Appendix H1a1

Assessment of Effect of Reservoir Storage on Reservoir Release Temperatures

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Appendix H1a1
Assessment of Effect of Reservoir Storage on Reservoir Release Temperatures

H1a1.1 Introduction

This appendix describes the use of historical data to evaluate the effect of reservoir storage on release temperatures. This assessment informed Sacramento Water Allocation Model (SacWAM) carryover (end-of-September) storage target assumptions and carryover storage ranges in the December 2025 revised draft Bay-Delta Plan. It includes an evaluation of Black Butte, Folsom, New Bullards Bar, Oroville, New Hogan, Camp Far West, Whiskeytown, and Camanche Reservoirs and Lake Berryessa. The evaluation is based mostly on measured data and pertinent literature. Shasta Reservoir is evaluated in a cursory manner here because the carryover storage ranges for this reservoir rely on specific targets that have been identified for other regulatory purposes. These reservoirs are potentially subject to the cold water habitat objective under the regulatory pathway.

Carryover storage is a useful indicator of the volume of cold water available throughout the critical temperature season of summer through early fall. The purpose of the carryover storage target ranges is to ensure that some accessible cold water remains at the bottom of each reservoir going into the fall to provide for maintenance of adequate temperatures for cold-water fish species of concern through the fall, as well as minimum supplies for health and safety needs and other purposes. Table H1a1-1 lists carryover storage target ranges specified in the December 2025 revised draft Bay-Delta Plan and the fish of concern downstream of each reservoir. The upper ends of the carryover ranges are not an upper limit on what is allowed, but instead are the upper end of what is needed to meet the purpose stated above.

This appendix is similar to Appendix A1c, *Preliminary Assessment of Effect of Reservoir Storage on Reservoir Release Temperatures*, except it incorporates additional data, reservoirs, and discussion. Neither Appendix A1c nor this appendix focuses solely on evaluating the carryover storage volumes that would best protect anadromous fish present in the fall. Appendix A1c provided some initial consideration beyond the relationship between carryover storage and release temperature. For example, full attainment of ideal temperatures for fall fish was considered infeasible in Black Butte and Folsom Reservoirs due to warm release temperatures and the small size of these reservoirs compared to the demand for summer releases for water supply purposes and to protect anadromous fish present in the summer. Similarly, this appendix not only considers the needs of anadromous fish present in the fall, but also other additional factors, such as water supply reliability, variable hydrologic conditions, temperature and flow needs of fish that are present in the summer, location of fish that are present in the fall, and feasibility of providing protection for different species and life stages of fish. Consideration of these factors has informed the proposed ranges for carryover requirements for drought and non-drought years included in the December 2025 revised draft Bay-Delta Plan. Carryover storage ranges for the regulatory pathway may change further based on long-term temperature management strategies to be developed for reservoirs as part of full implementation of the cold water habitat objective.

From mid-spring through mid-fall, deep reservoirs typically have a warm surface layer, cool bottom layer, and a transition zone, or thermocline, in between. The *cold water pool* is defined here as the cool bottom layer with relatively uniform low temperatures. As water is withdrawn from deep in the reservoir, the surface mixed volume and the thermocline drop lower into the reservoir. When this happens, the thermocline "stretches" to extend deeper into the reservoir. The stretching occurs because the top of a reservoir occupies more area and volume than the bottom of a reservoir. When the reservoir is full, the warm surface layer occupies a relatively large surface area and volume. When water is withdrawn from near the bottom of a reservoir, the large warm surface volume is pulled deeper as it is squeezed into a zone with smaller cross-sectional area. Shallow reservoirs that lack a cold water pool usually still have a temperature gradient, with cooler temperatures deeper in the reservoir. The cold water pool is depleted when the bottom of the thermocline reaches the dam intake elevation. The storage levels for attaining temperature indicators for fish are influenced by the size and shape of the reservoir (steep-walled and deep versus shallow), temperature and volume of reservoir inflow, elevation of the reservoir dam intakes, operation of temperature control structures, and volume of water released from the reservoir during the year.

Reservoir operations that result in low storage in late summer and fall months can cause release temperatures to become too warm for cold water fish. This is typically a concern during August through October, when low storage may occur at the same time as warm meteorological conditions. November release temperatures can also be a concern, but cooler meteorological conditions in November can limit the warming effect of low storage on reservoir release temperatures and limit warming as water flows downstream from reservoirs.

Each reservoir has a slightly different elevation-volume relationship and dam intake elevation configuration that influences the minimum carryover storage that provides adequate cold water release. The reservoirs described here have variable levels of infrastructure for controlling release temperature based on the elevation where water is withdrawn. All these reservoirs have at least one dam intake that is generally well below the water surface. In some cases, cool water near the bottom of the reservoir can be preserved by withdrawing water near the surface of the reservoir when the temperature of the surface water will not harm fish.

If water levels are too low or water temperatures are too high, hydropower facilities may be bypassed, and water may be released from a deep, bottom outlet. However, the volume of water at the bottom of most reservoirs between the river outlet and the lowest power penstock is usually relatively small, so switching from using a hydropower penstock intake to a lower, bottom outlet may only provide a limited amount of additional cold water.

Meeting carryover targets does not necessarily indicate ability to fully meet cold water habitat objectives. The effect of reservoir storage on reservoir release temperatures is just one factor that affects water temperature in regulated streams. Volume of water released, selection of dam intake elevation, and meteorology are other key factors that affect water temperature.

Temperature in a river is affected by both reservoir release temperatures and flow, with reservoir release temperatures being more important farther upstream than downstream. Commonly, it is most important for anadromous fish to have adequate temperatures in the most upstream accessible portion of a stream because this is where temperatures will be coolest and spawning habitat will be most suitable. In this portion of a river, reservoir release temperature may have more effect on temperature than flow due to minimal travel time for meteorological conditions to affect temperature. Because anadromous fish habitat extends downstream from the rim dams, reservoir release temperatures would ideally be cooler than the fish requirements because, during warmer times of the year, water temperature will increase as water moves downstream. Cool release temperatures combined with sufficient flow to prevent excessive meteorological warming is necessary for managing water temperatures for fish. Flow has additional benefits beyond helping carry cool temperatures downstream (e.g., suitable conditions for upstream and downstream migration of fish). For this reason, there is a delicate balance between the use of water for instream flows, diversion, and carryover storage. This analysis focuses on reservoir storage.

Ultimately, management of cold water habitat must be based on further analysis that considers times of year that various life stages of anadromous fish are present, locations in the river that are utilized by anadromous fish, and the flow required to maintain suitable water temperatures far enough downstream to protect sensitive life stages from adverse temperature effects. The flow needed to meet fish water temperature indicators depends on reservoir release temperature, channel geometry, meteorology, and shade. Actual reservoir protocols needed to meet the cold water habitat objective of the regulatory pathway would be developed through additional analysis and planning that would be performed in coordination with the Delta inflow objective. The additional planning would include consideration of the effect of changes in storage patterns, the effect of flow on temperatures downstream of reservoirs, and potential effectiveness of other possible actions. The results of these additional analyses would be described in long-term temperature management strategies and annual operations plans that would be implemented to meet the cold water habitat objective.

Table H1a1-1. Carryover (End-of-September) Storage Target Ranges[1] (TAF) and Cold Water Fish of Concern

Reservoir (with Capacity)	Drought Years[2]	Non-Drought Years	Cold Water Fish of Concern Present Downstream of Dam
Shasta (4,552 TAF)	1,500 – 2,000	>2,000 – 3,000	• All runs of Chinook[a] • Steelhead[a] • Green sturgeon[b] • White sturgeon[c, d]
Whiskeytown[3] (241 TAF)	200 - 210	>210 - 240	• Steelhead[e] • Fall-run Chinook[f] • Late fall-run Chinook (intermittent)[f,g] • Spring-run Chinook[f]
Oroville (3,538 TAF)[b]	1,000 - 1,200	>1,200 - 1,600	• Spring-run and fall-run Chinook[h] • Steelhead[h] • White sturgeon[d] • Green sturgeon[h]
New Bullards Bar (960 TAF)	400 - 600	400 - 600	• Steelhead[a] • Fall-run and spring-run Chinook[a] • White sturgeon[d] • Green sturgeon[b]
Camp Far West (105 TAF)	10 - 20	>20 - 50	• Steelhead (intermittent)[a] • Fall-run Chinook (intermittent)[i] • White sturgeon[d]
Folsom (976 TAF)	300 - 400	>400 - 500	• Fall-run Chinook[j] • Steelhead[a]
Pardee[4] (204 TAF)	100 - 160	>160 - 180	See Camanche
Camanche[4] (417 TAF)	150 - 200	>200 - 250	• Fall-run Chinook[k] • Steelhead[a]
New Hogan (317 TAF)	50	>50 - 100	• Steelhead (intermittent)[j] • Fall-run Chinook (intermittent)[l]
Berryessa (1,602 TAF)	500 - 700	>700 – 1,000	• Rainbow trout (in inter-dam reach)[m] • Small numbers of fall-run Chinook[n]

TAF = thousand acre-feet
[1] These ranges are designed to prevent reservoir depletion for multiple purposes (health and safety, meeting other minimum flows, etc.) and provide some level of protection for cold water habitat in the fall. In most cases, at the low end of the ranges, additional actions would likely be needed to protect cold water habitat.
[2] Drought is defined as two or more consecutive dry or critically dry water years or years in which there is proclamation of drought in the applicable watershed issued by the governor of California. Under the most extreme drought circumstances, lower carryover storage levels could also apply on a temporary one-year basis as approved by the Executive Director.
[3] As part of Reclamation's development of a long-term temperature management strategy, Reclamation may propose for the Board's approval that Whiskeytown Reservoir does not require carryover storage levels or levels within this range to maintain temperature management on Clear Creek, while avoiding redirected impacts to the Trinity River.
[4] Pardee and Camanche Reservoirs are operated jointly to manage temperature in the Mokelumne River. As such, the storage target ranges may be evaluated on the basis of the total storage of both reservoirs, and the operations of both reservoirs should be addressed in the same temperature management strategy.
Sources:
[a] ^NMFS 2014a Recovery Plan,
[b] ^NMFS 2021 Five Year Review
[c] ^Klimley et al. 2015
[d] CDFW 2024a White Sturgeon
[e] ^NMFS 2016a Five Year Review
[f] CDFW 2024b GrandTab
[g] Schaefer et al. 2019
[h] NMFS 2020 BiOp
[i] Yoshiyama et al. 2001
[j] Day and Morris 2023
[k] Del Real and Hunter 2018
[l] Stockton East Water District (SEWD) and FISHBIO 2019
[m] Weaver and Mehalick 2010
[n] Willmes et al. 2021

H1a1.2 Methods for Carryover Storage Analysis

This evaluation uses historical data, temperature indicators for fish, and other information and considerations to develop carryover storage target ranges for drought and non-drought years. The evaluation incorporates two main types of information.

- Historical relationships between reservoir storage and reservoir release temperatures based on measured data and any available prior studies – the primary months of interest are August through October because this period has warm meteorological conditions combined with low reservoir storage. As a result, these months are when changes in reservoir storage are most likely to affect release temperatures.
- Temperature indicators for fish below the reservoirs – these indicators are based on existing regulatory requirements or management goals for individual tributaries or general thermal thresholds for individual life stages. These indicators were chosen for a basic analysis that focuses on fish survival below the dams. Refinement of this analysis using different indicators and downstream locations will likely be necessary to best meet the cold water habitat objective.

H1a1.2.1 Data and Additional Considerations

The main sources of historical data used for this analysis were the California Data Exchange Center (CDEC) website, which is maintained by the California Department of Water Resources, and the U.S. Geologic Survey (USGS) National Water Information System (NWIS) website. The monthly storage values for this analysis are end-of-month values or monthly minimum of daily values, which approximate the end-of-month values for August through October. The monthly temperature values presented here are typically the monthly average values (monthly average of the daily averages), although in some cases the monthly average of the daily minimum and maximum temperatures are also presented.

Infrastructure and geographic information such as reservoir volume, depth of dam intakes, and upstream limits of anadromous fish migration are provided for each reservoir because these parameters affect the volume of cold water, the ability to access cooler or warmer temperatures, and the amount of warming that may occur between the reservoir release and fish habitat. Unless otherwise noted, information regarding reservoir capacity, water surface elevation at capacity, and bottom elevation are the same as what is used by SacWAM (^SacWAM 2023).

Multiple additional factors were considered in the development of carryover storage ranges to prevent reservoir depletion, including:

- Typical carryover storage values under existing conditions.
- Distance between dam and closest special-status cold water fish.
- Whether fish use the habitat only intermittently when conditions are suitable.
- Need for summer flow to protect fish downstream of dams. Under the flow scenarios, full protection of fish farther downstream or during the summer may require flow shaping of unimpaired flow volume (see water temperature analysis for AQUA-a and AQUA-d in Section 13.7.6.2, *Aquatic Biological Resources*).
- Ability of returning adults to hold before spawning.
- Temperature modeling information from other agencies (e.g., East Bay Municipal Utility District [EBMUD] and U.S. Bureau of Reclamation [Reclamation]).
- Effect of cold water protection on use of the reservoir for water supply including water needed for health and safety.
- Water needed to meet other minimum flow requirements.
- Temperature model results for Shasta, Oroville, New Bullards Bar, and Folsom Reservoirs.
- Possible effect of lower spring storage under the flow scenarios on carryover storage needed to protect cold water supply. It is possible that other measures, such as flow shaping to attain higher carryover storage or infrastructure improvements, may be necessary for protection of cold water habitat under the flow scenarios.
- Consideration of watershed runoff relative to reservoir capacity

Comparisons of runoff to watershed storage are shown in Table H1a1-2. This information indicates how rapidly a reservoir may be able to recover from substantial drawdown. If watershed runoff is substantially greater than storage capacity, the reservoir is more likely to refill each year. If the reservoir is more likely to refill each year, there is less need to retain water in the reservoir through the fall for use in the subsequent water year.

Table H1a1-2. Watershed Storage and Runoff for Sacramento/Delta Tributaries

River	Mean Annual Runoff (TAF/yr)[a]	Total Storage as Modeled in SacWAM (TAF)[a]	Runoff to Storage Ratio
Sacramento River upstream of Shasta Dam	5,589	4,552[b]	1.23
Clear Creek	140	241	0.58
Feather River	4,998	5,131	1.17
Yuba River	1,654	1,408	1.17

River	Mean Annual Runoff (TAF/yr)[a]	Total Storage as Modeled in SacWAM (TAF)[a]	Runoff to Storage Ratio
Bear River	472	176	2.67[c]
American River	2,711	1,759	1.54[c]
Mokelumne River	744	998	0.74
Calaveras River	160	317	0.50
Stony Creek	418	245	1.71[c]
Putah Creek	358	1,602	0.22

TAF = thousand acre-feet
[a] Values from SacWAM (see Draft Staff Report, Chapter 2, Hydrology and Water Supply, Table 2.1-1).
[b] Not including reservoirs upstream of Shasta Reservoir.
[c] Average runoff substantially greater than reservoir storage capacity, indicating a higher likelihood of reservoir refill each year.

For some reservoirs, few water temperature data have been collected at very low reservoir storage. The limited data do not capture the full range of temperature variability that might be expected at low storage. However, increases in release temperature at low storage beyond what is typically seen at higher storage levels are indicative of the effect of low storage on water temperature. The relationship between low storage and higher release temperatures is a well-known phenomenon due to known physical processes, and even sparse data with low storage and high release temperatures may contain useful information regarding this relationship for a particular reservoir. Because release temperatures at any given storage are variable, the carryover storage ranges are rounded values that are not driven by a precise fit to limited data points.

H1a1.2.2 Temperature Indicators

The temperature indicators used for the evaluation in this appendix are presented in Table H1a1-3. The evaluation in this appendix is a more targeted analysis than the more wide-ranging evaluation of the effect of simulated water temperatures on fish, which used many temperature indices as described in Appendix H1b, *Water Temperature Modeling and Fish Assessment for the Sacramento, Feather, American, and Yuba Rivers*. The temperature indicators in Table H1a1-3 were chosen to help reconcile achievability with fish protection and to focus on fish habitat below dams and on key months and life stages most likely to be affected by carryover storage. Sturgeon habitat is often farther downstream than steelhead and Chinook salmon habitat, increasing the importance of flow for these fish. For this reason, the evaluation of carryover storage focuses on temperature indicators for steelhead and Chinook salmon.

Many of the temperature indices considered in the fish effects analysis of simulated temperatures are for the 7-day average of the daily maximum temperatures (7DADM). Because reservoir release temperatures tend to have little diurnal fluctuation, differences between daily minimum, average, and maximum measured temperatures downstream of dams are generally associated with warming that occurs after water is released from a dam, which is affected by flow. For this reason, the evaluation of the relationship between reservoir storage and release temperatures in this appendix uses average temperatures and not daily maximum temperatures.

An additional reason it is appropriate to use the monthly average measured temperatures instead of the average of the maximum temperatures is that the temperature indicators are for attainment of optimal temperatures that are well below lethal thresholds. For example, the adult holding indicator for spring-run Chinook salmon is 60 degrees Fahrenheit (°F) (Table H1a1-3), whereas lethal temperatures are around 69 °F or more (Thompson et al. 2012). Temperatures that exceed the indicators, within certain limits, may reduce fish survival and spawning success but would not necessarily result in direct mortality. Consequently, anadromous fish may still be able to use the habitat below reservoirs if temperatures exceed the indicators by a few degrees Fahrenheit. In addition, anadromous fish can respond to suboptimal temperatures in ways that reduce their exposure to such temperatures. For example, migrating fall-run Chinook salmon have been documented to avoid exposure to high water temperatures in mainstem rivers by temporarily using cooler tributaries (Goniea et al. 2006), and juvenile steelhead can move upstream or to the bottoms of deep pools if temperatures are too warm (Nielsen et al. 1994). Use of daily maximum temperatures in the analysis could unnecessarily restrict reservoir operations and reduce opportunities to release water for augmentation of instream flow for fish and water supply. The ideal carryover requirements would ensure cold water remains at the bottom of a reservoir but not be so stringent as to preclude use of water for human consumption or release of cold water earlier in the year to protect other species and life stages of fish.

Table H1a1-3. Temperatures Indicators for Chinook Salmon and Steelhead

Period	Indicator [a] (°F)	Notes
Feather River Hatchery (Mean Daily Temperature) [b]		
Sep 1 – Sep 30	56	Spring-run spawning
Oct 1 – May 31	55	Chinook and steelhead spawning
Jun 1 – Aug 31	60	Spring-run holding
Feather River Hatchery (Maximum Hourly Temperature) [b]		
Sep 1 – Sep 30	56	
Oct 1 – May 15	55	
May 16 – May 31	59	
Jun 1 – Jun 15	60	
Jun 16 - Aug 15	64	
Aug 16 – Aug 31	62	
Feather River at Robinson Riffle (Mean Daily Temperature) [b]		
Jan 1 – Apr 30	56	Fall-run incubation and steelhead spawning
May 1 – May 15	56–63	Transition period
May 16 – Aug 31	63	Steelhead and Chinook juvenile rearing
Sep 1 – Sep 8	58–63	Transition period
Sep 9 – Sep 30	58	Fall- and spring-run pre-spawning adults
Oct 1 – Dec 31	56	Fall- and spring-run spawning
American River (Mean Daily Temperature) [c]		
Oct 1 – Oct 31	60	Hazel Avenue Bridge, fall-run migration and staging
Nov 1 – Dec 31	56	Hazel Avenue Bridge, fall spawning
May 15 – Oct 31	65	Watt Avenue, steelhead rearing
Yuba River at Smartsville (Water Temperature Index) [d]		
Jan 1 – Apr 30	54	Steelhead spawning
May 1 – Aug 31	60	Spring-run holding
Sep 1 – Dec 31	56	Spring- and fall-run spawning and incubation
Bear River (Mean Daily Temperatures at Highway 70 for Chinook salmon and steelhead) [e]		
Oct 1-14	60	
Oct 15 – Dec 15	57	

Period	Indicator [a] (°F)	Notes
Jan - Mar	57	
Apr - Jun	60	
Jul - Sep	65	
Composite Temperature Table		
Jan 1 – Apr 30	56	Fall-run incubation and steelhead spawning
May 1 – May 31	60	Transition period
Jun 1 – Aug 30	65	Steelhead rearing
	60	Spring-run holding
Sep 1 – Oct 31	60	Fall-run migration and pre-spawning
Sep 1 – Sep 30	56	Spring-run spawning
Oct 1 – Dec 31	56	Fall- and spring-run spawning and incubation

[a] These indicators were chosen for a basic analysis that focuses on fish survival below the dams. Refinement of this analysis using different indicators and downstream locations will likely be necessary to best meet the cold water habitat objective.
°F = degrees Fahrenheit
Sources:
[b] ^DWR 2006.
[c] ^Reclamation et al. 2006.
[d] Lower Yuba River Accord River Management Team Planning Group 2010
[e] ^CALFED 2000; USFWS 1995.

H1a1.3 Shasta Reservoir

Carryover storage ranges specified for Shasta Reservoir in the revised December 2025 revised draft Bay-Delta Plan are 1,500–2,000 thousand acre-feet (TAF) for drought years and 2,000–3,000 for non-drought years. Years with carryover storage less than 2,000 TAF have been associated with elevated mortality of winter-run Chinook salmon. However, a lower range value of 1,500 TAF is an acknowledgement that there have been and likely will continue to be times when storage in Shasta Reservoir will fall below 2,000 TAF. Carryover storage of 2,000 TAF corresponds to the targets for Bin 2 and 3a years (drier years) described in Alternative 2 of the Final EIS for Long-Term Operation (LTO) of the Central Valley Project (CVP) and State Water Project (SWP) (Reclamation 2024a) and adopted in the LTO of the CVP and SWP Record of Decision (ROD) (Reclamation 2024b). Carryover storage of 3,000 TAF corresponds to the targets for Bin 1A years (wet years) described in Alternative 2 of the Final EIS for LTO of the CVP and SWP, as adopted in the ROD. The bin levels are based on spring storage and an initial estimate of projected September storage.

H1a1.4 Black Butte Reservoir

H1a1.4.1 Infrastructure and Geography

Black Butte Reservoir captures water from the Stony Creek watershed located on the west side of the Sacramento Valley. The reservoir is relatively small, with maximum storage of approximately 144 TAF and a water surface elevation of about 474 feet. The minimum pool elevation is 414.6 feet, which is near the bottom of the reservoir (USACE 1977). The reservoir is typically operated to maintain at least 20 TAF storage (about 430 feet in elevation). Black Butte Reservoir was constructed by the U.S. Army Corps of Engineers and one of the primary purposes of the reservoir is flood control. Much of the reservoir volume is used for flood control during the October–March 15 flood season (USACE 1977). Average watershed runoff is substantially greater than reservoir storage capacity (Table H1a1-2).

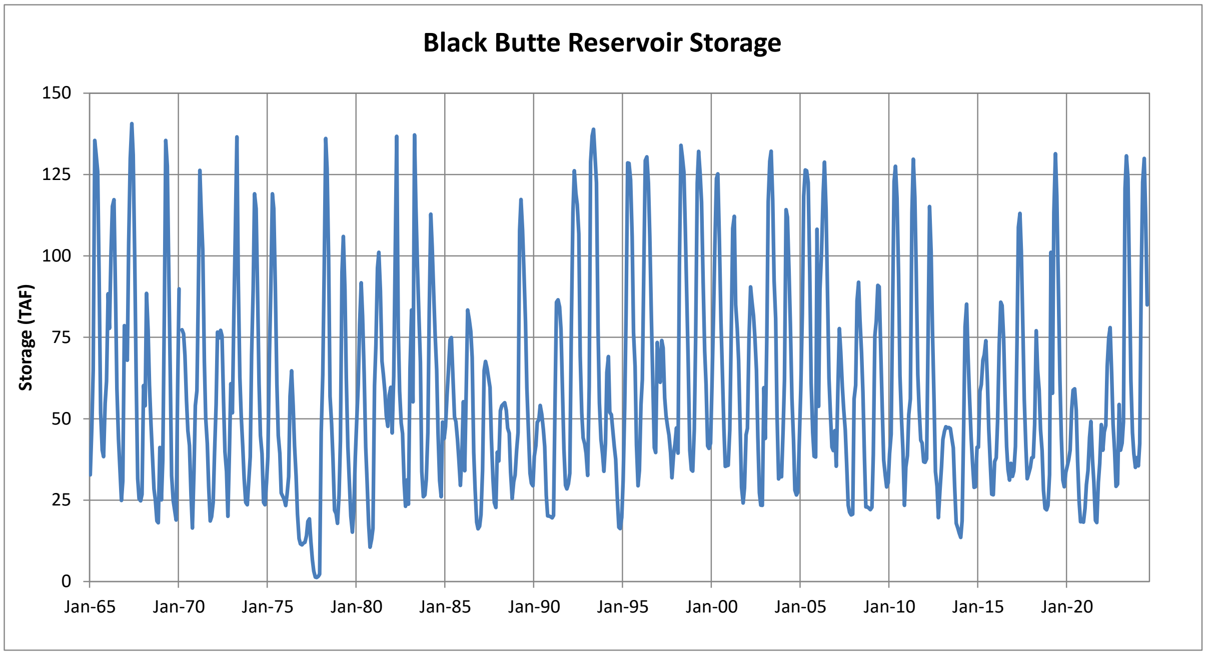
H1a1.4.2 Other Studies

As part of development of the Lower Stony Creek Fish and Wildlife Management Plan (Reclamation 1998), CH2MHill staff provided the following flow and water temperature assessment.

> "Mean daily water temperatures in October (65.8 °F) have exceeded the maximum threshold of temperature tolerances for prespawning Chinook salmon (60 °F) during 1970–1994. During 1970–1994, water temperatures in November (54.4 °F) in the study area remained below the thresholds of prespawning/spawning (60 °F) and egg incubation (56 °F). Stream temperatures then remain below the maximal threshold temperature (65 °F) for fry/juvenile rearing through at least May."
>
> "During 1970 through 1994, the earliest dates in which Stony Creek reached spawning (60 °F) and optimal egg incubation (56 °F) temperatures were October 19 and October 27, respectively…The latest these temperatures were reached were November 10 and November 25, respectively. Also, the optimal temperature for fry/juvenile rearing of 65°F has been exceeded as early as May 4 and as late as June 15."
>
> "Releases made from Black Butte Reservoir are made from the outlet located at the bottom of the reservoir, ensuring the coldest temperatures possible. Thermal monitoring within Black Butte Reservoir has indicated that, while there is a slight to moderate thermal stratification during the late spring and summer months (April–September), by the early fall at lowest pool elevations, temperatures within the reservoir are relatively uniform and cool. This indicates that there is little, if any, opportunity to affect current downstream temperature with Black Butte Dam releases in the early fall or late spring to provide more optimal than current temperature conditions for Chinook salmon.[internal citations omitted]"

H1a1.4.3 Data

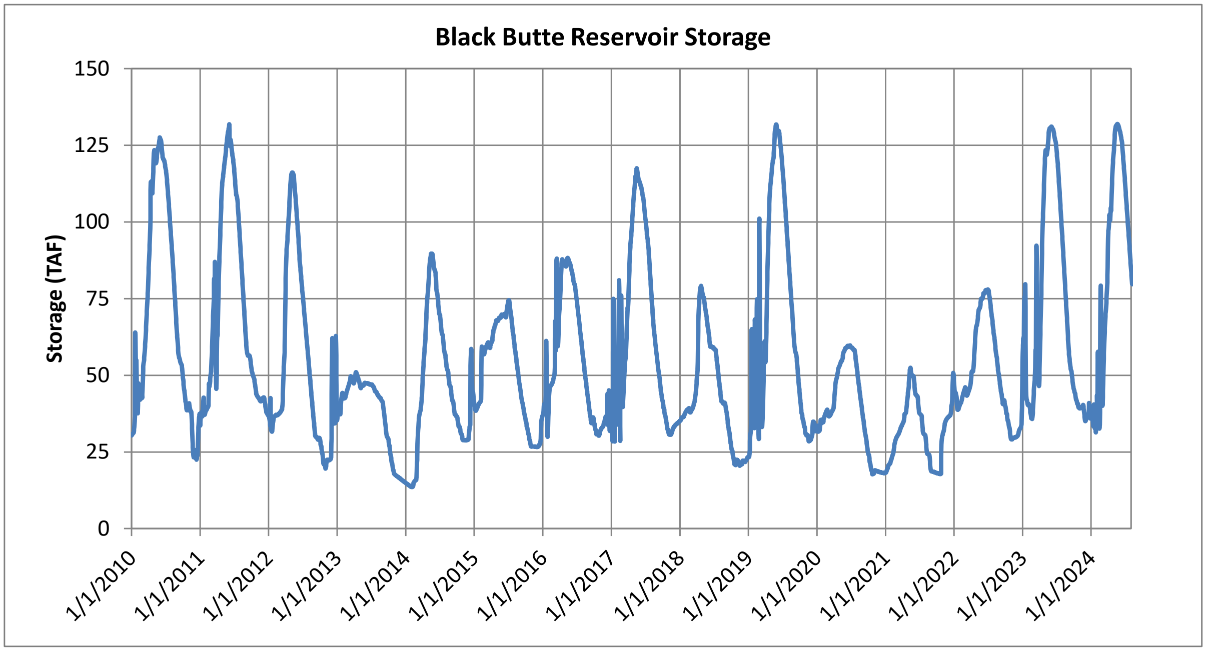
Figure H1a1-1 shows the historical end-of-month Black Butte Reservoir storage pattern for 1965–2024 (CDEC Station BLB). The minimum storage was 0 TAF in 1977 and was close to 20 TAF in many other years. Storage in Black Butte Reservoir declines annually during scheduled irrigation diversions for the Orland Project through South Canal below the dam and North Canal about 5 miles downstream of the dam, typically from April through October.



Source: DWR 2024 (CDEC Station BLB).
TAF = thousand acre-feet

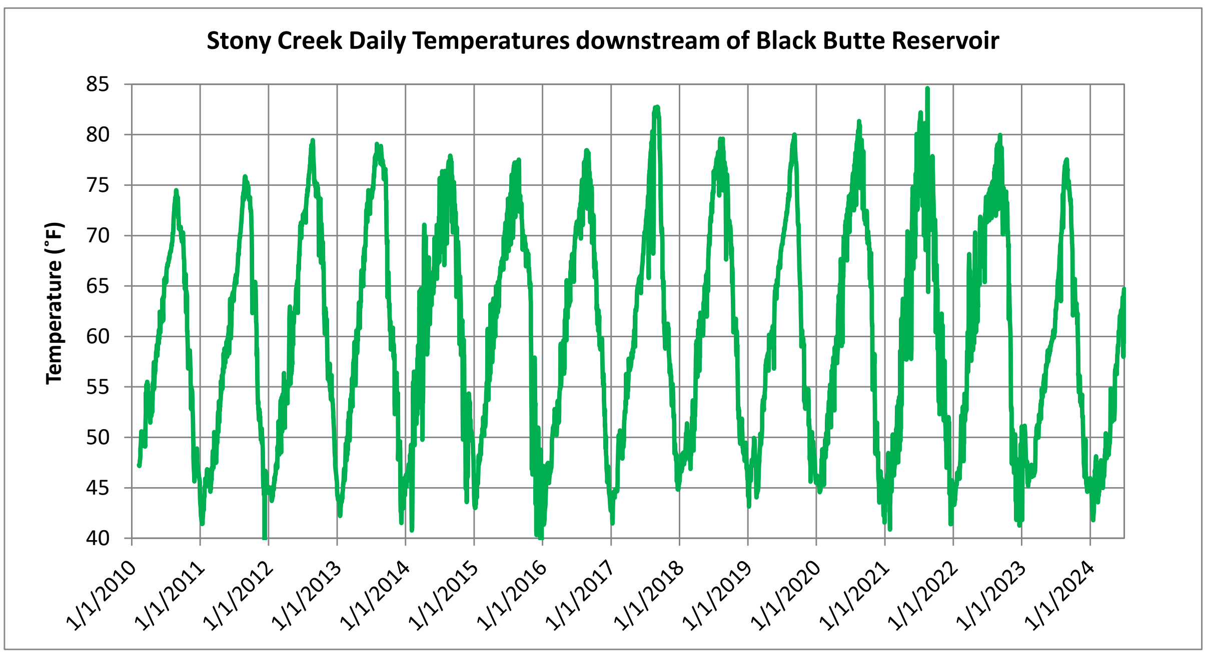
Figure H1a1-1. Historical Black Butte Reservoir Storage (TAF) (1965–2024)

To focus more on the period of record with measured release temperatures, Figure H1a1-2 shows the historical daily Black Butte Reservoir storage for 2010–2024 (CDEC Station BLB), and Figure H1a1-3 shows the historical daily Stony Creek temperatures below Black Butte Reservoir (CDEC Station BBQ, located approximately 0.8 mile downstream of the dam). Since 2010, the annual maximum Black Butte Reservoir storage has been about 130 TAF (in 2011 and 2019).



Source: DWR 2024 (CDEC Station BLB).
TAF = thousand acre-feet

Figure H1a1-2. Historical Daily Black Butte Reservoir Storage (TAF) (2010–2024)



Source: DWR 2017 and 2024 (CDEC Station BBQ).
°F= degrees Fahrenheit

Figure H1a1-3. Historical Daily Average Temperatures (°F) below Black Butte Reservoir (2010–2024)

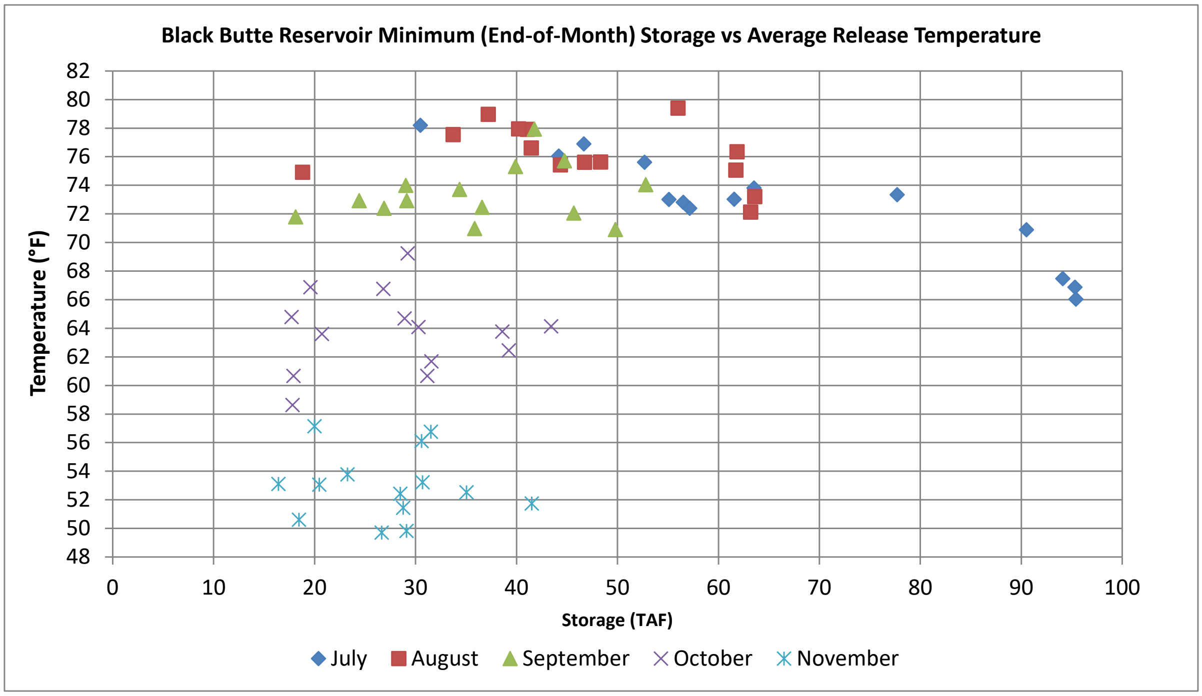
H1a1.4.4 Data Evaluation

Figure H1a1-4 shows historical monthly average temperatures below Black Butte Reservoir compared to end-of-month (minimum monthly) reservoir storage during July through November of 2010–2023. Because the maximum water depth is less than 75 feet, there is no opportunity for a cold water pool as defined for this appendix (i.e., no cool bottom layer with relatively uniform low temperature), but the reservoir can be stratified in the summer as indicated by the cooler releases at higher storage. During the warmest months, July and August, release temperatures appear to have had an almost linear relationship with storage, with average temperatures increasing from 66 °F to 79 °F as end-of-month reservoir storage decreased from about 95 to 35 TAF (Figure H1a1-4). With cooling meteorological conditions, both storage and temperatures decreased in September through November (Figure H1a1-4).

Although some opportunistic use by Chinook salmon and steelhead takes place below Black Butte Reservoir, these opportunities are limited both spatially and temporally because of high water temperatures during spring, summer, and early fall months (^NMFS 2014b, Appendix A). Only the fall-run Chinook life history is compatible with existing conditions of lower Stony Creek; however, at present, Stony Creek does not support a sustained annual run of anadromous salmon (^NMFS 2014b, Appendix A).

Because water temperatures released from Black Butte Reservoir are substantially above water temperature indicators during July through October even when storage is relatively high (as listed below by month), it would be difficult for increased storage in Black Butte Reservoir to substantially improve temperature conditions for anadromous fish in Stony Creek to such a degree that the temperature indicators for steelhead or fall-run Chinook salmon would be met. The December 2025 revised draft Bay-Delta Plan does not specify carryover storage target ranges for Black Butte Reservoir.

- **July and August.** During July and August, monthly average Black Butte Reservoir release temperatures were generally above the 65 °F temperature indicator for steelhead rearing, even when the reservoir storage was greater than 90 TAF (Figure H1a1-4).
- **September.** Fall-run Chinook salmon may migrate in September, with a temperature indicator of 60 °F. Black Butte Reservoir storage tends to be low (less than 60 TAF) in September, and release temperatures are quite high (greater than 70 °F). Based on the temperature-versus-storage relationship for July and August and the high September temperatures, it is unlikely that increased storage in Black Butte Reservoir could produce release temperatures suitable for migrating Chinook salmon in September (i.e., less than 60 °F).
- **October.** Monthly average October release temperatures were almost always greater than 60 °F, the temperature indicator for migration and pre-spawning fall-run Chinook salmon. Even if the reservoir was minimally used for human water supply and reservoir storage was maintained above 100 TAF, it is not clear whether release temperatures less than 60 °F would be possible.
- **November.** By November, temperatures may be suitable for fall-run Chinook salmon spawning (i.e., 56 °F or below) due to cooler meteorological conditions. However, reservoir storage has little effect on release temperatures in November.



Source: DWR 2017 and 2024 (CDEC Stations BLB and BBQ).
°F= degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-4. Historical Monthly Average Temperatures (°F) below Black Butte Reservoir Compared to Reservoir Storage (TAF) for July through November (2010–2023)

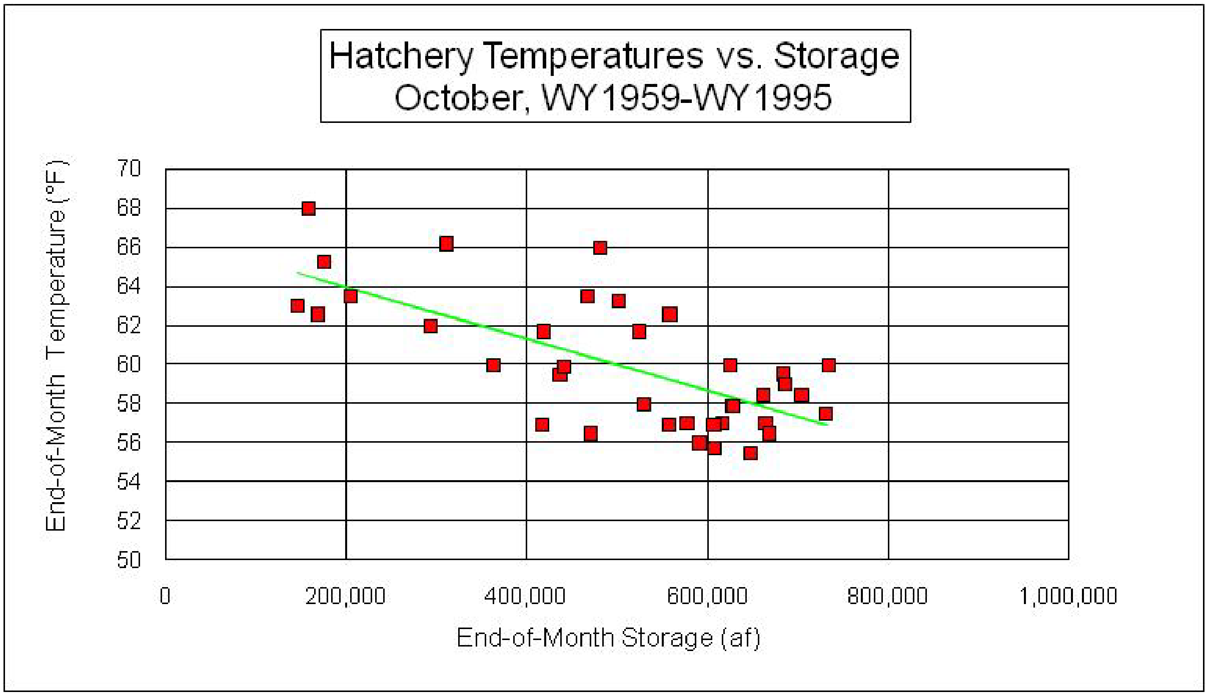
H1a1.5 Folsom Reservoir

H1a1.5.1 Infrastructure and Geography

Folsom Reservoir captures water from the American River watershed. The bottom of Folsom Reservoir is at an elevation of approximately 205 feet, and the elevation at the maximum storage of about 976 TAF is 466 feet. The power penstocks are at 307 feet, and the intake for the lowest river outlets are at 210 feet (CVFPB et al. 2019). Folsom Reservoir has a maximum depth of about 261 feet, but the maximum depth to the penstock (at 307 feet) is only about 160 feet. Temperature control shutters on the power penstocks help regulate release temperatures. Lake Natoma, a small re-regulating reservoir with a 9 TAF storage capacity, is downstream of Folsom Reservoir and is formed by Nimbus Dam, located approximately 6.7 miles downstream of Folsom Dam. Nimbus Dam is the upstream limit for anadromous fish.

H1a1.5.2 Other Studies

Temperature data from 1959–1995 at the Nimbus Fish Hatchery were used to demonstrate the effect of Folsom Reservoir storage on release temperatures in the draft *Environmental Impact Report/Environmental Impact Study for the East Bay Municipal Utility District Supplemental Water Supply Project* (Jones & Stokes 1997). The hatchery temperatures are similar to temperatures at Nimbus Dam. These temperatures are slightly warmer than the Folsom Dam release temperatures but represent the coldest temperatures available for anadromous fish. Figure H1a1-5 shows the relationship between end-of-month storage and end-of-month hatchery temperatures for October as presented in Figure 6 from Jones & Stokes 1997.



Source: Jones & Stokes 1997.
°F = degrees Fahrenheit
af = acre-feet

Figure H1a1-5. Relationship between Folsom Reservoir Storage (af) and Nimbus Fish Hatchery Temperatures (°F) for October (1959–1995)

A 2007 study of temperature control options in Lake Natoma included modeling of Folsom Reservoir water temperatures in 2001–2003 (Bender et al. 2007). Figure 6 from Bender et al. 2007 (presented as Figure H1a1-6) illustrates seasonal and year-to-year changes in release temperatures due to changes in storage and meteorological conditions along with more short-term variation in temperature caused by operations of the power penstock temperature control shutters or by major changes in outflow or meteorology. The operations of the temperature control shutters on the power penstocks were apparent in several rapid reductions in the release temperatures when the elevations of the temperature control shutter openings were lowered.

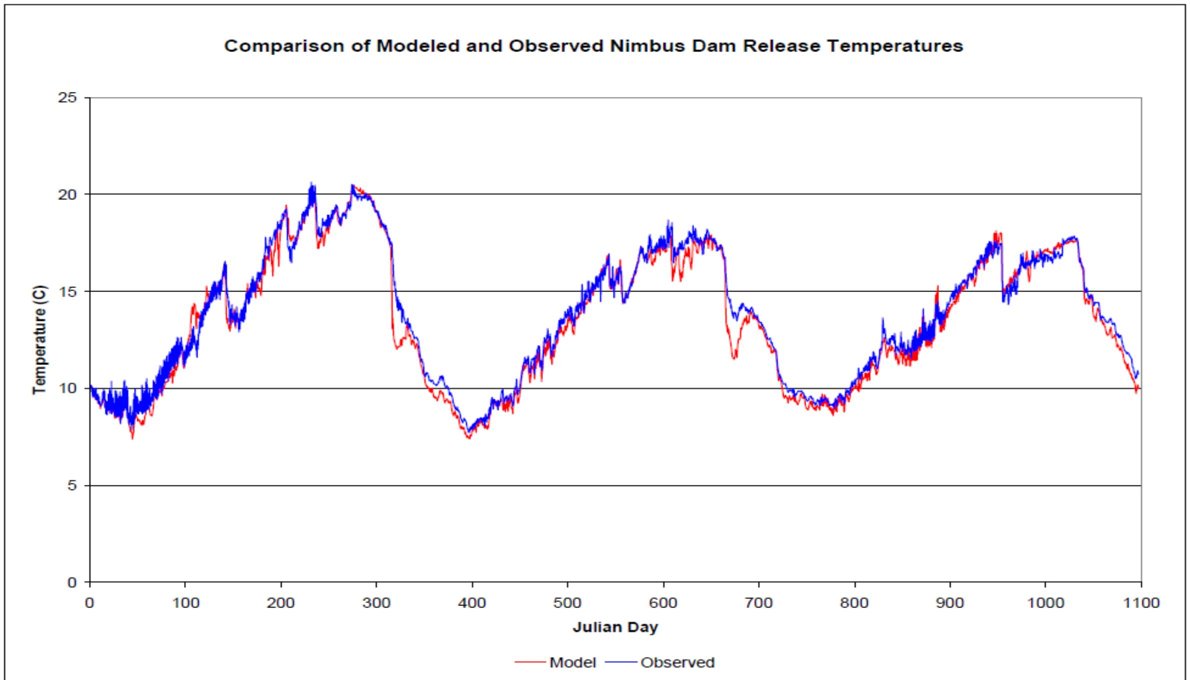


Figure 6.—Modeled and observed Nimbus Dam release temperature versus time during 2001, 2002, and 2003.

Source: Bender et al. 2007.
°C = degrees Celsius

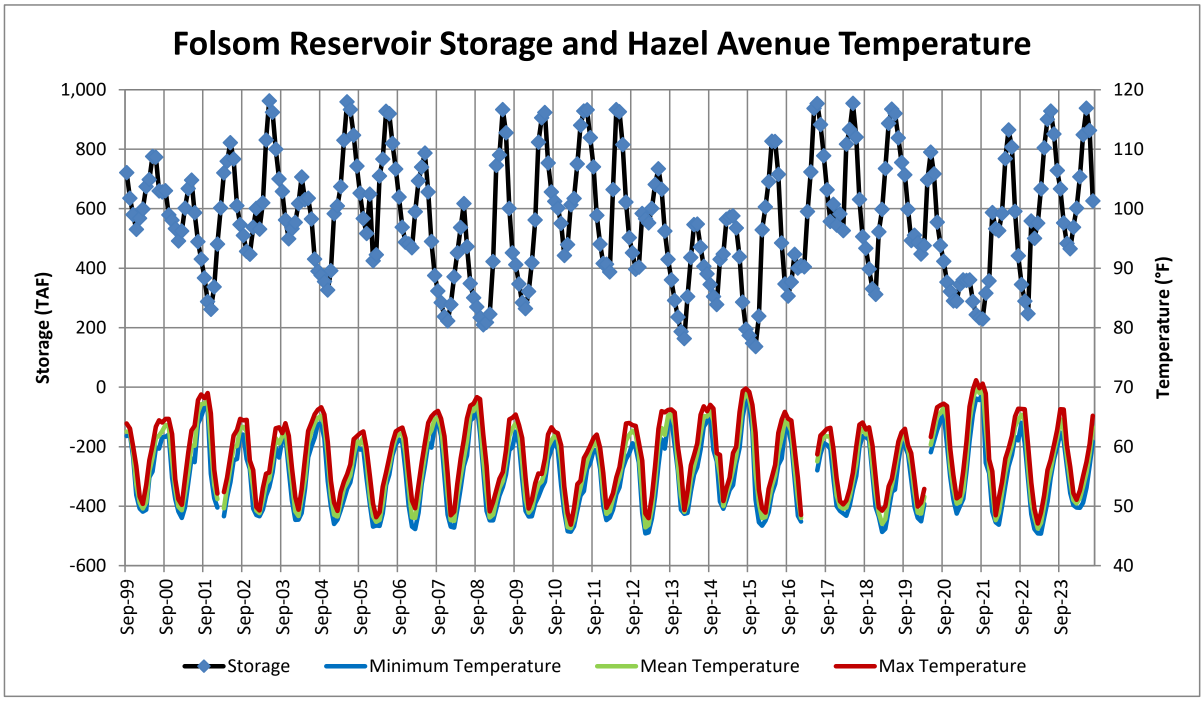
Figure H1a1-6. Hourly Temperatures (°C) of Nimbus Dam Releases (2001–2003)

Another temperature study (Martinez et al. 2014) evaluated the operation of the temperature control shutters but did not provide information about the effect of reservoir storage on water temperature. The study authors simulated water temperatures for 2001–2011 historical conditions and found that shutter operations could be optimized to reduce water temperatures during critical period for fish.

H1a1.5.3 Data

The release temperatures evaluated here were measured downstream of Nimbus Dam near Hazel Avenue (CDEC Stations AFO and AHZ) representing a location near the upstream extent of anadromy. Measured data are also available downstream of Folsom Dam (CDEC Station AFD). Temperatures at Hazel Avenue are approximately 2 °F warmer than temperatures downstream of Folsom Dam during the summer, but average differences between the two locations decrease from August through November from 2.1 °F to 0.6 °F (based on data from CDEC Stations AFO, AHZ, and AFD [DWR 2017 and 2024]).

Figure H1a1-7 shows the historical monthly Folsom Reservoir storage levels (CDEC Station FOL) and temperatures near Hazel Avenue (CDEC Stations AFO and AHZ) for September 1999–July 2024. The lowest carryover storage was 174 TAF in 2015, (with 195 TAF in August, 148 TAF in October, and 137 TAF in November of 2015). Some of the highest Hazel Avenue temperatures occurred at that time; the monthly average of the maximum daily temperatures during August, September, and October 2015 were 69.8 °F, 69.2 °F, and 67.0 °F, respectively.



Source: DWR 2017 and 2024 (CDEC Stations AFO, AHZ, and FOL).
°F= degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-7. Historical Monthly Folsom Reservoir Storage (TAF) and Hazel Avenue Temperatures (°F) (1999–2024)

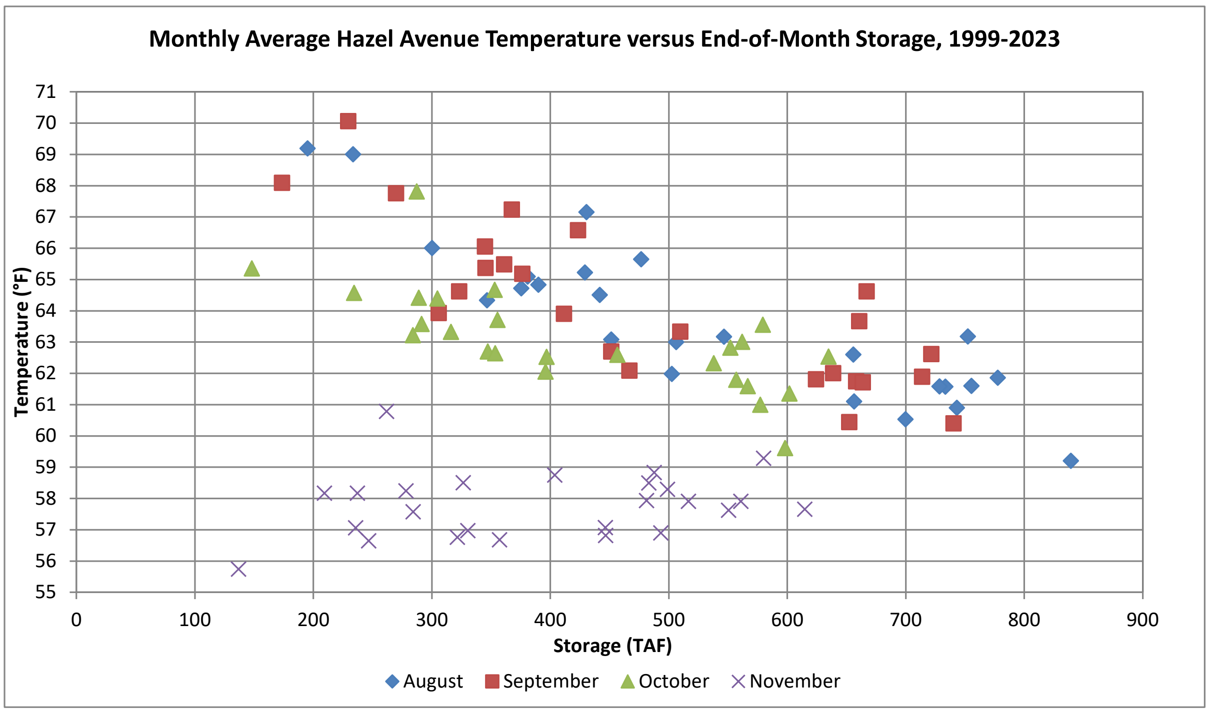
H1a1.5.4 Data Evaluation

Figure H1a1-8 shows the relationship between end-of-month storage in Folsom Reservoir and monthly average temperatures near Hazel Avenue for August–November during 1999–2023. August–October are months with the highest temperatures at Hazel Avenue and are the months most likely to be affected by low storage in Folsom Reservoir.

As indicated in Table H1a1-3, the fish life stages with the most stringent temperature indicators likely to be affected by Folsom carryover storage include steelhead rearing in the river year-round (65 °F) and fall-run Chinook salmon migration and staging in October (60 °F). Because the measured Hazel Avenue temperatures for October are not substantially lower than the August and September temperatures (Figures H1a1-8), the 60 °F indicator for October is more difficult to attain than the 65 °F indicator for August and September.

Almost all the average October temperatures were greater than 60 °F. By November, average water temperature at Hazel Avenue is minimally affected by storage and approaches, but is still greater than the 56°F temperature indicator for fall-run spawning (Table H1a1-3 and Figure H1a1-8). Because water temperatures are not optimal for fall-run migration and staging in October (60 °F indicator) and fall-run Chinook salmon may need to wait until water temperatures drop before spawning, meeting the steelhead rearing indicator of 65°F during the months with highest water temperature at Hazel Avenue (August–October) may be a more realistic and important outcome. The data show average August–October Hazel Avenue temperatures that are usually below 65 °F when end-of-month storage is above 400 TAF (temperatures between approximately 59 °F and 67 °F) and always less than 65°F at storage levels greater than 500 TAF.

From 1999 to 2023, carryover storage in Folsom Reservoir was less than 400 TAF more than a third of the time (Figure H1a1-8). Maintaining carryover storage greater than 400 TAF in more years could be beneficial to migrating fall-run Chinook salmon and rearing steelhead. However, because of the high demand for this water for agricultural and municipal use, and because of the relatively small, approximately 1,000-TAF reservoir capacity, maintaining storage greater than 400 TAF more frequently may be difficult considering water supply tradeoffs. Because the reservoir has a relatively high likelihood of refilling in any given year based on the ratio of watershed runoff to reservoir capacity (Table H1a1-2), the need to conserve water for subsequent years is somewhat less for Folsom Reservoir compared to other reservoirs. In addition, flow is needed to carry cooler temperatures farther downstream, which necessitates a certain amount of reservoir releases and creates a tradeoff between reservoir storage and releases. In consideration of the temperature requirements for steelhead rearing and the need for reservoir releases for instream flow and water supply, temperature indicator for steelhead rearing and the December 2025 revised draft Bay-Delta Plan specifies carryover storage target ranges of 300 – 400 TAF for drought years and 400 – 500 TAF for non-drought years.



Source: DWR 2017 and 2024 (CDEC Stations AFO, AHZ, and FOL).
°F= degrees Fahrenheit
TAF = thousand acre-feet

Figure A1c-8. Historical Monthly Average Hazel Avenue Temperatures (°F) Compared to End-of-Month Storage (TAF) for August through November (1999–2023)

H1a1.6 New Bullards Bar Reservoir

H1a1.6.1 Infrastructure and Geography

New Bullards Bar Reservoir collects water from the North Yuba River and provides water to the Colgate Powerhouse. Maximum storage is approximately 960 TAF at an elevation of about

1,957 feet. The bottom of the reservoir is at about 1,450 feet elevation in a narrow canyon. Releases from the reservoir are made through the Colgate Powerhouse, the minimum flow powerhouse at the base of the dam, a low-level outlet at the base of the dam, and/or the gated spillway (FERC and USACE 2019).

Englebright Dam is located about 10 miles downstream from Colgate Powerhouse and is the upstream limit of anadromous fish migration on the Yuba River. Fish passage is possible around Daguerre Dam, located downstream of Englebright, and there has been a recent agreement to improve passage around this dam (CDFW 2023a).

Two penstock intakes (at approximately 1,630 feet and at 1,810 feet at centerline) are connected to the Colgate Powerhouse, giving the option to draw water from the elevation that provides the best temperature for downstream fish (FERC and USACE 2019). This flexibility permits dam operators to release warmer water so colder water is reserved for later use. The low-level outlet (invert elevation approximately 1,445 feet [the invert is the lowest interior point of an opening]), which supplies the New Bullards Bar Minimum Flow Powerhouse, has a maximum design capacity of 3,500 cubic feet per second at full reservoir pool, and an actual release capacity of 1,250 cubic feet per second (^YCWA 2014).

After the reservoir filled in 1970, water was drawn from the upper penstock intake at 1,810 feet during spring to release warmer water for better growth and rearing conditions for fish. However, since September 1993, the deeper intake (1,630 feet) has been used for all controlled releases to provide colder water temperatures through Englebright Reservoir for Chinook spawning and egg incubation in the lower Yuba River (Lower Yuba River Accord River Management Team Planning Group 2010; YCWA 2013). Use of the lower intake provides for release of the coldest water possible year-round. Almost all water released from the reservoir passes through the Colgate Powerhouse via the lower intake. This water mixes with flow from the Middle and South Forks of the Yuba River and an insignificant flow (approximately 5 cfs [SWRCB 2003]) in the North Fork Yuba River prior to entering Englebright Reservoir, a relatively small reservoir with a capacity of approximately 50 TAF. Cold water flows along the bottom of Englebright Reservoir with some warming from the surface water.

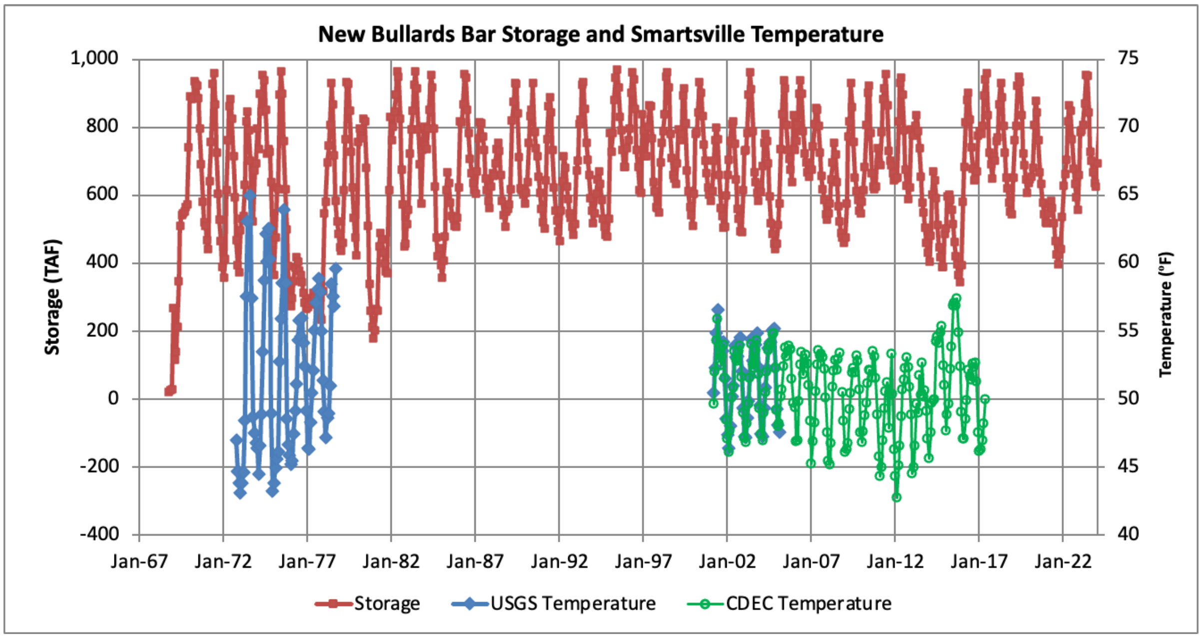
H1a1.6.2 Other Studies

Temperature modeling for New Bullards Bar Reservoir and the Yuba River below Englebright Reservoir was completed for the Federal Energy Regulatory Commission (FERC) relicensing process (YCWA 2013). Extensive river temperature measurements and reservoir profiles were collected for the relicensing process and as part of the YCWA flow and temperature monitoring program since 1993. The relicensing operations and temperature models (HEC-5Q for river reaches and CE-QUAL-W2 for New Bullards Bar Reservoir) covered only 2009–2012 and did not include periods when New Bullards Bar Reservoir storage was less than 500 TAF (Figure H1a1-9).

H1a1.6.3 Data

Water temperature has been measured at Smartsville, approximately 1 mile downstream of Englebright Dam. Temperature measurements were recorded for 1972–1977 (USGS Station 11418000) and 2001–2017 (CDEC Station YRS). Figure H1a1-9 shows the monthly historical New Bullards Bar storage (from CDEC Station BUL) for 1968–2024 and the historical monthly temperatures near Smartsville. Storage dropped to about 250 TAF in 1976 and 1977, and to about 200 TAF in 1980, but storage remained close to or above 400 TAF in all subsequent years until it dropped to approximately 350 TAF in 2015. The highest temperatures were measured in 1973–1975, possibly when the upper intake was used during summer months. Maximum summer temperatures remained less than 60 °F during 1976–1977, when minimum storage was about 250

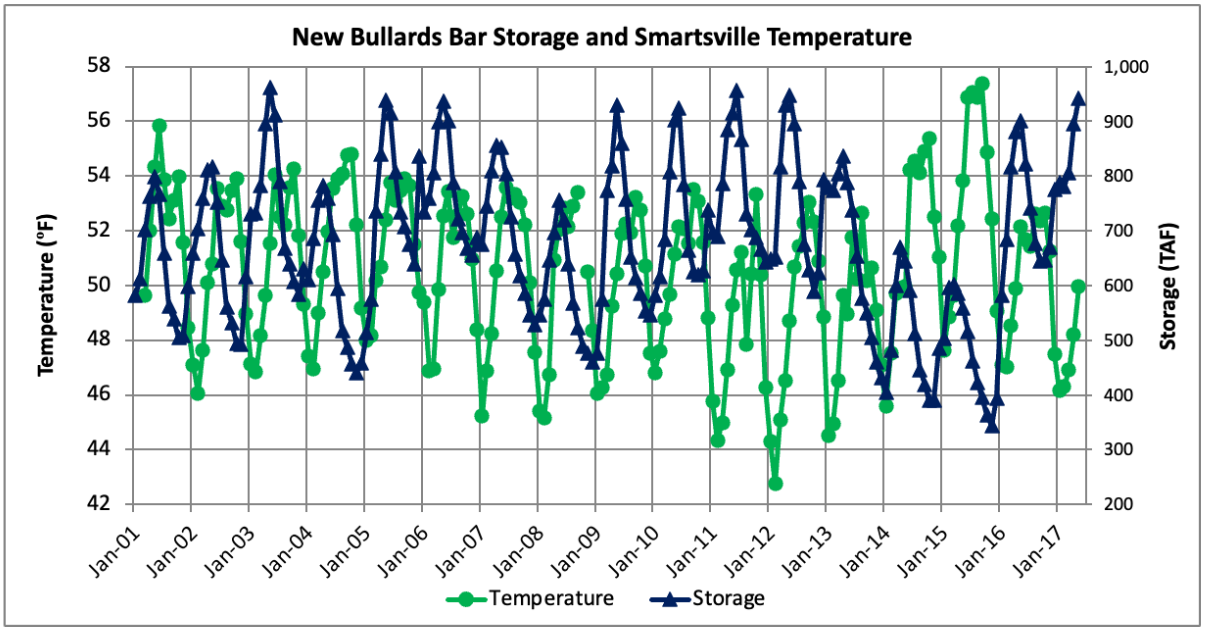
TAF. Effects of minimum storage of about 200 TAF in 1980 on temperatures cannot be identified because temperatures were not measured from 1978 to 2000.



Sources: DWR 2017 and 2024 (CDEC Stations BUL and YRS); USGS 2017 (Station 11418000).
°F = degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-9. Monthly Historical New Bullards Bar Reservoir Storage (TAF) and Yuba River Temperatures (°F) at Smartsville (1968–2024)

Figure H1a1-10 focuses on the historical monthly storage and temperature for New Bullards Bar Reservoir below Englebright Reservoir near Smartsville for the recent period of 2001–2017 (CDEC Station YRS; this station stopped recording temperatures in 2017). The low-level penstock intake (1,630 feet elevation) was used during this time. Historical monthly temperatures were relatively consistent for these 16 years, with some variation in the winter temperatures (range of 42–48 °F). Minimum storage approached 400 TAF in 2004, 2008, and 2013–2015; but maximum temperatures generally remained less than 54 °F except during 2001, 2014, and 2015.



Source: DWR 2017 (CDEC Stations BUL and YRS).
°F= degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-10. Monthly Historical New Bullards Bar Reservoir Storage (TAF) and Yuba River Temperatures (°F) at Smartsville (2001–2017)

H1a1.6.4 Data Evaluation

The fish life stages with the most stringent temperature indicators likely to be affected by New Bullards Bar carryover storage include spring-run Chinook salmon holding in August (60 °F) and spring- and fall-run Chinook salmon spawning in September and October (56 °F).

Water from New Bullards Bar Reservoir mixes with water from the South and Middle Forks of the Yuba River and travels through Englebright Reservoir before reaching Smartsville. Both the temperature and flow of water through Colgate powerhouse can affect the temperature of water released from Englebright Reservoir. Higher powerhouse flow reduces travel time through Englebright Reservoir and increases the ratio of the cold north fork water relative to the south and middle fork water. Higher carryover storage in New Bullards Bar helps maintain cold-water supply in the reservoir and allows for sufficient powerhouse flows to counteract longitudinal warming and the effect of warmer water in the north and south forks of the Yuba River.

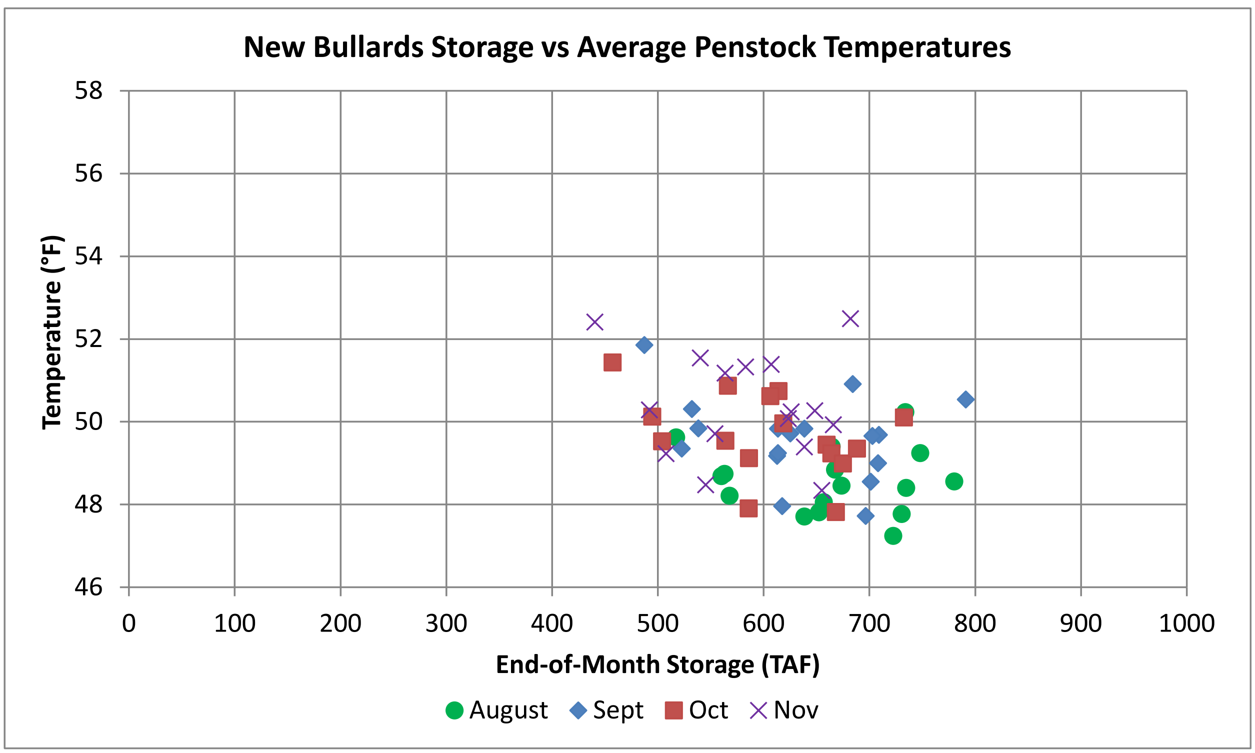
YCWA has measured powerhouse penstock temperatures, which indicate New Bullards Bar release temperatures prior to changes between the powerhouse and Smartsville. Figure H1a1-11 shows August - November monthly average temperatures at the Colgate Powerhouse penstock compared to New Bullards Bar Reservoir storage for 1995 – 2012. Monthly average temperature of water flowing through the Colgate Powerhouse penstocks during August through November was generally between 47 °F and 52 °F (Figure H1a1-11).

Figure H1a1-12 shows August–November monthly Yuba River temperatures at Smartsville compared to New Bullards Bar Reservoir storage for 2001–2016 when the low-level intake was used. Data for 1973–1978 were not included in the evaluation due to potential use of upper power intake, which was discontinued in 1993. For the 2001–2016 data evaluated, storage was rarely less than 400 TAF.

Water temperatures measured near Smartsville below Englebright Dam during August through October are approximately 4 °F warmer (generally 52 °F – 54 °F) than those measured at the Colgate Powerhouse penstock (generally 48 °F – 51 °F) when New Bullards Bar storage is greater than 550 TAF. While the November penstock temperatures were very similar to the September and October temperatures, the November temperatures at Smartsville were lower than the September and October temperatures due to the effect of cooler meteorological conditions.

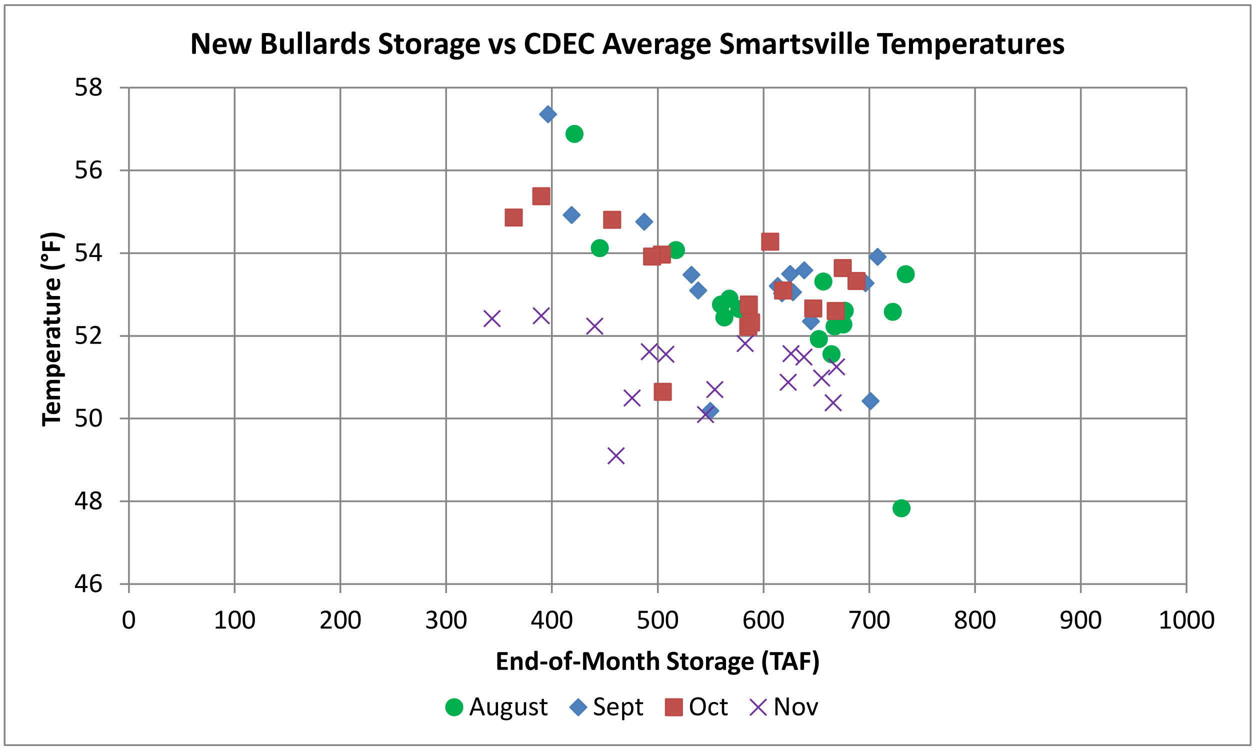
New Bullards Bar Reservoir storage of less than 400 TAF in September and October could cause average September and October temperatures in the lower Yuba River at Smartsville to exceed the 56 °F temperature indicator for spawning (Figure H1a1-12). August, with a temperature indicator of 60 °F, is unlikely to be problematic unless storage were to fall below 300 TAF. Thus, maintaining a storage of 400 TAF or above may be important for meeting water temperature needs for spring- and fall-run Chinook salmon spawning and incubation, which generally begins in September. Since 1986, there has only been one instance of New Bullards Bar Reservoir storage being substantially less than 400 TAF (364 TAF in October 2015) (Figure H1a1-10). The lower end of the carryover storage range specified in the December 2025 revised draft Bay-Delta Plan is 400 TAF for all years.

Storage greater than about 550 TAF seems to have had little effect on release temperatures, with monthly average temperatures generally at 52–54 °F (Figure H1a1-12). A carryover storage of 600 TAF would provide lower temperatures and increased reserve for subsequent years. A carryover storage of 600 TAF frequently occurs under existing conditions. YCWA has also proposed operating to this carryover storage level in above normal, below normal, and dry water year types (instead of 650 TAF) under the VA pathway. The upper end of the carryover storage range specified in the December 2025 revised draft Bay-Delta Plan is 600 TAF for all years.



Source: YCWA 2013.
°F= degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-11. Historical Monthly Average Temperatures (°F) at Colgate Powerhouse Penstock Compared to New Bullards Bar Reservoir Storage (TAF) for August through November (1995–2012)



Source: DWR 2017 and 2024 (CDEC Stations BUL and YRS).
°F= degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-12. Historical Monthly Average Temperatures (°F) at Smartsville Compared to New Bullards Bar Reservoir Storage (TAF) (2001–2016)

H1a1.7 Oroville Reservoir

H1a1.7.1 Infrastructure and Geography

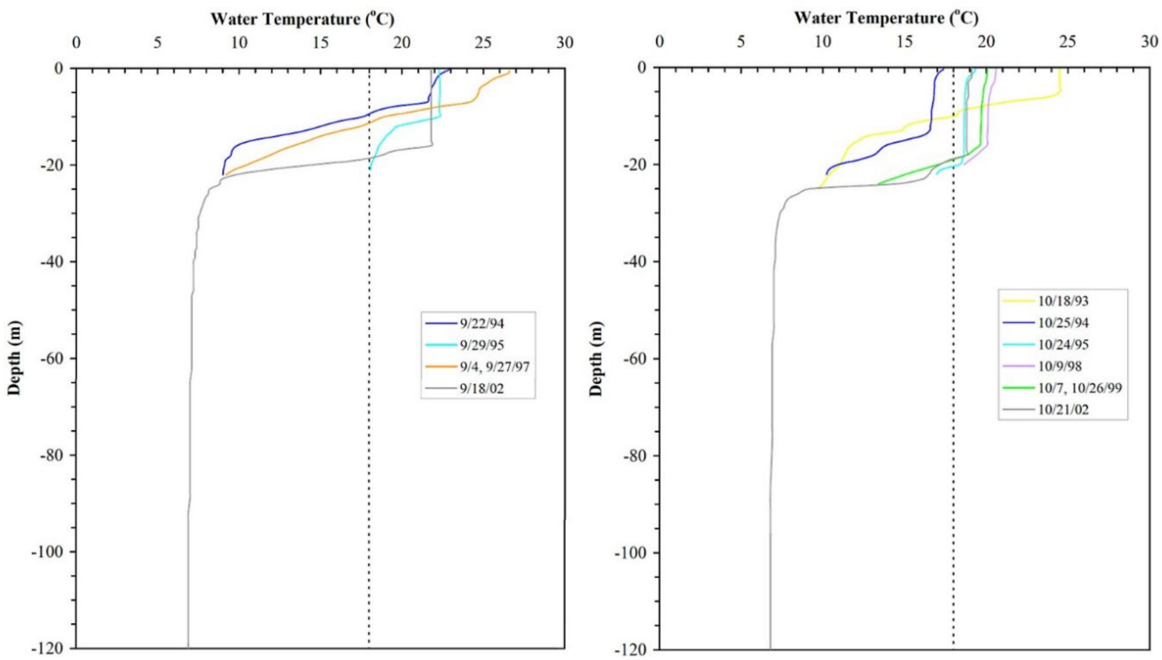
Oroville Reservoir captures water from the Feather River watershed. Maximum reservoir capacity is about 3,500 TAF at a water surface elevation of about 900 feet. Almost all releases are made through the Hyatt Powerhouse, although there is also a river outlet. The powerhouse penstock intake is connected to a slanted temperature control structure that allows withdrawal of water from multiple elevations in the reservoir (^NMFS 2016d; Reclamation 1965). The penstocks can draw water from as low as 613 feet (^NMFS 2016d). The reservoir is considered to be at dead pool (i.e., water cannot pass through the powerhouse), when the water surface elevation is at 640 feet, which corresponds to a reservoir storage of approximately 850 TAF (USGS 2025).

The reservoir bottom is at approximately 210 feet elevation, although storage below an elevation of 300 feet is minimal. A river valve outlet system in diversion tunnel No. 2 can bypass the power turbines and release water from 225 feet near the bottom of the reservoir (^NMFS 2016d).

Releases from Oroville Dam flow downstream to Thermalito Diversion Dam, where most of the water is diverted to Thermalito Forebay and Afterbay, where water is warmed for rice production and diverted for agricultural purposes. The remainder of the water stays in the Feather River channel. In the river channel below the Thermalito Diversion Dam, the fish barrier dam diverts water to the Feather River Fish Hatchery. The fish barrier dam is located approximately 5 miles downstream from Oroville Dam and is the upper limit of anadromous fish migration on the Feather River. The Low Flow Channel (LFC) of the Feather River extends from the Fish Hatchery Dam downstream approximately 8 miles to the point where excess water in the Thermalito Afterbay is returned to the Feather River, forming the upstream end of the high flow channel.

H1a1.7.2 Other Studies

Figure H1a1-13 shows Oroville Reservoir temperature profiles measured in September and October. These temperature profiles were used to evaluate cold water pool as part of Oroville FERC relicensing (SWRI 2003). The temperatures were less than 10 degrees Celsius (°C) (50 °F) below 20–25 meters (60–75 feet).



Source: SWRI 2003, Appendix A.
°C = degrees Celsius
m = meters

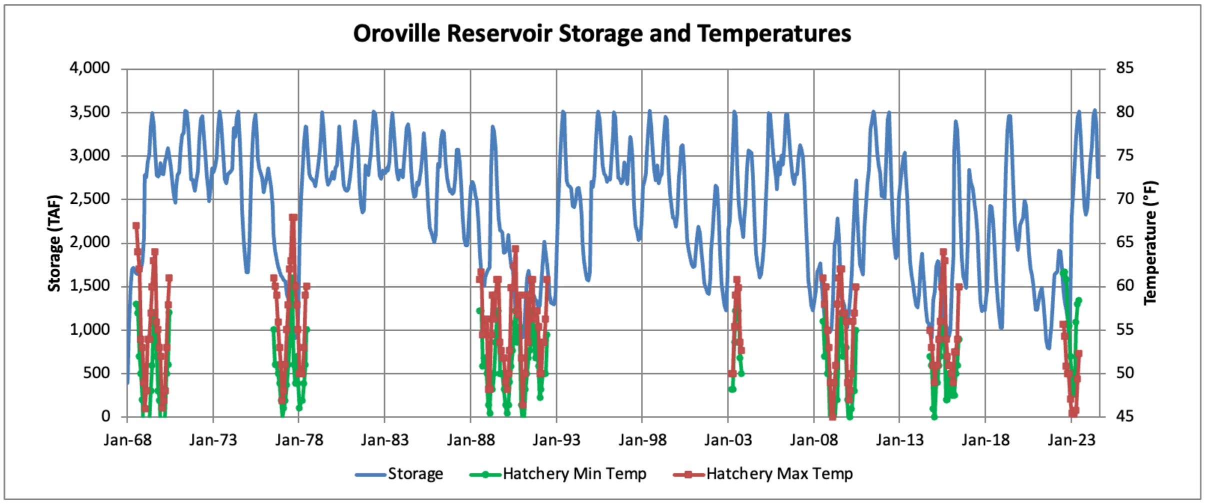
Figure H1a1-13. Measured Temperature Profiles (°C) in Oroville Reservoir in September and October

H1a1.7.3 Data

Figure H1a1-14 shows the historical monthly Oroville Reservoir storage for 1968–2024 (CDEC Station ORO). No measurements of Hyatt Powerhouse release temperatures are available. However, water temperatures have been measured at two locations approximately 5 miles downstream of Oroville Dam, at the fish hatchery and USGS Station 11407000 (Feather River at Oroville). Water temperature also has been measured about 10 miles downstream of Oroville Dam at CDEC Station FRA, near Robinson Riffle.

Daily hatchery temperatures provide a historical record of increased temperatures at low storage. A few annual hatchery reports were obtained from the California Department of Fish and Wildlife document library (CDFW 2017; CDFW 2023b). Additional monthly data were extracted from recent annual hatchery reports and provided by Feather River Fish Hatchery staff (Kastner pers. comm.).

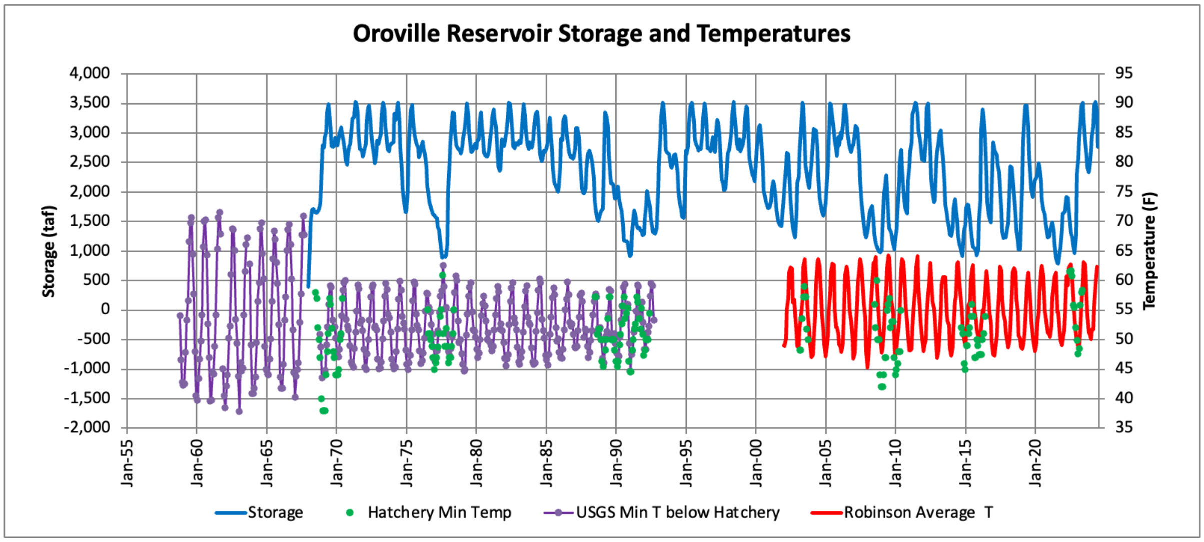
The monthly minimum and maximum of the daily temperatures for years with low storage are compared to the historical Oroville Reservoir storage data in Figure H1a1-14.



Sources: CDFW 2017; CDFW 2023b; Kastner pers. comm. ; DWR 2024 (CDEC Station ORO).
°F= degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-14. Historical Monthly Oroville Reservoir Storage (TAF) and Feather River Fish Hatchery Temperatures (°F) (1968–2024)

Figure H1a1-15 shows the monthly Oroville Reservoir storage and temperatures in the Feather River at the USGS Oroville Station (11407000) for 1958–1992, and at Robinson Riffle (CDEC Station FRA), approximately 2.5 miles upstream of the Thermalito Afterbay outlet, for 2002–2024. The data show three distinct periods. The 1958–1967 USGS temperatures indicate the natural temperatures (40–70 °F range) for Feather River at Oroville, before Oroville Reservoir was constructed and filled in 1969. The 1969–1992 USGS temperatures indicate the release temperatures at the hatchery location; construction of the dam reduced the seasonal range to between 45 and 60 °F. The 2002–2024 CDEC temperatures at Robinson Riffle are similar to the USGS temperatures at the hatchery but were slightly (2–3 °F) warmer because this station is approximately 5 miles downstream of the hatchery. Even at Robinson Riffle, maximum summer temperatures were less than 65 °F, indicating good rearing temperatures for juvenile steelhead.



Sources: DWR 2024 (CDEC Stations FRA and ORO); USGS 2017 (Station 11407000); CDFW 2017; CDFW 2023b; Kastner pers. comm.
°F = degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-15. Oroville Reservoir Storage (TAF) and Monthly Average Temperatures (°F) in the Feather River Downstream of Oroville Dam (1958–2024)

H1a1.7.4 Data Evaluation

The fish life stages with the most stringent temperature indicators likely to be affected by carryover storage in Oroville Reservoir include spring-run Chinook salmon holding in August (60 °F), spring-run Chinook salmon spawning in September (56 °F), and spring-run and fall-run Chinook salmon spawning in October (55 °F) (Table H1a1-3).

If cooler water is needed for cold water habitat, power bypass could allow access to a substantial volume of cooler water in the case of Oroville Reservoir. Hyatt Powerhouse penstocks can draw water from as low as 613 feet (^NMFS 2016d), but there is a substantial volume of cold water in Oroville Reservoir below this elevation, approximately 700 TAF (based on CDEC data for Station ORO, DWR 2025). There is a river outlet at the bottom of the reservoir at 225 feet that can release this cold water, but water released in this manner bypasses the hydropower facility, resulting in a reduction in hydropower generation. Water released from the bottom of the reservoir through the river outlet can be blended with water that passes through the powerhouse to meet downstream water temperature targets.

Figure H1a1-16 compares end-of-month Oroville Reservoir storage and average USGS temperatures (near the hatchery) during August through November for 1968–1992. Oroville Reservoir storage seems to have had little effect on release temperatures when storage was greater than about 1,500 TAF. Based on these historical data, carryover storage of approximately 1,200 TAF was sufficient for meeting temperature indicators for spring-run and fall-run Chinook salmon. The fact that August temperatures are substantially higher than the September and October temperatures may indicate operation of the temperature control structure to release warmer water when it is not expected to harm fish.

The lowest carryover storage of approximately 800 TAF occurred in 2021. During August and September of this year storage was too low for power generation. With extensive use of power bypass during July - December, temperature requirements at the fish hatchery and Robinson Riffle were met (Figure H1a1-17, DWR 2021). While power bypass may result in adequately cool temperatures at this low storage, a carryover target of 1,000 TAF would allow more power generation than if carryover storage were at 800 TAF and would potentially provide more storage for the subsequent year than a target of 800 TAF.

Figure H1a1-18 compares monthly Oroville Reservoir storage and average temperatures at Robinson Riffle in August through November for 2002-2024. Oroville Reservoir storage seems to have had little effect on Robinson Riffle temperatures during this time period. Even though Robinson Riffle temperatures are slightly (2–3 °F) warmer than release temperatures due to its location approximately five miles downstream of the hatchery, August temperatures still remained below 65 °F, which is an operational target for this location. The apparent lack of effect of reservoir storage on temperatures at Robinson Riffle may be caused by a combination of the reservoir release temperatures being obscured by variable longitudinal warming and by use of power bypass to meet temperature requirements in more recent years.

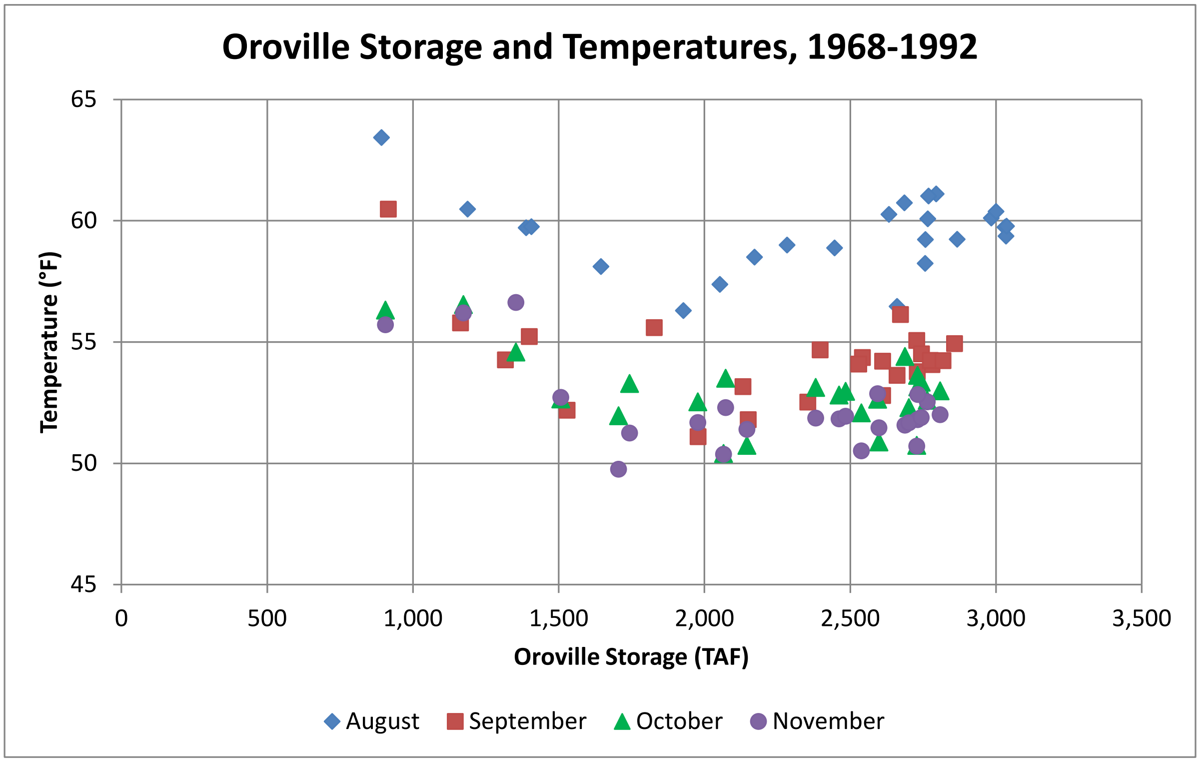
Oroville Reservoir storage seems to have had little effect on temperatures near the upstream end of the low flow channel when storage was greater than about 1,500 TAF under existing conditions (Figure H1a1-16). Increased spring releases under the flow scenarios could result in lower initial volumes of cold water such that carryover storage may need to be higher to meet temperature indicators in the absence of sufficient power bypass or other actions. Carryover storage is regularly over 1,600 TAF under existing conditions.

The December 2025 revised draft Bay-Delta Plan specifies carryover storage target ranges for Oroville Reservoir of 1,000 – 1,200 TAF for drought years and 1,200 – 1,600 TAF for all other years. As described above, a carryover storage of 1,000 TAF may permit release of sufficiently cool water temperatures when power bypass is utilized and would ensure some water availability for the next year. Historically, carryover storage of approximately 1,200 TAF was sufficient to meet temperature indicators for spring-run and fall-run Chinook salmon at the upper end of the LFC. A carryover storage of 1,600 TAF could be sufficient to have release temperatures be less than the indicator temperatures even with increased spring releases. Increased carryover storage of 1,600 TAF could also help minimize use of power bypass.

Additional measures, other than power bypass, could be taken that might improve water temperature conditions in the Feather River. If water temperatures are made more suitable for fish as a result of operational or infrastructure modifications, carryover storage requirements could be adjusted. Examples of possible measures include:

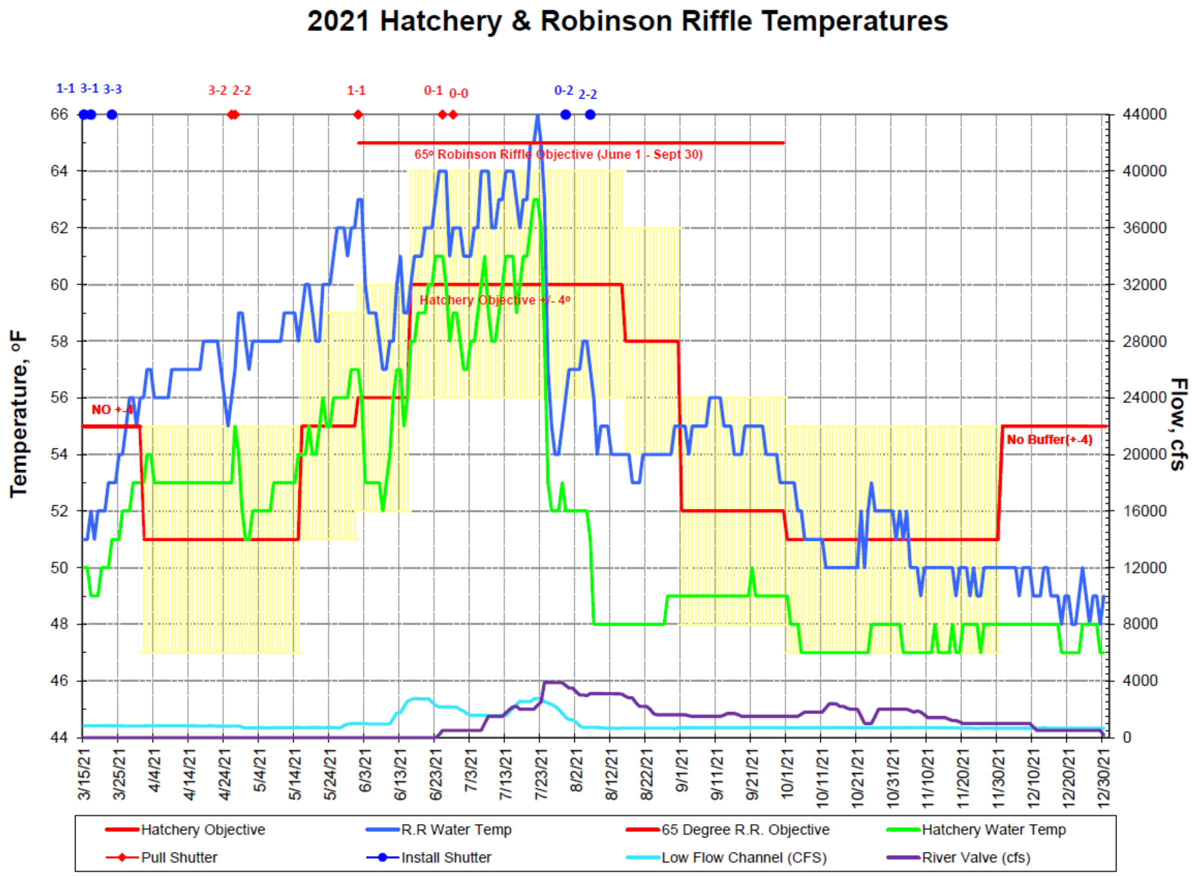
- Extending the Hyatt Powerplant intake structure deeper in Oroville Reservoir to access colder water. The NMFS Biological Opinion on the relicensing of the Oroville Facilities Hydroelectric Project concludes that "The inability of the turbines to withstand the low pressures created by operation below the 640–foot dead pool may eliminate this alternative from further consideration" (^NMFS 2016d). However, this concern may be about running water through the powerhouse when the reservoir water surface elevation is less than 640 feet and not about accessing colder water when water surface elevation is greater than 640 feet.
- Improving Palermo Canal to allow more water through the outlet works that are relatively deep in the reservoir (drawing water from approximately 550 feet). Some of this cold water could be conveyed through a pipeline to the Feather River (^NMFS 2016d).
- Adding an alternative outlet to Thermalito Afterbay that would return water to the Feather River downstream of the existing outlet location (^NMFS 2016d)
- Implementing one of several possible infrastructure projects to speed the passage of water from Thermalito Powerplant back to the Feather River, thereby reducing warming that the water would experience in the afterbay (^NMFS 2016d),

- Increasing flow through the LFC if usable habitat in the LFC is not substantially reduced.



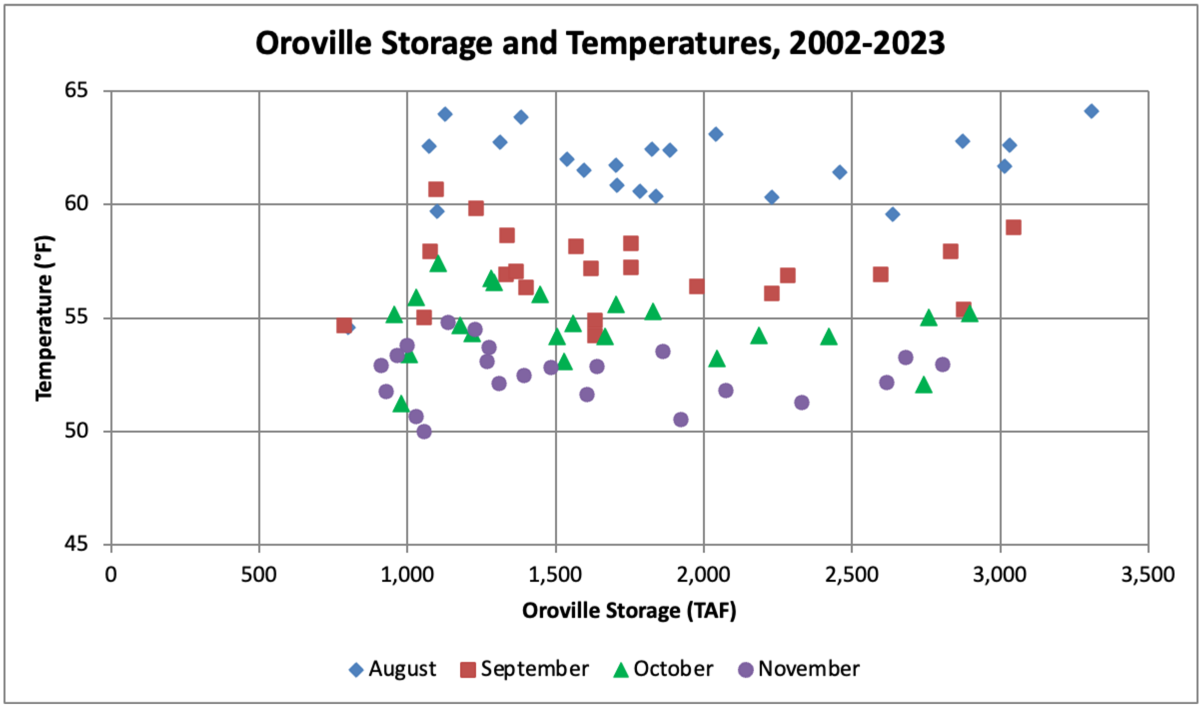
Sources: DWR 2024 (CDEC Station ORO); USGS 2017 (Station 11407000).
°F = degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-16. Historical Monthly Average River Temperatures (°F) near the Feather River Fish Hatchery Compared to Oroville Reservoir Storage (TAF) for August through November (1968–1992)



Source: DWR 2021.
°F = degrees Fahrenheit
cfs = cubic feet per second

Figure H1a1-17. Feather River Hatchery and Robinson Riffle Temperature Operations in 2021



Sources: DWR 2024 (CDEC Station ORO and FRA).
°F = degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-18. Monthly Average River Temperatures (°F) near at Robinson Riffle Compared to Oroville Reservoir Storage (TAF) for August, September, October, and November (2002–2023)

H1a1.8 Lake Berryessa

H1a1.8.1 Infrastructure and Geography

Monticello Dam captures water from the Putah Creek watershed to form Lake Berryessa. Monticello Dam has a base elevation of approximately 252 feet, with a volume of 1,551 TAF at the spillway elevation of 440 feet based on the storage-elevation curve received from the Solano County Water Agency (SCWA 2024). The penstock to the powerhouse at the dam is near the base of the dam, so only the coldest water is released to lower Putah Creek unless the water level is high enough to overtop the glory hole spillway. The penstock to the powerhouse is at an elevation of approximately 255 feet (Reclamation 1959), so the maximum water depth above the penstock intake elevation is about 185 feet.

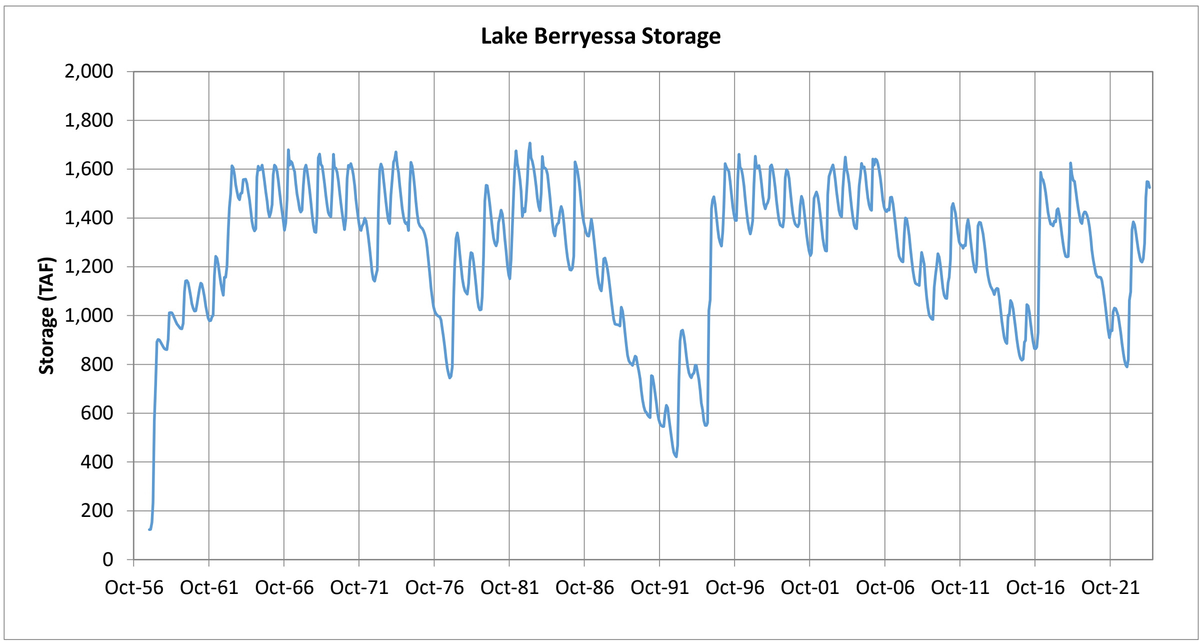
Resident rainbow trout live in the 6-mile inter-dam reach between Monticello Dam and Putah Diversion Dam. Anadromous fish can swim only as far upstream as Putah Diversion Dam. Small numbers of fall-run Chinook salmon spawn downstream of Putah Diversion Dam (Willmes et al. 2021). Adult salmon are blocked by the Los Rios Check Dam in the Yolo Bypass until the dam is removed, typically in October or November (Davis 2021), although plans are being considered for providing earlier creek access to these adults (Davis Enterprise 2024).

H1a1.8.2 Other Studies

Jones & Stokes (1996) developed an hourly water temperature model for Putah Creek below Putah Diversion Dam. For that analysis, temperature recorders were placed in the creek during summers of 1993 and 1994, when the storage dropped to approximately 750 TAF and 550 TAF, respectively (Figure H1a1-19). The average daily water temperatures below Putah Diversion Dam were relatively constant, about 12–13 °C (53.6–55.4 °F) during June–September in 1993, with a diel variation of 1–4 °C (2–7 °F). The average daily water temperatures were 13–14 °C (55.4–57.2 °F) during the June–September 1994, with a diel variation of 2–4 °C (3–7 °F).

H1a1.8.3 Data

Figure H1a1-19 shows the monthly historical Lake Berryessa storage pattern for water years 1957–2024 (CDEC Station BER). The storage was reduced to about 750 TAF in 1977 and was reduced to about 400 TAF in 1992; storage during the 2014–2015 and 2021–2022 droughts remained approximately at or above 800 TAF.



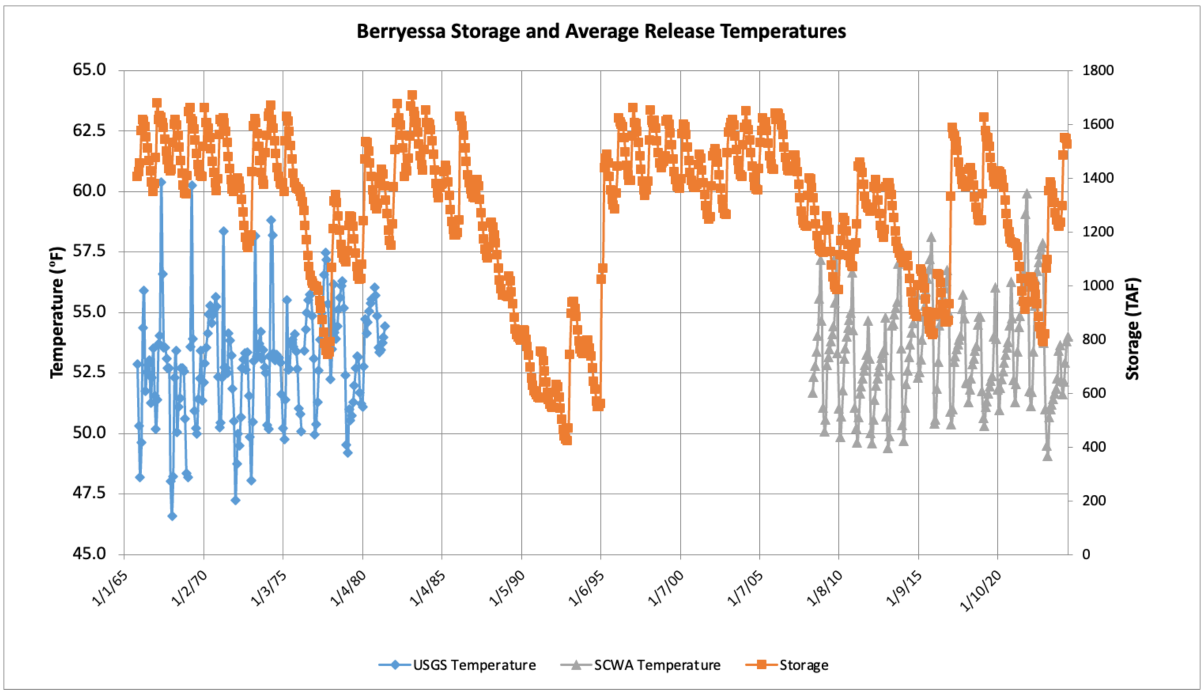
Source: DWR 2024 (CDEC Station BER).
TAF = thousand acre-feet

Figure H1a1-19. Monthly Historical Lake Berryessa Storage (TAF) (1957–2024)

From 1965 to 1980, the Lake Berryessa release temperatures were measured (daily minimum and maximum reported) at the USGS station approximately 1.3 miles downstream of Monticello Dam (Station 11454000, Putah Creek near Winters). From 2008 to 2024, Lake Berryessa reservoir temperature profile measurements were taken by SCWA; the deepest measurements were from 70-feet below the surface and represent temperatures closest to what might be expected in the reservoir releases. Temperatures at the USGS gage and 70-feet deep in the reservoir indicate conditions experienced by the resident rainbow trout downstream of Monticello Dam, but temperatures are expected to be warmer downstream of Putah Diversion Dam by about 3.6 °F in the summer (Jones & Stokes 1996).

Figure H1a1-20 shows the monthly average USGS and SCWA temperatures compared to the end-of-month storage value for 1965–2024. The daily temperatures normally reflect the release temperatures, except for periods with runoff from a local creek (Cold Creek) that likely raised the daily temperatures. Cold Creek is ephemeral and does not affect temperatures in late summer and early fall. The measured temperatures may also increase when the reservoir is full and water from the surface spills through the glory hole. The SCWA temperature measurements from 70-feet deep are also shown in Figure H1a1-20.

The average release temperatures in January and February were usually about 51 °F or lower, but January through February temperatures were about 52 °F or greater in 1970, 1978, and 1980, indicating that warmer winter inflow could have contributed to the release temperatures in summer and fall of these years being warmer than in most other years and that the winter inflow temperatures may contribute to some of the variability in late summer and fall release temperatures. The seasonal warming of the release temperatures was usually small; the summer release temperatures were about 52–56 °F in many years. The measured seasonal warming was greatest in 1977, when the storage was reduced from 1,000 to 750 TAF, and again in 2022 when storage was reduced to 790 TAF.



Sources: USGS 2017 (Station 11454000); DWR 2024 (CDEC Station BER); SCWA 2024.
°F= degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-20. Monthly Lake Berryessa Storage (TAF), Average USGS Release Temperatures (°F), and Average SCWA Temperatures at 70-Foot Depth near Monticello Dam (1965-2024)

H1a1.8.4 Data Evaluation

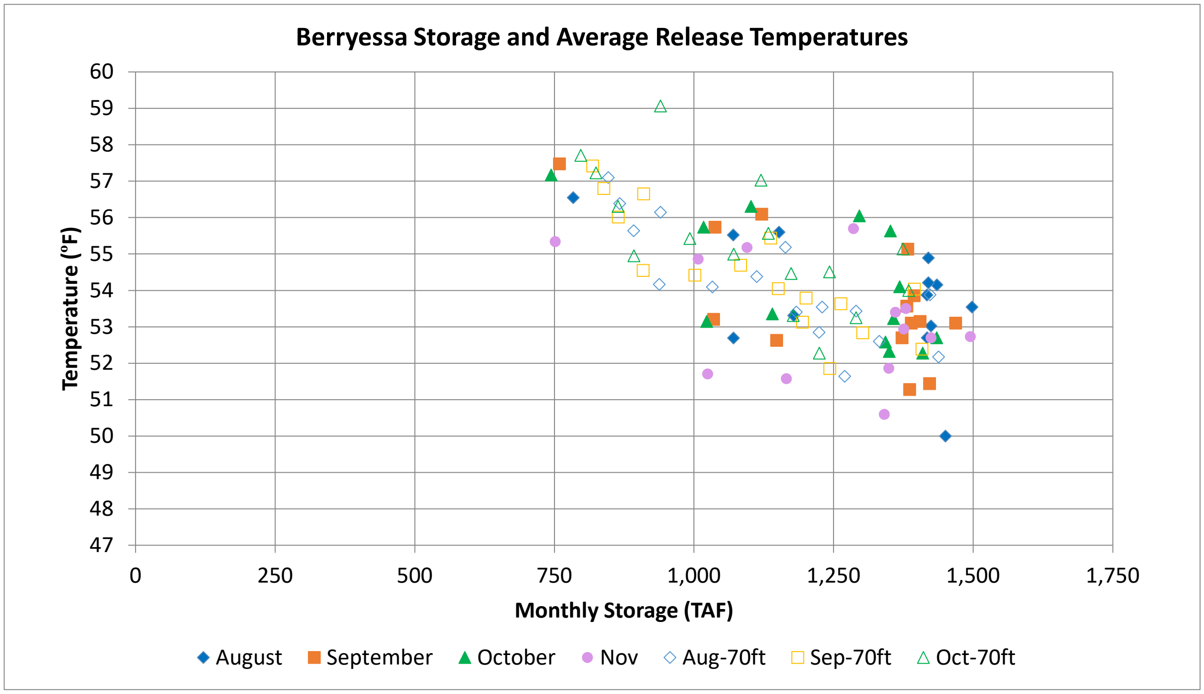
Figure H1a1-21 shows the end-of-month storage levels compared to the monthly average August–November temperatures measured by the USGS downstream of Monticello Dam during 1966–1980 and the monthly average temperatures measured by SCWA at 70-foot depth in Lake Berryessa near Monticello Dam during 2008-2023. The data indicate an increase in release temperature at the lowest storage levels (less than 1,000 TAF). November temperatures from 70-feet deep in the reservoir are not shown in the graph because they are starting to become warmer than the release temperatures and make the graph difficult to read. In November the thermocline is likely extending deeper in the reservoir and affecting the temperatures 70 feet below the surface.

There are no temperature indicators for fish specific to Putah Creek. Therefore, the composite temperature indicators at the bottom of Table H1a1-3 were used to assess Lake Berryessa storage. As observed for other reservoirs, temperature indictors would be most difficult to obtain in October when water temperatures of 56 °F or lower are needed to provide for Chinook salmon spawning and incubation (Figure H1a1-21). Because fall-run Chinook salmon could wait until water temperatures drop before spawning, meeting the resident rainbow trout rearing indicator of 65°F (same indicator as for steelhead) could be a more realistic and important outcome.

Based on the measured data, average monthly release temperatures occasionally exceeded the 56 °F October temperature indicator even when storage was greater than 1,000 TAF. Considering the total reservoir storage capacity of 1,551 TAF, it would be difficult to maintain carryover storage at a level that could guarantee release temperatures below 56 °F in October, especially when considering the warming that would occur between Monticello Dam and the Putah Diversion Dam, the upstream limit of anadromy.

Due to data limitations and the effect of variable winter meteorological conditions, it is unclear at exactly what point the cold water pool would be lost. Based on the plateau of release temperatures at 1,000–1,350 TAF, 1,000 TAF may be an appropriate estimate of a storage level that could protect the cold water pool.

The December 2025 revised draft Bay-Delta Plan specifies carryover storage target ranges for Lake Berryessa of 500 – 700 TAF for drought years and 700 – 1,000 TAF for all other years. Lake Berryessa storage dropped below 500 TAF on only one occasion, in 1992. The effect of a 500 TAF storage level on water temperature suitability for the resident rainbow trout below the dam is uncertain. Carryover storage of 700 TAF would ensure sufficiently cool water (temperature indicators below 65 °F) for the resident rainbow trout below Monticello Dam (Figure H1a1-21). Carryover storage of 1,000 TAF would provide suitable temperatures for resident rainbow trout for a greater distance below the dam and potentially could provide suitable conditions for fall-run Chinook spawning below the Solano Irrigation Dam as early as September in some years (56 °F, Figure H1a1-21).



Sources: USGS 2017 (Station 11454000); DWR 2024 (CDEC Station BER); SCWA 2024.
°F = degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-21. Lake Berryessa Storage (TAF) Compared to Release Temperatures (°F) in August–November (1966–1980; filled markers) and in August–October at 70-foot Reservoir Depth (2008–2023; unfilled markers)

H1a1.9 New Hogan Reservoir

H1a1.9.1 Infrastructure and Geography

New Hogan Reservoir captures water from the Calaveras River watershed. The maximum storage in New Hogan Reservoir is about 317 TAF, with a water surface elevation of approximately 713 feet. The outlet, with an intake invert elevation of 535 feet (USACE 1983), is very close to the bottom of the reservoir at 530 feet. Old Hogan Dam, with a crest elevation of 633 feet and outlets at multiple elevations, is still standing upstream of New Hogan Dam (USACE 1983).

Downstream of New Hogan Dam, much of the flow in the river is diverted at Bellota resulting in several possible pathways for the water to reach the San Joaquin River: through Mormon Slough, through the Old Calaveras River, and through a combination of the upper portion of Mormon Slough, the Stockton Diverting Canal, and the lower portion of the Old Calaveras River (SEWD and FISHBIO 2019). The section of river between New Hogan and Bellota generally has year-round flow, but flow downstream of Bellota is unreliable (SEWD and FISHBIO 2019). Mormon Slough and the Stockton Diverting Channel now provide better passage opportunities and are the principal migration routes for salmonids (SEWD and FISHBIO 2019). Migrating fish encounter many impediments in the Calaveras River, but efforts are underway to improve upstream and downstream passage (SEWD and FISHBIO 2019).

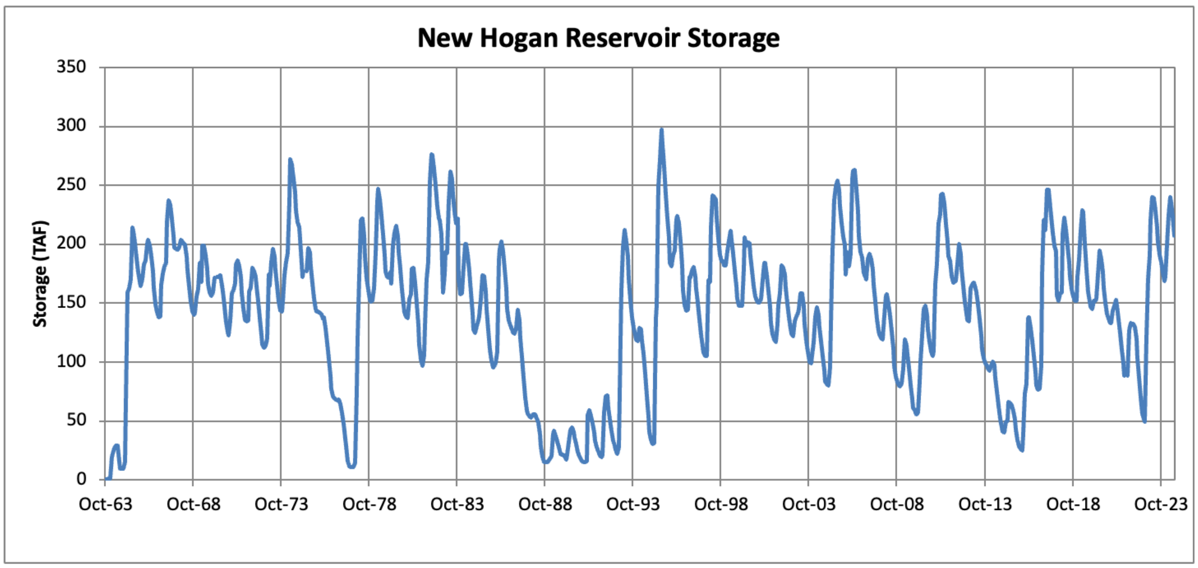
H1a1.9.2 Other Studies

A temperature model for the Calaveras River below New Hogan Dam was suggested to facilitate an adaptive management approach to managing release flows and temperatures (^Stillwater Sciences 2004).

H1a1.9.3 Data

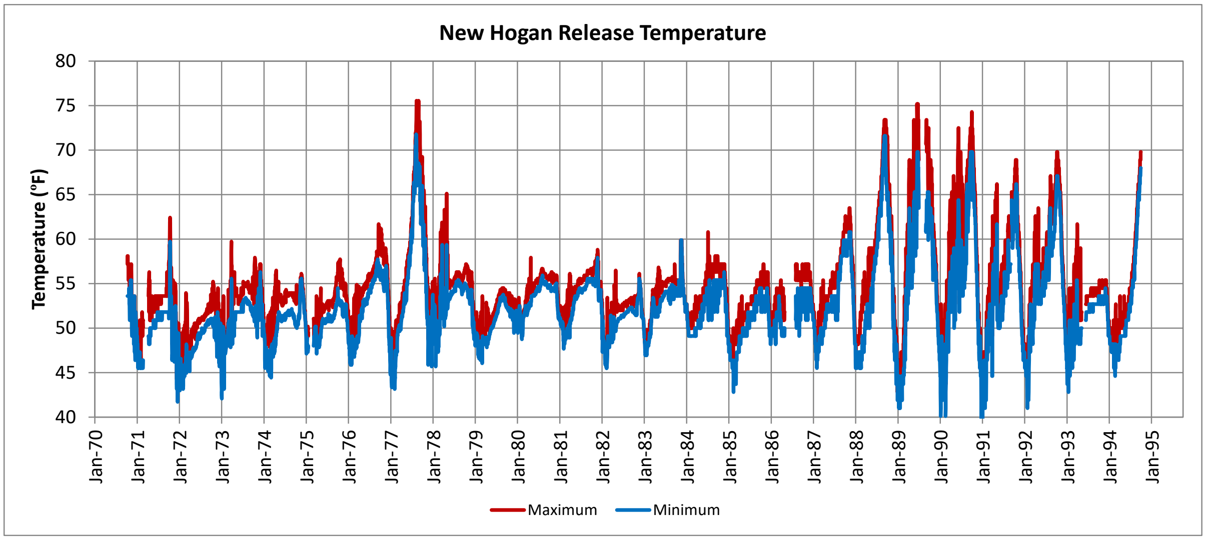
Figure H1a1-22 shows the historical New Hogan Reservoir storage for 1963–2024 (CDEC Station NHG). The minimum storage of about 11 TAF occurred in 1977, and storage was intermittently less than 25 TAF in 1988–1992. Although the maximum storage is about 325 TAF, the reservoir has rarely been filled to more than 250 TAF. Data suggest that the seasonal inflow pattern, the flood-control storage curve, and the releases for water supply prevent the reservoir from filling in most years.

Figure H1a1-23 shows the historical daily minimum and maximum water temperatures measured by USGS in the Calaveras River below New Hogan Reservoir from 1970 to 1994 (USGS Station 11308900 Calaveras River, 0.7 mile below New Hogan Dam). Because the outlet is very close to the bottom of the reservoir, the daily maximum temperatures usually remain cold, less than 60 °F, unless storage drops substantially below 100 TAF.



Source: DWR 2017 and 2024 (CDEC Station NHG).
TAF = thousand acre-feet

Figure H1a1-22. New Hogan Reservoir Storage (TAF) (1963–2016)



Source: USGS 2017 (Station 11308900).
°F = degrees Fahrenheit

Figure H1a1-23. Historical Daily Water Temperatures (°F) in the Calaveras River below New Hogan Reservoir (1970–1994)

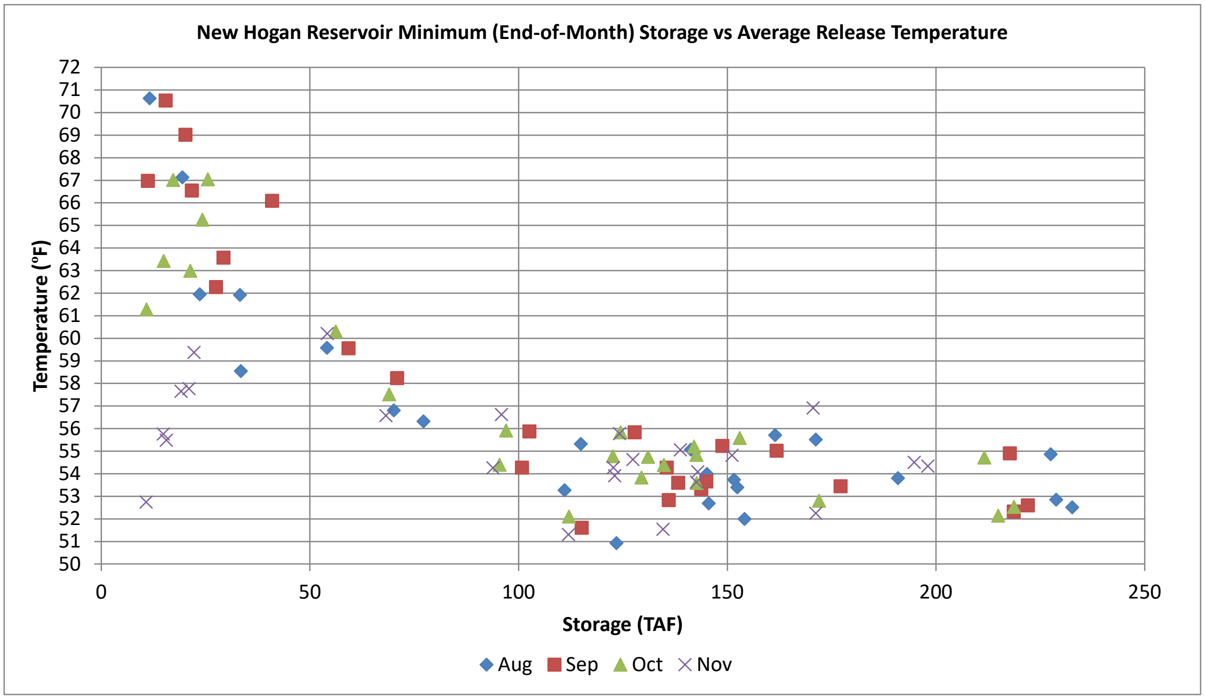
H1a1.9.4 Data Evaluation

The Calaveras River below New Hogan Dam has been used opportunistically by steelhead and fall-run Chinook salmon and is within the Central Valley steelhead Distinct Population Segment (DPS) and designated critical habitat for this species (SEWD and FISHBIO 2019).

Figure H1a1-24 shows the average release temperature for August, September, October, and November compared to the monthly minimum (end-of-month) storage. New Hogan Reservoir release temperatures are remarkably cool for a reservoir of its size and southern location. The low temperatures occur despite the relatively small size of the reservoir because the reservoir is fairly deep; at a storage level of 100 TAF, the water surface elevation is approximately 645 feet, which is about 110 feet above the river outlet at 535 feet.

There are no temperature indicators for fish specific to the Calaveras River. Therefore, the composite temperature indicators at the bottom of Table H1a1-3 were used to assess New Hogan Reservoir storage. The reservoir storage levels needed to meet these water temperature indicators would be highest in October (and November in this case) when water temperatures of 56 °F or lower are needed to meet the requirements for Chinook salmon spawning and incubation (Figure H1a1-24). Temperatures below the dam may often be suitable for fall-run Chinook salmon spawning, and limited upstream fish passage may be the primary factor currently limiting steelhead and Chinook salmon populations in the Calaveras River (^Stillwater Sciences 2004).

Average August–October release temperatures remain below 56 °F even when storage is as low as 100 TAF. At storage levels below 100 TAF, temperatures increase markedly. The temperature data indicate the presence of a cold water pool at storage levels of 100 TAF and above; reservoir release temperature is minimally affected by storage if storage is greater than 100 TAF and average August–October release temperatures remained below 56 °F even when storage was as low as 100 TAF (Figure H1a1-24). Based on this analysis, it appears that a carryover target of 100 TAF may be sufficient for maintaining temperatures below 56 °F for opportunistic use of the Calaveras River for fall-run Chinook salmon spawning.



Source: USGS 2017 (Stations 11308700 and 11308900).
°F= degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-24. New Hogan Storage (TAF) Compared to Release Temperatures (°F) for August through November (1970–1994)

Historical carryover storage in New Hogan Reservoir typically has been close to or above 100 TAF during average or wet conditions but has dropped substantially below 100 TAF during dry conditions such as the late 1970s, late 1980s/early 1990s, and most recent droughts (Figure H1a1-22). At storage levels below 100 TAF, temperatures increase markedly. However, when storage is at 50 TAF, August through November temperatures remain at about 60 °F and are still suitable for juvenile steelhead rearing and Chinook migration. At this lower storage level, fall-run Chinook salmon could wait until later in the fall for water temperatures to become sufficiently cool for spawning. The December 2025 revised draft Bay-Delta Plan specifies carryover storage target ranges for New Hogan Reservoir of 50 TAF for drought years and 50 – 100 TAF for all other years.

H1a1.10 Camp Far West Reservoir

H1a1.10.1 Infrastructure and Geography

Camp Far West Reservoir captures water from the Bear River, a tributary to the Feather River. The capacity of Camp Far West Reservoir (105 TAF) is relatively small compared to the watershed runoff (average of 472 TAF/yr, Table H1a1-2). The dam has a powerhouse intake with an invert elevation of 197 feet and a low-level intake (river outlet) with an invert elevation of 175 feet, about 25 feet above the bottom of the reservoir. The powerhouse intake and low-level intake are supplied by intake towers that are 22 feet and 25 feet high, respectively (SSWD 2016). Approximately one mile downstream of Camp Far West Dam, South Sutter Water District (SSWD) has a diversion dam that marks the upstream extent of anadromy.

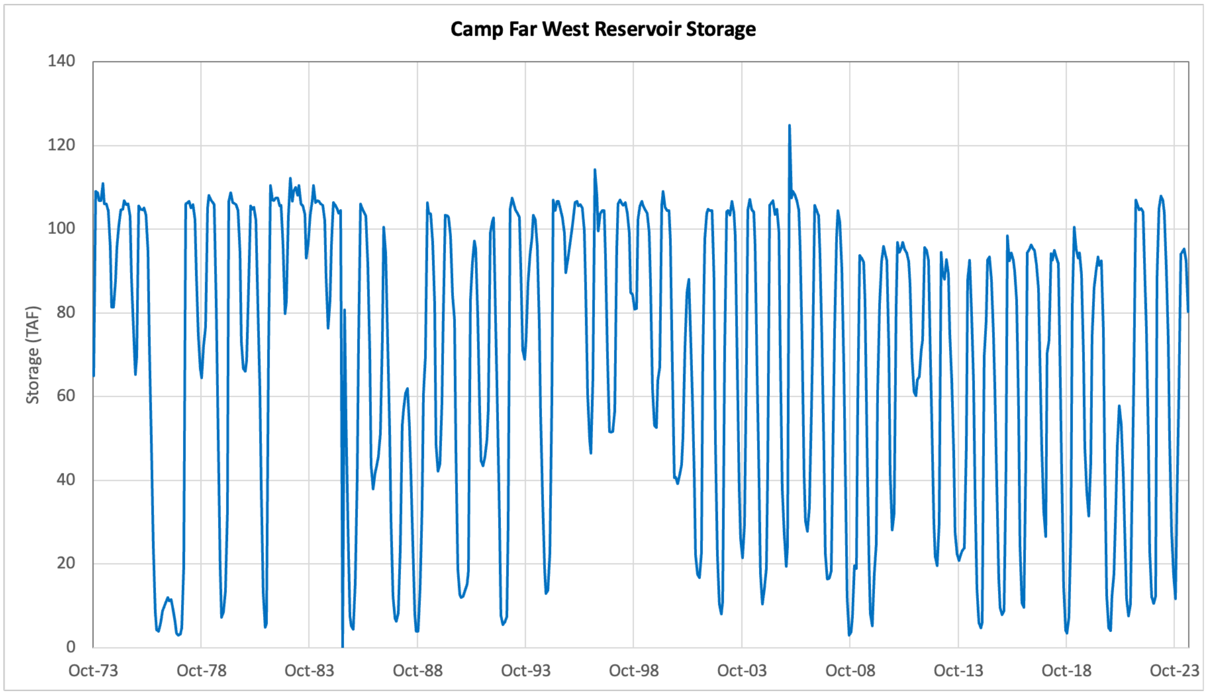
H1a1.10.2 Other Studies

The Bear River is used intermittently by steelhead/rainbow trout and fall-run Chinook salmon, particularly in the spring (Janes et al 2018 and SSWD 2018b). Temperatures in the Bear River are not optimal for anadromous fish (USFWS 1995; Jones & Stokes 2005). Both USFWS (1995) and Jones & Stokes (2005) describe other inadequacies of the Bear River for anadromous fish, including inadequate stream flow, excessive fine sediment, and lack of spawning gravel. However, USFWS has not ruled out successful use of the Bear River by anadromous fish (USFWS 1995). When fall flows are high, some Chinook salmon have been observed to successfully reach spawning areas; between 1978 and 1986, estimates of Chinook salmon adults spawning in the lower Bear River ranged from zero or 1 in years of low fall flows and up to 300 in years with exceptionally high fall flows (1982–1984) (USFWS 1995).

SSWD has completed multiple studies for the relicensing of Camp Far West Hydroelectric Project including water temperature and fish studies (SSWD 2016, SSWD 2018a; SSWD 2018b). The evaluation of Camp Far West Reservoir in this appendix is largely based on this information from SSWD.

H1a1.10.3 Data

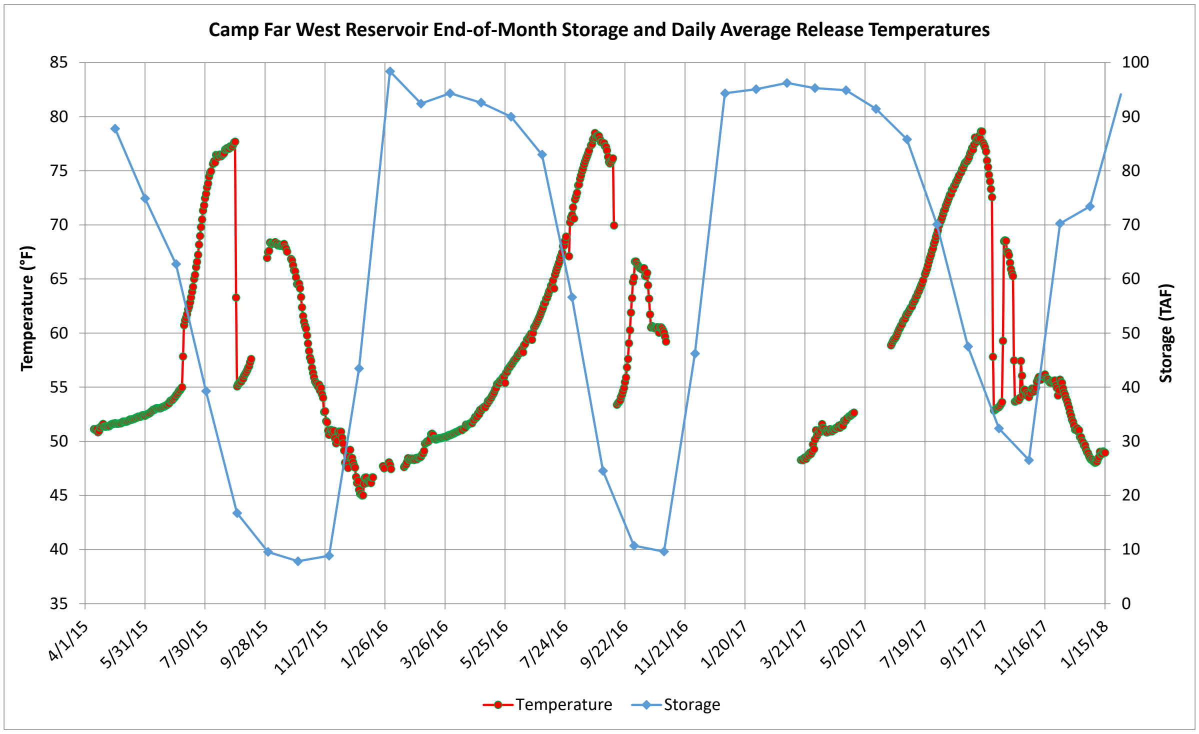
Operation of Camp Far West Reservoir is similar to operation of Black Butte Reservoir in that storage (CDEC Station CFW) is typically drawn down to very low levels in the fall. In many years, storage in Camp Far West Reservoir is drawn down to less than 20 TAF (Figure H1a1-25), which corresponds to a lake elevation of approximately 240 feet (SSWD 2016).



Source: DWR 2017 and 2024 (CDEC Station CFW).
TAF = thousand acre-feet

Figure H1a1-25. Historical Storage (TAF) in Camp Far West Reservoir (1973–2024)

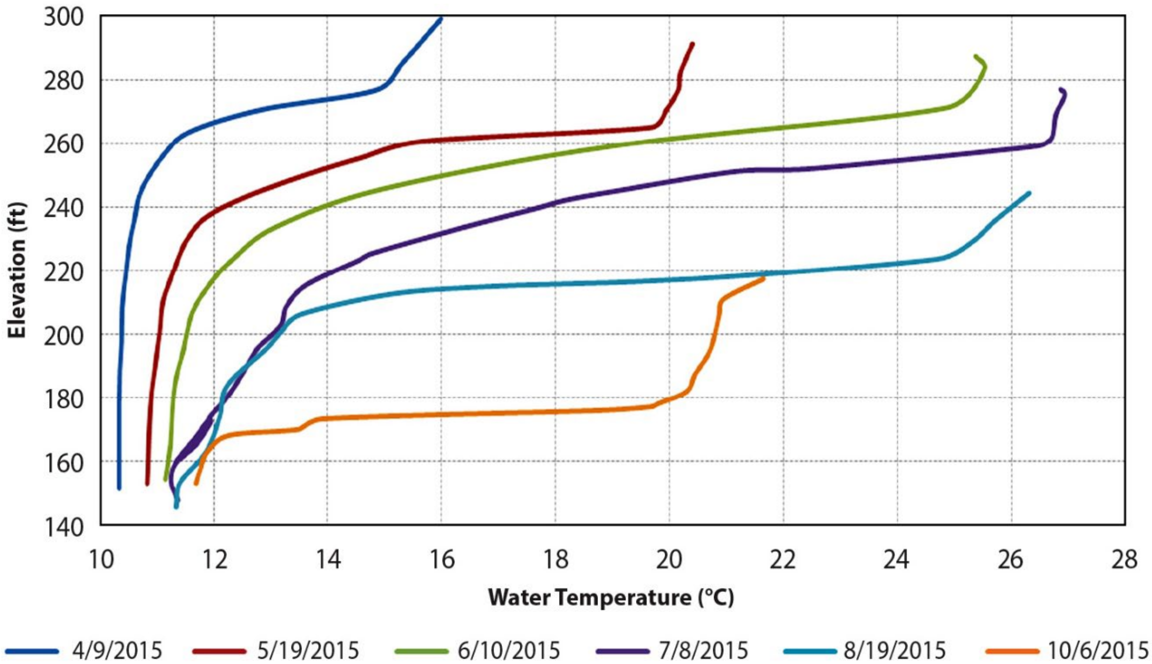
Daily water temperature measurements taken below the Bear River powerhouse by SSWD from 2015 through 2017 were downloaded from SSWD's web site (SSWD 2021). The average temperatures in August were above 70 °F in all three years (Figure H1a1-26), exceeding the temperature indicator (Table H1a1-3) for juvenile steelhead rearing.



Source: DWR 2017 and 2024 (CDEC Station CFW); SSWD 2021
°F= degrees Fahrenheit
TAF = thousand acre-feet

Figure H1a1-26. End-of-Month Storage (TAF) in Camp Far West Reservoir and Daily Average Temperatures Below the Powerhouse (2015–2017)

SSWD collected reservoir temperature profiles near the Camp Far West Dam during 2015–2017 (SSWD 2016 and 2018a). Even at a storage of 20 TAF, there can be strong stratification in the reservoir. For example, on August 19, 2015, storage was slightly greater than 20 TAF (i.e., water surface elevation slightly greater than 240 feet) and a strong temperature gradient was present. Even when the reservoir was down to approximately 10 TAF on October 6, 2015, a strong temperature gradient was still present (Figure H1a1-27). However, the volume of colder water is small. Release temperatures roughly track air temperatures in the fall except briefly after the switch from the power intake to the river intake, resulting in a short period of cold releases until the cold water is depleted (Figure H1a1-26).



Source: SSWD 2016, Figure 3.2.2-36.
°C = degrees Celsius
ft = feet

Figure H1a1-27. Water Temperature (°C) Profiles Measured in Camp Far West Reservoir by South Sutter Water District during 2015

H1a1.10.4 Data Evaluation

The type of analysis used for other reservoirs cannot be used for Camp Far West Reservoir because there is no long record of water temperature data collected below Camp Far West Dam. Water temperature data collected below Camp Far West Dam from 2015 to 2018 were used to assess temperatures in the river relative to reservoir storage.

Based on available (2015 – 2017) water temperature measurements (Figure H1a1-28), August temperatures are unsuitable for steelhead rearing (indicator of 65 °F [18.3 °C]) and September and October temperatures are unsuitable for Chinook spawning (indicators of 56 °F [13.3° C]). Temperature indicators specified for the Bear River at Highway 70 (Table H1a1-3), approximately 14.5 miles downstream of the Camp Far West Dam, are higher than the 56 °F Chinook spawning indicator and include a 65 °F indicator for September and a 60 °F decreasing to 57 °F indicator for October. During 2015–2017, these higher indicators were often not even met below Camp Far West Dam, where water would be cooler than at Highway 70.

Large alterations to Camp Far West Reservoir operations that substantially increase reservoir carryover storage are unlikely to improve water temperatures sufficiently such that temperatures could regularly be suitable downstream of the Camp Far West Dam for steelhead rearing in the summer and fall-run Chinook salmon spawning in September and October. Average monthly temperatures below Camp Far West Dam were approximately 65 °F in July of 2015, 2016, and 2017, when end of month storage was approximately 40 TAF, 55 TAF, and 70 TAF, respectively (i.e., moderately high for this 105-TAF capacity reservoir). These July values indicate that moderate reductions in reservoir releases in subsequent months would likely not produce steelhead rearing temperatures of 65 °F in August, the hottest month with 2015–2017 averages of 73 °F–76 °F, or spawning temperatures less than 56 °F in September and October, which during 2015–2017 remained above 65 °F until mid-October except when there were briefly cooler temperatures associated with the transition to use of the river outlet. Water temperatures might be suitable for fall-run Chinook salmon in November due to cooler meteorological conditions.

Due to the relatively small storage capacity in Camp Far West Reservoir (105 TAF) compared to the watershed runoff and consumptive use, the likelihood of using this reservoir to provide more than intermittent cold water habitat for steelhead rearing or Chinook spawning is low. The December 2025 revised draft Bay-Delta Plan specifies carryover storage target ranges for Camp Far West Reservoir of 10–20 TAF for drought years and 20–50 TAF for all other years. These carryover storage ranges were based roughly on historical operations after 1984.

Source: SSWD 2018a, Figure 4.
°C = degrees Celsius

Figure H1a1-28. Daily Average Water Temperature and Flow in the Bear River downstream of Camp Far West Dam and Daily Average Air Temperature near Camp Far West Dam Measured by South Sutter Water District (2015–2017)

H1a1.11 Whiskeytown Reservoir

H1a1.11.1 Infrastructure and Geography

Whiskeytown Reservoir is a relatively small reservoir with a capacity of 241 TAF. It receives inflow from Clear Creek and water transferred from the Trinity River watershed via the Clear Creek Tunnel into the Judge Francis Carr Powerplant. Water is released from Whiskeytown Reservoir to Clear Creek and the Spring Creek Powerhouse, which discharges into Keswick Reservoir on the Sacramento River.

Two temperature control curtains are present in Whiskeytown Reservoir. One located near Oak Bottom reduces mixing between colder Trinity River water entering Whiskeytown at the Judge Francis Carr Powerplant and the warmer surface water in the reservoir, thereby helping to maintain lower temperatures in the bottom of the reservoir (Vermeyen 1997). The other is in front of the Spring Creek Powerplant intake and helps to restrict entrainment of warmer surface water through the powerhouse (Vermeyen 1997), thereby helping to lower temperatures in the Sacramento River where the Spring Creek Powerplant releases water to Keswick Reservoir.

The invert of the Spring Creek tunnel intake is at 1,075 feet (Reclamation 2022). Water can be released from Whiskeytown Reservoir to Clear Creek from three intakes, a spillway at 1,210 feet, an upper-level dam intake with an invert at 1,110 feet, and a lower-level dam intake near the bottom of the reservoir at invert elevation of 972 feet (Reclamation 2022).

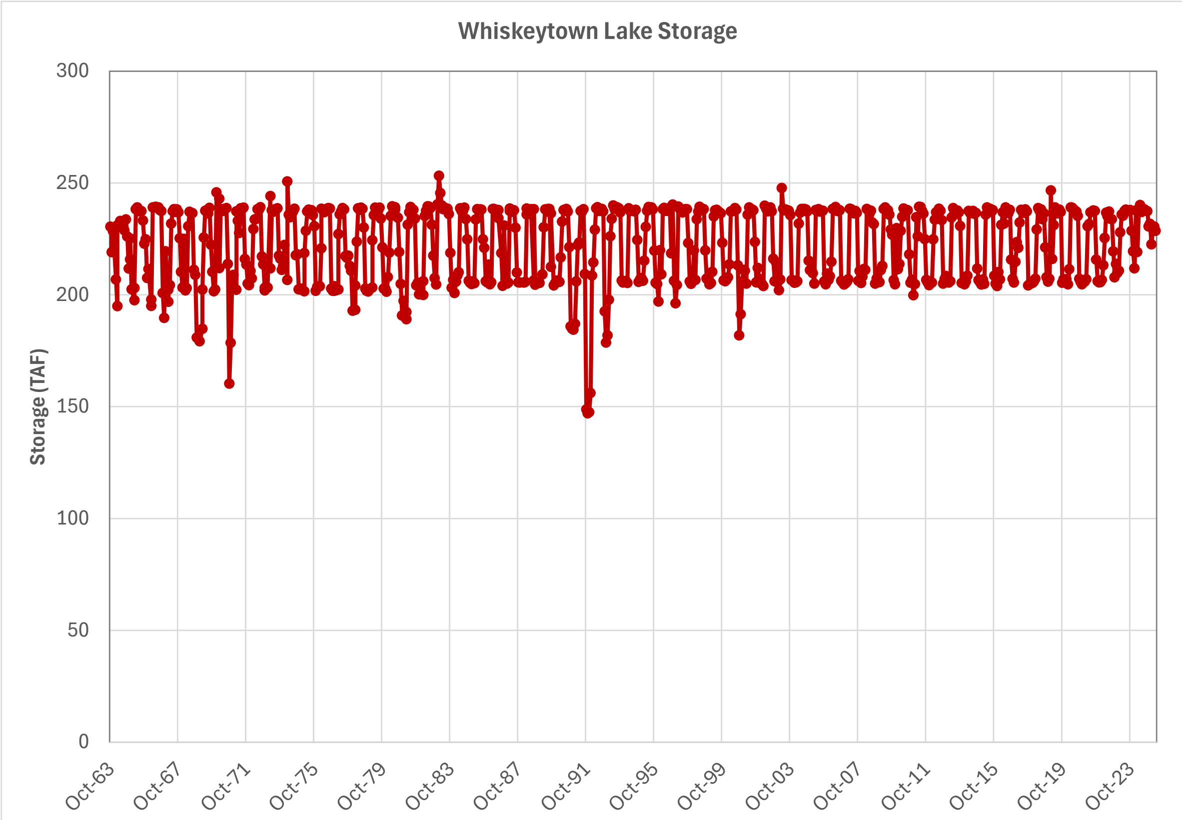
H1a1.11.2 Other Studies

Water temperature in Whiskeytown Reservoir has been modeled extensively, often as part of larger modeling efforts to evaluate water temperature in the Trinity and Sacramento Rivers. Modeling of Whiskeytown Reservoir water temperature started in the 1990s with both physical and numerical modeling (Vermeyen 1997; Deas and Lowney 2000) and has extended to recent years (Reclamation 2022).

H1a1.11.3 Data

Figure H1a1-29 shows the monthly historical Whiskeytown Reservoir storage pattern for water years 1964–2025 (CDEC Station WHI). The reservoir is more of a reregulating reservoir than a major storage facility and storage is typically maintained at a relatively high median value of 230 TAF with November to January typically having the lowest storage (Figure H1a1-29).

Carryover storage in Whiskeytown Reservoir has ranged from a minimum of approximately 210 TAF to a maximum of approximately 240 TAF. While minimum historical carryover storage is approximately 210 TAF, storage has dropped below 210 TAF in subsequent months. The minimum historical storage of approximately 150 TAF occurred in October – December of 1991.



Source: DWR 2025 (CDEC Station WHI)

Figure H1a1-29. Historical Monthly Whiskeytown Lake Storage (TAF) (1964–2025)

H1a1.11.4 Data Evaluation

The carryover storage target ranges for Whiskeytown Reservoir are 200 - 210 TAF for drought years and 210 – 240 TAF for all other years (December 2025 revised draft Bay-Delta Plan). These ranges are based on historical operations and would not interfere with existing operations or temperature control benefits. As part of Reclamation's development of a long-term temperature management strategy, Reclamation may propose for the Board's approval that Whiskeytown Reservoir does not require carryover storage levels or levels within this range to maintain temperature management on Clear Creek, while avoiding redirected impacts to the Trinity River.

H1a1.12 Camanche and Pardee Reservoirs

H1a1.12.1 Infrastructure and Geography

Pardee and Camanche Reservoirs are operated jointly to manage temperature in the Mokelumne River. As such, these reservoirs are discussed together and the operations of both reservoirs should be addressed in the same temperature management strategy.

Pardee Reservoir is a relatively small reservoir (capacity of 204 TAF) that receives inflow from the Mokelumne River. Pardee Dam is approximately 11 miles upstream of the Camanche Dam, and much of the reach between the two dams is inundated by Camanche Reservoir. Pardee and

Camanche Reservoirs are operated by East Bay Municipal Utility District (EBMUD). There is no fish passage around Camanche Dam.

EBMUD diverts water from Pardee Reservoir through the Pardee tower aqueduct intake. The tower intake gates are relatively high in the reservoir at approximately 460 – 550 feet elevation; the spillway crest is at approximately 568 feet and the lowest discharge pipe through Pardee Reservoir is at approximately 260 feet (Bray 2014). The high elevation of the Pardee tower intake necessitates relatively high storage and helps preserve the cold water pool. Pardee Reservoir storage is typically maintained at a relatively high median value of 190 TAF (Figure H1a1-30).

With a capacity of 417 TAF, Camanche Reservoir can store approximately twice as much water as Pardee Reservoir. Releases through Camanche Dam occur through a high-level and a low-level outlet with intakes at approximately 203 feet and 102 feet elevation, respectively (Bray 2014).

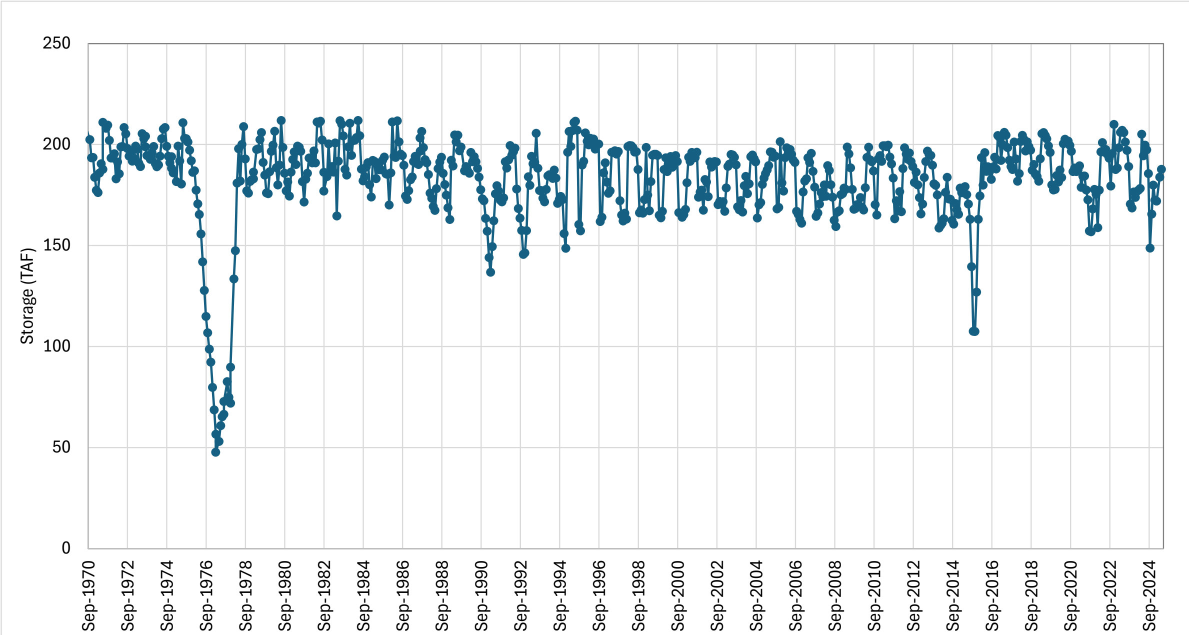
H1a1.12.2 Other Studies

EBMUD operates Camanche Reservoir in adherence with the Joint Settlement Agreement (JSA) and the Water Quality and Resource Management Program (WQRMP) (Lower Mokelumne River Partnership 1996 and 1999) and has performed many studies of water temperature and fish habitat in the Mokelumne River. One performance criterion of the WQRMP is to maintain at least 28 TAF of hypolimnetic volume of water colder than 16.4 °C (61.5 °F) in Camanche Reservoir whenever total storage in Pardee Reservoir is greater than 100 TAF (Lower Mokelumne River Partnership 1999). EBMUD has determined that this criterion is often met under existing conditions when Camanche Reservoir water surface elevation is greater than 190 feet at the end of October, which corresponds to a storage of approximately 147 TAF (Bray pers. comm.).

H1a1.12.3 Data

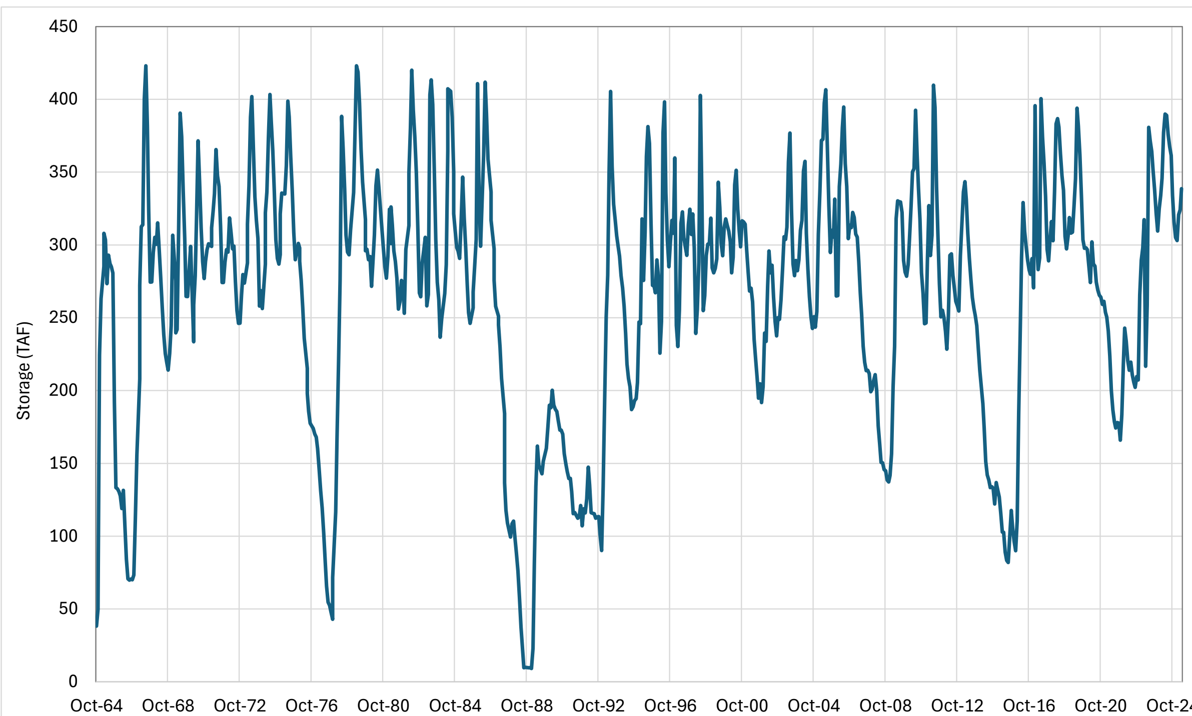
Figure H1a1-30 shows the historical Pardee Reservoir storage for 1970–2025 (CDEC Station PAR). In most years, storage in Pardee Reservoir has been maintained above 160 TAF and average carryover storage under historical conditions has been 180 TAF.

Figure H1a1-31 shows the historical storage in Camanche Reservoir for 1964–2025 (CDEC Station CMN). In most years, storage in Camanche Reservoir has been maintained above 250 TAF. However, during some droughts, storage has dropped below 100 TAF, reaching a low of approximately 10 TAF in 1988 before the JSA came into effect in 1998 (Lower Mokelumne River Partnership 1999).



Source: DWR 2025 (CDEC Station PAR)

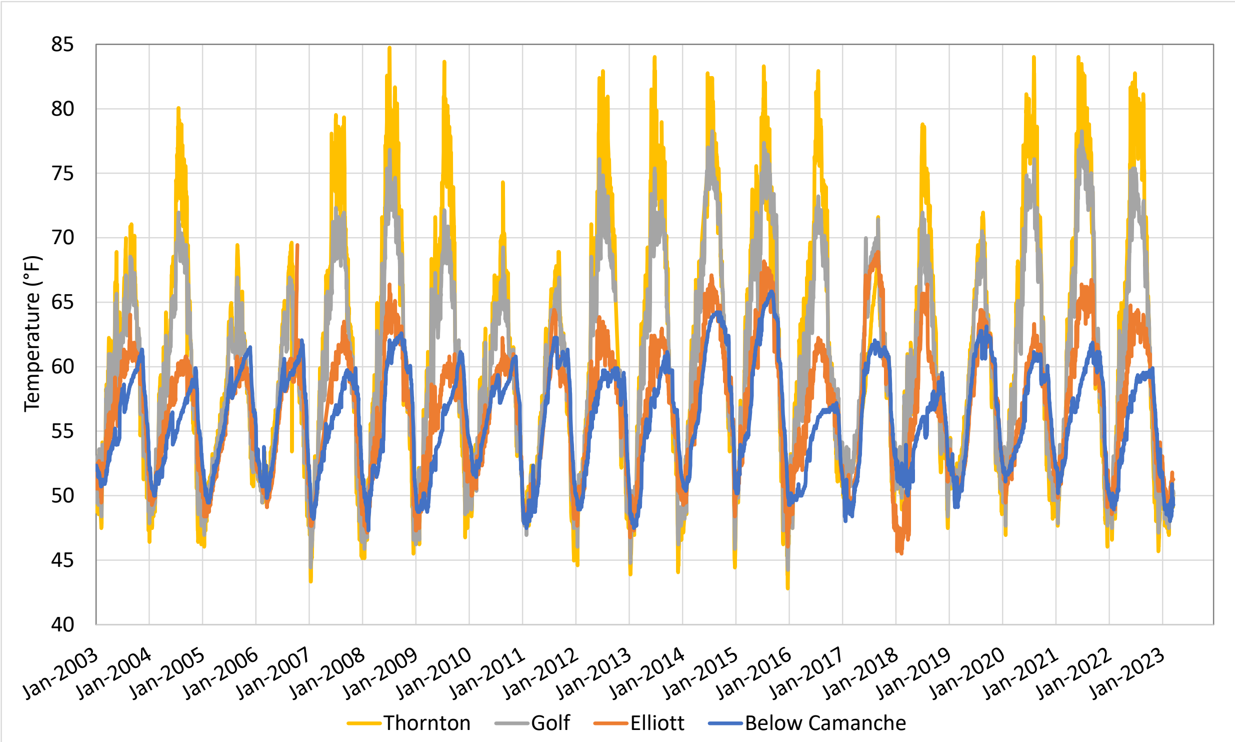
Figure H1a1-30. Historical Monthly Pardee Reservoir Storage (TAF) (1970–2025)



Source: DWR 2024 (CDEC Station CMN)

Figure H1a1-31. Historical Monthly Camanche Reservoir Storage (TAF) (1964–2025)

EBMUD monitors water temperatures in the Mokelumne River. EBMUD provided many of these measurements to State Water Board staff in 2023 (EBMUD 2023). Water temperature in the Mokelumne River increases as it flows downstream from below Camanche Dam to monitoring stations at Elliott, Golf, and then Thornton (Figure H1a1-32).



Source: EBMUD 2023

Figure H1a1-32. Historical Daily Average Water Temperature in the Mokelumne River (2003–2023)

H1a1.12.4 Data Evaluation

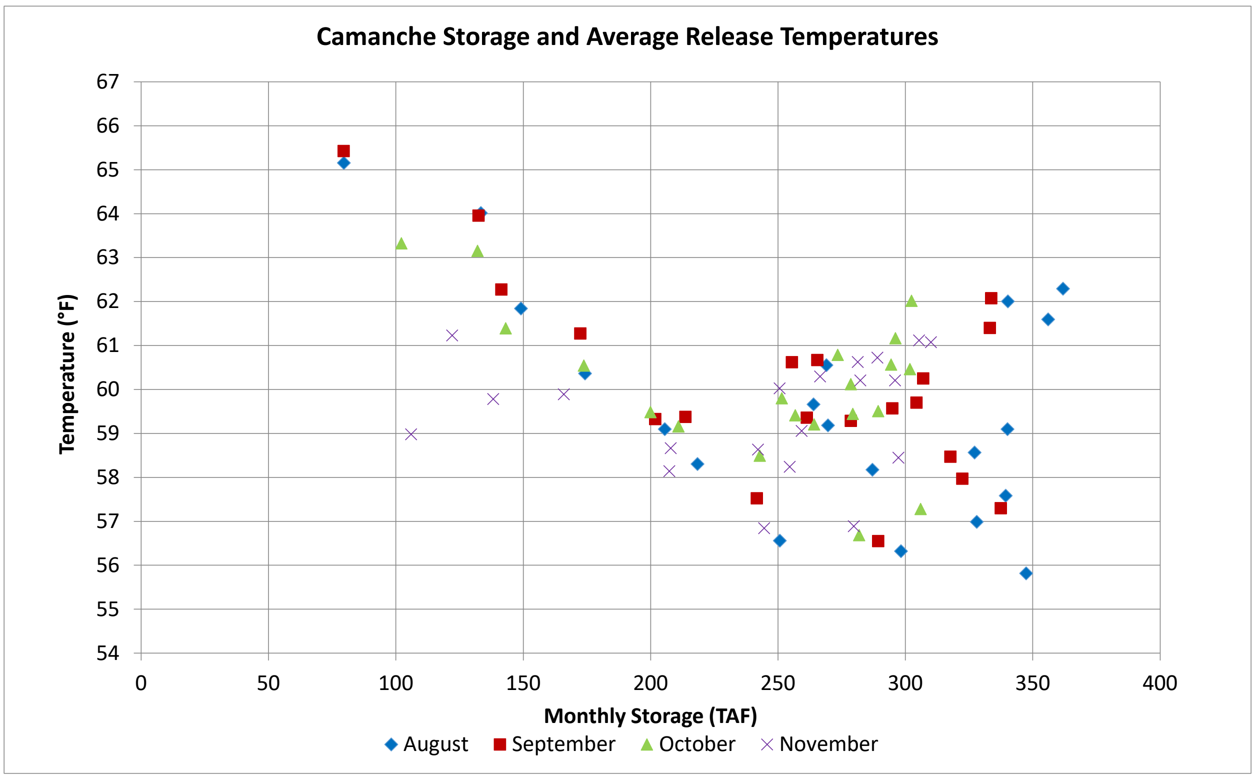
The carryover storage target ranges for Pardee Reservoir are 100–160 TAF for drought years and 160–180 TAF for all other years (December 2025 revised draft Bay-Delta Plan). These ranges are based on historical operations and would not interfere with existing operations or temperature control actions. In most years, storage in Pardee Reservoir has been maintained above 160 TAF and 180 TAF is approximately equal to the average carryover storage under historical conditions. At the lower end of the carryover storage range, 100 TAF would allow releases from Pardee Reservoir to provide cold water support for Camanche Reservoir and should not interfere with existing operations or temperature control actions associated with providing cold water to Camanche Reservoir.

Figure H1a1-33 shows the relationship between minimum (end-of-month) storage in Camanche Reservoir and monthly average temperatures below Camanche Dam for August–November during 2003–2022. These data indicate that August–October release temperatures may increase as storage drops below about 200 TAF. By November, storage has less effect on release temperatures, with the lowest storage levels possibly allowing for more meteorological cooling.

The fish life stages with the most stringent temperature indicators likely to be affected by carryover storage in the Mokelumne River include steelhead rearing in the river year-round (65 °F), fall-run

Chinook salmon migration and staging in October (60 °F), and fall-run Chinook salmon spawning in November (56° F) (Tables H1a1-1 and H1a1-3).

The December 2025 revised draft Bay-Delta Plan specifies carryover storage target ranges for Camanche Reservoir of 150–200 TAF for drought years and 200 – 250 TAF for all other years. End-of-October storage of approximately 150 TAF is the estimated volume needed to meet the Water Quality and Resource Management Program (WQRMP) goal to maintain at least 28 TAF of hypolimnetic volume of water colder than 16.4 °C (61.5 °F) under existing conditions. In consideration of low inflows and releases typical of fall conditions during drier years, the same storage level is applied to September here. A carryover storage target of 200 TAF may be sufficient to maintain reservoir release temperatures below 60 °F for most Septembers and Octobers for fall-run Chinook salmon migration. However, release temperatures have remained above the Chinook salmon spawning indicator temperature of 56 °F through November, so ideal water temperatures for Chinook spawning might not occur until December (Figure H1a1-33). Increases in fall storage above about 200 TAF may not result in cooler water being released from Camanche Reservoir but could improve water availability for increases in fall flows and for use in subsequent years (Figure H1a1-33).



Source: EBMUD 2023

Figure H1a1-33. Historical Monthly Average Camanche Reservoir Release Temperatures (°F) Compared to End-of-Month Storage (TAF) for August through November (2003–2023)

H1a1.13 Summary

The purpose of the carryover storage ranges is to protect cold water habitat by preventing depletion of storage and to preserve water in the reservoir in case of subsequent-year drought. The carryover storage ranges presented here are broad in recognition of variability in hydrologic conditions, the need to reconcile summer water supply and fall storage, and tradeoffs between benefits of summer flow versus carryover storage on water temperature.

Refinement of these storage ranges is likely to occur as part of additional analysis that is expected to occur as part of development of long-term temperature management strategies for each reservoir subject to the regulatory pathway. In some cases, climate change and increased reservoir bypass of winter and spring flows associated with implementation of the regulatory pathway could affect the conclusions made here based on historical data. These factors should be considered as part of long-term planning for temperature management. In some cases, the storage ranges may not be sufficient to protect cold-water habitat (e.g., because they are too low or more flow is needed to carry cold water downstream) and additional actions may be needed to protect cold water habitat.

H1a1.14 References

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