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Retrospective Analysis of the Relevance of Trinity River Flows to Trinity Lake (Reservoir) Levels, Water Years 1965-2021

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Filling of Trinity Lake (a reservoir), ca. 1961. Photo courtesy of the Van Metre family.

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Abstract

Water from Trinity Lake (a reservoir) flows in two directions: releases to the Trinity River and diversions to the Central Valley Project (CVP). Releases to the river are scheduled ahead of time, are publicized, and are highly visible to the public through direct observation of the river. Diversion to the CVP is done largely out of public view through tunnels to Whiskeytown Lake, where flow is not readily perceived, and diversion rates can only be found from data issued afterward. The result is a common, intuitive assumption is that the level of Trinity Lake is primarily affected by restoration releases to the river, both in terms of timing of peak volumes and in the water surface elevations experienced during recreational use. That assumption does not consider the volume of water diverted, the timing of diversions, or other factors.

This paper analyzes the timing of peaks in Trinity Lake water volume, and the fullness experienced on the 4^th^ of July, to determine the relative importance of carryover (storage) volume, inflow, diversion, and allocated release for restoration and maintenance of the Trinity River.

Results demonstrate that while the allocated release to the river is relevant to the timing of lake volume peaks and lake fullness on the 4^th^ of July, the relevance is small compared to other factors. For timing of the peak volume, inflow was of greatest relevance, followed by diversions to CVP; allocated volume for river release had weak statistical significance and carryover volume had no discernable relevance. For lake fullness on the 4^th^ of July, inflow was of greatest relevance again, followed by carryover, then diversions and finally allocated volume for the river. Diversion explained more than two times more variation than did allocation to the river.

Introduction

Trinity River Restoration Program (TRRP) schedules annual restoration flow releases that use water stored in Trinity Lake and that are often publicly perceived as 'draining the lake'. Trinity Lake is a reservoir managed by the U.S. Bureau of Reclamation (USBR) for the primary purpose of diverting water to the Central Valley Project (CVP). The reservoir began storing water in November of 1960 and achieved full operational capabilities in 1964. Through much of the first 2-3 decades of operation, water surface elevations (Figure 1) were sufficient for local economic development based on recreation on the lake, particularly during summer months. In more recent decades, water surface elevations are perceived to be lower during summer and recreation rates are perceived to have reduced. Meanwhile allocated river flows have increased and are a highly visible outlet of water from the reservoir.

Water stored in Trinity Lake is released to Lewiston Lake, where it can either be released to the river or exported through the Clear Creek Tunnels to the Judge Francis Carr Powerhouse and Whiskeytown Lake (Figure 2). From there it can go either through Whiskeytown Dam to Clear Creek and the Sacramento River, or through the Spring Creek Tunnels to Keswick Reservoir on the Sacramento River. According to USBR data, during the first 10 years of full operation (water years 1964-1973), the reservoir released a total of 13.86 million acre-feet of water, 12.32 million of which flowed through the Carr Powerhouse into Whiskeytown lake, resulting in an export rate of 89%.

Ecological problems began to develop within the Trinity River below the dams as soon as water storage began (e.g. dense vegetation encroaching on the lower banks of the river visible in aerial photography from 1965). In order to alleviate these problems, water diversion to the CVP has reduced so that releases to the river could increase. Water volumes allocated for release to the river were initially 120,500 af per year (approximately 10% of expected inflow). In 1981, U.S. Department of Interior Secretary Andrus, increased releases to the river to 340,000 af in normal or better years, 220,000 af in dry years, and 140,000 in critically dry years. With the Central Valley Project Improvement Act of 1992, congress increased releases to 340,000 af in all years. The 2000 Record of Decision (ROD) by U.S. Department of Interior Secretary Babbitt, with Hoopa Valley Tribal Council Chairman Sherman concurrence, further increased releases assigned to the river (Table 1). Implementation of ROD releases has resulted in an approximate 50/50 split (averaged over multiple years) between water released to the river versus water diverted to the CVP.

Table 1: ROD volumes.

Water Year Type	Inflow to Reservoirs (acre feet)	Restoration Allocation (acre feet)	Expected Frequency	Actual Frequency, Water Years 2001-2021
Extremely Wet	> 2,000,000	815,000	0.12	0.10
Wet	1,350,000 – 1,999,999	701,000	0.28	0.24
Normal	1,025,000 – 1,349,999	647,000	0.20	0.24
Dry	650,000 – 1,024,999	453,000	0.28	0.24
Critically Dry	< 650,000	369,000	0.12	0.19

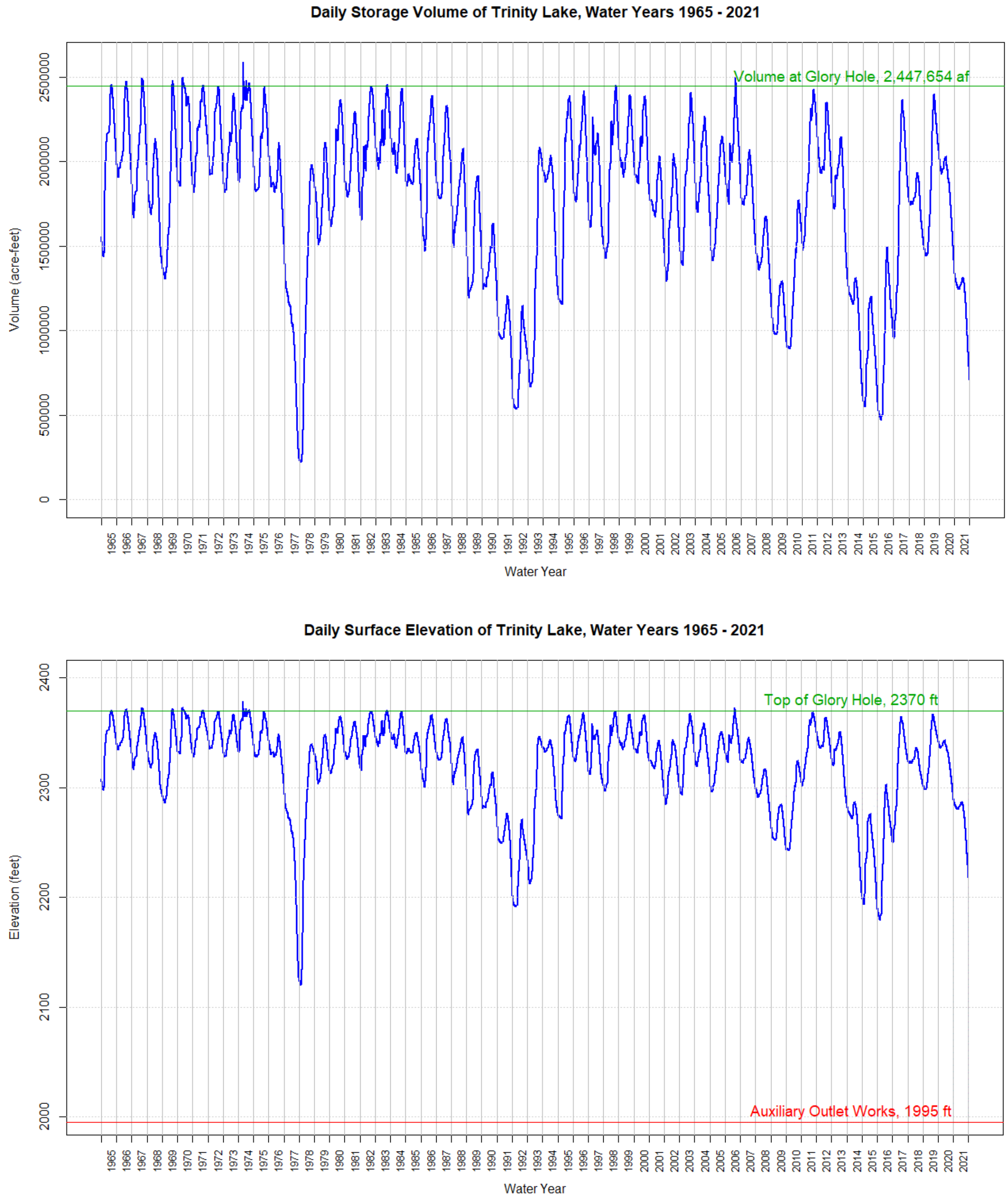

Figure 1: Trinity Lake daily storage volume and water surface elevation, water years 1965 through 2021.

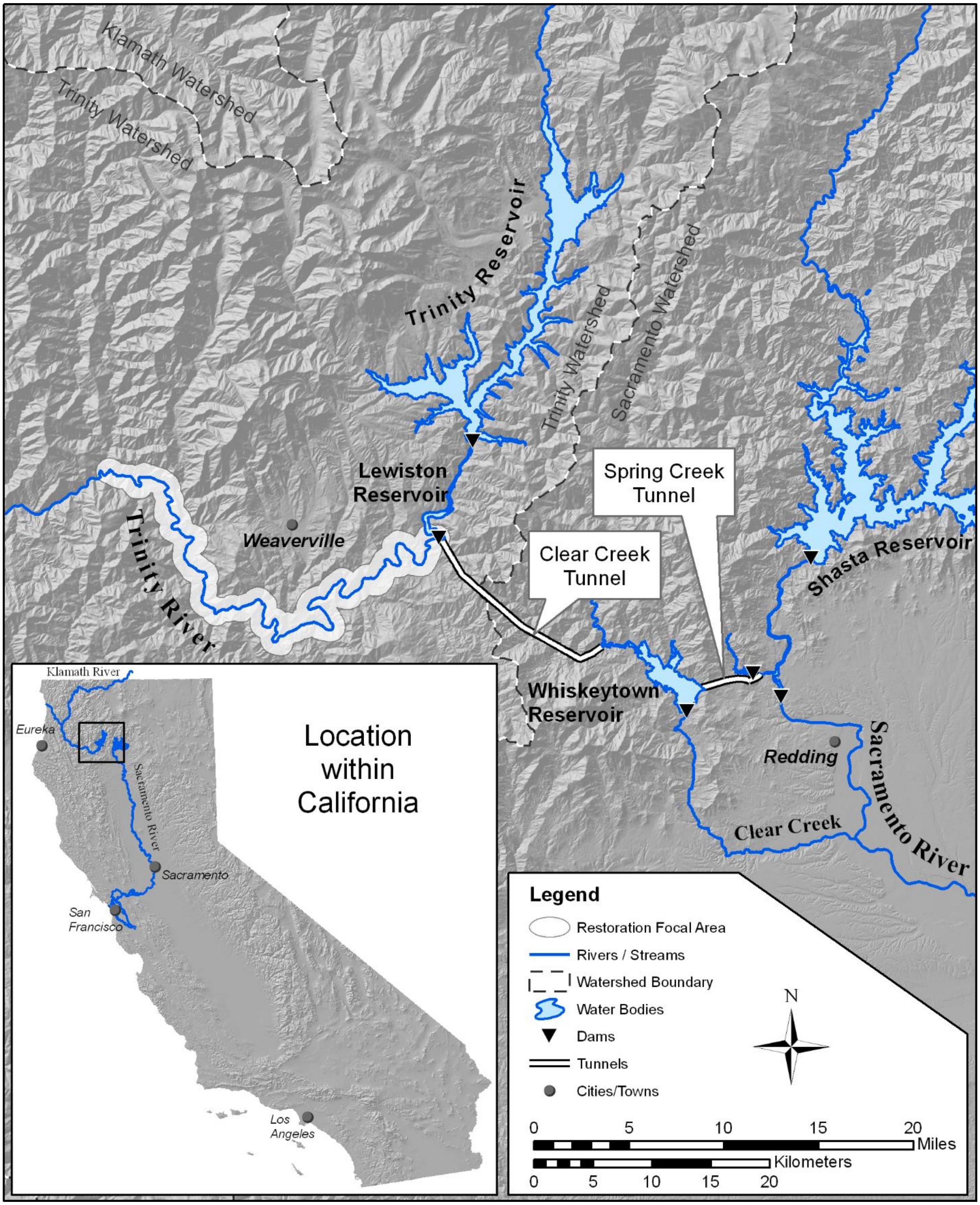

Figure 2: Map of the Trinity River Division of the Central Valley Project.

The current maximum release for river restoration of 11,000 cfs seems huge, even if it is trivial compared to pre-dam floods (e.g. 17,900 cfs at the Lewiston streamgage in Feburary, 1960, 21,200 cfs in 1959, 37,500 in 1958, and 71,600 cfs in 1955). With the increase in homes along the river, the traffic on highways near the river, and recreational fishing, the elevated releases for restoration are highly visible to the public. Meanwhile, half of the water coming into Trinity Lake continues to pass through tunnels to the CVP, visible only as Whiskeytown Lake. Whiskeytown is managed to maintain relatively constant surface elevations while water passes through, so the flow of water through the reservoir is difficult for the public to perceive. The visibility of river restoration flows, combined with knowledge that the water allocated to the river increased over the decades, has led to an intuitive assumption that restoration flows have both reduced lake levels sooner in the year, and to lower levels than before.

While producing a multi-decade graph of Trinity Lake water surface elevations on the TRRP website, I noticed that there were many years prior to the ROD when surface elevations peaked early in the year. There have also been a number of years since the ROD when the surface elevations peaked seemingly late. This led me to question that intuitive assumption of restoration flows cause earlier, lower lake levels.

Lake levels are a function of carry-over storage, inflow, and outflow. For Trinity Lake, the outflow can go to the river, be diverted to the CVP, or simply account for evaporation. For the purposes of analyzing the primary patterns of lake levels, evaporation is minimal and will be omitted. Water going to the river can include both the ROD allocation volumes (which include year-round baseflows) and special purpose flows for reservoir safety, Klamath River augmentation, and tribal ceremony. The latter three constitute much smaller volumes than ROD allocations and are intermittent, so will also be omitted from this analysis. Therefore, this analysis will cover:

$$lake\ level \sim f(carryover + inflow + diversion + river\ allocation)$$

This enables analysis of the intuitive assumption that TRRP restoration flows to the river 'drain the lake'. Relative influences of storage, inflow, diversion, and river allocation will be examined specifically for the timing of reservoir peaks, and for fullness on the 4th of July. While some statistical and technical details must be addressed, this report is written to also accommodate the general public.

Methods

Choice of analyses

Empirical statistical modeling was used to analyze patterns in past water years (1965-2021). Welch Two-Sample *t*-Tests were used to test the perceived pre-ROD versus post-ROD conditions. For these and other statistical tests, '*p*-values' represent the probability of arriving at a difference by chance. Thus, a *p*-value is a measure of uncertainty. In general, a *p*-value of 0.05 or less is accepted as strong statistical evidence and corresponds to a 5% chance that a difference is just a coincidence of randomized data (or 95% chance that the difference is real).

Linear regression was used to provide a correlative analysis of the relative weights of carryover, inflow, diversion, and river release as they have been implemented. Interpretation of the models should acknowledge that they are based on past management. USBR could change management strategy for diversion to CVP with consequences for reservoir volume (and changes are currently under consideration). Additionally, TRRP is evaluating earlier restoration releases, which could reduce need for dam safety releases, allowing for more storage of springtime inflows to the reservoir during wet years; this too could change the relative importance of inflow, diversion, and release.

The relationship between storage volumes and reservoir surface elevations does not form a straight line (Figure 3). Rather, surface elevations increase more rapidly per increase in volume when the reservoir is low and more slowly when the reservoir is high. Given that the inflow and outflow variables will all be in terms of volume, modeling will use the reservoir storage volume as the response variable, not elevation. Yet, there is a direct relationship between the two, as shown in Figure 3.

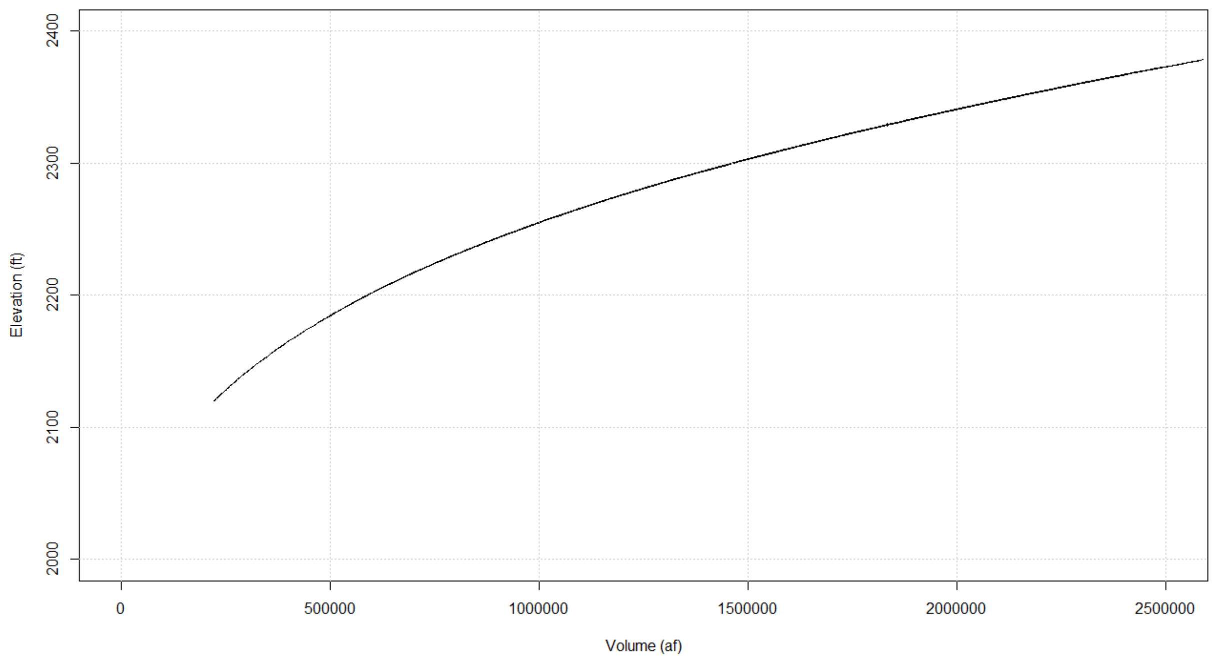

Figure 3: Relationship between Trinity Lake reservoir water surface elevation and storage volume, plotted using daily data for from water years 1965-2021.

Metrics were calculated from the output of linear regression models to determine the relative importance of storage, inflow, diversion, and river allocation. An R^2 value represents a model's ability to explain the data and can be interpreted as a proportion (or multiplied by 100 for a percent); that is, a model with an $R^2 = 0.34$ could be said to explain 34% of the variation within the data. To determine the ability of variables to explain the data, each variable can be individually removed from the model and a new R^2 calculated. The difference in the R^2 values with and without that variable (hereafter "differential variation") is the proportion of variation that the variable can explain after all other variables are considered. This is closely related to the "semi-partial correlation", but remains scaled to the total variation in the response variable[1]. If variables have overlap in the variation that they account for (collinearity), then their differential variations can sum to greater than 1.

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[1] See: https://stats.stackexchange.com/questions/60872
https://stats.stackexchange.com/questions/58734
https://en.wikipedia.org/wiki/Partial_correlation

Data

USBR maintains data for the Trinity Dam, Lewiston Dam, and exports to the CVP via the Clear Creek Tunnel and Carr Powerhouse. Daily records of inflows, outflows, and exports are available from October 1, 1963 to present. Since full operation is reported to have begun at some point in 1964, the data analyzed here begin with water year 1965 (starting October 1, 1964) and extend through water year 2021. Two response variables (aka 'dependent variables') will be analyzed:

- **PEAK (Figure 4) = day of the water year on which the reservoir volume peaked.** For years in which the maximum volume persisted for multiple days, the last day of the maximum was used. Several years reached the maximum during winter, however the public interest is toward warm-season recreational use of the lake, therefore a later peak after day 152 (March 1 or February 29 in leap years) was used. Resulting values ranged from day 152 in 1977 (March 1) to day 297 in 1978 (July 24) and are highly variable from one year to the next.
- **FOURTH (Figure 5) = storage volume on the Fourth of July.** Public interest is specifically in reservoir elevation (which relates to the bottom of boat ramps). However, to match the potential explanatory variables, which are volumetric measures, reservoir volume was used for analysis. Volume and elevation are directly tied to each other, although the relationship between elevation and volume is not exactly 1:1 (Figure 3) because the lake area narrows as elevations reduce. Reservoir volume is less variable from one year to the next than the peak timing (Figure 5).

Three USBR data variables, and one additionally constructed variable, were assessed as explanatory variables (aka 'independent variables') to explain the timing of peaks and the levels on July 4th, calculated as follows.

- **CARRYOVER (Figure 6) = Carryover storage in the reservoir.** This is USBR's Reservoir Storage data for the beginning of each water year (on October 1).
- **INFLOW (Figure 7) = Inflow to the reservoir, Trinity Lake, as of day 244 (June 1 or May 31 in leap years).** Data are from USBR. Given that interest in the peak timing and the fullness on July 4th, the total inflow over the full year may be less relevant than the volume received during winter and spring. Therefore, the volume of inflow from the beginning of the water year (October 1) through day 244 of the calendar year (June 1, or May 31 in leap years) was used. This volume was calculated by querying the data for the sum of daily inflow rates and multiplying by a conversion factor to a volume:
$$AF = \frac{60sec}{min} * \frac{60min}{hr} * \frac{24hr}{day} * \frac{1\ acre}{43560\ ft2} * \sum CFS$$
where CFS is the daily average flow rate in cubic feet per second (cfs) and AF is the total volume in acre-feet (af).
- **DIVERSION (Figure 8) = Water volume diverted to CVP via the Carr Powerhouse.** Data from USBR. Again the relevant volume is limited to winter and spring, so the volume diverted was calculated from the sum of daily diversion rates from the beginning of the water year through day-of-year 244.
- **RIVER (Figure 9) = Water volume allocated for release to the Trinity River.** USBR does not maintain a dataset of the volumes of water that have been assigned for release to the Trinity River. TRRP maintains a dataset for years beginning with water year 2001. Records for prior

years were inferred from minimum levels set by the Andrus decision in 1981 (USDI 1981) and by the Central Valley Project Improvement Act (CVPIA; Public Law 102-575, 1992). The Andrus decision stated that prior management targeted 120,500 acre feet per year for release to the river. The decision specified 3 flow volumes depending on water year type (140,000 af for critically dry, 220,000 af for dry, and 340,000 af for normal or above). The ruleset for determining water year type was not provided although the Environmental Impact Statement (EIS) on which the decision was based (USFWS 1980) stated that it used Shasta Lake inflows. The EIS Table C2-1 indicates the average anticipated inflows to Trinity Lake per water year type. The mid-points between averages for water year types were used as thresholds to reconstruct the water volumes allocated to the river from 1982 through 1991: Critically Dry = below 705,500 af; Dry = below 934,500 af; normal and above = all else. The Andrus decision mentions that flows would be 'gradually increased' to the new levels, but no attempt was made here to reconstruct this gradual increase. The news release that accompanied the decision stated that 287,000 af were provided as an interim decision for 1980, and was included for the dataset. The CVPIA specified a minimum of 340,000 acre feet in all water years starting in 1992 and continued until the ROD.

The volume allocated specifically to maintain or restore the Trinity River was used without inclusion of releases to the river for other purposes (safety of dams and reservoir management, late-summer or fall releases for the lower Klamath River, and releases to support tribal ceremonies).

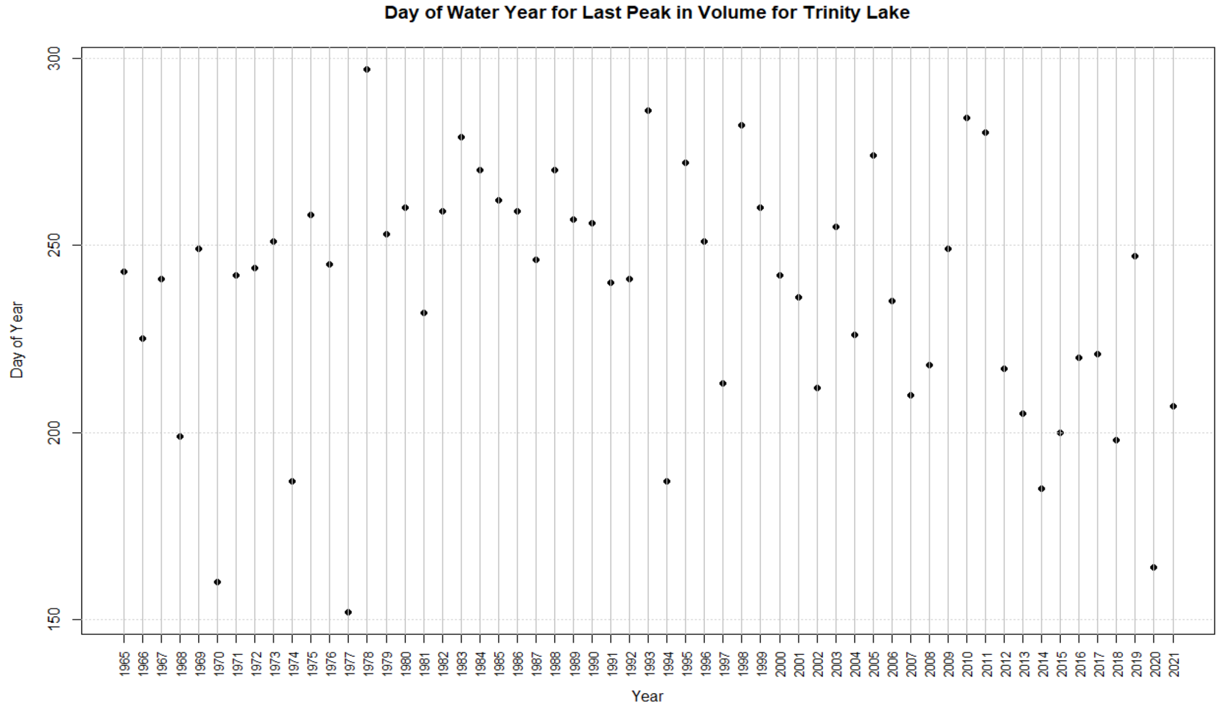

Figure 4: The PEAK response variable: day of water year (starting October 1) for the peak storage volume of Trinity Lake reservoir, water years 1965-2021.

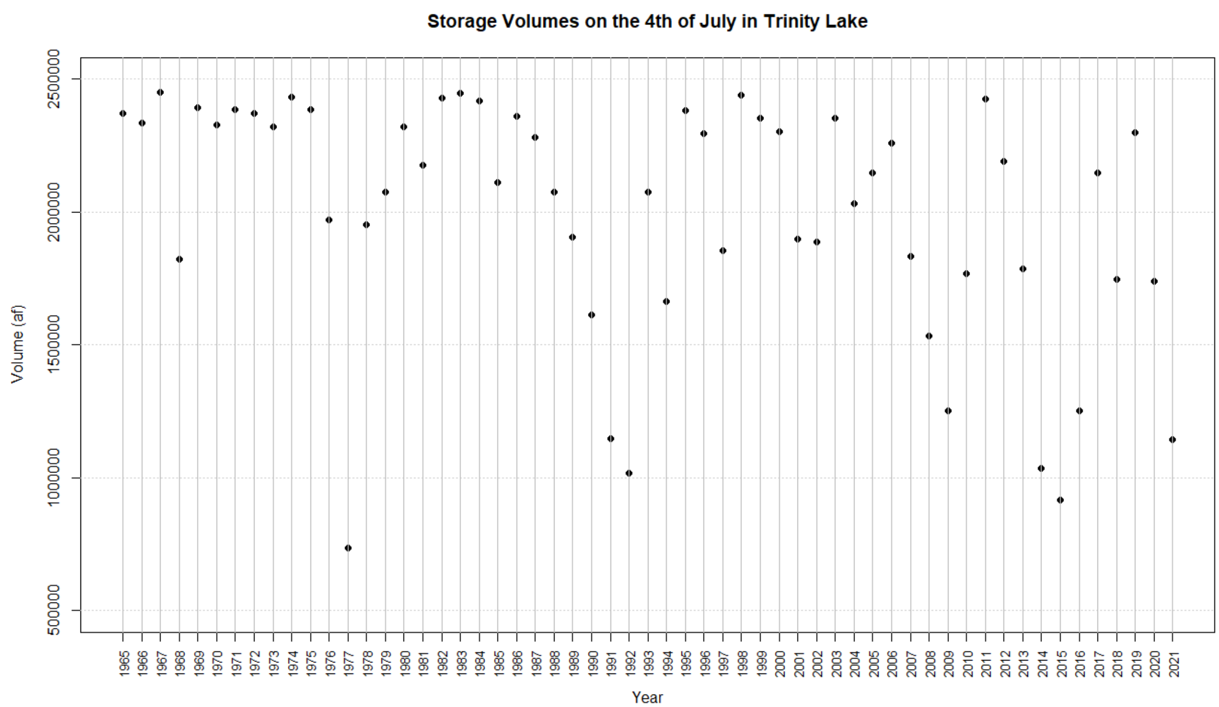

Figure 5: The FOURTH response variable: Trinity Lake reservoir storage volume (fullness) on the 4th of July, water years 1965-2021.

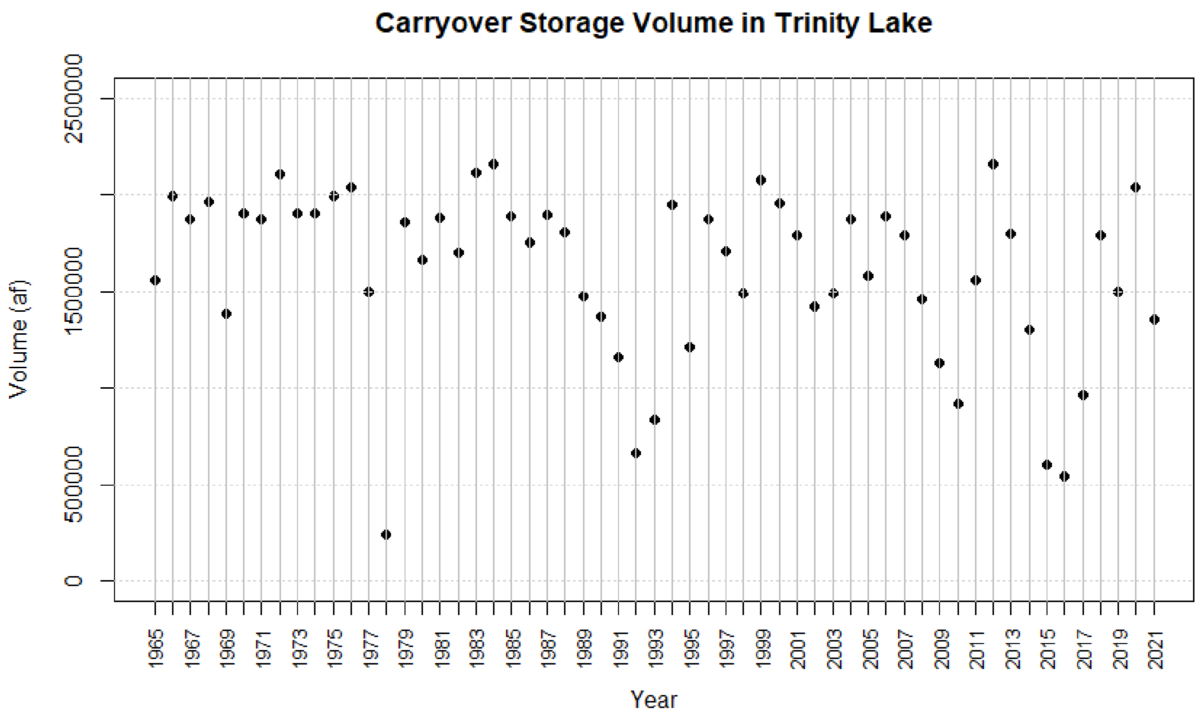

Figure 6: The CARRYOVER explanatory variable: Trinity Lake reservoir storage volume at the beginning of each water year, water years 1965-2021.

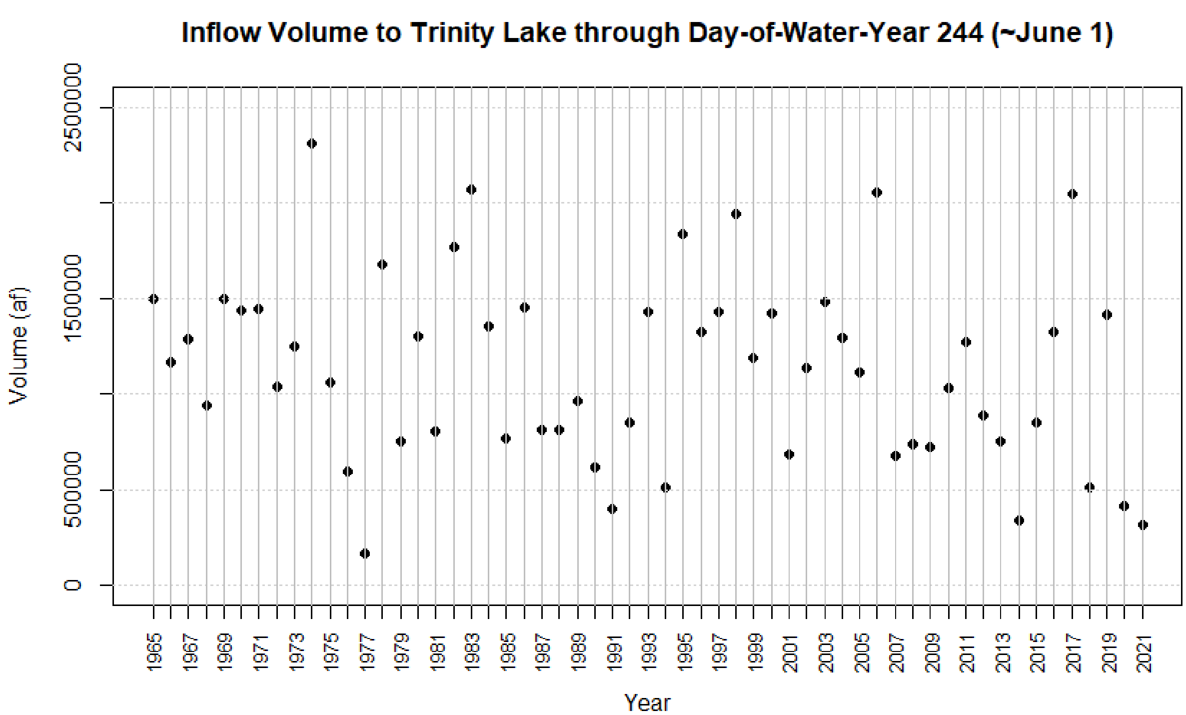

Figure 7: The INFLOW explanatory variable: Trinity Lake reservoir inflow volumes from the beginning of the water year through day 244 (June 1, or May 31 in leap years).

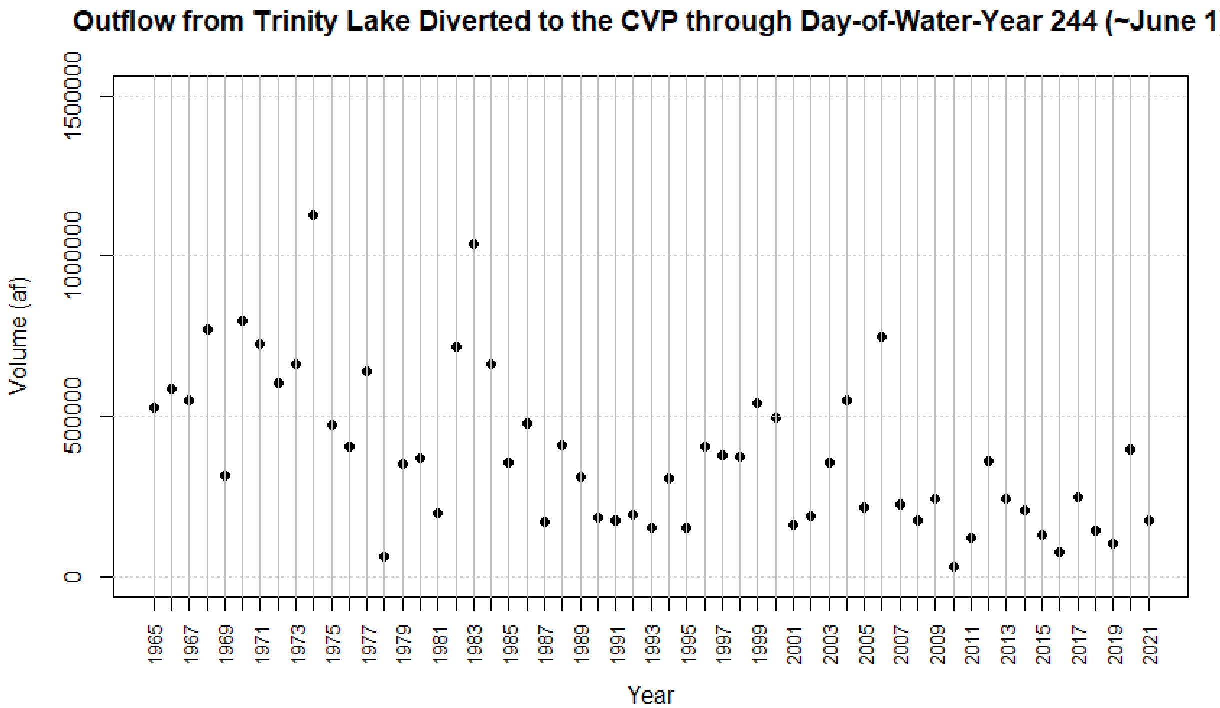

Figure 8: The DIVERSION explanatory variable: Trinity Lake reservoir outflow water volumes diverted to the Central Valley Project from the beginning of the water year through day 244 (June 1, or May 31 in leap years).

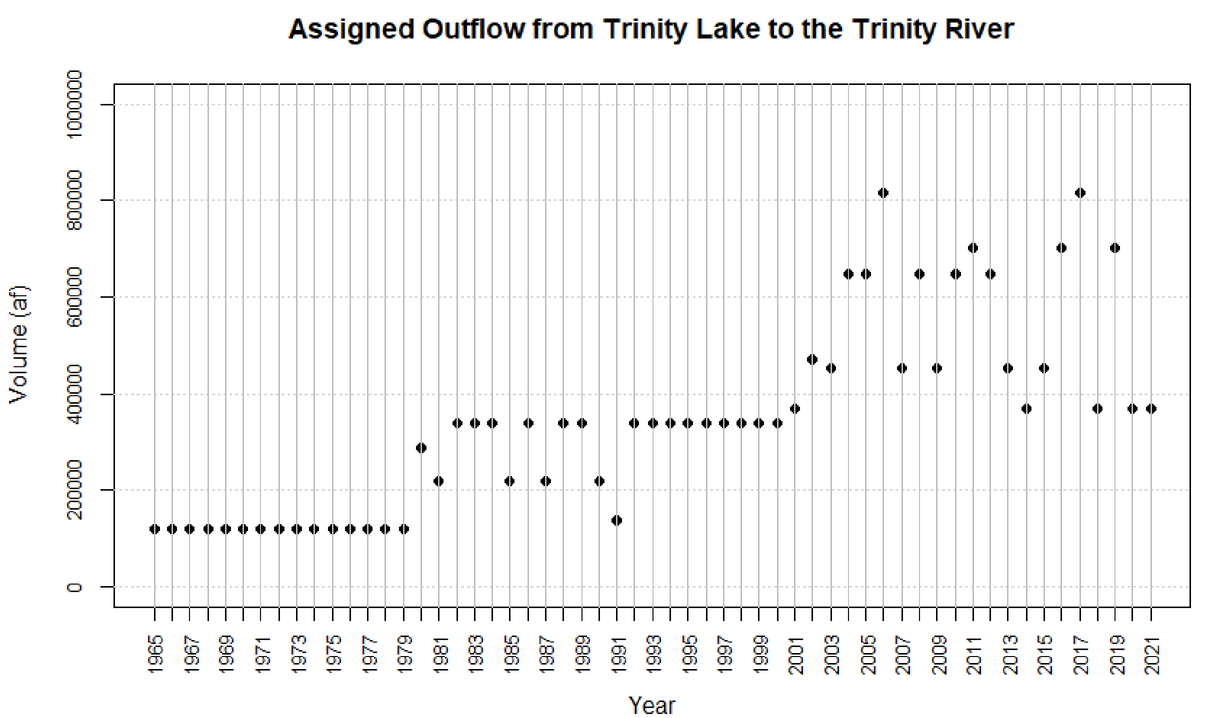

Figure 9: The RIVER explanatory variable: Trinity Lake reservoir outflow water volumes allocated for release to the Trinity River across the whole water year.

Results and Discussion

The perception that reservoir status has changed is statistically valid (Table 2): since the establishment of the ROD the lake does peak earlier (p=0.046) and is less full on the 4th of July (p=0.012). Comparing pre-ROD (1965-2000) versus post-ROD (2001-2021), the average day of year for the peak shifted 18 days earlier and the average July 4th storage volume decreased by 319,068 af. The reduction storage volumes at average lake levels corresponds to a reduction in water surface elevation of 22 feet.

Table 2: Welch Two-Sample T-Test results on differences in variables of interest between pre-ROD and post-ROD eras.

Variable	Pre-ROD Mean	Post-ROD Mean	*p*-value
PEAK	244 (June 1 or May 31 in leap years)	226 (May 14 or 13 in leap years)	0.046
FOURTH	2111494 af	1792426 af	0.012
Corresponding Surface Elevations on the 4th of July	2348.44 ft	2326.10	n/a
INFLOW	1,199,385 af	1,002,871 af	0.149

While this confirms that the time periods were different, it does not indicate why. It is also notable that inflows to Trinity Lake averaged 1,199,385 af before the ROD and 1,002,871 af since the ROD (a difference of 196,514 af). However, there is substantial variation between years such that the difference is statistically weak (p=0.149). This may allude to a shift in climate, but further analysis is beyond the scope of this report.

Before continuing into models of lake levels based on the explanatory variables, it is useful to look for correlation among these explanatory variables (collinearity). The greatest collinearity is between carry-over storage and diversion to the Central Valley (Table 3). The R^2 of 0.367 means that 36.7 % of the variation in diversions through day 244 can be explained by the carryover storage at the beginning of the water year. Therefore, models of lake levels, after accounting for one, could have difficulty detecting significance of the other[2]. Still, 63.3 % of the variation remains available for independence of the variables in the model.

Table 3: Correlation matrix (R^2) among explanatory variables.

	CARRYOVER	INFLOW	DIVERSION	RIVER
CARRYOVER	1			
INFLOW	0.001	1		
DIVERSION	0.367	0.186	1	
RIVER	0.060	0.019	0.139	1

Timing of Peak Lake Levels

Results of the regression analysis for PEAK (the timing of the peak lake level) are presented in **Error! Reference source not found.**, and for the statistically minded, partial residual plots are provided in Figure

[2] https://en.wikipedia.org/wiki/Multicollinearity

10. The R^2 value for this model is 0.365, meaning that CARRYOVER, INFLOW, DIVERSION, and RIVER explain 36.5% of the variation in timing, which seems low compared to the subsequent analysis (below). Timing is a challenging parameter to analyze when explanatory variables are summaries for years rather than patterns of inflows and outflows within the winter and spring.

Table 4: Results from regression analysis of reservoir elevation peak timing (PEAK). Beginning of year storage (CARRYOVER) was found to be not significant and thus was omitted from the reduced model. R^2 for the full model was 0.365 and 0.333 when reduced (CARRYOVER removed). Coefficients are from the reduced model. Differential variation of other variables were calculated between the reduced model (omitting CARRYOVER) and further reduced models that removed the variable in question.

Variable	Coefficient	p-value full model	p-value reduced model	Differential Variation
Intercept	229.8	<<0.001	<<0.001	n/a
CARRYOVER	n/a	0.112	n/a	0.032
INFLOW	0.0000440	<<0.001	<<0.001	0.306
DIVERSION	-0.0000727	<0.001	<0.001	0.183
RIVER	-0.0000414	0.034	0.057	0.043

The relative importance of CARRYOVER, INFLOW, DIVERSION, and RIVER is represented by the differential variation. The carryover storage was found to be not (or weakly) significant (p=0.112) for explaining the timing of the peak and its differential variation was just 0.032, meaning it could only explain 3.2 % of the variation in PEAK. This means that the CARRYOVER appears to have little relevance to the timing of the peak volume and was removed for subsequent analysis.

Among the remaining variables, differential variation was calculated by removing each individually from the reduced model without CARRYOVER. The differential variation of INFLOW (0.306) is much greater than for either DIVERSION (0.183) or RELEASE (0.043). Thus, INFLOW is much more reliable for determining the timing of the peak than either DIVERSION or RELEASE (the positive coefficient indicates that higher inflows correspond to later peaks). Indeed, the differential variation for the inflow variable was nearly equal to the R^2 for the entire model. The conclusion is that reservoir inflows have a much greater relevance to the timing of peak lake levels than do either diversion to CVP or restoration releases to the river.

The differential variation of DIVERSION is much greater than RIVER and in the reduced model, RIVER is only marginally significant (p=0.057). This means that the variation in timing of peak reservoir levels that is not accounted for by inflows, is nearly all accounted for by diversions to the CVP rather than the allocated releases to the river.

Lake Fullness on the 4th of July

Results from the regression analyses of lake storage volume on the 4th of July are presented in Table 5 and partial residual plots in Figure 11. The R^2 value for this model is 0.905, meaning that nearly all (90.5 %) variation in lake storage on the 4th of July can be explained by the CARRYOVER, INFLOW, DIVERSION, and RIVER variables.

Table 5: Results from regression analysis of reservoir storage on July 4th (FOURTH; R^2 = 0.905).

Variable	Coefficient	p-value	Differential Variation
Intercept	137100	0.198	n/a
CARRYOVER	0.9194	<<0.001	0.406
INFLOW	0.9533	<<0.001	0.606
DIVERSION	-1.266	<<0.001	0.147
RIVER	-0.6519	<<0.001	0.0596

INFLOW had the strongest differential variation, explaining 60.6 % of the variation in lake storage on the 4th of July, followed by CARRYOVER (40.6 %), then DIVERSION (14.7 %), and lastly RIVER (5.96 %). These sum to more than 100% because there is overlap in their ability to explain storage on the 4th of July, with the greatest overlap between CARRYOVER and DIVERSION (Table 3). Although RIVER only explains a small portion of variation and its coefficient is the smallest among the explanatory variables, the influence of RIVER is statistically significant (p<<0.001).

To conclude, the volumes of water allocated to the river do make a difference for lake levels on the 4th of July, but their affects are small compared to carryover storage, inflows, and diversions to CVP. Diversions are more than twice as capable of explaining the storage in Trinity Lake on the 4th of July, than the volume allocated to the river.

Further Questioning

Over time, the ratio of water diversions has shifted from nearly 90% of water going to the Central Valley during the first decade of full dam operations, to approximately 50% at present. So one might ask if the reason for diversions explaining more of the variation in lake levels is simply due to the analysis spanning that shift in water allocation. To answer this question, one more regression analysis was performed with data only since the ROD was established, starting with water year 2001 (Table 6). This analysis examines the affect of water year type for ROD allocation to the river, on lake storage volumes. Focusing just on post-ROD data shows even weaker relevance of RIVER for explaining variations in storage on the 4th of July with only 0.35 % of variation explained and no statistical significance (p=0.341). In other words, the water year type determined under the ROD has no discernable relevance to lake storage on the 4th of July.

Table 6: Results from regression analysis of reservoir storage on July 4th (FOURTH) for water years beginning 2001 (R^2 = 0.942). This analysis is nearly identical to that presented in Table 5, except that it is limited to post-ROD water years. RIVER was retained in this model, despite a lack of statistical significance, for comparing differential variation to the model in Table 5.

Variable	Coefficient	p-value	Differential Variation
Intercept	-167800	0.303	n/a
CARRYOVER	1.039	<<0.01	0.551
INFLOW	0.986	<<0.01	0.277
DIVERSION	-1.581	<<0.01	0.155
RIVER	-0.3156	0.341	0.0035

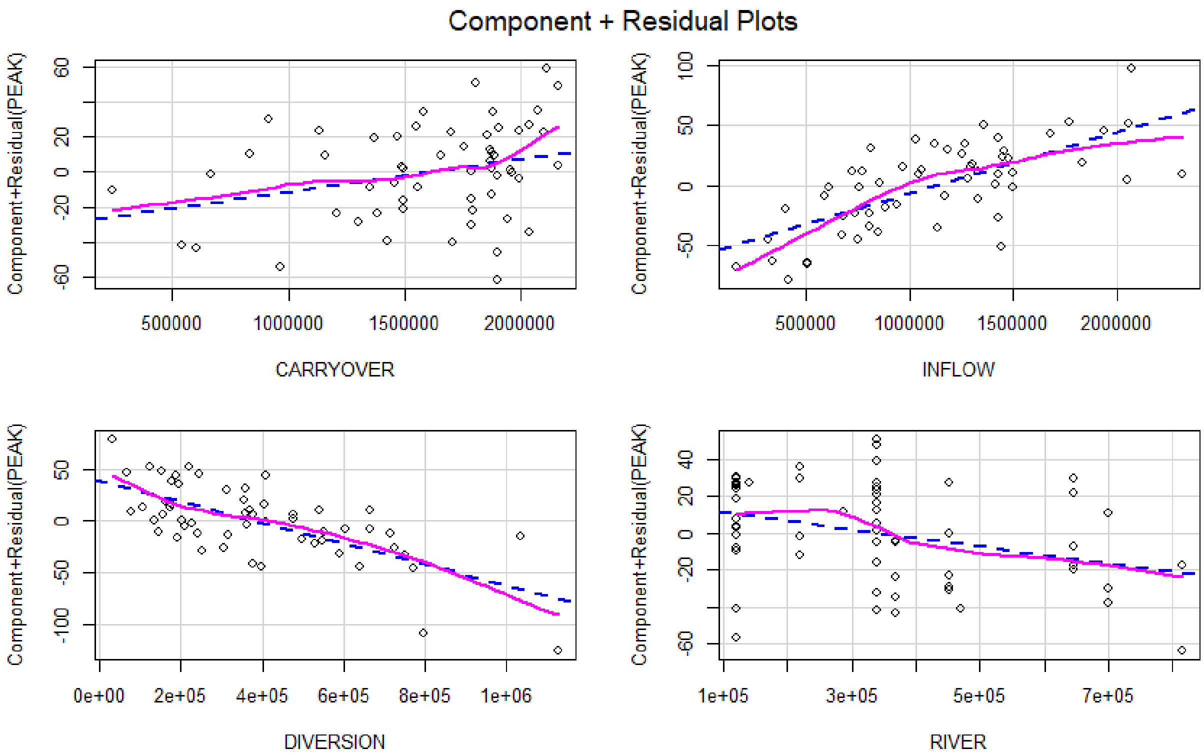

Figure 10: Component (partial) residual plots for the regression model of timing of peak reservoir elevation.

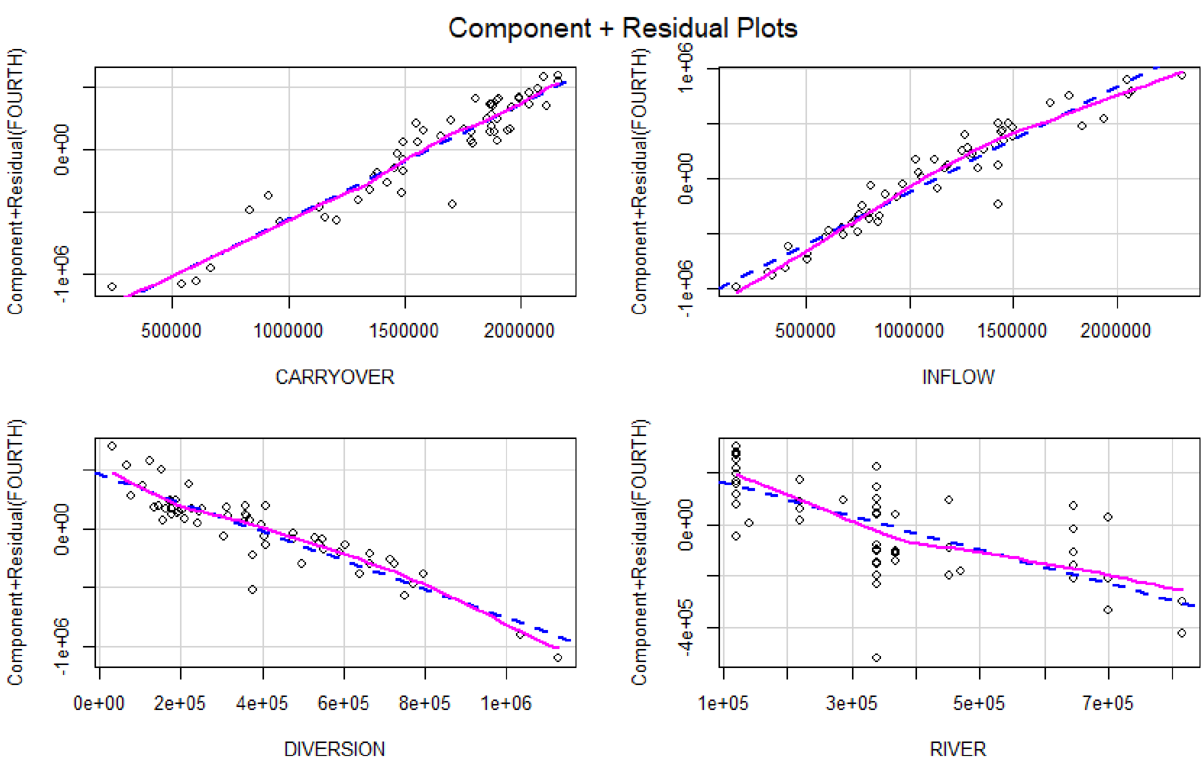

Figure 11: Component (partial) residual plots for the regression model of Trinity Lake reservoir storage on the fourth of July.

So if an acre-foot is an acre-foot, why are DIVERSION and RIVER not equally explanatory? The answer lies in the pattern of each across the range of inflow volumes experienced by Trinity Lake. A comparison is illustrated in Figure 12. Volumes allocated for release to river (blue dots) are dependent on April 1st estimates of reservoir inflows (per the ROD) which have been fairly accurate, thus the pattern for river volumes in Figure 12 increases with total inflow (R^2 = 0.701). The volumes diverted to the CVP (red triangles) have no such dependency. Indeed, the reservoir was intended to store water from wet years to be provided for agriculture in the Central Valley in dry years. Therefore, large volumes of water are often diverted in dry years and Figure 12 shows little relationship between volumes diverted and inflows (R^2 = 0.065).

Conclusion

River releases are only vaguely relevant to the timing of reservoir peaks. Releases are relevant to fullness on the 4th of July, but not to the degree generally perceived. The diversion of water to the CVP is more than twice as relevant to lake levels, but is out-of-sight, out-of-mind. Carry-over storage and inflows are much more important for affecting 4th of July lake levels than outflow in either direction.

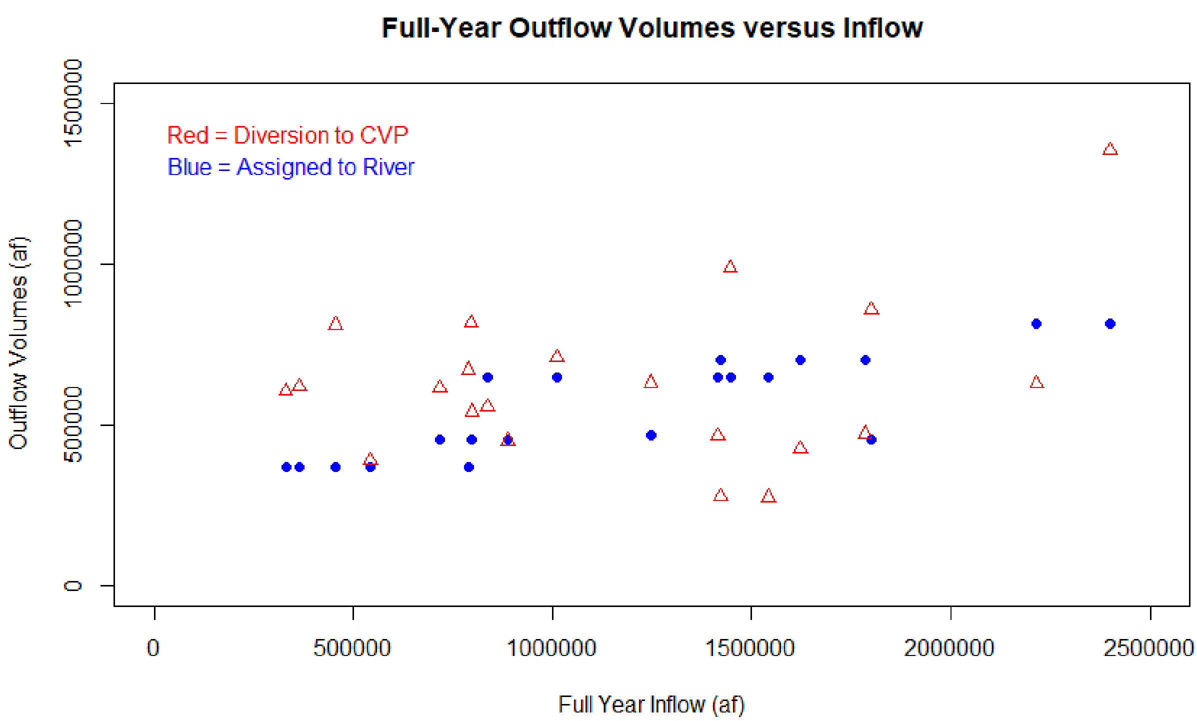

Figure 12: Comparison of ROD-era patters for diversion to CVP, and for allocated release to river, across Trinity Lake reservoir inflows (water years 2001-2021. Red triangles represent full-year volumes diverted to CVP. Blue dots represent the full-year release allocated to the Trinity River.

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