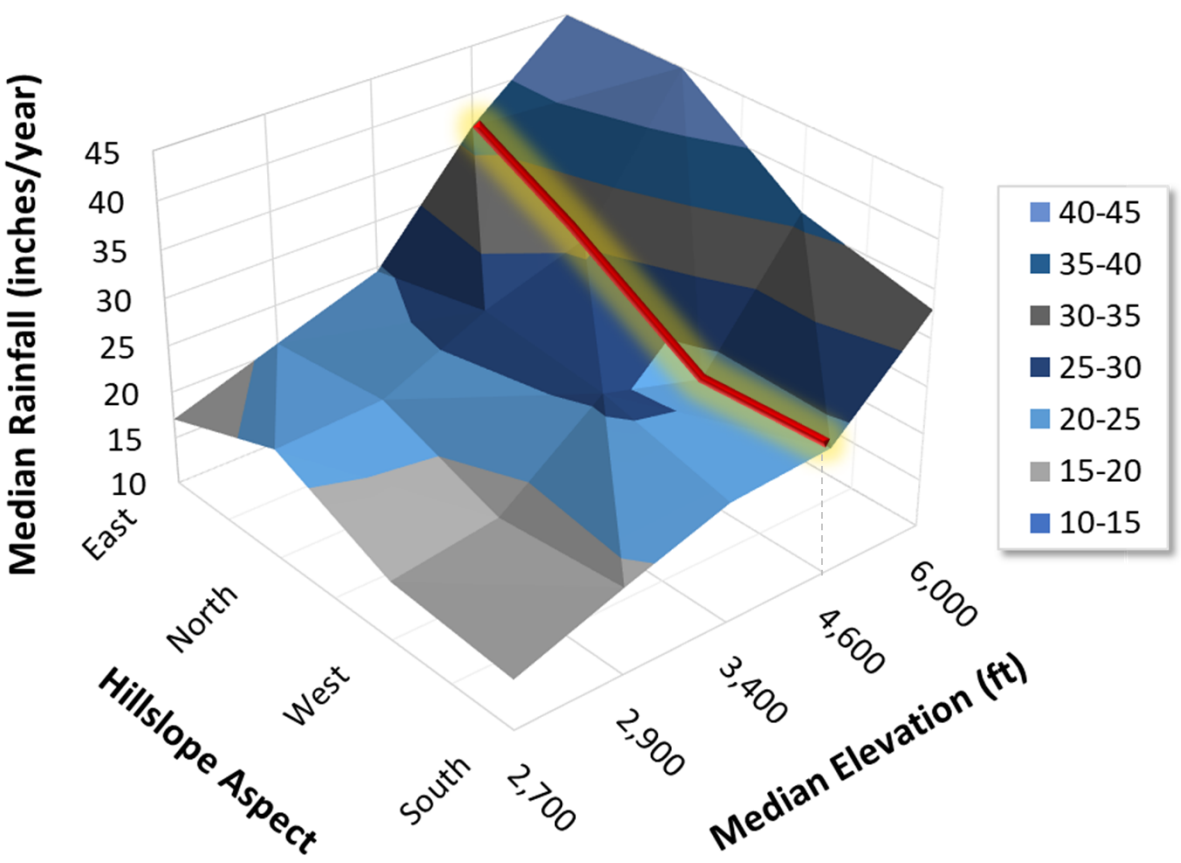
Results in 124 unique sets of meteorological timeseries

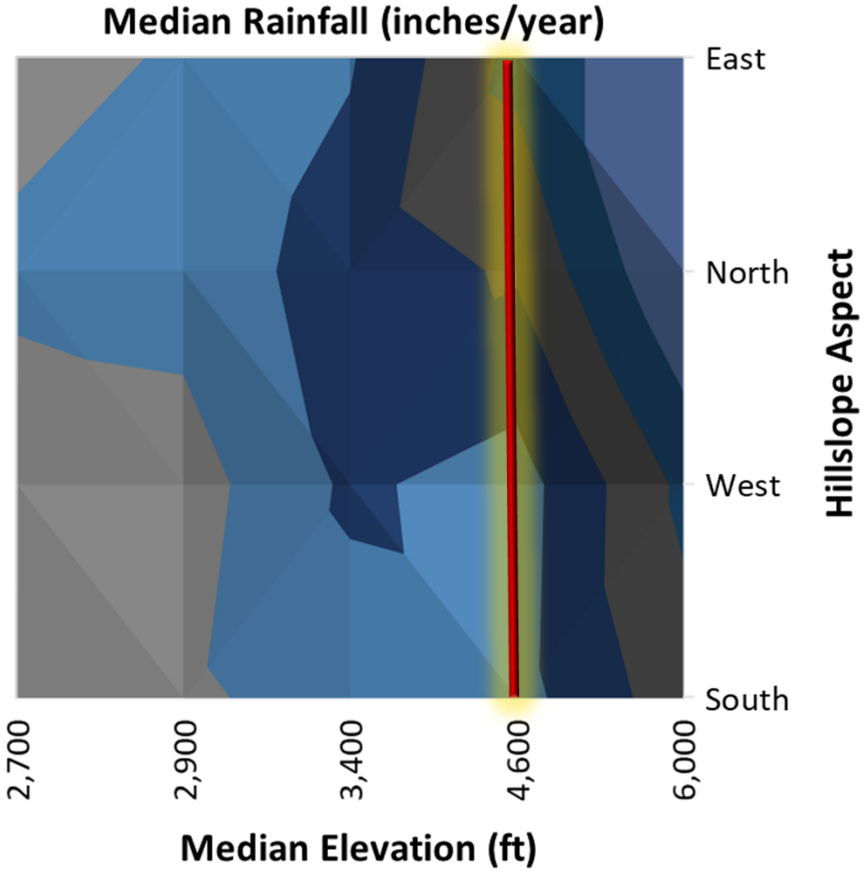


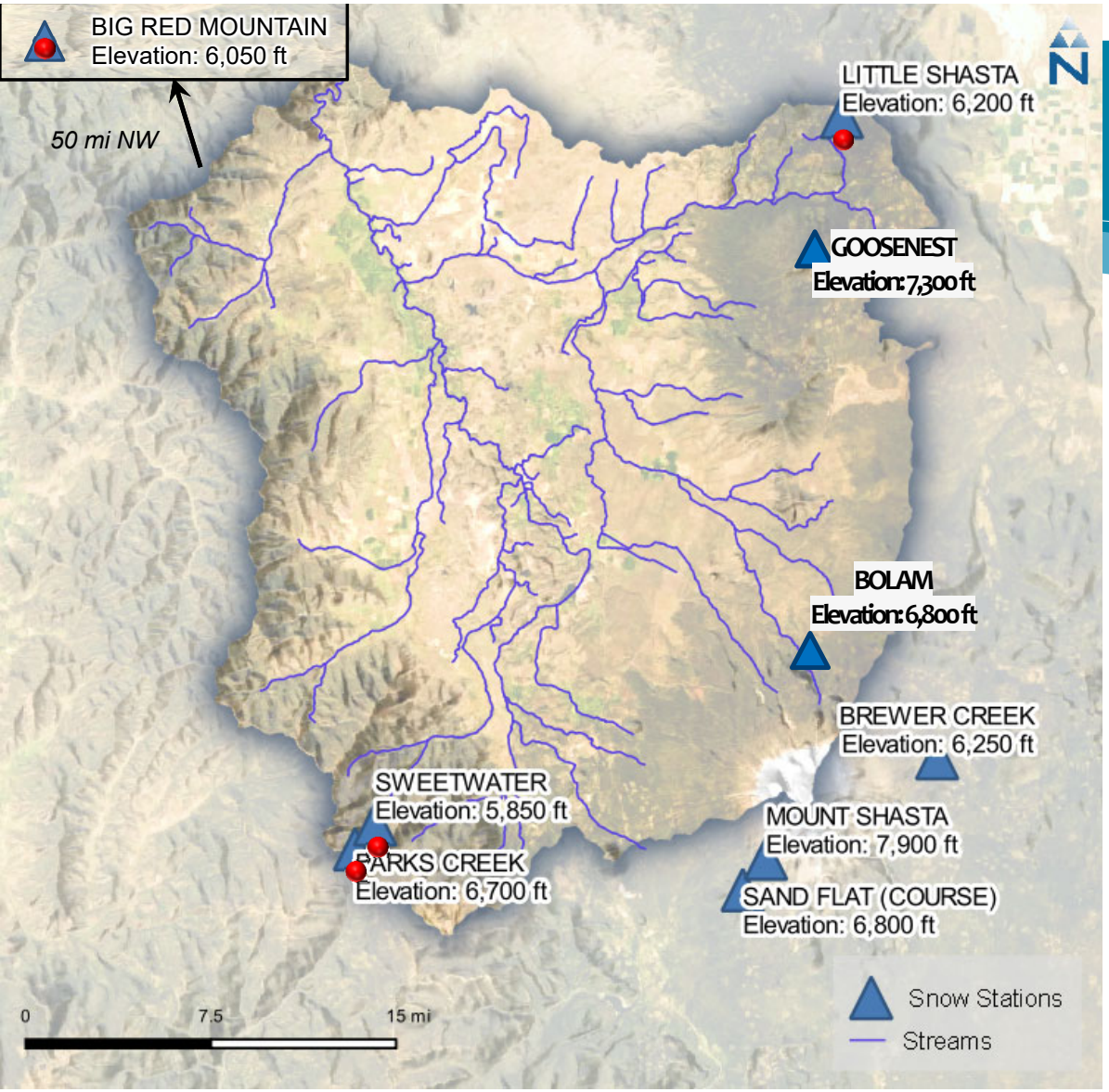
Rainfall Volume vs. Elevation



Rainfall Volume vs. Elevation and Aspect





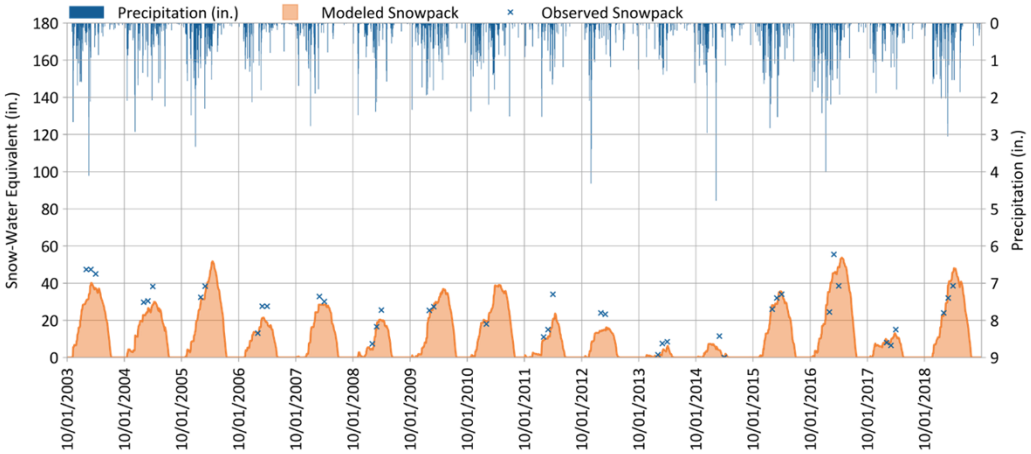


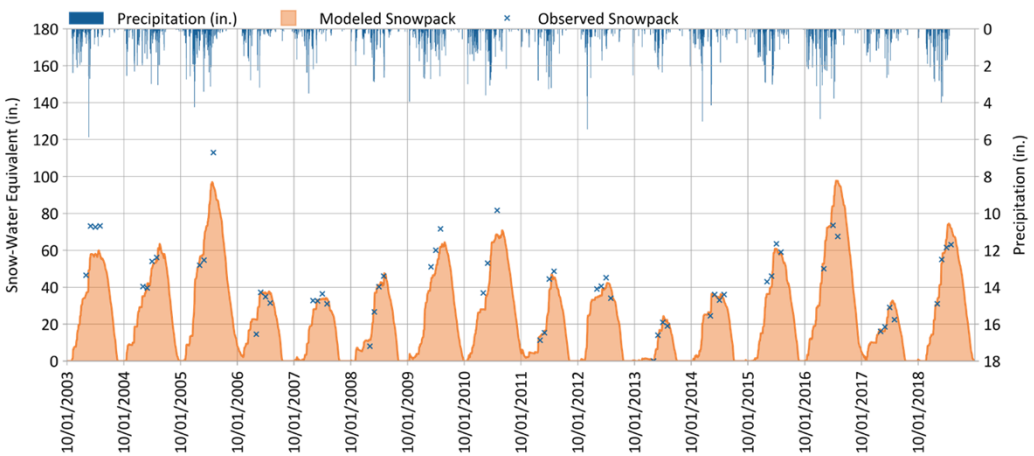
Calibration Stations

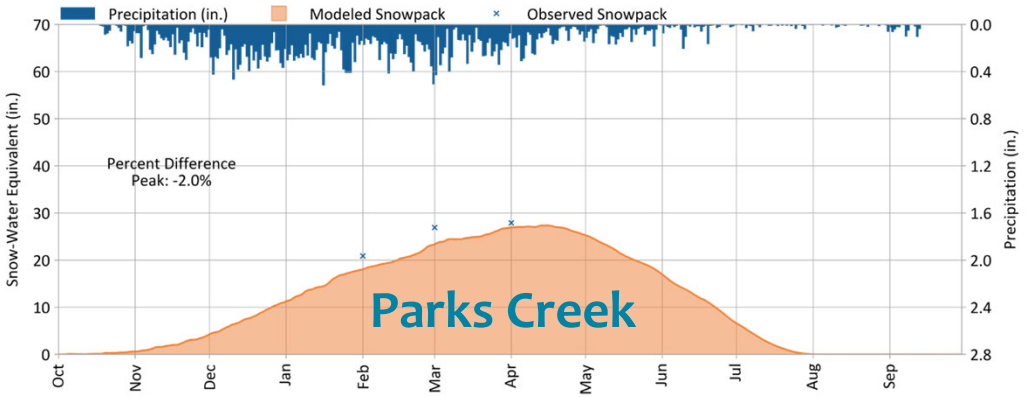
- CDEC Database (Monthly)
  - Parks Creek
  - Sweetwater
  - Little Shasta
- SNOTEL (Daily)
  - Big Red Mountain
    (50 miles NW of Yreka)

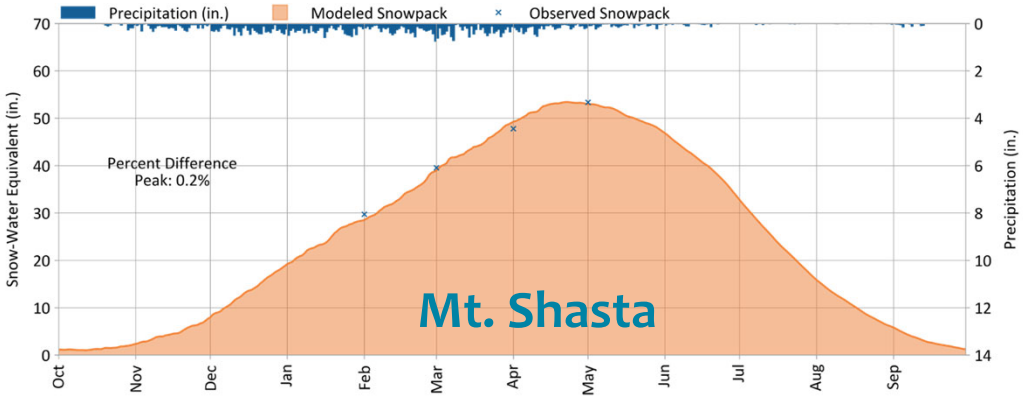
- Selected Locations

Snow Calibration: CDEC Monthly Snowpack

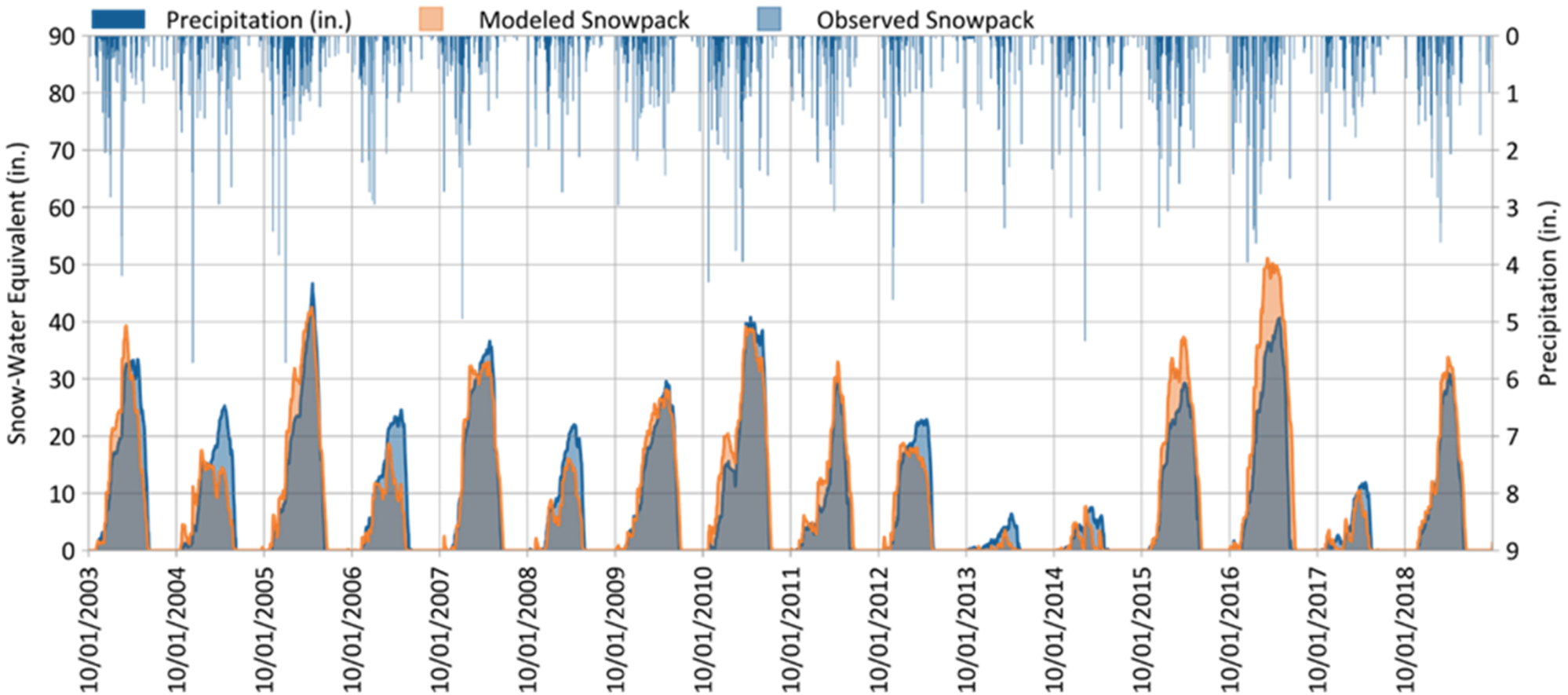


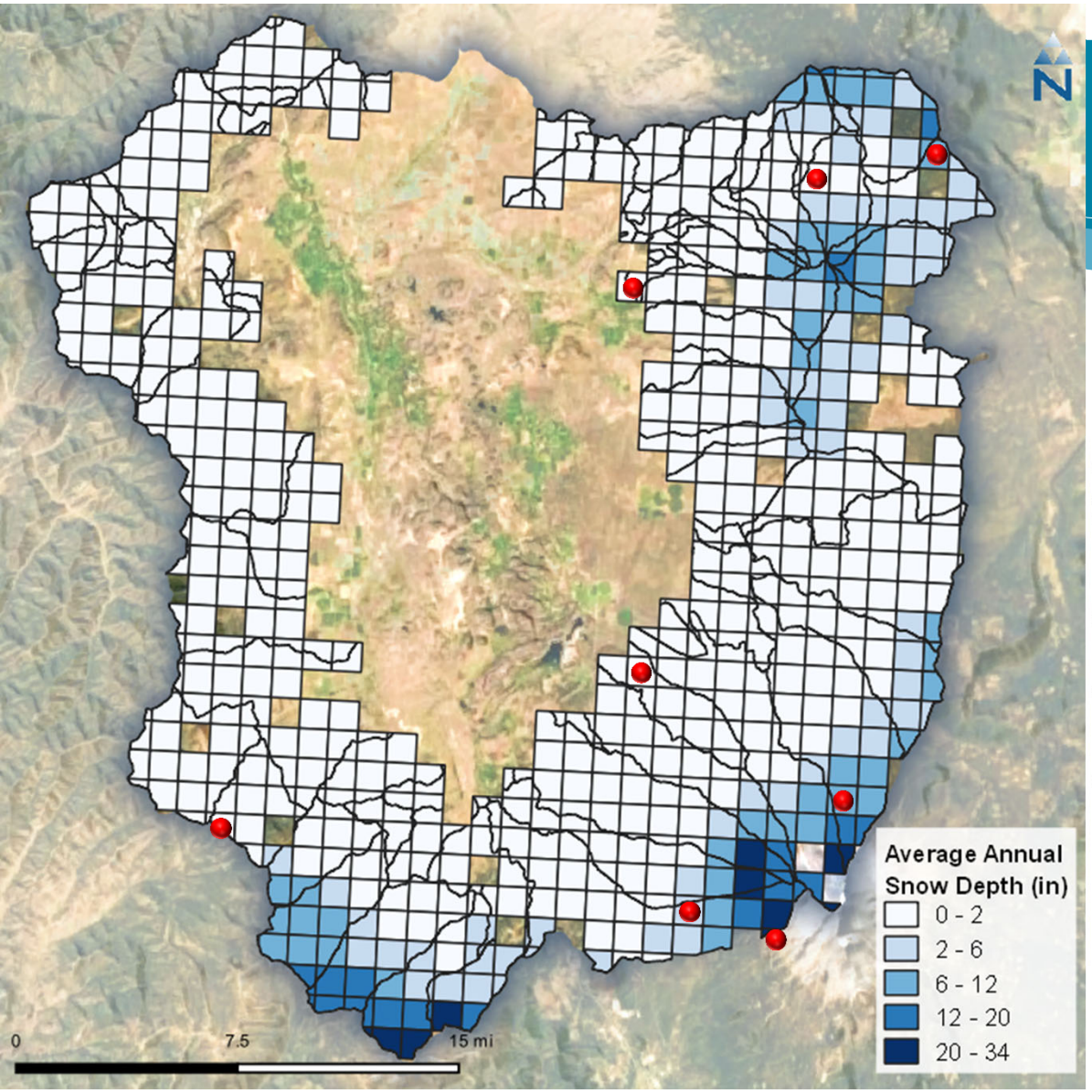






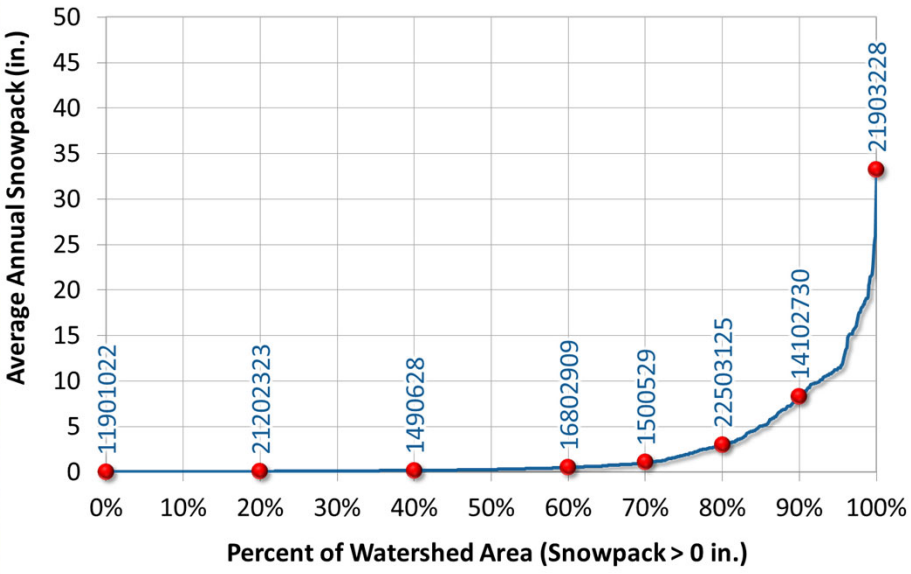
Snow Calibration: SNOTEL Big Red Mtn





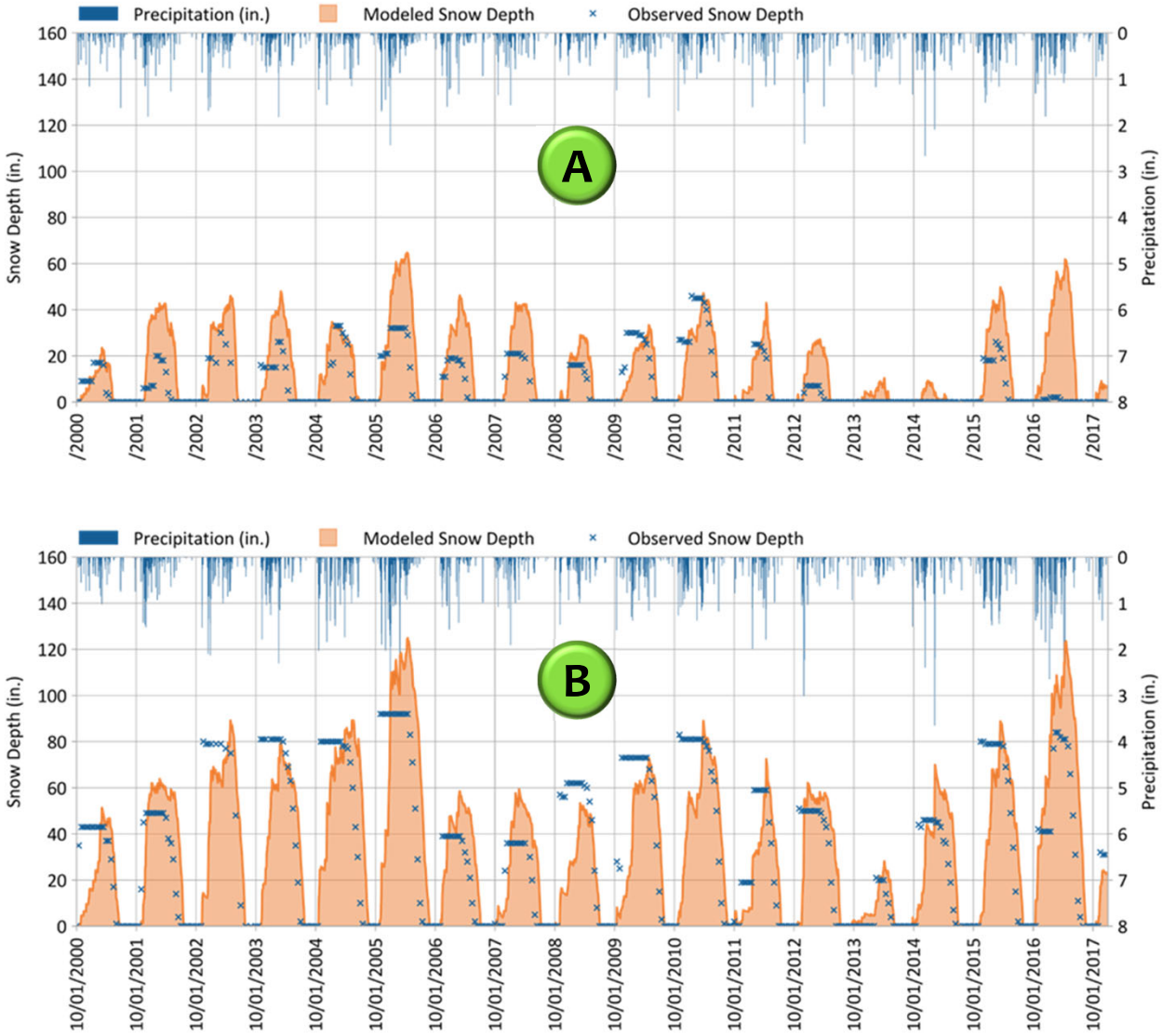
Validation Stations

- UCSB Snow Model

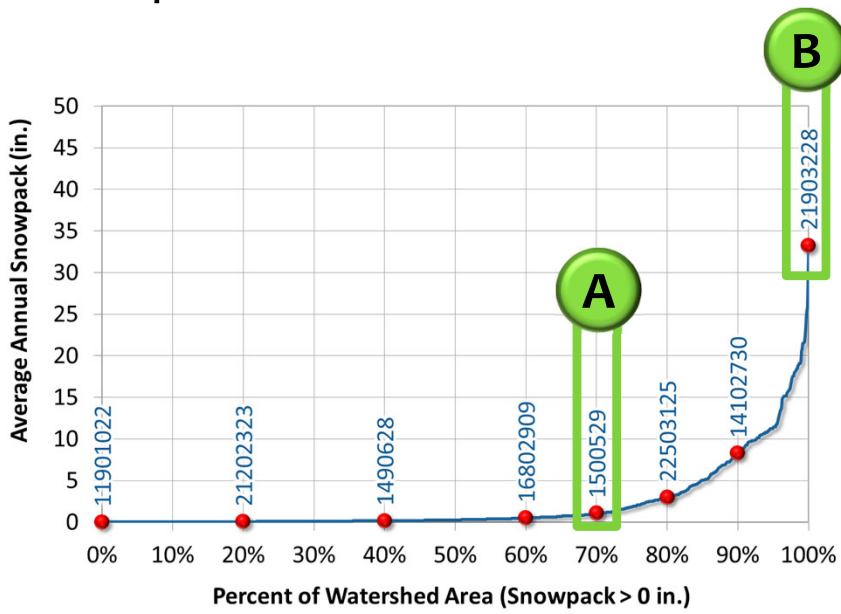


- Selected Locations

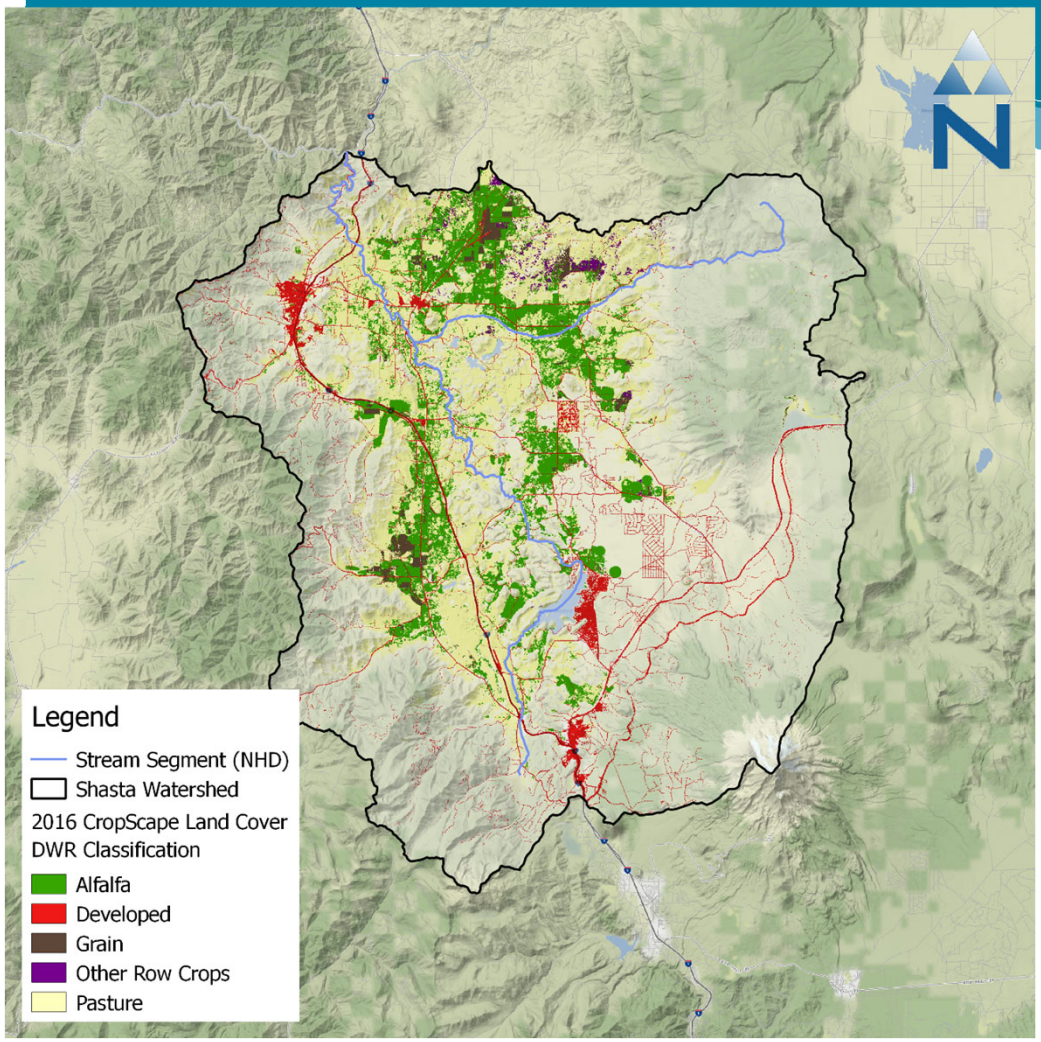
Snow Validation



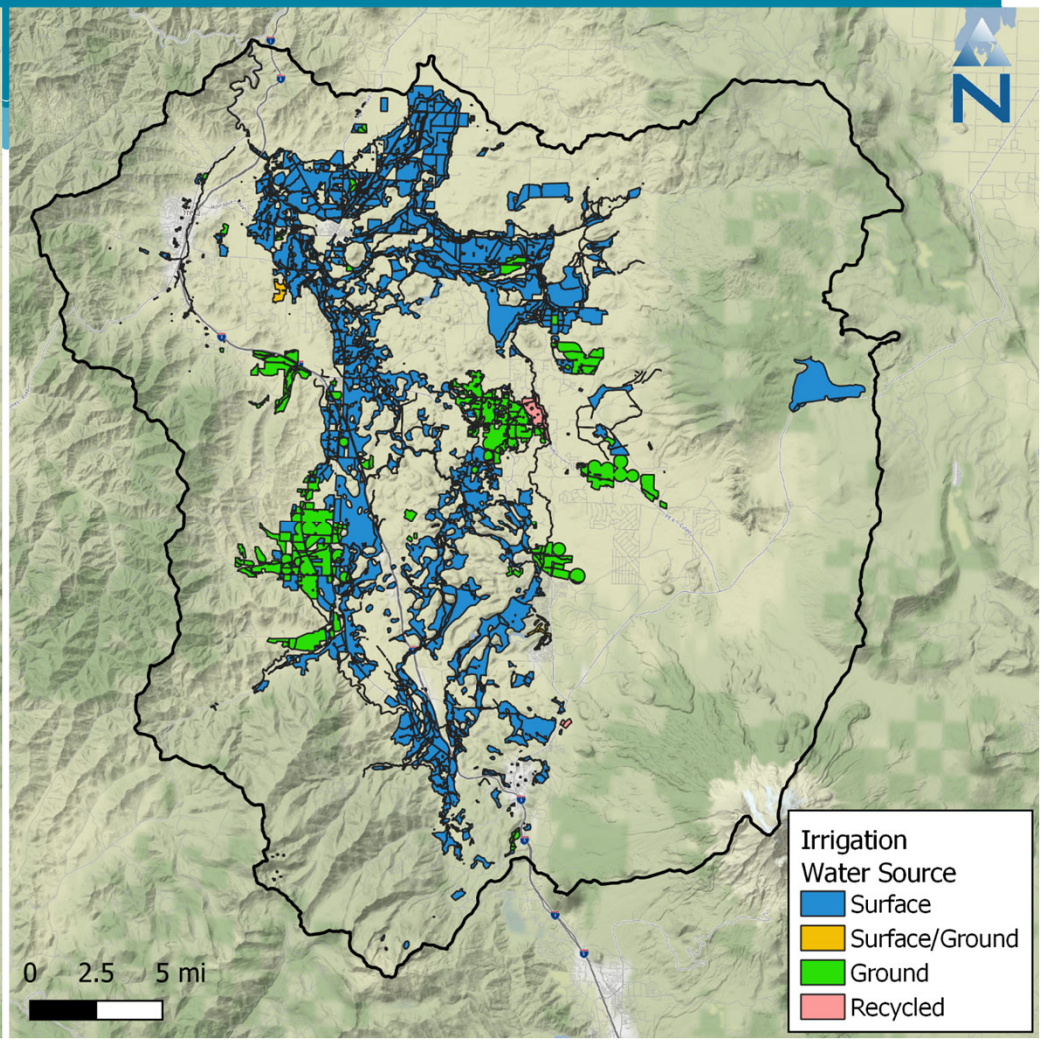
Compare to UCSB Snow Model



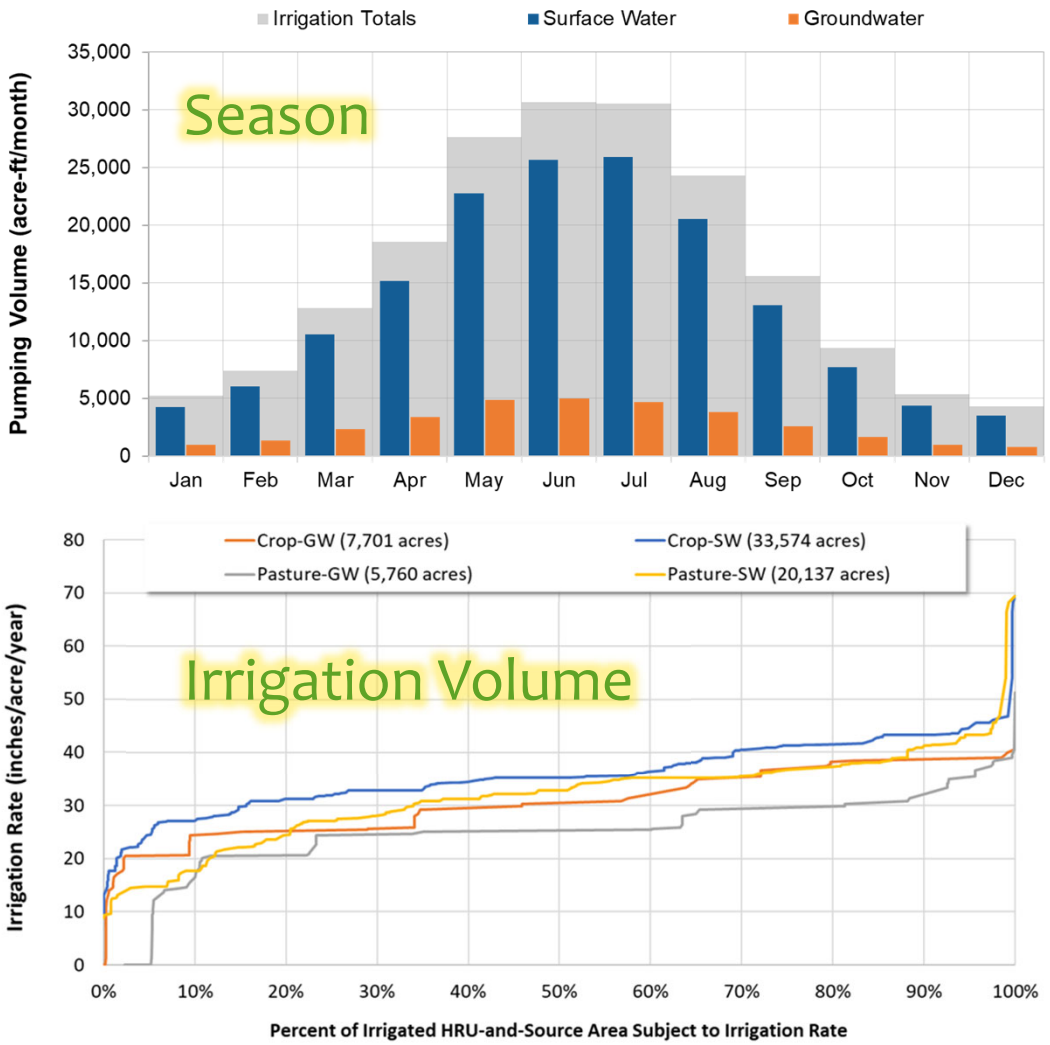
Grazing, Pasture, Crops



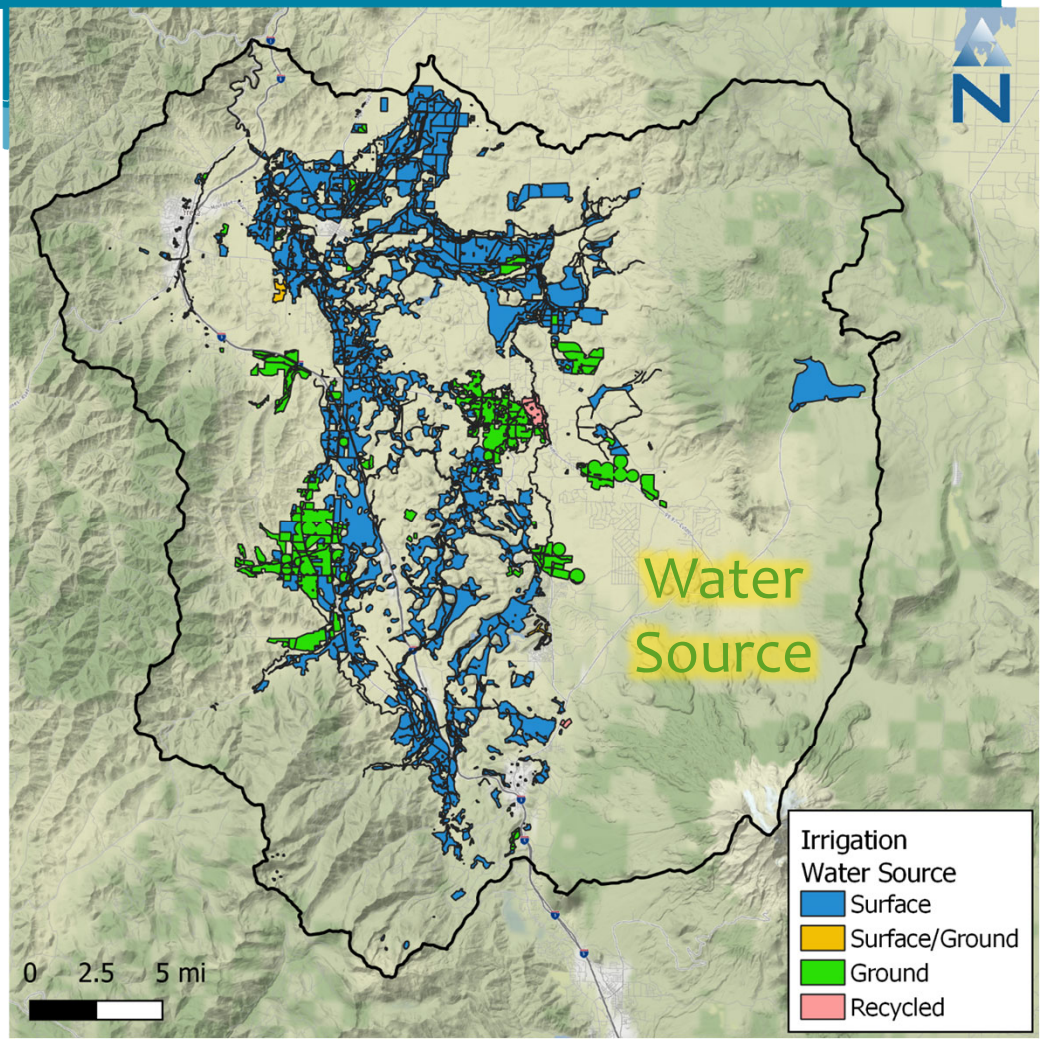
Irrigation Area/Water Source



Spatiotemporal Variation

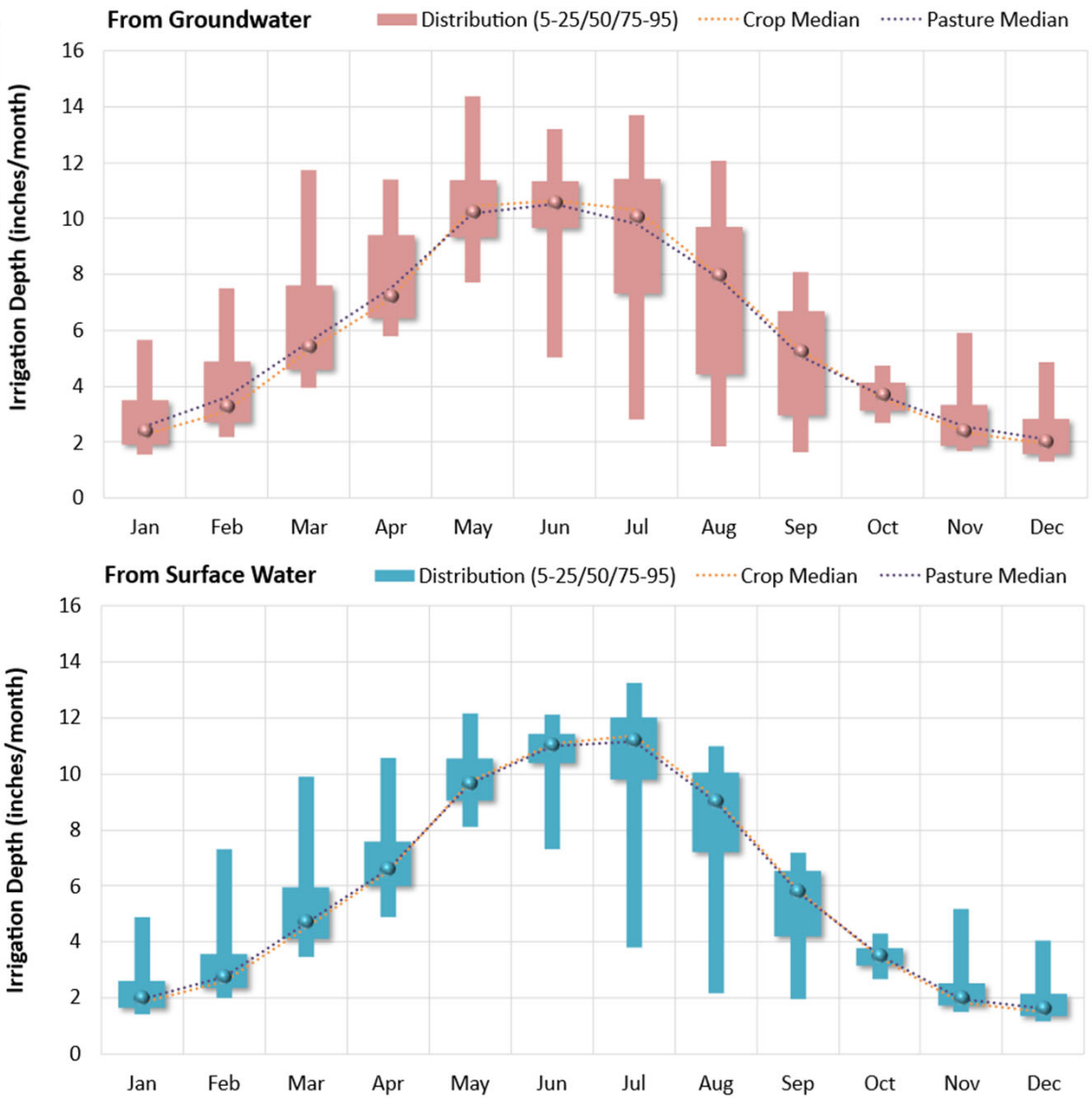


Irrigation Area/Water Source

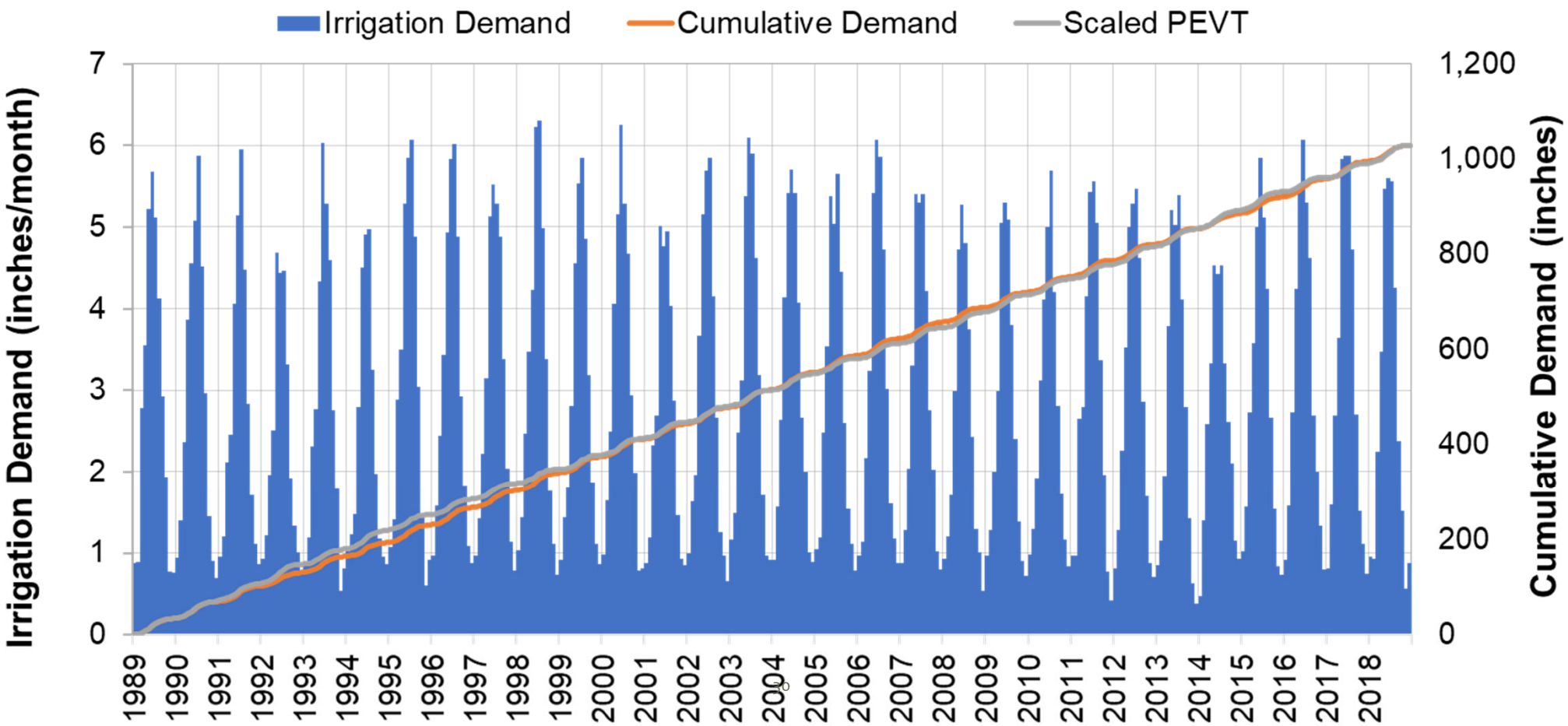


Irrigation Depths

- Unit-area irrigation per catchment is a function of:
  - Associated PET
  - Monthly average Et_c
- Volumes by catchment adjusted to match David's Engineering ET Demand



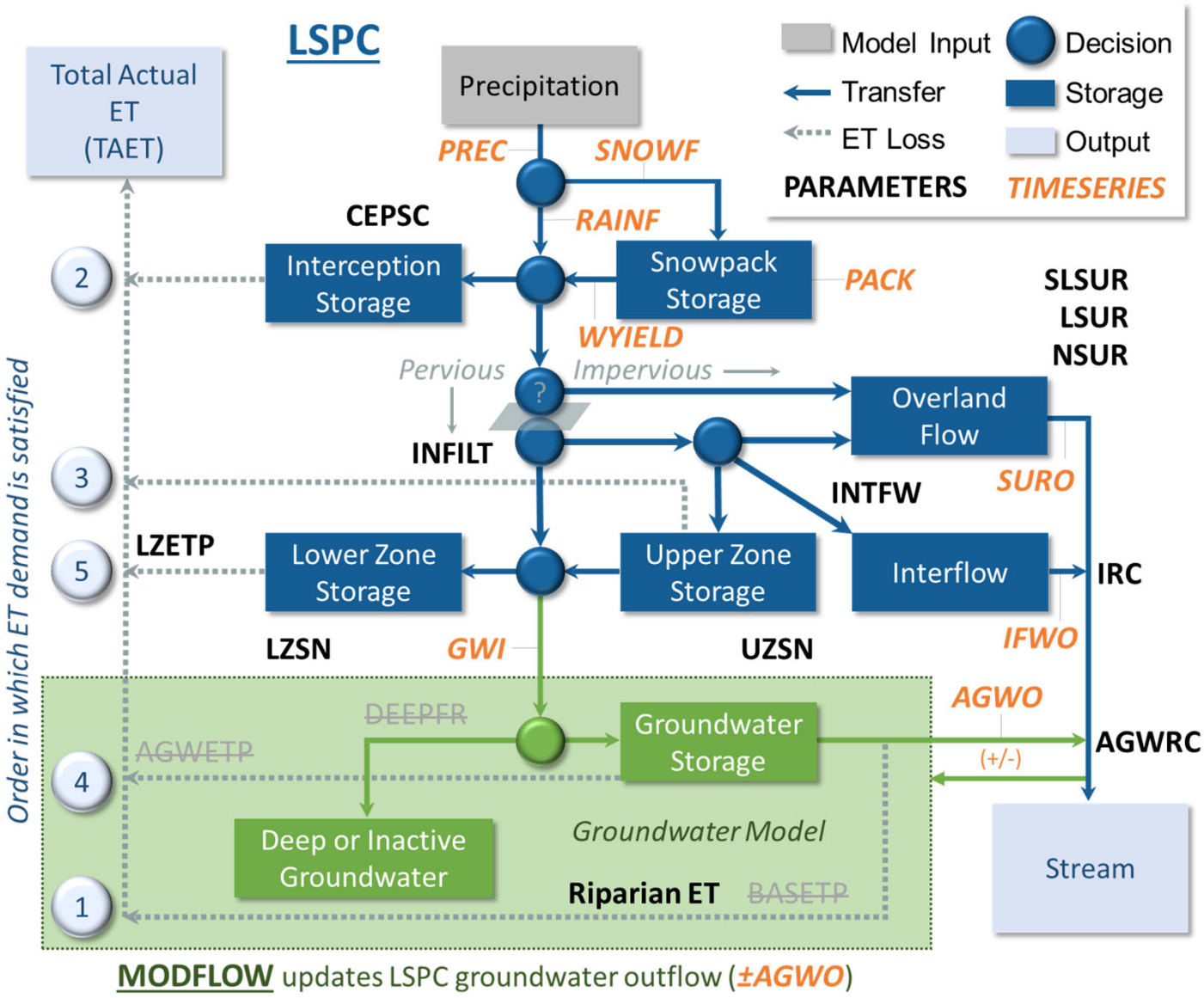
Long-Term Average Modeled vs. DE Demand

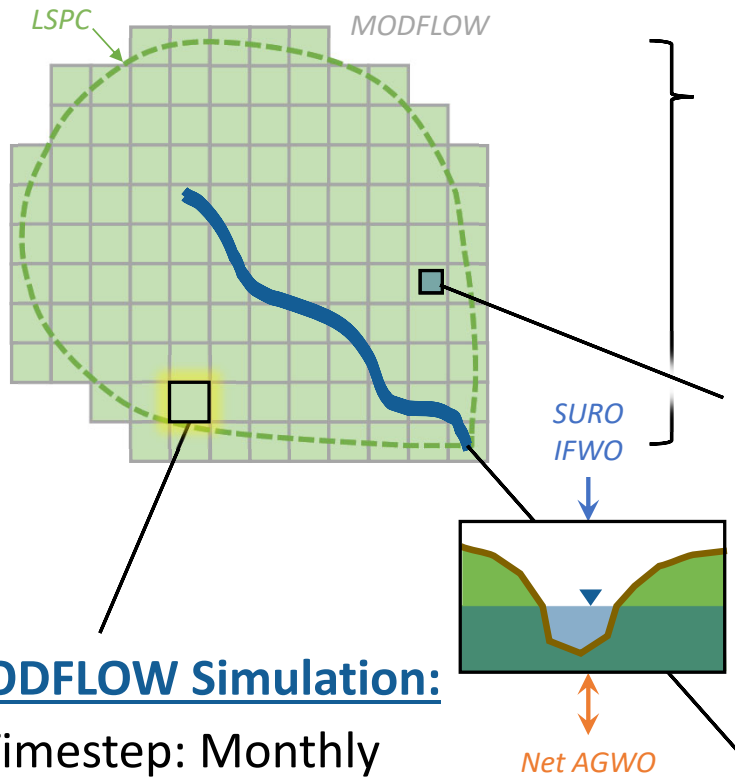


MODFLOW Linkage

LSPC & MODFLOW

- MODFLOW replaces **Groundwater Layer** in LSPC
- AGWO volumes adjusted (+/-) to match MODFLOW monthly volumes
- Linkage occurs at edge-of-stream to AGWO, prior to reach routing





LSPC Simulation (Hourly):

- Diversions + Irrigation + Return Flows
- Runoff (SURO) + Interflow (IFWO)
- **Groundwater Outflow (AGWO) iteratively adjusted w/ MODFLOW***

HRU Combinations:

- Resampled by MODFLOW grid
- **Groundwater Inflow (GWI)*** from LSPC aggregated monthly by MODFLOW grid (unique by grid)

MODFLOW Simulation:

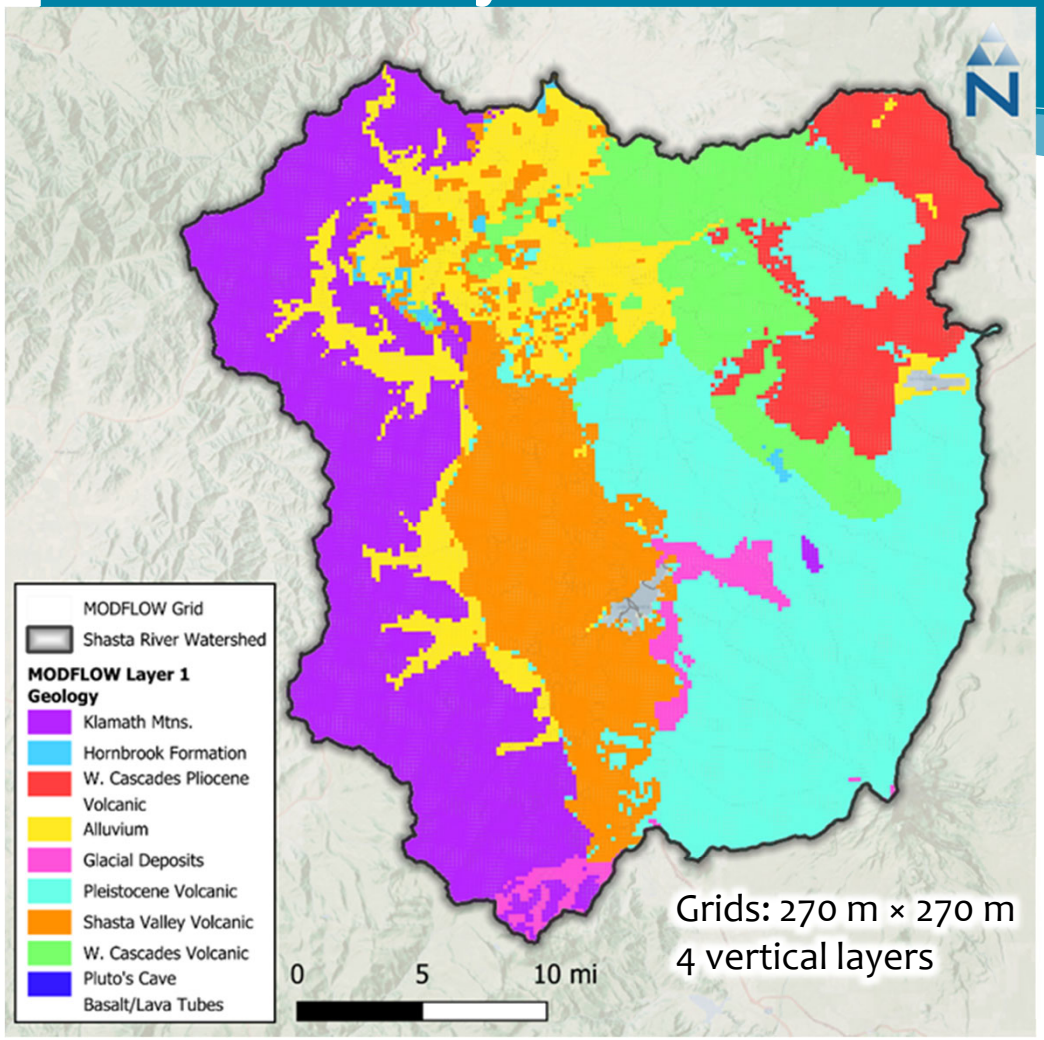
- Timestep: Monthly
- Inflow: **GWI** * + Canal Leakage
- Withdrawals: Pumping
- **Net Outflow: AGWO** *

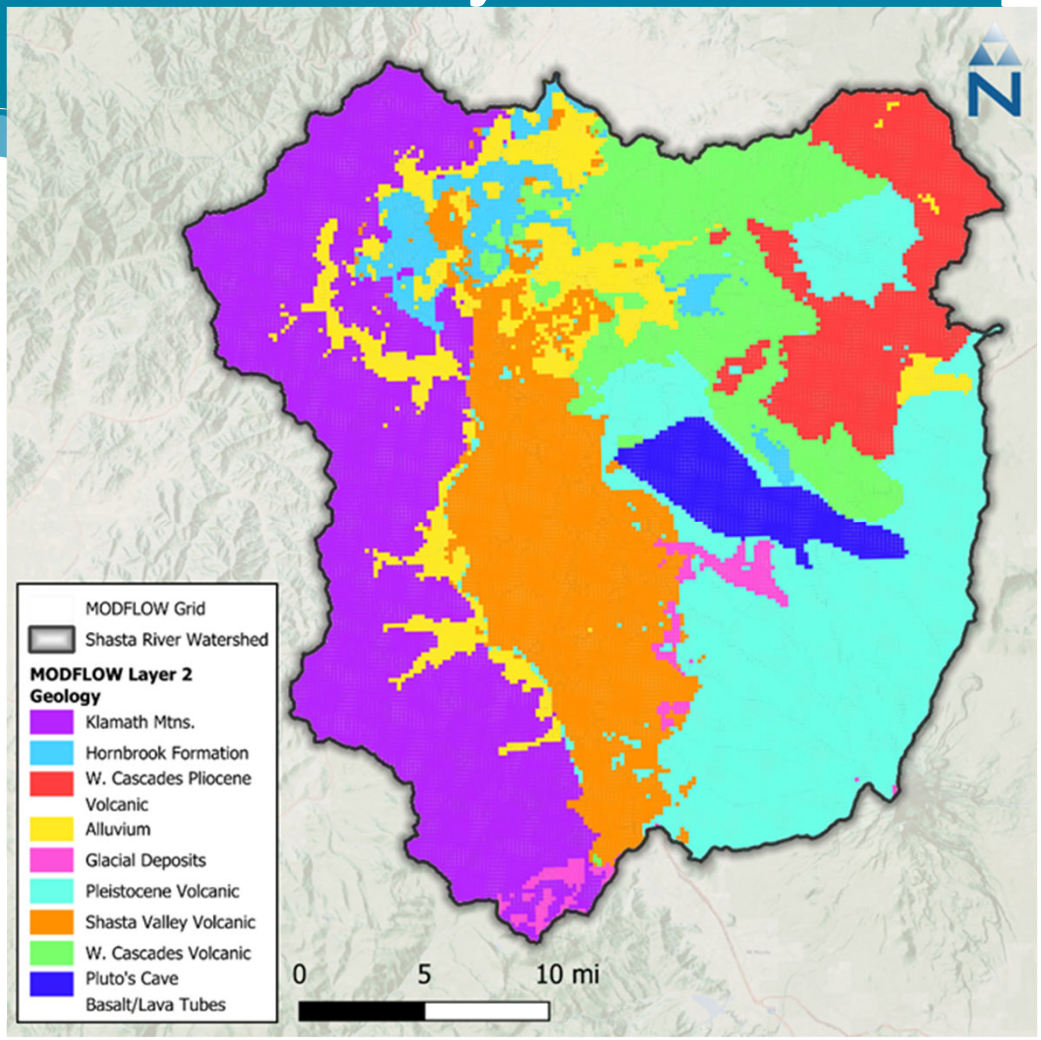
By Reach/Lake Segment:

- **AGWO "Deltas"** * derived to match monthly **MODFLOW Net Outflow**
- **AGWO** adjusted to close linkage

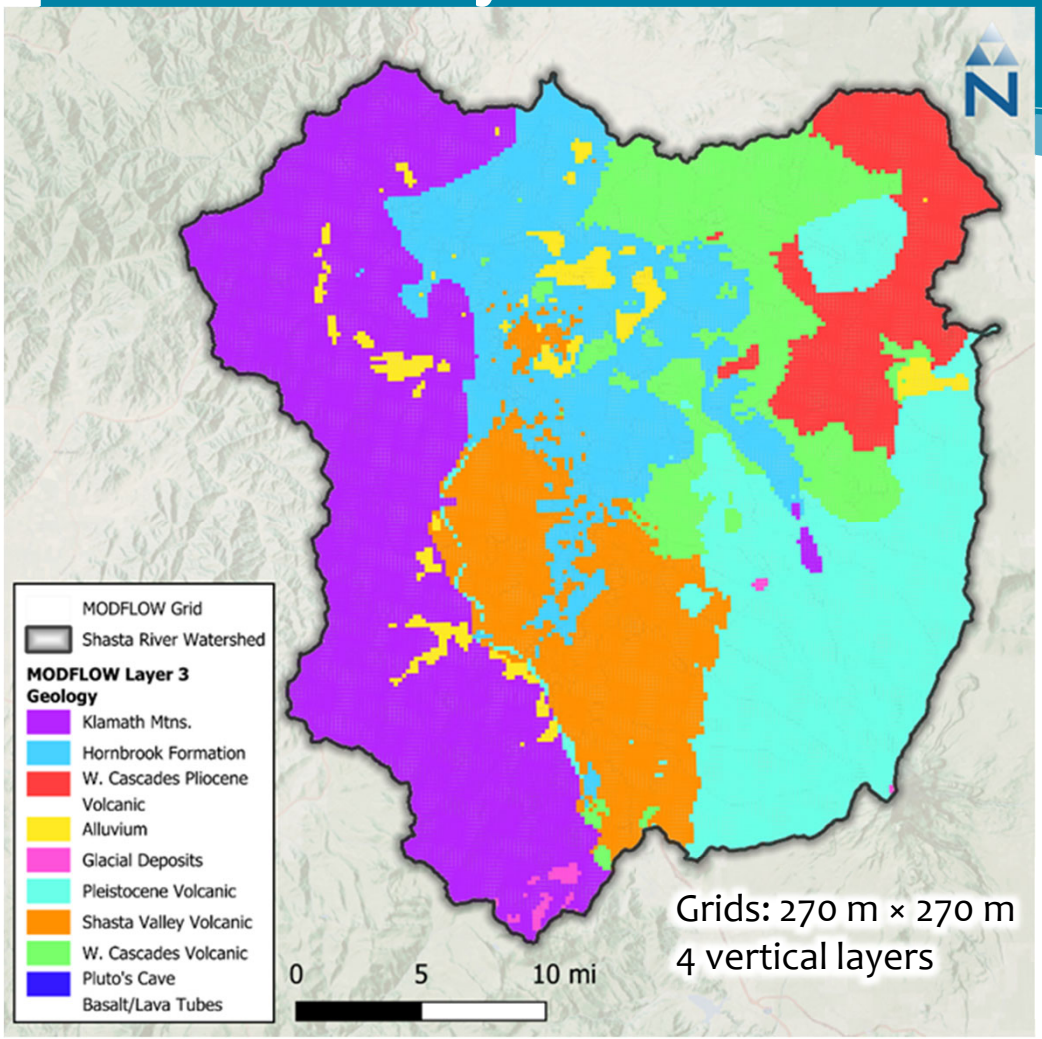
*** MODFLOW Linkages: Inflow (GWI) and Net Outflow (AGWO)**

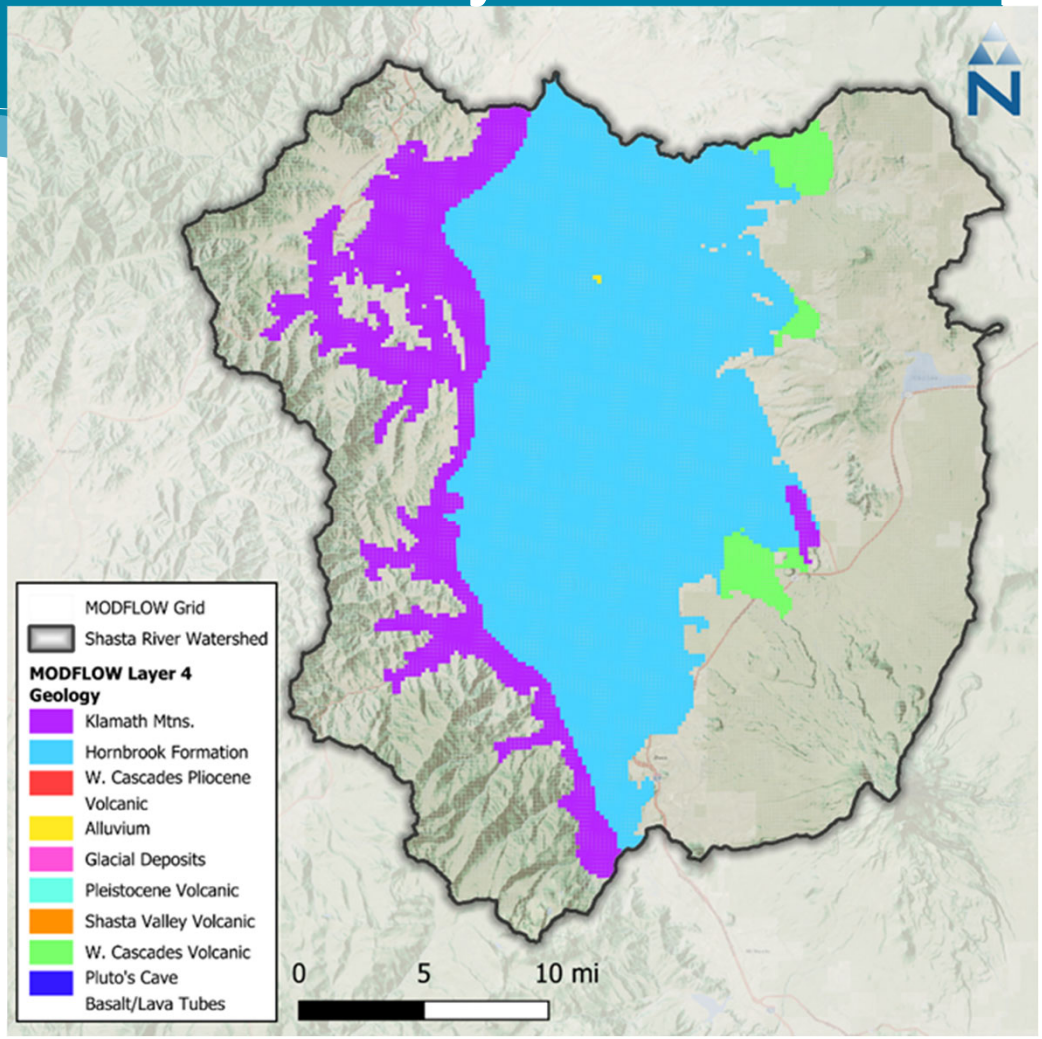
Layer 1 MODFLOW Layer 2





Layer 3 MODFLOW Layer 4



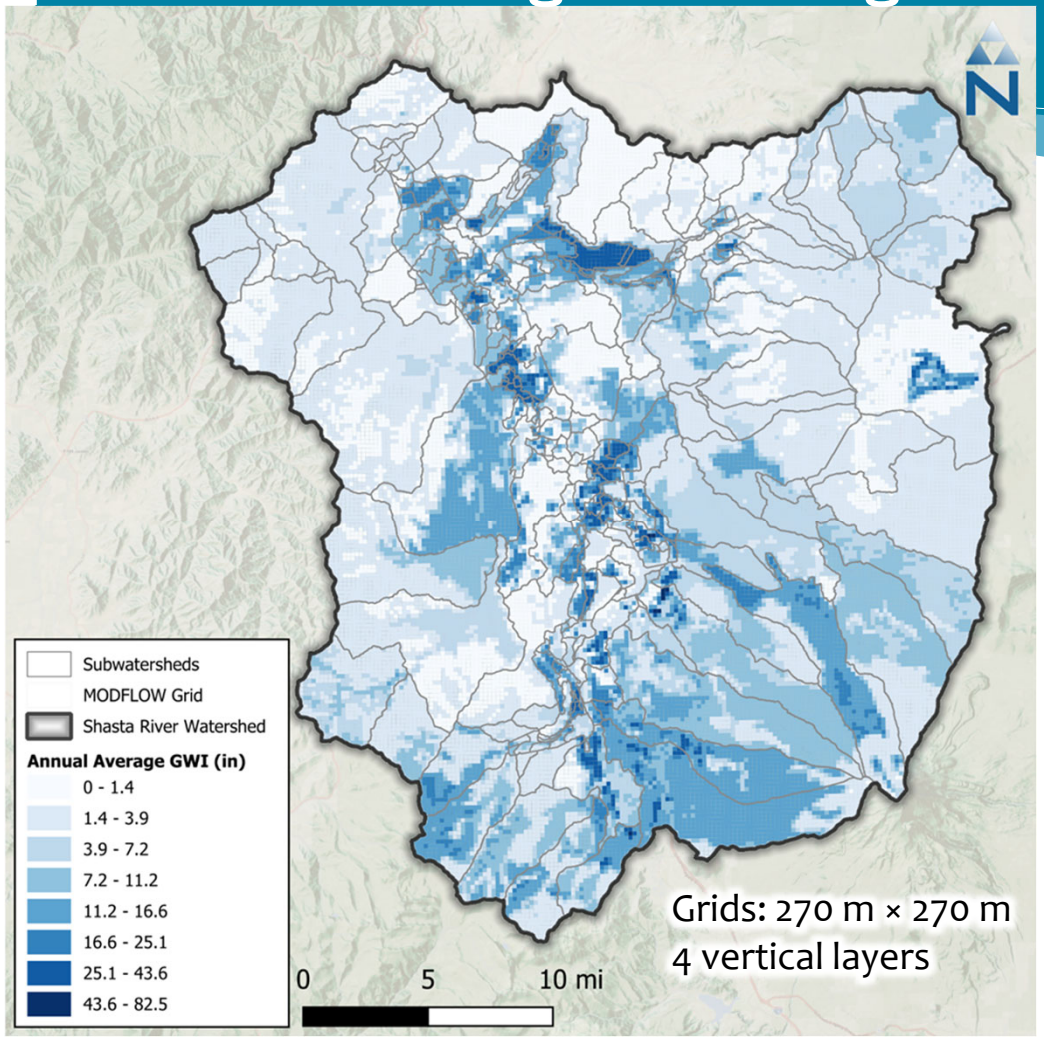


MODFLOW: Grids by Layer and Geological Group

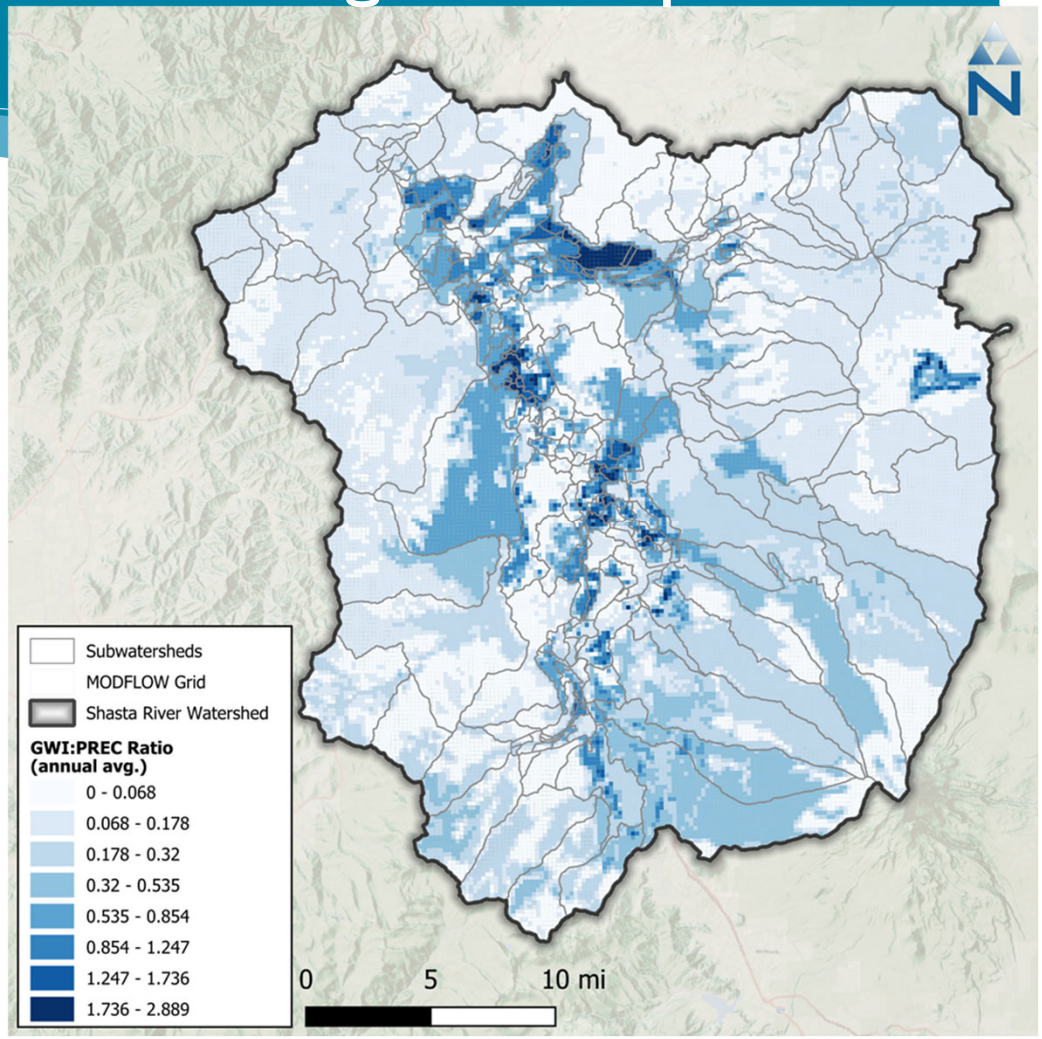
Geological Group	Horizontal Hydraulic Conductivity (feet/day)				Vertical Hydraulic Conductivity (feet/day)				Specific Storage (1/feet)	Specific Yield
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 1	Layer 2	Layer 3	Layer 4	All Layers	All Layers
Klamath Mountains	9.94	0.030	0.030	0.030	1.99	0.00025	0.00025	0.00025	6.23E-07	0.14
Hornbrook Formation	0.0084	0.0084	0.0084	0.0084	0.00055	0.00055	0.00055	0.00055	1.89E-05	0.055
Western Cascades Pliocene Volcanic	1.85	1.85	1.85	---	0.031	0.031	0.031	---	1.41E-05	0.12
Alluvium	136.05	27.53	27.53	27.53	13.549	4.03	4.03	4.03	1.70E-06	0.20
Glacial Deposits	0.46	0.46	0.46	---	0.011	0.011	0.011	---	5.82E-06	0.056
Pleistocene Volcanic	38.72	38.72	38.72	---	7.74	7.74	7.74	---	1.06E-04	0.28
Shasta Valley Volcanic	7.65	7.65	7.65	---	0.44	0.44	0.44	---	1.87E-07	0.28
Western Cascades Volcanic	0.41	0.27	0.27	0.27	0.04	0.05	0.05	0.05	1.88E-06	0.28
Pluto's Cave Basalt	---	3,652.47	---	---	---	379.49	---	---	1.25E-04	0.28

Estimated location of geological high-conductivity zones

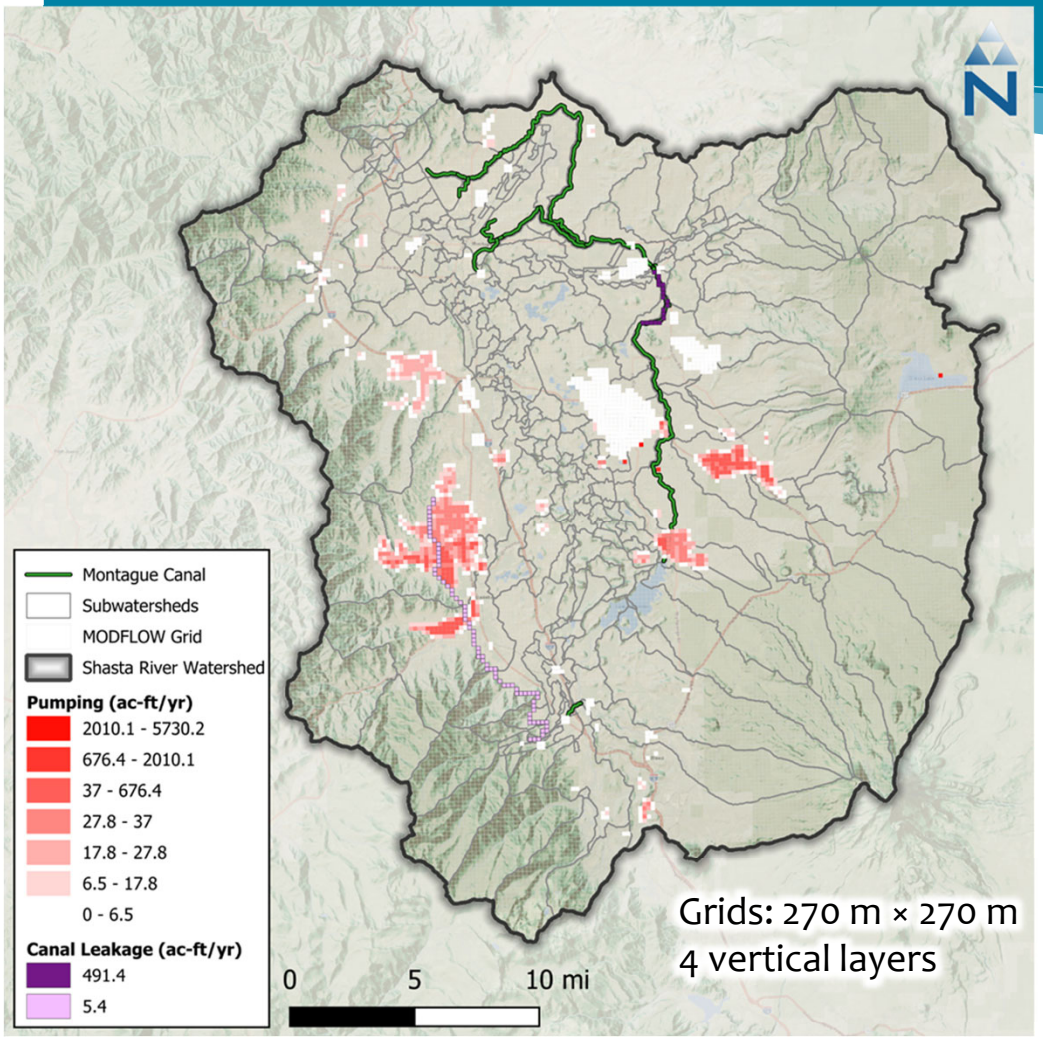
Annual Average Recharge

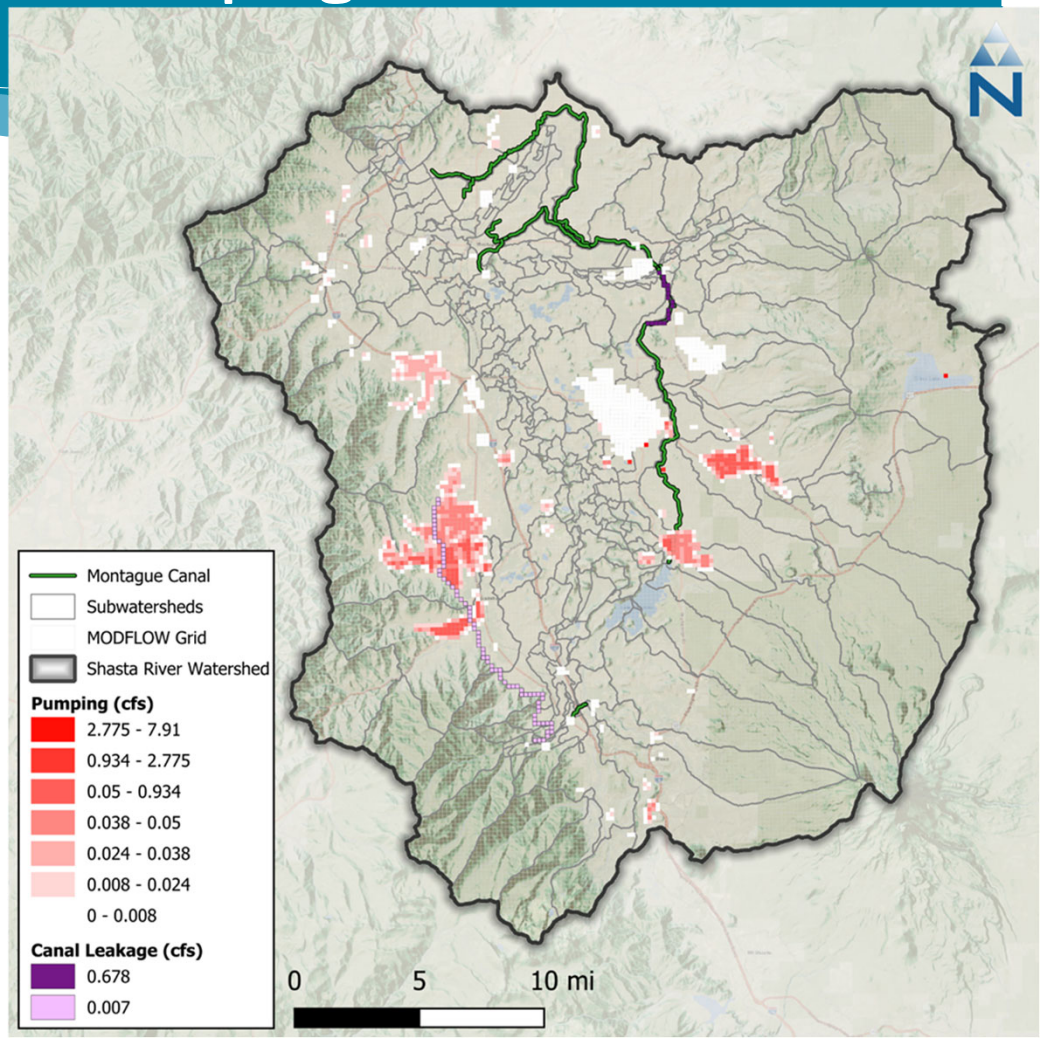


Recharge : Precipitation



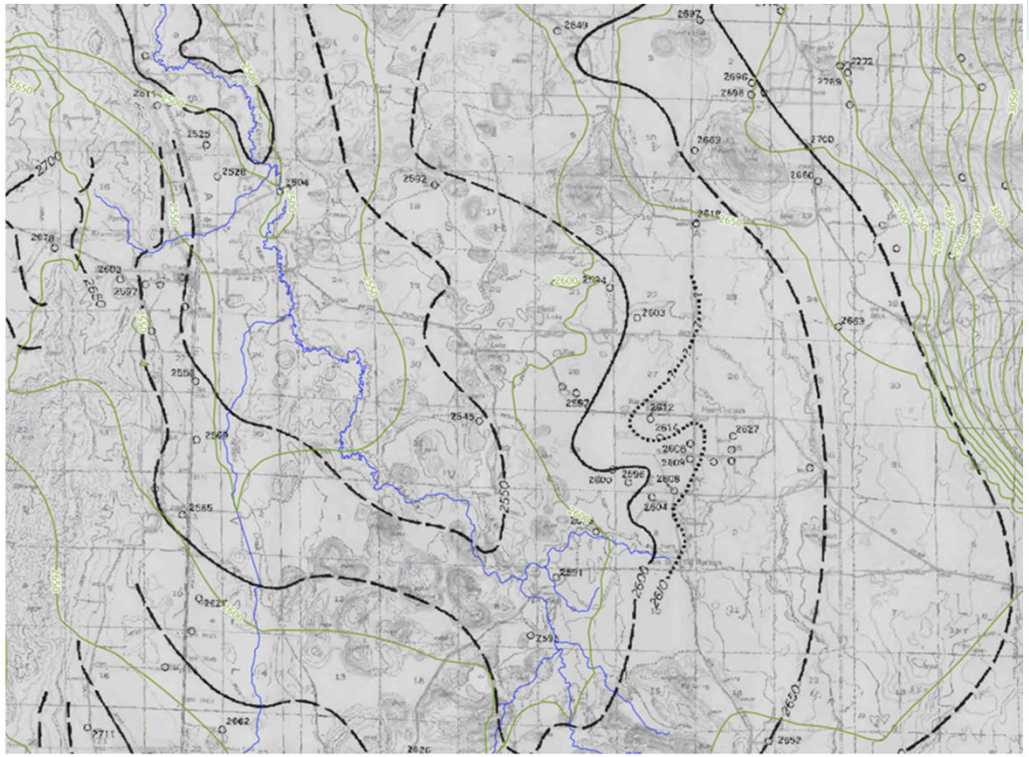
Groundwater Pumping





Initial Groundwater Levels

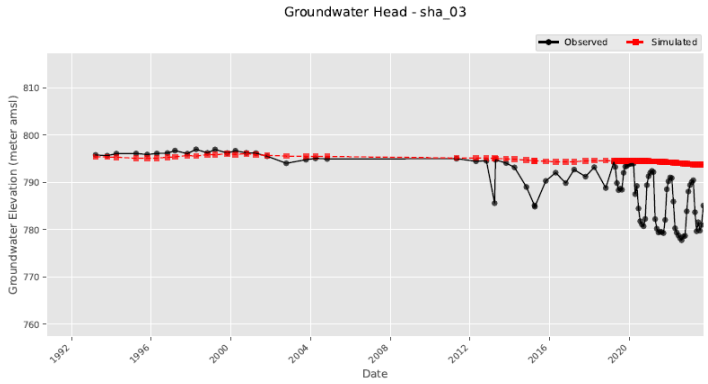
- Qualitative comparison shows good agreement between model-generated steady-state head distribution and Mack (1960) observed data representing Spring 1954 conditions.
- Steady-state heads represent 1990 conditions.

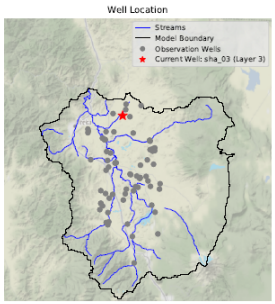


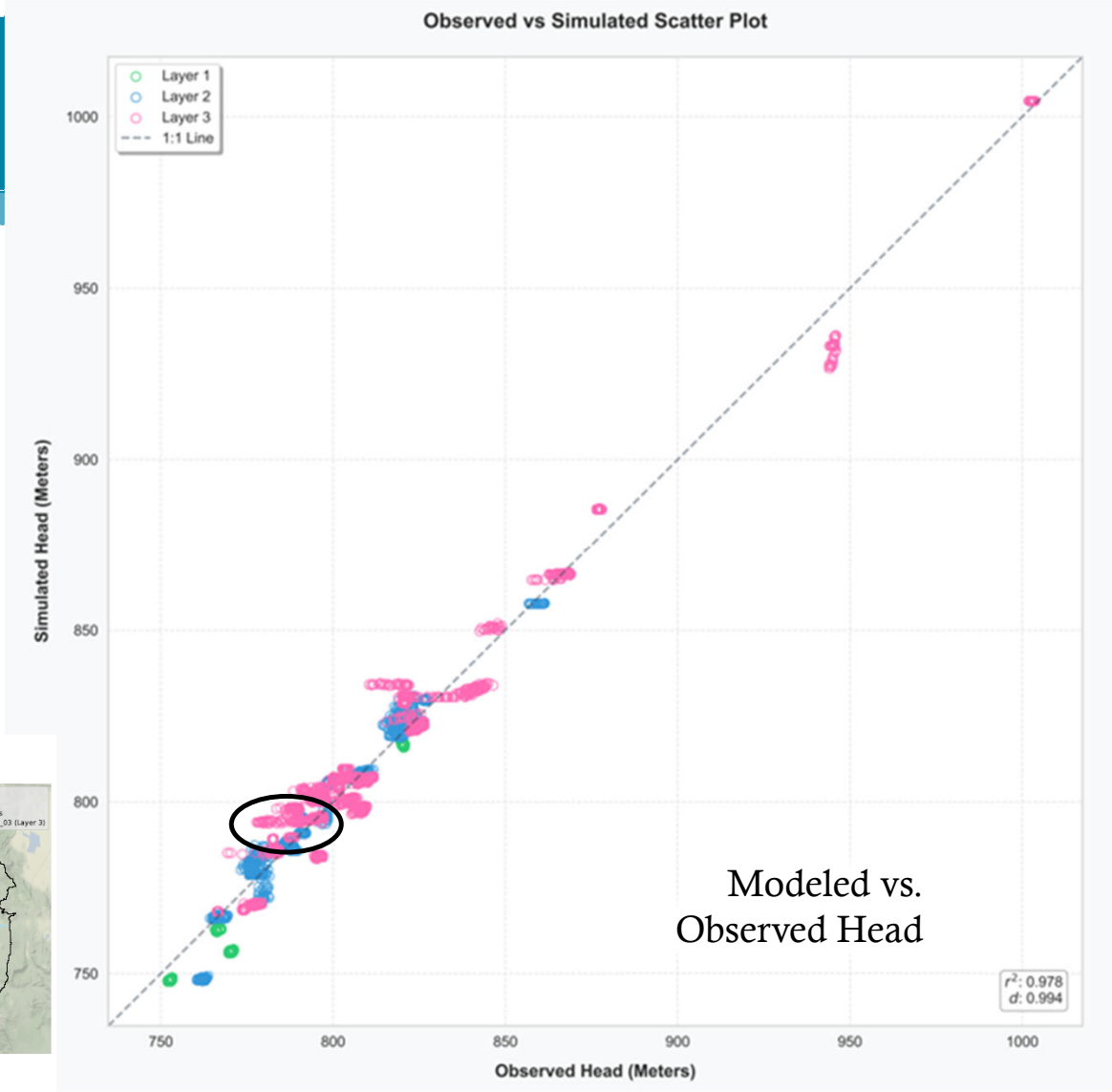
Head contours comparing observed data (black lines) for Spring 1954 (Mack, 1960) and model generated steady-state conditions (green lines).

Groundwater Levels

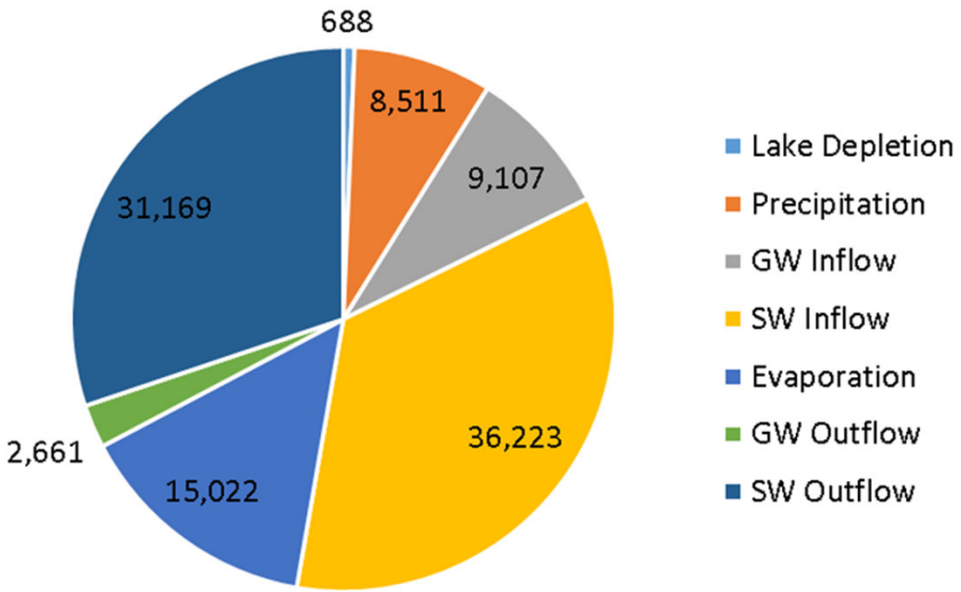
- History-matching shows a reasonable representation of overall groundwater level distribution.
- Example hydrograph illustrates unknown/approximate data (in this case pumping) and its effect on simulated results.

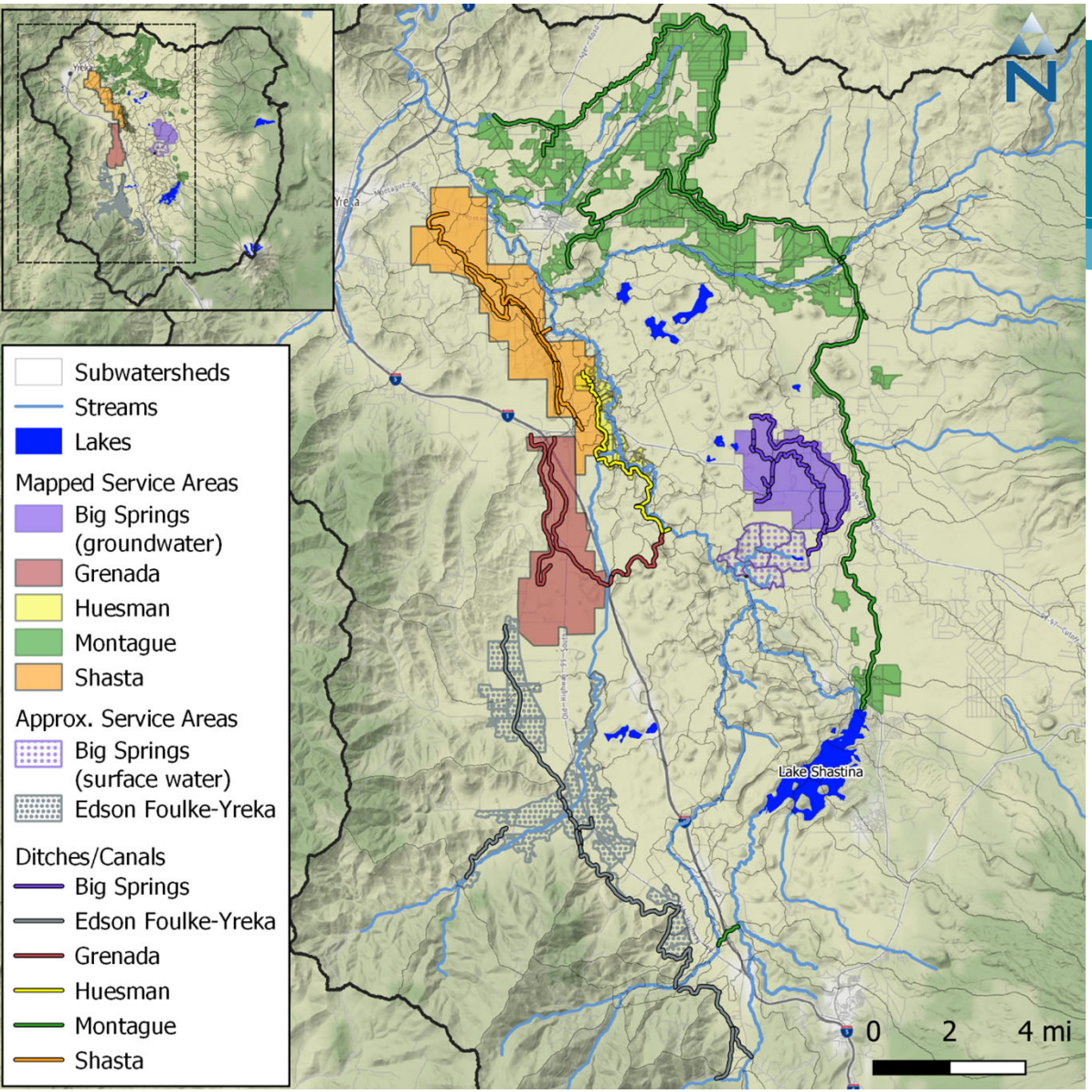






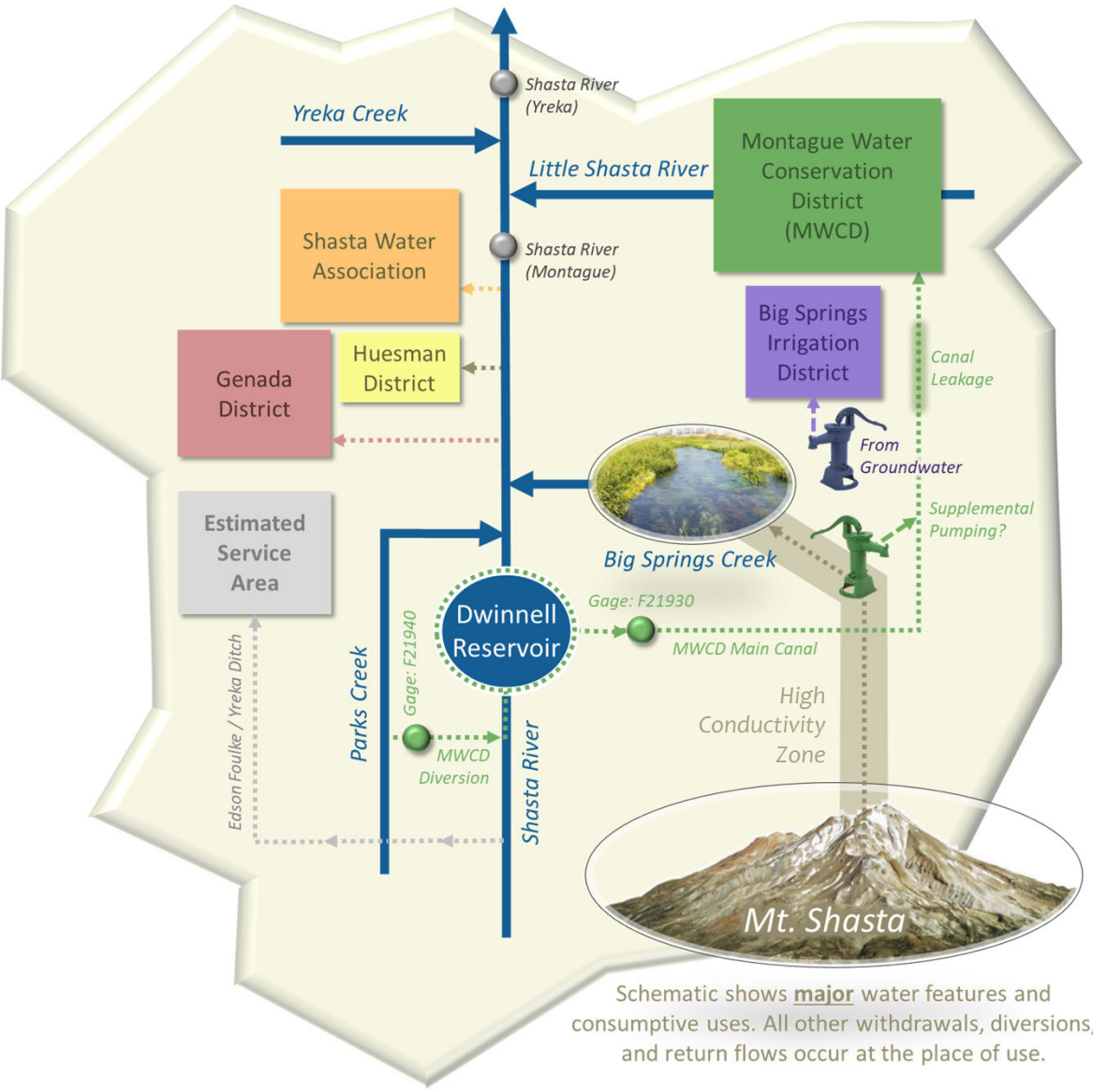
Lake Shastina Water Budget (Water Years 1991-2023)





Irrigation Districts

- Service Areas, Ditches, Canals
  - Big Springs
  - Grenada
  - Heusman
  - Montague
  - Shasta
  - Edson Foulke/Yreka Ditch
- Lakes and streams
- Points of diversion



Irrigation Districts

- Service Areas, Ditches, Canals
  - Big Springs
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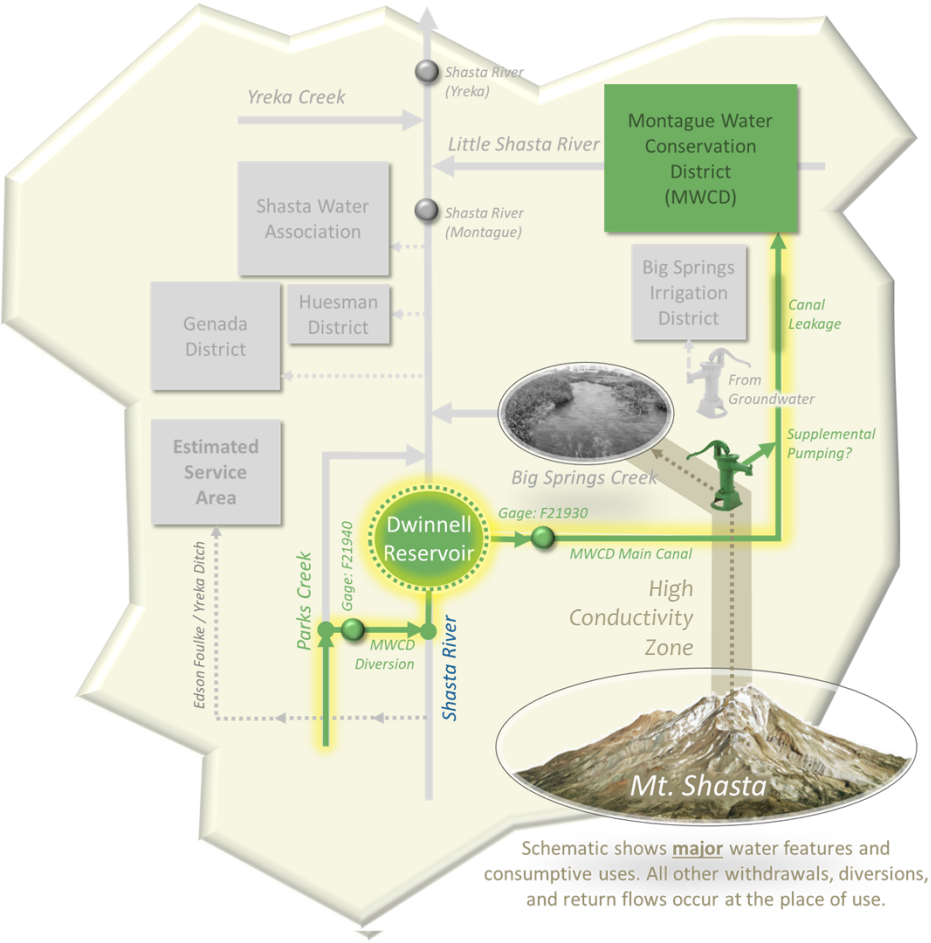
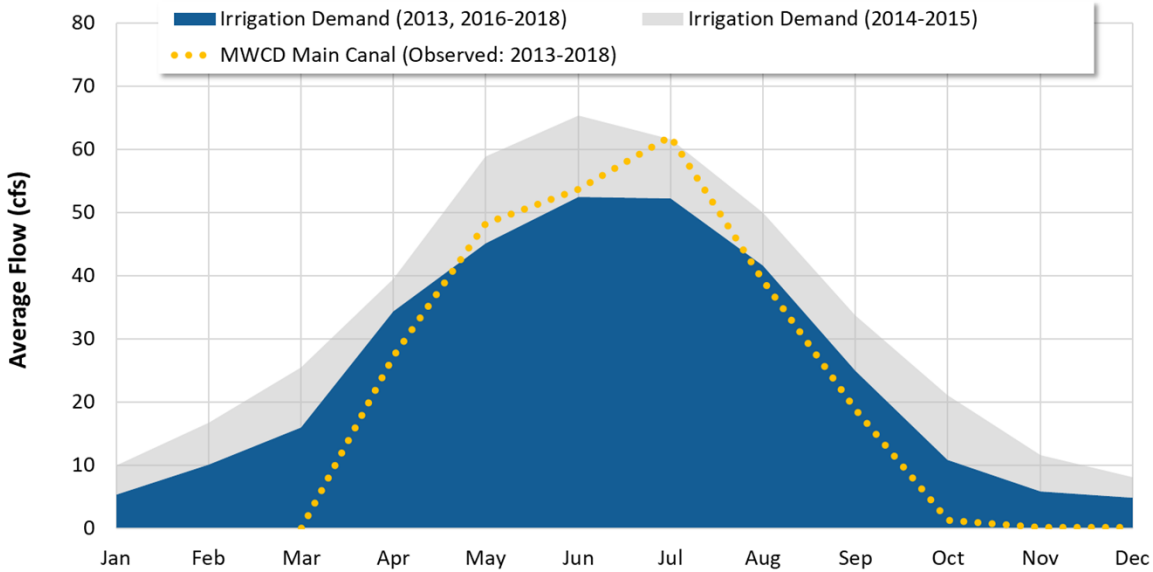
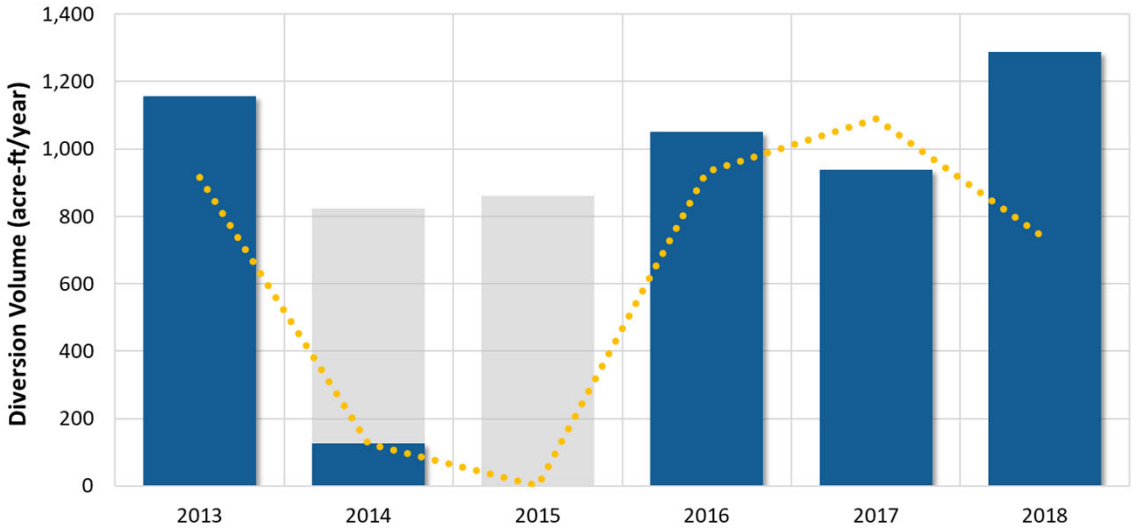
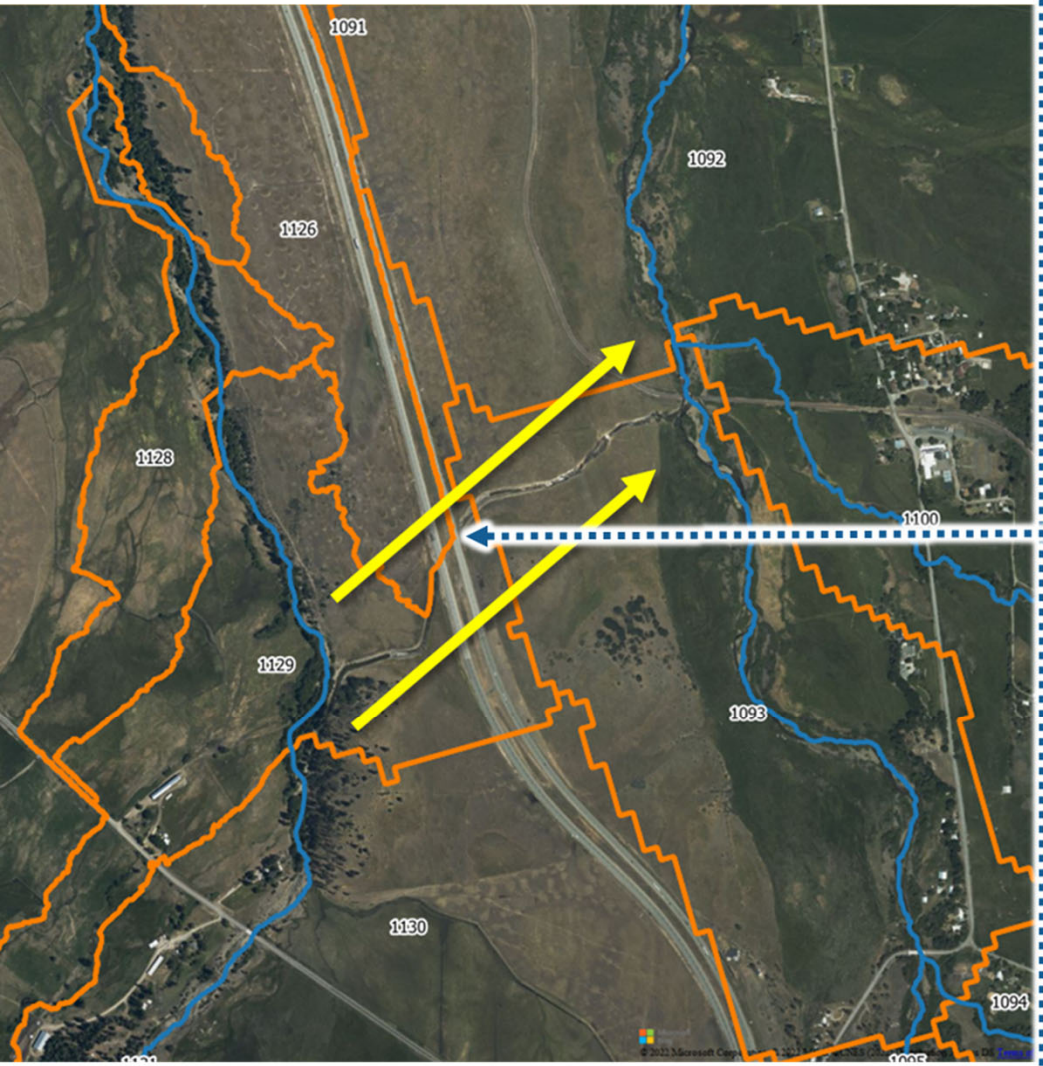
MWCD Canal



Schematic shows **major** water features and consumptive uses. All other withdrawals, diversions, and return flows occur at the place of use.



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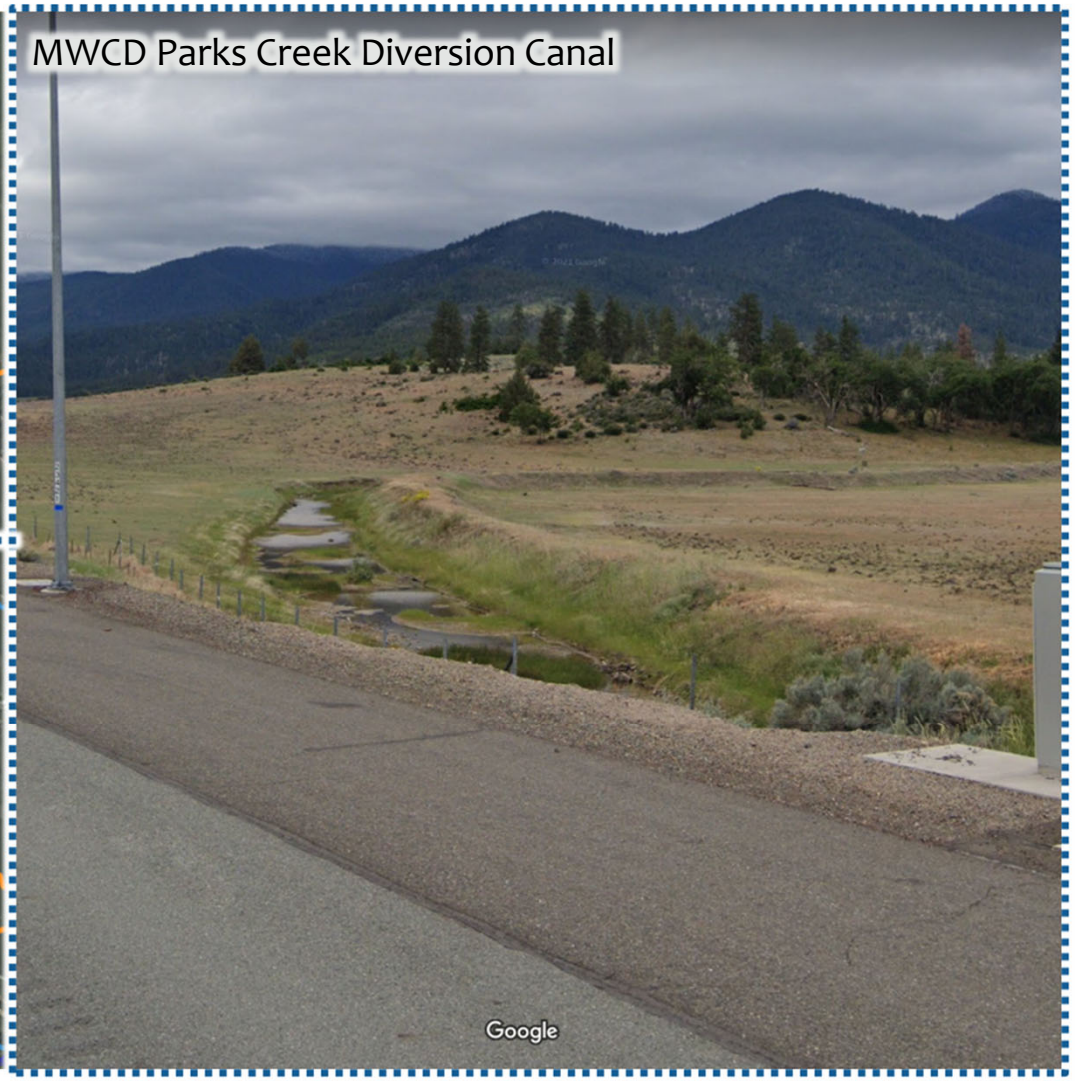
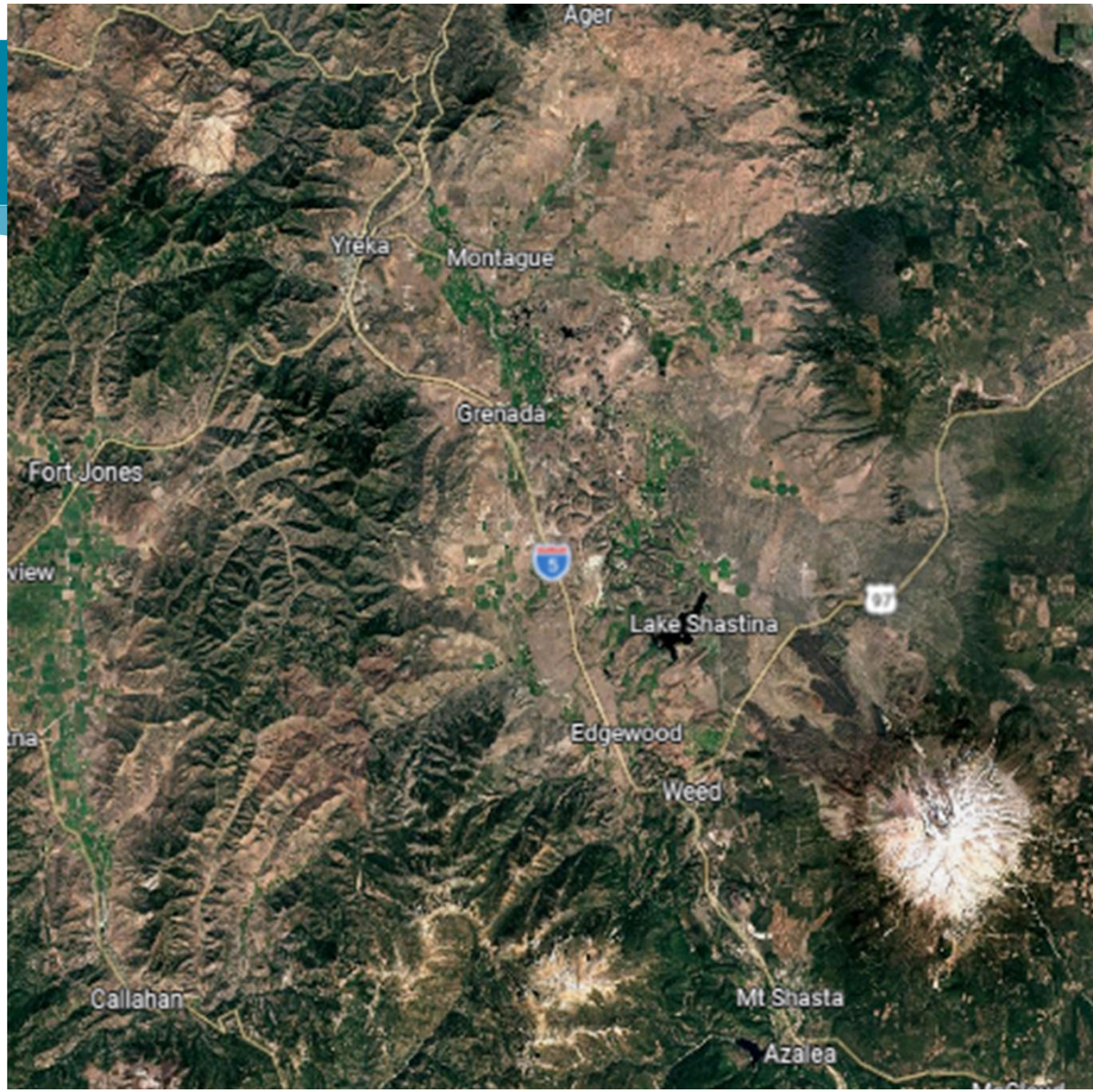
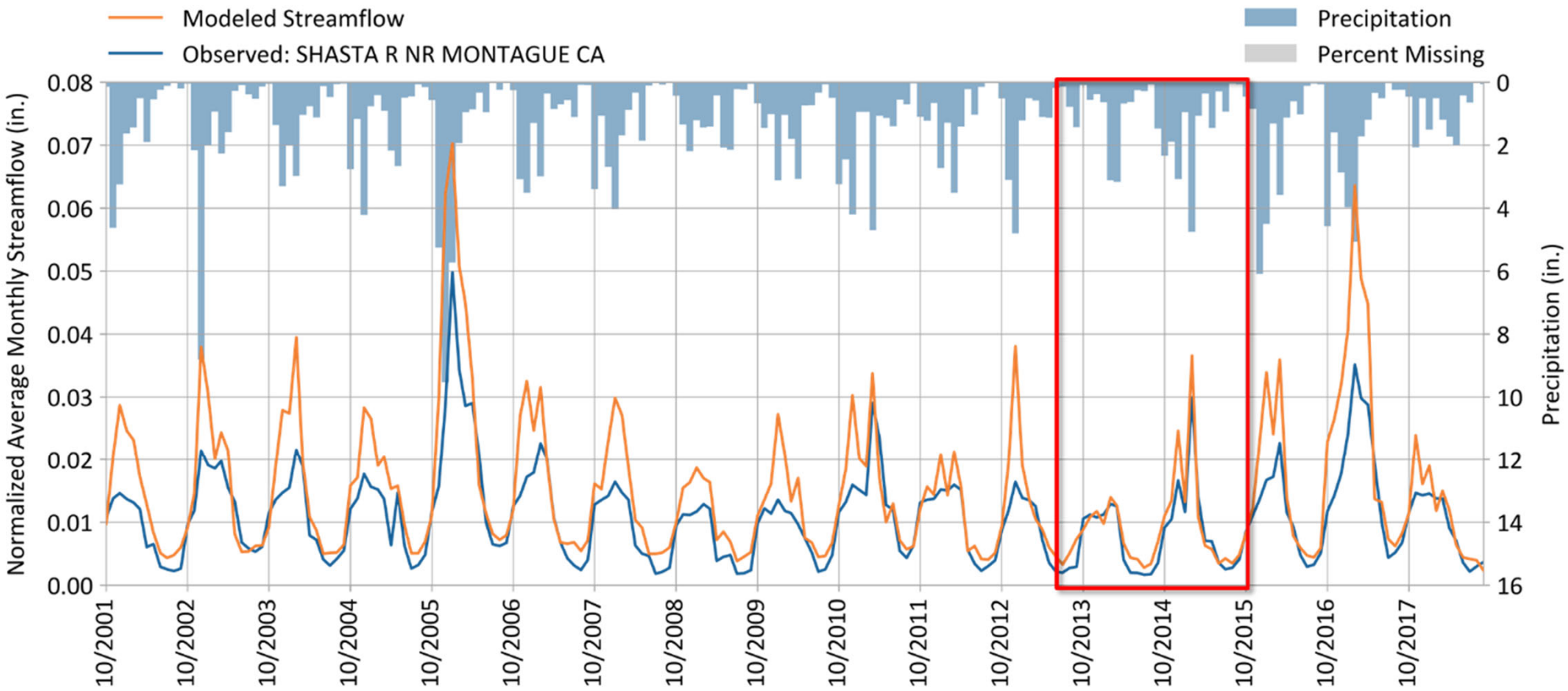

MWCD Parks Creek Diversion Canal
Google

Montague Canal and nearby irrigation fields

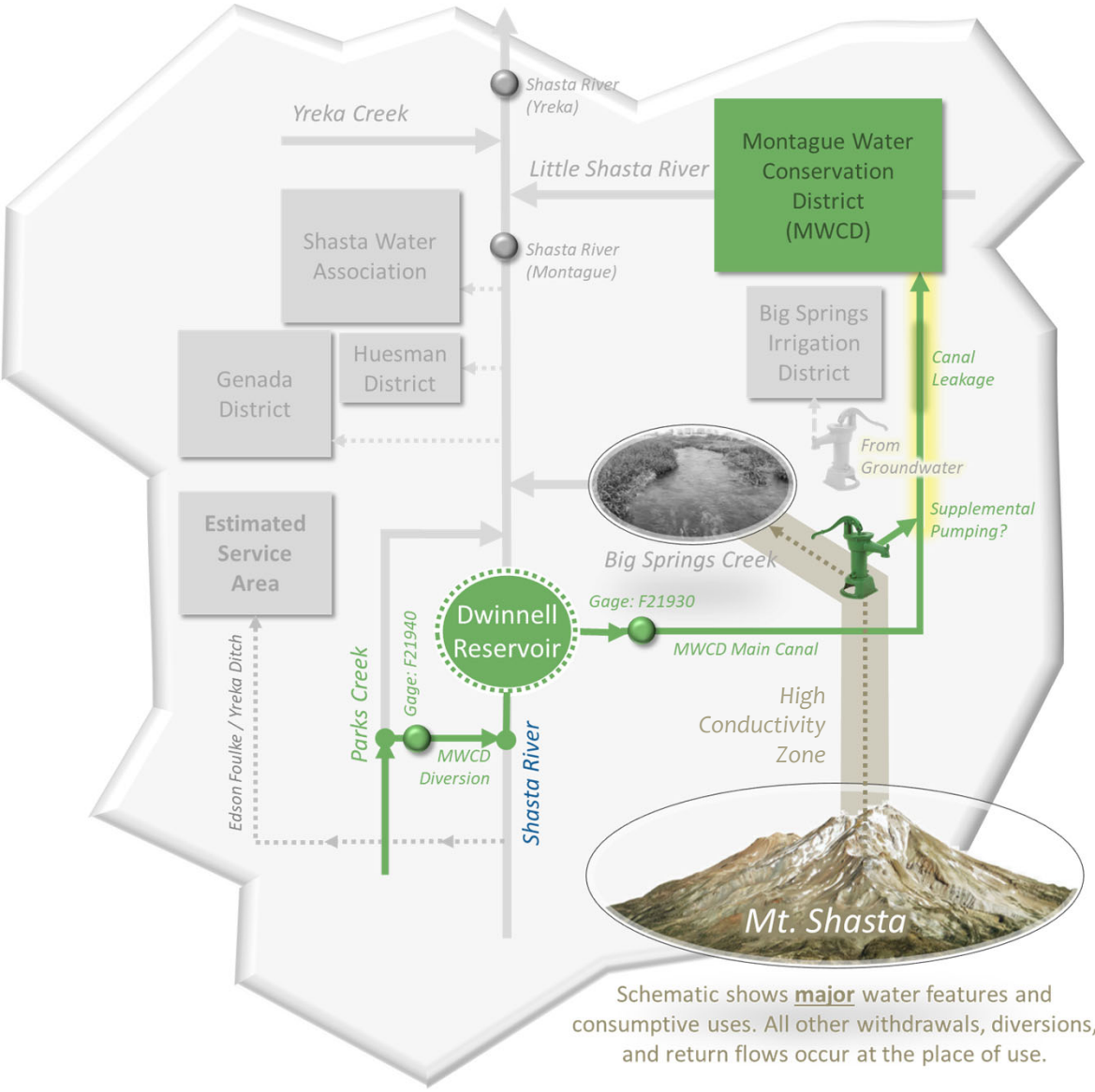
Shallow Groundwater Discharge

- Discharge hotspots: Little Shasta valley (aligns with aerial photos)
- MODFLOW head rises above ground → Seepage to surface
- Simulated as DRN (relatively small water-budget term)
- Discharge routed to nearest stream in LSPC





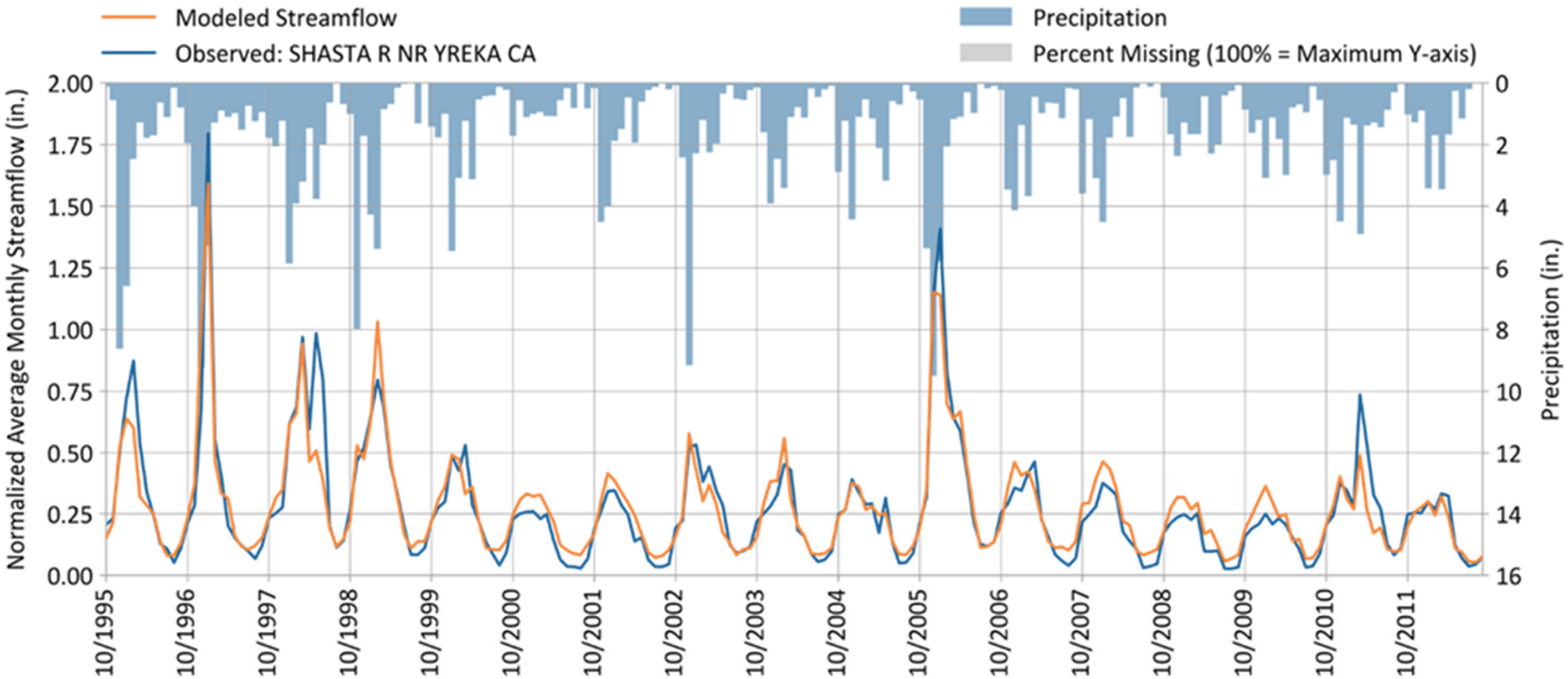
Modeled vs. Observed Streamflow at Montague, CA ***Before*** Linkage to MODFLOW



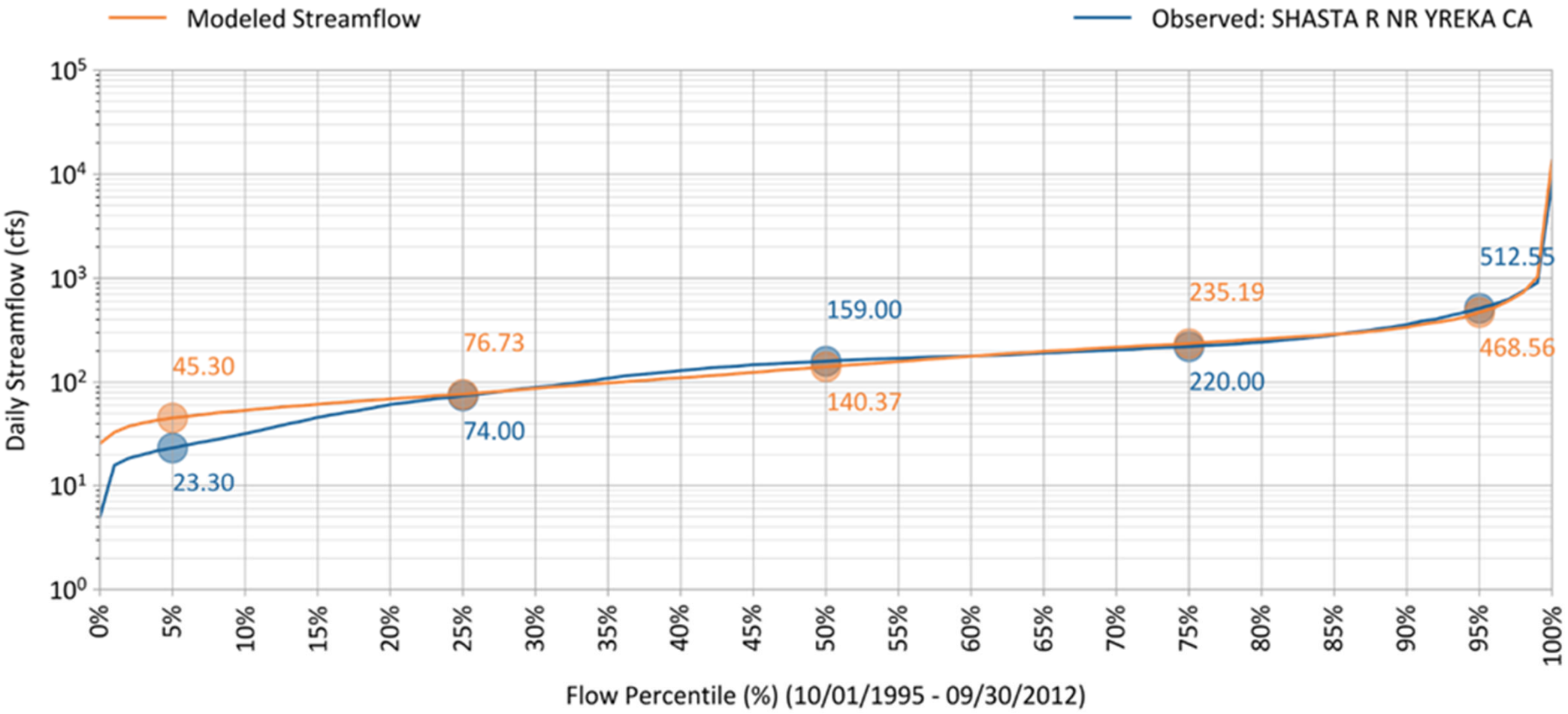
MWCD Canal

- Canal Leakage
  - Impacts water available for irrigation
- Water Balance Implications
  - Additional pumping into canal to offset leakage?
  - Excess pumping from reservoir to offset canal leakage?

Modeled vs. Observed Streamflow at Yreka



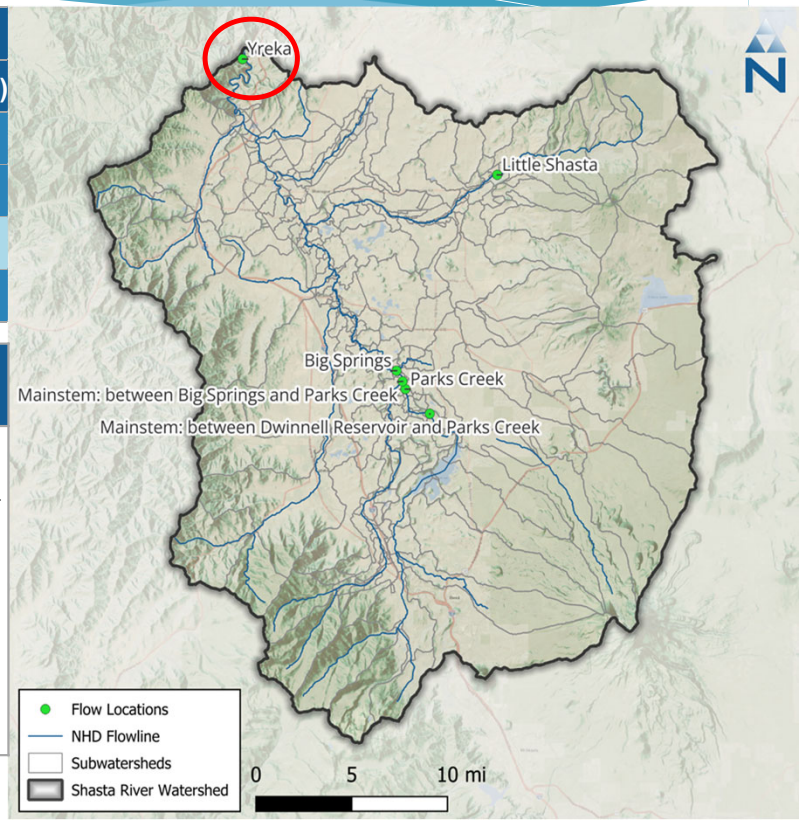
Modeled vs. Observed Streamflow at Yreka



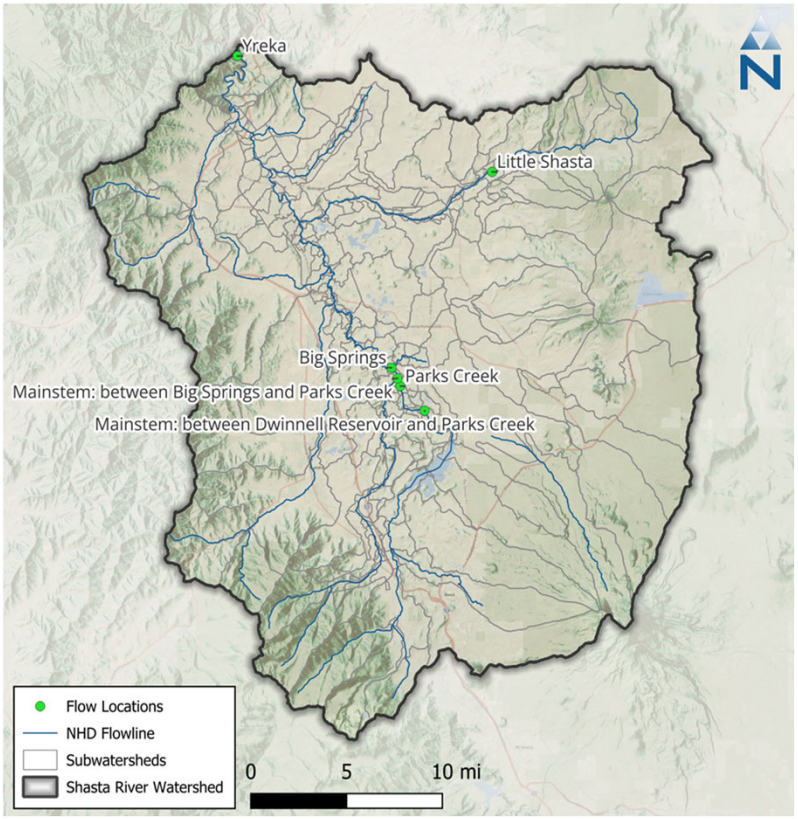
Modeled vs. Observed Calibration Statistics

Calibration Metrics for Monthly Flow (10/01/1995 - 09/30/2012)	Hydrological Condition		
	All (n = 204)	Wet Season (n = 119)	Dry Season (n = 85)
Percent Bias (PBIAS)	-2.4%	-1.8%	-4.7%
R-Squared (R^2)	0.88	0.86	0.82
Nash-Sutcliffe Efficiency (NSE)	0.87	0.86	0.68
RMSE-Std-Dev_Ratio (RSR^1)	0.36	0.37	0.56

Calibration Metrics (10/01/1995 - 09/30/2012)	Recommended Error Criteria				Reference
	Very Good	Good	Fair	Poor	
PBIAS (All Conditions)	<5%	5% - 10%	10% - 15%	>15%	Based on HSPF experience by A.A. Donigian, Jr.,prepared for USEPA (2000); Moriasi et al. (2015)
PBIAS (Seasonal Flows)	<10%	10% - 15%	15% - 25%	>25%	
R^2 (All Conditions)	>0.85	0.75 - 0.85	0.60 - 0.75	≤0.60	
R^2 (Seasonal Flows)	>0.75	0.60 - 0.75	0.50 - 0.60	≤0.50	
NSE (All Conditions)	>0.80	0.70 - 0.80	0.50 - 0.70	≤0.50	
NSE (Seasonal Flows)	>0.70	0.50 - 0.70	0.40 - 0.50	≤0.40	
RSR (All Conditions)	≤0.50	0.50 - 0.60	0.60 - 0.70	>0.70	
RSR (Seasonal Flows)	≤0.60	0.60 - 0.70	0.70 - 0.80	>0.80	



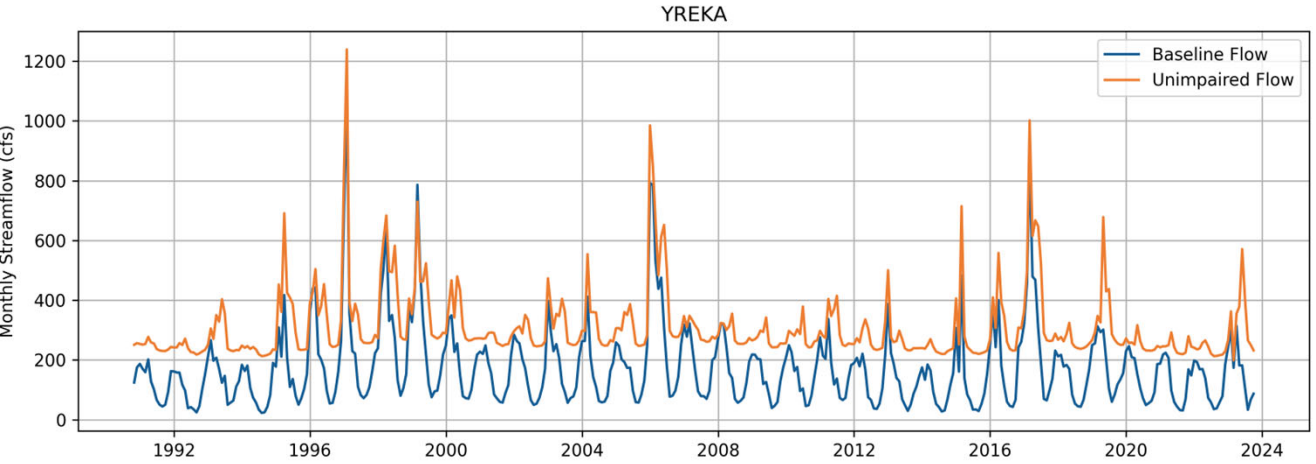
Unimpaired Flow vs. Baseline Flow

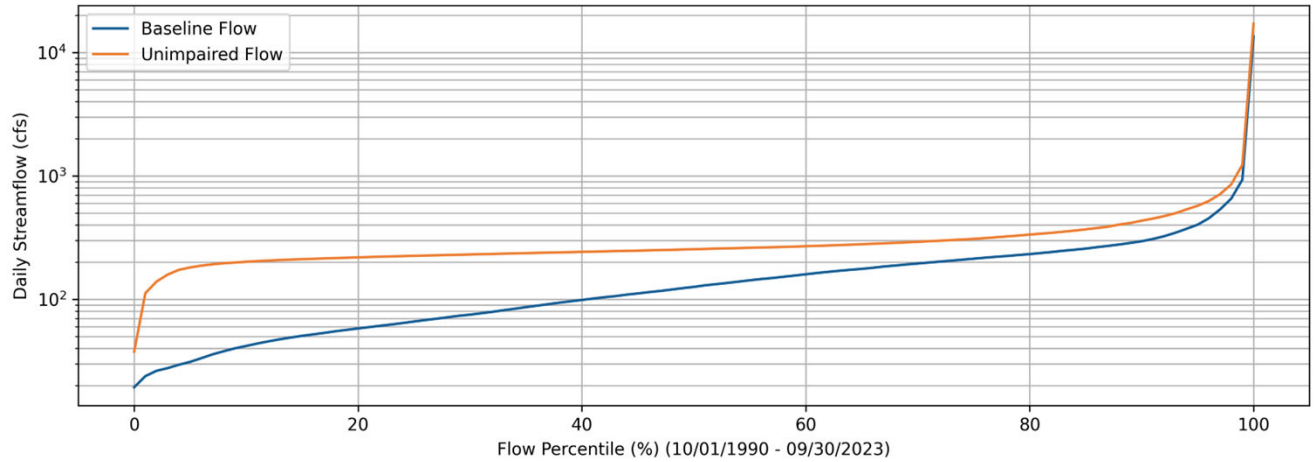


Unimpaired Flows:

- No Diversions
- No Irrigation
- No Reservoir
- No Pacey or Flying L Wells
- No Parks Creek Diversion
- No Non-irrigation Consumptive Use

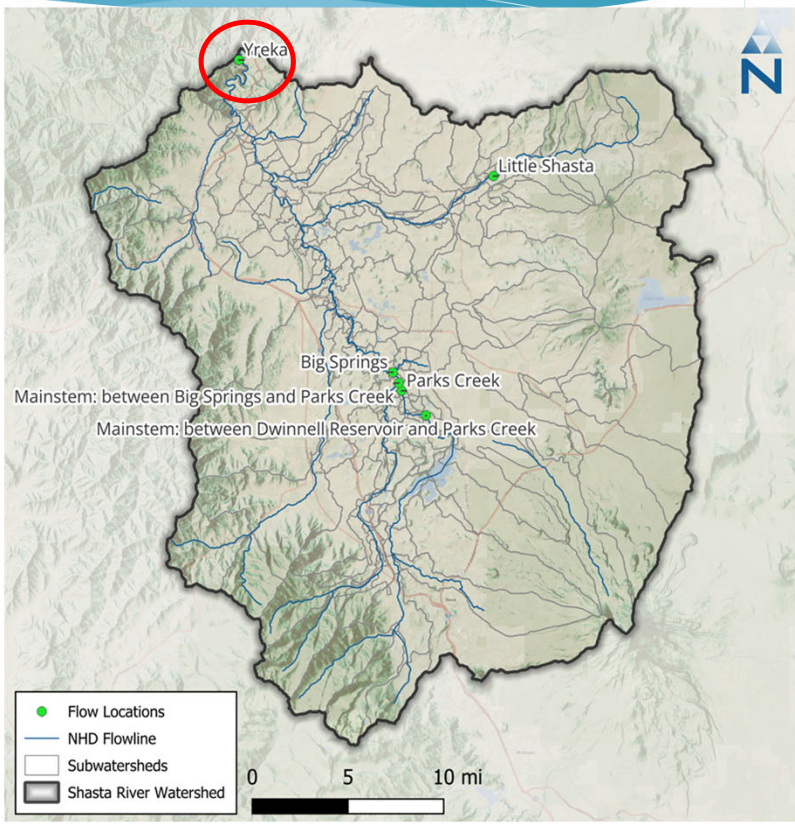
Unimpaired Flow vs. Baseline Flow at Yreka



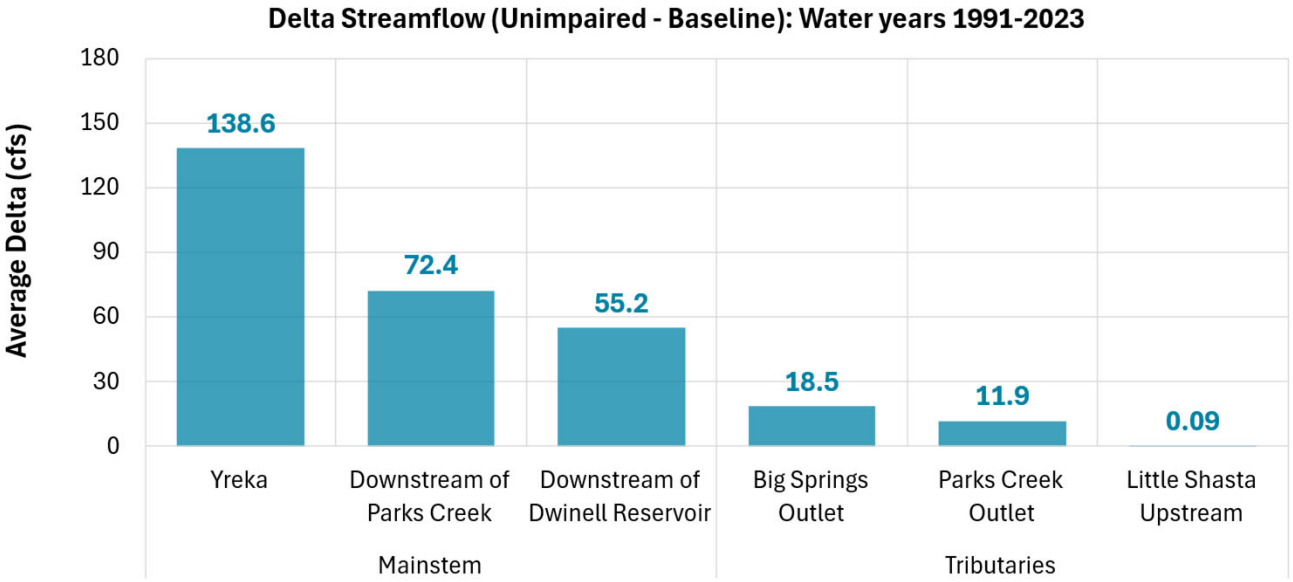


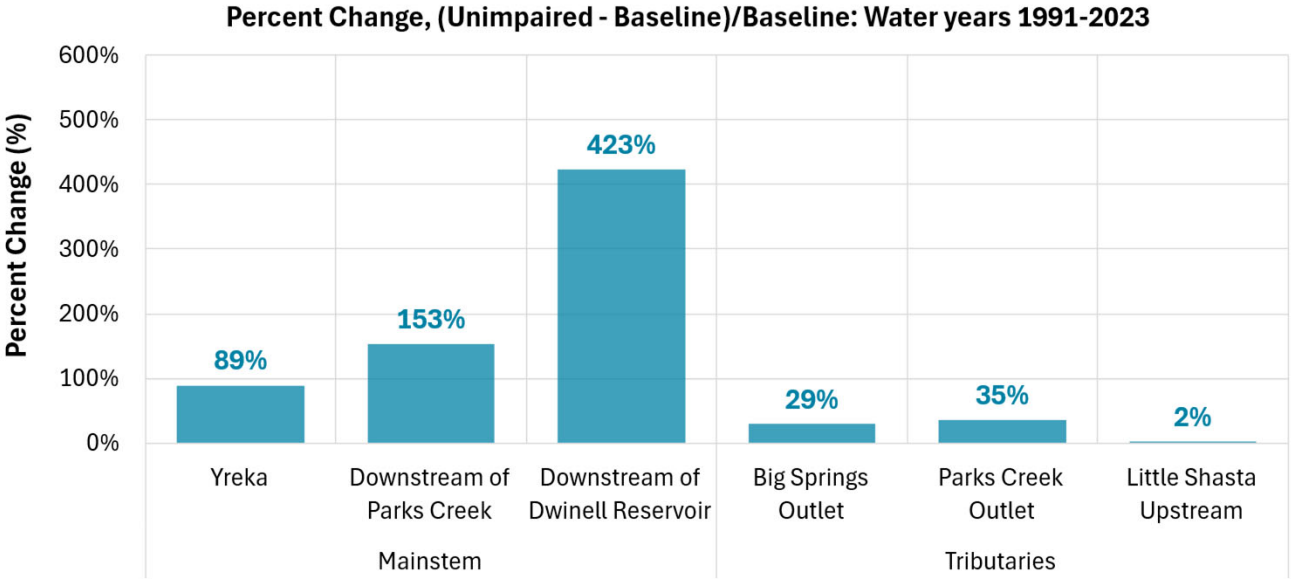
Month-wise Summary Statistics for Unimpaired Flows (cfs)

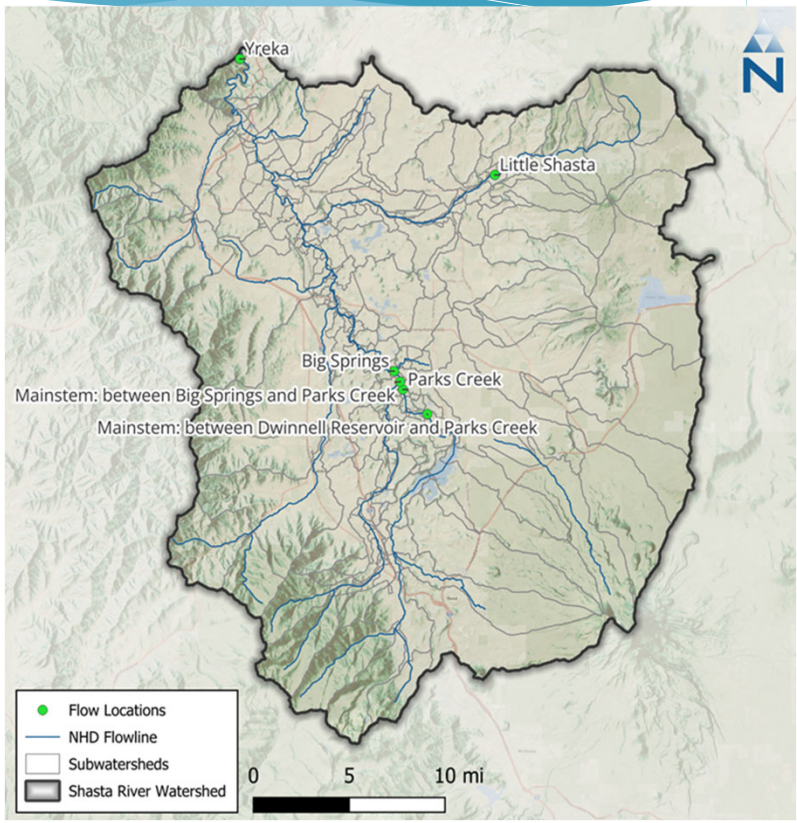
	January	February	March	April	May	June	July	August	September	October	November	December
mean	363.31	374.07	355.72	365.29	361.18	314.89	255.66	243.74	243.43	252.42	268.12	333.92
median	297.4	299.05	325.51	335.83	347.97	269.61	252.17	243.46	243.45	251.54	261.56	272.81
min	235.41	199.11	236.91	243.25	227.99	219.05	212.95	213.53	215.77	218.17	228.82	233.24
max	1238.89	1001.4	690.86	677.98	651.71	582.28	415.59	279.89	276.18	308.65	405.53	984.61



Unimpaired Flow vs. Baseline Flow
Δ at Selected Outlets







Project Insights

- Better configuration streamlines model calibration
- Stakeholder engagement & team collaboration improves outcomes
  - Siskiyou County, UC Davis, Larry Walker & Associates
  - Stockholm Environment Institute (water rights allocation model)
- Coupled model allows for more comprehensive system evaluation
  - Natural Influences vs. Anthropogenic Influences…
  - Evapotranspiration → Irrigation demand → Diversions…
  - Groundwater Pumping → Sustainable Environmental Flows ← Diversions

Next Steps (broader process)

- Comments are due by Friday, June 12, 2026.

- Second Workshop (General Technical Training on Model for Modelers): This workshop will be held on Wednesday, June 3, 2026, at 2:00 PM
  - If you would like to attend, please contact staff by May 29, 2026, at ScottShastaFlows@waterboards.ca.gov

Stay Informed

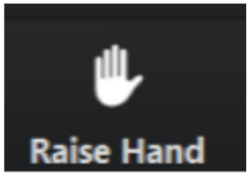
Additional Information

- State Water Board's Scott River and Shasta River Watersheds Emergency Regulation website
  - https://www.waterboards.ca.gov/drought/scott_shasta_rivers/

How to Receive Email Updates

- To receive email updates related to Scott and Shasta regulation and flow efforts visit:
  - https://www.waterboards.ca.gov/resources/email_subscriptions/
  - Sign up under "State Water Resources Control Board" and "Water Rights" for the "Scott-Shasta Drought & Flow Efforts" email subscription list

How to Participate



1. Provide questions:

   Raise your hand (click on react tab) to be placed in the speaker queue. When it is your turn, the facilitator will call your name and invite you to unmute yourself. **Please introduce yourself with your name and title/affiliation.**

   Telephone callers:

   - Press *9 to raise hand
   - Press *6 to unmute when prompted

   Submit questions in Chat

   - Send questions in chat directly to Dan Shultz

2. Email written comments to:

   ScottShastaFlows@waterboards.ca.gov

(written comments due June 12th)

Email comments to: ScottShastaFlows@waterboards.ca.gov