Recreating the Natural Flow Regime on the Upper Sacramento River

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Abstract

Shasta Dam is built on the mainstem Sacramento River and the largest dam in California with a maximum capacity of 4.5 million acre feet (MAF) of water in its reservoir. Irrigators and agriculture rely upon Shasta Reservoir for water supplies during the summer. The Sacramento River Settlement Contractors have rigid water supply contracts that were agreed upon in 1964. This project will model the natural flow regime of the Sacramento River below Shasta dam and attempt to characterize any changes in annual and seasonal runoff patterns. Climate change is expected to increase interannual variation and inter-seasonal variation in precipitation across California. As precipitation patterns change, the natural flow regime will shift accordingly. Results indicate the natural runoff has decreased by approximately 1 million acre feet from 1991-2021 when compared to 1950-1980. As the flow regime shifts but water supply contracts remain stable based on a 60 year old agreement, the system will be increasingly strained.

Introduction

Shasta Dam is built on the mainstem Sacramento River and is the largest dam in California with a maximum capacity of 4.5 million acre feet (MAF) of water in its reservoir. Construction of the dam began in 1938 with the purpose of flood control and salinity management in the Sacramento-San Joaquin River Delta. Since completion of the dam in 1945, the reservoir has become an integral part of the Central Valley Project (CVP). Operated by the U.S. Bureau of Reclamation (USBR), the CVP is a complex network of dams, reservoirs and canals which provides services such as flood control, power production, and supplies water to domestic and industrial users across the central valley.

On the upper Sacramento River, flows below Keswick reservoir are managed through what is known as the Shasta-Trinity Complex (Figure 1). Keswick Dam is located downstream of Shasta Dam on the Sacramento River and is used to stabilize flows on the Sacramento River. Flows into Keswick reservoir include releases from Shasta Dam and supplementary water that is diverted from Clear Creek and the Trinity River. Water diverted from the Trinity River is pumped from Lewiston Reservoir through the Carr Powerhouse on

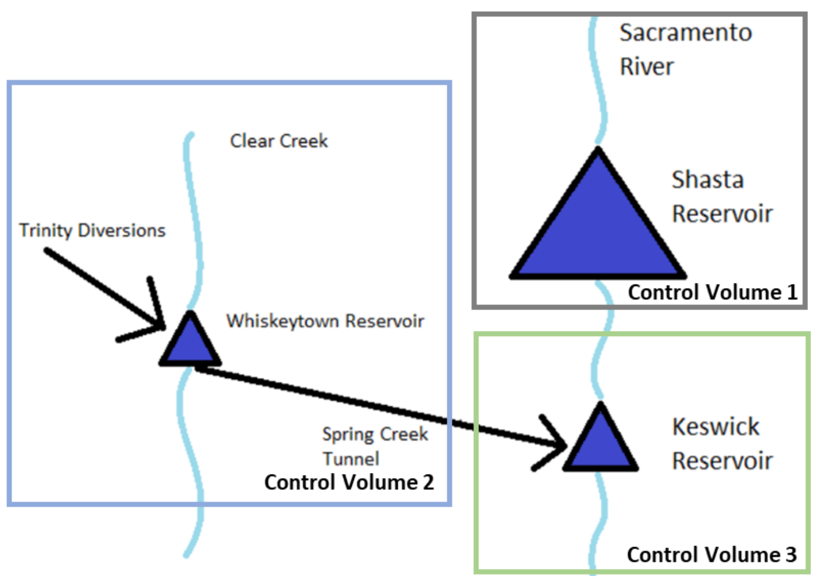

Figure 1. Diagram of the Shasta-Trinity Complex. Black arrows indicate pipelines for pumping water between reservoirs.

Whiskeytown Reservoir. From Whiskeytown, water from the Trinity River and natural inflows from Clear Creek are pumped via the Spring Creek Tunnel into Keswick Reservoir.

Today, the CVP is most known for its role in storing peak winter flows and delivering water in the summer for agriculture and irrigation. There are more than 250 contractors that have agreements with the CVP for water supplies each year. Of these, the largest and most influential are the Sacramento River Settlement Contractors (SRSC) who represent more than 100 irrigation districts and have rights to divert approximately 2.2 MAF of water annually (U.S. Bureau of Reclamation, 2004). The SRSC operated along the Sacramento River prior to the construction of Shasta Dam and possess more senior water rights than the CVP. In 1964, the SRSC signed settlement contracts with USBR to retain deliveries of their 2.2 MAF through the operation of Shasta Dam. These contracts were renewed in 2004 for another 40 years and their maximum allocation of 2.2 MAF remained unchanged.

Since these contracts were originally signed in 1964, the impacts of climate change have accelerated and precipitation patterns in California are projected to shift. California is expected to experience greater interannual variation in rainfall with more extreme droughts and wetter wet years in the future (Berg & Hall, 2015). Warmer temperatures will cause more precipitation to fall as rain instead of snow. Snow acts as natural storage and holds water until the summer months as warm temperatures begin to melt the snow. As the proportion rainfall to snow increases, the hydrology of the Sacramento will reflect a flashier system with peak flows becoming stronger and shorter in duration. As the snowpact melts earlier in the season, inflows into reservoir will end earlier and shorten the wet season and extending the dry season.

This project will be to model the natural flow regime of the Sacramento River below Shasta Dam. A mass balance approach will be used to balance the system and understand how water is moved through the multiple reservoirs on an annual and seasonal basis. Long term shifts in the natural flow regime will be investigated and how water allocations have shifted to accommodate a dynamic flow regime.

Objectives

- Use a mass balance approach to model the natural flow regime of the Sacramento River
- Characterize differences in the natural flow regime between pre 1960 and post 2000.
    - Annual runoff
    - Seasonal precipitation patterns
- Assess how the water contracts for the SRSC have failed to adapt to any shifts in the natural flow regime

Methods & Results

Functional Flow Regime

The functional flow regime for the Sacramento River will be identified using the Natural Flows database (Conservancy, 2022) that was developed by The Nature Conservancy. The Functional Flow Metrics and the estimated unimpaired flow will be collected for COMID: 2495224, the stream reach directly below

Keswick Reservoir, from 1950 through 2022. The functional flow regime will be compared to observed daily flows below Keswick which are available at the United States Geological Survey (USGS) website[1].

The functional flow regime of the upper Sacramento is typical of a snowmelt and rain stream classification (Lane et al., 2018). Some key features include the early fall pulse flow, increased winter base flow with a substantial winter peak pulse event, and springtime recession flows leading to low summer base flows. Observed flows (Figure 3) vary significantly from unimpaired flows during the summer base flow period and the timing of peak discharge. Observed flows display only one major peak in February/March and only during wet conditions greater than the 50% exceedance when Shasta Dam would be required to spill water for flood control. Summer base flows are typically the greatest flows observed on the Sacramento River, driven by releases for agricultural demand in the watershed. Peak flows for unimpaired conditions are significantly greater than observed flows with maximum discharges of greater than 120,000 cfs under unimpaired conditions, but less than 50,000 cfs under observed conditions.

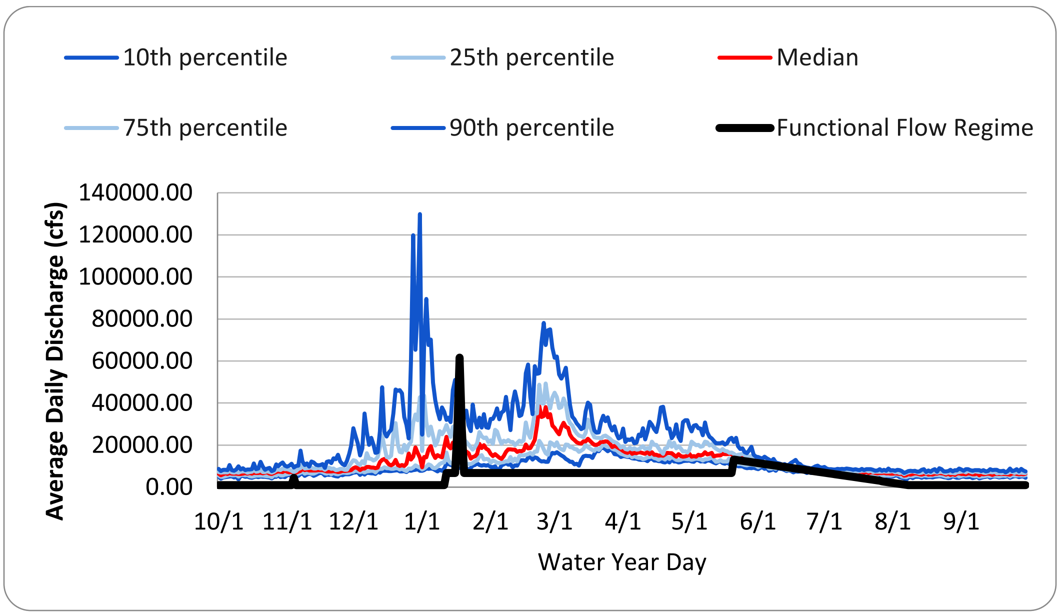

Figure 2. The functional flow regime for the stream reach below Keswick Reservoir.

[1] Available at: https://waterdata.usgs.gov/monitoring-location/11370500/#parameterCode=00065

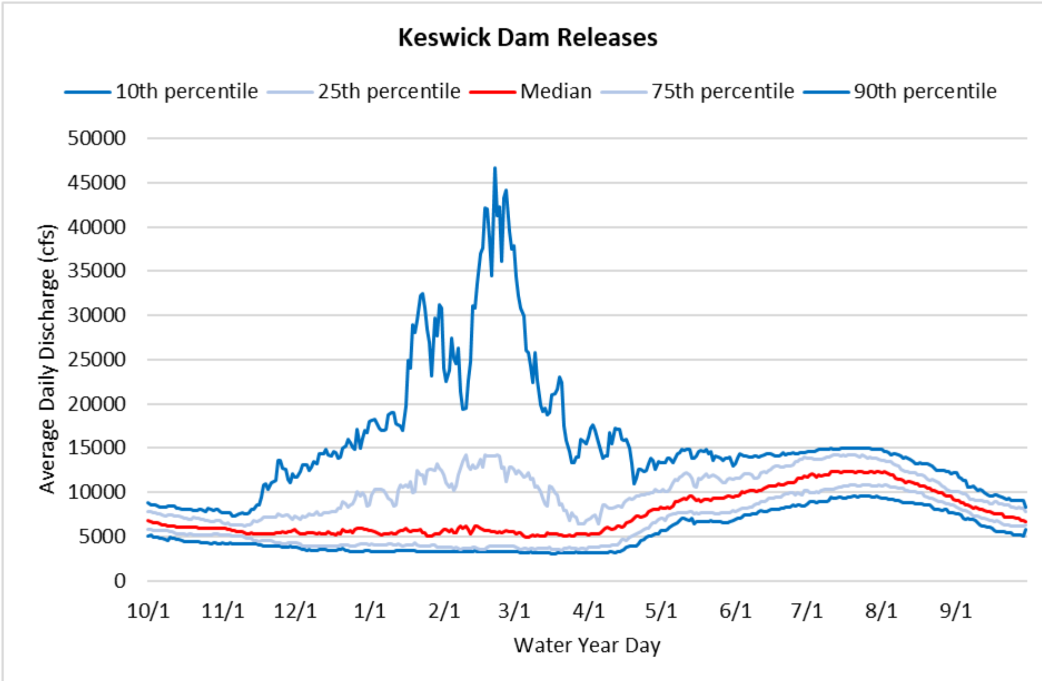

Figure 3. Observed flows below Keswick. USGS Gauge 11370500.

Mass Balance of the Shasta Trinity Complex

To model the Shasta Trinity Complex (Figure 1), a mass balance approach will be used as described in Equation 1. All data will be in monthly time steps and be converted into the units of thousand acre feet (TAF).

$$\Delta\, Storage = Inflows - Outflows \tag{1}$$

Equation 1 will be adapted to the 3 Control Volumes as described in Figure 1. These balance equations are described below. The mass balance for Shasta Reservoir (Control Volume 1):

$$\Delta\, \boldsymbol{Shasta\ Storage} = \boldsymbol{Shasta\ Inflows} - Shasta\ Outflows \tag{2}$$

The mass balance for Whiskeytown Reservoir (Control Volume 2):

$$\Delta\, \boldsymbol{Storage_{WT}} = \left(Inflows_{WT} + \boldsymbol{Diversions_{Trinity}}\right) - \left(\boldsymbol{Outflows_{WT}} + Diversions_{Spring\ Creek}\right) \tag{3}$$

The mass balance for Keswick Reservoir (Control Volume 3):

$$\Delta\, \boldsymbol{Storage_{Keswick}} = \left(Shasta\ Outflows + Diversions_{Spring\ Creek}\right) - \left(\boldsymbol{Outflows_{Kes}}\right) \tag{1}$$

All data for the variables in bold will be collected from CDEC except for Trinity River Diversion and Keswick Outflows**.** Monthly volumes diverted from the Trinity River were sourced from monthly reports produced by the U.S. Bureau of Reclamation for Lewiston Reservoir from 1998 – 2022[2]. Equations 2 through 4 will be solved for the variable not in bold.

[2] Available at: https://www.usbr.gov/mp/cvo/reports.html

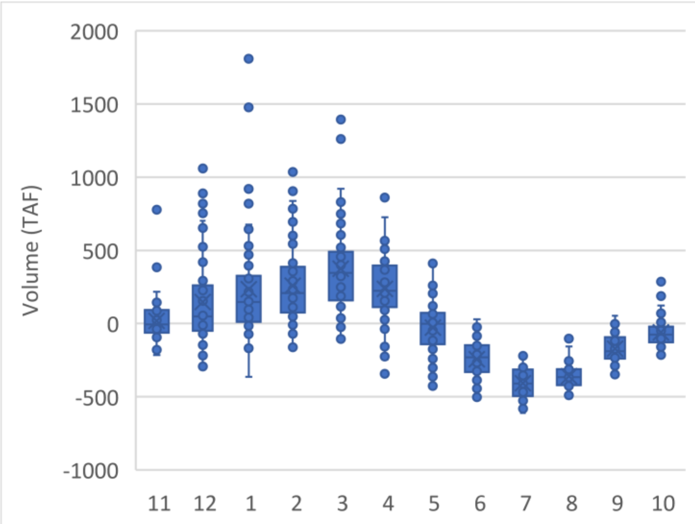

Figure 4. Changes in Shasta Storage by month.

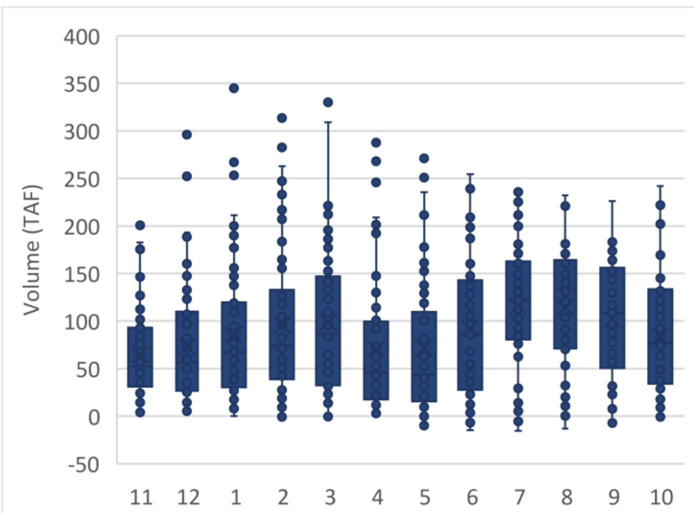

Figure 5. Spring Creek Tunnel Diversions into Keswick Reservoir

Changes in Shasta storage (Figure 4) reveal seasonal patterns of Shasta operations. Shasta is building storage (net positive change) from November through April, and depleting storage from May through October (net negative change). This reflects the pattern described above for the natural flow regime. Summer months experience naturally lower inflows into Shasta reservoir while observed releases are high to meet agricultural demands. This pattern indicates that in most years, storage in Shasta reservoir will peak in April.

Keswick outflows are substantially supplemented by diversions year round (Figure 5). Diversion schedules through the Spring Creek Tunnel peak during the growing season from July through September, typically importing more than 100 TAF of water each month. During the remainder of the year, diversions typically vary between 40 and 120 TAF, which minimum diversions occuring in April and May.

The seasonal pattern of diversions through Spring Creek Tunnel does not match the pattern of Trinity River diversions (Figure 6). Trinity River diversions peak from May through October (> 50 TAF) but are relatively small during the remainder of the years (<50 TAF). In the winter months, flows through the Spring Creek Tunnel are subsidized by natural inflows into Whiskeytown Reservoir from Clear Creek. As the natural inflows diminish after April, similar to Shasta Reservoir (Figure 4), Trinity River diversions increase and compose a greater proportion of the Spring Creek Tunnel flows.

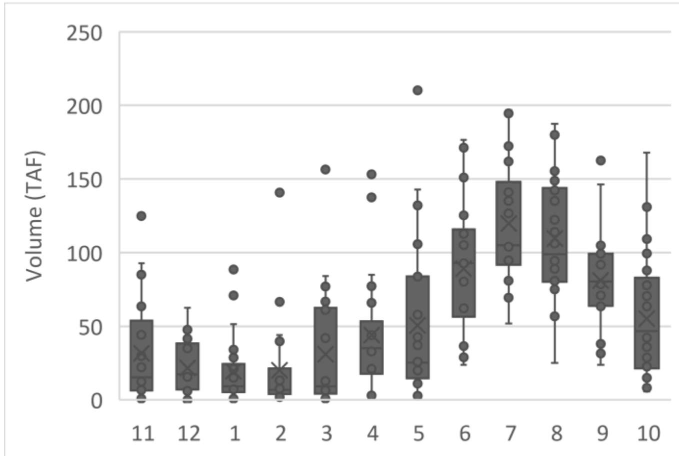

Figure 6. Trinity River Diversions by month.

Climatic Shift in Flow Regime

Annual observed flows and full natural flow data will be used to evaluate if a shift in precipitation patterns has occurred since the development of the SRSC contracts in 1964. Two time periods will be evaluated, 1950-1980 and 1991-2021. These 30 year periods straddle the original signing of the SRSC contracts in 1964 and the resigning of the contracts in 2004.

Full natural flow has indicated a reduction of 600 TAF in mean discharge and 1,000 TAF in median discharge (Figure 7) since the original SRSC contracts were signed in 1964. The median discharge from 1950 to 1980 was 6.3 million acre feet (MAF) compared to 5.3 MAF from 1991 to 2021. This reduction indicates a 16% loss in runoff in half the years.

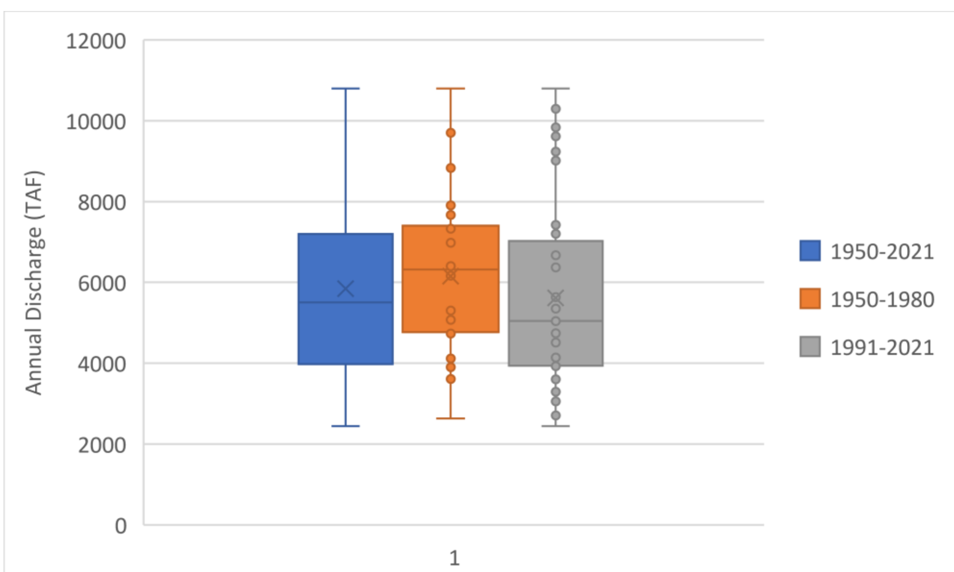

Figure 7. Annual full natural flow at Shasta Reservoir by time period.

Conclusions

Keswick releases typically exceed the functional flow requirements for the Upper Sacramento River. However, release schedules are heavily altered by agricultural demand and water quality standards related to dam presence during the summer months. On the Sacramento River, Water Right Order (WRO) 90-5 (1990) requires temperature management below Keswick Reservoir to improve spawning conditions for winter-run Chinook Salmon that would typically spawn above the Dam. Temperature conditions below the dam are improved by greater storage levels behind Shasta Dam and increased releases above a full natural flow.

Summer releases from Keswick reservoir are augmented by water diversions from Clear Creek and the Trinity River. Contributions of diverted water shift seasonally as natural flows on Clear Creek diminish in the summer months and Trinity River diversions increase. Winter diversions through Spring Creek Tunnel are used to meet minimum flow standards imposed by WRO 90-5 of 3,250 CFS and allows Shasta Reservoir to maximize increases in storage. Summer diversions likely support increased water supply for agriculture downstream during the growing season.

Long term patterns indicate that annual run off has significantly declined since SRSC contracts were signed in 1964. Since 1964, environmental standards have become increasingly strict in attempts to address declines in water quality and native aquatic species. Despite these declines in annual runoff and stricter environmental standards, the SRSC contracts remained unchanged when they were renewed in 2004. Failing to adapt all aspects of the water demands on the system in the face of a changing climate will increasingly strain the system and lead to management failures as operators continue to push the system to the breaking point. These failures are becoming evident during the current drought as reservoirs experience historically low storage and threaten basic health and safety needs in the name of maximizing agricultural deliveries.

References

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