

APPENDIX F. STREAM TEMPERATURE ANALYSIS

Technical Memorandum 3

TO: Stockton East Water District, Calaveras County Water District

CC: California Department of Water Resources

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RE: Stream Temperature Vulnerability under Climate Change

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1. PURPOSE

The purpose of this Technical Memorandum (TM) is to summarize an evaluation of potential impacts of climate-induced changes to reservoir storage and stream temperature in the Calaveras River, particularly directly below New Hogan Dam.

2. BACKGROUND

The 2019 Calaveras River Habitat Conservation Plan (CHCP) was drafted by Stockton East Water District (SEWD) and FISHBIO to establish protections for various salmonid populations that may exist within the Calaveras River (Stockton East Water District & FISHBIO, 2019). The CHCP provides operational criteria for SEWD to maintain habitat requirements in concert with necessary water supply operations at New Hogan Dam and other water delivery infrastructure.

According to the CHCP, the Calaveras River provides critical or potential habitat for several threatened and endangered populations of salmonids, including the Central Valley steelhead (*O. mykiss*), Sacramento River winter-run Chinook salmon (*O. tshawytscha*), Central Valley spring-run Chinook salmon (*O. tshawytscha*), and Central Valley fall and late fall-run Chinook salmon (*O. tshawytscha*). The lower reaches of the Calaveras River, downstream of New Hogan Dam, are designated critical habitat for Central Valley steelhead, a genetically unique and threatened population of salmonids present in the Sacramento and San Joaquin River watersheds. While Chinook salmon are not commonly observed in the Calaveras River, they may opportunistically utilize parts of the river. Further, the entirety of the San Joaquin Basin is designated as Essential Fish Habitat for Chinook salmon under the Magnuson-Stevens Act. Thus, the CHCP requires the maintenance of adequate habitat conditions for Sacramento River winter-run and Central Valley Chinook salmon upstream of the Bellota Weir.

The CHCP addresses the incidental take associated with several of SEWD's operational activities, including channel maintenance and the operation of infrastructure such as New Hogan Dam, the Old Calaveras River Headworks facility, diversion facilities, and small dams. The CHCP focuses on maintaining adequate flow rates through adaptive management of facilities along the Calaveras River, particularly between New Hogan Dam and the Bellota Weir. Year-round flow is essential for salmonid migration, spawning, and rearing.

Flow rates directly influence water temperature, a key factor in fish habitat viability. Salmonids are highly sensitive to stream temperature conditions (California Department of Fish and Wildlife, 2010). *O. mykiss* and other salmonid species require cold water for survival in all life stages, but particularly during spawning, incubation, rearing, and the early development of fry. To support successful spawning, egg incubation, and fry emergence, the US Environmental Protection Agency (2003) suggests that seven-day average water temperatures should not exceed 13°C (55°F). Temperature thresholds for other essential life history stages range from 14°C to 20°C (57 to 68°F). It is important to note that these criteria were developed based on studies of salmonids in the Pacific Northwest and may be overly conservative targets for *O. mykiss* inhabiting Central Valley streams. Studies of *O. mykiss* in the nearby Tuolumne River indicated that individuals could maintain 95% of their peak aerobic scope (i.e., the ability to provide oxygen for activity) even at temperatures as high as 24.6°C (76°F; (Verhille, English, Cocherell, Farrell, & Fangue, 2016)).

While many streams in the San Joaquin River Basin do not meet the temperature criteria necessary for salmonid survival, the relevant reaches of the Calaveras River have historically met water temperature criteria for the successful incubation of *O. mykiss* eggs and fry (Stockton East Water District & FISHBIO, 2019; California Department of Fish and Wildlife, 2010). Even so, stream temperatures are highly variable and sensitive to a range of factors. To ensure temperature thresholds are met, the CHCP requires careful monitoring at specific locations along the lower reaches of the Calaveras River.

FISHBIO has supported SEWD in CHCP compliance throughout its development and implementation, including maintaining a robust daily river temperature monitoring network. Figure 1 shows these monitoring locations mapped along the river.

While a more thorough five-year review is forthcoming, routine monitoring reveals that water temperatures within key spawning and rearing reaches (e.g., New Hogan Dam [RM 42] to Shelton Rd [RM 26]) has maintained adequate water temperatures during key life history periods across a range of water year types and stream flow conditions. Importantly, CHCP management actions center on providing year-round flow to Bellota (RM 23.8) in order to maintain water temperature criteria within the 18-mile Conservation Area upstream of Bellota. As such, much of the discussion regarding appropriate water temperature conditions is focused on this reach of the Calaveras River due to its importance to multiple phases of the salmonid life history.

During Water Year (WY) 2021, a critically dry year, water temperatures during the spawning and incubation periods of *O. mykiss* were typically less than 12°C (54°F) 7DADM between December 2020 and March 2021. During April to September, 7DADM temperatures, from New Hogan Dam to Bellota, were generally less than 18°C (64°F) for the majority of the reach from April to late September, with the upper three monitoring locations were typically right around or less than 16°C (61°F) in the late spring, summer, and early fall. These upper three monitoring locations would have met the criteria for 'core rearing' for *O. mykiss* of 16°C (61°F) throughout WY 2021. Shelton Road would have met the criteria for 'non-core rearing' for *O. mykiss* of 18°C (64°F) throughout WY 2021 (Cuthbert, Inman, & Peterson, Prepared for Stockton East Water District., 2021).

Similarly, during WY 2022 which was also categorized as a critically dry water year type, water temperatures during the spawning and incubation periods of *O. mykiss* were typically less than 12°C (54°F) 7DADM between December 2021 and February 2022. From April to late September, 7DADM temperatures were generally less than 18°C (64°F) for the majority of the reach from April to late September, with the exception of Bellota which began exceeding 18°C (64°F) by mid-March. The upper four monitoring locations (e.g., New Hogan, Jenny Lind, Gotelli, and Shelton) were typically less than 16°C (61°F) in the late spring and summer and approached or exceeded 16°C (61°F) by early fall. These upper four monitoring locations would have met the criteria for 'core rearing' for *O. mykiss* of 16°C (61°F) throughout the majority of WY 2022 (USEPA 2003). Jenny Lind, Gotelli, and Shelton would have met the criteria for 'non-core rearing' for *O. mykiss* of 18°C (64°F) throughout WY 2022 (U.S. Environmental Protection Agency, 2003) with the exception of a brief period in the late fall where all three sites began to exceed 18°C. Importantly, this was the second consecutive year in which the Calaveras River Basin was experiencing drought conditions (Cuthbert, Peterson, & Inman, 2022).

During WY 2023, a wet water year type, water temperatures during the spawning and incubation periods of *O. mykiss* were typically less than 12°C (54°F) 7DADM between December 2022 and April 2023. From New Hogan Dam to Bellota, 7DADM temperatures were generally less than 18°C (64°F) for most of the reach from April to late September, except for Bellota and Jenny Lind which began exceeding 18°C (64°F) by mid-April. The upper four monitoring locations (e.g., New Hogan, Jenny Lind, Gotelli, and Shelton) were typically less than 16°C (61°F) in the late spring through the summer. These upper four monitoring locations would have met the criteria for 'core rearing' for *O. mykiss* of 16°C (61°F) throughout the majority of WY 2023 (Cuthbert, Peterson, & Inman, 2024).

During WY 2024, categorized as an above normal water year type, water temperatures during the spawning and incubation periods of *O. mykiss* were typically less than 12°C (61°F) 7DADM between December 2023 and April 2024, however, some locations began exceeding the criteria in late March to early-April 2024. From New Hogan Dam to Shelton Road, 7DADM temperatures were generally less than 18°C (64°F) for most of the reach from April to late September. There was an increase in water temperature in mid-April, but New Hogan, Clements Place, and Jenny Lind remained at or below the 16°C (61°F) threshold. Shelton Road exceeded a 7DADM of 18°C (64°F) for a brief period in late April but remained at or below the 18°C (64°F) threshold. The upper four monitoring locations (e.g., New Hogan, Jenny Lind, Gotelli, and Shelton) were typically less than 18°C (64°F) in the late spring through the summer. The upper three monitoring locations would have met the criteria for 'core rearing' for *O. mykiss* of 16°C (61°F) throughout the majority of WY 2024 (Cuthbert & Pilger, 2025).

As part of the Calaveras River Watershed Resilience Plan vulnerability assessment, climate change impacts on river temperature were evaluated, building off of existing efforts to maintain salmonid habitat along the Calaveras River.

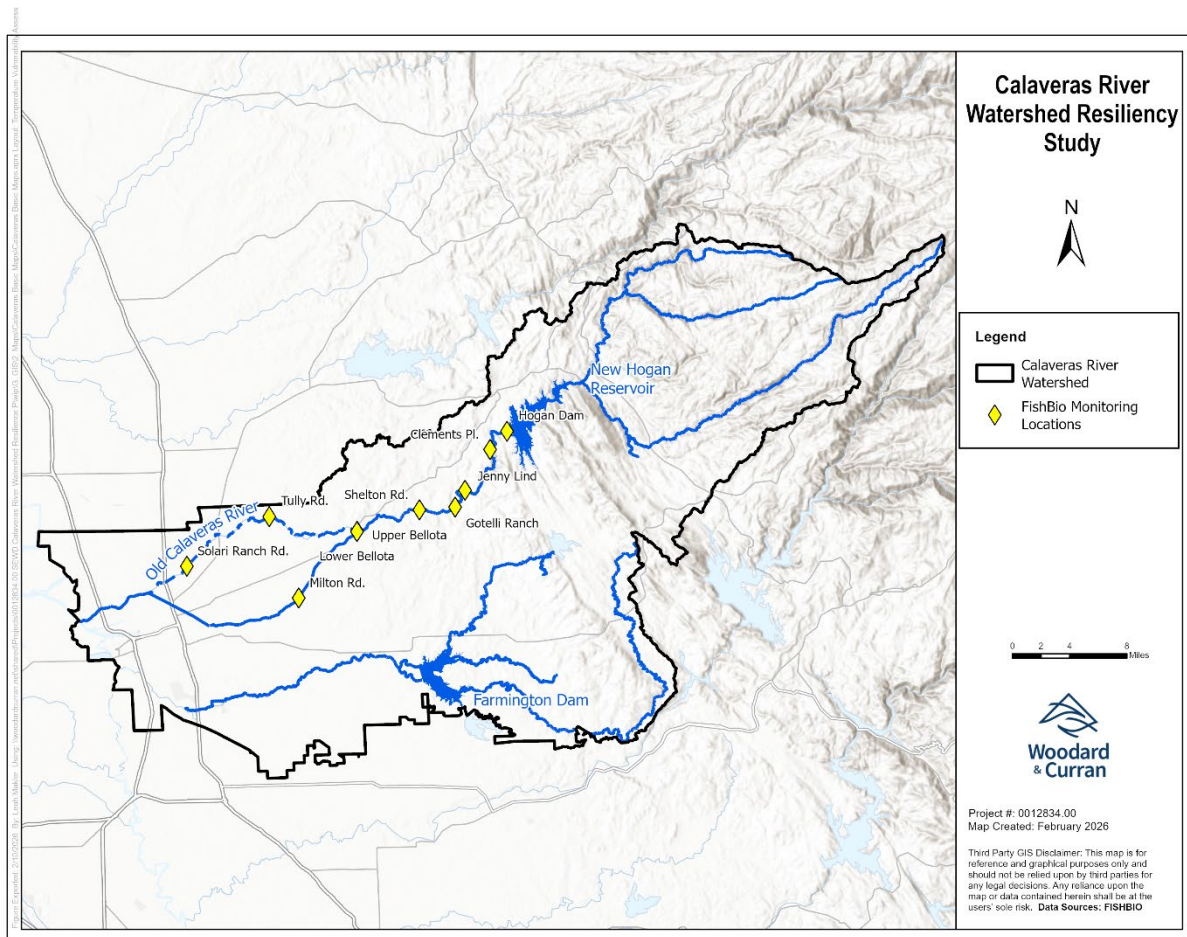


FIGURE 1: FISHBIO MONITORING LOCATIONS

3. APPROACH AND METHODS

3.1 Data Available

This analysis builds upon existing monitoring by FISHBIO and modeling completed by the California Department of Water Resources (DWR) as part of their Watershed Studies program. The following observed data and modeled simulations were used in this analysis:

Observed data:

- Daily New Hogan Releases (US Army Corps of Engineers, 2025)
- Daily New Hogan Reservoir Storage (US Army Corps of Engineers, 2025)
- Daily stream temperature measured along various locations along Calaveras River, as shown in Figure 1 (FISHBIO, 2025)

Model-simulated data:

- Daily ResSim reservoir outflow (DWR, Watershed Studies)
- Daily ResSim reservoir storage (DWR, Watershed Studies)

ResSim reservoir outflow and ResSim reservoir storage time series were compared to observed historical data in order to ensure reasonable simulation of observed conditions. Figure 2 compares reservoir releases (shown in blue) as measured at the New Hogan Dam station (NHG) just below the dam between 2000 and 2018 with ResSim reservoir outflow (shown in orange). Figure 3 presents a similar graph, but for reservoir storage by year, and Figure 4 shows the same data averaged by month to show seasonal variations. All of these figures indicate that the ResSim modeled time series captures trends in historical data well. Reservoir outflow during spill or high release periods is often either underestimated or overestimated. Reservoir storage is consistently under-simulated both on an annual average and in each month of the year. This is likely due to a variety of factors that were considered as part of calibration decisions made by DWR during model development. Calibration of releases was likely prioritized during calibration because of its importance for downstream supply. Additionally, the operations assumed in ResSim represent a version of future projected operations, whereas the observed reservoir storage reflects actual historical operations. More detail on this calibration can be found in DWR's documentation of this modeling effort to be available in a forthcoming publication in the coming year.

For the purposes of this analysis, simulated reservoir storage was still deemed reasonable enough to evaluate potential stream temperature changes under climate change. However, it is important to note that due to the under-simulation of reservoir storage, the results presented in Section 4 should be interpreted as conservative estimates of stream temperature increases.

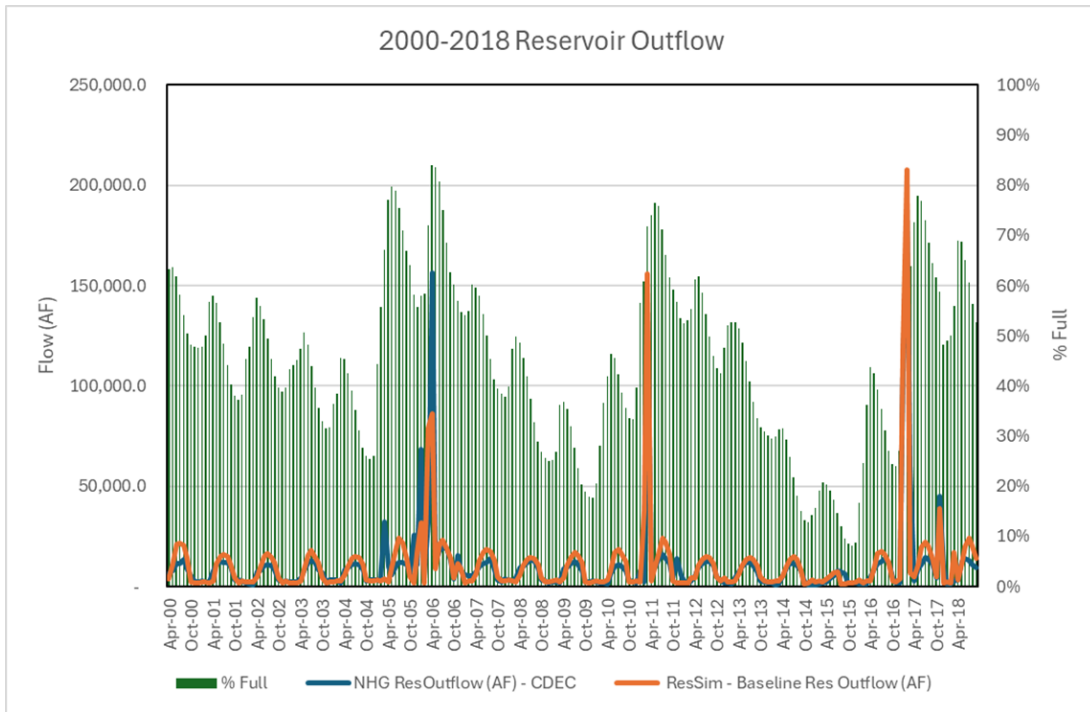


FIGURE 2: OBSERVED VS. SIMULATED RESERVOIR OUTFLOW (SOURCES: CDEC AND DWR)

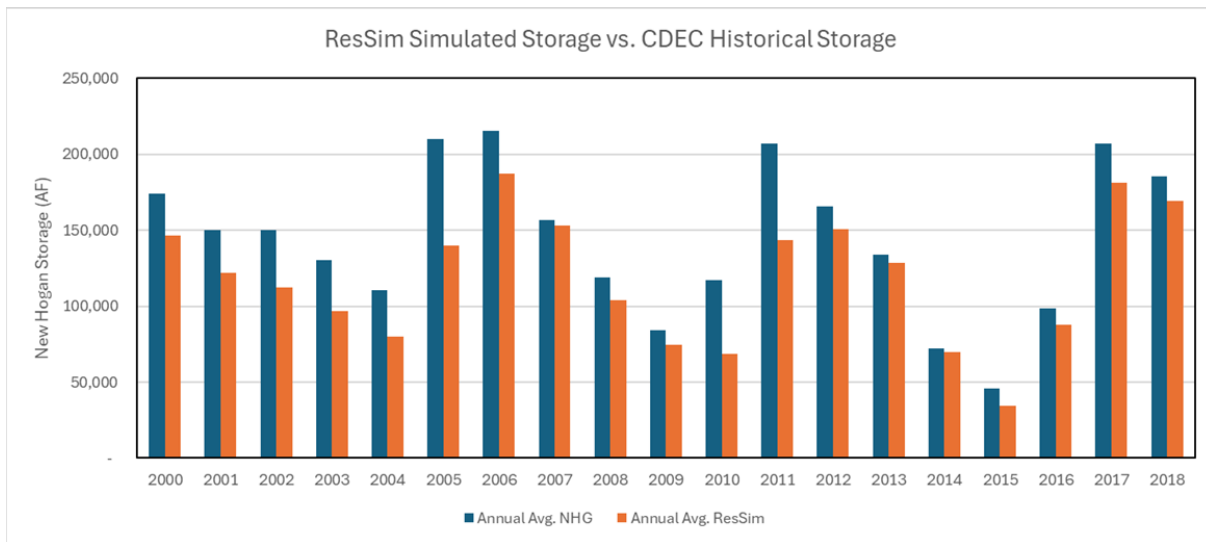


FIGURE 3: OBSERVED VS. SIMULATED RESERVOIR STORAGE, BY YEAR (SOURCES: CDEC AND DWR)

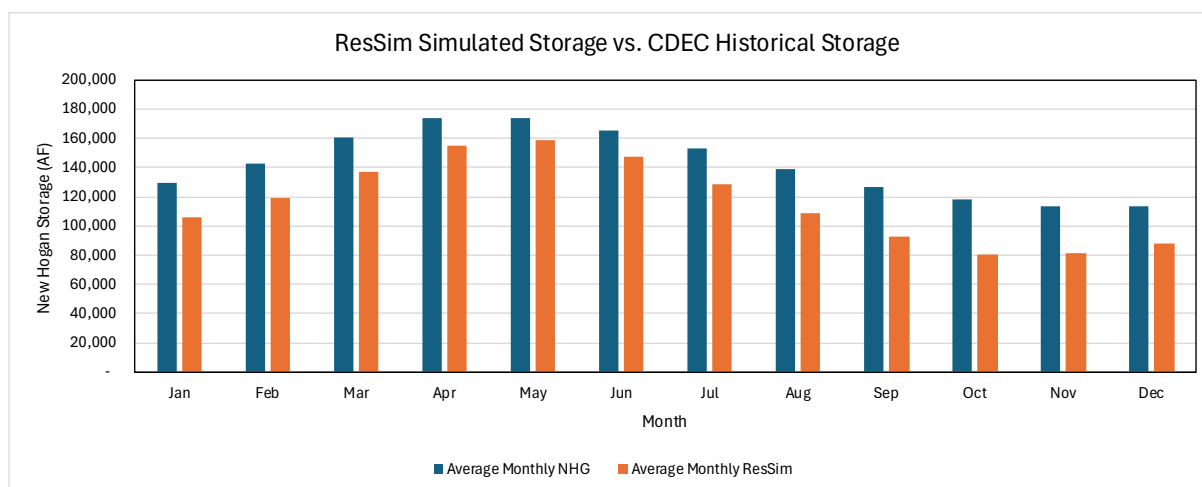


FIGURE 4: OBSERVED VS. SIMULATED RESERVOIR STORAGE, BY MONTH (SOURCES: CDEC AND DWR)

3.2 Relationship between Reservoir Storage and Stream Temperature Below Dam

New Hogan Reservoir storage data was acquired from the California Data Exchange Center (US Army Corps of Engineers, 2025). Data were filtered to include the storage at the end of each month from October 1999 (WY 2000) to September 2024 (WY 2024).

Water temperature data were available at the New Hogan gauge operated by FISHBIO from April 2000 (WY 2000) to September 2024 (WY 2024). Temperature data were filtered to ensure that the calculated mean monthly mean temperature was representative of the daily temperatures recorded during that month. Therefore, data from some months was excluded from further analyses due to missing data, which were: April – June 2004, June 2006, January – February 2008, July – August 2009, December 2009, September – October 2013, September – October 2015, and April – June 2016.

Preliminary graphs that were developed (not shown) indicated that a linear fit for all months would not properly characterize the data. In some months (e.g., January), a linear fit of the observed data appeared to be appropriate (Appendix A, Figure A1). This was judged by examining the residuals from the regression to examine for any patterning. Patterns in residuals (the standardized difference between the observed and predicted data) often indicate a poor fit. For other months (e.g., September), the relationship was clearly nonlinear and standard linear regression would not be appropriate to model the data (Figure 5). Instead, a piecewise linear regression was used that can estimate multiple slopes and the break point at which the slopes change. The main assumption of a piecewise linear regression is that the data on either side a break point can be modeled with a linear regression, though each can have a different slope and intercept.

Segmented regressions were used to model storage and water temperatures during the months of April – September. Simple linear regressions were sufficient for the remainder of the months (January – March and October – December). To illustrate the importance of the storage threshold and its impact on downstream temperature, we focus the results on the months of August and September. During these months, a complex

relationship between storage levels and water temperatures was observed. The impact of low reservoir storage in each month was striking. For example, during the month of August, if storage was greater than 115 TAF (Appendix A, Figure A8) and decreased by 10 TAF, water temperature was predicted to increase approximately 0.04°F. However, if storage was <115 TAF and decreased by 10 TAF, water temperature was predicted to increase 0.57°C (1.03°F). This represents about 15 times the rate of change below and above this threshold of 115 TAF. Results for September (Appendix A, Figure A9) showed the most drastic difference in slopes below and above its storage threshold. For September, the rate of change above and below about 100 TAF was about 136 times, with a predicted increase of 1.22°C (2.20°F) with a 10 TAF decrease in storage when total storage was <100 TAF. Above 100 TAF, water temperatures were predicted to only increase by about 0.01°C (0.02°F), which means that water temperature essentially does not change with decreased storage.

Data presented herein related to reservoir storage and downstream water temperatures should be viewed with appropriate caution for several reasons. These include: (1) months with limited or no water temperature data due to lost, stolen, or damaged water temperature loggers, (2) the location of the water temperature data is only representative of conditions immediately below New Hogan Dam, and (3) a relatively short data set with which to assess relationships. Each of these could be addressed through either additional data analyses and/or additional data collection. To account for periods of missing data, either redundant loggers or data interpolation could be used. To better assess how reservoir storage might affect the entire rearing reach of the Calaveras River (i.e., New Hogan Dam to Bellota), data from additional loggers could be incorporated into the analysis. Finally, water temperature data in additional years should (and will) be collected as required by the CHCP.

Appendix A contains the full set of curves developed for each month.

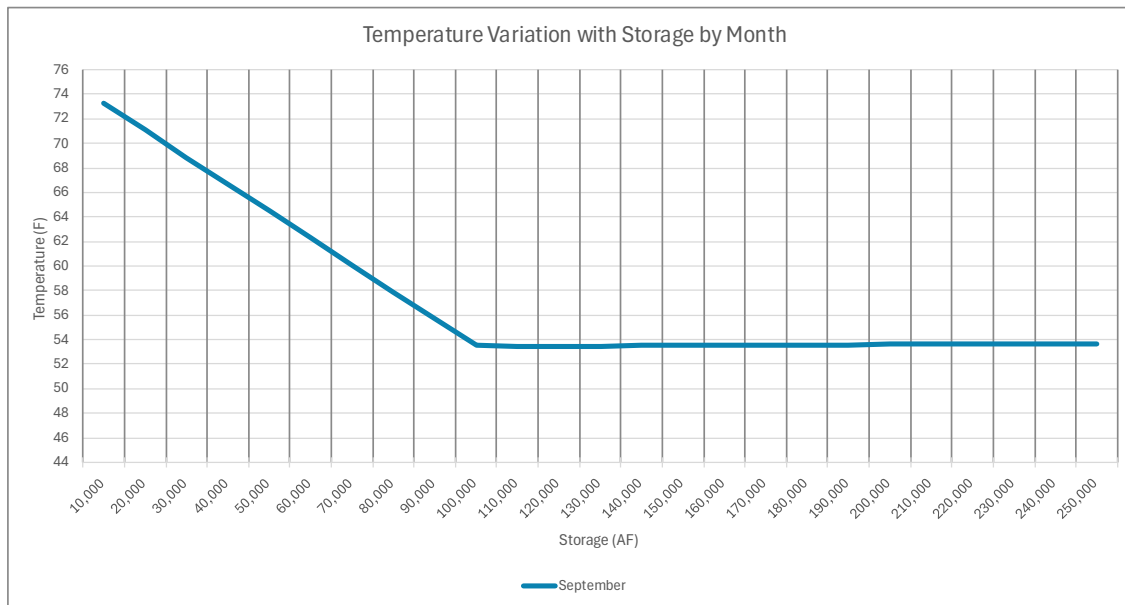


FIGURE 5: EXAMPLE RELATIONSHIP BETWEEN NEW HOGAN STORAGE (AF) AND TEMPERATURE (F) FOR SEPTEMBER (SOURCE: FISHBIO)

3.3 Reservoir Storage Under Climate Change

New Hogan Reservoir storage was simulated using ResSim across 15 different climate scenarios. These scenarios and their assumptions are discussed in detail in the Calaveras Watershed Report, developed as part of the San Joaquin Basin Flood-MAR Watershed Studies Program (Citation to be Confirmed), and built upon as part of the Calaveras Watershed Resiliency Plan (detailed in TM 2). Figure 6 shows annual simulated storage at New Hogan under the following four of these scenarios:

- Baseline: Represents current climate conditions
- "Extreme Heat": 4°C (39.2°F) temperature increase, and 100% of historical precipitation
- "Extreme Precipitation": 2°C (35.6°F) temperature increase, and 113% of historical precipitation
- "Most Probable": 2°C (35.6°F) temperature increase, and 100% of historical precipitation

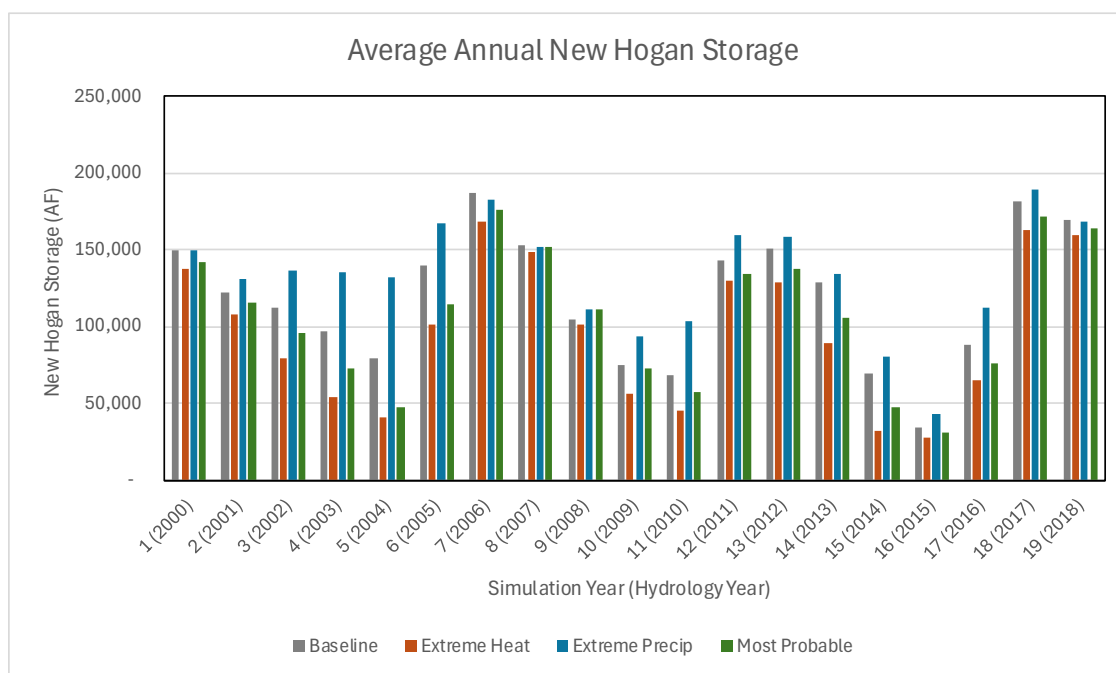


FIGURE 6: SIMULATED STORAGE UNDER THREE CLIMATE CHANGE SCENARIOS (SOURCE: DWR)

These simulated time series of storage under climate change were then used as inputs to the relationship curve for each month, as described in Section 3.2, to determine a predicted stream temperature under climate change. Figure 7 is a schematic showing the workflow followed to produce these estimations.

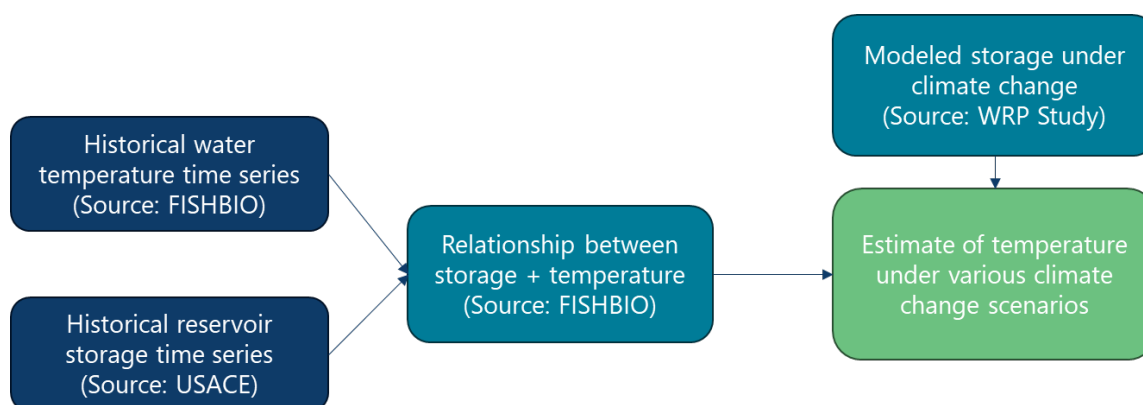


FIGURE 7: SCHEMATIC SHOWING METHOD

3.4 Assumptions of Analysis

A preliminary assessment of potential stream temperature changes under climate change was conducted using existing tools to develop an initial estimate of climate change impacts on stream temperature. Simplifying assumptions were made within the tools that are important to note in the interpretation of the

results presented in Section 4. Section 5.2 includes further discussion on the limitations of this analysis as a result of these assumptions.

Tools used to conduct the assessment summarized in Section 4 include:

- ResSim from Watershed Studies
- Reservoir storage-stream temperature historical data relationship curves

The following are the two most important assumptions made in this analysis:

- Simulated water temperatures are representative of one location at the most upstream limit of the spawning reach, just beneath the dam. The relationship between stream temperature and reservoir storage is most tightly coupled at this location and therefore was determined to be the most reasonable location at which to estimate the stream temperature changes under climate change in correlation with reservoir storage.
- The Calaveras River just below New Hogan Dam represents the coldest water temperatures along this corridor under all scenarios because of the location immediately below the reservoir discharge point, representing the coolest water originating from the reservoir resulting from stratification. Therefore, the impact of additional warming from ambient air heating up the water in channel is assumed to be negligible at this location. Downstream of this location, the channel experiences additional warming from ambient air as the water sits in the channel over time and cooler water from the reservoir disperses.

4. RESULTS AND DISCUSSION

Figure 8, Figure 9, and Figure 10 show simulated stream temperature by month during the critical rearing period (July to October) across 100 years of simulated storage for the “Most Probable”, “Extreme Heat”, and “Extreme Precipitation” scenarios, respectively. Figure 8 shows the Most Probable climate change scenario (green) against the current conditions Baseline scenario (dark blue). There is approximately a 1°F to 2°F increase in stream temperature under this climate change scenario. Those increases are larger in the late summer months. The minimum and maximum stream temperatures across the full hydrology period are very similar under climate change conditions compared to the Baseline scenario.

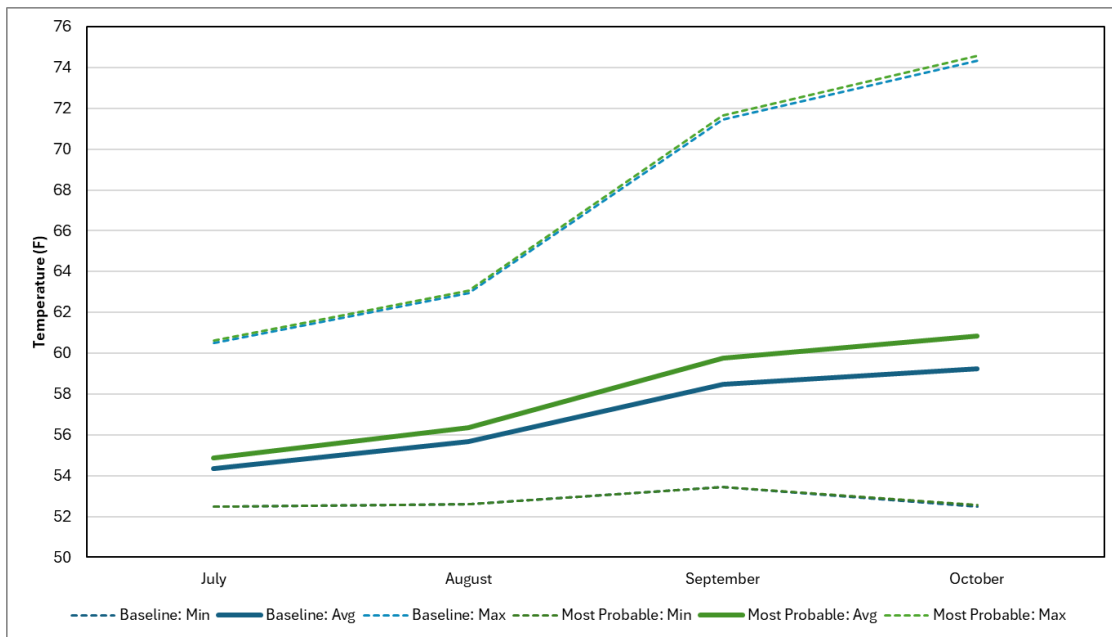


FIGURE 8: STREAM TEMPERATURE UNDER THE MOST PROBABLE CLIMATE CHANGE SCENARIO VS. CURRENT CONDITIONS BASELINE (JULY-OCTOBER)

Figure 9 shows the Extreme Heat (4°C increase in air temperature and no change in precipitation) scenario (orange) against the current conditions Baseline scenario (dark blue). On average, stream temperature increases range from 1°F to 3.5°F warmer under this climate change scenario. The same pattern is observed throughout the critical spawning months as under the Most Probable scenario, although the maximum stream temperature change between the Extreme Heat and Baseline scenarios is greater than under the Most Probable scenario.

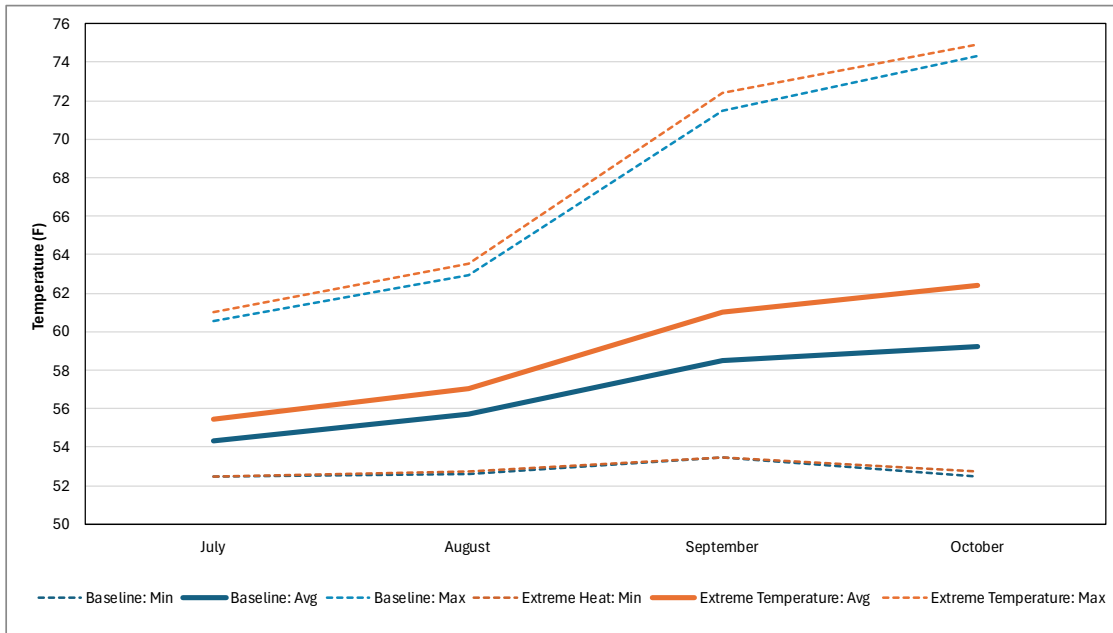


FIGURE 9: STREAM TEMPERATURE UNDER AN EXTREME HEAT CLIMATE CHANGE SCENARIO VS. CURRENT CONDITIONS BASELINE (JULY-OCTOBER)

Figure 10 shows an Extreme Precipitation (2°C increase in air temperature and 13% more precipitation than historical) scenario (black) against the current conditions Baseline scenario (dark blue). Under a wetter future climate scenario with 2°C increase in warming, this analysis shows a decrease in stream temperature just below New Hogan Dam between 1°F and 2°F during the critical spawning months. This decrease may indicate that the additional storage added under a high precipitation future has an insulating effect on the reservoir that offsets the impact of the 2°C increase in air temperature warming.

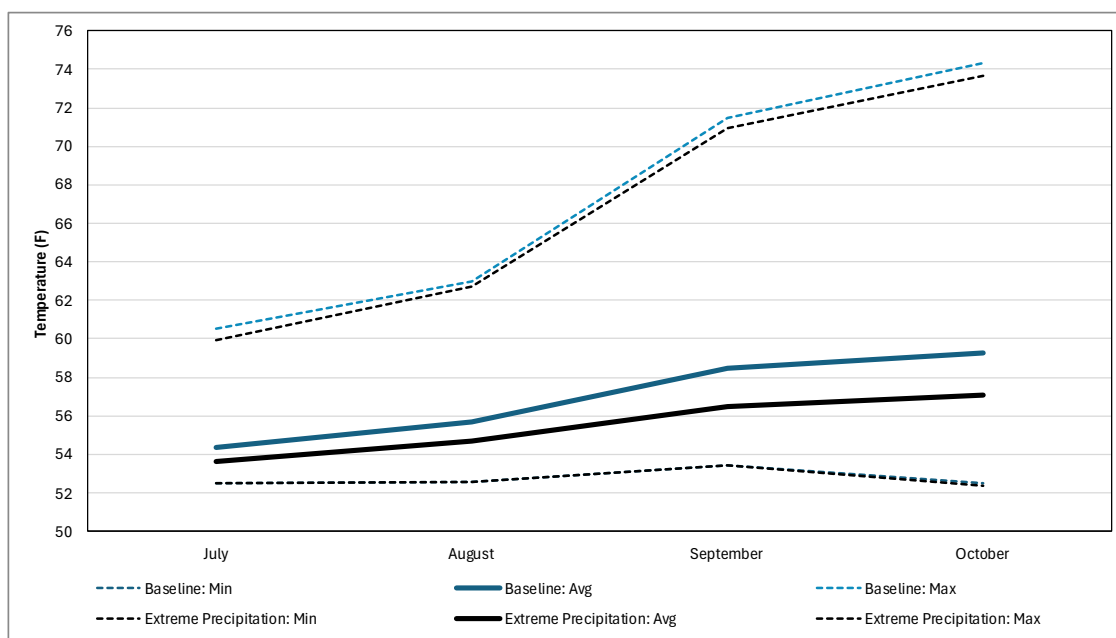


FIGURE 10: STREAM TEMPERATURE UNDER AN EXTREME PRECIPITATION CLIMATE CHANGE SCENARIO VS. BASELINE (JULY-OCTOBER)

Figure 11 and Figure 12 show boxplots of the resulting calculations for all 15 of the climate scenarios in comparison to the current conditions Baseline (TOP100) for a single month – August in Figure 11 and September in Figure 12. These plots are provided to show how stream temperature varies under the full range of climate scenarios. The boxplot at the far left represents the current conditions Baseline. The remaining boxplots each represent a climate scenario indicated by the temperature and precipitation change that the scenario represents. For example, “T1-P113” represents a 1°C increase in global air temperature and 113% of historical precipitation. “T5-P088” represents a 5°C increase in global air temperature and 88% of historical precipitation. As outlined in Section 3.3, the Most Probable scenario is represented by T2P100, the Extreme Heat scenario is represented by T4P100, and the Extreme Precipitation scenario is represented by T2P113.

Darker colors on these plots represent higher average temperatures than the baseline condition, while lighter colors represent lower average temperatures to provide a better visual comparison. All higher precipitation scenarios indicate lower average temperatures than baseline, regardless of the level of warming even in the warmest months of the year when reservoir storage tends to be lowest. This provides support for the potential conclusion that the insulating effect of the additional storage in the reservoir resulting from increased precipitation may be offsetting the impact of air temperature warming on the reservoir.

In the lower precipitation scenarios, all of the scenarios are warmer than the current conditions baseline. Stream temperature warming may be compounded by both the effect of the air temperature warming and

the lack of additional colder water from precipitation, where the stream temperature could increase by nearly 3°F under the Most Extreme (low precipitation and high heat) scenario.

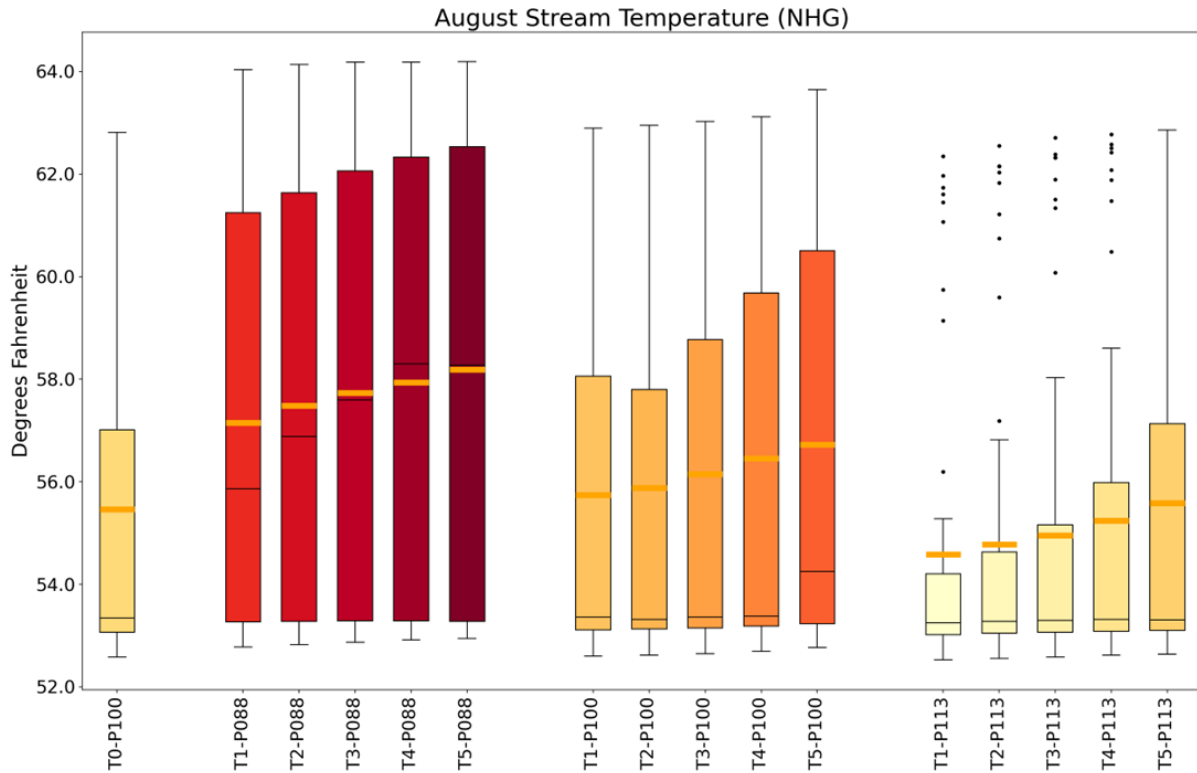


FIGURE 11: STREAM TEMPERATURE UNDER ALL CLIMATE SCENARIOS SHOWN IN BOXPLOT FOR AUGUST

Figure 12 shows the same plot for the month of September, where similar, but more extreme patterns are exhibited. In the lowest heat and lowest precipitation scenario, the stream temperature shows a nearly 4°F increase.

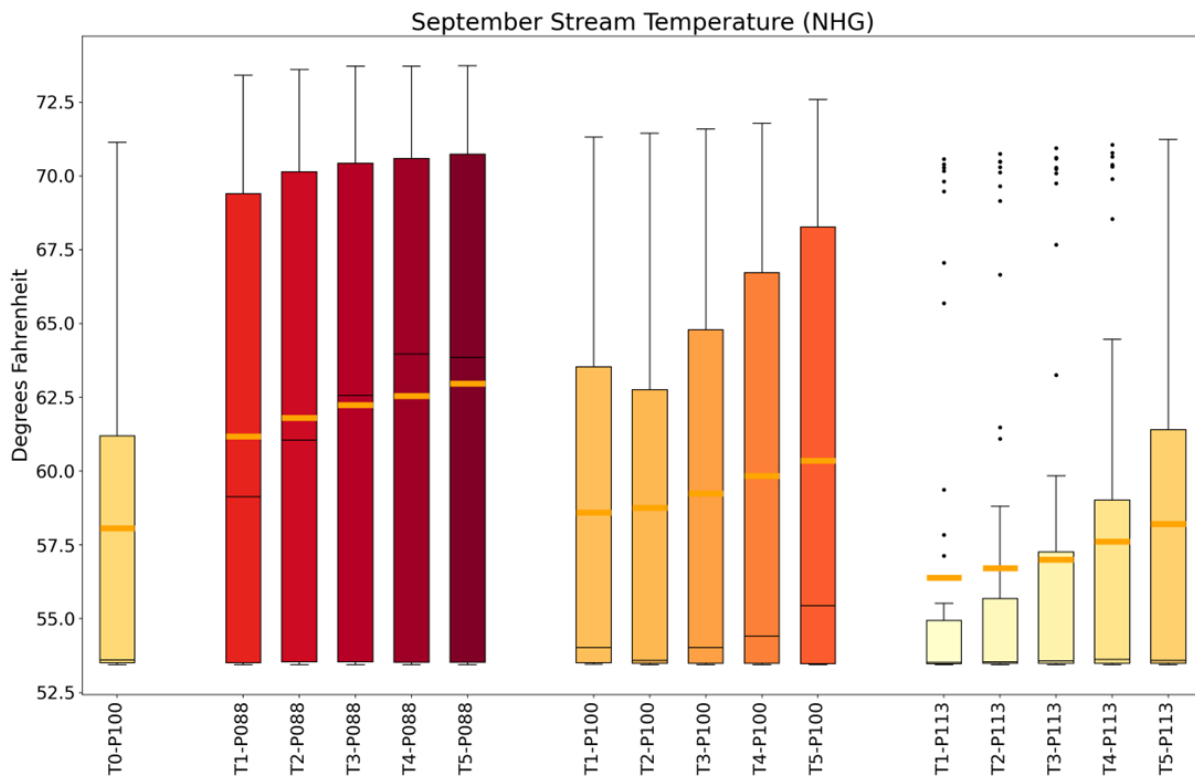


FIGURE 12: STREAM TEMPERATURE UNDER ALL CLIMATE SCENARIOS SHOWN IN BOXPLOT FOR SEPTEMBER

5. IMPLICATIONS AND LIMITATIONS

5.1 Implications for Calaveras River Temperature Management

- As previously discussed, CHCP water temperature criteria are based on critical thresholds developed from the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 2003). These include a critical threshold of 16°C for core rearing habitat and 18°C for non-core rearing habitat. It should be noted these temperature criteria were developed based on studies of salmonids in the Pacific Northwest and may be overly conservative targets for *O. mykiss* inhabiting Central Valley streams. Studies of *O. mykiss* in the nearby Tuolumne River indicated that individuals could maintain 95% of their peak aerobic scope (i.e., the ability to provide oxygen for activity) even at temperatures as high as 24.6°C (Verhille, English, Cocherell, Farrell, & Fanguie, 2016). This suggests that any increases in temperatures modeled above may have less than significant effects to Calaveras River salmonid populations.
- Calaveras salmonids, particularly *O. mykiss*, have demonstrated an ability to overcome low flow, high water temperature conditions in recent years. Snorkel surveys are conducted annually as part of CHCP compliance monitoring efforts to provide an estimate of abundance for the *O. mykiss* population within the conservation area. Snorkel surveys have been conducted in a comparable

fashion since 2011, with exception of 2014 and 2015 when snorkel surveys were not conducted due to severe drought. Following the 2014 and 2015 drought, surveys resumed in 2016, and the estimated abundance declined substantially to merely 638 individuals. Starting in 2017, the population had begun to rebound with a population spike in 2018 estimated at 23,089 individuals. From 2019 to 2022 populations increased incrementally from 7,391 to 17,393 individuals with a slight drop in 2023 when the population was estimated to be 13,137, which was still above the average abundance estimated since 2011. Surveys during 2024 saw the highest abundance on record of *O. mykiss* (all life stages combined) estimated at 30,429 fish (Cuthbert & Pilger, 2025).

- Results presented here could potentially build on existing uses of the segmented regressions discussed above, as a tool to provide a relative reference for discussion for future adaptive management decisions.

5.2 Limitations of Analysis and Future Work

This analysis represents a simplified estimate of stream temperature change under climate change using existing tools available as part of the much larger Calaveras Watershed Resiliency Study. The following is a summary of the limitations of this analysis:

- Results represent an estimate of relative climate impacts on the Calaveras River just below New Hogan Dam (at the dam release location), and this location represents the coldest water temperatures along this corridor. This location represents projected stream temperatures without the additional warming from ambient air that occurs on downstream reaches of the river.
- Any magnified effects of stream warming along the lower reaches of the Calaveras River, where the majority of spawning occurs, was not assessed.
- Results of this analysis could be used to develop thermal criteria to inform the investigation of physiological response to temperature stress and adaptability similar to research conducted on *O. mykiss* within the Tuolumne River (Verhille, English, Cocherell, Farrell, & Fangue, 2016).
- Results of this analysis may be used to inform adaptive management decisions with regard to potential instream flow operations in the face of a warming future.

6. CONCLUSIONS

This analysis represents an initial, desktop assessment of the impacts of climate change on stream temperature. The results of this analysis will be integrated as one component of the larger climate vulnerability assessment developed for the Calaveras River Watershed Resiliency Plan. The following summarize conclusions from this analysis:

- Climate change scenarios indicate possible 1°F to 4°F increases, on average, in Calaveras River water temperatures at base of the New Hogan Dam.
- Temperature increases appear to increase with each month between July and October.

- In a high precipitation future scenario, more storage may have an effect on lower water temperatures than increases in atmospheric temperature.
- Temperature increases determined in this analysis likely represent a minimum estimate of climate change impacts on stream temperatures along the full extent of the river because these temperature increases do not account for additional warming of the stream in downstream reaches resulting from ambient air temperature.

7. RECOMMENDATIONS FOR FUTURE WORK

7.1 Ecosystem and Habitat Vulnerability

While the current assessment addresses environmental risks qualitatively through streamflow metrics, a more comprehensive ecosystem vulnerability analysis would quantify climate impacts on aquatic and riparian habitats. Future work should incorporate ecological modeling components that evaluate habitat suitability under varying flow, temperature, and water quality conditions. This could include assessments of spawning habitat availability for native fish species, stress on riparian vegetation, and the effectiveness of environmental flow releases under different climate scenarios. Integrating ecosystem models would support evaluation of adaptation strategies that balance water supply objectives with ecological sustainability.

7.2 Stream Temperature Modeling

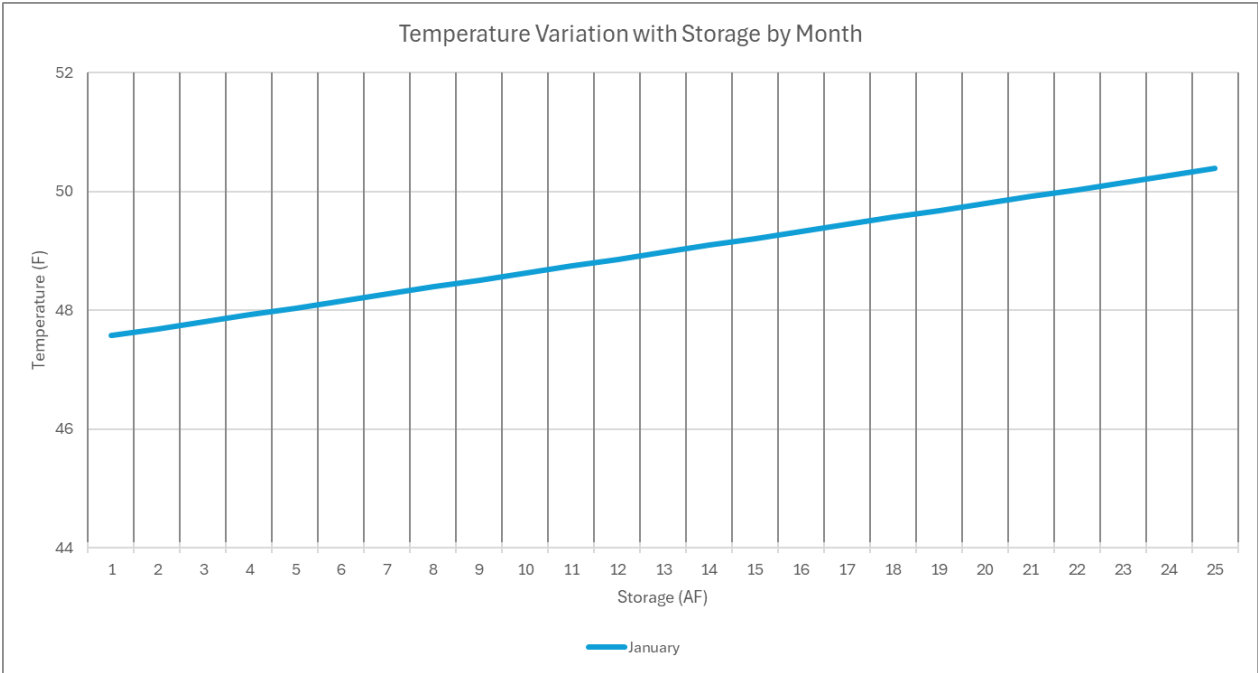
Water temperature represents a critical ecological stressor that climate change will intensify through both atmospheric warming and altered flow regimes. Future work should develop robust stream temperature modeling throughout the Calaveras River system to assess thermal habitat conditions under climate scenarios. This analysis would evaluate how reservoir operations, groundwater discharge, riparian shading, and flow augmentation strategies affect thermal conditions and species-specific thresholds. Enhanced temperature modeling would support evaluation of adaptation strategies that maintain thermal habitat alongside water supply and flood management objectives.

8. REFERENCES

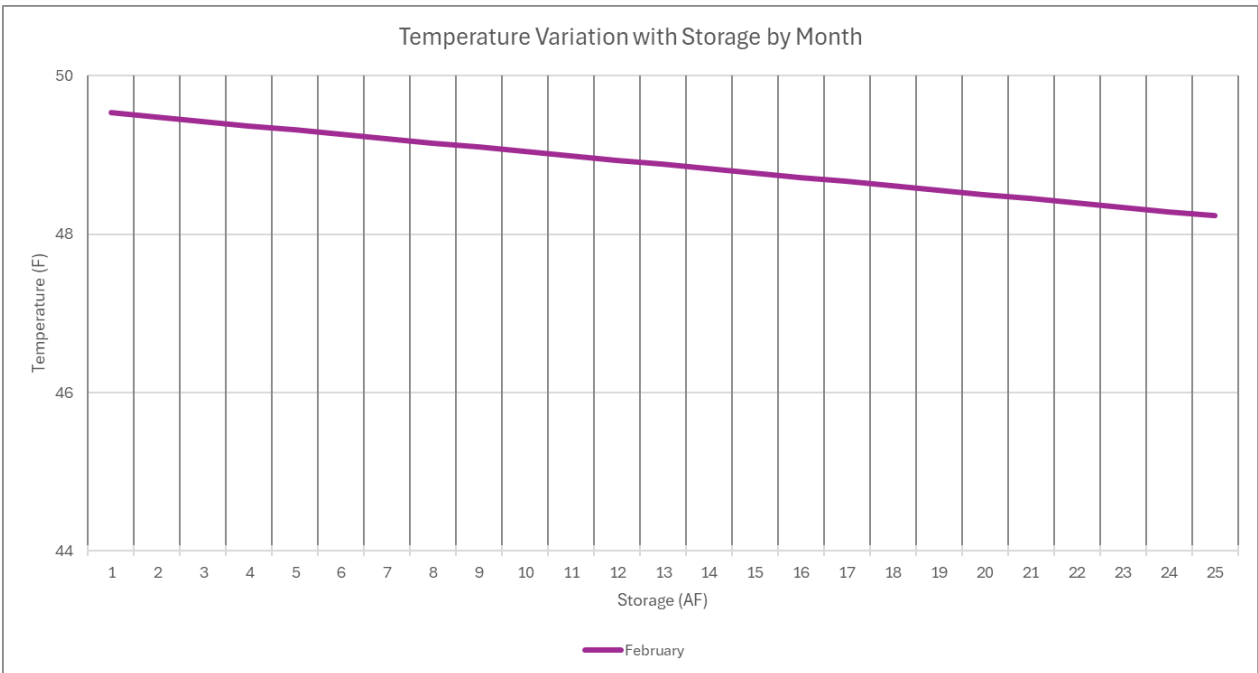
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APPENDIX A

January

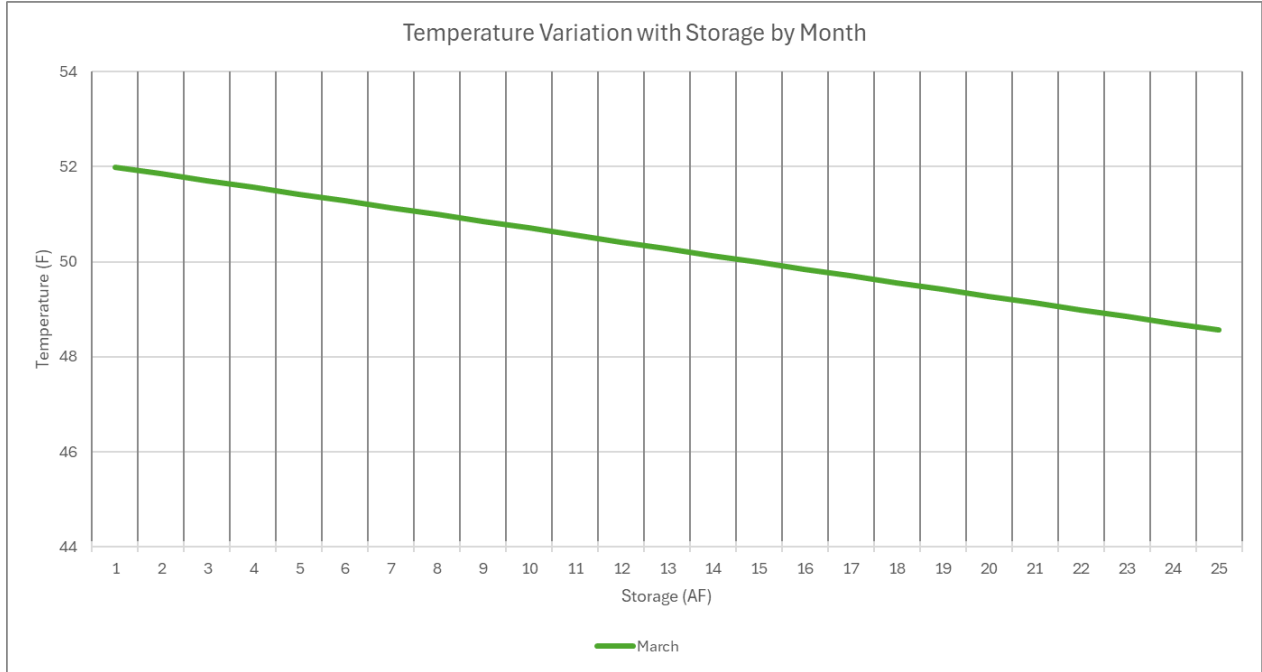


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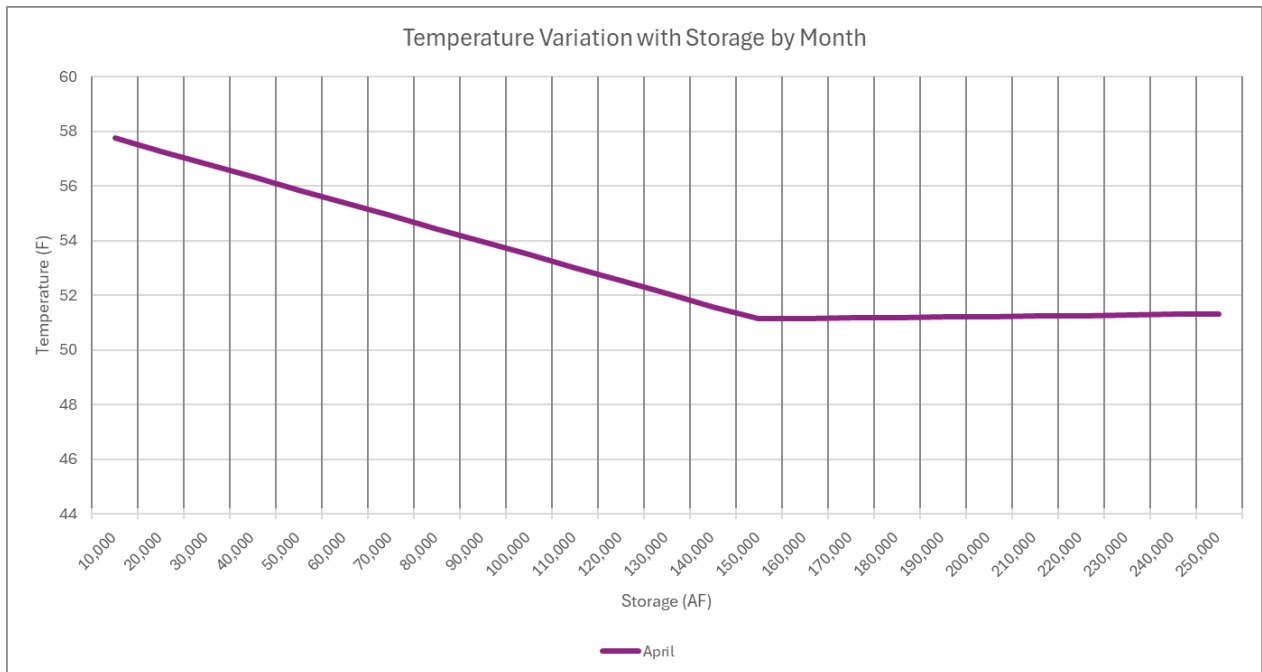




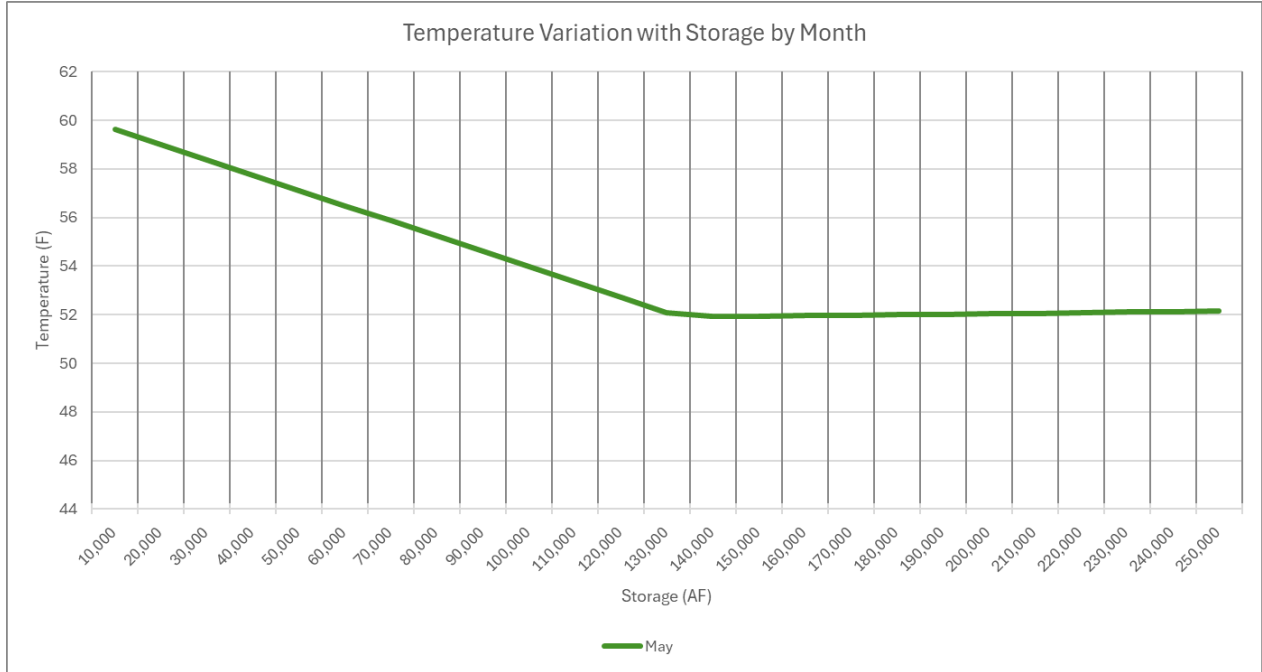
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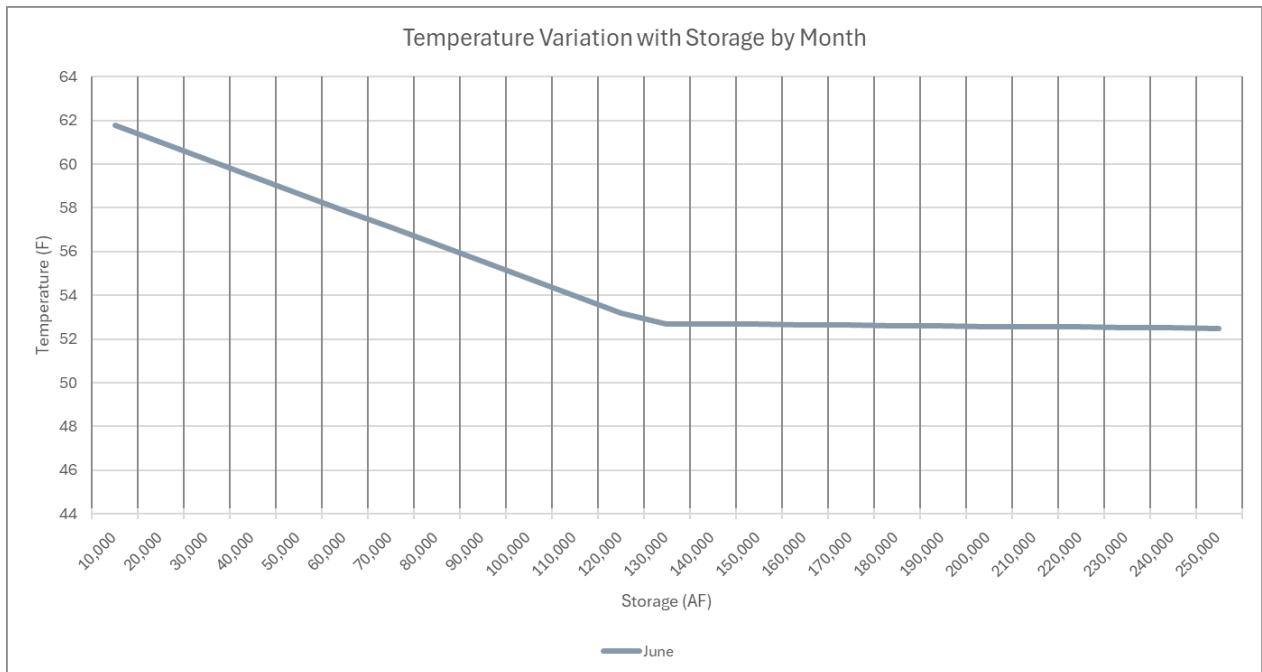
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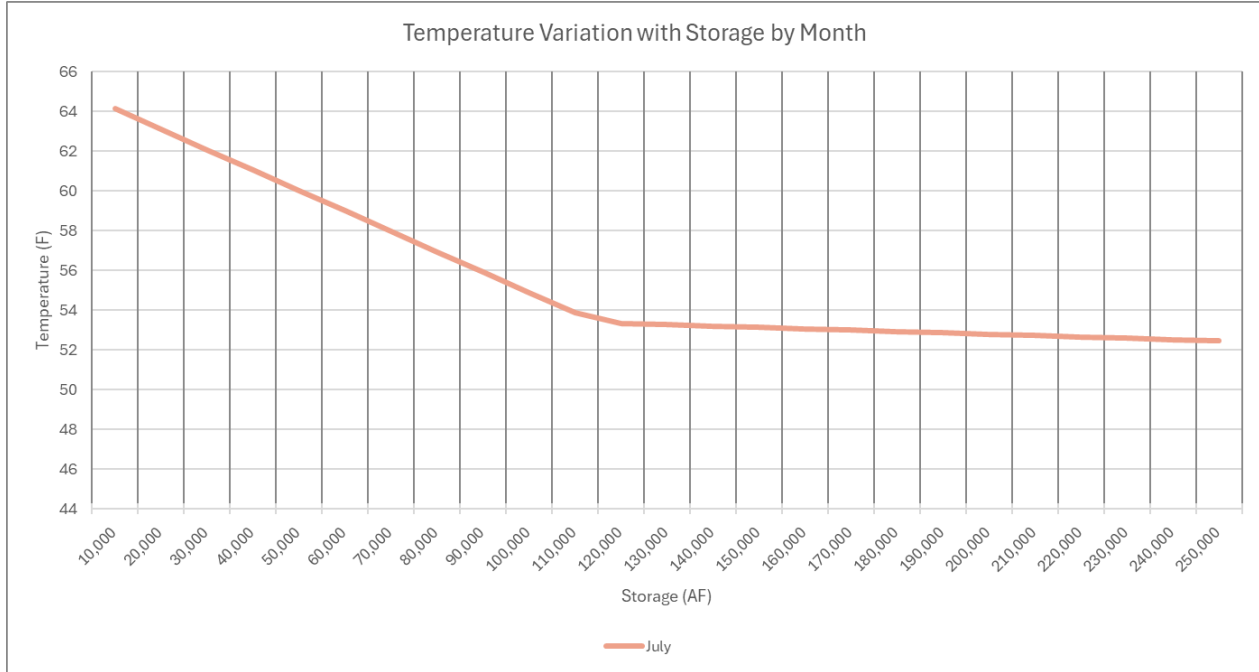
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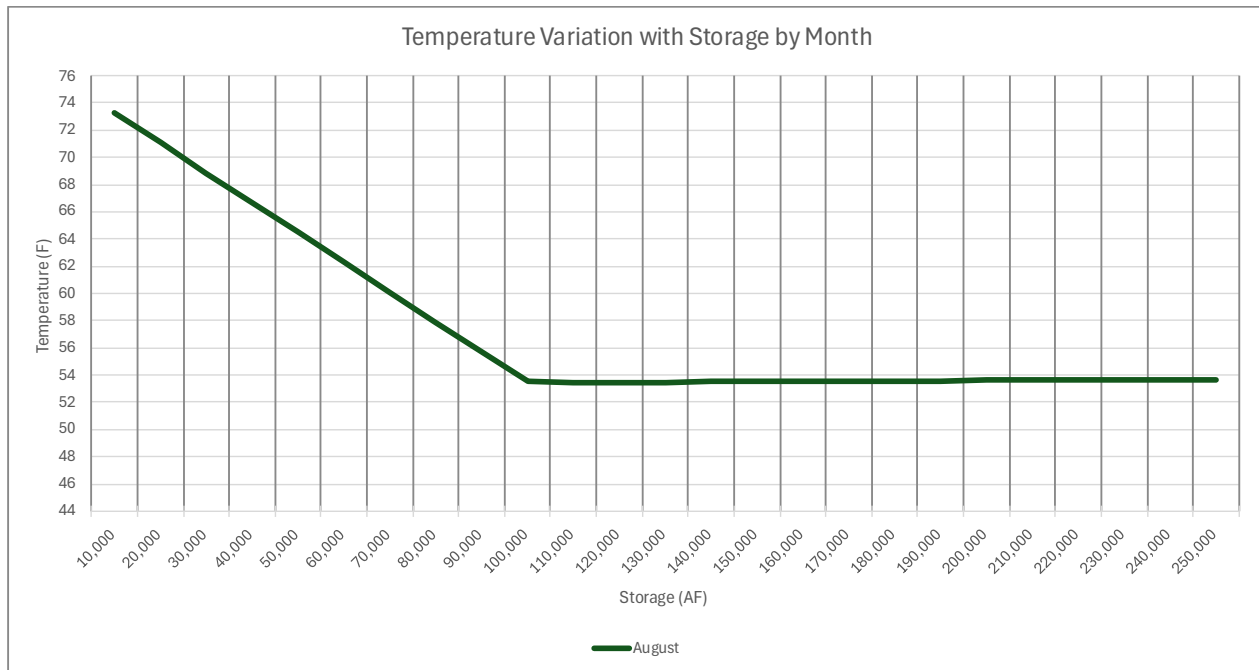
June



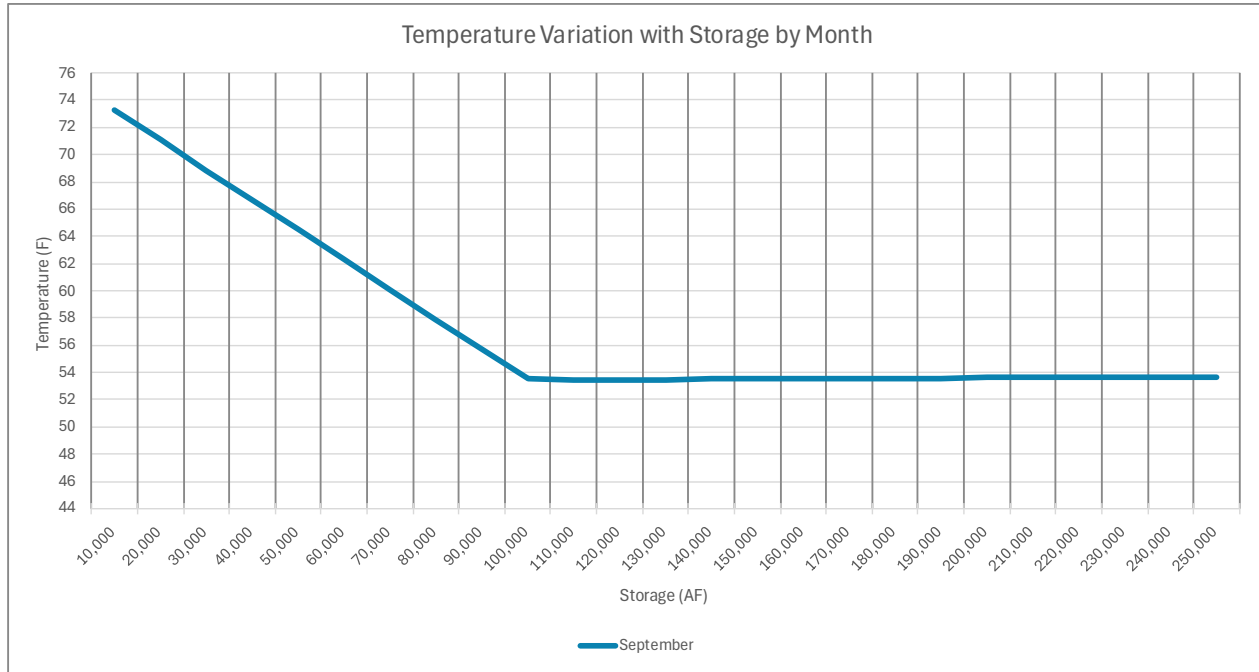
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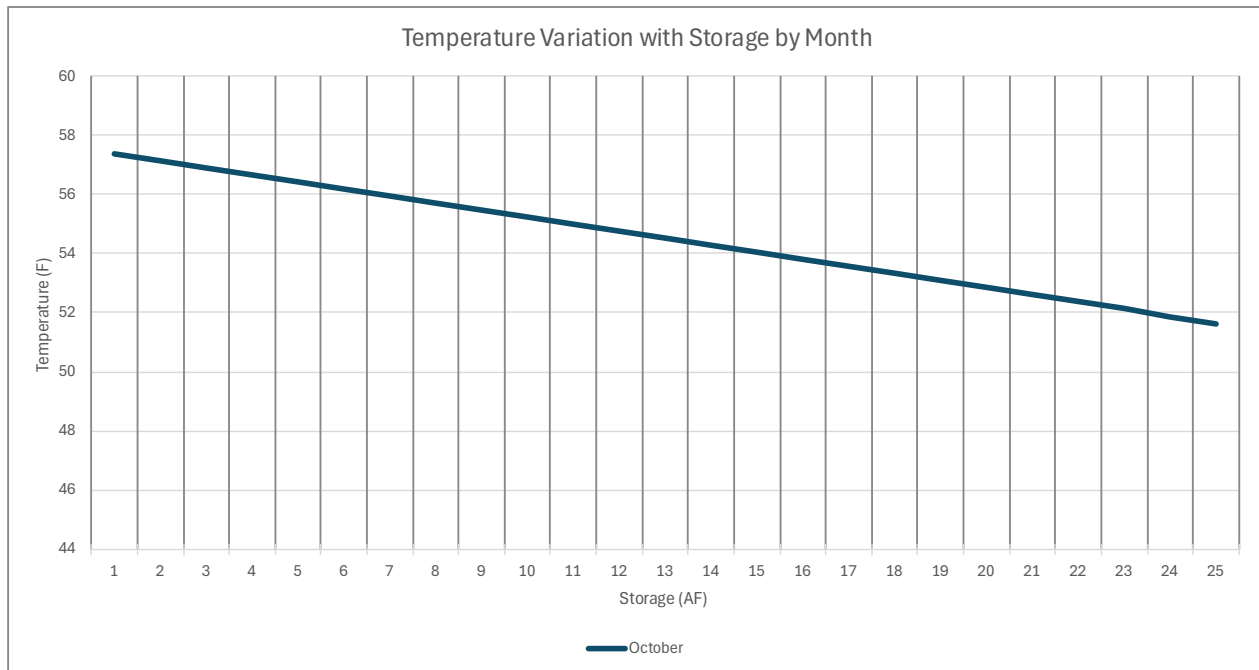
August



September

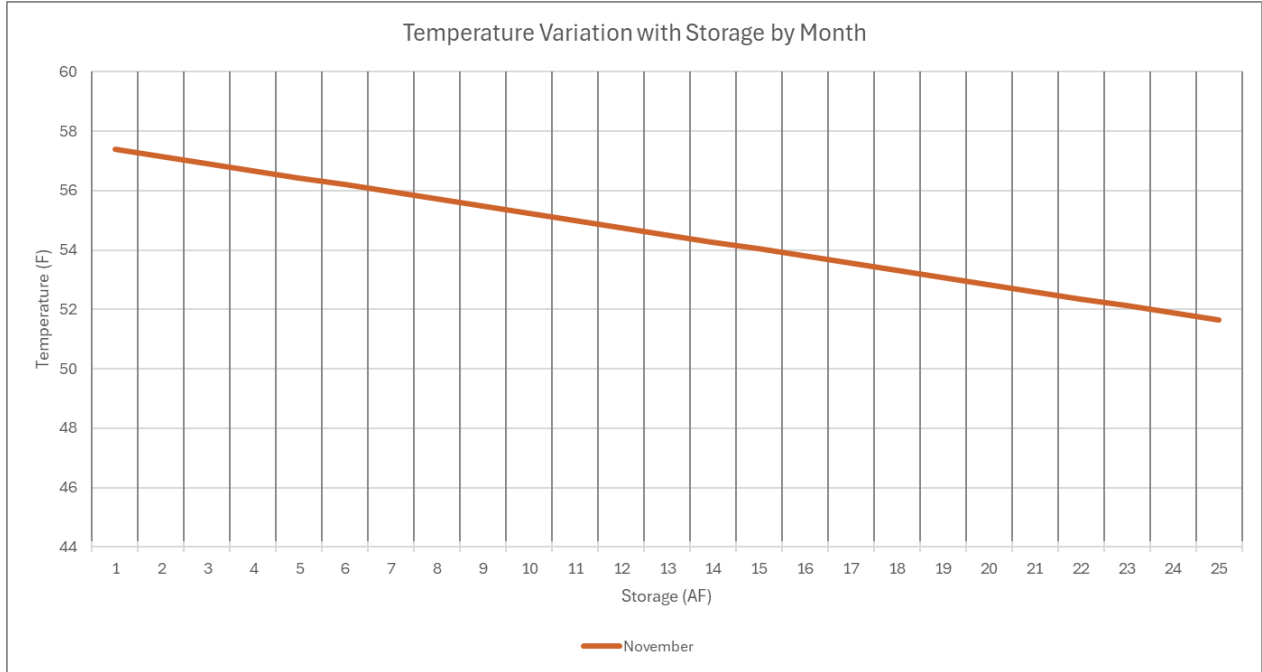


October





November



December

