CALIFORNIA DEPARTMENT OF WATER RESOURCES

# Procedures and Results of Extending Unimpaired and Natural Flows for the Central Valley of California for Water Years 2021-2022

Shalamu Abudu, Ph.D. and Tariq Kadir, Ph.D., P.E.

Modeling Support Office (MSO)

California Department of Water Resources

*CALIFORNIA WATER AND ENVIRONMENTAL MODELING FORUM*
*2023 Annual Meeting*
April 18, 2023

# Acknowledgements

Çan Doğrul (DWR)

Guobiao Huang (DWR)

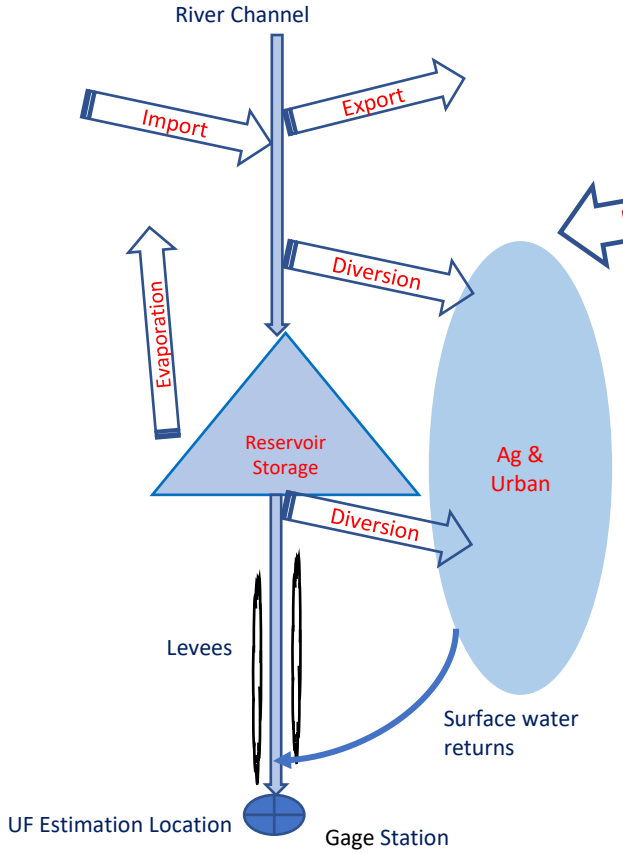
Steven Jepsen (DWR)

Norman Johns (DWR)

# Outline

- Background
- Methods
- Results
- Summary and Next Steps

# **BACKGROUND:** Unimpaired Flow (UF) and Natural Flow (NF)




UF

**UNIMPAIRED FLOW (UF)**

**Definition:** A flow or water supply index generated by removing impacts of upstream diversions, storage, or export/import of water to/from other watersheds.

**Assumption:** Current land use, levees, flood bypasses and weirs are all assumed to exist and stream gain/losses do not change.

**Estimation:** Explicit Mass Balance Equation

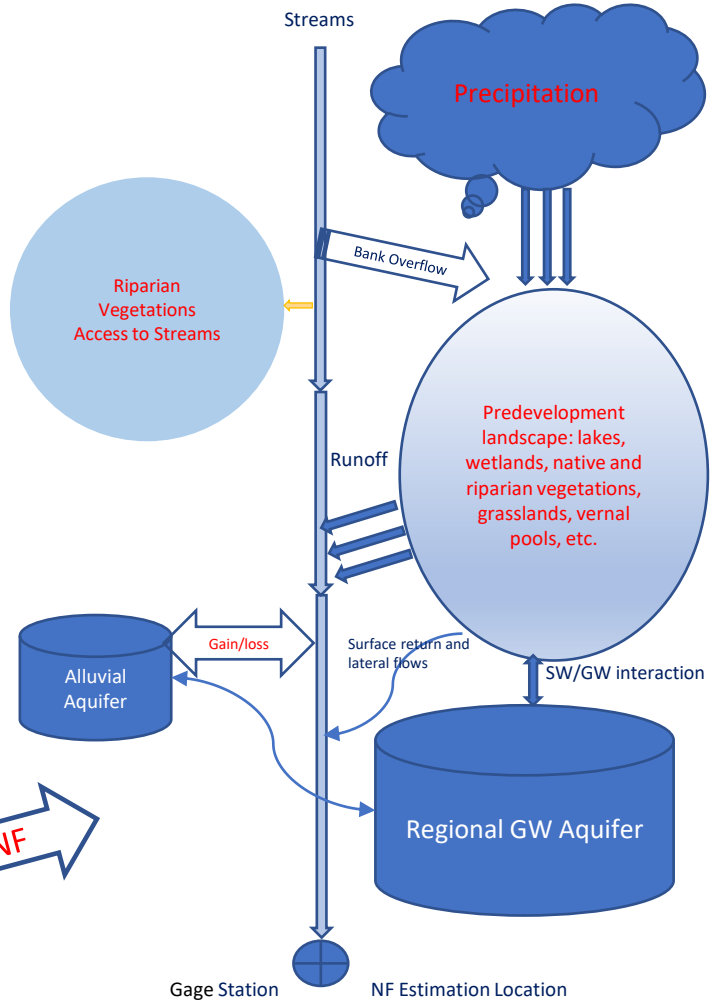
**NATURAL FLOW (NF)**

**Definition:** Theoretical flow that would have occurred in absence of all anthropogenic influences, as in predevelopment landscape or pristine state.

**Assumption:** Predevelopment lands use stays unchanged, no human alterations to the hydrologic system.

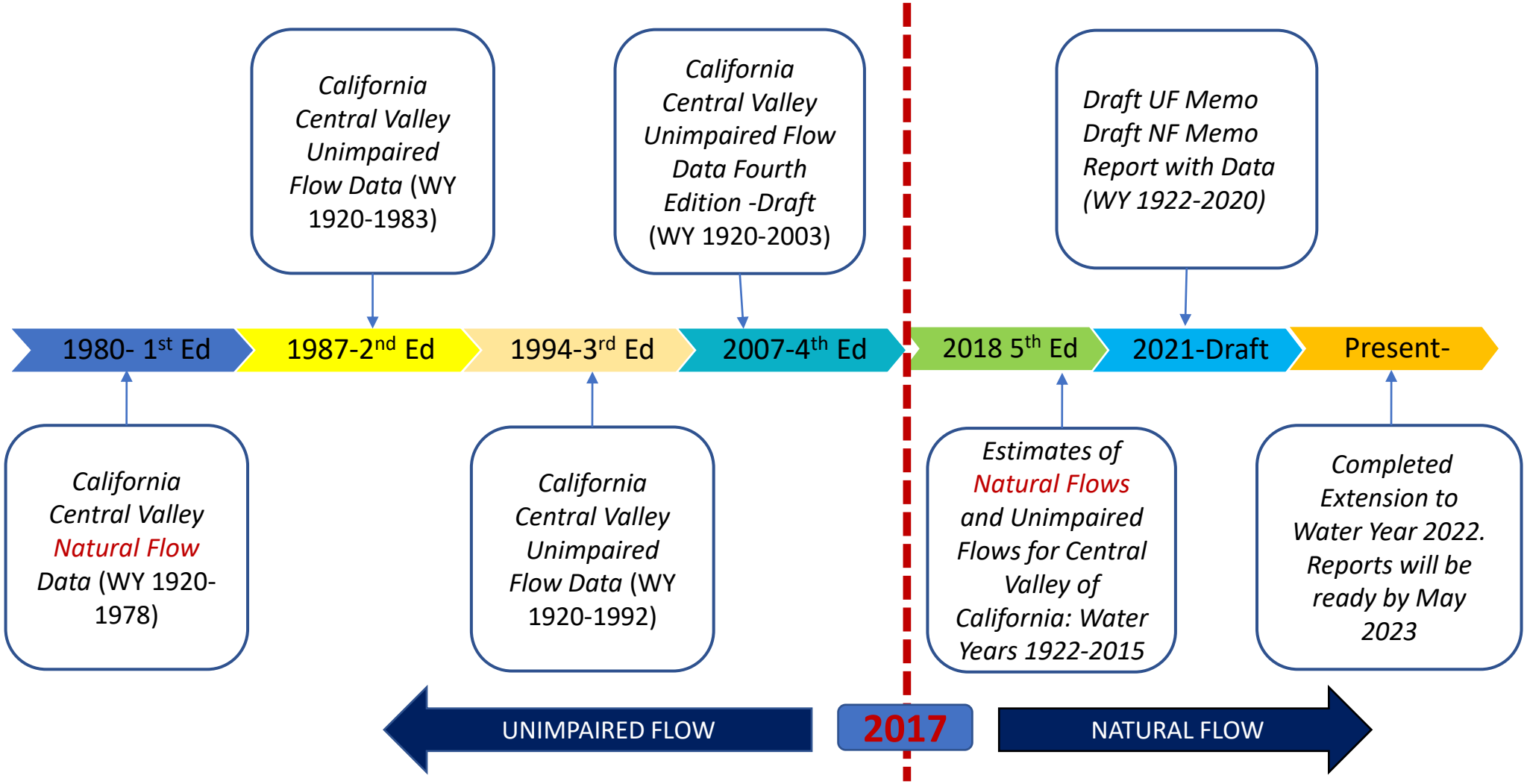
**Estimation:** Can be simulated with the aid of computer by using machine learning techniques or physically-based hydrological models.

NF




CALIFORNIA DEPARTMENT OF
**WATER RESOURCES**

# **BACKGROUND:** History of DWR's UF/NF Flow Reports and Data



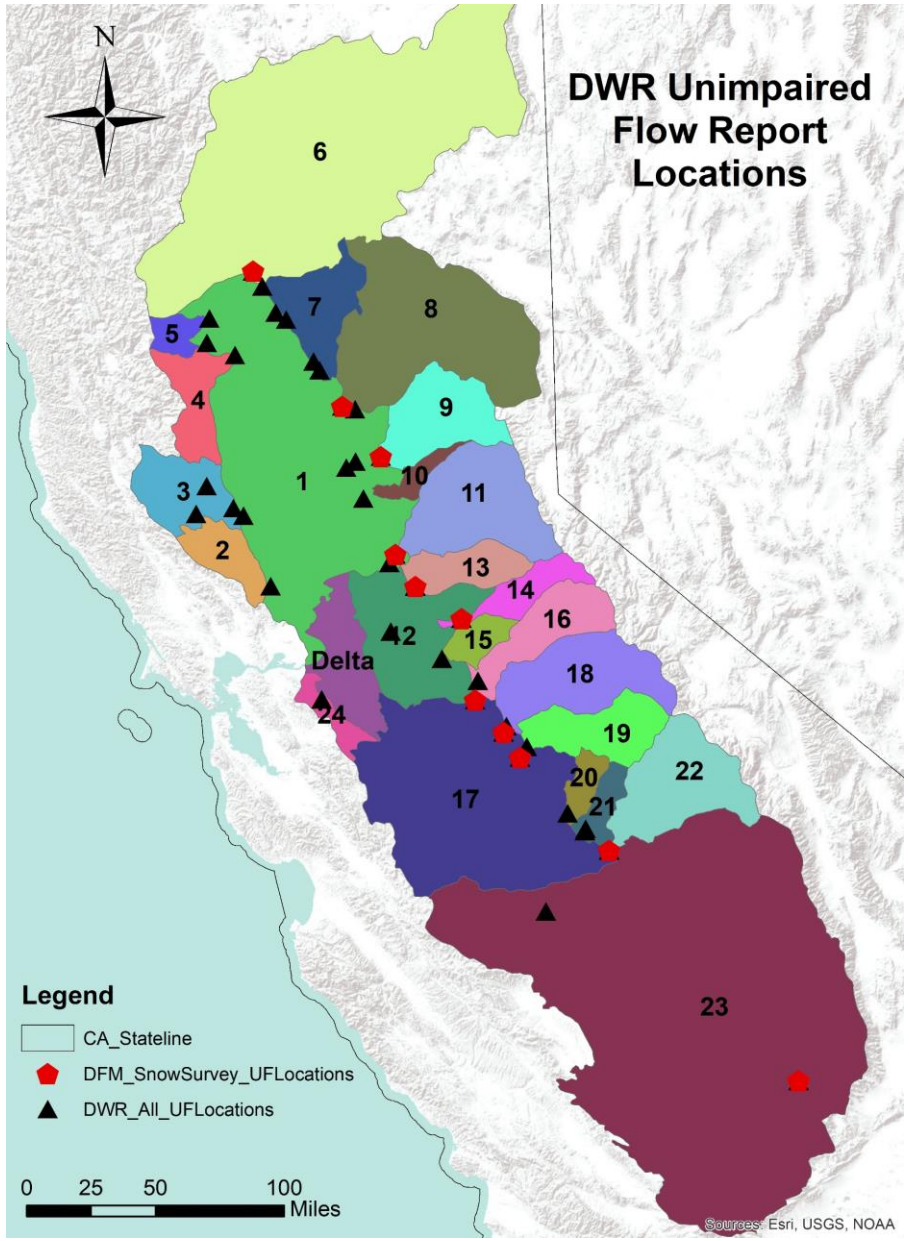

CALIFORNIA DEPARTMENT OF
**WATER RESOURCES**

# BACKGROUND:
## Unimpaired Flow Estimation

- UF estimation procedures in ***"Estimates of Natural Flows and Unimpaired Flows for Central Valley of California: Water Years 1922-2015"*** *(DWR, 2018).*

- **24** unimpaired flow data locations/subbasins reported by DWR
  - **10** of them are for major subbasins published in CDEC and maintained by DFM
  - **14** subbasins are for coastal rim watersheds or Sierra Nevada minor streams and Valley floor, the estimation is provided by MSO.

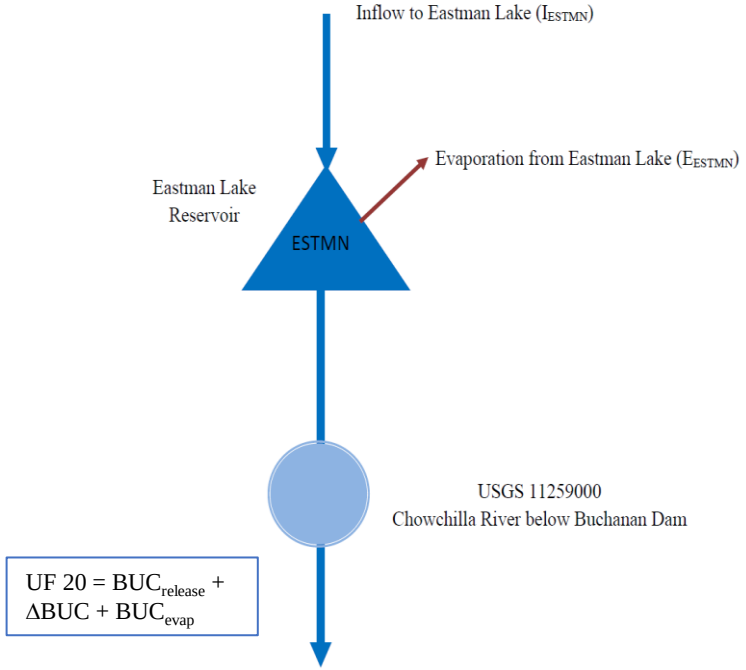
- Each location has explicit mass balance equation. Some missing data gaps are filled by regression methods using data from nearby watersheds.




CALIFORNIA DEPARTMENT OF
WATER RESOURCES

# **BACKGROUND:** Unimpaired Flow Estimation Examples

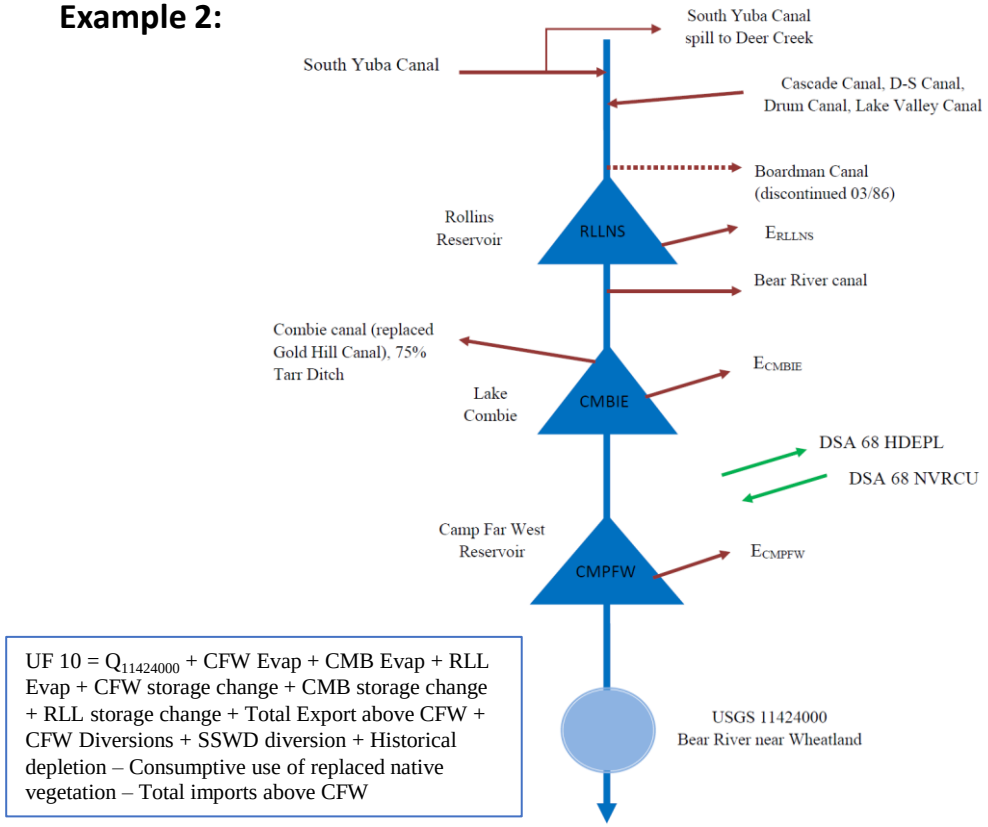
**Example 1:**




UF 20 = $BUC_{release}$ + $\Delta BUC$ + $BUC_{evap}$

Schematic of UF20 Estimation - Chowchilla River below Buchanan Dam

**Example 2:**




UF 10 = $Q_{11424000}$ + CFW Evap + CMB Evap + RLL Evap + CFW storage change + CMB storage change + RLL storage change + Total Export above CFW + CFW Diversions + SSWD diversion + Historical depletion – Consumptive use of replaced native vegetation – Total imports above CFW

Schematic of UF10 Estimation - Bear River near Wheatland

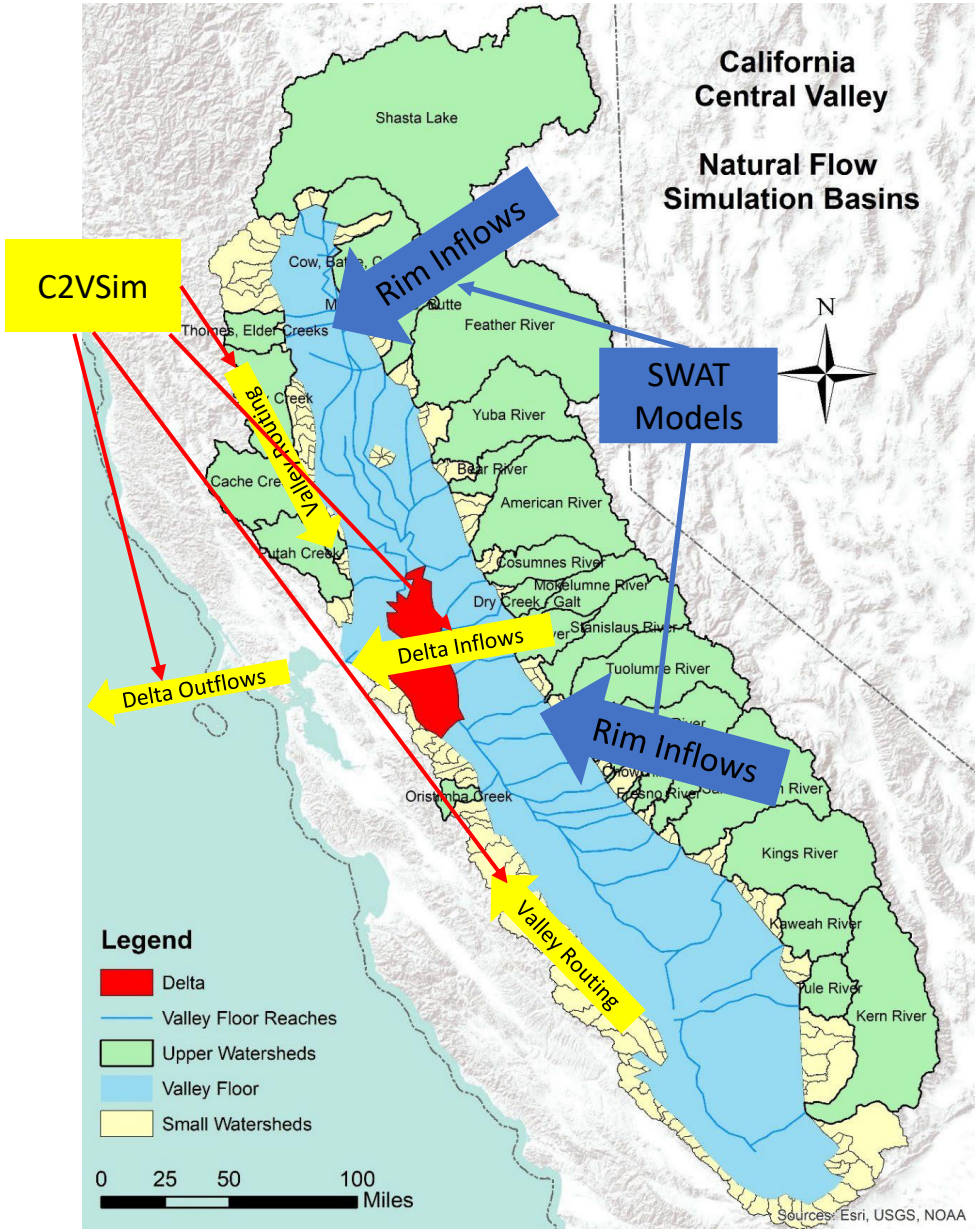
# **BACKGROUND:** DWR's Current Approach for Natural Flow

**For Upper Watersheds:**

- Soil Water Assessment Tool (SWAT) with current land cover for Natural Flows at Rim Inflow locations
- **25** SWAT models for **36** Rim inflow locations to create daily natural stream inflow data for C2Vsim

**For Central Valley Floor:**

- A modified C2VSim Natural Flow Daily Version for pre-development natural conditions – without diversions and groundwater pumping
- To route natural flows at daily time scale in Valley Floor and Delta.



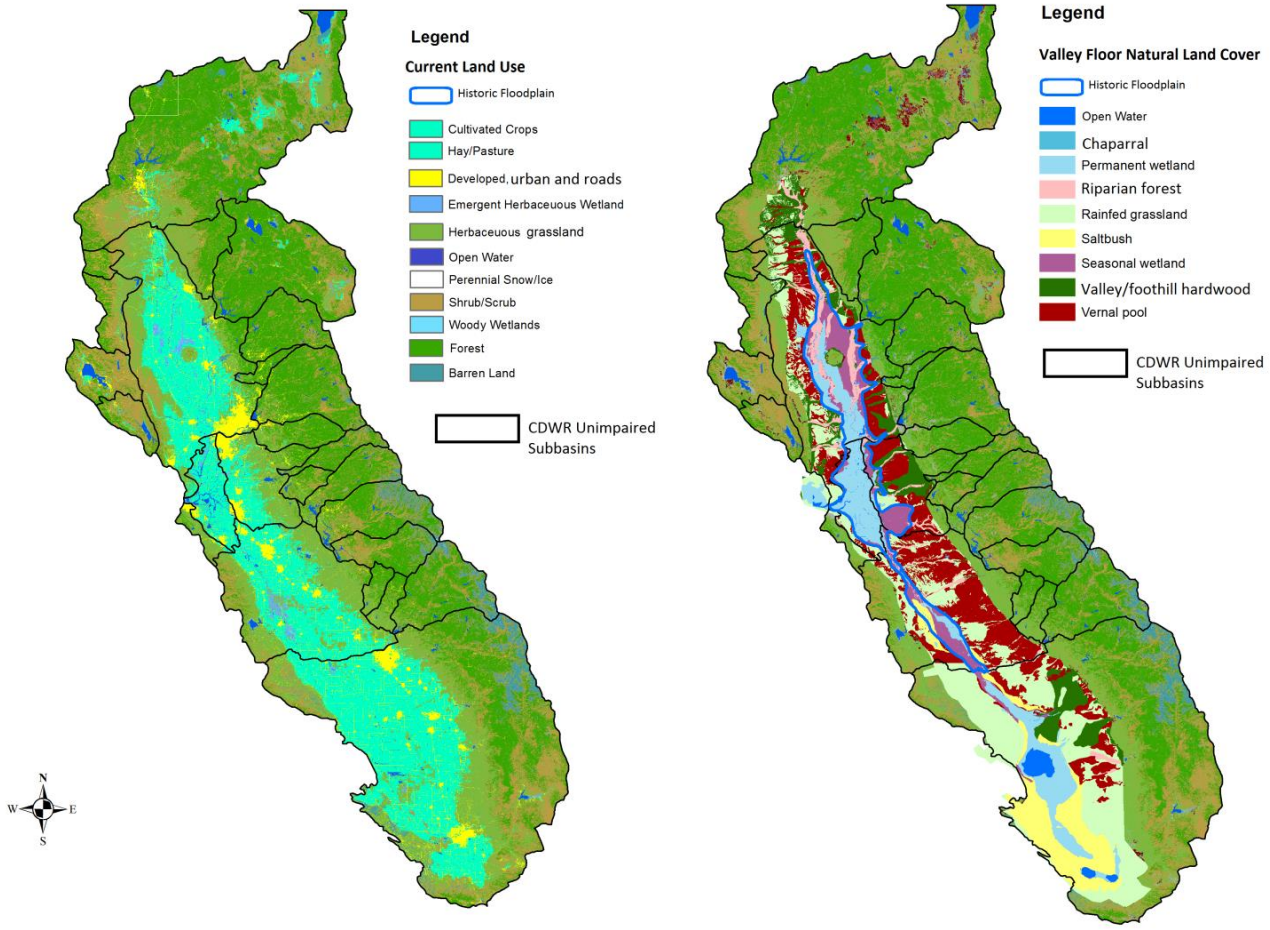
# BACKGROUND: Land Use and Land Cover Changes

**Upper Rim Watersheds:**

- Small land cover changes
- Natural flow ≈ Unimpaired Flow

**Valley Floor:**

- Significant land cover changes
- Natural flow ≠ Unimpaired Flow




**Regenerated from *CSU Chico (2003), Fox et al. (2015), Küchler (1977).***

# METHODS: In-House SWAT Models

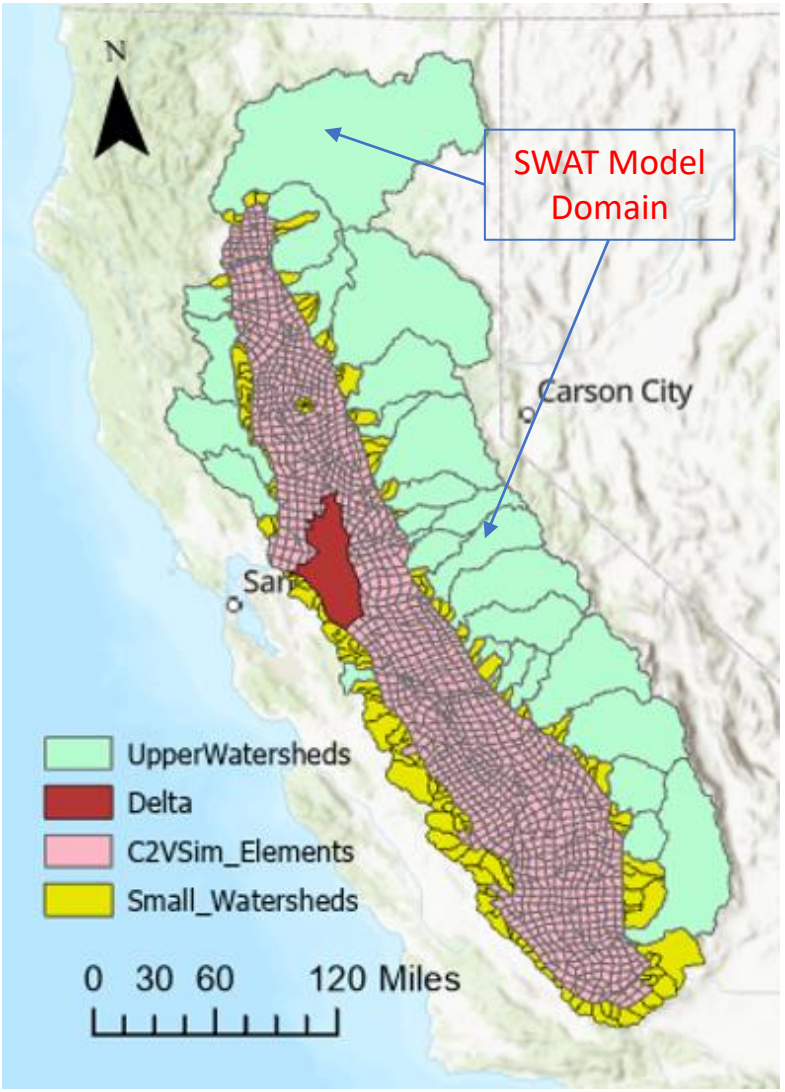
- SWAT models were developed using ArcSWAT 2009 for SWAT2009 version (except few with SWAT 2012)
  - Monthly unimpaired flow at the basin outlet as calibration target
  - Combination of SWAT-CUP automatic and Manual Calibration
  - Splitting to two periods: 1922-1970 as calibration period, 1971-2015 as validation period.

- Daily precipitation, maximum and minimum air temperature
  - 1915-1980: 1/8-degree (12 x 12km) PRISM-based gridded dataset (Hamlet and Lettenmaier, 2005).
  - 1981-2015: 1/24-degree (4 x 4km) PRISM grid

- Land use types: National Land Cover Database 2001

- Elevation Data: The 30-meter digital elevation model (DEM)

- Soil types: State Soil Geographic (STATSGO) dataset



# METHODS: SWAT Model Extension

- The goal is to extend C2VSim Stream Inflow Data File with 36 inflow locations
- 25 SWAT Models were modified and extended through WY2022
- PRISM Data (Precipitation, Tmax, Tmin) 800m resolution for 2016-2022
- Consistency checks on Potential ET methods: Hargreaves or Penman-Monteith
- Due to large workloads and data , developed and utilized automation of input data preparation process using Python packages (ArcPy), R and FORTRAN.


CALIFORNIA DEPARTMENT OF
WATER RESOURCES

# METHODS: Modification to C2VSim-CG Historical Model

**Developed and Extended a daily C2VSim Natural Flow version by:**

- **Kept as is:**
  - Calibrated Hydrogeologic parameters
  - Main model framework
- **Changes Made:**
  - Monthly to Daily time scale (1921-2022)
  - Historical land use to Pre-development natural land use
  - Historical Rim watershed inflows to Daily SWAT-simulated natural inflows
  - Daily Precipitation Data: California Simulation of Evapotranspiration of Applied Water (Cal-SIMETAW, Orang et al., 2013) (1921-1980) and PRISM 4km (1981-Present)
  - Daily ETo: Cal-SIMETAW Daily (1921-2003) and CIMIS Daily (2004-Present)
- **Removed Features:**
  - Diversions and Groundwater Pumping
  - Other human-made features (Tile drains, Stream bypasses, etc.)
- **Added Features:**
  - Kinematic wave routing to better simulate streamflow travel time and stream storage
  - Root zone groundwater uptake
  - Riparian vegetation access to stream water
  - Lake option (26 natural lakes and vernal pools)


C2VSimCG Model Domain

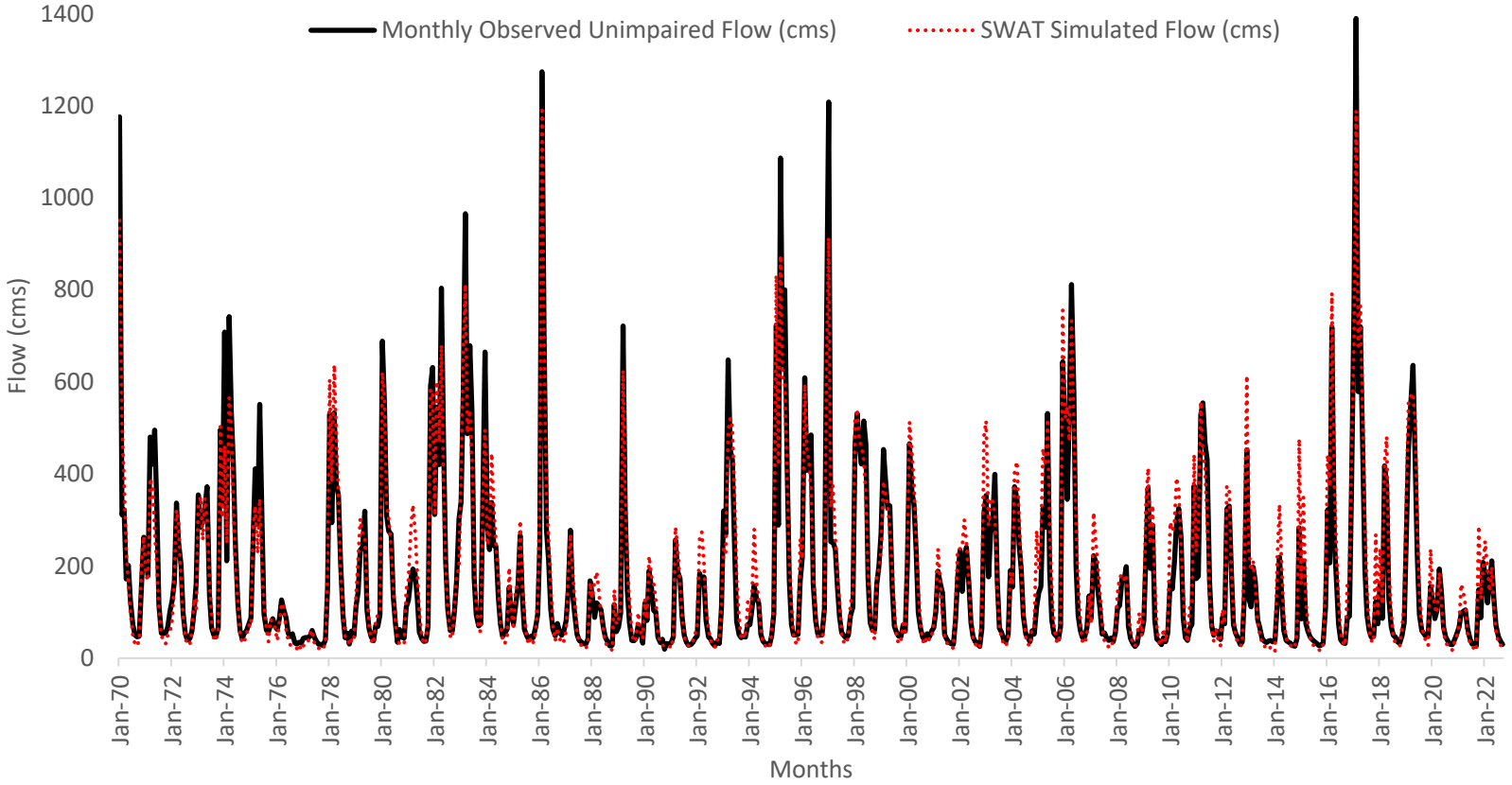
# RESULTS:

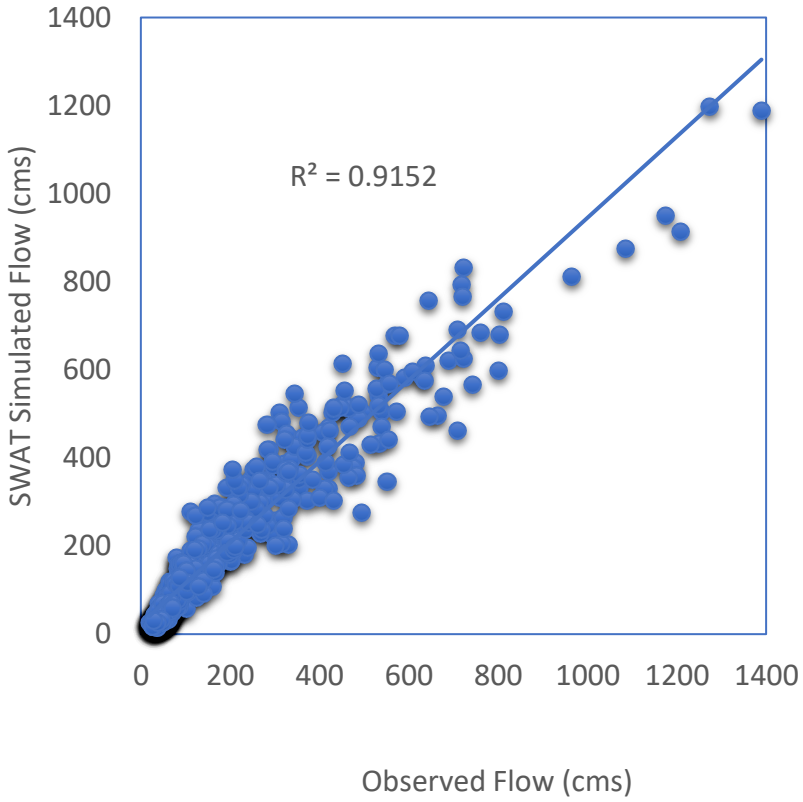
SWAT Model Performance Statistics Summary (WY 1922-2022)

| Watershed | No. of Subbasins | Drainage Area($km^2$) | $R^2$ | Nash-Sutcliffe Efficiency |
|---|---|---|---|---|
| Sacramento River at Shasta Lake (CDEC: SIS) | 25 | 16,261 | 0.90 | 0.90 |
| Feather River at Lake Oroville (CDEC: FTO) | 64 | 9,335 | 0.91 | 0.91 |
| Yuba River at SmartVille (CDEC: YRS) | 39 | 3,174 | 0.85 | 0.84 |
| American River at Folsom Lake (CDEC: AMF) | 31 | 4,943 | 0.89 | 0.88 |
| Bear River near Wheatland. | 19 | 752 | 0.88 | 0.84 |
| Putah Creek near Winters. | 27 | 1,506 | 0.88 | 0.84 |
| Cache Creek above Rumsey. | 25 | 2,440 | 0.83 | 0.80 |
| Stony Creek at Black Butte. | 29 | 1,963 | 0.70 | 0.69 |
| Cottonwood Creek | 29 | | 0.89 | 0.88 |
| Sacramento Valley west Side Minor Streams (**Thomes** and Elder creeks) | 36 | 699 | 0.73 | 0.73 |
| Sacramento Valley East Side Minor Streams (Cow, Battle, Paynes, Antelope, Mill, Big Chico, Butte, and **Deer creeks**) | 324 | 51,528 | 0.84 | 0.84 |
| Cosumnes River at Michigan Bar (CDEC: CSN) | 38 | 1,387 | 0.85 | 0.85 |
| Dry Creek at Galt | 19 | | 0.82 | 0.79 |
| Mokelumne River (CDEC: MKM) | 23 | 1,502 | 0.80 | 0.79 |
| Calaveras River at Jenny Lind | 25 | 933 | 0.87 | 0.87 |
| Stanislaus River at Melones Reservoir | 23 | 2,518 | 0.85 | 0.85 |
| Tuolumne River at Don Pedro Reservoir (CDEC: TLG) | 29 | 3,980 | 0.90 | 0.90 |
| Merced River at Exchequer Reservoir (CDEC: MRC) | 27 | 2,742 | 0.86 | 0.86 |
| Chowchilla River at Buchanan Reservoir | 27 | 669 | 0.79 | 0.76 |
| Fresno River near Daulton | 21 | 757 | 0.80 | 0.79 |
| San Joaquin River at Millerton Reservoir (CDEC: SJF) | 31 | 4,296 | 0.91 | 0.91 |
| Kings River | 38 | 4,413 | 0.79 | 0.77 |
| Kaweah River | 75 | 1,453 | 0.81 | 0.80 |
| Tule River | 30 | 986 | 0.71 | 0.69 |
| Kern River | 26 | 5372 | 0.78 | 0.76 |

Notes: HRU = hydrologic Response Unit, $km^2$ = square kilometer, $R^2$ = Coefficient of Determination

# **RESULTS:** Feather River SWAT Model Performance

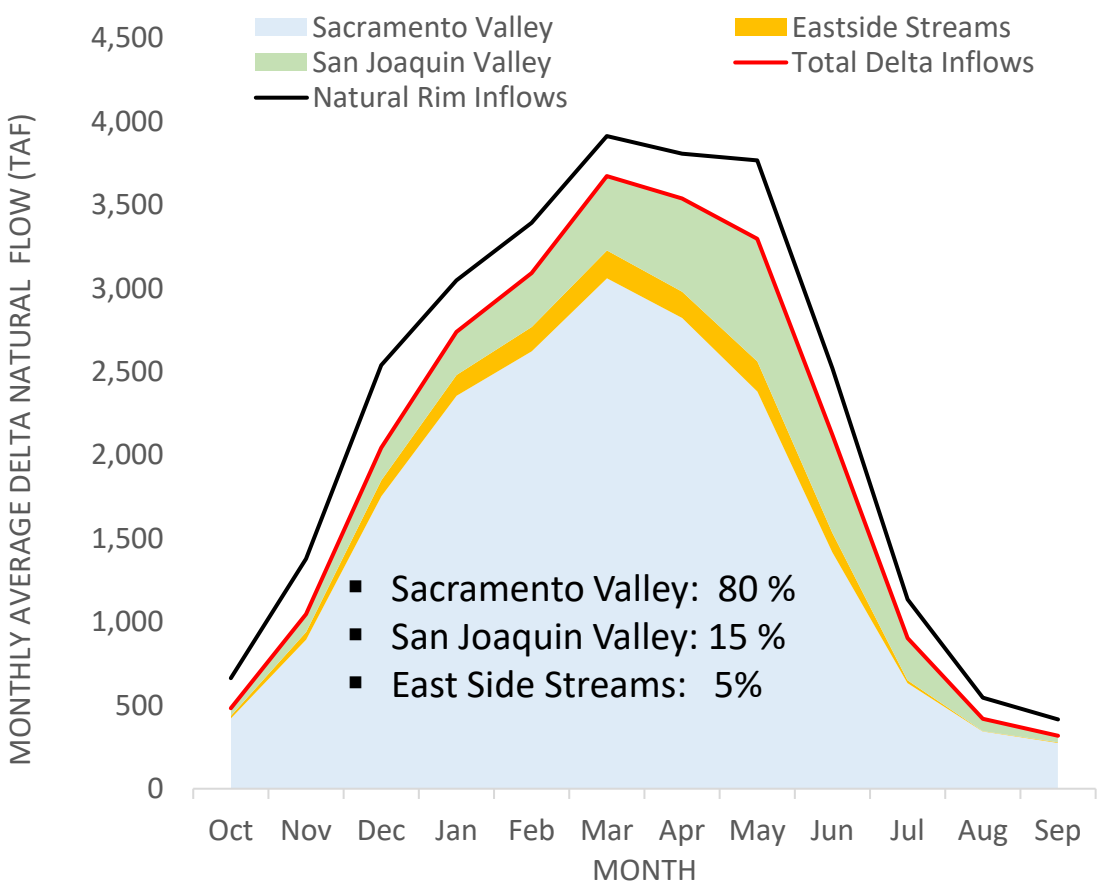


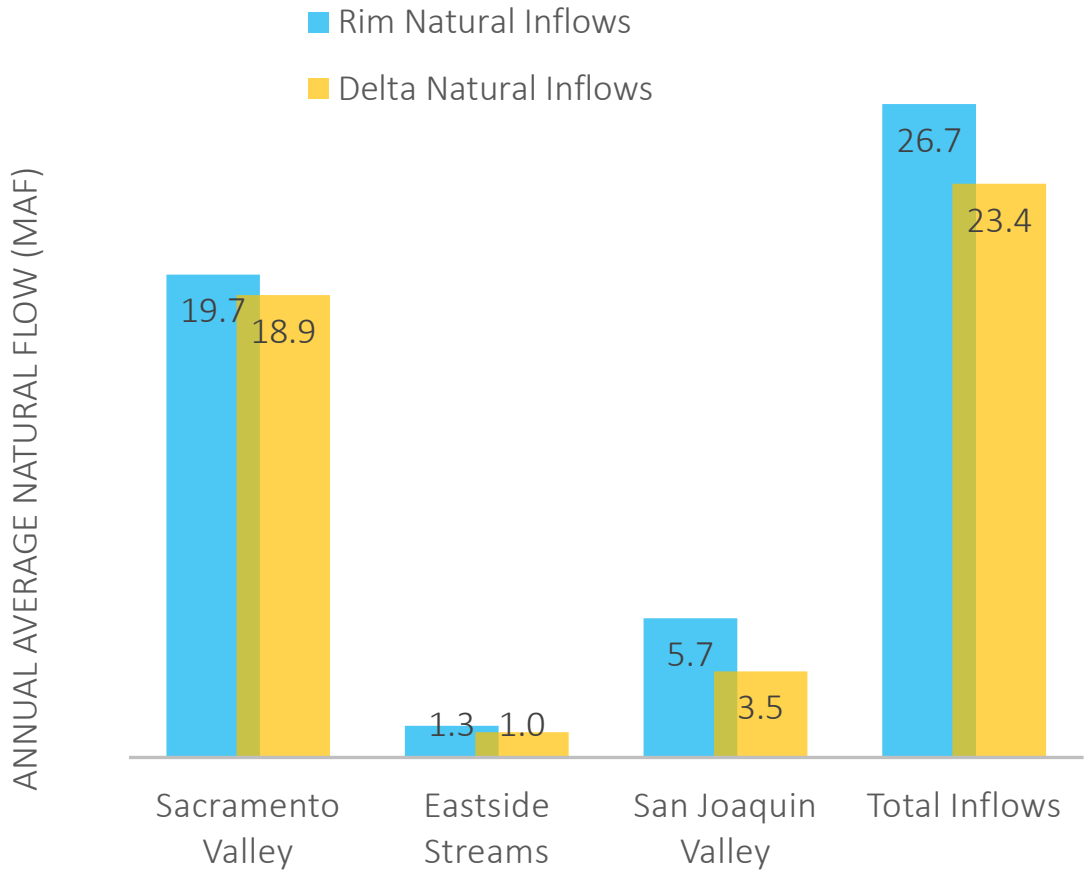




***Example:*** SWAT model performance for validation period (1970-2022)- Feather River at Lake Oroville

CALIFORNIA DEPARTMENT OF
**WATER RESOURCES**

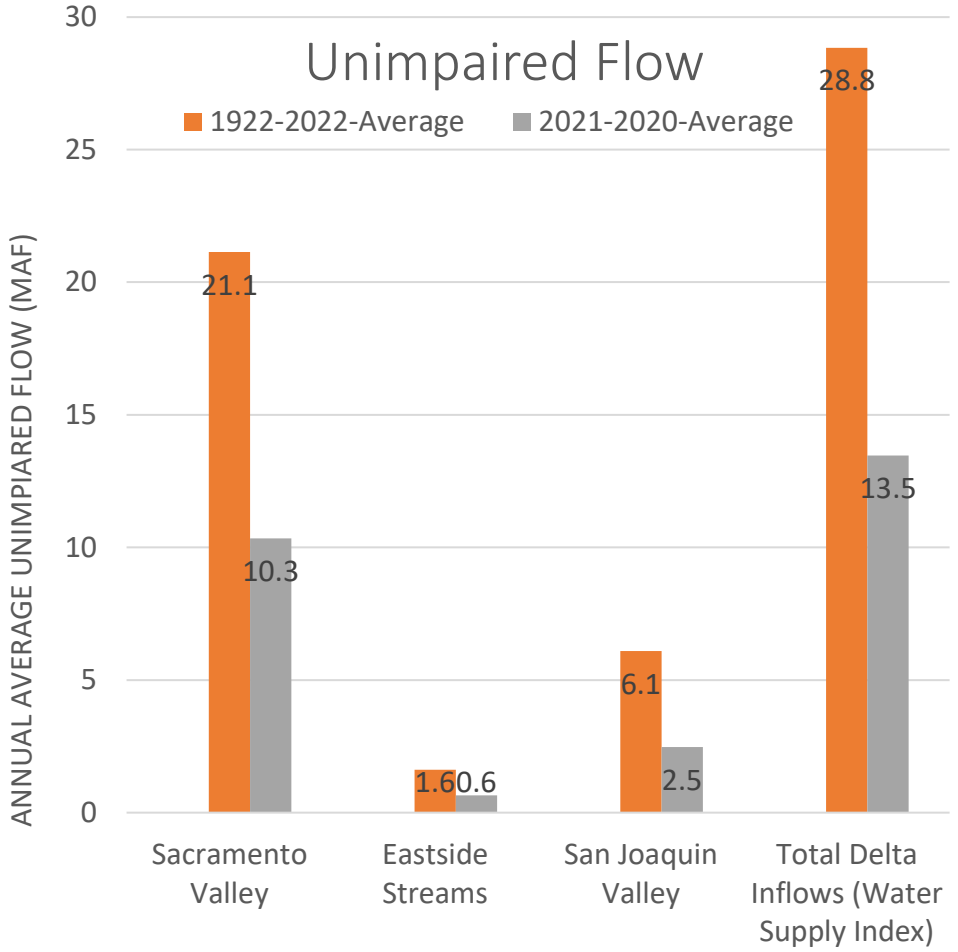
# **RESULTS:** Average Monthly and Annual Natural Rim/Delta Inflows (WY1922-2022)

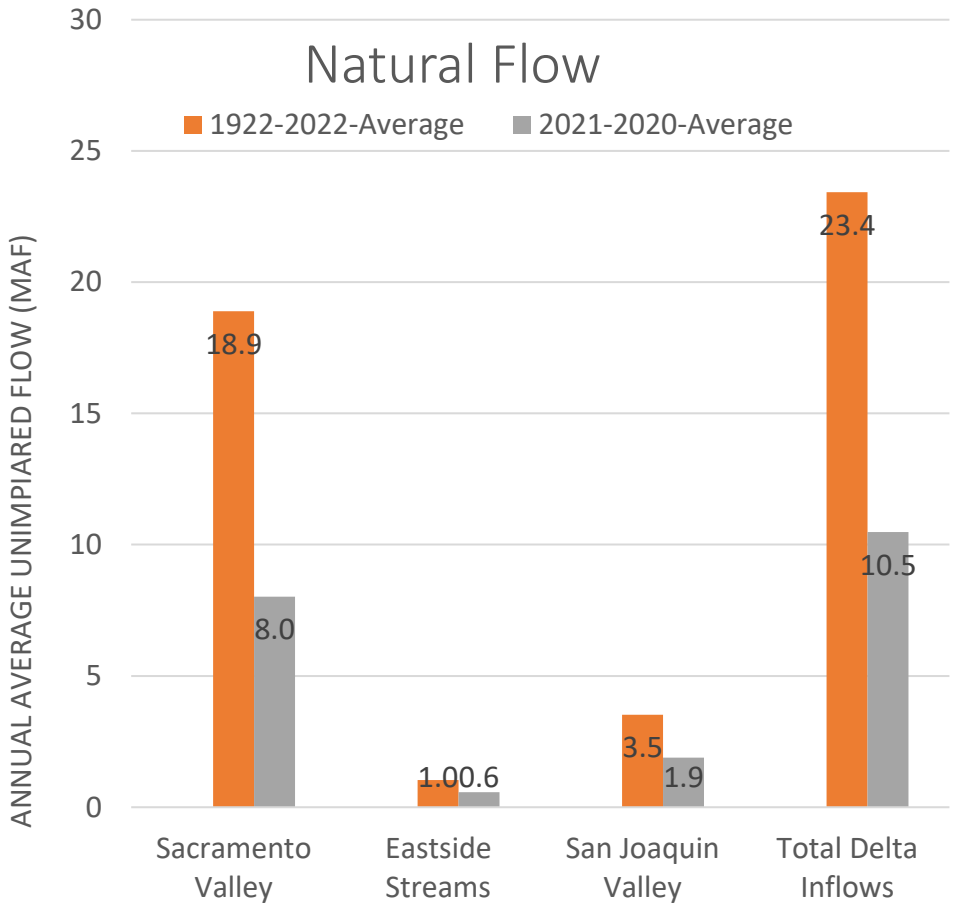



Simulated Average Natural Inflows at Rim and Delta Inflow Locations

# **RESULTS:** Comparison of Unimpaired/Natural Delta Inflows



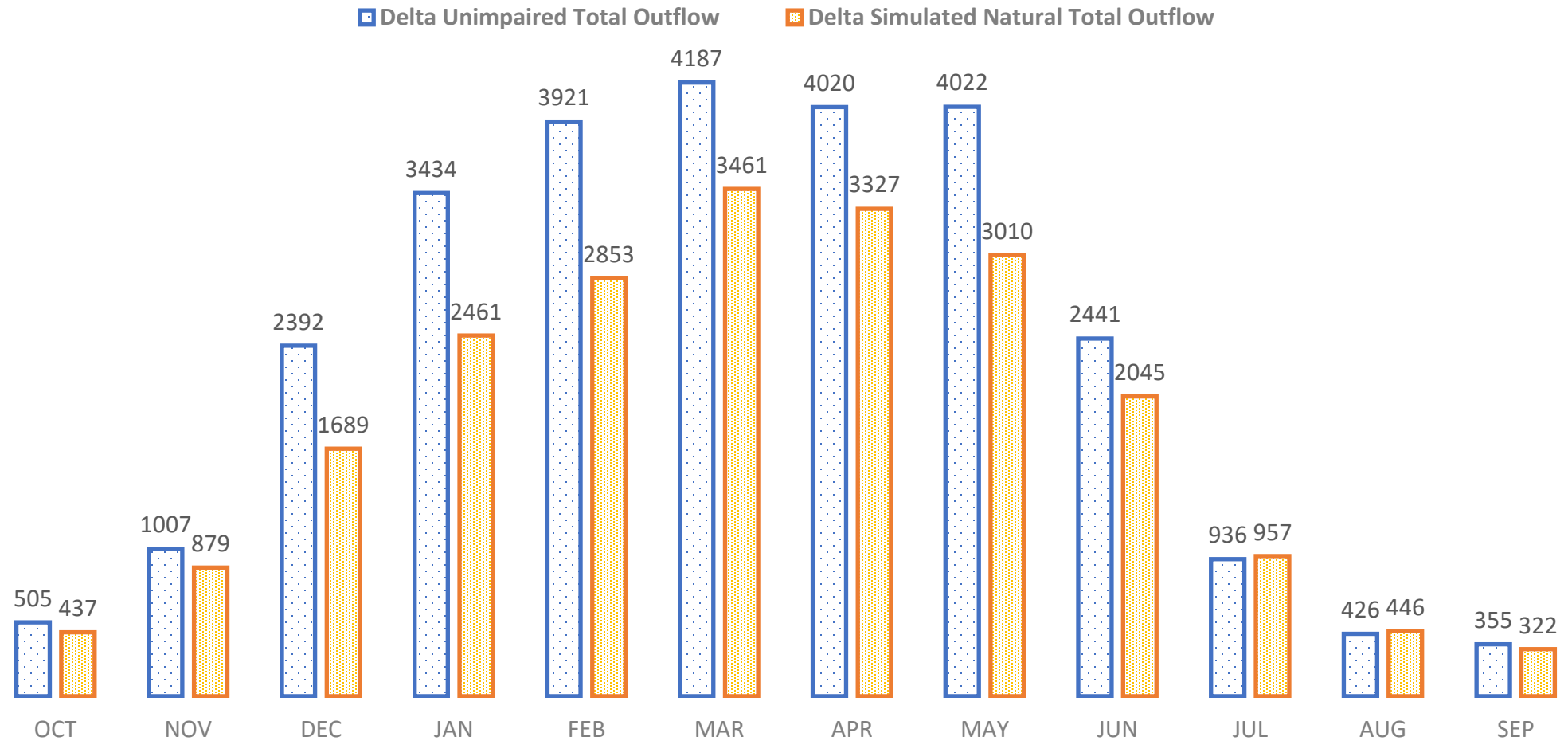




Comparison of 2021-2022 annual average UF/NF Delta inflows to Long-term averages of UF/NF data (WY1922-2022)

.

CALIFORNIA DEPARTMENT OF
**WATER RESOURCES**

# RESULTS- Monthly UF/NF Delta Outflows

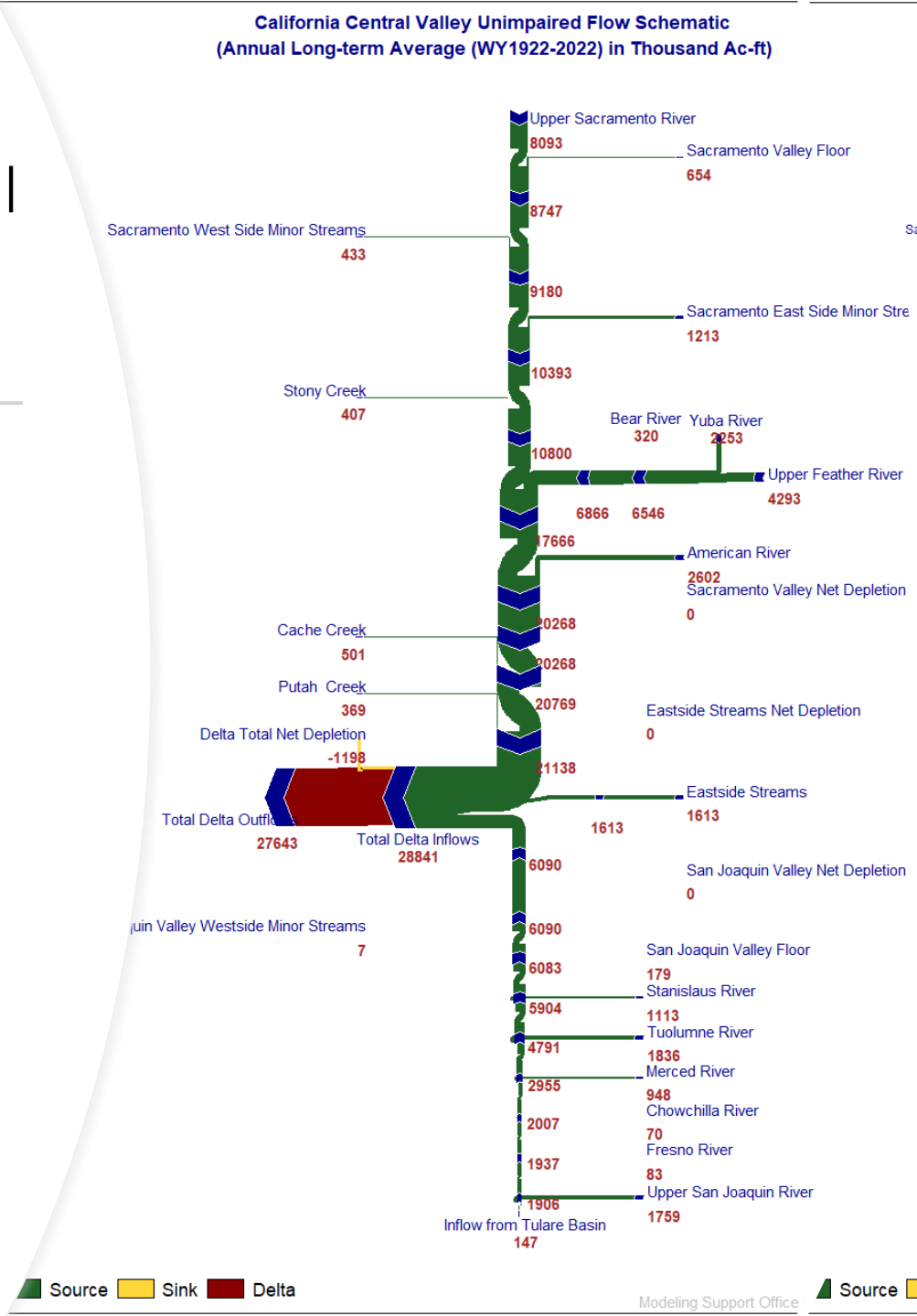


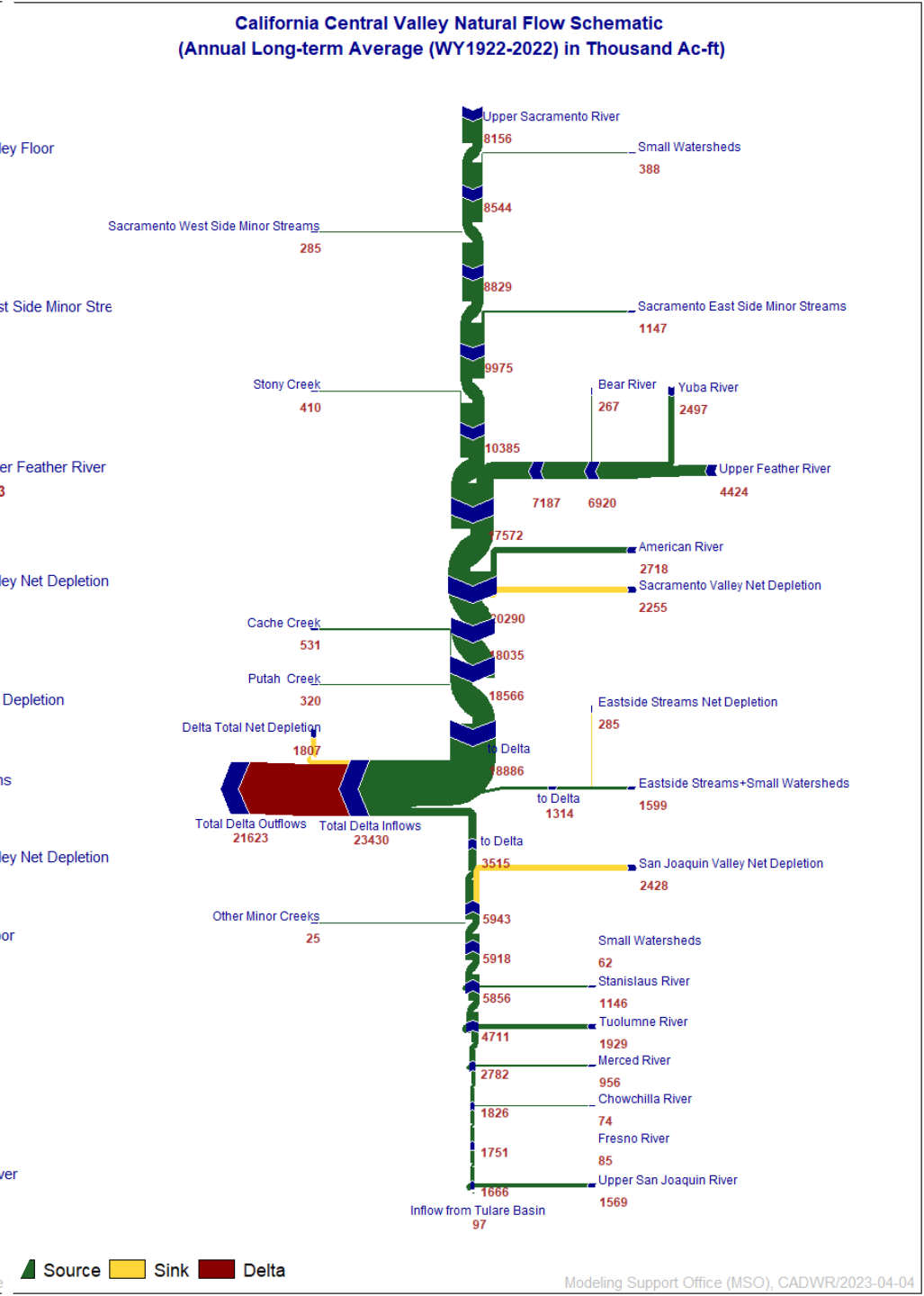

Comparison of monthly average natural and unimpaired delta outflow estimates for Water Years 1922-2022 (TAF)

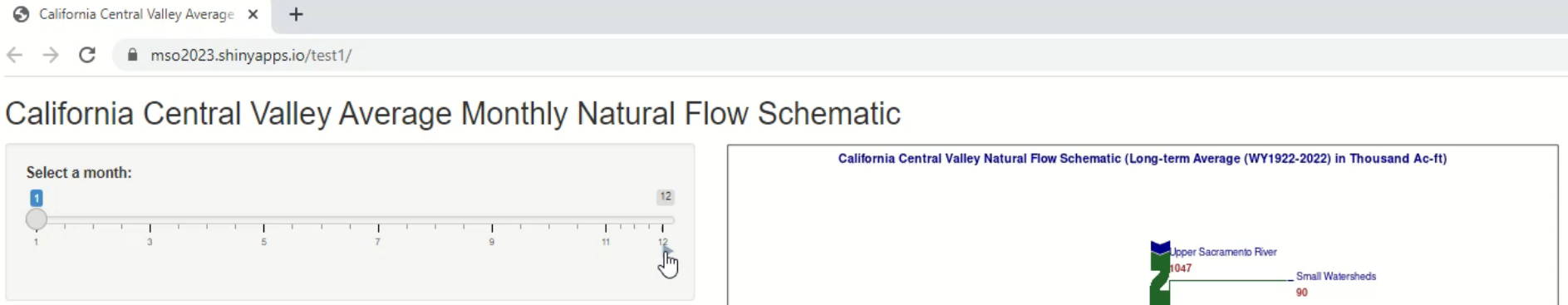
CALIFORNIA DEPARTMENT OF
WATER RESOURCES

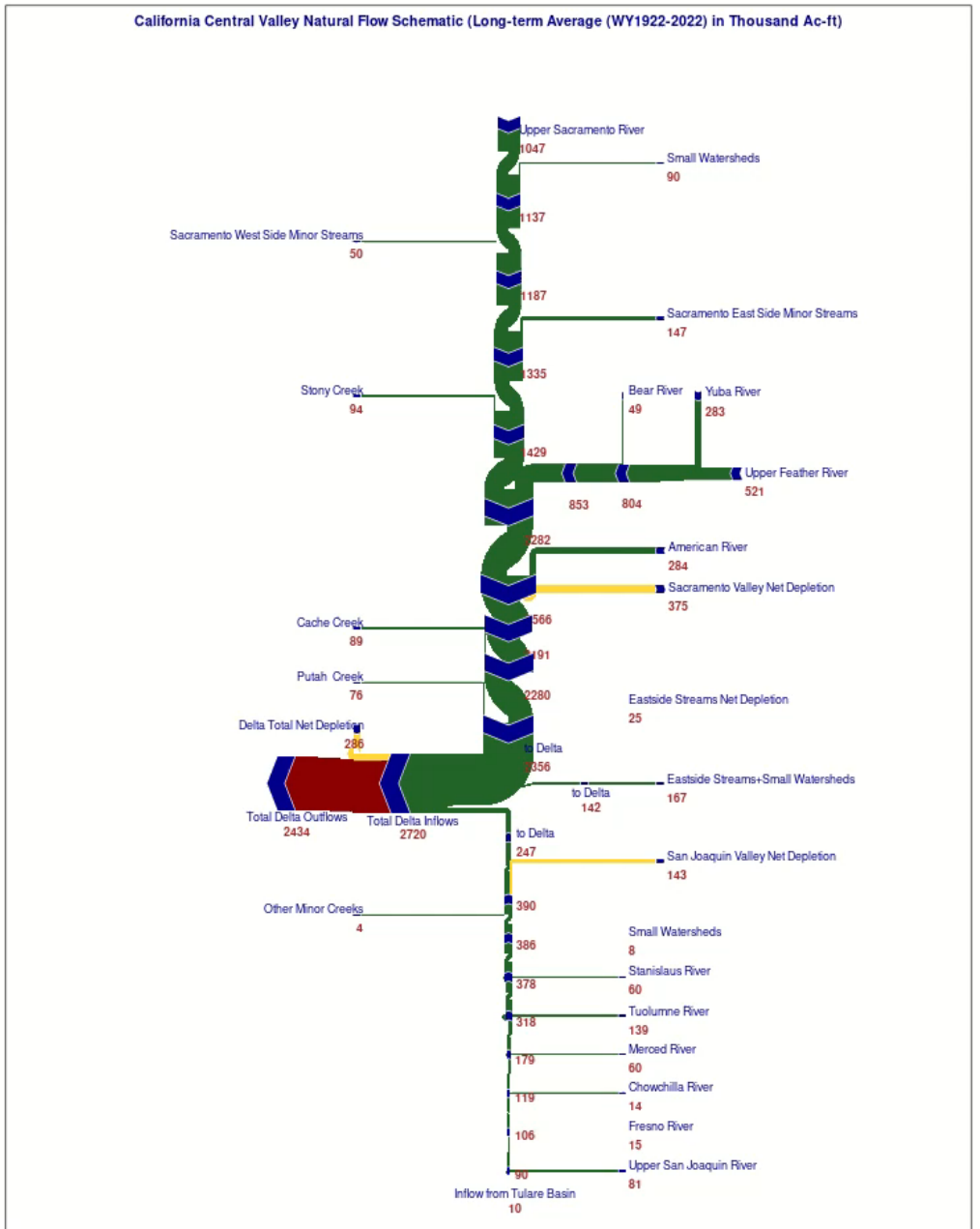
# **RESULTS:** Sankey Diagrams for Annual UF and NF

- The contributions from each stream are shown with the estimated quantity in TAF/year.
- Thickness of the reach represents the magnitude of the flows.
- Include contributions from small watersheds for natural flow






**RESULTS:** Monthly Average Natural Flow Animation via Sankey

https://mso2023.shinyapps.io/test1/

CALIFORNIA DEPARTMENT OF
**WATER RESOURCES**

https://mso2023.shinyapps.io/test1/_w_d52e63a8/#

# SUMMARY AND NEXT STEPS

- Modified, enhanced and extended 25 upper watershed SWAT models and C2VSim NF Daily model for the period of WY 1922-2022 to simulate and route daily natural flows from upper watersheds through Central Valley and Delta.

- For Delta inflow, UF is more of a water supply index, while NF is streamflow simulated by combination of physically-based hydrologic models, and better represent the Delta inflow under natural conditions.

- Daily natural flow data for WY1922-2022 and the corresponding reports should be publicly available Summer 2023.

- Current natural flow estimates are the result of the best SWAT model simulation runs. Additional uncertainty evaluation to construct probabilistic natural flow simulations being considered.

- Additional work on automation of data preparation and post-processing to reduce future period extension workloads.

# REFERENCES


- California State University Chico (CSU Chico). 2003. *The Central Valley Historic Mapping Project,* Dept. of Geography and Planning and Geographic Information Center, California State University, Chico, California.

- Fox, P., P.H. Hutton, D.J. Howes, A.J. Draper, and L. Sears. 2015. Reconstructing the Natural Hydrology of the San Francisco Bay-Delta Watershed. *Hydrol. Earth Syst. Sci*., 19, 4257-4274.

- Hamlet, A. F., and D. P. Lettenmaier, 2005: Production of temporally consistent gridded precipitation and temperature fields for the continental United States*. J. Hydrometeor.,* 6 , 330–336

- Küchler, A.W. 1977. *Natural vegetation of California. Terrestrial vegetation of California*, J. Major and M.G. Barbour, eds., Wiley, New York.

- Morteza N Orang, Richard L Snyder, Geng Shu, Quinn J Hart, Sara Sarreshteh, Matthias Falk, Dylan Beaudette, Scott Hayes, Simon Eching (2013). *California Simulation of Evapotranspiration of Applied Water and Agricultural Energy Use in California*. J. Integr. Agric., 12(8), 1371–1388.

Thank you!

Shalamu.Abudu@water.ca.gov

Tariq.Kadir@water.ca.gov