Appendix A1c
Preliminary Assessment of Effect of Reservoir Storage on Reservoir Release Temperatures

A1c.1 Introduction

This document contains an initial assessment of the effect of reservoir storage on release temperatures from Black Butte, Folsom, New Bullards Bar, Oroville, New Hogan, and Camp Far West Reservoirs and Lake Berryessa that is based on measured data and related references. This assessment was performed to preliminarily inform the Sacramento Water Allocation Model (SacWAM) carryover storage target assumptions. See Appendix A1, *Sacramento Water Allocation Model Methods and Results*, Section A1.3, *Reservoir Carryover Storage Targets,* for more detail regarding storage target assumptions. Lake Shasta and Camanche Reservoirs were not evaluated because carryover storage target assumptions for these reservoirs rely on specific targets that have been identified for other purposes, as described in Section A1.3.

Meeting carryover targets does not specifically indicate fully meeting cold water habitat objectives. The effect of reservoir storage on reservoir release temperatures is just one factor that affects water temperature in regulated streams. Streamflow releases and other reservoir operations are other key factors that affect water temperature. This analysis focuses on reservoir storage. Actual reservoir protocols needed to meet the cold water temperature objective would be developed through specific analysis and planning that would be part of implementation of the cold water habitat objective in coordination with the inflow objective and would include consideration of changes in storage patterns and effect of flow on temperatures downstream of reservoirs and other appropriate considerations.

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 As water is withdrawn from deep in the reservoir, the surface mixed volume and the thermocline drop lower into the reservoir.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 than the bottom of a reservoir. When the reservoir is full, the warm surface layer occupies a relatively large surface area. When water is withdrawn from near the bottom of a reservoir, the large warm surface volume is pulled deeper as it is squeezed into a zone with smaller area. Shallow reservoirs that lack a cold water pool still may have a temperature gradient with cooler temperatures deeper in the reservoir.

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. Each reservoir has a slightly different elevation-volume relationship, and the elevation of the outlet and the maximum surface elevation influences the minimum carryover (end-of-September) storage that provides a 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 outlet 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. In other cases, 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 a reservoir is relatively small, so switching from using a hydropower penstock intake to a lower, bottom outlet provides only a limited amount of additional cold water.

This assessment uses historical data to evaluate the effect of reservoir storage on water temperature downstream of the dams for the purpose of developing storage targets sufficient to maintain cold release temperatures. While gate operations will vary from year to year, this analysis assumes that current procedures to optimize release temperatures are represented in the data and will continue into the future.

The evaluation incorporates two types of information.

- Temperature criteria for fish below the reservoirs (Table A1c-1) – These criteria are based on existing regulatory or management criteria for individual tributaries or general thermal thresholds for individual life stages. Note that these criteria were chosen for a basic analysis that focusses on fish survival below the dams. Refinement of this analysis using different criteria and downstream locations will likely be necessary to best meet the cold water habitat objective.
- 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 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.

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 criteria depends on reservoir release temperature, channel geometry, meteorology, and shade.

A1c.2 Methods

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 (https://waterdata.usgs.gov/nwis). Data were downloaded during the first half of 2017. The monthly storage values for this analysis are end-of-month values. The monthly temperature values presented here are typically the monthly average values (monthly average of the daily averages), although in some cases the monthly minimum and maximum of the daily averages are also presented.

One option for assessing the historical relationship between reservoir storage and release temperature is to evaluate the monthly average of the daily minimum temperatures because daily minimum temperatures are more similar to the reservoir release temperature before any meteorological warming occurs as the water flows downstream to the measurement site. However, to more closely match the metric of the fish criteria, most of the analyses presented here evaluate the monthly average temperature (monthly average of daily averages). An alternative approach would have been to use the monthly maximum of the daily averages for the evaluation, but this approach was not used to avoid basing conclusions on a single day.

One reason it is appropriate to use the monthly average instead of the average temperature for the warmest day is that the criteria are for attainment of optimal temperatures that are well below lethal thresholds. For example, adult holding criteria for spring-run Chinook salmon are 60 degrees Fahrenheit (°F) (Table A1c-1), whereas lethal temperatures are around 69 °F or more (Thompson et al. 2012). Temperatures that exceed the criteria, within certain limits, may reduce fish growth, 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 criteria by a few degrees. 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). Even when the criteria are met, there is no guarantee of temperature suitability for the entire length of river where fish may occur. Colder reservoir release temperatures result in a greater downstream extent of suitable temperatures. Flow and meteorological conditions also affect the downstream extent of suitable habitat.

The temperature criteria used in this evaluation are similar, but not all identical, to the criteria used to evaluate the results from the water temperature simulations for the Sacramento, Feather, and American Rivers. The criteria in Table A1c-1 were chosen to focus on fish habitat below dams, whereas the criteria for the fish-effects analysis of the simulated temperatures are more robust and numerous and include more recently established criteria and criteria for fish farther downstream of dams. Many of the temperature criteria considered in the evaluation 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, especially when water is released from the bottom of a deep reservoir, 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 and are affected by flow. For this reason, daily maximum temperatures were not a focus of this evaluation of the relationship between reservoir storage and release temperatures.

For some reservoirs, few water temperature data are collected at very low reservoir storage. Increases in release temperature at low storage are indicative of the effect of storage on water temperature. However, the limited data do not capture the full range of temperature variability that might be expected at low storage. Because conclusions depend on the metric evaluated, criteria are not thresholds for survival, cool temperatures need to travel downstream, and limited temperature data at low storage, determination of precise reservoir storage requirements is difficult.

The historical data were evaluated to identify two storage levels.

- A conservative level that prevents any substantial warming (i.e., storages greater than this level would not result in much cooler release temperatures). The level represents the storage that allows releases from a cold water pool, which is the volume of cold water at the bottom of large reservoirs that has an approximately uniform low temperature. Smaller reservoirs may also have a thermocline, with a gradient of cooler temperatures toward the bottom of the reservoir, but little or no cold water pool. This conservative storage level is seen as an inflection point in the graphs of release temperatures versus storage for the largest reservoirs.

- A less conservative level that may be sufficient to result in average monthly temperatures that meet temperature criteria downstream of the dam in most years, but not all years because of variability in release temperatures in response to factors other than storage. If reservoir storage approaches this threshold or if the cooler water needs to extend a certain distance downstream, further evaluation, such as temperature monitoring or modeling, would be warranted.

Table A1c-1. Temperatures for Chinook Salmon and Steelhead

Period	Criterion [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	
Jan - Mar	57	
Apr - Jun	60	

Period	Criterion [a] (°F)	Notes
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 – Sep 30	60	Fall-run migration and pre-spawning
	56	Spring-run spawning
Oct 1 – Dec 31	56	Fall- and spring-run spawning and incubation

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.
°F = degrees Fahrenheit
[a] These criteria were chosen for a basic analysis that focusses on fish survival below the dams. Refinement of this analysis using different criteria and downstream locations will likely be necessary to best meet the cold water habitat objective.

Infrastructure and geography information such as reservoir volume, depth of outlets, 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 comes from the SacWAM model (^SacWAM 2023).

A1c.3 Black Butte Reservoir

A1c.3.1 Infrastructure and Geography

Black Butte Reservoir captures water from the Stony Creek watershed. The reservoir is relatively small, with maximum storage of approximately 144 thousand acre-feet (TAF) and a water surface elevation of about 474 feet. The minimum pool elevation is at 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). Because the maximum water depth is less than 75 feet, there is no opportunity for a cold water pool, although the reservoir is stratified in summer.

A1c.3.2 Prior 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

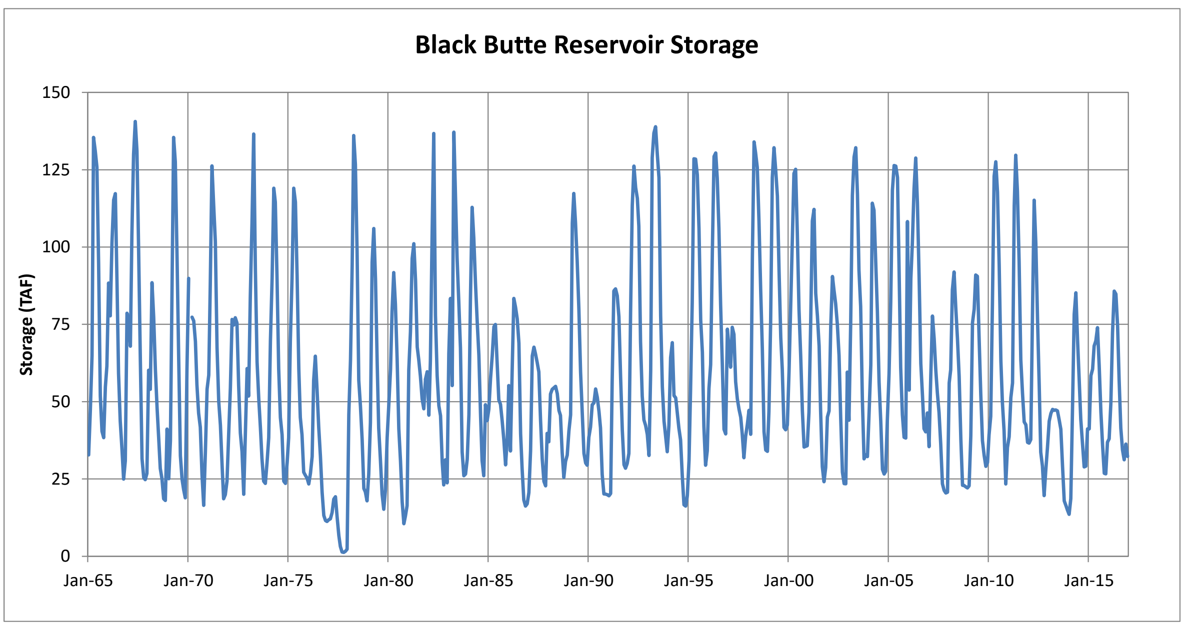
prespawning/spawning (60 °F) and egg incubation (56 °F). Stream temperatures then remain below the maximal threshold temperature (65 °F) for fry/juvenile rearing through at least May."

"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 (COE, 1987, DWR, 1988). 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."

A1c.3.3 Data

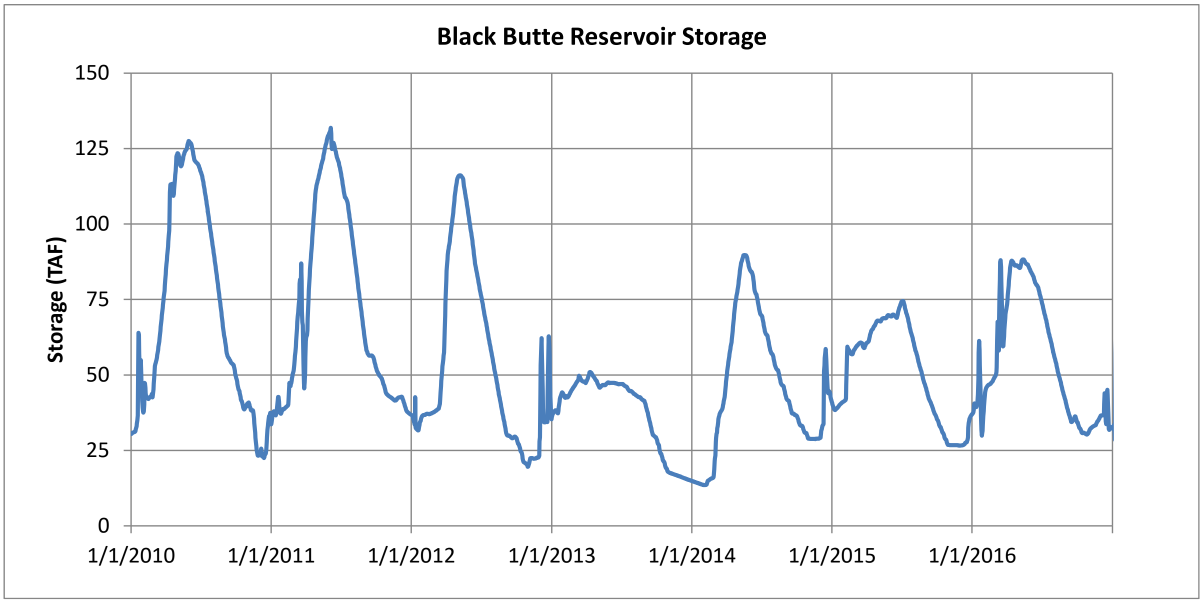
Figure A1c-1 shows the historical end-of-month Black Butte Reservoir storage pattern for 1965–2016 (CDEC station BLB). The minimum storage was 0 TAF in 1977 and was close to 20 TAF in many other years, reflecting the minimum storage requirement for fish habitat in the reservoir. Storage in Black Butte 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 2017 (CDEC Station BLB).
TAF = thousand acre-feet

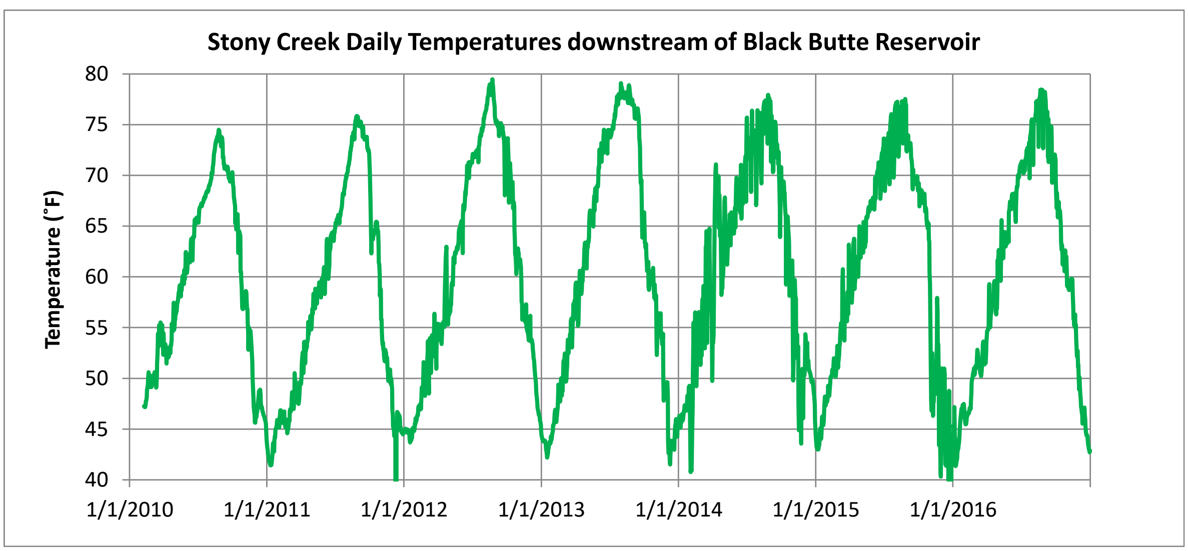
Figure A1c-1. Historical Black Butte Reservoir Storage (TAF) (1965–2016)

To focus more on the period of record with measured release temperatures, Figure A1c-2 shows the historical daily Black Butte Reservoir storage for 2010–2016 (CDEC station BLB), and Figure A1c-3 shows the historical daily Stony Creek temperatures below Black Butte Reservoir (CDEC station BBQ, located approximately 0.8 mile downstream of the dam). The annual maximum Black Butte Reservoir storage was 125 TAF in 2010–2012, 50 TAF in 2013, and about 75 TAF in 2014–2016.



Source: DWR 2017 (CDEC Station BLB).
TAF = thousand acre-feet

Figure A1c-2. Historical Daily Black Butte Reservoir Storage (TAF) for 2010–2016



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

Figure A1c-3. Historical Daily Average Temperatures (°F) below Black Butte Reservoir (2010–2016)

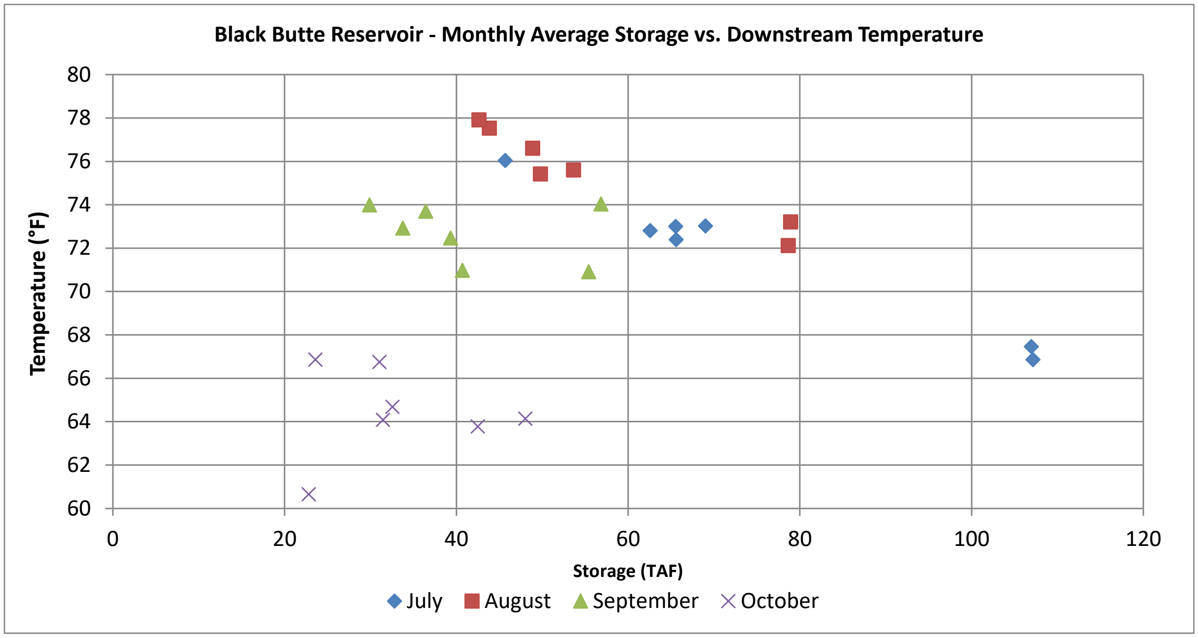
A1c.3.4 Data Evaluation

During the warmer part of the year, from late spring through early fall, Black Butte Reservoir is thermally stratified but has no cold water pool. During the warmest months, July and August, release temperatures appear to have had an almost linear relationship with storage, with temperatures increasing from 67 to 78 °F as reservoir storage decreased from about 110 to 40 TAF (Figure A1c-4). With flood control releases and cooling meteorological conditions, both storage and temperatures decreased in September and October (Figure A1c-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 2014, 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 2014, Appendix A).

Because water temperatures released from Black Butte Reservoir are substantially above water temperature criteria 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 criteria for steelhead or fall-run Chinook salmon would be met.

- **July and August.** During July and August, monthly average Black Butte Reservoir release temperatures were generally above the 65 °F criterion for steelhead rearing, even when the reservoir storage was greater than 100 TAF (Figure A1c-4).
- **September.** Fall-run Chinook salmon may migrate in September, with a temperature criterion of 60 °F. Black Butte Reservoir storage tends to be low (less than 60 TAF) in September, and 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 usually 64 °F or above, too warm for migration and pre-spawning fall-run Chinook salmon, which have a temperature criterion of 60 °F. Even if the reservoir were 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 (CDEC Stations BLB and BBQ).
°F = degrees Fahrenheit
TAF = thousand acre-feet

Figure A1c-4. Historical Monthly Average Temperatures (°F) below Black Butte Reservoir Compared to Reservoir Storage (TAF) (2010–2016)

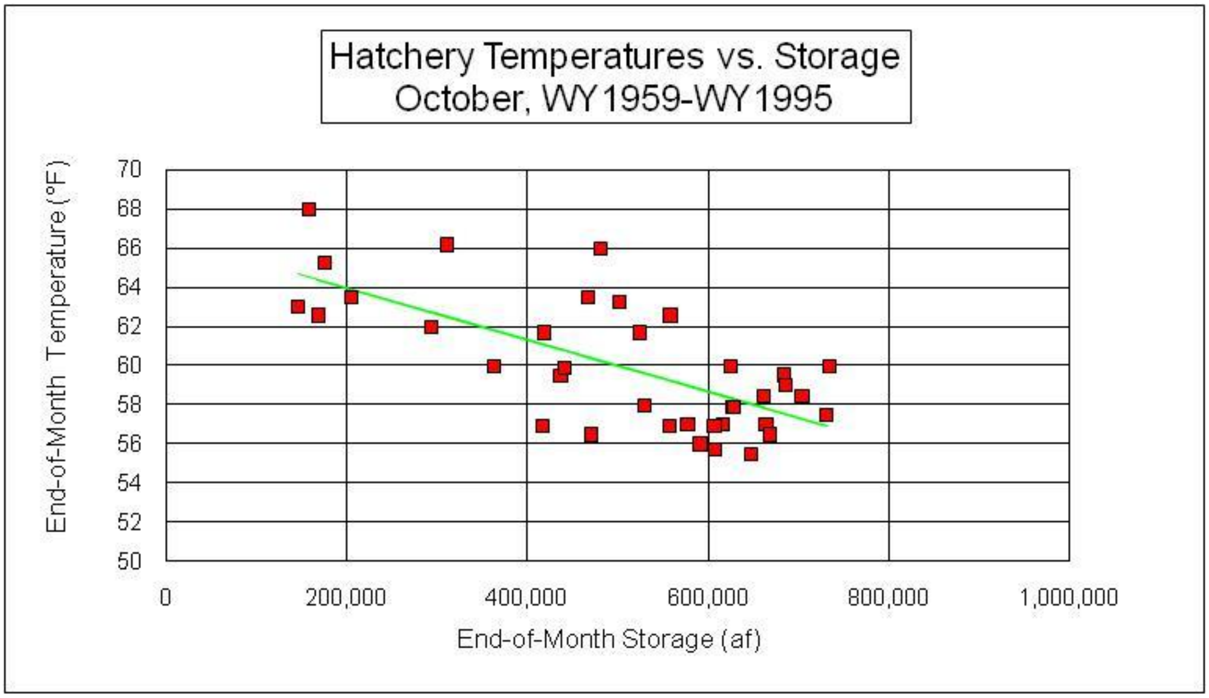
A1c.4 Folsom Reservoir

A1c.4.1 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 977 TAF is 466 feet. The power penstocks are at 307 feet, and 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.

A1c.4.2 Prior 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 A1c-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 A1c-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 A1c-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.

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

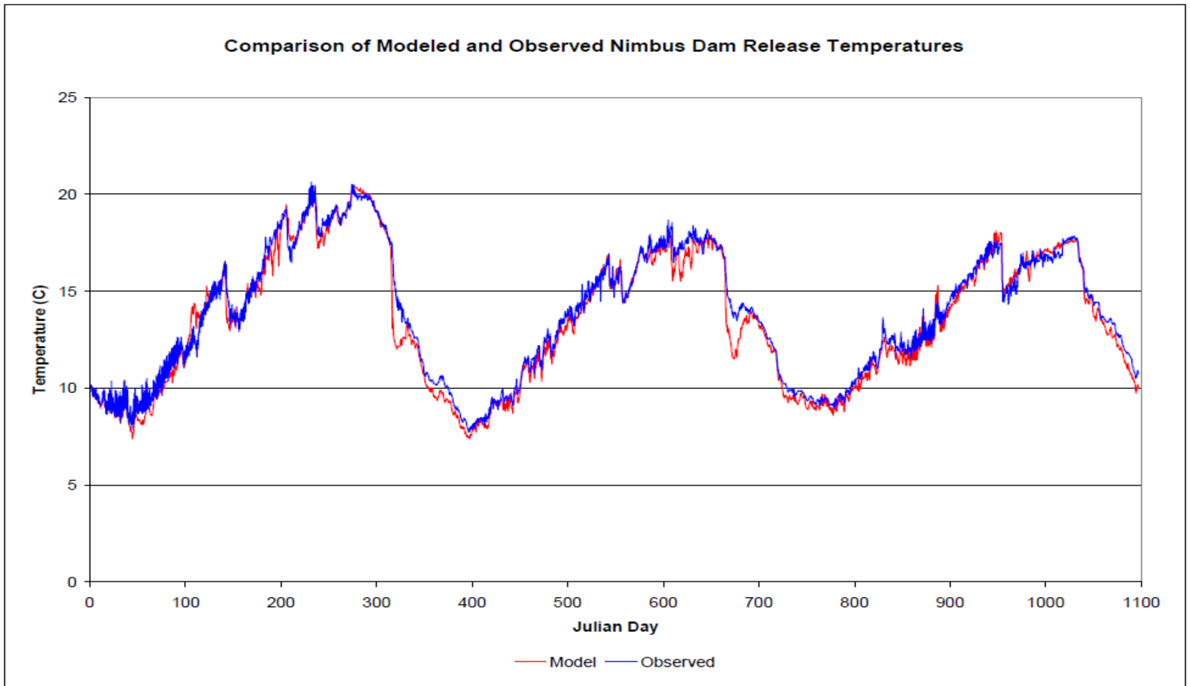


Figure 6.—Modeled and observed Nimbus Dam release temperature versus time during 2001, 2002, and 2003.

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

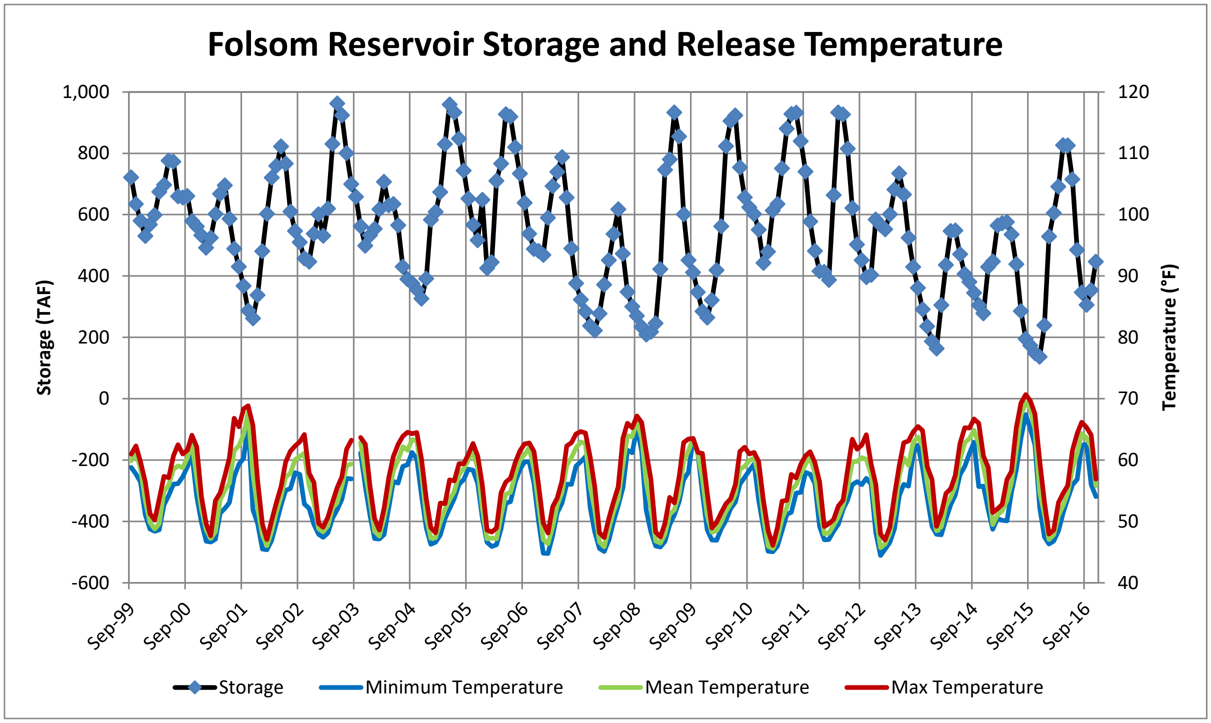
Figure A1c-6. Hourly Temperatures (°C) of Nimbus Dam Releases (2001–2003)

Another temperature analysis (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. This analysis of 2001–2011 temperature profiles and release temperature data indicated that downstream temperature criteria could generally be achieved. Modifications of the release temperature sequence each year was possible, but the cold water volume provides a basic constraint on the balance between release volume (storage drawdown) and the maximum release temperature in the July–October period.

A1c.4.3 Data

The release temperatures evaluated here were measured downstream of Folsom Dam (CDEC station AFD) but upstream of Lake Natoma. Measured data are also available downstream of Nimbus Dam near Hazel Avenue (CDEC station AHZ). However, the AFD station data were used in this evaluation instead of the AHZ station data because there are more than twice as many data from station AFD than from station AHZ, and during October there is little difference in temperatures between the two stations; the average warming between the AFD and AHZ stations was only 0.4 °F.

Figure A1c-7 shows the historical monthly Folsom Reservoir storage levels (CDEC station FOL) and release temperatures (CDEC station AFD) for September 1999–November 2016. The lowest carryover (September) storage was 175 TAF in 2015, (with 195 TAF in August, 150 TAF in October, and 140 TAF in November). Some of the highest reservoir release temperatures occurred in 2015; the maximum daily reservoir release temperatures during August, September, and October 2015 were 70.7 °F, 69.7 °F, and 67.5 °F, respectively.



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

Figure A1c-7. Historical Monthly Folsom Reservoir Storage (TAF) and Release Temperatures (°F) (2000–2016)

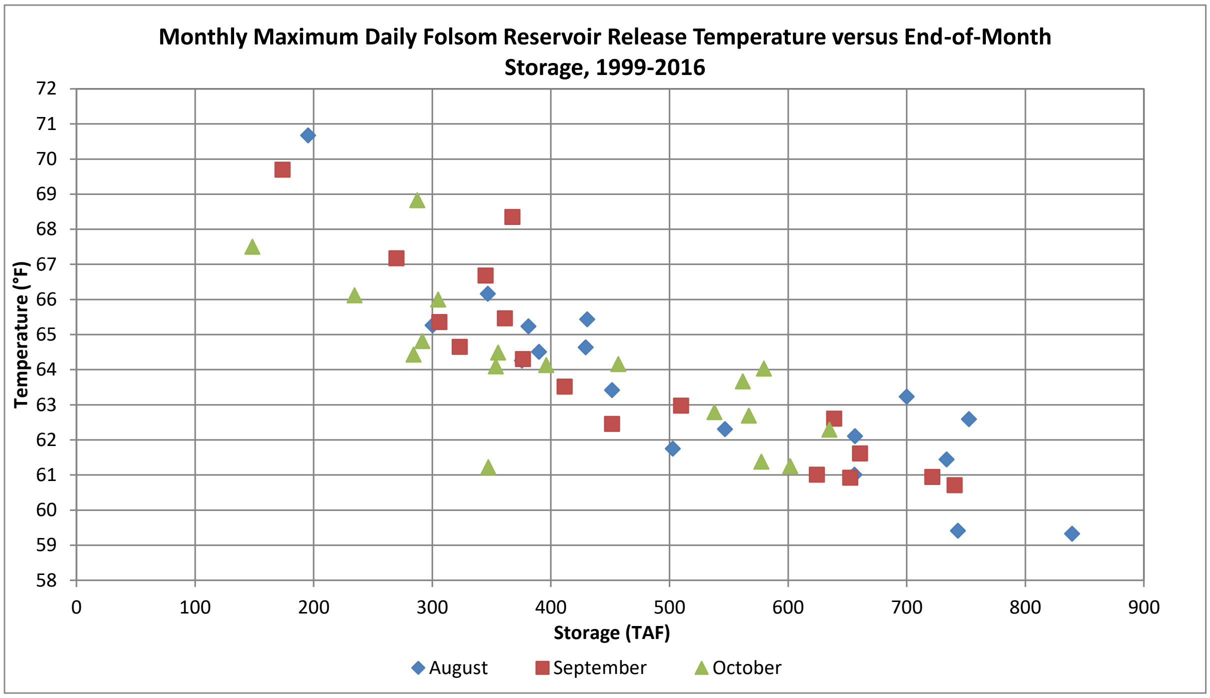
A1c.4.4 Data Evaluation

The Table A1c-1 temperature criteria most restrictive for Folsom Reservoir are the daily average criteria of 65 °F for August and September and 60 °F for October. Because the measured reservoir release temperatures for October are not substantially lower than the August and September temperatures (Figures A1c-8 and A1c-9), the 60 °F criterion for October is more difficult to attain than the 65 °F criterion for August and September.

Often the highest daily temperature in October occurs near the beginning of the month, and temperatures later become cooler and more suitable. Downstream of Folsom Reservoir, the October average temperature is about 1–4 °F cooler than the maximum daily average during October (Figure A1c-8 and A1c-9). Monthly average temperature is the metric being used to evaluate carryover storage, but if the metric were based on the maximum daily average temperature measured during October in order to focus on the warmer period at the beginning of the month, the data indicate that an October storage of over 750 TAF may be needed to keep all daily temperatures below 60 °F (Figure A1c-8). However, October storage for the period evaluated did not exceed 650 TAF. Considering the approximately 1,000-TAF capacity of Folsom Reservoir, 750 TAF would be very high carryover storage. In contrast, if the metric were based on minimum daily average temperatures, which are somewhat represented by the end-of-month temperatures shown in Figure A1c-5, an October storage of about 500 TAF may be needed to keep values below 60 °F.

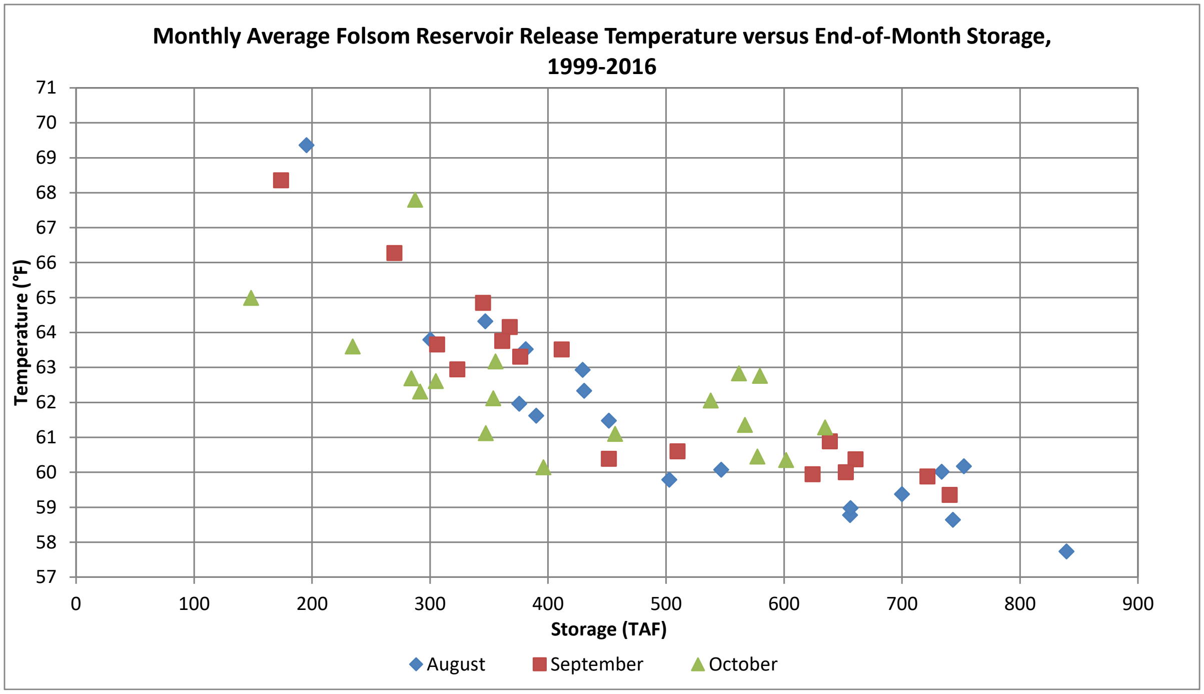
When the metric used to evaluate carryover storage targets is based on the monthly average temperature, the measured data indicate that the criterion is closer to attainment, although all the average October temperatures were still greater than 60 °F. The storage-versus-average temperature plot for October (Figure A1c-9) shows somewhat of an inflection point at 400 TAF, with storage levels less than 400 TAF seeming to affect release temperatures and storage levels greater than 400 TAF having no clear relationship with average October release temperatures.

The data show Folsom Reservoir release temperatures for October between 60 and 63 °F at storage levels greater than 400 TAF. Release temperatures less than 60 °F did not occur at the historical October storage levels, which were all less than 650 TAF. From 1999 to 2016, end-of-October storage in Folsom Reservoir was less than 400 TAF approximately half the time (Figures A1c-8 and A1c-9). Maintaining storage greater than 400 TAF in October in more years could be beneficial to fall-run Chinook salmon. However, because of the high demand for this water for agricultural and municipal use, and because of the relatively small 1,000-TAF reservoir capacity, maintaining storage greater than 400 TAF more frequently may be difficult considering water supply tradeoffs, and higher storage might not guarantee optimal temperatures.



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

Figure A1c-8. Historical Monthly Maximum of the Daily Folsom Reservoir Release Temperatures (°F) Compared to End-of-Month Storage (TAF) for August, September, and October (1999–2016)



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

Figure A1c-9. Historical Monthly Average Folsom Reservoir Release Temperatures (°F) Compared to End-of-Month Storage (TAF) for August, September, and October (1999–2016)

A1c.5 New Bullards Bar Reservoir

A1c.5.1 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 970 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). Two outlets (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), 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 outlet at 1,810 feet during spring to release warmer water for better growth and rearing conditions for fish. However, since September 1993, the deeper outlet (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). Since YCWA conducted a temperature advisory workshop in 1993, only the lower Colgate Powerhouse outlet has been used, as requested by the U.S. Fish and Wildlife Service (USFWS) and California Department of Fish and Wildlife (YCWA 2013). Use of the lower outlet provides for release of the coldest water possible year-round. This change in operations was implemented to improve the lower Yuba River fish habitat conditions, below Englebright Reservoir.

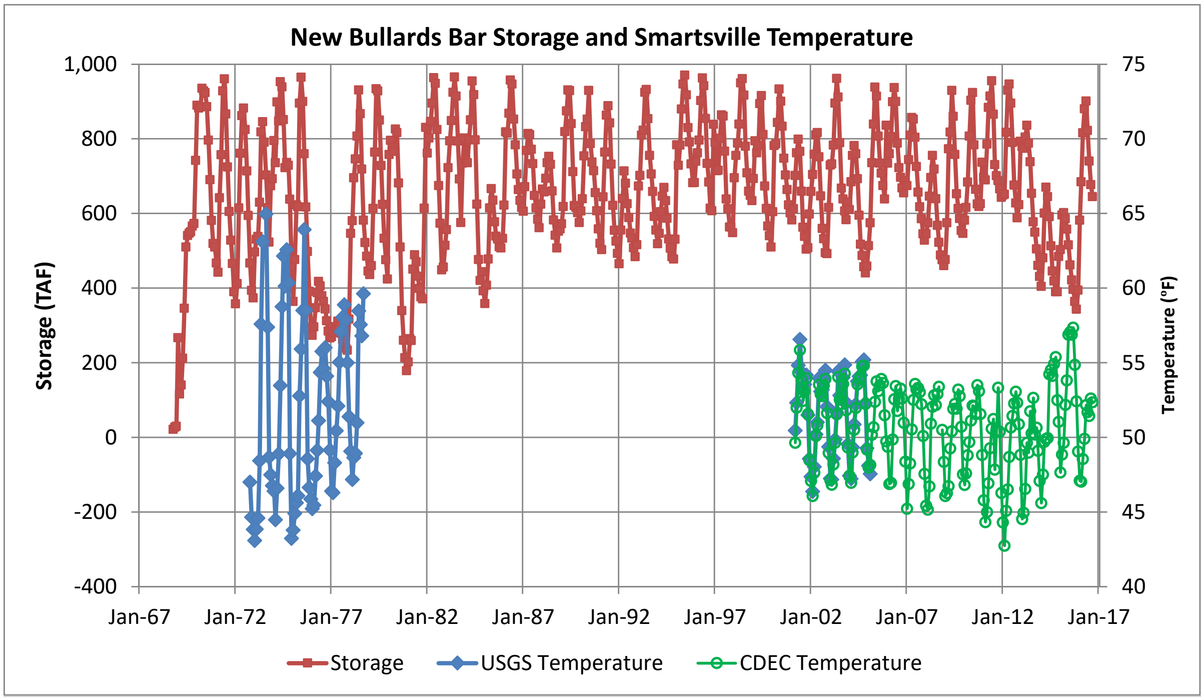
Cold water released from New Bullards Bar Reservoir at the Colgate Powerhouse re-enters the North Yuba River about 2 miles upstream of the upstream end of the main arm of Englebright Reservoir, which is near where the South Yuba River enters Englebright Reservoir. The North and Middle Yuba River confluence is upstream of Colgate Powerhouse. Englebright Reservoir, with a storage capacity of about 70 TAF, is relatively small compared to the 970-TAF capacity of New Bullards Bar Reservoir. Cold water flows along the bottom of Englebright Reservoir with some warming from the surface water. Englebright Dam is located about 10 miles downstream from Colgate Powerhouse and is the upstream limit of anadromous fish migration on the Yuba River. Water temperature is measured at Smartsville (CDEC station YRS), approximately 1 mile downstream of Englebright Dam. Smartsville temperatures are likely influenced by the Middle and South Yuba River flows as well as the fraction of water from New Bullards Bar Reservoir.

A1c.5.2 Prior Studies

Temperature modeling for New Bullards Bar Reservoir and the Yuba River below Englebright Reservoir was completed for the recent Federal Energy Regulatory Commission (FERC) relicensing process (YCWA 2013). Extensive river temperature measurements and reservoir profiles were collected for the relicensing and as part of the YCWA flow and temperature monitoring program since 1993. Unfortunately, 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 A1c-10). Additional investigation of temperatures at reservoir storage levels of less than 500 TAF is perhaps warranted. Reservoir modeling generally matched measured temperature profiles, with seasonal warming of surface water. There were some differences in deeper temperature profiles near the outlet at 1,630 feet elevation.

A1c.5.3 Data

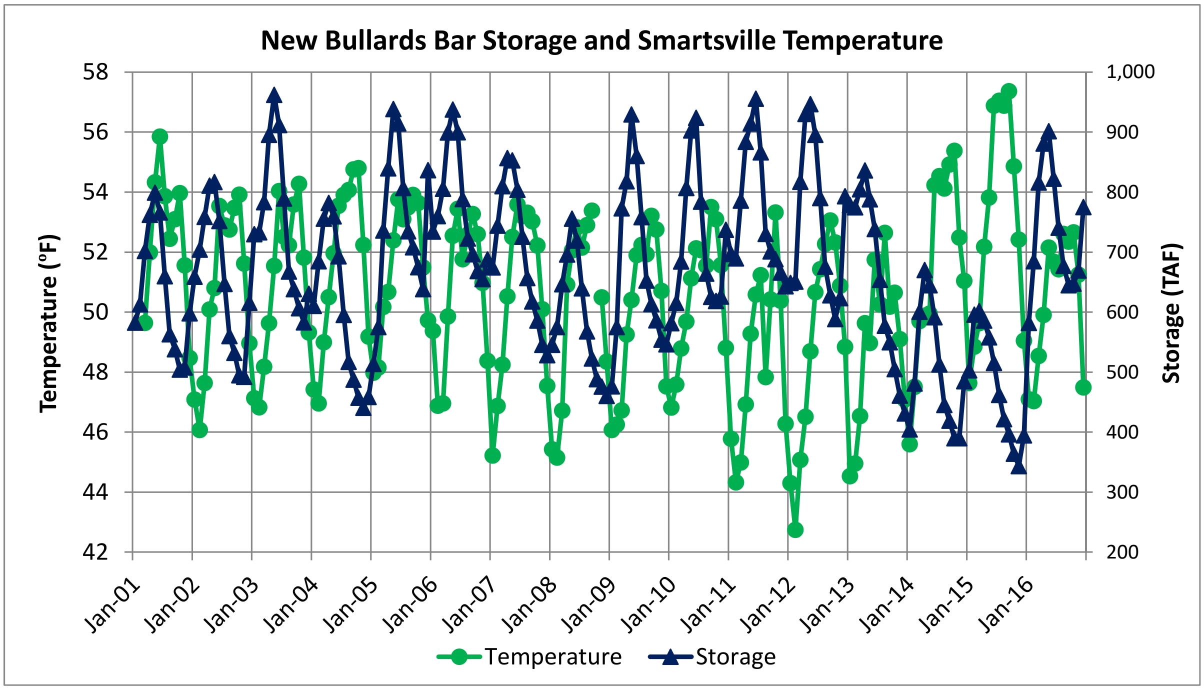
Figure A1c-10 shows the monthly historical New Bullards Bar storage (from CDEC station BUL) for 1968–2016 and the historical monthly temperatures below Englebright Dam at the USGS flow station (11418000 Yuba River below Englebright Dam near Smartsville CA; the Smartsville temperatures are now available on CDEC as station YRS). 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 outlet 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 (CDEC Stations BUL and YRS); USGS 2017 (Station 11418000).
°F = degrees Fahrenheit
TAF = thousand acre-feet

Figure A1c-10. Monthly Historical New Bullards Bar Reservoir Storage (TAF) and Yuba River Temperatures (°F) at Smartsville (1968–2016)

Figure A1c-11 focuses on the historical monthly storage and temperature for New Bullards Bar Reservoir below Englebright Reservoir near Smartsville for the recent period of 2001–2016 (CDEC station YRS). The low-level outlet (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.

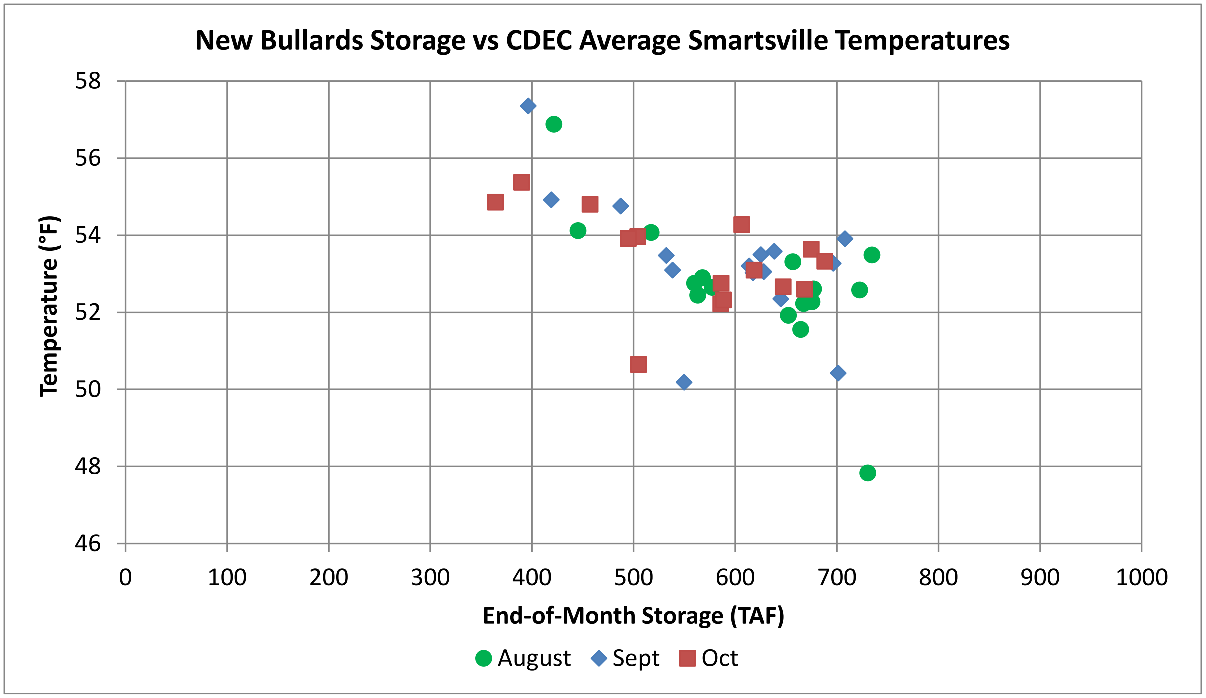


Source: DWR 2017 (CDEC Stations BUL and YRS).
°F = degrees Fahrenheit
TAF = thousand acre-feet

Figure A1c-11. Monthly Historical New Bullards Bar Reservoir Storage (TAF) and Yuba River Temperatures (°F) at Smartsville (2001–2016)

A1c.5.4 Data Evaluation

Figure A1c-12 shows August–October monthly Yuba River temperatures at Smartsville compared to New Bullards Bar Reservoir storage for 2001–2016 when the low-level outlet was used. 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 criterion (Figure A1c-12). August, with a temperature criterion of 60 °F, is unlikely to be problematic unless storage were to fall below 300 TAF. Thus, maintaining a storage of 400 TAF is important for meeting water temperature needs for 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 A1c-11). 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 A1c-12).



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

Figure A1c-12. Historical Monthly Average Temperatures (°F) at Smartsville Compared to New Bullards Bar Reservoir Storage (TAF) (2001–2016)

A1c.6 Oroville Reservoir

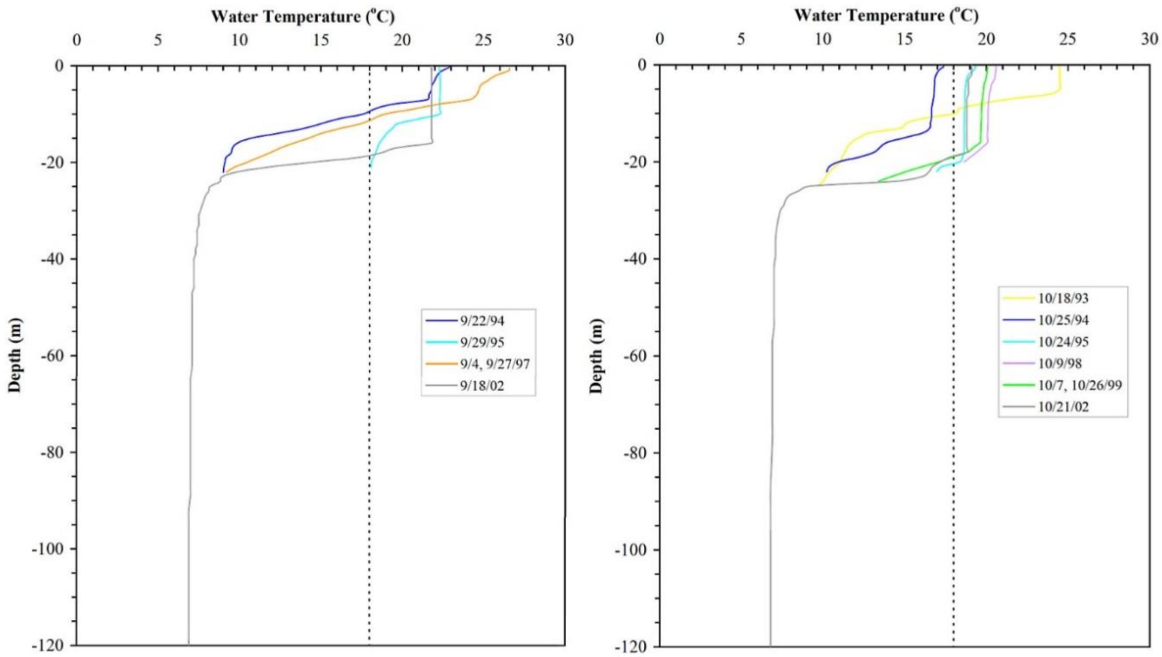
A1c.6.1 Infrastructure and Geography

Oroville Reservoir captures water from the Feather River watershed. Maximum reservoir capacity is about 3,538 TAF at a water surface elevation of about 900 feet. Hyatt Powerhouse penstocks can draw water from as low as 613 feet (NMFS 2016), but the penstock intake is connected to a slanted temperature control structure that allows withdrawal of water from higher in the reservoir (NMFS 2016; Reclamation 1965). The reservoir bottom is at approximately 210 feet, although storage below an elevation of 300 feet is minimal. A river valve outlet system in diversion tunnel No. 2 can release water from deeper in the reservoir, as low as 225 feet (NMFS 2016).

Downstream of Oroville Reservoir, Thermalito Diversion Dam forms the Thermalito Diversion Pool where water is diverted to Thermalito Forebay. Below the 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.

A1c.6.2 Prior Studies

Figure A1c-13 shows Oroville Reservoir temperature profiles measured in September and October. These temperature profiles were used to evaluate cold water pool as part of the 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

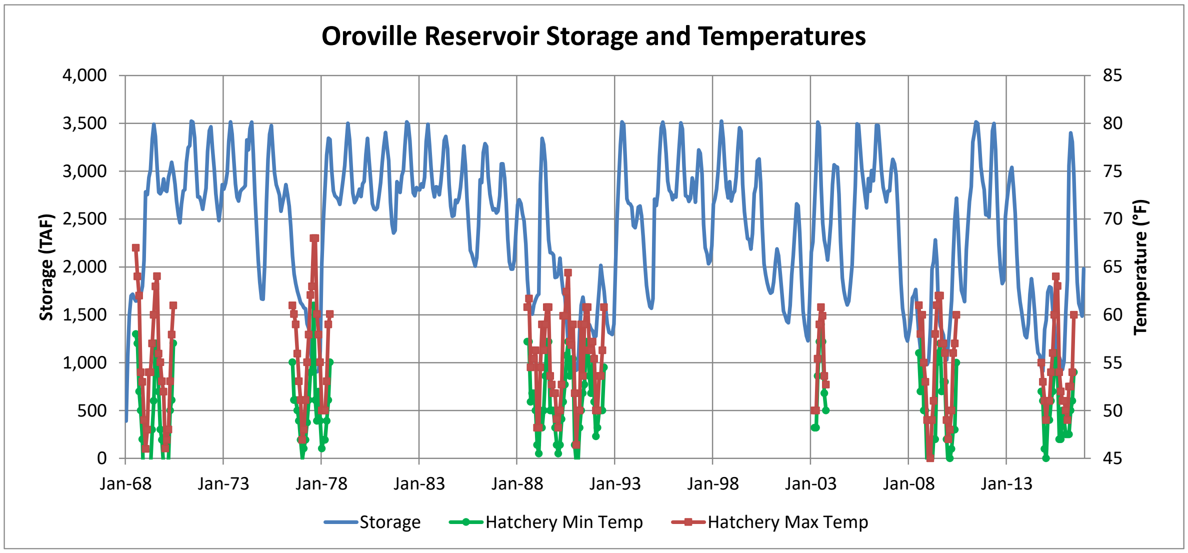
Figure A1c-13. Measured Temperature Profiles (°C) in Oroville Reservoir in September and October

A1c.6.3 Data

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: the fish hatchery and USGS Station 11407000. Water temperature also has been measured about 10 miles downstream of the dam at CDEC station FRA, near Robinson Riffle.

Figure A1c-14 shows the historical monthly Oroville Reservoir storage for 1968–2016 (CDEC station ORO). Because the water surface elevation must be about 50 feet above the outlet elevation to prevent cavitation damage to the turbine, the normal minimum elevation of Oroville Reservoir is approximately 665 feet, corresponding to a volume of approximately 1,000 TAF.

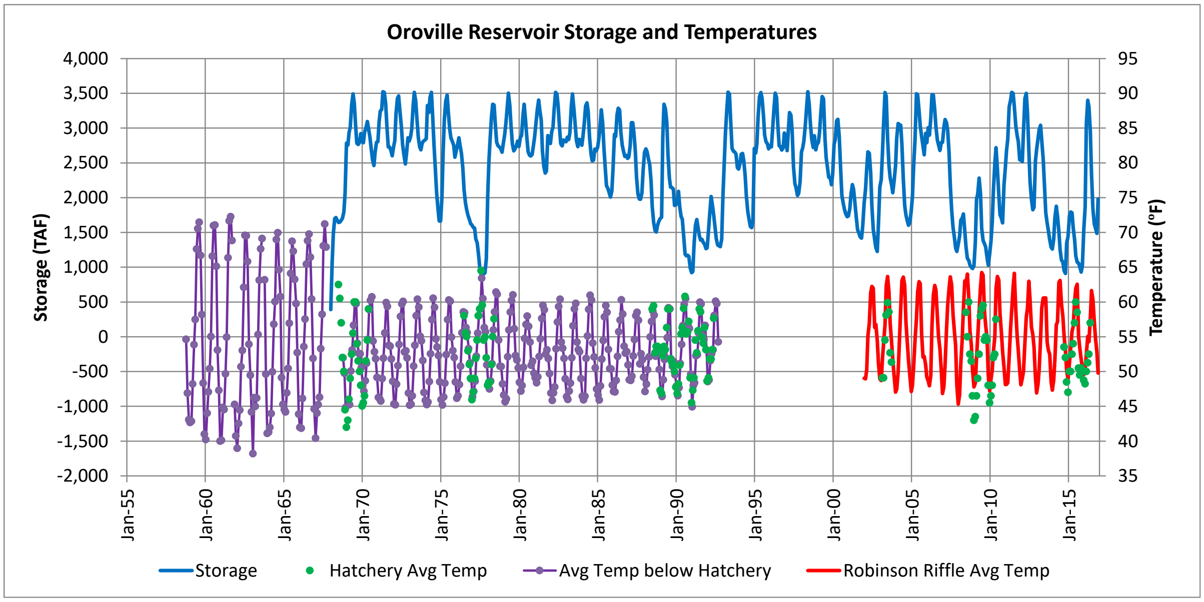
Daily hatchery temperatures provide a historical record of increased temperatures at low storage. A few annual hatchery reports were obtained from the California Department of Fish and Wildlife document library (CDFW 2017). Additional monthly data were extracted from recent annual hatchery reports and provided by Feather River Fish Hatchery staff (Kastner pers. comm. 2017). 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 A1c-14.



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

Figure A1c-14. Historical Monthly Oroville Reservoir Storage (TAF) and Feather River Fish Hatchery Temperatures (°F) (1968–2016)

Figure A1c-15 shows the monthly Oroville Reservoir storage and temperatures in the Feather River at the USGS Oroville station (11407000 Feather River at Oroville) for 1958–1992, and at Robinson Riffle (CDEC FRA), approximately 3 miles upstream of the Thermalito Afterbay outlet, for 2002–2016. 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; the seasonal range was considerably reduced to between 45 and 60 °F. The 2002–2016 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 2017 (CDEC Stations FRA and Oro); USGS 2017 (Station 11407000); CDFW 2017; Kastner pers. comm.
°F = degrees Fahrenheit
TAF = thousand acre-feet

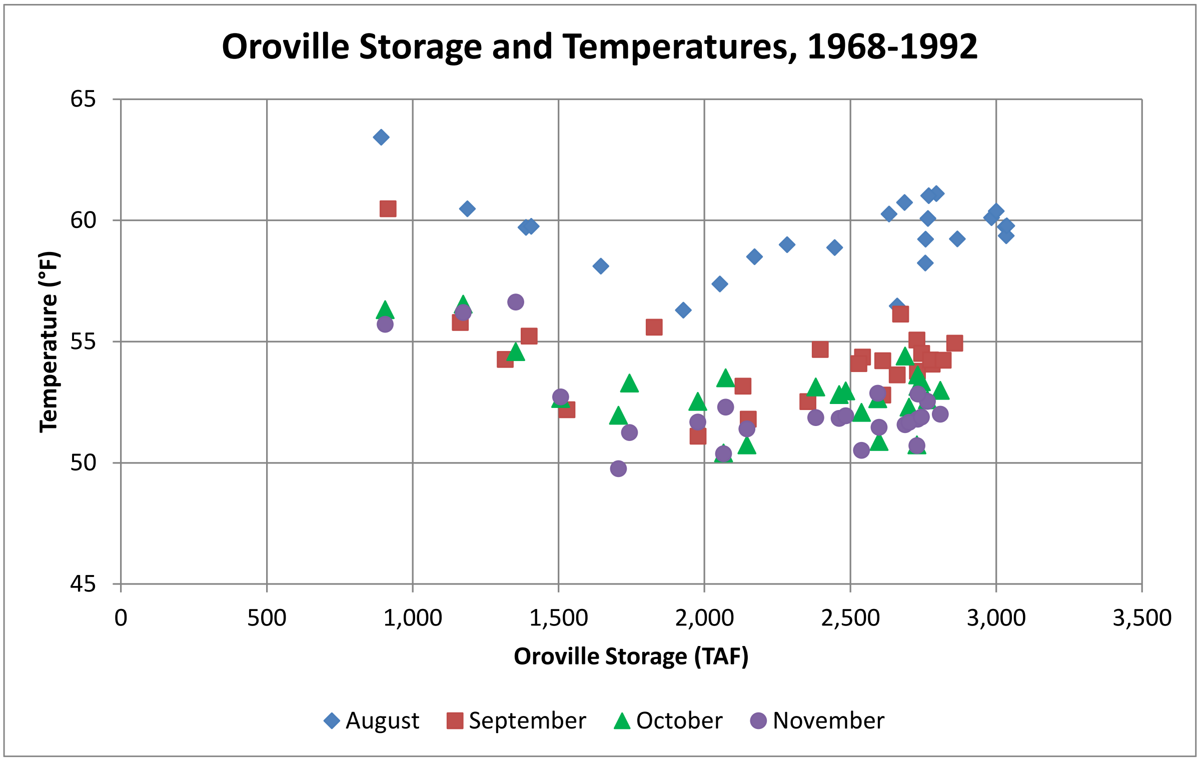
Figure A1c-15. Oroville Reservoir Storage (TAF) and Monthly Average Temperatures (°F) in the Feather River Downstream of Oroville Dam (1958–2016)

A1c.6.4 Data Evaluation

The temperature criteria for the Feather River Fish Hatchery are daily average temperatures less than 60 °F in August, 56 °F in September, and 55 °F in October. The hatchery criteria also include guidelines for maximum hourly temperatures, which are slightly higher than the average daily criterion in August and equal to the average daily criteria in September and October. Near the hatchery, the daily maximum temperatures are slightly higher than the average temperatures, so it is somewhat incongruous to have criteria for daily maximum temperatures that are equal to daily average temperatures. For this Oroville Reservoir analysis, as for the other reservoirs, the evaluation was based on the monthly average temperatures and the criteria for daily average temperatures.

Figure A1c-16 compares monthly Oroville Reservoir storage and average USGS temperatures (near the hatchery) in 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 the measured storage and temperature values, a storage of 1,200 TAF appears to be an approximate threshold for attaining average monthly temperatures that meet the criteria for August through October. The fact that August temperatures are substantially higher than the September and October temperatures indicates operation of the temperature control structure to release warmer water when it is not expected to harm fish. Increased use of the power bypass outlet closer to the bottom of the reservoir could allow storage to drop below 1,200 TAF, while still attaining the temperature criteria.

Since 1969, storage in Oroville Reservoir has dropped below 1,200 TAF in approximately 13 percent of the years (Figure A1c-14). Maintaining storage of more than 1,200 TAF in all years could improve conditions for fish, but the improvement may not be substantial considering that historical storage has been maintained at more than approximately 900 TAF in all years, and concerns about release temperature could be addressed by increased use of the power bypass outlet.



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

Figure A1c-16. Historical Monthly Average River Temperatures (°F) near the Feather River Fish Hatchery Compared to Oroville Reservoir Storage (TAF) for August, September, October, and November (1968–1992)

A1c.7 Lake Berryessa

A1c.7.1 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 1,602 TAF at the spillway elevation of 440 feet. The penstock to the powerhouse at the base of the dam is at an elevation of approximately 255 feet (Reclamation 1959), so the maximum water depth above the outlet elevation is about 185 feet.

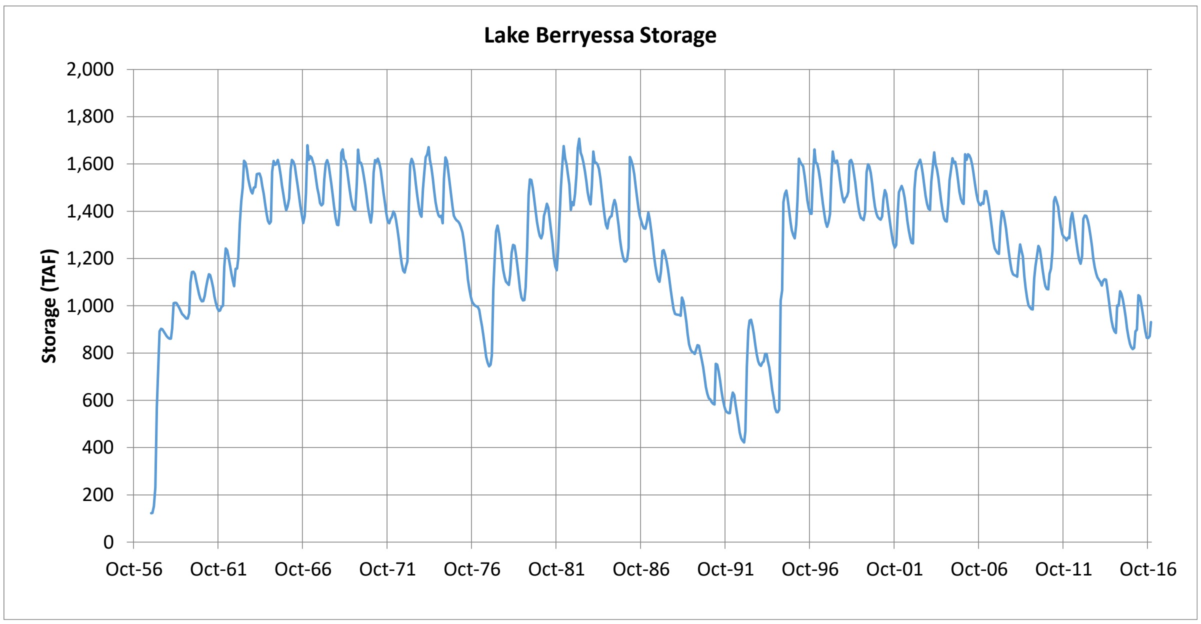
The reservoir release temperatures used in this evaluation were collected at USGS station 11454000, located approximately 1.3 miles downstream of Monticello Dam. Anadromous fish can swim only as far upstream as Solano Diversion Dam, 6 miles downstream from Monticello Dam. As a result, release temperatures ideally would be slightly cooler than the criteria to account for the small amount of warming expected between Monticello Dam and Solano Diversion Dam.

A1c.7.2 Prior Studies

Jones & Stokes (1996) developed an hourly water temperature model for Putah Creek below Solano Diversion Dam. For that analysis, temperature recorders were placed in the creek during summers of 1993 and 1994, when the storage was reduced to 750 TAF and 550 TAF, respectively (Figure A1c-17). The average daily water temperatures below Solano 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). These temperatures were slightly warmer than the release temperatures from the bottom of Monticello Dam. The approximately 1-°C (1.8-°F) increase in measured temperatures between 1993 and 1994 may be indicative of a small increase in reservoir release temperature associated with the lower reservoir storage in 1994.

A1c.7.3 Data

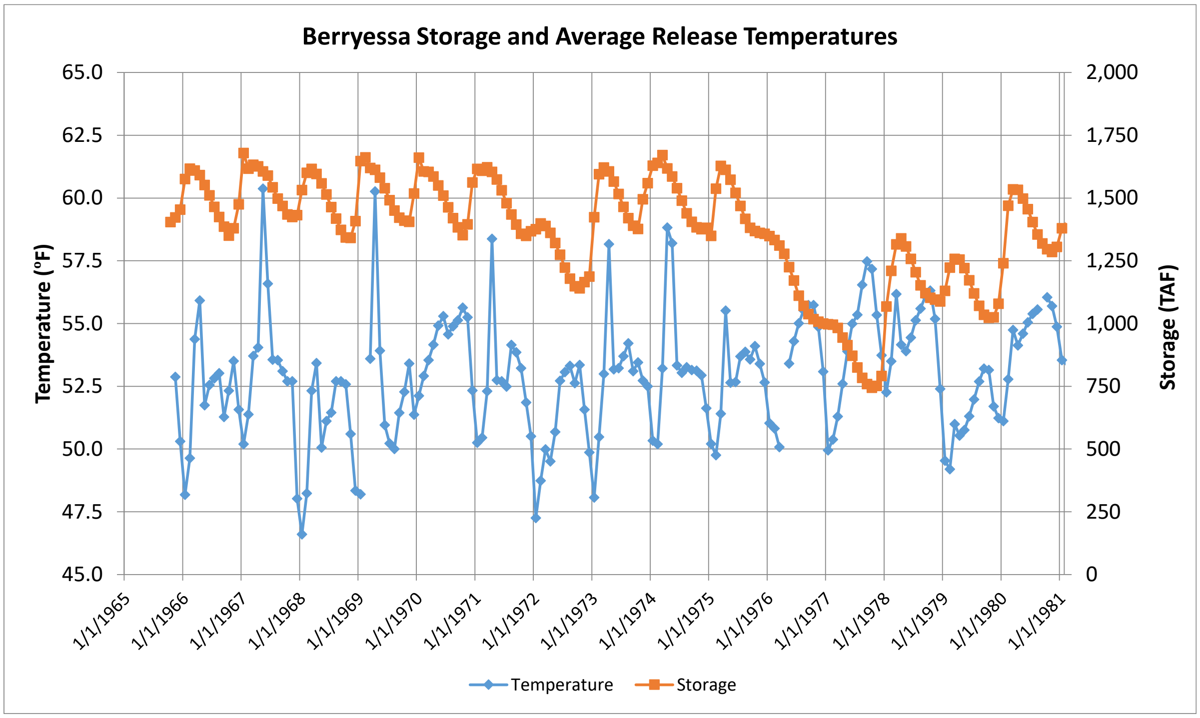
Figure A1c-17 shows the monthly historical Lake Berryessa storage pattern for water years 1957–2016 (CDEC station BER). The storage was reduced to about 750 TAF in 1977 and was reduced to about 400 TAF in 1992; storage during the 2014–2015 drought remained above 800 TAF.



Source: DWR 2017 (CDEC Station BER).
TAF = thousand acre-feet

Figure A1c-17. Monthly Historical Lake Berryessa Storage (TAF) (1957–2016)

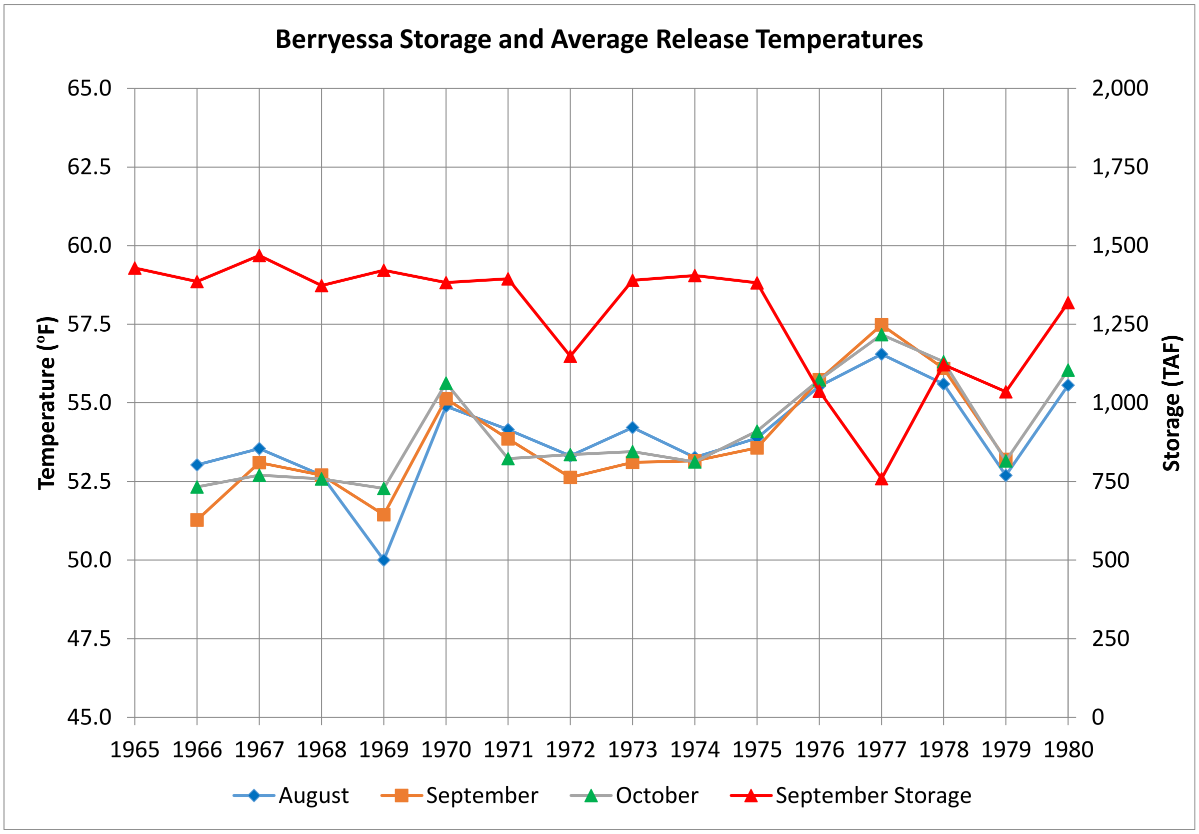
From 1965 to 1980, the Lake Berryessa release temperatures were measured (daily minimum and maximum reported) at the USGS station approximately 1.3 miles downstream of Monticello Dam (Station 11454000, Putah Creek near Winters). Figure A1c-18 shows the monthly average temperatures (average of daily minimum and maximum temperatures) compared to the end-of-month storage levels for 1965–1980. 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 substantially. Cold Creek is ephemeral and does not affect temperatures in late summer and early fall. The average temperatures in January and February were usually about 50 °F or lower, but January through February temperatures were about 52 °F in 1970, 1978, and 1980, causing the release temperatures in summer and fall of these years to be warmer than in most other years. The seasonal warming of the release temperatures was usually small; the summer release temperatures were about 53–54 °F in many years. The seasonal warming was greatest in 1977, when the storage was reduced from 1,000 to 750 TAF. Separating the effects of reduced storage on release temperatures may be difficult for these years of data because release temperatures also are influenced by winter temperatures, which determine the temperature of the cold water pool. However, in 1977, the winter release temperatures dropped to the typical 50 °F, indicating that the warming that occurred during August–October of 1977 was likely associated with lower storage.



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

Figure A1c-18. Monthly Lake Berryessa Storage (TAF) and Average Release Temperatures (°F) (1965–1980)

Figure A1c-19 shows the monthly average August–October temperatures compared to the end-of-September storage for 1966–1980. For most years, the release temperatures were very similar from August to October, indicating that the seasonal warming was minimal in most years. Release temperatures varied from year to year depending on the minimum temperatures achieved each winter. Although the release temperatures were greater than 56 °F in 1977 when storage was lowest, release temperatures also exceeded 55 °F in 1970, 1976, 1978, and in 1980 when end-of-September storage was above 1,000 TAF.



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

Figure A1c-19. Lake Berryessa End-of-September Storage (TAF) Compared to Monthly Average August–October Release Temperatures (°F) (1965–1980)

A1c.7.4 Data Evaluation

There are no temperature criteria for fish specific to Putah Creek. Therefore, the composite temperature criteria at the bottom of Table A1c-1 were used to assess Lake Berryessa storage. As observed for other reservoirs, the reservoir storage levels needed to meet these water temperature criteria would be highest in October when water temperatures of 56 °F or lower are needed to meet the requirements for Chinook salmon spawning and incubation (Figure A1c-20).

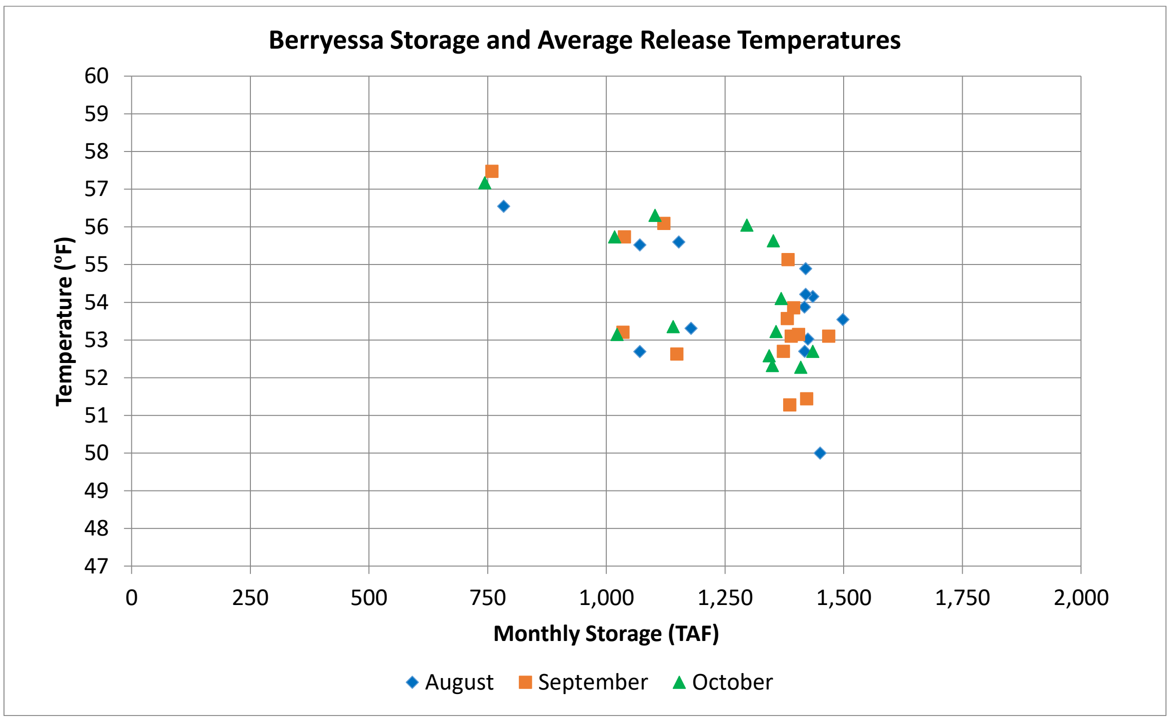
Figure A1c-20 shows the end-of-month storage levels and the monthly average August–October daily temperatures for 1966–1980. The data indicate a slight increase in release temperature at the lowest storage level, but there are not enough measurements at low storage values (e.g., less than 1,000 TAF) to clearly identify the effect of storage on release temperature.

For the period when measured temperatures were available (1966–1980), storage was almost always greater than 1,000 TAF. The data suggest two storage-versus-temperature inflection points, at approximately 1,350 TAF and between 750 and 1,000 TAF. Release temperatures at storage levels between 1,000 and 1,350 TAF seem to be relatively constant. At storage levels greater than 1,000 TAF, there does not appear to be a strong relationship between storage and release temperature, except that temperatures were approximately 1–2 °F cooler at the highest storage levels (greater than about 1,350 TAF). Based on physical processes, double inflection points are not expected, and it is likely that the appearance of the graph is affected by variable factors, such as temperature and volume of winter inflows.

One set of measurements at 750 TAF is indicative of warming at storage levels less than 1,000 TAF. The slightly warmer temperatures at 750 TAF potentially could be caused by variability in meteorological conditions. However, at 750 TAF, the reservoir water surface elevation is approximately 140 feet above the outlet, and it would not be surprising to start seeing a loss of cold water pool at this point. In addition, release temperatures during winter 1977 were cool, indicating that low rainfall and not warm winter meteorological conditions were the cause of the warmer temperatures.

Based on the measured data, average monthly release temperatures occasionally exceeded the 56 °F October criterion even when storage was maintained between 900 and 1,300 TAF. Considering the total reservoir storage capacity of 1,602 TAF, it would be difficult to maintain carryover storage at a level that could guarantee release temperatures below 56 °F in October.

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 temperatures at 1,000–1,350 TAF, 900 TAF may be an appropriate estimate of a storage level that could protect the cold water pool. Because average October release temperatures occasionally reach 56 °F even if storage is greater than 1,000 TAF, 900 TAF can serve as both the estimate to protect the cold water pool and the estimated storage to meet temperature criteria for fish.



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

Figure A1c-20. Lake Berryessa Storage (TAF) Compared to Release Temperatures (°F) in August–October (1966–1980)

A1c.8 New Hogan Reservoir

A1c.8.1 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, at invert elevation 535 feet (USACE 1983), is very close to the bottom of the reservoir at 530 feet. Storage has been drawn down to approximately 15 TAF (585 feet) on multiple occasions. 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).

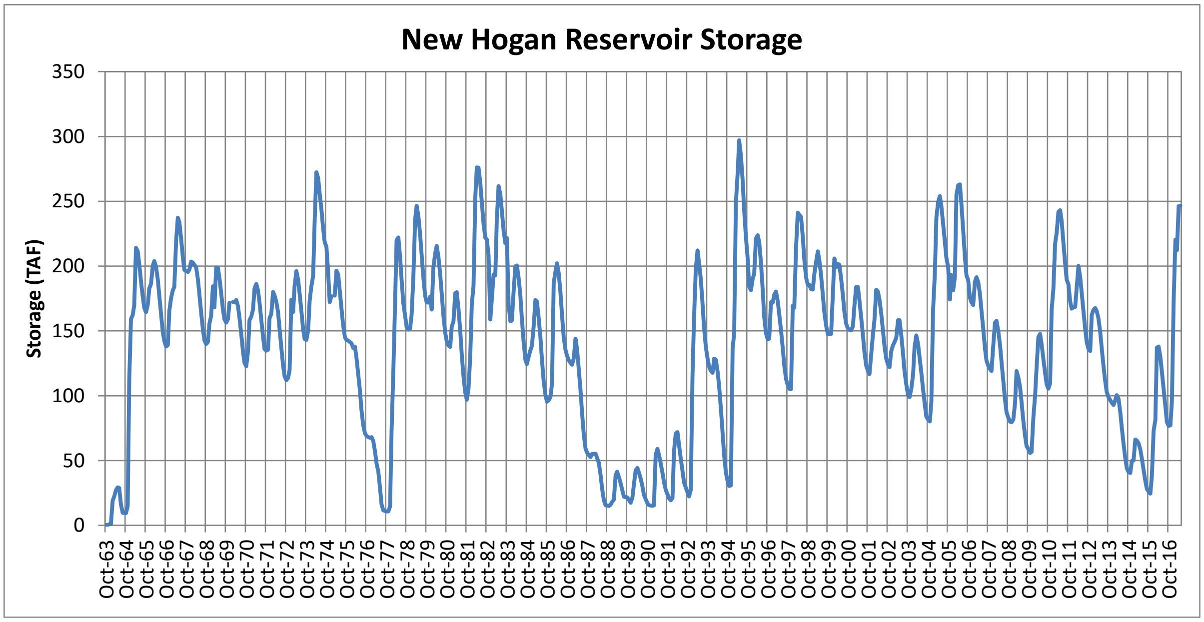
A1c.8.2 Prior Studies

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).

A1c.8.3 Data

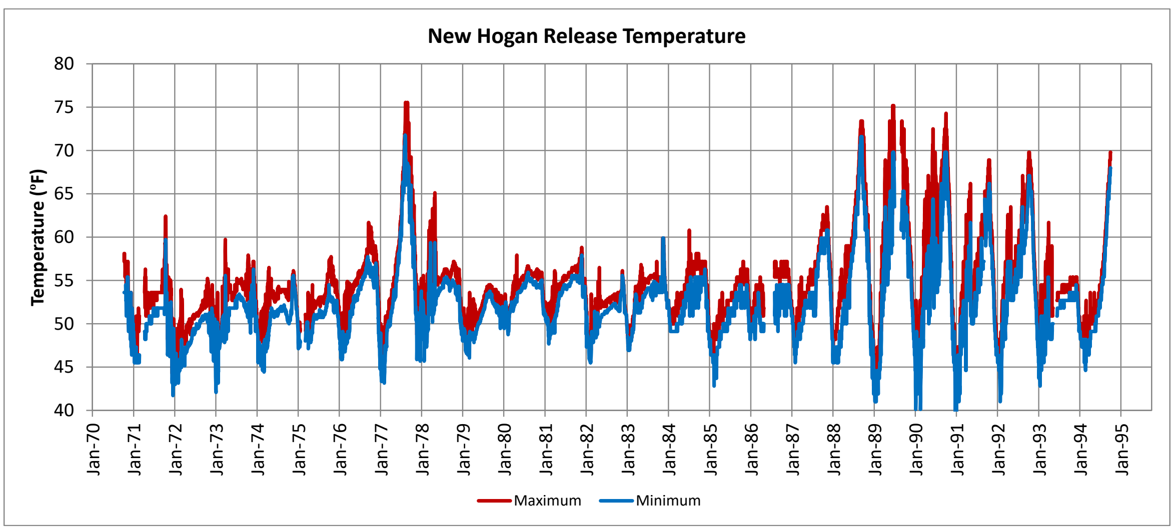
Figure A1c-21 shows the daily historical New Hogan Reservoir storage for 1963–2016 (CDEC station NHG). The minimum storage of about 11 TAF occurred in 1977, and storage was less than 25 TAF in 1988–1992 (5-year sequence). Although the maximum storage is about 325 TAF, the reservoir has rarely been filled to more than 250 TAF. Data suggest that the seasonal inflow pattern (no substantial snowmelt), the flood-control storage curve, and the releases for water supply prevent the reservoir from filling in most years.

Figure A1c-22 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 (CDEC Station NHG).
TAF = thousand acre-feet

Figure A1c-21. New Hogan Reservoir Storage (TAF) (1963–2016)



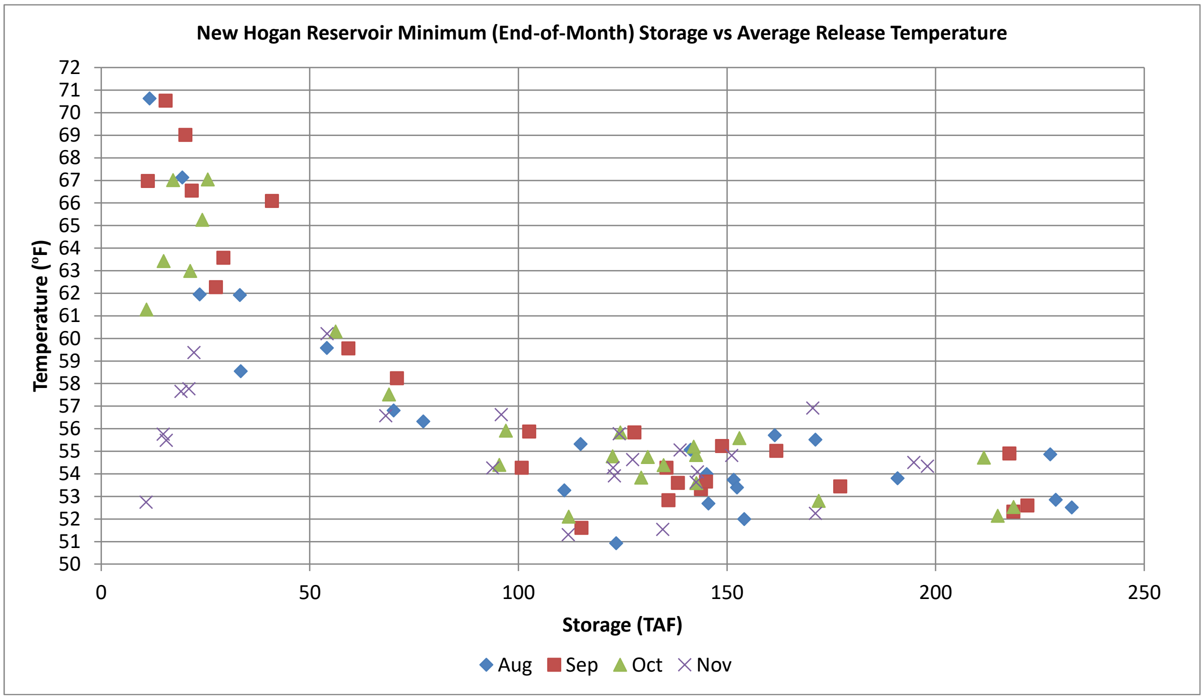
Source: USGS 2017 (Station 11308900).
°F = degrees Fahrenheit

Figure A1c-22. Historical Daily Water Temperatures (°F) in Calaveras River below New Hogan Reservoir (1970–1994)

A1c.8.4 Data Evaluation

There are no temperature criteria for fish specific to the Calaveras River. Therefore, the composite temperature criteria at the bottom of Table A1c-1 were used to assess New Hogan Reservoir storage. As observed for other reservoirs, the reservoir storage levels needed to meet these water temperature criteria 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 A1c-23).

Figure A1c-23 shows the average release temperature for August, September, October, and November compared to the monthly storage (TAF). New Hogan Reservoir release temperatures are remarkably cool for a reservoir of its size and southern location. 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. 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.



Sources: DWR 2017 (CDEC Station NHG); USGS 2017 (Station 11308900).
°F = degrees Fahrenheit
TAF = thousand acre-feet

Figure A1c-23. New Hogan Storage (TAF) Compared to Release Temperatures (°F) in August–October (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 A1c-21). Temperatures may often be suitable for fall-run Chinook salmon spawning, and limited upstream fish passage is the primary factor currently limiting steelhead and Chinook salmon populations in the Calaveras River (Stillwater Sciences 2004). Based on this analysis, it appears that a carryover target of 100 TAF may be sufficient.

A1c.9 Camp Far West Reservoir

A1c.9.1 Infrastructure and Geography

As documented by South Sutter Water District (SSWD) (2016), Camp Far West Reservoir captures water from the Bear River, a tributary to the Feather River. Camp Far West Reservoir storage capacity is 94 TAF at an elevation of 300 feet, a little less than the 144-TAF capacity of Black Butte Reservoir. The dam has a powerhouse inlet with a sill elevation of 197 feet and a low-level inlet with a sill 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. A diversion dam approximately 1.1 mile downstream of Camp Far West Dam is the upper limit of anadromous fish migration.

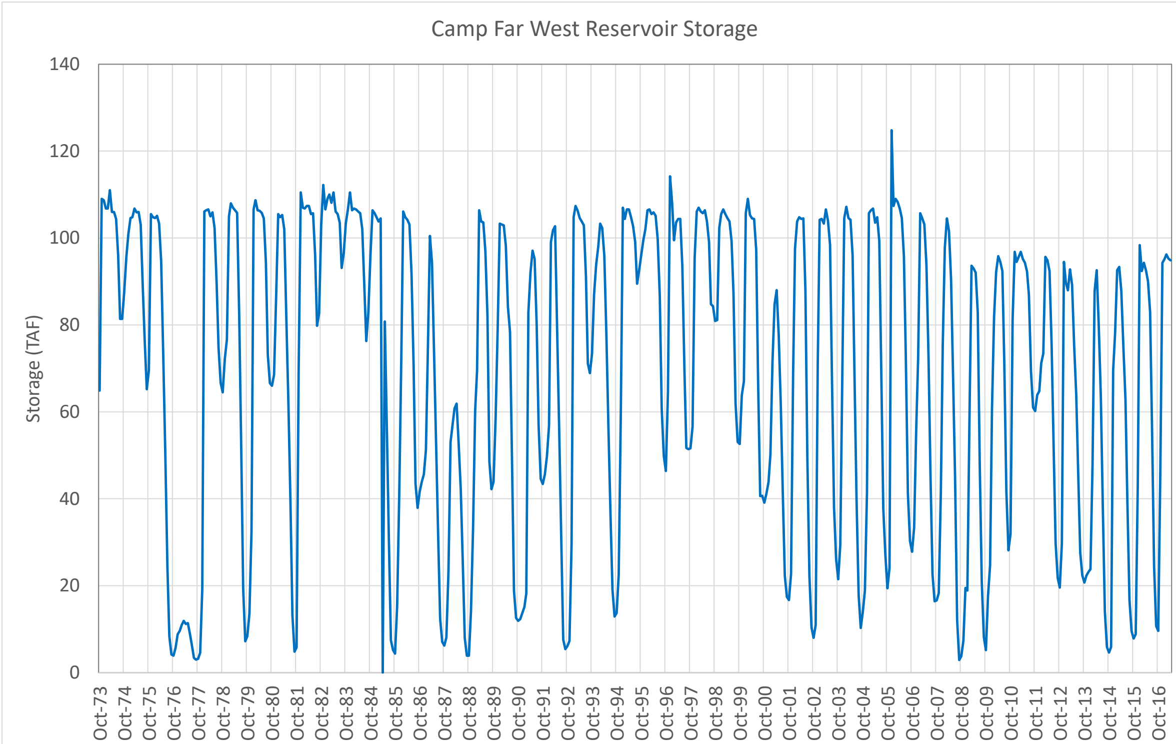
A1c.9.2 Prior Studies

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. Some documentation of temperature and habitat conditions for anadromous fish in the Bear River was compiled by SSWD as part of a FERC relicensing process (SSWD 2016). SSWD has gathered limited pre-existing water temperature data and in 2015, started to collect new water temperature data with the intent of developing a water temperature model. This discussion on Camp Far West Reservoir is largely based on information from SSWD (2016).

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).

A1c.9.3 Data

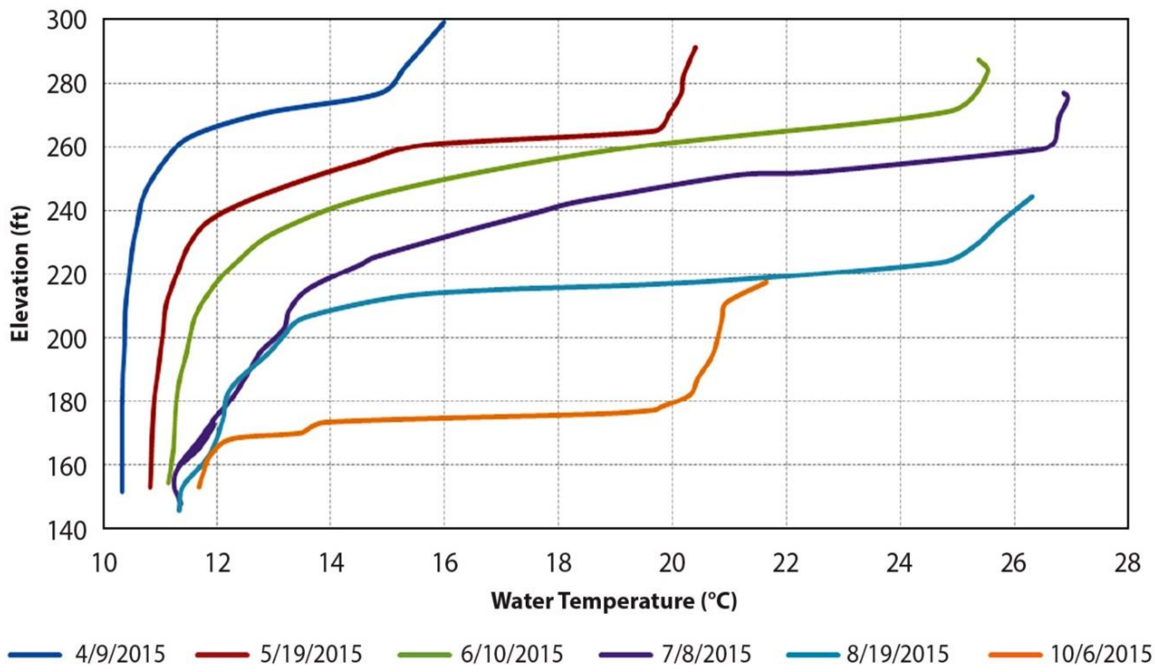
Operation of Camp Far West Reservoir is similar to operation of Black Butte Reservoir in that storage (CDEC station CFW) is typically drawn down to very low levels in fall. In many years, storage in Camp Far West Reservoir is drawn down to less than 20 TAF (Figure A1c-24), which corresponds to a lake elevation of approximately 240 feet (SSWD 2016).



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

Figure A1c-24. Historical Storage (TAF) in Camp Far West Reservoir (1973–2016)

SSWD collected reservoir temperature profiles near the Camp Far West Dam during 2015. 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 A1c-25).



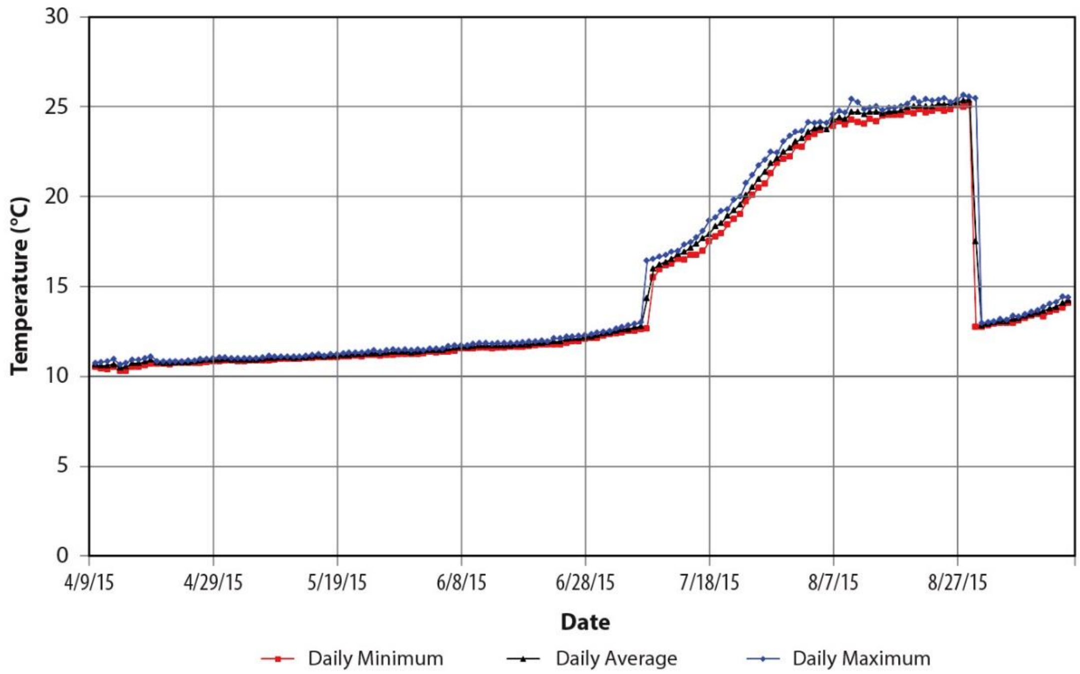
Source: SSWD 2016, Figure 3.2.2-36.
°C = degrees Celsius
ft = feet

Figure A1c-25. Water Temperature (°C) Profiles Measured Downstream of Camp Far West Reservoir in the Bear River by South Sutter Water District (2015)

A1c.9.4 Data Evaluation

Despite the strong vertical temperature gradient and conservation of cold water, when the reservoir is drawn down to low levels, temperatures may exceed the 60 °F (15.6 °C) and 57 °F (13.9 °C) criteria (Table A1c-1) for fall-run Chinook salmon migration and spawning in the Bear River during October. During 2015, by mid-September, release temperatures were approaching 15 °C (59 °F) and likely exceeded 15 °C in October, despite conservation of cool water through the summer by using the higher-level powerhouse outlet from July 1 to September 1, when fall-run Chinook salmon are unlikely to be present. This resulted in release of warmer water and conservation of cooler water (Figure A1c-26).

By the end of September 2015, storage was too low (10 TAF) to provide adequate release temperatures for fall-run Chinook salmon spawning. Based on the 2015 measurements, it appears that release temperatures were close to 14°C (57.2°F), the upper limit of optimal temperature for fall-run Chinook salmon spawning, after about the first week of September, when storage was approximately 15 TAF. It is possible that relatively small increases in carryover storage compared to 2015 could produce release temperatures that would be adequate for fall-run Chinook salmon migration in October. Increased storage through the summer might make it possible to delay the need to switch to use of the low-level outlet and better conserve cool water for a more prolonged cool-water release from the low-level outlet. Based on the reservoir temperature profiles, it appears that a carryover target of 20 TAF may be sufficient, although temperature modeling or additional data collection would ideally eventually be used to confirm this estimate.



Source: SSWD 2016, Figure 3.2.2-39.
°C = degrees Celsius

Figure A1c-26. Camp Far West Reservoir Release Temperatures (°C) Measured by South Sutter Water District (2015)

A1c.10 Summary

The useful cold water pool is lost when the bottom of the thermocline reaches the reservoir outlet. Depth and shape of the thermocline changes throughout the year. Generally, as the year progresses from spring to fall, the thermocline extends deeper through the water column. The storage levels for attaining the temperature criteria described in this preliminary assessment are driven by the size and shape of the reservoir (steep-walled and deep versus shallow), temperature and volume of reservoir inflow, elevation of the reservoir outlets, operation of temperature control structures, and volume of water released from the reservoir during the year.

These storage levels and key observations are summarized in Table A1c-2. These levels are based on the observed temperatures evaluated in this analysis; they are somewhat affected by year-to-year variability in the parameters affecting temperature and by the completeness of the data sets (e.g., years of data and range of storage levels).

Table A1c-2. Range of Reservoir Storage Targets to Protect Cold Water Supply

Reservoir	Storage to Protect Releases from Cold Water Pool (Conservative Level in TAF)	Storage to Meet Temperature Criteria (Less Conservative Level in TAF)	Notes Regarding Evaluation Approach and Conclusions
Black Butte Reservoir	NA	NA	Temperatures are unsuitable for anadromous fish and increases in storage are unlikely to allow criteria to be met.
Folsom Reservoir	NA	400	60 °F October criterion not always attained at 400 TAF, but greater carryover storage would diminish supply without a guarantee of suitable temperatures.
New Bullards Bar Reservoir	550	400	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. Temperatures at the Smartsville monitoring station may be affected by warming through Englebright Reservoir and inflow from the Middle and South Yuba River.
Oroville Reservoir	1,500	1,200	Increased use of the power bypass outlet could allow attainment of criteria at storage less than 1,200 TAF.
Lake Berryessa	900	900	Very little data available for storage less than 1,000 TAF. Average monthly release temperatures could occasionally exceed the 56 °F October criterion even if storage is maintained above 900 TAF. A carryover storage target that could reliably produce a 56 °F October release temperature would approach the full storage capacity of the reservoir.
New Hogan Reservoir	100	100	Historical storage levels have been close to or above 100 TAF during average or wet conditions and drop below 100 TAF during dry conditions.
Camp Far West Reservoir	NA	20	Not enough data to create the same storage-versus- release temperature graphs as for other reservoirs.

°F = degrees Fahrenheit
NA = not attainable based on historical data and existing infrastructure
TAF = thousand acre-feet

A1c.11 References

A1c.11.1 Common References

^SacWAM 2023: State Water Resources Control Board (SWRCB). 2023. Sacramento Water Allocation Model (SacWAM) Documentation.

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