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A method for scheduling Lewiston Dam releases to mimic diel variations in flow on unregulated streams

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INTRODUCTION

Diel oscillations in discharge are common on most streams for most of the year. In winter, the diel or diurnal variability can result from daytime melting of snow and water conveyance in soil and streams (Caine, 1992). Later, in spring through fall, diel variability can occur from direct evaporation and solar radiation in daytime causing evapotranspiration to redirect groundwater towards the soil surface until night when water in the vadose zone resumes travel downslope (Burt, 1979). Evapotranspiration can also draw directly from groundwater reservoirs in daytime for replenishment by hyporheic exchange with the stream bed and banks at night.

From these effects, a cosine-wave oscillation between higher and lower flows can result in a 24-hr period. The timing of the flow peaks and troughs vary with many factors, including a watershed's geology, steepness, channel incision, dominant vegetation, and the daily meteorology and aspect of the sun or time of year (Kefford et al., 2022). These factors in combination help promote flow and temperature diversity in rivers that can benefit the river biome. For example, peak daily water temperatures often occur when the daily low flow occurs in the heat of the day, which benefits poikilothermic species such as Foothill yellow-legged frogs and Western Pond turtles (Wheeler et al., 2014; Snover et al., 2015). The relatively warm daytime temperatures and low flows also promotes thermal stratification in deep river pools that provide cold water refuge to juvenile and adult salmon (Buxton et al., 2024). Conversely, daily high flows can help stabilize or lower temperatures by providing a larger thermal mass of water in a river. Variations in thermodynamics associated with such flow and temperature changes can enable species to exhibit periods of inactivity or intense activity, learn behavioral thermoregulation, and develop plasticity responses to environmental stressors to benefit their growth and survival (Ørsted et al., 2022).

Natural diel variations in flow are often eliminated by dams. Such elimination results on the Trinity River in Northern California from the diel variability in flow in unregulated portions of the basin upstream of Trinity Dam being captured by Trinity Reservoir (Figure 1). Discharges released from Trinity and Lewiston dams are then maintained at static levels from summer until the following spring outside of flow changes for temperature management, baseflow adjustments, tribal ceremonies, or emergency flow releases for safety of dams. To help restore benefits of flow variability downstream of Lewiston Dam, the Flow Workgroup of the Trinity River Restoration Program recommended that flow releases exhibit diel fluctuations during recessional limbs in spring hydrographs until the start of summer baseflow releases. The releases for diel variability in flow were further recommended to coincide in time with diel fluctuations on Rush Creek (Figure 1), the nearest major tributary located 4.2 river miles (RM) downstream of Lewiston Dam, and be scaled to daily average flows on local, unregulated streams (Figure 2). This report details methods for deriving these relationships and results for implementation when scheduling annual flow releases to the river.

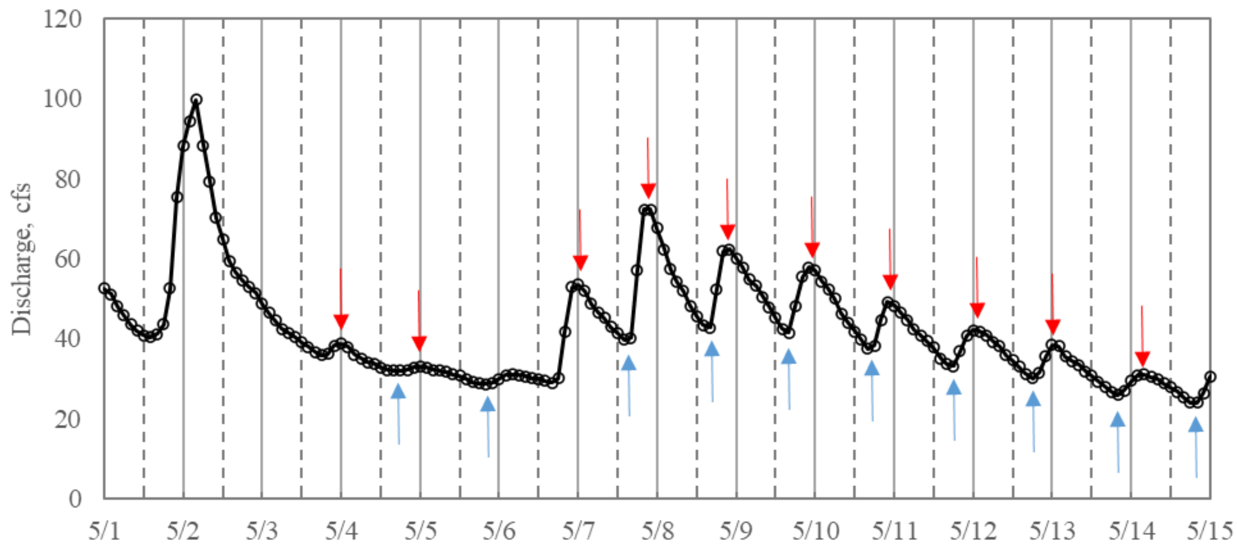

Figure 1. Two-hour record of a spring rainfall-driven flow event and recession followed by diel fluctuations in discharge on Rush Creek in WY 2007. The solid vertical lines show midnight, and the dotted lines are at noon. The red arrows show diel peaks and the blue arrows show diel troughs. Note how the diel variability mimics a cosine wave, varies in its magnitude and timing of peak and troughs, is muted during cool weather (5/4-6), and is absent when flows rapidly rise or fall (as in the case of the rainfall-driven peak shown here).

METHODS AND RESULTS

Timing of diel flow variations on Rush Creek

The title information was extracted from the 2-hr average flows taken from the 15-minute flow record for the U.S. Geologic Survey (USGS) gage on Rush Creek (number 11525530; see Figure 1). The averaging was done to make it easier to discern the diel peaks and troughs in the flow record. The Rush Creek gage is located 1,400 ft upstream of the confluence with the Trinity River and so records the timing of diel variations in the creek not long before they reach the river. Inspection of the flow records were made to determine the time of day when the diel high and low flow occurred from water year (WY) 2006 through 2018. Variation in the timing of diel highs and lows varied little between years, making data in the analysis representative of the period of record (WY 2003-2023) for Rush Creek flows.

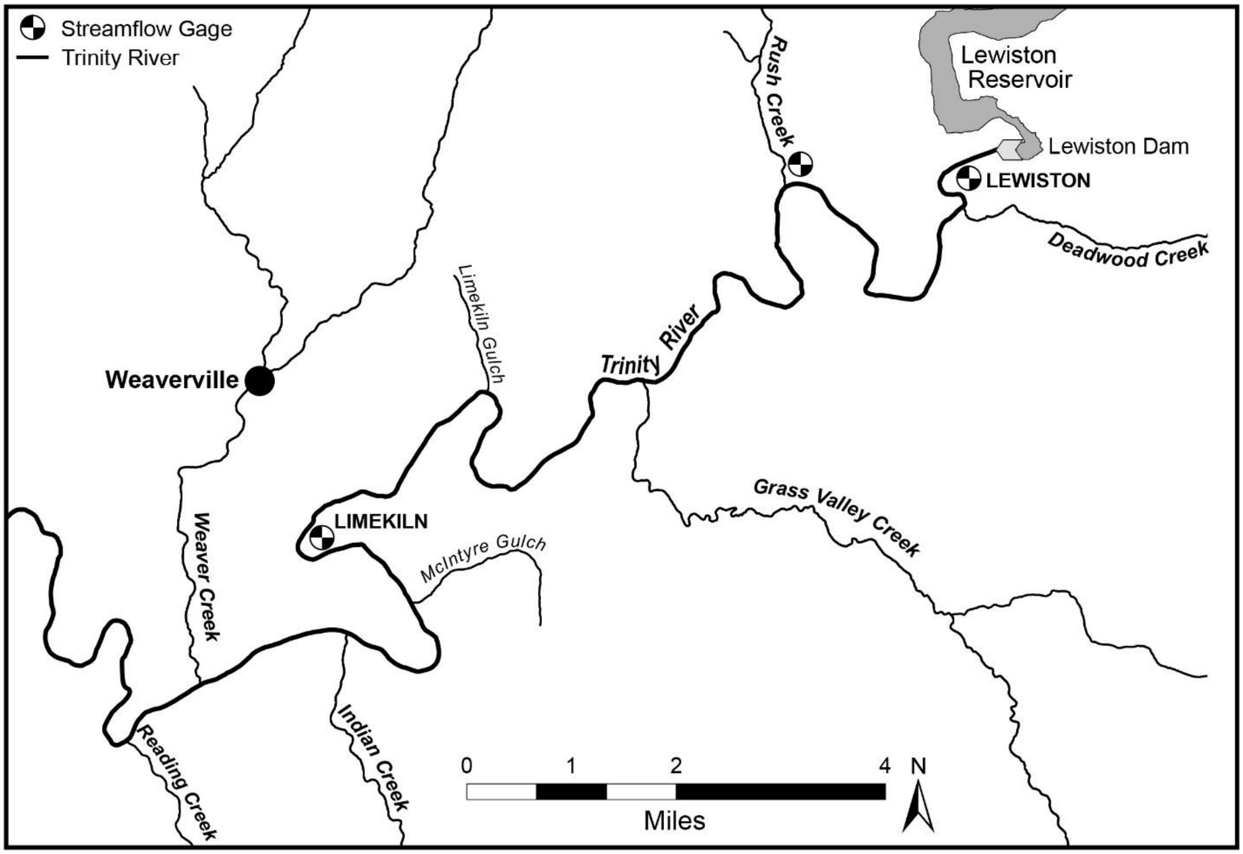

Figure 2. Location of flow gages and Rush Creek relative to Lewiston Dam on the Trinity River.

Results were summarized by water year type as defined in the Trinity River Record of Decision (ROD, 2000) for the Trinity River at Lewiston, California. A water year is the 12-month period from October 1 through September 30, which begins earlier than the calendar year so that precipitation that falls as snow and runs off in spring is included in a single period. Nomenclature for water years associates them with the calendar year in which they end. For example, November 4, 2023 and March 1, 2024 are in WY 2024. The data indicated that similar distributions of timings occurred for critically dry and dry water years (i.e., dry and drier) and normal, wet, and extremely wet water year types (i.e., normal and wetter). In dry and drier water years, diel fluctuations in discharge were observed from April 6 through August 6 and most closely followed linear trends (Table 1, Figure 3). In normal and wetter water years, diel variations were apparent from April 19 through September 30 and followed polynomial trends. The longer duration of diel fluctuations for normal and wetter water years probably reflects the larger snowpack and water volume for enabling fluctuations in snowmelt, evaporation, and evapotranspiration in these years.

Flow travel time between Lewiston Dam and Rush Creek

To release diel fluctuations in flow from Lewiston Dam so they reach Rush Creek when diel variations in creek flow are occurring there, a travel time curve between these stations is needed. The curve was developed by inspecting the 15-minute flow records from the USGS gage at Lewiston (number 11525500, 0.4 RM downstream of the dam) and the next closest downstream USGS gage at Limekiln (number 11525655, 12.8 RM downstream of the Lewiston gage) for WY

2006-2018. The analysis was done by identifying when flow changes at Lewiston arrived at Limekiln Gulch (Figure 4), dividing the duration by the distance between these locations to get flow speed, and then multiplying the flow speed by the distance between Lewiston Dam and Rush Creek to determine the travel distance as a function of daily average flow at Lewiston (Figure 5). A polynomial curve was fit to the results and used to adjust flow change schedules for Lewiston Dam to release water slightly earlier so that it reaches the Rush Creek delta when the creek's diel flows peaks or troughs are occurring there.

Table 1. Equations for the time of day of diel high and low flows on Rush Creek near Lewiston as a function of day of water year (*d*).

Water year type	Diel high flow	Diel low flow
Normal and wetter water years	[a]Time of day = $-9.17e\text{-}7d^3 + 7.77e\text{-}4d^2 - 2.12e\text{-}1d + 19.72$	[b]Time of day = $-4.83e\text{-}7d^3 + 4.15e\text{-}4d^2 - 1.14e\text{-}1d + 10.71$
Dry and drier water years	[c]Time of day = $0.0041d + 0.392$	[d]Time of day = $0.0039d + 0.041$

a) Correlation coefficient (r^2) = 0.69; b) r^2 = 0.70; c) r^2 = 0.40; d) r^2 = 0.43

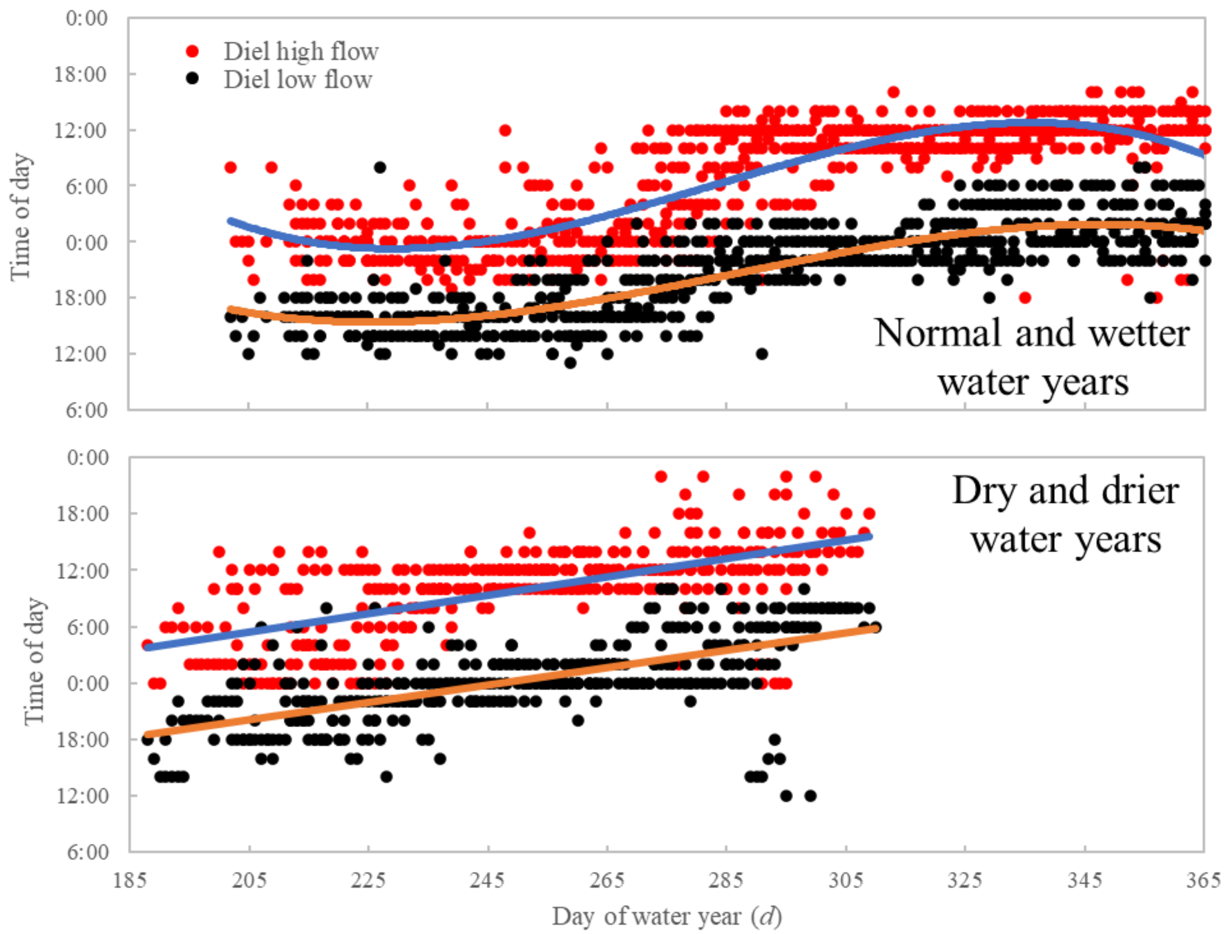

Figure 3. Time of day that diel high and low flows occurred on Rush Creek near Lewiston. The day of water year (*d*) is one on October 1 and 365 on September 30. The curves are polynomials for normal and wetter water years and linear equations for dry and drier water years (Table 1).

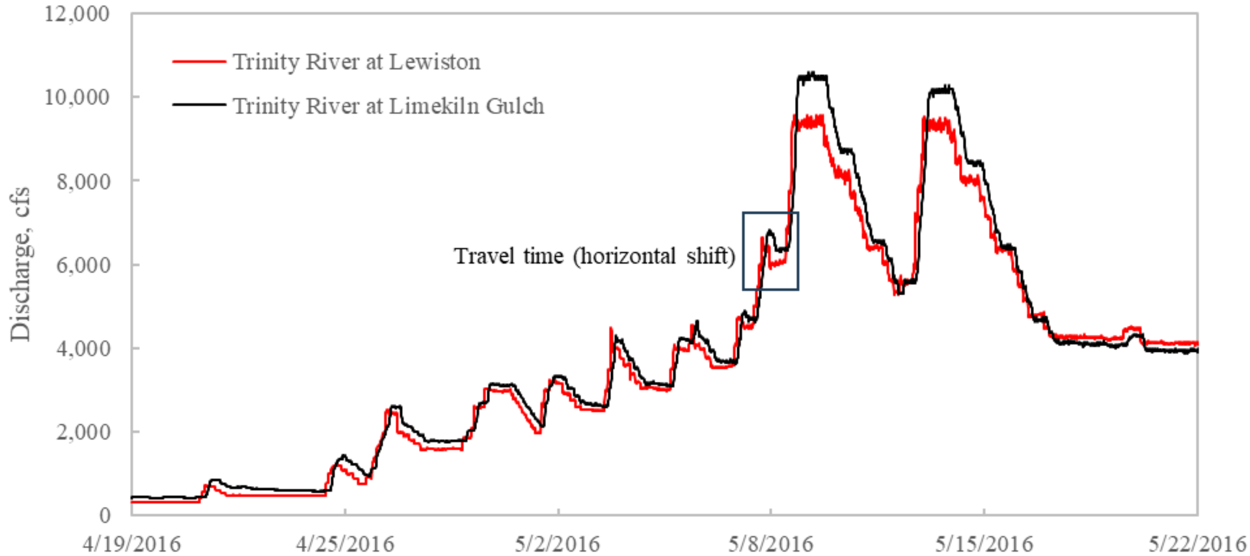

Figure 4. Example hydrographs showing the horizontal shift in time that is required for a flow change at Lewiston Dam (red line) to reach the USGS gage at Limekiln Gulch. The decrease in river flow between Lewiston and Limekiln Gulch is likely to withdraws from riparian water right holders and losses to groundwater in this reach.

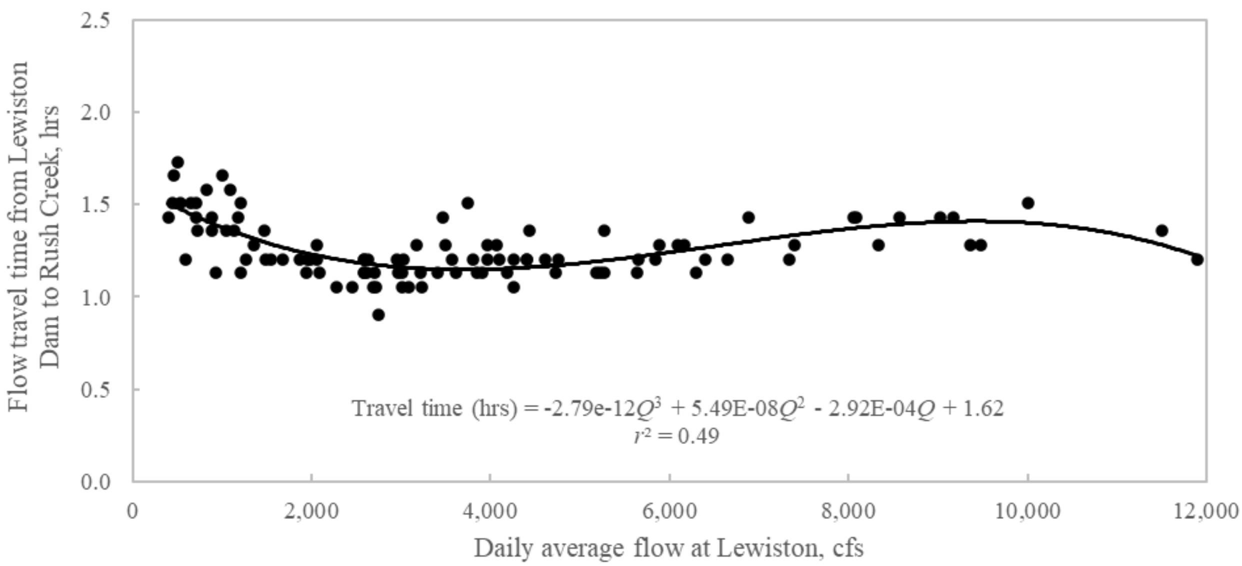

Figure 5. Time for Lewiston Dam releases of water to reach Rush Creek as a function of daily average flow at Lewiston. The travel time decreases until flows begin to enter vegetated areas and slow due to the increased roughness.

<u>Magnitude of diurnal flows</u>

The two-hour flow records for Rush Creek, Trinity River above Coffee Creek, and Salmon River at Somes Bar, California were inspected to determine ratios of diel high (λ_H) and low flows (λ_L) normalized by the daily average flow (Q) for WYs 2006-2018. The ratios are needed to set the magnitude of diurnal flows released from Lewiston Dam. The streams are unregulated and free-flowing with drainage areas of 22.3, 149, and 751 mi^2 and linear distances from Lewiston Dam of 1.5, 26, and 57 miles, respectively.

Results were comparable between the larger basins for both dry and drier water years and normal and wetter years, except the range of dates when diel flows were observable was notably shorter on the Salmon River perhaps due to the propensity of bedrock and deeply incised channels in this basin (Figures 6 and 7). Normalized diel flow magnitudes at Rush Creek most closely followed those on the Trinity River above Coffee Creek but ranged considerably wider than the other stations in all water years likely due to the sensitivity of the ratio to the comparatively lower creek than river flows. The decision was therefore made to use normalized diel flow magnitudes for the Trinity River above Coffee Creek in setting the magnitude of diurnal flow releases with variations daily average flows scheduled for release from Lewiston Dam (Table 2, Figure 8).

Table 2. Equations for diel high and low flows normalized by daily average flow on the Trinity River above Coffee Creek.

Water year type	Diel high flow	Diel low flow
Normal and wetter water years	$\lambda_H Q^{-1} = 2.769\text{e-}6d^2 - 1.979\text{e-}3d + 1.383$	$\lambda_L Q^{-1} = -2.196\text{e-}6d^2 + 1.776\text{e-}3d + 0.628$
Dry and drier water years	$\lambda_H Q^{-1} = -6.018\text{e-}6d^2 + 3.254\text{e-}3d + 0.636$	$\lambda_L Q^{-1} = 4.218\text{e-}6d^2 - 2.102\text{e-}3d + 1.197$

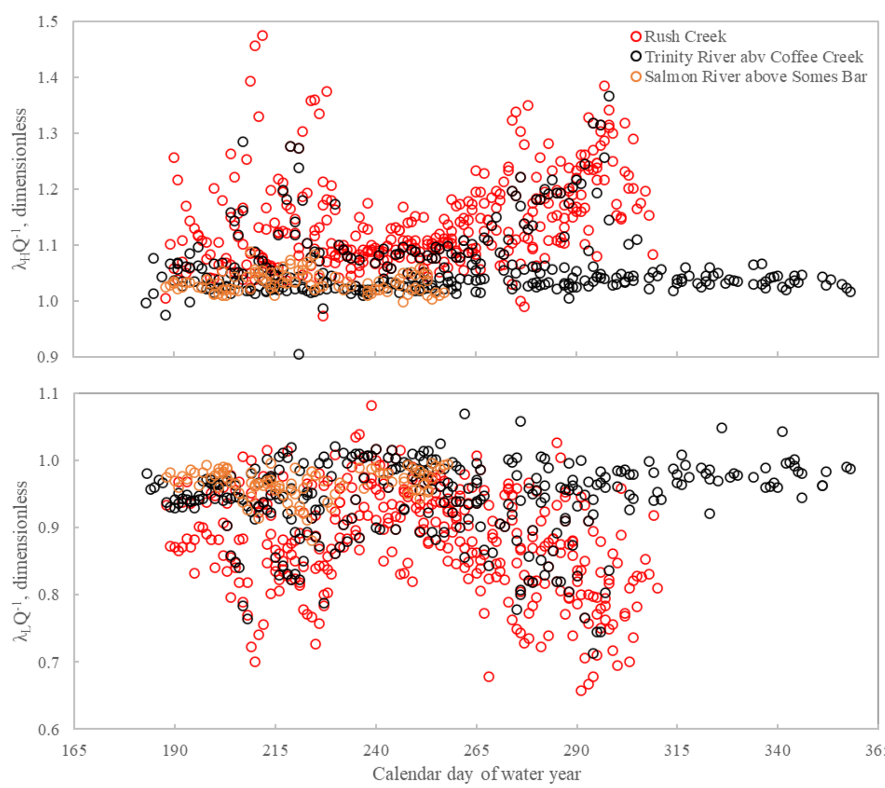

Figure 6. Ratios of the diel high (top panel) and low flow to the daily average flow on unregulated streams in dry and drier water years.

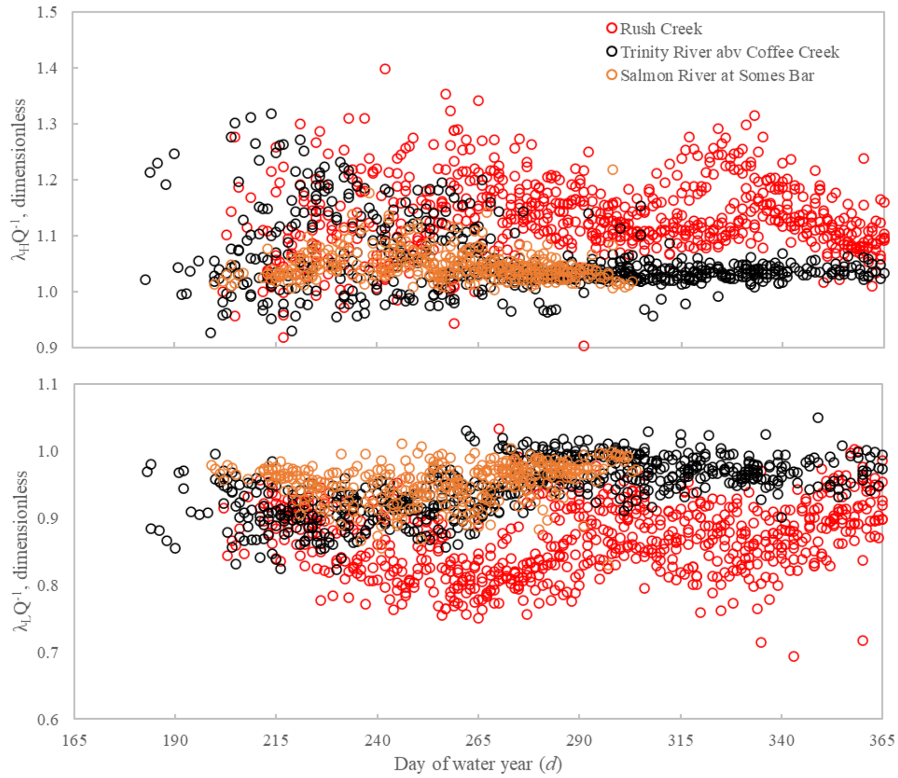

Figure 7. Ratios of the diel high (top panel) and low flow to the daily average flow on unregulated streams in normal and wetter water years.

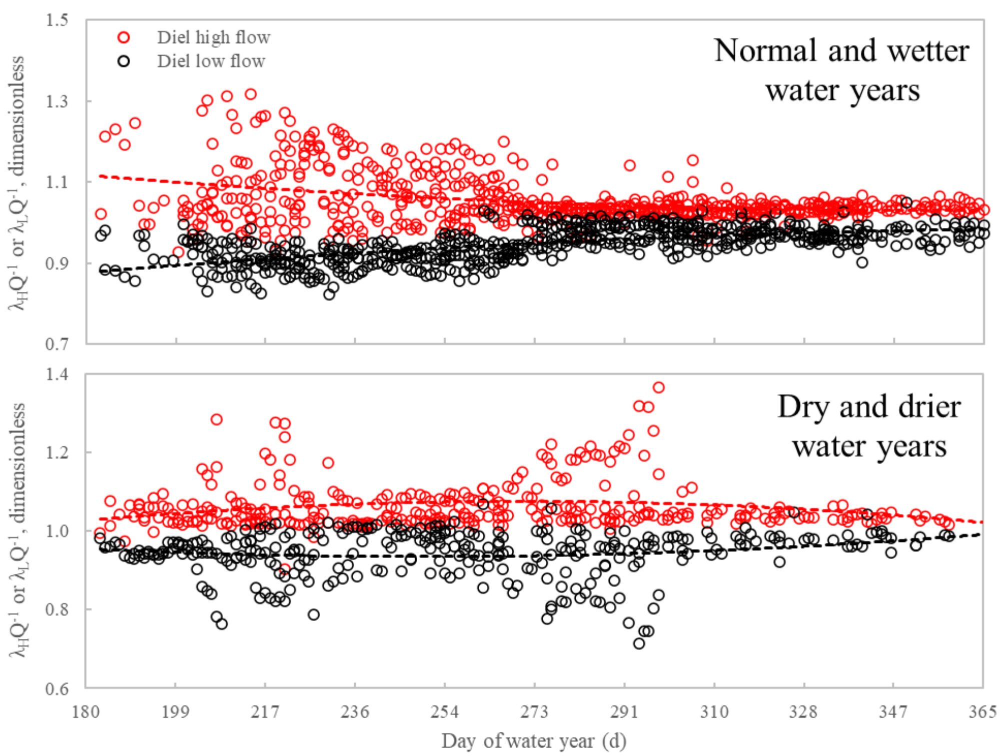

Figure 8. Diel high and low flows normalized by daily average flow on the Trinity River above Coffee Creek. The curves are polynomial equations listed in Table 2.

Application of equations for diel flow variability

An excel spreadsheet was developed for implementing the suite of arguments for scheduling diel flow releases from Lewiston Dam to:

1) Temporally coincide with diel flows on Rush Creek after taking travel time of water to the creek's delta into account;

2) Be consistent with the magnitude of diel high and low flows normalized by daily average flows on the unregulated portion of the Trinity River upstream of Trinity Reservoir near Coffee Creek; and

3) Meet operations, infrastructure, and legal constraints on the flow releases.

In recognition that flows vary somewhat smoothly as a cosine function, the change in flow between peaks and troughs was computed with $(\cos(x)+1)/2$, where $x=0$ at the diel peak and $x=\pi$ at the diel trough, with values between 0 and π in equal increments of time in 1-hr steps between these occurrences. The resulting diel flows are averaged in 2-hr increments that Central Valley Operations implements flow changes at Lewiston Dam. The schedule is next adjusted to meet infrastructure capabilities by rounding the computed discharges to the nearest 50 cfs increment, which is the accuracy that flows can be released from the dam. The resulting schedule is then manually adjusted to meet EIS ramping rate requirements for the Trinity River (USFWS, USBR, HVT, and Trinity County, 2000) before final adjustments are made to release the ROD allocation of water within the water year (USDOI ROD, 2000).

Computed diel variability in flow

The spreadsheet was used to compute diel flow variability within the guidelines of 1) through 3) for hydrographs proposed for release in WY 2019. The equations performed well in setting the diel variabilities beginning at the start of the spring flow period (4/15) and ending when summer baseflow discharges commences (Figure 9). As observed on local unregulated streams, the hydrographs lacked diel flow variability during the rising and falling limbs of flow peaks (Figure 1), increased in diurnal variability through spring, reached maximum variability around mid-June, and minimized diel variability going into summer (Figure 8). Addition examples of the performance of the methodology presented above are in Appendix A.

SUMMARY AND CLOSURE

A methodology was developed for computing diel variability in flows for daily average flow hydrographs scheduled for release from Lewiston Dam. The computed diel flows are set to temporally coincide with observed diel flow peaks and troughs on Rush Creek after adjusting the Lewiston flow releases for travel time to the Rush Creek delta. The magnitude of the diel highs and lows are defined by these observed flows on the Trinity River above Coffee Creek, which gages an unregulated portion of the basin. The arguments developed for these flow characteristics are applied using a cosine function to vary flow between the diel peaks and troughs, and the resulting flow schedules are adjusted for operations, infrastructure, and legal constraints. The methodology is shown to produce diel flow variabilities that are realistic appearing and have the same or similar functional and seasonal characteristics of diel flows observed on local unregulated streams.

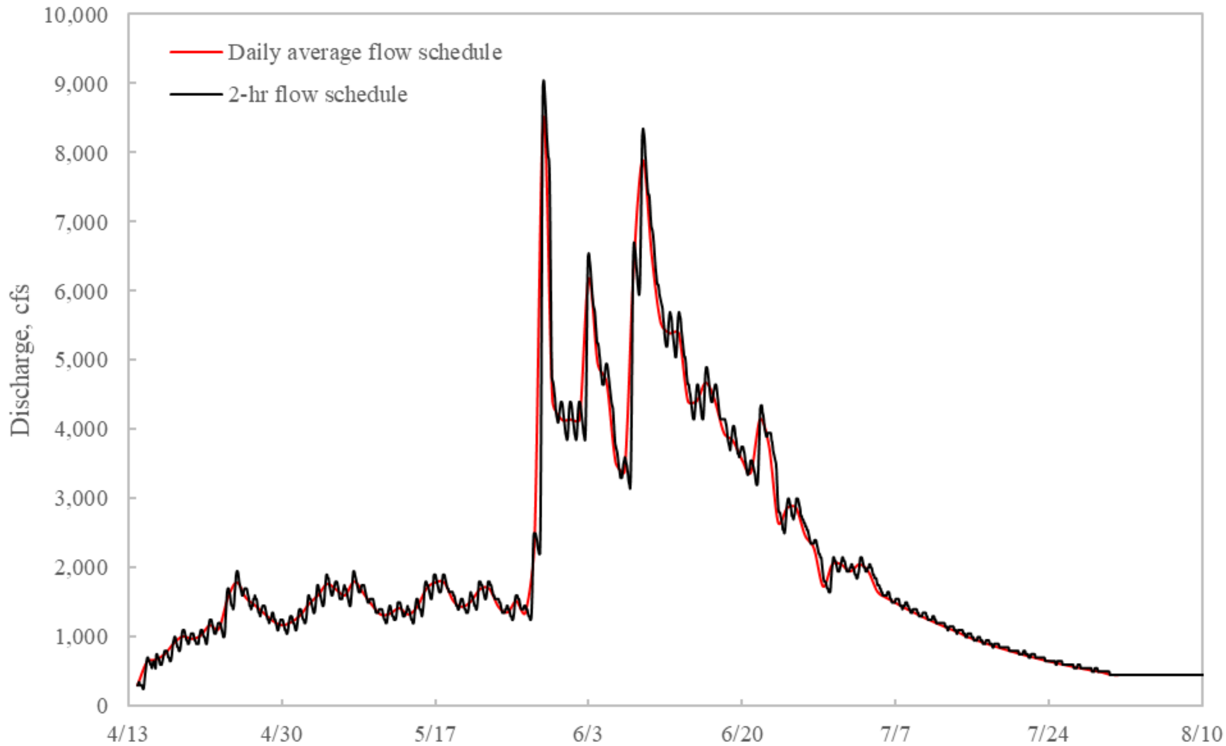

Figure 9. Hydrograph proposed for implementation in WY 2019 showing the daily average flow schedule used with the above methodology to compute a 2-hr flow schedule with diel variability.

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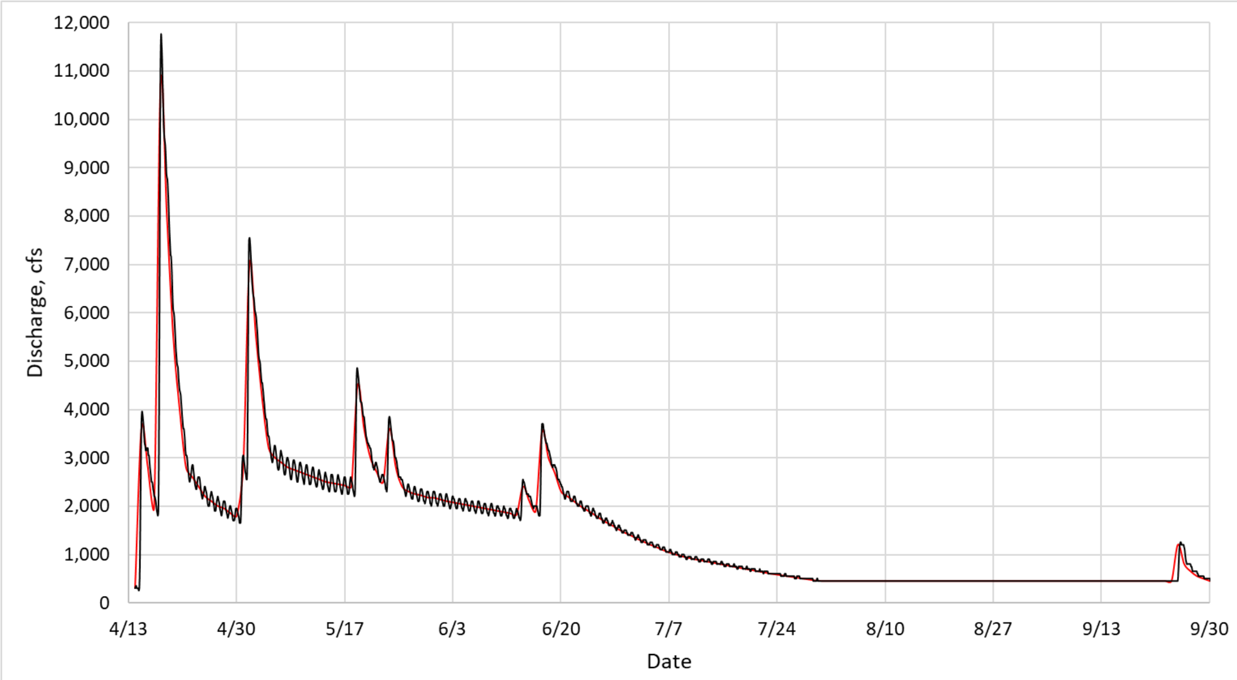
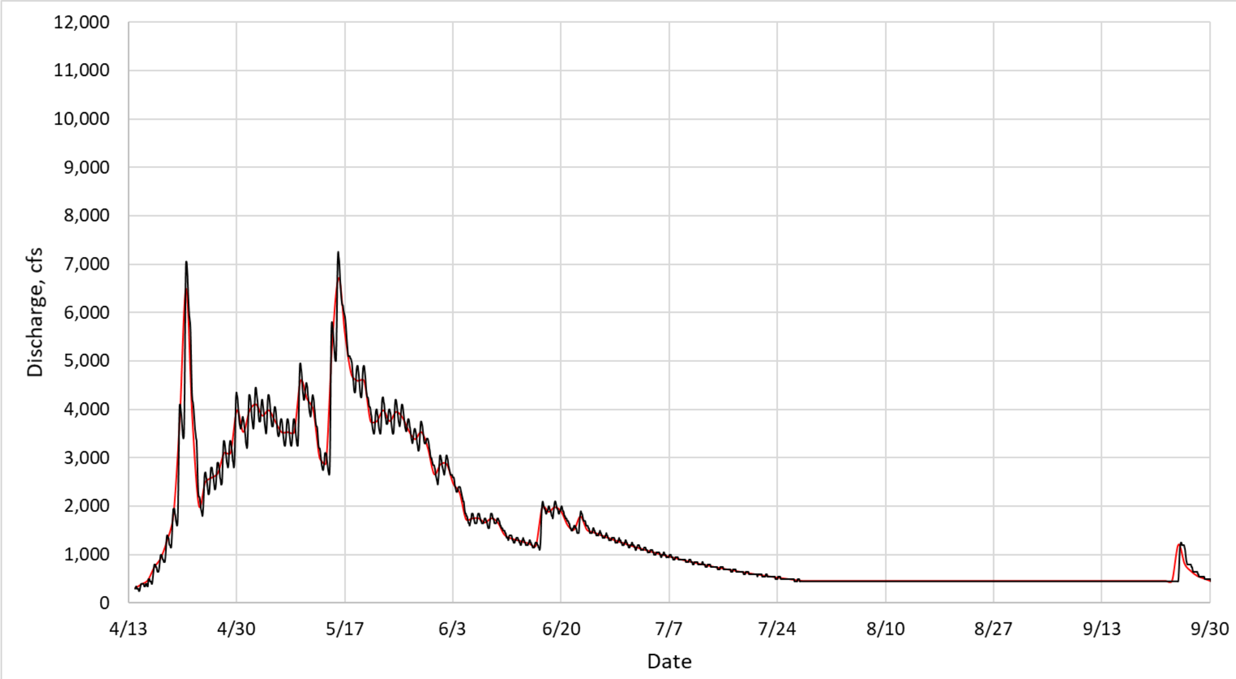
APPENDIX A



APPENDIX A (continued)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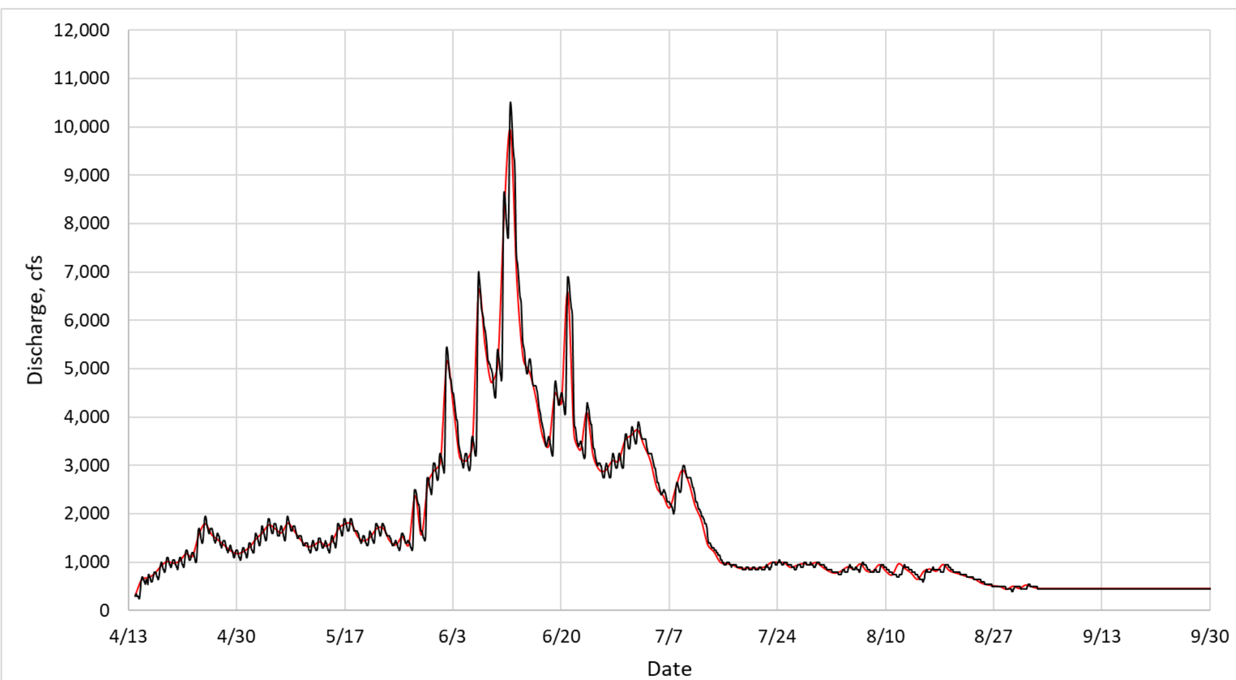
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