Drought Water Rights Allocation Tool
Eel River Application

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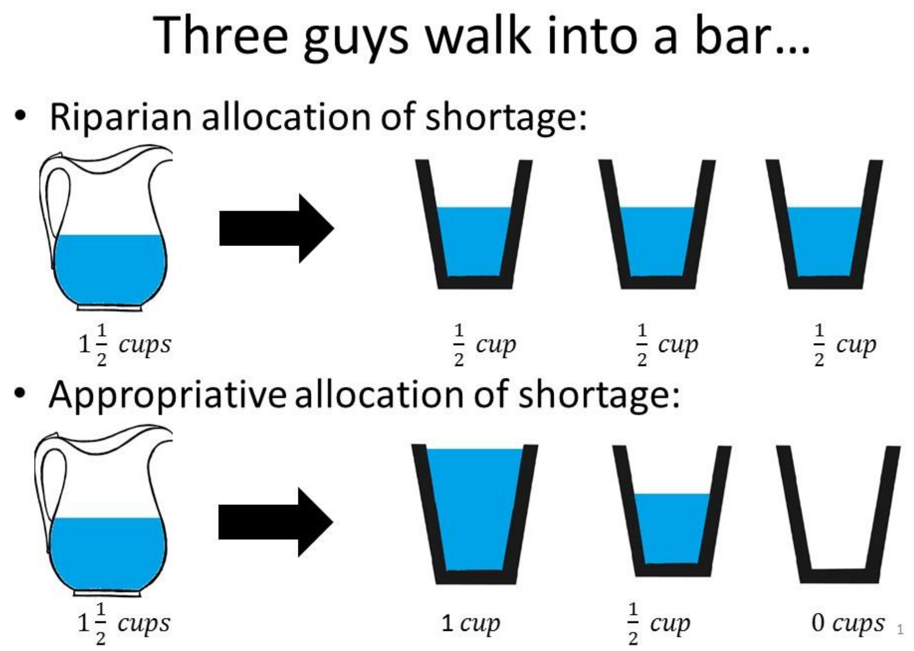
Outline

- Drought Water Management
- DWRAT Components
- DWRAT Methods
- Eel River DWRAT
- Questions and Discussion

Drought Water Management

- Historic droughts
- California's Surface Water Rights System
  - Administered by the State Water Resources Control Board (SWRCB)
- Riparian Rights
  - Shared Shortage
- Appropriative Rights
  - First in Time, First in Right
- Very few historical curtailments



Water Shortage Notices

- 2014: Eel, Russian, Scott, Sacramento, and San Joaquin basins
- 2015: Scott, Sacramento, and San Joaquin basins

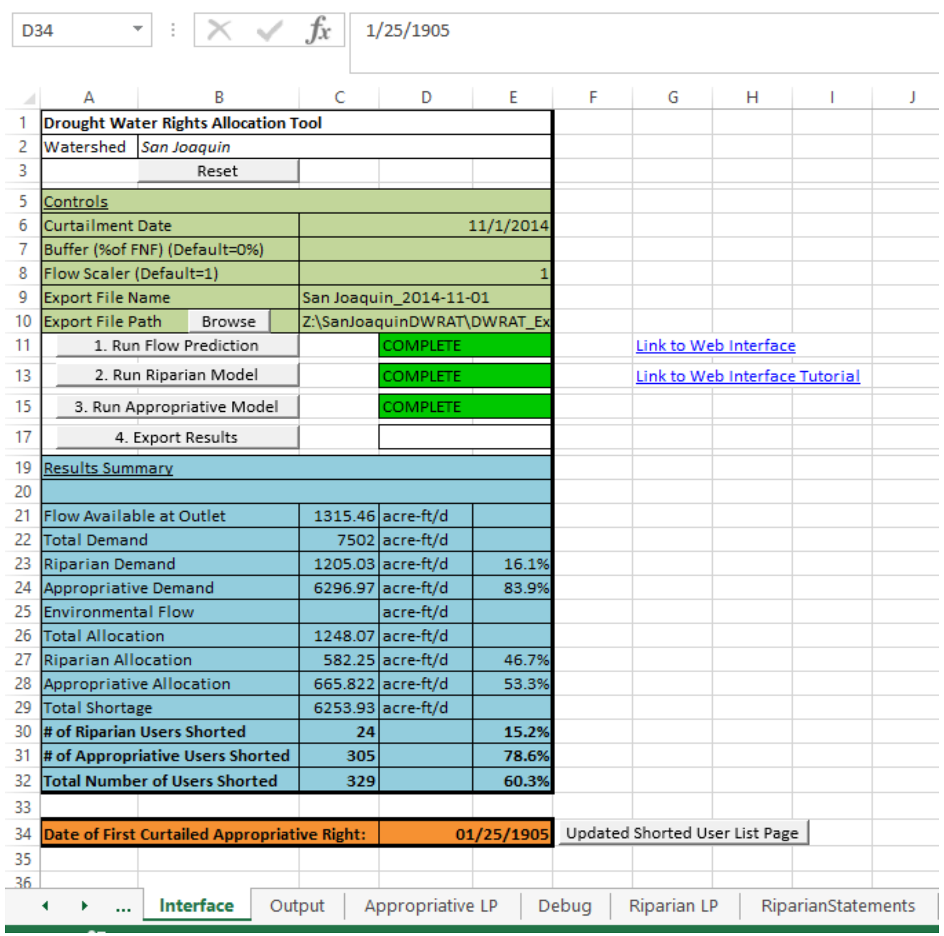
Discussing Water Rights, A Western Pastime

The Task: Develop a Tool

- Account for geography of demand, supply, and priority
- Use publicly available data
- Provide an explicit, transparent, and rigorous method for calculating water right curtailments following water law principles
- This model so far reflects only the work of the authors
  - Not yet peer-reviewed; not yet submitted to the Division of Water Rights
  - Not tasked with reviewing or critiquing the Division 2014 or 2015 methodology

Drought Water Rights Allocation Tool (DWRAT)

- Excel Workbook, User Interface
- Statistical Hydrologic Model
- Unimpaired Flow Data
  - CDEC
  - CNRFC
- Water Right User Data
  - SWRCB Database
  - Monthly reported demand for 2010-2013 (averaged)
- Riparian and Appropriative Linear Programs
  - Solver Studio: Free, open-source solver
  - “Making water law into an algorithm”



Hydrologic Model

- Developed around USGS Hydrologic Unit (HUC12)
  - Unimpaired flow estimates, WY 1950-2011
- Basin Connectivity
- Flow Scaling Ratios
  - Dry-Year Average Flow
  - Unimpaired / FNF gage locations

$$Q_{HUC,i} = Q_{R,i} \times \frac{Q_{HUC,i}}{Q_{HUC,R}} \times \frac{A_{R,HUC,i}}{A_{R,i}}$$

- Assumes users in each HUC have access to flow at the HUC outlet

Riparian & Appropriative Linear Programs

Linear Program	Objective Function	Goal
Riparian	$min\, z = \alpha \sum_{k} w_k P_k - \sum_{i} A_i$	**Allocate as much water to as many users possible (minimize total basinwide shortage)** A_i = water allocation for user i α = weight factor in objective function P_j = proportion of normal usage allowed for all users in basin j w_k = unit penalty for P, increases with downstream basins
Appropriative	$min\, z = \sum_{\mathrm{i}} \mathrm{p_i}(\mathrm{u_i} - \mathrm{A_i})$	**Minimize total basinwide shortage penalty** A_i = water allocation for user i p_i = unit shortage penalty for user i, increases with seniority of water right u_i = normal usage (demand) for user i

Riparian LP

Objective Function:	$min\ z = \alpha \sum_k w_k P_k - \sum_i A_i$	Allocate as much water to as many users possible
Constraints:	$A_i = P_k u_i, \forall\, i, i \in k_{upstream-most}$	All users in a sub-basin *k* receive the same portion, P_k, of demand
	$P_j \leq P_k, \forall\, k, j \in k$	Upstream portions cannot exceed downstream portions
	$\sum_{i \in k} A_i \leq v_k - e_k, \forall\, k$	Allocations upstream of *k* cannot exceed available water at *k*'s outlet
	$0 \leq P_k \leq 1, \forall k$	Portions must be between 0 and 1
	$A_i \geq 0, \forall\, i$	Allocations must be greater than or equal to 0
	$A_i \geq u_{i,Public\ Health\ and\ Safety}, \forall i$	Allocations must meet public health and safety needs
	$w_k = \frac{n_k}{n_{k,outlet}}$	Unit penalty for *P* increases with downstream basins
	$\alpha < Min\left(\frac{w_{k,i}}{u_{k,i}}\right) \forall\, i$	Defines the relative weight for *P* values in the objective function

A_i = water allocation for user i
α = weight factor in objective function
P_j = proportion of normal usage allowed for all users in basin j
n_k = number of basins upstream of k

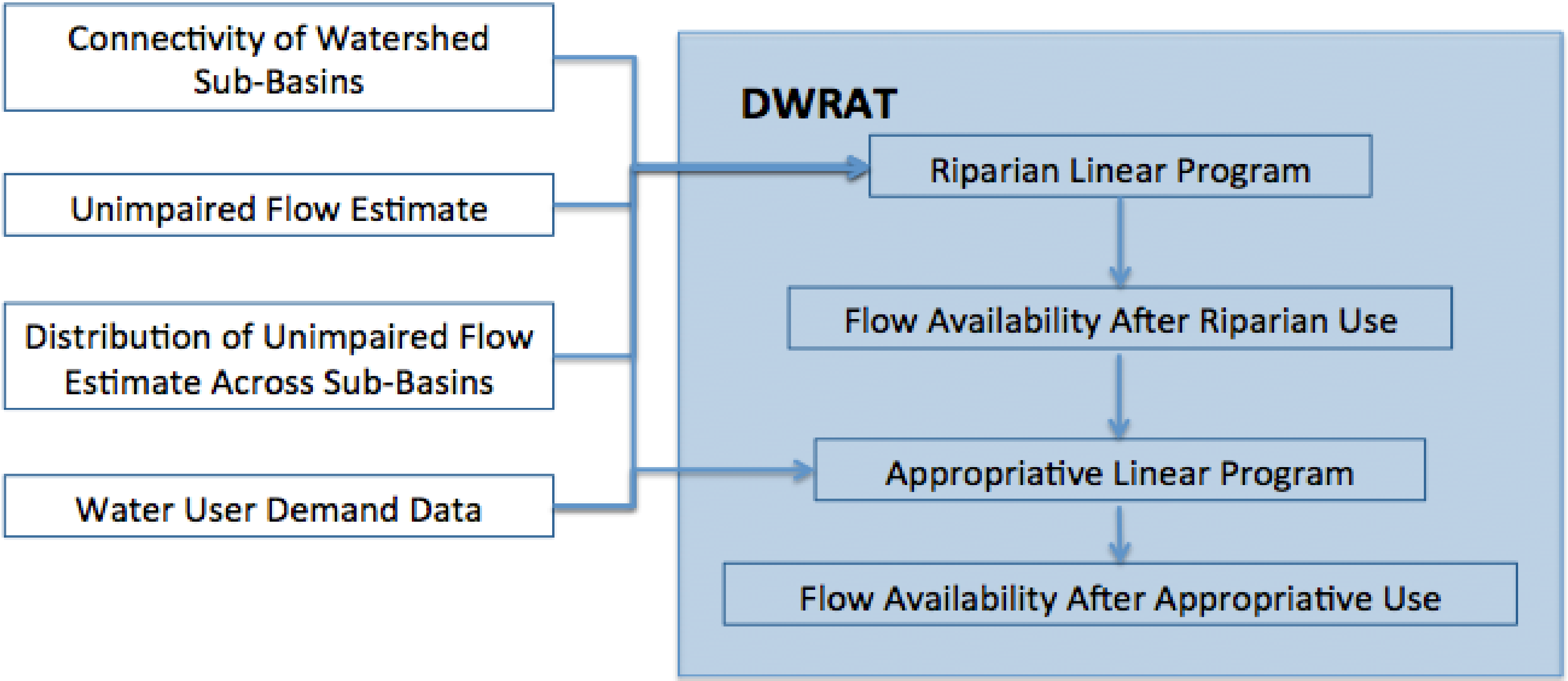
w_k = unit penalty for *P*, increases with downstream basins
v_k = flow in basin k
e_k = environmental flow requirement in basin k
u_i = normal usage (demand) for user i

Appropriative LP

Objective Function	$$min\ z = \sum_i p_i(u_i - A_i)$$	Minimize total shortage penalty; unit penalties increase with water right seniority
Constraints:	$$\sum_{i \in k} A_i \ \leq \ v_k - e_k - \sum_{i \in k} A_{upstream\ riparian\ users\ i}, \forall\ k$$	Allocations cannot exceed available water remaining after riparian allocations
	$$A_i \ \leq u_i, \forall\ i$$	Allocations cannot exceed reported use
	$$A_i \ \geq 0, \forall\ i$$	Allocations must be greater than or equal to zero
	$$A_i \geq u_{i,Public\ Health\ and\ Safety}, \forall i$$	Allocations must meet PHS needs

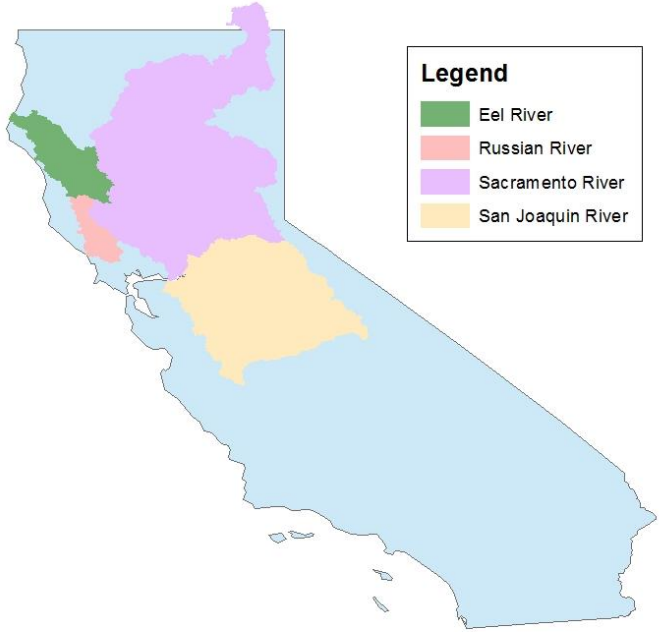
A_i = water allocation for user i
p_i = unit shortage penalty for user i, increases with seniority of water right
v_k = flow in basin k
e_k = environmental flow requirement in basin k
u_i = normal usage (demand) for user i

DWRAT Flowchart



Current DWRAT Models

- Eel River
- Russian River
  - SCWA Reservation Water Rights
- Sacramento River
  - Improved Hydrologic Model
  - Return Flows
- San Joaquin River (in development)

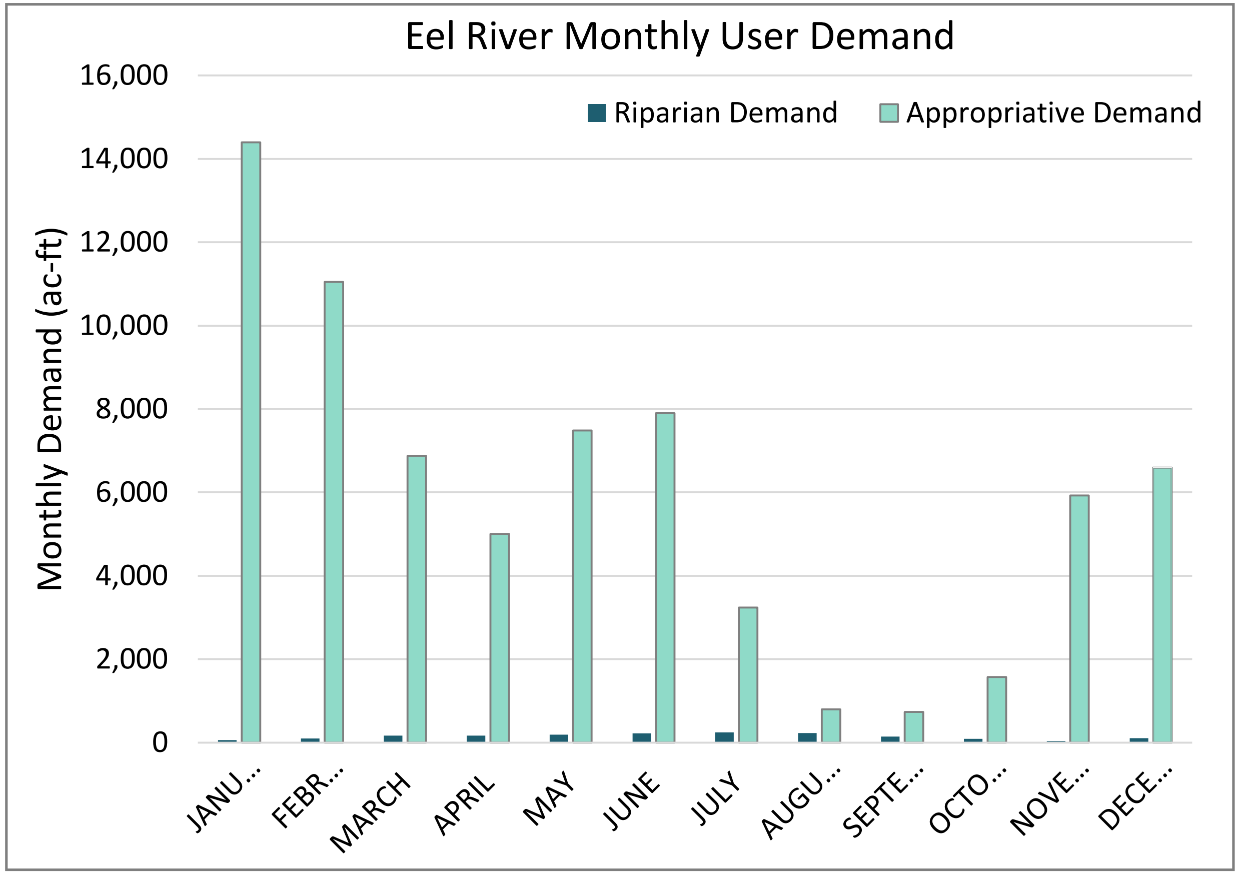


Eel River DWRAT

- Eel River
  - North Fork, Middle Fork, South Fork, Van Duzen River
- 3684 mi^2 area
- 113 HUCs (Hydrologic Unit Code)
- 584 Total Water Right holders
  - 331 Riparian right holders
  - 253 Appropriative right holders
- Current/Historical Gage Data
  - CDEC
  - CNRFC

User Demand – Eel River Basin

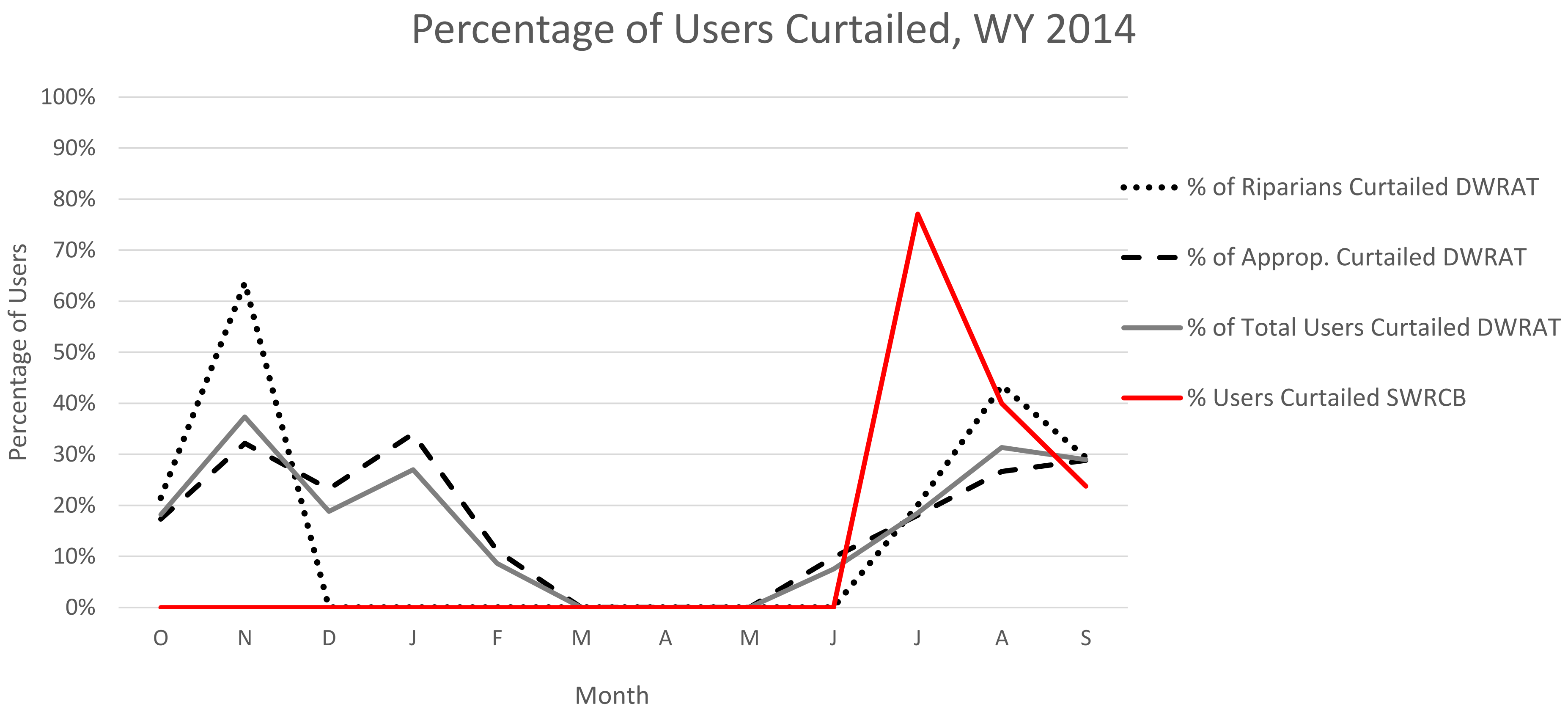
Right Type	# of Right Holders	% of Total Right Holders	Annual Water Use (ac-ft)	% of Total Water Use
Riparian	336	56%	1,750	2%
Pre-1914	47	8%	56,793	77%
Post-1914	216	36%	14,787	20%
TOTAL	599	100%	73,330	100%



Water Year 2014 SWRCB Water Shortage Notices

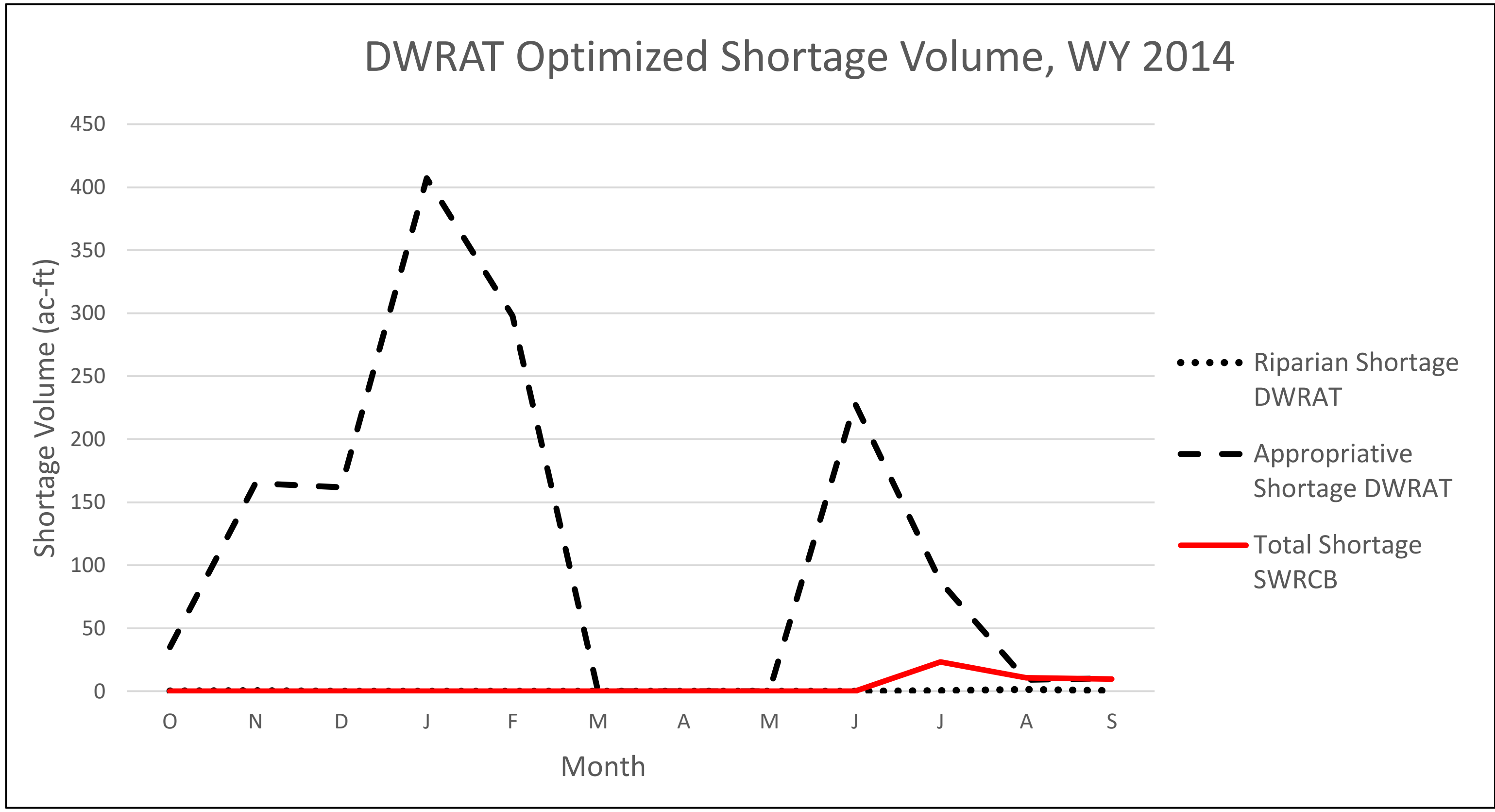
- June 30, 2014: All Post-1914 appropriative right holders on the North Fork, and Main stem of the Eel River, and Van Duzen River are curtailed except for health and safety related rights and completely non-consumptive rights
- August 1, 2014: 22 Right holders downstream of the confluence of the Main stem and South Fork of the Eel River are released from curtailment on recalibration of gauges at Scotia and Fort Seward
- September 3, 2014: All curtailed users on the Van Duzen River are released from curtailment based on flow data from a gauge at Bridgeville and a reduction in user demand in August and September

2014 Results – Eel River Users Curtailed



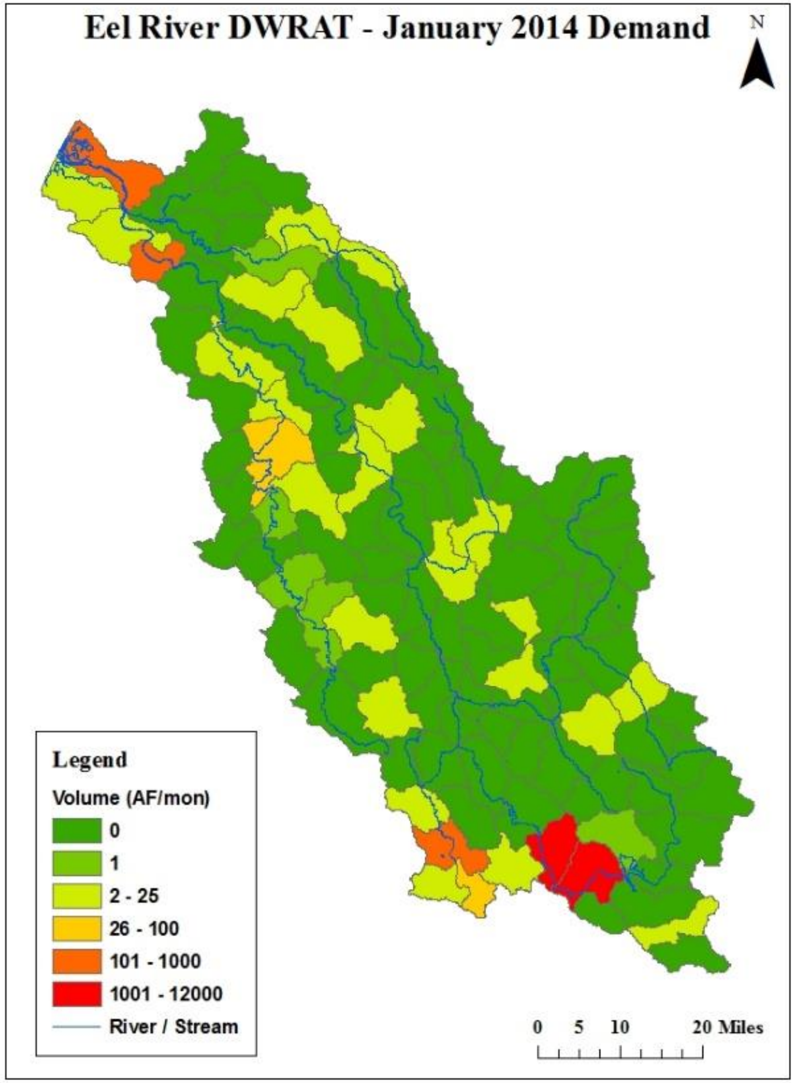
Water Year 2014 Results and Conclusions

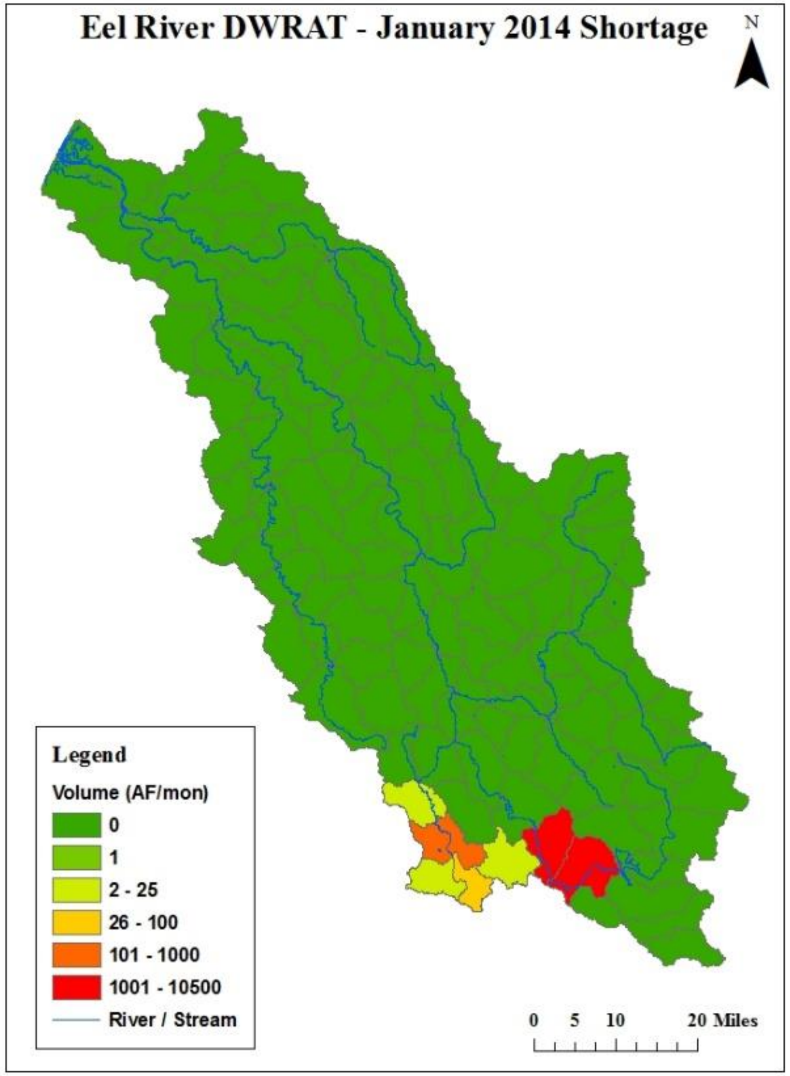
- Apart from large curtailments of Pre-1914 water rights, decent agreement between DWRAT and SWRCB
- SWRCB actions only applied to Post-1914 appropriative users
- Greatly reduced demand in last months reduced shortage
- DWRAT curtailed riparian and some appropriative users in the winter
- The model will distribute very small shortages among a large amount of riparian users



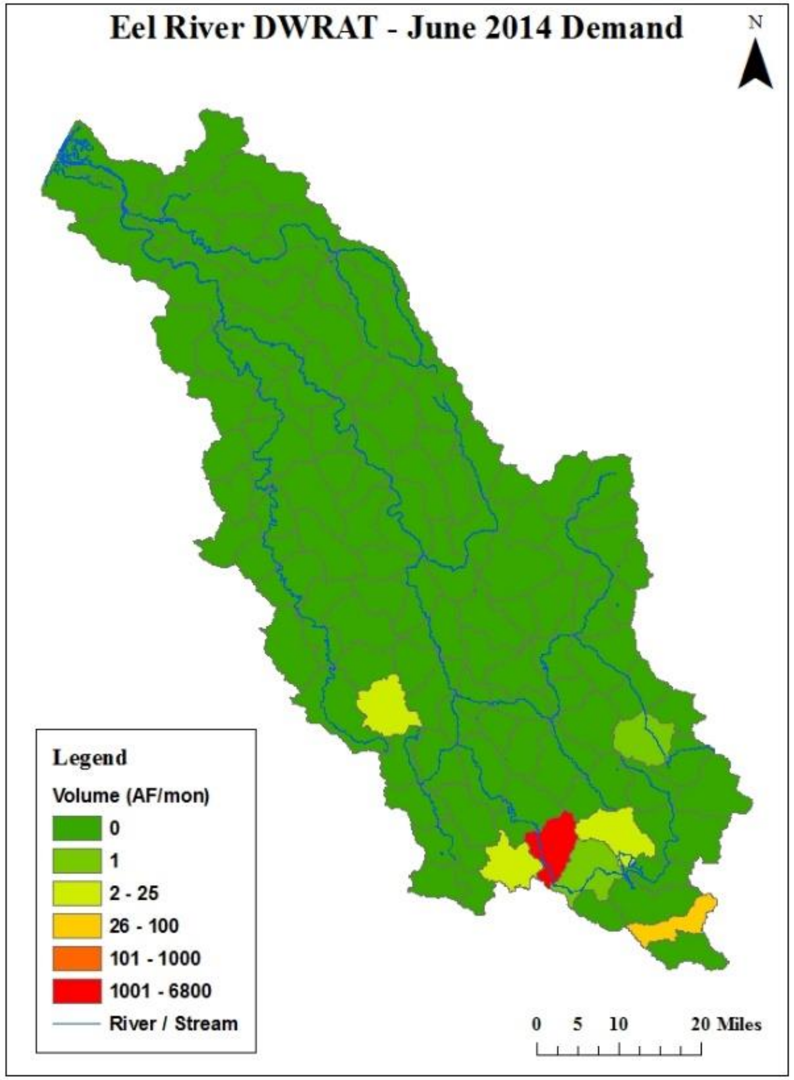
*The number, percentage, and volume of SWRCB users from applying SWRCB actions to appropriative users in the DWRAT database

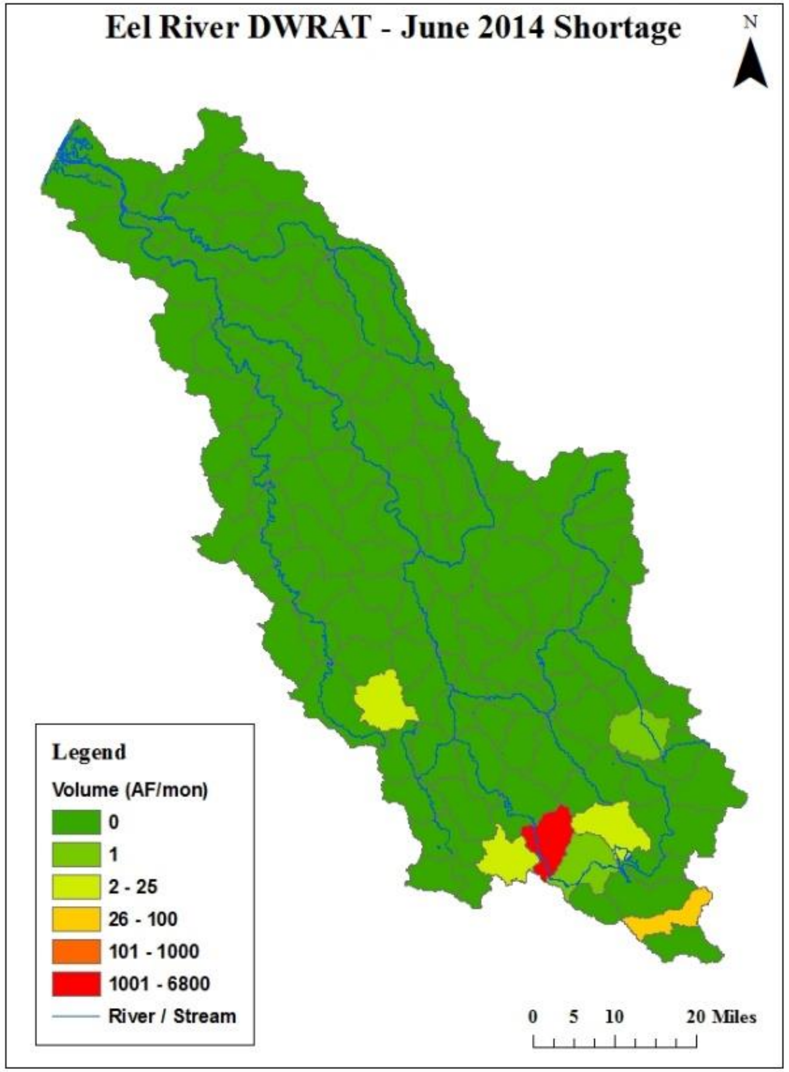
January Demand and Shortage - DWRAT





June Demand and Shortage - DWRAT



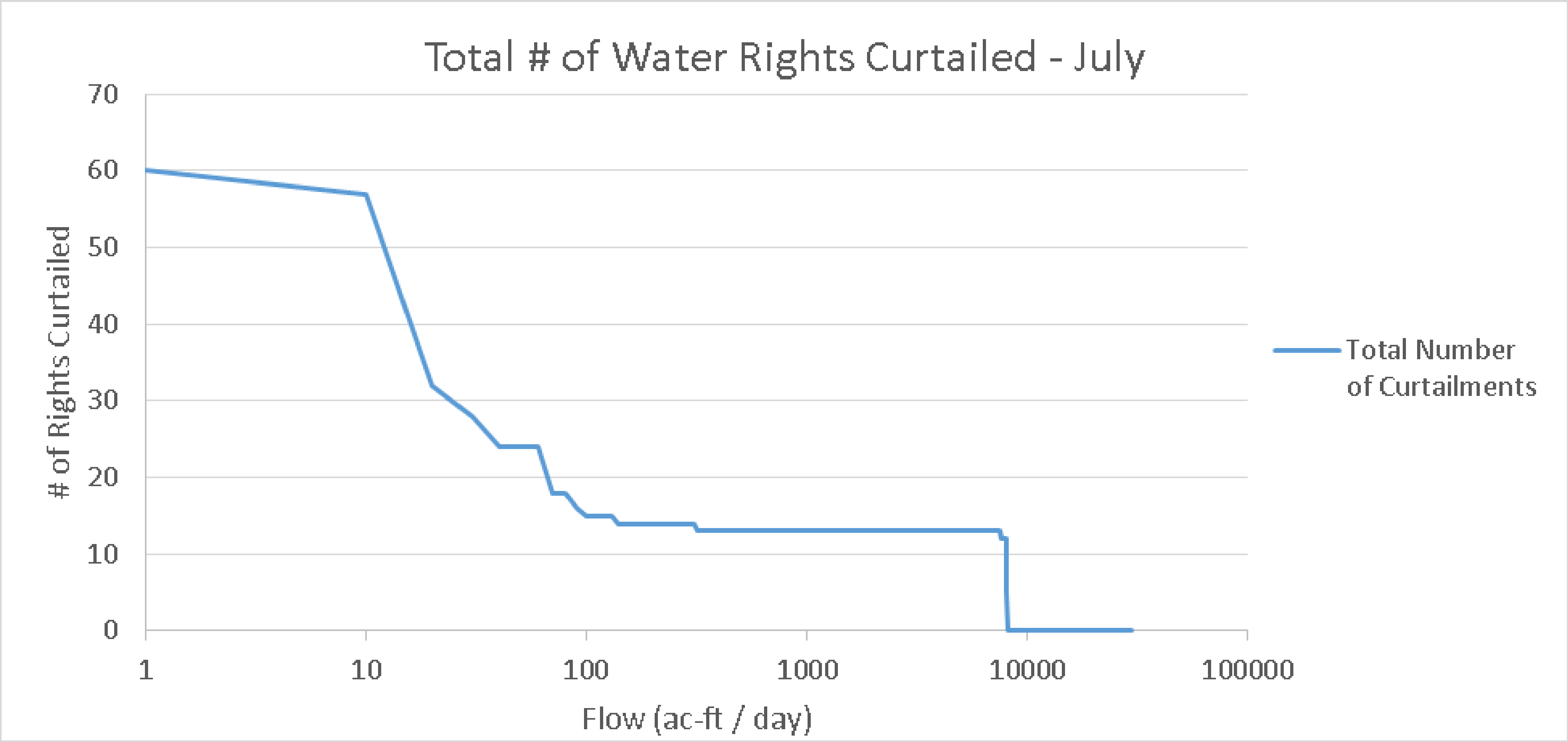


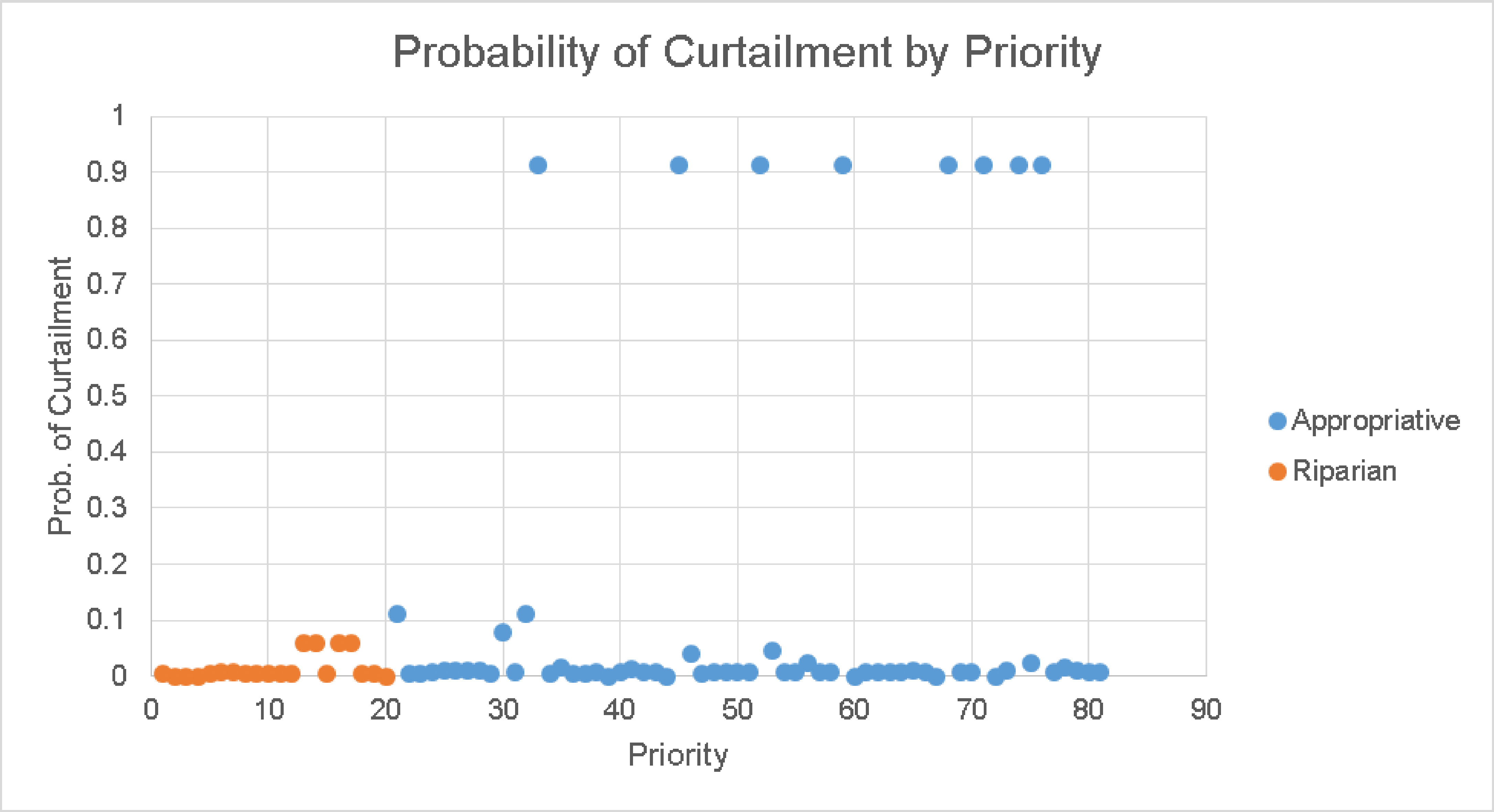
Implicit Stochastic Optimization - Methods

Apply synthetic streamflow to DWRAT to create curtailment rules

1. Generate synthetic streamflow based on historical data
2. Optimize curtailments for each input
3. Use output set to determine reliability for each right
4. Determine curtailment rules from output

Preliminary Results





Probability of Curtailment by Priority
Prob. of Curtailment
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
Priority
Appropriative
Riparian

Ongoing Work

- Flow Error Analysis
  - Scaling Ratio Analysis
  - Unimpaired Flow Error
- Forecast Curtailment Decisions
- Monte Carlo Analysis for Curtailment Probabilities
- Curtailment/Shortage Error Analysis
  - Buffer flows – False allocation promises / false curtailments
- Additional model tools to improve output and usability

References

- Special thanks to the SWRCB for technical and financial support

- Previous theses available from: https://watershed.ucdavis.edu/shed/lund/

  - Lord, B. (2015), "Water rights curtailments for drought in California: Method and Eel River Application" (Master's Thesis), University of California, Davis.
  - Tweet, A. (2016), "Water Right Curtailment Analysis for California's Sacramento River: Effects of Return Flows" (Master's Thesis), University of California, Davis.
  - Whittington, C. (2016), "Russian River Drought Water Right Allocation Tool (DWRAT)" (Master's Thesis), University of California, Davis.

- For additional information:

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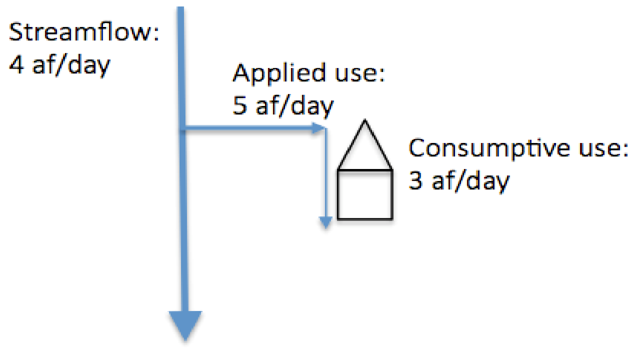
  - Wesley Walker; wfwalker@ucdavis.edu

Return Flows

- Current DWRAT build assumes fully consumptive use
- Each user has some fraction of their demand flow that will return to the surface water source
- 4 Return flow methods available
  - Fully consumptive
  - Reduce consumptive use to applied use (under curtails)
  - Explicit Return Flows (over curtails)
  - Precisely Represented Return Flows (data/time intensive)
- Study performed to compare options 2 and 3

Consumptive Use Diversions



Explicitly Return Flows Downstream