Attachment A. Los Angeles River Temperature Model Report

December 2025

CITY OF LOS ANGELES AND CITY OF BURBANK

Los Angeles River Temperature Model

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City of Los Angeles Sanitation and Environment

City of Burbank Public Works Department

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EXECUTIVE SUMMARY

The Donald C. Tillman (DCT or DCTWRP) and Los Angeles/ Glendale (LAG or LAGWRP) Water Reclamation Plants (WRPs) operated by the City of Los Angeles (CLA), Bureau of Sanitation and Environment (LASAN), and the Burbank Water Reclamation Plant (BWRP), operated by the City of Burbank Public Works Department, discharge tertiary-treated disinfected wastewater effluent in the Los Angeles River (LA River or LAR) watershed. The DCT and LAG WRPs discharge into the mainstem of the LAR, while the BWRP discharges to Burbank Western Channel (BWC), which is a tributary to the LAR. The Los Angeles Regional Water Quality Control Board (Regional Board) reinterpreted the Water Quality Control Plan: Los Angeles Region Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties (Basin Plan) water quality objective (WQO) for temperature and, consequently, lowered the effluent limits for temperature in the National Pollutant Discharge Elimination System (NPDES) discharge permits issued to the WRPs. The NPDES permits for the three WRPs now include a maximum temperature limitation of 80 degrees Fahrenheit (°F) for treated wastewater effluent and receiving water bodies as well as a receiving water limitation requiring that the WRPs not alter receiving waters by more than 5°F (herein referred to as delta 5).

The Cities of Los Angeles and Burbank (Cities) developed and implemented a Temperature Study (Study) to better understand and characterize the relationship between effluent temperature and potential impacts to the WARM beneficial use in the LA River downstream of the DCTWRP, LAGWRP, and BWRP discharges. A Workplan[1] was developed by the Cities and revised based on input from a Technical Advisory Committee (TAC), which was comprised of subject matter specialists including Regional Board staff. Modeling was included as a component of the Workplan to support an assessment of current conditions, effect of potential control measures, and potential implications of climate change. The following describes the model, its calibration, and its use to evaluate the effect of WRP discharges on the LA River and BWC, and the response to control measures and climate change.

Model Description

The hydraulic model of the LA River used for this study was developed as part of the Los Angeles River Environmental Flows Project (Environmental Flows Project; Stein 2021a)[2]. The model simulates the river cross-sectional attributes such as depth, width, velocity along the LA River from Sepulveda Dam to the estuary. The LA River Environmental Flows model was constructed from a series of existing one-dimensional HEC-RAS models to cover the whole model domain. The Environmental Flows Project was a collaboration of the State Water Resources Control Board (State Water Board), Regional Board, and the City and County of Los Angeles to develop a process for establishing flow criteria, apply the process to provide recommendations for flow criteria in the LA River, and to produce tools and approaches to evaluate management scenarios necessary to achieve recommended flow criteria

The full energy budget water temperature model[3] integrated within HEC-RAS was utilized as it provides an advanced computational framework designed to simulate the thermal dynamics of riverine environments.

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[1] Larry Walker Associates (LWA). 2024. Draft Workplan: Assessing the Effects of Water Reclamation Plant Effluent Temperature on Aquatic Life in the Los Angeles River Watershed. *Developed for:* the City of Los Angeles Sanitation and Environment and the City of Burbank Public Works Department.

[2] Stein, E. D., K. Taniguchi-Quan, J. Wolfand, E. Gallo, K. Irving, D. Philippus, R. Abdi, V. Hennon, A. Tinoco, P. Mohammadi, A. Rust, T. S. Hogue (2021a). Process and Decision Support Tools for Establishing Flow Recommendations to Support Aquatic Life and Recreational Beneficial Uses of the Los Angeles River. SCCWRP Tech. Report #1196. April 2021. For more information visit https://www.sccwrp.org/about/research-areas/ecohydrology/los-angeles-river-flows-project.

[3] https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%20Water%20Quality%20User's%20Manual-v6.4.1.pdf

The calibration of the model was conducted over two stages: an initial calibration, and the re-calibration or final calibration. The initial calibration was performed with data obtained from the California Integrated Water Quality System Project (CIWQS) data management website and studies conducted by Mongolo et al. (2017)[4] and Heal the Bay. These datasets only allowed a single-point calibration where the same calibration parameters were applied to the whole modeling domain. The continuous water temperature data collected through this study were used to enhance the calibration of HEC-RAS water temperature model by both providing dense concurrent receiving water temperatures in the region of interest, and by allowing refinement of the upstream boundary conditions. The model calibration parameters were systematically modified and model output analyzed with four metrics root mean square error (RMSE), mean absolute error (MAE), mean absolute percentage error (MAPE), and coefficient of determination (r^2). The calibrated model receiving water temperatures are generally within 1.2°C and under 5% of the observed values. This calibration is considered "very good" as described in guidelines for modeling developed by the Regional Board[5].

Modeling of Potential Control Measures

The following three potential control measures were modeled to evaluate their effects on receiving water temperatures and compared to the baseline (no action):

- **Effluent Temperature Reduction:** The effluent temperature control measure seeks to ensure the WRP discharges are compliant with the temperature limits identified in their NPDES permits (i.e., effluent temperatures are not more than 80°F and receiving waters are not raised by more than 5°F). The effluent temperature reductions needed to meet the NPDES permit limits vary by month from as low as 6°F for the LAGWRP in June to as high as 37°F for the BWRP in February. Note that for most months the temperature reduction requirements are driven by the delta 5°F limit. The current condition baseline LA River temperatures downstream of the DCTWRP discharges are compared to the temperatures with effluent cooling for conditions on August 6, 2024 on **Figure ES-1**. The effect of cooled effluent on receiving water temperature reduces as the flow moves downstream, typically further downstream during cooler months. The BWC and LA River have a similar response downstream of the BWRP and LAGWRP, respectively. The receiving water temperatures downstream of the BWRP and LAGWRP discharges are presented on **Figure ES-1**. The distance downstream where receiving water temperatures become negligibly different from baseline (i.e., within ± 1°F) below the WRPs vary by season as follows:
  - DCTWRP:
    - August: less than 1 mile from the discharge
    - January: 10 miles on average
  - BWRP:
    - August: within 2 miles from the discharge
    - January: at the confluence of the LA River (2.7 miles downstream)
  - LAGWRP:
    - August: at the point of discharge
    - January: within 2 miles downstream

[4] Mongolo, Jennifer, Nina Trusso, Rosi Dagit, Andres Aguilar, and Sabrina L. Drill. 2017. "A Longitudinal Temperature Profile of the Los Angeles River from June through October 2016." *Bulletin, Southern California Academy of Sciences* 116 (3): 174–92. https://doi.org/10.3160/soca-116-03-174-192.1

[5] Los Angeles Regional Water Quality Control Board (LARWQCB). 2014. Guidelines for Conducting Reasonable Assurance Analysis in a Watershed Management Program, Including an Enhanced Watershed Management Program.

As shown in **Figure ES-1**, factors including local air temperature and solar radiation result in receiving waters downstream of the WRPs exceeding the 80°F objective even though the WRPs' effluent is meeting limits.

- **Reduced Effluent Flowrate:** To evaluate the effect of the reduced flowrate, the model was run using a 5, 10, 25, and 50 percent WRP effluent flowrate reduction. **Figure ES-2** presents a comparison of the baseline receiving water temperatures to the temperatures if the WRPs' effluent flow rates were reduced by 50 percent on August 6, 2024. As shown in **Figure ES-2**, when effluent flow rates are reduced there is little effect on receiving water temperatures. Similar to effluent cooling, in colder months, the receiving water temperature returns to baseline further downstream. The distance downstream where receiving water temperatures become negligibly different from baseline below the WRPs vary by season as follows:
  - DCTWRP:
    - August: at the point of discharge
    - January: 4 miles on average
  - BWRP:
    - August: within 0.5 miles of discharge
    - January: at the confluence of the LA River (2.7 miles downstream)
  - LAGWRP:
    - August: at the point of discharge
    - January: at the point of discharge
- **Riparian Shading:** To determine the effect of tree shading on receiving water temperatures, the reduction of solar radiation incident on the water surface was simulated assuming 100% tree cover along the receiving water outside of the established channel. Temperatures in the respective receiving waters downstream from the three WRPs for the riparian shading control measure for August 6, 2024 are presented in **Figure ES-3**. As shown in **Figure ES-3**, there is little difference from the baseline and shading does not reduce temperatures downstream of the WRPs below the 80°F objective.

It should also be noted that, water temperatures upstream of the DCTWRP and LAGWRP (i.e., without WRP influence) consistently exceeded 80°F in the warmer months and exceed upstream of the BWRP, though less frequently than for the DCT and LAG WRPs. Additionally, modeling demonstrated that the receiving water temperature downstream of the WRPs following the mixing of effluent can increase by more than 5°F under both current conditions and with effluent cooling.

Modeling of Scenarios

Scenarios seek to combine control measures to investigate potential synergies in combining actions. The following scenarios were compared to both the baseline (no action) and to the effluent temperature reduction control measure as it had the greatest effect on receiving water temperatures:

- **Effluent Temperature Reduction and Flowrate Reduction:** Because the flowrate of the cooled effluent is reduced, this scenario has less effect on receiving water temperature than just reducing effluent temperature. Receiving water temperatures from this scenario are not substantively different from the effluent temperature reduction control measure. Receiving water temperatures downstream of the DCTWRP, BWRP, and LAGWRP for this scenario are presented in **Figure ES-4**.
- **Effluent Temperature Control and Riparian Shading:** Under this scenario, the receiving water temperatures downstream of the WRP discharges reach the corresponding baseline temperatures, albeit slightly further downstream. Receiving water temperatures downstream of the DCTWRP, BWRP, and LAGWRP for this scenario are presented in **Figure ES-5**.

- **Effluent Temperature Control, Effluent Flowrate Reduction, and Riparian Shading:** Under this scenario, the receiving water temperatures downstream of the WRP discharges reach the corresponding baseline temperatures, similar to effluent temperature reduction alone. Receiving water temperatures downstream of the DCTWRP, BWRP, and LAGWRP for this scenario are presented in **Figure ES-6**.

As shown in **Figure ES-4**, **Figure ES-5**, and **Figure ES-6**, receiving waters downstream of the WRPs exceed the 80°F objective even though the WRPs effluent is meeting the limits and other control measures are implemented.

Climate Change

To assess the effect of climate change, the future air temperatures in the LA Basin were determined through the Coupled Model Intercomparison Project Phase 5 (CMIP5) North America downscaled by Localized Constructed Analogs (LOCA) statistical dataset, downloaded from Cal-Adapt[6]. The model was run using projected future air temperatures. These projections are made for 30 years in the future corresponding to the potential life cycle of effluent temperature control measures. Receiving water temperatures downstream of the current DCTWRP, BWRP, and LAGWRP discharges are compared to conditions 30 years in the future in response to climate change and for effluent temperature controls under climate change on **Figure ES-7**. On **Figure ES-7**, the black line corresponds to current conditions (baseline), the green line is the baseline after 30 years of climate change (i.e. 30-years in the future), and the blue line is effluent temperature reduction after 30 years of climate change. Predicted mean monthly water temperatures increased by approximately 2°F in August due to increased air temperature.

Exploration of Additional Scenarios for River Shading

Given that shading along the banks of the Study area did not result in meaningful changes to receiving water temperatures, the TAC requested that the Cities use the model to explore two additional shading scenarios. The first was an evaluation of planting dense riparian vegetation in the current unlined sections of the LA River (i.e., LA River Reaches 3 and 5) that might result in blocking 80% of the incident solar radiation. The second was identifying the amount of shading required to maintain the river temperature below 80°F. As exploratory scenarios, they were modeled regardless of whether they would be implementable. In summary, the exploration found the following:

- **80% Shading in Current Unlined Sections:** Under this exploratory scenario, solar radiation was reduced 80% over unlined channels. While receiving water temperatures decreased in the shaded areas, the receiving water temperature quickly increased and returned to the previous equilibrium downstream of the unlined sections.
- **River-wide Shading to Maintain River Temperatures Below 80°F:** Under this exploratory scenario, the potential for consistent attainment of 80°F in receiving waters was evaluated. It was determined that the entire mainstem of the LA River and BWC would have to be shaded to reduce solar radiation by 80%, and in addition, the local air temperatures would simultaneously need to be reduced by 15%.

[6] https://cal-adapt.org/data/download/

Conclusions

A temperature model for the LA River and BWC was created for this study to evaluate potential control measures, climate change effects, and water temperature changes downstream of discharges. The backbone for the temperature model was the LA River Environmental Flows HEC-RAS hydraulic model, which was updated to include the BWC and the three WRPs as explicit boundary conditions. The model was successfully calibrated and achieved a mean absolute error of 1.2°C and a mean absolute percent error under 5%, which is considered very good.

The temperature model was used to evaluate effluent temperature control, effluent flowrate reduction, and riparian shading control measures. Scenarios comprised of multiple control measures implemented concurrently were also analyzed. Additionally, the effect of climate change on the receiving water temperatures and future effectiveness of control measures were assessed. Effluent temperature reduction was determined to have the greatest effect on receiving water temperatures at the point of discharge. However, during the hottest months of the year, receiving water temperatures returned to baseline (i.e., within ± 1°F) downstream of the WRPs in less than 0.5 to 2 miles on average. The model produced similar results for the effluent flowrate reduction control measure, with receiving water temperatures quickly returning to equilibrium conditions. The shading control measure also had limited effect on receiving water temperatures.

In addition, it was determined that the scenarios combining potential control measures did not show synergetic gains in temperature reduction. Similar to the results for the individual control measures, either receiving water temperatures are not significantly affected or they relatively quickly return to baseline conditions due to factors outside of the control of the WRPs. None of the individual control measures or combinations of control measures result in the consistent attainment of the 80°F objective downstream of the WRPs. Furthermore, it was found that temperatures downstream of the WRPs can still increase more than 5°F due to other factors such as air temperature and solar radiation. It should also be noted that the 80°F objective is, at times, exceeded even upstream of the WRPs.

Finally, the effects of climate change were assessed for a time period extending 30-years in the future, and the model indicated that the receiving water temperatures would increase by a few degrees. On the river reach scale, there is no meaningful difference in the receiving water temperature for individual control measures or combinations of control measures, as temperatures returned to the baseline within the reach.

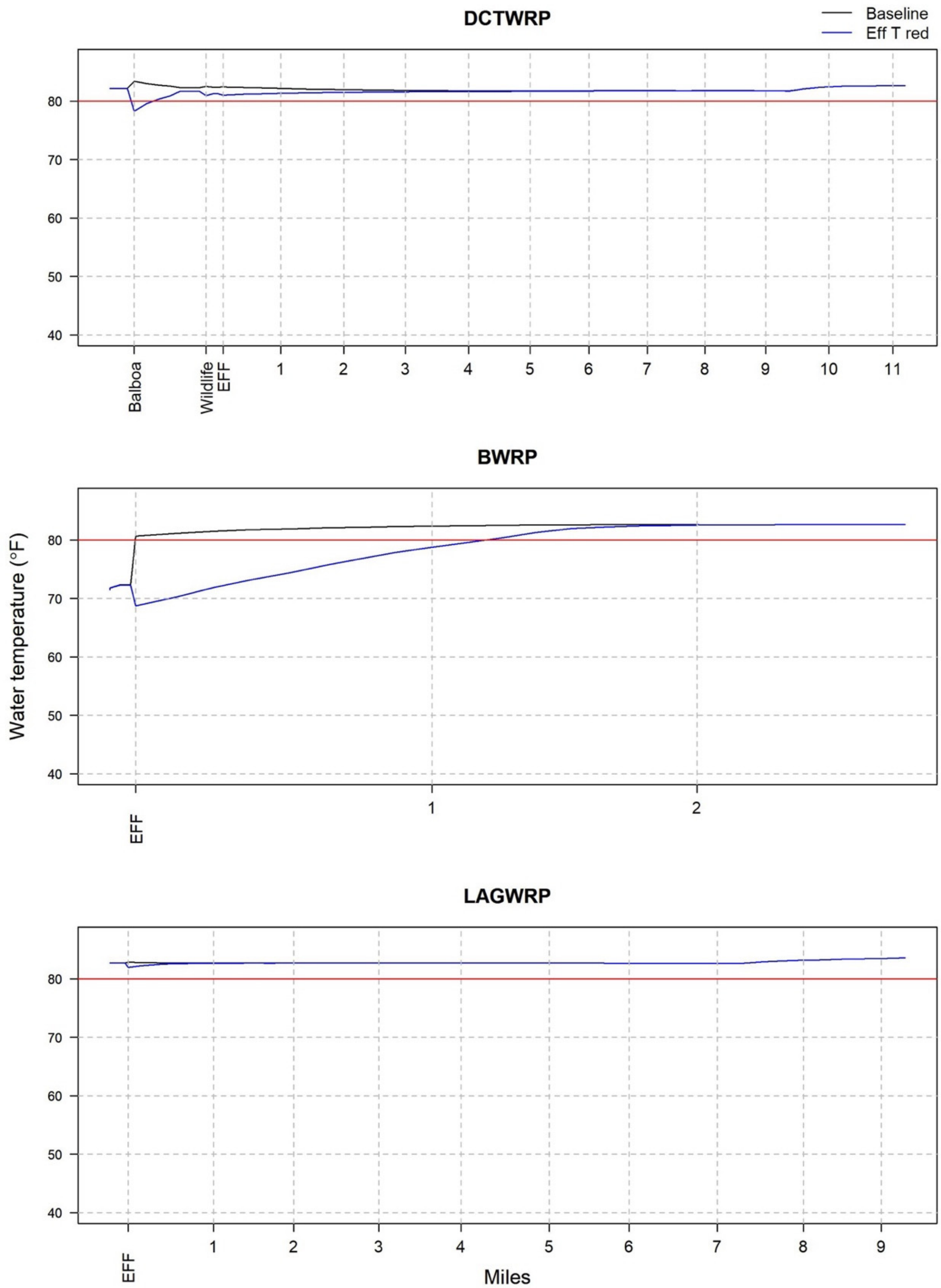

Figure ES-1. Receiving water temperatures at and downstream from WRPs for current condition and with effluent cooling for August 6, 2024

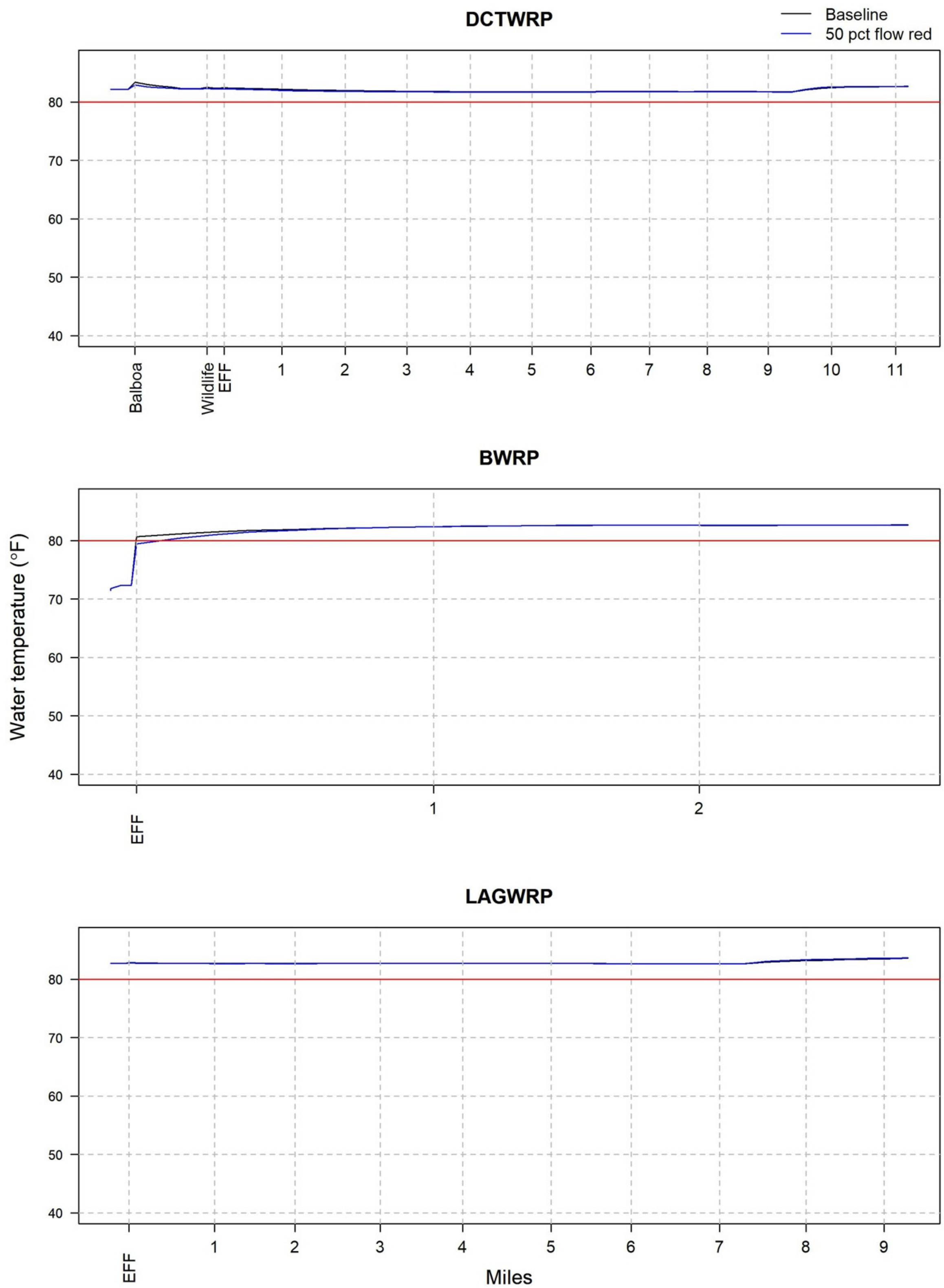

Figure ES-2. Receiving water temperatures downstream of WRPs in response to a 50 percent reduction in discharge flowrate for August 6, 2024

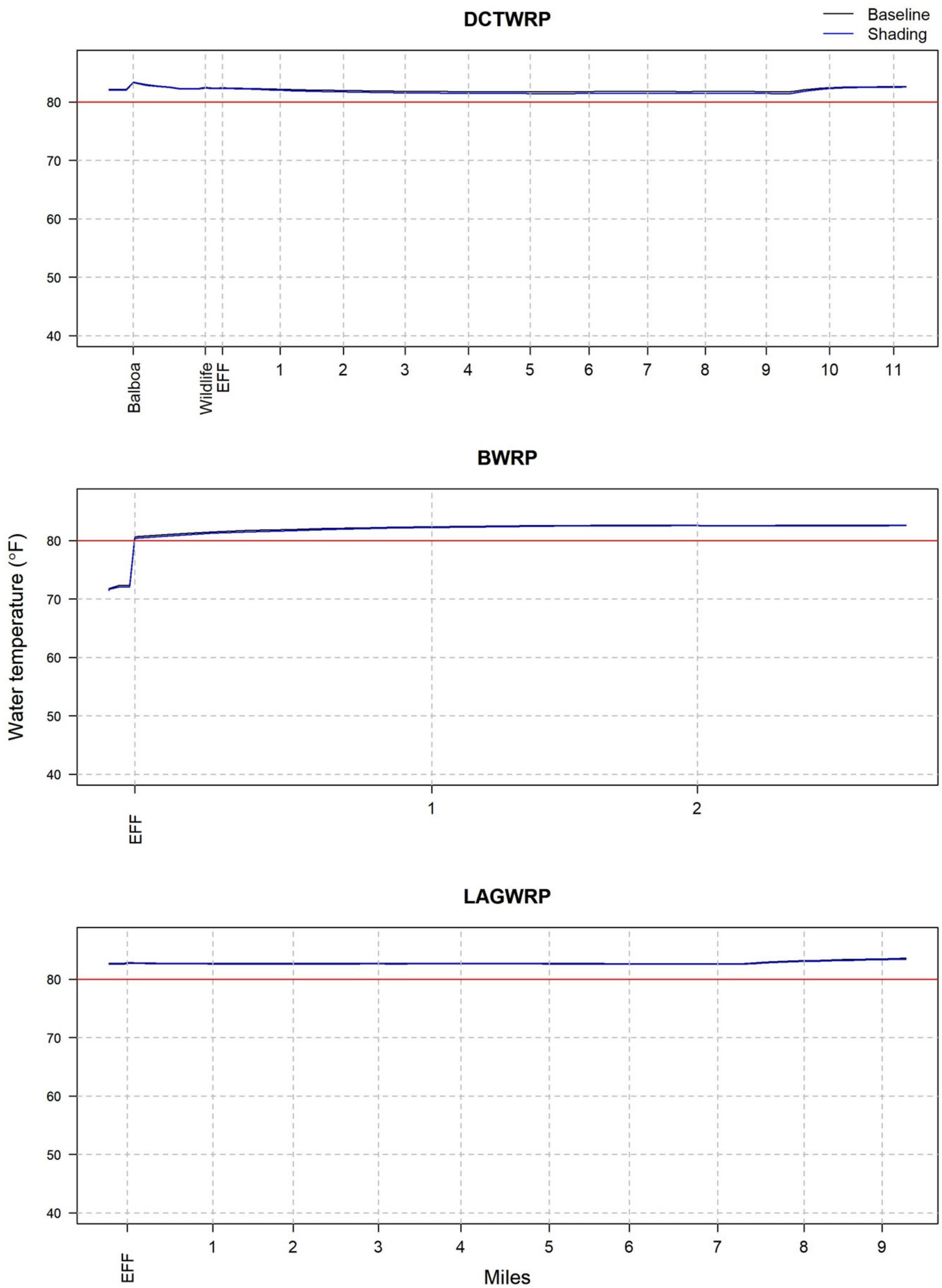

Figure ES-3. Receiving water temperatures downstream of WRP discharges with 100 percent edge of channel shading for August 6, 2024

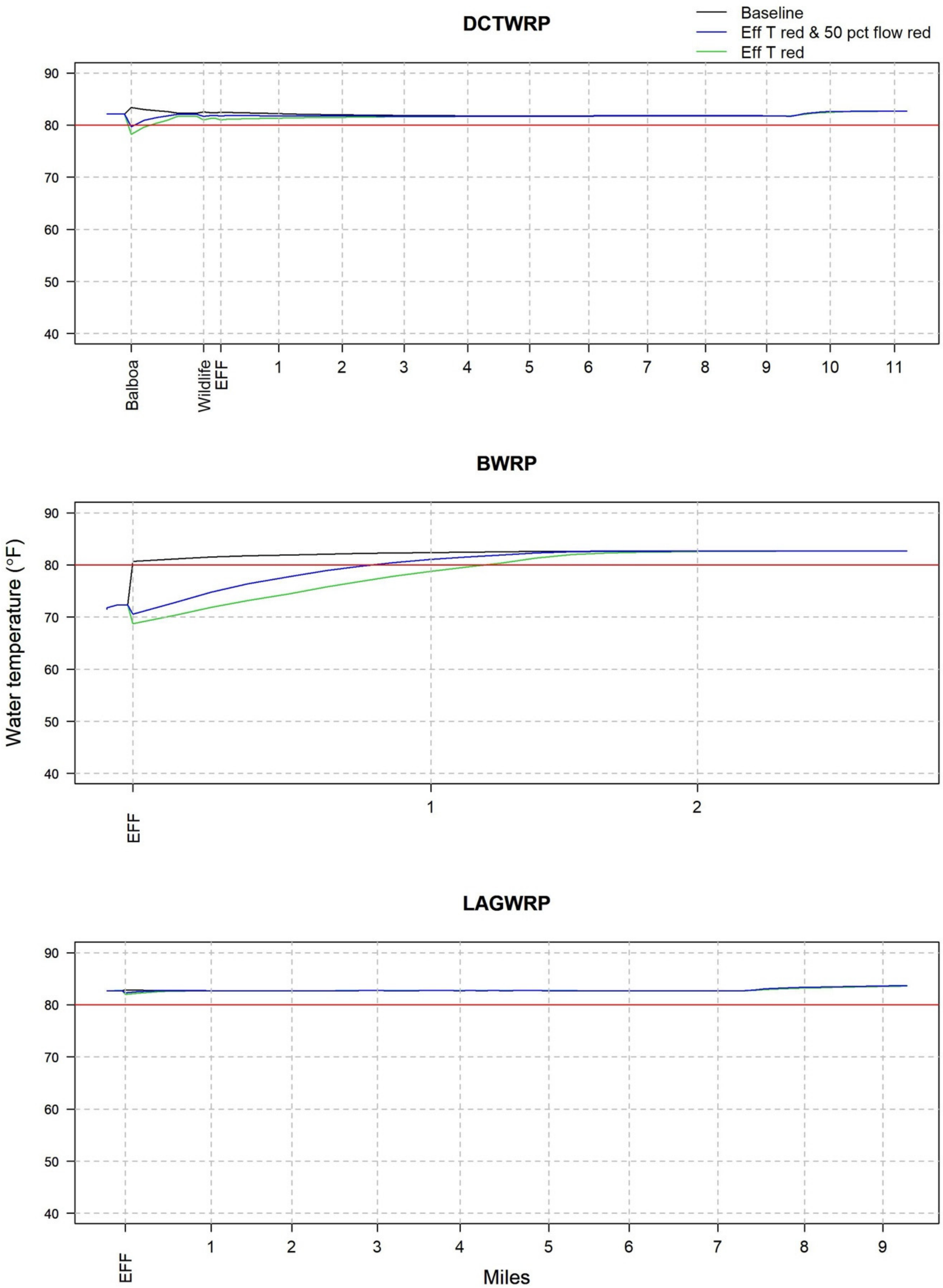

Figure ES-4. Receiving water temperatures downstream of WRPs for the effluent temperature and flowrate reduction for August 6, 2024

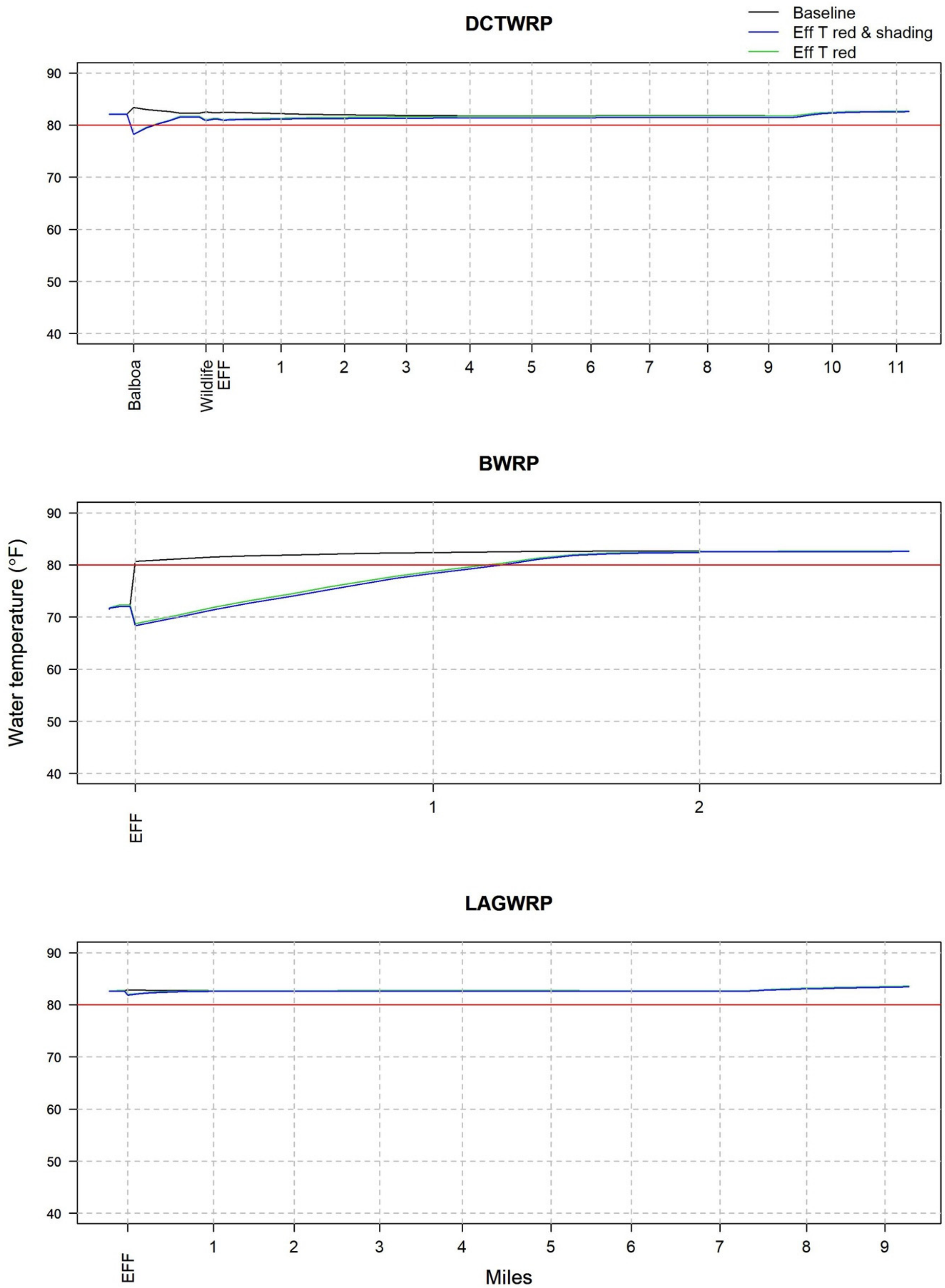

Figure ES-5. Receiving water temperatures downstream of WRP discharges for effluent cooling and riparian shading on August 6, 2024

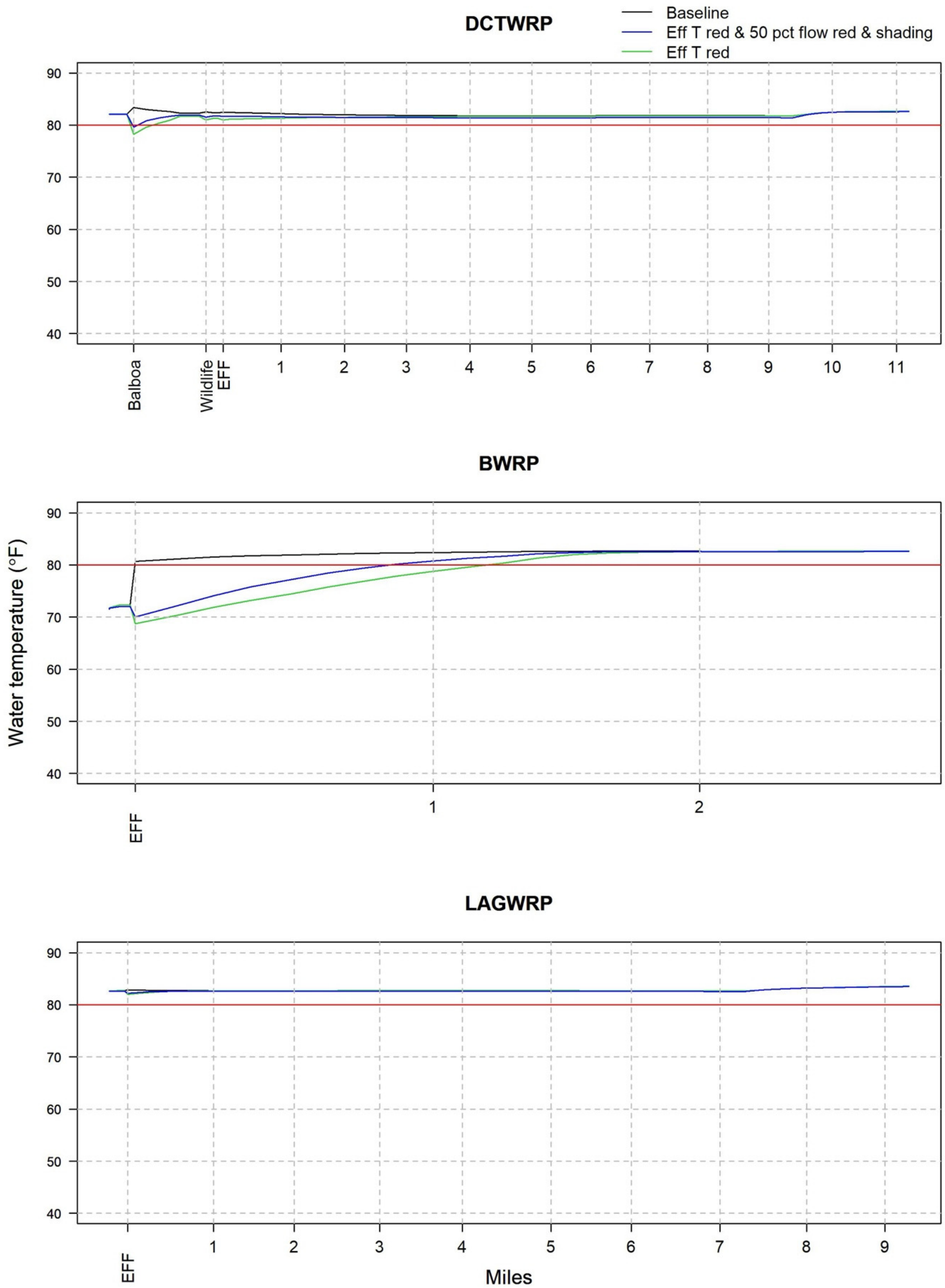

Figure ES-6. Receiving water temperatures downstream of WRPs for all three potential control measures concurrently on August 6, 2024

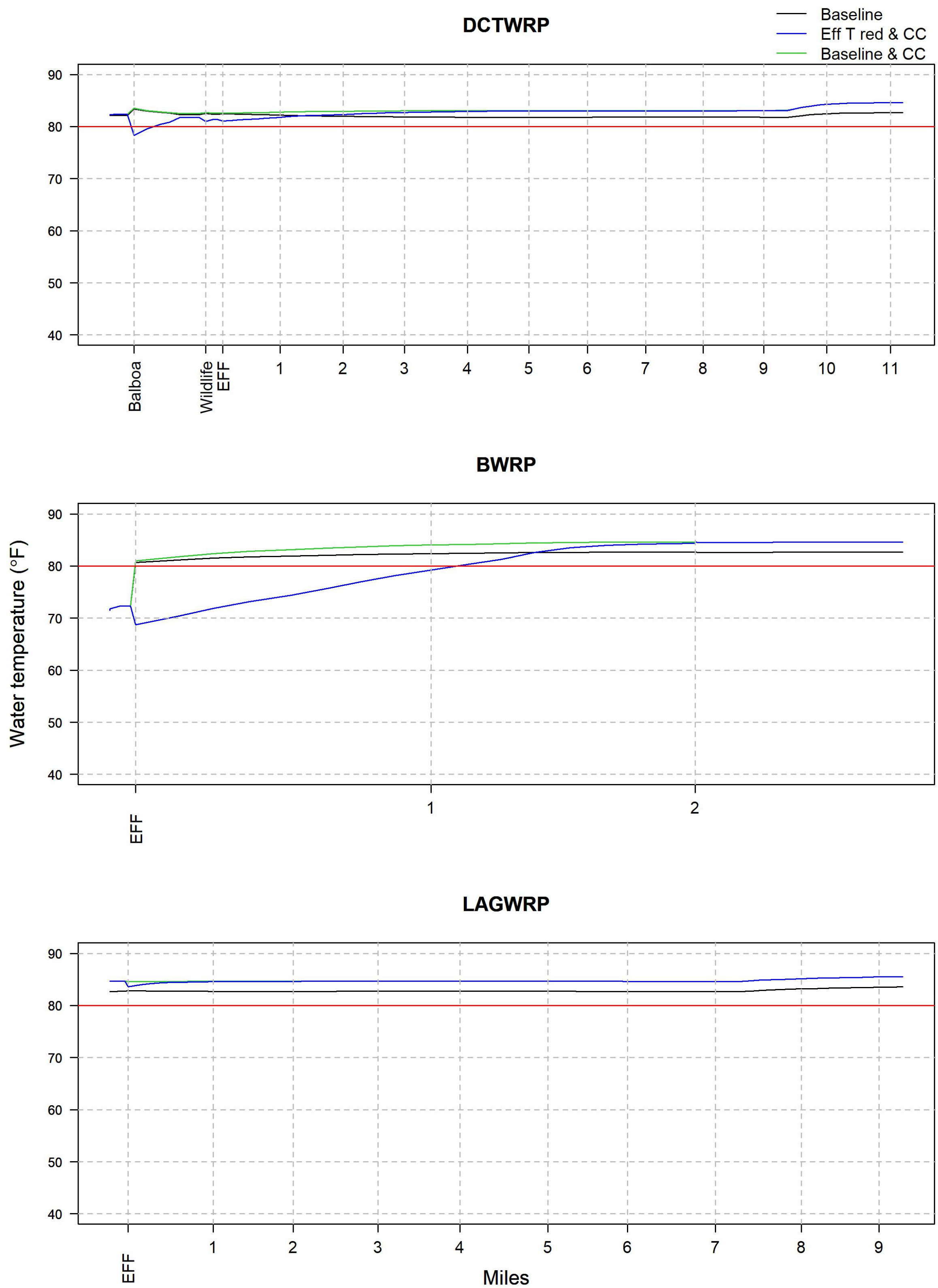

Figure ES-7. Receiving water temperatures downstream of WRP for baseline (current conditions, black line), baseline conditions with climate change (blue line), and effluent reduction with climate change (green line)

SECTION 1 INTRODUCTION

The Donald C. Tillman (DCTWRP or DCTWRP) and Los Angeles/ Glendale (LAGWRP or LAGWRP) Water Reclamation Plants (WRPs) operated by the City of Los Angeles, Bureau of Sanitation and Environment (LASAN), and the Burbank Water Reclamation Plant (BWRP), operated by the City of Burbank Public Works Department, discharge tertiary-treated disinfected wastewater effluent in the Los Angeles River (LA River or LAR) watershed. The DCTWRP and LAGWRP WRPs discharge into the mainstem of the LAR, while the BWRP discharges to Burbank Western Channel (BWC), which is a tributary to the LAR. The Los Angeles Regional Water Quality Control Board (Regional Board) reinterpreted the Water Quality Control Plan: Los Angeles Region Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties (Basin Plan)[7] water quality objective (WQO) for temperature and, consequently, lowered the effluent limits for temperature in the National Pollutant Discharge Elimination System (NPDES) discharge permits issued to the WRPs.[8] The NPDES permits for the three WRPs now include a maximum temperature effluent limitation of 80 degrees Fahrenheit (°F) for treated wastewater effluent as well as a receiving water limit that requires that WRP effluent not raise receiving water temperatures by more than 5°F (herein referred to as delta 5°F). The prior permits[9] contained 86°F as a temperature effluent limitation and stated that “[t]he temperature of wastes discharged shall not exceed 86°F except as a result of external ambient temperature.” The 80°F permit limit is based on the Regional Board’s new interpretation and implementation of the WQO for temperature contained in the Basin Plan, which states:

> *The natural receiving water temperature of all regional waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Board that such alteration in temperature does not adversely affect beneficial uses. Alterations that are allowed must meet the requirements below.*
>
> *For waters designated WARM, water temperature shall not be altered by more than 5°F above the natural temperature. At no time shall these WARM-designated waters be raised above 80°F as a result of waste discharges.*

In recognition that effluent temperatures from the WRPs can sometimes exceed the new 80°F permit limit, particularly during summer months when ambient air temperatures are warmest and solar radiation is at peak levels, the Cities of Los Angeles and Burbank (Cities) requested and were granted in-permit compliance schedules that includes the development and implementation of a special study that identifies the potential impacts of the WRPs’ effluent temperature and potential control measures that can be implemented to address those potential impacts.

A Workplan was submitted to the Regional Board to address the requirements of the City of Los Angeles’ WRP Permits in November 2023 and revised in February 2024 based on input from the Technical Advisory Committee (TAC), which was initially formed in June 2023 by the City of Los Angeles and expanded in February

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[7] Los Angeles Region Basin Plan can be accessed here: https://www.waterboards.ca.gov/losangeles/water_issues/programs/basin_plan/basin_plan_documentation.html

[8] DCTWRP NPDES No. CA0056227 Order R4-2022-0341 and LAGWRP NPDES No. CA0053953 Order R4-2022-0343;BWRP NPDES No. CA0055531 Order R4-2023-0358

[9] DCTWRP NPDES No. CA0056227 Order R4-2017-0062 and LAGWRP NPDES No. CA0053953 Order R4-2017-0063; BWRP NPDES No. CA0055531 Order R4-2017-0064

2024 to add members in response to the City of Burbank joining the Study. The TAC was comprised of subject matter specialists including Regional Board staff. A revised draft of the Workplan was submitted to the Regional Board on April 26, 2024 to incorporate the requirements of the City of Burbank's WRP Permit and sampling efficiencies through coordination with monitoring conducted by the Los Angeles River Watershed Monitoring Program (LARWMP). The Workplan was revised based on comments received by the Regional Board and resubmitted in May 2024 (LWA 2024)[10]. Submittals of the Workplan were submitted consistent with the schedule presented in **Table 1**.

The mainstem of the LA River is a 51-mile-long urban river that flows through 14 cities and unincorporated areas in LA County. **Figure 1** presents the location of the three WRPs operated by the Cities in the LA River watershed. The Study area encompasses the waterbodies potentially impacted by the thermal component of the WRPs' discharges (LA River reaches 1 through 5, Bull Creek, and BWC). **Table 2** lists the waterbodies in the LA River that receive effluent from the three WRPs and their associated beneficial uses identified in Chapter 2 of the Basin Plan. Approximately 94% of the mainstem of the LA River (or 48 miles) is contained in concrete flood control channels, with the remaining approximately three miles of the Sepulveda Flood Control Basin (Sepulveda Basin) in LA River Reach 5 being the only portion not contained in concrete flood control channels. There are currently approximately nine miles of river with unlined channels, which occur at in the Glendale Narrows in LA River Reach 3 and the Sepulveda Flood Control Basin in LA River Reach 5 (**Figure 1**).

A temperature model of the Study area was developed to support an assessment of current conditions, effect of potential control measures, and potential implications of climate change. This report summarizes the efforts to develop the model and evaluate the effects of potential control measures and climate change on receiving water temperatures.

[10] Larry Walker Associates (LWA). 2024. Draft Workplan: Assessing the Effects of Water Reclamation Plant Effluent Temperature on Aquatic Life in the Los Angeles River Watershed. *Developed for:* the City of Los Angeles Sanitation and Environment and the City of Burbank Public Works Department.

Table 1. Compliance Schedule and Milestone Dates Contained in the DCTWRP, LAGWRP, and BWRP Permits (Orders R4-2022-0341, R4-2022-0343, and R4-2023-0358, respectively)

Task[1]		Completion Date	
		DCTWRP and LAGWRP Permits	BWRP Permit
1	Submit and Begin Implementation of Pollution Prevention Plan (PPP) for Source Control	April 1, 2023	February 1, 2024
2	Select members for the Technical Advisory Committee and Stakeholder Committee and regularly convene the committee members to initiate the development of a Technical Workplan that includes a temperature study that identifies the potential impacts of the WRP's effluent temperature and potential control measures (including nature-based solutions) that can be implemented to protect beneficial uses.	May 1, 2023	March 1, 2024
3	Finalize and submit a Technical Workplan for the Los Angeles Water Board Approval, secure the necessary permits for Los Angeles River Channel access and deployment of in-situ monitoring devices, and initiate bidding and procurement for any necessary equipment and/or services.	November 1, 2023	September 1, 2024
4	Implement the Technical Workplan, initiate testing and deployment of any necessary equipment, and continue securing the necessary permits for Los Angeles River Channel access and deployment of in-situ monitoring devices.	April 1, 2024	February 1, 2025
5	Implement the Technical Workplan and begin drafting a Final Technical Report.	December 1, 2024	October 1, 2025
6	Complete and submit the Final Technical Report	December 1, 2025	October 1, 2026
7	Notify Los Angeles Water Board of Selected Preferred Project and Identify Regulatory Approval Process (if appropriate given the study findings), Present Results of Technical Workplan at Next Scheduled Los Angeles Water Board Meeting	February 1, 2026	December 1, 2026
8	Begin Preliminary Design and Environmental Review	July 1, 2026	May 1, 2027
9	Complete Preliminary Design	April 30, 2027	February 28, 2028
10	Complete Environmental Review	April 30, 2028	February 28, 2029
11	Design Preferred Project	April 30, 2029	February 28, 2030
12	Issue Notice to Proceed for Project Work	April 30, 2030	February 28, 2031
13	Complete Preferred Project	February 1, 2031	December 1, 2031

1. Tasks 2 through 6 are relevant to the Study and this report.

Figure 1. City of Los Angeles and Burbank Operated Water Reclamation Plants in the Los Angeles River Watershed

Table 2. Los Angeles River Watershed Waterbodies Identified in the Basin Plan that Receive Effluent from the Donald C. Tillman (DCT), Los Angeles Glendale (LAG), and Burbank Water Reclamation Plants (WRPs)[1] and Associated Beneficial Uses

Waterbody	WRP Direct Discharge	Beneficial Use														
		MUN	IND	PROC	GWR	WARM	MAR	WILD	RARE	MIGR	SPWN	SHELL	WET	REC1	REC2	High Flow Suspension
Los Angeles River Reach 1		P*	P	P	E	E	E	E	E	P	P	P[2]		E[2]	E	Y[3]
Los Angeles River Reach 2		P*	P		E	E		P						E[2]	E	Y[3]
Los Angeles River Reach 3	LAG	P*	P		E	E		E					E	E	E	Y[3]
Los Angeles River Reach 4	DCT	P*	P		E	E		E					E	E	E	Y[3]
Los Angeles River Reach 5		P*	P		E	E		E					E	E	E	Y[3]
Sepulveda Flood Control Basin	DCT Indirect[4]	P*			E	E		E					E	E	E	
Bull Creek		P*			I	I		E						I[5]	I	
Burbank Western Channel	BWRP	P*				P		P						P[5]	I	Y[3]

E: Existing beneficial use. P: Potential beneficial use. I: Intermittent beneficial use.

* Asterisked MUN designations are designated under SB 88-63 and RB 89-03. However, the Los Angeles Regional Water Quality Control Board has only conditionally designated the MUN beneficial use.

1. See Chapter 2 of the Water Quality Control Plan: Los Angeles Region Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties for definitions of the beneficial uses.
2. Access is prohibited by Los Angeles County Department of Public Works.
3. The High Flow Suspension only applies to water contact recreational activities associated with the swimmable goal as expressed in the federal Clean Water Act section 101(a)(2) and regulated under the REC-1 use, non-contact water recreation involving incidental water contact regulated under the REC-2 use, and the associated bacteriological objectives set to protect those activities. Water quality objectives set to protect (1) other recreational uses associated with the fishable goal as expressed in the federal Clean Water Act section 101(a)(2) and regulated under the REC-1 use and (2) other REC-2 uses (e.g., uses involving the aesthetic aspects of water) shall remain in effect at all times for waters where this footnote appears.
4. The DCTWRP directly discharges to LA River Reach 4 through discharge point 008 immediately downstream of the Sepulveda Dam. The DCTWRP indirectly discharges to LA River Reach 5 through Lake Balboa and Wildlife Lake, Bull Creek and Hayvenhurst Channel through Lake Balboa, and Haskell Flood Control Channel through Wildlife Lake. The DCTWRP also discharges to the Japanese Gardens, which drains through discharge point 008 to LA River Reach 4. Note that Hayvenhurst Channel and Haskell Flood Control Channel are not named waterbodies in the Basin Plan and do not have designated uses or associated water quality objectives.
5. Access prohibited by the Los Angeles County Department of Public Works in the concrete-channelized areas.

SECTION 2 STUDY OBJECTIVES

As presented in the fact sheets of the WRPs' NPDES permits, the Federal Clean Water Act (CWA) requires point source dischargers to control the amount of conventional, non-conventional, and toxic pollutants that are discharged into the waters of the United States. The control of pollutants is intended to protect beneficial uses of waterbodies through establishing limitations such as the effluent and receiving water limits for temperature included in the WRPs' NPDES permits. There are other factors not addressed through NPDES permits that can impact beneficial uses in the Study area such as habitat modifications for flood control purposes. However, those factors are outside of the Cities' control as they cannot take unilateral action to address habitat modifications in the Study area. As such, this study is intended to develop a better understanding of the relationship between effluent temperature, which is regulated by the Cities' NPDES permits, and potential impacts to the WARM beneficial use in the LA River downstream of the DCTWRP, LAGWRP, and BWRP discharges. Additionally, the Study identifies and evaluates different types of potential control measures (including nature-based solutions) to determine if those control measures will meet the limits while also considering the potential adverse implications related to energy use and greenhouse gas (GHG) emissions. The Study was focused on the WARM beneficial use as the temperatures limits in the WRPs' permits are based on the water quality objective established for the protection of the WARM beneficial use, which is defined in the Basin Plan as:

> *Uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates*.

To support the Study, the Cities, in consultation with the TAC, identified the following Study Objectives:

1. Determine the wholly or partially aquatic-dependent[11] taxa that are present, were historically present, or could be present given the current habitat conditions in the Los Angeles River.
2. For each taxon identified in Objective 1, describe the relationship between waterbody temperatures and the probability (or likelihood) that different aquatic life stages are supported.
3. Determine how the relationships between waterbody temperature and the support of aquatic life vary based on the taxon's location in the river and seasonality.
4. Determine the critical exposure times, durations, and/or frequencies associated with the temperature relationships described in Objectives 1 through 3.
5. Evaluate how other physical factors (e.g., shading, groundwater discharge, availability of substrate, flow, etc.) and climate change could potentially influence temperature effects on biological communities.
6. Analyze relationships between effluent discharge temperature and in-river temperature, including how river temperature changes as a function of distance from the discharge location and downstream physical characteristics.

Study Objectives 5 and 6 are best addressed through a flow and temperature model of the LA River and BWC. Objectives 5 and 6 require assessment of receiving water conditions that may occur when changes to the system are completed. Modeling can provide estimates of how the system will respond to potential control measures or climate change.

[11] Aquatic-dependent is defined as a major life stage that resides in the river or relies on the river for food and forage.

SECTION 3 STUDY SETTING

The Los Angeles Basin is a coastal southern California semi-arid region. It is set in a Mediterranean climate dominated by long dry summers and usually brief winters with short, sometimes intense cyclonic winter storms[12]. The taller mountains in the region receive a portion of their precipitation as snow, which typically contributes water to streams until mid- to late-summer. Much of the higher elevations of the region are undeveloped and remain partially protected in national forests and a network of national, state, and county parks. The lower elevations in the region have been pervasively altered by urbanization or conversion to agriculture[13]. Flowing waterbodies in the region fall into two basic types: 1) short coastal streams draining mountain ranges immediately adjacent to the coast, and 2) larger river systems, such as the LA River, which extend inland through gaps in the coastal ranges.

The LA River watershed dominates the geographical setting of the nation's second largest but most densely populated urban area (2020 Census Urban Areas Facts)[14]. As of 2020, approximately 25 percent of California's residents live in LA County. Until the completion of the Los Angeles Aqueduct for the importation of water, the LA River was the primary agricultural, industrial, and domestic water source for the Los Angeles region, through river surface water diversions and groundwater pumping[12]. Periodic, severe floods affected the partially developed floodplain areas along the LA River into the 1930s when the US Army Corp of Engineers (USACE) began a project of channelizing the LA River. Since completion of the channelization, the LA River serves primarily as a flood control channel.

The conversion of the LA River to a flood control channel has eliminated most of the adjacent riverine and riparian natural communities along the LA River, greatly reducing its plant and wildlife diversity. The entire LA River corridor is now heavily degraded ecologically[12]. With the exception of the Glendale Narrows, the LA River's historical surface flow prior to channelization was reportedly intermittent in stretches in the San Fernando Valley (LAR Reaches 4, 5, and 6) and downstream of downtown Los Angeles[15]. Today, the mostly concrete channel of the LA River carries a relatively constant low-flow year-round[16]. As described in the 2022 LA River Master Plan, the Los Angeles County Flood Control District (LACFCD) and the United States Army Corps of Engineers (USACE) are responsible for maintaining the mainstem of the LA River, with each maintaining approximately half of the LA River. Permits for projects along and in the right-of-way are issued by these two entities depending on the project type and location.

The LA River and BWC are shown on **Figure 1**. The figure includes the WRP discharge locations, reach labels, and indicates sections of the channels with concrete bottom and those with unlined. The majority of the San Fernando Valley area of the LA River (Reach 4), including BWC is concrete lined. The Sepulveda Basin (Reach 5), a short section between the confluence of BWC and confluence of Verdugo Wash (Reach 4), and the Glendale Narrows (Reach 3) are the only freshwater segments with unlined bottoms. The unlined sections in Reach 3 are generally the areas with groundwater exfiltration making concrete bottoms impractical. While the channels were designed to convey flood waters, they are effective at conveying discharges from the WRPs downstream. Apart from the Sepulveda Basin, the San Fernando Valley area of the LA River (upstream of

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[12] U.S. Fish and Wildlife Service (USFWS). 2015. Revised Final Fish and Wildlife Coordination Act Report for the proposed Los Angeles River Ecosystem Restoration Project Los Angeles County, California. Report FWS-LA-14B0040-15CPA0063. Carlsbad Fish and Wildlife Office, Carlsbad, California

[13] Mazor, R.D., D.J. Gillett, K. Schiff. 2011. Ecological Condition of Watersheds in Coastal Southern California: Summary of the Stormwater Monitoring Coalition's Stream Monitoring Program First Year (2009).

[14] 2020 Census Urban Areas Facts: https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural/2020-ua-facts.html

[15] Gumprecht, B. 1999. The Los Angeles River: Its Life, Death, and Possible Re-Birth. Johns Hopkins University Press, Baltimore.

[16] Los Angeles River Revitalization Corporation (LARRC). 2011. Los Angeles River: Water Quality. http://thelariver.com/about/water-quality/

Glendale Narrows), including the BWC, is characterized by large segments of channel that are almost entirely concrete lined, with dense urban development along the former floodplain. The lower reaches of the LA River (downstream of Glendale Narrows) are also heavily constrained by development, including downtown Los Angeles and an adjacent heavy industrial corridor that contains a major power transmission line and a freeway system running alongside the River. Due to the intensity of surrounding development, the BWC and the reaches of the LA River above and below Glendale Narrows have lower potential for ecological connectivity to regional "core areas" (e.g., the Santa Monica Mountains)[12]. **Table 3** summarizes channel characteristics of the Study area (LA River reaches 1 through 5 and BWC) as well as other major waterbodies (LA River Reach 6 and major tributaries along reaches 1 through 6).

Table 3. Physical Characteristics of Waterbodies in the Los Angeles River Temperature Model

Waterbody	WRP Direct Discharge	Bottom Substrate[1]	Channel Width[2]	Channel Shape	Low Flow Channel	Canopy Cover
Waterbodies Influenced by City of Burbank and Los Angeles WRP Discharges						
Los Angeles River Reach 1	No	Concrete	VL	Trapezoidal	Yes	Open
Los Angeles River Reach 2	No	Concrete	L-VL	Trapezoidal	Partial	Open
Los Angeles River Reach 3	LAG	Concrete/ Unlined	L-VL	Trapezoidal	Partial	Partial
Los Angeles River Reach 4	DCT	Concrete/ Unlined	M-L	Box and Trapezoidal	Partial	Open
Los Angeles River Reach 5	DCT Indirect[3]	Concrete/ Unlined	M-L	Other	No	Partial
Burbank Western Channel	BWRP	Concrete	S-M	Box	No	Open
Other Waterbodies						
Compton Creek	No	Concrete/ Unlined	S-M	Trapezoidal	No	Open
Rio Hondo	No	Concrete/ Unlined	M-VL	Trapezoidal and Other	No	Partial

1. With the exception of LAR Reaches 3 and 5, the remaining waterbodies noted as concrete/unlined are almost entirely concrete bottoms.
2. Based on width at the bottom of the channel: S (Small <50 feet); M (Medium 50-100 feet); L (Large 100-200 feet); VL (Very Large >200 feet).
3. DCTWRP indirectly discharges to LAR Reach 5 through Lake Balboa and Wildlife Lake, Bull Creek and Hayvenhurst Channel through Lake Balboa, and Haskell Flood Control Channel through Wildlife Lake.

SECTION 4 TEMPERATURE MODEL

A temperature model of the LA River must include both hydraulics (flowrate, depth, width, etc) and the energy balance (heat input of discharges, solar radiation, atmospheric temperature, etc). The model requirements include: consideration of inputs from major tributaries, assess current and future conditions in the LA River and BWC, and the system response to potential control measures. As discussed below the Hydrologic Engineering Center's River Analysis System (HEC-RAS) was selected to model both river hydraulic parameters and temperature at key assessment points along the LA River.

4.1 Hydraulic Model

A hydraulic model of the LA River was developed as part of the Los Angeles River Environmental Flows Project (Environmental Flows Project; Stein et al 2021a)[17]. The Environmental Flows Project was a collaboration of the State Water Resources Control Board (State Water Board), Regional Board, City of Los Angeles Bureau of Sanitation, City of Los Angeles Department of Water and Power, Los Angeles County Department of Public Works, and Los Angeles County Sanitation Districts to develop a process for establishing flow criteria, apply the process to provide recommendations for flow criteria in the LA River, and to produce tools and approaches to evaluate management scenarios necessary to achieve recommended flow criteria. . The model simulates channel cross-sectional attributes such as depth, width, velocity along the LA River from Sepulveda Dam to the estuary. The LA River Environmental Flows model is constructed from a series of existing one-dimensional HEC-RAS models were compiled together, including:

- HEC-RAS Model for Stormwater Management Plan. (U.S. Army Corps of Engineers 2004)
- HEC-RAS Model for Upper Los Angeles River and Tujunga Wash. (U.S. Army Corps of Engineers 2005)
- HEC-RAS Model for San Gabriel River, San Jose Creek, Compton Creek, Upper Rio Hondo, Coyote Creek, Verdugo Wash, Arroyo Seco. (HDR CDM 2011)
- HEC-RAS Model for Burbank 2017 Wastewater Change Petition. (Environmental Science Associates 2017)
- HEC-RAS Model for Glendale 2018 Wastewater Change Petition. (Environmental Science Associates 2018)

The channel geometry of the model was validated with LiDAR data, as-built drawings, and Google Earth to ensure that the low-flow channel was properly represented. The stitched existing models were expanded to include Sepulveda Basin and upper Rio Hondo using LiDAR data. The model includes approximately 3,000 nodes over both channelized and soft-bottomed portions of the LA River between the estuary and Sepulveda Dam, Compton Creek, and Rio Hondo up to Whittier Narrows Dam. The model includes two

[17] Stein, E. D., K. Taniguchi-Quan, J. Wolfand, E. Gallo, K. Irving, D. Philippus, R. Abdi, V. Hennon, A. Tinoco, P. Mohammadi, A. Rust, T. S. Hogue (2021). Process and Decision Support Tools for Establishing Flow Recommendations to Support Aquatic Life and Recreational Beneficial Uses of the Los Angeles River. SCCWRP Tech. Report #1196. April 2021. For more information visit https://www.sccwrp.org/about/research-areas/ecohydrology/los-angeles-river-flows-project.

geometries, one corresponding to low-flow simulations and the other to high-flows scenarios, where portions of the LA River have differing Manning's roughness coefficients based on model calibration but are otherwise identical. The high-flow version is used as flowrates increase past the 100-300 cubic feet per second (cfs) range. Complete hydraulic model development and calibration is detailed in Stein, 2021b[18].

The dry-weather flowrates determined for gauges along the LA River are presented from upstream to downstream in **Figure 2**. The Environmental Flows Project considered the discharges from the three WRPs, groundwater exfiltration, and urban and industrial non-stormwater flows. Above the DCTWRP discharges, non-stormwater flows comprise the entire river flow rate. Downstream of DCTWRP discharges in LA River Reach 4, the WRP flows dominate with a significant component from non-stormwater flows. Through the Glendale Narrows, there is some groundwater exfiltration that contributes approximately 5% of the total flow at that point (groundwater exfiltration is set to a constant 0.12 cubic meters per second (cms), or 4.3 cfs, whereas the total flowrate at the end of Glendale Narrows is approximately 85 cfs). Toward the bottom of the watershed, the integrated contribution of the urban area results in non-stormwater flows comprising approximately 50% of the total river flow.

This study required the addition of BWC to the model. The as-built drawings from LACFCD were used to enter the channel geometry at stations positioned nominally every 100 feet. The roughness calibrated for the other concrete channel sections in the model was used for the BWC. Additionally, the discharges from the three WRPs were explicitly added to the model, setting them as boundary conditions for flowrate and temperature.

The flowrates for the WRP discharges were updated to include data from 2020 through 2023 to reflect current operation. **Table 4** lists the average discharge flowrate for the three WRPs observed for May through September from 2020 to 2023.

The HEC-RAS model calculated cross-sectionally averaged hydraulic parameters, such as water depth, width, cross-sectional area, and wetted perimeter to inform relationships between the parameters and the calculated receiving water temperature at those locations where appropriate.

[18] Stein, E. D., J. Wolfand, R. Abdi, K. Irving, V. Hennon, K. Taniguchi-Quan, D. Philippus, A. Tinoco, A. Rust, E. Gallo, C. Bell, T. S. Hogue. 2021b. Assessment of Aquatic Life Use Needs for the Los Angeles River: Los Angeles River Environmental Flows Project. Southern California Coastal Water Research Project Technical Report #1154.

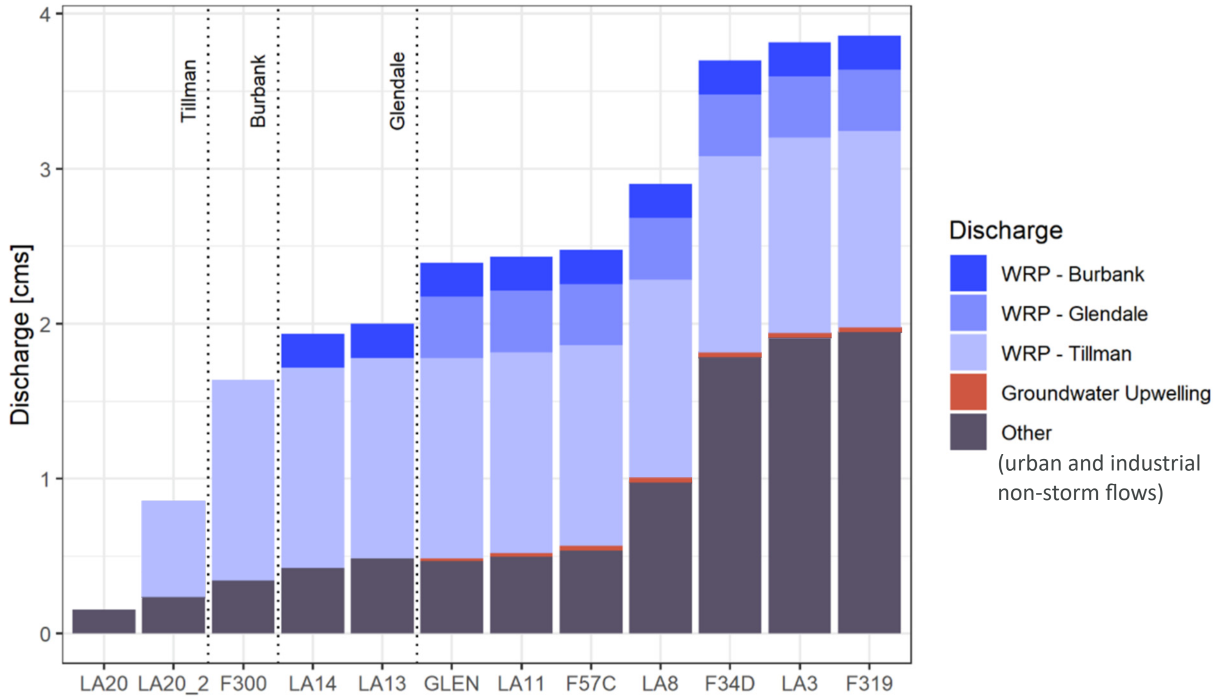

Figure 2. Dry weather LA River flowrates at gauges on the LA River (after Stein 2021c[19])

Table 4. Current WRP Discharge Flowrates (average May – September 2020-2023)

WRP	Current Dry-Weather Flowrate (MGD)
DCTWRP	21.6
BWRP	3.0
LAGWRP	8.5

4.2 Temperature Model

The most straightforward and efficient approach to complete the temperature evaluations was to retain one modeling system, HEC-RAS. The full energy budget water temperature model[20] integrated within HEC-RAS provides an advanced computational framework designed to simulate the thermal dynamics of riverine environments. The net heat flux defines the full energy budget for a water quality cell and is the sum of the short wave (solar) radiation, net long wave radiation (atmospheric downwelling and back

[19] Stein, E. D., K. Taniguchi-Quan, J. Wolfand, E. Gallo, K. Irving, D. Philippus, R. Abdi, V. Hennon, A. Tinoco, P. Mohammadi, A. Rust, T. S. Hogue (2021c), Process and Decision Support Tools for Evaluating Flow Management Targets to Support Aquatic Life and Recreational Beneficial Uses of the Los Angeles River: Los Angeles River Environmental Flows Project, April 2021

[20] https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%20Water%20Quality%20User's%20Manual-v6.4.1.pdf

upwelling), sensible heat, latent heat, and sediment water interface flux. The parameters are defined in **Table 5**.

$$q_{net} = q_{sw} + (q_{atm} - q_b) + q_h - q_l + q_{sed}$$

The short wave radiation is a direct input and can be modified (decreased or increased by a factor) to reflect shading or other processes so that it is the main calibration "lever". The other fluxes are calculated internally in HEC-RAS from the meteorological data. The sensible and latent heat are affected by the windspeed, and parameters in HEC-RAS control how much the wind affects them are used as an additional calibration refinement. Time series data for solar radiation, air temperature, relative humidity, atmospheric pressure, and cloudiness are required elements for the water temperature model. The net heat flux with the boundary and initial conditions and flow data allows simulation of the water temperature over time.

Table 5. HEC-RAS Energy Budget Computation Factors for the Net Heat Flux for a Water Quality Cell

Energy Budget Computation	Symbol	Requires
Short-wave solar radiation	q_{sw}	Direct time series of solar radiation Cloudiness time series
Long-wave (downwelling) radiation flux	q_{atm}	Air temperature time series Cloudiness time series
Long-wave back (upwelling) radiation flux	q_b	Function of water temperature and emissivity
Sensible heat flux density	q_h	Air temperature time series Windspeed time series
Latent heat flux density	q_l	Vapor pressure time series Windspeed time series Atmospheric pressure time series

4.3 Los Angeles River Model Considerations

The current configuration of the HEC-RAS hydraulic model does not include explicit consideration of lateral inflows, including explicit groundwater, hyporheic, and wet weather stormflows (i.e., stormwater) temperature inputs. These flows are not explicitly calculated by the hydraulic model, and therefore would require direct measurement of flow and temperature data or synthesized boundary conditions through an estimation method. If complete removal of WRP discharges were a control measure under consideration, it would be appropriate to explicitly model the lateral inflows. However, these flows are a minor component of the total receiving water flow and are well modeled implicitly through temperature calibration of receiving waters. These lateral contributions are unlikely to be a component of the control measures considered. The majority of the mainstem LA River is concrete lined which excludes the inclusion of groundwater exfiltration, or near-bottom cycling of surface-groundwater (hyporheic effects) in the majority of the mainstem. The critical period for temperature is summer where the likelihood of significant stormwater is low. Non-stormwater inputs may be considered relatively constant as they are the result of the average activities of the population living in the drainage area.

The advantage of explicitly modeling the lateral flows is in restoration, where surface non-stormwater or stormwater may be infiltrated and cooled through the groundwater and enter the river through exfiltration, or the concrete may be removed to enhance the hyporheic interactions. To date, removal of concrete from the channels is not being considered as a control measure, precluding the need to model the lateral flows. Where groundwater does exfiltrate into the river, the Basin is contaminated[21] and groundwater tightly controlled to prevent movement of the plumes. Modification of the groundwater flow in the Burbank area is unlikely to be a viable control measure.

SECTION 5 MODEL CALIBRATION

5.1 Hydraulic Model

As discussed previously, a base hydraulic model of the LA River was compiled as part of the Los Angeles River Environmental Flows Project[22]. The model simulates the channel cross-sectional attributes such as depth, width, velocity along the LA River from Sepulveda Dam to the estuary. The model includes approximately 3,000 nodes over both concrete and unlined portions of the LA River between the Estuary and Sepulveda Dam, Compton Creek, and Rio Hondo up to Whittier Narrows Dam. Modifications necessary to fully evaluate receiving water temperatures and effects of control measures include:

- Adding Burbank Western Channel to the HEC-RAS domain
- Explicitly adding the WRP discharges
- Implementation of the Temperature Model

To correctly model the effect of WRP discharges on receiving water flow and temperature, WRP discharge structures and associated tributaries were added to the channel geometry of the existing HEC-RAS model.

5.1.1 DCTWRP Discharges

The DCTWRP is located in the Sepulveda Flood Control Basin. The DCTWRP directly discharges to LA River Reach 4 through discharge point 008 immediately downstream of the Sepulveda Dam. The DCTWRP indirectly discharges to LA River Reach 5 through Lake Balboa (Discharge Point 002) and Wildlife Lake (Discharge Point 003), Bull Creek and Hayvenhurst Channel through Lake Balboa, and Haskell Flood Control Channel through Wildlife Lake. The DCTWRP also discharges to the Japanese Gardens, which drains through Discharge Point 008 to LA River Reach 4. Based on the annual average flow over the past 4 years, the discharge to Lake Balboa account for 62% of the DCTWRP effluent and the Wildlife Lake discharge and Discharge Point 008 each account for 19%. The details of each discharge location are presented below.

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[21] https://semspub.epa.gov/work/HQ/100002333.pdf

[22] Stein, E. D., K. Taniguchi-Quan, J. Wolfand, E. Gallo, K. Irving, D. Philippus, R. Abdi, V. Hennon, A. Tinoco, P. Mohammadi, A. Rust, T. S. Hogue (2021c), Process and Decision Support Tools for Evaluating Flow Management Targets to Support Aquatic Life and Recreational Beneficial Uses of the Los Angeles River: Los Angeles River Environmental Flows Project, April 2021

5.1.1.1 Lake Balboa Spillway Discharge

The spillway channel from Lake Balboa to LA River Reach 5 is approximately 1,045 feet long and begins at the south end of Lake Balboa. The channel consists of a section of gravel riprap and then turns into a natural bottom channel before discharging to the LAR. USGS DEM Raster data (1 meter resolution) was used to create the necessary cross sections and channel geometry data to model the flow discharged from Lake Balboa to the LAR. Portions of the channel have bridges and underground culverts which were incorporated into the channel geometry. The Manning's roughness coefficient that was used for the riprap portions of the channel was 0.033 and the Manning's roughness coefficient that was used for the natural portion of the channel was 0.035.

5.1.1.2 Wildlife Lake Spillway Discharge

The spillway channel from Wildlife Lake to LA River Reach 5 is approximately 1,975 feet long and begins at the south end of the Wildlife Lake. Most of the channel consists of a natural bottom channel with several underground concrete culverts before discharging to the LAR. USGS DEM Raster data (1 meter resolution) was used to create the necessary cross sections and channel geometry data to model the flow discharged from the Wildlife Lake to the LAR. The Manning's roughness coefficient that was used for the natural portion of the channel was 0.035 and the Manning's roughness coefficient that was used for underground concrete culverts was 0.013.

5.1.1.3 Discharge Point 008

The discharge structure for Discharge Point 008 to LA River Reach 4 consists of an underground reinforced concrete pipe that has a diameter of 108 inches that discharges treated effluent from DCTWRP and the Japanese gardens to the LAR. The pipe elevations were obtained from the Los Angeles County sewer pipe online inventory. Near the discharge point below Sepulveda Dam, the reinforced concrete pipe splits into two pipes before discharging to the LAR. However, to maintain the simplicity of the HEC-RAS flow model, one pipe is used to prevent issues associated with minimum reach lengths. The Manning's roughness coefficient that was used for the reinforced concrete pipe was 0.013.

5.1.2 BWRP Discharge

The BWRP discharges directly to the BWC through a sidewall discharge structure approximately 25 feet in the length. The Manning's roughness coefficient for the BWRP discharge that was used was 0.013 to align with the Manning's roughness coefficient for reinforced concrete pipe.

5.1.3 LAGWRP Discharge

The LAGWRP discharges directly to the LA River Reach 3 and the length of the discharge structure is approximately 40 feet. Engineering drawings were not obtained for the discharge structure, and it was assumed that the width of the discharge point (40 feet) was the width of the discharge structure. The Manning's roughness coefficient for the LAGWRP discharge that was used was 0.013 to align with the Manning's roughness coefficient for reinforced concrete pipe.

5.2 HEC-RAS Temperature Model

The full energy budget water temperature model[23], integrated within HEC-RAS provides an advanced computational framework designed to simulate the thermal dynamics of riverine environments. Time series data for solar radiation, air temperature, relative humidity, atmospheric pressure, and cloudiness are required elements for the water temperature model. These inputs are used to calculate the net heat flux for a water quality cell as the sum of heat flux density at the air-water interface, including: radiation fluxes (short- and long-wave), and surface fluxes (latent and sensible heat) and heat flux, and heat flux at the sediment-water interface. The net heat flux with the boundary and initial conditions and flow data allows simulation of the water temperature over time.

5.2.1 Water Quality Cells

The water quality cell is the computational element size for calculating water quality parameters, including temperature. By default, the cell size is set to the distance between hydraulic cross-sections. The advection-dispersion transport equations are calculated via a QUICKEST24 numerical scheme, so small cell size necessitate small delta-t for numeric stability. The cell size was balanced to set a small size, while maintaining an acceptable run-time. The minimum water quality cell size is set to a length of 2,000 feet.

5.2.2 Flow Data

Steady-state flowrates were considered for the calibration of the LA River temperature model. Input flowrates are listed in **Table 6**. Flowrates considered in the calibration process included the maximum dry-weather monthly, the average dry-weather monthly, and minimum dry-weather monthly. The calibration process utilized the average dry-weather monthly flowrates.

[23] https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%20Water%20Quality%20User's%20Manual-v6.4.1.pdf

[24] https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%20Water%20Quality%20Technical%20Reference-v6.4.1.pdf

Table 6. Flow boundary conditions in the Los Angeles River water temperature model

Description	Model Node	Dry Weather Monthly Flows (cfs)			Source	Notes
		Maximum	Average	Minimum		
Lake Balboa Spillway	1045	21.15	15.95	5.99	Observed flow data	Annual average flow data to determine percentage of effluent discharge goes to discharge point and then multiplied by effluent flow in May-September, 2020-2023
LA River at Balboa	242590.8	69.00	12.09	6.00	Observed flow data	RSW-LATT612(I) from May-September, 2020-2023
LA River downstream of Hayvenhurst Channel	233484.6	90.15	28.04	11.99	Computed	---
Wildlife Lake Spillway	1974	6.90	5.21	1.96	Observed flow data	Used annual average flow data to determine percentage of effluent discharge goes to discharge point and then multiplied by effluent flow in May-September, 2020-2023
LA River below Haskell Flood Control Channel	227201	97.05	33.25	13.95	Computed	---
DCTWRP EFF-008	9049	15.11	11.39	4.28	Observed flow data	Used annual average flow data to determine percentage of effluent discharge goes to discharge point and then multiplied by effluent flow in May-September, 2020-2023
LA River at Sepulveda	225498	112.16	44.64	18.23	Computed	---
BWC	13000	11.00	1.17	0.02	Observed flow data	Data from May-September, 2020-2023
BWRP Discharge	1289	7.63	3.24	0.36	Observed flow data	Data from May-September, 2020-2023
BWC	12500	18.63	4.41	0.38	Computed	---
LA River downstream BWC	168989.7	130.79	49.05	18.61	Computed	---
LAGWRP Discharge	1364	17.17	9.79	4.64	Observed flow data	Data from May-September, 2020-2023

Description	Model Node	Dry Weather Monthly Flows (cfs)			Source	Notes
		Maximum	Average	Minimum		
LA River downstream LAG	156292.5	147.96	58.84	23.25	Computed	---
Rio Hondo	59077	431.00	61.59	0.01	Observed flow data	Whittier Dam Narrows (1 mile downstream) in May-September, 1967-2023
LA River below Rio Hondo	63900.3	578.96	120.43	23.26	Computed	---
Compton Creek	52494.08	94.50	0.73	0.01	Observed flow data	F37B-R (slightly downstream of cross section) in May-June, 2024
LA River Below Compton Creek	29266	673.46	121.16	23.27	Computed	---

5.2.3 Meteorological Data

The HEC-RAS water temperature model requires weather data, including atmospheric pressure, air temperature, humidity, shortwave radiation, cloudiness, and wind speed. These data were sourced from various agencies, such as National Oceanic and Atmospheric Administration (NOAA)[25], California Irrigation Management Information System (CIMIS)[26], and National Weather Service (NWR)[27]. The weather data were initially obtained on an hourly basis and then averaged into daily values. The weather data were obtained for 14 weather stations, as illustrated in **Figure 3A**. Gaps and missing data were addressed by employing linear correlations with the nearest stations among these 14 weather stations and interpolating the missing values based on a time series analysis. Finally, the weather data from 8 weather stations were utilized for HEC-RAS from 14 weather stations due to their continuous and long-term records, as depicted in **Figure 3B**. The approximate weather station location and coverage of the LA River and tributaries considered in the temperature model are presented in **Figure 4**.

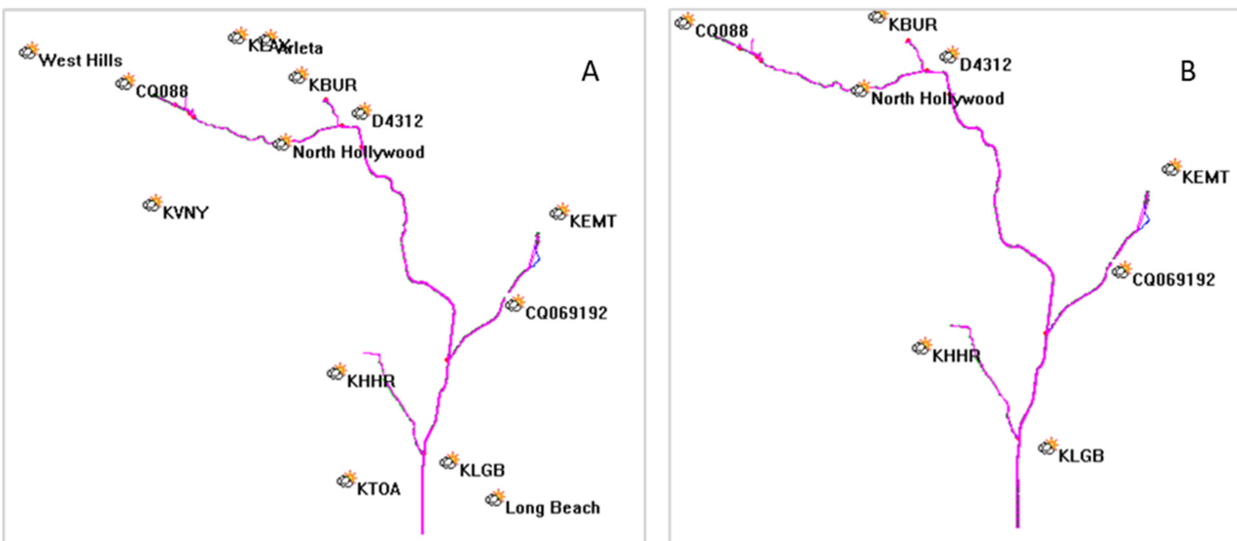

Figure 3. 14 weather stations considered in the HEC-RAS water temperature model

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[25] https://www.ncei.noaa.gov/cdo-web/
[26] https://cimis.water.ca.gov/WSNReportCriteria.aspx
[27] https://www.weather.gov/lox/observations_historical

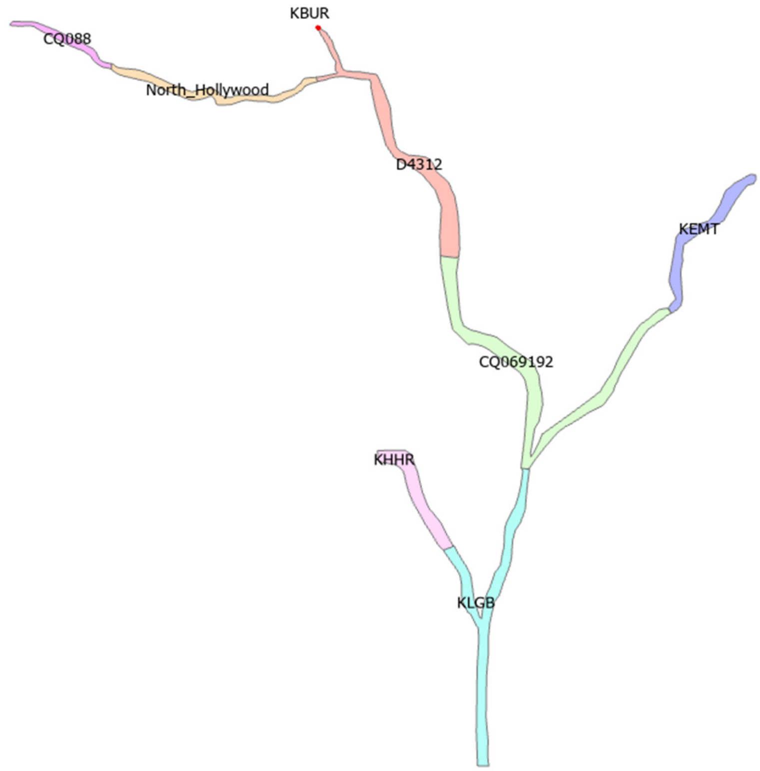

Figure 4. Weather station coverage of the LA River and tributaries

5.2.4 Water Temperature Data

Long term daily water temperature data at the WRPs were obtained from the California Integrated Water Quality System Project[28] (CIWQS) data management website. These data generally include upstream and downstream receiving water temperatures with the effluent temperature. Since the water temperature data at WRPs have daily time steps, the weather time series data were aggregated to daily and integrated into HEC-RAS. Studies by Mongolo et al. (2017)[29] and Heal the Bay measured hourly water temperature at various locations along the LA River. While these data covered the LA River, the length of data collection were limited and not all sites were collected concurrently. These datasets embody the available receiving water temperature data prior to this study.

To bolster the available data, continuous (every 30 minutes) diel (24-hour) ambient water temperature data was collected May through October 2024 at 16 receiving water locations in LA River Reaches 3, 4, and 5; above and below WRP outfalls; and four WRP discharge locations. Six stations were located in LA River

[28] https://ciwqs.waterboards.ca.gov/ciwqs/readOnly/CiwqsReportServlet?inCommand=reset&reportName=esmrAnalytical

[29] Mongolo, Jennifer, Nina Trusso, Rosi Dagit, Andres Aguilar, and Sabrina L. Drill. 2017. "A Longitudinal Temperature Profile of the Los Angeles River from June through October 2016." *Bulletin, Southern California Academy of Sciences* 116 (3): 174–92. https://doi.org/10.3160/soca-116-03-174-192.1

Reaches 4 and 5, as well as one each in the spillways of Lake Balboa and Wildlife Lake, to evaluate thermal conditions upstream and downstream of the DCTWRP discharge. Five stations were located in the BWC and LA River Reaches 3 and 4 to evaluate the thermal influence of the BWRP discharge on the BWC and the LA River. Five stations were in Reaches 2 and 3 to evaluate the thermal influence of the LAGWRP discharge on the LA River. The combined datasets of daily water temperature data from the sources listed above were used to establish the boundary conditions for water temperature within the HEC-RAS model. The sites with available water temperature are shown on **Figure 5**. However, not all sites were active concurrently, providing a patchwork of available data over time. Details of data used for calibration are discussed in **Section 5.2.5**.

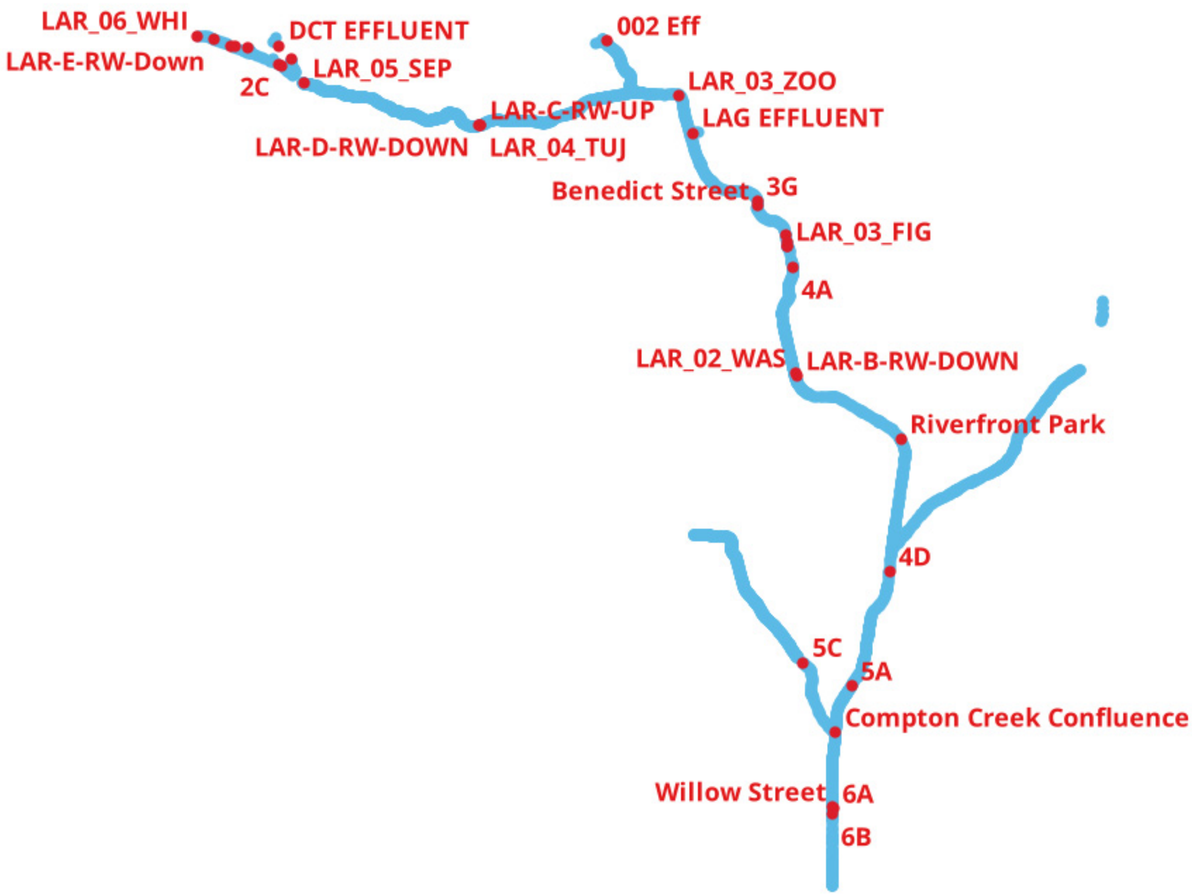

Figure 5. Locations of combined available water temperature data sourced from Heal The Bay and California Integrated Water Quality System Project (CIWQS)

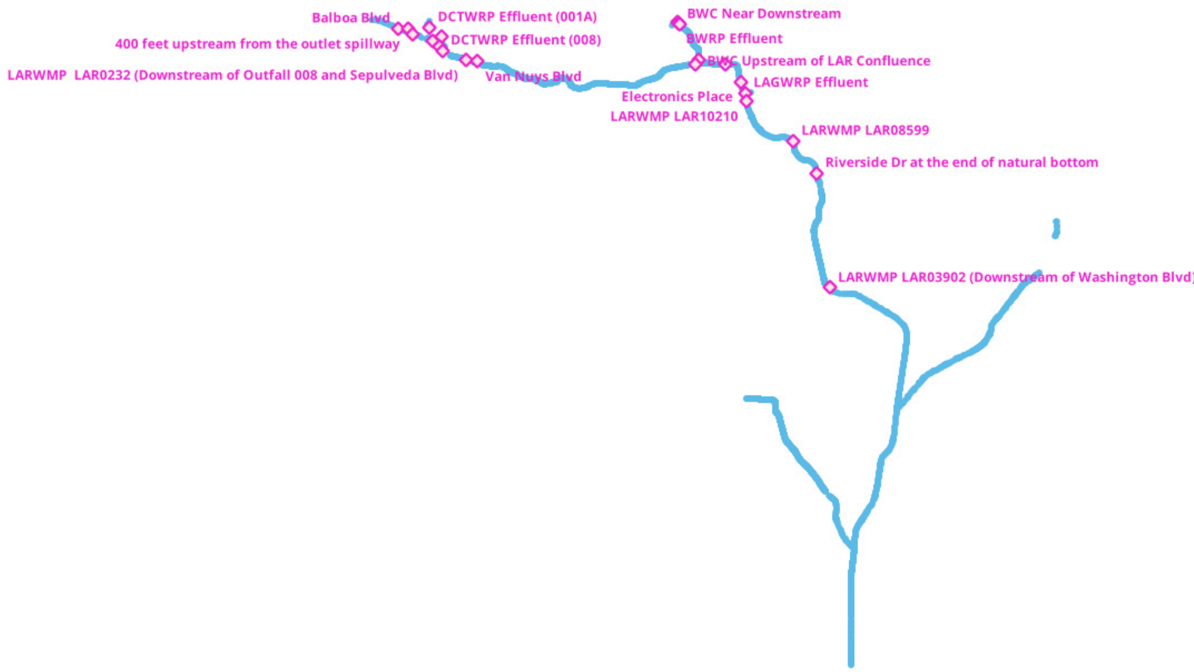

Figure 6. Locations of thermistors measuring water temperature data along the LA River and Burbank Western Channel between April and October 2024

5.2.5 Calibration

The calibration of the HEC-RAS water temperature model included two stages: the initial calibration and the re-calibration to obtain a final calibration.

5.2.5.1 Initial calibration

The initial calibration involved fine-tuning several key parameters: correction coefficients (day_coef and night_coef) in the short-wave solar radiation equations, wind coefficients in the HEC-RAS wind function (wind_a, wind_b, wind_c), and the diffusivity ratio (wind_kh_kw). Additionally, seasonal correction coefficients on short-wave solar radiation (monthly correction coefficients) were evaluated, but this approach was unsuccessful in that the calibration was not improved over using constant values. However, this approach may result in better calibration if long term high frequency data were available to capture seasonality with the monitoring data. The adjustment of short-wave solar radiation (SWR) was similar to an approach USGS adopted[30] in the following equations.

[30] Stonewall, Adam J., and Norman L. Buccola. 2015. "Development of a HEC-RAS Temperature Model for the North Santiam River, Northwestern Oregon." 2015–1006. *Open-File Report*. U.S. Geological Survey. https://doi.org/10.3133/ofr20151006.

$$If\ SWR < 110, SWR = 110 \quad (1)$$

$$If\ T_{SWR} < 15{:}00, SWR = SWR * day\_coef \quad (2)$$

$$If\ T_{SWR} \geq 15{:}00, SWR = SWR * night\_coef \quad (3)$$

where:

SWR is short-wave solar radiation (watts per square meter or W/m^2)

T_{SWR} is the measurement time of the short-wave solar radiation using a 24-hour clock (midnight is 00:00)

The value of day_coef is higher than night_coef because short-wave solar radiation during the day (before 15:00) is stronger than at night (after 15:00). Values of day_coef and night_coef greater than 1 indicate an increase in short-wave solar radiation, which results in higher water temperatures, and vice versa. The wind coefficients in the HEC-RAS wind function and the diffusivity ratio has recommended range of 0 to 10. Larger values for these coefficients and the diffusivity ratio suggest a decrease in water temperature, while smaller values increase temperatures. The initial calibration was conducted over 15 potential model parameterizations. The selected model had the best performance of metrics which include the smallest values of root mean squared error (RMSE), mean absolute error (MAE), mean absolute percentage error (MAPE); and the highest coefficient of determination (r^2).

Water temperature data at the available sites have data gaps as presented in **Figure 7**, where each row is a specific site and dots correspond to available data. Initially, linear correlations were used with the nearest sites to fill these gaps. The remaining gaps were addressed by applying linear correlations with local air temperature stations. Time series interpolation was used to fill the remaining gaps. Finally, the selected sites and available water temperature data for the modeling are shown on **Figure 8**. However, there are still some days with missing data due to the absence of corresponding weather data and the lack of temperature data from the nearest stations on those days. Lack of consistent, congruent temperature data were a limitation to the calibration process. However, the MAE was 1.7°C and the MAPE was 8% indicating a "good" calibration based on modeling guidelines developed by the Regional Board[31].

[31] Los Angeles Regional Water Quality Control Board (LARWQCB). 2014. Guidelines for Conducting Reasonable Assurance Analysis in a Watershed Management Program, Including an Enhanced Watershed Management Program.

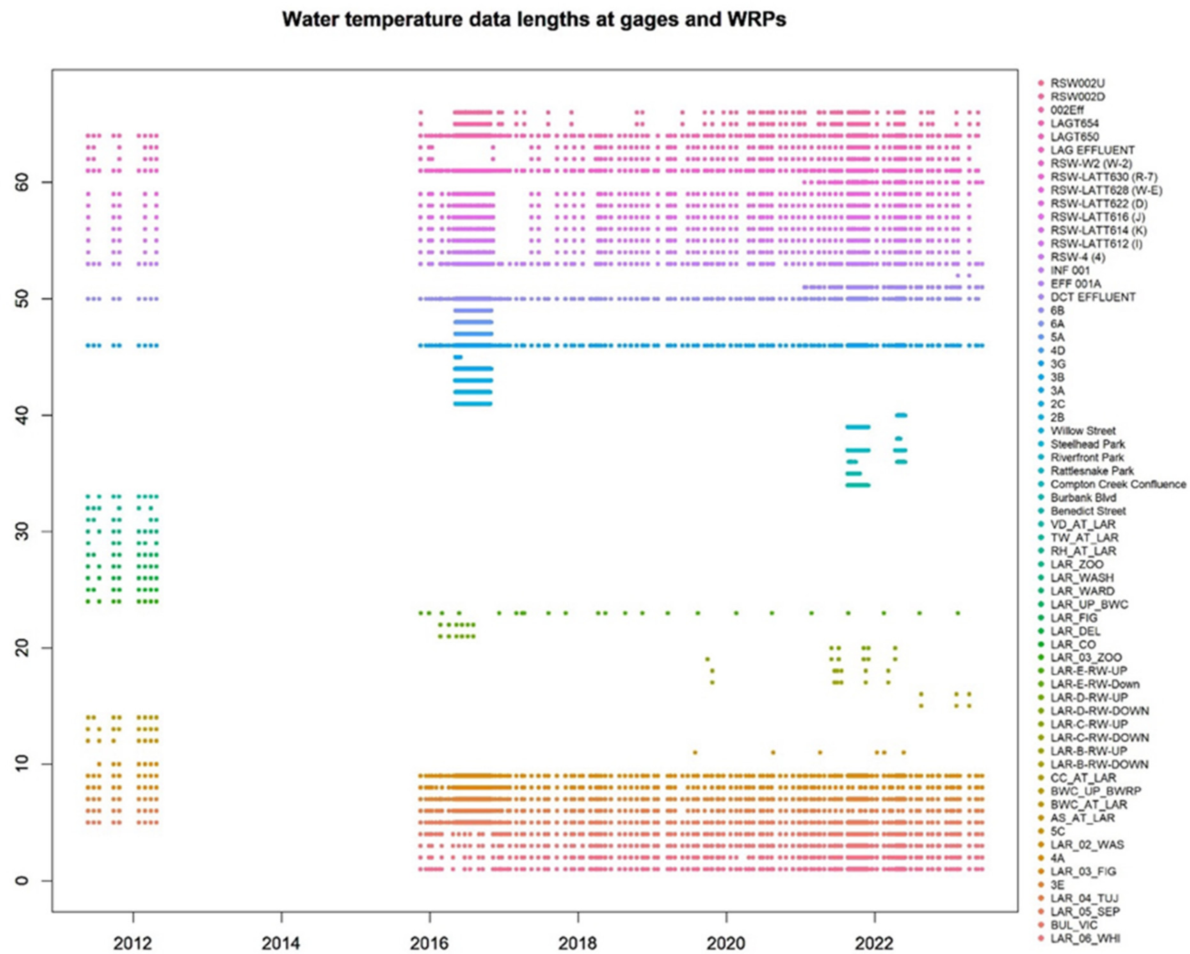

Figure 7. Water temperature data availability. Gaps indicate data not available gages

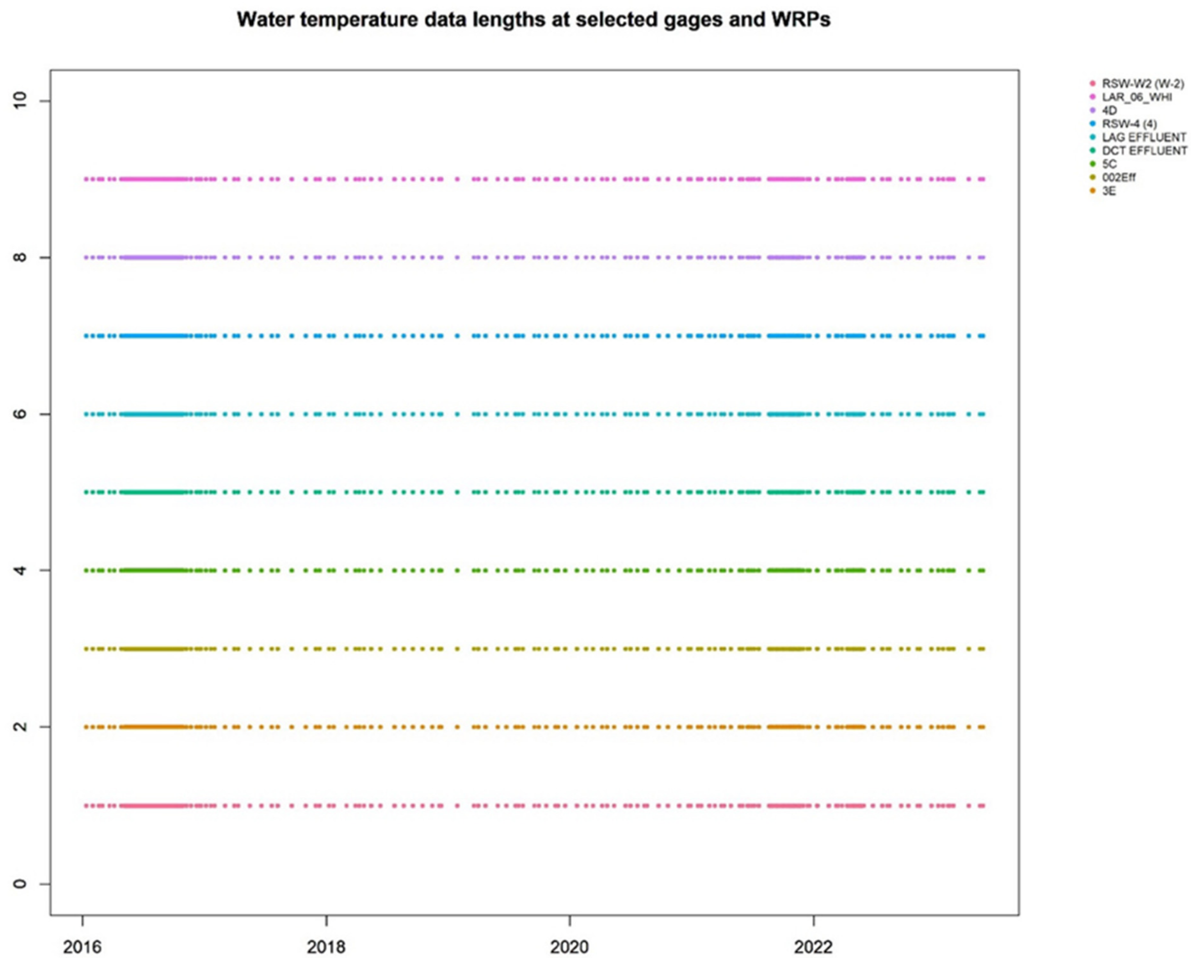

Figure 8. Water temperature data gaps at selected gages and WRPs after linear correlation and interpolation in the initial calibration

5.2.5.2 Final Calibration

Recent and continuous water temperature data were measured from newly installed thermistors along the LA River. These data were used to enhance the HEC-RAS water temperature model calibration. Thermistors from different sites have different start dates of measurement in April 2024. Thermistor water temperature data were used to complete the boundary conditions providing a continuous input data set. In **Figure 8**, the observed data gaps in the WRPs and gages used as boundary conditions in the HEC-RAS water temperature model in the initial calibration were filled and water temperature data were continuous in the final calibration (**Figure 10**). This advantage of continuous data in boundary conditions helps improve the final calibration of the model. **Appendix A** presents additional details on the boundary conditions in the model.

To re-calibrate the HEC-RAS water temperature model, the consistent time-period among thermistors from the different sites was used: May 1, 2024 to October 30, 2024. In the final calibration, wind coefficients ("wind_a", "wind_b", "wind_c", "wind_kh_kw") and solar radiation values of downstream weather stations were modified in model trials 16 to 30 (**Table 7**). When "downstream_soleqn" is True (T), the solar radiation of weather stations of D4312 and CQ069192 are multiplied with "downstream_soleqn_coef". In models 16 to 30, values of RMSE, MAE, MAPE, and r^2 between predicted and observed water temperature at thermistor sites were computed in the period of May 1, 2024 to October 30,2024. The optimal model was selected so that the means of RMSE, MAE, MAPE values was the lowest and the mean of r^2 values is the highest. Moreover, the selected optimal model required satisfactory performance at the downstream thermistors to avoid the accumulation of errors when moving downstream of LA River (**Table 8** and **Figure 11**). Model 28 was selected over of model 19 to ensure consistent results over the length of the river despite these two models having comparable performances based on mean values of RMSE, MAE, MAPE, and r^2 from just the thermistor sites (**Table 7**). The calibrated model receiving water temperatures are generally within 1.2^oC and under 5% of the observed values indicating a "very good" calibration as described in guidelines for modeling developed by the Regional Board[32].

While the calibration is very good over the range of conditions experienced in the study area, during periods of extremely high air temperatures (i.e., >100^0F) the model tends to overpredict the water temperature. However, for the bulk of summer days, which do not have extremely high air temperatures, the model predictions represent the measured receiving water temperatures well. The primary use case of the model is to investigate the modeled receiving water temperature response to control measures compared to modeled baseline conditions. Under some modeling circumstances, a post-processing "correction factor' may be applied to the predicted receiving water temperatures. For this use case, application of a correction factor to the model output would be applied to both baseline and control measure/scenario model runs, essentially cancelling itself out. Ultimately, the model would retain the observed behavior of water temperature returning to baseline conditions downstream of the applied control measure.

[32] Los Angeles Regional Water Quality Control Board (LARWQCB). 2014. Guidelines for Conducting Reasonable Assurance Analysis in a Watershed Management Program, Including an Enhanced Watershed Management Program.

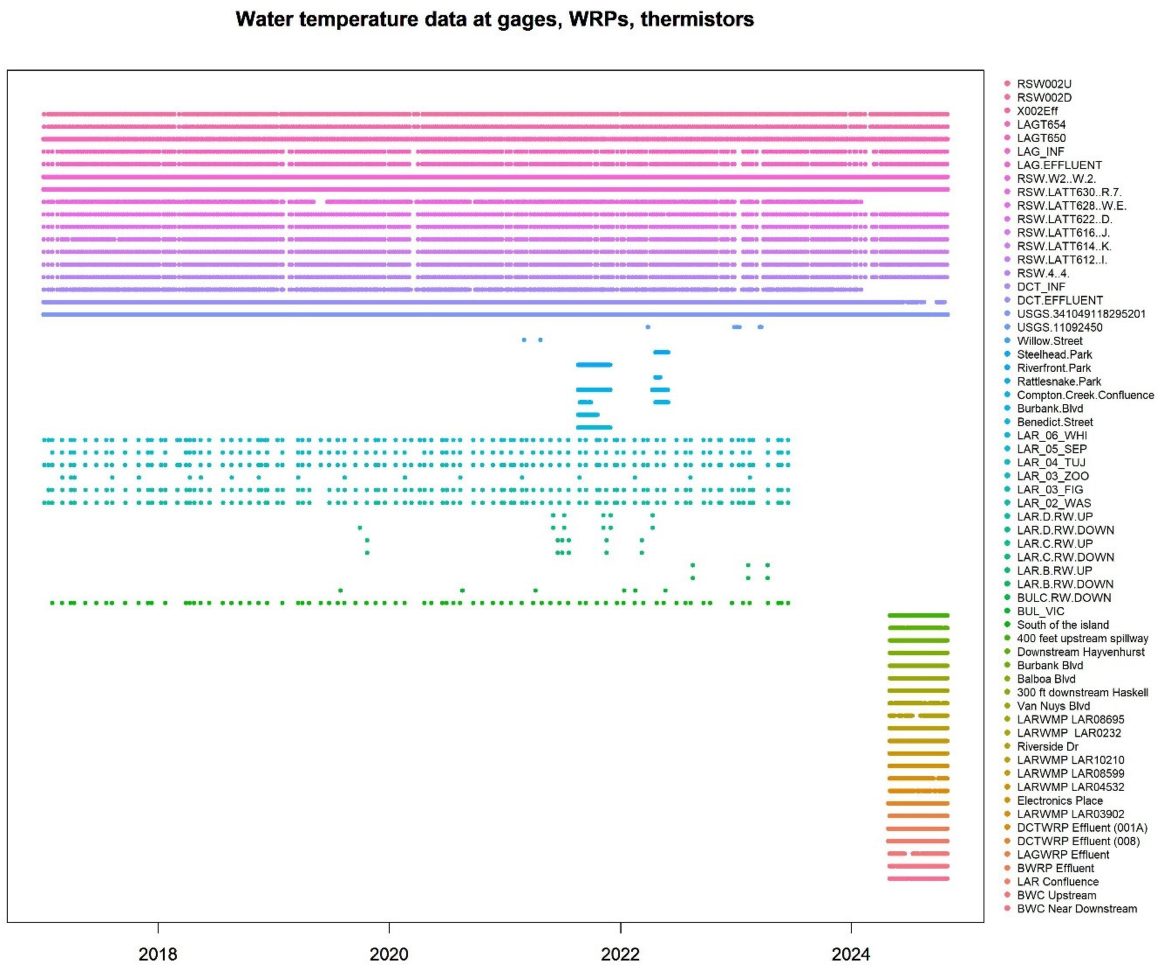

Figure 9. Water temperature data gaps at all available gages, WRPs, and continuous newly installed thermistors

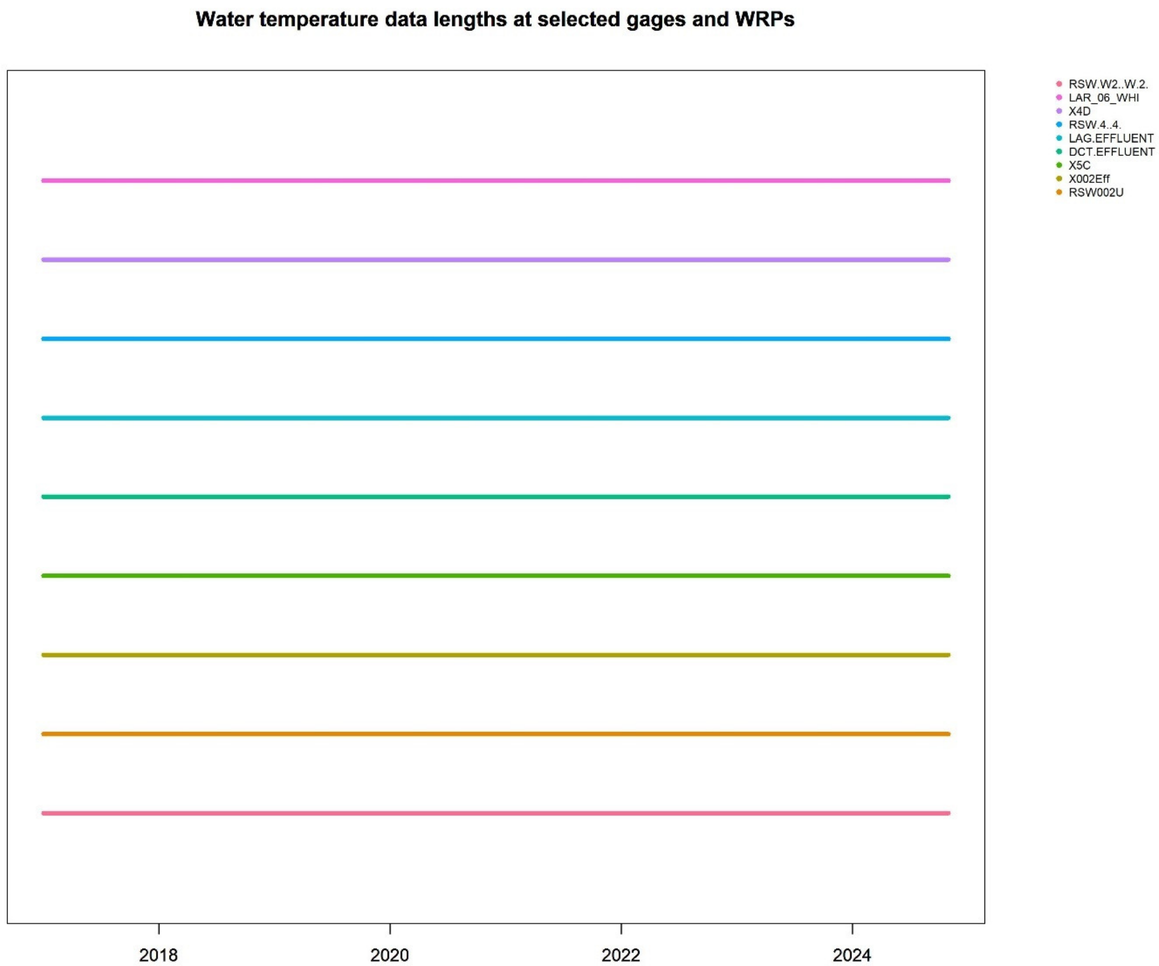

Figure 10. Water temperature data gaps at selected gages, WRPs, and continuous newly installed thermistors after linear correlation and interpolation in the re-calibration

Table 7. Parameter sets for final calibration of Los Angeles River water temperature model
***Bold** numbers represent the best performance. The selected optimal model is model 28.*

Parameters	Baseline	Calibration Run															
		7*	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
wind_a	9.2	1	1	1	2	1	1	2	5	3	3	3	3	3	3	3	3
wind_b	4.6	2	2	2	2	3	2	3	4	4	2	2	2	2	2	2	2
wind_c	2	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1
wind_kh_kw	1	0.5	0.5	1	0.5	0.5	0.5	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5
day_coef	1	1.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
night_coef	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
downstream_soleqn	F	F	F	F	F	F	F	F	F	F	F	F	F	T	T	T	T
downstream_soleqn_coef														2	1.7	1.5	1.6
soleqn	F	T	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
soleqn_hourly	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
soleqn_min110	T	T	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
RMSE (deg. C)	4.9	2.2	1.5	1.5	1.6	**1.5**	1.8	1.7	2.5	2.1	1.9	1.8	1.8	1.8	**1.5**	1.5	1.5
MAE (deg. C)	4.4	1.7	1.2	1.2	1.2	**1.2**	1.5	1.4	2.1	1.8	1.6	1.5	1.5	1.5	**1.2**	1.2	1.2
MAPE (%)	18.3	7.9	5.0	5.1	5.3	**4.9**	6.2	5.9	9.0	7.5	6.6	6.1	6.3	6.4	**4.9**	5.2	5.0
R2	0.8	0.8	0.8	0.8	0.9	**0.8**	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	**0.8**	0.8	0.8

Table 8. MAE values between predicted and observed water temperature for receiving water thermistor sites for calibration run 19 and 28

Thermistor Site	MAE values in Calibration Run (°C)	
	19	28[1]
Balboa Blvd	1.6	1.2
LAR downstream of Hayvenhurst Channel	1.4	1.1
Burbank Blvd	1.0	1.3
300 ft downstream of the Haskell Flood Control Channel	1.1	1.0
LARWMP LAR0232 (Downstream of Outfall 008 and Sepulveda Blvd)	1.0	1.5
Van Nuys Blvd	1.1	0.9
LARWMP LAR08695 (Upstream of BWC Confluence)	1.2	1.4
BWC Near Downstream	1.1	1.2
BWC Upstream of LAR Confluence	1.6	1.8
LARWMP LAR04532 (Downstream of BWC Confluence)	1.6	1.6
Electronics Place	1.7	1.7
LARWMP LAR10210	1.7	1.8
LARWMP LAR08599	1.8	1.8
Riverside Dr at the end of natural bottom	1.8	1.7
LARWMP LAR03902 (Downstream of Washington Blvd)	1.6	1.1

1. Model 28 selected for overall best performance

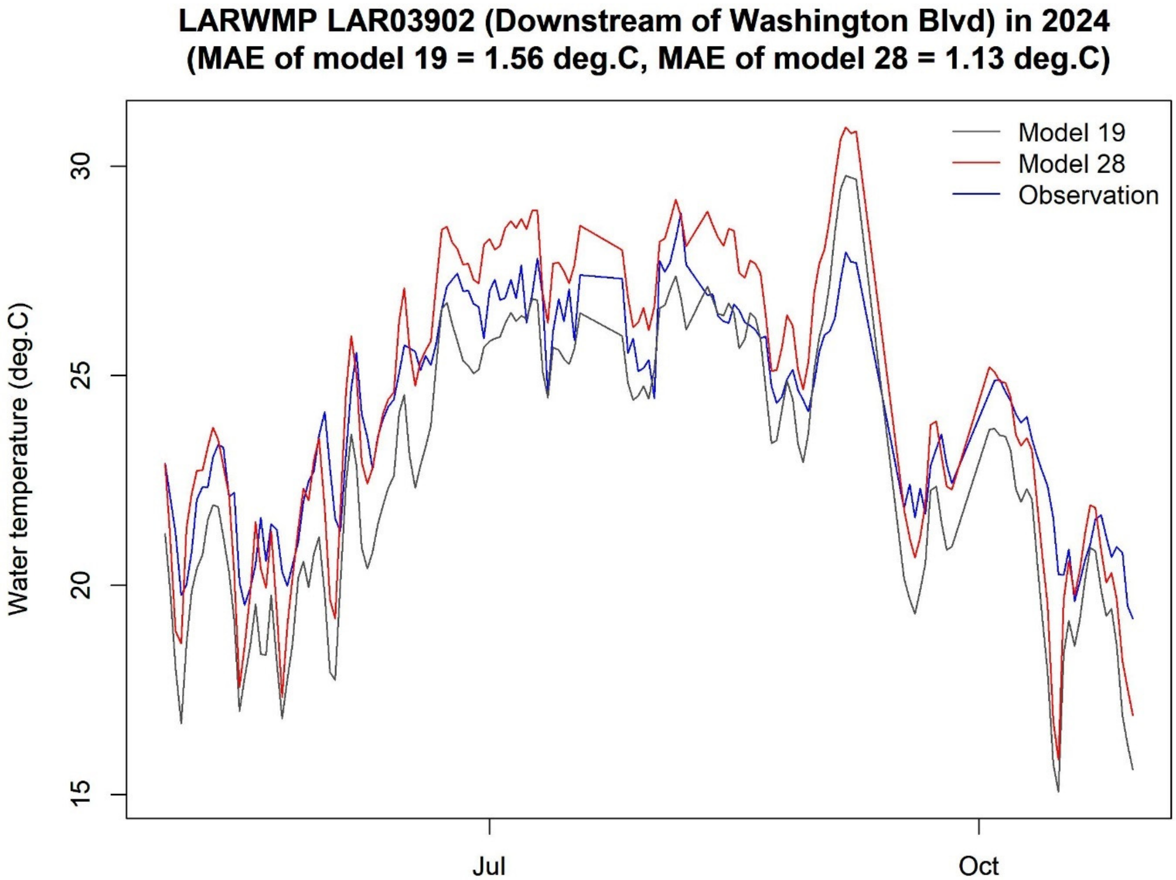

Figure 11. Comparison between time series of predicted and observed water temperature in thermistor site "Balboa Blvd" in 2024 for model 19 and model 28 (selected optimal model)

SECTION 6 POTENTIAL CONTROL MEASURES

The following three potential control measures were identified to control the effect of WRP discharge temperature on the temperatures in the LA River and the BWC: effluent temperature reduction, effluent flowrate reduction, and riparian shading. The following subsections present the results of the evaluation of potential control measures.

6.1 Effluent Temperature Reduction

The effluent temperature reduction control measure seeks to ensure the WRP discharges are compliant with the temperature limits identified in their NPDES permits (i.e., effluent temperatures are not more than 80°F and receiving waters are not raised by more than 5°F). The required monthly effluent temperature reductions are listed in **Table 9** for the three WRPs and are based on data from 2000 to 2024. The required reductions were determined monthly through a three-step process. First, where the effluent temperatures were greater than 80°F the reduction to reach 80°F was calculated. In the second step, the receiving water upstream and downstream were compared and where the measured difference was greater than 5°F, the reduction necessary to bring the effluent temperature to within 5°F of the upstream temperature was calculated. The last step was to select the greater required reduction. In the table the reductions necessary to meet the 80°F objective are shaded, and those necessary to meet the delta 5°F are unshaded. Note that for most months the temperature reductions are necessary to meet the delta 5°F objective.

Table 9. Required effluent temperature reduction to meet both the delta 5°F and maximum 80°F Basin Plan objective

Month	Temperature Reduction[1] (°F)		
	DCTWRP	LAGWRP	BWRP
January	29	29	33
February	29	30	37
March	23	22	29
April	26	24	29
May	14	19	22
June	13	6	24
July	9	7	20
August	11	8	18
September	14	7	24
October	24	35	25
November	30	34	35
December	32	34	33

1. Shaded cells correspond to reduction necessary to meet 80°F, non-shaded cells required reduction to meet the delta 5°F objective.

To conduct the modeling analysis of this potential control measure, effluent temperatures in the model were reduced so that the limits were met with all other conditions remaining constant (e.g., flow, air temperature, etc.). The modeled reduced effluent temperature from DCTWRP leads to water temperature reduction at Balboa and Wildlife Lakes' spillways, and DCTWRP Effluent 008 (downstream of DCTWRP Effluent to LA River). **Figure 12** presents a comparison of the baseline receiving water temperatures to the receiving water temperatures if the DCT's effluent temperatures were reduced to comply with the limits (i.e., effluent temperatures are not more than 80°F and receiving waters are not raised by more than 5°F). The figure represents temperatures on two example dates: January 9, 2024 and August 6, 2024. Time series of receiving water temperatures at select locations at and downstream of the DCTWRP are presented in **Figure 13**. The effect of cooled effluent on the receiving water temperature reduces as the flow moves downstream, typically persisting further downstream during cooler months than for warmer months. The location where the difference between receiving water temperatures with and without a control measure reduces to a negligible level (i.e., ± 1°F) defines the extent of the receiving water returning to baseline. The distance downstream where receiving water temperatures become negligibly different from baseline below the DCTWRP vary by season as follows:

- August: less than 1 mile from the discharge on average
- January: 10 miles on average

The receiving water temperature differential between upstream of the DCTWRP discharges and locations downstream are presented in **Figure 14** for both the current condition and with the modeled effluent cooling. As shown on **Figure 13** and **Figure 14**, the receiving water temperature exceeds 80°F at times upstream and downstream of the discharge. Additionally, the receiving water temperature downstream of the DCTWRP following the mixing of effluent increase by more than 5°F under both current conditions and with effluent cooling. It appears the WRP heat addition (baseline) or subtraction (effluent cooling control measure) is not as significant as the local meteorological conditions (air temperature and solar radiation) because the receiving water moves toward the same equilibrium temperature downstream of the discharge with or without cooling.

The BWC has a similar response downstream of the BWRP discharge. The receiving water temperature downstream of the BWRP discharge are presented as **Figure 15**. As with DCT, the effluent with cooled temperatures propagates further downstream in January, than it does when compared to August. However, looking at the time series of temperature response in the BWC after effluent cooling (**Figure 16**) the water temperature is negligibly different from the baseline as follows:

- August: within 2 miles from the discharge on average (upstream of the confluence with the LA River)
- January: approximately at the confluence of the LA River (2.7 miles downstream) on average

In all cases the temperature difference is eliminated downstream of the confluence with the LA River, as the larger river flow assimilates the channel flow. Under both the current condition and with the effluent cooling control measure, temperatures exceed 80°F downstream of BWRP. The temperature differential between the BWC upstream of the BWRP and at the BWRP discharge and points downstream is presented as **Figure 17**. The temperature difference of the receiving water upstream of the discharge and at locations downstream of the BWRP discharge are at times greater than 5°F under both the baseline and as modeled with the effluent cooling control measure, indicating that increases in receiving water temperatures of more than 5°F are caused by factors other than the BWRP's effluent.

The LA River downstream from the LAGWRP shows an even smaller response than either DCTWRP or BWRP, as the upstream flowrate is larger in comparison to the discharge flowrate. The receiving water temperatures downstream from LAGWRP are shown in **Figure 18** and the time series are shown in **Figure 19**. For the LAGWRP, the temperatures with and without cooling are negligibly different seasonally as follows:

- August: at the point of discharge on average
- January: within 2 miles downstream on average

At times the receiving water temperature upstream and downstream of the LAGWRP discharge is greater than 80°F. The temperature differential between the LAR upstream of LAGWRP and points downstream of LAGWRP is presented in **Figure 20**. At the point of discharge, the current condition approaches but does not exceed a delta 5°F. As the water continues downstream it begins to warm and approaches a 5°F differential 9 miles downstream for both current condition and with effluent cooling.

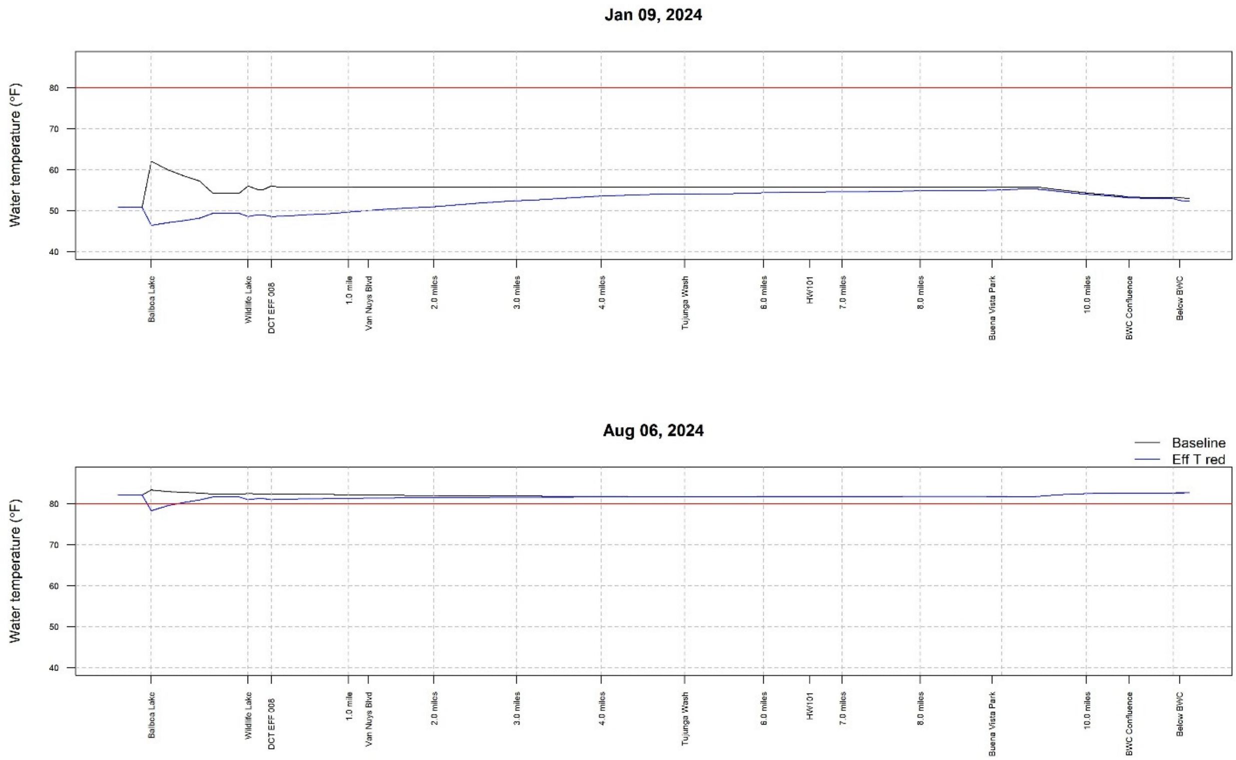

Figure 12. LA River temperatures at and downstream of the DCTWRP for current condition and with effluent cooling

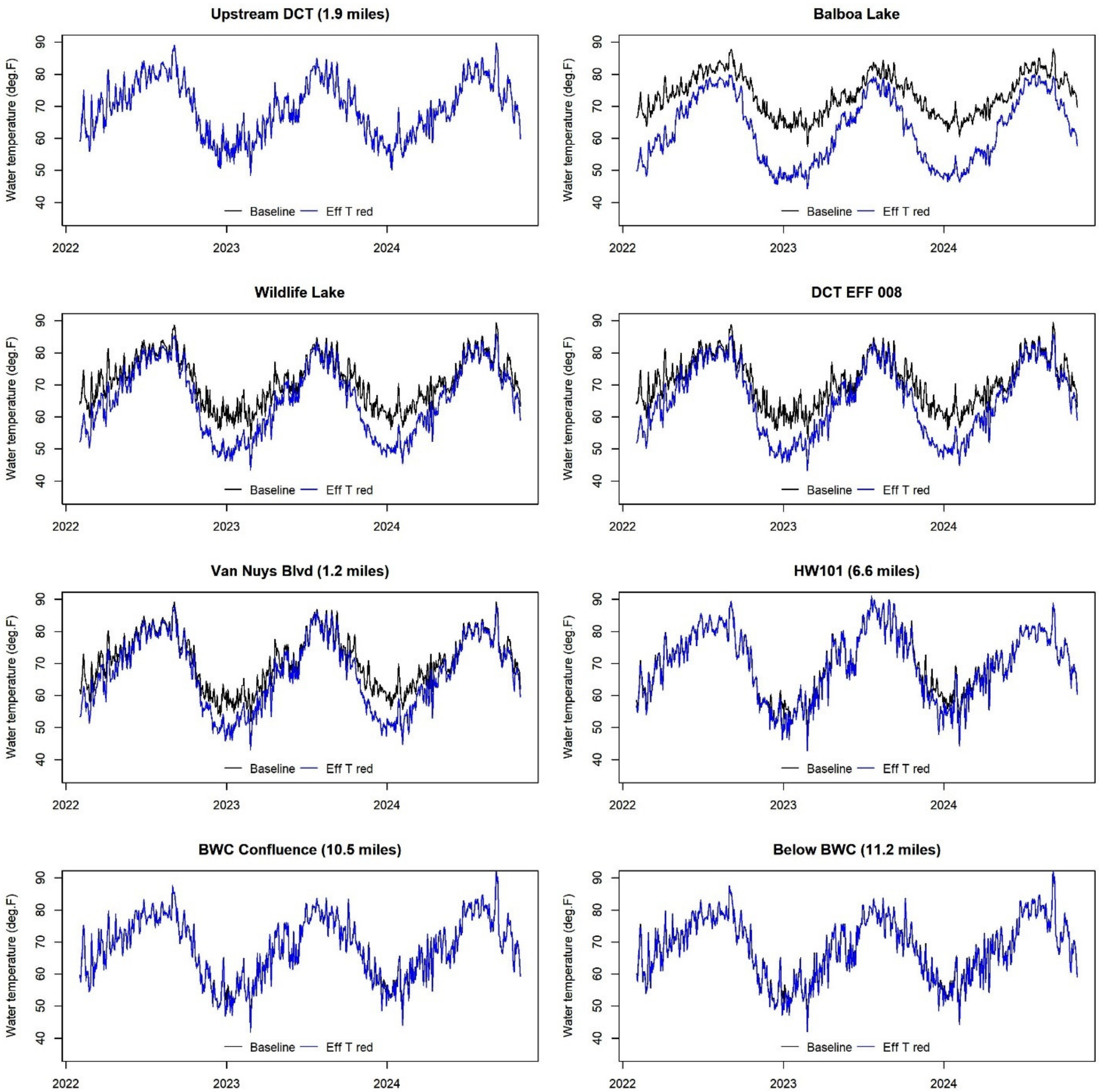

Figure 13. Time series of LA River temperatures for current conditions and with effluent cooling at select locations at and downstream of DCTWRP discharges

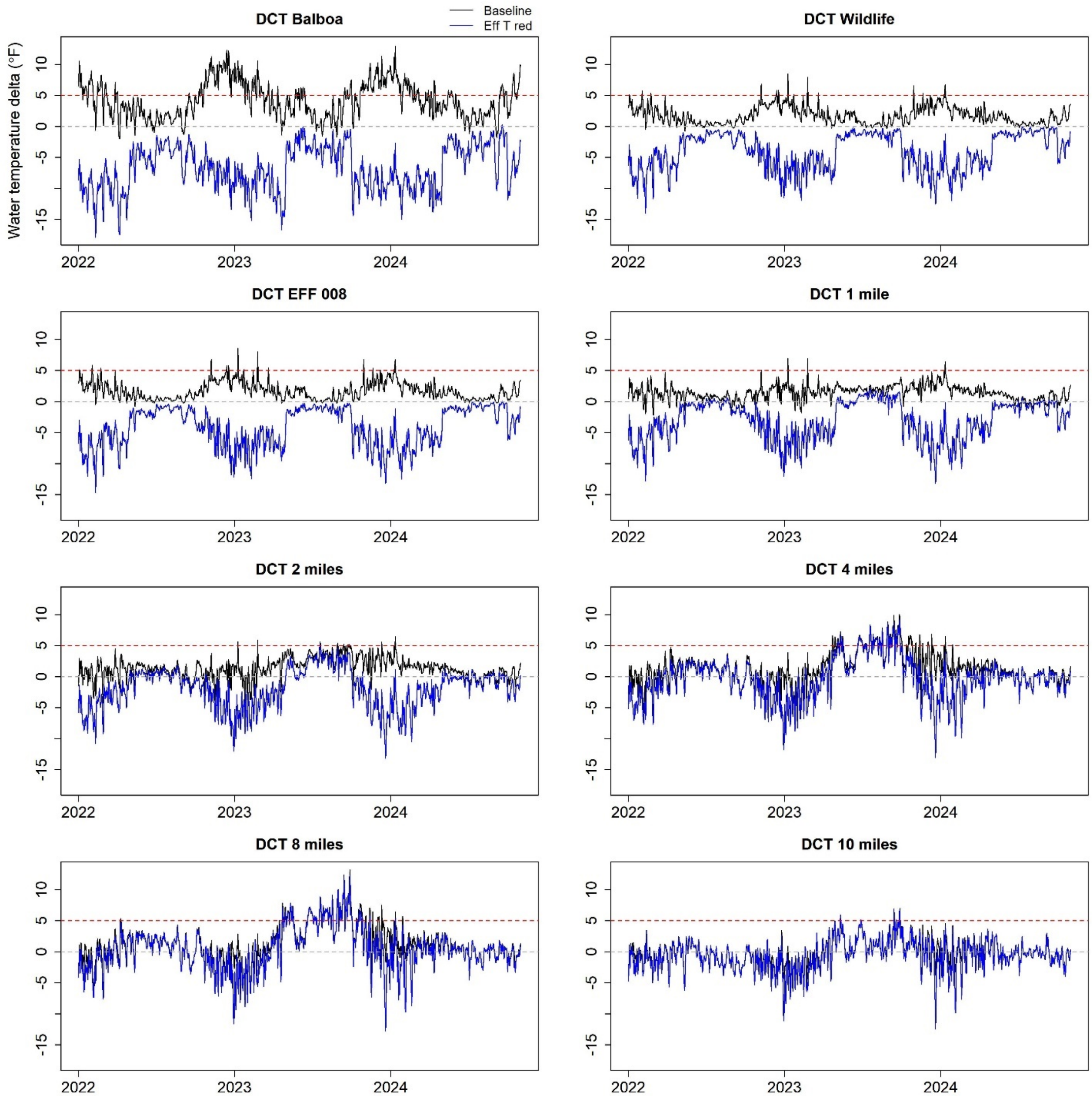

Figure 14. Temperature differential between LAR upstream of DCTWRP discharges and locations at and downstream of DCTWRP discharges

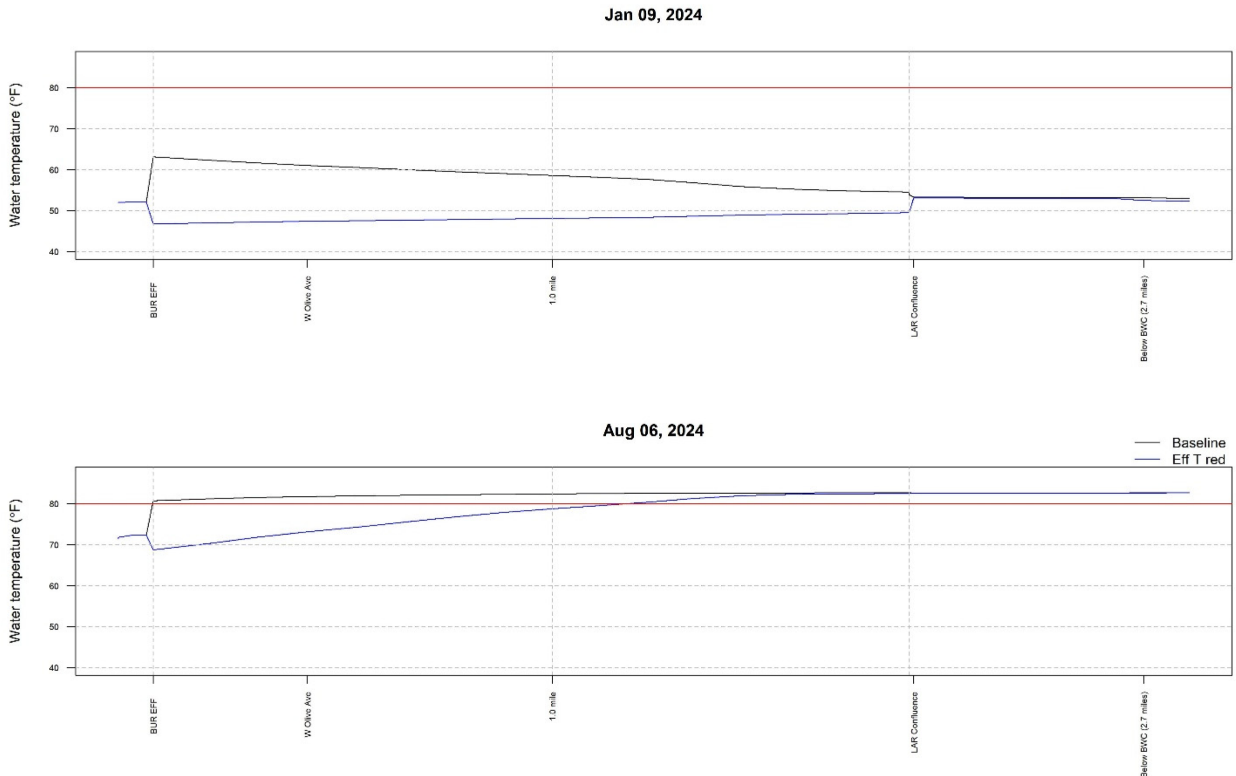

Figure 15. BWC temperatures for current conditions and with effluent cooling downstream of the BWRP

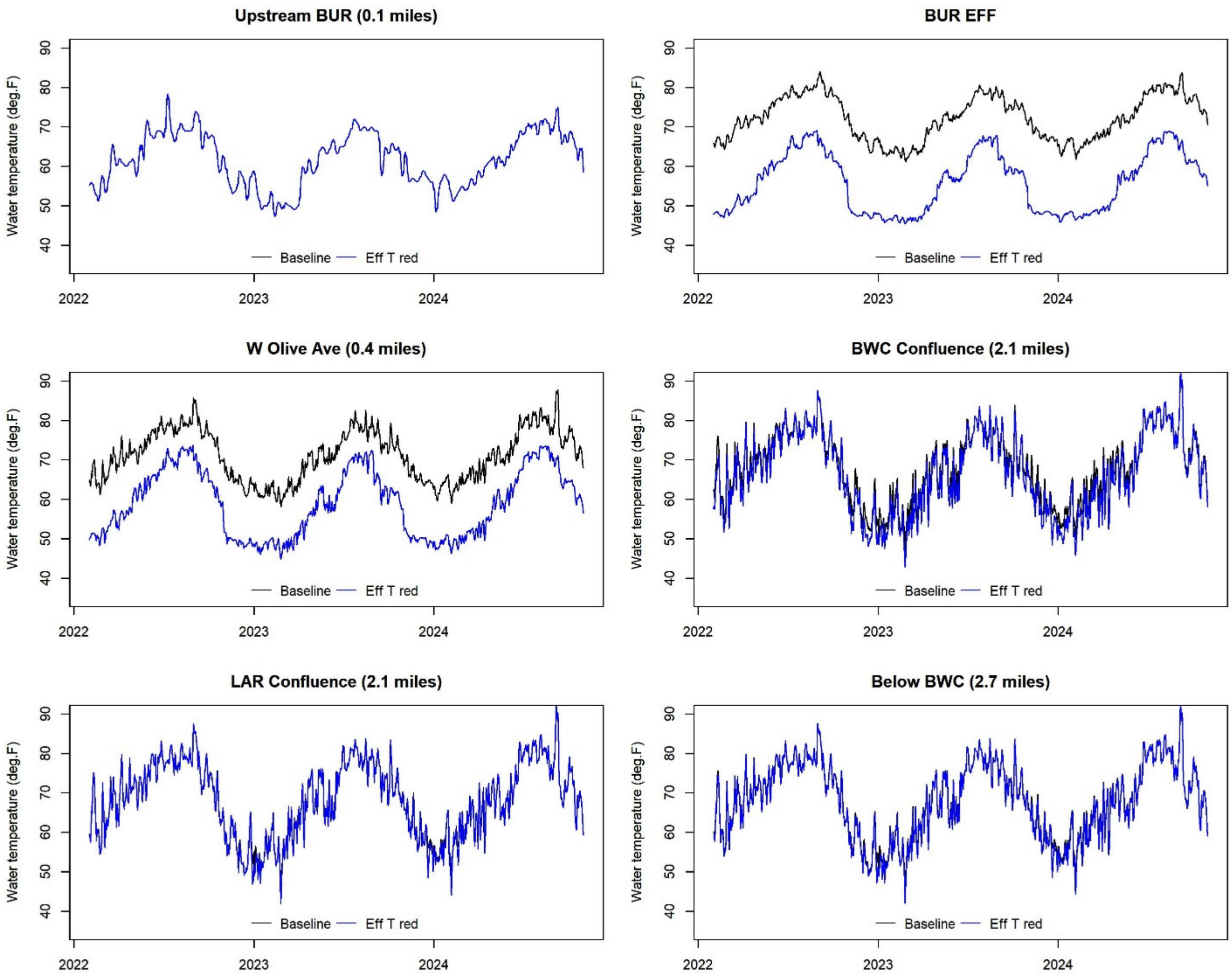

Figure 16. Time series of BWC temperatures for current conditions and with effluent cooling at select locations at and downstream of the BWRP

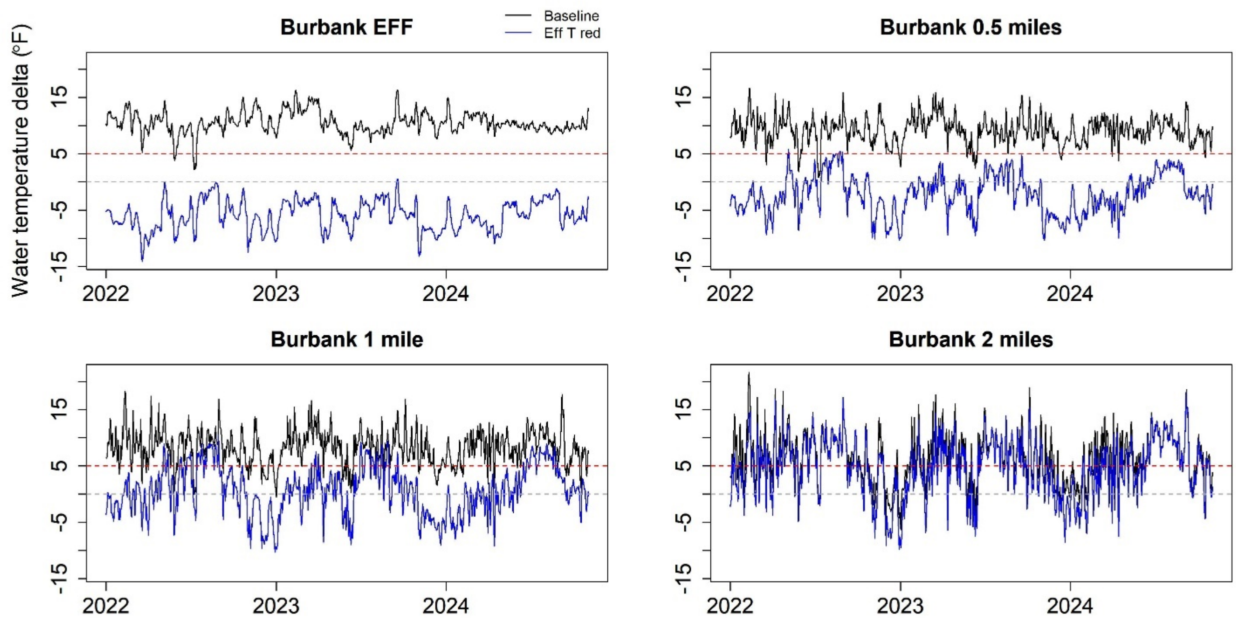

Figure 17. Temperature differential between BWC upstream of the BWRP and locations downstream

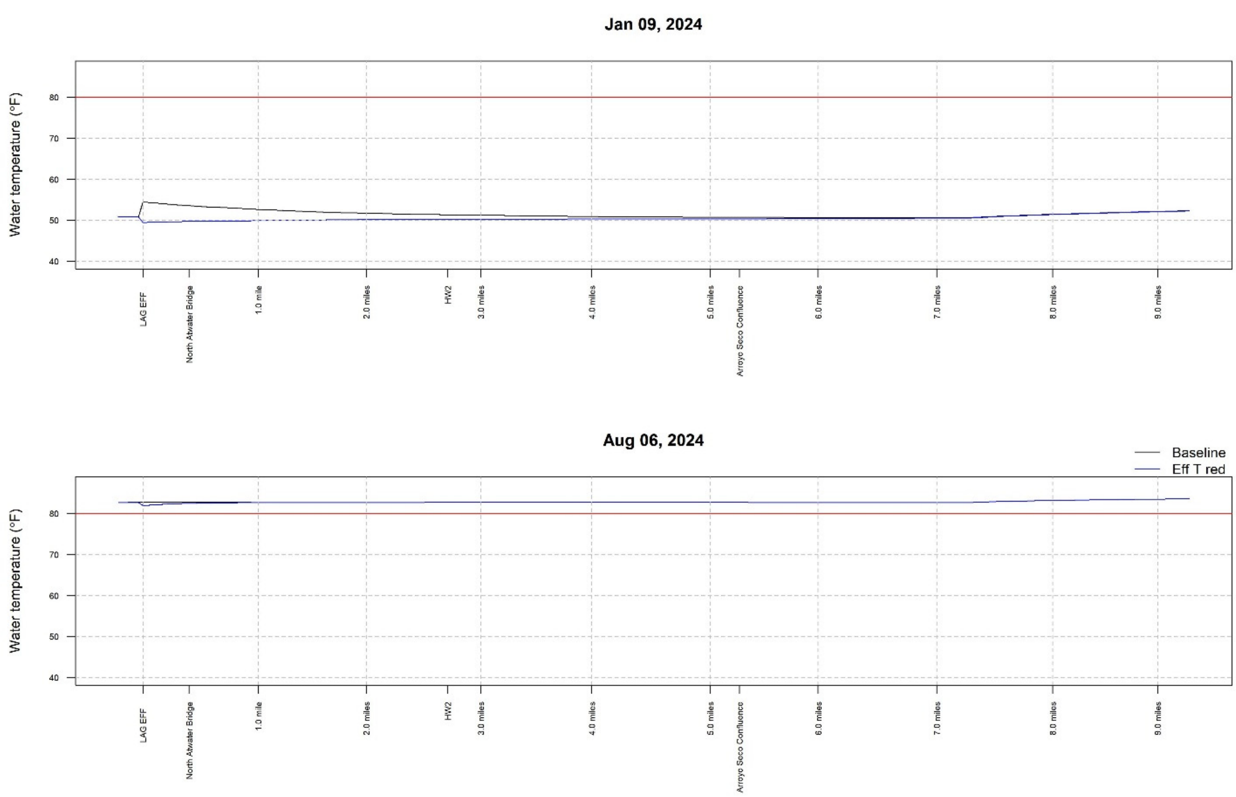

Figure 18. LA River temperatures at and downstream from the LAGWRP for current condition and with effluent cooling

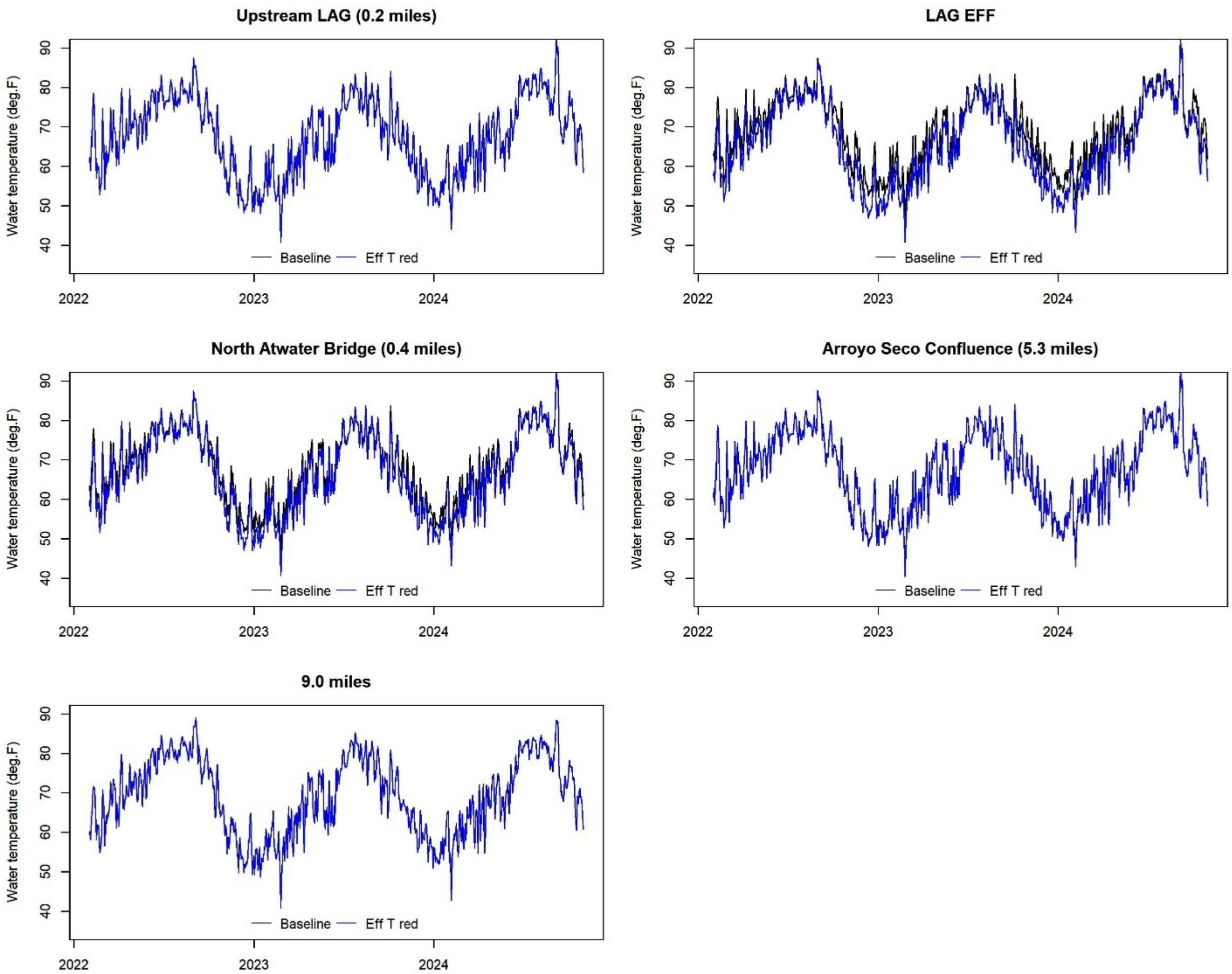

Figure 19. Time series of LA River temperatures for current conditions and with effluent cooling at select locations at and downstream of the LAGWRP

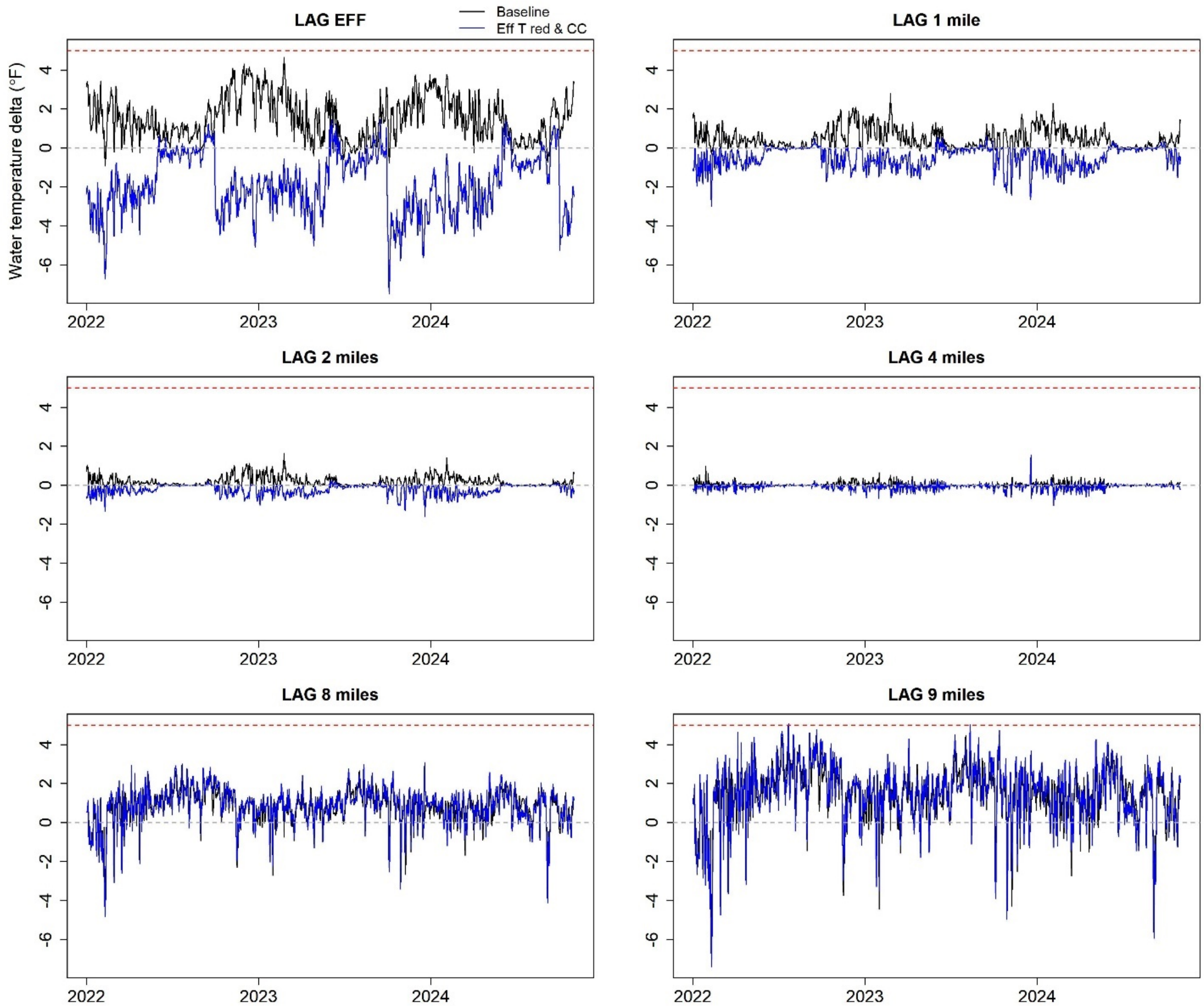

Figure 20. Temperature differential between LAR upstream of LAGWRP discharges and locations at and downstream of the discharge

6.2 Effluent Flowrate Reduction

When effluent flowrate is reduced, it reduces the impact of effluent heat compared to the LA River. If effluent flowrate is reduced, there will be a smaller change in receiving water temperature. To evaluate the effect of the reduced flowrate, the model was run using a 5, 10, 25, and 50 percent WRP flowrate reduction. Changes in receiving water temperatures in response to 5 percent flow reduction were exceedingly small. The 50 percent reduction case is presented below to illustrate the effect reducing effluent flowrates may have on receiving water temperatures. In general, there is a larger effect during colder months as the difference between effluent and receiving water temperatures is greater. In warmer months where effluent and river temperatures are similar, there is little effect from reducing the effluent flowrates.

Temperatures in the LA River downstream of DCTWRP for current flowrates and with a 50 percent reduction in flowrate are presented in **Figure 21**. The corresponding time series are presented in **Figure 22**. The distance downstream where receiving water temperatures become negligibly different from baseline below the DCTWRP vary by season as follows:

- August: at the point of discharge on average
- January: 4 miles on average

At times the receiving water temperature downstream from DCTWRP are 5°F greater than those upstream of the discharges for both current condition and with reduced flowrate.

BWC temperature downstream of BWRP, in response to a 50 percent reduction in discharge flowrate, are presented in **Figure 23**. Time series of receiving water temperatures at current discharge and at a 50 percent reduction are shown on **Figure 24**. The distance downstream where receiving water temperatures become negligibly different from baseline below the BWRP vary by season as follows:

- August: within 0.5 miles of discharge on average
- January: at the confluence of the LA River (2.7 miles downstream) on average

At times the receiving water temperature downstream from BWRP are 5°F greater than those upstream of the discharges for both current condition and with reduced flowrate.

The LA River downstream of LAGWRP shows a minimal response to decreasing the flowrate. The receiving water temperatures downstream from LAGWRP are presented in **Figure 25**. Time series of the temperatures at current flowrate and after a 50 percent reduction are shown on **Figure 26**. The distance downstream where receiving water temperatures become negligibly different from baseline below the LAGWRP vary by season as follows:

- August: at the point of discharge on average
- January: at the point of discharge on average

At the LAGWRP discharge, the current condition approaches but does not exceed delta 5°F. As the water continues downstream it begins to warm and approaches a 5°F differential approximately 9 miles downstream.

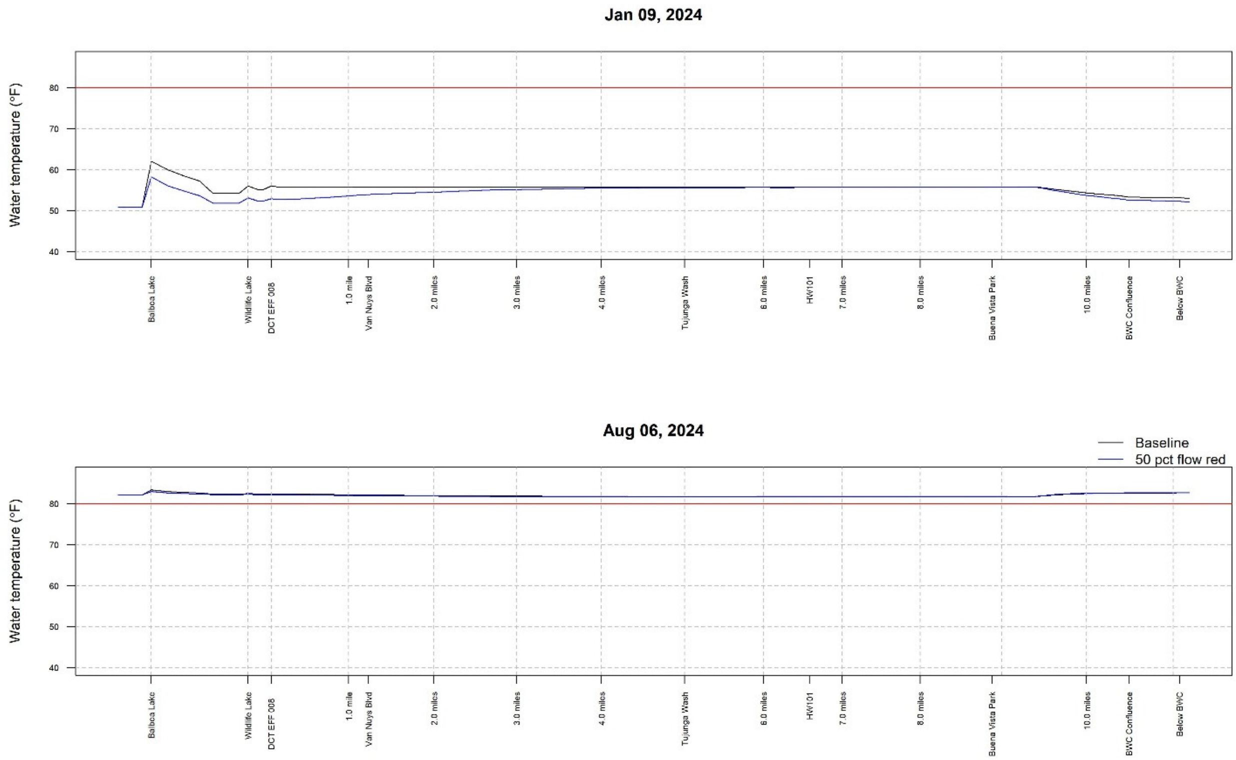

Figure 21. LA River temperatures downstream of the DCTWRP in response to a 50 percent reduction in discharge flowrate

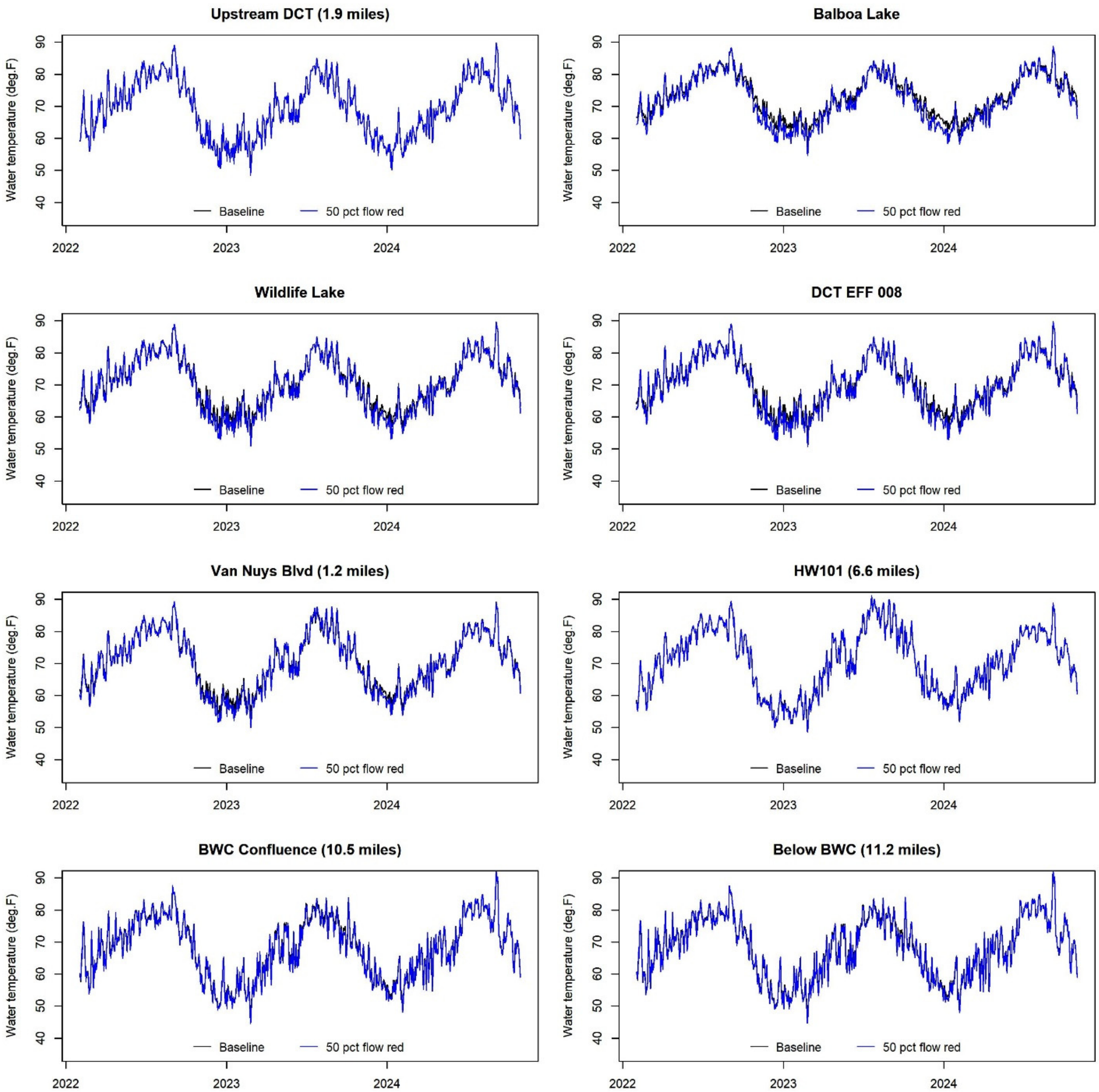

Figure 22. Time series of LA River temperatures downstream of the DCTWRP in response to reducing discharge flowrate by 50 percent

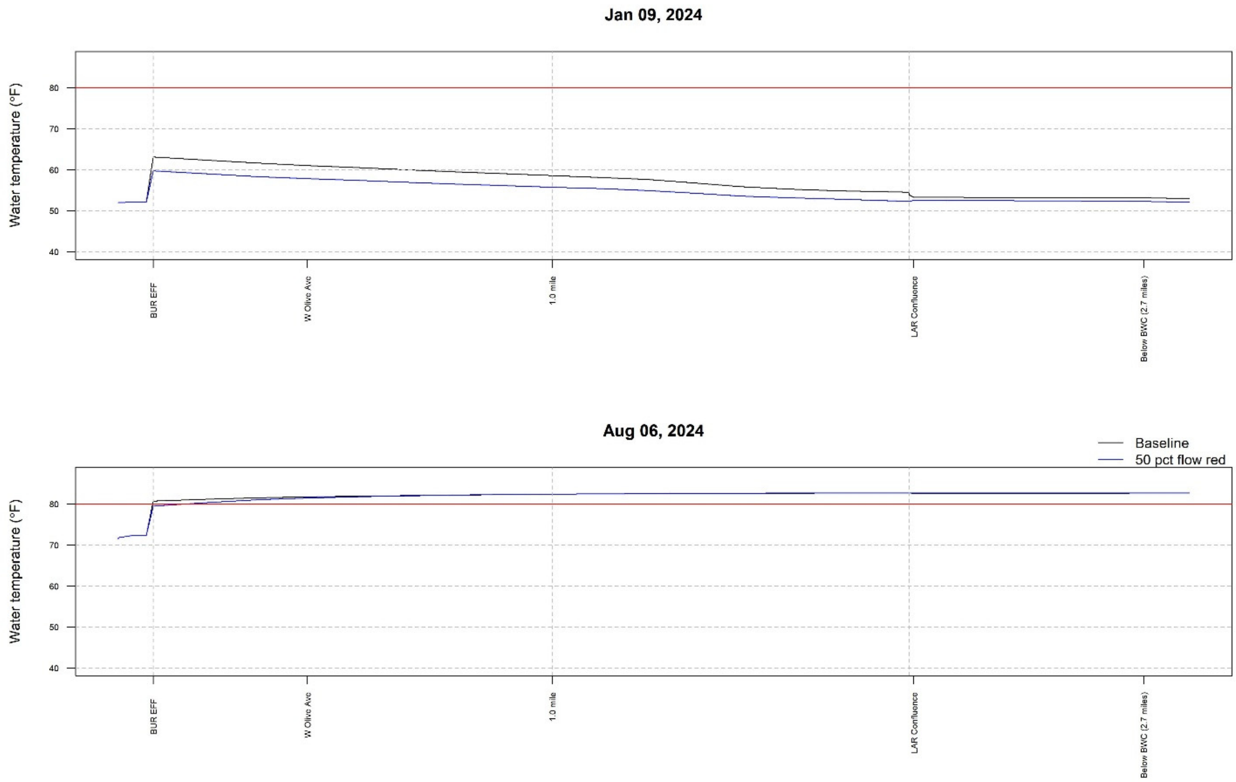

Figure 23. BWC temperatures downstream of the BWRP in response to a 50 percent reduction in discharge flowrate

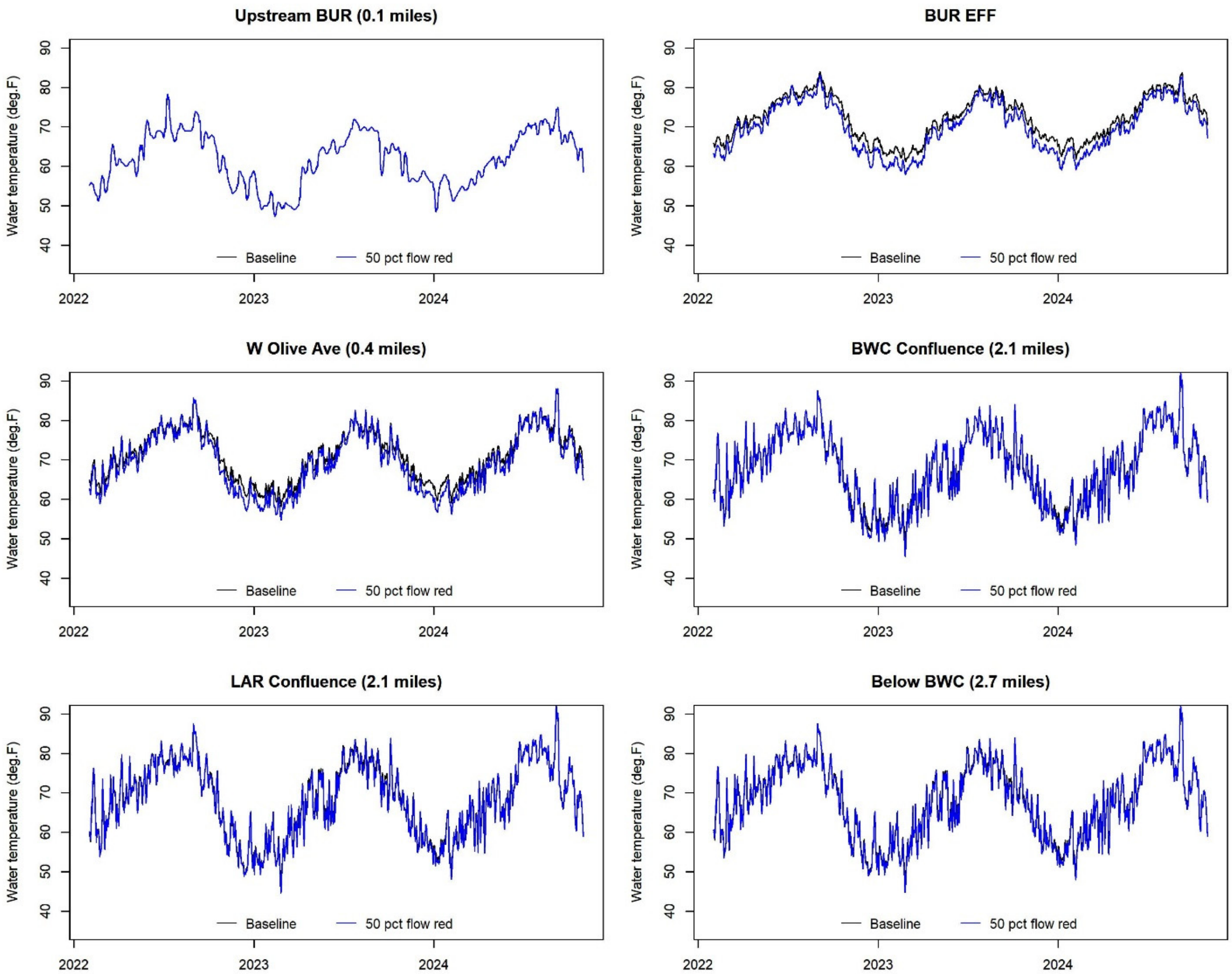

Figure 24. Time series of BWC temperatures downstream of the BWRP in response to reducing discharge flowrate by 50 percent

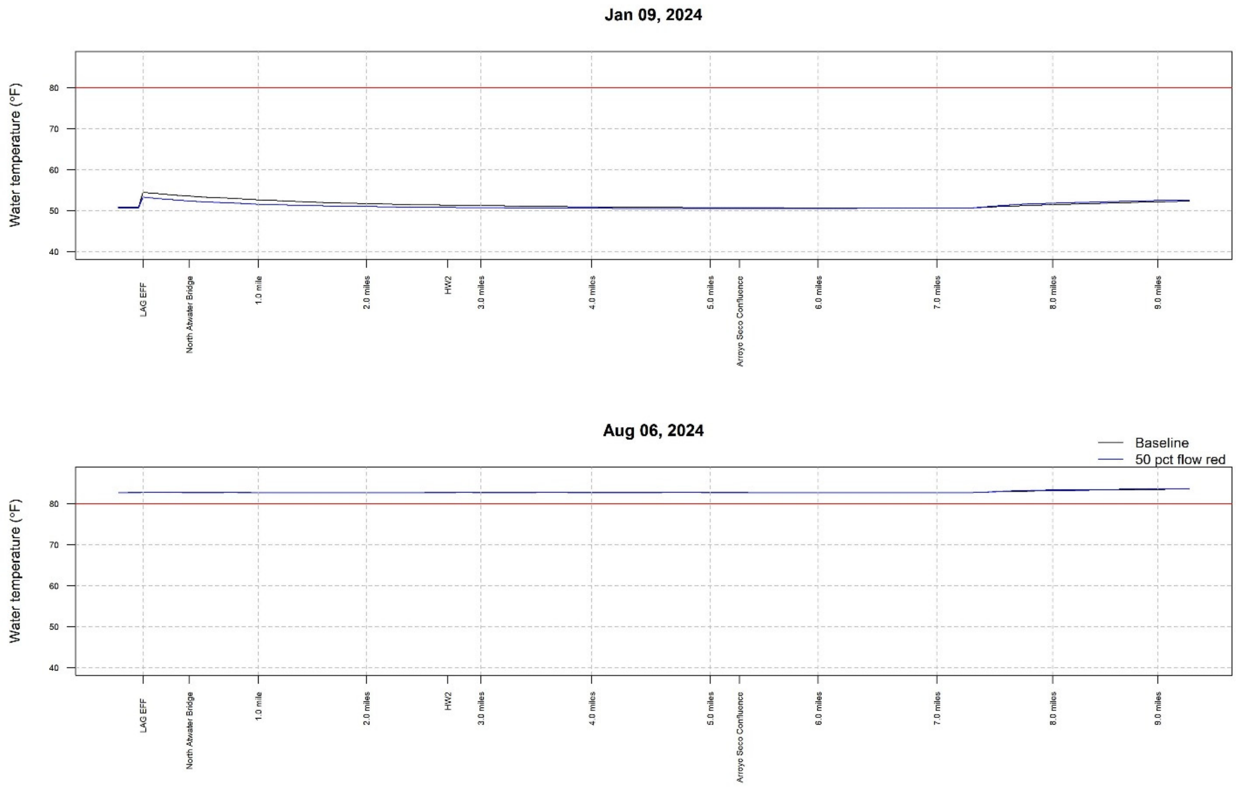

Figure 25. LA River temperatures downstream of the LAGWRP in response to a 50 percent reduction in discharge flowrate

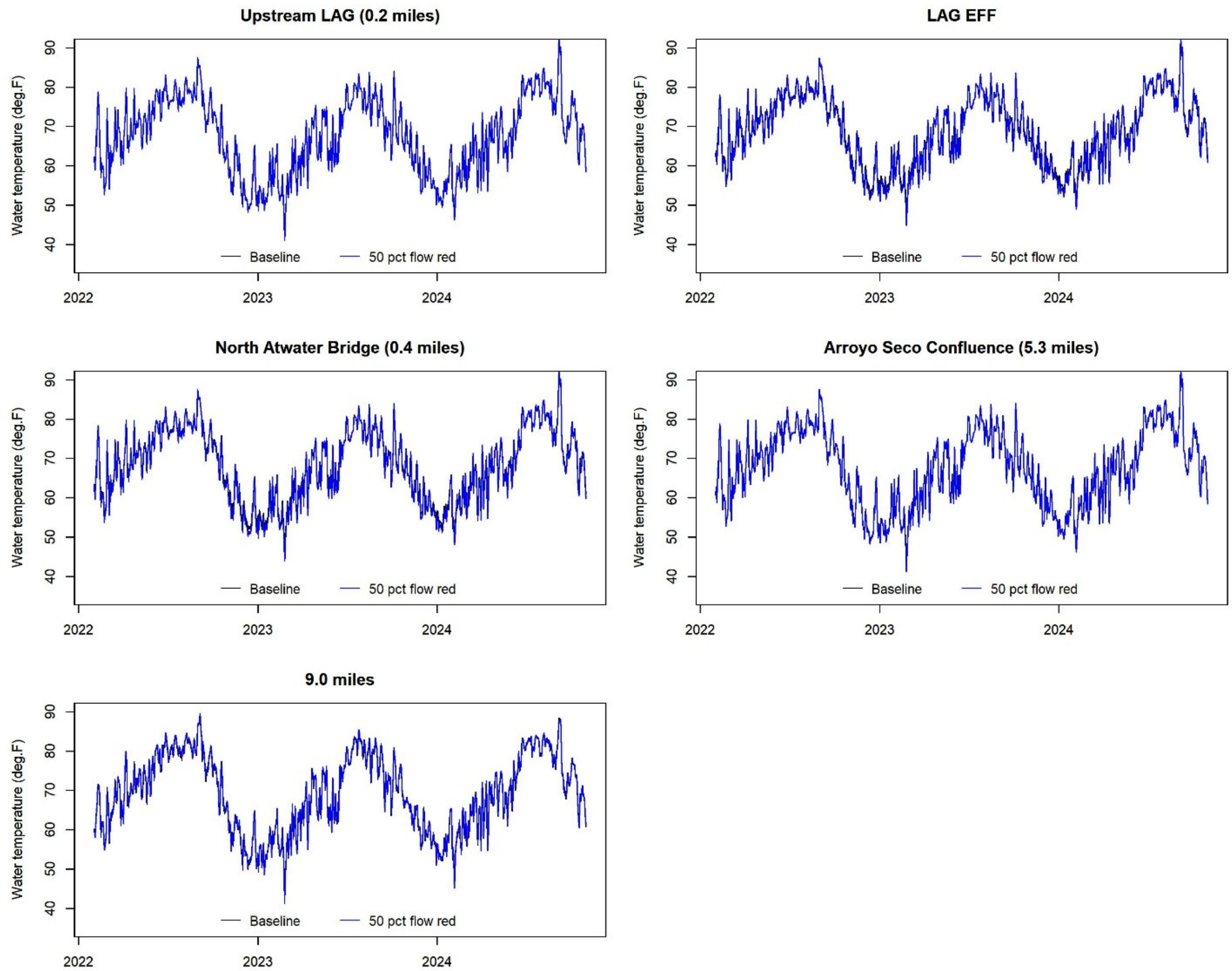

Figure 26. Time series of LA River temperatures downstream of the LAGWRP in response to reducing discharge flowrate by 50 percent.

6.3 Riparian Shading

To determine the effect of riparian shading from trees on incoming solar radiation, the incoming solar radiation was simulated within the low flow extent of the receiving water in a baseline scenario, and the analysis repeated assuming 100% tree cover along the receiving water outside of the established channel. For this simulation, a Digital Elevation Model (DEM) of the area was modified to raise the elevation (pixel value) of any pixel that intersected with the bank lines of the channel. Incoming solar radiation was simulated over a year in both of these scenarios to determine the reduction due to shading. These updated solar radiation values were simulated in the HEC-RAS model to determine the effect on receiving water temperatures. The process is presented schematically in **Figure 27**. In winter, when the sun is lower in the sky, the shadows cast are longer than in summer when the sun is higher in the sky. The analysis results over the course of a year for the eight meteorological stations in the model are presented in **Figure 28**. Details of the shading calculation method are shown in **Appendix B**.

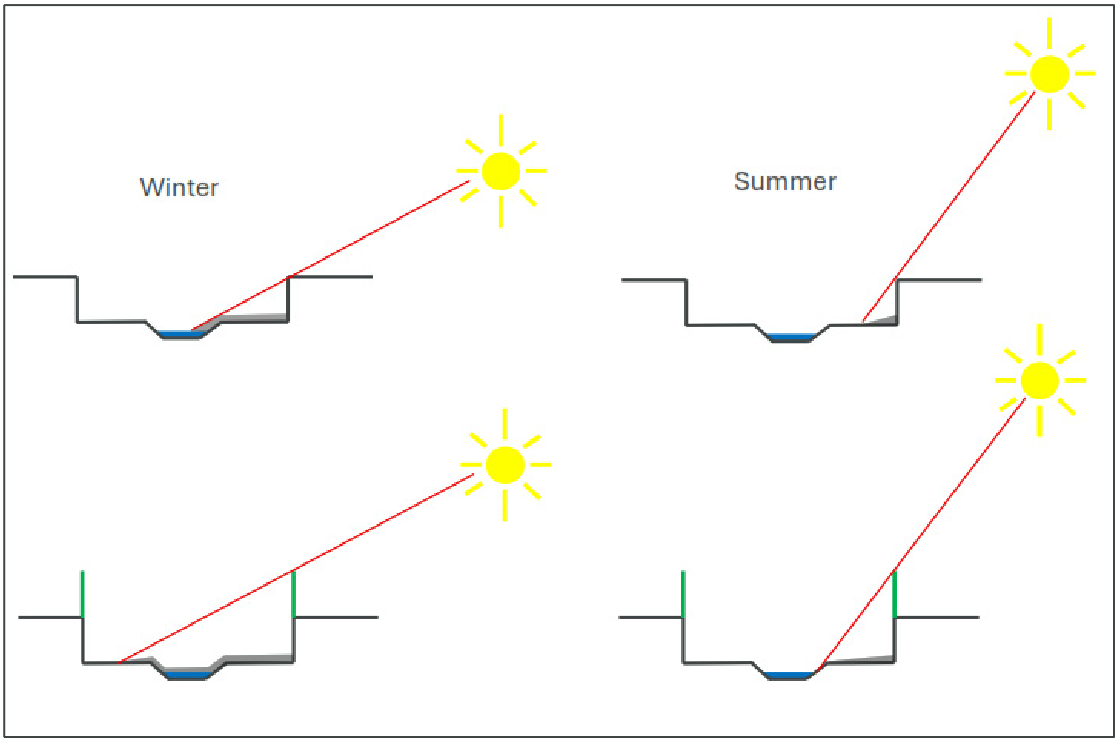

Figure 27. Schematic of shading for a concrete channel with a low flow section

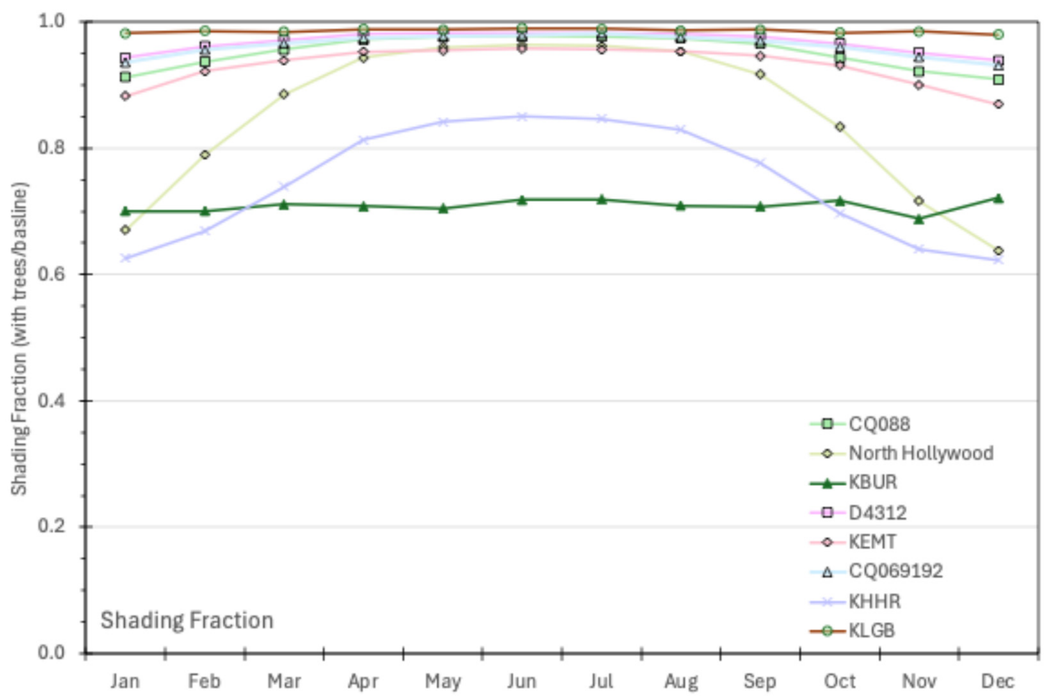

Figure 28. Fraction of solar radiation reaching the water surface for the reaches in the LA River Temperature Model

Temperatures in the LA River downstream from DCTWRP with and without the riparian shading control measure are presented in **Figure 29**. BWC temperatures downstream from BWRP with and without shading are shown in **Figure 30**. LA River temperature with and without shading downstream from LAGWRP are shown in **Figure 31**. There is negligible difference in receiving water temperature with and without shading. Corresponding time series plots are not shown as shading has minimal effect on the water surface, there is little difference between baseline and with shading even in winter months.

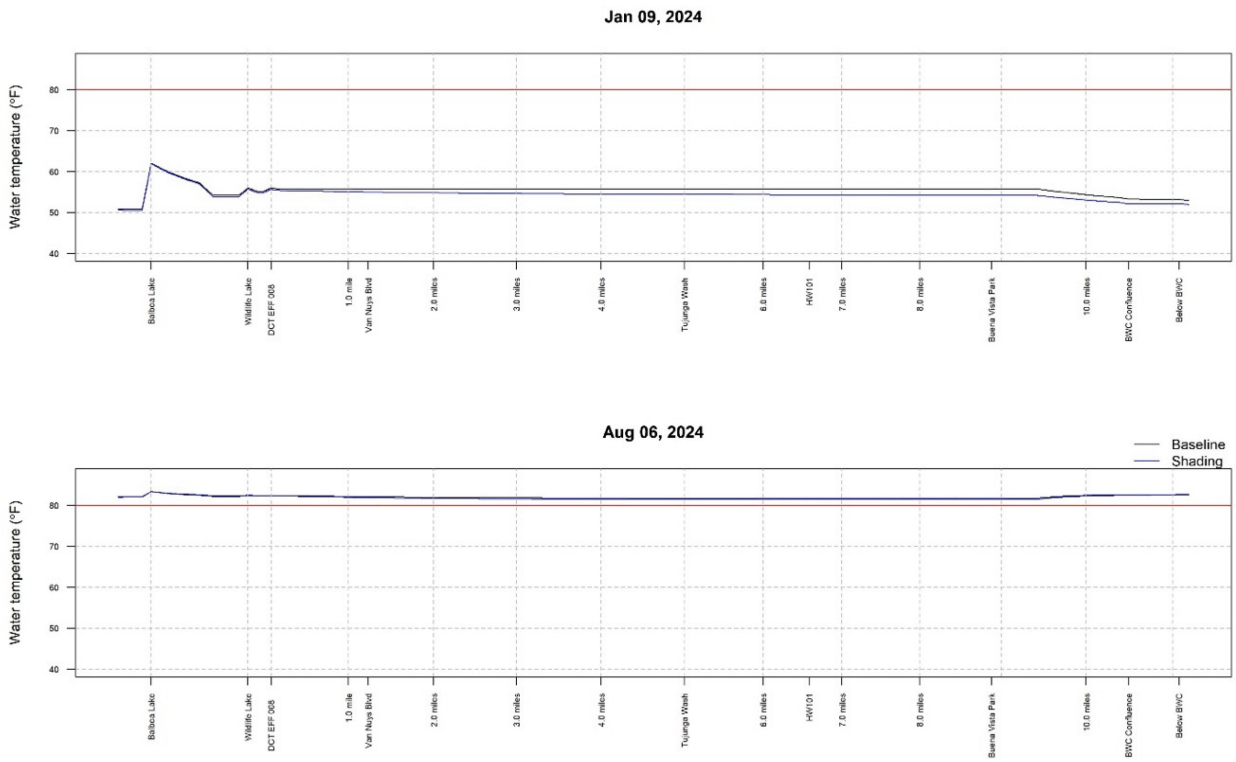

Figure 29. LA River temperature downstream of the DCTWRP with 100 percent edge of channel shading

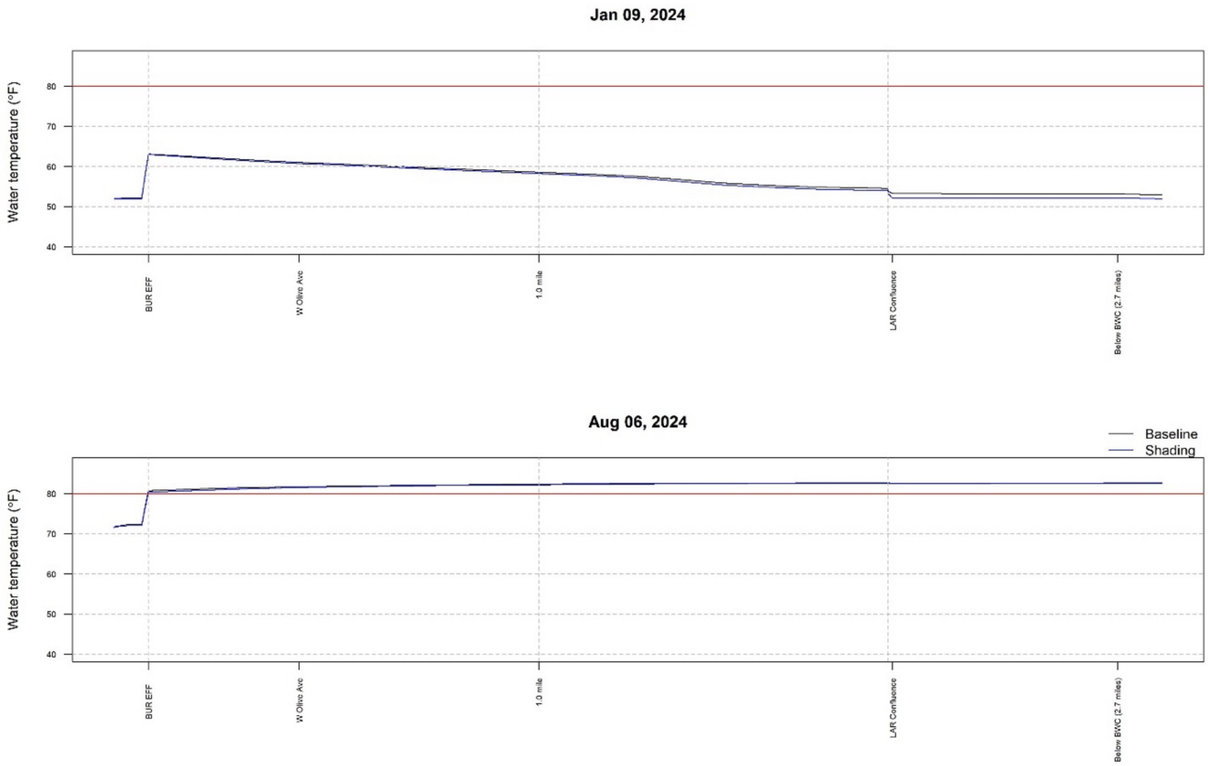

Figure 30. BWC temperatures downstream of the BWRP with 100 percent edge of channel shading

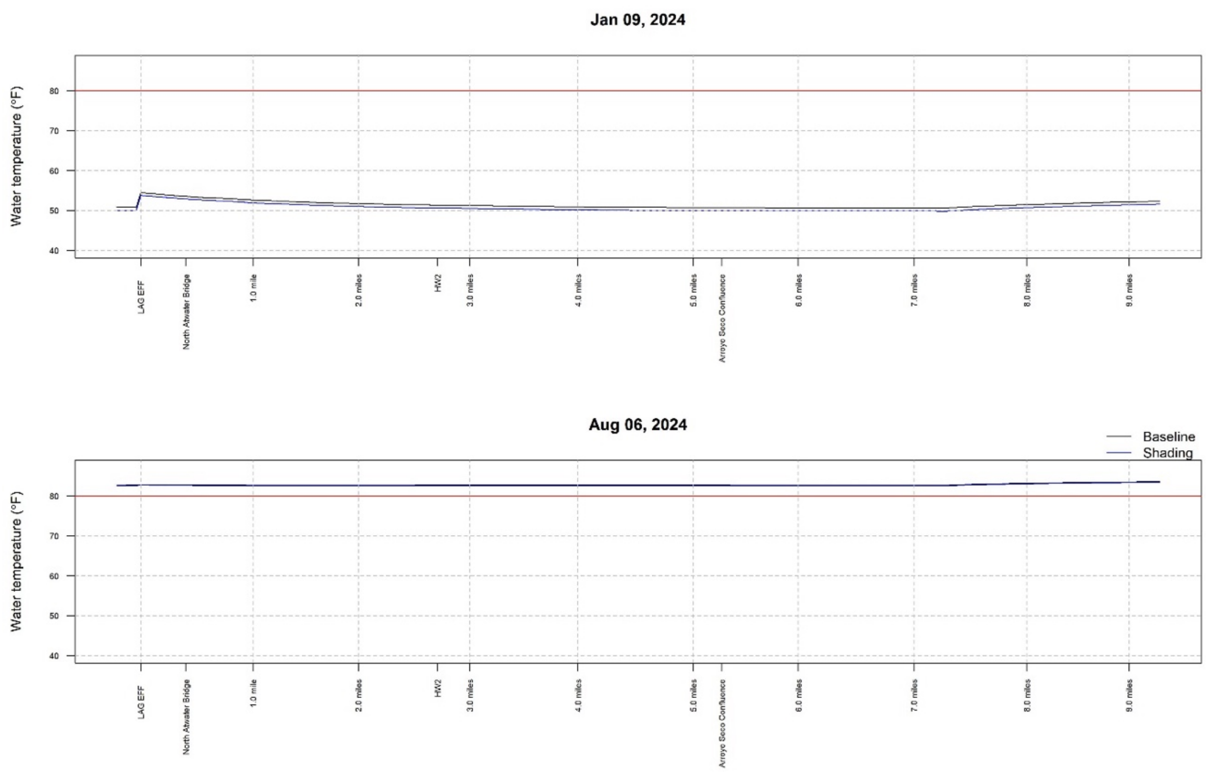

Figure 31. LA River temperature downstream of the LAGWRP with 100 percent edge of channel shading

SECTION 7 SCENARIOS

Scenarios seek to combine control measures to investigate potential synergies in combining actions. Each scenario presented in the following subsections is compared to both the baseline (no action) and to the effluent temperature reduction control measure as it had the greatest effect on receiving water temperatures.

7.1 Effluent Temperature Reduction and Flowrate Reduction

This scenario combines the effluent cooling and flowrate reduction. Under this scenario, because effluent flowrate and effluent temperature are reduced, the combination has less effect on receiving water temperature than just effluent temperature reduction alone. LA River temperatures downstream of DCTWRP for the baseline, effluent cooling only, and the effluent cooling and flow reduction are presented in **Figure 32**. BWC temperatures downstream of BWRP are presented in **Figure 33**, and the LA River temperatures downstream of LAGWRP are presented in **Figure 34**. Corresponding time series plots of this scenario compared to the baseline are not presented as they are not substantively different from the effluent temperature reduction control measure presented in **Section 6.1**.

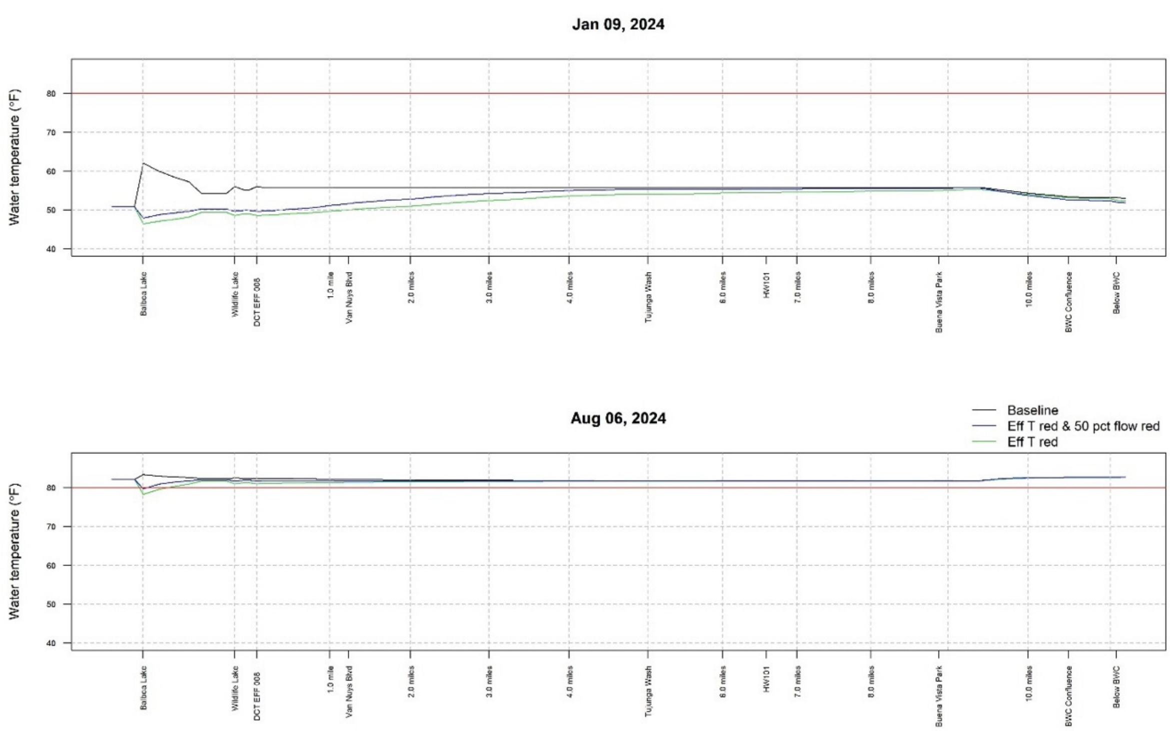

Figure 32. LA River temperatures downstream of the DCTWRP for the Effluent temperature and flowrate reduction

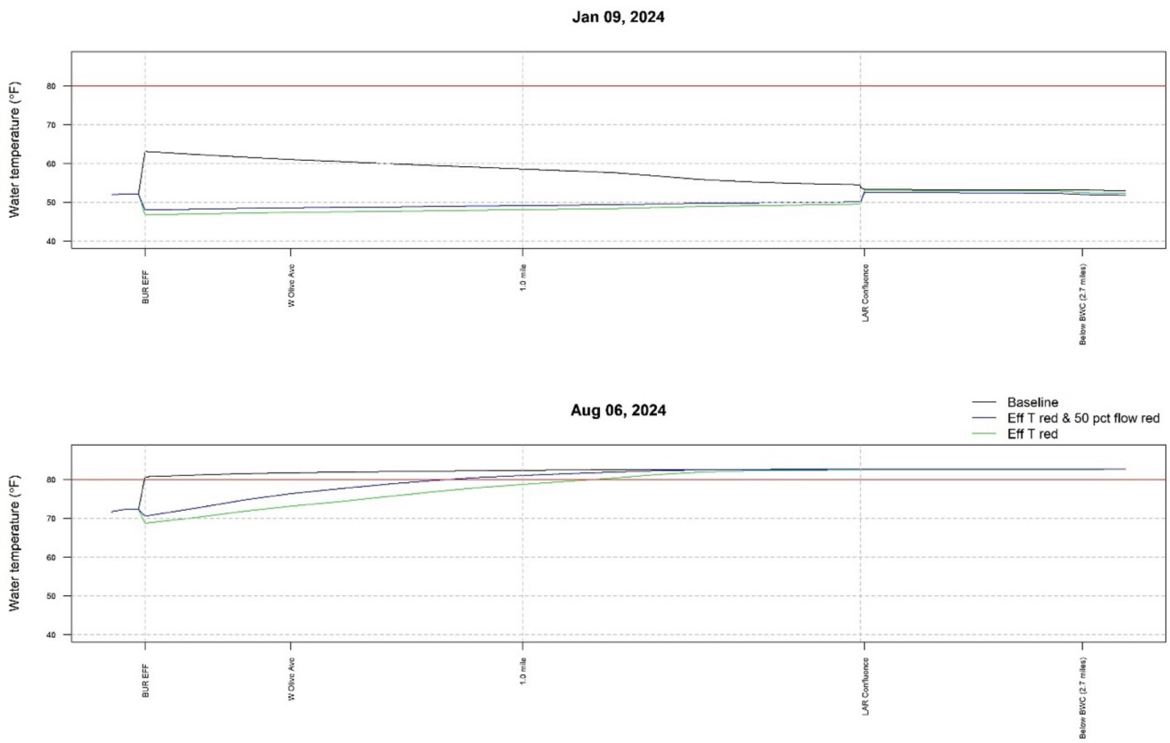

Figure 33. BWC temperatures downstream of the BWRP for the effluent temperature and flowrate reduction scenario

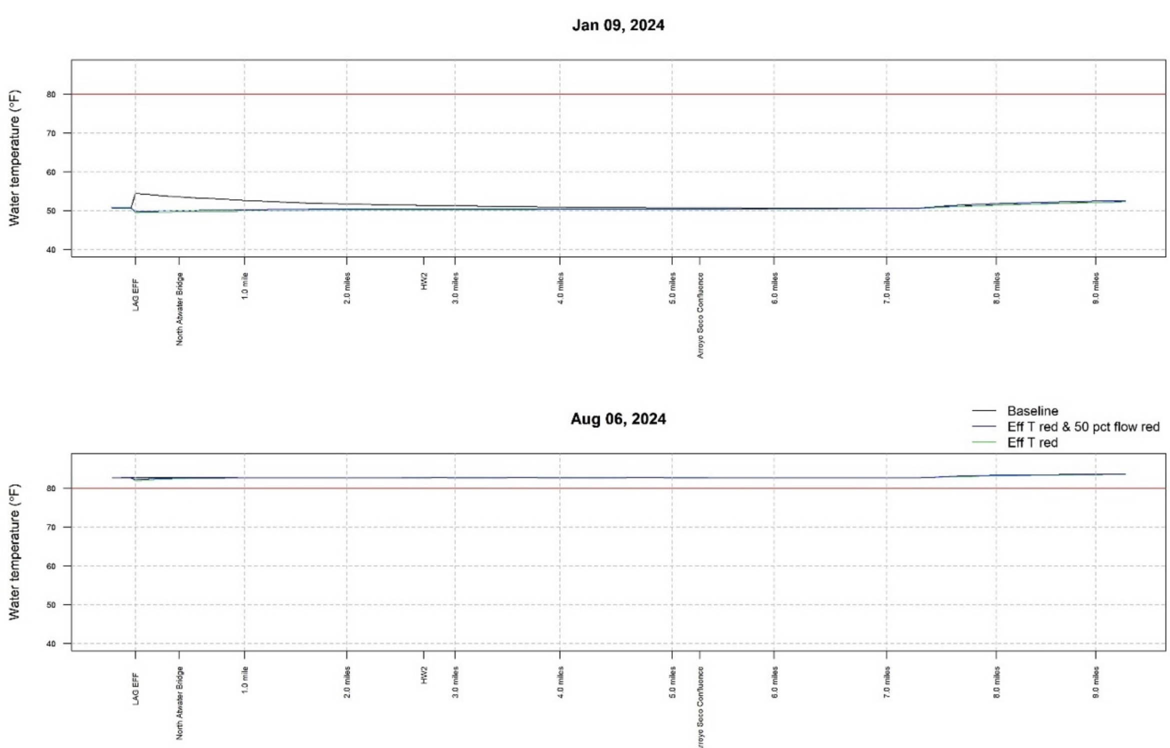

Figure 34. LA River temperatures downstream of the LAGWRP for the effluent temperature and flowrate reduction scenario

7.2 Effluent Temperature Control and Riparian Shading

When effluent temperature control is combined with riparian shading, the receiving water temperatures downstream of the WRP discharges still reach the corresponding baseline temperatures, albeit slightly further downstream. LA River temperatures downstream of the DCTWRP for this scenario are presented in **Figure 35**. BWC temperatures downstream from the BWRP are presented in **Figure 36**. LA River temperatures downstream of the LAGWRP are presented in **Figure 37**. Corresponding time series plots of this scenario compared to the baseline are not presented as they are not substantively different from the effluent temperature reduction control measure presented in **Section 6.1**.

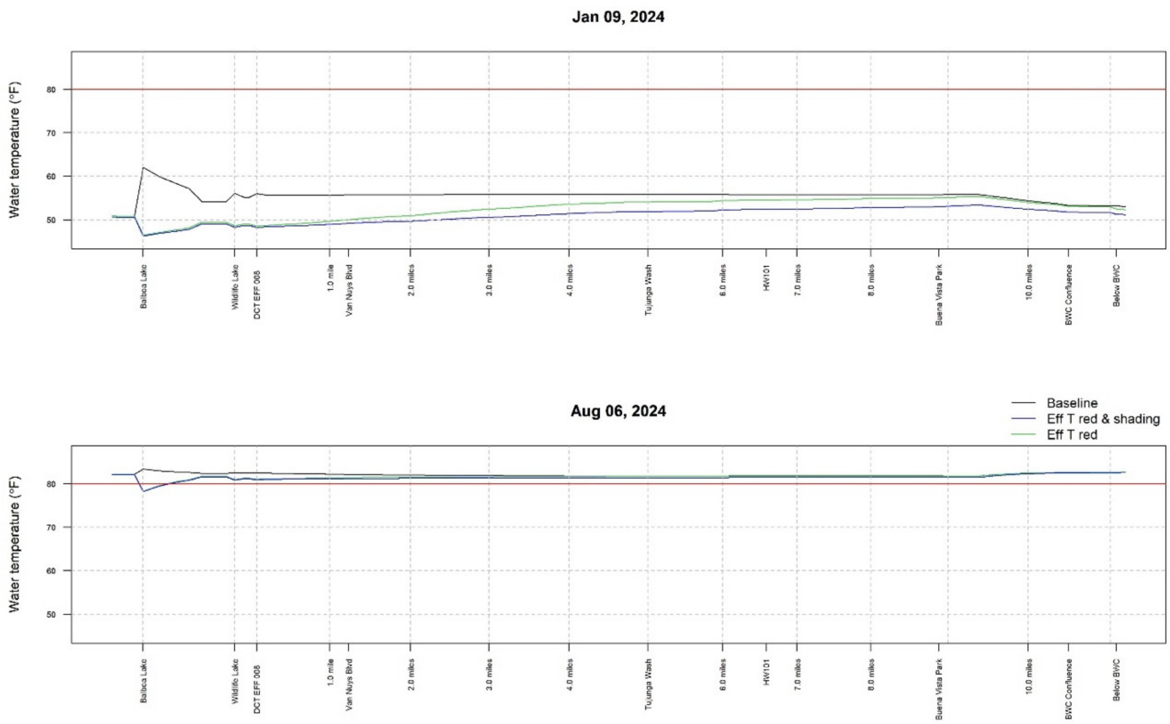

Figure 35. LA River temperatures downstream of the DCTWRP for effluent cooling and riparian shading

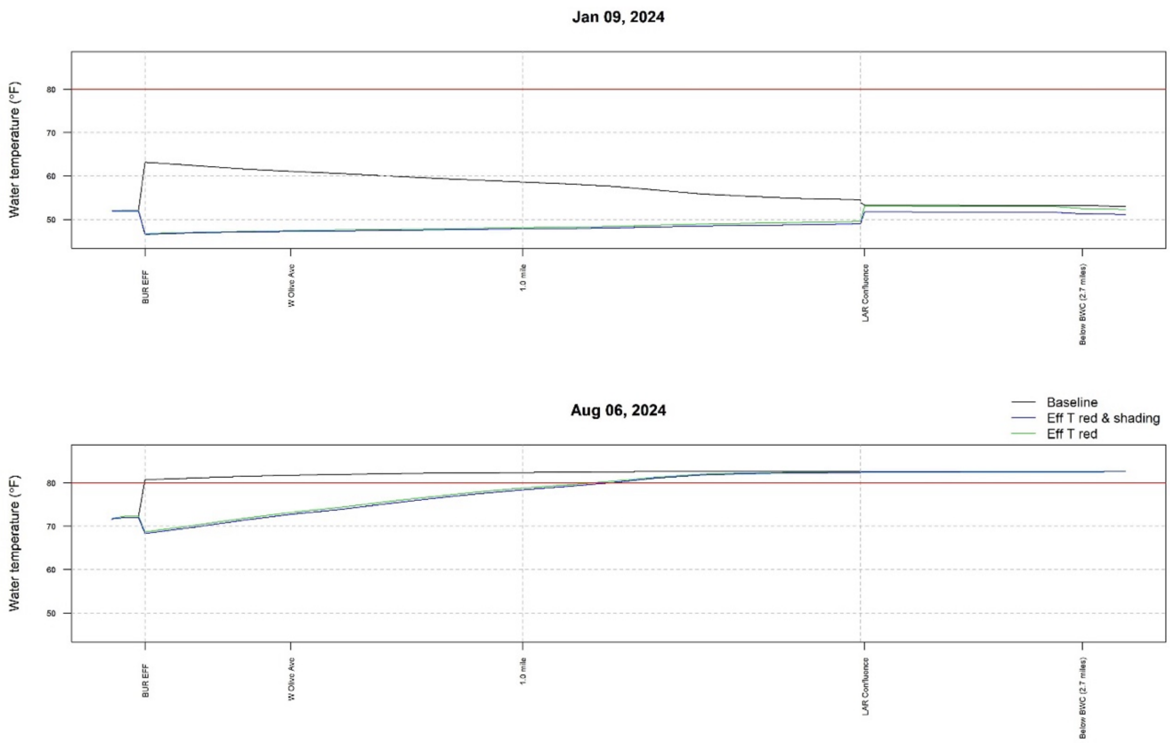

Figure 36. BWC temperatures downstream of the BWRP with effluent cooling and riparian shading

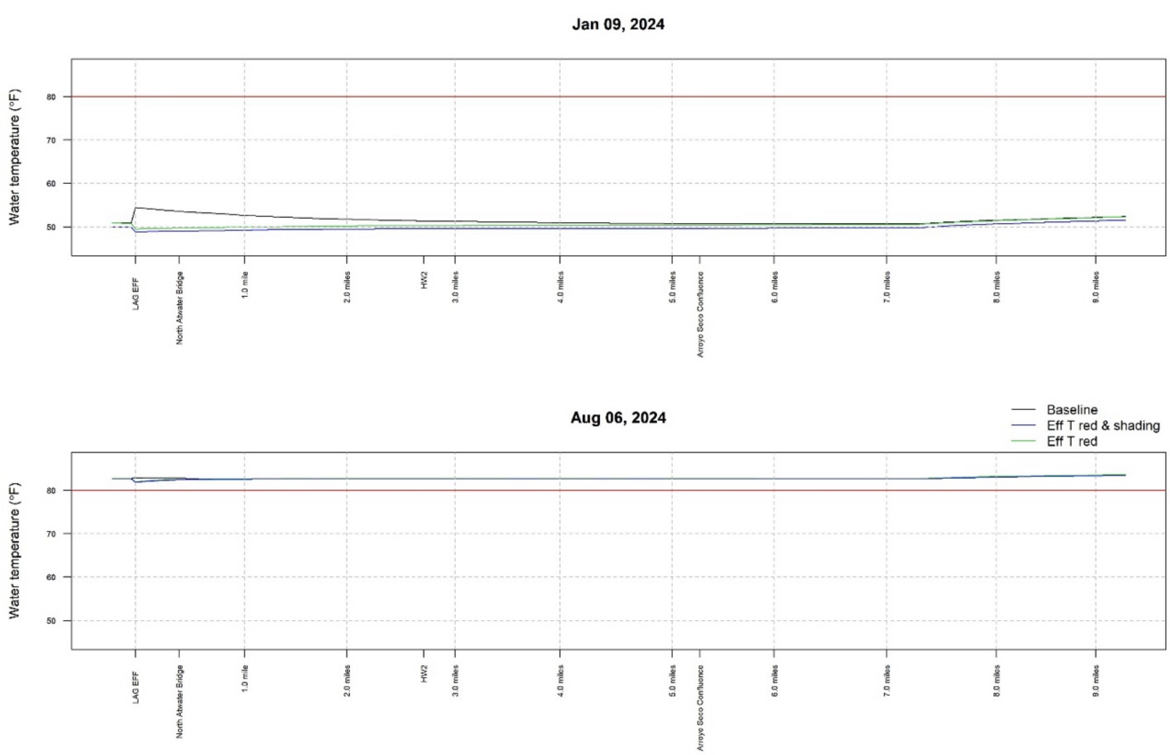

Figure 37. LA River temperatures downstream of the LAGWRP for effluent cooling and riparian shading

7.3 Effluent Temperature Control, Effluent Reduction, and Riparian Shading

When effluent temperature control is combined with effluent reduction and riparian shading, the receiving water temperatures downstream of the WRP discharges reach the corresponding baseline temperatures, similar to effluent reduction alone. LA River temperatures downstream of DCTWRP for this scenario are presented in **Figure 38**. BWC temperatures downstream from the BWRP are presented in **Figure 39**. LA River temperatures downstream of LAGWRP for are presented in **Figure 40**. Corresponding time series plots of this scenario compared to the baseline are not presented as they are not substantively different from the effluent temperature reduction control measure presented in **Section 6.1**.

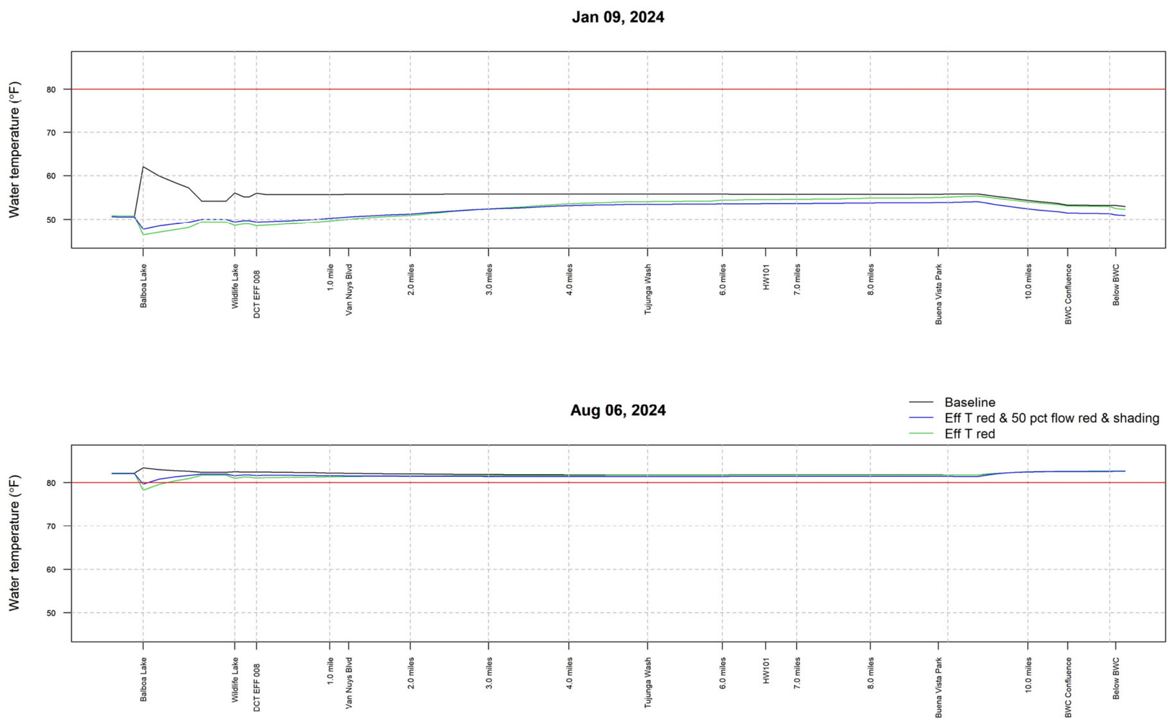

Figure 38. LA River temperatures downstream of the DCTWRP for all three control measures concurrently

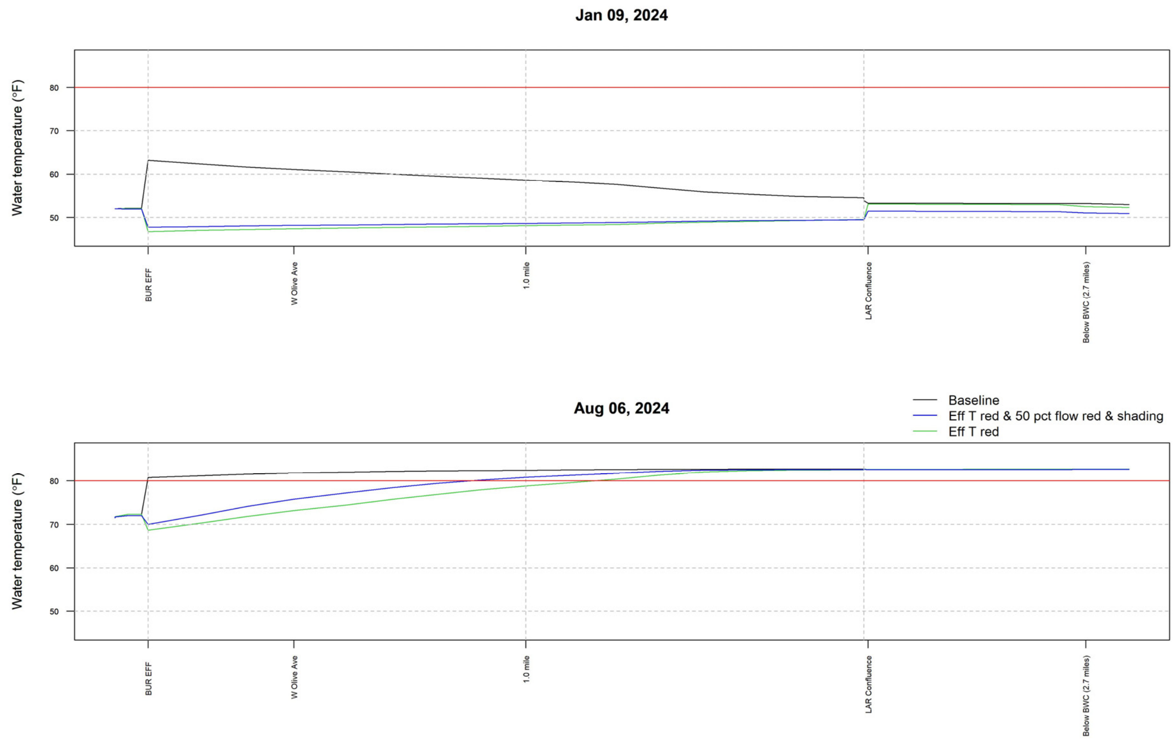

Figure 39. BWC temperatures downstream of the BWRP for all three control measures concurrently

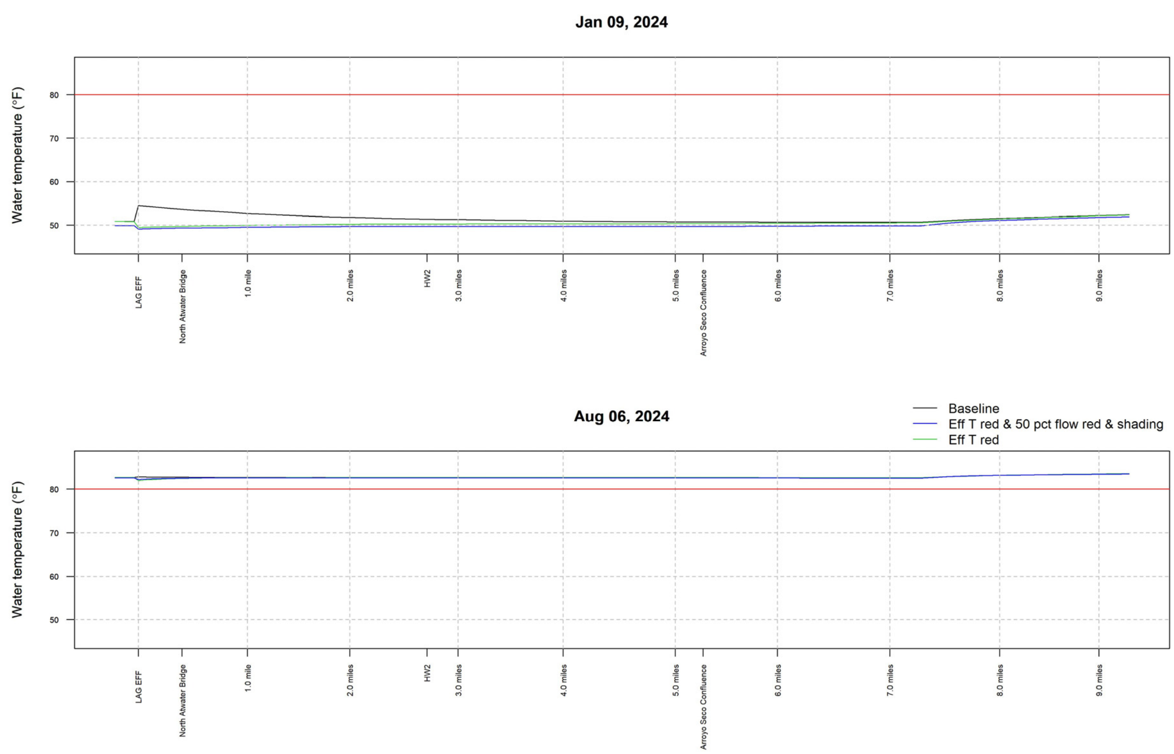

Figure 40. LA River temperatures downstream of the LAGWRP for all three control measures concurrently

7.4 Climate Change

To assess the effect of climate change, the future temperatures in the LA Basin were determined through the Coupled Model Intercomparison Project Phase 5 (CMIP5) North America downscaled by Localized Constructed Analogs (LOCA) statistical dataset, downloaded from Cal-Adapt[33]. Predicted mean monthly water temperatures in January and August 2022-2024 increase due to increased air temperature in climate change scenarios. These projections are made for 30 years in the future corresponding to the life cycle of effluent temperature control machinery.

LA River temperatures downstream of the current DCTWRP discharge are compared to conditions 30 years in the future in response to climate change and for effluent temperature controls under climate change on **Figure 41**. Corresponding BWC temperatures downstream of BWRP are shown in **Figure 42**. LA River downstream of LAGWRP for these conditions are shown in **Figure 43**.

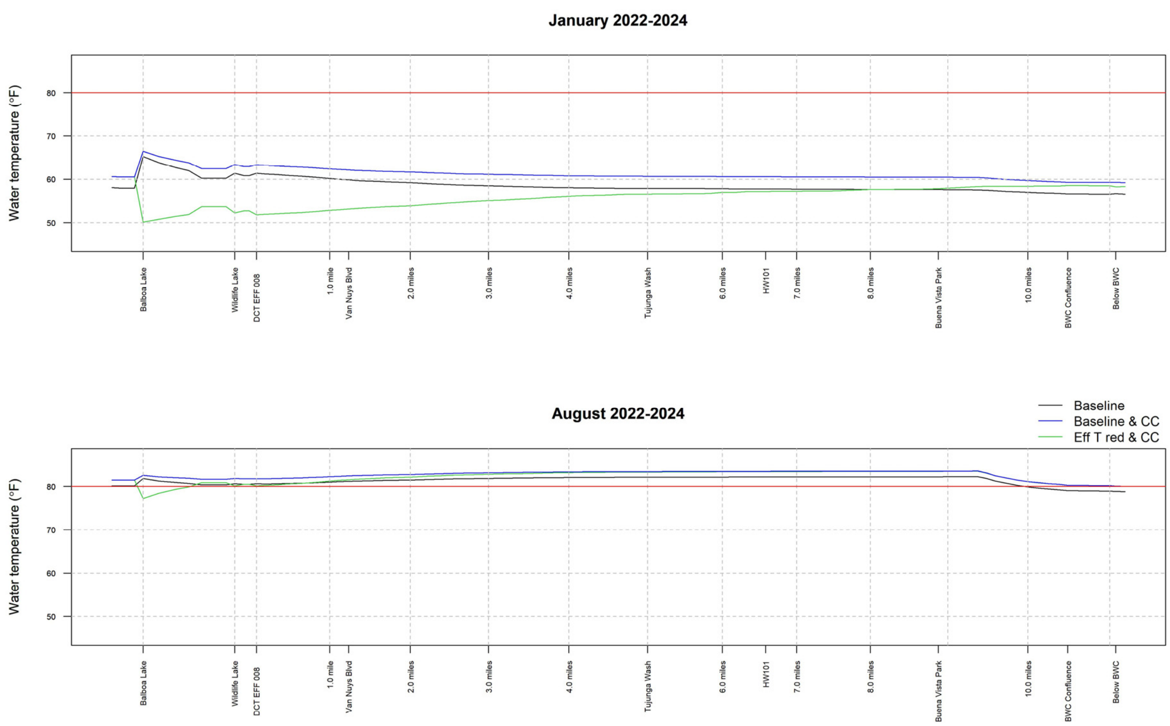

Figure 41. LA River temperatures downstream of the DCTWRP for baseline (current conditions, black line), baseline conditions with climate change (blue line), and effluent reduction with climate change (green line)

[33] https://cal-adapt.org/data/download/

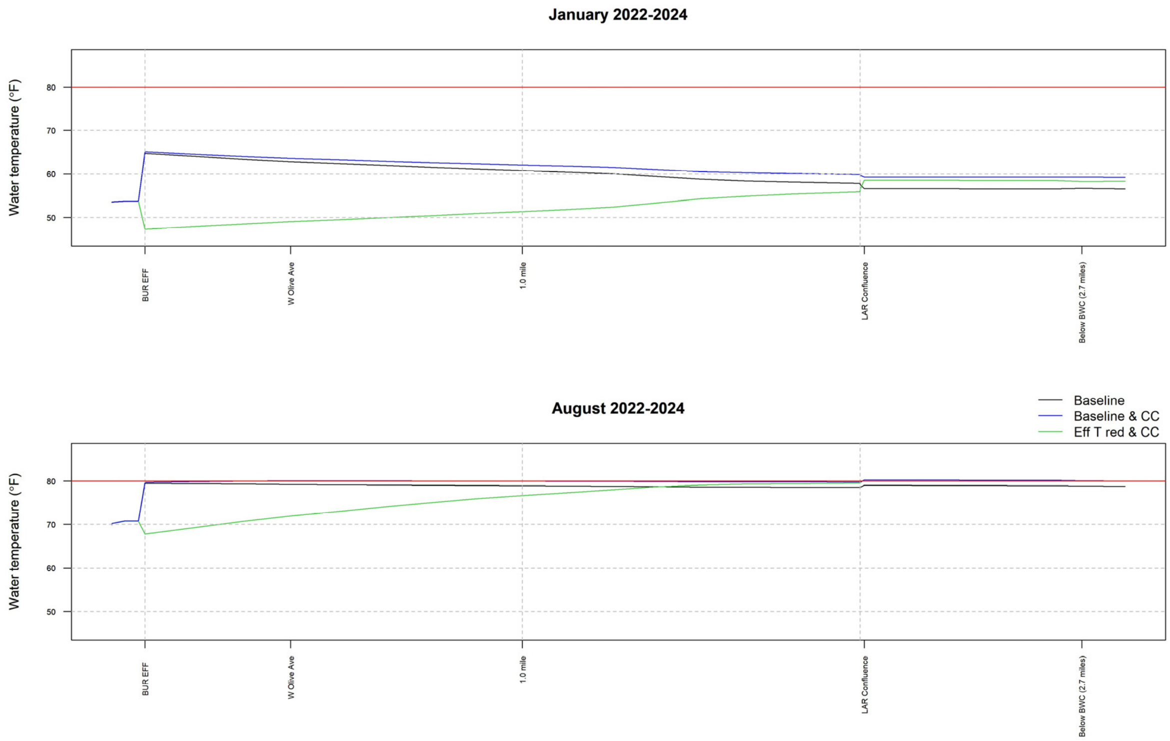

Figure 42. BWC temperatures downstream of the BWRP for baseline (current conditions, black line), baseline conditions with climate change (blue line), and effluent reduction with climate change (green line)

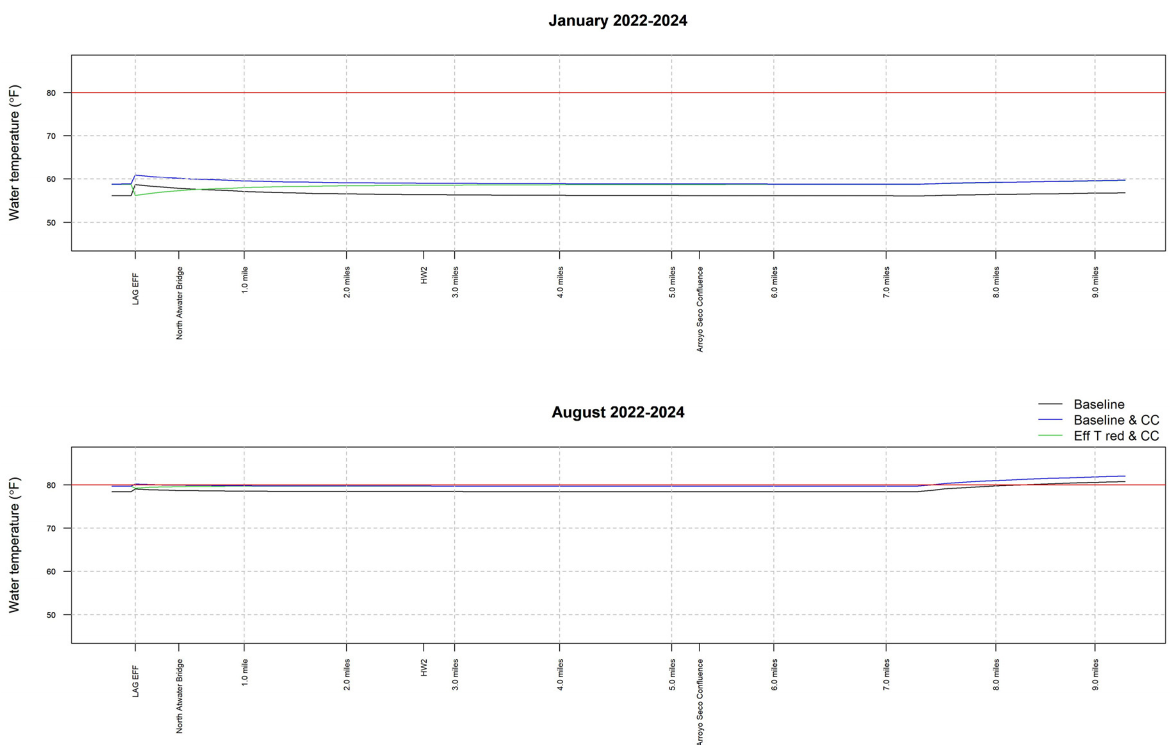

Figure 43. LA River temperatures downstream of the LAGWRP for baseline (current conditions, black line), baseline conditions with climate change (blue line), and effluent reduction with climate change (green line)

SECTION 8 EXPLORATION OF ADDITIONAL SCENARIOS FOR RIVER SHADING

Given that shading along the banks of the Study area did not result in meaningful changes to receiving water temperatures, the TAC requested that the Cities use the model to explore the following two additional shading scenarios:

- The first was an evaluation of planting dense riparian vegetation in the current unlined sections that might result in blocking 80% of the incident solar radiation. The first scenario would require dense vegetation in the unlined sections that may affect flood protection levels and would likely preclude some uses of the river such as kayaking.
- The second was identify what amount of shading would be required to maintain receiving water temperatures below 80°F. As exploratory scenarios, they were modeled regardless of whether they would be implementable. The second scenario would require removal of concrete to allow establishment of dense vegetation, would affect flood capacity necessitating channel widening, and as discussed below would require densification of the urban forest to affect a 15% reduction in the local air temperature.

Actions necessary to act on these exploratory scenarios are well outside the ability of the Cities to perform.

8.1 80% Shading in Current Unlined Sections

The current unlined sections include the Sepulveda Basin (LAR Reach 5), a short section of LAR Reach 4 downstream of the confluence with BWC, and LAR Reach 3 through the Glendale Narrows. Over each of these sections, the solar radiation was reduced by 80% in the model for this scenario. The reduction was specified so an analysis of the type(s) of vegetation or the planting density to achieve the selected shading was not performed.

The modeled receiving water temperatures around DCTWRP are presented in **Figure 44**. The receiving water in the area in the unlined Sepulveda Basin is cooled from the heavy shading. However, the receiving water temperature returns to the baseline equilibrium a short distance downstream of the unlined section. Time series of receiving water temperatures at and downstream of DCTWRP comparing current conditions with 80% shading over unlined sections is shown on **Figure 45**. The air temperature is superimposed on the figure. Note the extreme warm day late in 2024 and how the water temperature increases to meet the air temperature. There are no unlined sections in the BWC, so there is no temperature difference downstream of BWRP under this scenario. Modeled receiving water temperatures below LAGWRP for this scenario compared to the current condition are plotted in **Figure 46**. As with DCTWRP the shading was effective over the unlined section reducing the water temperature, but where the channel returned to concrete and shading ceased the receiving water temperature returned to the previous equilibrium. Time series of water temperature at locations downstream of LAGWRP for current conditions and with 80% shading over unlined sections are presented in **Figure 47**. The local air temperature is superimposed on the figure. The five miles downstream of LAGWRP is unlined. By four miles downstream from LAGWRP, the water temperature is mimicking the air temperature. At five miles downstream of the discharge, the channel returns to concrete. By eight miles downstream the solar radiation is increasing the water temperature back to the previous equilibrium.

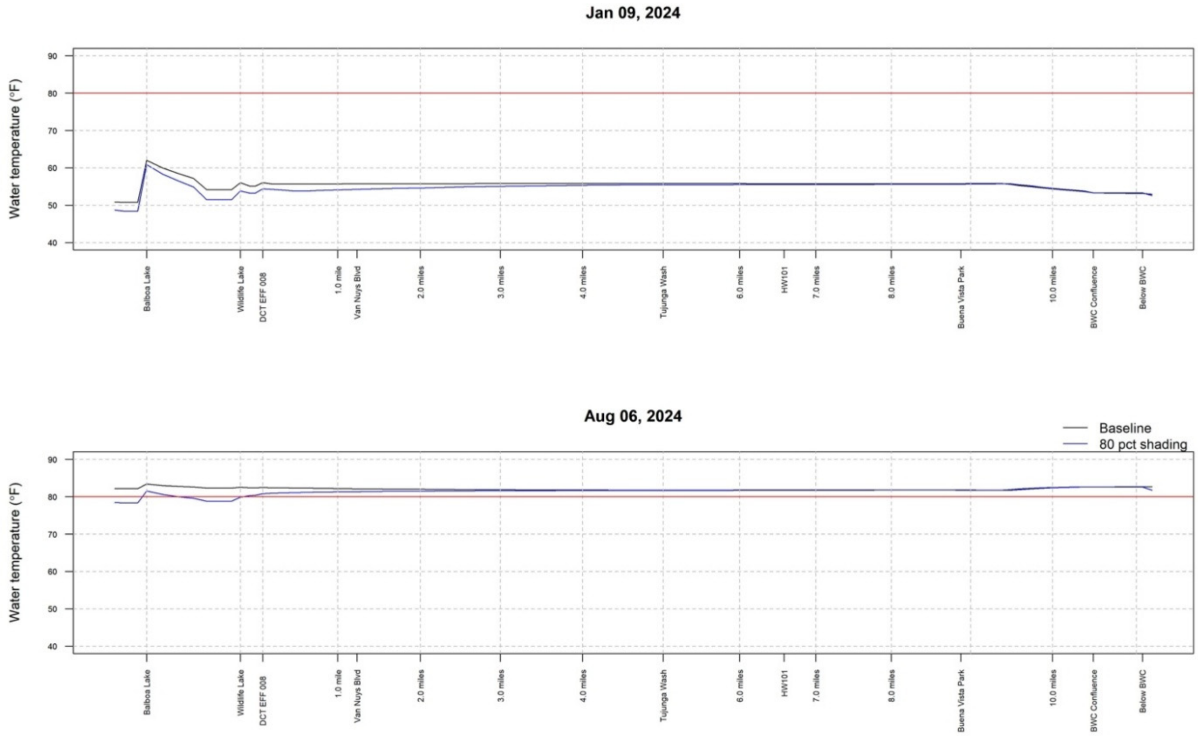

Figure 44. LA River temperatures downstream of the DCTWRP with 80% shading over unlined sections

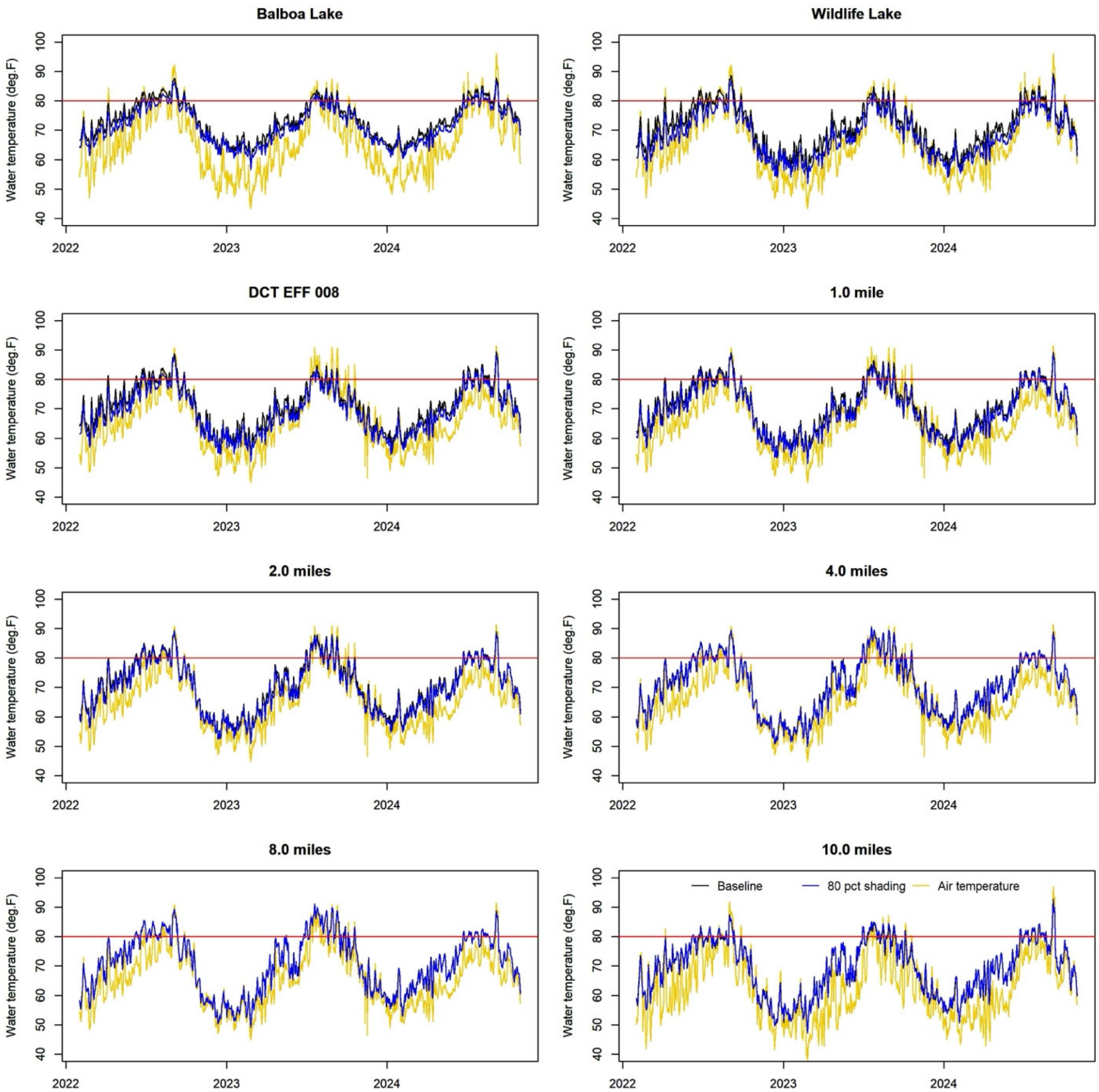

Figure 45. Time series of LA River temperatures and air temperature for current conditions and with solar radiation reduced 80% over soft-bottom channels for select locations at and downstream from the DCTWRP

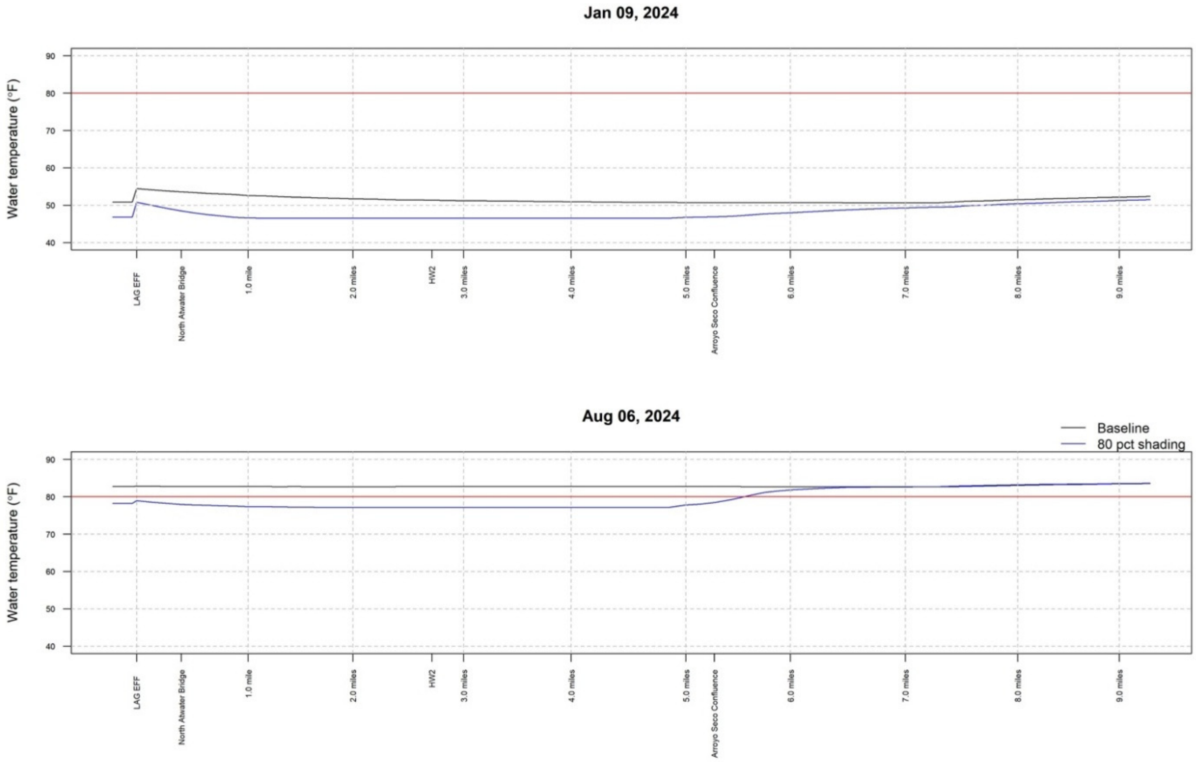

Figure 46. LA River temperatures downstream of the LAGWRP with 80% shading over unlined sections

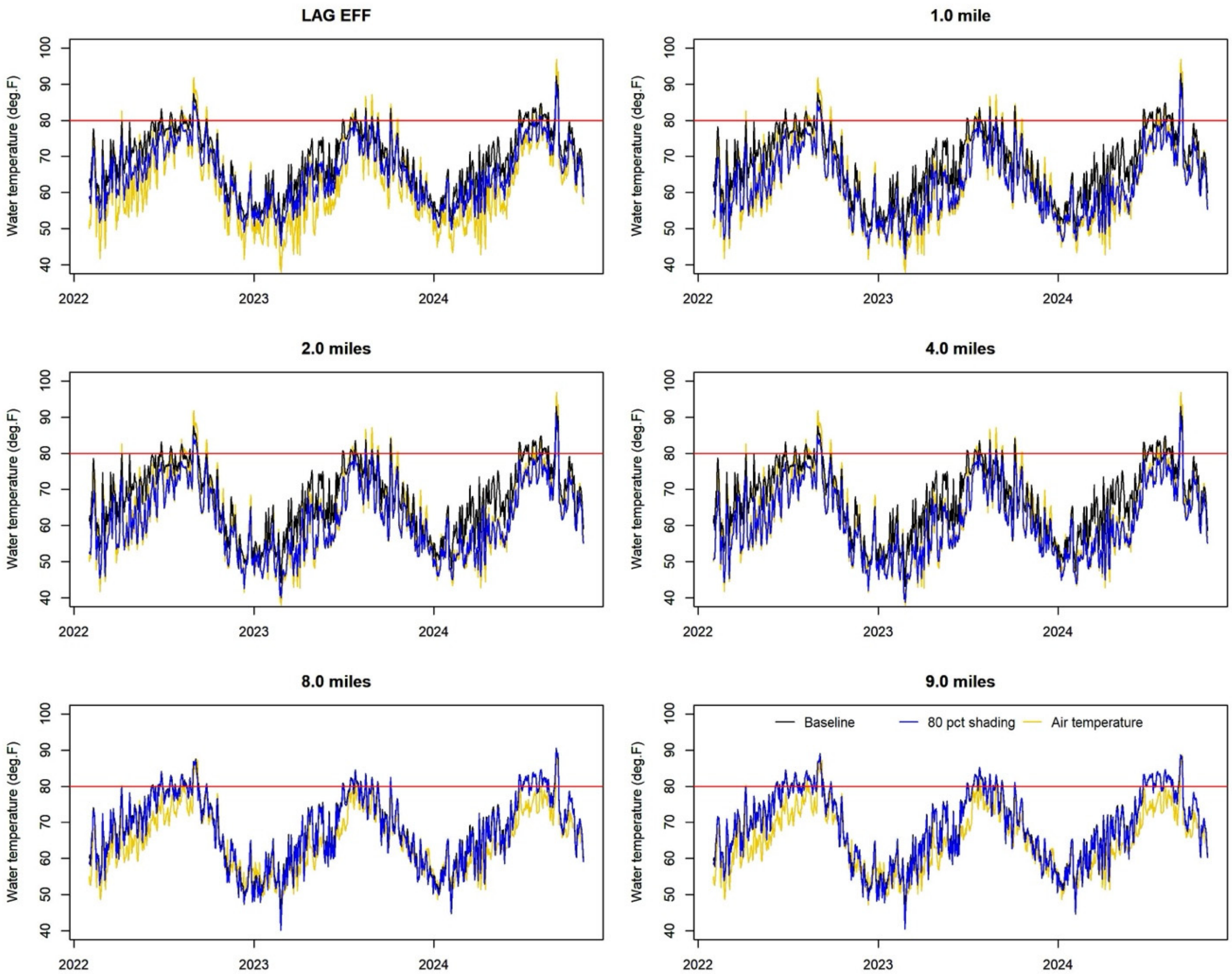

Figure 47. Time series of LA River temperatures and air temperature for current conditions and with solar radiation reduced 80% over only soft-bottom channels at select locations at and downstream from the LAGWRP

8.2 River-wide Shading to Maintain River Temperatures Below 80°F

To maintain the receiving water temperature below 80°F, the river would require 80% solar radiation reduction and 15% local air temperature reduction. These levels were determined through iterating with the model. Initially a 100% reduction of solar radiation was evaluated and while receiving water temperatures remained below 80°F for the majority of the simulation, the ambient air temperature would increase receiving water temperature over 80°F on abnormally warm days. The 80% solar radiation reduction over unlined and 100% reduction simulation results combined with their associated relationships between air temperature and water temperature were used to develop the 80% solar radiation reduction and 15% local air temperature reduction river-wide scenario. As an exploratory scenario, the shading and air temperature reductions were not optimized.

LA River temperatures downstream of DCTWRP for current conditions and with the river-wide scenario are presented in **Figure 48**. The corresponding time series of water temperatures and current air temperatures are presented in **Figure 49**. Similarly, BWC temperatures downstream of BWRP are present in **Figure 50**, with corresponding time series in **Figure 51**. Modeled current condition and river-wide scenario LA River water temperatures downstream of LAGWRP are presented on **Figure 52** with the corresponding time series shown in **Figure 53**. On the hottest days the combination of 80% solar radiation reduction and 15% air temperature reduction maintained receiving water temperatures below 80°F.

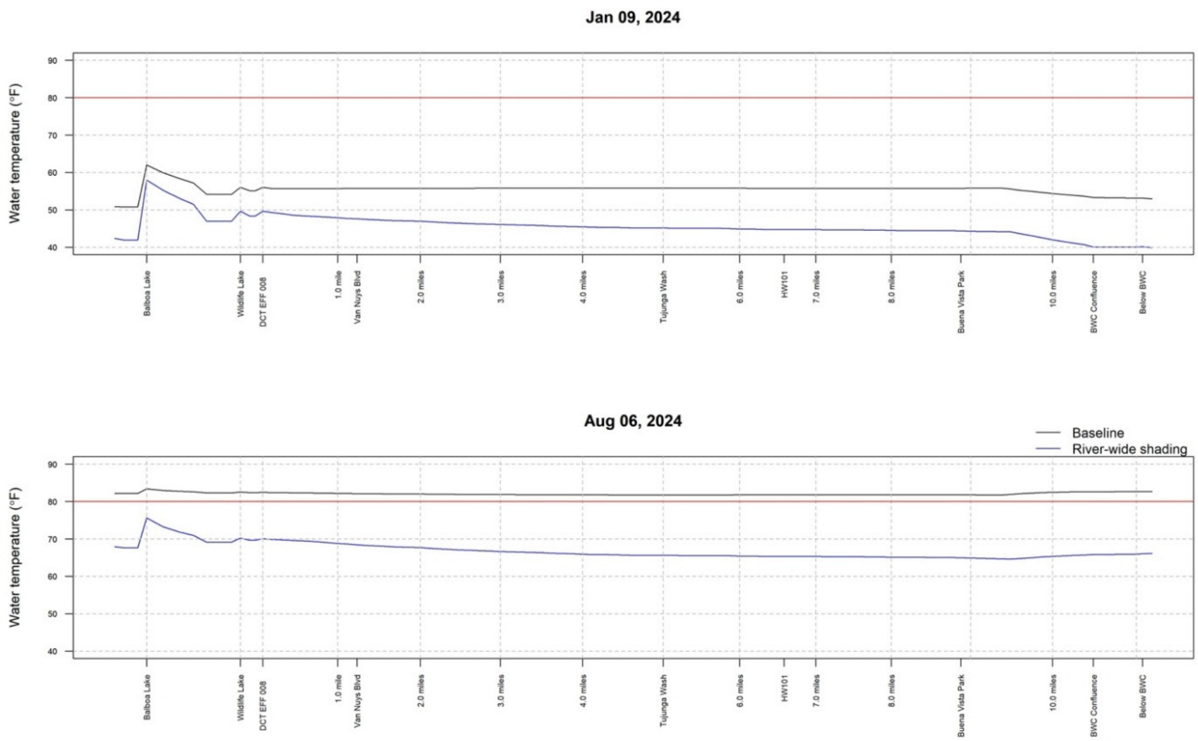

Figure 48. LA River water temperatures downstream of the DCTWRP for current conditions and with river-wide shading (80% shading and 15% reduction in local air temperature)

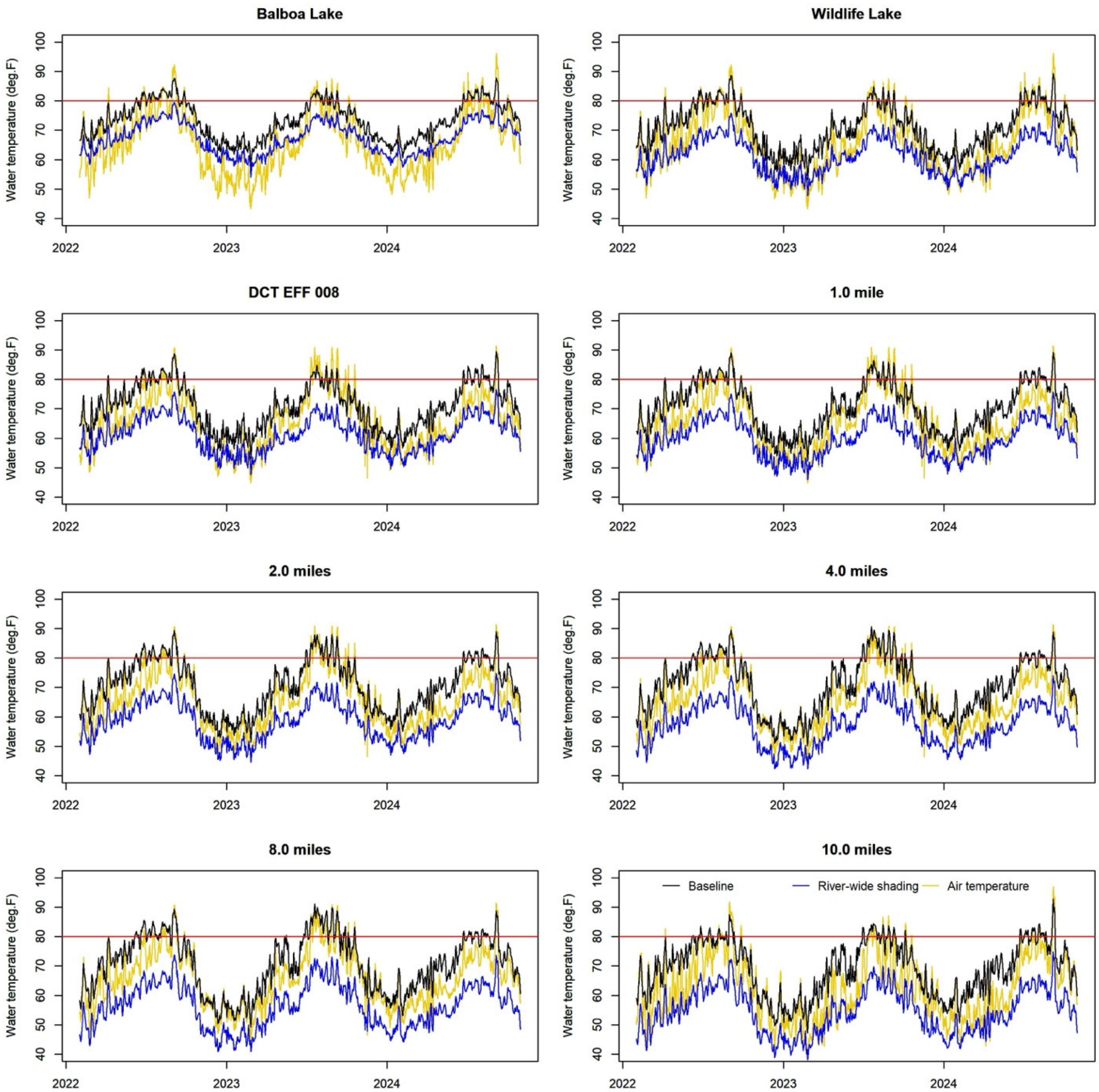

Figure 49. Time series of LA River temperatures and air temperature for current conditions and with river-wide shading (80% shading and 15% reduction in local air temperature) at and downstream from the DCTWRP

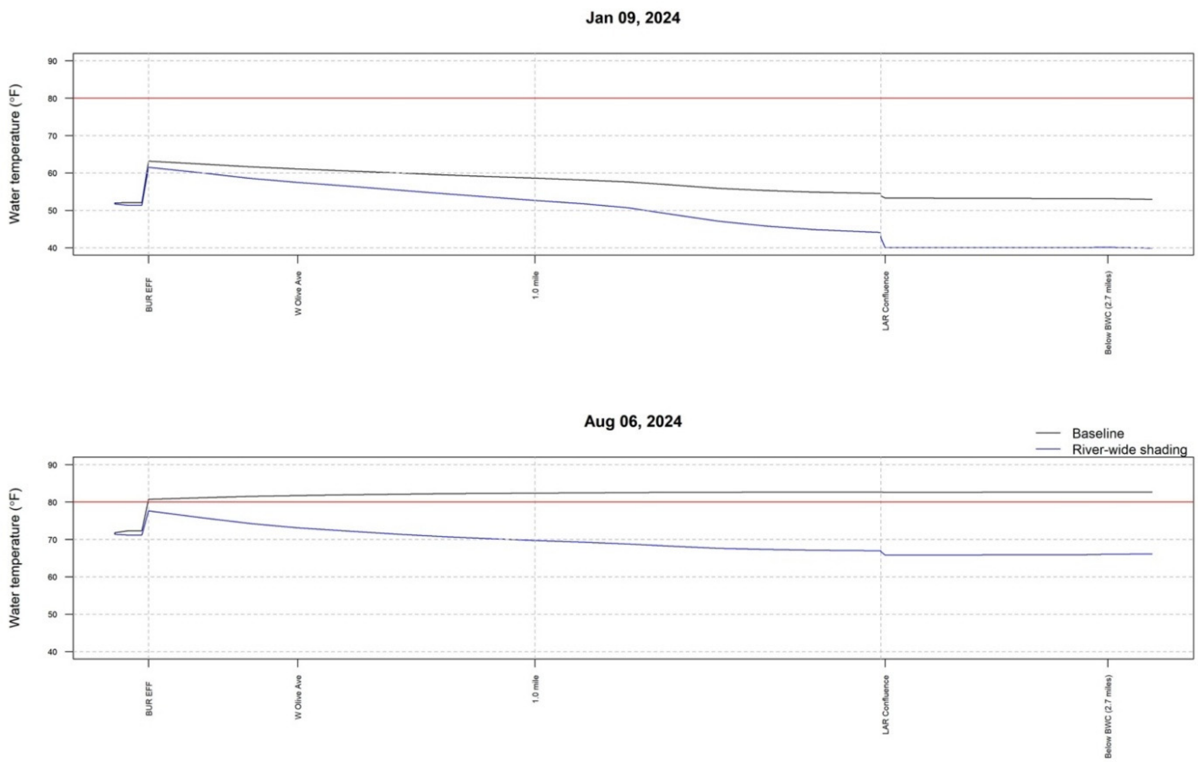

Figure 50. BWC water temperatures downstream of the BWRP for current condition and with river-wide shading (80% shading and 15% reduction in local air temperature)

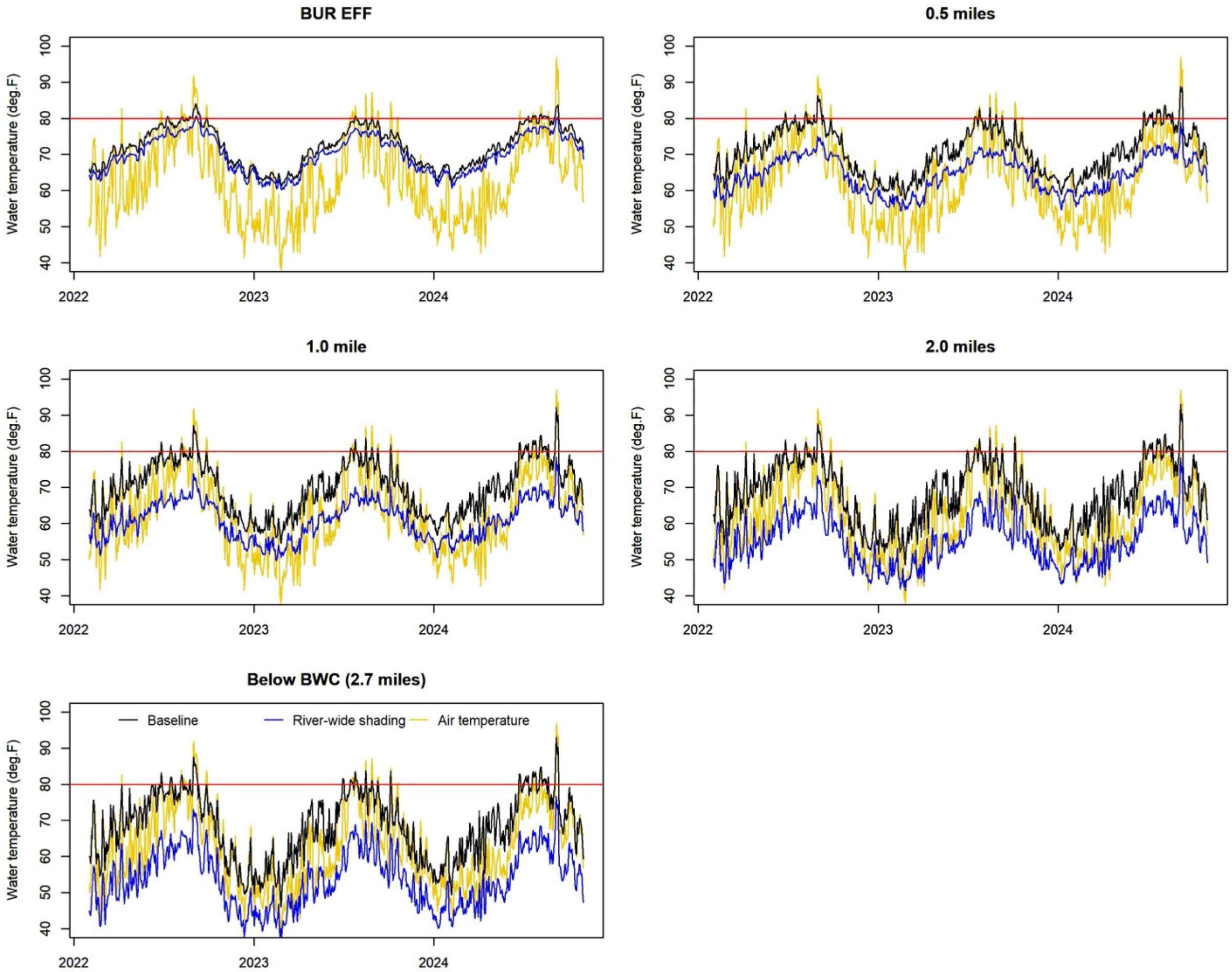

Figure 51. Time series of BWC temperatures and air temperature for current conditions and with river-wide shading (80% shading and 15% reduction in local air temperature) at and downstream from the BWRP

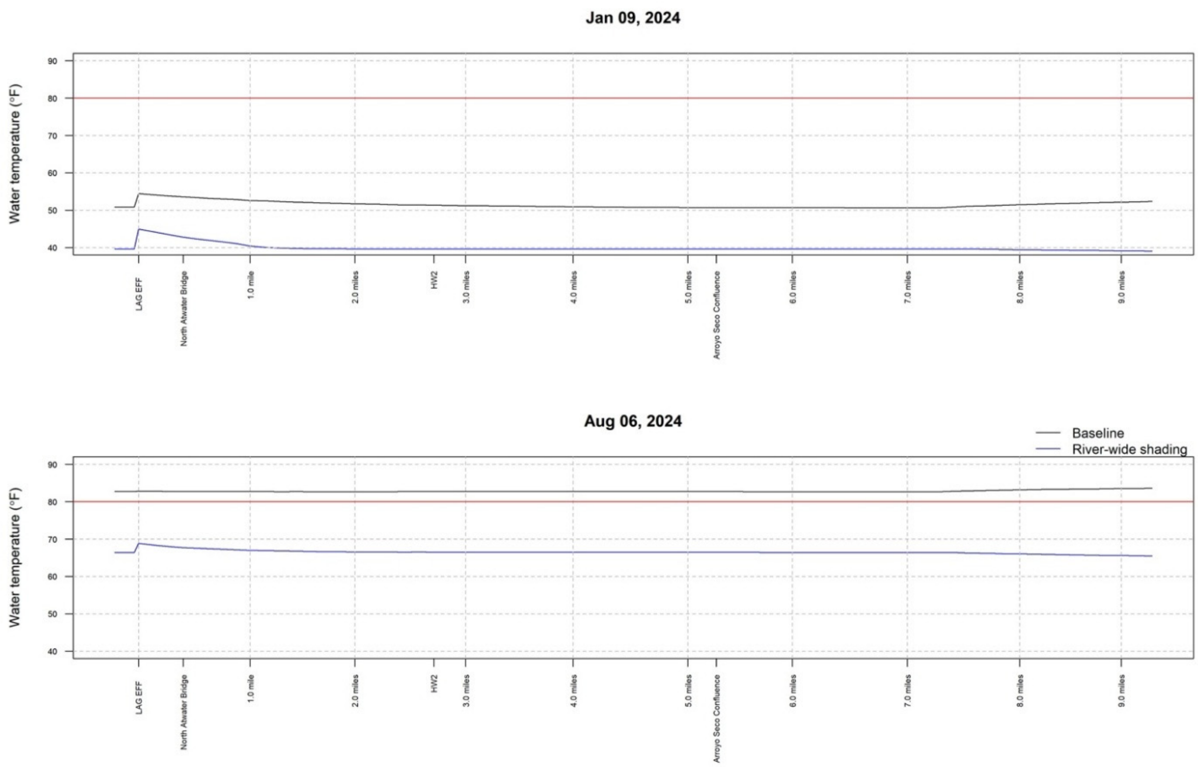

Figure 52. LA River water temperatures downstream of the DCTWRP for current condition and with river-wide shading (80% shading and 15% reduction in local air temperature)

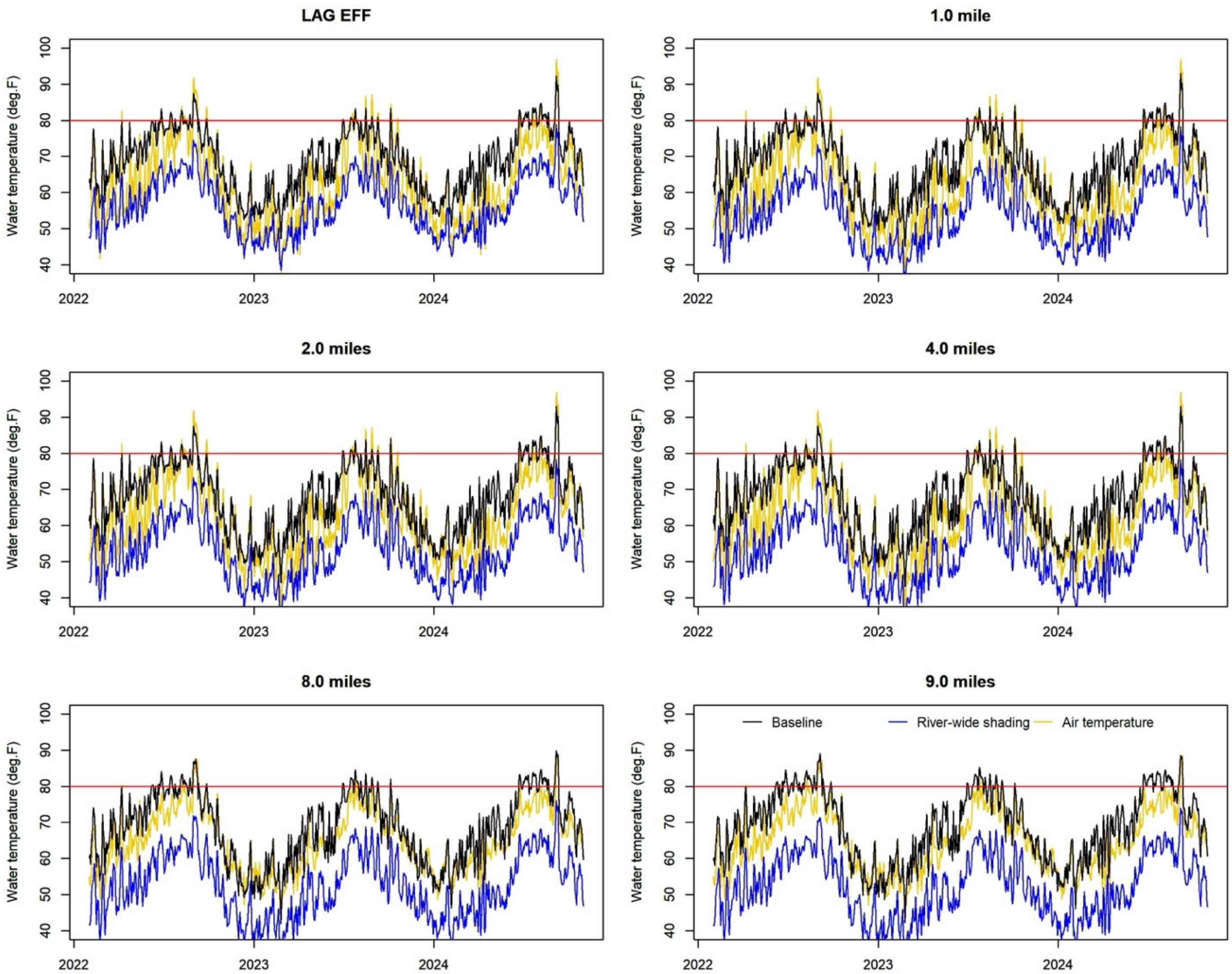

Figure 53. Time series of LA River temperatures and air temperature for current conditions and with river-wide shading (80% shading and 15% reduction in local air temperature) at and downstream from the LAGWRP

SECTION 9 SUMMARY

A temperature model for the LA River and BWC was created for this study to evaluate potential control measures, climate change effects, and water temperature changes downstream of discharges. The backbone for the temperature model was the LA River Environmental Flows HEC-RAS hydraulic model, which was updated to include the BWC and the three WRPs as explicit boundary conditions. The model was successfully calibrated and achieved a mean absolute error of 1.2°C and a mean absolute percent error under 5%, which is considered very good as described in guidelines for modeling developed by the Regional Board[34].

The temperature model was used to evaluate effluent temperature control, effluent flowrate reduction, and riparian shading control measures. Scenarios comprised of multiple control measures implemented concurrently were also analyzed. Additionally, the effect of climate change on the receiving water temperatures and future effectiveness of control measures were assessed. Effluent temperature reduction was determined to have the greatest effect on receiving water temperatures at the point of discharge. However, during the hottest months of the year, receiving water temperatures returned to baseline (i.e., within ± 1°F) downstream of the WRPs in less than 0.5 to 2 miles on average. The model produced similar results for the effluent flowrate reduction control measure, with receiving water temperatures quickly returning to equilibrium conditions. The shading control measure also had limited effect on receiving water temperatures.

In addition, it was determined that the scenarios combining potential control measures did not show synergetic gains in temperature reduction. Similar to the results for the individual control measures, either receiving water temperatures are not significantly affected or they relatively quickly return to baseline conditions due to factors outside of the control of the WRPs. None of the individual control measures or combinations of control measures result in the consistent attainment of the 80°F objective downstream of the WRPs. Furthermore, it was found that temperatures downstream of the WRPs can still increase more than 5°F due to other factors such as air temperature and solar radiation. It should also be noted that the 80°F objective is, at times, exceeded even upstream of the WRPs.

The effects of climate change were assessed for a time period extending 30-years in the future, and the model indicated that the receiving water temperatures would increase by a few degrees. On the river reach scale, there is no meaningful difference in the receiving water temperature for individual control measures or combinations of control measures, as temperatures returned to the baseline within the reach.

Lastly, at the request of the TAC, two additional river shading scenarios (involving densified vegetation) were also explored. However, the first scenario did not result in consistent attainment of the 80°F objective, while the other effectively required the de-urbanization of areas surrounding the waterbodies in the Study area. Both scenarios were found to be infeasible to implement due to effects on flood control capacity, other beneficial uses, and, in the case of the second scenario, de-urbanization, which are beyond the responsibilities of the WRPs.

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[34] Los Angeles Regional Water Quality Control Board (LARWQCB). 2014. Guidelines for Conducting Reasonable Assurance Analysis in a Watershed Management Program, Including an Enhanced Watershed Management Program.

Appendices

Appendix A: Temperature Model Boundary Conditions and Calibration

A.1 Boundary Conditions

Data sources used for flow and temperature boundary conditions for the temperature model. are listed in **Table A-1**. Data availability for each location are shown in **Section 5.2.5**. Linear interpolation was used to fill data gaps in the WPR data. Where data gaps exist in receiving water boundary condition datasets, they are filled by a combination of interpolation and regression with air temperature. The initial calibration of the model was performed prior to collection of the high frequency coordinated temperature monitoring in 2024. The initial calibration largely relied on the daily or weekly WRP temperature monitoring. A final calibration was performed after the 2024 monitoring data were available.

Table A-1. Boundary conditions in initial and final calibrations of HEC-RAS water temperature model.

Boundary conditions	Initial calibration	Final calibration	
		WRPs and gauges for data before Apr 2024	Thermistors for data in Apr - Oct 2024
Upstream LA River Boundary (Upper Sepulveda Basin)	LAR_06_WHI	LAR_06_WHI	
DCTWRP to Balboa Lake Weir	RSW-4 (4)	DCTWRP Effluent	DCTWRP Eff 001
DCTWRP to Wildlife Lake	RSW-W2 (W-2)	DCTWRP Effluent	DCTWRP Eff 001
DCTWRP Discharge to LA River	DCTWRP Effluent	DCTWRP Effluent	DCTWRP Eff 001
Upstream BWC Boundary	RSW002U	RSW002U	BWC Up
BWRP Discharge to BWC	002 Eff	002 Eff	BWRP Eff 001
LAGWRP Discharge to LA River	LAGWRP Effluent	LAGWRP Effluent	LAGWRP Eff 001
Rio Hondo Channel Boundary	4D	4D	
Compton Creek Boundary	5C	5C	

For DCTWRP discharges from Balboa and Wildlife Lakes, the initial calibration utilized the respective receiving water monitoring data for the boundary condition. To assess a simplification of using the DCTWRP effluent temperature for the lakes and direct river discharge, the heat energy balance predicted using only Eff 001 was compared to the energy balance calculated using the thermistor measured values. If the total heat energy of the only DCTWRP Eff 001 is similar to the heat balance of using individual temperatures, the model can be simplified and effluent temperature control measures modeled in a straightforward manner. The heat balance using only DCTWRP Eff 001 is calculated with the following equation:

$$Tw_{prediction} = \frac{Q_{Balboa}}{Q_{Total}} \times Tw_{Balboa} + \frac{Q_{Wildlife}}{Q_{Total}} \times Tw_{Wildlife} + \frac{Q_{008}}{Q_{Total}} \times Tw_{008}$$

$$= 0.622 \times Tw_{Eff001} + 0.154 \times Tw_{Eff001} + 0.224 \times Tw_{Eff001}$$

$$= Tw_{Eff001}$$

$$Q_{Total} = Q_{Balboa} + Q_{Wildlife} + Q_{008}$$

The heat balance using the thermistor measurements are calculated using the below equation:

$$Tw_{Thermistors} = 0.622 \times Tw_{Balboa\ (thermistor)} + 0.154 \times Tw_{Wildlife\ (thermistor)} + 0.224 \times Tw_{008\ (thermistor)}$$

With $Q_{Total}, Q_{Balboa}, Q_{Wildlife}, Q_{008}$ are respectively mean values of total DCTWRP flow, Balboa Lake flow, Wildlife flow, and DCT effluent discharge 008 during January 1, 2022 and October 31, 2024; $Tw_{prediction}, Tw_{Balboa}, Tw_{Wildlife}, Tw_{008}$ are respectively predicted water temperature as energy balance between heat and flow from Balboa, Wildlife Lakes, and DCT effluent discharge 008, predicted water temperature downstream of Balboa Lake, Wildlife Lake, DCT effluent discharge 008; in **Figure A-1**, $Tw_{Balboa\ (thermistor)}$ is measured at thermistor "400 feet upstream from the outlet spillway"; $Tw_{Wildlife\ (thermistor)}$ is measured at thermistor "South of the island, near the westerly lake shoreline"; $Tw_{008\ (thermistor)}$ is measured at thermistor "DCTWRP Effluent (008)".

Figure A-1. Predicted water temperatures, derived from an energy balance of flow and heat, were compared to thermistor measurements downstream of Balboa, Wildlife Lakes, and DCTWRP effluent 008 in 2024

The predicted water temperatures from the above energy balances are shown in **Figure A-2**. The modeled water temperature matched the measured water temperature well. As such, using the simplification of DCTWRP Effluent temperature for boundary conditions at Balboa and Wildlife Lakes is acceptable.

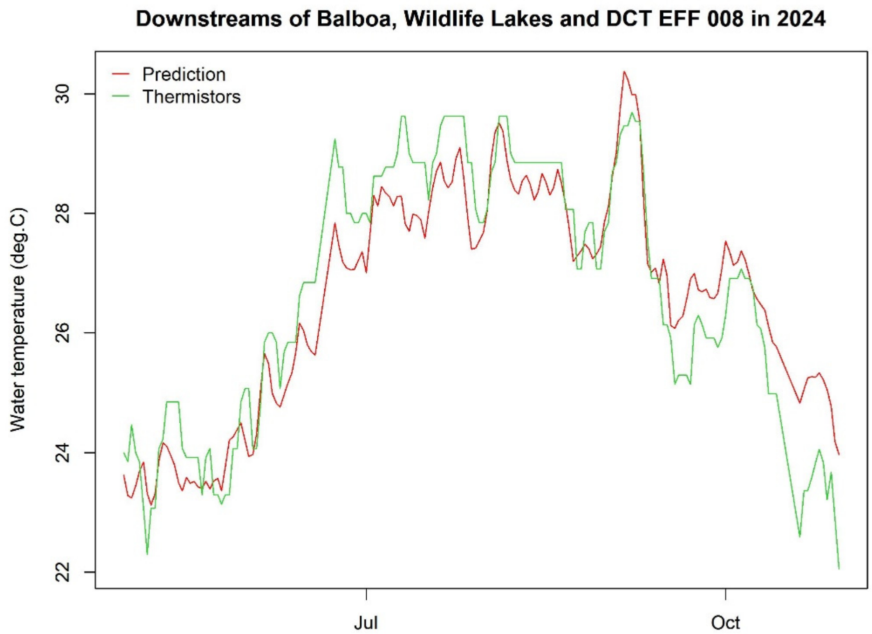


Figure A-2. Modeled water temperatures, derived from an energy balance of flow and heat, were compared to thermistor measurements downstream of Balboa, Wildlife Lakes, and DCT effluent 008 in 2024

A.2 Calibration

The initial calibration of the HEC-RAS temperature model was performed using data available prior to April 2024. As shown in the data availability plots in **Section 5.2.5**, outside of the WRP specific data, receiving water data are relatively sparce and not congruent in time. Over 15 trial combinations of calibration parameters, the 7th was found to fit the available data best. Calibration parameters and model fit metrics are shown in **Table A-2**. While the model performance was "good"[1], the available data only allowed a single point calibration setting the model parameters constant across the domain.

After the 2024 high-frequency were available the model was recalculated. The trial calibrations 16 through 30 are listed in **Table A-3**. The density of data was sufficient to have a multiple-point calibration and resulted in a greatly improved calibration. Two trial calibrations had nearly identical performance metrics; however, the selected trial (#28) fit the receiving water locations in the upper and lower reaches of the model better (see **Section 5.2.5.1** for a discussion). The recalibrated model performance was rated "very good"[2]. Timeseries of modeled temperatures compared to the measured values for receiving water locations with available data are presented in **Figure A-3** through **Figure A-21**.

While the calibration is very good over the range of conditions experienced in the study area, during periods of extremely high air temperatures (i.e., >100^{0}F) the model tends to overpredict the water temperature. However, for the bulk of summer days, which do not have extremely high air temperatures, the model predictions represent the measured receiving water temperatures well. The primary use case of the model is to investigate the modeled receiving water temperature response to control measures compared to modeled baseline conditions. Under some modeling circumstances, a post-processing

[1] Los Angeles Regional Water Quality Control Board (LARWQCB). 2014. Guidelines for Conducting Reasonable Assurance Analysis in a Watershed Management Program, Including an Enhanced Watershed Management Program.

[2] Los Angeles Regional Water Quality Control Board (LARWQCB). 2014. Guidelines for Conducting Reasonable Assurance Analysis in a Watershed Management Program, Including an Enhanced Watershed Management Program.

“correction factor’ may be applied to the predicted receiving water temperatures. For this use case, application of a correction factor to the model output would be applied to both baseline and control measure/scenario model runs, essentially cancelling itself out. Ultimately, the model would retain the observed behavior of water temperature returning to baseline conditions downstream of the applied control measure.

Table A-2. Parameter sets for <u>initial calibration</u> of Los Angeles River water temperature model

Bold *numbers represent the best performance model. The selected optimal model is model 7*.*

Parameter	Baseline	Calibration Run														
		1	2	3	4	5	6	7*	8	9	10	11	12	13	14	15
Model Parameters																
wind_a	9.2	9.2	1.5	1.5	1.5	1	1	1	1	1	1	1	1	1	1	1
wind_b	4.6	4.6	3	3	3	3	2	2	2	2	1	2	2	2	2	2.5
wind_c	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
wind_kh_kw	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
day_coef	1	1	1	1.1	1.2	1.2	1.2	1.2	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
night_coef	1	0.8	0.8	0.9	1	1	1	1	1	1	1	1	1	1	1	1
coef1 (Jan)	---	---	---	---	---	---	---	---	0.9	0.85	---	0.85	0.95	0.85	0.95	---
coef2 (Feb)	---	---	---	---	---	---	---	---	1	1	---	1	1	1	1.03	---
coef3 (Mar)	---	---	---	---	---	---	---	---	1	1	---	1	1	1	1	---
coef4 (Apr)	---	---	---	---	---	---	---	---	1	1	---	1	1	1	1	---
coef5 (May)	---	---	---	---	---	---	---	---	1	1	---	1	1	1	1	---
coef6 (Jun)	---	---	---	---	---	---	---	---	1	1	---	1	1	1	1	---
coef7 (Jul)	---	---	---	---	---	---	---	---	1	1	---	1	1	1	1	---
coef8 (Aug)	---	---	---	---	---	---	---	---	1	1	---	1	1	1	1	---
coef9 (Sep)	---	---	---	---	---	---	---	---	1	1	---	1	1	1	1	---
coef10 (Oct)	---	---	---	---	---	---	---	---	0.9	1.05	---	1	1.05	1	1	---
coef11 (Nov)	---	---	---	---	---	---	---	---	0.9	1.05	---	1	1.05	1	1	---
coef12 (Dec)	---	---	---	---	---	---	---	---	0.9	1.05	---	1	1.05	1	1	---
Performance Metrics																
RMSE (deg. C)	4.91	4.91	2.85	2.85	2.85	2.64	2.33	**2.23**	2.24	2.19	2.22	2.2	2.21	2.2	2.22	2.35
MAE (deg. C)	4.41	4.41	2.39	2.39	2.39	2.17	1.82	**1.72**	1.72	1.70	1.63	1.7	1.71	1.7	1.71	1.85
MAPE (%)	18.3	18.3	10.3	10.3	10.3	9.39	8.19	**7.86**	7.78	7.71	7.86	7.72	7.81	7.72	7.79	8.24
R^2	0.75	0.75	0.77	0.77	0.77	0.78	0.77	**0.78**	0.78	0.79	0.77	0.79	0.78	0.79	0.78	0.78

Table A-3. Parameter sets for final calibration of Los Angeles River water temperature model
Bold *numbers represent the best performance. The selected optimal model is model 28.*

Parameters	Baseline	Calibration Run															
		7*	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Model Parameters																	
wind_a	9.2	1	1	1	2	1	1	2	5	3	3	3	3	3	3	3	3
wind_b	4.6	2	2	2	2	3	2	3	4	4	2	2	2	2	2	2	2
wind_c	2	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1
wind_kh_kw	1	0.5	0.5	1	0.5	0.5	0.5	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5
day_coef	1	1.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
night_coef	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
downstream_soleqn	F	F	F	F	F	F	F	F	F	F	F	F	F	T	T	T	T
downstream_soleqn_coef														2	1.7	1.5	1.6
soleqn	F	T	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
soleqn_hourly	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
soleqn_min110	T	T	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Performance Metrics																	
RMSE (deg. C)	4.9	2.2	1.5	1.5	1.6	**1.5**	1.8	1.7	2.5	2.1	1.9	1.8	1.8	1.8	**1.5**	1.5	1.5
MAE (deg. C)	4.4	1.7	1.2	1.2	1.2	**1.2**	1.5	1.4	2.1	1.8	1.6	1.5	1.5	1.5	**1.2**	1.2	1.2
MAPE (%)	18.3	7.9	5.0	5.1	5.3	**4.9**	6.2	5.9	9.0	7.5	6.6	6.1	6.3	6.4	**4.9**	5.2	5.0
R2	0.8	0.8	0.8	0.8	0.9	**0.8**	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	**0.8**	0.8	0.8

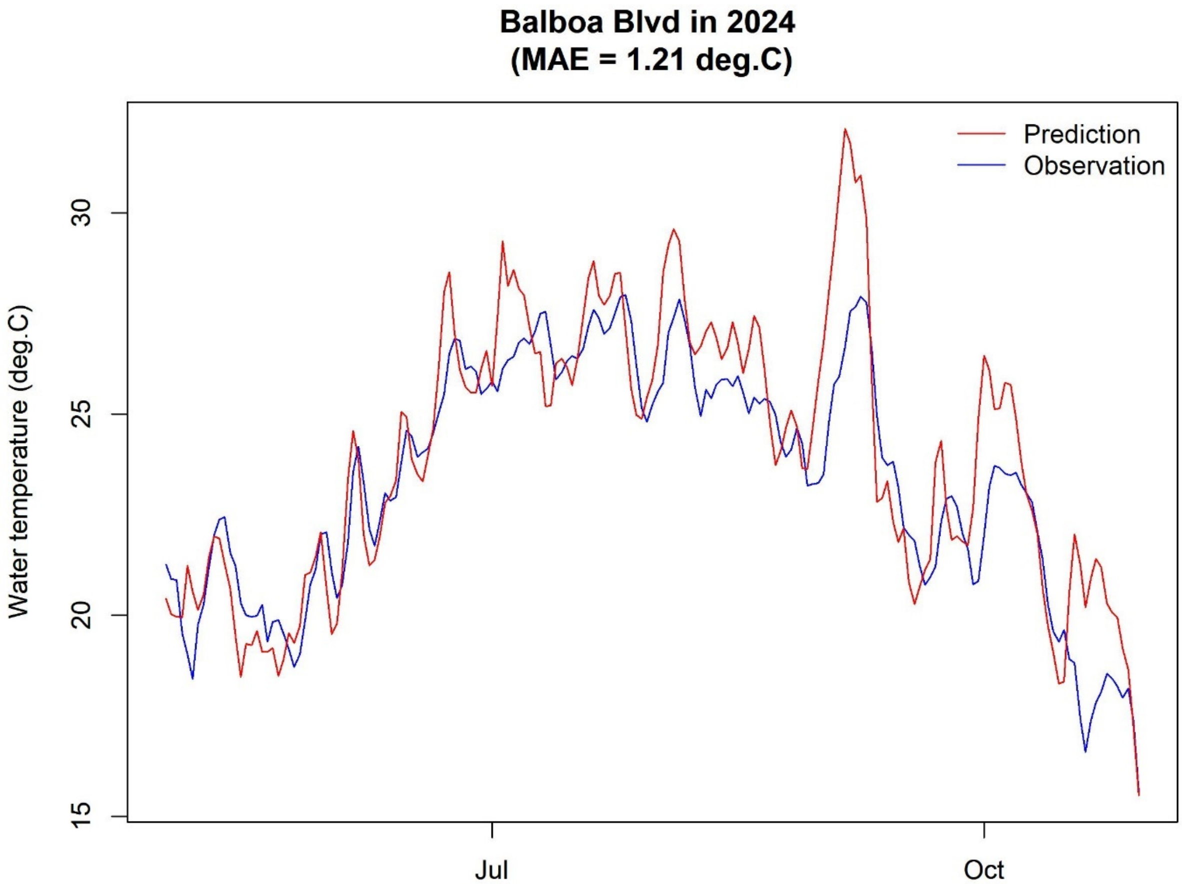


Figure A-3. Comparison between time series of modeled and observed water temperature in thermistor site "Balboa Blvd" in 2024

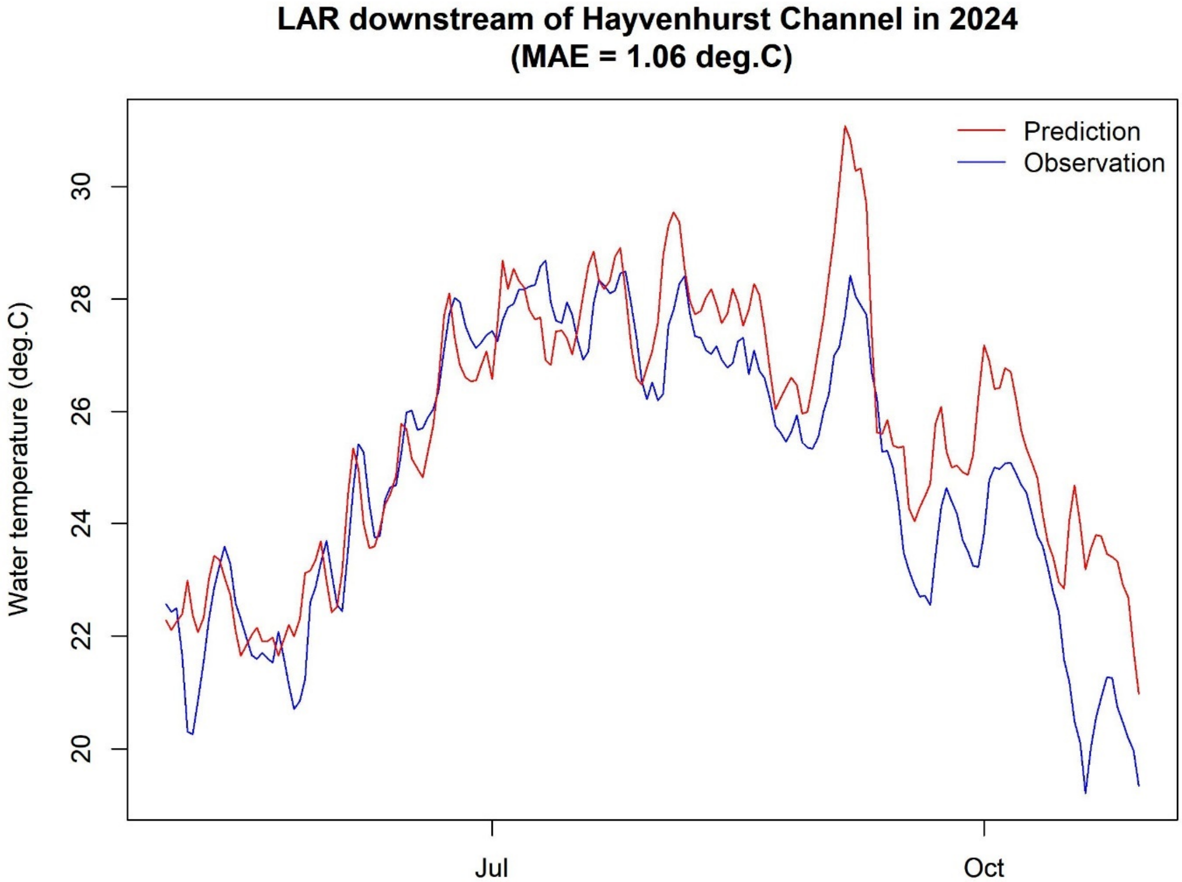


Figure A-4. Comparison between time series of predicted and observed water temperature in thermistor site "LAR downstream of Hayvenhurst Channel" in 2024

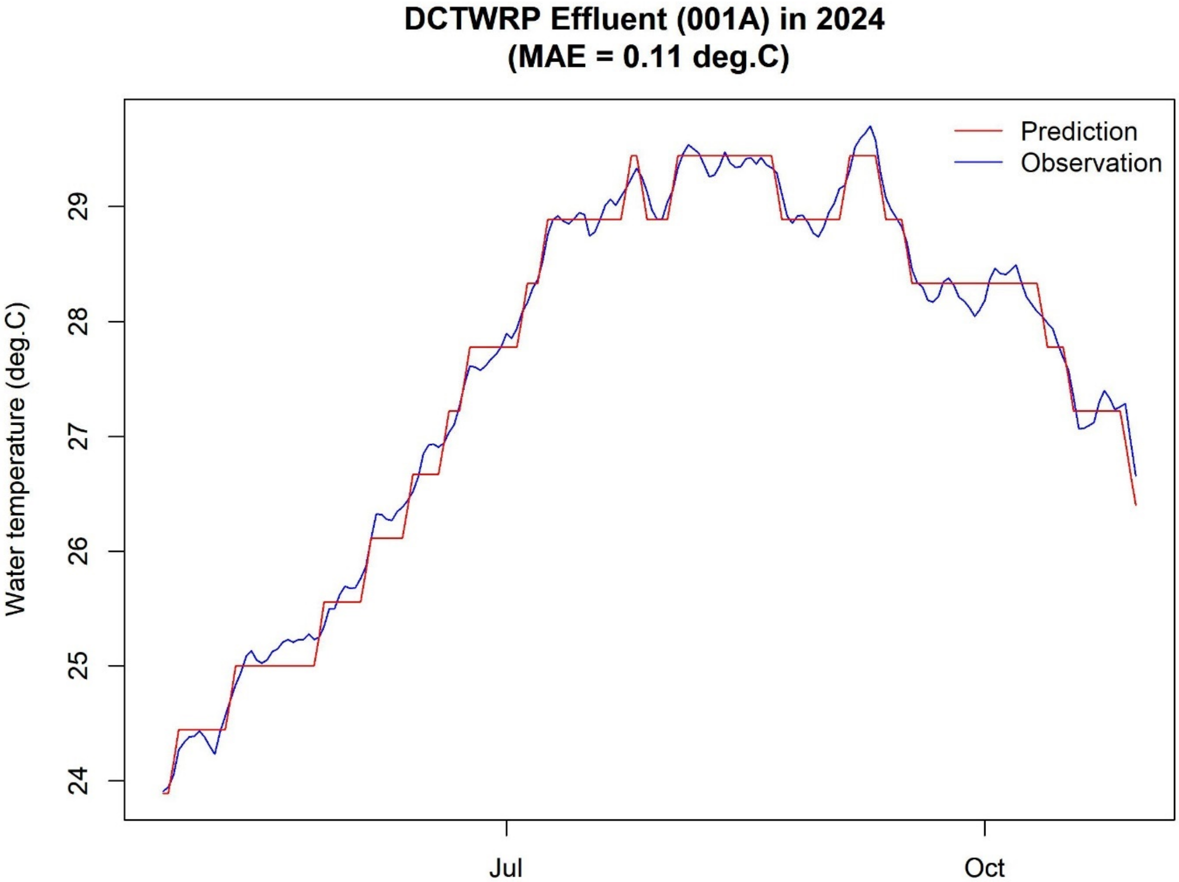


Figure A-5. Comparison between time series of modeled and observed water temperature in thermistor site "DCTWRP Effluent (001A)" (boundary condition) in 2024

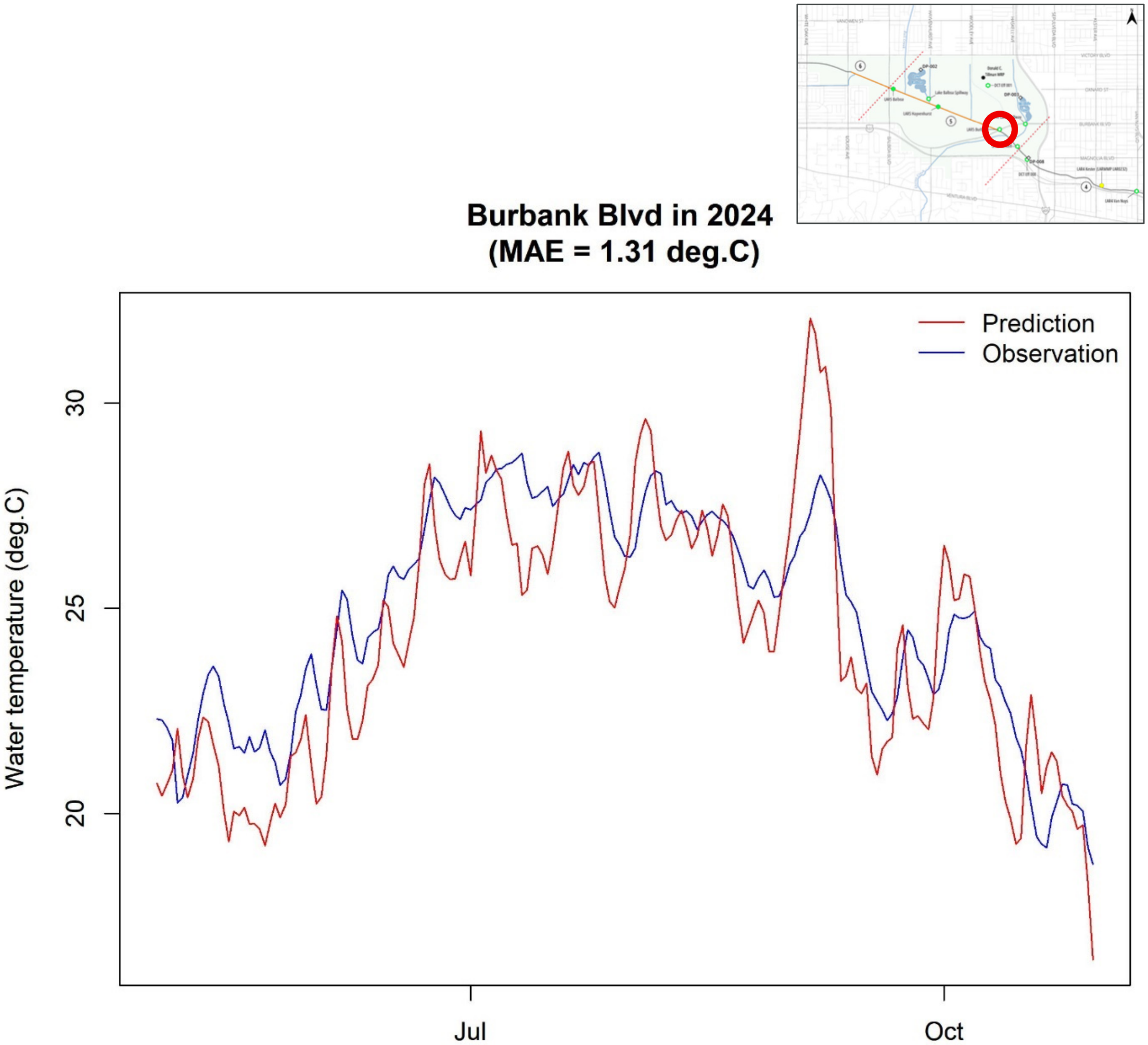


Figure A-6. Comparison between time series of predicted and observed water temperature in thermistor site "Burbank Blvd" in 2024

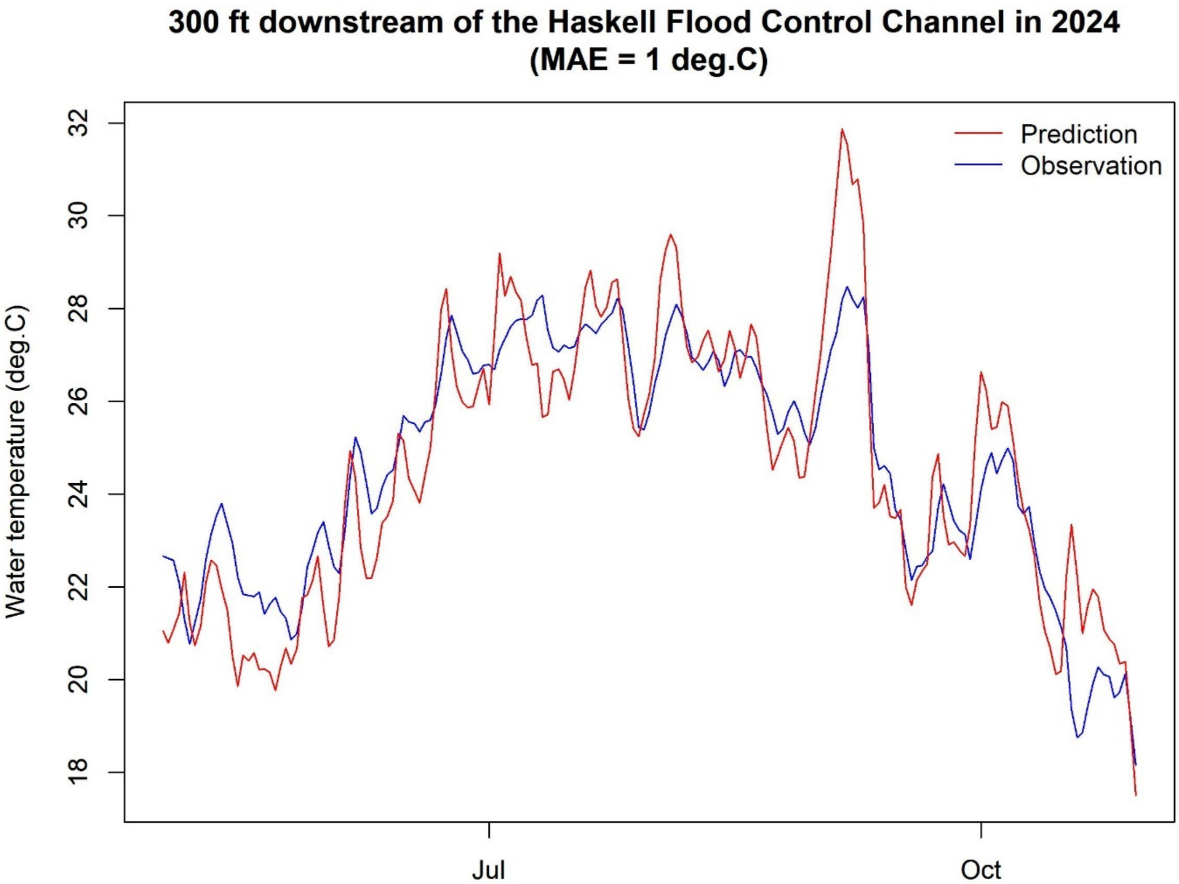


Figure A-7. Comparison between time series of predicted and observed water temperature in thermistor site "300 ft downstream of the Haskell Flood Control Channel" in 2024

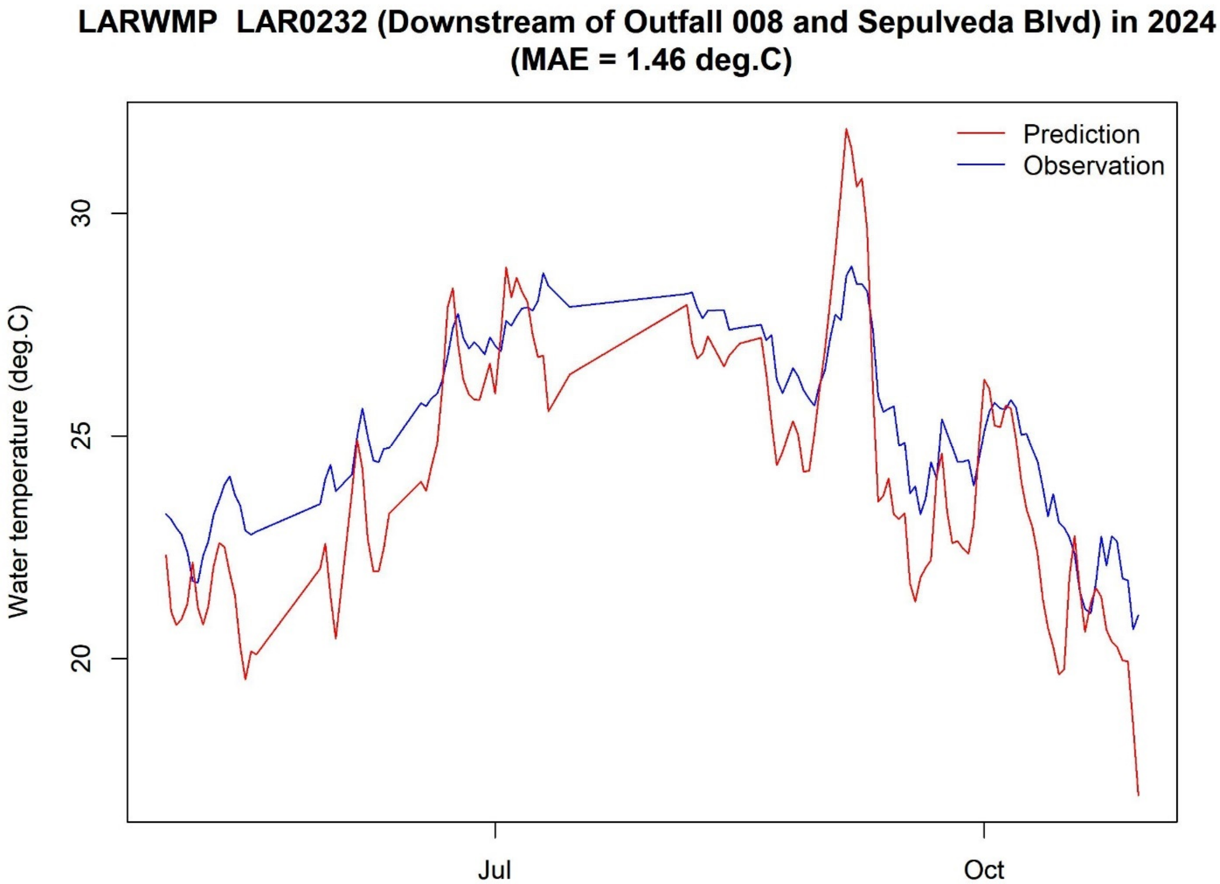


Figure A-8. Comparison between time series of predicted and observed water temperature in thermistor site "LARWMP LAR0232 (Downstream of Outfall 008 and Sepulveda Blvd)" in 2024

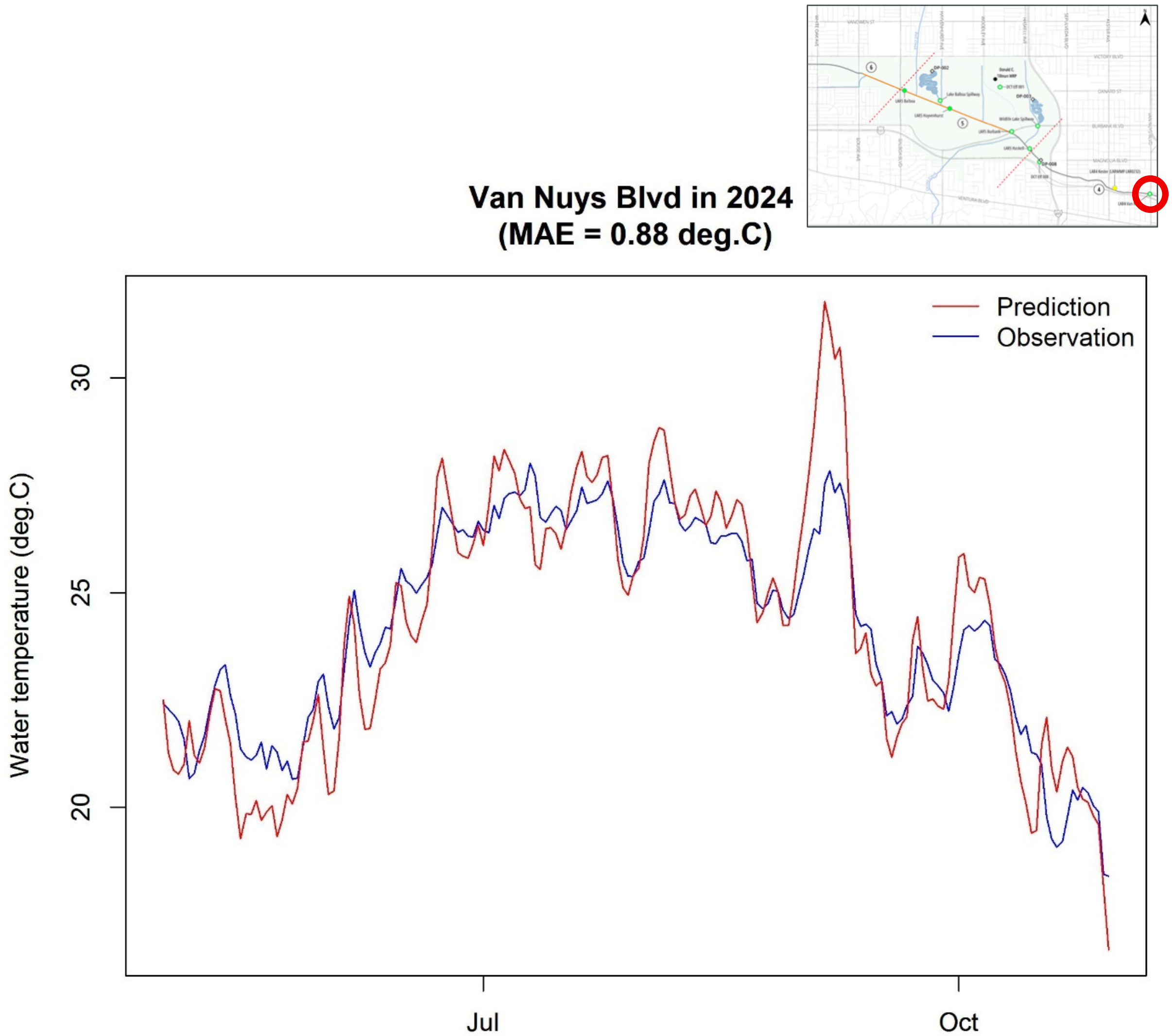


Figure A-9. Comparison between time series of predicted and observed water temperature in thermistor site "Van Nuys Blvd" in 2024

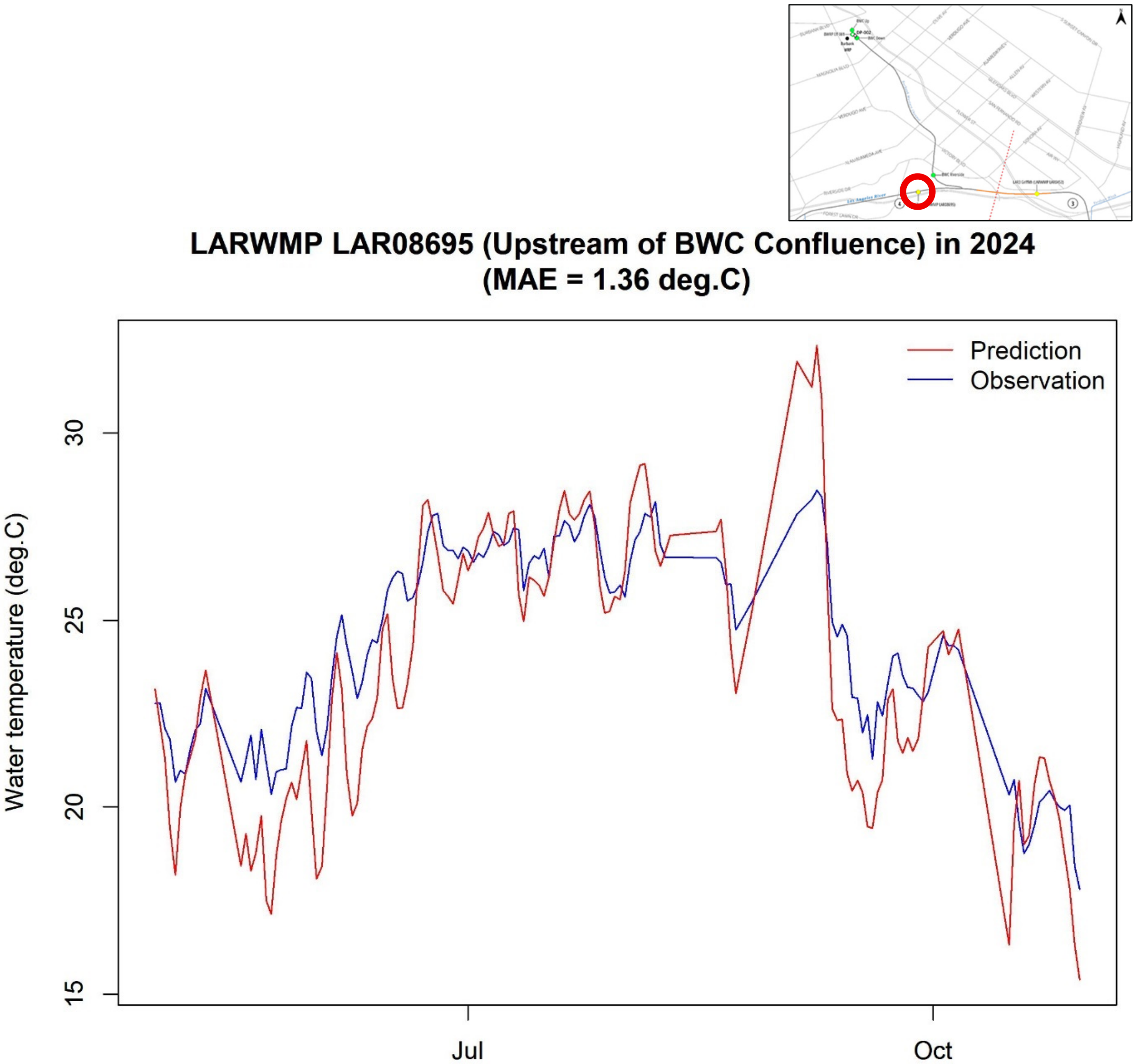


Figure A-10. Comparison between time series of predicted and observed water temperature in thermistor site “LARWMP LAR08695 (LAR4 Zoo Upstream of BWC Confluence)” in 2024

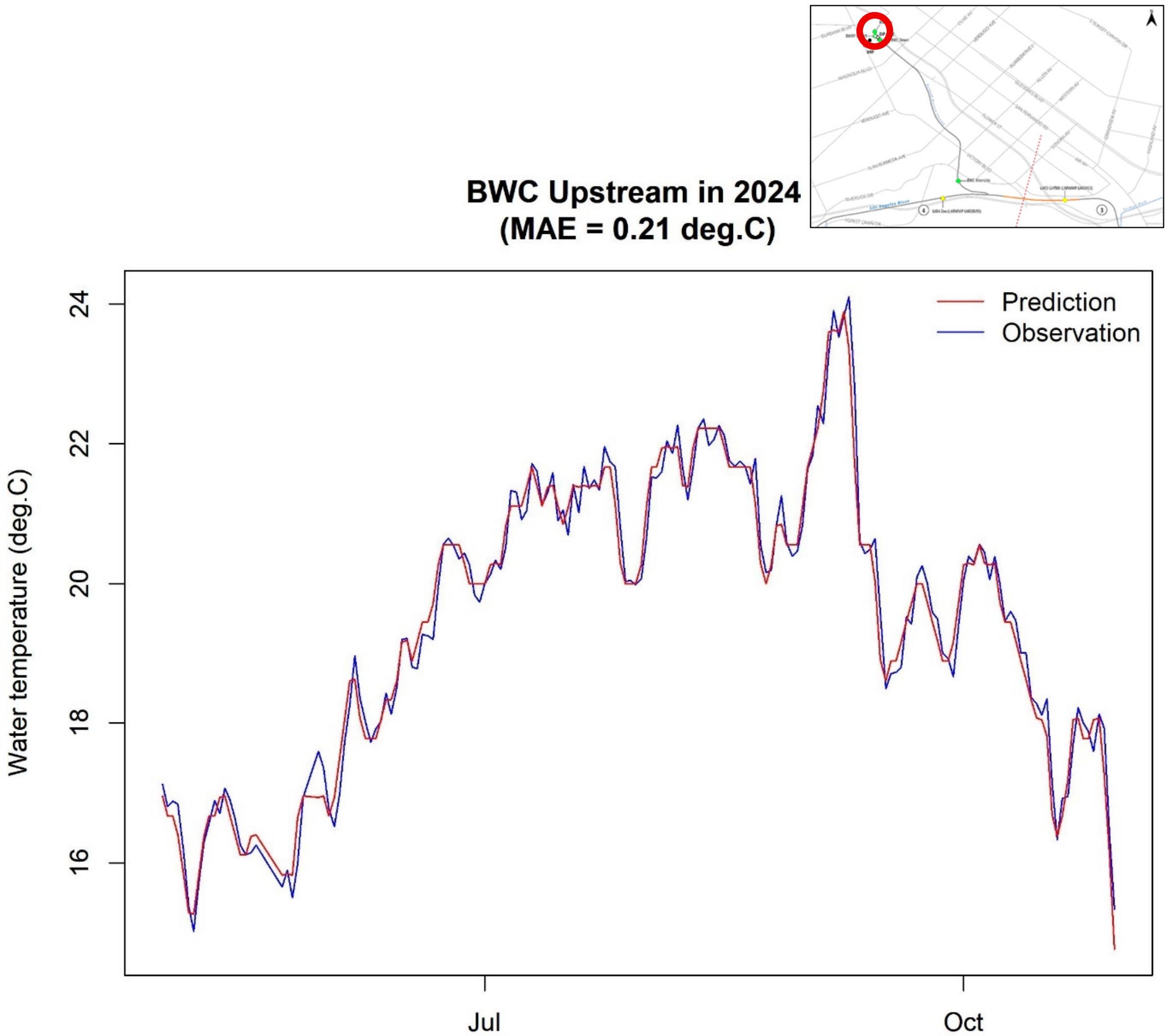


Figure A-11. Comparison between time series of modeled and observed water temperature in thermistor site "BWC Upstream" (boundary condition) in 2024

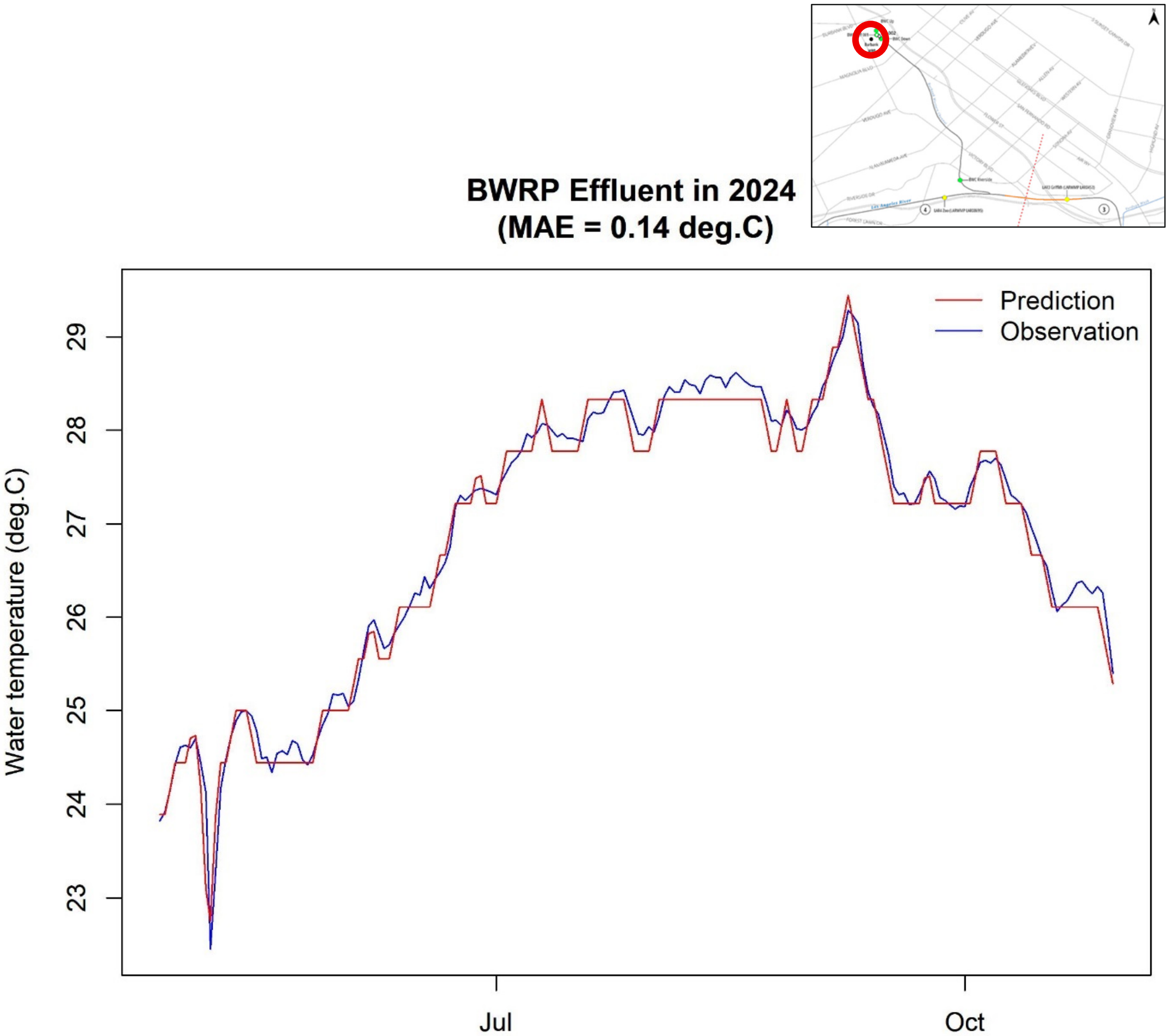
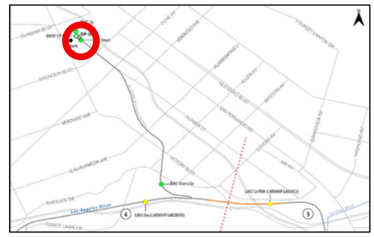


Figure A-12. Comparison between time series of modeled and observed water temperature in thermistor site "BWRP Effluent" (boundary condition) in 2024



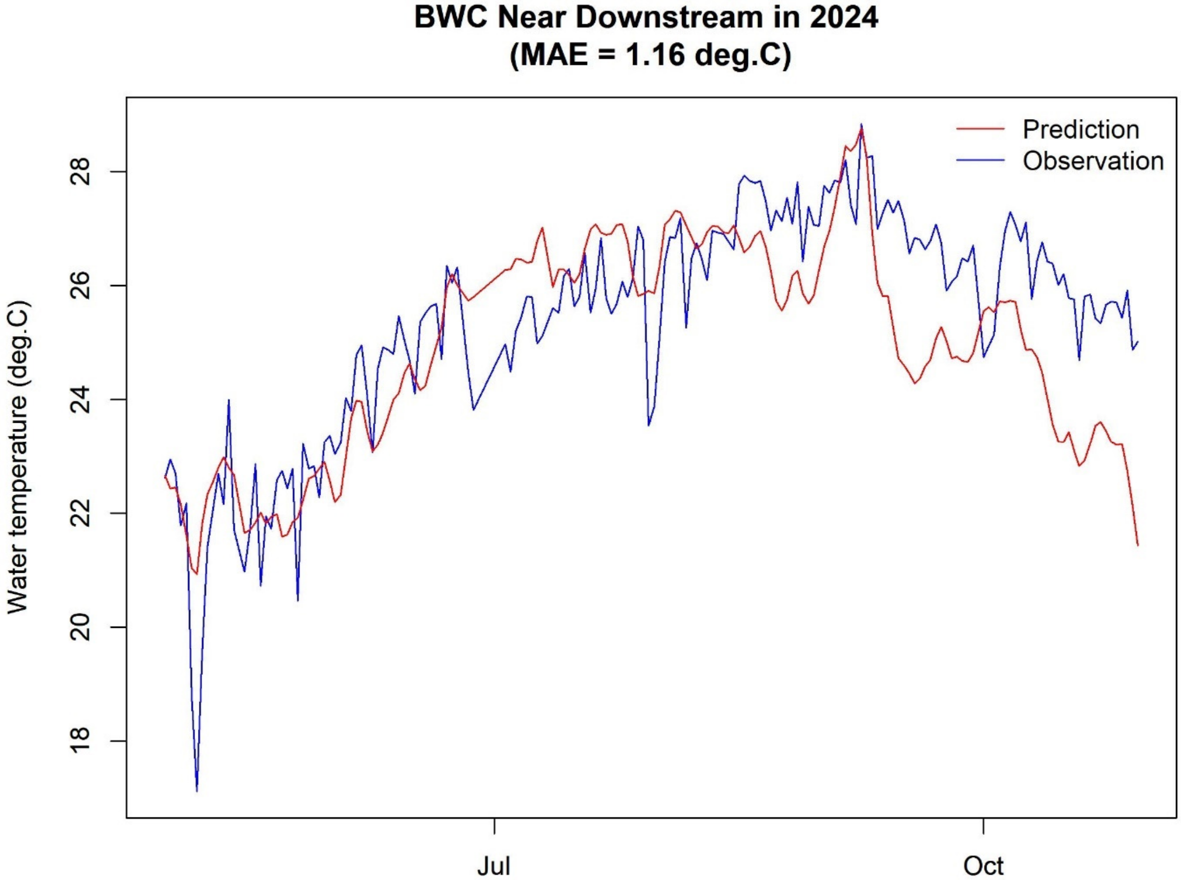
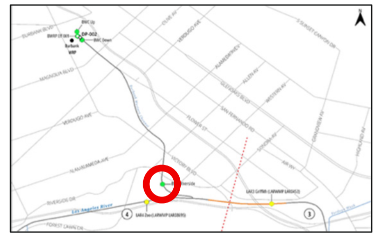


Figure A-13. Comparison between time series of predicted and observed water temperature in thermistor site "BWC Near Downstream" in 2024



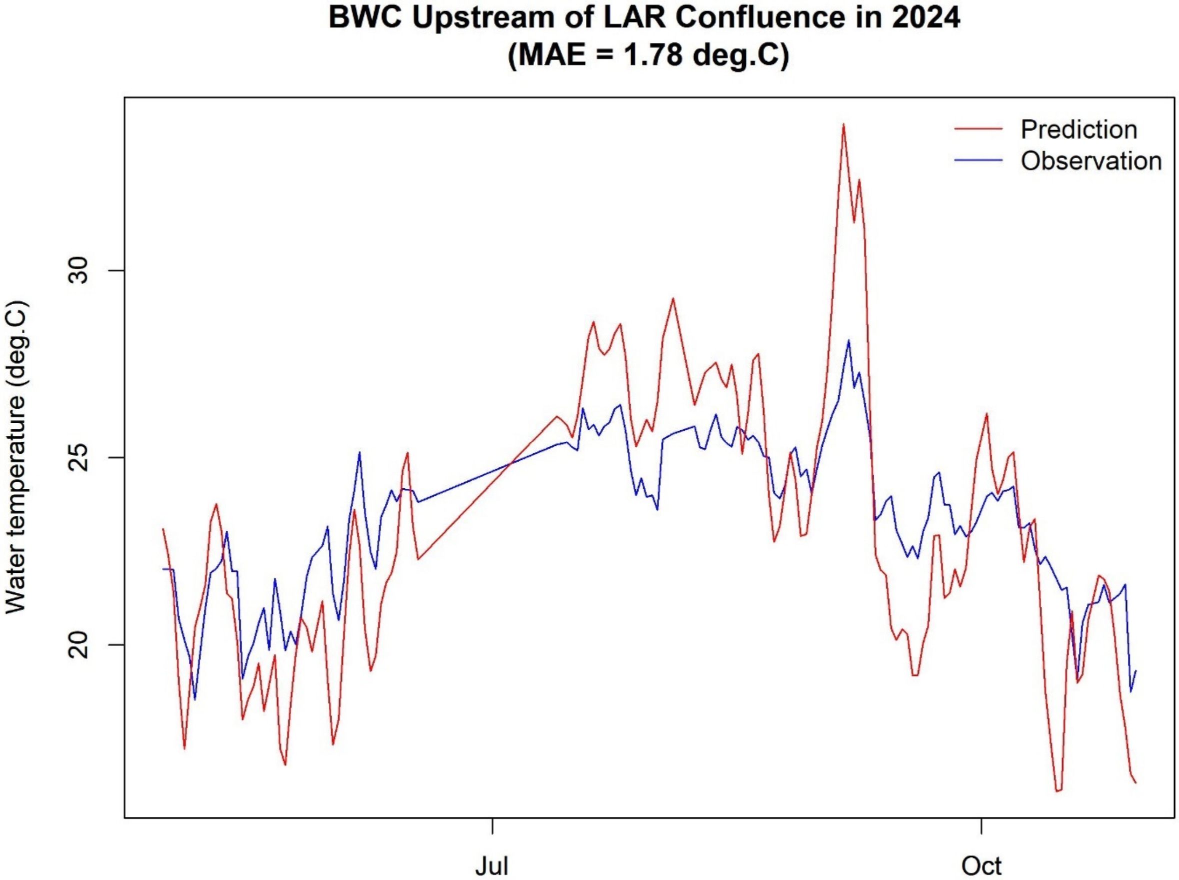


Figure A-14. Comparison between time series of predicted and observed water temperature in thermistor site "BWC Upstream of LAR Confluence" in 2024

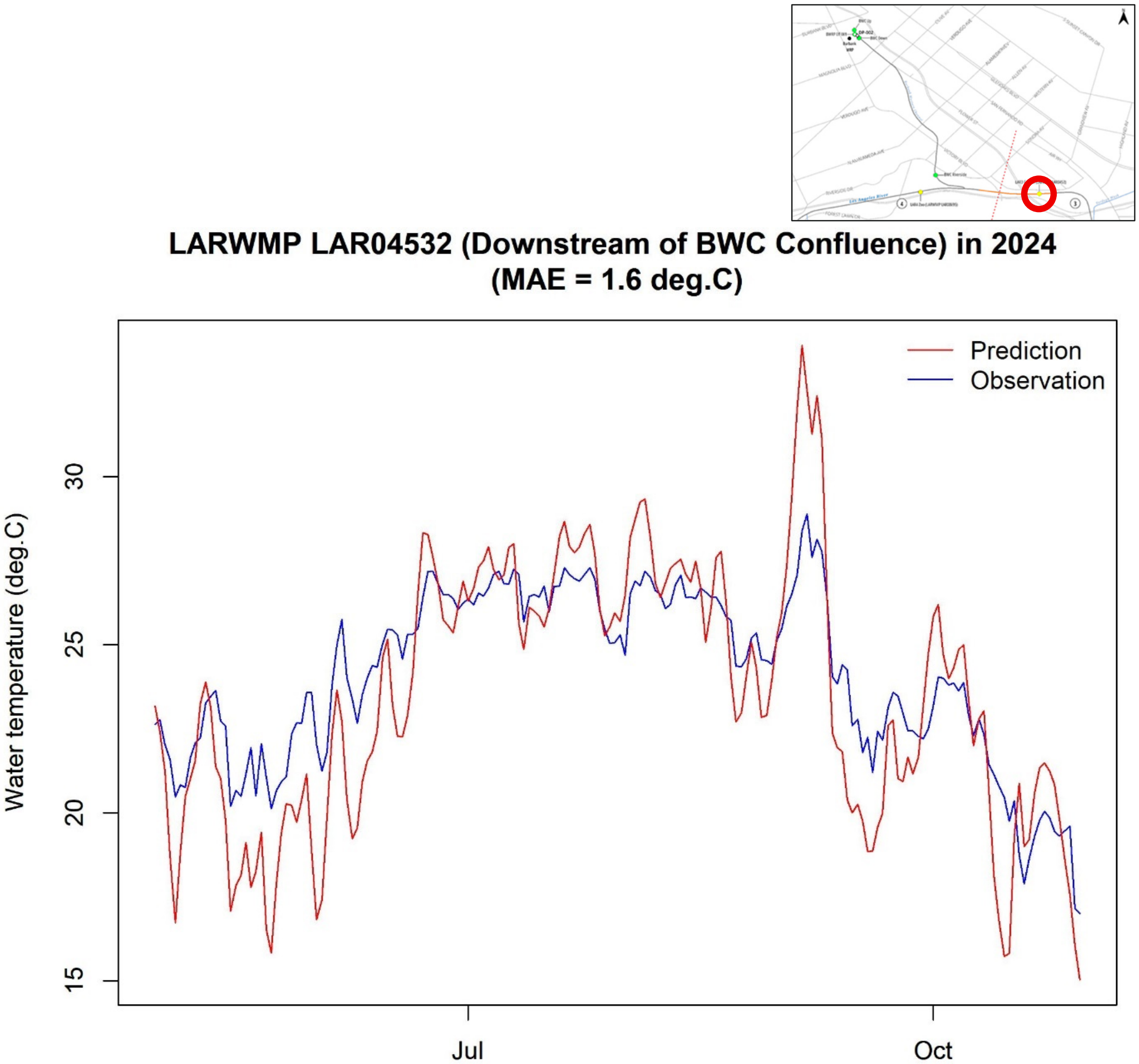
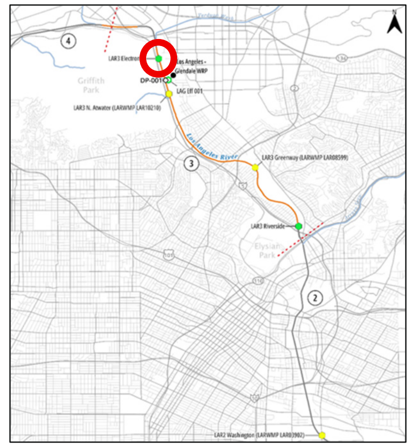


Figure A-15. Comparison between time series of predicted and observed water temperature in thermistor site "LARWMP LAR04532 (LAR3 Griffith Downstream of BWC Confluence)" in 2024



Electronics Place in 2024
(MAE = 1.7 deg.C)

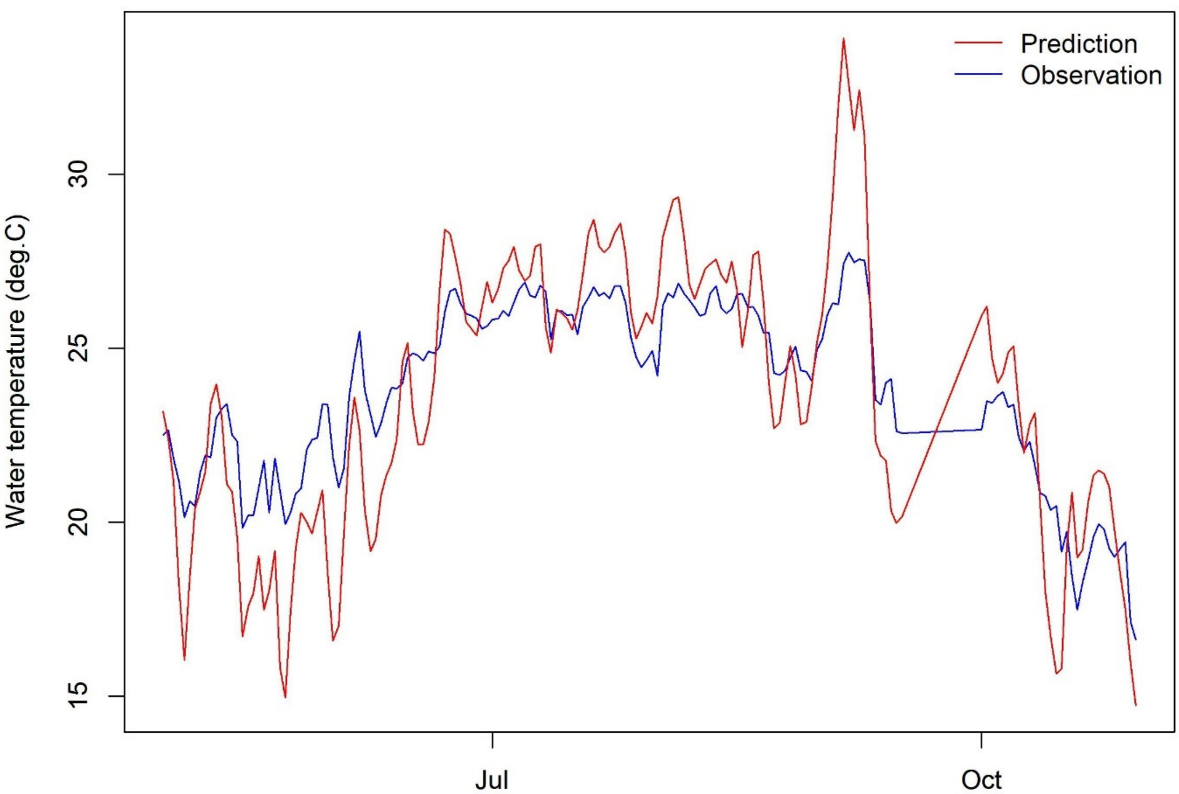


Figure A-16. Comparison between time series of predicted and observed water temperature in thermistor site "Electronics Place" in 2024

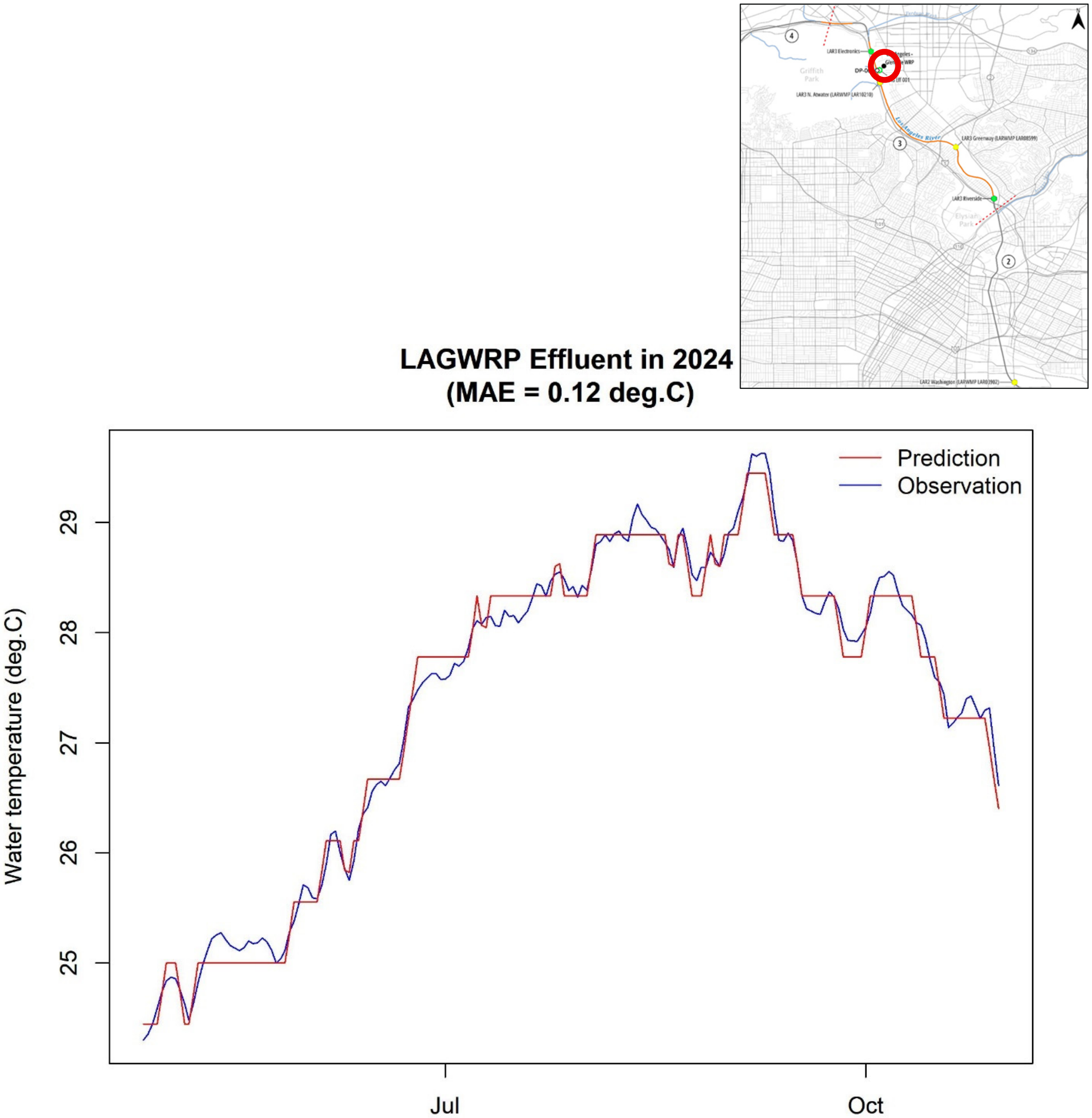


Figure A-17. Comparison between time series of modeled and observed water temperature in thermistor site "LAGWRP Effluent" (boundary condition) in 2024

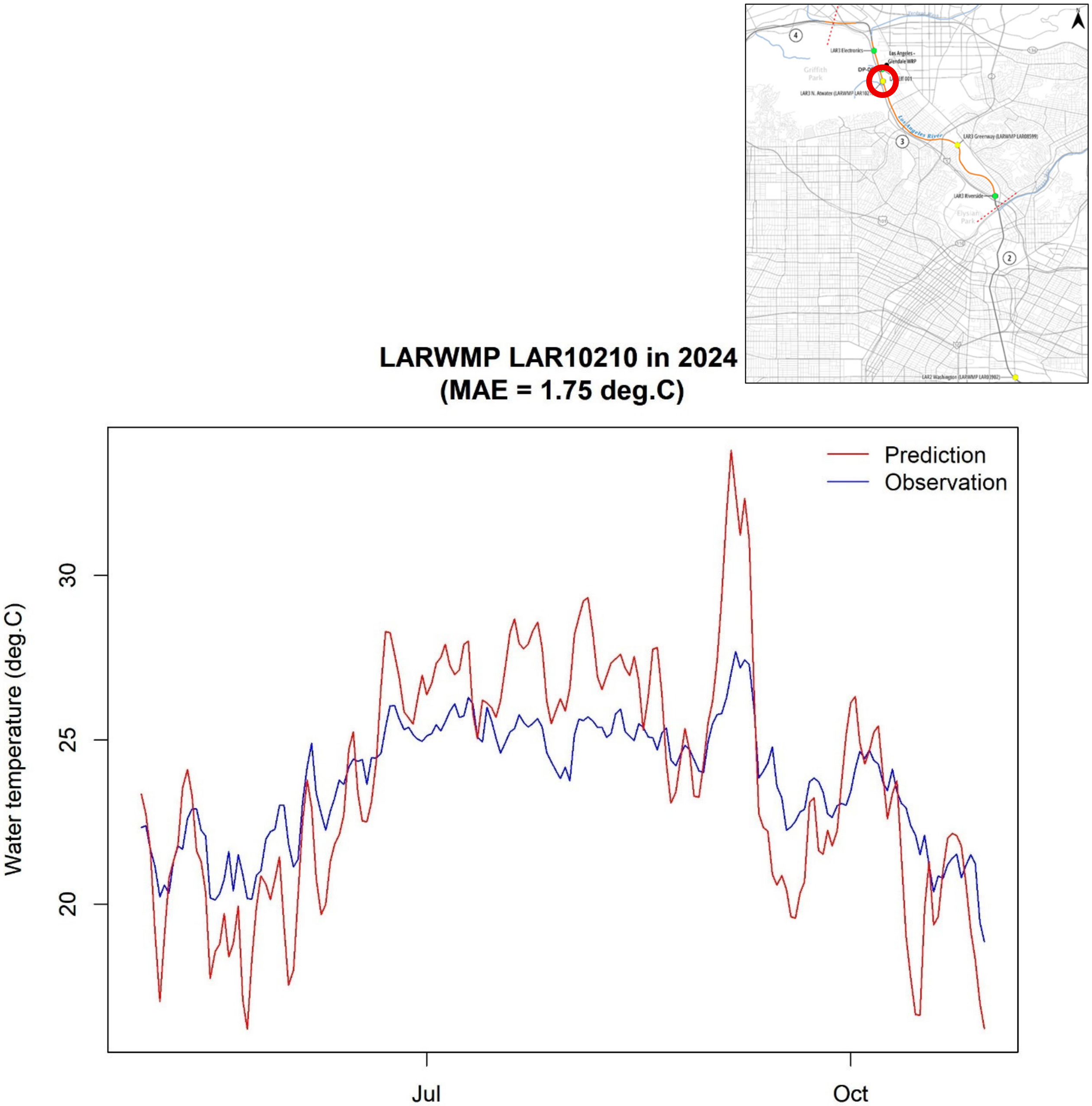


Figure A-18. Comparison between time series of predicted and observed water temperature in thermistor site "LARWMP LAR10210" in 2024

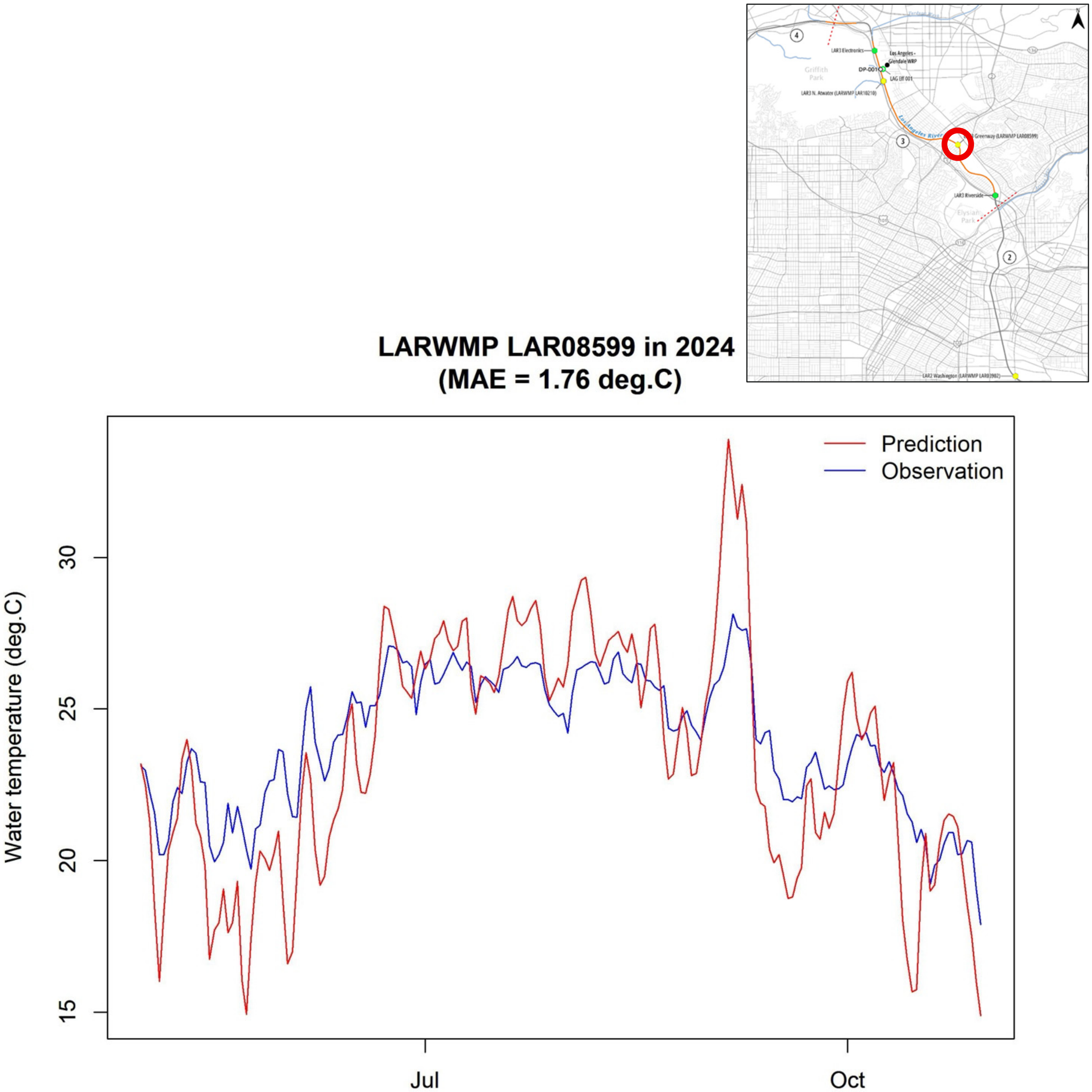
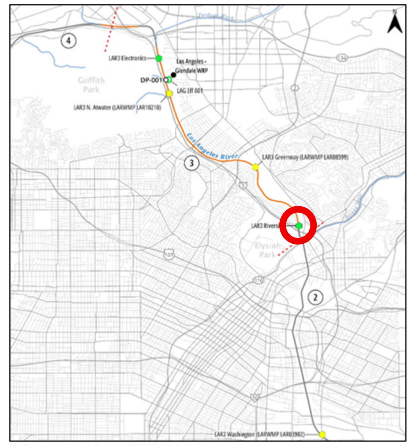


Figure A-19. Comparison between time series of predicted and observed water temperature in thermistor site "LARWMP LAR10210" in 2024



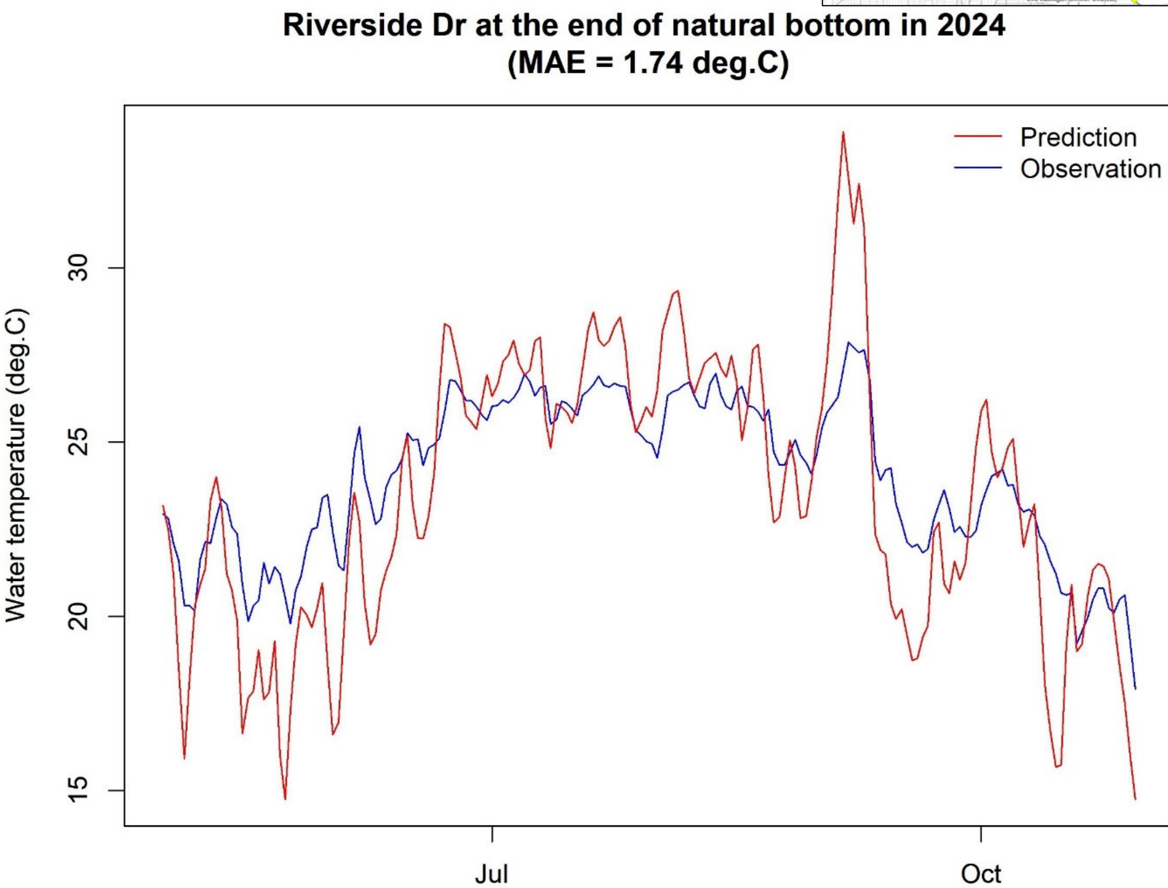
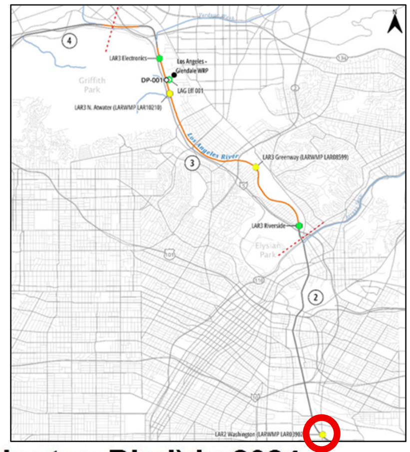


Figure A-20. Comparison between time series of predicted and observed water temperature in thermistor site "Riverside Dr at the end of natural bottom" in 2024



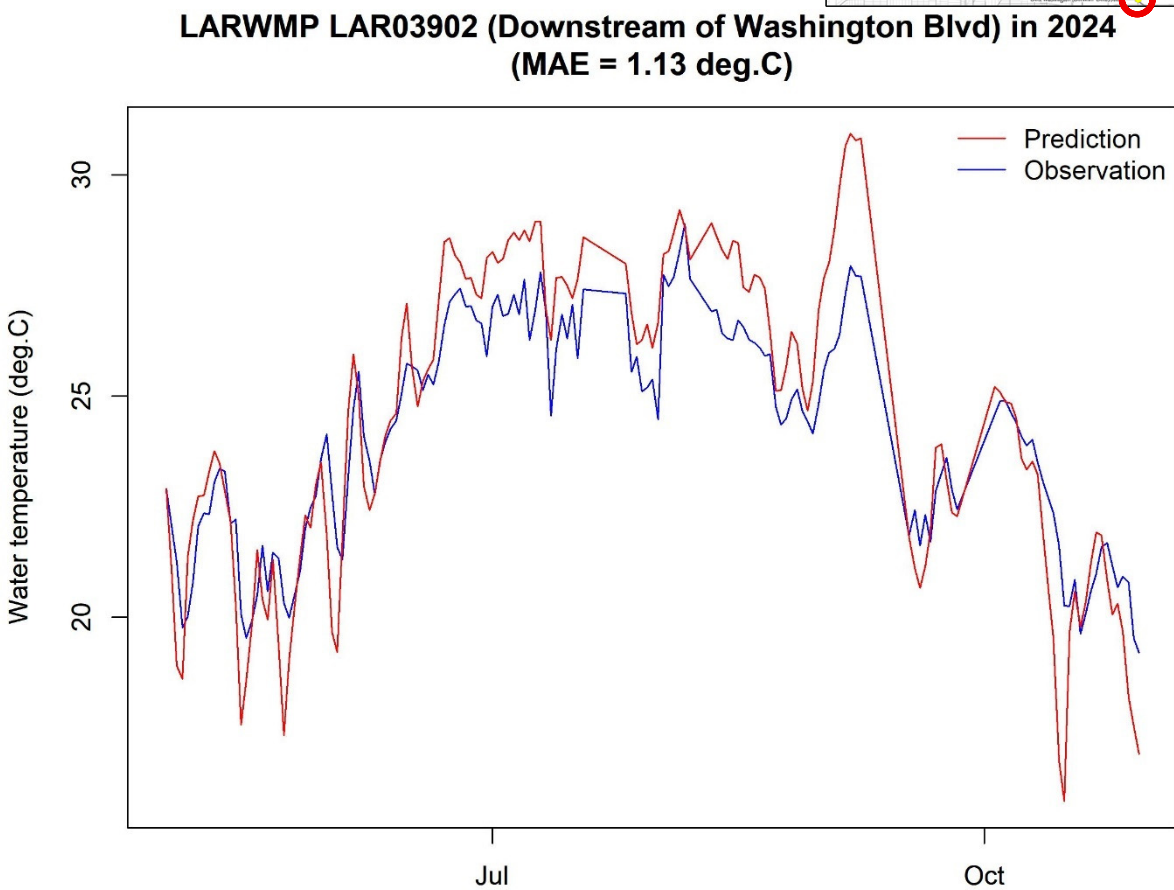


Figure A-21. Comparison between time series of predicted and observed water temperature in thermistor site "LARWMP LAR03902 (Downstream of Washington Blvd)" in 2024

Appendix B: Quantifying Riparian Shading

B.1 Introduction

To determine the effect of tree shading on incoming solar radiation, the incoming solar radiation illuminating the low flow extent of the channel was determined. The analysis was performed for the baseline scenario (current conditions), and for the riparian shading control measure where it was assumed 100% tree cover along the flood control channel. For the baseline, the Digital Elevation Model (DEM) of the area was used to evaluate incident solar radiation on the water surface. For the riparian shading control measure, the DEM was modified to raise the elevation (pixel value) of any pixel that intersected with the channel edge along the river. Incoming solar radiation was then simulated across a year in both of these conditions. For the riparian shading control measure, the incident solar radiation was reduced by the ratio of incident solar for the control measure/incident solar for the baseline.

B.2 Methodology

B.2.1 Data

Data necessary for the analysis are listed in **Table B-1**.

Table B-1. Data used for shading analysis

Name	Agency	Year	Source
One-meter Digital Elevation Model	NOAA Office for Coastal Management	2015	https://coast.noaa.gov/dataviewer/#/
NAIP (National Agricultural Imagery Program)	USDA	2024, 2020	https://nrcs.app.box.com/v/naip
Meteorological stations	National Weather Service	1998-2024	https://www.weather.gov/lox/observations_historical

B.2.2 Workflow

The procedure for calculating the incident solar radiation on the receiving water surface is as follows:

1. Digital Elevation Data from 2015, in the form of a Bare Earth DEM at a spatial resolution of ~1 m was acquired using the NOAA Data Access Viewer.
2. Optical Imagery at a spatial resolution of 0.6 m was acquired from the National Agricultural Imagery Program (NAIP) for 2024 and 2020. These images were captured in July of their respective years.
3. The extent of the receiving water during low flow was digitized as a spatial polygon using the 2024 NAIP imagery, with the 2020 imagery as a backup for when the river appeared completely dry in the 2024 image.
4. The banks of the channel were digitized as spatial lines using the 2024 NAIP imagery.
5. The DEM and created geometries were split using zones created given the proximity of the receiving water from specific weather stations.

6. For each section:
   a) A control measure DEM was created using Rasterio in Python, where, for all pixels intersecting the channel bank lines, elevation (pixel values) was increased by 30 ft. This 30 ft wall on both sides of the channel banks acted as a simulated tree wall.
   b) For both the baseline and control measure DEMs, the processing outlined in **Figure B-1** was performed. The calculations were performed hourly every 15th day monthly to simulate a whole year.
   c) Incident solar radiation on the 15th of each month was then interpolated over all days in a year to develop a complete set of solar reduction due to riparian shading.

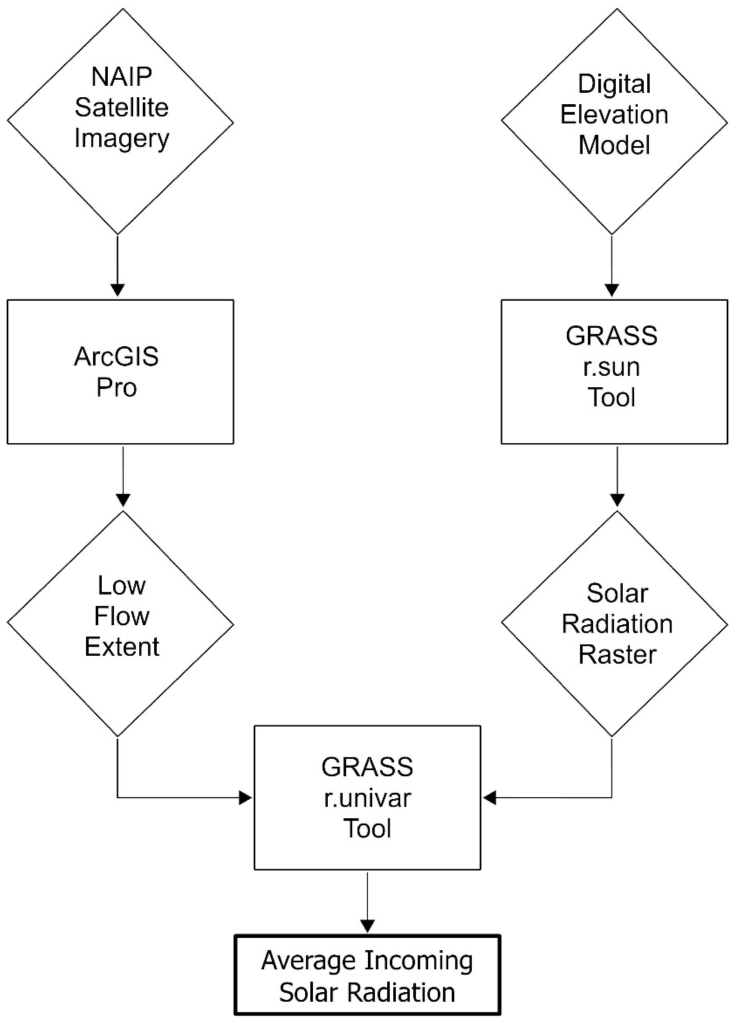


Figure B-1. Flow chart for shading process

Appendix C: Additional Model Results for Control Measures

This appendix contains the model outputs comparing baseline conditions to scenarios not presented in **Section 7**.

C.1 Baseline with Climate Change

Baseline conditions are compared to climate change conditions expected for 30 years in the future. To assess the effect of climate change, the future temperatures in the LA Basin were determined through the Coupled Model Intercomparison Project Phase 5 (CMIP5) North America downscaled by Localized Constructed Analogs (LOCA) statistical dataset, downloaded from Cal-Adapt[3]. Predicted mean monthly water temperatures in January and August 2022-2024 increase due to increased air temperature in climate change scenarios. These projections are made for 30 years in the future corresponding to the life cycle of effluent temperature control machinery. Climate change results for the three WRPs are presented in **Figure C-1** to **Figure C-3**.

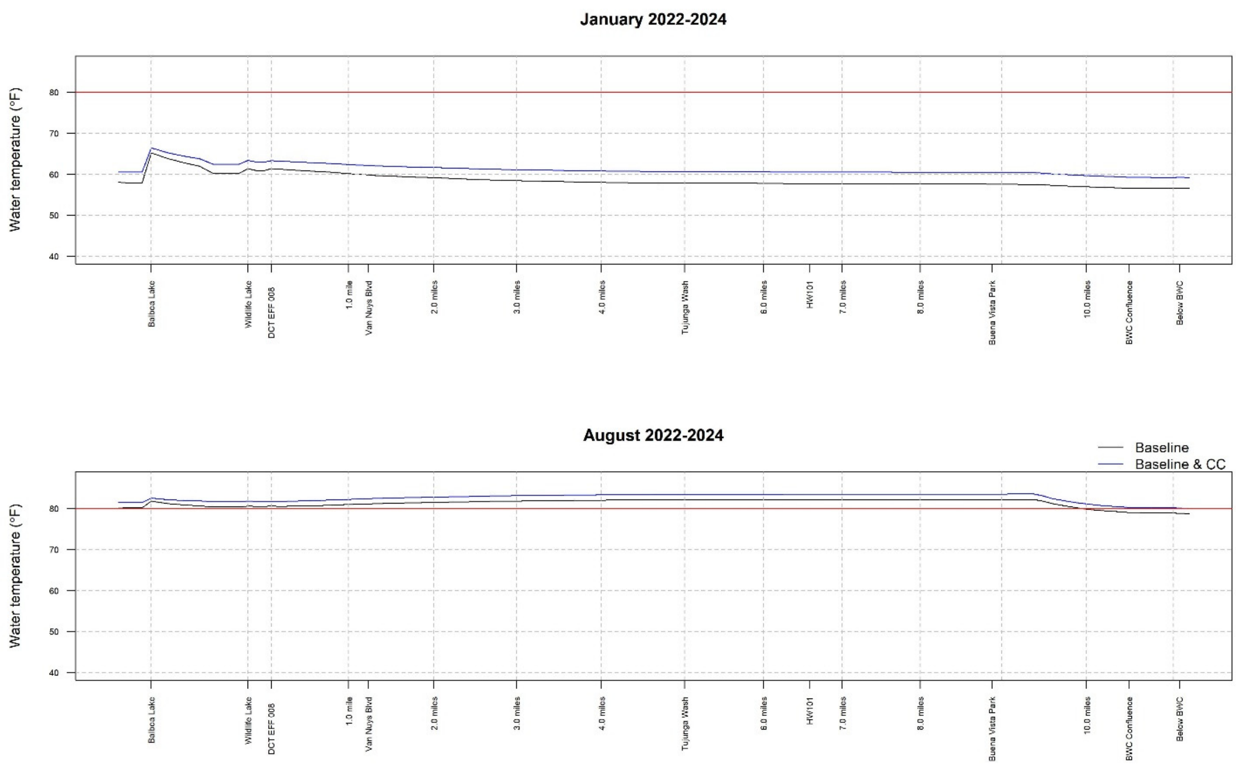


Figure C-1. Predicted mean monthly water temperatures in January and August 2022-2024 for the DCTWRP under baseline without and with climate change (baseline & CC)

[3] https://cal-adapt.org/data/download/

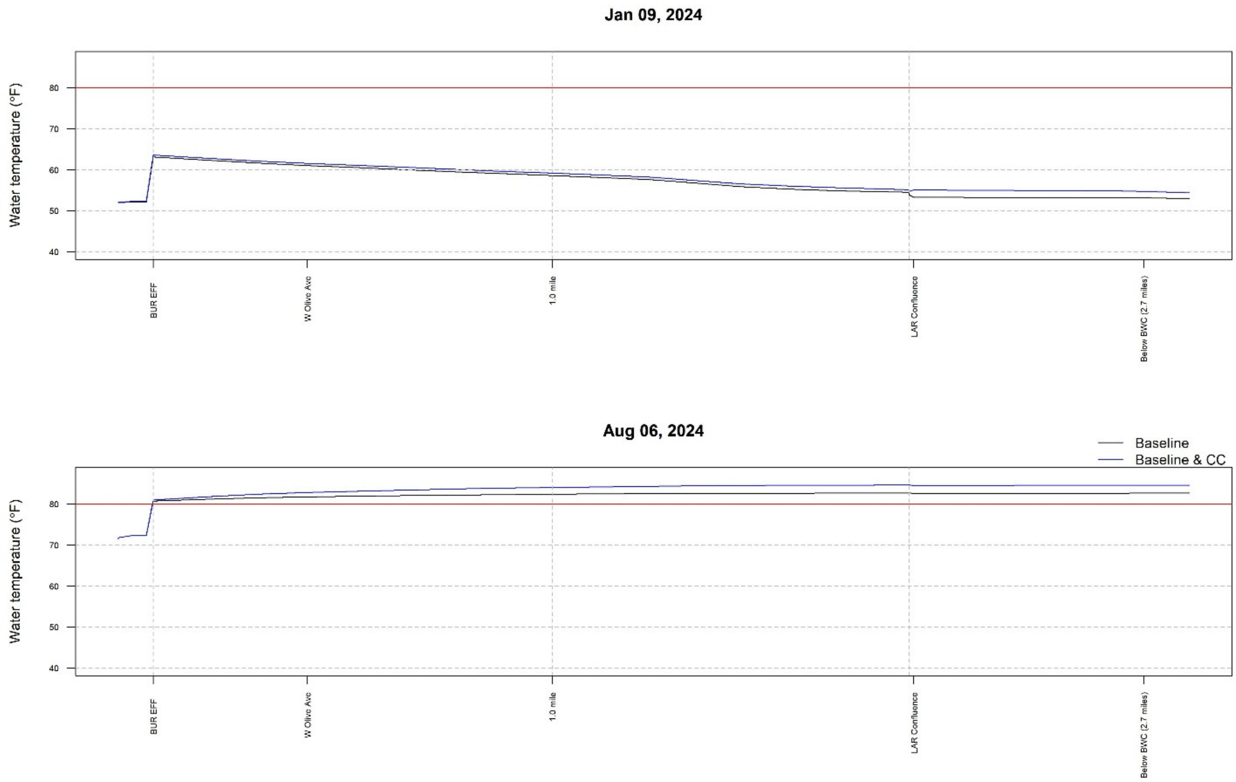


Figure C-2. Predicted mean monthly water temperatures in January and August 2022-2024 for the BWRP under baseline without and with climate change (baseline & CC)

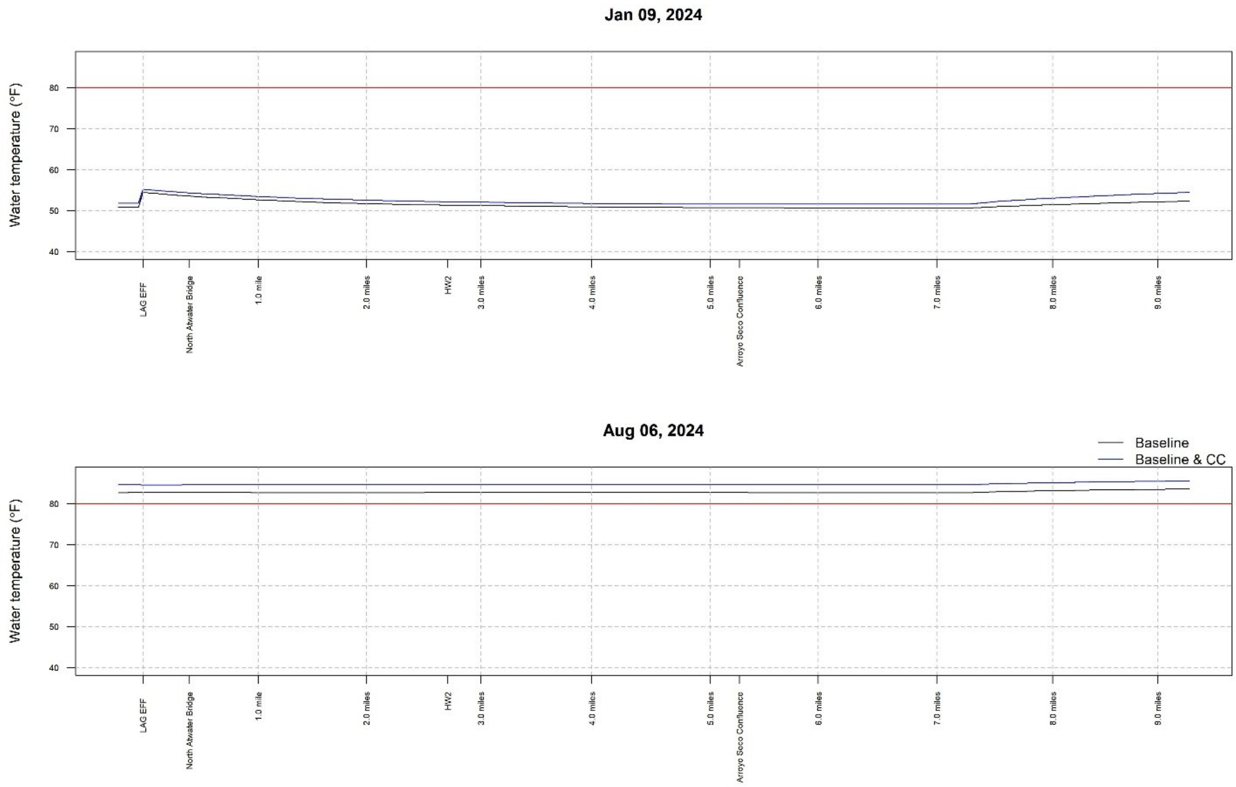
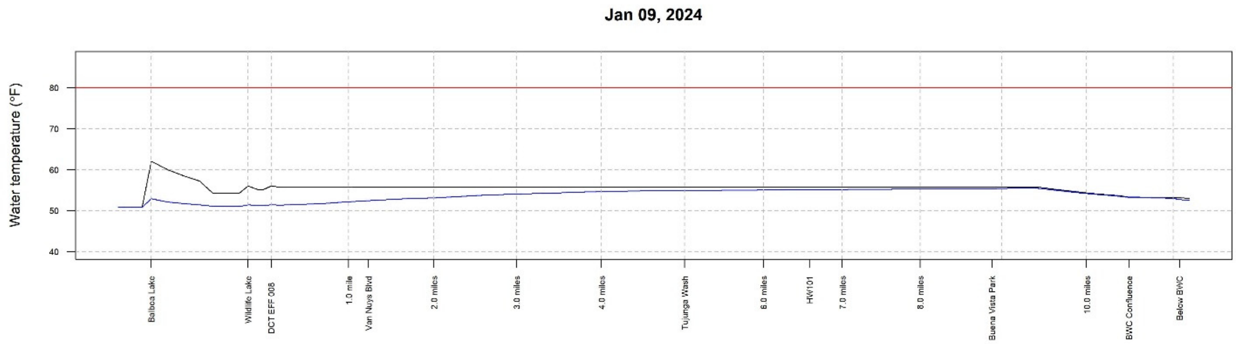


Figure C-3. Predicted mean monthly water temperatures in January and August 2022-2024 for the LAGWRP under baseline without and with climate change (baseline & CC)

C.2 WRP Effluent Temperature Equal to Upstream Receiving Water

This scenario is performed to evaluate the receiving water response to the ambient meteorological conditions. The WRP discharges are set to the upstream receiving water temperature and maintain the discharge flowrate. By maintaining the WRP flowrate, the receiving water depth, surface area, and velocities will remain consistent for both baseline and scenario. By modifying the WRP effluent temperature to match the upstream temperature, there is no effect of the WRP discharge on the receiving water temperature. This scenario can be used to determine the equilibrium temperature in the receiving water. The scenario results are presented in **Figure C-4** to **Figure C-6**.



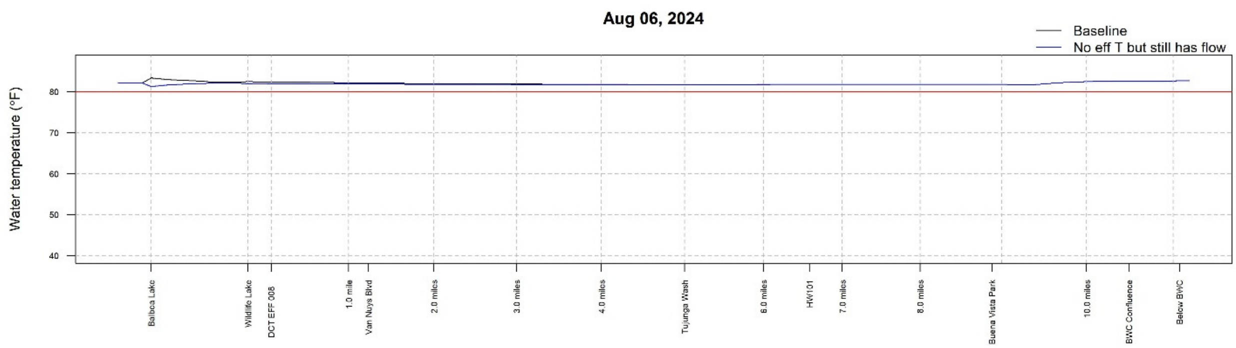


Figure C-4. Predicted receiving water temperatures on January 9 and August 6, 2024 for the DCTWRP under baseline and WRP effluent temperatures set at upstream temperatures

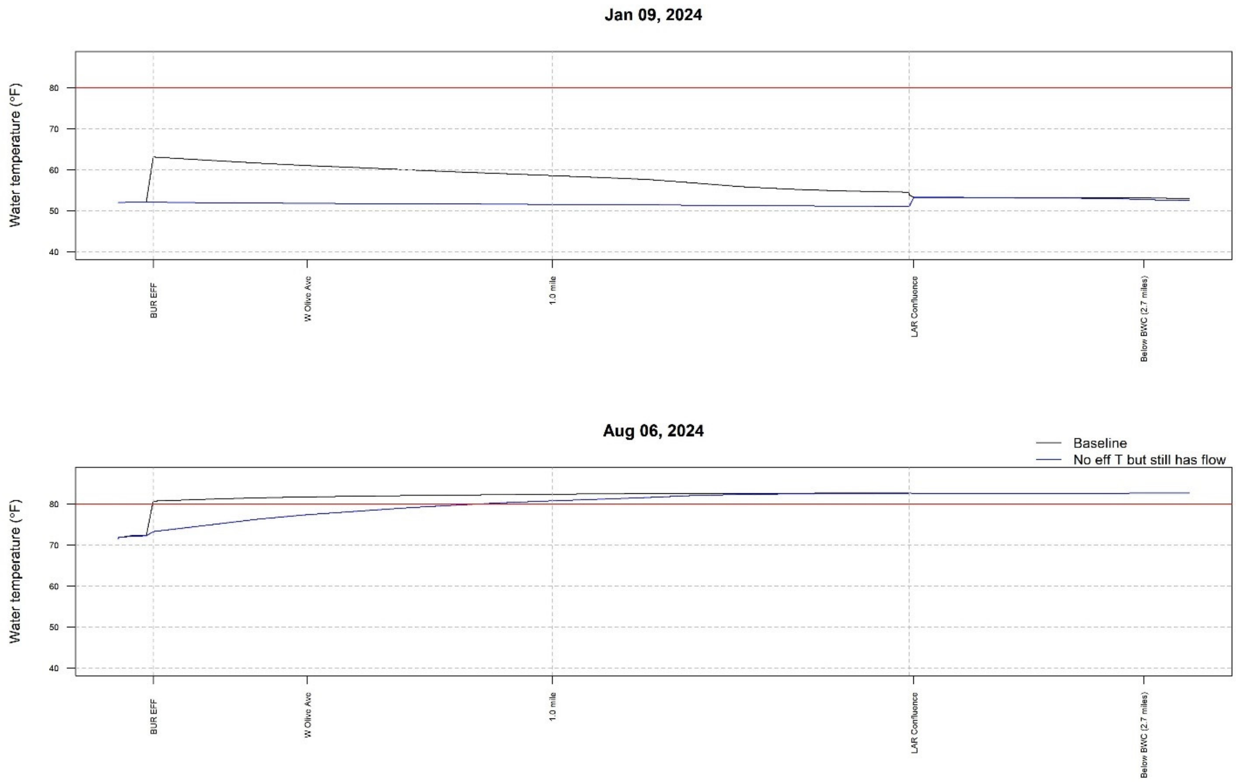


Figure C-5. Predicted receiving water temperatures on January 9 and August 6, 2024 for the BWRP under baseline and WRP effluent temperatures set at upstream temperatures

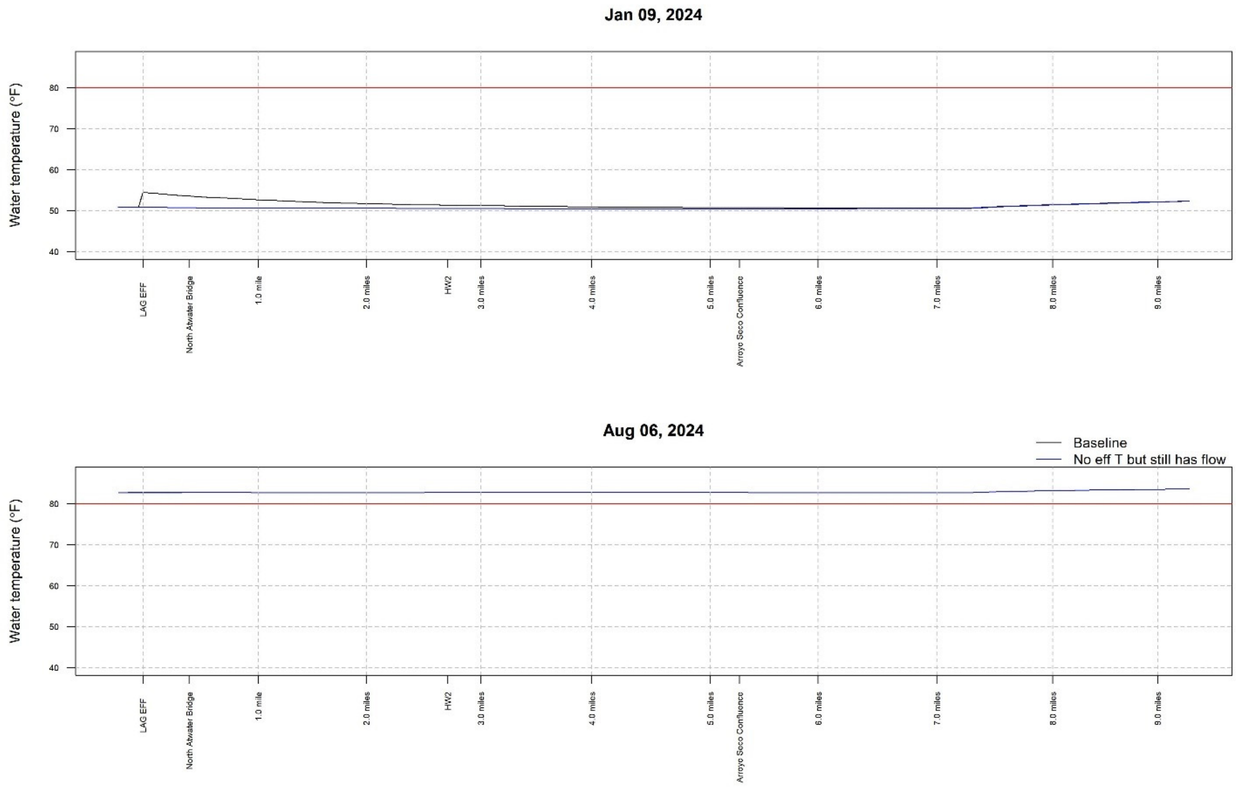


Figure C-6. Predicted water temperatures on January 9 and August 6, 2024 for the LAGWRP under baseline and WRP effluent temperatures set at upstream temperatures

C.3 Effluent Temperature Control and 10% Flow Reduction

This scenario is similar to **Section 7.1**, in that effluent temperatures are cooled to meet temperature limits; however, the effluent flowrates are reduced by 10%. Scenario results are presented in **Figure C-7** to **Figure C-9**.

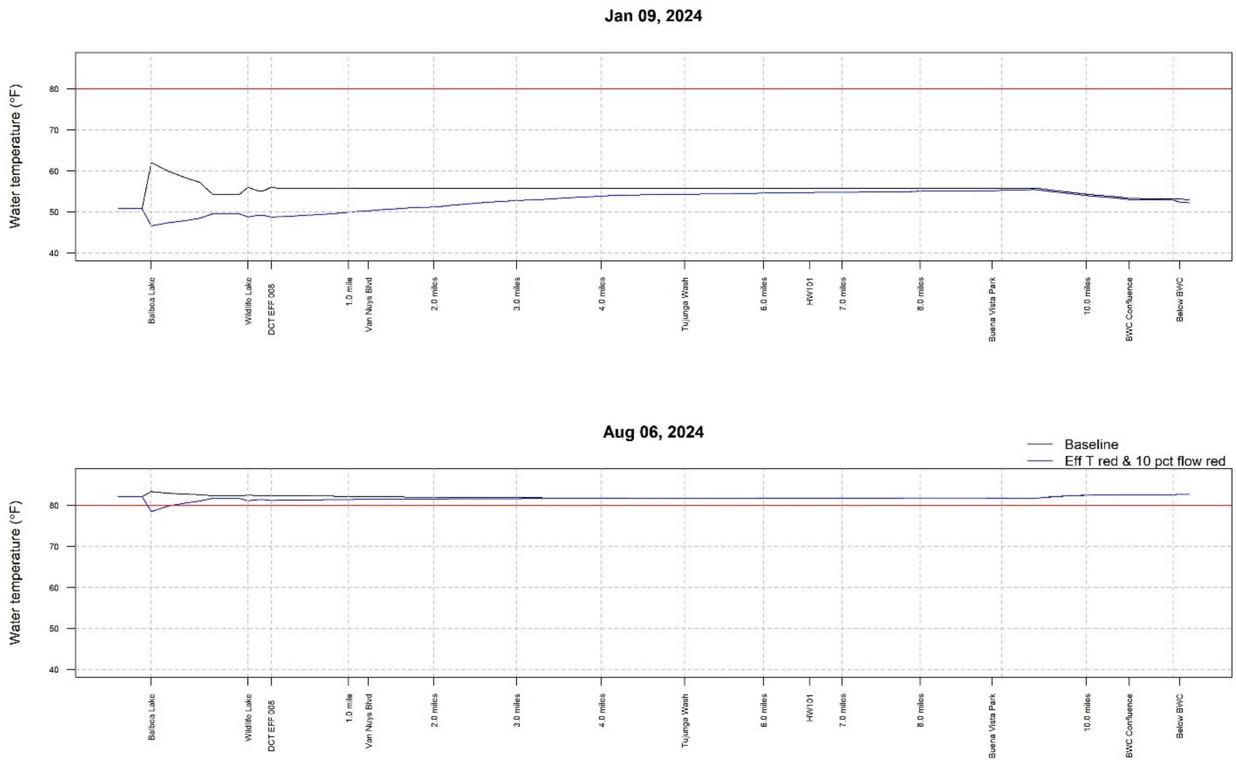


Figure C-7. Predicted receiving water temperatures on January 9 and August 6, 2024 for the DCTWRP under baseline and effluent temperature control and 10% flow reduction (eff T red & 10 pct flow red)

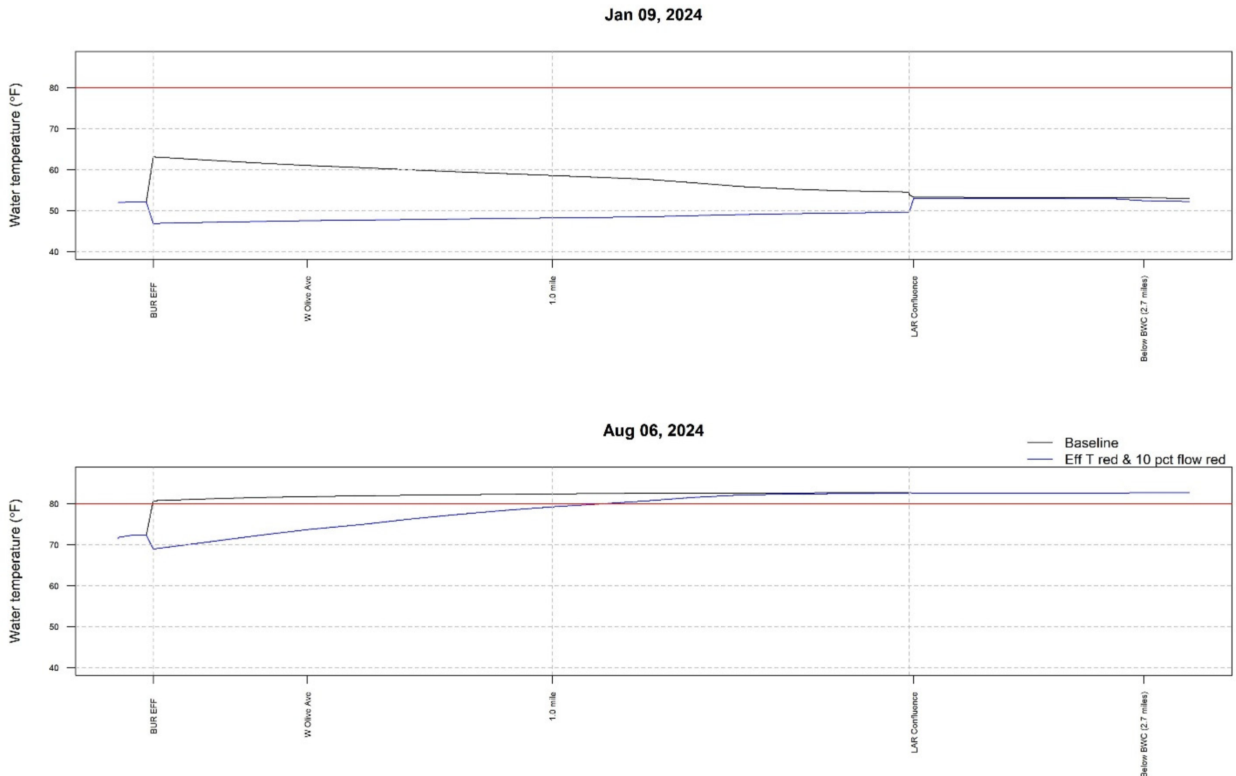


Figure C-8. Predicted receiving water temperatures on January 9 and August 6, 2024 for the BWRP under baseline and effluent temperature control and 10% flow reduction (eff T red & 10 pct flow red)

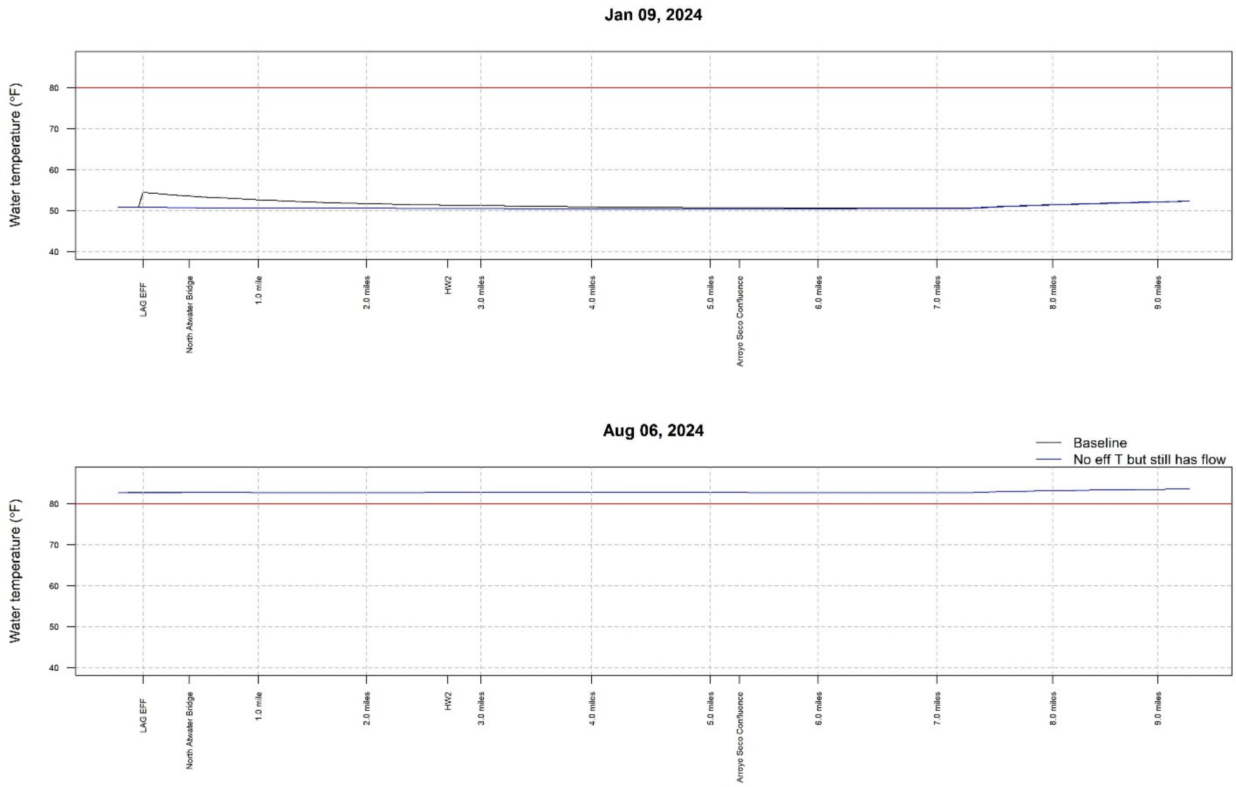


Figure C-9. Predicted receiving water temperatures on January 9 and August 6, 2024 for the LAGWRP under baseline and effluent temperature control and 10% flow reduction (eff T red & 10 pct flow red)

Appendix D: Exploration of Shading Necessary to Achieve 80°F Temperature Objective

Given that shading along the banks of the Study area did not result in meaningful changes to receiving water temperatures, the Technical Advisory Committee requested that the Cities use the model to explore the following two additional shading scenarios.:

- Scenario 1: Evaluation of planting dense riparian vegetation in the current unlined sections that might result in blocking 80% of the incident solar radiation. The first scenario would require dense vegetation in the unlined channels that may affect flood protection levels and would likely preclude some uses of the river such as kayaking. The model results for this scenario are presented in **Section 8.1**.
- Scenario 2: Identification of the amount of shading that would be required to maintain receiving water temperatures below 80°F. As exploratory scenarios, they were modeled regardless of whether they would be implementable. The second scenario would require removal of concrete to allow establishment of dense vegetation, would affect flood capacity necessitating channel widening, and as discussed below would require densification of the urban forest to affect a 15% reduction in the local air temperature.

This appendix provides additional information on how Scenario 2 was developed. To develop Scenario 2, the results from Scenario 1 were augmented with an additional model run that assumed no solar radiation (100% reduction) to evaluate the effect on receiving water temperatures. This particular scenario is a solely a modeling exercise as no solar radiation would likely reduce the local air temperature; however, the results are useful in determining the requirements for Scenario 2. Please note that actions necessary to act on these exploratory scenarios are well outside the ability of the Cities to perform.

D.1 100% Reduction of Solar Radiation over the entire Model Domain

Figure D-1, **Figure D-2**, and **Figure D-3** respectively illustrate the water temperature profiles at DCTWRP, BWRP, and LAGWRP in the scenario of 100% solar radiation reduction over the whole model domain. No solar radiation can reduce water temperature around 10°F downstream from these WRPs. **Figure D-4**, **Figure D-5**, and **Figure D-6** show time series of water temperature in current condition (baseline), and the scenario of no solar radiation. Air temperature is superimposed on the time series figures. Note that even with 100% solar radiation reduction the river temperature will exceed 80°F when the local air temperature is abnormally high.

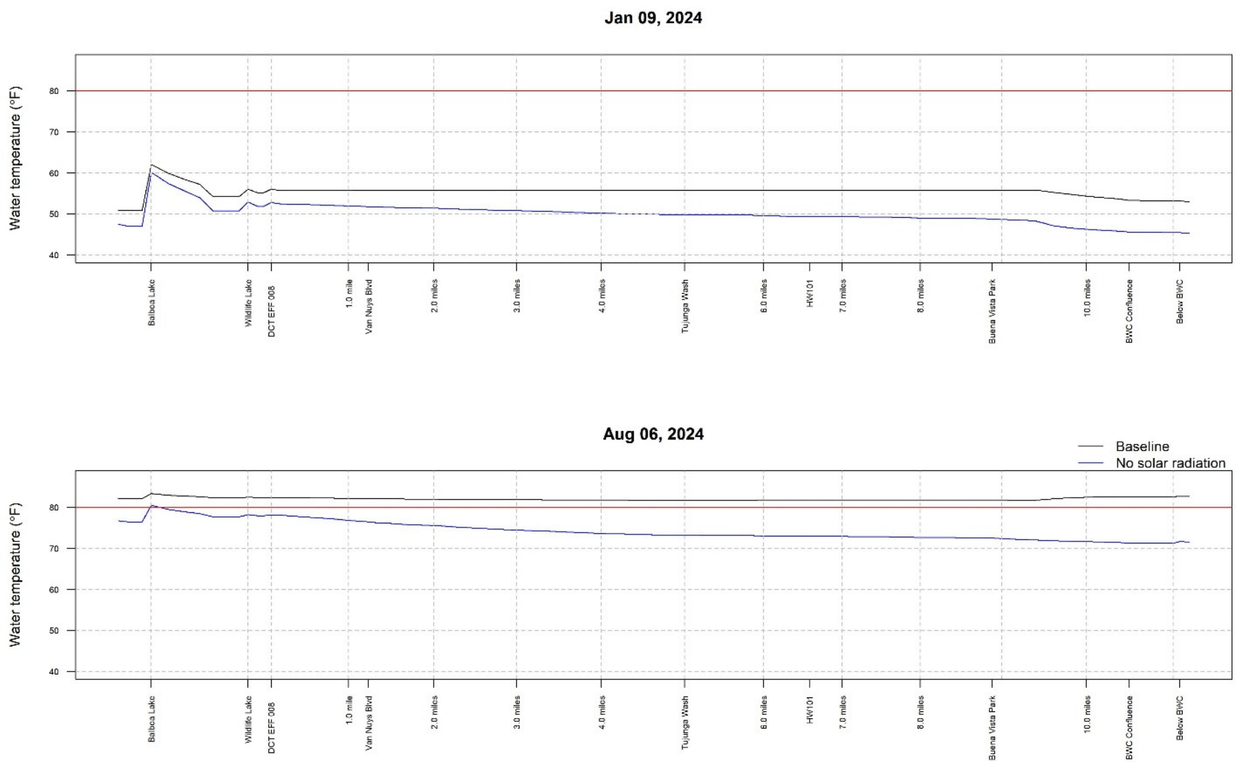


Figure D-1. Predicted receiving water temperatures on January 9 and August 6, 2024 for the DCTWRP under baseline and no solar radiation

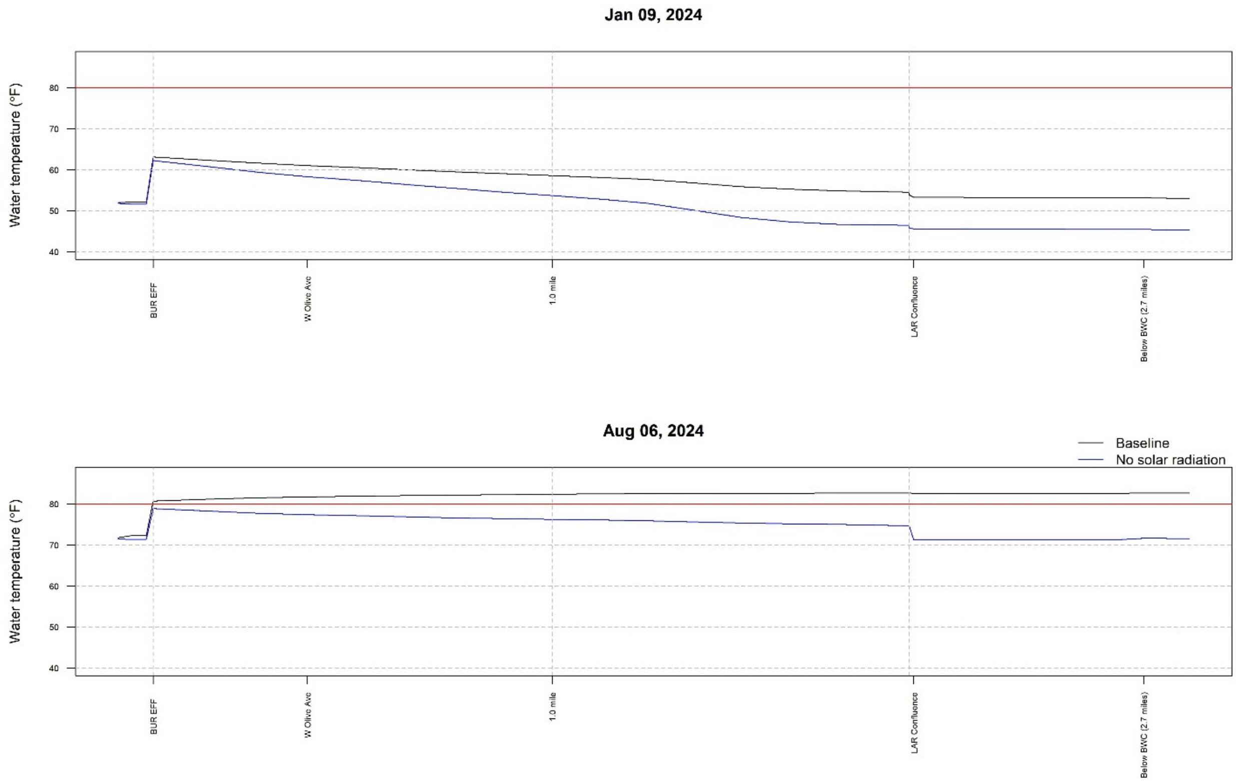


Figure D-2. Predicted receiving water temperatures on January 9 and August 6, 2024 for the BWRP under baseline and no solar radiation

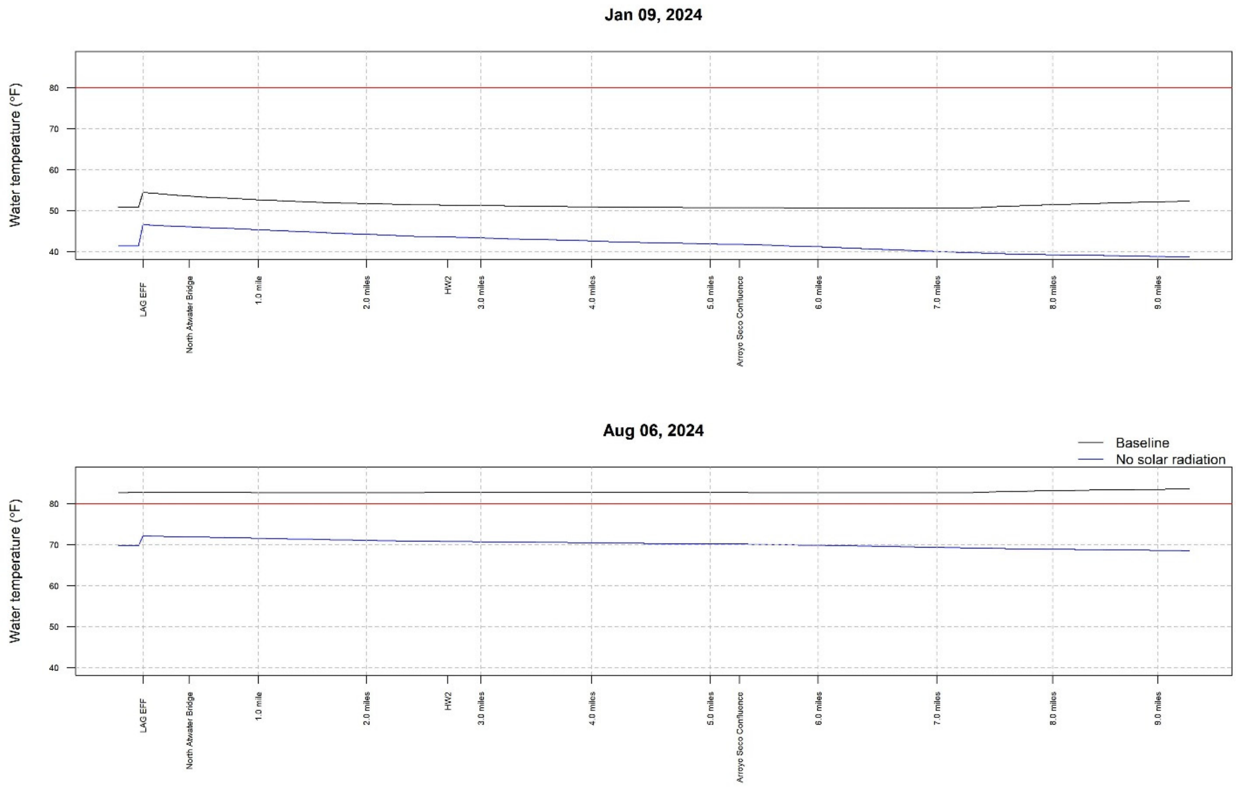


Figure D-3. Predicted receiving water temperatures on January 9 and August 6, 2024 for the LAGWRP under baseline and no solar radiation

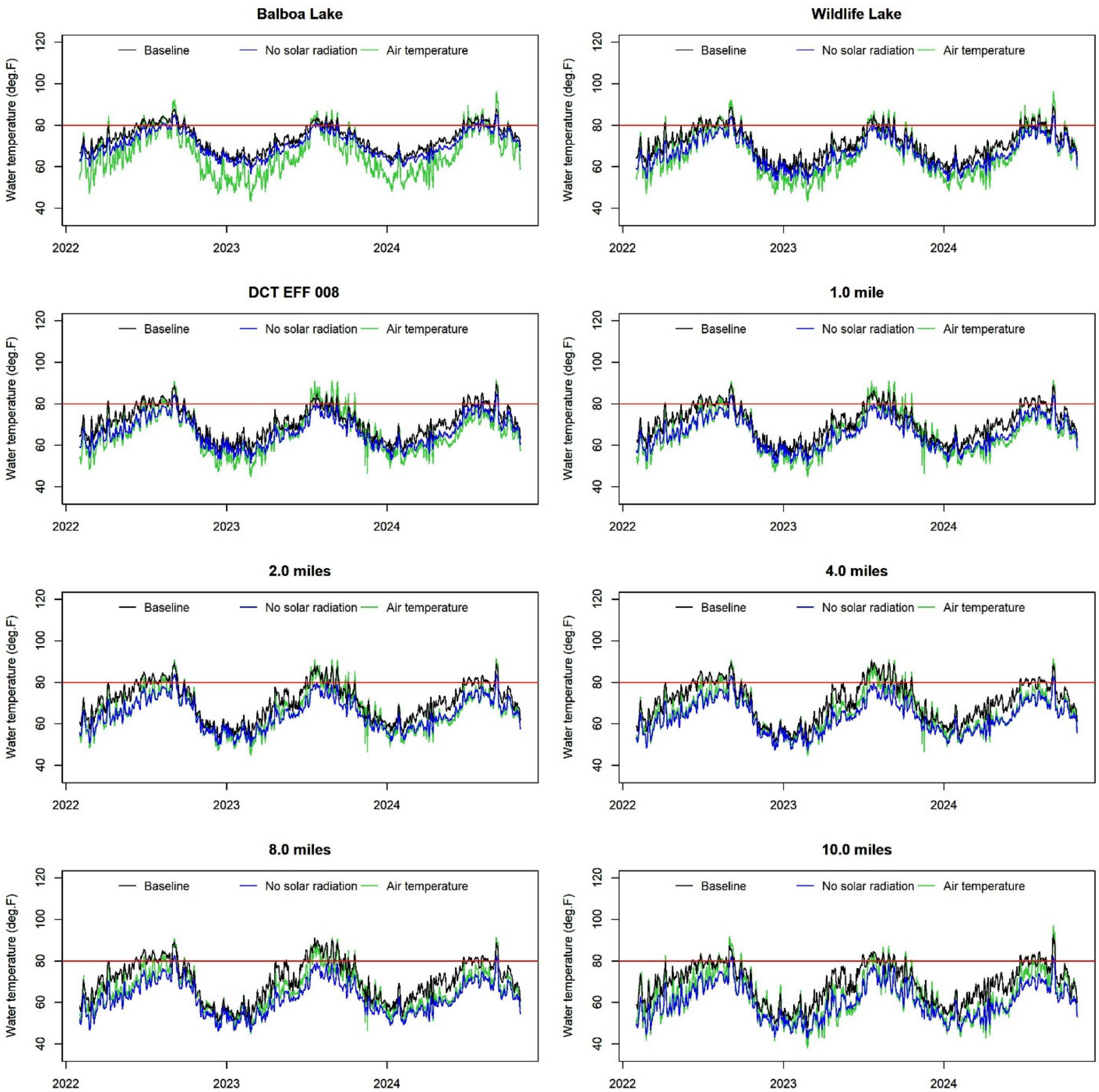


Figure D-4. Time series of receiving water temperatures and air temperature for current conditions and with 100% solar radiation reduction over the entire model domain at select locations at and downstream from the DCTWRP

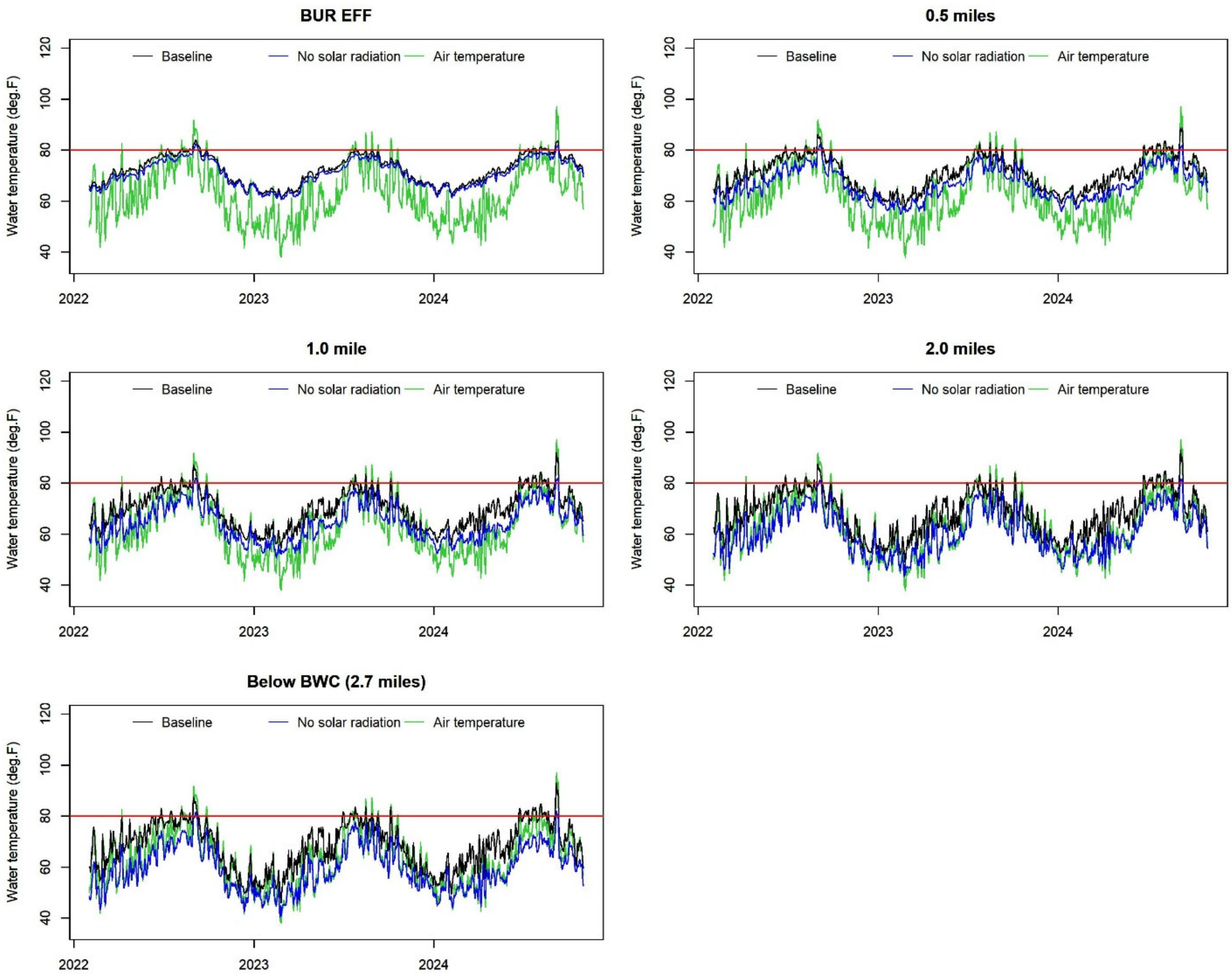


Figure D-5. Time series of receiving water temperatures and air temperature for current conditions and with 100% solar radiation reduction over the entire model domain at select locations at and downstream from the BWRP

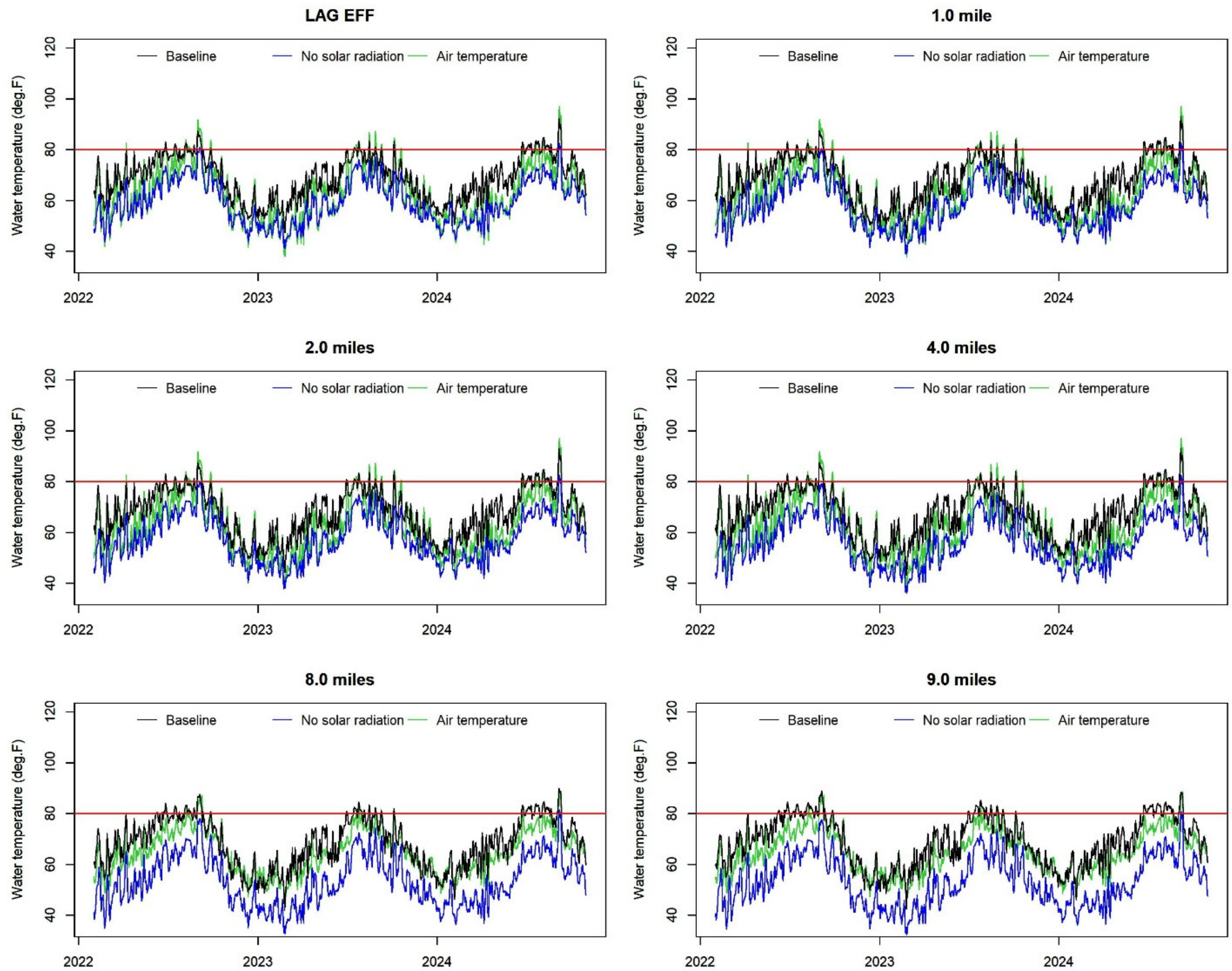


Figure D-6. Time series of receiving water temperatures and air temperature for current conditions and with 100% solar radiation reduction over the entire model domain at select locations at and downstream from the LAGWRP

D.2 Determining Requirements for Scenario 2

The above scenario and Scenario 1 were used to inform the solar radiation and air temperature reductions necessary to maintain the receiving waters below 80°F. **Figure D-7** and **Figure D-8** respectively show the percentage of days with water temperatures over 80°F, and maximum water temperature between January 1, 2022 and October 31, 2024 for the DCTWRP. **Figure D-9** and **Figure D-10** present the same information for the BWRP, and **Figure D-12** and **Figure D-13** for the LAGWRP.

At the three WRPs, the maximum water temperature during 2022–2024 still exceeded 80°F under both the no-solar-radiation scenario and the scenario of reducing solar radiation by 80% over unlined channels. In the no-solar-radiation scenario, the maximum water temperature decreased progressively downstream, thereby reducing the percentage of days having water temperature exceeding 80°F. However, in the scenario of 80% solar radiation reduction over soft-bottom channels, the maximum water temperature increased where the receiving water reentered lined sections.

Only the scenario combining 80% solar radiation reduction and a 15% reduction in air temperature successfully maintained maximum water temperatures below 80°F throughout receiving waters, resulting in 0% of days exceeding 80°F. The only exception occurred in the BWC below the BWRP (BWC - Reach 2_BelowEFF_12500_11800), where the water temperature slightly exceeded 80°F (less than 80.7°F) (see **Figure D-11**). A reduction of 80% in solar radiation and 15% in air temperature over the entire Study area represents an extreme scenario; therefore, no further reductions or optimizations were considered.

Water temperature depends not only on solar radiation but also on air temperature, as the two are positively correlated. Thus, maintaining river temperatures below 80°F at all points would require both 80% shading (solar radiation reduction) and a 15% decrease in air temperature, a combination that is unrealistic in practice. The LA River watershed is located in a hot climate, where baseline conditions already contribute to heating of receiving waters. To achieve such reductions, the entire channel would need to be shaded and surrounded by large-scale forest cover, an effort that would demand major urban planning modifications to lower air temperature by 15%. Consequently, regardless of WRP operations, the receiving waters remains susceptible to heating, and under future climate change scenarios, this condition is expected to worsen.

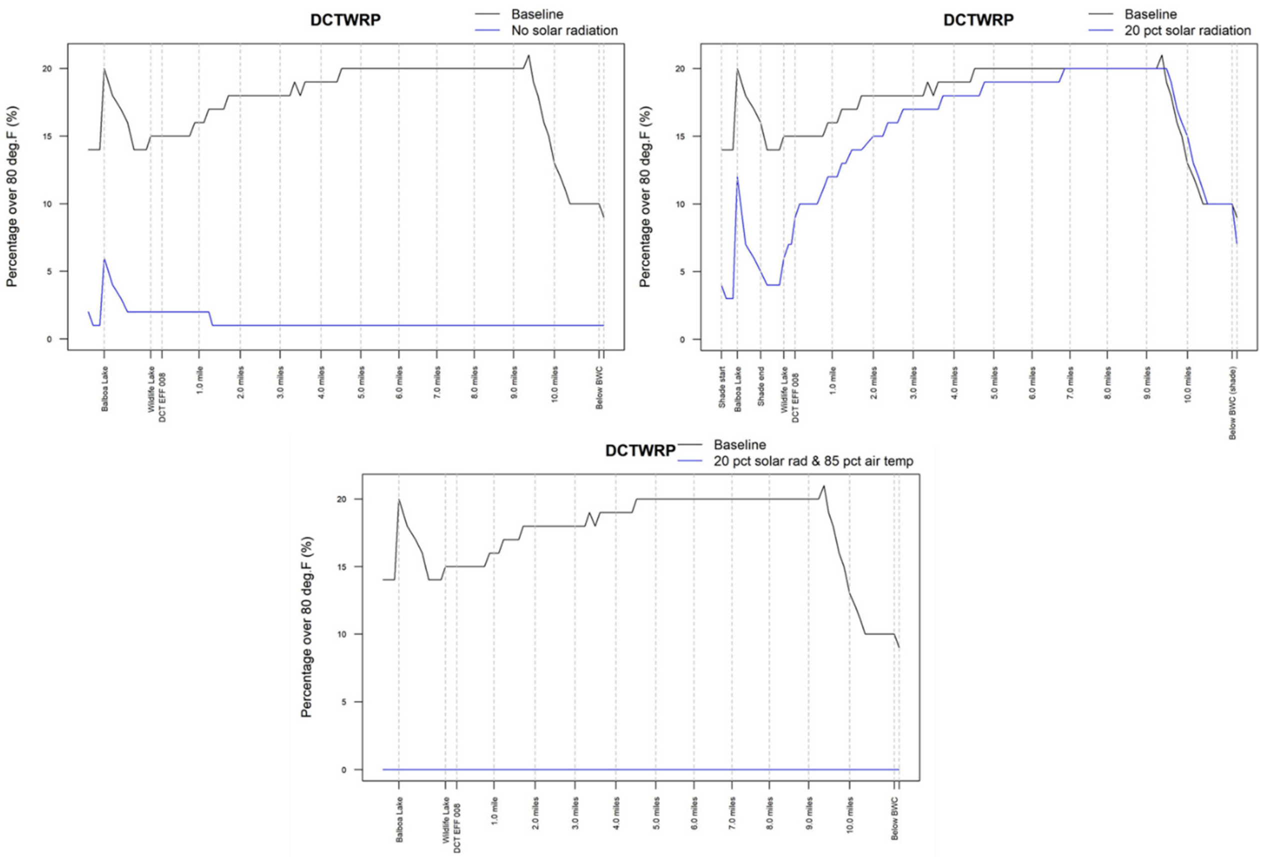


Figure D-7. Percentage of days with water temperature over 80°F between January 1, 2022 and October 31, 2024 at the DCTWRP from three scenarios: reduced solar radiation by 100% over the entire LA River, reduced solar radiation by 80% over soft-bottom channels only, reduced solar radiation by 80% and air temperature by 15% over the entire Study area

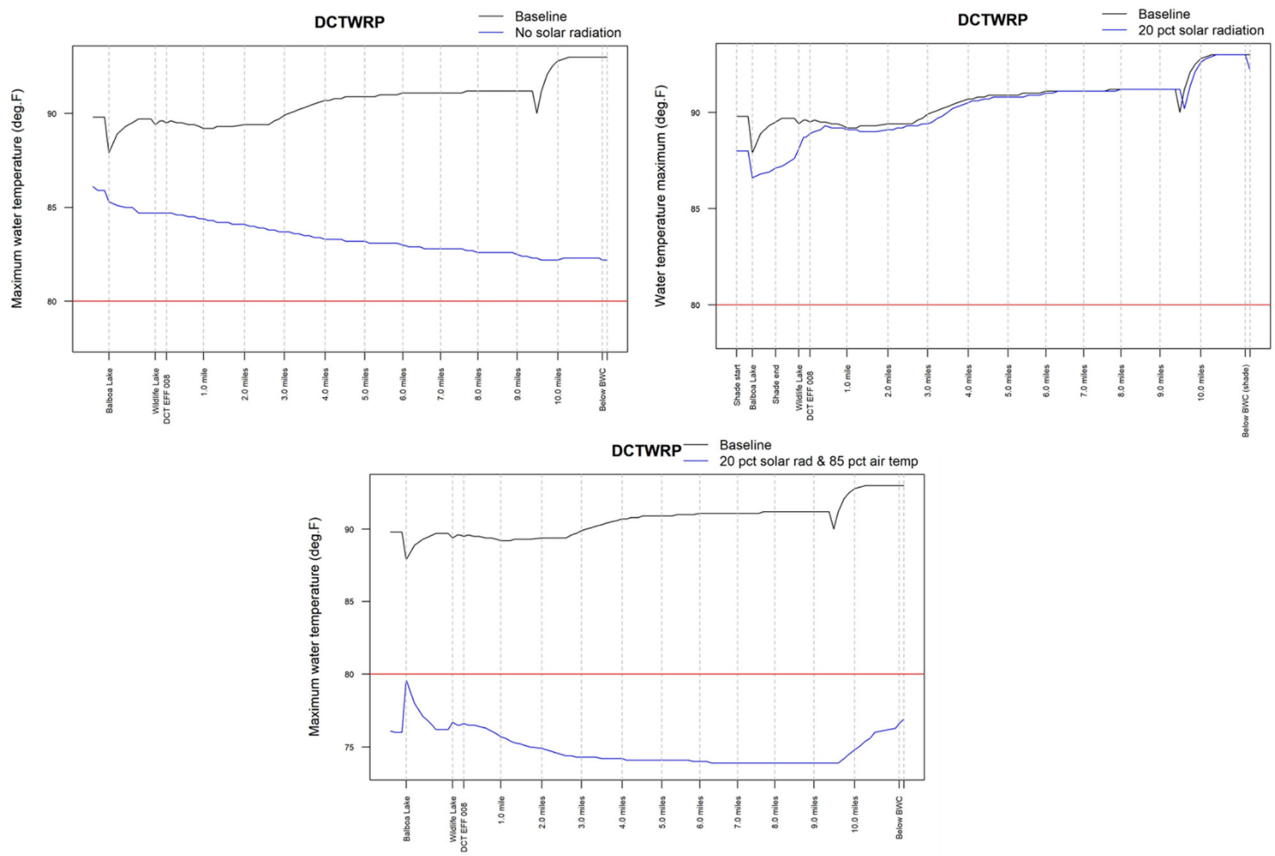


Figure D-8. Maximum water temperature between January 1, 2022 and October 31, 2024 at the DCTWRP from three scenarios: reduced solar radiation by 100% over the entire Study area, reduced solar radiation by 80% over unlined channels only, reduced solar radiation by 80% and air temperature by 15% over the entire Study area

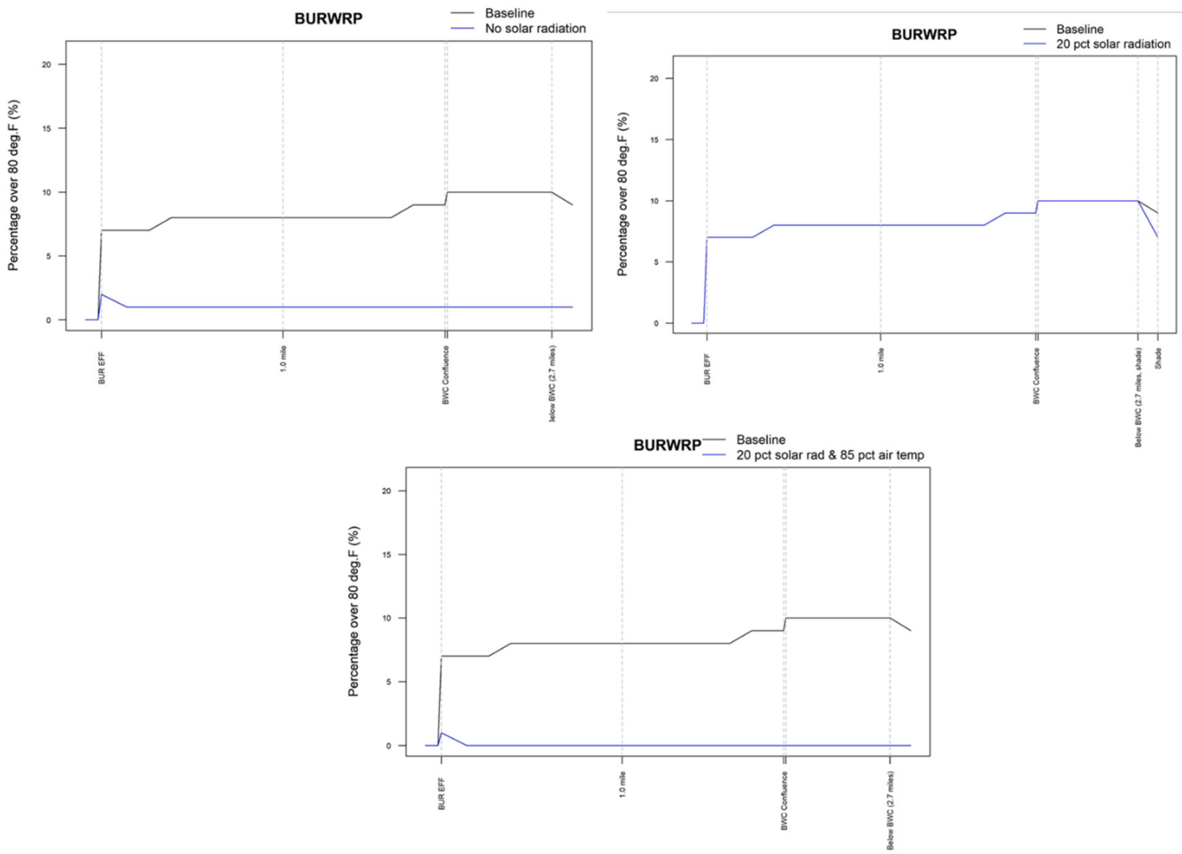


Figure D-9. Percentage of days having water temperature over 80°F between January 1, 2022 and October 31, 2024 at the BWRP from three scenarios: reduced solar radiation by 100% over the entire Study area, reduced solar radiation by 80% over unlined channels only, reduced solar radiation by 80% and air temperature by 15% over the entire Study area

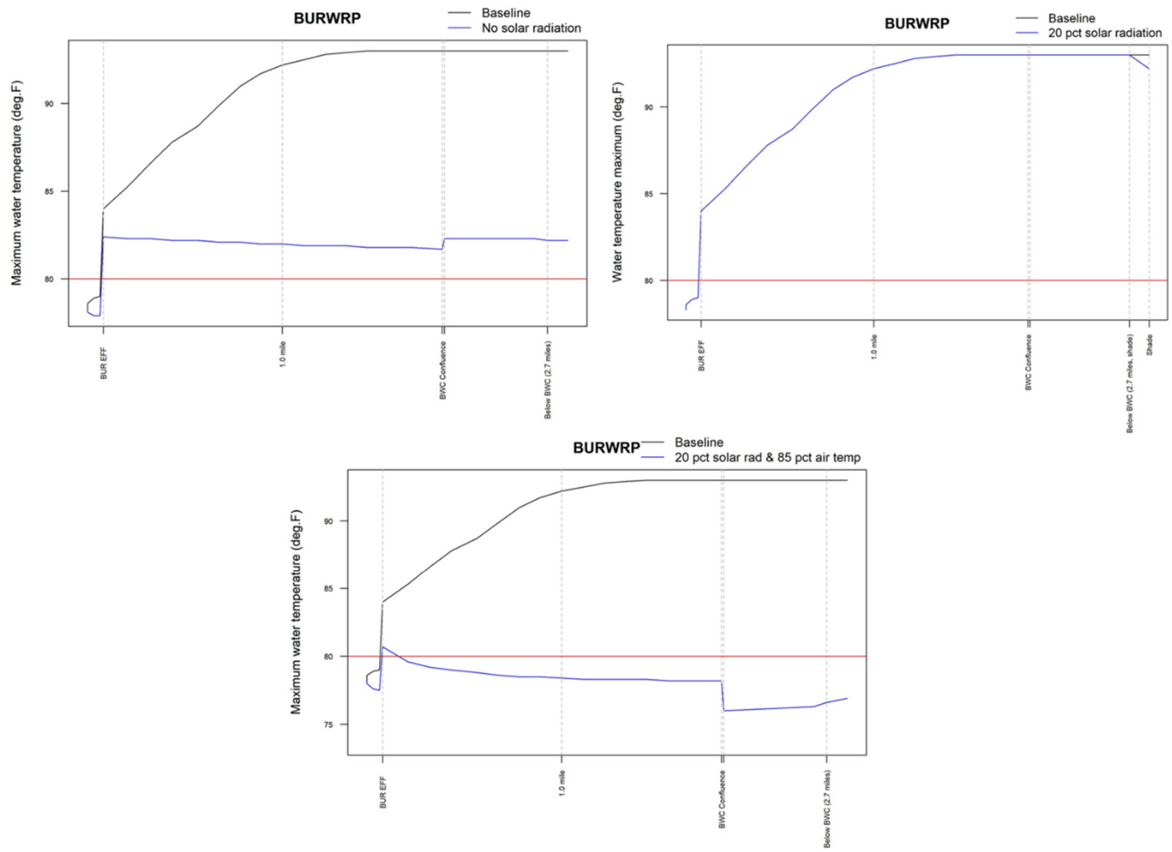


Figure D-10. Maximum water temperature between January 1, 2022 and October 31, 2024 at the BWRP from three scenarios: reduced solar radiation by 100% over the entire Study area, reduced solar radiation by 80% over unlined channels only, reduced solar radiation by 80% and air temperature by 15% over the entire Study area

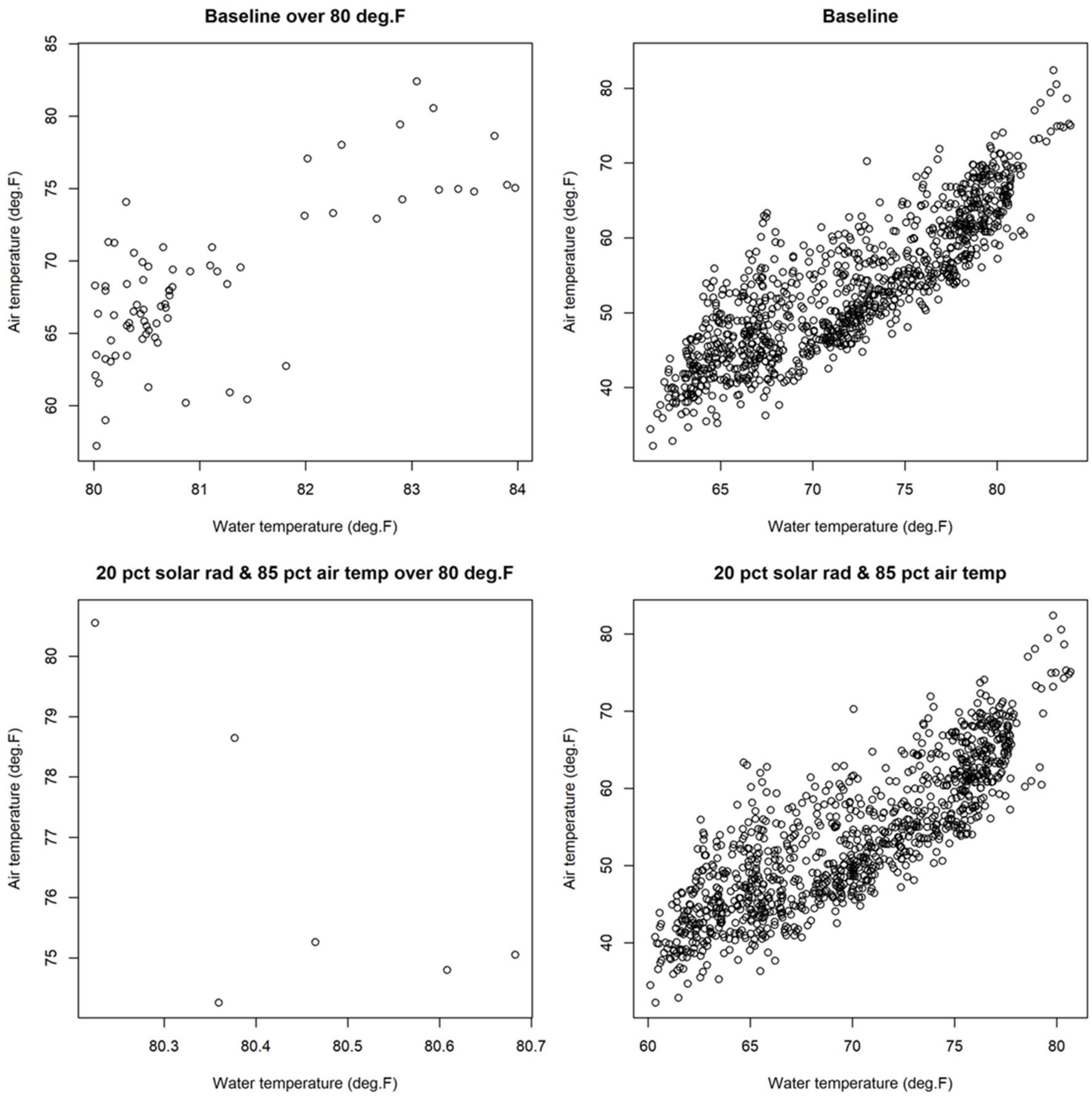


Figure D-11. Correlation between air and water temperature at a reach below the BWRP effluent (BWC - Reach 2_BelowEFF_12500_11800) for water temperature over 80°F (left panel) and the entire dataset (right panel) in the current condition (top panel) and in the scenario of reduced solar radiation by 80% and air temperature by 15% over the entire Study area (bottom panel)

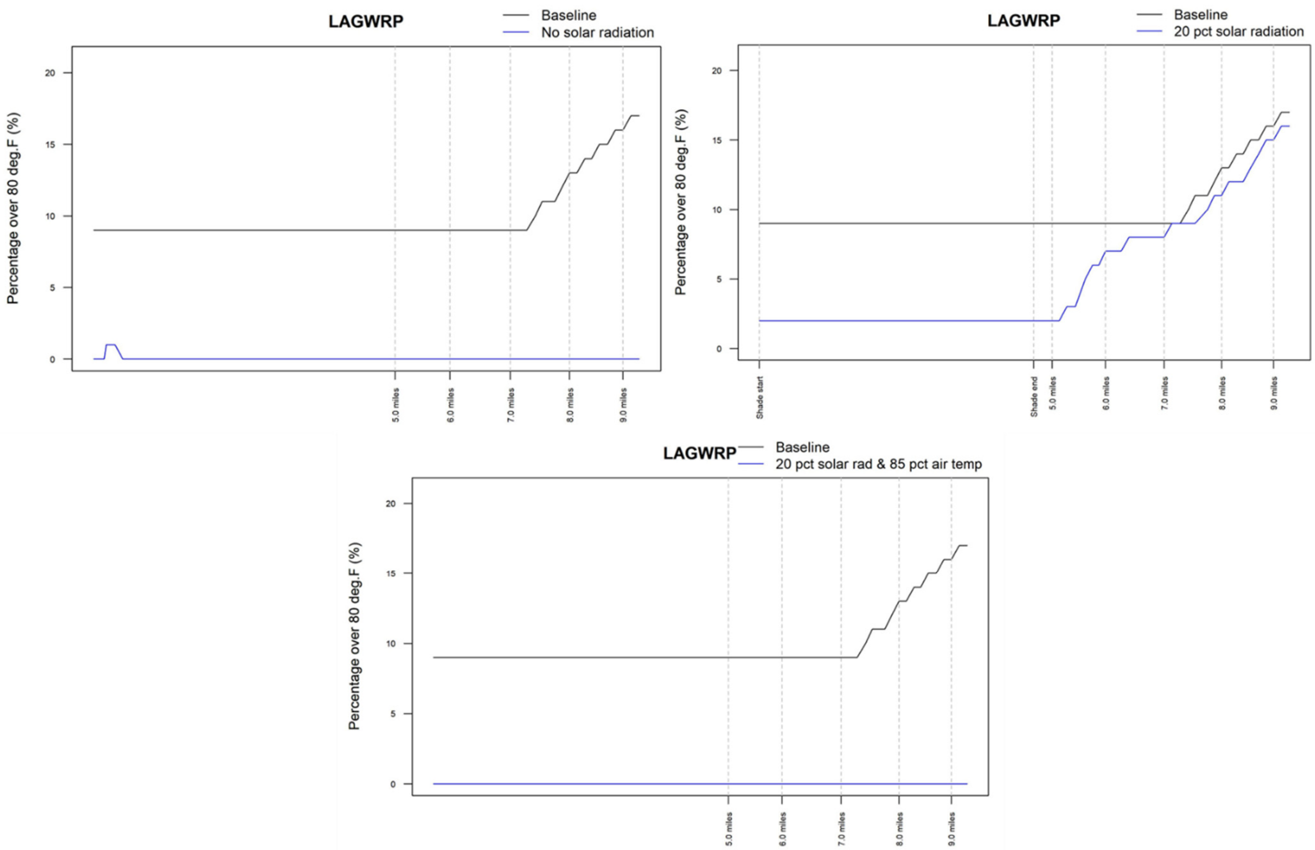


Figure D-12. Percentage of days having water temperature over 80°F between January 1, 2022 and October 31, 2024 at the LAGWRP from three scenarios: reduced solar radiation by 100% over the entire Study area, reduced solar radiation by 80% over unlined channels only, reduced solar radiation by 80% and air temperature by 15% over the entire Study area

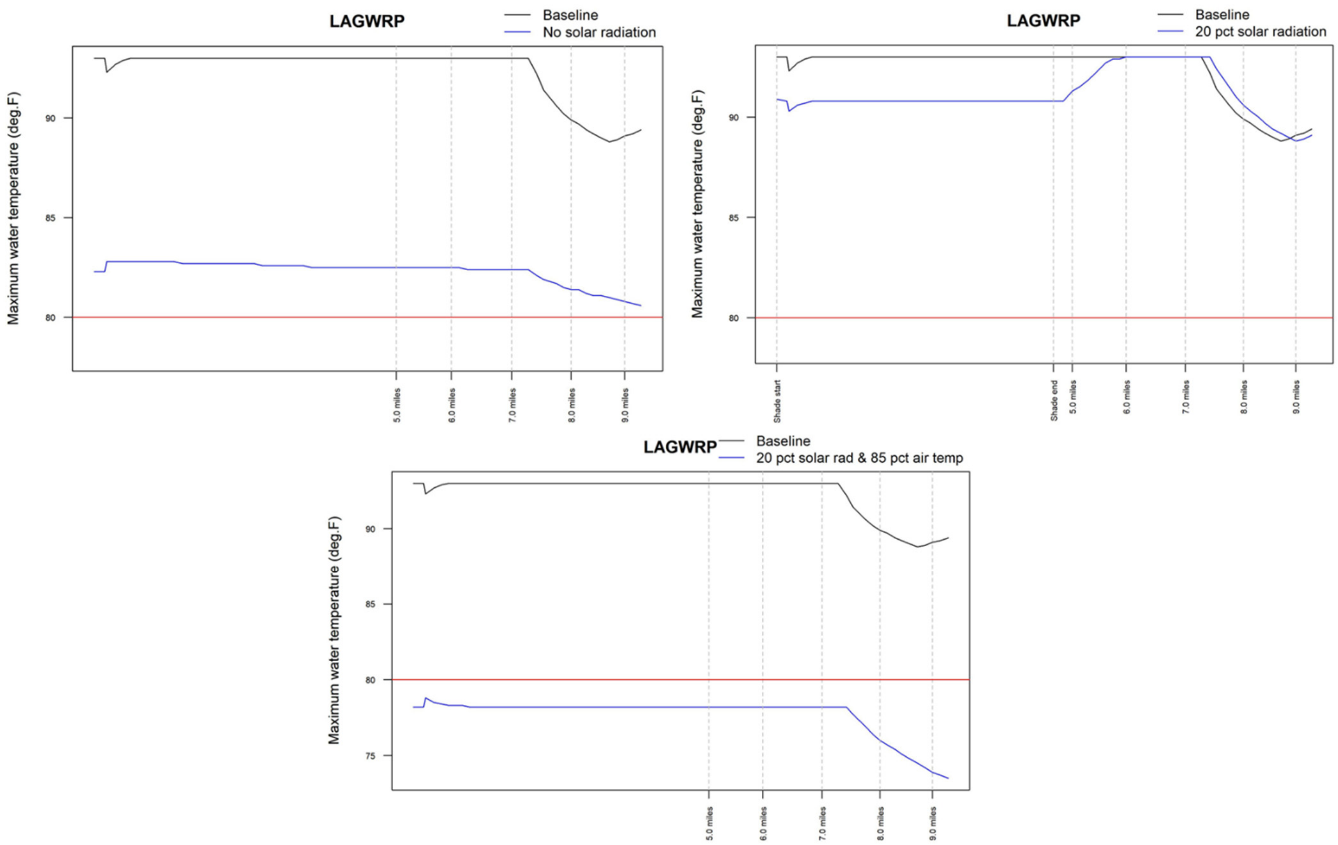


Figure D-13. Maximum water temperature between January 1, 2022 and October 31, 2024 at the LAGWRP from three scenarios: reduced solar radiation by 100% over the entire Study area, reduced solar radiation by 80% over unlined channels only, reduced solar radiation by 80% and air temperature by 15% over the entire Study area