DRAFT SCIENTIFIC BASIS REPORT SUPPLEMENT FOR THE TUOLUMNE RIVER VOLUNTARY AGREEMENT PROPOSAL

Prepared by:
State Water Resources Control Board
California Department of Water Resources
California Department of Fish and Wildlife

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Contents

List of Tables iv
List of Figures x
List of Acronyms and Abbreviations xxvi

Executive Summary ES-1
ES.1 Introduction ES-1
ES.2 Background ES-2
ES.3 Project Description ES-5
ES.4 Summary of Analysis and Results ES-5

Chapter 1 Introduction 1-1
1.1 Overview of the Bay-Delta Water Quality Control Plan Update Process 1-1
1.2 Background on the 2018 Bay-Delta Plan 1-1
1.3 Status of Fish Populations in the Tuolumne River 1-2
1.4 Description of the Proposed Voluntary Agreement 1-6
1.5 Overview of Chapters 1-7
1.6 References 1-8
1.6.1 Printed References 1-8

Chapter 2 Aquatic Ecosystem Stressors in the Tuolumne River 2-1
2.1 Physical Habitat Loss or Alteration 2-2
2.2 Ecosystem Productivity and Food Supply 2-4
2.3 Predation 2-5
2.4 Temperature 2-6
2.5 Flow 2-14
2.6 Hatchery-Origin Strays in the Tuolumne 2-18
2.7 Direct Take 2-19
2.8 Limiting Factors Analysis 2-19
2.8.1 Background 2-19
2.8.2 Model Formulation 2-20
2.8.3 Model Interpretation 2-22
2.8.4 Results and Discussion 2-22
2.9 References 2-30
2.9.1 Printed References 2-30
2.9.2 Personal Communications 2-39

Chapter 3 Description of Flow and Non-Flow Assets 3-1
3.1 Tuolumne River Voluntary Agreement 3-1
3.1.1 Flow Commitments 3-2
3.1.2 Non-flow Commitments 3-4
3.2 References 3-8
3.2.1 Printed References 3-8
Chapter 4 Tuolumne River Hydrology and Operations Modeling Methods and Results 4-1
4.1 Introduction 4-1
4.2 Tuolumne Basin Existing Conditions 4-2
4.2.1 Water Diversion and Use 4-2
4.2.2 Existing Instream Flow Requirements (FERC 1995) 4-4
4.2.3 Proposed Instream Flow Requirements (2020 FERC Final Environmental Impact Statement) 4-5
4.2.4 Tuolumne River Hydrology 4-8
4.3 TVA Overview 4-13
4.3.1 TVA Flow Requirements 4-14
4.4 Hydrologic Modeling Analysis of the TVA 4-16
4.4.1 Tuolumne River Modeling Methods and Results Using WSE 4-16
4.4.2 Lower San Joaquin River Modeling Methods and Results Using WSE 4-47
4.4.3 TVA Accounting Procedures and Historical Analysis 4-55
4.5 References 4-58
4.5.1 Printed References 4-58
Chapter 5 Water Temperature 5-1
5.1 Introduction 5-1
5.1.1 Temperature Effects on Aquatic Species 5-1
5.1.2 Habitat Degradation 5-2
5.1.3 2018 Bay-Delta Plan's Recommendations to Other Agencies 5-2
5.2 Evaluation of Water Temperatures Resulting from the TVA 5-3
5.2.1 Methods 5-3
5.2.2 Results 5-12
5.2.3 Discussion 5-90
5.3 References 5-92
5.3.1 Printed References 5-92
Chapter 6 Predator Control 6-1
6.1 Introduction 6-1
6.1.1 2018 Bay-Delta Plan's Recommendations to Other Agencies 6-2
6.2 Methods 6-3
6.3 Literature Review 6-4

6.4 Discussion 6-6
6.5 References 6-7
6.5.1 Printed References 6-7
6.5.2 Personal Communications 6-9
Chapter 7 Spawning and Rearing Habitat 7-1
7.1 Introduction 7-1
7.1.1 Habitat Effects on Aquatic Species 7-1
7.1.2 Habitat Degradation 7-2
7.1.3 2018 Bay-Delta Plan's Recommendations to Other Agencies 7-3
7.2 Habitat Restoration 7-5
7.2.1 Spawning Habitat 7-6
7.2.2 Rearing Habitat 7-12
7.2.3 Summary of Potential Benefits 7-16
7.3 Habitat Modeling 7-17
7.3.1 Methods 7-17
7.3.2 Results 7-27
7.4 Discussion 7-40
7.5 References 7-43
7.5.1 Printed References 7-43
Chapter 8 Traditional Ecological Knowledge of California Native American Tribes 8-1
8.1 Introduction 8-1
8.2 Traditional Ecological Knowledge 8-1
8.2.1 Consideration of Traditional Ecological Knowledge in the Bay-Delta Plan 8-1
8.2.2 Description of Traditional Ecological Knowledge 8-2
8.2.3 Benefits of Incorporating TEK in the Bay-Delta Plan 8-2
8.2.4 Tribal Connections to Native Fish and Plant Species 8-3
8.2.5 Traditional Land Stewardship Practices 8-3
8.2.6 Importance of Flow and Water Quality to Tribal Uses of Water 8-4
8.2.7 Effects of Aquatic Ecosystem Stressors on Tribal Uses of Water 8-4
8.3 References 8-6
8.3.1 Printed References 8-6
8.3.2 Personal Communications 8-7
Chapter 9 Conclusions and Uncertainties 9-1

Appendix A Stock-Recruitment Modeling

Appendix B Hydrologic and Water Quality Modeling

Appendix C Draft Tuolumne Accounting Spreadsheet Model

Appendix D Habitat Modeling Methods

Tables

Table ES-1. Proposed Increases in Tuolumne River Flow Requirements as Identified in the TVA MOU (Thousand-Acre Feet [TAF]; January Through June). ES-3

Table ES-2. Non-flow Assets and Measures in the TVA MOU ES-4

Table ES-3. Hydrologic, Temperature, and Habitat Modeling Scenarios Evaluated ES-5

Table ES-4. Estimates for New Flow Contributions Resulting from the TVA at La Grange Dam During January Through June Averaged for All Years and by WYT (in TAF). ES-7

Table ES-5. January Through June Expected Change (Relative to Existing Conditions) in Delta Outflow Averaged by WYT from the TVA Accounting Spreadsheet (in TAF). ES-7

Table ES-6. A Comparison of the Percentage of Time That USEPA Temperature Benchmarks for Salmonid Life Stage Protective Conditions Are Attained Each Month on the Tuolumne River Under the Modeled Scenarios. ES-8

Table ES-7. Median of Annual Mean Spawning Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses. ES-10

Table ES-8. Median of Annual Mean Combined (In-channel and Floodplain) Rearing Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses. ES-11

Table 1-1. Annual O. Mykiss Passage at the Adult Counting Weir, Sampling Dates, Counts of Fish Larger than 16 Inches, and Counts of Fish with Adipose Clips 2009–2022. 1-3

Table 1-2. Common and Scientific Name of Non-Salmonid Fish Captured in the 2022 Seine Survey, Rotary Screw Trap (RST), and Snorkel Survey. Names in Bold Indicate Native Species. 1-5

Table 2-1. Main Aquatic Stressors on the Tuolumne River and TVA Assets Expected to Address Them. 2-1

Table 2-2. Unspawned Females, Partially Spawned Females, and Total Female Fish Handled during the Tuolumne River Carcass Surveys from 2012–2019. 2-9

Table 2-3. Survival Indices through the Lower Tuolumne River between Waterford and Grayson. 2-17

Table 2-4. Summary of Detections for Acoustic-Tagged Fall-Run Chinook Salmon at Grayson, River Flow at La Grange, and Water Temperature at Roberts Ferry Bridge. 2-18

Table 2-5. Estimated Percentage of Tuolumne River Adult Salmon Returns from Hatchery Origin 2010–2019.....2-19

Table 2-6. Summary Results of Fall-Run Chinook Salmon Stock-Recruitment Models, Comparing Density-Dependent (Ricker) and Density-Independent Models with Different Environmental Covariates. The Table Includes Columns Describing the Model Considered, the Stock- Recruitment Equation Used To Fit the Model, and the Parameters Included in the Model (α for Spawner Abundance, β for Density-Dependence, and γ for the Environmental Covariate). The 'Estimate' Column Is the Estimated Direction (+ or -) and Magnitude of the Effects of Spawner Abundance, Density-Dependence, and Environmental Covariates (Flow, Temperature, and Habitat Area) on Juvenile Abundance Along with the Standard Error, t-Value, and p-Value Associated with Each Parameter Estimate. Significant Estimates of Covariate Effects ($p < 0.05$) Are in Bold. Estimates Are on the Natural Log Scale. Models Are Ranked by AIC and ΔAIC Value. Models with a Lower ΔAIC Have More Empirical Support. 2-23

Table 3-2. Non-Flow Assets and Measures for the Lower Tuolumne River.....3-5

Table 3-3. Gravel Augmentation Rates. 3-8

Table 4-1. Reported Surface Water Diversions for MID and TID (in Acre-Feet or AF).....4-3

Table 4-2. Tuolumne Year Type Classifications Under the 1995 Settlement Agreement. 4-4

Table 4-3. Minimum Monthly Flow Requirements at La Grange Dam on the Tuolumne River per the 1995 FERC Settlement Agreement (in cubic feet per second or cfs). 4-5

Table 4-4. 2020 FERC FEIS Proposed Base Flow Requirements at La Grange Dam (in cfs). 4-6

Table 4-5. Expected Infiltration Gallery Diversion Rates (in cfs).....4-6

Table 4-6. Representation of the 2020 FERC FEIS Outmigration Pulse Flow. 4-7

Table 4-7. Representation of the 2020 FERC FEIS Floodplain Inundation Pulse Flow. 4-7

Table 4-8. Summary of Monthly and Annual UF in the Tuolumne River from 2004–2023 (in TAF). 4-8

Table 4-9. Summary of Monthly and Annual Inflow to New Don Pedro from 2004–2023 (in TAF). 4-9

Table 4-10. Summary of Monthly and Annual Flow below La Grange Dam from 2004–2023 (in TAF). 4-11

Table 4-11. Summary of Monthly and Annual Flow at Modesto from 2004–2023 (in TAF).....4-11

Table 4-12. Summary of Monthly and Annual Flow on the San Joaquin River at Vernalis from 2004–2023 (in TAF). 4-12

Table 4-13. TVA January Through June Baseflow Requirements at La Grange Dam (in cfs). 4-14

Table 4-14. Representation of the Outmigration Pulse Flow under the TVA in WSE. 4-15

Table 4-15. Representation of the Floodplain Inundation Pulse Flow under the TVA in WSE. 4-15

Table 4-16. Summary of Tuolumne River Analysis Scenarios. 4-18

Table 4-17. Required Flow from January Through June Averaged by SJR WYT in the Tuolumne River Under the Modeled Scenarios (in TAF and as a % of January Through June UF). 4-22

Table 4-18. Change in Required Flow from January Through June in the Tuolumne River Averaged by SJR WYT Under the TVA and UF Objective Scenarios Relative to Existing Conditions (in TAF). 4-22

Table 4-19. Average Resulting Flow from January Through June in the Tuolumne River at La Grange Dam Under the Modeled Scenarios (in TAF and as a % of January Through June UF). 4-25

Table 4-20. Change in Average Resulting Flow from January Through June in the Tuolumne River at La Grange Dam Under the TVA and UF Objective Scenarios Relative to Existing Conditions (in TAF). 4-26

Table 4-21. Average Resulting Flow from January Through June on the Tuolumne River at Modesto Under the Modeled Scenarios (in TAF and as a % of January Through June UF). 4-26

Table 4-22. Change in Average Resulting Flow from January Through June in the Tuolumne River at Modesto Under the TVA and UF Objective Scenarios Relative to Existing Conditions (in TAF). 4-26

Table 4-23. Average End-of-September Carryover Storage in New Don Pedro Reservoir Under the Modeled Scenarios (in TAF). 4-30

Table 4-24. Change in Average End-of-September Carryover Storage in New Don Pedro Reservoir Under the TVA and UF Objective Scenarios Relative to Existing Conditions (in TAF). 4-31

Table 4-25. Annual Required Flow Averaged by SJR WYT in the Tuolumne River Under the Modeled Scenarios (in TAF). 4-38

Table 4-26. Change in Annual Required Flow in the Tuolumne River Averaged by SJR WYT Under the TVA+2020FERC and UF Objective Scenarios Relative to Existing Conditions (in TAF). 4-38

Table 4-27. Average Annual Resulting Flow in the Tuolumne River at La Grange Under the Modeled Scenarios (in TAF). 4-41

Table 4-28. Change in Average Annual Resulting Flow in the Tuolumne River at La Grange Under the TVA+2020FERC and UF Objective Scenarios Relative to Existing Conditions (in TAF). 4-42

Table 4-29. Average Annual Resulting Flow in the Tuolumne River at Modesto Under the Modeled Scenarios (in TAF). 4-42

Table 4-30. Change in Average Annual Resulting Flow in the Tuolumne River at Modesto Under the TVA+2020FERC Scenario and UF Objective Scenarios Relative to Existing Conditions (in TAF). 4-42

Table 4-31. Average End-of-September Carryover Storage in New Don Pedro Reservoir Under the Modeled Scenarios (in TAF). 4-45

Table 4-32. Change in Average End-of-September Carryover Storage in New Don Pedro Reservoir Under the TVA+2020FERC and UF Objective Scenarios Relative to Existing Conditions (in TAF). 4-45

Table 4-33. Summary of Lower San Joaquin River Analysis Scenarios. 4-49

Table 4-34. Average Total Resulting Flow from January Through June on the Stanislaus River at Ripon Under Existing Conditions and the TVA (in TAF). 4-50

Table 4-35. Average Total Resulting Flow from January Through June in the San Joaquin at Vernalis Under Existing Conditions and the TVA (in TAF). 4-50

Table 4-36. Average Total Resulting Flow from January Through June in the Merced River at Stevinson Under the 40% UF Objective and TVA + 2018 BDP (in TAF). 4-52

Table 4-37. Average Total Resulting Flow from January Through June in the Stanislaus River at Ripon Under the 40% UF Objective and TVA + 2018 BDP (in TAF). 4-52

Table 4-38. Average Total Resulting Flow from January Through June in the San Joaquin River at Vernalis Under the 40% UF Objective and TVA + 2018 BDP (in TAF). 4-53

Table 4-39. Average Resulting Flow during January Through June on the San Joaquin River at Vernalis Under Existing Conditions, and the Increase in Flow under the TVA, the TVA + 2018 BDP, and the 40% UF Objective Scenario (in TAF). 4-55

Table 4-40. Estimates for New Flow Contributions Resulting from the TVA at La Grange Dam During January Through June Averaged for All Years and by WYT (in TAF). 4-57

Table 4-41. Expected Change (Relative to Existing Conditions) in Delta Outflow Averaged by WYT from the TVA Accounting Spreadsheet (in TAF). 4-58

Table 5-1. Summary of Water Temperature Modeling Scenarios for the Tuolumne River and Lower San Joaquin River. 5-5

Table 5-2. USEPA Recommended Temperature Guidance for Protective Conditions. 5-6

Table 5-3. SEP Temperature Parameters That Are Supportive, Stressful, and Detrimental to Salmon and the Steelhead Form of *O. mykiss*. 5-7

Table 5-4. Geographic and Seasonal Occurrence for Fall-Run Chinook Salmon and *O. mykiss* (Rainbow Trout and Steelhead). 5-9

Table 5-5. Evaluation Time Periods, Primary Salmonid Life Stage, Primary Evaluation Locations, and Evaluation Temperature Benchmarks for the Tuolumne River. 5-10

Table 5-6. Evaluation Time Periods, Primary Salmonid Life Stage, Primary Evaluation Locations, and Evaluation Temperature Thresholds for the Lower San Joaquin River. 5-11

Table 5-7. A Comparison of the Percentage of Time that USEPA Temperature Benchmarks for Salmonid Life Stage Protective Conditions Are Attained Each Month on the Tuolumne River Under the Modeled Scenarios. 5-17

Table 5-8. A Comparison of the Percentages of Time That the 20° Celsius Harmful Temperature Benchmark for Salmonids Is Attained Each Month in the Tuolumne River Under the Modeled Scenarios. 5-18

Table 5-9. A Comparison of the Percentages of Time That the 25° Celsius Lethal Temperature Benchmark for Salmonids Is Attained Each Month in the Tuolumne River Under the Modeled Scenarios. 5-18

Table 5-10. A Comparison of the Percentages of Time That USEPA Temperature Benchmarks for Salmonid Life Stage Protective Conditions Are Attained Each Month on the San Joaquin River Under the Modeled Scenarios 5-73

Table 5-11. A Comparison of the Percentages of Time That the 20° Celsius Harmful Temperature Benchmark for Salmonids Is Attained Each Month on the San Joaquin River Under the Modeled Scenarios. 5-74

Table 5-12. A Comparison of the Percentage of Time That the 25° Celsius Lethal Temperature Benchmark for Salmonids Is Attained Each Month on the San Joaquin River Under the Modeled Scenarios. 5-74

Table 7-1. Habitat Stressors from Human Manipulation of Habitat in the Tuolumne River, and Their Effects on Chinook Salmon. 7-3

Table 7-2. Summary of the Doubled Escapement of Fall-Run on the Tuolumne River, Number of Juveniles, and Rearing and Spawning Habitat Needed to Support the Doubled Escapement. Values Are Shown for Calculations Using Fixed Parameters and for the Mean and Median. 7-25

Table 7-3. Input parameters Used to calculate the Rearing and Spawning Habitat Area Needed to Support the Doubling Goal Population. 7-25

Table 7-4. Median of Annual Mean Spawning Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses. 7-29

Table 7-5. Median of Annual Mean In-Channel Rearing Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses. 7-31

Table 7-6. Median of Annual Mean Floodplain Rearing Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses. 7-34

Table 7-7. The Proportion of MFE Occurrence for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios on the Tuolumne River, Calculated with and without the Temperature Filter Applied. Values Shown Are the Proportion of Floodplain Event Occurrence Delineated by Floodplain Rearing Area Needed to Support Percent of Doubling Goal (25%, 50%, 75%, and 100%) with Lower and Upper Bounds Shown in Parentheses. The Lower Bound Represents the Proportion of Event Occurrence When MFE Criteria Are Restricted to Require Floodplain Events 4 out of 5 Years, and Upper Bound Represents the Proportion of Event Occurrence When MFE Criteria Are Loosened to Require Floodplain Events 1 out of 2 Years. 7-37

Table 7-8. Median of Annual Mean Combined (In-Channel and Floodplain) Rearing Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses 7-39

Table 7-9. The Percentage of Temperature Filtered Habitat to Total (Unfiltered) Habitat. Temperature Filtered Habitat Uses Temperature Benchmarks and WUA Physical Criteria to Evaluate Habitat Suitability Versus Total (Unfiltered) Habitat Using WUA Only. 7-42

Figures

Figure ES-1. Tuolumne River Fall-Run Chinook Salmon Annual and Decadal Average Escapement from CDFW GrandTab (2025). The Salmon Doubling Goal (17,800) Represents the Estimated Tuolumne River Salmon Escapement Needed to Meet the Narrative Salmon Protection Objective. ES-3

Figure ES-2. Median of Annual Mean Temperature Filtered Spawning Habitat (Acres) Across All Modeled Years (1970–2003) Under the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of this Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. ES-9

Figure ES-3. Median of Annual Mean Temperature Filtered Rearing (In-channel and Floodplain Combined) Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios. The Solid Line Represents Area of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of this Estimate, and Dashed Lines Represent 25% of the Doubling Goal Area. Error Bars Represent the 25% and 75% Quartiles..... ES-10

Figure 1-1. Tuolumne River Fall-Run Chinook Salmon Annual and Decadal Average Escapement from CDFW GrandTab (2025). The Salmon Doubling Goal (17,800) Represents the Estimated Tuolumne River Salmon Escapement Needed to Meet the Narrative Salmon Protection Objective. 1-2

Figure 1-2. *O. mykiss* Counts during the June through September Snorkel Surveys 2001–2022 (TID and MID 2023). 1-4

Figure 2-1. Number of Fall-Run Chinook Salmon Passing the Counting Weir (RM 24.5) per Day and the Average Daily Water Temperature at the Weir, September 1, 2017, through December 31, 2017) (Reproduced from TID and MID 2018). Adult Migration Was Observed in September, When Water Temperatures Were Suitable in the Tuolumne River. The Red Dash Line Represents the USEPA (2003) 18°C Benchmark for Adult Salmon Migration. 2-7

Figure 2-2. Number of Fall-Run Chinook Salmon Passing the Counting Weir (RM 24.5) per Day and the Average Daily Water Temperature at the Weir and Modesto Gage, September 1, 2015, through December 31, 2015) (Reproduced from TID and MID 2016). The Red Dash Line Represents the USEPA (2003) 18°C Benchmark for Adult Salmon Migration..... 2-8

Figure 2-3. Tuolumne River Flows (cfs) at the La Grange gage, Water Temperature at Riffle K1 (RM 41.7) and Hickman Bridge (RM 31.6), Upper Limit for Successful Egg Incubation (13°C 7DADM) and Number of Live Fish and Redds Counted during Escapement Survey (Murphey 2024a). 2-9

Figure 2-4. 7DADM Temperatures at Selected Locations from RM 51.6–32 for 2011, USEPA (2003) Recommended Temperatures for Core (16°C) and Non-Core Juvenile Rearing (18°C) and Temperatures Considered to be Supportive, Stressful, Sub-Optimal, and Detrimental for Rearing O. mykiss (Murphey 2024c). 2-10

Figure 2-5. 7DADM Temperatures at Selected Locations from RM 51.6–32 for 2006, USEPA (2003) Recommended Temperatures for Core (16°C) and Non-Core Juvenile Rearing (18°C) and Temperatures Considered to be supportive, Stressful, Sub-Optimal, and Detrimental for Rearing O. mykiss (Murphey 2024d)..... 2-11

Figure 2-6. 7DADM Temperatures at Selected Locations from RM 51.6–32 for 2012. USEPA (2003) Recommended Temperatures for Core (16°C) and Non-Core Juvenile Rearing (18°C) and Temperatures Considered to be Supportive, Stressful, Sub-Optimal, and Detrimental for Rearing O. mykiss. (Murphey 2024e)..... 2-12

Figure 2-7. 7DADM Temperatures at Selected Locations from RM 51.6–32 for 2013. USEPA (2003) Recommended Temperatures for Core (16°C) and Non-Core Juvenile Rearing (18°C) and Temperatures Considered to be Supportive, Stressful, Sub-Optimal, and Detrimental for Rearing O. mykiss (Murphey 2024f). 2-13

Figure 2-8. 7DADM Temperatures at A1 (RM 51.6), K1 (RM 42.6) and Shiloh (RM 3.4), for 2011 (Wet Year; Illustrated with Solid Lines) and 2015 (Critically Dry Year; Illustrated with Dashed Lines) USEPA Non-Core Rearing (18°C), and Temperatures Considered Supportive, Stressful, and Detrimental for Rearing Fall-Run Chinook Salmon (Murphey 2024g). 2-14

Figure 2-9. Tuolumne River Median Monthly Flow (Thousand Acre-Feet [TAF]) from 1984 to 2009 under Unimpaired, Observed, and 40% Unimpaired Flow Conditions. (Unimpaired and Observed Flow Data Are from Table 2.20 in Appendix C, Technical Report on the Scientific Basis for Alternative San Joaquin River Flow and Southern Delta Salinity Objectives [2018 Final SED]. The 40% Unimpaired Flow Objective Points in the Figure Are 40% of the Unimpaired Flow Points.) 2-15

Figure 2-10. Tuolumne River Fall-Run Chinook Salmon Escapement and Mean Streamflow in the Tuolumne River at Modesto (DWR Gage Data For MOD) from 1 February to 15 June Two Years Prior to the Escapement Estimates (Reproduced from CDFW 2018). 2-16

Figure 2-11. Density-Independent + Mean May Temperature. This Was the Top Model Overall (ΔAIC = 0.00), Describing the Relationship Between Spawner Abundance and the Natural Log of Juvenile Abundance, Modeled as a Density-Independent Function with an Additive Effect of Mean May Temperature (in Celsius). Points Represent Annual Observed Spawner and Juvenile Abundance; Point and Line Colors Represent Mean May Temperature; Solid Lines Show the Predicted Stock-Recruitment Relationship Based on the Fitted Model Using Mean May Temperature as the Predictor Variable. 2-26

Figure 2-12. Density-Independent + Mean Jan–May Flow. This Was the Top Model That Included a Flow Covariate (ΔAIC = 4.21), Describing the Relationship Between Spawner Abundance and the Natural Log of Juvenile Abundance, Modeled as a Density-Independent Function With an Additive Effect of Mean Jan–May Flow (cfs). Points Represent Annual Observed Spawner and Juvenile Abundance; Point and Line Colors Represent Mean Jan–May Flow; Solid Lines Show the Predicted Stock-Recruitment Relationship Based on the Fitted Model Using Mean Jan–May Flow as the Predictor Variable. 2-27

Figure 2-13. Correlation Plot Depicting the Pearson Correlation Coefficient (Pearson r) for All Environmental Covariates Considered in Stock-Recruitment Models. Dark Blue Colors With Large Circles Indicate a Strongly Positive Correlation (e.g., r = 1), and Dark Red Colors with Large Circles Indicate a Strongly Negative Correlation (e.g., r = -1) Among Paired Covariates 2-28

Figure 2-14. Density-Independent + Mean Floodplain Weighted Usable Area. This Was the Top Model That Included a Habitat Covariate (ΔAIC = 6.52), Describing the Relationship Between Spawner Abundance and the Natural Log of Juvenile Abundance, Modeled as a Density- Independent Function With an Additive Effect of Mean Floodplain WUA (Acres). Points Represent Annual Observed Spawner and Juvenile Abundance; Point and Line Colors Represent Floodplain WUA Modeled Using Observed Flows; Solid Lines Show the Predicted Stock-Recruitment Relationship Based on the Fitted Model Using Floodplain WUA as the Predictor Variable. 2-29

Table 3-1. Proposed Increases in Tributary Flow Requirements as Identified in the MOU (Thousand-Acre Feet; January through June). 3-2

Figure 4-1. Monthly UF in the Tuolumne River Compared with Historical Inflow to New Don Pedro Reservoir for Water Years 2013 Through 2023 (DWR n.d.(a); DWR n.d.(b)). 4-9

Figure 4-2. Timeseries of Monthly UF Estimated at La Grange Dam Compared with Historical Flow on the Tuolumne River below New Don Pedro Dam, below La Grange Dam, and at Modesto for Water Years 2013 Through 2023 (DWR n.d.(a); DWR n.d.(c); USGS n.d.(a); USGS n.d.(b)). 4-10

Figure 4-3. Timeseries of Monthly Flow in the Tuolumne River at Modesto Compared with the flow in the San Joaquin River at Vernalis for Water Years 2013 Through 2023 (USGS n.d.(b); USGS n.d.(c)). 4-13

Figure 4-4. Critical (C) Year January Through June Flow Requirements in the Tuolumne River Under Existing Conditions, the UF Objective, and the TVA Scenarios. 4-19

Figure 4-5. Dry (D) Year January Through June Flow Requirements on the Tuolumne River Under Existing Conditions, the UF Objective, and the TVA Scenarios. 4-20

Figure 4-6. Below Normal (BN) Year January Through June Flow Requirements on the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and the TVA. 4-20

Figure 4-7. Above Normal (AN) Year January Through June Flow Requirements on the Tuolumne River Under Existing Conditions, the UF Objective, and the TVA Scenarios. 4-21

Figure 4-8. Wet (W) Year January Through June Flow Requirements on the Tuolumne River Under Existing Conditions, the UF Objective, and the TVA Scenarios. 4-21

Figure 4-9. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Dam Under Existing Conditions and the TVA. 4-23

Figure 4-10. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Dam Under the 30% UF Objective and the TVA. 4-24

Figure 4-11. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Dam Under the 40% UF Objective and the TVA. 4-24

Figure 4-12. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Dam Under the 50% UF Objective and the TVA. 4-25

Figure 4-13. Timeseries of End of Month Storage in New Don Pedro Reservoir from 1921 Through 2003 Displaying the TVA with Existing Conditions. 4-28

Figure 4-14. Timeseries of End of Month Storage in New Don Pedro Reservoir for 1921 Through 2003 Displaying the TVA with the 30% UF Objective. 4-28

Figure 4-15. Timeseries of End of Month Storage in New Don Pedro Reservoir for 1921 Through 2003 Displaying the TVA with the 40% UF Objective. 4-29

Figure 4-16. Timeseries of End of Month Storage in New Don Pedro Reservoir for 1921 Through 2003 Displaying the TVA with the 50% UF Objective. 4-29

Figure 4-17. Exceedance Chart of End-of-September Storage in New Don Pedro Reservoir Displaying Existing Conditions, the UF Objective Scenarios, and the TVA. 4-30

Figure 4-18. Critical (C) Year Annual Required Flows in the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and TVA+2020FERC. 4-33

Figure 4-19. Dry (D) Year Annual Required Flows in the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and TVA+2020FERC. 4-34

Figure 4-20. Below Normal (BN) Year Annual Required Flow in the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and TVA+2020FERC. 4-34

Figure 4-21. Above Normal (AN) Year Annual Required Flows in the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and TVA+2020FERC. 4-35

Figure 4-22. Wet (W) Year Annual Required Flows in the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and TVA+2020FERC. 4-35

Figure 4-23. Critical (C) Year IG Diversions Compared to Required Baseflow at La Grange Dam Under the Existing Conditions and TVA+2020FERC from June Through October. 4-36

Figure 4-24. Dry (D) Year IG Diversions Compared to Required Baseflow at La Grange Dam Under the Existing Conditions and TVA+2020FERC from June Through October. 4-36

Figure 4-25. Below Normal (BN) Year IG Diversions Compared to Required Baseflow at La Grange Dam Under the Existing Conditions and TVA+2020FERC from June Through October. 4-37

Figure 4-26. Above Normal (AN) Year IG Diversions Compared to Required Baseflow at La Grange Dam Under the Existing Conditions and TVA+2020FERC from June Through October. 4-37

Figure 4-27. Wet (W) Year IG Diversions Compared to Required Baseflow at La Grange Dam Under the Existing Conditions and TVA+2020FERC from June Through October. 4-38

Figure 4-28. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Under Existing Conditions and the TVA+2020FERC. 4-39

Figure 4-29. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Under the 30% UF Objective and the TVA+2020FERC. 4-40

Figure 4-30. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Under the 40% UF Objective and the TVA+2020FERC. 4-40

Figure 4-31. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Under the 50% UF Objective and the TVA+2020FERC. 4-41

Figure 4-32. Timeseries of End of Month Storage in New Don Pedro Reservoir from 1921 Through 2003 Displaying the TVA+2020FERC with Existing Conditions. 4-43

Figure 4-33. Timeseries of End of Month Storage in New Don Pedro Reservoir from 1921 Through 2003 Displaying the TVA+2020FERC with the 30% UF Objective. 4-43

Figure 4-34. Timeseries of End of Month Storage in New Don Pedro Reservoir from 1921 Through 2003 Displaying the TVA+2020FERC with the 40% UF Objective. 4-44

Figure 4-35. Timeseries of End of Month Storage in New Don Pedro Reservoir from 1921 Through 2003 Displaying the TVA+2020FERC with the 50% UF Objective. 4-44

Figure 4-36. Exceedance Chart of End-of-September Storage in New Don Pedro Reservoir Displaying Existing Conditions, the UF Objective Scenarios, and the TVA+2020FERC. 4-45

Figure 4-37. Box Plots Displaying Resulting Flow in the San Joaquin River at Vernalis Under Existing Conditions and the TVA. 4-50

Figure 4-38. Annual Timeseries of the Total January Through June Change in Flow in the LSJR Tributaries and in the San Joaquin River at Vernalis Under the TVA Compared to Existing Conditions. 4-51

Figure 4-39. Box Plots Displaying Resulting Flow in the San Joaquin River at Vernalis Under the 40% UF Objective and the TVA + 2018 BDP. 4-53

Figure 4-40. Annual Timeseries of the Total January Through June Change in Flow on the LSJR Tributaries and in the San Joaquin River at Vernalis Under the TVA + 2018 BDP Compared to the 40% UF Objective. 4-54

Figure 5-1. Tuolumne River Running 7DADM Water Temperatures Downstream of La Grange Dam (RM 53.5) Averaged Across All Water Years from 1970 to 2003. The USEPA Benchmark Line Represents the Life Stage with the Lowest Temperature Threshold for Each Month. 5-20

Figure 5-2. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration during September Averaged Across All Water Year Types from 1970 to 2003. 5-21

Figure 5-3. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration During September Averaged Across Wet Water Year Types from 1970 to 2003. The 40% and 50% UF Objective Scenarios Reflect Temperature Improvements Due to Flow Shifting Through Allowable Adaptive Methods of the Bay-Delta Plan. 5-22

Figure 5-4. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration During September Averaged Across Critical Water Year Types from 1970 to 2003. 5-22

Figure 5-5. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration During October Averaged Across All Water Year Types from 1970 to 2003. 5-24

Figure 5-6. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration During October Averaged Across Wet Water Year Types from 1970 to 2003. The 40% and 50% UF Objective Scenarios Reflect Temperature Improvements Due to Flow Shifting Through Allowable Adaptive Methods of the Bay-Delta Plan. 5-24

Figure 5-7. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration during October Averaged Across Critical Water Year Types from 1970 to 2003. 5-25

Figure 5-8. Tuolumne River Running 7DADM Water Temperatures at RM 0 for Adult Migration in September and October Averaged Across All Water Year Types from 1970 to 2003. 5-25

Figure 5-9. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During October Averaged Across All Water Year Types from 1970 to 2003. 5-26

Figure 5-10. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During October Averaged Across Wet Water Year Types from 1970 to 2003. 5-27

Figure 5-11. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During October Averaged Across Critical Water Year Types from 1970 to 2003. 5-27

Figure 5-12. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence during November Averaged Across All Water Year Types from 1970 to 2003. 5-28

Figure 5-13. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence during November Averaged Across Wet Water Year Types from 1970 to 2003. 5-28

Figure 5-14. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During November Averaged Across Critical Water Year Types from 1970 to 2003. 5-29

Figure 5-15. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During December Averaged Across All Water Year Types from 1970 to 2003. 5-30

Figure 5-16. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During January Averaged Across All Water Year Types from 1970 to 2003. 5-30

Figure 5-17. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During February Averaged Across All Water Year Types from 1970 to 2003. 5-31

Figure 5-18. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During February Averaged Across Critical Water Year Types from 1970 to 2003. 5-31

Figure 5-19. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During March Averaged Across All Water Year Types from 1970 to 2003. 5-32

Figure 5-20. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During March Averaged Across Wet Water Year Types from 1970 to 2003. 5-33

Figure 5-21. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During March Averaged Across Above Normal Water Year Types from 1970 to 2003. 5-33

Figure 5-22. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During March Averaged Across Below Normal Water Year Types from 1970 to 2003. 5-34

Figure 5-23. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During March Averaged Across Critical Water Year Types from 1970 to 2003. 5-34

Figure 5-24. Tuolumne River Running 7DADM Water Temperatures at RM 23.54 Averaged Across All Water Year Types from 1970 to 2003 for Spawning, Egg Incubation, and Fry Emergence. 5-35

Figure 5-25. Tuolumne River Running 7DADM Water Temperatures at RM 38.29 Averaged Across All Water Year Types from 1970 to 2003 for Spawning, Egg Incubation, and Fry Emergence. 5-36

Figure 5-26. Tuolumne River Running 7DADM Water Temperatures at RM 38.29 Averaged Across Dry Water Year Types from 1970 to 2003 for Spawning, Egg Incubation, and Fry Emergence. 5-36

Figure 5-27. Tuolumne River Running 7DADM Water Temperatures at RM 38.29 Averaged Across Critical Water Year Types from 1970 to 2003 for Spawning, Egg Incubation, and Fry Emergence. 5-37

Figure 5-28. Tuolumne River Running 7DADM Water Temperatures at RM 49.87 Averaged Across All Water Year Types from 1970 to 2003 for Spawning, Egg Incubation, and Fry Emergence. 5-37

Figure 5-29. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During March Averaged Across All Water Year Types from 1970 to 2003. 5-38

Figure 5-30. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During March Averaged Across Critical Water Year Types from 1970 to 2003. 5-39

Figure 5-31. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across All Water Year Types from 1970 to 2003. 5-40

Figure 5-32. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across Dry Water Year Types from 1970 to 2003. 5-40

Figure 5-33. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across Critical Water Year Types from 1970 to 2003. 5-41

Figure 5-34. Tuolumne River Running 7DADM Water Temperatures at RM 0 Averaged Across Critical Water Year Types from 1970 to 2003 for Core Juvenile Rearing. 5-41

Figure 5-35. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across All Water Year Types from 1970 to 2003. 5-42

Figure 5-36. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Wet Water Year Types from 1970 to 2003. 5-43

Figure 5-37. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Above Normal Water Year Types from 1970 to 2003. 5-43

Figure 5-38. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Dry Water Year Types from 1970 to 2003. 5-44

Figure 5-39. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Critical Water Year Types from 1970 to 2003. 5-44

Figure 5-40. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 Averaged Across All Water Year Types from 1970 to 2003 for Core Juvenile Rearing. 5-45

Figure 5-41. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During April Averaged Across All Water Year Types from 1970 to 2003. 5-46

Figure 5-42. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During April Averaged Across Wet Water Year Types from 1970 to 2003. 5-46

Figure 5-43. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During April Averaged Across Critical Water Year Types from 1970 to 2003. 5-47

Figure 5-44. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During May Averaged Across All Water Year Types from 1970 to 2003. 5-48

Figure 5-45. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During May Averaged Across Wet Water Year Types from 1970 to 2003. 5-48

Figure 5-46. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During May Averaged Across Critical Water Year Types from 1970 to 2003. 5-49

Figure 5-47. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During June Averaged Across All Water Year Types from 1970 to 2003. 5-50

Figure 5-48. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During June Averaged Across Wet Water Year Types from 1970 to 2003. 5-50

Figure 5-49. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During June Averaged Across Above Normal Water Year Types from 1970 to 2003. 5-51

Figure 5-50. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During June Averaged Across Dry Water Year Types from 1970 to 2003. 5-51

Figure 5-51. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During June Averaged Across Critical Water Year Types from 1970 to 2003. 5-52

Figure 5-52. Tuolumne River Running 7DADM Water Temperatures at RM 0 Averaged Across All Water Year Types from 1970 to 2003 for Smoltification. 5-52

Figure 5-53. Tuolumne River Running 7DADM Water Temperatures at RM 13.2 Averaged Across Above Normal Water Year Types from 1970 to 2003 for Smoltification. 5-53

Figure 5-54. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across All Water Year Types from 1970 to 2003. 5-54

Figure 5-55. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Wet Water Year Types from 1970 to 2003. 5-54

Figure 5-56. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Above Normal Water Year Types from 1970 to 2003. 5-55

Figure 5-57. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Below Normal Water Year Types from 1970 to 2003. 5-55

Figure 5-58. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Dry Water Year Types from 1970 to 2003. 5-56

Figure 5-59. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Critical Water Year Types from 1970 to 2003..... 5-56

Figure 5-60. Tuolumne River Running 7DADM Water Temperatures at RM 38.29 Averaged Across All Water Year Types from 1970 to 2003 for *O. mykiss* Core Juvenile Rearing..... 5-57

Figure 5-61. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across All Water Year Types from 1970 to 2003. 5-59

Figure 5-62. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across Wet Water Year Types from 1970 to 2003. The 40% and 50% UF Objective Scenarios Reflect Temperature Improvements Due to Flow Shifting Through Allowable Adaptive Methods of the Bay-Delta Plan. 5-59

Figure 5-63. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across Above Normal Water Year Types from 1970 to 2003. 5-60

Figure 5-64. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across Below-Normal Water Year Types from 1970 to 2003. 5-60

Figure 5-65. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across Dry Water Year Types from 1970 to 2003..... 5-61

Figure 5-66. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across Critical Water Year Types from 1970 to 2003. 5-61

Figure 5-67. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across All Water Year Types from 1970 to 2003. 5-62

Figure 5-68. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across Wet Water Year Types from 1970 to 2003. The 40% and 50% UF Objective Scenarios Reflect Temperature Improvements Due to Flow Shifting Through Allowable Adaptive Methods of the Bay-Delta Plan. 5-62

Figure 5-69. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across Above Normal Water Year Types from 1970 to 2003. 5-63

Figure 5-70. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across Below Normal Water Year Types from 1970 to 2003. 5-63

Figure 5-71. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across Dry Water Year Types from 1970 to 2003. 5-64

Figure 5-72. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across Critical Water Year Types from 1970 to 2003. 5-64

Figure 5-73. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1987 Which Is the First Critical Water Year Type in a Sequence of Critical Years and Is Not an Off-Ramp Year. 5-66

Figure 5-74. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1988 Which Is the Second Critical Water Year Type in a Sequence of Critical Years and Is an Off-Ramp Year. 5-66

Figure 5-75. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1989 Which Is the Third Critical Water Year Type in a Sequence of Critical Years and Is an Off-Ramp Year. 5-67

Figure 5-76. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1990 Which Is the Fourth Critical Water Year Type in a Sequence of Critical Years and Is an Off-Ramp Year. 5-67

Figure 5-77. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1991 Which Is the Fifth Critical Water Year Type in a Sequence of Critical Years and Is an Off-Ramp Year. 5-68

Figure 5-78. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1992 Which Is the Sixth Critical Water Year Type in a Sequence of Critical Years and Is an Off-Ramp Year. 5-68

Figure 5-79. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 2001 Which Is the First Dry Water Year Type in a Sequence of Dry Years and Is Not an Off-Ramp Year. 5-69

Figure 5-80. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 2002 Which Is the Second Dry Water Year Type in a Sequence of Dry Years and Is an Off-Ramp Year. 5-70

Figure 5-81. Lower San Joaquin River Running 7DADM Water Temperatures at RM 69.31 (Vernalis) Averaged Across All Water Year Types from 1970 to 2003 for Adult Migration. 5-76

Figure 5-82. Lower San Joaquin River Running 7DADM Water Temperatures at RM 69.31 (Vernalis) Averaged Across Wet Water Year Types from 1970 to 2003 for Adult Migration. 5-76

Figure 5-83. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During September Averaged Across All Water Year Types from 1970 to 2003. 5-77

Figure 5-84. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During September Averaged Across Wet Water Year Types from 1970 to 2003. 5-77

Figure 5-85. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During September Averaged Across Critical Water Year Types from 1970 to 2003. 5-78

Figure 5-86. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During October Averaged Across All Water Year Types from 1970 to 2003. 5-78

Figure 5-87. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During November Averaged Across All Water Year Types from 1970 to 2003. 5-79

Figure 5-88. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During December Averaged Across All Water Year Types from 1970 to 2003. 5-79

Figure 5-89. Lower San Joaquin River Running 7DADM Water Temperatures at RM 69.31 (Vernalis) Averaged Across All Water Year Types from 1970 to 2003 for Core Juvenile Rearing. 5-80

Figure 5-90. Lower San Joaquin River Running 7DADM Water Temperatures at RM 69.31 (Vernalis) Averaged Across Wet Water Year Types from 1970 to 2003 for Core Juvenile Rearing. 5-81

Figure 5-91. Lower San Joaquin River Running 7DADM Water Temperatures at RM 69.31 (Vernalis) Averaged Across Critical Water Year Types from 1970 to 2003 for Core Juvenile Rearing. 5-81

Figure 5-92. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During February Averaged Across All Water Year Types from 1970 to 2003. 5-82

Figure 5-93. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During March Averaged Across All Water Year Types from 1970 to 2003. 5-82

Figure 5-94. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During March Averaged Across Wet Water Year Types from 1970 to 2003. 5-83

Figure 5-95. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During March Averaged Across Critical Water Year Types from 1970 to 2003. 5-83

Figure 5-96. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across All Water Year Types from 1970 to 2003. 5-84

Figure 5-97. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across Wet Water Year Types from 1970 to 2003. 5-85

Figure 5-98. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across Critical Water Year Types from 1970 to 2003. 5-85

Figure 5-99. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across All Water Year Types from 1970 to 2003. 5-86

Figure 5-100. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Wet Water Year Types from 1970 to 2003. 5-87

Figure 5-101. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Critical Water Year Types from 1970 to 2003. 5-87

Figure 5-102. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across All Water Year Types from 1970 to 2003. 5-88

Figure 5-103. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Wet Water Year Types from 1970 to 2003. 5-89

Figure 5-104. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Critical Water Year Types from 1970 to 2003. 5-89

Figure 7-1. Fall-Run Chinook Salmon Fish-Habitat Relationships at the Bobcat Flat Restoration Site on the Tuolumne River (Source: USFWS 2013). 7-7

Figure 7-2. Atlantic Salmon Embryo Survival Rate as Fine Sediment Increases (Source: Kemp et al. 2011). 7-9

Figure 7-3. Fish Responses to LWD Augmentation and Other Instream Habitat Improvement Projects Shown as Percent Increases of Various Salmonid Species (Original Examination by Whiteway et al. 2010). 7-12

Figure 7-4. Feeding Success Compared Between Sacramento River (Closed Bars) and Yolo Bypass (Open Bars) (Source: Sommer et al. 2001). 7-15

Figure 7-5. Fork Length and Overall Health Condition Differences in Fish Reared for 54 Days in River Habitat (Length) and Floodplain Habitat (Right) (Source: Jeffres et al. 2008)..... 7-16

Figure 7-6. Map of Hydraulic Model Extents for Spawning (Dark Blue), Instream Rearing (Light Blue), and Floodplain Rearing (Gold) for the Existing Habitat Quantification. Flow and Temperature Nodes (Open Circles) Represent River Mile (RM) Locations of Simulated. 7-18

Figure 7-7. Flow-to-Suitable Spawning Habitat Relationships for the Tuolumne River Under Existing (Orange) and Existing + VA Conditions (Purple) (Hume and Baker 2024). 7-19

Figure 7-8. Flow-to-Suitable In-Channel Rearing Habitat Relationships for the Tuolumne River Under Existing (Orange) and Existing + VA Conditions (Purple). The Dotted Vertical Line Represents the Floodplain Inundation Threshold Value of 1,000 CFS (Hume and Baker 2024). 7-20

Figure 7-9. Flow-to-Suitable Floodplain Habitat Relationships for the Tuolumne River Under Existing (Orange) and Existing + VA Conditions (Purple). The Dotted Vertical Line Represents the Floodplain Inundation Threshold Value of 1,000 CFS (Hume and Baker 2024). 7-21

Figure 7-10. Workflow for Combining Modeled Flow, Flow-to-Suitable Area Relationships, and Modeled Temperature..... 7-22

Figure 7-11. Median of Annual Mean Temperature Filtered Spawning Habitat (Acres) Across All Modeled Years (1970–2003) Under the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Line Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. 7-28

Figure 7-12. Median of Annual Mean Temperature Filtered Spawning Habitat (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios by Water Year Type. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. Across All Water Year Types, the TVA Offers More Spawning Habitat (October Through December) Than the Existing Conditions and UF Objective Scenarios. Across Critical to Wet Water Year Types, the TVA Offers 9–12% More Spawning Habitat in the Tuolumne River. 7-29

Figure 7-13. Median of Annual Mean Temperature Filtered In-Channel Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. The TVA Shows a 4% Increase Over Existing Conditions, and the 30% and 40% UF Objective Scenarios Show a 4% Increase Over the TVA Conditions. 7-31

Figure 7-14. Median of Annual Mean Temperature Filtered In-Channel Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios by Water Year Type. The Solid Line Represents the Acreage of Habitat Required To Support the Doubling Goal Population, the Gray Band Represents Area of Habitat Required to Support the Doubling Goal Population, the Grey Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. Across All Water Year Types the TVA Conditions Represent an Increase in In-Channel Rearing Habitat Over Existing Conditions. 7-32

Figure 7-15. Median of Annual Mean Temperature Filtered Floodplain Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. The TVA Shows a 14% Increase Over Existing Conditions, and the 40% and 50% UF Objective Scenarios Show a 10–14% Increase Over the TVA. 7-34

Figure 7-16. Median of Annual Mean Temperature Filtered Floodplain Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios by Water Year Type. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. The TVA and the 40% and 50% UF Objective Scenarios Are Predicted to Provide an Increase in Floodplain Rearing Habitat Over Existing Conditions in All Water Year Types. The Appearance of Negative Values Are an Artifact of the Log Scale, and Median of Annual Mean Suitable Habitat for Existing Conditions and 30% UF Objective Scenarios Are 0 Acres for Critical Years. 7-35

Figure 7-17. The Proportion of MFE Occurrence for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios on the Tuolumne River. This Bar Chart Is Oriented Horizontally. The X-Axis Represents Proportion of Event Occurrence, and the Y-Axis Represents Floodplain Rearing Area Needed to Support the Percentage of the Doubling Goal Acreage. The Lower Bounds of the Error Bars Represent the Proportion of Event Occurrence When MFE Criteria Are Restricted to Require Floodplain Events 4 out of 5 Years. The Upper Bounds of the Error Bars Represent the Proportion of Event Occurrence When MFE Criteria Are Reduced Only to Require Floodplain Events 1 out of 2 Years. 7-36

Figure 7-18. Median of Annual Mean Total Temperature Filtered Rearing (In-Channel and Floodplain Combined) Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Scenarios. The Solid Line Represents Area of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Area. Error Bars Represent the 25% and 75% Quartiles. Combined Rearing Habitat for The TVA Shows an 18% Increase Over Baseline Conditions. All Flow Scenarios Reach the Doubling Goal Target for Rearing Habitat with In-Channel and Floodplain Habitat Combined. 7-38

Figure 7-19. Median of Annual Mean Total Temperature Filtered Rearing (In-Channel and Floodplain Combined) Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Scenarios by Water Year Type. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. In All Water Year Types, the TVA Scenario Shows an Increase in Rearing Habitat Over Existing Conditions. 7-39

Acronyms and Abbreviations

Acronym or Abbreviation	Definition
2016 Scientific Basis Report	2016 Technical Report on the Scientific Basis for Alternative San Joaquin River Flow and Southern Delta Salinity Objectives
7DADM	7-day average of the daily maximum
AFLA	Amended Final License Application
AFRP	Anadromous Fish Restoration Program
AIC	Akaike's Information Criterion
Bay-Delta Plan	Water Quality Control Plan for the San Francisco Bay/Sacramento-–San Joaquin Delta Estuary
BMI	benthic macroinvertebrate
CCSF	City and County of San Francisco
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife
cfs	cubic feet per second
CNRA	California Natural Resources Agency
CUAW	Consumptive use of applied water
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
D-1422	Water Right Decision 1422
Delta	Sacramento–San Joaquin River Delta
Districts	Turlock Irrigation District and Modesto Irrigation District
Draft TVA Scientific Basis Report	Draft Scientific Basis Report Supplement for the Tuolumne River Voluntary Agreement Proposal
DWR	California Department of Water Resources
FEIS	Final Environmental Impact Statement
FERC	Federal Energy Regulatory Commission
IG	infiltration gallery
ISAP	Independent Scientific Advisory Panel
LSJR	Lower San Joaquin River
LWD	large woody debris
MAF/y	million acre-feet per year
MFE	Meaningful Floodplain Event
MID	Modesto Irrigation District
MOU	Memorandum of Understanding
NMFS	National Marine Fisheries Service
NMI	New Melones Index
NOAA	National Oceanic and Atmospheric Administration
NPMSRP	Northern Pikeminnow Sport Reward Program
Pearson's r	Pearson's correlation coefficient
PID	Patterson Irrigation District

Acronym or Abbreviation	Definition
Projects	State Water Project and the Central Valley Project
Reclamation	U.S. Bureau of Reclamation
RM	river mile
RST	Rotary Screw Trap
SED	Substitute Environmental Document
SEP	Scientific Evaluation Process
SEWD	Stockton East Water District
SFPUC	San Francisco Public Utilities Commission
SJR	San Joaquin River
SJR index	San Joaquin River 60-20-20 index
SJRRP	San Joaquin River Restoration Program
SOI	Sphere of Influence
SR	summer rearing
SRP	Stepped Release Plan
State Water Board	State Water Resources Control Board
steelhead	anadromous California Central Valley Steelhead
SUB	Subsistence Fishing
SWP	State Water Project
TAF	thousand-acre feet
TAF/y	thousand acre-feet per year
TDS	total dissolved solids
TEK	traditional ecological knowledge
TID	Turlock Irrigation District
T-SUB	Tribal Subsistence Fishing
Tuolumne Parties	San Francisco Public Utilities Commission, Modesto Irrigation District, and Turlock Irrigation District
TVA	Tuolumne River Voluntary Agreement
UF	Unimpaired Flow
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
VA	voluntary agreement
VAMP	Vernalis Adaptive Management Plan
WIDD	Woodbridge Irrigation District Dam
WSE	Water Supply Effects
WSID	West Stanislaus Irrigation District
WUA	Weighed Useable Area

ES.1 Introduction

The State Water Resources Control Board (State Water Board or Board) is currently in the process of updating and implementing the Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary (Bay-Delta Plan or Plan). In 2018 the State Water Board updated the Plan's Lower San Joaquin River flow objectives for the protection of fish and wildlife beneficial uses and Southern Delta salinity objectives for the protection of agricultural beneficial uses. At that time State and federal agencies and water users in the Bay-Delta watershed were developing possible Voluntary Agreements (VAs) for updating and implementing the Bay-Delta Plan for consideration by the Board, but had not completed those proposed VAs. The Board indicated in its adoption of the 2018 updates that the Board could consider a future VA proposed by the Tuolumne River parties. In March 2022, the State Water Board received a Memorandum of Understanding (MOU or hereafter also referred to as the VA Term Sheet) signed by State and federal agencies and water users proposing VAs, which is now also referred to as the Healthy Rivers and Landscapes proposal, for consideration as part of the ongoing Bay-Delta Plan update of the provisions for the protection of fish and wildlife within the Sacramento River waterhed, Delta eastside tributaries, and the Delta (Sacramento/Delta update). In November 2022, the Board received an amended MOU that included a proposed VA for the Tuolumne River (TVA).

This *Draft Scientific Basis Report Supplement for the Tuolumne River Voluntary Agreement Proposal* (Draft TVA Scientific Basis Report) has been prepared to document the scientific basis for the TVA, which the TVA parties are proposing as a possible change to the current Lower San Joaquin River flow provisions of the Bay-Delta Plan adopted in 2018. Although the TVA was included in the updated VA MOU, the State Water Board must consider it in a separate process from the Sacramento/Delta update as it is outside of the scope of that update and would require amendments to the Bay-Delta Plan program of implementation adopted in 2018. The scientific analysis presented in this report, and summarized in this executive summary, will inform the State Water Board's consideration of the TVA.

This Draft TVA Scientific Basis Report was developed by the State Water Board with support from the California Department of Fish and Wildlife (CDFW) and California Department of Water Resources (DWR). This Draft TVA Scientific Basis Report will be made available for public comment. Following receipt of public comments, the draft will be revised as appropriate and the revised Draft TVA Scientific Basis Report will be submitted for scientific peer review pursuant to the requirements of California Public Health and Safety Code section 57004, which requires that the scientific basis of any statewide plan, basin plan, plan amendment, guideline, policy, or regulation undergo external scientific peer review before potential State Water Board adoption.

ES.2 Background

In December of 2018, the State Water Board approved updates to the Lower San Joaquin River (LSJR) flow components of the Bay-Delta Plan for the reasonable protection of fish and wildlife. Those updates include a flow requirement of 30–50% of unimpaired flow, starting at 40%, from

February through June, as well as other requirements. The 2018 Bay-Delta Plan updates were supported by the Final Substitute Environmental Document (SED) which was both the staff report and Environmental Impact Report equivalent for the project and included the 2016 *Technical Report on the Scientific Basis for Alternative San Joaquin River Flow and Southern Delta Salinity Objectives* (2016 Scientific Basis Report). The SED and 2016 Scientific Basis Report evaluated the expected benefits to the ecosystem, salmonids, and other native fish species from the LSJR components of the Bay-Delta Plan, and documented expected improvements in river temperatures, floodplain habitat, and Chinook salmon abundance (see Chapter 19, Appendix C which is the 2016 Scientific Basis Report, and Master Response 3.1).[1] This Draft TVA Scientific Basis Report presents scientific information for the flow and non-flow habitat restoration actions proposed by the TVA.

As described further in this report and the 2016 Scientific Basis Report, native aquatic species have declined substantially in the San Joaquin River and its salmon-bearing tributaries due to anthropogenic stressors, including climate change, degradation of habitat, and changes in river flows. The annual estimates of adult fall-run Chinook salmon escapement for the Tuolumne River from CDFW (2025) have ranged from a high of 45,900 salmon in 1959 to a low of 77 in 1991 (Figure ES1). Starting from 1952 through 2024, the decadal average escapement of Tuolumne River adult fall-run Chinook salmon has fallen from over 25,000 salmon to less than 1,000 (Figure ES-1). This is substantially less than the salmon production needed to attain the Anadromous Fish Restoration Program doubling objective for the Tuolumne River of 38,000 naturally produced adult salmon that survive to the ocean (USFWS 1995), which is equivalent to a doubling goal escapement value of 17,800 Tuolumne River adult salmon spawners.[2]

[1] Available on the State Water Board website at Bay-Delta Plan Update: Amendments and Substitute Environmental Document (SED) for Lower San Joaquin River and Southern Delta.

[2] The doubling goal (referred to as the Narrative Salmon Objective in the VA Term Sheet) is the doubled (average) natural production during the 1967 to 1991 time period. The habitat quantification methodology assumes the amount of habitat needed to support the doubling goal population on the Tuolumne River is equivalent to supporting 17,800 spawners and their offspring (see Chapter 7, *Spawning and Rearing Habitat*).

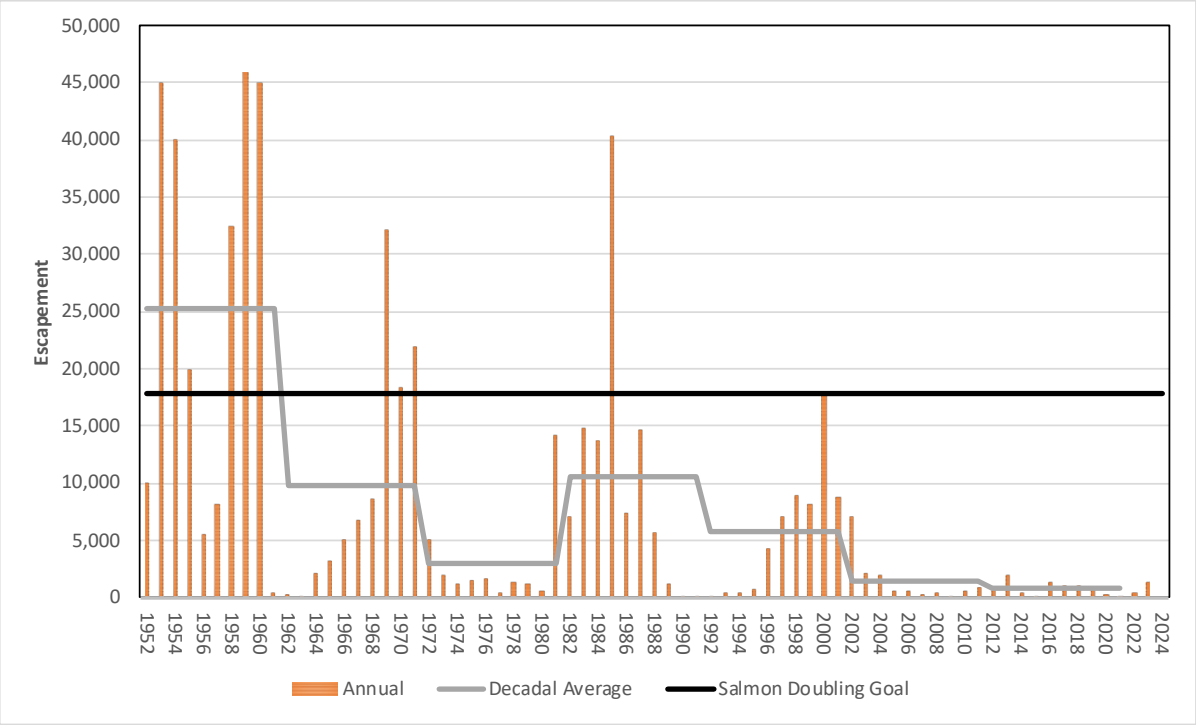


Figure ES-1. Tuolumne River Fall-Run Chinook Salmon Annual and Decadal Average Escapement from CDFW GrandTab (2025). The Salmon Doubling Goal (17,800) Represents the Estimated Tuolumne River Salmon Escapement Needed to Meet the Narrative Salmon Protection Objective.

Chapter 2, *Aquatic Ecosystem Stressors in the Tuolumne River*, provides additional information regarding stressors to native fish species in the Tuolumne River. Aquatic ecosystem stressors include factors that negatively impact the health or function of an organism, population, and/or an ecosystem. For example, reduced flows, increased water temperatures, loss of floodplain habitat, and competition and predation from introduced species are aquatic stressors to native fish populations on the Tuolumne River and within the Bay-Delta watershed. The TVA proposes restoration actions, called "assets" (Table ES-1 and Table ES-2; also see Chapter 3, *Description of Flow and Non-Flow Assets*), to reduce the impact of these stressors over the proposed 8 year term of the TVA (with the possibility of extension). The proposed restoration assets include increases in required river flows that vary by water year type (WYT), conducting non-flow habitat restoration actions targeted at improving spawning and rearing capacity for salmonids and other native fishes, and conducting predator control actions to improve juvenile rearing and migration survival.

Table ES-1. Proposed Increases in Tuolumne River Flow Requirements as Identified in the TVA MOU (Thousand-Acre Feet [TAF]; January Through June).[a]

	Water Year				
	Critical	**Dry**	**Below Normal**	**Above Normal**	**Wet**
Tuolumne River downstream of La Grange Dam	86(17)	140(40)	127(98)	138	138

[a] These volumes are proposed flows to be added above existing January through June minimum flow requirements. These flows are additive to existing requirements rather than additive to existing flow conditions. Existing requirements are from the Federal Energy Regulatory Commission (FERC) license for the Don Pedro Project and measured at the U.S. Geological Survey gage downstream of La Grange Dam. Values in parenthesis apply in critical, dry, and below normal years following a critical, dry, or below normal year (i.e., for sequential dry year off-ramps). The MOU also identified additional maximum Tuolumne River flow volumes that would be provided to avoid impacts to DWR's and Reclamation's water supplies and not for environmental flow purposes, which are not shown here.

Table ES-2. Non-flow Assets and Measures in the TVA MOU[a]

Project No.	Project and location	Description
1	Riffle A2 Rehabilitation River Mile (RM) 50.6/50.7	Add appropriately sized gravel to improve substrate conditions for spawning and incubation.
2	Riffle A3 Rehabilitation RM 50.4 to 50.6	Add appropriately sized gravel to improve substrate conditions for spawning and incubation.
3	Riffles 3A and 3B RM 49.2 to 49.6	Add appropriately sized gravel; restore banks to appropriate floodplain elevation and function; remove invasive hardwood.
4	Gravel Cleaning RM 45–49	Clean select gravel patches to expand availability of high quality gravel to improve spawning and incubation.
5	Lower Tuolumne River Habitat Improvement Program RM 5–48	$19M capital fund shall be used for a variety of improvement and restoration projects to be developed in conjunction with the Tuolumne River Partnership Advisory Committee (TRPAC). Examples of likely projects include floodplain lowering, floodplain connectivity, riparian plantings, and in-channel placement of LWD.
6	Riffle A5 RM 51.2	Construct alternative riffle/pool morphology.
7	Riffle A6 RM 51.0	Construct alternative riffle/pool morphology.
8	Basso Pool RM 47.0–47.3	Construct medial bar: riffle pool-tail morphology.
9	Large Woody Debris (LWD)	Improve instream habitat complexity through targeted addition of LWD to the lower Tuolumne River.
10	Infiltration Galleries (IG) RM 26	Construct IG#2 and operate IG#1 (existing) and IG#2 (proposed) from June through mid-October, enabling an increase of flow between La Grange; the IGs to benefit *O. mykiss*.
11	Riffle A3/A4 (RM 51.5); Gravel Augmentation	Spawning gravel size and distribution integrated with VA flow regime.
12	Fish Counting Barrier and Weir RM 25	Improve rearing and migration conditions upstream of the weir by preventing access by striped bass and other predators.
13	Predator Control	Improve rearing and migration conditions by reducing predation.
14	Reduce Redd Superimposition (seasonal weir) RM 47–52	Construct a seasonal weir when upstream gravel patches are at capacity to encourage use of suitable habitats at downstream locations.

[a] The projects and their associated attributes listed in Table ES-2 were derived as part of ongoing FERC relicensing activities and are subject to adjustment as part of ongoing and future project specific design; RM = River Mile (2024 Global Agreement).

ES.3 Project Description

The TVA parties, including San Francisco Public Utilities Commission, Modesto Irrigation District, and Turlock Irrigation District (Tuolumne Parties), propose the flow and habitat actions summarized in Table ES-1 and Table ES-2 in lieu of implementing the unimpaired flows and related actions required in the 2018 updates to the Bay-Delta Plan. This scientific basis report supplement is being prepared to support Board consideration of possible updates to the Bay-Delta Plan that would allow the TVA to be incorporated in the program of implementation.

ES.4 Summary of Analysis and Results

This Draft TVA Scientific Basis Report provides a review of the best available science on aquatic stressors related to flow and non-flow habitat on the Tuolumne River for the purposes of considering the TVA (see Chapter 2).

This Draft TVA Scientific Basis Report evaluates modeled Tuolumne River flows under the TVA proposal and includes quantitative evaluations of the projected changes in suitable habitat for native species from the TVA flows and non-flow habitat restoration actions. Modeled flow and habitat changes resulting from the TVA are compared to modeled existing environmental conditions and modeled potential implementation of the 2018 Bay-Delta Plan percent of unimpaired flow objectives. The modeled existing environmental conditions (Existing Conditions) represent the flows resulting from the 1995 FERC Settlement Agreement for the New Don Pedro hydroelectric project, and the modeled potential implementation of the Bay-Delta Plan percent of unimpaired flow objectives range, including flows of 30%, 40%, and 50% of unimpaired flow (% UF Objective).

Table ES-3. Hydrologic, Temperature, and Habitat Modeling Scenarios Evaluated

Scenario Name	Summary of Model Representation
Existing Conditions	Represents existing environmental conditions resulting from the implementation of the 1995 FERC Settlement Agreement.
TVA	Represents conditions resulting from the potential implementation of the Tuolumne River Voluntary Agreement.
30% UF Objective	Represents conditions resulting from the potential implementation of the 2018 Bay Delta Plan Lower San Joaquin Flow Objective at 30% unimpaired flow (low end of the unimpaired flow range).
40% UF Objective	Represents conditions resulting from the potential implementation of the 2018 Bay Delta Plan Lower San Joaquin Flow Objective at 40% unimpaired flow (starting point for the unimpaired flow objective).
50% UF Objective	Represents conditions resulting from the potential implementation of the 2018 Bay Delta Plan Lower San Joaquin Flow Objective at 50% unimpaired flow (high end of the unimpaired flow range).

The analysis of potential habitat outcomes for Chinook salmon spawning and rearing uses modeled acres of weighted usable area (WUA). WUA is an analysis that estimates the surface area of suitable habitat at various stream flows. Suitable habitat in a WUA analysis is defined by water depths, water velocities, and other physical habitat metrics that are suitable for fish species at specific life stages. For this analysis, the modeled acres of WUA were reduced (i.e., filtered) if water temperatures were

not also suitable. Chapter 7, *Spawning and Rearing Habitat*, includes more detailed information on habitat modeling, and Chapter 5, *Water Temperature*, includes more detailed information on water temperature modeling. Temperature benchmarks used in this analysis are based on the U.S. Environmental Protection Agency (USEPA) recommended temperature guidance for protection of salmonids.

This report also compares the amount of temperature filtered WUA for each scenario to the quantity of habitat that is predicted to be needed to support the doubling goal for the Tuolumne River Chinook salmon population. A qualitative literature review was also conducted to evaluate possible benefits from a predator control program (see Chapter 6, *Predator Control*).

This Draft TVA Scientific Basis Report also documents Traditional Ecological Knowledge (TEK) from California Native American Tribes within Northern California and the Sacramento–San Joaquin Delta watershed including its tributaries, to inform reasonable protection of beneficial uses, including tribal beneficial uses that are being considered as part of the Sacramento/Delta Update to the Bay-Delta Plan (see Chapter 8, *Traditional Ecological Knowledge of California Native American Tribes*).

In addition, consistent with peer review recommendations from the Sacramento/Delta VA scientific basis report (supplement), Chapter 2 includes a statistical modeling analysis to determine which environmental conditions affect fall-run Chinook salmon populations in the Tuolumne River (see Section 2.8, *Limiting Factors Analysis*). The analysis evaluates whether observed hydrologic, physical habitat, or temperature conditions in the past show relationships with fall-run Chinook salmon juvenile abundance. The statistical modeling analysis indicates spring water temperatures have the greatest effect on juvenile salmon abundance. The modeling also indicates spring flow rates and acres of floodplain habitat strongly influence juvenile salmon abundance but to a lesser extent than temperature. These modeling results indicate that improvements to river temperature, flow volumes and pattern, and floodplain habitat availability will likely yield the most reliable and largest improvements to juvenile salmon abundance.

Expected changes to Tuolumne River flows and Delta outflows from the TVA proposal are summarized in Table ES-4 and Table ES-5, respectively (see Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*, for details on hydrological modeling and accounting). The TVA is expected to result in new flow contributions (change relative to Existing Conditions) downstream of La Grange Dam from January through June that range from 2 to 12 thousand-acre feet (TAF) per year on average, depending on the model used for the calculation. The TVA Parties and DWR have agreed that one or two flow pulses from the TVA will be bypassed through the Delta to contribute to Delta outflows. This range of potential contributions to Delta outflow is presented in Table ES-5.[3] The TVA is expected to result in new contributions to Delta outflow that range from 7 to 17 TAF per year on average depending on the amount of TVA flow at Vernalis that is not diverted in the Delta.

[3] Options for determining new Delta outflow contributions that are currently being negotiated by Voluntary Agreement parties include the bypass of the TVA outmigration flow pulse or both the floodplain and outmigration flow pulses. The flow pulses correspond to time periods or protection periods (Table ES-5) that the State Water Project and Central Valley Project will bypass TVA flow contributions through the Delta. The VA Term sheet identifying the actual protection period will be finalized prior to any potential update to the Bay-Delta Plan.

Table ES-4. Estimates for New Flow Contributions Resulting from the TVA at La Grange Dam During January Through June Averaged for All Years and by WYT (in TAF).[a]

Water Year Type	Critically Dry	Dry	Below Normal	Above Normal	Wet	All Years
New TVA flow estimates using the TVA Parties' VA Accounting Spreadsheet [b]	37	50	58	-46	-89	2.1
New TVA flow estimates using the WSE model [c]	38	42	32	6	-28	12

[a] The TVA Term Sheet included different numbers that were developed in 2022 using an older version of State Water Board's Water Supply Effects (WSE) model that had not received all the updates described in Appendix B, *Hydrologic and Water Quality Modeling*.

[b] Values from the TVA Accounting Spreadsheet are averaged over the 25-year period from 1999 through 2023.

[c] Values from the WSE model are averaged over the 82-year period from 1922 through 2003. Using a different range in years can contribute to different estimated values.

Table ES-5. January Through June Expected Change (Relative to Existing Conditions) in Delta Outflow Averaged by WYT from the TVA Accounting Spreadsheet (in TAF).

Water Year Type	Protection Period	Critically Dry	Dry	Below Normal	Above Normal	Wet	All Years
New outflow if flows are protected for both TVA pulse periods [a]	March 16–May 31	26	47	52	19	-40	17
New outflow if flows are protected for only the TVA outmigration pulse period [a]	April 16–May 31	13	33	49	-1	-42	7

[a] Values estimated using the draft TVA accounting spreadsheet.

The temperature modeling for the TVA flow scenario predicts some improvements to March through May water temperatures compared to Existing Conditions in most reaches of the Tuolumne River. On average, May water temperatures under the TVA flow scenario are expected to increase the number of days the USEPA temperature benchmarks for core rearing (16°C or 60.8°F) are met by 12% to 19% in approximately 40 river miles, from river mile 13 to 53 (at La Grange Dam). Modeling of the TVA scenario also estimates improvements in temperatures from river mile 0 at the confluence with the San Joaquin River to river mile 13, but by a smaller amount, with a 7% increase in the number of days that meet the USEPA benchmarks for core rearing on average (Table ES-6, see Chapter 5 for details on water temperature modeling).

Table ES-6. A Comparison of the Percentage of Time That USEPA Temperature Benchmarks for Salmonid Life Stage Protective Conditions Are Attained Each Month on the Tuolumne River Under the Modeled Scenarios.

Temperature Effects		Confluence (RM 0)					1/4 River (RM 13.2)					IGD (RM 23.54)					IGU (RM 28.1)					3/4 River (RM 38.29)				
			Scenario					Scenario					Scenario					Scenario					Scenario			
Life Stage	Month/ USEPA Benchmark (°C)	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA
AM	Sep (18)	**2%**	2%	2%	2%	2%	**3%**	3%	5%	5%	3%	**16%**	12%	27%	26%	14%	**18%**	13%	29%	29%	15%	**36%**	29%	38%	37%	32%
AM	Oct (18)	**24%**	22%	30%	30%	24%	**34%**	32%	40%	39%	33%	**61%**	59%	62%	62%	60%	**68%**	65%	68%	68%	66%	**84%**	83%	83%	83%	83%
R	Oct (13)	**0%**	0%	0%	0%	0%	**0%**	0%	0%	0%	0%	**0%**	0%	0%	0%	0%	**0%**	0%	0%	0%	0%	**0%**	0%	0%	0%	0%
R	Nov (13)	**27%**	27%	28%	27%	27%	**34%**	33%	34%	33%	33%	**23%**	21%	24%	22%	23%	**24%**	22%	24%	21%	23%	**30%**	26%	26%	23%	28%
R	Dec (13)	**99%**	99%	99%	99%	99%	**100%**	100%	99%	99%	100%	**96%**	96%	96%	96%	96%	**96%**	96%	95%	96%	95%	**95%**	94%	94%	94%	94%
R	Jan (13)	**100%**	98%	98%	98%	99%	**100%**	99%	99%	99%	100%	**99%**	98%	98%	98%	99%	**99%**	98%	98%	98%	99%	**100%**	99%	99%	99%	100%
R	Feb (13)	**73%**	74%	74%	77%	69%	**77%**	79%	80%	82%	75%	**74%**	79%	81%	85%	72%	**74%**	79%	81%	85%	72%	**80%**	84%	88%	91%	78%
R	Mar (13)	**39%**	37%	36%	39%	36%	**53%**	51%	52%	54%	52%	**57%**	62%	68%	76%	60%	**58%**	63%	69%	77%	61%	**60%**	70%	81%	88%	66%
CR	Mar (16)	**68%**	74%	83%	90%	75%	**74%**	81%	91%	94%	79%	**82%**	97%	99%	99%	89%	**83%**	98%	99%	99%	91%	**91%**	100%	100%	100%	99%
CR	Apr (16)	**52%**	60%	74%	86%	59%	**55%**	75%	86%	92%	63%	**67%**	95%	96%	98%	71%	**69%**	96%	97%	98%	72%	**81%**	97%	99%	100%	82%
CR	May (16)	**24%**	39%	58%	65%	31%	**36%**	65%	79%	85%	48%	**50%**	87%	96%	99%	69%	**51%**	89%	97%	100%	70%	**66%**	98%	100%	100%	84%
S	Apr (14)	**27%**	29%	30%	35%	30%	**40%**	43%	48%	59%	46%	**55%**	70%	84%	91%	62%	**56%**	74%	86%	93%	63%	**64%**	91%	95%	96%	68%
S	May (14)	**4%**	4%	5%	7%	3%	**18%**	20%	29%	43%	18%	**37%**	61%	76%	81%	50%	**38%**	66%	78%	83%	52%	**47%**	84%	91%	96%	64%
S	Jun (14)	**0%**	0%	0%	0%	0%	**3%**	4%	4%	10%	2%	**20%**	29%	36%	43%	18%	**21%**	32%	38%	46%	19%	**31%**	54%	66%	72%	23%
CR	Jun (16)	**5%**	7%	11%	16%	4%	**19%**	32%	40%	52%	17%	**31%**	62%	70%	74%	24%	**31%**	64%	72%	75%	25%	**33%**	74%	77%	85%	31%
SR	Jun (18)	**26%**	40%	55%	65%	21%	**30%**	58%	67%	74%	23%	**33%**	75%	78%	85%	32%	**33%**	75%	79%	87%	32%	**36%**	83%	90%	91%	35%
SR	Jul (18)	**8%**	6%	7%	6%	7%	**19%**	17%	19%	15%	16%	**24%**	22%	38%	38%	20%	**24%**	22%	39%	40%	21%	**28%**	26%	41%	41%	24%
SR	Aug (18)	**0%**	0%	0%	0%	0%	**2%**	2%	2%	2%	2%	**8%**	7%	9%	8%	7%	**8%**	7%	9%	8%	7%	**12%**	10%	20%	18%	12%

AM = Adult Migration.
R = Reproduction (Spawning, Egg Incubation, and Fry Emergence).
CR = Core Rearing (*O. mykiss* only in June).
S = Smoltification.
SR = Summer Rearing.
IGD = Infiltration Gallery Downstream.
IGU = Infiltration Gallery Upstream.

The habitat modeling predicts that the TVA will increase the suitable spawning and juvenile rearing habitat compared to Existing Conditions (see Chapter 7 for details on habitat modeling). The TVA flow and non-flow contributions together are expected to provide an annual median of 16 acres of suitable spawning habitat, which is an increase above the Existing Conditions by 14% (Figure ES-2 and Table ES-7). The Existing Conditions and 30%, 40%, and 50% UF Objective scenarios are expected to provide 14 acres, 13.3 acres, 13.1 acres, and 12.6 acres of suitable spawning habitat respectively (Table ES-7).

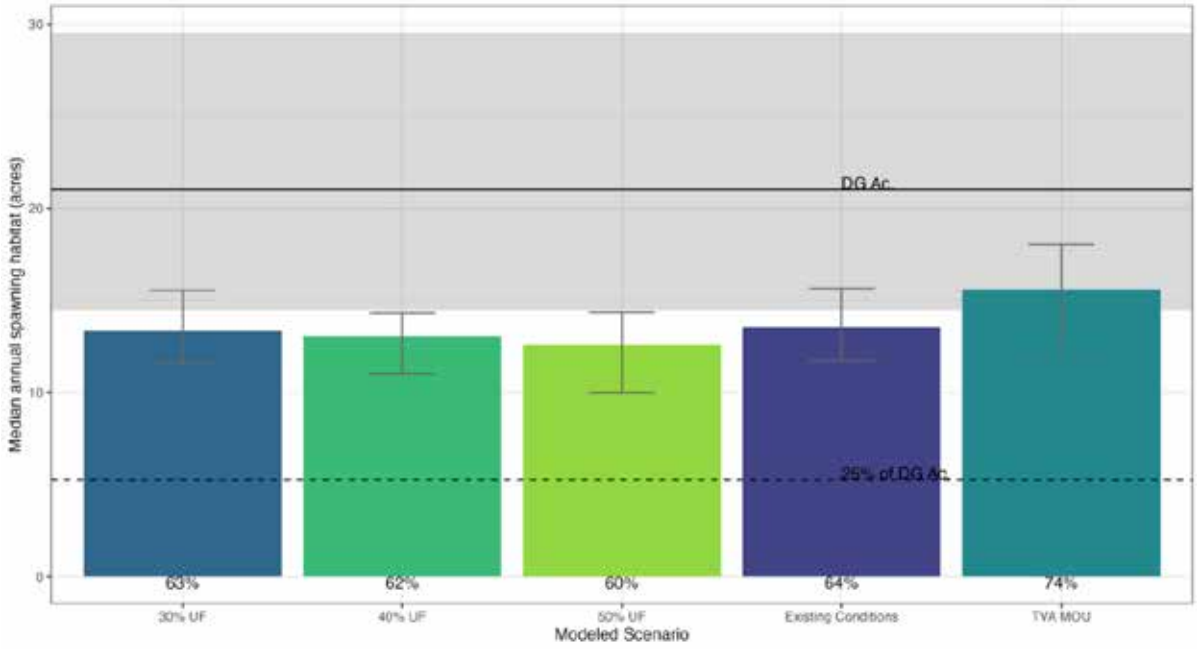


Figure ES-2. Median of Annual Mean Temperature Filtered Spawning Habitat (Acres) Across All Modeled Years (1970–2003) Under the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of this Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles.

Table ES-7. Median of Annual Mean Spawning Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses.

			No temperature filter		Temperature filter	
Scenario	Habitat Type	Doubling goal acreage	Median estimated acres	Percent of doubling goal acreage	Median estimated acres	Percent of doubling goal acreage
30% UF	Spawning	21 (14, 30)	28 (23, 30)	135%	13.3 (12, 16)	63%
40% UF	Spawning	21 (14, 30)	28 (19, 30)	133%	13.1 (11, 14)	62%
50% UF	Spawning	21 (14, 30)	28 (19, 30)	133%	12.6 (10, 14)	60%
Existing Conditions	Spawning	21 (14, 30)	28 (23, 30)	133%	14 (12, 16)	64%
TVA	Spawning	21 (14, 30)	33 (27, 35)	157%	16 (12, 18)	74%

The TVA is expected to provide an annual median of 298 acres of temperature filtered combined rearing habitat (Figure ES-3 and Table ES-8). The TVA is estimated to increase the quantity of combined rearing habitat acres above Existing Conditions by 10%. The Existing Conditions and 30%, 40%, and 50% UF Objective scenarios are predicted to provide 271, 327, 344, and 376 acres of suitable temperature filtered combined juvenile rearing habitat.

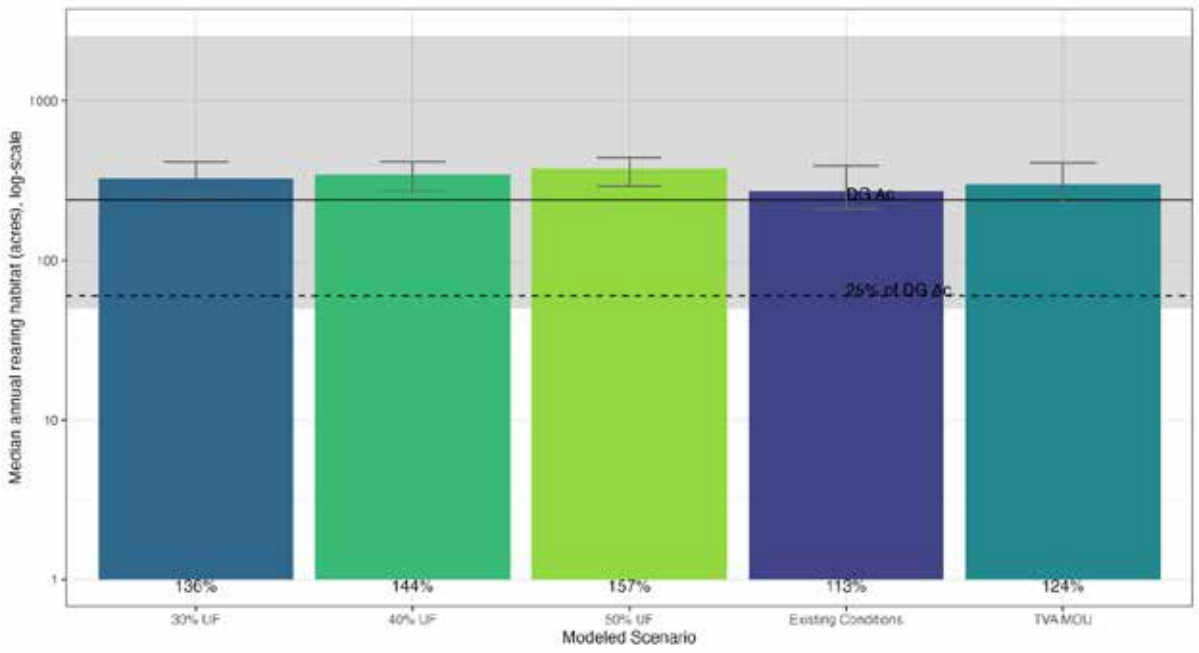


Figure ES-3. Median of Annual Mean Temperature Filtered Rearing (In-channel and Floodplain Combined) Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios. The Solid Line Represents Area of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of this Estimate, and Dashed Lines Represent 25% of the Doubling Goal Area. Error Bars Represent the 25% and 75% Quartiles.

Table ES-8. Median of Annual Mean Combined (In-channel and Floodplain) Rearing Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses.

			No temperature filter		Temperature filter	
Scenario	**Habitat Type**	**Doubling goal acreage**	**Median estimated acres**	**Percent of doubling goal acreage**	**Median estimated acres**	**Percent of doubling goal acreage**
30% UF	Rearing	240 (50, 2,563)	359 (326, 429)	150%	327 (255, 412)	136%
40% UF	Rearing	240 (50, 2,563)	358 (325, 422)	149%	344 (272, 412)	144%
50% UF	Rearing	240 (50, 2,563)	379 (333, 448)	158%	376 (292, 440)	157%
Existing Conditions	Rearing	240 (50, 2,563)	389 (371, 439)	162%	271 (211, 391)	113%
TVA	Rearing	240 (50, 2,563)	386 (365, 463)	161%	298 (234, 407)	124%

As with all modeling analyses, the quantitative results have uncertainty arising from assumptions and simplifications, unexpected events, unanticipated consequences, and unknowns in the system. Additional uncertainties in TVA outcomes arise from the timing of non-flow habitat restoration action completion; assumptions of the suitability of TVA habitat assets; limitations in the habitat modeling approaches; the lack of a quantitative connection between certain aspects of habitat and species abundance; the focus on a few at-risk species; and other factors (see Chapter 9, *Conclusions and Uncertainties*, for details on the uncertainty and a summary of the findings). The TVA, if approved, would include a set of implementation criteria and habitat suitability and utilization criteria, along with a monitoring program, to ascertain the actual benefits realized and to evaluate overall program success.

Chapter 1
Introduction

1.1 Overview of the Bay-Delta Water Quality Control Plan Update Process

The 2018 Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary[1] (Bay-Delta Plan) provides pathways for voluntary agreements to implement the Lower San Joaquin River (LSJR) flow portions of the Bay-Delta Plan for the "[t]ributaries as a whole, an individual tributary, or some combination thereof." The proposed Tuolumne River Voluntary Agreement (TVA) does not fully conform to the current Bay-Delta Plan, including the required percent of unimpaired flow level. Accordingly, provisions of the Bay-Delta Plan adopted in 2018 would need to be updated to allow for the State Water Resources Control Board (State Water Board) to approve the TVA. Specifically, the program of implementation would need to be modified to allow for the TVA to be implemented for the proposed 8-year period (with the possibility of extension) in order to approve the TVA.

1.2 Background on the 2018 Bay-Delta Plan

On December 12, 2018, through State Water Board Resolution 2018-0059, the State Water Board amended the Bay-Delta Plan, establishing new and revised LSJR flow objectives and revised southern Delta salinity objectives. On February 25, 2019, the Office of Administrative Law approved the Bay-Delta Plan amendments. The State Water Board, through a separate process, is currently developing a regulation and taking other actions to implement the 2018 Bay-Delta Plan.

The LSJR flow objectives include a narrative objective that requires inflow conditions from the San Joaquin River watershed to the Delta at Vernalis sufficient to support and maintain the natural production of viable native San Joaquin River fish populations migrating through the Delta and a numeric objective from February through June that requires 40% of the unimpaired flow be maintained in the Stanislaus, Tuolumne, and Merced Rivers, within an adaptive range of 30 to 50 percent of the unimpaired flow, inclusive. In addition, from February through June, the flow at Vernalis as provided by the percent of unimpaired flow objective is required to be no lower than the base flow value of 1,000 cubic feet per second (cfs) with an adaptive management range between 800 and 1,200 cfs, inclusive. This means that if the percentage of unimpaired flow is being met but flows are insufficient to achieve the base flow requirement at Vernalis, then additional flows from each tributary would be necessary. During the month of October, the LSJR flow objectives and program of implementation also require the maintenance of a minimum baseflow, as measured at Vernalis on the San Joaquin River, of 1,000 cfs, plus an additional 28,000 acre-feet pulse flow or enough additional water to achieve a minimum monthly average flow of 2,000 cfs, whichever is less.

[1] Available on the State Water Board website at 2018 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary.

1.3 Status of Fish Populations in the Tuolumne River

Fish monitoring on the Tuolumne River primarily focuses on the abundance of salmonid species of concern, Chinook salmon (*Oncorhynchus tshawytscha*) and *Oncorhynchus mykiss* (*O. mykiss*, both California Central Valley Steelhead and rainbow trout). Other native and non-native fish species are captured as bycatch in the salmonid monitoring surveys; however, the long-term abundance of these other species is not typically estimated.

The California Department of Fish and Wildlife (CDFW) produces annual estimates of adult fall-run Chinook salmon escapement, which for the Tuolumne River, have ranged from a high of 45,900 fish in 1959 to a low of 77 in 1991 (Figure 1-1). The escapement estimate for 2024 was 2,128 individuals (CDFW 2025). Starting from 1952 through 2024, the decadal average escapement of Tuolumne River adult fall-run Chinook salmon has fallen from over 25,000 fish to less than 1,000 (Figure 1-1). From 2012 to 2022, the 10-year estimated averaged is less than 800 adults (CDFW 2025). This is substantially less than the estimated escapement needed to attain the Anadromous Fish Restoration Program doubling objective of 38,000 natural ocean production (USFWS 1995), which is equivalent to an escapement value of 17,800 adult spawners, see Chapter 7, *Spawning and Rearing Habitat*, for more information on the salmon escapement doubling goal estimation.

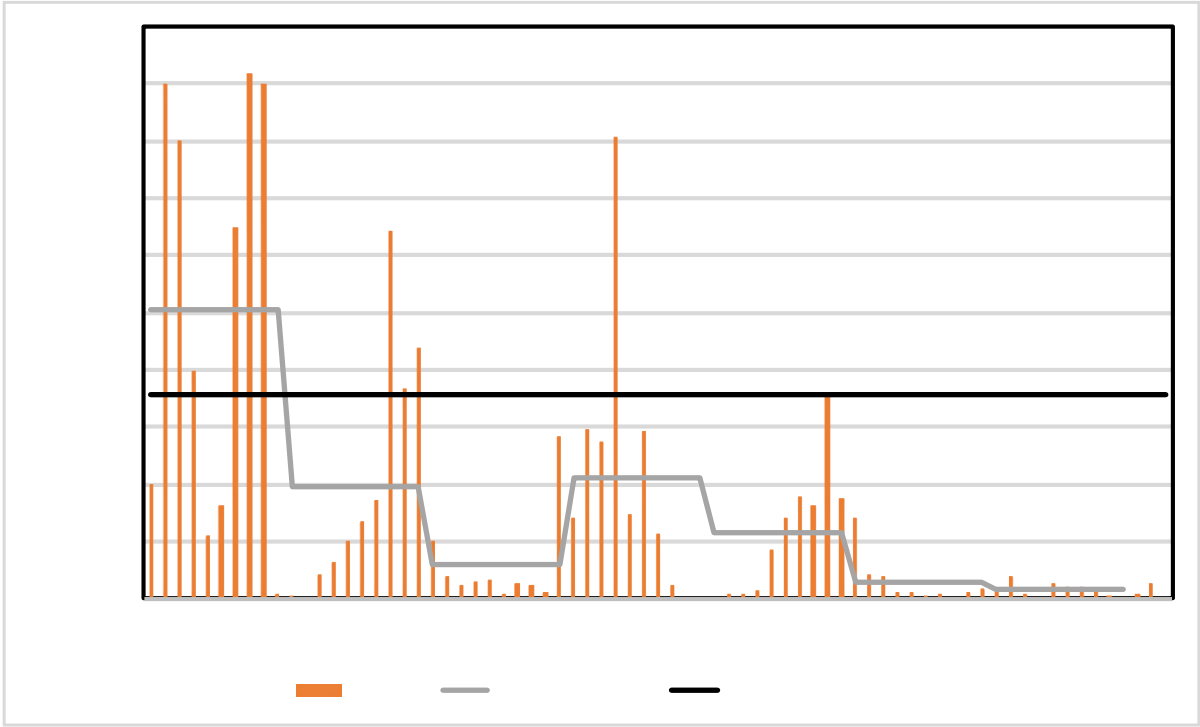


Figure 1-1. Tuolumne River Fall-Run Chinook Salmon Annual and Decadal Average Escapement from CDFW GrandTab (2025). The Salmon Doubling Goal (17,800) Represents the Estimated Tuolumne River Salmon Escapement Needed to Meet the Narrative Salmon Protection Objective.

O. mykiss reside in the Tuolumne River year round. *O. mykiss* exhibit two life history types or behaviors, including resident rainbow trout and migratory steelhead. The anadromous California Central Valley Steelhead (steelhead) are listed as threatened under the federal Endangered Species Act, which includes steelhead populations in the Tuolumne River. *O. mykiss* observed in the Tuolumne River mainly express resident rainbow trout behavior; however, there is evidence of the steelhead life history type as well (Zimmerman et al. 2008). The adult counting weir operated at river mile 24.5 monitors and records passages of *O. mykiss*, and is generally operated from September until the spring, when flows exceed the operable range of about 1,300 cfs (TID and MID 2011) due to flood control operations or the spring pulse flow (Table **1**-**1**). Total upstream counts from 2009 to 2023 range from 0 to 16, with at least 1 migratory fish counted in most years (10 of 14) (Table **1**-**1**); however, no fish passage data are available for flows above 1,300 cfs, so these observations may underestimate actual *O. mykiss* migration occurrences given that *O. mykiss* migration and spawning has been associated with high flows (McEwan 2001).

The adult counting weir monitoring provides additional information important for understanding the dynamics of migratory *O. mykiss*. First, *O. mykiss* longer than 16 inches are generally characterized as steelhead and potentially anadromous; however, limited to no data are available for LSJR steelhead to confirm an occurrence of ocean residence. Second, the monitoring data identify the observation of adipose-fin clipped (ad-clipped) fish, indicating a hatchery origin rather than being naturally produced. No comprehensive monitoring program exists for steelhead in the LSJR watershed, so data are limited.

Table 1-1**. Annual O. Mykiss Passage at the Adult Counting Weir, Sampling Dates, Counts of Fish Larger than 16 Inches, and Counts of Fish with Adipose Clips 2009–2022.**

Monitoring Season	Start Date	End Date	Total *O. mykiss* Passage	# *O. mykiss* >16"	# of ad-clipped *O. mykiss*
2009/10	22-Sep	14-Apr	1	0	0
2010/11	9-Sep	30-Nov	0	0	0
2011/12	16-Sep	22-Jun	16	4	3
2012/13	24-Sep	22-May	4	1	0
2013/14	24-Sep	7-May	0	0	0
2014/15	29-Sep	31-Mar	0	0	0
2015/16	28-Sep	13-May	3	1	1
2016/17	19-Sep	3-Jan	1	0	1
2017/18	26-Sep	21-Mar	2	2	0
2018/19	12-Sep	4-Feb	2	2	0
2019/20	10-Sep	17-Mar	4	1	0
2020/21	28-Sep	1-Apr	2	2	1
2021/22	29-Sep	11-Apr	1	0	0
2022/23	30-Sep	6-Jan	0	0	0

Source: TID and MID 2023.

Annual summer snorkel surveys at fixed locations, which have been sampled since 1996, have observed *O. mykiss* every year when flows were increased[2] in the Tuolumne River (Figure 1-2). These fish are primarily characterized as resident rainbow trout and consist of both juvenile and adult fish. The survey in 2019 found 278 *O. mykiss*, with 224 identified as juveniles based on a fork length of less than 150 mm, and 63 adults, with a fork length greater than 150 mm, including a fish estimated to be greater than 400 mm (TID and MID 2020). The snorkel surveys produce counts of adult and juvenile fish. However, adequate monitoring to perform population abundance estimates of *O. mykiss* is rarely performed in the Tuolumne River. From 2001 to 2022[3] counts ranged from a low of 12, to as high as 1,179 (Figure 1-2).

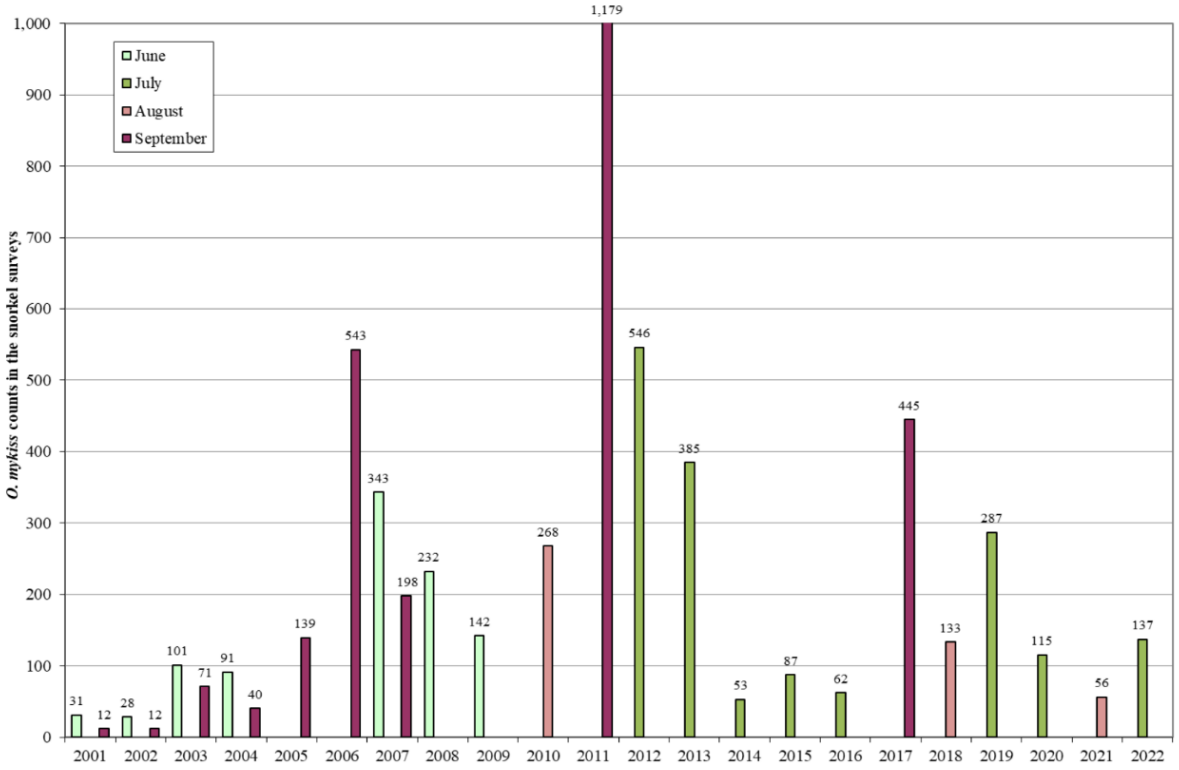


Figure 1-2. *O. mykiss* Counts during the June through September Snorkel Surveys 2001–2022 (TID and MID 2023).

[2] Pursuant to Federal Energy Regulatory Commission licensing flow requirements (See Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*).

[3] This range of years is the most comparable for showing presence or absence along the lower Tuolumne River by year and allows for a general indication of abundance based on observed counts.

Other native and non-native species occur in the Tuolumne River, but there are no monitoring surveys to specifically count them or produce population estimates. All the monitoring projects, except the CDFW escapement survey, document all fish species caught thereby providing, at minimum, presence and geographic data for non-target species. Seine surveys and rotary screw traps sample annually at fixed locations during the winter and spring and capture both native and non-native fish. These sampling methods are targeted for juvenile salmonids and are not ideal for capturing larger, more mobile fishes (Johnson et al. 2007). The summertime snorkel surveys also occur at fixed locations and can observe both native and non-native species of all sizes regardless of the fish's swimming ability. In 2022, these surveys captured or observed five native and 14 non-native fishes (Table 1-2). In the past, seine surveys have captured additional fish species, including Sacramento blackfish (*Orthodon microleptidotus*), tule perch (*Hysterocarpus traskii*), black bullhead (*Ameiurus melas*), brown bullhead (*Ameiurus nebulosus*), common carp (*Cyprinus carpio*), and threadfin shad (*Dorosoma petenese*) (TID and MID 2023). This may be an indication that there has been a loss of species richness or abundance.

Table 1-2. Common and Scientific Name of Non-Salmonid Fish Captured in the 2022 Seine Survey, Rotary Screw Trap (RST), and Snorkel Survey. Names in Bold Indicate Native Species.

Common Name	Scientific Name	Seine	RST	Snorkel
Channel catfish	*Ictalurus punctatus*		x	
White catfish	*Ictalusus catus*	x	x	x
Pacific lamprey	*Entosphenus tridentatus*	x		
Mosquitofish	*Gambusia affinis*	x	x	
Golden shiner	*Notemigonus crysoleucas*	x	x	
Hardhead	*Mylopharodon conocephalus*		x	x
Inland silverside	*Menidia beryllina*	x		
Red shiner	*Notemigonus crysoleucas*	x	x	
Sacramento pikeminnow	*Ptychelius grandis*		x	x
Sacramento sucker	*Catostomus occidentalis*	x		x
Prickly sculpin	*Cottus asper*	x	x	x
Bluegill	*Lepomis macrochirus*	x	x	x
Green sunfish	*Lepomis cyanellus*		x	
Largemouth bass	*Micropterus salmodies*		x	x
Redear sunfish	*Lepomis microlophus*	x	x	x
Smallmouth bass	*Micropterus dolomieu*		x	x
Spotted bass	*Micropterus punctulatus*		x	x
Warmouth	*Lepomis gullosus*		x	
Striped Bass	*Morone saxatilis*			x

Source: TID and MID 2023.

1.4 Description of the Proposed Voluntary Agreement

In March 2022, the State Water Board received a *Memorandum of Understanding Advancing a Term Sheet for the Voluntary Agreements to Update and Implement the Bay-Delta Water Quality Control Plan, and Other Related Actions* (MOU; Voluntary Agreement Parties 2022).[4] Subsequently, in November 2022, the State Water Board received a Revised MOU (Revised MOU or MOU used interchangeably from here on) with additional proposals for voluntary agreements including the TVA proposed by: San Francisco Public Utilities Commission, Modesto Irrigation District, and Turlock Irrigation District (Tuolumne Parties). The signatories in the TVA propose an 8-year term and a set of flow and non-flow assets in lieu of implementing the unimpaired flows and related actions required in the 2018 updates to the Bay-Delta Plan, which are described in more detail in Chapter 3, *Description of Flow and Non-Flow Assets*. Additionally, see Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*, for a more detailed description of the TVA proposed flow commitments.

The proposed flow commitments would occur in January through June and would be additive to the average minimum instream flows provided under the Federal Energy Regulatory Commission license for the Don Pedro Project. Two pulse flow volumes are included that can be released with variability within the March through June period. A floodplain pulse would be timed with Chinook salmon rearing with a default release time of March. A spring outmigration pulse would correspond to outmigrating juvenile fish but would fall within the period of April 16 through May 31.

The proposed non-flow assets, in combination with the proposed flow assets, are intended to improve salmonid spawning and rearing habitat on the lower Tuolumne River. Non-flow assets include additional in-channel spawning and rearing habitat, as well as 77 acres of rearing/floodplain habitat that would be inundated at the proposed flow levels. The proposed projects include a mixture of habitat features that include both instream and floodplain benefits. In addition, TVA proposes the construction and operation of a fish barrier and counting weir to prevent striped bass movement into the upstream habitats where rearing juvenile fall-run Chinook salmon congregate, and active removal of striped bass to reduce predation on salmon.[5]

The MOU for the larger voluntary agreements proposal that includes the TVA includes a proposed Governance Program that would "direct flows and habitat restoration, conduct assessments, develop strategic plans and annual reports, implement a Science Program, and hire staff and contractors" (Voluntary Agreements Parties 2022). This Governance Program would include a Systemwide Governance Committee to oversee overall coordination of the voluntary agreement program, and Tributary/Delta Governance Entities that would oversee implementing the agreements for which that entity is responsible. The MOU also includes commitments for a Science Program[6] to "(A) inform decision-making by the Systemwide Governance Committee, Tributary/Delta Governance Entities, and voluntary agreement Parties; (B) track and report progress relative to the metrics and outcomes stated in Appendix 4; (C) reduce management-relevant uncertainty; and (D) provide

[4] Available on the State Water Board website at: Revised Memorandum of Understanding.

[5] This may include removal or isolation methods such as electro-fishing, fyke netting, seining, or other collection methods.

[6] Available on the State Water Board website at Proposals for Voluntary Agreements to Update and Implement the Bay-Delta Plan.

recommendations on adjusting management actions to the Systemwide Governance Committee, Tributary/Delta Governance Entities and VA Parties" (Voluntary Agreements Parties 2022). The TVA is proposed to remain in effect for a term of eight years, with the possibility of extension.

1.5 Overview of Chapters

Following is a summary of the chapters and appendices in this *Draft Scientific Basis Report Supplement for the Tuolumne River Voluntary Agreement Proposal* (Draft TVA Scientific Basis Report):

- **Chapter 1, *Introduction*,** provides an overview of the Bay-Delta Plan Update process, background on the 2018 Bay-Delta Plan, the status of fish populations, and a description of the TVA.
- **Chapter 2, *Aquatic Ecosystem Stressors*,** describes aquatic stressors on the Tuolumne River and how flow and non-flow assets in the TVA are expected to ameliorate these stressors.
- **Chapter 3, *Description of Flow and Non-Flow Assets*,** summarizes the flow and non-flow assets that are included in the TVA.
- **Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*,** describes the changes in hydrology and system operations that could occur as a result of the TVA.
- **Chapter 5, *Water Temperature*,** evaluates potential benefits to river temperatures from the TVA.
- **Chapter 6, *Predator Control*,** discusses the potential effectiveness and benefits of the predator control non-flow asset included in the TVA.
- **Chapter 7, *Spawning and Rearing Habitat*,** evaluates potential benefits to spawning and rearing habitat from the TVA.
- **Chapter 8, *Traditional Ecological Knowledge of California Native American Tribes*,** describes the role of traditional ecological knowledge in informing science and management and the harm that aquatic ecosystem stressors have inflicted to tribes in the Bay-Delta watershed.
- **Chapter 9, *Conclusions and Uncertainties*,** presents the findings of this Draft TVA Scientific Basis Report and includes a characterization of uncertainties associated with anticipated outcomes.
- **Appendix A, *Stock-Recruitment Modeling*,** presents the modeling approach and results for evaluating how fall-run Chinook salmon juvenile production in the Tuolumne River is influenced by adult spawner abundance and environmental covariates.
- **Appendix B, *Hydrologic and Water Quality Modeling*,** describes the hydrologic, water supply, and water quality modeling methods and assumptions used to analyze the effects of the TVA in Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*; Chapters 5, *Water Temperature*; and Chapter 7, *Spawning and Rearing Habitat*.

- **Appendix C, *Draft Tuolumne Accounting Spreadsheet Model*,** provides a description of the accounting and instructions on how to manipulate and use the spreadsheet.
- **Appendix D, *Doubling Goal Habitat Estimate and Input Parameter Uncertainty Analysis*,** provides technical information and uncertainty estimates supporting the analyses in Chapter 7, *Spawning and Rearing Habitat* including information on the distributions that were generated for several parameters that factor into calculating the amount of habitat required to support doubling of the spawning and rearing habitat.

1.6 References

1.6.1 Printed References

California Department of Fish and Wildlife (CDFW). 2025. Grandtab 2025.06.09 California Central Valley Chinook Escapement Database Report. Compiled by J. Azat. And D. Killam. Available at https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=84381&inline.

Johnson, D.H., B.M Shrier, J.S. O'Neal, J.A. Kuntzen, X. Augerot, T.A. O'Neil, and T.N. Pearsons. 2007 Salmonid field protocols handbook: techniques for assessing status and tends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

McEwan. 2001. Central Valley Steelhead. Fish Bulletin 179. Contributions to the Biology of Central Valley Salmonids, Volume 1.

Turlock Irrigation District/Modesto Irrigation District (TID and MID). 2011. Turlock and Modesto Irrigation Districts Project No. 2299- Article 58 Annual Report for 2011.

Turlock Irrigation District/Modesto Irrigation District (TID and MID). 2020. Turlock and Modesto Irrigation Districts Project No. 2299- Article 58 Annual Report for 2019.

Turlock Irrigation District/Modesto Irrigation District (TID and MID). 2023. Turlock and Modesto Irrigation Districts Project No. 2299- Article 58 Annual Report for 2022.

U.S. Fish and Wildlife Service. 1995. Working Paper on restoration needs: habitat restoration actions to double natural production of anadromous fish in the Central Valley of California. Volume 3. May 9, 1995. Prepared for the U.S. Fish and Wildlife Services under the direction of the Anadromous Fish Restoration Program Core Group. Stockton, CA.

Voluntary Agreements Parties. 2022. *Memorandum of Understanding Advancing a Term Sheet for the Voluntary Agreements to Update and Implement the Bay-Delta Water Quality Control Plan, and Other Related Actions.* California Natural Resource Agency, California Environmental Protection Agency, State Water Contractors, et al.

Zimmerman, C.E., G.W. Edwards, and K. Perry. 2008. *Maternal Origin and Migratory History of Oncorhynchus mykiss captured in rivers of the Central Valley, California.* Final Report prepared for California Department of Fish and Game, Contract P0385300.

Chapter 2
Aquatic Ecosystem Stressors in the Tuolumne River

The 2018 Final Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary: San Joaquin River Flows and Southern Delta Water Quality (Final SED;[1] SWRCB 2018) describes the Delta inflow needs from the San Joaquin River Basin for San Joaquin River Basin fall-run Chinook salmon and Central Valley steelhead, including the Tuolumne River. The life histories and other information regarding these species are described in Appendix C[2] and Chapter 7 of the 2018 Final SED. This chapter briefly summarizes the best available science on aquatic stressors related to flow and non-flow habitat in the Tuolumne River for the purpose of considering the Tuolumne River Voluntary Agreement (TVA). Table 2-1 provides an overview of the most important of these aquatic stressors and how flow and non-flow assets in the proposed TVA may reduce the effects of these stressors.

Table 2-1. Main Aquatic Stressors on the Tuolumne River and TVA Assets Expected to Address Them.

Aquatic Stressor	Subfactor	How TVA Flow Actions Are Expected to Help	How TVA Non-Flow Actions are Expected to Help
Loss and Alteration of Physical Habitat	History of Gravel Mining	Not applicable	Restoration increases salmonid habitat suitability.
	Spawning Habitat	Not applicable	Restoration increases salmonid habitat suitability.
	Floodplain Habitat	Higher flows increase frequency of floodplain inundation.	Restoration increases habitat area, allows inundation at lower flows.
Predation	Non-native fish as predators and competitors	Flow moves juvenile salmonids through high predation areas more quickly. More natural flow regimes generally favor native species.	Habitat restoration may provide refugia from predation.
Temperature Impairments	Dams and diversions have altered natural water temperature conditions	Higher flows typically decrease water temperatures below dams.	Riparian restoration may increase shading and lower water temperatures.
Flow Impairments	Dams and diversions have altered natural flow conditions	Higher flows and correct flow timing can help to support native species.	Restoration may help to reduce channel width and increase water velocity.
Hatcheries	Salmon hatcheries have a large reproductive contribution relative to in-river reproduction	Higher flows expected to increase survival of Tuolumne River origin salmonids, which can help to reduce hatchery influence.	Restoration may provide additional/better rearing habitat to increase juvenile survival.

[1] Available on the State Water Board website at Bay-Delta Plan Update: Amendments and Substitute Environmental Document (SED) for Lower San Joaquin River and Southern Delta.

[2] Appendix C is the Technical Report on the Scientific Basis for Alternative San Joaquin River Flow and Southern Delta Salinity Objectives. See Chapter 3 of Appendix C, Scientific Basis for Developing Alternate San Joaquin River Flow Objectives.

2.1 Physical Habitat Loss or Alteration

Historically, the Tuolumne River had 99 miles of anadromous fish habitat, and currently there are approximately 52 miles of accessible habitat (USFWS 2008). La Grange Dam marks the upstream terminus of accessible anadromous fish habitat on the Tuolumne River, blocking about half of the habitat historically available. La Grange and Don Pedro dams also block the transport and maintenance of coarse sediment (gravel, cobbles, boulders) and large woody debris (LWD) into downstream reaches of the Tuolumne River. Coarse sediment and LWD are important habitat components for salmonids and other native fish. In addition, habitats in the Tuolumne River downstream from La Grange Dam have been impacted by former gold mining and gravel mining activities (USBR 2011). As a result, there is limited suitable spawning habitat available, which can lead to redd superimposition and egg mortality at times (Stillwater Sciences 2001; Moyle 2002).

During the early twentieth century, the Tuolumne River channel and floodplain were dredged for gold. The gold dredges excavated channel and floodplain deposits to the depth of bedrock (approximately 25 ft [7.6 m]) and often realigned the river channel. Due to gravel mining activities, the channel has become constrained by dredge tailings, restricting channel meander and reducing delivery of gravel to the river. Riparian vegetation is also scarce due to dredge tailings. By the end of the gold mining era, the floodplain adjacent to 12.5 miles (20 km) of the river (river mile (RM) 50.5–38) had been converted to tailings deposits. Tailings also remain in the river from RM 45.4–40.3 (Stillwater Sciences 2001). Additionally, mining pits were made in the river channel that now provide suitable habitat conditions (e.g., slower water velocities and higher temperatures) for largemouth bass and other predatory fish species (see Section 2.3, *Predation*).

Land clearing for gold dredging, aggregate mining, and agricultural and urban development has resulted in the loss of 85% of the Tuolumne River's historical riparian forest. Vegetation that once extended from bluff to bluff prior to the Gold Rush is now confined to a narrow band along the active channel margins in many areas or has been eliminated entirely. Nearly all the areas in the gravel-bedded zone that historically supported riparian forests have been mined, grazed, or farmed (Stillwater Sciences 2001).

As part of the Federal Energy Regulatory Commission (FERC) relicensing process, Turlock Irrigation District and Modesto Irrigation District (Districts) analyzed gravel in the lower Tuolumne River to determine the amount of and change in spawning gravel availability. Stillwater Sciences (2013) estimates that 25 million yd^3 of sediment has been trapped in the Don Pedro Reservoir since 1971. Modeling of sediment movement in the lower Tuolumne River based on bedload transport rates and historical flows found that without gravel augmentation, the coarse bed material in the spawning reach will be depleted over time (Stillwater Sciences 2013). During 1971–2012, approximately 6% of the coarse bed material that was augmented through restoration actions was lost from the spawning reach study area through natural sediment transport processes (Stillwater Sciences 2013). This study also used topographic differencing of Digital Terrain Models from 2005 and 2012 which found a loss of 7,292 yd^3 from RM 52.2–45.8. Pools were found to commonly scour three to five feet during this time, while riffle crests were commonly aggraded one to three feet. The authors note that although the overall change in sediment storage is small, "areas of significant scour and fill are apparent" (Stillwater Sciences 2013). Overall, based on both analyses, the channel in the 12.4 miles downstream of La Grange Dam will degrade without periodic gravel augmentation in this area.

Salmonid spawning is not evenly distributed throughout the spawning reach (~RM 26–52). The majority of fall-run Chinook salmon redds (48.2%) are typically located in the most upstream reach (RM 52.0–47.4), while only 7% of redds are in the most downstream reach (RM 31.6–22.0) (FISHBIO 2013b). *Oncorhynchus mykiss* (*O. mykiss*) redds were also found most frequently (63.2%) in the most upstream reach, and 97% were located upstream of RM 42 (FISHBIO 2013b). The study did not indicate any factors leading to the uneven distribution of spawning. In most years, the majority of the redds observed occurred in Section 1 (RM 52.0–47.4) which is the section just downstream of La Grange Dam (Murphey 2014, 2015; Murphey and Tsao 2019). The uneven distribution of spawning does result in redd superimposition, but only at relatively low rates, with 15.2% of redds superimposed during surveys in 2012/13. The rates of superimposition varied by RM, but the highest rates were found in the most upstream survey reach (RM 52.0–47.4) (FISHBIO 2013b). Redd superimposition results in egg mortality and reduces juvenile productivity.

Existing habitat availability on the lower Tuolumne River is far less than what is estimated to be required to recover listed salmonid species populations. For example, it is estimated that rearing habitat in the Tuolumne River can only support the offspring from no more than 434 fall-run Chinook salmon adults during managed flow releases (Mesick 2009). A hydraulic assessment of floodplains on the lower Tuolumne River suggests that between 31–242 acres of usable habitat exist along the lower Tuolumne River for fry and juvenile fall-run Chinook salmon at flows between 1,000 and 3,000 cfs, which are flows that occur with enough frequency to provide floodplain inundation benefits (HDR Inc and Stillwater Sciences 2017).

The effects of moderate or episodic flow depletions on riparian and aquatic ecosystems can be subtle, ranging from transient physiological stress to structural and functional changes involving reductions in species richness and primary productivity or increases in non-native species (Auble et al. 2005; James et al. 2016; Lytle & Merritt 2004). Significant depletions can lead to dewatering of the channel and floodplain, resulting in a variety of structural and functional changes, including mortality of riparian vegetation and aquatic biota, destabilization of channel banks, and encroachment of upland vegetation and non-native weeds into the riparian zone (Auble et al. 2005; Rood et al. 2005; Tonkin et al. 2017; Ward et al. 2002).

LWD has important functions for juvenile salmonid rearing: it provides instream cover (Cederholm et al. 2000, USFWS 2010), invertebrate food sources (Wipfli and Baxter 2010), and micro-habitat complexity (Cederholm et al. 2000; Crispin et al. 1993; Wipfli and Baxter 2010). A survey of LWD conducted in the lower Tuolumne River estimated 1,053 pieces of woody debris between RM 51.8–24 with a total volume of 11,702 ft^3 (Stillwater Sciences 2017). The extrapolated estimated volume for the entire lower Tuolumne River was 25,257 ft^3 of wood; however, it is estimated that 70,761 ft^3 of wood was captured in Don Pedro Reservoir annually between 2005 and 2013. In addition, the size distribution of the woody debris in the lower Tuolumne River tended to be smaller than the wood trapped in the reservoir. Furthermore, the survey found that much of the LWD in the lower Tuolumne River was partially or fully outside the wetted channel. Stillwater Sciences (2017) found that the majority of LWD in the study area likely did not provide significant cover and habitat value for *O. mykiss* due to the generally small size, locations, and lack of complexity of the LWD.

2.2 Ecosystem Productivity and Food Supply

Reductions of the magnitude, frequency, and duration of flood flows and confinement of the natural floodway of the Tuolumne River has disrupted the natural processes that create high-quality salmon spawning and rearing habitat, including shallow, slow-water river margins and floodplain habitat to support rearing juveniles and other native fishes (McBain & Trush 2000). Losses and degradation of floodplain habitat and reductions in natural hydrologic variability that connect rivers to their floodplains have been identified as major stressors on native Central Valley fish populations through direct impacts on spawning and rearing habitat availability and indirect impacts on aquatic productivity and food web support provided by seasonal floodplain inundation (see Appendix C, *Technical Report on the Scientific Basis for Alternatives San Joaquin River Flow and Southern Delta Salinity Objectives*). Previous research indicates that regulated flows downstream of dams and losses of overbank flooding have likely contributed to historical declines and current limitations on native fish populations through reductions in primary and secondary production (phytoplankton and invertebrate production) associated with seasonal floodplain inundation (Sommer et al. 2004; Ahearn et al. 2006; Goertler et al. 2018).

Specific food web studies have not been conducted in the Tuolumne River; however, related invertebrate studies provide information about the river productivity and food supply. Benthic macroinvertebrate (BMI) surveys have found shifts in the BMI metrics, with a significant increase in percentage of EPT taxa (Ephemeroptera, Plecoptera, and Trichoptera) at a reference riffle since the 1996 settlement agreement resulted in increased summer flows (TID and MID 1992; TID and MID 1997; TID and MID 2003; TID and MID 2009). On the other hand, the surveys also have found a general decrease in percentage of EPT taxa from upstream to downstream, attributed to increased downstream temperature and fine sediment, as well as decreases in invertebrate density over time (TID and MID 2009).

Other indicators of sufficient food production can be inferred through surveys of juvenile salmonids. Annual seine surveys, mainly conducted in-channel (as opposed to the floodplains), have found an increase in average fork length over the January through June season (TID and MID 2019a). Growth rates reported in seine surveys (TID and MID 2011) are within the range reported for other Central Valley Chinook Salmon (Williams 2006). Finally, smolt-sized fish are caught near the confluence with the San Joaquin River in April through June (TID and MID 2019b), which is consistent with the expected timing for the Tuolumne River and other San Joaquin Tributaries (Rich and Loudermilk 1991). While these indicators suggest that productivity and food supply may be adequate to support the current abundances of salmonid populations, the current population abundances are greatly depressed and it is unclear whether a greater abundance will be supported.

2.3 Predation

Studies of predator abundance, habitat use, and predation rates on juvenile fall-run Chinook salmon in the Tuolumne River indicate that predation by largemouth bass, smallmouth bass, and other non-native fishes may be a limiting factor for fall-run Chinook salmon outmigrant survival and may be a source of mortality under low flow conditions (EA 1992; TID and MID 1992; FISHBIO 2013a).

A 2012 FERC relicensing study estimated predation rates on juvenile fall-run Chinook salmon and predator populations between RM 30.3 and 5.1(FISHBIO 2013a). The study found that predation rates on Chinook salmon varied by predator species, with striped bass average predation rate (or the mean consumption of juvenile Chinook per predator) equaling 0.68, followed by smallmouth bass at 0.09, largemouth bass at 0.07, and Sacramento pikeminnow with no predation of Chinook salmon observed. These predation rate estimates were expanded to estimate the total amount of Chinook salmon consumed from March 1 to May 31 (FISHBIO 2013a); however, because of concerns[3] with the methodology used in the predator abundance estimates and digestion rates, FERC staff determined the estimates to be unreliable and required an additional study using different methodology. The additional predation study has not been completed (CDFW 2014). A review of the 2012 predation study by Grossman (et al. 2016) considered the predation rates in the Tuolumne River to be "moderate" for the Central Valley. Although the 2012 predation study contains shortcomings, the report provides information indicating that flow conditions affect predation vulnerability. Specifically, Table 5.4-2 of that study shows that under high flow conditions, 43 tagged Chinook salmon (of 75 in Release Group #1) passed station SRP 10, but under much lower flow conditions, only 2 tagged Chinook salmon (of 73 in Release Group #3) passed station SRP 10 (FISHBIO 2013a).

In general, reduced spring flows, elevated water temperatures, and the presence of low-velocity habitats (including former in-channel aggregate mining pits) in the lower reaches of the Tuolumne River favor fish communities dominated by non-native, warmwater species, such as largemouth bass and other potential predators on native salmonids (EA 1992; McBain & Trush 2000; Brown and Ford 2002). Another predation study performed on the Tuolumne River at high flows found no salmonid predation occurred (Stillwater Sciences and McBain & Trush 2006). This was attributed to low water temperatures rather than species segregation caused by high flows or restoration actions. Increased flows reduce predation encounter rates by increasing the amount of available juvenile habitat (Bowen and Bark 2010), providing escape cover through higher turbidity (Gregory 1993; Gregory and Levings 1996, 1998) and decreasing travel times through some reaches (Buchanan et al. 2018; FISHBIO 2013a).

In-channel aggregate extraction pits that are further exacerbated by the sediment retention of upstream reservoirs, and low reservoir flow releases that lack energy to mobilize sediments, appear to provide ideal habitat for predators (McBain & Trush 2004). In addition, juvenile salmonids have very little floodplain refugia and few side channels in the lower Tuolumne River to escape predation. The largemouth bass population in the lower Tuolumne River has been estimated to be appreciable (FISHBIO 2013a). Such predators likely compete with and prey upon juvenile salmonids (FISHBIO 2013a).

[3] A detailed description of concerns with the methodology used in FISHBIO 2013a is found in Master Response 3.1 of the 2018 Final SED.

2.4 Temperature

Providing suitable water temperatures is critical to the health of the lower Tuolumne River aquatic ecosystem. Water temperature influences every freshwater life stage of anadromous salmonids including:

- successful migration into nursery areas to spawn;
- location and timing of spawning;
- viability of eggs and timing of hatch;
- survival once salmonids emerge from their redd;
- location and timing of juvenile residence and rearing as well as growth rate during rearing;
- timing and duration of smoltification; and
- successful river emigration from susceptibility factors such as disease prevalence, contaminants, predation, and growth.

Water temperatures immediately downstream of La Grange Dam are generally cold due to cold water stored in and released out of Don Pedro Reservoir immediately upstream. As the water travels downstream, it begins to equilibrate with the air temperature, generally warming during the spring through fall and cooling during the winter. This seasonal warming constricts the amount of suitable habitat. Higher flows during the spring, summer, and fall create more miles of habitat downstream of La Grange Dam that have suitable water temperatures compared to lower flows.

Both juvenile and adult salmonid populations in the Tuolumne River are exposed to higher than optimal (USEPA 2003) water temperatures, and the lower Tuolumne River was listed on the US Environmental Protection Agency (USEPA) 303d list as being impaired for temperature in 2011 (SWRCB 2022). Research indicates that elevated water temperatures have resulted in reduced egg viability, reduced growth rates, increased rates of disease, higher predation rates, and direct mortality (Rich 2007).

Adult fall-run Chinook salmon migrate into the Tuolumne River from September to December with most spawners migrating in October and November. In most years, water temperatures exceed the 18°C threshold (64.4°F) recommended by the USEPA for adult salmonid migration (USEPA 2003) in September and early October with temperatures decreasing during October. Monitoring data show a trend of an increasing number of adult fall-run Chinook salmon moving into the Tuolumne River as water temperature decreases (e.g., 2013, 2014, 2016, 2018, 2019) (TID and MID 2014; TID and MID 2015; TID and MID 2017; TID and MID 2019; TID and MID 2020). The concomitant trends in migration and decreasing temperatures suggest that elevated water temperatures may be impacting adult migration timing. For example, adult fall-run Chinook salmon migration was documented in September 2017 when cooler suitable water temperatures were observed in the Tuolumne River, and adult fall-run Chinook salmon began to arrive in late September and early October, with a peak in late October (TID and MID 2018) (Figure 2-1).

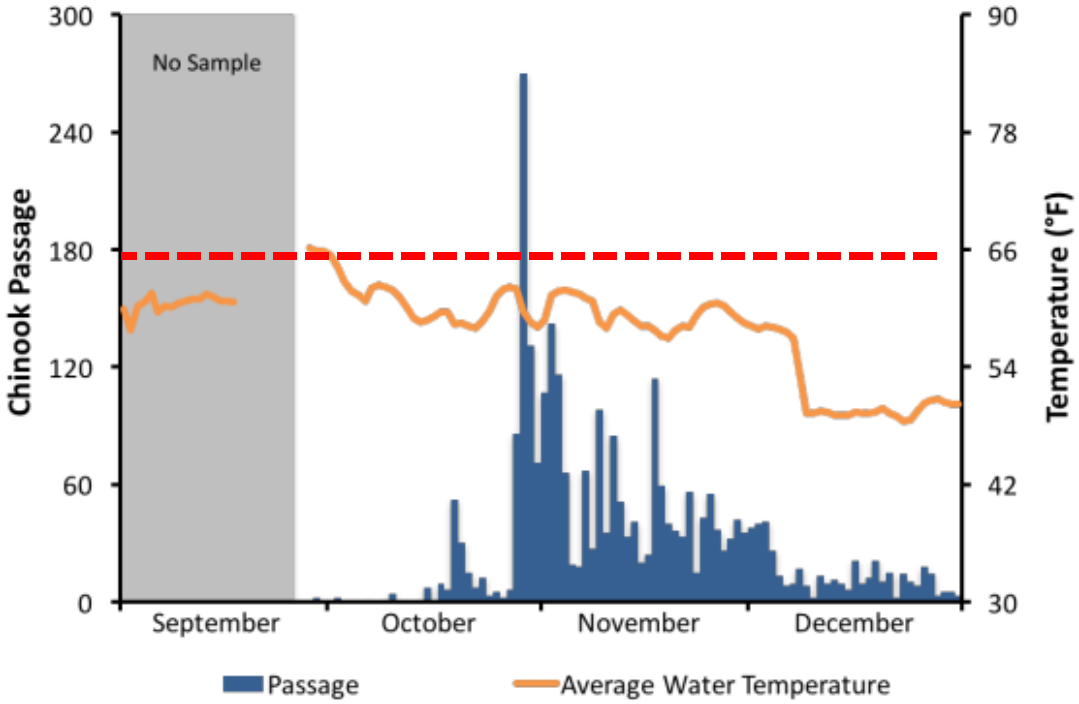


Figure 2-1. Number of Fall-Run Chinook Salmon Passing the Counting Weir (RM 24.5) per Day and the Average Daily Water Temperature at the Weir, September 1, 2017, through December 31, 2017) (Reproduced from TID and MID 2018). Adult Migration Was Observed in September, When Water Temperatures Were Suitable in the Tuolumne River. The Red Dash Line Represents the USEPA (2003) 18°C Benchmark for Adult Salmon Migration.

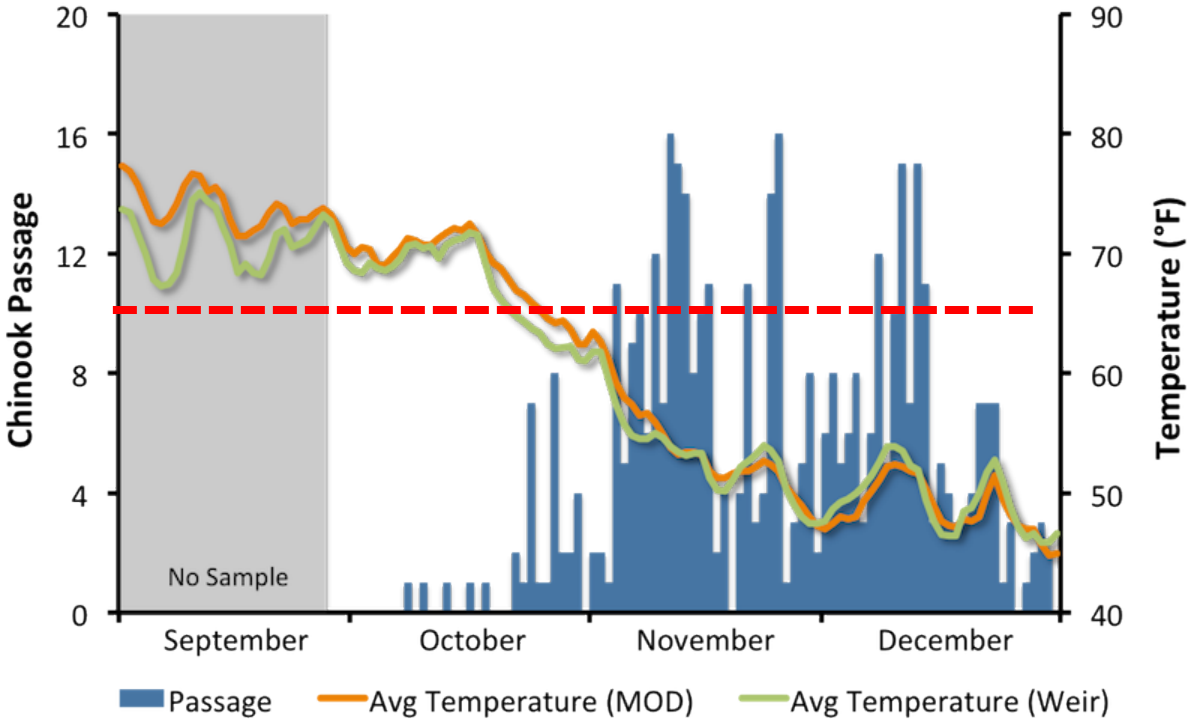


Figure 2-2. Number of Fall-Run Chinook Salmon Passing the Counting Weir (RM 24.5) per Day and the Average Daily Water Temperature at the Weir and Modesto Gage, September 1, 2015, through December 31, 2015) (Reproduced from TID and MID 2016). The Red Dash Line Represents the USEPA (2003) 18°C Benchmark for Adult Salmon Migration.

In general, by the time adult fall-run Chinook salmon begin to appear on the spawning grounds, water temperatures are decreasing below lethal and harmful conditions (Figure 2-2). Figure 2-3 shows that increases in live adult salmon and redd counts begin after water temperatures reach the USEPA (2003) temperature benchmark for successful egg incubation of 13°C.

Pre-spawn mortality has been associated with high water temperatures and can lead to population decline (Bowerman et al. 2017). Pre-spawn mortality is documented as part of the California Department of Fish and Wildlife's (CDFW) annual escapement survey, and the occurrence of pre-spawn mortality on the Tuolumne River is low, with few to no fish found in most years (Table 2-2). Based on the temperatures measured on the spawning grounds and low incidence of pre-spawn mortality, water temperature during adult spawning does not appear to be detrimental to the fall-run Chinook salmon population in the Tuolumne River in many years. However, in years when high water temperatures delay adult immigration (Peterson et al. 2017), spawning may be delayed. Delayed adult spawning coupled with warm temperatures later in the juvenile emigration season may limit the window for successful completion of the in-river life stage (Mesick 2009) which could be causing a reduction in life history diversity and population abundance.

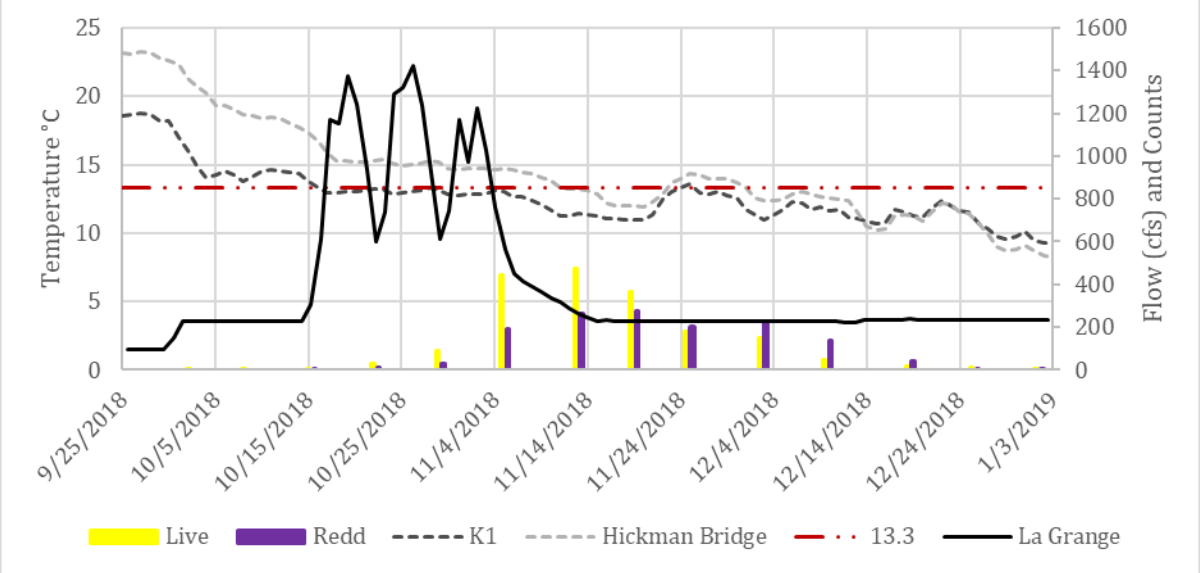


Figure 2-3. Tuolumne River Flows (cfs) at the La Grange gage, Water Temperature at Riffle K1 (RM 41.7) and Hickman Bridge (RM 31.6), Upper Limit for Successful Egg Incubation (13°C 7DADM[4]) and Number of Live Fish and Redds Counted during Escapement Survey (Murphey 2024a).

Table 2-2. Unspawned Females, Partially Spawned Females, and Total Female Fish Handled during the Tuolumne River Carcass Surveys from 2012–2019.

Year	Unspawned	Partially Spawned	Female Fish Handled
2012	0	0	173
2013	3	2	475
2014	0	0	17
2015	0	0	2
2016	0	0	290
2017	7	3	191
2018	0	0	170
2019	0	0	197

Source: Murphey 2024b.

Adult steelhead (anadromous *O. mykiss*) generally migrate into the Tuolumne River from September to May (TID and MID 2021). Temperatures in the Tuolumne River can exceed the USEPA (2003) recommended 7DADM criteria of 18^0C at various locations and times over the nine months of adult steelhead migration.

[4] Recommended unit of measurement for USEPA (2003) temperature guidance for protection of salmonids which is the 7-day average of the daily maximum. The measurement represents the maximum temperatures that fish can be exposed to while providing protective conditions.

O. mykiss can be found in the Tuolumne River year-round, with some individuals spending their entire lives in the river. In 2011, an Intermediate Below Normal-Above Normal Year with flood control releases, temperatures remained below both the USEPA recommended temperatures for core and non-core juvenile rearing[5] at almost all sites downstream to approximately RM 35 (Figure 2-4). A similar trend was seen in 2006, a wet year with flood releases, where temperatures are supportive, and below the USEPA benchmark temperatures for juvenile rearing down to about RM 35 (Figure 2-5). In contrast, during 2012, a Median Dry, and 2013, a Median Critical year, all sites downstream of RM 45 had temperatures for parts of the summer that would be considered stressful or detrimental (Anchor QEA 2019) (Figure 2-6 and Figure 2-7). This shows that the amount of suitable rearing habitat is typically constrained due to high temperatures during low flow years and is expanded during high flow years with cooler water temperatures.

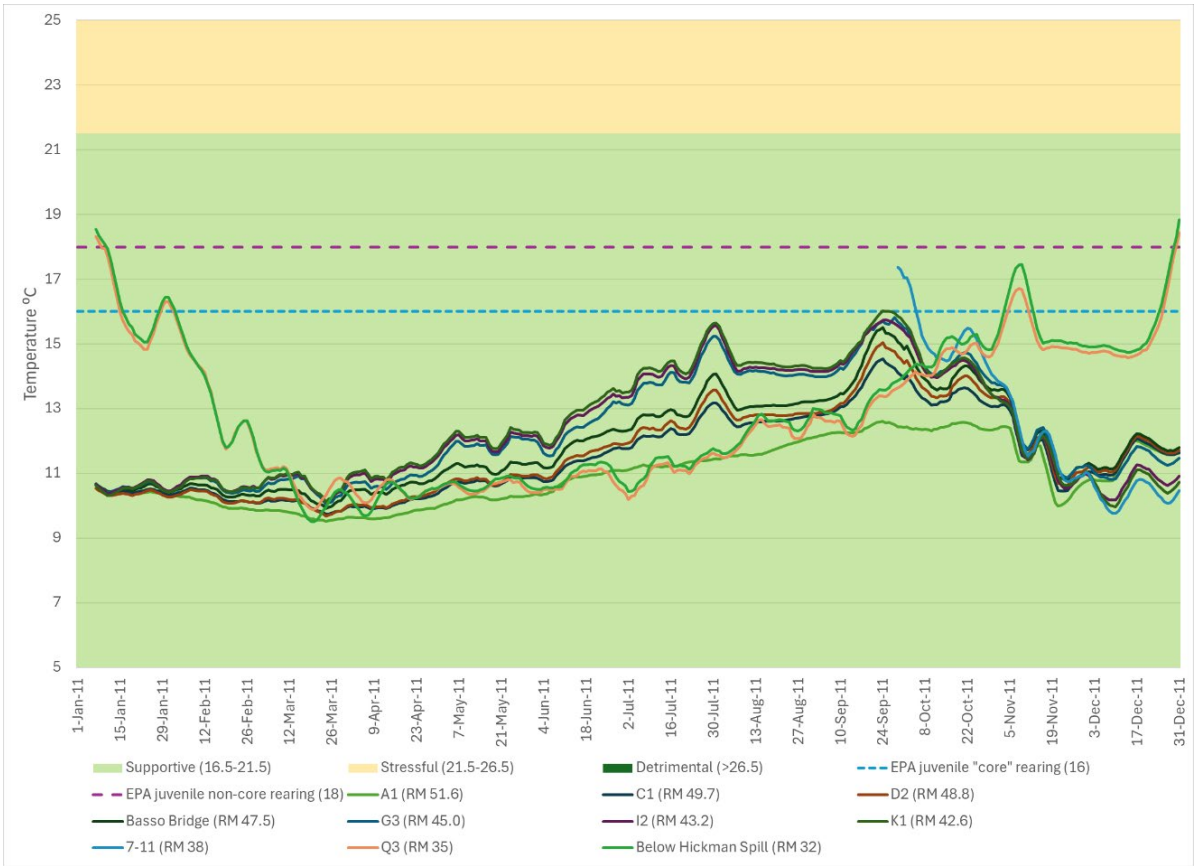


Figure 2-4. 7DADM Temperatures at Selected Locations from RM 51.6–32 for 2011, USEPA (2003) Recommended Temperatures for Core (16°C) and Non-Core Juvenile Rearing (18°C) and Temperatures Considered to be Supportive, Stressful, Sub-Optimal, and Detrimental[6] for Rearing *O. mykiss* (Murphey 2024c).

[5] See Section 5.2.1.3, *Temperature Benchmarks* of Chapter 5, *Water Temperature,* for a discussion of core vs non-core juvenile rearing.

[6] Supportive, stressful (sub-optimal), and detrimental conditions are terms defined in Cain et al. (2019). Supportive conditions contribute to the health and growth of individuals and the population without harmful effects. Stressful conditions are associated with dome degree of impact at the individual or population level (e.g., observable or measurable stress, increased vulnerability to disease, reduced growth, reduced survival). Detrimental conditions are associated with a significant level of harm at the individual or population level.

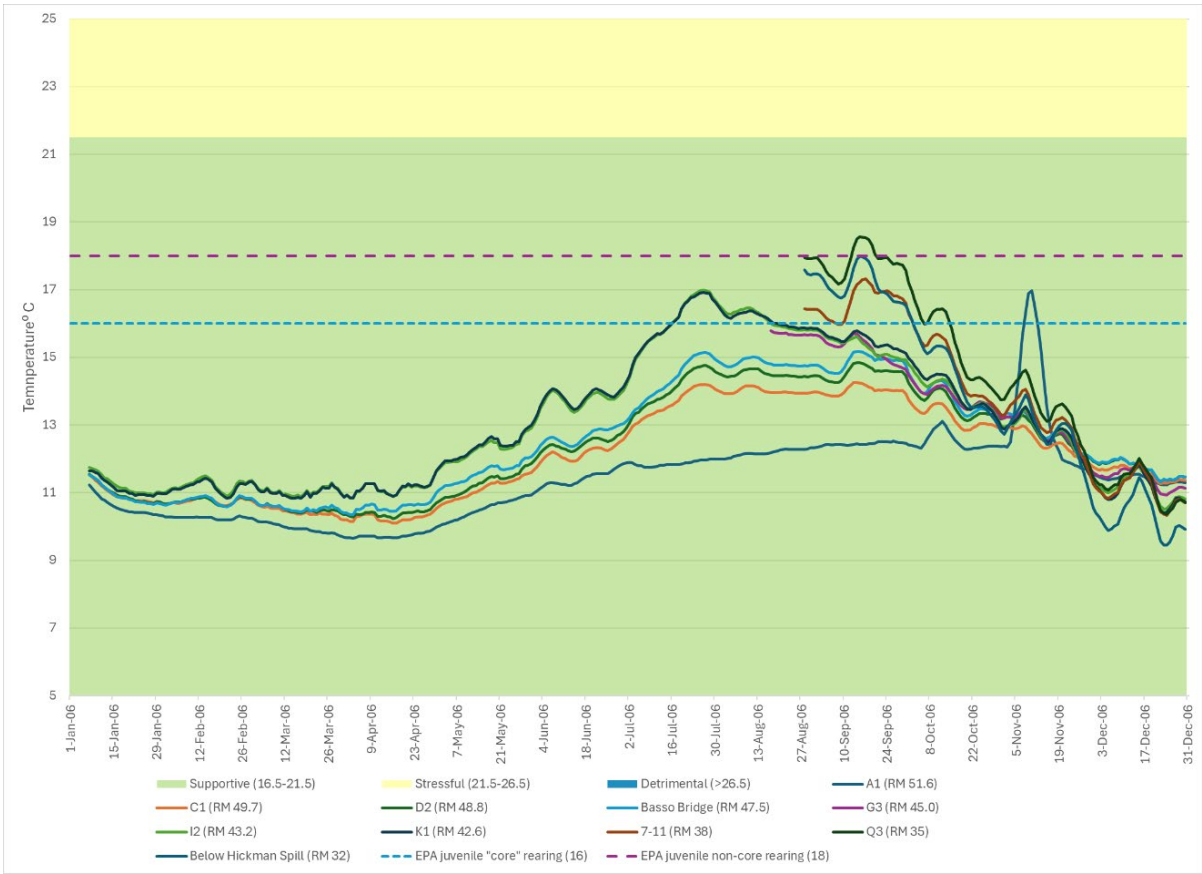


Figure 2-5. 7DADM Temperatures at Selected Locations from RM 51.6–32 for 2006, USEPA (2003) Recommended Temperatures for Core (16°C) and Non-Core Juvenile Rearing (18°C) and Temperatures Considered to be supportive, Stressful, Sub-Optimal, and Detrimental for Rearing *O. mykiss* (Murphey 2024d).

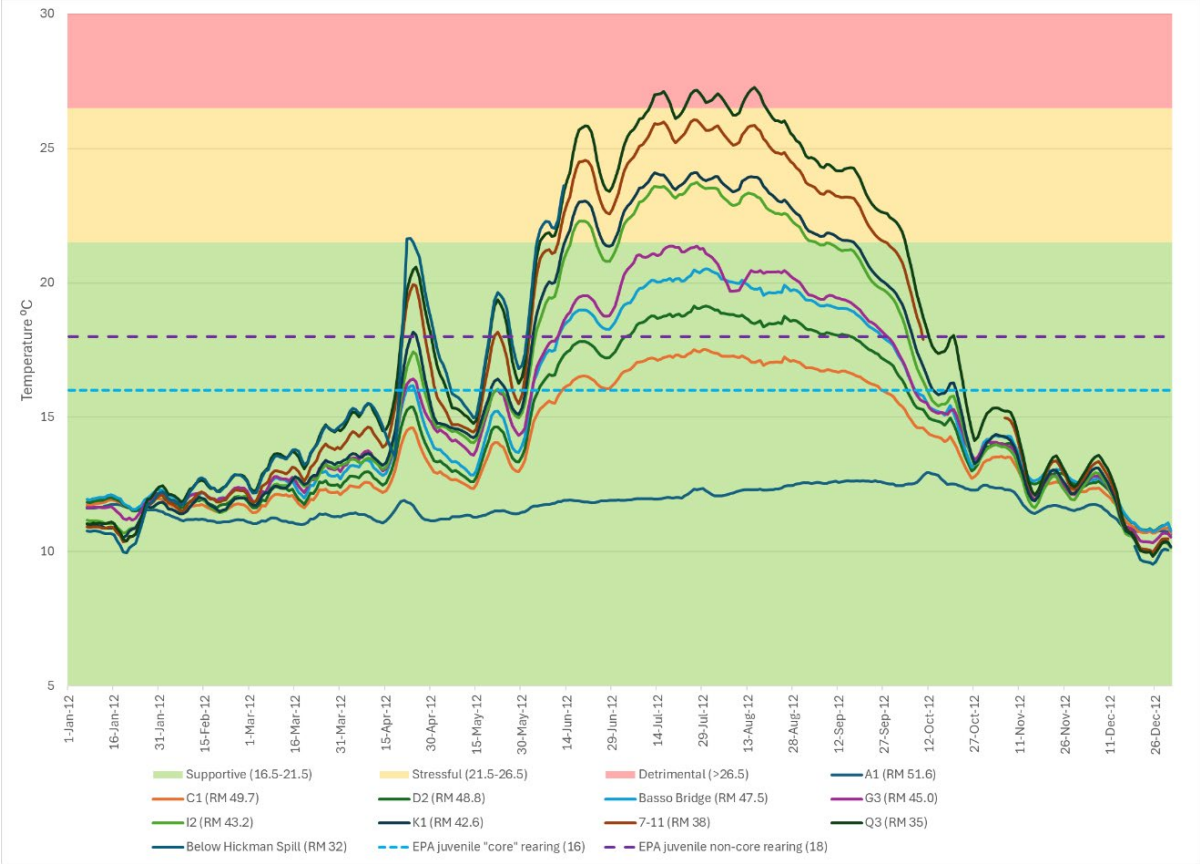


Figure 2-6. 7DADM Temperatures at Selected Locations from RM 51.6–32 for 2012. USEPA (2003) Recommended Temperatures for Core (16°C) and Non-Core Juvenile Rearing (18°C) and Temperatures Considered to be Supportive, Stressful, Sub-Optimal, and Detrimental for Rearing *O. mykiss*. (Murphey 2024e).

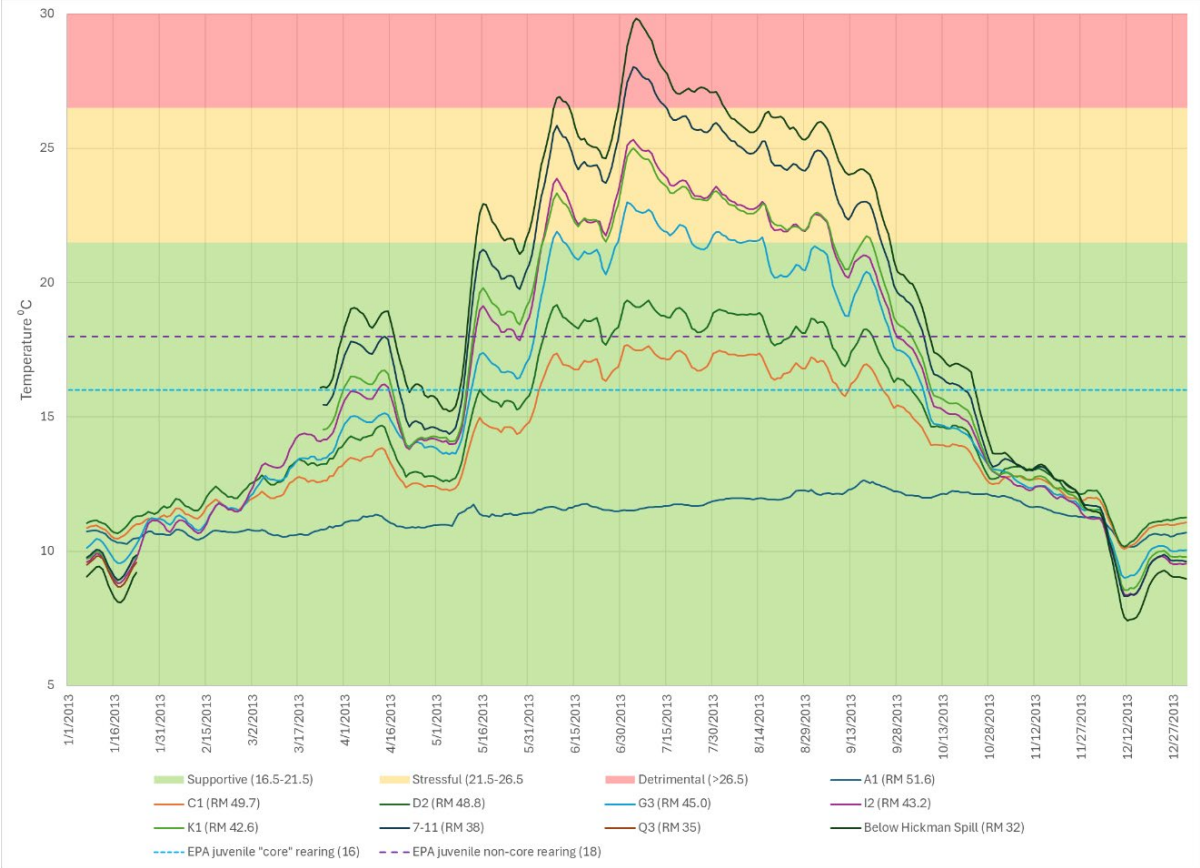


Figure 2-7. 7DADM Temperatures at Selected Locations from RM 51.6–32 for 2013. USEPA (2003) Recommended Temperatures for Core (16°C) and Non-Core Juvenile Rearing (18°C) and Temperatures Considered to be Supportive, Stressful, Sub-Optimal, and Detrimental for Rearing *O. mykiss* (Murphey 2024f).

The juvenile salmon life stage has been identified as particularly at risk of adverse impacts from chronic high water temperature exposure. Protracted exposure to elevated water temperatures (> 20°C) has been demonstrated to decrease growth and appetite, alter smolt physiology, and increase predation vulnerability for juvenile fall-run Chinook salmon when compared to juveniles reared in near optimal temperatures of 13–16°C (Marine and Cech 2004).

Fall-run Chinook salmon juveniles rear in the San Joaquin River tributaries and migrate to the Delta between January and June. In some years, June emigration comprises a substantial proportion of the total number of emigrants (e.g., 1998, 2006, and 2011) (CDFW 2017a). However, high temperatures in the Tuolumne River likely hinder successful emigration in dryer years. For example, as seen in Figure 2-8, 7DADM temperatures in 2015 entered the stressful range at Shiloh (RM 3.4) by mid-February and surpassed the USEPA (2003) recommendation by March. Even at the upstream K1 riffle location, higher than optimal temperatures occurred from March through June and surpassed USEPA recommendations by the end of April. In contrast, during 2011 7DADM in all measured locations remained below USEPA (2003) temperature recommendations and stayed within the range considered to be optimal (Anchor QEA 2019) through mid-June.

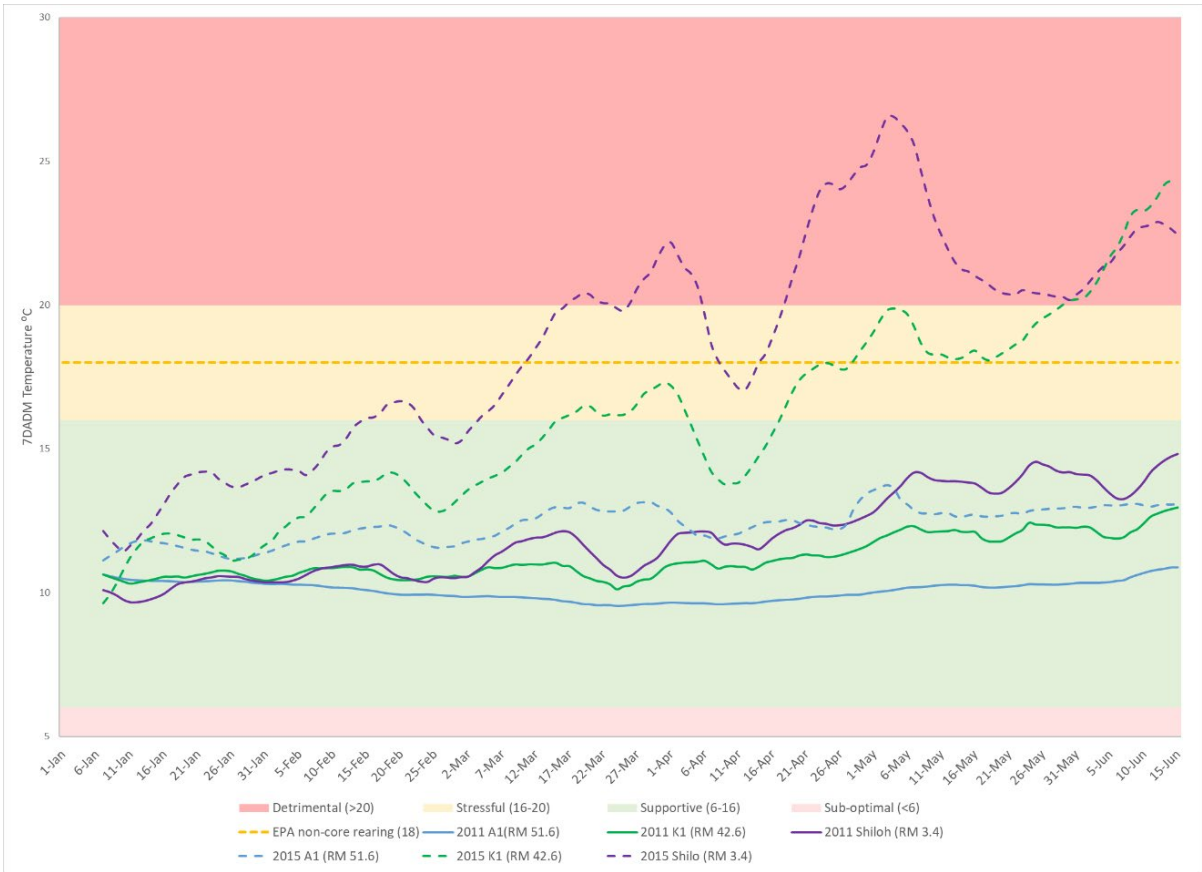


Figure 2-8. 7DADM Temperatures at A1 (RM 51.6), K1 (RM 42.6) and Shiloh (RM 3.4), for 2011 (Wet Year; Illustrated with Solid Lines) and 2015 (Critically Dry Year; Illustrated with Dashed Lines) USEPA Non-Core Rearing (18°C), and Temperatures Considered Supportive, Stressful, and Detrimental for Rearing Fall-Run Chinook Salmon (Murphey 2024g).

2.5 Flow

As described in Appendix C of the 2018 Final Substitute Environmental Document (SED), scientific evidence indicates that reductions in flows and alterations to the flow regime in the San Joaquin River Basin resulting from water development over the past several decades have negatively affected fish and wildlife beneficial uses. The magnitude of the hydrologic alteration caused by water development in the Tuolumne Rivers is summarized in Figure 2-9. By comparing the unimpaired annual hydrograph to present-day observed conditions, this figure illustrates that wet season flows have become dramatically lower, and dry season flows have become higher in the Tuolumne River.

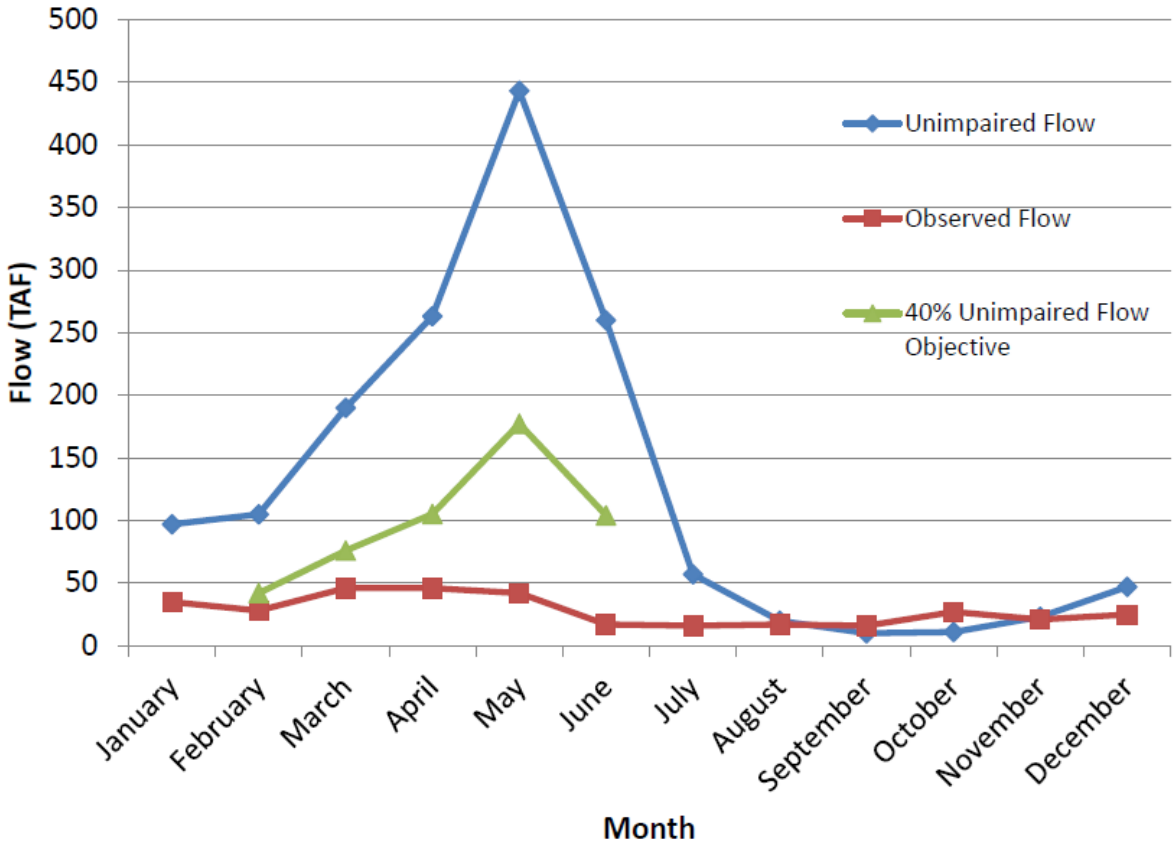


Figure 2-9. Tuolumne River Median Monthly Flow (Thousand Acre-Feet [TAF]) from 1984 to 2009 under Unimpaired, Observed, and 40% Unimpaired Flow Conditions. (Unimpaired and Observed Flow Data Are from Table 2.20 in Appendix C, Technical Report on the Scientific Basis for Alternative San Joaquin River Flow and Southern Delta Salinity Objectives [2018 Final SED]. The 40% Unimpaired Flow Objective Points in the Figure Are 40% of the Unimpaired Flow Points.)

Fish habitat quantity and quality on the Tuolumne River is primarily controlled by flows. Flow requirements for the Lower Tuolumne River are specified in the New Don Pedro Proceeding (P-2299-024) Settlement Agreement and the FERC License Amendment for the New Don Pedro Project. The intent of the flow requirements is to protect fall-run Chinook salmon populations spawning below La Grange Dam. Despite the minimum flow requirements, adult Tuolumne River fall-run Chinook salmon continued to significantly decline after the 1995 New Don Pedro Proceeding Settlement Agreement (Mesick 2008). Mesick (2008) found that instream flow releases in the Tuolumne River, from February 1 through June 15, explained approximately 82% of the variation in Tuolumne River fall-run Chinook salmon adult recruitment, while factors outside of the Tuolumne River explained very little variation.

Mesick (2008) also found that winter and spring flows affected juvenile fall-run Chinook salmon survival in the Tuolumne River. For example, the observed minimal instream flows during the winter and spring of dry and normal years coincide with very few fall-run Chinook salmon smolts out-migrating from the rivers and fewer adults from that cohort returning over the next few years. Conversely, when high instream flows occur for several months in the winter and spring of wet years, numerous fall-run Chinook salmon smolts out-migrate and many adults return over the next few years, although this relationship has degraded in recent years (Figure 2-10). This is consistent with increases in fry, smolt, and total juvenile survival indices between Tuolumne River rotary screw trap monitoring at Waterford (RM 29.8) and Grayson (RM 5.2) when flows were elevated from flood control releases (Table 2-3). For example, total juvenile survival indices were 24.9% and 94.8% for 2011 and 2017, respectively, whereas survival was below 8% in the other years.

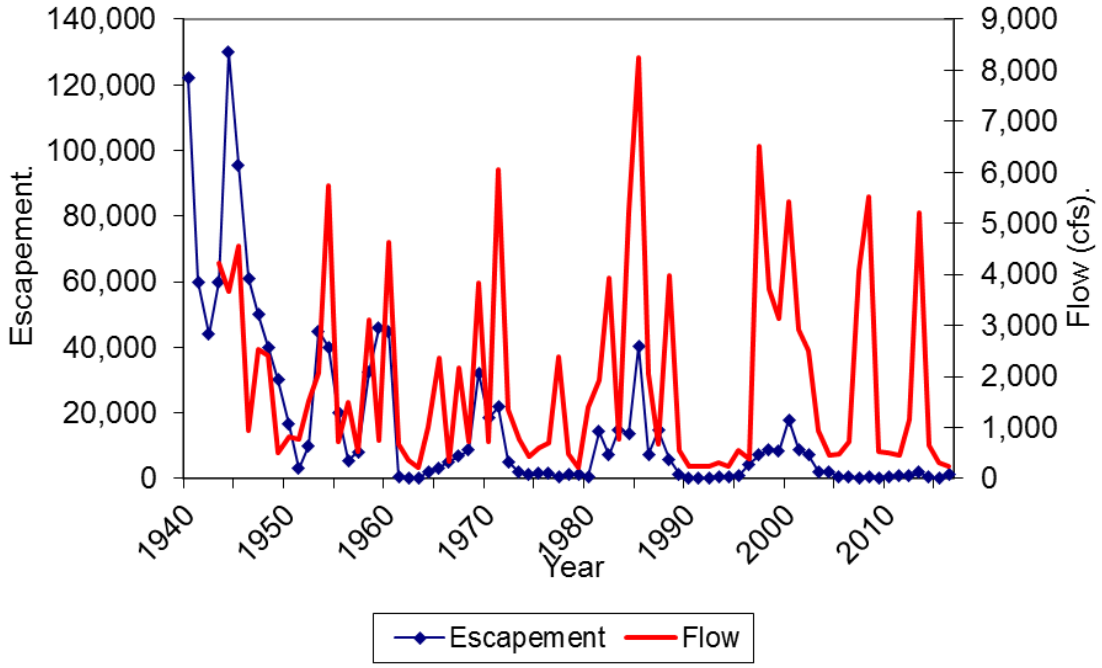


Figure 2-10. Tuolumne River Fall-Run Chinook Salmon Escapement and Mean Streamflow in the Tuolumne River at Modesto (DWR Gage Data For MOD) from 1 February to 15 June Two Years Prior to the Escapement Estimates (Reproduced from CDFW 2018).[7]

[7] The large deviation in 2007 reflects poor returns that were attributed to poor ocean conditions (Lindley et al. 2009) and resulted in the closure of the fishery.

Table 2-3. Survival Indices through the Lower Tuolumne River between Waterford and Grayson.

Year	Total Survival Index	Fry Survival Index	Peak Fry Daily Avg. Flow at MOD	Smolt Survival Index	Peak Smolt Daily Avg. Flow at MOD
2007	–	–	957	2.9	1,020
2008	6.2	6.5	1,690	6.4	1,320
2009	7.9	0.3	1,300	14.2	1,020
2010	3.0	0.8	767	3.4	3,300
2011	24.9	23.1	7,490	31.2	8,180
2012	3.8	0.2	599	9.7	1,950
2013	1.7	0.03	510	4.0	1,140
2014	– [a]	– [a]	279	– [a]	1,100
2016	– [a]	– [a]	2,200	6.3	2,170
2017	94.8	95.8	15,500	60.6	10,400

Source: Reproduced from 2017 Annual Report TID and MID 2018.
[a] Survival index not calculated due to incomplete sampling at Grayson.

There are many studies that document a positive relationship between salmonid growth and access to off-channel areas and floodplains (e.g., Bellmore et al. 2013; Jeffres et al. 2008; Sellheim et al. 2016; Hayes et al. 2008; Limm and Marchetti 2009; NMFS 2014; Opperman 2012; Opperman et al. 2010; Sommer et al. 2001; Sturrock et al. 2015; and Zeug et al. 2014). The US Fish and Wildlife Service (USFWS) calculated that without the Don Pedro Project the median number of acre-days of floodplain inundation from 1971–2012 at flows greater than 1,000 cfs would be 77,640 (Millsap and Gard 2018). This can be compared to current conditions for the same period where a median of 5,205 acre-days of inundation was estimated (Millsap and Gard 2018), which is a 93% reduction. A minimum inundation period is also needed for the establishment of BMI guilds [shredders, conditioners, collectors (Poff and Zimmerman 2010; Short and Maslin 1977)] that are the prey base for juvenile salmonids (Allan et al. 2003).

Flow rates in the Tuolumne River appear to have an impact on the rate of predation on juvenile Chinook salmon. As discussed above, during the 2012 predation study, 222 hatchery juvenile fall-run Chinook salmon were implanted with acoustic tags to determine survival at different flows. The first group was released at a flow of 2,100 cfs and had about 49% survive over a 26-mile reach. The second and third release groups were released at flows of 280 and 415 cfs and had survival rates of 1.3% and 0% respectively (Table 2-4). This is consistent with the 2006 predation study discussed in Section 2.3, *Predation*, where the authors found that predation rates were zero in the presence of high flows (>6,000 cfs), even though both juvenile Chinook salmon and predator bass were present (Stillwater Sciences and McBain & Trush 2006). The authors attributed the low rates of predation on unsuitable predator habitat, low temperatures (10.7–12.8°C), and high turbidity due to the high flows.

Table 2-4. Summary of Detections for Acoustic-Tagged Fall-Run Chinook Salmon at Grayson, River Flow at La Grange, and Water Temperature at Roberts Ferry Bridge.

	Release Group		
	1	2	3
Release Dates	May 9–10	May 16–17	May 21–22
Target flow at La Grange	2,100	280	415
Water Temperature at Roberts Ferry (C)	12.6 (range 11.0–14.3)	16.3 (range 14.6–18.7)	16.7 (range 13.8–17.1)
Total # Released	75	74	73
Detected at Grayson	37	1	0

Source: Data obtained from FISHBIO 2013a.

Low flows in late October during adult fall-run Chinook salmon migration has been identified as one of the causes of low population numbers (Mesick 2009). The mechanism causing increases in adult immigration in response to fall attraction flows is unclear, and there are several unknowns such as the location of holding fish (TID and MID 2020).

2.6 Hatchery-Origin Strays in the Tuolumne

Hatchery operations and hatchery strays can impact salmonid populations in both streams with and without hatcheries through competition and by influencing the genetic suitability of populations. Competition between wild and hatchery fish can occur during all life stages, with juveniles competing for food and habitat (Tatara and Berejikian 2012) and adults competing for spawning locations and mates (Weber and Fausch 2003). Hatchery fish also impact the genetics of the population when hatchery fish stray into the Tuolumne River and mate with wild fish (Sturrock et al. 2019). Due to concerns about hatchery-origin spawner impacts on populations of wild fish, viable salmonid population criteria were developed by Lindley et al. (2007) to achieve a low risk of extinction of the population, which suggested that no more than 5% of a spawning population should be comprised of hatchery fish.

There is no hatchery on the Tuolumne River, although a small number of hatchery fish are released in many years for rotary screw trap efficiency studies. From 2010 to 2019 hatchery fish have been estimated to comprise 17–88% of fall-run Chinook salmon spawning in the Tuolumne River (Table 2-5). Estimates of hatchery strays (from other rivers containing hatcheries) to the Tuolumne River from 2010–2019 are similar to the Stanislaus or Merced Rivers, but the overall average is lower (Kormos et al. 2012; Palmer-Zwahlen and Kormos 2013; Palmer-Zwahlen and Kormos 2015; Palmer-Zwahlen et al. 2018; Palmer-Zwahlen et al. 2019a; and Palmer-Zwahlen et al. 2019b; Palmer-Zwahlen and Kormos 2020; Letvin et at. 2020; Letvin et al. 2021a; Letvin et al. 2021b). Coded-wire tag recoveries have identified fish from the Coleman National Fish Hatchery, Nimbus Hatchery, Feather River Hatchery, Merced River Fish Facility, San Joaquin Restoration Program Hatchery, with the majority originating at the Mokelumne River Fish Hatchery (Kormos et al. 2012; Palmer-Zwahlen and Kormos 2013; Palmer-Zwahlen and Kormos 2015; Palmer-Zwahlen et al. 2018; Palmer-Zwahlen et al. 2019a; and Palmer-Zwahlen et al. 2019b; Palmer-Zwahlen and Kormos 2020; Letvin et at. 2020; Letvin et al. 2021a; Letvin et al. 2021b).

Table 2-5. Estimated Percentage of Tuolumne River Adult Salmon Returns from Hatchery Origin 2010–2019.

Year	Estimated % of Hatchery Origin
2010	49%
2011	73%
2012	36%
2013	28%
2014	65%
2015	65%
2016	88%
2017	87%
2018	57%
2019	17%

2.7 Direct Take

Direct take includes removal from fishing (legal and illegal), as well as entrainment into unscreened or poorly screened diversions. Juvenile fall-run Chinook salmon become entrained in the numerous unscreened diversions along the Tuolumne River (Herren and Spencer 2001), but entrainment into diversions is difficult to quantify. Adult fall-run Chinook salmon have also been found in, and rescued from, the Districts' canal systems (CDFW 2017b). Adjustments to water operations by the Districts (TID n.d.; MID n.d.) and a recently installed fish barrier at the TID Harding Drain (NMFS 2020) have potentially reduced the chances of entrainment into the canal systems.

The Tuolumne River is closed to fishing upstream of Hickman Bridge (RM 31) from October 31 through January 1 (CDFW 2023) to protect spawning fall-run Chinook salmon. Fishing is permitted year-round downstream of Hickman Bridge, but there is no data to quantify the magnitude of take. Poaching almost certainly occurs on the Tuolumne River. CDFW staff encounter poachers or evidence of poaching just upstream of Old La Grange Bridge (Murphey 2014, 2015). CDFW carcass survey crews have also reported finding fish frames (skeletons with filets removed) and whole fish (found on the road) indicative of poaching (Murphey 2014). In addition to evidence of poaching in the La Grange area, it is very likely poaching also occurs at other locations in the Tuolumne River (Guptill pers. comm.).

2.8 Limiting Factors Analysis

2.8.1 Background

Stock-recruitment models are commonly used in fisheries management to describe the relationship between the number of adult spawners (the stock) and the total number of adult or juvenile recruits they produce (Quinn II and Deriso 1999) and to inform fisheries management decisions. For example, Satterthwaite (2023) modeled stock-recruitment relationships of Sacramento River fall-run Chinook salmon to evaluate the probability that meeting spawning escapement goals will achieve goals for hatchery and natural production. Stock-recruitment models can also be used to

evaluate the effects of environmental factors (e.g., flow, water temperature) and local management actions (e.g., habitat restoration) on long-term trends in productivity and abundance of salmon (Adkison 2022). For example, Sturrock et al. (2020) used stock-recruitment modeling to assess how regulated flow has influenced production of fall-run Chinook salmon on the Stanislaus River, and Munsch et al. (2020) evaluated how flow and habitat restoration have affected Chinook salmon fry density in the Sacramento–San Joaquin Delta.

Stock-recruitment models were developed for this Draft TVA Scientific Basis Report to evaluate potential environmental factors limiting the production of juvenile fall-run Chinook salmon in the Tuolumne River, including historical flow, temperature, and area (acres) of spawning and rearing habitat. Detailed rationale, methods, and results of stock-recruitment modeling are presented in Appendix A, *Stock-Recruitment Modeling*.

2.8.2 Model Formulation

The simplest of the stock-recruitment models is the density-independent model, which predicts that the number of juvenile recruits increases at a constant rate with an increasing number of adult spawners. The density-independent model does not typically reflect the population dynamics of most natural populations because the model does not consider the effects of density-dependence on growth, mortality, fecundity, and recruitment (Wootton 1990). Density-dependent effects refer to intrinsic processes that are either positively or negatively affected by increasing population density.

The more complex Beverton-Holt and Ricker models build upon the simple density-independent model by incorporating density-dependence. The models predict that at low spawner abundances, density-independent factors (e.g., environmental stressors and background birth and death rates) exert a relatively greater influence on population dynamics than density-dependent factors (e.g., competition for habitat area). However, as the number of spawners increases, density-dependent factors become more influential on population dynamics (Subbey et al. 2014). The Beverton-Holt and Ricker models can produce different results and line curvature due to differences in underlying assumptions. The Beverton-Holt model assumes a high mortality rate of recruits at larger population sizes due to juvenile competition and predation. The Beverton-Holt model form is usually selected when it is hypothesized that recruitment is limited by food availability or habitat space, and that predators can rapidly adjust their feeding rates based on changes in prey abundance. The Ricker model assumes egg and juvenile mortality is proportional to the initial juvenile cohort size. This model is generally selected if it is hypothesized that cannibalism of juveniles by adults is high, redd superimposition is significant, and the effects of predators are not immediate and display a time lag (Wootton 1990). Nonetheless, both models lead to less per capita recruitment as spawning stock size increases (i.e., fewer juveniles are produced per adult spawner at higher spawner densities).

The following three stock-recruitment model forms were considered for the Tuolumne River:

$R_t = \alpha * S_t + \gamma * F_t$, Density-independent (1)

Here, R_t represents the total annual number of juvenile recruits for year t, S_t is the annual estimate of adult spawner abundance, and α is intrinsic productivity (i.e., the slope near the origin). F_t is an environmental covariate (flow, temperature, or habitat area), and γ is the coefficient value for the covariate effect (i.e., estimate of the effect of flow, temperature, or habitat area on juvenile recruitment).

$$R_t = (\alpha * S_t / 1 + \beta * S_t) + \gamma * F_t, \text{ Beverton-Holt} \quad (2)$$

$$R_t = \alpha * S_t * \exp(-\beta * S_t) + \gamma * F_t, \text{ Ricker} \quad (3)$$

In the Beverton-Holt (eqn. 2) and Ricker model forms (eqn. 3), β is the density-dependent term, expressing the effect of diminishing numbers of juvenile recruits per adult spawner as the number of spawners increases.

Results of two stock-recruitment model forms are presented below: density-independent and density-dependent (Ricker). Density-independent and Ricker models were fitted separately to estimate the effects of spawner abundance (density-independent and Ricker), density-dependence (Ricker), and additive effects of individual environmental covariates (density-independent and Ricker), including temperature, flow, and habitat area (see Tables A-1 and A-2 in Appendix A for a list of covariates), to identify which factors best explain interannual variation in juvenile production.

Adult spawner abundance estimates were sourced from GrandTab escapement estimates. Juvenile abundance estimates were based on passage data from a rotary screw trap site near Waterford, CA (Section A.3.1, *Spawner and Juvenile Abundance Estimates*, in Appendix A). Flow and temperature covariates are from USGS gage data at Modesto, CA, and habitat covariates were modeled as wetted area or weighted usable area (WUA) using historical flow data (Section A.3.2, *Environmental Covariates*, in Appendix A) following approaches described in Chapter 7, *Spawning and Rearing Habitat*, Section 7.3, *Habitat Modeling*. Data covered the years 2007–2022, excluding 2020.

For the Draft TVA Scientific Basis Report, 32 stock-recruitment models were fitted and model performance was assessed using Akaike's Information Criterion (AIC). AIC is one of the most applied statistical tools for comparing the level of empirical support for different models fit to the same set of data (Cavanaugh and Neath 2019). A model that has a lower AIC value provides a relatively better fit to the data than a model with a higher AIC value, meaning that models with lower AIC have a more appropriate structure given the observed data. In addition, models with lower AIC values are less likely to be overly simplistic or complex (i.e., they are less likely to contain too many or too few parameters) and are more likely to include parameters that explain patterns in the data well. By contrast, models with higher AIC values may contain parameters with lower explanatory power and have less ability to predict future outcomes. The difference among AIC values ($AIC_i - AIC_{min} = \Delta AIC$) between a given model under consideration (AIC_i) and the best-fitting model (model with the lowest AIC value, AIC_{min}) indicates the relative level of support. ΔAIC = 0-2 indicates that the model is substantially supported, ΔAIC = 4-7 indicates substantially less support, and ΔAIC > 10 indicates essentially no support (Cavanaugh and Neath 2019). Therefore, ΔAIC was used to compare the relative performance of each model for explaining the stock-recruitment relationship. Estimated temperature, flow, and habitat covariate effects from models were considered statistically significant if $p < 0.05$. Covariate values were natural log- or natural log (x +1)-transformed prior to fitting models. In addition, Pearson's correlation coefficient (Pearson's r) was calculated for all covariate combinations to evaluate their inter-relationships (Section A.3.3, *Modeling Approach*, in Appendix A). All model estimates in Table 2-6 are presented on the natural log scale.

2.8.3 Model Interpretation

This limiting factors analysis is intended to describe the general direction (positive or negative) and magnitude of effects of historical flow, temperature, and modeled habitat area on juvenile fall-run Chinook salmon recruitment. Because environmental covariates are based on historical data, the stock-recruitment models do not evaluate the effects of the specific flow or habitat actions analyzed in other chapters of this report. In addition, the models should not be used to predict the effects of flow, temperature, and habitat area on juvenile salmon abundance; rather, the models can be used to understand whether covariates likely had positive or negative effects on past abundance. Because the covariate values were not standardized prior to analysis, the estimated effects of the covariates from Table 2-6 below should not be directly compared as effect sizes. Rather, the ΔAIC should be used to interpret the overall model performance for explaining the stock-recruitment relationship, and the p-value associated with each parameter estimate should be used to evaluate whether that parameter (e.g., habitat area) strongly influenced juvenile abundance.

2.8.4 Results and Discussion

Density-independent models generally outperformed density-dependent Ricker models (see Density-Independent and Density-Dependent May Temperature models in Table 2-6), suggesting that due to low population size, density-dependence does not strongly affect juvenile Chinook salmon abundance in the Tuolumne River. Estimated effects of spawner abundance and density-dependence from the top-performing Ricker models were generally not significant ($p > 0.05$). Estimated effects of environmental covariates during the juvenile rearing period were generally significant, suggesting that juvenile abundance is more strongly driven by environmental conditions than by intrinsic population dynamics (Table 2-6).

Overall, models including environmental covariates of flow, temperature, or floodplain habitat area during the juvenile rearing period had more support than models that included only an effect of spawner abundance or included a covariate effect of spawning habitat, spawning temperature, in-channel rearing habitat, or total rearing habitat (Table 2-6). However, spawning area, in-channel wetted area, and total rearing habitat area were estimated to have positive effects on juvenile recruitment, even though models including an effect of those covariates had higher ΔAIC values (ΔAIC > 10; see further discussion below).

Stock-recruitment modeling identified key limiting factors to juvenile recruitment in the Tuolumne River. The best-fitting temperature models, with the lowest ΔAIC values, were the Density-Independent + May Temperature (ΔAIC = 0), Density-Independent + January–May Temperature (ΔAIC = 0.94), and Density-Dependent + May Temperature models (ΔAIC = 2). ΔAIC values for these models were between 0 and 2, indicating substantial support for these models. The best-fitting flow model was the Density-Independent + Mean January-May Flow model (ΔAIC = 4.21); and the top habitat model was the Density-Independent + Floodplain WUA model (ΔAIC = 6.52) (Table 2-6). Because the ΔAIC value of the top flow and habitat models was between 4 and 7, these models are less supported than the top temperature models.

Table 2-6. Summary Results of Fall-Run Chinook Salmon Stock-Recruitment Models, Comparing Density-Dependent (Ricker) and Density-Independent Models with Different Environmental Covariates. The Table Includes Columns Describing the Model Considered, the Stock-Recruitment Equation Used To Fit the Model, and the Parameters Included in the Model (α for Spawner Abundance, β for Density-Dependence, and γ for the Environmental Covariate). The 'Estimate' Column Is the Estimated Direction (+ or -) and Magnitude of the Effects of Spawner Abundance, Density-Dependence, and Environmental Covariates (Flow, Temperature, and Habitat Area) on Juvenile Abundance Along with the Standard Error, t-Value, and p-Value Associated with Each Parameter Estimate. Significant Estimates of Covariate Effects (p < 0.05) Are in Bold. Estimates Are on the Natural Log Scale. Models Are Ranked by AIC and ΔAIC Value. Models with a Lower ΔAIC Have More Empirical Support.

Model	Equation	Parameter	Estimate	Standard Error	t-value	p-value	AIC	Δ AIC
Density-Independent + May Temperature	1	α (spawner abundance)	1.63E+06	2.32E+06	0.7	0.5	20.46	0.00
		γ (covariate effect)	**-3.19**	**0.48**	**-6.67**	**<0.01**		
Density-Independent + January–May Temperature	1	α (spawner abundance)	4.31E+07	8.60E+07	0.5	0.63	21.4	0.94
		γ (covariate effect)	**-4.69**	**0.73**	**-6.39**	**<0.01**		
Density-Dependent (Ricker) + May Temperature	3	α (spawner abundance)	1.63E+06	2.57E+06	0.63	0.54	22.46	2.00
		β (density-dependence)	1.47E-06	2.51E-04	0.01	1		
		γ (covariate effect)	**-3.19**	**0.51**	**-6.21**	**<0.01**		
Density-Dependent (Ricker) + January–May Temperature	3	α (spawner abundance)	5.97E+07	1.33E+08	0.45	0.66	23.19	2.73
		β (density-dependence)	1.05E-04	2.63E-04	0.4	0.7		
		γ (covariate effect)	**-4.78**	**0.8**	**-6.01**	**<0.01**		
Density-Independent + Mean January–May Flow	1	α (spawner abundance)	2.17	1.65	1.31	0.21	24.67	4.21
		γ (covariate effect)	**0.62**	**0.11**	**5.46**	**<0.01**		
Density-Dependent (Ricker) + Mean January–May Flow	3	α (spawner abundance)	2.1	1.65	1.27	0.23	26.33	5.87
		β (density-dependence)	1.56E-04	2.98E-04	0.52	0.61		
		γ (covariate effect)	**0.65**	**0.12**	**5.16**	**<0.01**		
Density-Independent + Floodplain WUA	1	**α (spawner abundance)**	**67.05**	**13.41**	**5**	**<0.01**	26.98	6.52
		γ (covariate effect)	**0.29**	**0.06**	**4.84**	**<0.01**		
Density-Independent + Floodplain Wetted Area	1	**α (spawner abundance)**	**64.41**	**13.44**	**4.79**	**<0.01**	27.31	6.85
		γ (covariate effect)	**0.27**	**0.06**	**4.75**	**<0.01**		
Density-Dependent (Ricker) + Floodplain WUA	3	**α (spawner abundance)**	**68.77**	**19.19**	**3.58**	**<0.01**	28.96	8.50
		β (density-dependence)	4.38E-05	3.21E-04	0.14	0.89		
		γ (covariate effect)	**0.29**	**0.07**	**4.49**	**<0.01**		

Model	Equation	Parameter	Estimate	Standard Error	t-value	p-value	AIC	Δ AIC
Density-Dependent (Ricker) + Floodplain Wetted Area	3	**α (spawner abundance)**	**64.25**	**18.5**	**3.47**	**<0.01**	29.31	8.85
		β (density-dependence)	-4.14E-06	3.22E-04	-0.01	0.99		
		γ (covariate effect)	**0.27**	**0.06**	**4.41**	**<0.01**		
Density-Independent + Total Rearing Wetted Area	1	α (spawner abundance)	0.1	0.28	0.35	0.73	31.01	10.55
		γ (covariate effect)	**1.04**	**0.41**	**2.55**	**0.03**		
Density-Independent + Floodplain WUA Acre Days	1	**α (spawner abundance)**	**54.87**	**16.03**	**3.42**	**<0.01**	31.70	11.24
		γ (covariate effect)	**0.15**	**0.04**	**3.64**	**<0.01**		
Density-Independent + Floodplain Wetted Acre Days	1	**α (spawner abundance)**	**54.49**	**16.35**	**3.33**	**<0.01**	32.08	11.62
		γ (covariate effect)	**0.14**	**0.04**	**3.55**	**<0.01**		
Density-Dependent (Ricker) + Floodplain WUA Acre Days	3	**α (spawner abundance)**	**44.81**	**17.03**	**2.63**	**0.02**	32.82	12.36
		β (density-dependence)	-3.00E-04	-3.54E-04	-0.85	0.42		
		γ (covariate effect)	**0.15**	**0.04**	**3.56**	**<0.01**		
Density-Dependent (Ricker) + Floodplain Wetted Acre Days	3	**α (spawner abundance)**	**43.51**	**16.94**	**2.57**	**0.03**	33.05	12.59
		β (density-dependence)	-3.27E-04	-3.57E-04	-0.92	0.38		
		γ (covariate effect)	**0.14**	**0.04**	**3.51**	**<0.01**		
Density-Independent + Flow Variation	1	α (spawner abundance)	2.98	3.75	0.79	0.44	34.19	13.73
		γ (covariate effect)	**0.66**	**0.22**	**3.03**	**0.01**		
Density-Dependent (Ricker) + Flow Variation	3	α (spawner abundance)	2.5	3.24	0.77	0.46	35.40	14.94
		β (density-dependence)	-3.10E-04	3.90E-04	-0.8	0.44		
		γ (covariate effect)	**0.65**	**0.22**	**2.95**	**0.01**		
Density-Independent + Total Rearing WUA	1	α (spawner abundance)	0.1	0.47	0.21	0.84	36.94	16.48
		γ (covariate effect)	1.18	0.78	1.52	0.16		
Density-Independent + In-Channel Wetted Area	1	α (spawner abundance)	0.1	0.99	0.1	0.92	37.61	17.15
		γ (covariate effect)	1.07	1.47	0.73	0.48		
Density-Dependent (Ricker) + Total Rearing WUA	3	α (spawner abundance)	0.1	0.52	0.19	0.85	38.89	18.43
		β (density-dependence)	-9.11E-05	4.75E-04	-0.19	0.85		
		γ (covariate effect)	1.17	0.88	1.34	0.21		
Density-Dependent (Ricker) + In-Channel Wetted Area	3	α (spawner abundance)	0.1	1.06	0.09	0.93	39.30	18.84
		β (density-dependence)	-2.23E-04	4.71E-04	-0.47	0.65		

Model	Equation	Parameter	Estimate	Standard Error	t-value	p-value	AIC	Δ AIC
		γ (covariate effect)	1.04	1.6	0.65	0.53		
Density-Independent	1	**α (spawner abundance)**	**128.72**	**31.4**	**4.1**	**<0.01**	40.14	19.68
Density-Independent + Spawning Wetted Area	1	α (spawner abundance)	0.1	2.85	0.04	0.97	40.91	20.45
		γ (covariate effect)	1.08	4.3	0.25	0.81		
Density-Dependent (Ricker)	3	**α (spawner abundance)**	**100.21**	**43.02**	**2.33**	**0.04**	41.55	21.09
		β (density-dependence)	-3.56E-04	4.97E-04	-0.72	0.49		
Density-Independent + October-November Temperature	1	α (spawner abundance)	4.20E+05	4.96E+06	0.08	0.93	41.6	21.14
		γ (covariate effect)	-2.9	4.23	-0.68	0.51		
Density-Independent + Spawning WUA	1	α (spawner abundance)	7.24	54.42	0.13	0.9	41.97	21.51
		γ (covariate effect)	0.87	2.28	0.38	0.71		
Density-Independent + In-Channel WUA	1	α (spawner abundance)	128.72	339.28	0.38	0.71	42.14	21.68
		γ (covariate effect)	0	0.46	0	1		
Density-Dependent (Ricker) + Spawning Wetted Area	3	α (spawner abundance)	0.1	2.95	0.03	0.97	42.37	21.91
		β (density-dependence)	-3.27E-04	5.03E-04	-0.65	0.53		
		γ (covariate effect)	1.05	4.45	0.23	0.82		
Density-Dependent (Ricker) + Mean Oct-Nov Temperature	3	α (spawner abundance)	2.12E+05	2.98E+05	0.07	0.94	43.37	22.91
		β (density-dependence)	-2.50E-05	5.86E-04	-0.43	0.68		
		γ (covariate effect)	-1.89	4.98	-0.38	0.71		
Density-Dependent (Ricker) + Spawning WUA	3	α (spawner abundance)	34.65	283.11	0.12	0.91	43.53	23.07
		β (density-dependence)	-3.29E-04	5.58E-04	-0.59	0.57		
		γ (covariate effect)	0.33	2.52	0.13	0.9		
Density-Dependent (Ricker) + In-Channel WUA	3	α (spawner abundance)	100.21	300.72	0.33	0.75	43.55	23.09
		β (density-dependence)	-3.56E-04	5.50E-04	-0.65	0.53		
		γ (covariate effect)	0	0.5	0	1		

2.8.4.1 Temperature Effects

The density-independent model incorporating an effect of May temperature yielded the best fit to the data (ΔAIC = 0), indicating that thermal conditions during the juvenile rearing and emigration period are a primary determinant of recruitment success (Table 2-6; Figure 2-11). Spawner abundance had a small, nonsignificant effect (α = 1.63E+06, p = 0.5), and May temperature had a strong, significant negative effect on recruitment (γ = -3.19, p < 0.01), indicating that warmer temperature conditions reduce juvenile survival, likely due to thermal stress. The second-ranked model, which included January–May mean temperature (ΔAIC = 0.94), showed a similar pattern with an even more strongly negative effect of temperature (γ = -4.69, p < 0.01) and a nonsignificant effect of spawner abundance (α = 4.31E+07, p = 0.63).

Fitzgerald and Martin (2022) demonstrated that through effects on metabolism, higher temperature increases pre-spawn mortality, embryonic mortality, and juvenile mortality of fall-run Chinook salmon on the Tuolumne River, especially during warm and dry years. When high temperatures increase the metabolic rate of juvenile Chinook salmon, they require higher prey consumption, and their oxygen demand increases, yet less dissolved oxygen is held by warmer water (Martin et al. 2017, Fitzgerald 2025; see Section 2.4, *Temperature*). Additionally, there is evidence for higher predation rates on Chinook salmon during smolt outmigration in the Delta (Nobriga et al. 2021). High water temperatures affect a wide range of ecological processes and are a key limiting factor on stock-recruitment in the Tuolumne River.

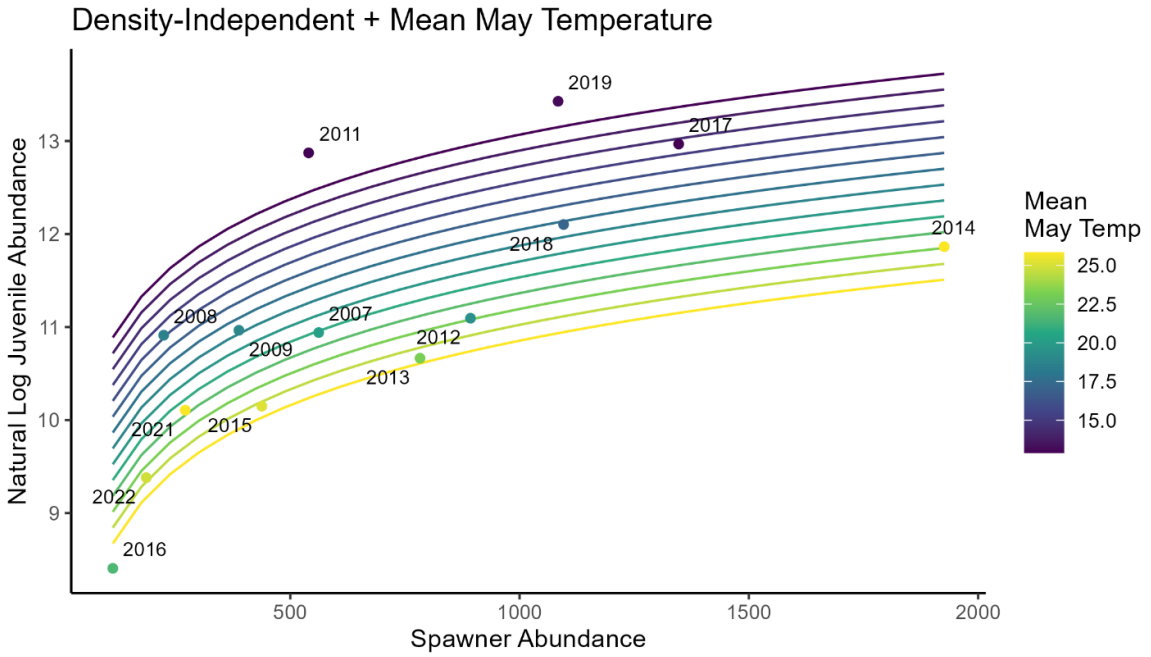


Figure 2-11. Density-Independent + Mean May Temperature. This Was the Top Model Overall (ΔAIC = 0.00), Describing the Relationship Between Spawner Abundance and the Natural Log of Juvenile Abundance, Modeled as a Density-Independent Function with an Additive Effect of Mean May Temperature (in Celsius). Points Represent Annual Observed Spawner and Juvenile Abundance; Point and Line Colors Represent Mean May Temperature; Solid Lines Show the Predicted Stock-Recruitment Relationship Based on the Fitted Model Using Mean May Temperature as the Predictor Variable.

2.8.4.2 Flow Effects

Among the flow models, the density-independent model with mean January–May flow had the most support (ΔAIC = 4.21; Table 2-6; Figure 2-12). Spawner abundance had a positive but nonsignificant effect ($\alpha = 2.17$, $p = 0.21$) and flow had a highly significant positive effect on juvenile recruitment ($\gamma = 0.62$, $p < 0.01$), demonstrating that higher flows during the rearing period are associated with higher juvenile production. Flow may affect juvenile survival in part through its effects on temperature or habitat availability. Mean flow and temperature on the Tuolumne River during the rearing period (Jan-May) are strongly negatively correlated (Figure 2-13; Pearson r = -0.99), with higher spring water temperatures occurring during years with lower flows. Higher flows also activate floodplain rearing habitat for juvenile Chinook salmon. Mean flow and floodplain habitat area on the Tuolumne River during the rearing period are strongly, positively correlated (Figure 2-13), with higher spring flow resulting in more floodplain habitat.

In the Tuolumne River, the volume and timing of winter–spring flows exert a strong influence on juvenile Chinook salmon survival. Due to the benefits of flow for juvenile salmon, Mesick (2009) suggests late winter flow pulses are needed on the Tuolumne River to increase fry survival, which is supported by this Tuolumne River stock-recruitment modeling. Additionally, in the Stanislaus River Sturrock et al. (2020) linked lower, less variable flows to diminished fall-run Chinook production and recruitment.

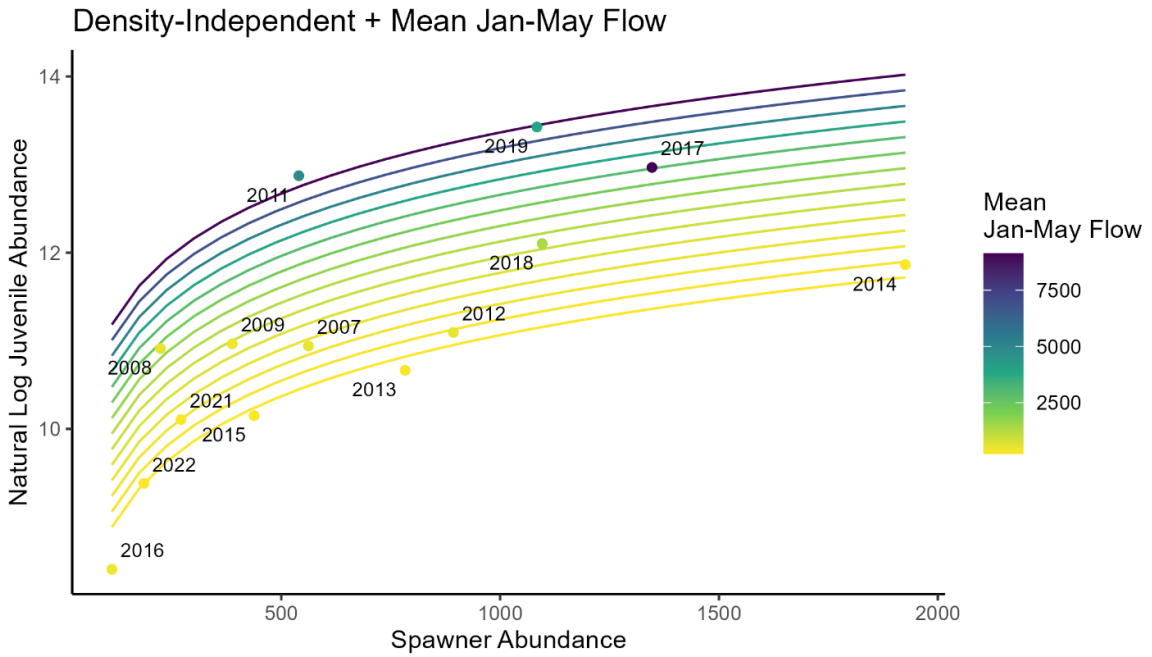


Figure 2-12. Density-Independent + Mean Jan–May Flow. This Was the Top Model That Included a Flow Covariate (ΔAIC = 4.21), Describing the Relationship Between Spawner Abundance and the Natural Log of Juvenile Abundance, Modeled as a Density-Independent Function With an Additive Effect of Mean Jan–May Flow (cfs). Points Represent Annual Observed Spawner and Juvenile Abundance; Point and Line Colors Represent Mean Jan–May Flow; Solid Lines Show the Predicted Stock-Recruitment Relationship Based on the Fitted Model Using Mean Jan–May Flow as the Predictor Variable.

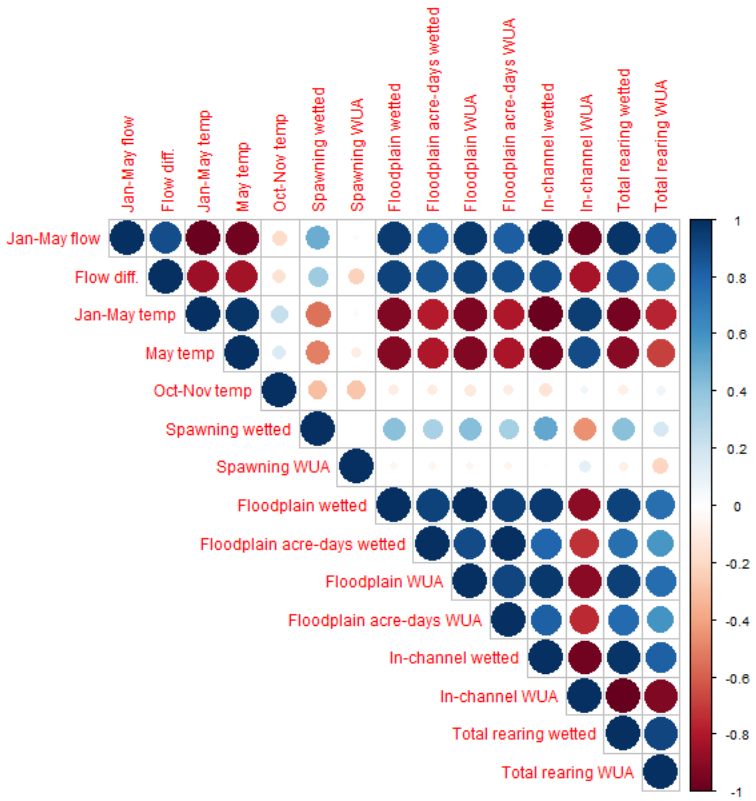


Figure 2-13. Correlation Plot Depicting the Pearson Correlation Coefficient (Pearson r) for All Environmental Covariates Considered in Stock-Recruitment Models. Dark Blue Colors With Large Circles Indicate a Strongly Positive Correlation (e.g., r = 1), and Dark Red Colors with Large Circles Indicate a Strongly Negative Correlation (e.g., r = -1) Among Paired Covariates.

2.8.4.3 Habitat Size and Availability

Models incorporating measures of floodplain inundation also provided support for the role of floodplain habitat availability in influencing stock-recruitment relationships. The Density-Independent + Floodplain WUA model (ΔAIC = 6.52) was the best-performing habitat model (Table 2-6; Figure 2-14). This model featured statistically significant, positive effects of spawner abundance ($\alpha = 67.05$, $p < 0.01$) and floodplain WUA (acres) ($\gamma = 0.29$, $p < 0.01$), suggesting that higher spawner abundance and larger floodplain habitat area are associated with higher juvenile recruitment. Although modeling results indicate that floodplain habitat effects are secondary to temperature and flow, these results nevertheless highlight the ecological value of floodplain inundation during the rearing period, which may offer increased access to high-quality foraging habitat and refuge from predators.

Other habitat-related models, including Density-Independent + Floodplain Wetted Area, Density-Dependent (Ricker) + Floodplain WUA, Density-Dependent (Ricker) + Floodplain Wetted Area, Density-Independent + Total Rearing Wetted Area, Density-Independent + Total Acre-Days Wetted Area, and Density-Independent + Floodplain WUA Acre-Days models also showed statistically significant, positive covariate effects but had higher ΔAIC values compared to the top habitat model (Table 2-6). Models incorporating covariate effects of spawning and in-channel rearing habitat area consistently had high ΔAIC values and non-significant parameter estimates. For example, the Density-Independent + Spawning WUA model had a ΔAIC value of 21.51, with positive but

nonsignificant effects of spawner abundance (α = 7.24, *p* = 0.9) and spawning WUA (γ = 0.87, *p* = 0.71) on juvenile recruitment. Similarly, the Density-Independent + In-Channel WUA model had a ΔAIC value of 21.68, a positive but nonsignificant effect of spawner abundance (α = 128.72, *p* = 0.71), and in-channel WUA was estimated to have no effect on juvenile recruitment (γ = 0, *p* = 1). These findings suggest that spawning habitat and instream rearing habitat are not as limiting to recruitment as temperature, flow, and floodplain habitat during the rearing period in the Tuolumne River (Table 2-6).

Floodplain habitat provides substantial benefits to juvenile Chinook salmon by supporting faster growth and higher survival through improved access to drift invertebrate prey, greater feeding success, and refuge from predators (Sommer et al. 2001; Jeffres 2008; see Section 7.2.2.2, *Growth Benefits in Floodplains*, of Chapter 7). Floodplain habitats are generally shallower and warmer than in-channel wetted areas. Although elevated temperatures can sometimes reduce survival, warm floodplain waters are rich in prey, including terrestrial invertebrates and aquatic macroinvertebrates and zooplankton.

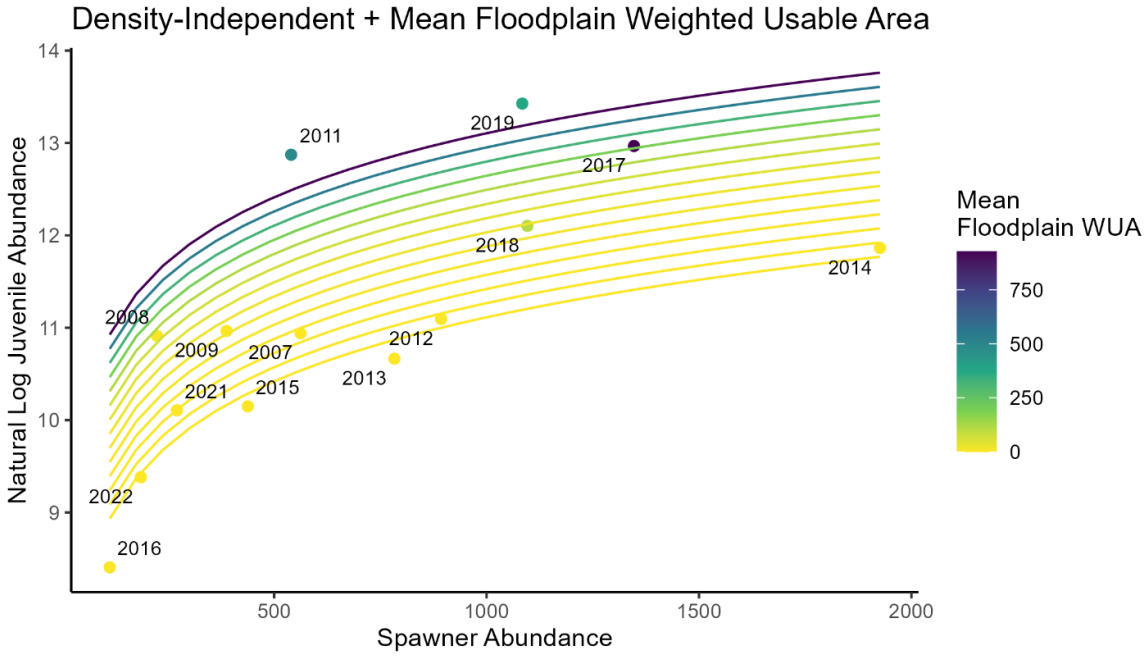


Figure 2-14. Density-Independent + Mean Floodplain Weighted Usable Area. This Was the Top Model That Included a Habitat Covariate (ΔAIC = 6.52), Describing the Relationship Between Spawner Abundance and the Natural Log of Juvenile Abundance, Modeled as a Density-Independent Function With an Additive Effect of Mean Floodplain WUA (Acres). Points Represent Annual Observed Spawner and Juvenile Abundance; Point and Line Colors Represent Floodplain WUA Modeled Using Observed Flows; Solid Lines Show the Predicted Stock-Recruitment Relationship Based on the Fitted Model Using Floodplain WUA as the Predictor Variable.

2.9 References

2.9.1 Printed References

Ahearn, D. S., J. H. Viers, J. F. Mount, and R.A. Dahlgren. 2006. Priming the productivity pump: flood pulse driven trends in suspended algal biomass distribution across a restored floodplain. *Freshwater Biology* 51: 1417–1433.

Adkison, M.D. 2022. A Review of Salmon Spawner-Recruitment Analysis: The Central Role of the Data and Its Impact on Management Strategy, Reviews in Fisheries Science & Aquaculture, 30(3), pp. 391-427.

Allan, J.D., M.S. Wipfli, J.P. Caouette, A. Prussan, and J. Rodgers. 2003. Influence of streamside vegetation on inputs of terrestrial invertebrates to salmonid food webs. Canadian Journal of Fisheries and Aquatic Sciences 60(3) pp. 309–302.

Anchor QEA. 219. Conservation Planning Foundation for Restoring Chinook Salmon (*Oncorhynchus tshawytscha*) and *O. mykiss* in the Stanislaus River.

Auble, G.T., M.L. Scott, and J.M. Friedman. 2005. Use of individualistic streamflow-vegetation relations along the Fremont River, Utah, USA to assess impacts of flow alteration on wetland and riparian areas Wetlands, 25(1) pp. 143–154.

Bellmore, J.R., C.V. Baxter, K.Martens, and P.J. Connolly. 2013. The floodplain food web mosaic: a study of its importance to salmon and steelhead with implications for their recovery. Ecological Applications 23(1) pp. 189–207.

Bowen, M.B., R. Bark. 2010. (DRAFT) 2010 Effectiveness of a Non-Physical Fish Barrier at the Divergence of the Old and San Joaquin Rivers (CA). U.S. Department of Interior/Bureau of Reclamation. Technical Memorandum 86- 68290-10-07.

Bowerman, T., A. Roumasset, M. L. Keefer, C. S. Sharpe and C.C. Caudill. 2017. Prespawn Mortality of Female Chinook Salmon Increases with Water Temperatures and Percent Hatchery Origin. Transactions of the American Fisheries Society.

Brown, L. R., and T. Ford. 2002. Effect of Flow on the Fish Communities of a Regulated California River: Implications for Managing Native Fishes. River Research and Applications 18(4):331–342

Buchanan, R.A., P.L. Brandes, and J.R. Skalski. 2018. Survival of Juvenile Fall-Run Chinook Salmon through the San Joaquin River Delta, California, 2010–2015. North American Journal of Fisheries Management 38: 663–679.

Cain J., J. Ferguson, E. Greene, M. L. Ratliff, J. Rosenfield, A. Weber-Stover, S. Louie, J. Shelton, T. Heyne, B. Elrott, S. Franks, M. Gutierrez, R. Reed, D. Swank, S. Edmundson, K. Schmidt, R. Johnson, J. Howard, J. Zimmerman, C. Carr, D. Worth, R. Henery, J. Israel, P. Cadrett, R. Martin, and J. D. Wikert. 2019. Conservation Planning Foundation for Restoring Chinook Salmon (Oncorhynchus Tshawytscha) and O. mykiss in the Stanislaus River. Prepared by Anchor QEA, LLC (Seattle, Washington).

California Department of Fish and Wildlife (CDFW). 2014. Comments on Request for Extension of Time to Conduct FERC-Approved Predation Study for Don Pedro Hydroelectric Project (Project) Federal Energy Regulatory Commission (Commission) No. 2299-075 Tuolumne River. Filed with FERC eLibrary :20140428-5041.

California Department of Fish and Wildlife (CDFW). 2014. Response to Notice of Ready for Environmental Analysis FEDERAL POWER ACT SECTION 10(j) AND 10(a) RECOMMENDATIONS Merced River Hydroelectric Project (Project No. 2179-042) Mariposa and Merced Counties. Filed with FERC eLibrary: 20140721-5150.

California Department of Fish and Wildlife (CDFW). 2017a. Comments regarding the Recirculated Draft of the Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary: San Joaquin River Flows and Southern Delta Water Quality. CDFW, Water Branch, letter sent to SWRCB. March 15, 2017

California Department of Fish and Wildlife (CDFW). 2017b. 2017 Fall Attraction Pulse Flow Schedule. Filed with FERC eLibrary: 20171003-0013.

California Department of Fish and Wildlife (CDFW). 2018. Response to Notice of Ready for Environmental Analysis FEDERAL POWER ACT SECTION 10(j) AND 10(a) RECOMMENDATIONS for the Amendment of Application for Don Pedro Hydroelectric Project (FERC No. 2299) and for the Final License Application of La Grange Hydroelectric Project (FERC no. 14581) Stanislaus and Tuolumne Counties, California. Filed with FERC eLibrary:20180129-5315

California Department of Fish and Wildlife (CDFW). 2023. California Freshwater Sport Fishing Regulations 2023–2024.

California Department of Water Resources (DWR). 2016. Central Valley Flood Protection Plan Conservation Strategy. November 2016 Draft.

Cavanaugh JE, Neath AA. 2019. The Akaike information criterion: Background, derivation, properties, application, interpretation, and refinements. WIREs Computational Stats. 11:e1460. https://doi.org/10.1002/wics.1460.

Cederholm, C.J., D.H. Johnson, R.E. Bilby, L.G. Dominguez, A.M. Garrett, W.H. Graeber, E.L. Greda, M.D. Kunze, B.G. Marcot, J.F. Palmisano, R.W. Plotnikoff, W.G. Pearcy, C.A. Simenstad, and P.C. Trotter. 2000. Pacific salmon and wildlife-ecological contexts relationships, and implications for management. Special Edition Technical Report, Prepared for D.H. Johnson and T.A. O'Neil, Managing Directors, Wildlife-Habitat Relationships in Oregon and Washington. Washington Department of Fish and Wildlife, Olympia Washington.

Crispin, V., R. House, and D. Roberts. 1993. Changes in instream habitat, large woody debris, and salmon habitat after restructuring of a coastal Oregon stream. North American Journal of Fisheries Management 13: 96–102.

EA Engineering, Science and Technology (EA). 1992. Appendix 22 Lower Tuolumne River Predation Study Report. Don Pedro Project Fisheries Study Report FERC Article 29, Project No. 2299. Prepared for Turlock Irrigation District and Modesto Irrigation District.

FISHBIO. 2013a. Predation Study Report Don Pedro Project FERC No. 2299. Prepared for Turlock Irrigation District and Modesto Irrigation District. https://donpedro-relicensing.com/study-reports/.

FISHBIO. 2013b. Salmonid Redd Mapping Study Report Don Pedro Project FERC No. 2299. Prepared for the Turlock Irrigation District and Modesto Irrigation District.

FitzGerald, A.M. 2025. Incorporating local information to predict thermal stress for diverse species. Canadian Journal of Fisheries and Aquatic Sciences.

FitzGerald A.M., Martin BT. 2022. Quantification of thermal impacts across freshwater life stages to improve temperature management for anadromous salmonids. Conservation Physiology. 10:coac013. https://doi.org/10.1093/conphys/coac013

Goertler, P., Jones, K., Cordell, J., Schreier, B. and Sommer, T., 2018. Effects of extreme hydrologic regimes on juvenile Chinook salmon prey resources and diet composition in a large river floodplain. *Transactions of the American Fisheries Society*, *147*(2), pp.287–299.

Gregory, R.S. 1993. Effect of turbidity on the predator avoidance behaviour of juvenile chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fish and Aquatic Science (50) pp 241–246.

Gregory, R.S. and C.D. Levings. 1998. Turbidity Reduces Predation on Migrating Juvenile Pacific Salmon. Transactions of the American Fisheries Society (127) pp. 275–285.

Gregory, R.S. and C.D. Levings. 1996. The effects of turbidity and vegetation on the risk of juvenile salmonids *Oncorhynchus* spp., to predation by adult cutthroat trout *O. clarkia*. Environmental Biology of Fishes (47) pp 279–288.

Grossman, G.D., T. Essington, B. Johnson, J. Miller, N.E. Monsen, and T. N. Perasons. 2013. Effects of fish predation on salmonids in the Sacramento River- San Joaquin Delta and associated ecosystems.

Hayes, S.A., M.H. Bond, C.V. Hanson, E.V. Freund, J.J. Smith, E.C. Anderson. 2008. Steelhead growth in a small central California watershed: upstream and estuarine rearing patterns. Transactions of the American Fisheries Society 137(1) pp. 114–128.

HDR Inc and Stillwater Sciences. 2017. Lower Tuolumne River Floodplain Hydraulic Assessment Study Report Don Pedro Project FERC No. 2299. Prepared for Turlock Irrigation District and Modesto Irrigation District.

Herren, J.R., and S.S. Kawasaki. 2001. Inventory of Water Diversions in Four Geographic Areas in California's Central Valley. Fish Bulletin 179 Contributions to the Biology of Central Valley Salmonids Vol 2:343–355.

James, C.S., S.J. Mackay, A.H. Arthington, S.J. Capon, A. Barnes, B. Pearson. 2016. Does stream flow structure woody riparian vegetation in subtropical catchments? Ecology and evolution 6(16) pp. 5950–5963.

Jeffres, C.A., J.J. Opperman, and P.B. Moyle. 2008. Ephemeral floodplain habitats provide the best growth conditions for juvenile Chinook salmon in a California River. Environmental Biology of Fishes, 83(4), 99. 449–458.

Kormos, B., M. Palmer-Zwahlen and A. Low. 2012. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement and Ocean Harvest in 2010. California Department of Fish and Game Fisheries Branch Administrative Report 2012-02.

Letvin, A., M. Palmer-Zwahlen, and B. Kormos. 2020. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2017.

Letvin, A., M. Palmer-Zwahlen, and B. Kormos. 2021a. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2018.

Letvin, A., M. Palmer-Zwahlen, B. Kormos, and P. Mchugh. 2021b. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2019.

Limm, M.P., and M.P. Marchetti. 2009. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) growth in off-channel and main-channel habitats on the Sacrament River, CA using otolith increment widths. Environmental Biology of Fish 85 pp. 141–151.

Lindley, S.T., R.S. Schick, E. Mora, P.B. Adams, J.J. Anderson, S. Greene, C. Hanson, B.P. May, E. McEwan, R.B. MacFarlane, C. Swasnson, and J.G. Williams. 2007. Framework for Assessing Viability of Threatened and Endangered Chinook Salmon and Steelhead in the Sacramento-San Joaquin Basin. San Francisco Estuary and Watershed Science 5:1.

Lytle, D.A., and D.M. Merritt. 2004. Hydrologic regimes and riparian forests: a structured population model for cottonwood. Ecology 58(9) pp. 2493–2503.

Marine, K. P., and J. J. Cech Jr. 2004. Effects of High Water Temperature on Growth, Smoltification, and Predator Avoidance in Juvenile Sacramento River Chinook Salmon. North American Journal of Fisheries Management 24:198–210.

Martin, B.T., A. Pike, S.N. John, N. Hamda, J. Roberts, S.T. Lindley, and E.M. Danner. 2017. Phenomenological vs. biophysical models of thermal stress in aquatic eggs. Ecology Letters 20:50–59.

McBain & Trush. 2000. Habitat Restoration Plan for the Lower Tuolumne River Corridor. Prepared for the Tuolumne River Technical Advisory Committee with assistance from U.S. Fish and Wildlife Service, Anadromous Fish Restoration Program, Sacramento, California. Arcata, California. March 2000.

McBain & Trush. 2004. Coarse Sediment Management Plan for the Lower Tuolumne River. Revised Final Report. Prepared by McBain & Trush, Arcata, California for Tuolumne River Technical Advisory Committee, Turlock and Modesto Irrigation Districts, USFWS Anadromous Fish Restoration Program, and California Bay-Dela Authority.

Mesick, C.F. 2008. The Moderate to High Risk of Extinction for the Natural Fall-Run Chinook Salmon Population in the Lower Tuolumne River due to Insufficient Instream Flow Releases. USFWS Report

Mesick, C. 2009. The High Risk of Extinction for the Natural Fall-Run Chinook Salmon Population in the Lower Tuolumne River due to Insufficient Instream Flow Releases.

Millsap, S., and M. Gard. 2018. Use of cumulative acre-days to evaluate changes in floodplain inundation in the lower Tuolumne River under different hydrological regimes and quantification of mitigation measures. Attachment 5 of Department of the Interior COMMENTS, RECOMENDATIOND, PRELIMINARY TERMS AND CONDITIONS, and PRELIMINARY FISHWAY PRESCRIPTIONS on the Federal Energy Regulatory Commission Ready for Environmental Analysis Notice for the Don Pedro hydroelectric Project, Federal Energy Regulatory Commission Project No. P-2299-082, Tuolumne River, Tuolumne and Stanislaus Counties, California. E Filed with FERC eLibrary 20180129-5298.

Modesto Irrigation District (MID). n.d. Plan to Prevent Salmon from Entering Canals During Upstream Migration.

Moyle, P. B. 2002. Inland Fishes of California Revised and Expanded. University of California Press. pp. 502.

Munsch, S.H., C.M. Greene, R.C. Johnson, W.H. Satterthwaite, H. Imaki, P.L. Brandes, and M.R. O'Farrell. 2020. Science for integrative management of a diadromous fish stock: interdependencies of fisheries, flow, and habitat restoration. Canadian Journal of Fisheries and Aquatic Sciences 77:1487–1504. https://doi.org/10.1139/cjfas-2020-0075

Murphey, G. 2014. Draft 2013 Tuolumne River Fall Chinook Salmon Escapement Survey. California Department of Fish and Game Annual Report (unpublished).

Murphey, G. 2015. Draft 2014 Tuolumne River Fall Chinook Salmon Escapement Survey. California Department of Fish and Game Annual Report (unpublished).

Murphey, G. and H. S. Tsao. 2019. Draft 2018 Tuolumne River Fall Chinook Salmon Escapement Survey. California Department of Fish and Game Annual Report (unpublished).

Murphey, G. 2024a. Figure 2.3 data source: California Department of Fish and Wildlife (CDFW) thermographs and escapement databases, California Data Exchange Center flow (Excel spreadsheet).

Murphey, G. 2024b. Table 2.2 data source: California Department of Fish and Wildlife (CDFW) escapement database (Excel spreadsheet).

Murphey, G. 2024c. Figure 2.4 data source: California Department of Fish and Wildlife (CDFW) thermograph database (Excel spreadsheet).

Murphey, G. 2024d. Figure 2.5 data source: California Department of Fish and Wildlife (CDFW) thermograph database (Excel spreadsheet).

Murphey, G. 2024e. Figure 2.6 data source: California Department of Fish and Wildlife (CDFW) thermograph database (Excel spreadsheet).

Murphey, G. 2024f. Figure 2.7 data source: California Department of Fish and Wildlife (CDFW) thermograph database (Excel spreadsheet).

Murphey, G. 2024g. Figure 2.8 data source: California Department of Fish and Wildlife (CDFW) thermograph database (Excel spreadsheet).

National Marine Fisheries Service (NMFS), 2014. Recovery Plan for the Evolutionary Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead. California Central Valley Area Office. July 2014.

National Marine Fisheries Service (NMFS). 2020. Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response Harding Drain Fish Barrier. NMFS Consultation Number: WCRO-2020-1956.

Nobriga, M.L., C.J. Michel, R.C. Johnson, and J.D. Wikert. 2021. Coldwater fish in a warm water world: Implications for predation of salmon smolts during estuary transit. Ecology and Evolution 11(15):10381–10395. https://doi.org/10.1002/ece3.7840

Opperman, J.J. 2012. A Conceptual Model for Floodplains in the Sacramento–San Joaquin Delta. San Francisco Estuary and Watershed Science 10(3).

Opperman J.J., R. Luster, B.A. McKenney, M. Roberts, and A.W. Meadows. 2010. Ecologically Functional Floodplains: Connectivity, Flow Regime, and Scale. Journal of the American Water Resources Association pp. 1–16.

Palmer-Zwahlen, M., and B. Kormos. 2013. *Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2011*. California Department of Fish and Wildlife. December.

Palmer-Zwahlen, M., V. Gussman, and B. Kormos. 2018. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2013.

Palmer-Zwahlen, M., V. Gussman, and B. Kormos. 2019a. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2014.

Palmer-Zwahlen, M., V. Gussman, and B. Kormos. 2019b. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2015.

Palmer-Zwahlen, M., and B. Kormos. 2015. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2012. California Department of Fish and Wildlife Fisheries Administrative Report 2015-4.

Palmer-Zwahlen, M., and B. Kormos. 2020. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2016.

Peterson, M.L., A.N. Fuller, and D. Demko. 2017.Environmental Factors Associated with the Upstream Migration of Fall-Run Chinook Salmon in a Regulated River. North American Journal of Fisheries Management. 37:1, 78-93.

Poff, N.L. and J.K.H. Zimmerman. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology 55 pp. 194–205.

Quinn, T.J. II, and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press, Oxford.

Rich, A.A. and W.E. Loudermilk. 1991. Preliminary evaluation of Chinook salmon smolt quality in the San Joaquin drainage.

Rich, A.A. 2007. Impacts of Water Temperature on Fall-Run Chinook Salmon (*Oncorhynchus tshawytscha*) and Steelhead (*O. mykiss*) in the San Joaquin River. Report by A.A. Rich and Associates for the California Department of Fish and Game Region 4.

Rood, S.B., G.M. Samuelson, J.H. Braatne, C.R. Gourley, G.M. Hughes, J.M. Mahoney. 2005. Managing river flows to restore floodplain forests. Frontiers in Ecology and the Environment 3(4) pp. 193–201.

Satterthwaite W.H. 2023. An Approach to Defining a Sacramento River Fall Chinook Escapement Objective Considering Natural Production, Hatcheries, and Risk Tolerance. San Francisco Estuary and Watershed Science 21(3):Art 3 [accessed 2024 Mar 29]. https://doi.org/10.15447/sfews.2023v21iss3art3

Sellheim, K.L, M. Vaghti, and J.E. Merz. 2016. Vegetation recruitment in an enhanced floodplain: Ancillary benefits of salmond habitat enhancement. Limnologica-Ecology and Management of Inland Waters, 58, pp. 94–102.

Short, R.A., and P.E. Maslin. 1977. Processing of Leaf Litter by Stream Detritivore: Effect on Nutrient Availability to Collectors. Ecology 58 pp. 935–938.

Sommer, T.R., M.L. Nobriga, W.C. Harrell, W. Batham, and W.J. Kimmerer. 2001. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fish and Aquatic Science 58 pp. 325–333.

State Water Resources Control Board (SWRCB). 2018. Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: San Joaquin River Flows and Southern Delta Water Quality. Final (SCH#2012122071). July. (ICF 00427.11.) Sacramento, CA. Prepared with assistance from ICF International, Sacramento, CA.

State Water Resources Control Board (SWRCB). 2022. Final Staff Report 2020–2022 Integrated Report for Clean Water Act Sections 303(d) and 305(b).

Stillwater Sciences. 2001. AFRP/CALFED Adaptive Management Forum. Tuolumne River restoration program summary report. Summary of studies, conceptual models, restoration projects, and ongoing monitoring. Prepared by Stillwater Sciences with Tuolumne River Technical Advisory Committee, Berkeley, CA.

Stillwater Sciences. 2006. Lower Tuolumne River Predation Assessment. Final Report. Berkeley, CA. Prepared by Stillwater Sciences and McBain & Trush, Inc. Prepared for the Tuolumne River Technical Advisory Committee, Turlock and Modesto Irrigation Districts, USFWS Anadromous Fish Restoration Program, and California Bay-Delta Authority.

Stillwater Sciences. 2013. Spawning Gravel in the Lower Tuolumne River Study Report Don Pedro Project FERC No. 2299. Prepared for Turlock Irrigation District and Modesto Irrigation District.

Stillwater Sciences. 2017 *Oncorhynchus mykiss* Habitat Survey Amended Study Report Don Pedro Project FERC No. 2299. Prepared for Turlock Irrigation District and Modesto Irrigation District.

Stillwater Sciences and McBain & Trush. 2006. Lower Tuolumne River Predation Assessment Final Report. Prepared for the Tuolumne River Technical Advisory Committee, Turlock and Modesto Irrigation Districts, and USFWS Anadromous Fish Restoration Program.

Sturrock, A.M., J.D. Wikert, T. Heyne, C. Mesick, A.E. Hubbard, T.M. Hinkelman, P.K. Weber, G.E. Whitman, J.J. Glessner, and R.C. Johnson. 2015. Reconstructing the Migratory Behavior and Long-Term Survivorship of Juvenile Chinook Salmon under Contrasting Hydrologic Regimes. PLoS ONE 10(5).

Sturrock, A.M., W.H. Satterthwaite, K.M. Cervaantes-Yoshida, E.R. Huber, H.J.W. Sturrock, S. Nussle, and S.M. Carlson. 2019. Eight Decades of Hatchery Salmon Releases in the California Central Valley: Factors Influencing Straying and Reliance. Fisheries 44(9):433–444.

Sturrock, A.M., S.M. Carlson, J.D. Wikert, T. Heyne, S. Nusslé, J.E. Merz, H.J.W. Sturrock, and R.C. Johnson. 2020. Unnatural selection of salmon life histories in a modified riverscape. Global Change Biology 26:1235–1247. https://doi.org/10.1111/gcb.14896.

Subbey, S., J.A. Devine, R. Schaarschmidt, and D.M. Nash. 2014. Modelling and forecasting stock–recruitment: current and future perspectives. ICES Journal of Marine Science 71:2307–2322. http://doi.org/10.1093/icesjms/fsu148Tatara, C.P., and B.A. Berejikian. 2012. Mechanisms influencing competition between hatchery and wild juvenile anadromous Pacific salmonids in fresh water and their relative competitive abilities. Journal of Environmental Biology of Fishes 94:7–19.

Tonkin, J.D., D.M. Merritt, J.D. Olden, L.V. Reynolds, D.A. Lytle. 2017. Flow regime alteration degrades ecological networks in riparian ecosystems. Nature Ecology & Evolution.

Turlock Irrigation District (TID). n.d. Plan to Prevent Salmon from Entering Canals During Upstream Migration.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 1992. Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project. FERC Project No. 2299.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 1997. 1996 FERC Report Volume VI. FERC Project No. 2299

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2003. 2002 Lower Tuolumne River Annual Report. FERC Project No. 2299

Turlock Irrigation District and Modesto Irrigation District (TID and MID) 2009. 2009 Lower Tuolumne Rive Annual Report, Report 2009-7, 2009 Aquatic Invertebrate Monitoring and Summary Update.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2011. 2011 Lower Tuolumne River Annual Report. FERC No. 2299.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2014. Turlock and Modesto Irrigation District Project No. 2299- Article 58 Annual Report for 2013. Submitted to FERC March 38,2014.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2015. Turlock and Modesto Irrigation District Project No. 2299- Article 58 Annual Report for 2014. Submitted to FERC March 30,2015.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2016. Turlock and Modesto Irrigation District Project No. 2299- Article 58 Annual Report for 2015. Submitted to FERC March 30,2016.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2017. Turlock and Modesto Irrigation District Project No. 2299- Article 58 Annual Report for 2016. Submitted to FERC March 30,2017

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2018. Turlock and Modesto Irrigation District Project No. 2299- Article 58 Annual Report for 2017. Submitted to FERC March 30,2018.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2019a. Turlock and Modesto Irrigation District Project No. 2299- Article 58 Annual Report for 2018. Submitted to FERC March 29,2019.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2019b. Turlock and Modesto Irrigation District Project No. 2299- Article 58 Annual Report for 2019. Submitted to FERC March 30,2020.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2020. Comments of Turlock Irrigation District and Modesto Irrigation District in Response to Commission Staff's October 28, 2019, Summary of 10(j) Meeting. FERC No. 2299 & 14581. Filed with FERC January 10,2020. eLibrary: 20200110-5257.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2021. Turlock and Modesto Irrigation District Project No. 2299- Article 58 Annual Report for 2020. Submitted to FERC March 30,2021.

U.S. Environmental Protection Agency (USEPA). 2003 USEPA Region 10 guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water. Seattle, WA.

U.S. Bureau of Reclamation (USBR). 2011. Draft Program Environmental Impact Statement/Environmental Impact Report. Prepared for the San Joaquin River Restoration Program. SCH #2007081125. 1,706 pp.

U.S. Fish and Wildlife Service (USFWS). 2008. *Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP).* 396 pp.

U.S. Fish & Wildlife Service (USFWS). 2010. Identification of the Instream Flow Requirements for Anadromous Fish in the Streams within the Central Valley Of California and Fisheries Investigations: Annual Progress Report, Fiscal Year 2009. United State Fish and Wildlife Service. Sacramento, California. January 19, 2010

Ward, J.V., Malard, F. and Tockner, K., 2002. Landscape ecology: a framework for integrating pattern and process in river corridors. Landscape Ecology, 17, pp.35–45.

Weber, E.D., and K.D. Fausch. 2003. Interactions between hatchery and wild salmonids in streams: differences in biology and evidence for competition. Canadian Journal of Fish and Aquatic Science 60:1018–1036.

Williams, J.G. 2006. Central Valley Salmon A Perspective on Chinook and Steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science 4:3.

Wipfli, M.S., and C.V. Baxter. 2010. Linking Ecosystems, Food Webs, and Fish Production: Subsidies in Salmonid Watersheds. Fisheries 35(8) pp 373–390.

Wootton, R.J. 1990. Ecology of Teleost Fishes. Springer Netherlands.

Zeug, S.C., K. Sellheim, C. Watry, B. Rook, J. Hannon, J. Zimmerman, D. Coz, and J. Merz. 2013. Gravel Augmentation Increase Spawning Utilization by Anadromous Salmonids: A Case Study from California USA.

2.9.2 Personal Communications

Guptill, Chris. October 16, 2020 – Email on Evidence of Poaching?

Chapter 3
Description of Flow and Non-Flow Assets

3.1 Tuolumne River Voluntary Agreement Assets

The Tuolumne River Voluntary Agreement (TVA) proposes flow and non-flow restoration assets that are outlined in the November 9, 2022, *Memorandum of Understanding Advancing a Term Sheet for the Voluntary Agreements to Update and Implement the Bay-Delta Water Quality Control Plan, and other Related Actions* (MOU).[1] The proposed TVA flow commitments apply during January through June at La Grange Dam and are described in the MOU as additive to existing minimum instream flow requirements established in the 1964 Federal Energy Regulatory Commission (FERC) license as amended in the 1996 FERC order amending the license (FERC 1996). The TVA is proposed by Turlock Irrigation District, Modesto Irrigation District, and the San Francisco Public Utilities Commission (SFPUC), a department of the City and County of San Francisco (CCSF)(Tuolumne Parties).

The Tuolumne Parties own and operate the large reservoirs and hydroelectric projects in the Tuolumne River watershed and hold the majority of water rights in the watershed. Two of the hydroelectric projects associated with Don Pedro Reservoir and La Grange Dam are currently involved in a relicensing process through the FERC. As part of this relicensing process, the Final Environmental Impact Statement (FEIS) for the FERC relicensing of the Don Pedro and La Grange hydroelectric projects (2020 FERC FEIS) was released on July 7, 2020 (FERC 2020). The relicensing process is ongoing, and it is unclear when a new FERC license will be issued. As part of the 2020 FERC FEIS, updated base and pulse flow requirements were proposed by FERC staff that would increase flow requirements in the Tuolumne River relative to the current FERC license requirements. Although these proposed FERC flow requirements are not currently in effect, they are important to understand because the January through June components are a core part of the proposed TVA. The 2020 FERC FEIS also includes proposed updates to July through December flow requirements, but those are not part of what is proposed in the TVA.

In addition to January through June flow commitments, the TVA proposes habitat restoration measures described below that are additive to physical conditions and regulatory requirements existing as of December 2018, when the State Water Board adopted Resolution 2018-0059, updating the Bay-Delta Plan.[2] Implementation of such habitat measures by Tuolumne Parties after December 2018, but prior to execution of the VAs, will count as contributing toward implementation of the proposed TVA. The proposed habitat projects will be funded by the Tuolumne Parties and implemented within the 8-year term of the TVA, subject to and depending on obtaining applicable requirements for project-specific environmental review or regulatory approval. Similar to the flow assets, the non-flow assets proposed by the TVA are derived from ongoing FERC relicensing activities and are subject to adjustment as part of ongoing and future project-specific design (see

[1] Available on the State Water Board website at: Revised Memorandum of Understanding.

[2] Available on the State Water Board website at: Resolution No. 2018-0059.

March 29, 2024, *Draft Global Agreement to the Healthy Rivers and Landscapes Program in the Bay-Delta* for additional detail[3]).

3.1.1 Flow Assets

3.1.1.1 MOU Description of Flow Assets

The TVA flow assets presented in the MOU represent an increase in required flows during all year types to provide ecological benefits for the system. The proposed TVA flow requirements are additive to the average January through June minimum flow requirements in the 1996 FERC order for the Don Pedro Project. However, the resulting flows are not always additive to existing flow conditions. The proposed TVA flow commitments are proposed to apply at La Grange Dam. These additional flow requirements include 86 thousand-acre feet (TAF) in Critical years, 140 TAF in Dry years, 127 TAF in Below Normal years, and 138 TAF in Above Normal and Wet years (Table 3-1). Flow values in parentheses in Table 3-1 are considered off-ramp years and would apply in critical, dry, or below normal years following a critical, dry, or below normal year. For a more detailed description of the TVA flow requirements and the potential effects of implementing them see Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*, Chapter 5, *Water Temperature*, and Chapter 7, *Spawning and Rearing Habitat*.

Table 3-1. Proposed Increases in Tributary Flow Requirements as Identified in the MOU (Thousand-Acre Feet; January through June).[a]

	Water Year				
	Critical	**Dry**	**Below Normal**	**Above Normal**	**Wet**
Tuolumne River downstream of La Grange Dam	86(17)	140(40)	127(98)	138	138

[a] These volumes are proposed flows to be added above existing January through June minimum flow requirements. These flows are additive to existing requirements rather than additive to existing flow conditions. Existing requirements are from the FERC license for the Don Pedro Project and measured at the U.S. Geological Survey gage downstream of La Grange Dam. Values in parenthesis apply in critical, dry, and below normal years following a critical, dry, or below normal year (i.e., for sequential dry year off-ramps). The MOU also identified additional maximum Tuolumne River flow volumes that would be provided to avoid impacts to DWR and Reclamation and not for environmental flow purposes, which are not shown here.

[3] Available on the California Natural Resources Agency website at https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Support-Healthy-Rivers-and-Landscape/20240408-HRL-Agreements-0408--2-pm.pdf.

3.1.1.2 Additional Information Regarding the TVA Flow Commitments

The MOU quantifies the volumes (TAF) of additional flow requirements proposed by the Tuolumne Parties. The Tuolumne Parties propose Additional Maximum Tuolumne Flows that would be provided to avoid impacts to Department of Water Resources (DWR) and U.S. Bureau of Reclamation (Reclamation) (see the MOU). The Tuolumne Parties will work collaboratively with DWR, Reclamation, and other VA parties (Collaborators) during the term of the TVA to determine the total volumetric need for these additional flows. The Additional Maximum Tuolumne Flows from the Tuolumne River will equal one-third of total volumes agreed upon with the Collaborators, or the Additional Maximum Tuolumne Flow contribution, whichever is less (2024 Global Agreement). These volumes, when provided, will not be subject to flow protection below La Grange Diversion Dam. It's expected that these flows will be released when the State Water Project and the Central Valley Project (Projects) would be able to increase exports, which means these flows would not result in Delta outflow.

Although the Additional Maximum Tuolumne Flows are defined in the MOU, they have not been described by the Tuolumne Parties with enough detail to evaluate in this Draft Scientific Basis Report for the Tuolumne River Voluntary Agreement (Draft TVA Scientific Basis Report) (see Chapter 4 and Appendix B, *Hydrologic and Water Quality Modeling*, for additional detail). Additional flows are identified as 16 TAF in Critical years, 19 TAF in Dry years, 30 TAF in Below Normal years, 8 TAF in Above Normal years. No additional water is proposed in Wet years for the Additional Maximum Tuolumne Flows. This Draft TVA Scientific Basis Report incorporates additional information to further understand the intended implementation of the TVA which is included in Chapter 4, Appendix B, and Appendix C, *Draft Tuolumne Spreadsheet Model*.

3.1.1.3 Summary of TVA Flow Assets

Utilizing information sources listed above the TVA proposal can be summarized as follows. The TVA includes base flows that are set according to water year type (WYT) and calendar date and two pulse flow volumes with flexible release timing during the March through June period. The proposed baseflows are the same as those proposed in the 2020 FERC FEIS. The first pulse flow is for floodplain inundation that would be timed to coincide with Chinook salmon rearing. Actual release timing of the floodplain pulse would be determined based on monitoring, but the default timing would typically start in March. The second pulse would be a spring outmigration pulse flow to promote juvenile fish outmigration during the April 16 through May 31 period. As with the baseflows, the pulse flow requirements are based on the pulses described in the 2020 FERC FEIS and depend on San Joaquin River WYT. The TVA makes no changes to the outmigration pulse relative to the 2020 FERC FEIS but does add an additional 10 TAF to the floodplain pulse in Below Normal water year types without off-ramps and for all Dry and Critical water years, both with and without off-ramps. In addition, the TVA redefines the target flow for the inundations pulse to be 1,700 cfs, instead of 2,750 cfs in the 2020 FERC FEIS, so that the release duration can be increased. Sequential dry year off-ramps are still applied for both pulses under the TVA consistent with the 2020 FERC FEIS. Adaptive management principles will be applied to optimize the timing, duration, and flow rate of the pulse flow as data are collected on the resulting outmigration survival. Both pulses would also include drought off-ramps where the pulse volume, timing, and duration could be adjusted during a sequence of dry years.

Additional details on how the TVA is represented in the State Water Board's modeling analysis performed for this Draft TVA Scientific Basis Report are provided in Chapter 4 and Appendix B of this report.

3.1.2 Non-flow Assets

In addition to the flow assets, the TVA proposes fourteen habitat restoration projects for implementation in the lower Tuolumne River (Table 3-2). These projects in coordination with the flows are intended to improve salmonid spawning and rearing habitat and include 77 acres of improvement and restoration projects to be developed, but may include recontouring floodplain, native plant restoration, and backwater slough connections.

Eight of the projects will benefit spawning habitat through gravel augmentation and gravel cleaning. Projects 1, 2, 3, 6, 7, 8, and 11 will improve spawning gravel quantity through gravel augmentation as described in Table 3-3. Projects 1, 2, 6, 7, and 8 will augment approximately 75,000 tons of spawning gravel between RM 52 and 47 (Table 3-3). New projects, to be determined, would augment an additional 25,000 tons of gravel between RM 39 and 24.5.

Project 5 will include additional habitat improvements that will benefit fall-run Chinook and *Oncorhynchus mykiss* juvenile rearing through floodplain restoration, including recontouring floodplain areas and planting native vegetation between RM 48 and 5. The placement of approximately 6,500 cubic feet of large woody debris (Project 9) would also improve instream habitat by creating micro-habitats for fish and allowing for potential scouring of fines needed for spawning.

Projects 12 and 13 include the construction and operation of a fish barrier and counting weir to prevent predatory striped bass movement into the upstream habitats utilized by juvenile fall-run Chinook salmon. The proposed predator control project also acts as a means to isolate and remove predatory smallmouth bass and black bass through electro-fishing, netting, and seining.

Table 3-2. Non-Flow Assets and Measures for the Lower Tuolumne River.[a]

Project No.	Project and location	Description	Life stage	Benefits	Implementation timing				Total
					Early Implementation (Dec 2018–2024)	Years 1–3	Years 4–6	Years 7–8	
1	Riffle A2 Rehabilitation River Mile (RM) 50.6/50.7	Add appropriately sized gravel to improve substrate conditions for spawning and incubation	Spawning and incubation	Increased spawning opportunity and improved egg-to-emergence survival	–	0.15 acre		–	0.15 acre
2	Riffle A3 Rehabilitation RM 50.4 to 50.6	Add appropriately sized gravel to improve substrate conditions for spawning and incubation	Spawning and incubation	Increased spawning opportunity and improved egg-to-emergence survival	–	1.00 acre		–	1.00 acre
3	Riffles 3A and 3B RM 49.2 to 49.6	Add appropriately sized gravel; restore banks to appropriate floodplain elevation and function; remove invasive hardwood	Spawning incubation and juvenile rearing	Improved egg-to-emergence survival and expanded floodplain rearing habitat	–	–	0.50 acre	–	0.50 acre
4	Gravel Cleaning RM 45–49	Clean select gravel patches to expand availability of high quality gravel to improve spawning and incubation	Spawning and incubation	Improved spawning habitat quality and egg-to-emergence survival	–	Clean selected gravel patches in the lower Tuolumne River at or below the confluence of intermittent streams downstream from La Grange Diversion Dam, including Gasburg Creek (RM 50.3) and Peaslee Creek (RM 45.5), for two to three weeks each year for 5 years		–	–

Project No.	Project and location	Description	Life stage	Benefits	Implementation timing				
					Early Implementation (Dec 2018–2024)	Years 1–3	Years 4–6	Years 7–8	Total
5	Lower Tuolumne River Habitat Improvement Program RM 5–48	$19M capital fund shall be used for a variety of improvement and restoration projects to be developed in conjunction with the Tuolumne River Partnership Advisory Committee [4] Examples of likely projects include floodplain lowering, floodplain connectivity, riparian plantings, in-channel placement of large woody debris (LWD)	Juvenile rearing, smolt outmigration	Expanded floodplain rearing; expanded in-channel rearing; and improved smolt outmigration survival		–	77 acres	–	77 acres
6	Riffle A5 RM 51.2	Construct alternative riffle/pool morphology	Over-summering *O. mykiss* juvenile and adults	Improved juvenile rearing; improved foraging; improved spawning habitat	2.78 acres	–	–	–	2.78 acres
7	Riffle A6 RM 51.0	Construct alternative riffle/pool morphology	Over-summering *O. mykiss* juvenile and adults	Improved juvenile rearing; improved foraging; improved spawning habitat	2.29 acres	–	–	–	2.29 acres
8	Basso Pool RM 47.0-47.3	Construct medial bar: riffle pool-tail morphology	Over-summering *O. mykiss* juvenile and adults	Improved juvenile rearing; improved foraging; improved spawning habitat	–	–	8.78 acres	–	8.78 acres
9	Large Woody Debris	Improve instream habitat complexity through targeted addition of LWD to the lower Tuolumne River	*O. mykiss* Juvenile rearing	Improved juvenile rearing and increased in-channel rearing area	–	Place 6,535 cubic feet of large woody material	–	–	6,535 cubic feet of large woody material

[4] A group formed by the Turlock and Modesto Irrigation Districts to provide advice regarding the selection and design of individual habitat projects and the management of spill to benefit salmonids.

Project No.	Project and location	Description	Life stage	Benefits	Implementation timing				
					Early Implementation (Dec 2018–2024)	Years 1–3	Years 4–6	Years 7–8	Total
10	Infiltration Galleries (IG) RM 26	Construct IG#2 and operate IG#1 (existing) and IG#2 (proposed) from June through mid- October, enabling an increase of flow between La Grange and the IGs to benefit *O. mykiss*	*O. mykiss* Juvenile rearing and over-summering adults.	Improve temperature conditions for *O. mykiss* juvenile rearing and adult habitat	–	Operate IG #1	Construct IG #2	–	–
11	Riffle A3/A4 (RM 51.5); Gravel Augmentation	Spawning gravel size and distribution integrated with VA flow regime	Stream geomorphology	Resorting gravels and improved gravel size for Chinook spawning	–	–	5.85 acres	–	5.85 acres
12	Fish Counting Barrier and Weir RM 25	Improve rearing and migration conditions upstream of the weir by preventing access by striped bass and other predators	Fry and juvenile rearing; smolt outmigration	Reduce predation on fry and juvenile fall-run Chinook salmon	–	Construct Fish Counting and Barrier Weir	–	–	–
13	Predator Control	Improve rearing and migration conditions by reducing predation	Fry and juvenile rearing; smolt outmigration	Reduce predation on fry and juvenile fall-run Chinook salmon	–	–	Implement Predator Control		–
14	Reduce Redd Superimpositio n (seasonal weir) RM 47–52	Construct a seasonal weir when upstream gravel patches are at capacity to encourage use of suitable habitats at downstream locations	Spawning and incubation	Improve overall fall-run Chinook spawning success by reducing red superimposition	–	Implement seasonal weir operational when >5,000 female spawners are observed in the Tuolumne River			–

Source: 2024 Global Agreement.

[a] The projects and their associated attributes listed in Table 3-2 were derived as part of ongoing FERC relicensing activities and are subject to adjustment as part of ongoing and future project-specific design; RM = River Mile.

Table 3-3. Gravel Augmentation Rates.

Project #	Riffle location	Volume (cubic yards)	Tons
1	Riffle A2	519	700
2	Riffle A3	3,707	5,000
6	Riffle A5	9,637	13,000
7	Riffle A6	14,456	19,500
8	Basso Pool	27,281	36,800
Totals		**55,600**	**75,000**
3	Riffle 3A/3B [a]	TBD	TBD
11	Riffle A3/A4 [a]	TBD	TBD
–	New Project(s) TBD between RM 39 and 24.5	18,535	25,000

Source: Global Agreement submitted in March/April 2024 as part of draft VA documents and available on the California Natural Resources Agency website at Global, Implementing, and Enforcement Agreements.

[a] These projects include gravel augmentation that goes above the TVA commitment of 75,000 tons of new gravel.

3.2 References

3.2.1 Printed References

Federal Energy Regulatory Commission (FERC). 1996. Order Amending License and Dismissing Rehearing Requests for Don Pedro Hydroelectric Project, FERC Project No. 2299-024 and 031. Division of Hydropower Licensing. Washington, D.C. July.

Federal Energy Regulatory Commission (FERC). 2020. Final Environmental Impact Statement for Hydropower Licenses. Don Pedro Hydroelectric Project, FERC Project No. 2299-082; La Grange Hydroelectric Project, FERC Project No. 14581-002. Division of Hydropower Licensing. Washington, D.C. July.

Chapter 4

Tuolumne River Hydrology and Operations Modeling Methods and Results

4.1 Introduction

This chapter describes changes in hydrology, diversion practices, and reservoir operations that could result from the Tuolumne River Voluntary Agreement (TVA). In addition, this chapter presents changes to flow in the San Joaquin River (SJR) at Vernalis, which may result from implementation of the TVA. The analysis in this chapter is performed by comparing modeling results that represent the TVA to other hydrologic scenarios using the Water Supply Effects (WSE) model. The WSE model was developed by the State Water Resources Control Board (State Water Board) to support its efforts to update the Bay-Delta Water Quality Control Plan in 2018 (2018 Bay-Delta Plan). Since 2018, WSE has received several updates to better represent existing conditions as of 2023 within the lower San Joaquin River (LSJR) watershed, and to improve its usability. These updates are described in Appendix B, *Hydrologic and Water Quality Modeling*.[1] The WSE model is used for the analysis of the TVA because the model was designed to analyze the effects of possible flow regimes in the LSJR, including within the Tuolumne River, and using the WSE model allows for the most direct method to compare the effects of the TVA relative to the 2018 Bay-Delta flow requirements.

Understanding the appropriate uses and limitations of the WSE model is important. As further explained below, the WSE model results should not be taken as predicting exact changes in water supply and river flows from implementation of the proposed TVA, but the results should instead be used to indicate the general volumes, timing, and trends that may occur if the proposed TVA is implemented. Actual outcomes from implementation of the proposed TVA would vary from modeled results presented in this chapter for many reasons, including unknown future precipitation and real-time implementation decisions. For example, the proposed TVA includes provisions for flexibility in the timing of flows, which can result in river flows and reservoir levels not exactly matching the modeled results. In addition, "Additional Maximum Flows" have been proposed as part of the TVA; however, implementation of these specific flows have not been described with enough detail to represent in the WSE model, and those flows would be provided to avoid impacts to the State Water Project's and the Central Valley Project's (Projects) water supplies and not for environmental flow purposes.

[1] The original version of the model used for the 2018 Bay Delta Plan is fully described in Appendix F.1 to the Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay-Sacramento San Joaquin Delta Estuary San Joaquin River Flows and Southern Delta Water Quality, or 2018 Final SED (SWRCB 2018).

4.2 Tuolumne Basin Existing Conditions

The Tuolumne River originates in the high elevations of the Sierra Nevada, draining an area of about 1,900 square miles. From the upper watershed, the river flows westward for approximately 155 miles until it joins with the LSJR about 8 miles upstream of the Stanislaus River confluence and 35 miles downstream of the Merced River confluence. New Don Pedro Dam is located on the Tuolumne River about 55 miles upstream of the confluence with the SJR and this dam divides the river into upper and lower parts of the watersheds. The upper watershed covers about 82% of the drainage area, mostly in the mountains and foothills and contains the North, Middle, and South Forks of the Tuolumne River, as well as various minor creeks. The lower watershed, on the other hand, is dominated by irrigated farmland and several urban areas associated with Modesto, Waterford, and Ceres. There is one notable tributary, Dry Creek, in the lower watershed that joins the river around the City of Modesto (about 16 miles upstream from the confluence with the SJR).

4.2.1 Water Diversion and Use

Water is diverted from the Tuolumne River and used at numerous locations by many users, including Turlock Irrigation District (TID), Modesto Irrigation District (MID), and the San Francisco Public Utilities Commission (SFPUC), a department of the City and County of San Francisco (CCSF).[2] Based on information from the 2018 Final SED, in the Tuolumne River watershed there are 165 licensed or permitted post-1914 appropriative water rights with a combined face value of approximately 7.2 million acre-feet (MAF). Of these 165 rights, 5 are used for hydropower and are non-consumptive, meaning water is returned to the river after use. The remaining 160 water rights have a face value of approximately 2.65 MAF. Of these 160 rights, 5 are held by TID and MID with a face value of about 2.62 MAF, which accounts for 99% of the water authorized for diversion (based on face value or maximum diversion amount) under non-power water rights in the Tuolumne River watershed (SWRCB 2018). However, the amount of water diverted each year is typically less than the total face value reported above and varies depending on hydrologic conditions. In addition, TID currently has a pending appropriative water right application on the Tuolumne River with a requested face value of 2.7 MAF (TID 2022). There are also numerous statements of diversion and use on file with the State Water Board, accounting for both pre-1914 appropriative and riparian water rights which do not include a face value.

TID and MID are the largest water diverters on the Tuolumne River, generally diverting between 700 and 900 thousand acre-feet per year (TAF/y) for irrigation and municipal and industrial (M&I) demands, although this estimate can be much lower during droughts. Table 4-1 presents the surface water diversions made by TID and MID from 2010 through 2019 as they were reported in their respective Agricultural Water Management Plans (AWMPs).

[2] Depending on the context, either SFPUC or CCSF may be referenced.

Table 4-1. Reported Surface Water Diversions for MID and TID (in Acre-Feet or AF).

Water Year	WY Type	MID	TID [a]	Total
2010	AN	261,728	531,107	792,835
2011	W	282,640	537,685	820,325
2012	D	311,500	445,579	757,079
2013	C	316,571	460,420	776,991
2014	C	176,087	320,862	496,949
2015	C	149,442	281,667	431,109
2016	D	215,476	384,036	599,512
2017	W	295,656	472,798	768,454
2018	BN	269,479	509,326	778,805
2019	W	307,327	470,271	777,598
Average	-	258,591	441,375	699,966

W = Wet; AN = Above Normal; BN = Below Normal; D = Dry, C = Critical.

Values for years 2010–2014 are reported in MID 2015 and TID 2015.

Values for years 2015–2019 are reported in MID 2021and TID 2021.

[a] TID surface water diversion is measured below Turlock Lake, a regulating reservoir used to manage irrigation deliveries. Actual river diversions are higher because of seepage and evaporative losses from Turlock Lake and from the upper main canal system that brings water from the Tuolumne River to Turlock Lake. These losses are estimated as 46,800 AF/y in the water supply modeling shown below (see Appendix B, *Hydrologic and Water Quality Modeling*).

TID and MID own and operate New Don Pedro Reservoir, the largest water storage facility on the Tuolumne River with a capacity of 2,030,000 TAF (divided 68.46% for TID and 31.54% for MID) (TID 2021). New Don Pedro is used primarily to store water for agricultural use, but is also used for hydropower generation, M&I needs, recreational activities, and flood control. Water released from New Don Pedro is diverted by TID and MID at the La Grange Diversion Dam, about 2.5 miles downstream. The La Grange Diversion Dam, also owned by TID and MID, is the most downstream dam on the Tuolumne River, impounding a very small reservoir with a capacity of only 400 AF. This dam operates primarily as a point of diversion for TID and MID and for hydropower generation.

Upstream of New Don Pedro Reservoir in the upper watersheds of the Tuolumne River, SFPUC operates additional reservoirs to provide water supply storage and hydropower generation. These facilities include Cherry Lake (capacity 270 TAF), Lake Eleanor (capacity 30 TAF) and Hetch Hetchy Reservoir (capacity 360 TAF). From these storage reservoirs CCSF transfers about 250 TAF/y to the San Francisco Bay Area, providing 85% of CCSF's Bay Area M&I water supply (FERC 2020). SFPUC also owns and operates the lower Cherry Creek Diversion Dam and Early Intake Diversion Dam, which are used to re-divert water supplied by SFPUC's Cherry Creek facilities during emergencies and extreme drought conditions.

4.2.2 Existing Instream Flow Requirements (FERC 1995)

On the Tuolumne River, the existing minimum flow requirement below La Grange Diversion Dam is described by Article 37 of the Federal Energy Regulatory Commission (FERC) license for the New Don Pedro hydroelectric project (Project Number 2299).[3] The original FERC license was issued on March 10, 1964, but Article 37 was amended in 1995 in a settlement agreement between TID, MID, CCSF, the California Department of Fish and Wildlife (CDFW), the U.S. Fish and Wildlife Service (FWS), and other non-governmental organizations (FERC 1995). Under the agreement, 10 year type classifications were defined, ranging from very dry to very wet conditions, which would determine how much flow is required each year. The year type is initially determined based on forecasts for the San Joaquin Basin 60-20-20 Water Supply Index (SJR index) in early April and applies from April 15 to April 14 of the next calendar year. As more accurate estimates of unimpaired flow (UF) become available after April 1 the volume of annual required flow can be periodically readjusted upon agreement among TID, MID, CDFW, and FWS. Table 4-2 presents the year type classifications and corresponding SJR index values, while Table 4-3 shows the current monthly and annual minimum flows required under each year type classification.

Table 4-2. Tuolumne Year Type Classifications Under the 1995 Settlement Agreement.

SJR Index [a]	Year Type Classification	Frequency of Occurrence [b]	Crosswalk with SJR WYT [c]
>=4773	Median W/Maximum	13.30%	W
>=3903	Intermediate AN-W	15.40%	W
>=3669	Median AN	5.10%	AN, W
>=3073	Intermediate BN-AN	15.50%	BN, AN
>=2642	Median BN	10.30%	BN
>=2352	Intermediate D-BN	9.10%	D, BN
>=2061	Median D	10.80%	C, D
>=1955	Intermediate C-D	6.10%	C
>=1441	Median C	8.00%	C
> 0	C and below	6.40%	C

[a] Index values defining each classification are updated annually to maintain approximately the same frequency of occurrence for each year type. The index values shown here have been updated to incorporate index values from 1906 through 2021, as described in the 2022 lower Tuolumne River annual FERC report (TID and MID 2023).

[b] Frequency of occurrence for each year type was originally defined in the 1995 settlement agreement based on SJR index values for 1906 to 1995.

[c] San Joaquin 60-20-20 water year type (SJR WYT or WYT) designations are W if SJR index >= 3800, AN if index <3800 and >3100, BN if index <=3100 and >2500, D if index <=2500 and >2100, and C if index <=2100. (SWRCB 2000).

[3] Although unimpaired flow requirements were adopted for the Stanislaus, Tuolumne, and Merced Rivers in the 2018 Bay Delta Plan, these requirements have not yet been implemented and the 1995 FERC requirements still currently govern instream flows in the Lower Tuolumne River.

Table 4-3. Minimum Monthly Flow Requirements at La Grange Dam on the Tuolumne River per the 1995 FERC Settlement Agreement (in cubic feet per second or cfs).

Year Type Classification	Intermediate BN-AN and above [a]	Median BN	Intermediate D-BN	Median D	Intermediate C-D	Median C	C and below
January	300	175	180	150	150	150	150
February	300	175	180	150	150	150	150
March	300	175	180	150	150	150	150
April	300	175	180	150	150	150	150
May	300	175	180	150	150	150	150
June	250	75	75	75	50	50	50
July	250	75	75	75	50	50	50
August	250	75	75	75	50	50	50
September	250	75	75	75	50	50	50
October 1–15	300	200	180	150	150	100	100
October 16–31	300	175	180	150	150	150	150
November	300	175	180	150	150	150	150
December	300	175	180	150	150	150	150
April Pulse (in AF)	44,941	30,014	17,960	18,530	16,310	10,046	5,546
May Pulse (in AF)	44,941	30,014	17,960	18,530	16,310	10,046	5,546
October Pulse (in AF)	5,950	1,736	1,676	0	0	0	0

Source: FERC 1995.

[a] The 1995 settlement agreement defines 10 water year classifications, but this table only shows information for 7 of them because the 4 wettest classifications (Intermediate BN-AN, Median AN, Intermediate AN-W, and Median W/Maximum) require the same minimum flows.

4.2.3 Proposed Instream Flow Requirements (2020 FERC Final Environmental Impact Statement)

On July 7, 2020, the Final Environmental Impact Statement (FEIS) for the FERC relicensing of the Don Pedro and La Grange hydroelectric projects (2020 FERC FEIS) was released (FERC 2020). The relicensing process is currently ongoing, and it is unclear when a new FERC license will be issued for the Don Pedro and La Grange hydroelectric projects. As part of the 2020 FERC FEIS, updated base and pulse flow requirements were proposed that would increase flows in the Tuolumne River. Although these proposed flow requirements are not currently in effect, they are important to understand for various modeling scenarios described later in this document. Table 4-4 presents the FERC staff proposed monthly baseflow requirements from the 2020 FERC FEIS, which would be required at La Grange Diversion Dam and determined based on SJR WYT. According to the FEIS, preliminary WYTs for the baseflow requirements would be determined starting in February using a 90% exceedance forecast of the SJR index, with updates in March and April also based on the monthly 90% exceedance forecasts. The final WYT would be determined in May based on the 75% exceedance forecast of the SJR index and would govern flows from May through January of the following calendar year.

During the period from June through October 15, TID and MID propose to operate two in-river infiltration galleries (IGs) at approximately river mile (RM) 25.9. The IGs are proposed subsurface diversion structures that could allow TID and MID to re-divert a portion of their New Don Pedro Reservoir releases at the IG locations instead of at La Grange Dam (RM 53.5). TID and MID indicate that moving the point of re-diversion further downstream is intended to provide river flows and cold-water fish habitat between RM 53.5 and 25.9, while also maintaining TID and MID's water diversions. If the IGs become operational in the future, the additional releases for the downstream re-diversion would then be incorporated into the FERC baseflow requirement at La Grange Dam. The FEIS includes interim baseflow requirements to be met at La Grange Dam during the period between final FERC relicensing and implementation of the IGs; these interim baseflows are shown in parentheses in Table 4-4. The expected IG diversion rates are given in Table 4-5.

Table 4-4. 2020 FERC FEIS Proposed Base Flow Requirements at La Grange Dam (in cfs).

Period	Days in Period	Critically Dry	Dry	Below Normal	Above Normal	Wet
January	31	175	200	225	225	225
February	28/29	175	200	225	225	225
March	31	200	225	250	250	250
April 1–15	15	200	225	250	250	250
April 16–30	15	200	250	275	275	275
May 1–15	15	200	250	275	275	275
May 1–31	16	225	275	300	300	300
June [a]	30	200 (125)	200 (125)	200 (150)	200 (150)	200 (150)
July [a]	31	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
August [a]	31	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
September [a]	30	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
October 1–15 [a]	15	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
October 16–31	16	200	225	275	275	275
November	30	200	225	275	275	275
December	31	200	225	275	275	275

[a] Values in parentheses are the interim release requirements at La Grange Dam to be provided until both IGs are operational.

Table 4-5. Expected Infiltration Gallery Diversion Rates (in cfs).

Period	Days in Period	Critically Dry	Dry	Below Normal	Above Normal	Wet
June	30	75	75	100	100	100
July	31	175	163	142	142	142
August	31	175	170	147	147	147
September	30	175	168	145	145	145
October 1–15	15	175	175	150	150	150
October 16–31	16	0	0	0	0	0

Table 4-6 and Table 4-7 describe the outmigration and floodplain pulse flows associated with the 2020 FERC FEIS, including the duration, volume, and assumed timing. As with the base flows, the pulse flow requirements are dependent on SJR WYT. The spring outmigration pulse is intended to encourage outmigration and increase survival of parr and smolt salmon during the spring. The volume of the outmigration pulse decreases as the SJR WYT determinations get drier. The floodplain inundation pulse is designed to provide floodplain habitat for juvenile Chinook salmon during the rearing life stage by maintaining flows at about 2,750 cfs for a continuous period of 9 to 20 days. The duration of the floodplain pulse decreases as SJR WYT determinations get drier. Both pulses include dry year off-ramps to conserve water during drought conditions by reducing the pulse volumes. The off-ramps for the outmigration pulse occur each year during any sequence of C and/or D years that follow a C or D year. For the floodplain inundation pulse, an off-ramp occurs each year during any sequence of C, D, and/or BN years that follow a C or D year. The 2020 FERC FEIS also includes an additional 1,000 cfs fall flushing pulse for 3 days (about 5,950 AF) in October of every SJR WYT, intended for cleaning gravels of built-up algae, debris, and surface fines prior to the start of substantial salmon spawning in late October and November.

Table 4-6. Representation of the 2020 FERC FEIS Outmigration Pulse Flow.

SJR WYT	Pulse Period Start Date [a]	Pulse Period End Date [a]	Pulse Length (Days)	Total Pulse Volume (AF) [b]	April Pulse Volume (AF) [c]	May Pulse Volume (AF) [c]
Wet	17-Apr	30-May	44	150,000	44,000	106,000
Above Normal	17-Apr	30-May	44	150,000	44,000	106,000
Below Normal	17-Apr	30-May	44	100,000	29,333	70,667
Dry	17-Apr	30-May	44	75,000	22,000	53,000
Critically Dry	17-Apr	30-May	44	35,000	10,267	24,733
Dry Year Off-Ramp	17-Apr	30-May	44	45,000	13,200	31,800
Critically Dry Year Off-Ramp	17-Apr	30-May	44	11,000	3,227	7,773

[a] Includes 6 days of up ramping in April (17–22) and 7 days of down ramping in May (24–30).

[b] Pulse volumes in this table are in addition to 2020 FERC FEIS base flows.

[c] The April and May Pulse Volumes represent how the Total Pulse Volume is divided between the two months, based on the information provided by the TVA Parties (TID, MID, CCSF 2024).

Table 4-7. Representation of the 2020 FERC FEIS Floodplain Inundation Pulse Flow.

SJR WYT	Pulse Period Start Date	Pulse Period End Date	Pulse Length (Days)	Target Flow Rate (cfs) [a]	Pulse Volume (AF) [b]
Wet	1-Mar	20-Mar	20	2,750	99,174
Above Normal	1-Mar	20-Mar	20	2,750	99,174
Below Normal	1-Mar	20-Mar	18	2,750	89,256
Dry	1-Mar	16-Mar	14	2,750	70,116
Critically Dry	1-Mar	9-Mar	9	2,750	45,521
Below Normal Year Off-Ramp	1-Mar	14-Mar	14	2,750	69,421
Dry Year Off-Ramp	NA	NA	0	NA	0
Critically Dry Year Off-Ramp	NA	NA	0	NA	0

[a] Target flow rate is inclusive of the baseflow required during the timing of the pulse flow. The baseflow requirements from March 1 through April 15 are 200 cfs for critical years, 225 cfs for dry years, and 250 cfs for below normal, above normal, and wet years.

[b] The pulse volume is the release needed to meet the target flow rate minus the 2020 FERC FEIS base flows over the pulse length.

4.2.4 Tuolumne River Hydrology

The Tuolumne River receives most of its flow from late spring and early summer snowmelt; however, high river flows can also occur during winter rain events. Table 4-8 summarizes the monthly and annual UF in the Tuolumne River as estimated during each water year (October 1 through September 30) at La Grange from 2004 to 2023. The greatest runoff typically occurs between March and June with peak flows generally in May. The distribution of annual UF ranges from 607 TAF/y (10th percentile) to 3,587 TAF/y (90th percentile). The average UF was 1,900 TAF/y, but this is heavily weighted by a few very wet years including 2005, 2006, 2011, 2017, 2019, and 2023 (all W years based on the SJR index). The average annual UF in these wet years is 3,640 TAF/y, while for all other years the average is much lower at 1,154 TAF/y.

Table 4-8. Summary of Monthly and Annual UF in the Tuolumne River from 2004–2023 (in TAF).

Percentile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual [a]
10%	4	7	13	24	36	88	174	208	56	13	7	4	607
20%	5	11	26	34	47	104	187	243	62	17	8	5	870
30%	6	13	31	64	59	120	223	251	85	20	9	5	1,041
40%	9	18	40	72	98	138	256	317	128	30	10	6	1,112
50%	13	22	70	78	107	195	263	354	179	34	13	7	1,493
60%	18	28	76	96	116	273	296	372	253	49	15	10	1,731
70%	31	43	105	128	125	330	353	533	601	162	27	16	2,216
80%	54	60	193	187	146	358	451	606	666	247	43	22	3,067
90%	86	66	214	287	207	401	479	818	776	361	78	30	3,587
Wet Year Average [b]	54	44	184	330	296	400	463	725	726	325	63	28	3,640
Non-Wet Year Average [b]	20	27	57	62	78	162	239	298	157	34	11	7	1,154
Overall Average	30	32	95	143	143	234	306	426	328	121	26	13	1,900

Source: California Data Exchange Center (CDEC) gage TLG, Monthly Full Natural Flow (which is equivalent to UF) (DWR n.d.(a)).

[a] The values of the annual cumulative distribution do not equal the total of the monthly values but instead represent the distribution of actual annual values.

[b] The Wet Year Average includes 2005, 2006, 2011, 2017, 2019, and 2023.

Inflows to New Don Pedro Reservoir are less than UF estimates at the TLG gage because diversions in the upper watershed, including those by CCSF, reduce the amount of water that flows into the reservoir. Figure 4-1 shows a monthly timeseries of Tuolumne UF compared with inflow to New Don Pedro Reservoir from 2013 to 2023. Based on the figure, peak inflows during March to June tend to be reduced compared to the UF while the summer low flows are a bit higher. Table 4-9 summarizes the monthly and annual inflow to New Don Pedro Reservoir from 2004 to 2023. The distribution of annual inflow ranges from 448 TAF/y to 3,314 TAF/y. The average inflow is 1,598 TAF/y, which is about 302 TAF less than, or approximately 84% of, the average annual UF. In wet years, the average inflow is 3,323 TAF/y (317 TAF less than, or 91% of, the UF). The non-wet year average is 858 TAF/y (295 less than, or 74% of, the UF). In addition to CCSF's diversions upstream of New Don Pedro Reservoir, other relatively small water right diversions exist in the upper Tuolumne River watershed.

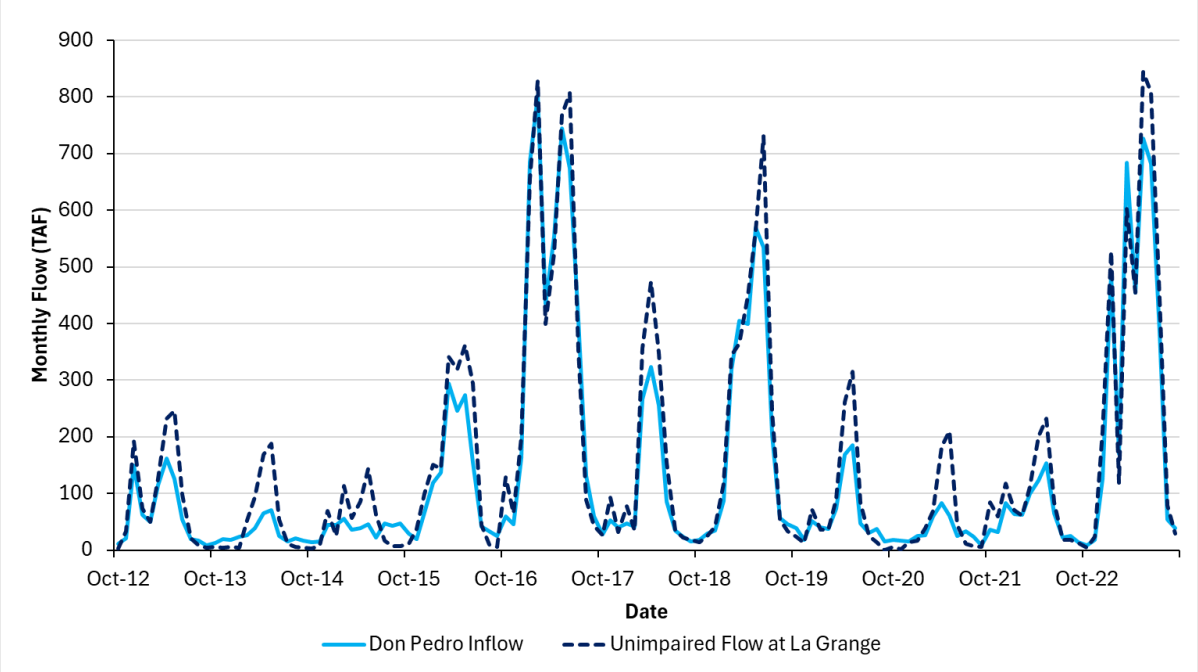


Figure 4-1. Monthly UF in the Tuolumne River Compared with Historical Inflow to New Don Pedro Reservoir for Water Years 2013 Through 2023 (DWR n.d.(a); DWR n.d.(b)).

Table 4-9. Summary of Monthly and Annual Inflow to New Don Pedro from 2004–2023 (in TAF).

Percentile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual [a]
10%	11	15	16	26	26	58	81	70	25	19	16	9	448
20%	13	17	21	38	41	77	115	117	44	22	19	10	650
30%	17	18	33	46	52	90	155	136	56	28	22	13	727
40%	18	19	37	63	60	109	176	173	77	34	24	15	787
50%	22	20	42	68	79	173	192	221	114	37	25	16	1,075
60%	26	26	50	80	110	231	244	337	167	44	34	20	1,373
70%	28	30	71	97	142	305	303	442	388	116	39	25	1,866
80%	36	37	130	187	178	360	392	573	534	210	47	38	2,750
90%	41	50	165	270	220	436	464	652	626	385	58	46	3,314
Wet Year Average [b]	32	39	149	316	311	441	450	621	571	295	63	35	3,323
Non-Wet Year Average [b]	22	23	44	56	64	128	160	185	99	34	26	17	858
Overall Average	25	28	76	134	138	222	247	316	241	112	37	23	1,598

Source: CDEC gage DNP (daily Inflow to Don Pedro) (DWR n.d.(b)).

[a] The values of the annual cumulative distribution do not equal the total of the monthly values but instead represent the distribution of actual annual values.

[b] The Wet Year Average includes 2005, 2006, 2011, 2017, 2019, and 2023.

Figure 4-2 shows the timeseries of total monthly UF at La Grange compared with flow on the Tuolumne River at the release from New Don Pedro Dam (RM 55), below La Grange Dam (RM 52), and farther downstream at Modesto (RM 16) from 2013 to 2023. Releases from New Don Pedro are made primarily to provide irrigation water for TID and MID, meet downstream flow requirements below La Grange Diversion Dam, and, in wetter years, manage flood risk. As the irrigation season spans the dry summer period, peak releases from the reservoir are shifted in time compared to the

natural hydrograph with high outflow generally during April through August. However, once the flow reaches La Grange Diversion Dam most of the water is diverted. The flow below La Grange Dam is governed by the 1995 FERC license requirements imposed on TID and MID for the New Don Pedro hydroelectric project. During wetter years, flood spills from New Don Pedro Reservoir can significantly increase Tuolumne River flows above the minimum FERC requirements.

Between La Grange Dam and the City of Modesto, various sources contribute to the flow in the Tuolumne River including runoff from Dry Creek, agricultural return flows, groundwater inflow to the river, and operational spills from irrigation canals. Estimates of monthly accretion flows in the lower Tuolumne River range from 40 to 200 cfs with an estimated annual average accretion flow rate of 152 cfs (or 110 TAF/y). There are also many relatively small diversions present throughout the lower portion of the Tuolumne River, with an estimated withdrawal capacity of 77 cfs (or 56 TAF/y) (FERC 2020). Table 4-10 and Table 4-11 summarize the monthly and annual flow below La Grange Dam and at Modesto from 2004 to 2023. Below La Grange Dam, the annual flows range from 120 TAF/y to 2,343 TAF/y, with an average of 821 TAF/y. Between La Grange Dam and Modesto there is generally a net influx of water, with Modesto annual flows ranging from 145 TAF/y to 2,541 TAF/y and averaging 910 TAF/y (an increase of 89 TAF above La Grange Dam flows). The average values provided above are skewed high because of flood spills during wet years. The average annual flow at La Grange Dam and Modesto for wet years was 2225 TAF/y and 2398 TAF/y, respectively (a difference of 173 TAF). The average annual flow at La Grange Dam and Modesto excluding wet years was 220 TAF/y and 273 TAF/y, respectively (a difference of 53 TAF).

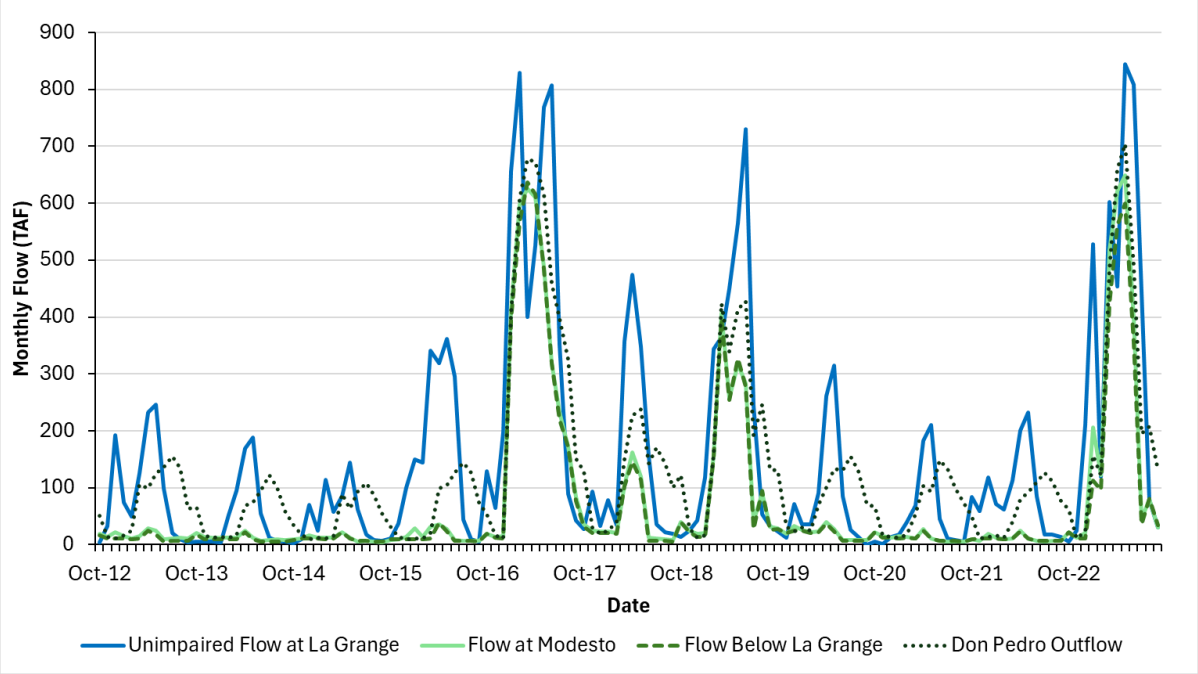


Figure 4-2. Timeseries of Monthly UF Estimated at La Grange Dam Compared with Historical Flow on the Tuolumne River below New Don Pedro Dam, below La Grange Dam, and at Modesto for Water Years 2013 Through 2023 (DWR n.d.(a); DWR n.d.(c); USGS n.d.(a); USGS n.d.(b)).

Table 4-10. Summary of Monthly and Annual Flow below La Grange Dam from 2004–2023 (in TAF).

Percentile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual [a]
10%	9	10	10	10	9	10	21	11	6	6	6	5	120
20%	10	10	10	10	9	10	23	17	6	6	6	6	138
30%	15	10	11	11	10	11	25	23	6	6	6	6	149
40%	18	11	11	11	13	15	31	25	7	7	6	6	192
50%	20	12	11	14	16	21	37	42	8	7	6	6	225
60%	23	14	14	17	20	40	68	75	8	7	7	6	351
70%	27	20	17	21	43	143	178	179	174	30	24	19	819
80%	29	22	22	42	107	272	303	305	277	50	54	25	1,737
90%	30	22	30	254	157	400	454	483	301	119	100	37	2,343
Wet Year Average [b]	25	17	63	177	204	379	430	400	292	97	97	42	2,225
Non-Wet Year Average [b]	18	14	14	14	13	24	41	41	17	9	7	7	220
Overall Average	21	15	29	63	70	130	158	148	100	36	34	17	821

Source: USGS gage 11289650 (USGS n.d.(a)).

[a] The values of the annual cumulative distribution do not equal the total of the monthly values but instead represent the distribution of actual annual values.

[b] The Wet Year Average includes 2005, 2006, 2011, 2017, 2019, and 2023.

Table 4-11. Summary of Monthly and Annual Flow at Modesto from 2004–2023 (in TAF).

Percentile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual [a]
10%	10	11	13	12	12	12	25	11	7	6	6	6	145
20%	15	13	15	14	13	14	26	22	7	7	8	7	181
30%	19	13	15	19	14	18	28	27	9	10	9	8	207
40%	21	13	17	22	20	23	36	35	12	11	11	10	250
50%	22	15	19	24	23	29	39	50	14	13	12	11	309
60%	26	19	20	28	26	52	76	80	15	15	15	13	438
70%	30	21	22	29	57	156	190	184	178	42	34	27	918
80%	36	25	28	83	132	302	323	303	281	67	65	32	1,812
90%	38	27	37	287	163	418	504	488	308	134	97	42	2,541
Wet Year Average [b]	29	20	72	212	225	410	452	412	304	112	100	50	2,398
Non-Wet Year Average [b]	22	17	20	21	18	30	46	45	21	14	11	10	273
Overall Average	24	18	35	78	80	144	168	155	105	43	38	22	910

Source: USGS gage 11290000 (USGS n.d.(b)).

[a] The values of the annual cumulative distribution do not equal the total of the monthly values but instead represent the distribution of actual annual values.

[b] The Wet Year Average includes 2005, 2006, 2011, 2017, 2019, and 2023.

About 16 miles downstream from Modesto, the Tuolumne River joins the LSJR. Upstream of the Tuolumne River confluence, the LSJR receives other major inflows from the Merced River and Upper SJR. Downstream of the Tuolumne River confluence, the LSJR receives major inflows from the Stanislaus River. From its confluence with the Tuolumne River the LSJR flows north to Vernalis and into the southern Delta before joining with the Sacramento River through to the San Francisco Bay. Table 4-12 summarizes the monthly and annual flow at Vernalis from 2004 to 2023. Annual flows at Vernalis ranges from 622 TAF/y to 7,388 TAF/y, with an average of 2,741 TAF/y. Water from the Tuolumne River can represent a significant portion of the flow entering the southern Delta as shown in Figure 4-3, which compares the timeseries of observed monthly flow on the Tuolumne River at Modesto with the observed monthly flow on the LSJR at Vernalis from 2013 to 2023. On average, the Tuolumne River contributes about 33% of the flow at Vernalis (910 TAF at Modesto compared to 2,741 TAF at Vernalis), but the contribution is higher in wet years at 37% (2,398 TAF at Modesto compared to 6,517 TAF at Vernalis). For non-wet years flow from the Tuolumne represents about 24% of the flow at Vernalis (273 TAF at Modesto compared to 1,122 TAF at Vernalis).

Table 4-12. Summary of Monthly and Annual Flow on the San Joaquin River at Vernalis from 2004–2023 (in TAF).

Percentile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual [a]
10%	47	51	57	64	58	58	68	50	33	17	16	17	622
20%	63	60	64	68	77	77	99	103	43	28	24	22	746
30%	76	66	70	96	86	95	110	125	63	36	33	41	1,009
40%	90	70	76	112	120	124	129	148	71	54	40	54	1,288
50%	108	83	85	120	130	130	143	178	90	59	53	57	1,425
60%	113	96	96	139	136	176	233	286	102	77	61	60	1,688
70%	135	102	117	152	213	387	529	511	451	172	128	111	2,442
80%	162	116	137	471	320	767	984	719	677	290	205	156	5,015
90%	182	128	218	792	481	1,078	1,588	1,246	854	401	240	193	7,388
Wet Year Average [b]	110	89	161	590	581	1,053	1,272	1,065	815	367	237	179	6,517
Non-Wet Year Average [b]	119	89	98	103	100	117	142	146	75	48	40	45	1,122
Overall Average	117	89	116	249	244	398	481	421	297	144	99	85	2,741

Source: USGS gage 11303500 (USGS n.d.(c)).

[a] The values of the annual cumulative distribution do not equal the total of the monthly values but instead represent the distribution of actual annual values.

[b] The Wet Year Average includes 2005, 2006, 2011, 2017, 2019, and 2023.

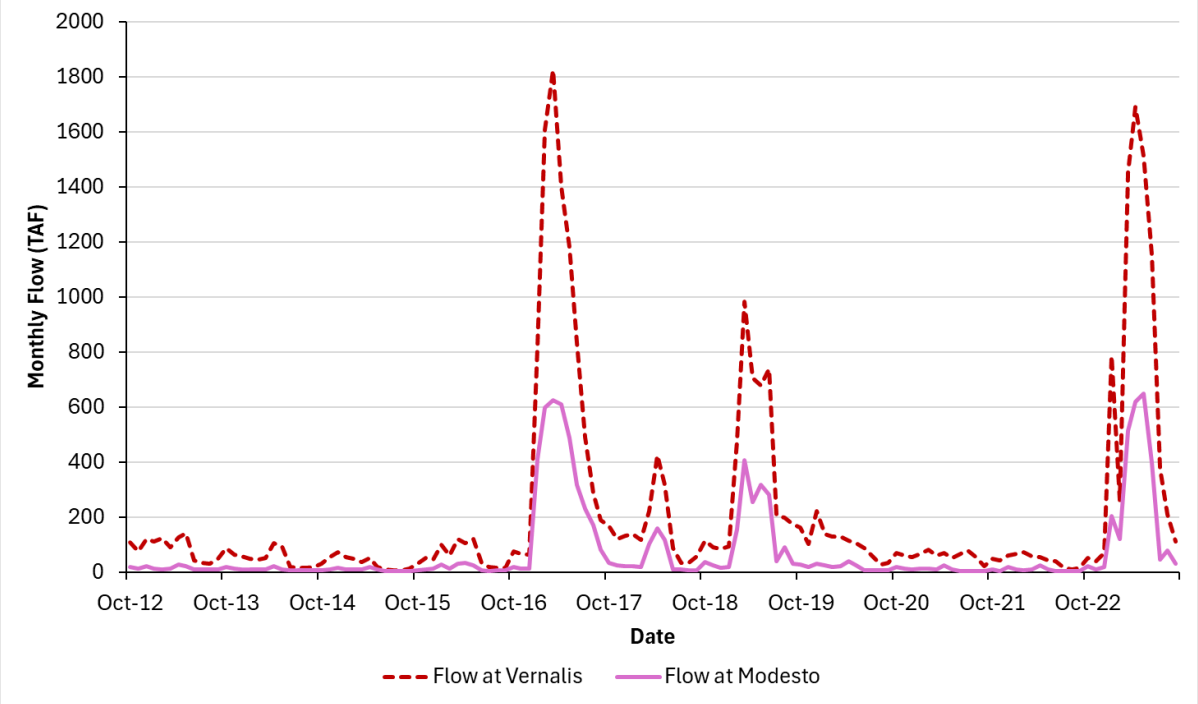


Figure 4-3. Timeseries of Monthly Flow in the Tuolumne River at Modesto Compared with the flow in the San Joaquin River at Vernalis for Water Years 2013 Through 2023 (USGS n.d.(b); USGS n.d.(c)).

4.3 TVA Overview

The proposed TVA is described in the November 9, 2022, "Memorandum of Understanding Advancing a Term Sheet for the Voluntary Agreements to Update and Implement the Bay-Delta Water Quality Control Plan, and Other Related Actions–Revised" (MOU).[4] The MOU provides a narrative description of the TVA proposal and includes a summary of the flow commitments to be released from La Grange Dam during January through June of each year during the term of the VA. Further details were provided by the TVA parties (TID, MID, and CCSF) in April of 2023, and again in June of 2024, indicating that the VA flow proposal is based on the recommended requirements described in the 2020 FERC FEIS, with a few modifications (TID, MID, CCSF 2023; TID, MID, CCSF 2024). Note that the 2020 FERC FEIS requirements include flow requirements year-round, not just during the January to June period of the TVA. Though the process to complete FERC relicensing for New Don Pedro and La Grange is ongoing, the January through June baseflow and pulse flow recommendations from the FEIS are essentially the same as TVA proposal.

[4] Available at https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/2023/revised-va-mou-swrcb-copy.pdf.

4.3.1 TVA Flow Requirements

The flow commitments proposed by the TVA parties to improve habitat for native fish consist of minimum baseflows, outmigration pulse flows, and floodplain inundation pulse flows. Each of these components of the proposed flow commitments are described below. Table 4-13 presents the January through June TVA baseflow requirements, which are the same as the proposed January through June baseflow requirements in the 2020 FERC FEIS. Baseflow requirements are proposed to be measured at the La Grange Diversion Dam and determined based on the SJR WYT. Because the TVA only proposes January through June flows, flows during July through December would depend on New Don Pedro's FERC license requirements. If the VA were in place today, July through December flows would be governed by the 1995 FERC settlement agreement, but that could change in the future if the new FERC license requirements are approved. As mentioned above, it is unclear how long the relicensing process could take and it may not be completed until part way through the term of the TVA, depending on when and if the VA is approved and when the new FERC license is issued.

Table 4-13. TVA January Through June Baseflow Requirements at La Grange Dam (in cfs).

Period	Days in Period	Critically Dry	Dry	Below Normal	Above Normal	Wet
January	31	175	200	225	225	225
February	28/29	175	200	225	225	225
March	31	200	225	250	250	250
April 1–15	15	200	225	250	250	250
April 16–30	15	200	250	275	275	275
May 1–15	15	200	250	275	275	275
May 16–31	16	225	275	300	300	300
June [a]	30	200 (125)	200 (125)	200 (150)	200 (150)	200 (150)

[a] Values in parentheses are the interim release requirements at La Grange Dam to be provided until both IGs are operational (see below).

Table 4-14 and Table 4-15 describe the outmigration and floodplain pulse flows associated with the TVA, including the duration, volume, and assumed timing. As with the baseflows, the pulse flow requirements are based on the pulses described in the 2020 FERC FEIS and depend on SJR WYT. The TVA makes no changes to the outmigration pulse, but the TVA does add an additional 10 TAF to the March floodplain pulse in BN years without off-ramps and for all D and C years, both with and without off-ramps. In addition, the TVA redefines the target flow for the inundations pulse to be 1,700 cfs, instead of 2,750 cfs in the 2020 FERC FEIS, so that the release duration can be increased. Dry year off-ramps are still applied for both pulses under the TVA consistent with the 2020 FERC FEIS.

Table 4-14. Representation of the Outmigration Pulse Flow under the TVA in WSE.

SJR WYT	Pulse Period Start Date [a]	Pulse Period End Date [a]	Pulse Length (Days)	Total Pulse Volume (AF) [b]	April Pulse Volume (AF) [c]	May Pulse Volume (AF) [c]
Wet	17-Apr	30-May	44	150,000	44,000	106,000
Above Normal	17-Apr	30-May	44	150,000	44,000	106,000
Below Normal	17-Apr	30-May	44	100,000	29,333	70,667
Dry	17-Apr	30-May	44	75,000	22,000	53,000
Critically Dry	17-Apr	30-May	44	35,000	10,267	24,733
Dry Year Off-Ramp	17-Apr	30-May	44	45,000	13,200	31,800
Critically Dry Year Off-Ramp	17-Apr	30-May	44	11,000	3,227	7,773

[a] Includes 6 days of up ramping in April (17–22) and 7 days of down ramping in May (24–30).

[b] Pulse volumes in this table are in addition to 2020 FERC FEIS baseflows.

[c] The April and May Pulse Volumes represent how the Total Pulse Volume is divided between the two months, based on the information provided by the TVA Parties (TID, MID, CCSF 2024).

Table 4-15. Representation of the Floodplain Inundation Pulse Flow under the TVA in WSE.

Water Year Type	Pulse Period Start Date	Pulse Period End Date	Pulse Length (Days)	Target Flow Rate (cfs) [a]	Pulse Volume (AF) [b]	Ramping Volume (AF) [c]	Total Volume (AF)
Wet	10-Mar	12-Apr	34	1,700	97,785	1,389	99,174
Above Normal	10-Mar	12-Apr	34	1,700	97,785	1,389	99,174
Below Normal	10-Mar	12-Apr	34	1,700	97,785	1,389	99,174
Dry	15-Mar	10-Apr	27	1,700	78,992	1,124	80,116
Critically Dry	20-Mar	6-Apr	18	1,700	53,554	1,967	55,521
Below Normal Year Off-Ramp	21-Mar	12-Apr	23	1,700	66,149	3,272	69,421
Dry Year Off-Ramp	20-Mar	22-Mar	3	1,700	8,777	1,223	10,000
Critically Dry Year Off-Ramp	20-Mar	22-Mar	3	1,700	8,926	1,074	10,000

[a] Target flow rate is inclusive of the baseflow required during the timing of the pulse flow. The baseflow requirements from March 1 through April 15 are 200 cfs for critical years, 225 cfs for dry years, and 250 cfs for below normal, above normal, and wet years.

[b] Pulse volume is the release needed to meet the target flow rate minus the baseflow over the pulse length.

[c] The ramping volume is assumed to be divided in half to provide 1 day of up ramping the day before the pulse period start date and 1 day of down ramping the day after the pulse period end date.

4.4 Hydrologic Modeling Analysis of the TVA

To explore the potential hydrologic effects of the TVA, a comparative modeling analysis was performed for the Tuolumne River using the WSE model. WSE is a spreadsheet-based, hydrologic water balance model for the LSJR and the three eastside tributaries, the Stanislaus, Tuolumne, and Merced Rivers (eastside tributaries). The model domain for the Tuolumne River extends from New Don Pedro Reservoir down to the confluence with the LSJR. Model output is generated on a monthly timestep from 1922 to 2003, using historical Don Pedro Reservoir inflow estimates from the CALSIM II model, but assuming a current level of development (e.g., water demands and infrastructure). For more information on WSE please see Appendix B to this report and Appendix F.1, *Hydrologic and Water Quality Modeling*, to the 2018 Final SED.

For this analysis, the proposed TVA was simulated in WSE, and results were compared to existing conditions and with UF levels representing the regulatory conditions described in the 2018 Bay-Delta Plan. The model results compared here are the required and resulting flows in the Tuolumne River and storage in New Don Pedro Reservoir. In addition, flows at Vernalis in the SJR are compared between VA alternatives and existing conditions to understand how flow changes in the Tuolumne River would contribute to Delta outflows and associated environmental conditions.

In addition to the WSE modeling analysis, the TVA parties provided a spreadsheet analysis of the TVA that models how the TVA would have been implemented over the 1999 to 2023 period, assuming no reduction in diversion from historical levels under the TVA (TID, MID, CCSF 2025). Unlike WSE, the TVA parties' spreadsheet model operates on a daily timestep over the period from 1999 to 2023 and includes representation of upstream CCSF storage and diversions. The TVA parties' spreadsheet model also includes initial accounting procedures and conducts a preliminary analysis of how the TVA could affect Delta outflow. Modeled TVA flow contributions from this analysis are presented and discussed below, and where possible, these results are compared to the results of the WSE model analysis. Additional details on the TVA parties' model and analysis can be found in Appendix C, *Draft Tuolumne Accounting Spreadsheet Model*.

4.4.1 Tuolumne River Modeling Methods and Results Using WSE

4.4.1.1 Description of Tuolumne River Modeling Alternatives

Existing Conditions[5]

To evaluate the TVA, expected conditions under the TVA are compared to conditions existing as of 2023, which is the water year when the TVA was submitted. The flow requirements in the Tuolumne River during this period are the FERC flows defined in the 1995 settlement agreement, as described in Section 4.2.2. Irrigation district water demands are modeled based on the most recent information from CALSIM II and district AWMPs. Water is allocated within WSE to meet demands as described in Appendix F.1 of the 2018 Final SED. New Don Pedro Reservoir operation parameters were determined based on calibration to the CALSIM II model and are described in Appendix B.

[5] The Existing Conditions modeling scenario is referred to as Baseline within the WSE model and in Appendix B.

Assumptions and modeling for the Merced and Stanislaus Rivers do not affect results on the Tuolumne River, but they are important to understand the flows in the SJR, including at Vernalis. The flow standards modeled in the existing conditions scenario for the Merced River are the 1964 FERC minimum flow requirements for Lake McClure plus releases made under the Cowell Agreement. The flow requirements modeled in this scenario for the Stanislaus River are the New Melones Reservoir Stepped Release Plan requirements and the dissolved oxygen objective below Goodwin Dam. In addition, New Melones Reservoir is responsible for meeting Water Right Decision 1641 (D-1641) flow and salinity requirements at Vernalis. Flow requirements on the Merced and Stanislaus Rivers are described in more detail in Appendix B. As with the Tuolumne River, Merced and Stanislaus River water demands are modeled based on the most recent information available from CALSIM II and district AWMPs and water is allocated in WSE to meet those demands as described in Appendix F.1 of the 2018 Final SED. Reservoir operation parameters for Lake McClure and New Melones Reservoir have not changed from the values used in WSE modeling for the 2018 Final SED.

Unimpaired Flow Objective Scenarios

The UF objectives scenarios assume implementation of the 2018 Bay-Delta Plan UF objectives in the Stanislaus, Tuolumne, and Merced Rivers. The 2018 Bay-Delta Plan requires 40% UF at the confluence of each tributary with the LSJR during February through June, with an adaptive range that can be adjusted between 30% UF and 50% UF. As such, three separate UF objective scenarios are included, with requirements of 30%, 40%, and 50% UF, to show the range of conditions that could be expected under the Bay-Delta Plan. For these scenarios, the Bay-Delta Plan UF objectives apply February through June, while requirements during July through January are the same as in the existing conditions scenario for all tributaries. For the 40% and 50% UF modeling scenarios, flow shifting is applied as described in Appendix F.1 of the 2018 Final SED, thereby shifting a portion of the February through June required volume to the fall to manage temperature conditions. On the SJR at Vernalis, D-1641 February through June flow requirements are replaced by a minimum flow requirement of 1000 cfs with responsibility divided between all three tributaries. These scenarios also include updated reservoir operations compared to the existing conditions to maintain water supply reliability and maintain stream temperatures to avoid impacts to fish (see Appendix B for more detail on the reservoir parameters and values used). All other parameters and assumptions for these model runs are the same as in the existing conditions scenario.

TVA

The TVA (or TVA MOU) scenario represents the TVA flows applying from January through June, as described in Section 4.3.1. During the July through December period, it is assumed that current flow requirements under the 1995 FERC settlement agreement apply. The proposed IG diversions are not included as part of this alternative and the baseflow requirements in June are the interim values defined in Table 4-13. In addition, based on assumptions in the Tuolumne River accounting spreadsheet provided by the TVA parties (TID, MID, CCSF 2025), it is assumed that there will be no reduction in Tuolumne River diversions compared to existing conditions. All other parameters and assumptions in this alternative are the same as in the existing conditions scenario.

TVA with 2020 FERC

A second TVA alternative is analyzed to explore the effects of the January through June VA proposal in combination with the July through December 2020 FERC FEIS recommendations, as described in Table 4-4. It is assumed in this alternative that the IGs are operational (see Table 4-5 IG diversion volumes) and that non-interim baseflow requirements from Table 4-4 and Table 4-13 are applied during the IGs period of use, from June 1 through October 15. Based on the VA party modeling, the IG diversions estimated in June are reduced from 100 to 50 cfs during BN, AN, and W years. As in the TVA MOU alternative, it is assumed that there will be no reduction in Tuolumne River diversion compared to existing conditions. All other parameters and assumptions for this alternative are the same as in the existing conditions scenario.

Summary of Modeling Scenarios

Table 4-16 summarizes the modeling alternatives used to analyze the effects of the TVA on the Tuolumne River.

Table 4-16. Summary of Tuolumne River Analysis Scenarios.

Scenario	January–June Flow Requirements	July–December Flow Requirements	IG Operations	Flow Shifting
Existing Conditions	1995 FERC	1995 FERC	Not Operational	None
30% UF Objective	• *January:* 1995 FERC • *February–June:* 30% UF Objective	1995 FERC	Not Operational	None
40% UF Objective	• *January:* 1995 FERC • *February–June:* 40% UF Objective	1995 FERC	Not Operational	As described in Appendix F.1 of the 2018 Final SED
50% UF Objective	• *January:* 1995 FERC • *February–June:* 50% UF Objective	1995 FERC	Not Operational	As described in Appendix F.1 of the 2018 Final SED
TVA	Based on the MOU and the 2020 FERC FEIS	1995 FERC	Not Operational	None
TVA+2020FERC	Based on the MOU and the 2020 FERC FEIS	2020 FERC FEIS	Operational	None

4.4.1.2 Evaluation of Changes in Hydrology

Required Flow in the Tuolumne as Represented in WSE

Figure 4-4 through Figure 4-8 show the monthly flow requirements (not including other flows that may be present in the system, such of flood flows and return flows) under existing conditions, the UF scenarios, and the TVA scenarios during January through June for each SJR WYT. Multiple water year classifications from the 1995 FERC Settlement Agreement (abbreviated as 1995 FERC) are presented in each graph because the 1995 year type classifications do not perfectly align with SJR WYTs, as shown in Table 4-2.[6] The flows shown for the UF objectives represent the average monthly UF requirement for each WYT at the confluence of the Tuolumne during February through June, before flow shifting is applied. Table 4-17 summarizes the average January through June flow requirements under the modeled scenarios by SJR WYT (in both TAF and as a % of January through June UF). Table 4-18 summarizes the change in total January through June flow requirements under the TVA and UF objectives relative to existing conditions.

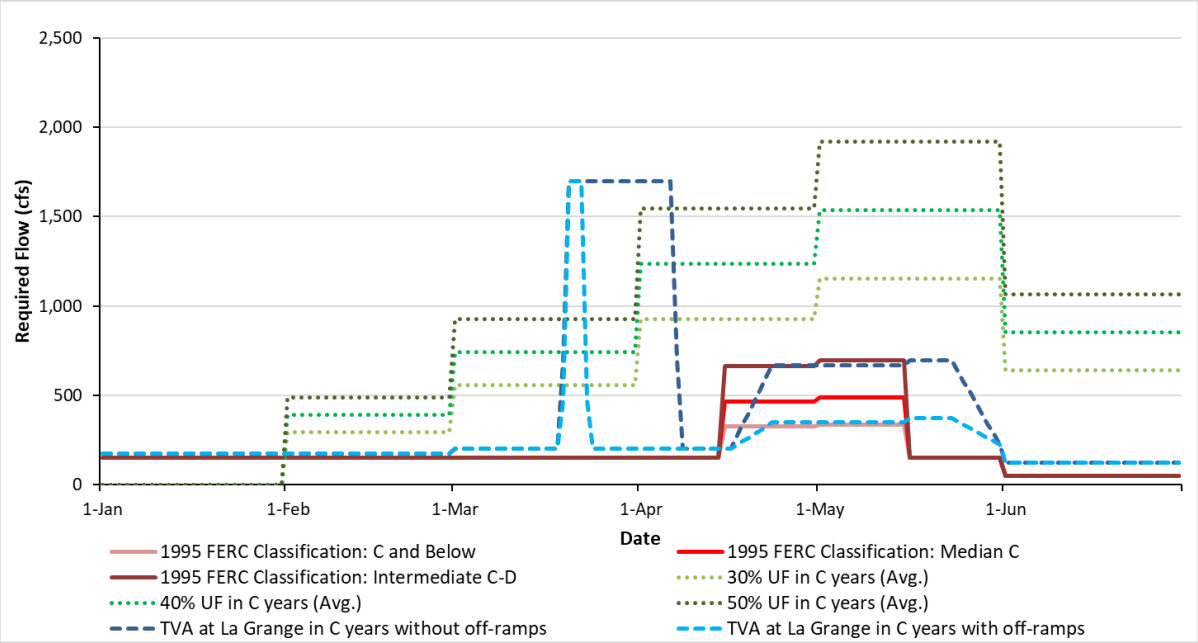


Figure 4-4. Critical (C) Year January Through June Flow Requirements in the Tuolumne River Under Existing Conditions, the UF Objective, and the TVA Scenarios.

[6] Note that the April pulse flow volume under the 1995 FERC requirements is assumed to be released entirely between April 15 and April 30 to be consistent with how the settlement agreement defined when the flow schedule starts and ends, from April 15 to April 14 of the next calendar year. The pulse end date is set to May 15 to be consistent with VA party modeling of the current conditions (TID, MID, CCSF 2024).

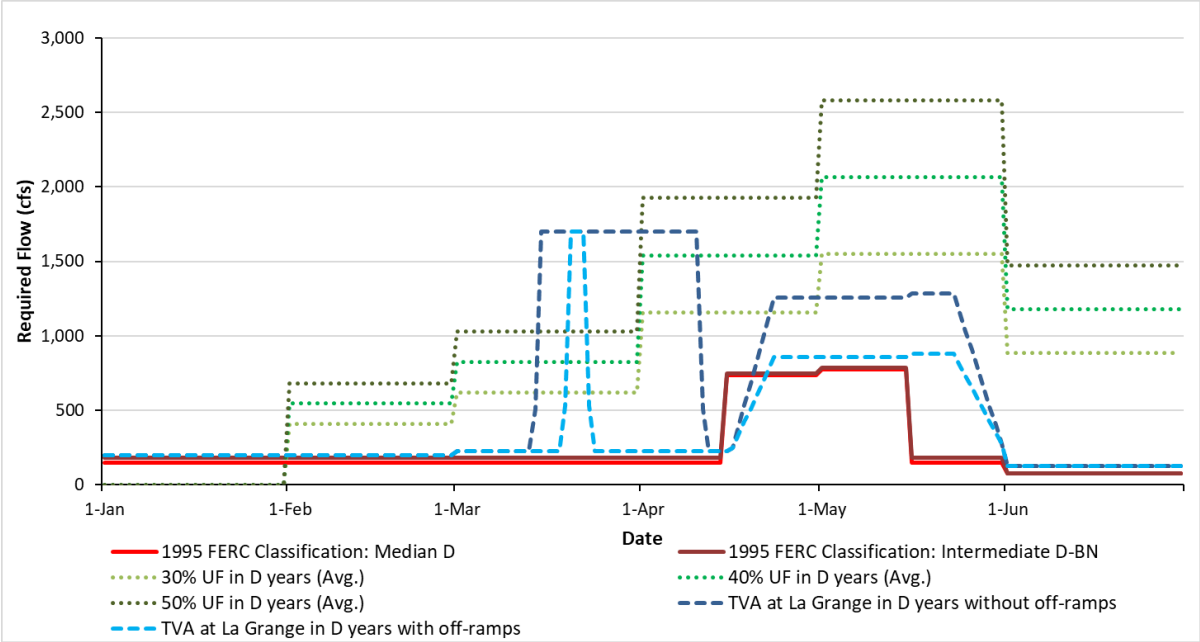


Figure 4-5. Dry (D) Year January Through June Flow Requirements on the Tuolumne River Under Existing Conditions, the UF Objective, and the TVA Scenarios.

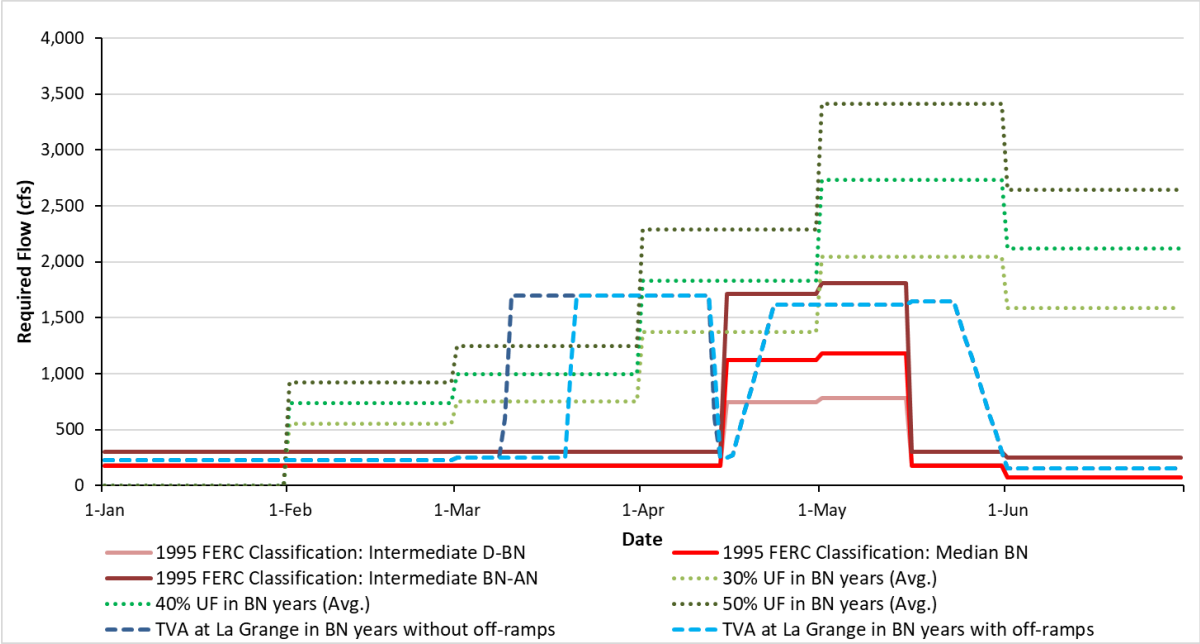


Figure 4-6. Below Normal (BN) Year January Through June Flow Requirements on the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and the TVA.

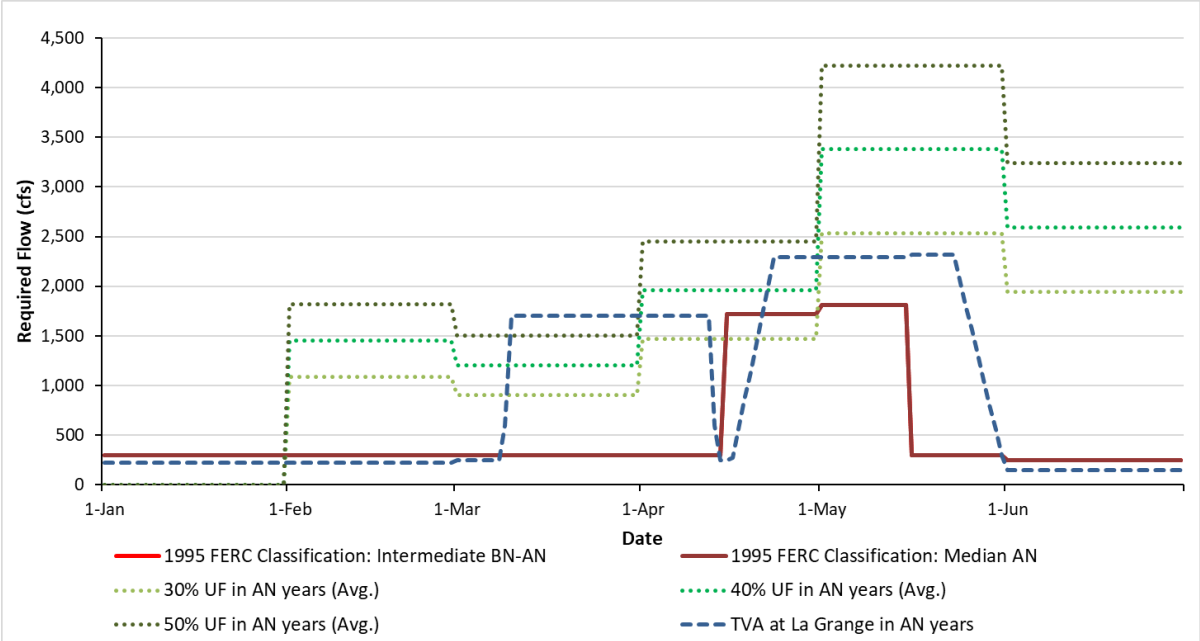


Figure 4-7. Above Normal (AN) Year January Through June Flow Requirements on the Tuolumne River Under Existing Conditions, the UF Objective, and the TVA Scenarios.

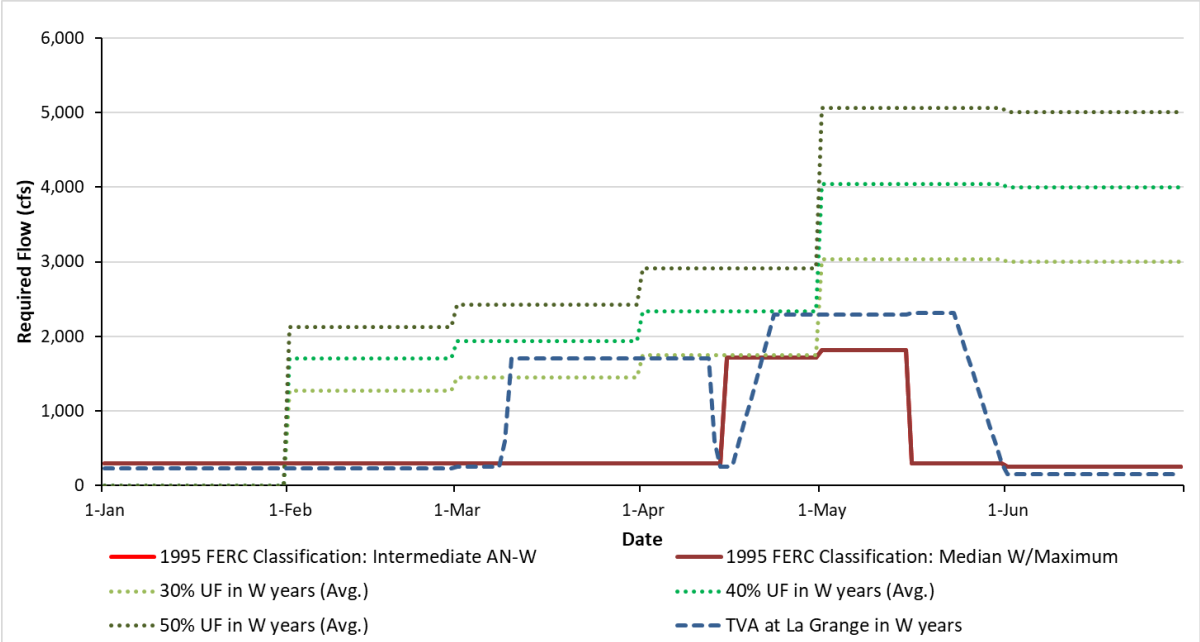


Figure 4-8. Wet (W) Year January Through June Flow Requirements on the Tuolumne River Under Existing Conditions, the UF Objective, and the TVA Scenarios.

Table 4-17. Required Flow from January Through June Averaged by SJR WYT in the Tuolumne River Under the Modeled Scenarios (in TAF and as a % of January Through June UF).

SJR WYT	Jan–Jun Unimpaired Flow	Existing Conditions [a]		30% UF Objective [b, c]		40% UF Objective [b, c]		50% UF Objective [b, c]		TVA	
Overall	1,533	129	8%	437	28%	578	38%	718	47%	233	15%
Wet	2,349	181	8%	644	27%	854	36%	1,064	45%	330	14%
Above Normal	1,724	154	9%	488	28%	646	37%	805	47%	283	16%
Below Normal	1,325	106	8%	393	30%	519	39%	645	49%	200	15%
Dry	976	100	10%	293	30%	386	40%	478	49%	180	18%
Critical	743	71	10%	226	30%	297	40%	369	50%	109	15%

[a] 1995 FERC settlement agreement flows are required at La Grange Dam.

[b] UF requirements are required at Modesto.

[c] Volumes represent the specified percentage of average February through June UF, plus the January required flow under the 1995 FERC settlement agreement. The volumes may differ from the specified percentage of the UF objective because that objective only refers to the percentage of UF from February through June.

Table 4-18. Change in Required Flow from January Through June in the Tuolumne River Averaged by SJR WYT Under the TVA and UF Objective Scenarios Relative to Existing Conditions (in TAF).

SJR WYT	TVA minus Existing Conditions	30% UF Objective minus Existing Conditions	40% UF Objective minus Existing Conditions	50% UF Objective minus Existing Conditions
Overall	104	307	448	589
Wet	149	463	673	883
Above Normal	129	334	492	651
Below Normal	94	287	414	540
Dry	80	194	286	378
Critical	38	155	226	298

Resulting Flow on the Tuolumne

Resulting flow is the flow modeled in WSE when implementing the required flows for each scenario. The resulting flow can be different from the required flow because of flood spills, accretions/depletions, diversions, etc. WSE is configured so that required flow under the alternatives is always met, therefore the resulting flow will either equal the required flow or be greater at the compliance point. At locations downstream of a compliance point it is possible that the resulting flow will fall below the upstream required flow due to depletions (e.g., seepage to groundwater, evaporation, etc.) or diversions.

Figure 4-9 through Figure 4-12 present box plots of monthly resulting flow on the Tuolumne at La Grange displaying the TVA MOU with existing conditions and UF objective scenarios. For the box plots the horizontal line in the center of the box is the median flow, the lower and upper extent of the box represents the interquartile range (25th to 75th percentiles respectively) of flows, and the whiskers show the minimum and maximum values over the modeled hydrologic record. Table 4-19 summarizes the average total January through June resulting flow at La Grange Dam under the modeled scenarios by SJR WYT. Table 4-20 summarizes the change in average January through June resulting flow under the TVA and UF objectives relative to existing conditions. Table 4-21 presents average January through June resulting flow at Modesto under existing conditions and the TVA scenarios, respectively. The changes shown in Table 4-22 represent the modeled change in outflow from the Tuolumne River under the TVA and UF objectives relative to existing conditions.

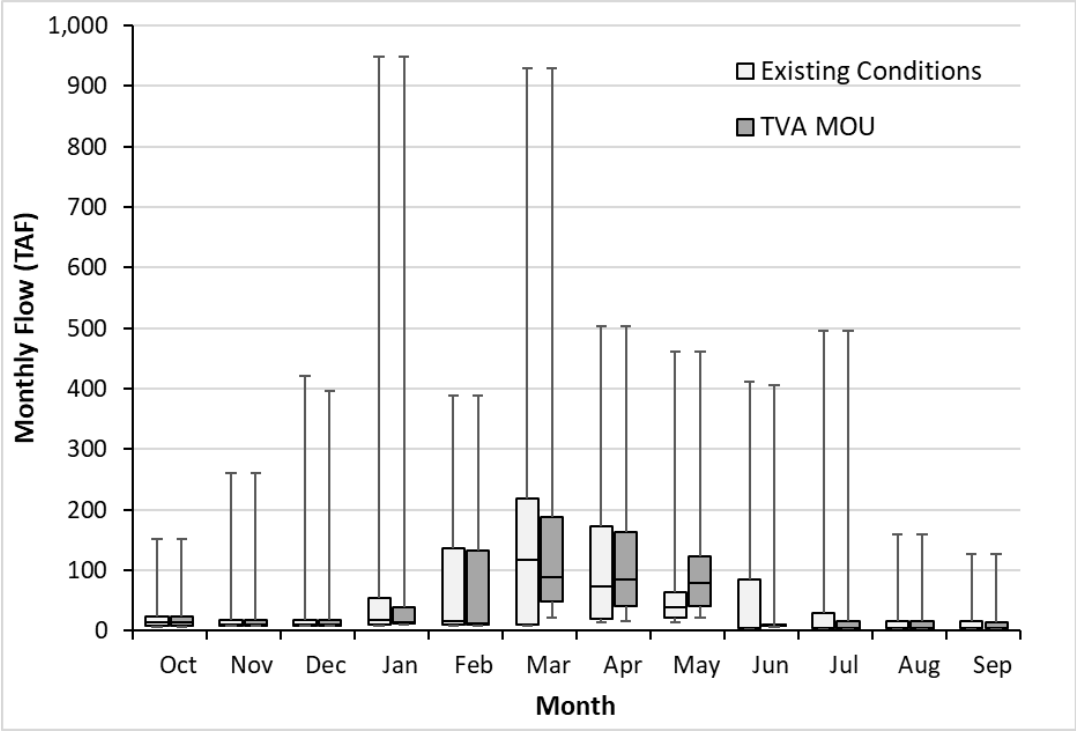


Figure 4-9. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Dam Under Existing Conditions and the TVA.

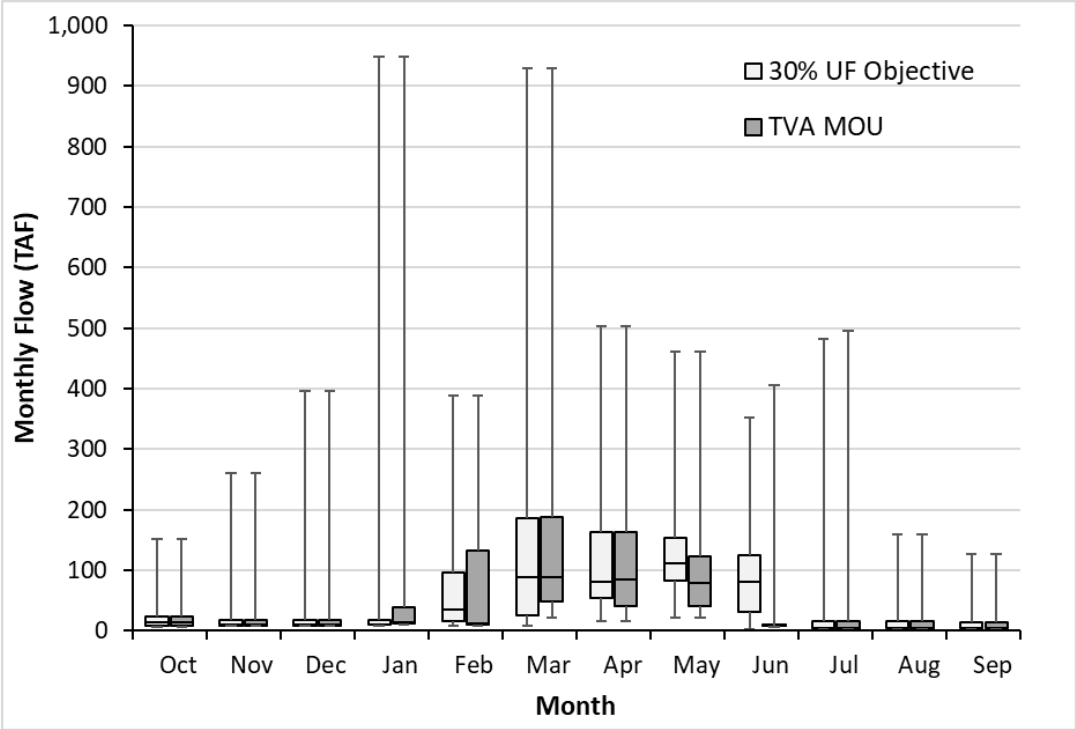


Figure 4-10. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Dam Under the 30% UF Objective and the TVA.

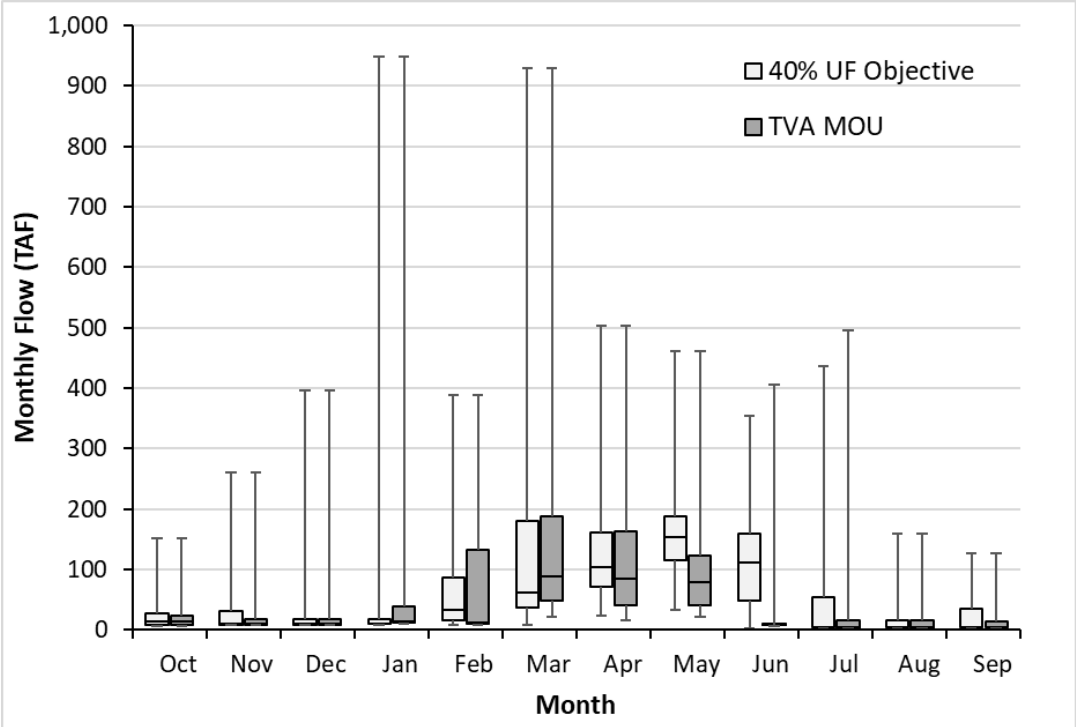


Figure 4-11. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Dam Under the 40% UF Objective and the TVA.

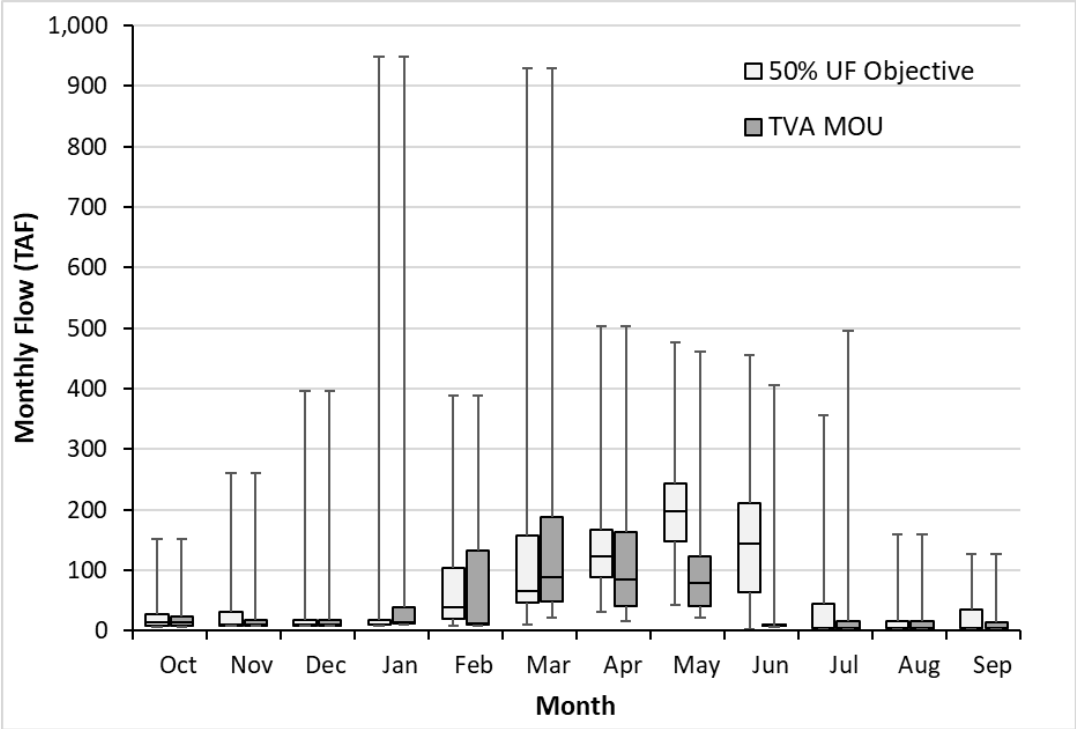


Figure 4-12. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Dam Under the 50% UF Objective and the TVA.

Table 4-19. Average Resulting Flow from January Through June in the Tuolumne River at La Grange Dam Under the Modeled Scenarios (in TAF and as a % of January Through June UF).

SJR WYT	Jan – Jun Unimpaired Flow	Existing Conditions		30% UF Objective		40% UF Objective [a]		50% UF Objective [a]		TVA	
Overall	1,533	534	35%	611	40%	653	43%	738	48%	546	36%
Wet	2,349	1,187	51%	1,184	50%	1,163	50%	1,233	52%	1,159	49%
Above Normal	1,724	551	32%	676	39%	738	43%	844	49%	557	32%
Below Normal	1,325	245	18%	368	28%	443	33%	557	42%	277	21%
Dry	976	166	17%	251	26%	319	33%	404	41%	208	21%
Critical	743	71	10%	176	24%	242	33%	310	42%	109	15%

[a] Flow shifting is applied in wet years under the 40% and 50% UF Objectives to shift up to 25% of the required flow in February through June to the fall.

Table 4-20. Change in Average Resulting Flow from January Through June in the Tuolumne River at La Grange Dam Under the TVA and UF Objective Scenarios Relative to Existing Conditions (in TAF).

SJR WYT	TVA minus Existing Conditions	30% UF Objective minus Existing Conditions	40% UF Objective minus Existing Conditions	50% UF Objective minus Existing Conditions
Overall	12	77	119	204
Wet	-28	-3	-24	46
Above Normal	6	125	187	293
Below Normal	32	123	198	312
Dry	42	85	153	238
Critical	38	105	171	239

Table 4-21. Average Resulting Flow from January Through June on the Tuolumne River at Modesto Under the Modeled Scenarios (in TAF and as a % of January Through June UF).

SJR WYT	Jan – Jun Unimpaired Flow	Existing Conditions		30% UF Objective		40% UF Objective [a]		50% UF Objective [a]		TVA	
Overall	1,533	649	42%	725	47%	767	50%	853	56%	661	43%
Wet	2,349	1,330	57%	1,327	56%	1,306	56%	1,376	59%	1302	55%
Above Normal	1,724	673	39%	797	46%	860	50%	965	56%	679	39%
Below Normal	1,325	359	27%	482	36%	557	42%	670	51%	391	29%
Dry	976	268	27%	353	36%	421	43%	506	52%	310	32%
Critical	743	148	20%	252	34%	318	43%	387	52%	186	25%

[a] Flow shifting is applied in wet years under the 40% and 50% UF Objectives to shift up to 25% of the required flow in February through June to the fall.

Table 4-22. Change in Average Resulting Flow from January Through June in the Tuolumne River at Modesto Under the TVA and UF Objective Scenarios Relative to Existing Conditions (in TAF).

SJR WYT	TVA MOU minus Existing Conditions	30% UF Objective minus Existing Conditions	40% UF Objective minus Existing Conditions	50% UF Objective minus Existing Conditions
Overall	12	77	119	204
Wet	-28	-3	-24	46
Above Normal	6	125	187	293
Below Normal	32	123	198	312
Dry	42	85	153	238
Critical	38	105	171	239

New Don Pedro Reservoir Storage

Figure 4-13 through Figure 4-16 present the timeseries of monthly storage levels in New Don Pedro Reservoir over the entire modeling period in WSE for the TVA and compares it with the storage timeseries for existing conditions and for the UF objective scenarios. Figure 4-17 presents an exceedance chart of end-of-September storage in New Don Pedro Reservoir, which summarizes the range of carryover[7] storage levels that occur in the model under each scenario. End-of-September carryover storage is important because it represents the amount of cold-water (often referred to as the cold-water pool) stored in the reservoir. Typically, higher carryover storage levels help provide colder release temperatures, which is particularly important during the salmon spawning season to promote reproductive success. Table 4-23 summarizes the average September carryover storage in New Don Pedro Reservoir under the modeled alternatives by SJR WYT. Table 4-24 summarizes the change in average September carryover storage in New Don Pedro Reservoir, by SJR WYT, under the TVA and UF objectives relative to the existing conditions.

[7] Carryover, or carryover storage, is a term used to describe the reservoir storage level at the end of the water year, which indicates how much water is being carried over from one year to the next.

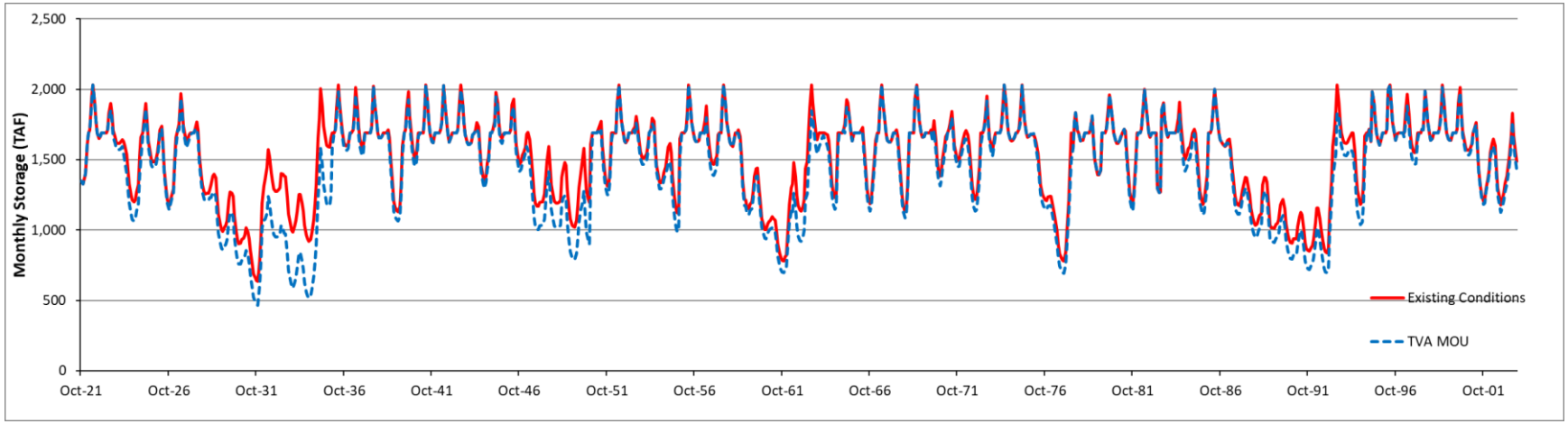


Figure 4-13. Timeseries of End of Month Storage in New Don Pedro Reservoir from 1921 Through 2003 Displaying the TVA with Existing Conditions.

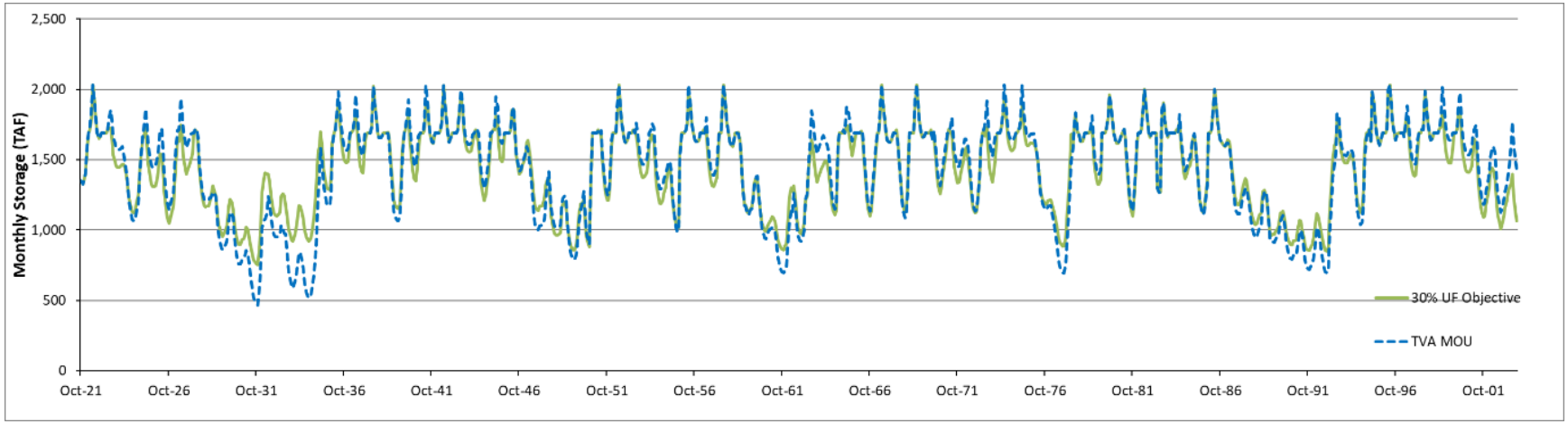


Figure 4-14. Timeseries of End of Month Storage in New Don Pedro Reservoir for 1921 Through 2003 Displaying the TVA with the 30% UF Objective.

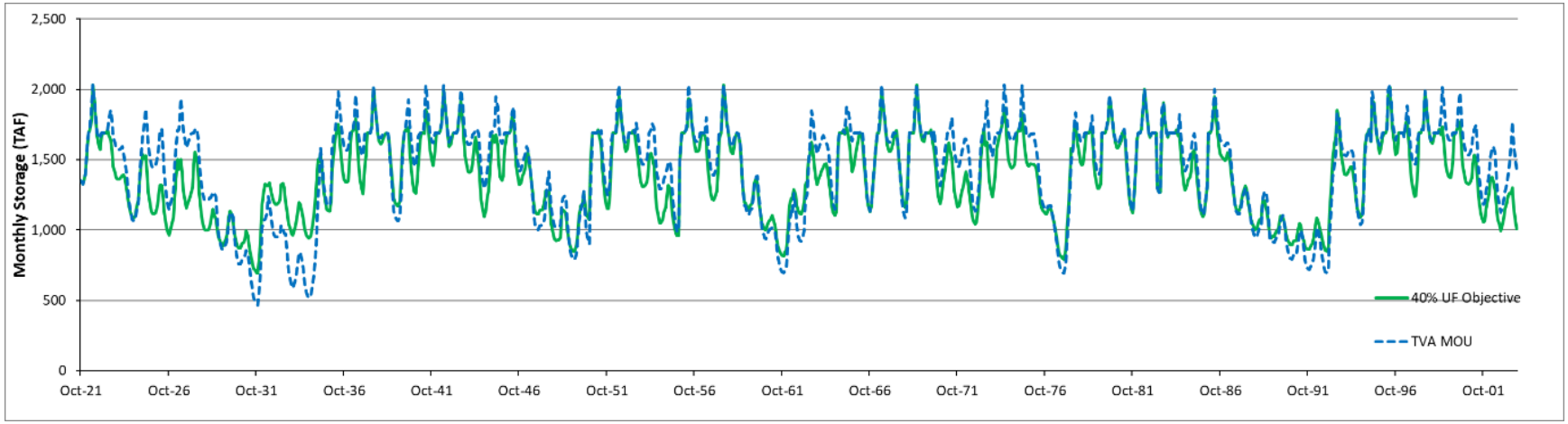


Figure 4-15. Timeseries of End of Month Storage in New Don Pedro Reservoir for 1921 Through 2003 Displaying the TVA with the 40% UF Objective.

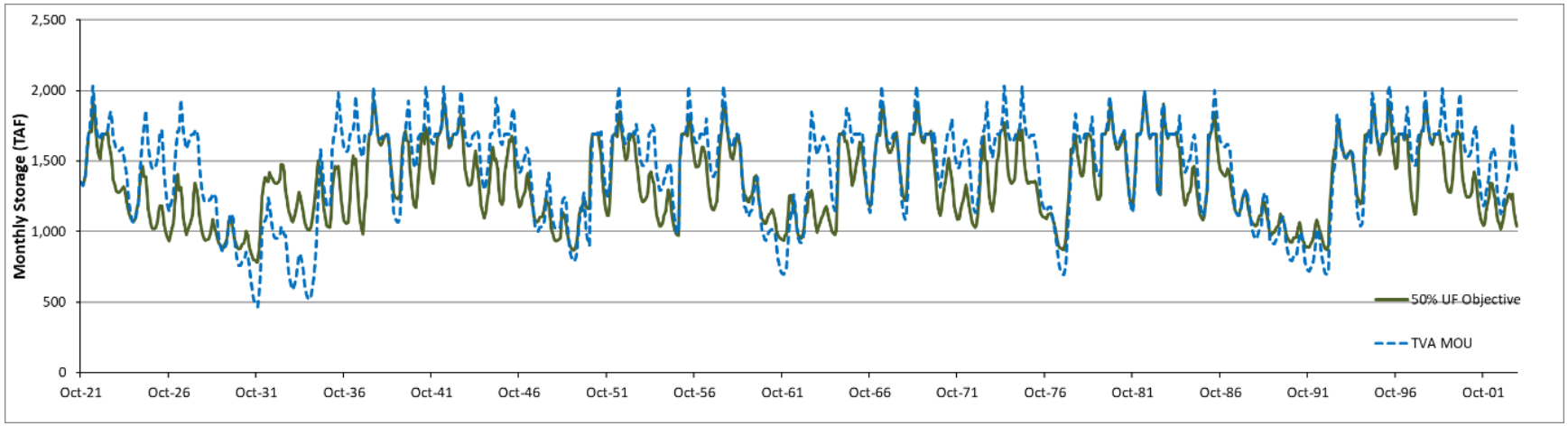


Figure 4-16. Timeseries of End of Month Storage in New Don Pedro Reservoir for 1921 Through 2003 Displaying the TVA with the 50% UF Objective.

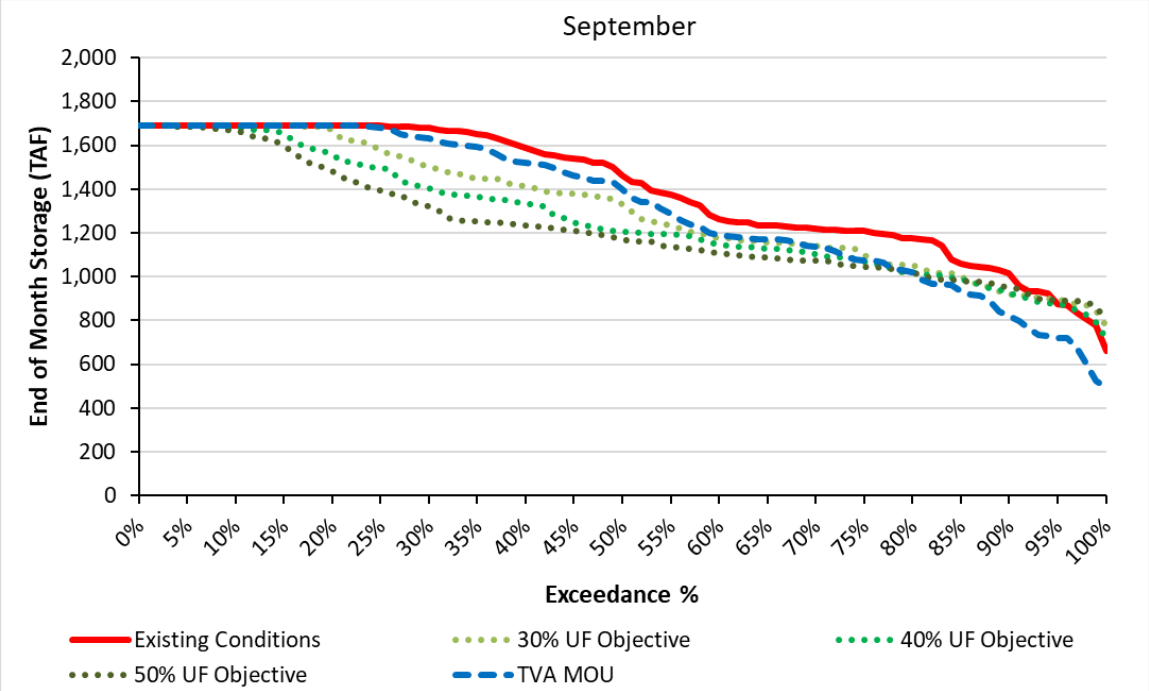


Figure 4-17. Exceedance Chart of End-of-September Storage in New Don Pedro Reservoir Displaying Existing Conditions, the UF Objective Scenarios, and the TVA.

Table 4-23. Average End-of-September Carryover Storage in New Don Pedro Reservoir Under the Modeled Scenarios (in TAF).

SJR WYT	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA
Overall	1,400	1,315	1,264	1,228	1,323
Wet	1,686	1,652	1,603	1,548	1,676
Above Normal	1,573	1,407	1,319	1,207	1,487
Below Normal	1,363	1,178	1,121	1,086	1,256
Dry	1,200	1,118	1,098	1,103	1,104
Critical	989	986	952	987	859

Table 4-24. Change in Average End-of-September Carryover Storage in New Don Pedro Reservoir Under the TVA and UF Objective Scenarios Relative to Existing Conditions (in TAF).

SJR WYT	TVA minus Existing Conditions	30% UF Objective minus Existing Conditions	40% UF Objective minus Existing Conditions	50% UF Objective minus Existing Conditions
Overall	-77	-85	-136	-171
Wet	-10	-34	-83	-137
Above Normal	-86	-166	-254	-366
Below Normal	-106	-185	-242	-277
Dry	-95	-81	-102	-97
Critical	-130	-3	-37	-2

Discussion

January through June required flows under the TVA alternative are higher on average in all WYTs compared to the 1995 FERC requirements. Most of the increase in required flow occurs during the March to May TVA pulse flow periods, although pulse flow off-ramps diminish the amount of additional flow required in successive dry years (i.e., sequential dry year off-ramps). Outside of the pulse periods, TVA base flows in January, February, and June are similar to the levels in the 1995 FERC requirements, with slightly higher flows in drier years and slightly lower flows in wetter years. When comparing the TVA to the UF objective scenarios (30% to 50% UF), the TVA required flows are lower than what would be required on average in the 30% UF scenario, the minimum UF requirement in the adaptive range of the 2018 Bay-Delta Plan, for all WYTs.

Although resulting flows are generally higher under the TVA relative to the 1995 FERC requirements, the increase in resulting flows is not as large as the increase in required flows. This is primarily caused by reservoir reoperation, with the higher flow requirements in dry years lowering reservoir storage levels, allowing the reservoir to store additional water in the future that would have otherwise become flood spill. Compared to existing conditions, January through June resulting flows at La Grange under the TVA increase in all but wet years, though above normal years only see a slight increase. On a monthly basis, the greatest increase in resulting flows under the TVA occurs in May. Compared to the UF objective scenarios, January through June resulting flow at La Grange under the TVA is lower in all year types, though wet years tend to be similar due to flood spills. On a monthly basis, May and June experience generally higher flows with the UF objective requirements in place compared to the TVA. Because the IGs are not operational in the TVA scenario, the change in flow downstream at Modesto between the TVA and existing conditions is the same as the change in flow at La Grange Dam.

With higher instream flow releases under the TVA, greater demand is placed on reservoir storage, particularly during dry years. Under the TVA, reservoir storage averages almost 100 TAF lower in all but wet WYTs compared to existing conditions due to the assumption that diversions in the TVA would not change relative to existing conditions. Compared to the UF objective scenarios, storage remains higher in most years under the TVA as the increase in required flow under the TVA is still much less than under a 30% UF objective. However, during long drought sequences storage under the TVA falls well below what is modeled with the UF objectives because the UF scenarios include carryover storage guidelines to protect cold-water pools.

4.4.1.3 TVA with 2020 FERC Results and Comparison with Existing Conditions and the UF Objective Scenarios

Required Flow on the Tuolumne as Represented in WSE

Figure 4-18 through Figure 4-22 show the monthly required flow under existing conditions, the UF scenarios, and the TVA+2020FERC scenario over the entire year for each SJR WYT. During January through May required flows under the TVA+2020FERC scenario are the same as in the TVA scenario, but during June the required flow is greater because the TVA+2020FERC scenario includes operation of the IGs and proposed non-interim 2020 FERC FEIS flow requirements at La Grange. During July through December, the TVA+2020FERC scenario uses the proposed flow requirements from the 2020 FERC FEIS. Multiple classifications from the 1995 FERC are presented in each graph because they do not perfectly align with the SJR WYTs, as shown in Table 4-2. The flows shown for the UF objectives represent the average monthly UF requirement at the confluence of the Tuolumne River during February through June, before flow shifting is applied. Figure 4-23 through Figure 4-27 focus on the June through October period to compare the required baseflows at La Grange under the TVA+2020FERC with the amount expected to be diverted downstream by the IGs (shaded area). The expected baseflow downstream of the IGs follows the bottom of the shaded area, however, due to accretions/depletions between La Grange and the IGs the actual baseflow downstream of the IGs may not equal the difference between the required La Grange baseflow and the IG diversion. Table 4-25 summarizes the average annual required flows under the modeled scenarios by SJR WYT. Table 4-26 summarizes the change in average annual required flow under the TVA+2020FERC and UF objectives relative to existing conditions.

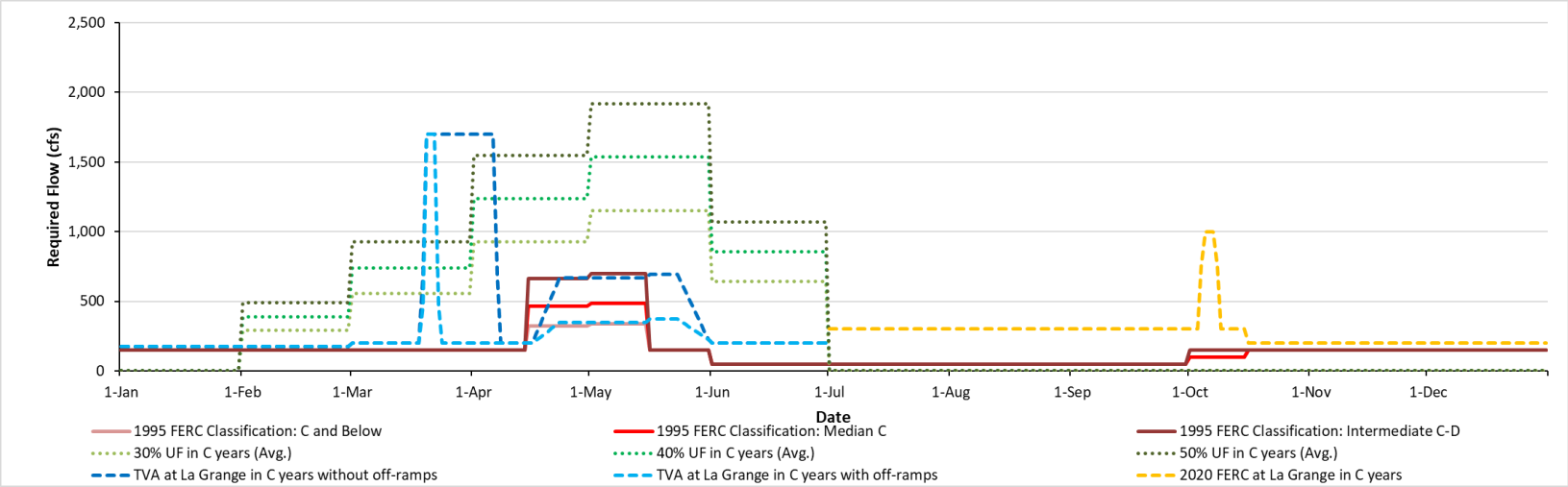


Figure 4-18. Critical (C) Year Annual Required Flows in the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and TVA+2020FERC.

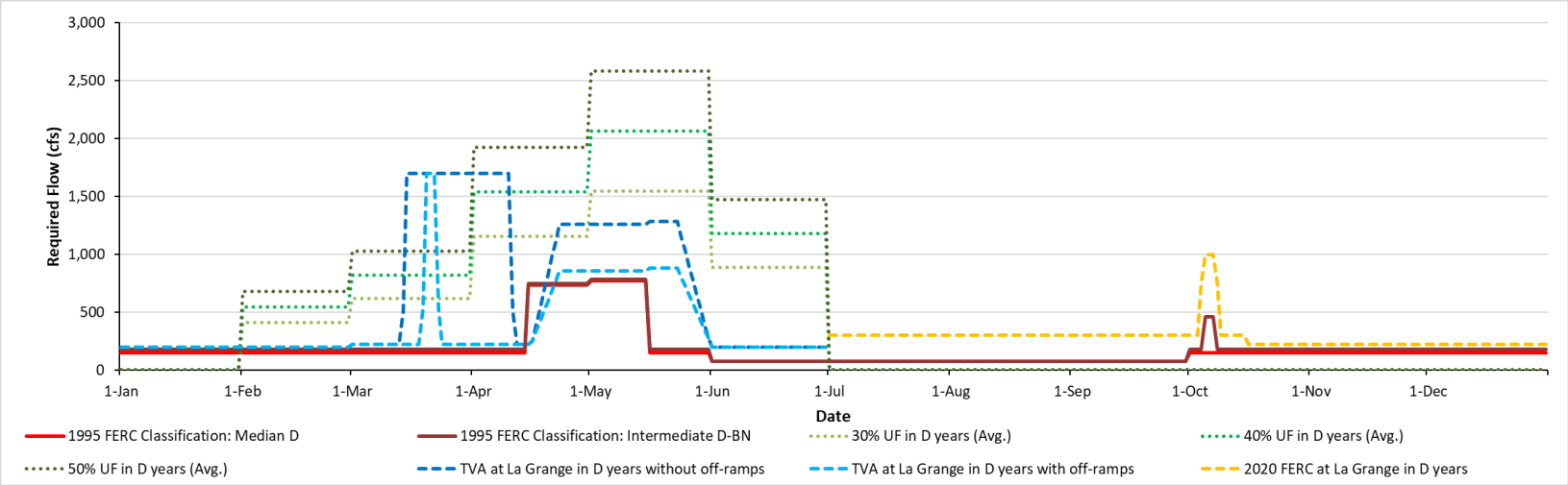


Figure 4-19. Dry (D) Year Annual Required Flows in the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and TVA+2020FERC.

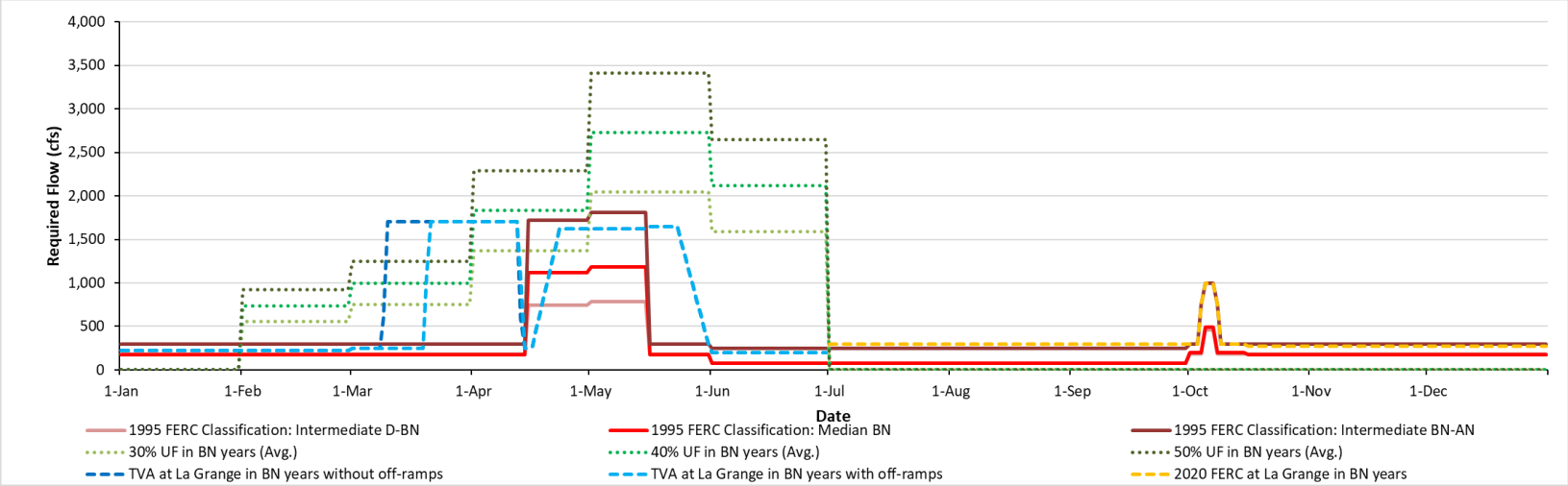


Figure 4-20. Below Normal (BN) Year Annual Required Flow in the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and TVA+2020FERC.

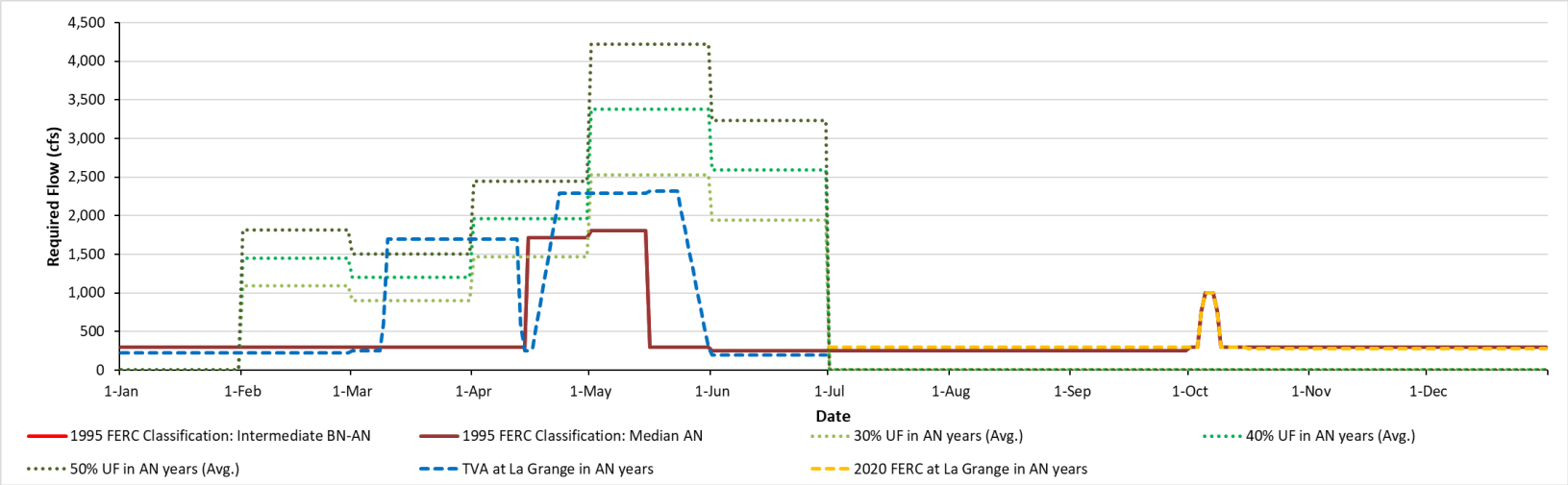


Figure 4-21. Above Normal (AN) Year Annual Required Flows in the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and TVA+2020FERC.

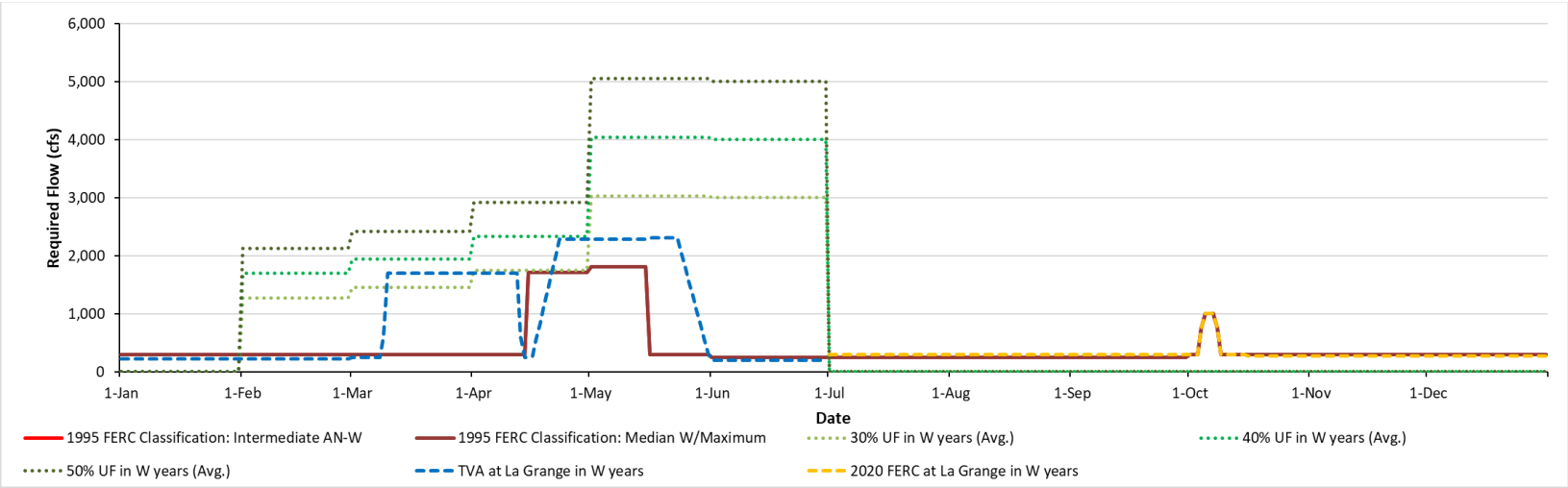


Figure 4-22. Wet (W) Year Annual Required Flows in the Tuolumne River Under Existing Conditions, the UF Objective Scenarios, and TVA+2020FERC.

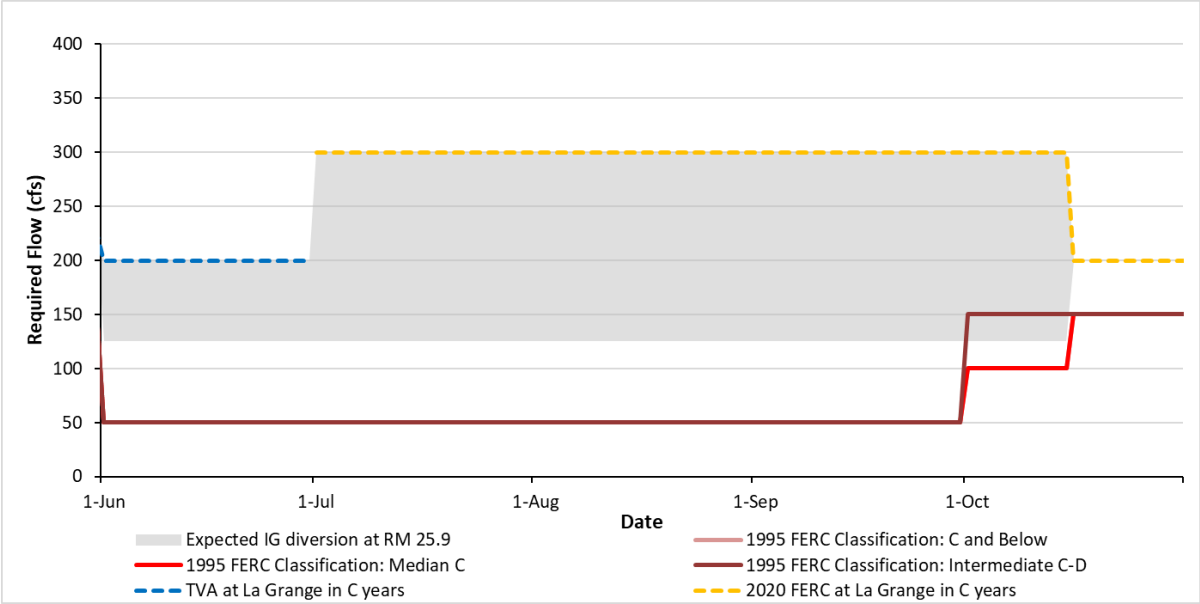


Figure 4-23. Critical (C) Year IG Diversions Compared to Required Baseflow at La Grange Dam Under the Existing Conditions and TVA+2020FERC from June Through October.

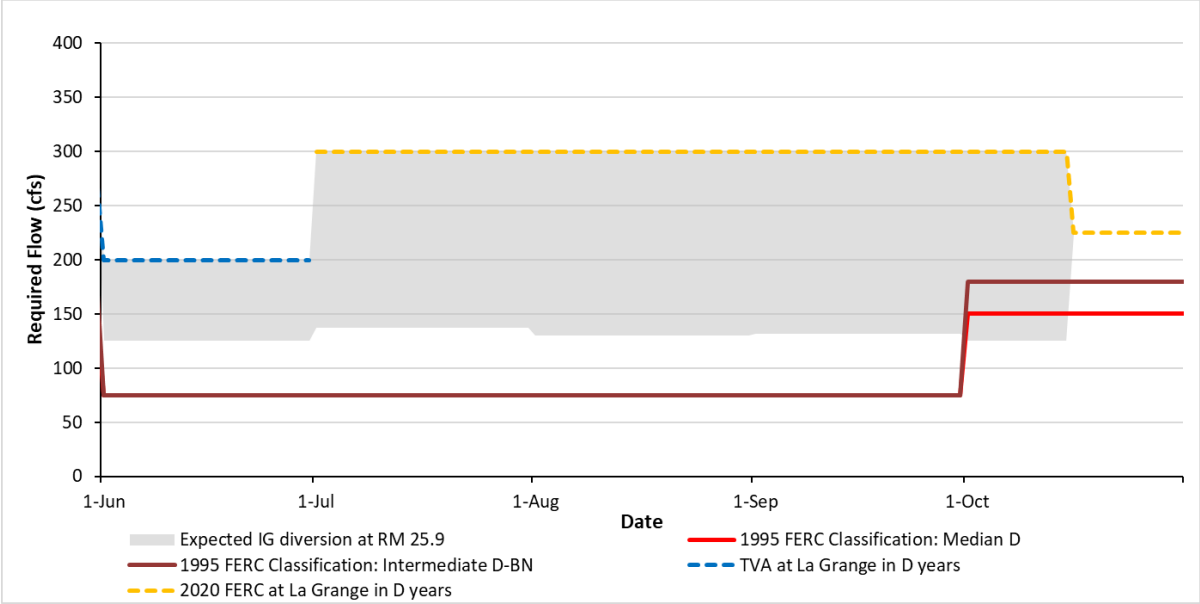


Figure 4-24. Dry (D) Year IG Diversions Compared to Required Baseflow at La Grange Dam Under the Existing Conditions and TVA+2020FERC from June Through October.

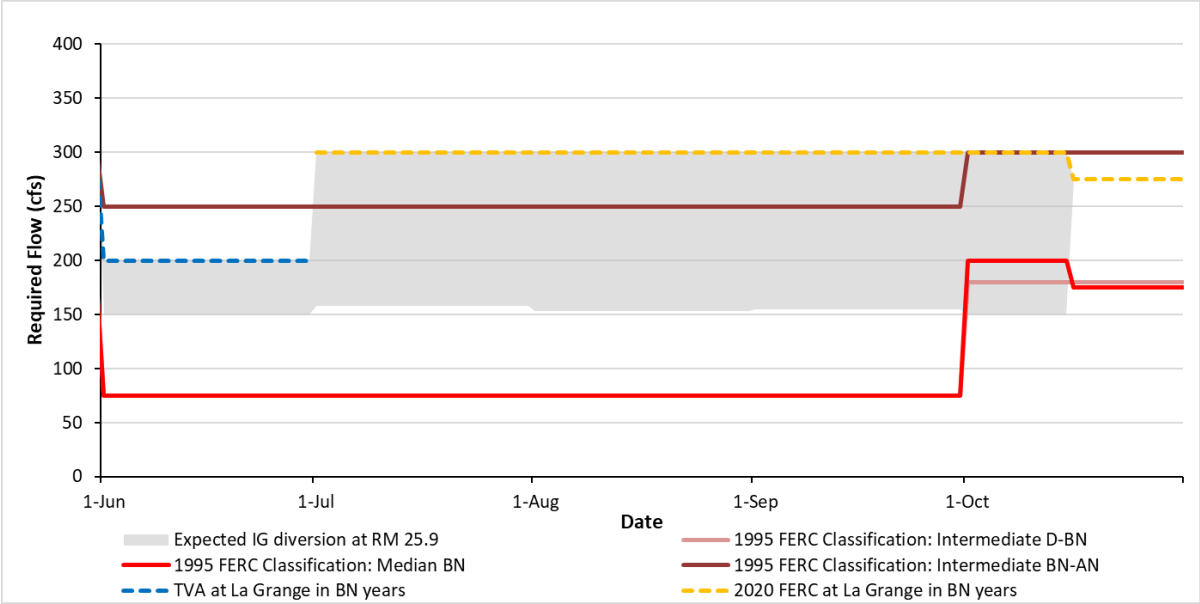


Figure 4-25. Below Normal (BN) Year IG Diversions Compared to Required Baseflow at La Grange Dam Under the Existing Conditions and TVA+2020FERC from June Through October.

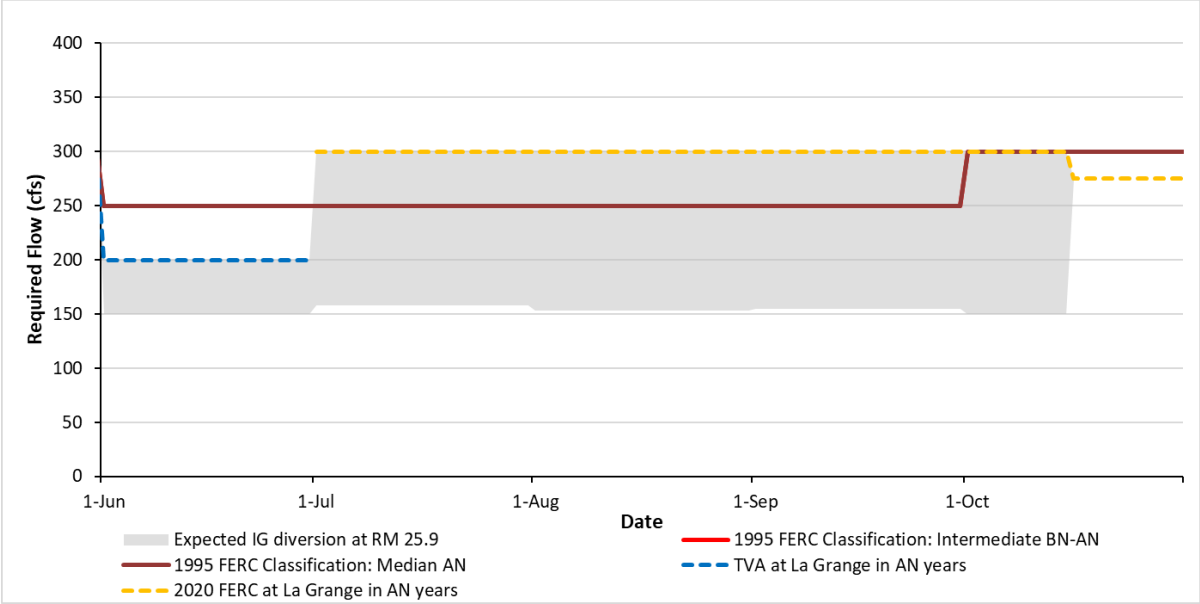


Figure 4-26. Above Normal (AN) Year IG Diversions Compared to Required Baseflow at La Grange Dam Under the Existing Conditions and TVA+2020FERC from June Through October.

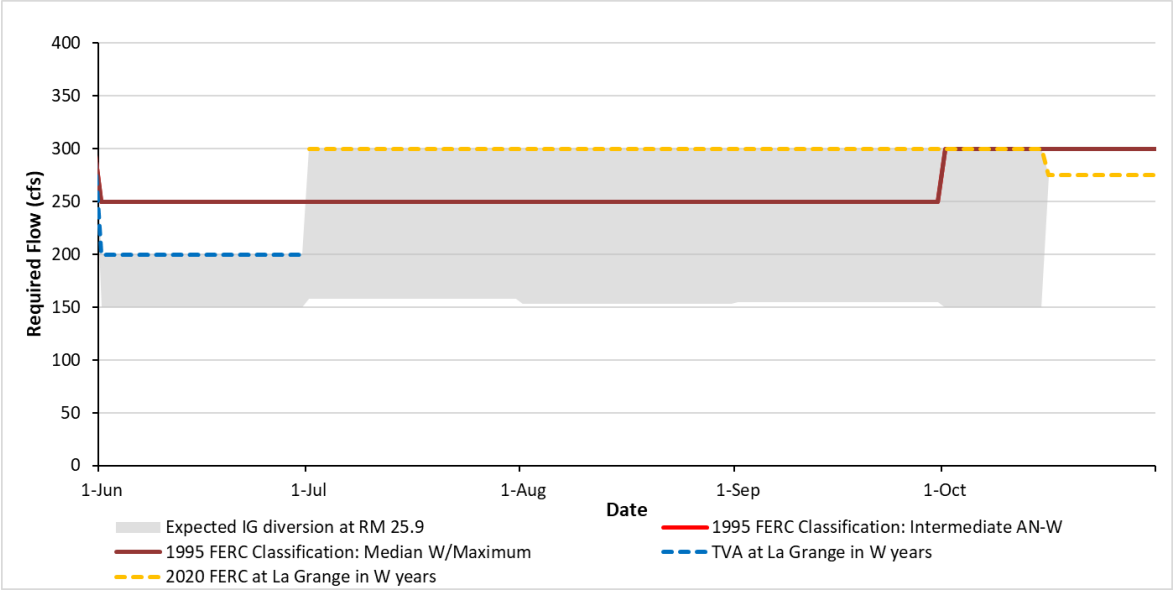


Figure 4-27. Wet (W) Year IG Diversions Compared to Required Baseflow at La Grange Dam Under the Existing Conditions and TVA+2020FERC from June Through October.

Table 4-25. Annual Required Flow Averaged by SJR WYT in the Tuolumne River Under the Modeled Scenarios (in TAF).

SJR WYT	Existing Conditions [a]	30% UF Objective [b, c]	40% UF Objective [b, c]	50% UF Objective [b, c]	TVA + 2020FERC
Overall	200	507	648	789	345
Wet	272	735	945	1,155	442
Above Normal	234	568	727	885	395
Below Normal	166	454	580	706	311
Dry	165	359	451	544	296
Critical	114	269	341	412	218

[a] 1995 FERC Settlement Agreement flows are required at La Grange.

[b] UF requirements are required at Modesto.

[c] Value represents the specified % of average Feb-Jun UF plus the July–January required flow under the 1995 FERC settlement agreement.

Table 4-26. Change in Annual Required Flow in the Tuolumne River Averaged by SJR WYT Under the TVA+2020FERC and UF Objective Scenarios Relative to Existing Conditions (in TAF).

SJR WYT	TVA + 2020FERC minus Existing Conditions	30% UF Objective minus Existing Conditions	40% UF Objective minus Existing Conditions	50% UF Objective minus Existing Conditions
Overall	145	307	448	589
Wet	170	463	673	883
Above Normal	161	334	492	651
Below Normal	144	287	414	540
Dry	130	194	286	378
Critical	103	155	226	298

Resulting Flow in the Tuolumne

Figure 4-28 through Figure 4-31 present box plots of monthly resulting flow in the Tuolumne River at La Grange Dam displaying the TVA+2020FERC scenario with existing conditions and the UF objective scenarios. Table 4-27 summarizes the average annual resulting flows at La Grange Dam under the modeled scenarios by SJR WYT. Table 4-28 summarizes the average change in resulting flow under the TVA+2020FERC and UF objectives relative to existing conditions. Table 4-29 and Table 4-30 present average annual resulting flow at Modesto, downstream of the IGs, under existing conditions and the TVA+2020FERC scenario, respectively. The changes shown in Table 4-30 represent the modeled change in outflow from the Tuolumne River under the TVA+2020FERC and UF objectives relative to existing conditions.

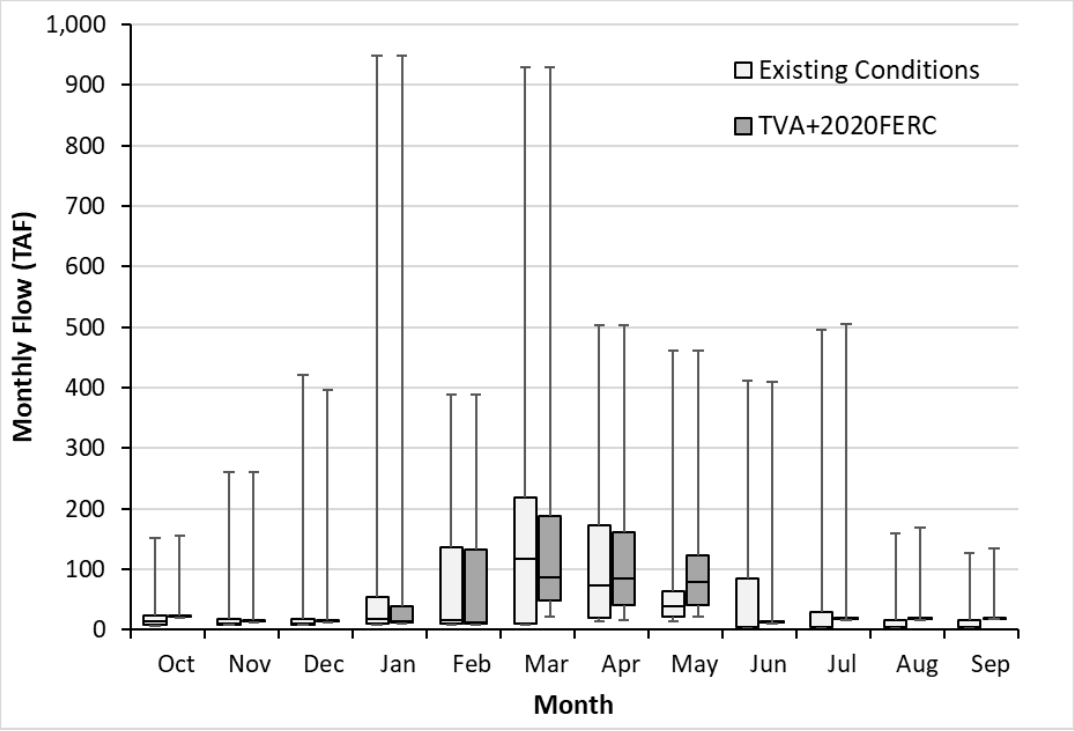


Figure 4-28. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Under Existing Conditions and the TVA+2020FERC.

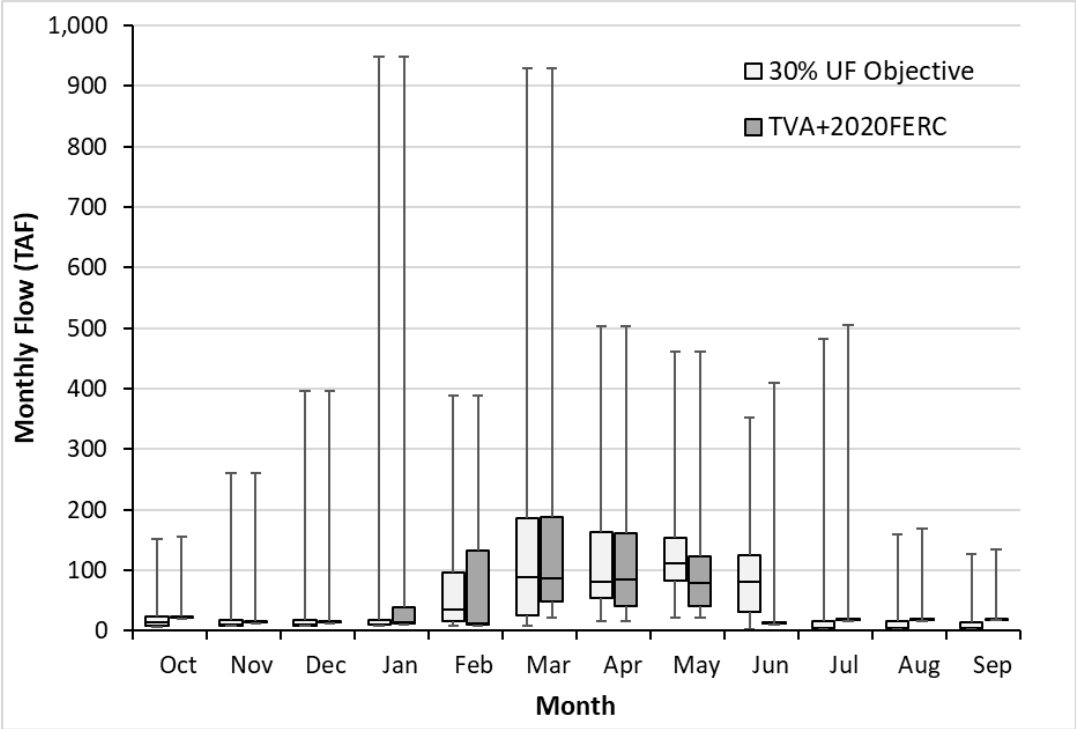


Figure 4-29. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Under the 30% UF Objective and the TVA+2020FERC.

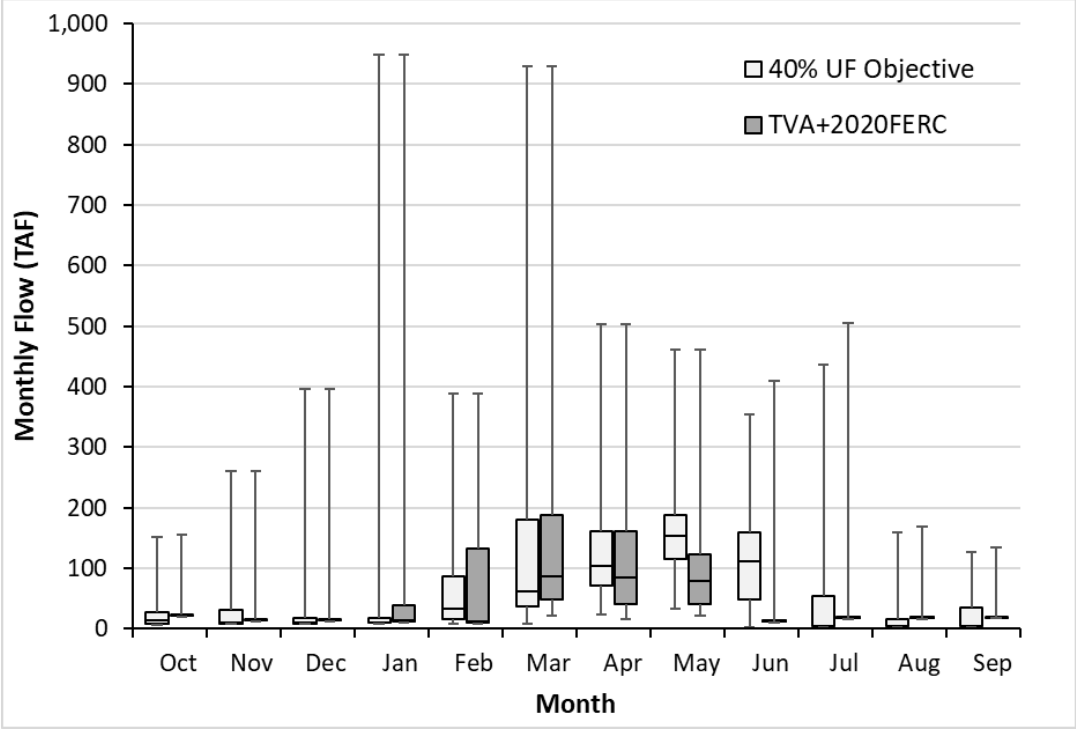


Figure 4-30. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Under the 40% UF Objective and the TVA+2020FERC.

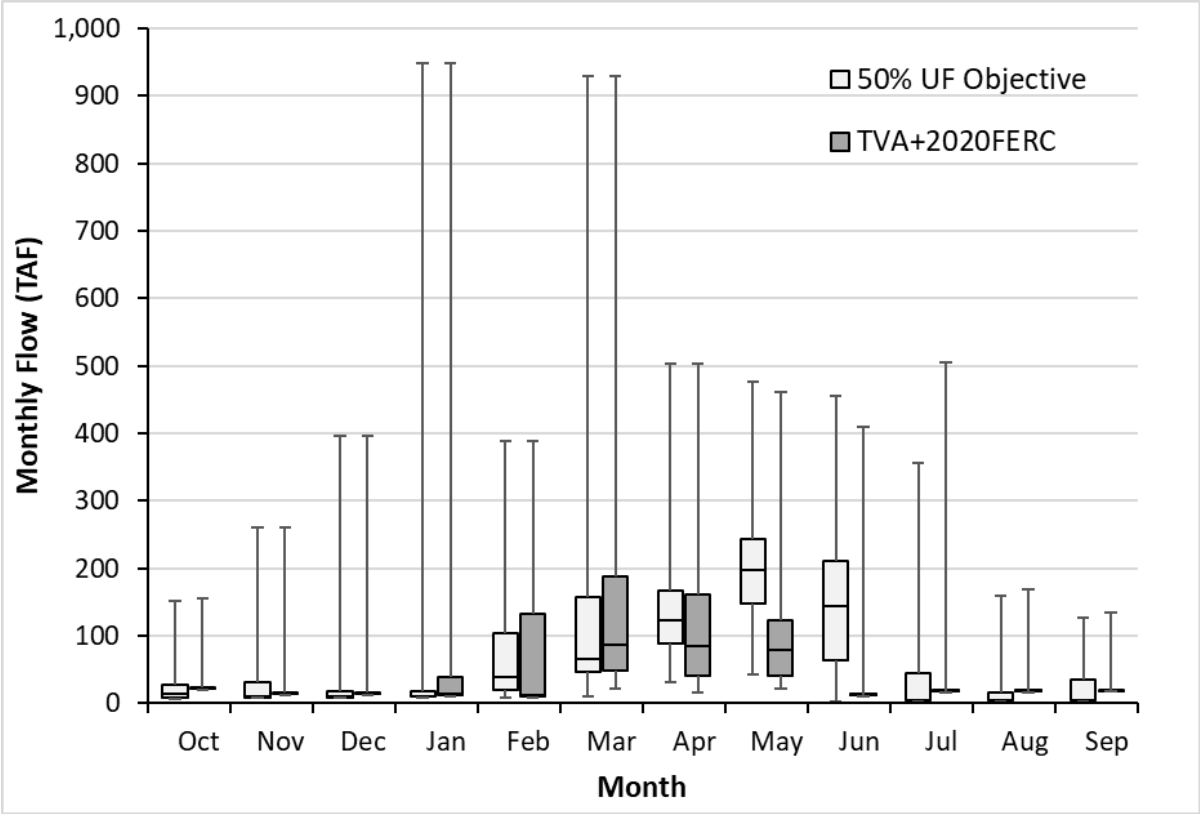


Figure 4-31. Box Plots Displaying Resulting Flow in the Tuolumne River at La Grange Under the 50% UF Objective and the TVA+2020FERC.

Table 4-27. Average Annual Resulting Flow in the Tuolumne River at La Grange Under the Modeled Scenarios (in TAF).

SJR WYT	Existing Conditions	30% UF Objective	40% UF Objective [a]	50% UF Objective [a]	TVA + 2020FERC
Overall	686	745	803	877	727
Wet	1,489	1,456	1,463	1,486	1,469
Above Normal	723	810	888	999	713
Below Normal	312	429	519	633	399
Dry	234	317	398	482	326
Critical	115	219	291	359	219

[a] Flow shifting is applied in wet years under the 40% and 50% UF Objectives to shift up to 25% of the required flow in February through June to the fall (see Appendix B).

Table 4-28. Change in Average Annual Resulting Flow in the Tuolumne River at La Grange Under the TVA+2020FERC and UF Objective Scenarios Relative to Existing Conditions (in TAF).

SJR WYT	TVA + 2020FERC minus Existing Conditions	30% UF Objective minus Existing Conditions	40% UF Objective minus Existing Conditions	50% UF Objective minus Existing Conditions
Overall	41	59	118	191
Wet	-19	-33	-26	-3
Above Normal	-10	87	165	276
Below Normal	87	117	207	321
Dry	93	83	164	249
Critical	104	104	175	244

Table 4-29. Average Annual Resulting Flow in the Tuolumne River at Modesto Under the Modeled Scenarios (in TAF).

SJR WYT	Existing Conditions	30% UF Objective	40% UF Objective [a]	50% UF Objective [a]	TVA + 2020FERC
Overall	900	960	1,018	1,091	905
Wet	1,741	1,708	1,715	1,738	1,688
Above Normal	953	1,040	1,118	1,229	909
Below Normal	523	641	731	844	575
Dry	432	515	596	680	487
Critical	273	377	448	516	335

[a] Flow shifting is applied in wet years under the 40% and 50% UF Objectives to shift up to 25% of the required flow in February through June to the fall (see Appendix B).

Table 4-30. Change in Average Annual Resulting Flow in the Tuolumne River at Modesto Under the TVA+2020FERC Scenario and UF Objective Scenarios Relative to Existing Conditions (in TAF).

SJR WYT	TVA + 2020FERC minus Existing Conditions	30% UF Objective minus Existing Conditions	40% UF Objective minus Existing Conditions	50% UF Objective minus Existing Conditions
Overall	5	59	118	191
Wet	-53	-33	-26	-3
Above Normal	-44	87	165	276
Below Normal	51	117	207	321
Dry	55	83	164	249
Critical	62	104	175	244

New Don Pedro Storage

Figure 4-32 through Figure 4-35 present the time series comparisons of the TVA+2020FERC scenario with existing conditions and the UF objective scenarios to show how storage levels compare across the entire modeling period. Figure 4-36 presents an exceedance chart of end-of-September storage in New Don Pedro Reservoir, summarizing the range of carryover storage levels that occur in each modeled scenario. Table 4-31 summarizes the average September carryover storage in New Don Pedro Reservoir under the modeled alternatives by SJR WYT. Table 4-32 summarizes the change in average September carryover storage in New Don Pedro Reservoir under the TVA+2020FERC and UF objectives relative to existing conditions.

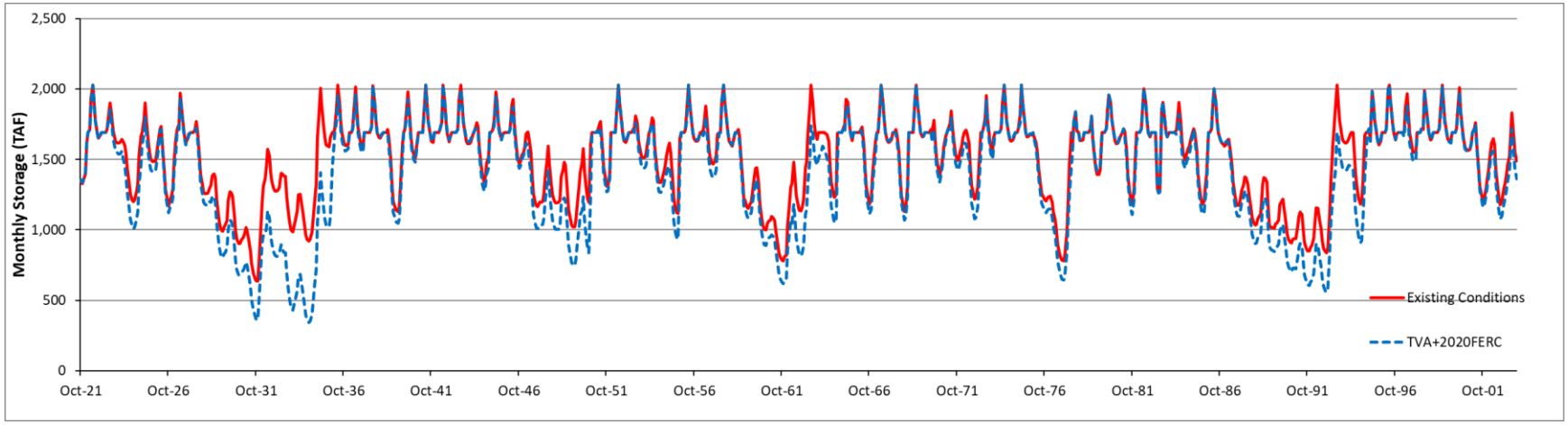


Figure 4-32. Timeseries of End of Month Storage in New Don Pedro Reservoir from 1921 Through 2003 Displaying the TVA+2020FERC with Existing Conditions.

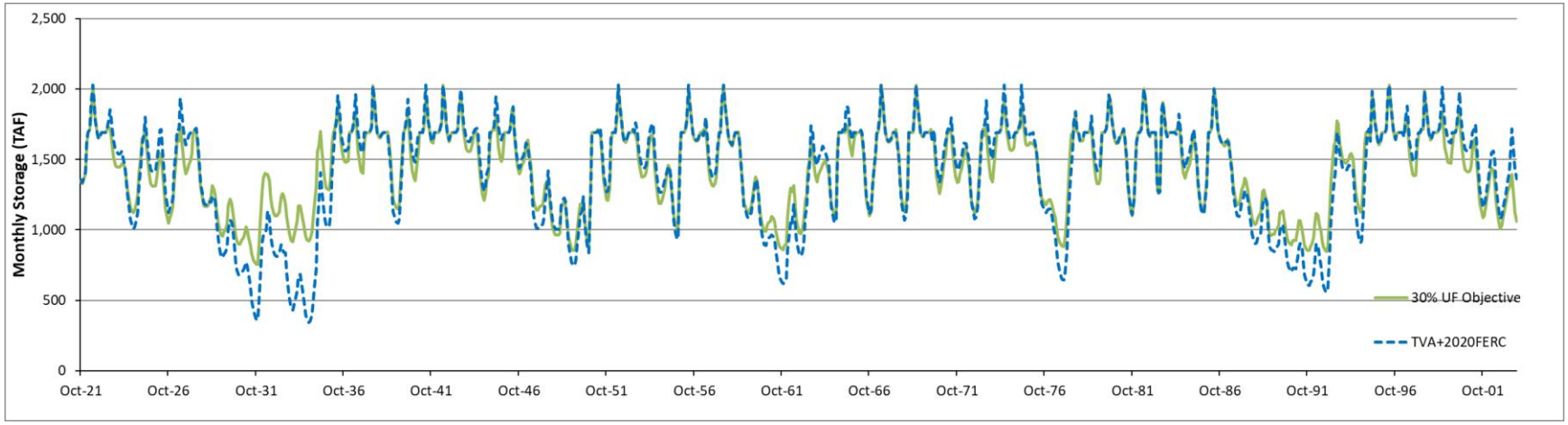


Figure 4-33. Timeseries of End of Month Storage in New Don Pedro Reservoir from 1921 Through 2003 Displaying the TVA+2020FERC with the 30% UF Objective.

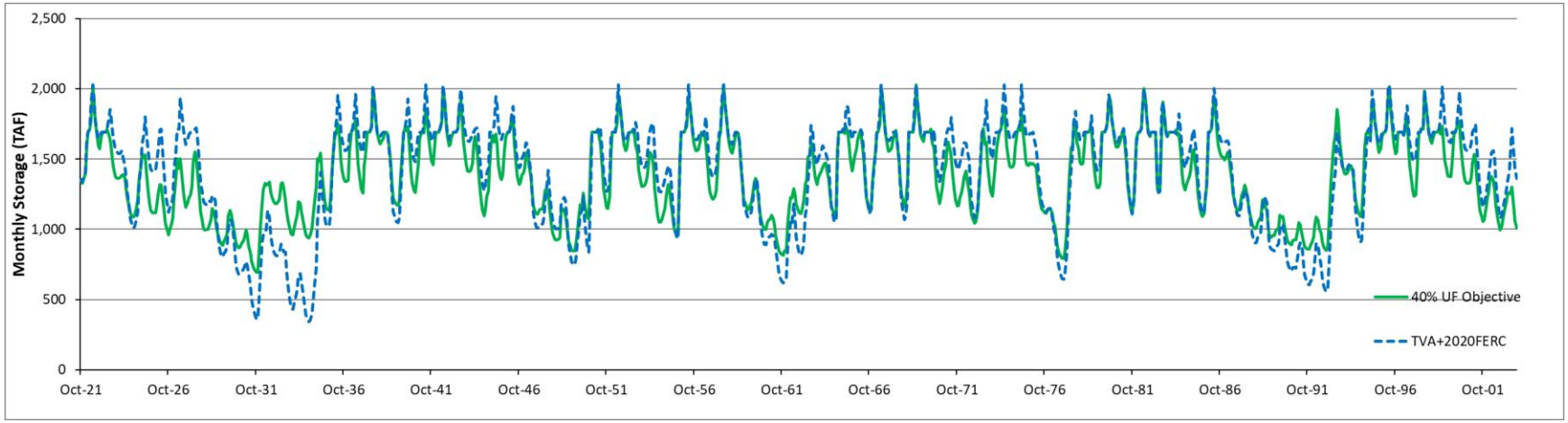


Figure 4-34. Timeseries of End of Month Storage in New Don Pedro Reservoir from 1921 Through 2003 Displaying the TVA+2020FERC with the 40% UF Objective.

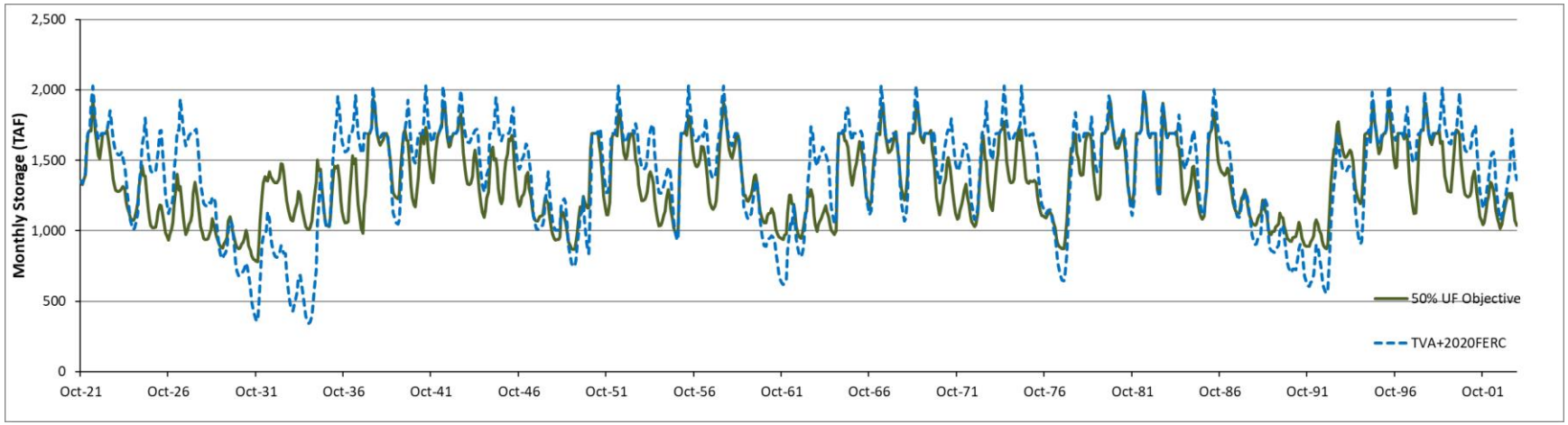


Figure 4-35. Timeseries of End of Month Storage in New Don Pedro Reservoir from 1921 Through 2003 Displaying the TVA+2020FERC with the 50% UF Objective.

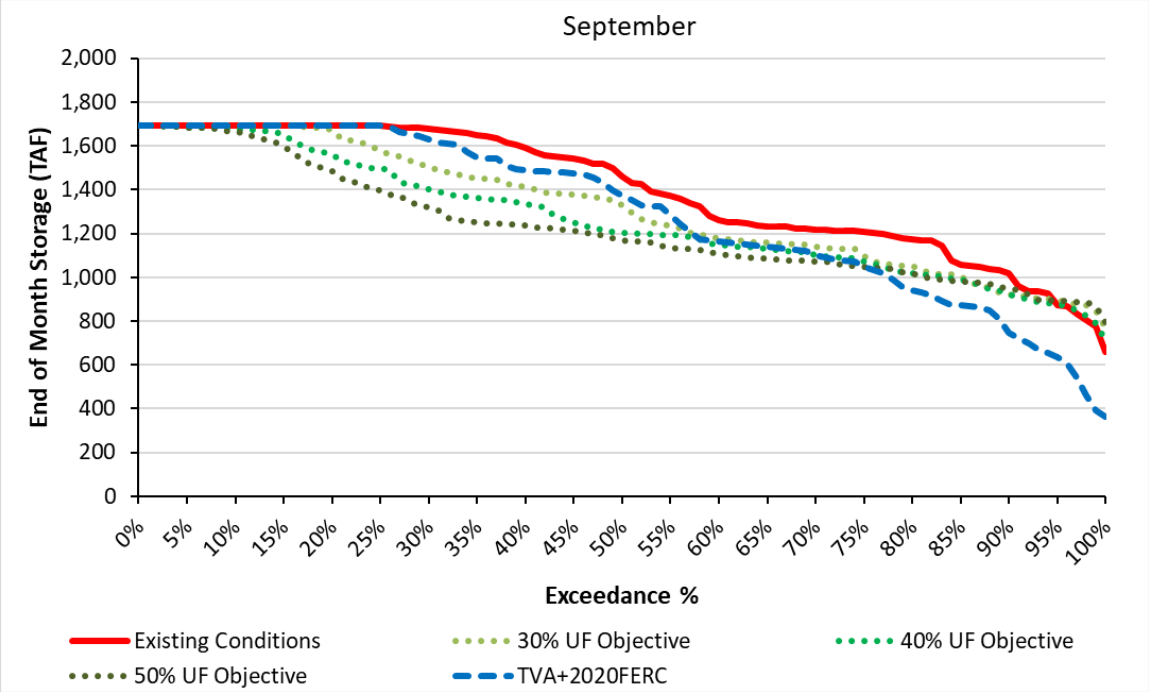


Figure 4-36. Exceedance Chart of End-of-September Storage in New Don Pedro Reservoir Displaying Existing Conditions, the UF Objective Scenarios, and the TVA+2020FERC.

Table 4-31. Average End-of-September Carryover Storage in New Don Pedro Reservoir Under the Modeled Scenarios (in TAF).

SJR WYT	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA + 2020FERC
Overall	1,400	1,315	1,264	1,228	1,296
Wet	1,686	1,652	1,603	1,548	1,674
Above Normal	1,573	1,407	1,319	1,207	1,471
Below Normal	1,363	1,178	1,121	1,086	1,227
Dry	1,200	1,118	1,098	1,103	1,072
Critical	989	986	952	987	791

Table 4-32. Change in Average End-of-September Carryover Storage in New Don Pedro Reservoir Under the TVA+2020FERC and UF Objective Scenarios Relative to Existing Conditions (in TAF).

SJR WYT	TVA + 2020FERC minus Existing Conditions	30% UF Objective minus Existing Conditions	40% UF Objective minus Existing Conditions	50% UF Objective minus Existing Conditions
Overall	-104	-85	-136	-171
Wet	-12	-34	-83	-137
Above Normal	-102	-166	-254	-366
Below Normal	-136	-185	-242	-277
Dry	-128	-81	-102	-97
Critical	-199	-3	-37	-2

Discussion

Annual required flows at La Grange Dam under the TVA+2020FERC scenario are higher on average in all WYTs compared to existing conditions, but lower on average in all WYTs compared to the 30% UF objective scenario. Because the TVA is mostly the same as the TVA+2020FERC during January through June, the comparison of the TVA+2020FERC scenario with the other scenarios is mostly the same during these months. For the July through December period, both the existing conditions and the UF objective scenarios assume the 1995 FERC requirements are in place. During July through mid-October, the TVA+2020FERC scenario provides generally higher required flows at La Grange compared to the 1995 FERC requirements, particularly during drier year types. The increase in summer flows comes with implementation of the IGs allowing some diversions to be shifted downstream. During wetter year types, the IG diversions could cause flows to fall below levels required under the 1995 FERC requirements in the lower half of the river. From late October through December required flows at La Grange Dam are higher under the TVA+2020FERC scenario during drier year types and slightly lower during wetter year types than for the 1995 FERC requirements.

Compared to existing conditions, average annual resulting flow at La Grange Dam under the TVA+2020FERC scenario increases in all year types except above normal and wet years. As with the TVA, reservoir reoperation and reduced flood spills in the TVA+2020FERC alternative cause annual resulting flows to increase less than annual required flows when compared with existing conditions. On a monthly basis, the greatest benefits in flow under the TVA+2020FERC alternative occur in May and over the summer from July through October. Despite the IG diversions, the increase in annual average flow at Modesto is still greater under the TVA+2020FERC relative to the TVA in critical, dry, and below normal years. Compared to the 30% UF objective scenario, average annual resulting flow at La Grange Dam under the TVA+2020FERC scenario is lower in above and below normal years, the same in critical years, and higher in wet and dry years.[8] On a monthly basis, May and June generally experience higher flows with the UF requirements in place compared to the TVA+2020FERC. Downstream of the IGs at Modesto, average annual resulting flows under the TVA+2020FERC scenario is less than the 30% UF objective scenario in all WYTs.

With higher instream flow releases under the TVA+2020FERC scenario greater demand is placed on reservoir storage, particularly during dry years. Under the TVA+2020FERC scenario, reservoir storage averages over 100 TAF lower in all but wet WYT and about 200 TAF lower in critical years compared to existing conditions due to the assumption that diversions in the TVA+2020FERC scenario would not change from the existing levels. Compared to the UF flow objectives, storage remains higher in the wetter years under the TVA+2020FERC scenario as the increase in required flow is still much less than under a 30% UF objective. However, during drier years, storage under the TVA+2020FERC scenario falls well below what is modeled with the UF objectives because the UF scenarios include carryover storage guidelines to protect cold-water pools.

[8] Note that if the 2020 FERC license requirements were applied from July through January in the UF objective scenarios instead of the 1995 FERC requirements, the 30% UF objective scenario would result in more flow than the TVA+2020FERC and the comparison would be more in line with the TVA comparison to the 30% UF objective scenario.

4.4.2 Lower San Joaquin River Modeling Methods and Results Using WSE

4.4.2.1 Description of LSJR Modeling Scenarios

Existing Conditions

The existing conditions scenario used for modeling flow on the SJR at Vernalis is the same as the version used for analyzing effects on the Tuolumne River, which represents conditions on the Merced, Tuolumne, and Stanislaus Rivers as of 2023. The flow requirements modeled for the Tuolumne River are the FERC flows defined in the 1995 settlement agreement, as described in Section 4.2.2. The flows modeled for the Merced River are the 1964 FERC minimum flow requirements for Lake McClure plus releases made under the Cowell Agreement. The flows modeled for the Stanislaus River are the New Melones Reservoir Stepped Release Plan requirements and the dissolved oxygen objective below Goodwin Dam. In addition, New Melones Reservoir is responsible for meeting Water Right Decision 1641 (D-1641) flow and salinity requirements at Vernalis.

40% UF Objective

The 40% UF Objective scenario for modeling flow on the SJR at Vernalis is the same as the version used for analyzing effects on the Tuolumne River, representing implementation of 40% UF objectives from the 2018 Bay-Delta Plan on the Merced, Tuolumne, and Stanislaus Rivers. The 40% UF objective applies from February through June on each tributary. Requirements during July through January are the same as under existing conditions for each tributary. In addition to the UF objective requirements from the three LSJR tributaries, the 40% UF objective scenario also requires a flow rate of no less than 1,000 cfs be maintained at Vernalis, based on a minimum 7-day running average. This Vernalis baseflow requirement[9] is identified in Table 3 of the 2018 Bay-Delta Plan and serves as an additional layer of environmental protection if UF contributions from the LSJR tributaries, in combination with mainstem LSJR flows, are insufficient to maintain at least 1,000 cfs at Vernalis. Responsibility to achieve this Vernalis baseflow requirement is shared between the LSJR tributaries, with the Stanislaus River providing 29%, the Tuolumne River 47%, and the Merced River 24% of the additional total outflow needed to achieve and maintain the required base flow at Vernalis (based on proportional hydrologic responsibility under UF conditions).

[9] The Vernalis baseflow requirement in the 40% UF objective scenario replaces February through June D-1641 flow requirements represented in some of the other alternatives.

TVA

The TVA MOU scenario for modeling flow on the SJR at Vernalis is the same as the version used for analyzing effects on the Tuolumne River, representing implementation of the TVA from January through June. During the July through December period, it is assumed that current flow requirements under the 1995 FERC settlement agreement apply on the Tuolumne River. The proposed IG diversions are not included as part of this scenario and the baseflow requirements in June are the interim values defined in Table 4-13. In addition, based on assumptions in the Tuolumne River accounting spreadsheet provided by the TVA parties (TID, MID, CCSF 2025), it is assumed that there will be no reduction in Tuolumne River diversions compared to existing conditions. Requirements for the Merced and Stanislaus Rivers, and the LSJR at Vernalis, are the same as those described under existing conditions.

TVA with 2018 Bay-Delta Plan (TVA+BDP)

To represent implementation of the 2018 Bay-Delta Plan UF objectives in the Stanislaus and Merced Rivers, but the TVA in the Tuolumne River, a second variation of the TVA scenario is modeled (referred to as the TVA + 2018 BDP) that assumes 40% UF objectives apply on the Merced and Stanislaus Rivers while the TVA applies on the Tuolumne River. The TVA + 2018 BDP scenario uses the same assumptions as the TVA for modeling the Tuolumne River and uses the same assumptions as the 40% UF objective scenario for modeling the Merced and Stanislaus Rivers. In addition, the Vernalis 1,000 cfs minimum flow requirement is included in the TVA MOU + 2018 BDP alternative and responsibility is still divided between all three tributaries. Releases to meet the Vernalis baseflow requirement in the TVA +2018 BDP scenario can cause flows in the Tuolumne River to be slightly higher than the TVA scenario, however these releases are very rare and shouldn't significantly affect the results.[10]

Summary of Hydrologic Modeling

Table 4-33 summarizes the scenarios used in analyzing the effects of the TVA on flow at Vernalis.

[10] Under the TVA + 2018 BDP version releases from the Tuolumne to meet the Vernalis minimum flow occur in three months in the 82-year modeling period: March 1977 (3 TAF), June 1977 (3 TAF), and June 1992 (8 TAF).

Table 4-33. Summary of Lower San Joaquin River Analysis Scenarios.

Scenario	Tuolumne Requirements	Merced Requirements	Stanislaus Requirements	Vernalis Requirements
Existing Conditions	*Year Round:* 1995 FERC	*Year Round:* 1964 FERC + Cowell Agreement	*Year Round:* New Melones Stepped Release Plan	D-1641 Flow and Salinity (responsibility assigned to New Melones)
40% UF Objective	• *July–January:* 1995 FERC • *February–June:* 40% UF Objective	• *July–January:* 1964 FERC + Cowell Agreement • *February–June:* 40% UF Objective	• *July–January:* New Melones Stepped Release Plan • *February–June:* 40% UF Objective	• D-1641 Salinity and October Flow (responsibility assigned to New Melones) • *Feb–June:* 1000 cfs baseflow (responsibility assigned to all tributaries)
TVA	Based on TVA and the 2020 FERC FEIS	*Year Round:* 1964 FERC + Cowell Agreement	*Year Round:* New Melones Stepped Release Plan	D-1641 Flow and Salinity (responsibility assigned to New Melones)
TVA + 2018 BDP	Based on TVA and the 2020 FERC FEIS	• *July–January:* 1964 FERC + Cowell Agreement • *February–June:* 40% UF Objective	• *July–January:* New Melones Stepped Release Plan • *February–June:* 40% UF Objective	• D-1641 Salinity and October Flow (responsibility assigned to New Melones) • *Feb–June:* 1000 cfs baseflow (responsibility assigned to all tributaries)

4.4.2.2 TVA Results and Comparison with Existing Conditions

The TVA only applies to the Tuolumne River, however changes in flows in the Tuolumne River could affect flows and reservoir operations on the LSJR or its other tributaries. For example, the U.S. Bureau of Reclamation (Reclamation) is obligated to meet D-1641 flow and salinity requirements at Vernalis by adjusting New Melones Reservoir operations on the Stanislaus River, and changes in Tuolumne River flows may influence flows and salinity at Vernalis. Table 4-34 shows the average total January through June resulting flow on the Stanislaus River at Ripon for existing conditions and the TVA, both of which assume that the New Melones Stepped Release Plan requirements apply on the Stanislaus River. The change in outflow from the Stanislaus River in Table 4-34 is caused by differences in New Melones Reservoir releases to meet Vernalis D-1641 requirements, which in this case are influenced by Tuolumne River flow differences. The Merced River has no change in outflow because Lake McClure does not make releases to meet requirements on the SJR under existing conditions. Figure 4-37 and Table 4-35 summarize resulting flow in the SJR at Vernalis under existing conditions and the TVA. Figure 4-38 presents a timeseries of the annual change in total January through June flow on the LSJR tributaries and at Vernalis under the TVA compared to existing conditions. The total change in flow of the three tributaries equals the total change in flow at Vernalis. During years when the change in flow at Vernalis is negative, this indicates that reservoir reoperation under the TVA resulted in reduced flood spills compared to existing conditions.

Table 4-34. Average Total Resulting Flow from January Through June on the Stanislaus River at Ripon Under Existing Conditions and the TVA (in TAF).

SJR WYT	Existing Conditions	TVA	TVA minus Existing Conditions
Overall	345.9	344.3	-1.5
Wet	556.6	555.3	-1.3
Above Normal	408.9	412.6	3.7
Below Normal	298.0	296.0	-2.0
Dry	193.2	190.9	-2.4
Critical	129.5	123.5	-6.0

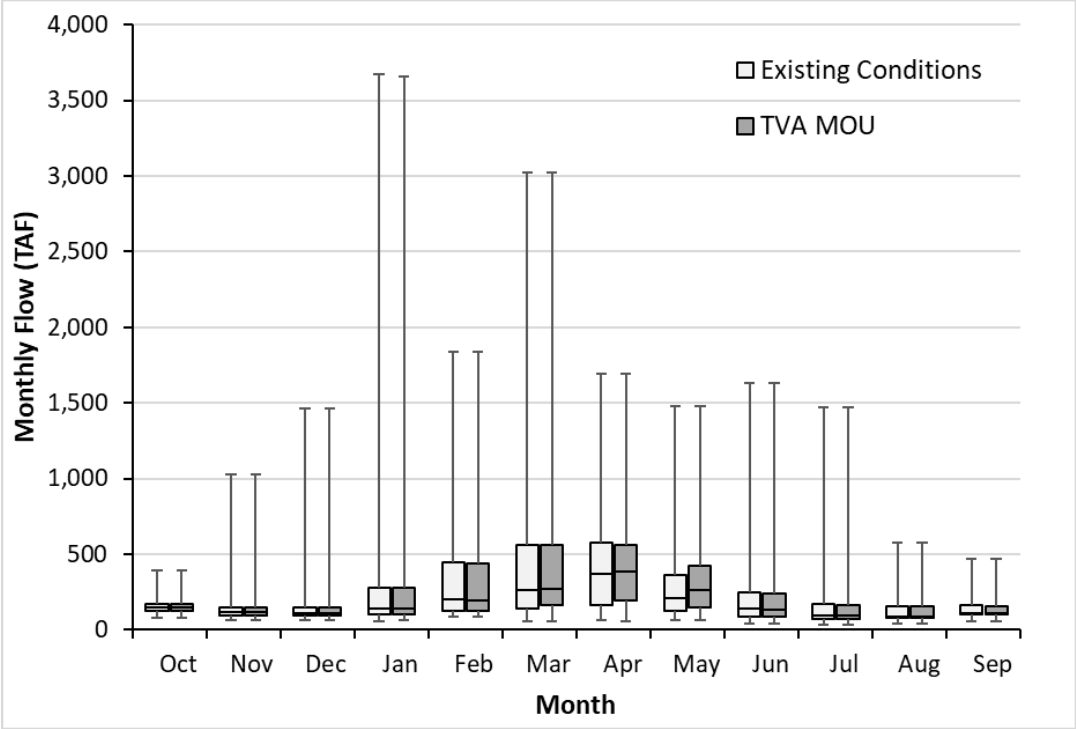


Figure 4-37. Box Plots Displaying Resulting Flow in the San Joaquin River at Vernalis Under Existing Conditions and the TVA.

Table 4-35. Average Total Resulting Flow from January Through June in the San Joaquin at Vernalis Under Existing Conditions and the TVA (in TAF).

SJR WYT	Existing Conditions	TVA	TVA minus Existing Conditions
Overall	2,145	2,156	11
Wet	4,428	4,399	-29
Above Normal	2,121	2,131	10
Below Normal	1,195	1,225	30
Dry	888	928	40
Critical	539	571	32

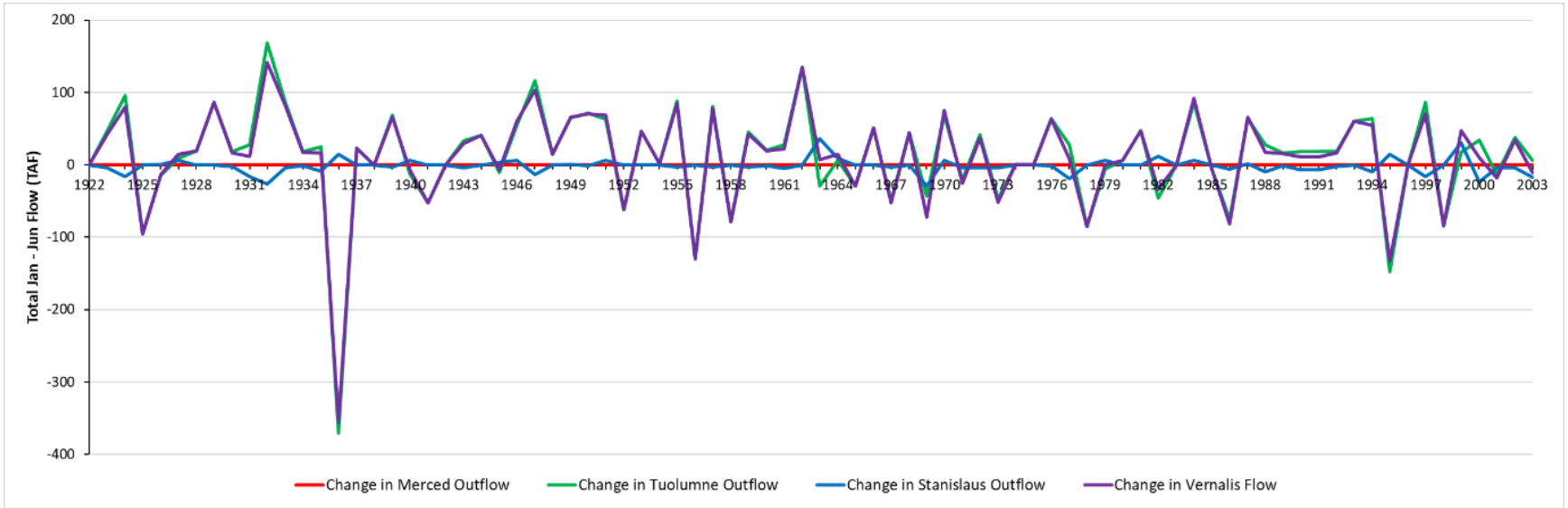


Figure 4-38. Annual Timeseries of the Total January Through June Change in Flow in the LSJR Tributaries and in the San Joaquin River at Vernalis Under the TVA Compared to Existing Conditions.

4.4.2.3 TVA with 2018 Bay-Delta Plan Results and Comparison with the 40% UF Objective Scenario

Under the UF objectives, the February through June D-1641 flow requirements are replaced with the Bay-Delta Plan Vernalis minimum baseflow requirement of 1000 cfs, with responsibility divided over all three tributaries. However, D-1641 salinity and October flow requirements are still the responsibility of Reclamation using New Melones Reservoir releases. Table 4-36 and Table 4-37 show the average total January through June outflow from the Merced and Stanislaus Rivers, respectively, under the 40% UF Objective and the TVA with 2018 BDP scenario. The only factor that would change the flow on the Merced River is a change in what is required to meet the Vernalis minimum flow, but there is little to no change in releases for that requirement. The change in outflow from the Stanislaus River shown in Table 4-37 is caused primarily by differences in releases to meet Vernalis D-1641 salinity requirements. Figure 4-39 and Table 4-38 summarize resulting flow on the San Joaquin at Vernalis under the 40% UF scenario and the TVA + 2018 BDP scenario. Figure 4-40 presents a timeseries of the annual change in total January through June flow on the eastside tributaries and at Vernalis under the TVA + 2018 BDP scenario compared to the 40% UF Objective. The total change in flow of the three tributaries equals the total change in flow at Vernalis.

Table 4-36. Average Total Resulting Flow from January Through June in the Merced River at Stevinson Under the 40% UF Objective and TVA + 2018 BDP (in TAF).

SJR WYT	40% UF Objective	TVA + 2018 BDP	TVA +2018 BDP minus 40% UF Objective
Overall	393.3	393.3	<0.1
Wet	733.9	733.9	<0.1
Above Normal	398.3	398.3	0
Below Normal	269.4	269.4	0
Dry	189.9	189.9	0
Critical	143.4	143.3	>-0.1

Table 4-37. Average Total Resulting Flow from January Through June in the Stanislaus River at Ripon Under the 40% UF Objective and TVA + 2018 BDP (in TAF).

SJR WYT	40% UF Objective	TVA MOU + 2018 BDP	TVA MOU+2018 BDP minus 40% UF Objective
Overall	412.3	412.8	0.5
Wet	633.5	633.4	-0.1
Above Normal	488.9	488.9	0.0
Below Normal	369.6	369.6	0.0
Dry	234.4	236.3	1.9
Critical	182.9	184.2	1.2

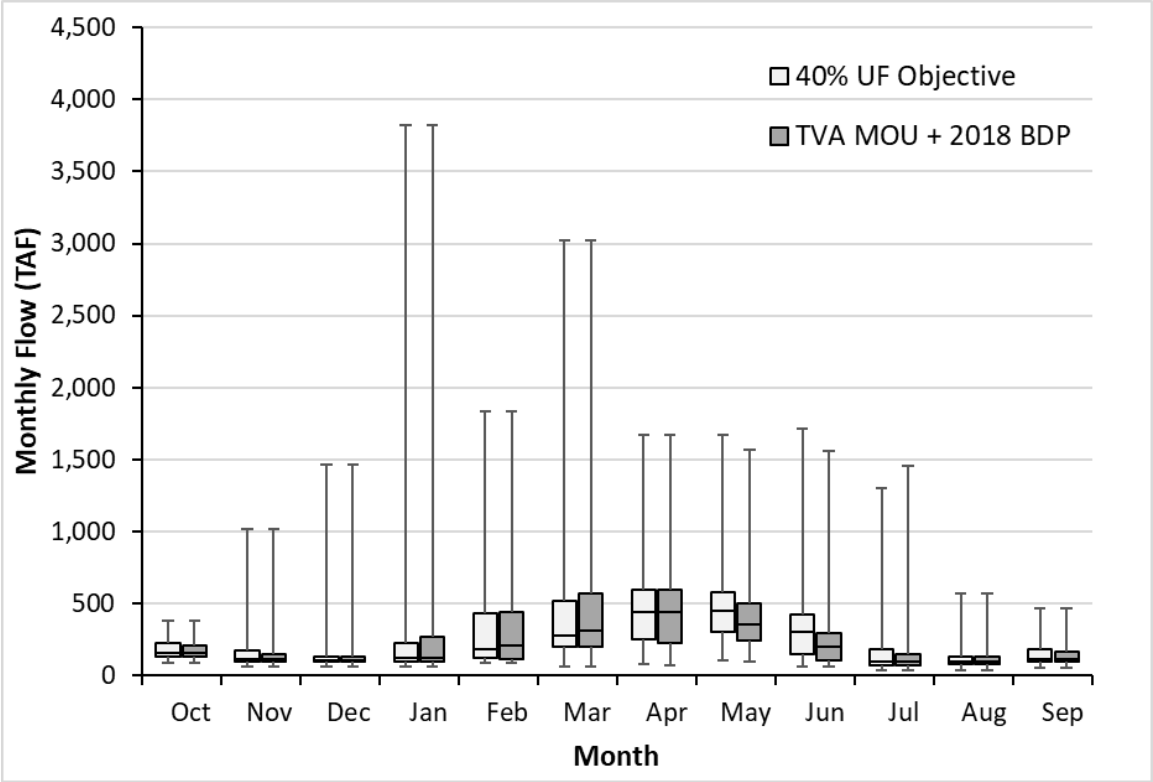


Figure 4-39. Box Plots Displaying Resulting Flow in the San Joaquin River at Vernalis Under the 40% UF Objective and the TVA + 2018 BDP.

Table 4-38. Average Total Resulting Flow from January Through June in the San Joaquin River at Vernalis Under the 40% UF Objective and TVA + 2018 BDP (in TAF).

SJR WYT	40% UF Objective	TVA + 2018 BDP	TVA +2018 BDP minus 40% UF Objective
Overall	2,435	2,329	-106
Wet	4,506	4,501	-5
Above Normal	2,547	2,366	-181
Below Normal	1,644	1,477	-166
Dry	1,193	1,084	-109
Critical	866	736	-131

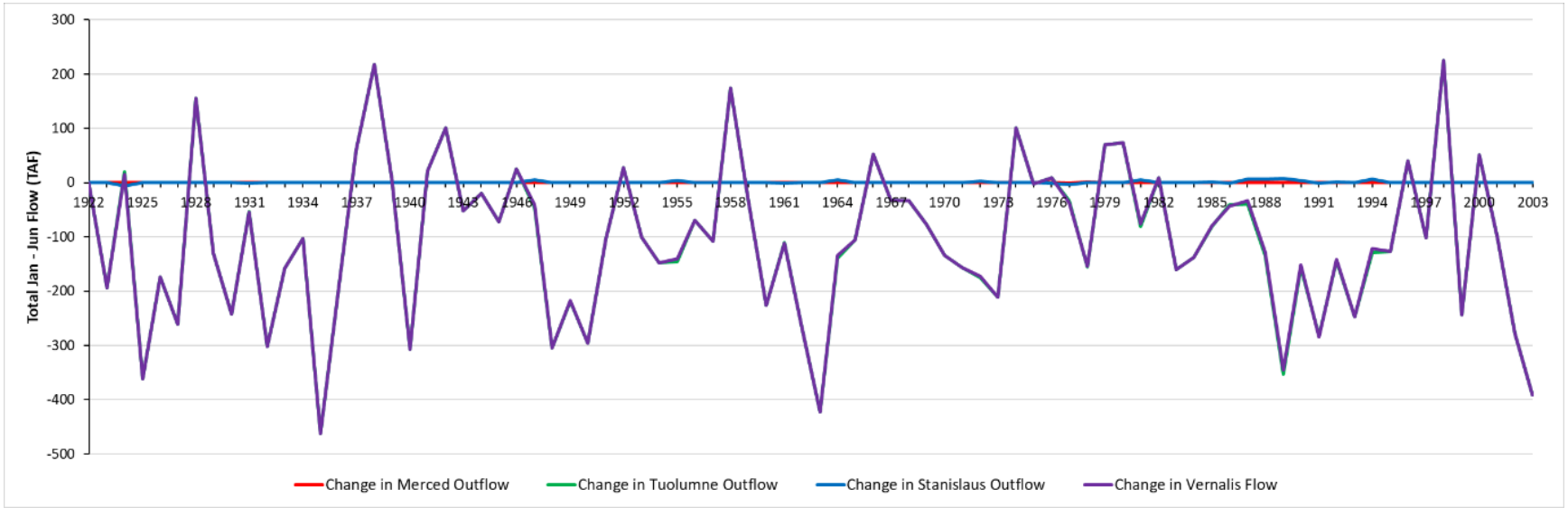


Figure 4-40. Annual Timeseries of the Total January Through June Change in Flow on the LSJR Tributaries and in the San Joaquin River at Vernalis Under the TVA + 2018 BDP Compared to the 40% UF Objective.

4.4.2.4 Discussion

The expected volume of new Delta outflow can vary depending on the implementation of many different processes, both within the TVA as well as external to the TVA. For example, the 2018 Bay-Delta Plan implementation of the LSJR flow objectives would require the Tuolumne, Stanislaus, and Merced Rivers to provide 40% UF from February through June, which would flow to Vernalis and be protected as Delta outflow (2018 Bay-Delta Plan). The timing of when the TVA implementation begins relative to when non-VA parties are assigned responsibility for the 2018 Bay-Delta Plan LSJR UF objectives could affect the volume of water reaching Vernalis and exiting the Delta. Table 4-39 summarizes the resulting flow from January through June on the LSJR at Vernalis under existing conditions and the difference compared to the TVA, the TVA + 2018 BDP, and the 40% UF objective scenario. As shown before, the TVA would be expected to provide an overall increase in Delta outflow compared to Existing Conditions, but the expected Delta outflow is less than when the TVA is implemented concurrently with the 40% UF Objective on the Stanislaus and Merced Rivers, and substantially less than if the 40% UF Objective is implemented on all three LSJR tributaries.

Table 4-39. Average Resulting Flow during January Through June on the San Joaquin River at Vernalis Under Existing Conditions, and the Increase in Flow under the TVA, the TVA + 2018 BDP, and the 40% UF Objective Scenario (in TAF).

SJR WYT	Existing Conditions	TVA minus Existing Conditions	TVA + 2018 BDP minus Existing Conditions	40% UF Objective minus Existing Conditions
Overall	2,145	11	183	289
Wet	4,428	-29	73	78
Above Normal	2,121	10	245	426
Below Normal	1,195	30	282	449
Dry	888	40	195	305
Critical	539	32	197	327

4.4.3 TVA Accounting Procedures and Historical Analysis

While the details of the TVA flow accounting are still in development, initial TVA accounting procedures were developed by the TVA parties to be used during implementation of the TVA to identify and quantify the amount of TVA water released at La Grange Dam that exceeds what would have been released under the 1995 FERC settlement agreement (i.e., “new flow” or “new water” contributions) for the 1999–2023 period (TID, MID, CCSF 2025; Appendix C). Establishing accounting procedures will be necessary to track implementation and deployment of TVA flows from La Grange Dam to Vernalis, as well as to identify the portion of the VA flows that will be bypassed by the Projects to result in new Delta outflow. The TVA parties provided a draft accounting spreadsheet model that can be used to identify and quantify the TVA’s contribution of new water both in the Tuolumne River and to Delta outflow.

During implementation of the TVA, the initial accounting procedures propose to compare the actual flows at the La Grange stream gage to those simulated by the accounting spreadsheet for the 1995 FERC requirements. TVA flows would be assessed daily, and the volume of required flow for the TVA that is greater than the simulated total flow under the 1995 FERC requirements would be identified for the day. Generally, the TVA is expected to produce an increase in flow during the January

through June period, but at times there are expected to be decreases in flow caused by reservoir reoperation and reduced flood spills. Once the change in flow resulting from the TVA is determined at Vernalis, consistent with the accounting spreadsheet procedures, the TVA parties would communicate the volume and timing to the Projects. The Projects would then add the additive flows from either one of the pulse flows or both of the pulse flows during the March 16-May 31 or April 16-May 31 period to Delta outflows. A determination has not yet been made on whether one or two pulses would be accounted for as contributing to Delta outflow under the TVA. This issue is expected to be resolved before this report is finalized.

In addition, as described in Section 4.1, *Introduction*, the TVA Additional Maximum Flows identified in the TVA MOU have not been described by the TVA parties with enough detail to be modeled or evaluated.[11] The TVA parties expect to coordinate the need for the Additional Maximum Flows with the Projects. If the Additional Maximum Flows are applied in a given year, the TVA parties expect them to be released at some point during the July through December period when the Projects would be able to increase exports. Because the flows are uncertain and would occur outside the January through June period, they are not further analyzed in this report.

Another issue that could affect whether and how the TVA contributes to Delta inflow and outflow is the operation of New Melones Reservoir. As mentioned above, Reclamation is obligated to meet D-1641 flow and salinity requirements at Vernalis by operating New Melones Reservoir on the Stanislaus River to provide additional flows when necessary. If the outflow from the Tuolumne River increases, it could allow Reclamation to reduce releases from New Melones Reservoir otherwise needed to meet the flow and salinity requirements at Vernalis. If Reclamation were to reduce flows on the Stanislaus River, that could offset TVA flow contributions, which means that the expected increase in SJR flow attributed to the TVA could be reduced at Vernalis. The potential for Reclamation to reduce Stanislaus River flows in response to the VA is not currently considered in the initial accounting procedures developed by the TVA parties.

4.4.3.1 Estimated TVA Flow Contributions on the Tuolumne

The TVA parties' draft accounting spreadsheet (TID, MID, CCSF 2025; see Appendix C) presents preliminary estimates of the flow provided under the TVA, both on the Tuolumne River and as Delta outflow. Table 4-40 presents estimates from the TVA parties' draft accounting spreadsheet for the new flow contribution of the TVA at La Grange during January through June, averaged for all years and by SJR WYT. For comparison, Table 4-40 also shows the new flow contributions of the TVA from Section 4.4.1.2, Table 4-20, (change in flow at La Grange between the TVA MOU alternative and existing conditions). The new flow contribution estimates in the draft accounting spreadsheet are negative during above-normal and wet year types due to reservoir reoperation and reduced flood spills under the TVA.

There are some inherent differences between WSE and the draft accounting spreadsheet model that cause the results to differ. First, the modeling period for the TVA Accounting Spreadsheet only covers 25 years (1999–2023), versus WSE, which covers 82 years (1922–2003). There is minimal overlap between the years covered, and the meteorological and hydrological conditions experienced over the two periods are not the same. The more recent time period is informative in that it

[11] Releases for Additional Maximum Flows were estimated for 1999 to 2023 in the Tuolumne River VA party accounting spreadsheet to indicate representative volumes and timing. Those flows would be provided to avoid impacts to the Projects' water supplies and not for environmental flow purposes.

represents recent hydrologic conditions and climate change, but the WYT averages produced from such a relatively short time span can be skewed because there aren't many values to produce the average (for example, there are only 2 BN years and only 3 AN years represented in the accounting spreadsheet for the 1999 to 2023 period). Second, the accounting spreadsheet is a daily operational model, whereas WSE is a monthly model. Finally, the accounting spreadsheet also includes representation of CCSF operations and Hetch Hetchy Reservoir which is not included in WSE. Despite the differences, the WSE model effectively represents the volumes and timing presented in the TVA draft account spreadsheet, while containing a more robust dataset that incorporates a large variation of hydrological conditions. The WSE model also incorporates the Stanislaus River and Merced River flows and reservoir operations, which is important when considering potential changes to LSJR and Delta flows.

Table 4-40. Estimates for New Flow Contributions Resulting from the TVA at La Grange Dam During January Through June Averaged for All Years and by WYT (in TAF).[a]

Water Year Type	Critically Dry	Dry	Below Normal	Above Normal	Wet	All Years
New TVA flow estimates using the TVA Parties' VA Accounting Spreadsheet [b]	37	50	58	-46	-89	2.1
New TVA flow estimates using the WSE model [c]	38	42	32	6	-28	12

[a] The TVA Term Sheet included different numbers that were developed in 2022 using an older version of State Water Board's WSE model that had not received all the updates described in Appendix B, *Hydrologic and Water Quality Modeling*.

[b] Values from the draft TVA Accounting Spreadsheet are averaged over the 25-year period from 1999 through 2023.

[c] Values from the WSE model are averaged over the 82-year period from 1922 through 2003. Using a different range in years can contribute to different estimated values.

4.4.3.2 Delta Throughflow Protection and New Delta Outflow

The draft accounting spreadsheet was used to estimate the TVA flow contributions that would be expected to be bypassed and accounted for as additive Delta outflow for comparative purposes. Table 4-41 presents the expected change in Delta outflow under the TVA compared to the 1995 Settlement Agreement during January through June averaged by WYT. The TVA MOU does not include information regarding how the Projects would bypass TVA flows through the Delta, so this report presents a range of potential volumes of Delta outflow contributions that the TVA might implement. Two scenarios are presented based on input from the TVA parties and DWR. The first scenario assumes that the TVA flows provided from March 16 through May 31, covering both the TVA floodplain and outmigration pulses would be accounted for as additive Delta outflow. The second scenario assumes that only flows provided from April 16 through May 31 during the outmigration pulse would be accounted for as additive Delta outflow.

The differences in volumes of Delta outflow that would be accounted for as additive between the scenarios are shown below. This report does not evaluate the biological benefits of the different volumes of TVA new Delta outflow.

Table 4-41. Expected Change (Relative to Existing Conditions) in Delta Outflow Averaged by WYT from the TVA Accounting Spreadsheet (in TAF).

Water Year Type	Protection Period	Critically Dry	Dry	Below Normal	Above Normal	Wet	All Years
New outflow if flows are protected for both TVA pulse periods [a]	March 16–May 31	26	47	52	19	-40	17
New outflow if flows are protected for only the outmigration pulse period [a]	April 16–May 31	13	33	49	-1	-42	7

[a] Values estimated using the draft TVA Accounting Spreadsheet.

4.5 References

4.5.1 Printed References

California Department of Water Resources (DWR). n.d.(a). Monthly Full Natural Flow on the Tuolumne River at La Grange, gage TLG. Available: https://cdec.water.ca.gov/dynamicapp/wsSensorData. Accessed: May 7, 2024.

California Department of Water Resources (DWR). n.d.(b). Don Pedro Reservoir Daily Inflow, gage DNP. Available: https://cdec.water.ca.gov/dynamicapp/wsSensorData. Accessed: May 7, 2024.

California Department of Water Resources (DWR). n.d.(c). Don Pedro Reservoir Daily Outflow, gage DNP. Available: https://cdec.water.ca.gov/dynamicapp/wsSensorData. Accessed: May 7, 2024.

Federal Energy Regulatory Commission (FERC). 1995. New Don Pedro Proceeding: P-2299-024. Settlement Agreement.

Federal Energy Regulatory Commission (FERC). 2020. Final Environmental Impact Statement for Hydropower Licenses. Don Pedro Hydroelectric Project, FERC Project No. 2299-082; La Grange Hydroelectric Project, FERC Project No. 14581-002. Division of Hydropower Licensing. Washington, D.C. July.

Modesto Irrigation District (MID). 2015. *Agricultural Water Management Plan 2015 Update.* December. Prepared by Provost & Pritchard Consulting Group.

Modesto Irrigation District (MID). 2021. *Agricultural Water Management Plan 2020 Update.* March 23. Prepared for MID.

State Water Resources Control Board (SWRCB). 2000. Revised Water Right Decision 1641. Revised March 15.

State Water Resources Control Board (SWRCB). 2018. Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: San Joaquin River Flows and Southern Delta Water Quality. Final. State Clearinghouse #2012122071. Division of Water Rights. Sacramento, CA.

Turlock Irrigation District (TID). 2015. *2015 Agricultural Water Management Plan.* Turlock, CA. November. Prepared by TID.

Turlock Irrigation District (TID). 2021. *2020 Agricultural Water Management Plan.* Final. Turlock, CA. March. Prepared by TID.

Turlock Irrigation District (TID). 2022. *Application to Appropriate Water by Permit.* Submitted January 26, 2022.

Turlock and Modesto Irrigation District (TID and MID). 2023. *2022 Lower Tuolumne River Annual Report.* March 30. Prepared for the Federal Energy Regulatory Commission.

Turlock Irrigation District, Modesto Irrigation District, and The City and County of San Francisco (TID, MID, CCSF). 2023. *Tuolumne River VA party responses to SWRCB technical questions.* Excel Spreadsheet (TIDMIDCCSF_2023_TVA_Modeling). April 7,2023.

Turlock Irrigation District, Modesto Irrigation District, and The City and County of San Francisco (TID, MID, CCSF). 2024. *Tuolumne River VA party modeling of daily flows under the FERC base case and updated TRVA hydrology.* Excel Spreadsheet (TIDMIDCCSF_2024_Daily_TVA_Flows). June 7, 2024.

Turlock Irrigation District, Modesto Irrigation District, and The City and County of San Francisco (TID, MID, CCSF). 2025. *Draft Tuolumne Accounting spreadsheet model.* Excel Spreadsheet (Tuol_Accounting_Model_Apr2025). April 4, 2025.

U.S. Geological Survey (USGS). n.d.(a). Monthly gage flow data on the Tuolumne River at La Grange, gage 11289650. Available: https://waterdata.usgs.gov/nwis/inventory/?site_no=11289650&agency_cd=USGS. Accessed: May 7, 2024.

U.S. Geological Survey (USGS). n.d.(b). Monthly gage flow data on the Tuolumne River at Modesto, gage 11290000. Available: https://waterdata.usgs.gov/ca/nwis/inventory/?site_no=11290000. Accessed: May 7, 2024.

U.S. Geological Survey (USGS). n.d.(c). Monthly gage flow data on the San Joaquin River at Vernalis, gage 11303500. Available: https://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=11303500. Accessed: May 7, 2024.

Chapter 5
Water Temperature

5.1 Introduction

The Tuolumne River Voluntary Agreement (TVA) includes January through June flow commitment that would affect water temperatures for native species in the Tuolumne River. This chapter evaluates potential changes to river temperatures from the TVA. Water temperatures are evaluated in terms of the frequency of attaining temperature benchmarks (see Section 5.2.1.3, *Temperature Benchmarks*), river miles of suitable temperatures, and changes relative to Existing Conditions and how those may affect fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and *Oncorhynchus mykiss* (*O. mykiss*, both California Central Valley steelhead and rainbow trout). These species, jointly referred to as salmonids, were selected based on their sensitivity to potential changes in environmental conditions and their utility in evaluating broader ecosystem and community-level effects of these changes on native aquatic resources. State Water Resources Control Board (State Water Board) staff performed a similar evaluation in the Final Substitute Environmental Document (SED)[1] in support of the 2018 Bay-Delta Plan Update (SWRCB 2018).

5.1.1 Temperature Effects on Aquatic Species

The importance of river temperatures and the deleterious effects that altered (from human activities) river temperature regimes have on aquatic organisms, and in particular cold-water species (e.g., fall-run Chinook salmon and *O. mykiss*) are described in the 2018 Final SED.[2] River temperatures directly influence an organism's metabolism, respiration, feeding, growth, and reproduction and is a primary determinant of their natural spatial and temporal distributions (Carlisle et al. 2013). Water temperature is likely the most important abiotic factor (besides water itself), in the environment for fish and the ecosystem for which they depend, because without suitable water temperatures habitats become unusable.

Like other aquatic organisms, water temperature significantly affects the distribution, health, survival, and reproduction of native salmonids. Because salmonids are ectothermic (cold-blooded), their success is dependent on water temperatures, and they will experience adverse effects when exposed to temperatures outside their optimal range (see Section 5.2.1.3, *Temperature Benchmarks*, and Table 5-2 and Table 5-3 for specific values). Myrick and Cech (2001) state that "water temperature is perhaps the physical factor with the greatest influence on Central Valley salmonids, short of a complete absence of water," and that "the changes made to Central Valley rivers have had, and will continue to have, far-reaching effects on Chinook salmon and steelhead populations." The

[1] Several chapters in the 2018 Final SED include descriptions of modeling and temperature evaluations that were used to support the Bay-Delta Plan Update including: Chapters 4, 5, 7, 19; Appendix C, and Appendix F.1; and Master Response 3.1, which are on the State Water Board website. As applicable, information in this chapter summarizes or references those descriptions.

[2] A detailed description of water temperature importance and effects are found in the 2018 Final SED: Chapters 7 and Chapter 19; Appendix C; and Master Response 3.1, on the State Water Board website.

limiting factors analysis (Section 2.8) presented in Chapter 2, *Aquatic Ecosystem Stressors*, suggests temperatures in spring have a strong influence on recruitment success in the Tuolumne River.

5.1.2 Habitat Degradation

The addition of water storage infrastructure and associated dam operations in rivers alter the natural flow and temperature regimes, often to the detriment of salmonids, other native fishes, and the ecosystem those species depend on (Brown and Bauer 2009; Brown and May 2006; CDFG 2010; Richter and Thomas 2007; Williams 2006). The Tuolumne River and the Lower San Joaquin River (LSJR) have been identified as not meeting water quality standards for temperature, and the Tuolumne River downstream of Don Pedro Dam to the confluence with the LSJR and the LSJR are included on the USEPA 303(d) list as being impaired for water temperature (SWRCB 2022). Beneficial uses determined to be impaired include fish migration, fish spawning, and cold freshwater habitat, which includes, but is not limited to, salmonid egg development, rearing, and smoltification life stages. For more detail, see Chapter 2, Section 2.5, *Temperature*. See Chapter 1, *Introduction*, Section 1.3, *Status of Fish Populations in the Tuolumne River*, for a discussion of current fish populations.

The Department of Fish and Wildlife (formerly California Department of Fish and Game [CDFG]) have concluded that a critical factor limiting salmonid population abundance is high water temperatures which exist during critical life stages in the tributaries and the main-stem San Joaquin River (CDFG 2010). Elevated water temperatures appear to be a factor in the continued decline in adult salmon escapement abundance in the San Joaquin River Basin Watershed, by: (1) inducing adult mortality as adults migrate into the San Joaquin River, and tributaries, to spawn (i.e., pre-spawn mortality); (2) reducing egg viability for eggs deposited in stream gravels (redds), (3) increasing stress levels and therefore reducing survival of juveniles within the tributary nursery habitats, and (4) reducing salmon smolt outmigration survival as smolts leave the nursery habitats within tributaries to migrate down the San Joaquin River to Vernalis and through the south Delta.

5.1.3 2018 Bay-Delta Plan's Recommendations to Other Agencies

The Program of Implementation (Chapter IV) in the 2018 Bay-Delta Plan[3] sets forth Recommendations to Other Agencies (Section C), consistent with the Porter-Cologne Water Quality Control Act, for implementation by agencies other than the State Water Board. These actions include improvements to habitat conditions both inside and outside of the Bay-Delta Estuary, many of which are under the authorities of other agencies. The State Water Board recognizes and incorporates recommendations to other agencies, in the Program of Implementation, as part of the overall effort to comprehensively address Delta and tributary ecosystem needs. The TVA includes a commitment by the TVA Parties[4] to work on development of a suitable temperature term to incorporate into the

[3] Available on the State Water Board website at 2018 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary.

[4] Turlock Irrigation District (TID), Modesto Irrigation District (MID), and the San Francisco Public Utilities Commission (SFPUC), a department of the City and County of San Francisco (CCSF).

Implementation Agreement[5] for the TVA. The Draft Global Agreement to the Healthy Rivers and Landscapes Program in the Bay-Delta, dated March 29, 2024 (Draft Global Agreement), includes a measure to monitor water temperatures in Don Pedro Reservoir and at five sites in the lower Tuolumne River to inform management of cold-water storage and scheduling the timing of spring pulse flows.

5.2 Evaluation of Water Temperatures Resulting from the TVA

5.2.1 Methods

A comparative modeling analysis was performed to evaluate how the TVA could change water temperatures in both the Tuolumne River and the LSJR, and to evaluate how those temperature changes could potentially affect fish and wildlife. Multiple modeling scenarios (see Section 5.2.1.2, *Modeling Scenarios*) were compared in each analysis to investigate how the potential implementation of the TVA could change the frequency with which temperature benchmarks for fall-run Chinook salmon and *O. mykiss* (rainbow trout/steelhead) are met. Modeled temperature results are presented in this chapter under Sections 5.2.2, *Results*, and 5.3, *Cumulative Effects Scenarios*, as well as in Appendix B, *Hydrologic and Water Quality Modeling*, Section C.5, *HEC-5Q Temperature Modeling–Summary Results*, and Appendix E, *Cumulative Effects of Water Right A033277*, Section D.3.2, *Temperature Results*. Additionally, in Chapter 7, *Spawning and Rearing Habitat*, Section 7.3, *Habitat Modeling*, a water temperature filter is used to quantify the availability of suitable habitat between the different Tuolumne River modeling scenarios.

5.2.1.1 Modeling Tools

The comparative temperature modeling analysis in this chapter relies on the Water Supply Effects (WSE) spreadsheet model[6] (developed by State Water Board staff) and the San Joaquin River Basin-Wide Water Temperature Model or SJR HEC-5Q model (temperature model) (CALFED 2009; CDFW 2013).[7] The modeling domain of this analysis is the Tuolumne River, from New Don Pedro Reservoir downstream to its confluence with the San Joaquin River, and from there on the San Joaquin River downstream to Vernalis. The models also represent the Merced and Stanislaus rivers, as well as a portion of the San Joaquin River above the confluence with the Merced River, up to Salt Slough, but these are not the focus of this analysis.[8] The WSE model and the temperature model were previously used by the State Water Board to support its efforts for updating the Bay-Delta Plan in 2018. See Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*, and Appendix B for more information on how WSE was used to model changes in hydrology associated with the TVA.

[5] The Implementation Agreement for the TVA specifies the responsibilities for implementation of the flow and non-flow commitments included in the MOU. This Implementation Agreement is Exhibit B9 of the draft VA documents submitted in March/April 2024 and is available on the State Water Board website at Global, Implementing, and Enforcement Agreements.

[6] For a description of WSE see Appendix B, *Hydrologic and Water Quality Modeling*, of this report and Appendix F.1 of the 2018 Final SED on the State Water Board website.

[7] For a description of the temperature model see Appendix B of this report and Appendix F.1 of the 2018 Final SED.

[8] A graphic representation of the water temperature model geography is found in Appendix F.1 (Figure F.1.6-1) of the 2018 Final SED on the State Water Board website.

To model how implementation of the TVA could affect water temperatures on the Tuolumne and San Joaquin rivers, the State Water Board used the temperature model to simulate river temperatures for the period of 1970 through 2003, based on historical climatic conditions and the modeled river flows and reservoir storage levels predicted by WSE. Raw results of the temperature model are output in 6-hour increments and include the water temperatures, flows, and reservoir storage values at each location represented in the model. These results are exported to excel postprocessors to produce the summary statistics, figures, and tables presented in this report. Relative effects associated with the TVA were determined by comparing temperature results for the TVA scenario against other scenarios representing Existing Conditions and the potential implementation of the 2018 Bay-Delta Plan.

5.2.1.2 Modeling Scenarios

The comparative modeling analysis for the Tuolumne River includes five modeling scenarios (Table 5-1) which reflect flows and temperatures for Existing Conditions, the 2018 Bay-Delta Plan unimpaired flow[9] requirements, and the TVA. The unimpaired flow scenarios are equivalent to those evaluated in the 2018 Final SED[10] for the Tuolumne River, with requirements ranging from 30 to 50% of the unimpaired flow, corresponding to the LSJR flow objectives (including the adaptive range) described in the 2018 Bay-Delta Plan.[11] The TVA scenario includes flows in the January through June period as described in the MOU,[12] but during the July through December period the existing flow requirements from the 1995 Settlement Agreement[13] apply. These results are presented in Section 5.2.2.1, *Tuolumne River*.

The comparative modeling analysis for the LSJR includes four modeling scenarios (Table 5-1) which reflect flows and temperatures for Existing Conditions, the 40% unimpaired flow objective on all tributaries, and the TVA. Temperatures in the LSJR are influenced by the flow inputs from the Tuolumne River, as well as flow inputs from the Merced and Stanislaus rivers. Accordingly, to evaluate potential impacts the TVA may have on temperatures in the LSJR under current conditions and with the implementation of the 2018 Bay-Delta Plan, conditions on the Stanislaus and Merced rivers need to be consistent between the scenarios being compared. Therefore, two TVA scenarios were modeled, one with Existing Conditions assumed for the Merced and Stanislaus rivers (identified as TVA) and one with 40% Unimpaired Flow (UF) Objective implemented on the Merced and Stanislaus rivers (identified as TVA + 2018 BDP) (see Chapter 4, Section 4.4.2, *Change in Flow on the Lower San Joaquin River at Vernalis*). These results are presented in Section 5.2.2.2, *Lower San Joaquin River*.

[9] Unimpaired flow is the flow that would have occurred had the natural hydrology remained unaltered in rivers instead of being stored in reservoirs, imported, exported, or diverted. Unimpaired flow is a modeled flow generally based on historical gage data with factors applied to primarily remove the effects of dams and diversion within the watersheds.

[10] A detailed description of the unimpaired flow modeling scenarios is found in the 2018 Final SED, Chapter 3 and Appendix F.1, on the State Water Board website.

[11] Available on the State Water Board website at 2018 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary.

[12] Available on the State Water Board website at Revised Memorandum of Understanding. As described in Section 4.3 and Appendix B, information in addition to the MOU were provided by the TVA parties to define the assumptions for the TVA scenario. TVA MOU may be used interchangeably with TVA in this report when summarizing overall results of the proposal.

[13] Available on the Tuolumne River Technical Advisory Committee website at New Don Pedro Proceedings: 1995 Settlement Agreement.

Table 5-1. Summary of Water Temperature Modeling Scenarios for the Tuolumne River and Lower San Joaquin River.

Name	Description
Tuolumne River Scenarios	
Existing Conditions	Operational conditions in 2023 on the Tuolumne River at the time the TVA was proposed in the MOU
30% UF Objective	Unimpaired flows set to 30% consistent with the 2018 Bay-Delta Plan
40% UF Objective	Unimpaired flows set to 40% consistent with the 2018 Bay-Delta Plan
50% UF Objective	Unimpaired flows set to 50% consistent with the 2018 Bay-Delta Plan
TVA	TVA flows from January through June; 1995 FERC settlement agreement flows from July through December
Lower San Joaquin River Scenarios	
Existing Conditions	Operational conditions in 2023 on the Lower San Joaquin River tributaries at the time the TVA was proposed in the MOU
40% UF Objective all tribs	Unimpaired flows set to 40% on all three tributaries consistent with the 2018 Bay-Delta Plan
TVA	Tuolumne River with operational conditions set to flows in the TVA scenario; Merced and Stanislaus Rivers with operational conditions in 2023 at the time the TVA was proposed in the MOU
TVA + 2018 BDP	Tuolumne River with operational conditions set to flows in the TVA scenario; Merced and Stanislaus Rivers with unimpaired flows set to 40% consistent with the 2018 Bay-Delta Plan

5.2.1.3 Temperature Benchmarks

The temperature benchmarks used in this evaluation are based on the U.S. Environmental Protection Agency (USEPA) recommended temperature guidance for protection of salmonids using the 7-day average of the daily maximum (7DADM) unit of measurement (USEPA 2003). The tabular results in Section 5.2.2, *Results*, and Section 5.3, *Cumulative Effects Scenarios*, are presented as the percentage of time[14] each modeling scenario meets the USEPA temperature benchmarks. Additionally, environmental objectives expressed as temperature ranges developed as part of the Scientific Evaluation Process (Cain et al. 2019) are used graphically as an informative supplement to USEPA's recommended temperature guidance. The temperatures from the two efforts above are used as benchmarks for the evaluation in this chapter and are discussed in more detail below and in Chapter 2 of this report.

USEPA Temperature Guidance

The 2003 USEPA temperature guidance[15] was developed to assist States and tribes to designate uses and establish temperature numeric criteria for waterbodies that help meet the goal of "protection and propagation of fish, shellfish, and wildlife" in section 101(a)(2) of the Clean Water Act. The guidance specifically addresses cold-water salmonid species and is based on a comprehensive review and synthesis of a large body of peer-reviewed studies and published papers, including

[14] The frequency of meeting the benchmarks in this analysis is the percentage of days during each month over the modeled 34-year period (1970–2003; n= number of days per specific month multiplied by 34 years).

[15] A detailed description of how this guidance was used in the temperature evaluations in the 2018 Final SED is found in Chapters 7 and 19; Appendix F.1; and Master Response 3.1, available on the State Water Board website.

temperature studies completed on Central Valley salmonids, and subsequent review by both an independent scientific panel and the public. The 7DADM is recommended because it describes the maximum temperatures that fish can be exposed to while providing protective conditions (USEPA 2003). The guidance includes different benchmarks for each life stage because each life stage has a different temperature tolerance (Table 5-2).

Table 5-2. USEPA Recommended Temperature Guidance for Protective Conditions.

Life Stage	Temperature (°C)
Salmon/Trout Spawning, Egg Incubation, and Fry Emergence	13
Steelhead Smoltification	14
Salmon/Trout Core Juvenile Rearing	16
Salmon/Trout Migration plus Non-Core Juvenile Rearing	18

Source: USEPA 2003.[16]

The distinction between core and non-core rearing is the difference in the location and densities of salmonids during the juvenile rearing life stage. Core rearing generally applies to salmonids found in the mid to upper reaches at moderate to high densities, whereas non-core rearing refers to salmonids found in the mid to lower part of the river at moderate to low densities.

Table 5-5 and Table 5-6 summarize these temperature benchmarks for the analyses on the Tuolumne River and LSJR. Section 5.2.1.4, *Life Stage and Timing*, provides more details regarding the importance of these temperature benchmarks according to geographic location and life stage.

USEPA also recommends a 20°C (68°F) temperature benchmark for the lower parts of major river reaches that are used almost exclusively for migration of juvenile and adult salmonids for a short amount of time during summer maximum conditions. A salmonid exposed to 20°C may experience harmful effects such as increased disease and decreased swimming performance in adults, and increased disease, impaired smoltification, reduced growth, and increased predation for migrating juveniles (McCullough et al. 2001). Additionally, thermal tolerance studies included in USEPA's comprehensive review and synthesis of peer-reviewed studies and published papers indicate that juvenile Chinook salmon and steelhead can be expected to exhibit significant mortality at chronic temperatures exceeding 25°C (77°F), which approximates the upper incipient lethal temperature reported for individuals that have been acclimated to water temperatures greater than or equal to 20°C (68°F) (McCullough et al. 2001).

Scientific Evaluation Process

The Scientific Evaluation Process (SEP) was a multi-agency and stakeholder effort to identify and synthesize the best available science on restoring ecological conditions in the LSJR and its tributaries, including restoration of sustainable native populations of fall-run Chinook salmon, spring-run Chinook salmon, and steelhead (Cain et al. 2019). The SEP developed environmental objectives presented as a range of specific measurable parameters (including temperature) that collectively define suitable environmental conditions for a particular species. The authors primarily relied on USEPA guidance to develop temperature parameters but supplemented that information when newer information and studies specific to Central Valley salmon, where available. The

[16] Available on the USEPA website at the Northwest Water Quality Temperature Guidance for Salmon, Steelhead and Bull Trout.

environmental objectives in Table 5-3 were categorized according to the conditions that fish experience (supportive, stressful, and detrimental)[17] acknowledging that temperature impacts to salmonids occur at a continuum[18] of exposures that are influenced by additional environmental conditions, e.g., availability of food or temperature refugia.

The SEP produced an independently peer-reviewed report that provides a framework for ecological restoration efforts on the Stanislaus River (Cain et al. 2019). Although the SEP report was developed specifically for the Stanislaus River, the benchmarks and scientific knowledge compiled and summarized in that report are valuable to inform the evaluation for salmonids presented in this chapter because the watersheds are adjacent and the salmonid populations experience similar climatic conditions.

Temperature objectives in the SEP report were identified from literature for each life stage such as adult upstream migration and spawning and were presented based on different increments such as weekly or daily averages. For consistency with USEPA (2003) guidance, temperature metrics based on the 7DADM were used. When available in the SEP report, specific temperature thresholds were identified for fall-run Chinook salmon, spring-run Chinook salmon, and steelhead. For some life stages, such as adult holding, one set of temperatures was identified for both Chinook salmon and steelhead. In other cases where different objectives were identified for Chinook salmon and *O. mykiss*, the Chinook salmon value was used since it best aligns with the life stages and timeframes analyzed in the 2018 Bay-Delta Plan (SWRCB 2018). The SEP report provides a well-documented guidance to contribute to the technical foundation necessary to restore conditions in the LSJR and its tributaries to support sustainable native fish populations.

Table 5-3. SEP Temperature Parameters That Are Supportive, Stressful, and Detrimental to Salmon and the Steelhead Form of *O. mykiss*.

Species	Time Period	Life Stage	Supportive (°C)	Stressful (°C)	Detrimental (°C)
Fall-run Chinook salmon	Late September to December	Adult Upstream Migration	<15.5	15.5 to 20.5	>20.5
Steelhead	September to April				
Fall-run Chinook salmon	Late October to March	Spawning	<12.5	12.5 to 13.8	>13.8
Fall-run Chinook salmon	Last week of January to second week of June	Juvenile Rearing, Migration, and Smoltification	<16.0	16.0 to 20.0	>20.0

[17] Expressed as ranges based on the SEP's review of literature. Supportive conditions contribute to the health and growth of individuals without harmful effects. Stressful conditions may result in some degree of negative impact at the individual or population level. Detrimental conditions may result in a significant level of harm at the individual or population level. The use of ranges for an evaluation of impacts is an alternative to the binary approach, i.e., above or below a specific benchmark, which acknowledges that temperature effects likely impact species and populations at variable levels depending on a multitude of factors, e.g., exposure duration and food availability.

[18] See Figure 3.1-33 in Master Response 3.1 of the 2018 Final SED on the State Water Board website.

Source: Adapted from Cain et al. 2019.[19]

5.2.1.4 Life Stage Timing and Location

Fall-run Chinook salmon and *O. mykiss* (rainbow trout/steelhead) need access to suitable temperatures at the right place and time to successfully complete their life cycles. Anadromous species and population segments use freshwater for only a portion of their lives before migrating to the ocean, while resident fish, such as rainbow trout spend their entire lives in freshwater. Fall-run Chinook in the Tuolumne River generally complete their freshwater life stages in several months. Alternatively, juvenile steelhead typically require more than one year to complete their freshwater life stages before emigrating to the ocean, so suitable river temperatures must be maintained year-round for steelhead to successfully complete their life cycle. Table 5-4 shows specific timing for fall-run Chinook, steelhead and rainbow trout, peak abundance periods,[20] and information about where geographically in the watershed each life stage can be found, as not every life stage occurs in all places in a river.

[19] The report is available on the ResearchGate website which is a project to make science available to all.

[20] The gray scale with darker coloration means higher abundance, and lighter colorations mean lower abundance.

Table 5-4. Geographic and Seasonal Occurrence for Fall-Run Chinook Salmon and *O. mykiss* (Rainbow Trout and Steelhead).

Life Stage	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Central Valley fall-run Chinook salmon													
Adult migration	Bay-Delta, SJR and three eastside tributaries												
Spawning/ incubation	Three eastside tributaries												
Juvenile rearing/ emigration	Bay-Delta, SJR and three eastside tributaries												
Central Valley steelhead													
Adult migration	Bay-Delta, SJR and three eastside tributaries												
Spawning/ incubation	Three eastside tributaries												
Juvenile rearing	Three eastside tributaries												
Juvenile emigration (age 1+)	Bay-Delta, SJR and three eastside tributaries												
Rainbow trout													
Adult migration (lake to stream)	New Melones, New Don Pedro, Lake McClure, and Lake McSwain												
Spawning/ incubation	Three eastside tributaries												
Juvenile rearing	Three eastside tributaries												

Sources: Style of table adapted from Rosenfield and Baxter 2007; Wang and Brown 1993; USFWS 1996; McEwan 2001; Moyle 2002; Hallock 1989; McBain & Trush 2002; NMFS 2009; and USBR and DWR 2011.

Primary occurrence periods.

Non-primary occurrence periods.

This analysis focuses on the life stage with the most sensitive temperature needs in each month for the Tuolumne and San Joaquin rivers using benchmarks based on USEPA temperature guidance for protective conditions (see Section 5.2.1.3, *Temperature Benchmarks*). Similarly, the most important locations in the river for each life stage were the focus of the analysis (Table 5-5 and Table 5-6). However, some temporal and geographical overlap is still presented when appropriate.

For the evaluation in the Tuolumne River, September 1 to October 31 is used as the adult migration period with the geographic scope as the entire river. October 1 through March 31 is analyzed for spawning, egg incubation, and fry emergence for locations from just below the infiltration galleries (IGs; river mile (RM) 25.9) to the dam. Core juvenile rearing (i.e., moderate to high density juvenile rearing, USEPA 2003) is analyzed from March 1 through May 31 with a geographic scope of the entire river. Smoltification has been identified as the most restrictive life stage occurring from April 1 through June 30 with a geographic scope of the entire river. Core juvenile rearing for *O. mykiss* is analyzed from upstream of the IGs to the dam, and non-core juvenile rearing (i.e., moderate to low density rearing) for *O. mykiss* is analyzed downstream of RM 28.1. Lastly, June 1 through August 31 is identified as an important time frame for juvenile *O. mykiss* summer rearing with a geographic scope from just downstream of the IGs to the dam.

Table 5-5. Evaluation Time Periods, Primary Salmonid Life Stage, Primary Evaluation Locations, and Evaluation Temperature Benchmarks for the Tuolumne River.[21]

Evaluation Time Period	Primary Life Stage (fall-run Chinook and *O. mykiss* unless specified)	Temperature Benchmarks (7DADM °C)	Temperature Benchmarks (7DADM °F)	Primary Evaluation Locations (River Mile)
September 1 to October 31	Adult Migration	18	64.4	• 0 • 13.2 • 23.54 • 28.1 • 38.29 • 53.5
October 1 to March 31	Spawning, Egg Incubation, and Fry Emergence	13	55.4	• 23.54 • 28.1 • 38.29 • 53.5
March 1 to May 31	Core Juvenile Rearing	16	60.8	• 0 • 13.2 • 23.54 • 28.1 • 38.29 • 53.5
April 1 to June 30	Smoltification	14	57.2	• 0 • 13.2 • 23.54 • 28.1 • 38.29 • 53.5

[21] See Chapter 7, *Spawning and Rearing Habitat*, for a map of the Tuolumne River.

Evaluation Time Period	Primary Life Stage (fall-run Chinook and *O. mykiss* unless specified)	Temperature Benchmarks (7DADM °C)	Temperature Benchmarks (7DADM °F)	Primary Evaluation Locations (River Mile)
June 1 to June 30	Core Juvenile Rearing (*O. mykiss*)	16	60.8	• 28.1 • 38.29 • 53.5
June 1 to June 30	Non-Core Juvenile Rearing (*O. mykiss*)	18	64.4	• 0 • 13.2 • 23.54 • 28.1
June 1 to August 31	Summer Rearing (*O. mykiss*)	18	64.4	• 23.54 • 28.1 • 38.29 • 53.5

°F is given as a convenient temperature reference. Results will only be shown in °C.
RM 0 = Confluence.
RM 13.2 = ¼ river.
RM 23.54 = Infiltration Gallery Downstream.
RM 28.1 = Infiltration Gallery Upstream.
RM 38.29 = ¾ river.
RM 53.5 = Below La Grange Dam.

In the LSJR, similar life stage timing was used as in the Tuolumne River, except the combined spawning, egg incubation, and fry emergence time period was not analyzed because salmonid reproduction typically does not take place in the LSJR. For the LSJR, the adult migration period is analyzed during September through December, the core juvenile rearing period is analyzed during February through June, and the smoltification period is analyzed February through June. Lastly, non-core juvenile rearing for *O. mykiss* is analyzed from June 1 to June 30.

Table 5-6. Evaluation Time Periods, Primary Salmonid Life Stage, Primary Evaluation Locations, and Evaluation Temperature Thresholds for the Lower San Joaquin River.

Evaluation Time Period	Primary Life Stage (fall-run Chinook and *O. mykiss* unless specified)	Temperature Benchmarks (°C as a 7DADM)	Temperature Benchmarks (°F as a 7DADM)	Primary Evaluation Locations (River Mile)
September 1 to December 31	Adult Migration	18	64.4	• 69.31 • 72.501 • 81.401 • 116.001
February 1 to June 30	Core Juvenile Rearing	16	60.8	• 69.31 • 72.501 • 81.401 • 116.001
February 1 to June 30	Smoltification	14	57.2	• 69.31 • 72.501 • 81.401 • 116.001

Evaluation Time Period	Primary Life Stage (fall-run Chinook and *O. mykiss* unless specified)	Temperature Benchmarks (°C as a 7DADM)	Temperature Benchmarks (°F as a 7DADM)	Primary Evaluation Locations (River Mile)
June 1 to June 30	Non-Core Juvenile Rearing (*O. mykiss*)	18	64.4	• 69.31 • 72.501 • 81.401 • 116.001

°F is given as a convenient temperature reference. Results will only be shown in °C.
RM 69.31 = Vernalis.
RM 72.501 = above the Stanislaus River confluence.
RM 81.401 = above the Tuolumne River confluence.
RM 116.001 = above the Merced River confluence.

In addition to evaluating the ability of scenarios to attain protective conditions, the evaluation also assessed the ability of the scenarios to avoid more extreme conditions. For example, the evaluation assessed whether different scenarios lower the occurrence of detrimental and lethal temperatures.[22]

5.2.2 Results

The results presented in this Chapter are predicted water temperature conditions that could occur under the modeling scenarios described using the WSE and SJR HEC-5Q models. The models use retrospective hydrological data and environmental interactions to predict the water temperature conditions that potentially could have occurred in the past, if the modeling scenarios were implemented instead of the historical conditions. The modeling results do not indicate the exact changes in water temperatures from implementing the modeling scenarios, nor do the models predict water temperature conditions in the future. The results indicate the relative changes in the timing and trends of water temperature conditions in the Tuolumne and San Joaquin River that may occur from the implementation of the modeling scenarios. The relative changes in water temperature conditions inform the potential changes in the quantity and quality of salmonid habitat in the Tuolumne and San Joaquin River.

5.2.2.1 Tuolumne River

The results presented in tables in the *Percentage of Time USEPA Benchmarks are Achieved* and *Percentage of Time Detrimental and Lethal Temperature are Avoided* sections are a comparative overview meant to be interpreted as a broad view of the potential occurrences of temperatures suitable[23] for fall-run Chinook salmon and *O. mykiss* (rainbow trout/steelhead) between modeled scenarios. Results are also presented in figures in the *Temporal and Life Stage Assessments* section and are organized according to each evaluation time period, life stage, and location.[24] These results are more granular such that the difference between the modeled scenarios can be tracked in more detail through space and time. The results presented in the *Sequential Dry Year Off-ramps* section

[22] A detailed description of using harmful and lethal temperatures in a benefits analysis is found in the 2018 Final SED: Master Response 3.1, on the State Water Board website.

[23] Refers to temperatures that are at or below USEPA's recommended numeric criteria for protective conditions. See Section 5.2.1.3, *Temperature Benchmarks.*

[24] Adult migration, September 1–October 31; spawning, egg incubation, and fry emergence, October 1–March 31; core juvenile rearing, March 1–May 31; smoltification, April 1–June 30; core juvenile rearing (*O. mykiss*), June 1–June 30; non-core juvenile rearing (*O. mykiss*), June 1–June 30; and summer rearing (*O. mykiss*), June 1–August 31.

provide a comparison of the modeled scenarios in Below Normal, Dry, and Critically Dry years to show the effects of the TVA drought based off-ramps (see Chapter 4 for more detail).

Frequency of Benchmark Attainment or Exceedance

In this section, the modeled frequency[25] of meeting temperature benchmarks based on USEPA guidance (7DADM unit of measurement; see Section 5.2.1.3, *Temperature Benchmarks*) are compared between Existing Conditions and the TVA or the % UF objectives (30%, 40%, and 50%) scenarios. The frequencies of attainment are displayed for 5 locations in the river, and for different life stage seasons and benchmarks. All of the values in the tables are the percentages that benchmarks are predicted to be attained.

The interpretation of these modeled results in terms of temperature benefits to fall-run Chinook salmon and *O. mykiss* (rainbow trout/steelhead) is discussed in Section 5.2.3.1, *Tuolumne River*.

Percentage of Time USEPA Benchmarks Are Achieved

Table 5-7 shows the percentage of time Tuolumne River modeled water temperatures are expected to attain USEPA temperature benchmarks for protective conditions (13°C, 14°C, 16°C, and 18°C) for the scenarios. A 10% or greater increase in frequency that the USEPA benchmarks are attained compared to Existing Conditions is considered a significant increase in the amount of time that protective conditions are achieved. None of the scenarios exhibited a significant (i.e., 10% or greater) decrease in the frequency of attaining the benchmarks compared to the Existing Conditions.

Below La Grange Dam (Not Shown)

At the most upstream evaluation location, below La Grange Dam (RM 53.5), there is little to no change between scenarios for the entire year. Water temperatures at La Grange Dam are almost always suitable under all of the evaluated scenarios (i.e., they are less than 13°C 98% of the time). As discussed in the sections below, other river locations that are further downstream often have water temperatures that exceed protective conditions.

Adult Migration September 1–October 31

Water temperatures in the Tuolumne River during September frequently exceed the USEPA benchmark of 18°C for adult migration for the Existing Conditions scenario. No significant increases or decreases occur under the TVA or 30% UF Objective scenarios during September. The 40% and 50% UF Objective scenarios significantly increase the frequency the benchmark for adult migration is achieved in September at RMs 28.1 and 23.54. The temperature improvements exhibited by the 40% and 50% UF Objective scenarios are likely due to Bay-Delta Plan adaptive implementation flow shifting[26] to avoid adverse temperatures outside the February to June period. Flow shifting is not implemented under the 30% UF Objective.

Compared to September, temperature conditions improve during October for adult migration under Existing Conditions. Attainment of the benchmark decreases spatially moving downstream, and none of the scenarios exhibit significant changes from the Existing Conditions.

[25] The frequency of meeting the benchmarks in this analysis is the percentage of days during each month over the modeled 34-year period (1970–2003; n= number of days per specific month multiplied by 34 years).

[26] The application of flow shifting is described in Appendix F.1 of the 2018 Final SED on the State Water Board website.

Spawning, Egg Incubation, and Fry Emergence October 1–March 31

During October through January, no significant changes in frequency of meeting the USEPA benchmark of 13°C for spawning, incubation, and fry emergence are exhibited in the evaluated spawning reach from RM 38.29 to RM 23.54. October water temperatures are characterized as containing no suitable temperatures for reproductive life stages, and November exhibits suitable temperatures around 21-30% of the time depending on location. In contrast, December and January water temperatures frequently attain the 13°C benchmark (i.e., ≥95%). As the season progresses water temperatures warm under the Existing Conditions scenario and February and March attain the benchmark ≤74% and ≤57% of the time, respectively. February and March are critical months for successful egg incubation and fry emergence. The TVA does not show significant changes from the Existing Conditions during February or March. In March, both the 40% and 50% UF Objective scenarios exhibit significant increases in frequency of attaining the benchmark throughout the spawning reach. During February, the 50% UF Objective scenario also shows a significant increase in frequency of meeting the 13°C benchmark compared to Existing Conditions throughout the spawning reach. In March, both the 40% and 50% UF Objective scenarios exhibit significant increases in frequency of attaining the benchmark throughout the spawning reach. The 30% UF Objective only shows a significant increase in frequency at RM 38.29 during March.

Core Juvenile Rearing March 1–May 31

Core juvenile rearing was evaluated from RM 38.29 downstream to the confluence, and the Existing Conditions scenario exhibited relatively a high frequency (i.e., 91%) of attaining the USEPA benchmark of 16°C for core juvenile rearing at RM 38.29 in March, but the frequency of attaining the benchmark decreases spatially moving downstream and temporally from March to May. The TVA scenario increases the frequency of attaining benchmarks during March through May, and the modeling indicates that the TVA scenario increases the frequency significantly during May. The 40% and 50% UF Objective scenarios exhibit significant increases in frequency of meeting the benchmark compared to the Existing Conditions during all months and throughout the core juvenile rearing reach. The 30% UF Objective scenario also has significant increases but at fewer locations and lesser magnitudes compared to the 40% and 50% UF Objectives.

Smoltification April 1–June 30

Compared to the Existing Conditions, the TVA scenario exhibits significant increases in the frequency of attaining the USEPA benchmark of 14°C for smoltification at RM 23.54 and upstream locations during May. The 30–50% UF Objective scenarios exhibit significant increases in the frequency of attaining the USEPA benchmark of 14°C for smoltification at RM 23.54 and upstream locations during all months (except in June at RM 23.54 for the 30% UF Objective scenario). The 40% and 50% UF Objective scenarios exhibit significant increases in the frequency of meeting the smoltification benchmark at RM 13.2 during May, and none of the scenarios show significant improvements in achieving this benchmark near the confluence with the LSJR.

Core Juvenile Rearing (O. mykiss) June 1–June 30

In June, TVA scenario is expected to reduce the frequency of attaining the USEPA benchmark of 16°C for core juvenile rearing for *O. mykiss* attained compared to Existing Conditions, but at less than a significant level. The 30%–50% UF Objective scenarios exhibit significant increases in frequency of attaining the benchmark for core juvenile rearing throughout the *O. mykiss* core rearing reach (RM 28.1–38.29).

Non-Core Juvenile Rearing (O. mykiss) June 1–June 30

The TVA scenario exhibits similar frequencies of attaining the USEPA benchmark of 18°C for *O. mykiss* non-core juvenile rearing to the Existing Conditions from RM 28.1 to the confluence. The 30%–50% UF Objective scenarios significantly increase the frequency of attaining the benchmark for *O. mykiss* non-core juvenile rearing throughout the rearing reach (RM 28.1 to the confluence) during June.[27]

Summer Rearing (O. mykiss) June 1–August 31

The frequency of attaining the USEPA benchmark of 18°C for summer rearing *O. mykiss* is significantly increased from Existing Conditions in June under the 30%–50% UF Objective scenarios throughout the summer rearing reach (RM 38.29 to 23.54) and again in July under the 40% and 50% Objective scenarios. No significant increases in frequency occur for either of the UF Objective scenarios in August, nor for the TVA scenario in any month. In July, the 40% and 50% UF Objective scenarios provide a significant increase in frequency of attaining the benchmark throughout the summer rearing reach.

Percentage of Time Harmful and Lethal Temperatures Are Avoided

Table 5-8 and Table 5-9 show the percentage of time in the Tuolumne River that USEPA temperature benchmarks for harmful and lethal effects for migrating juveniles and adults (20°C and 25°C, respectively) are attained for each scenario. A 10% or greater increase in frequency that the USEPA benchmarks are attained compared to Existing Conditions is considered a significant increase in the amount of time that protective conditions are achieved. None of the scenarios exhibited a significant (i.e., 10% or greater) decrease in the frequency of attaining the benchmarks compared to the Existing Conditions.

Harmful

Under all modeled scenarios, water temperatures in the Tuolumne River exceed the USEPA benchmark of 20°C for conditions harmful to migrating juveniles and adults at times, but temperatures primarily remain below the benchmark from November to March (Table 5-8). The TVA exhibits a significant increase in the frequency that harmful temperature conditions are avoided throughout the river during May. During April, the 30%–50% UF Objective scenarios significantly increase the frequency that harmful temperature conditions are avoided from RM 13.2 to the confluence, and in May, the 30%–50% UF Objective scenarios significantly increase the frequency that harmful temperatures are avoided throughout the Tuolumne River. In June, all the UF Objective scenarios increase the frequency of time that harmful conditions are avoided throughout the river, and in July, the 40% and 50% UF Objective scenarios significantly increase the frequency that harmful temperatures are avoided from RM 38.29 to RM 23.54. No significant increases in the frequency of avoiding harmful conditions are expected from August to October.

Lethal

The temperature modeling suggests that lethal water temperatures (i.e., ≥25°C) primarily occur in the Tuolumne River from June to September (Table 5-9) for Existing Conditions. The TVA increases the frequency that lethal temperatures are avoided during June at RM 38.29 and RM 28.1 which

[27] Non-core juvenile rearing is not specifically identified in Table 5-7; however, the information to assess the life stage is available in the summer rearing (SR) row from RM 28.1 down to the confluence.

should benefit the survival of rearing *O. mykiss* and any remaining juvenile Chinook salmon. The 30%, 40%, and 50% Objective scenarios significantly increase the frequency that lethal temperatures are avoided in June throughout the evaluated reach of the Tuolumne River, and the 40% and 50% UF Objective scenarios significantly increase the avoidance of lethal temperatures during July, throughout the evaluated reach as well. The 30% UF Objective scenario also significantly increases the frequency that lethal temperatures are avoided in July, but only from RM 28.1 to RM 23.54. These expected improvements in water temperatures would be expected to benefit rearing and migrating juvenile Chinook and core, non-core, and summer rearing and migrating *O. mykiss*.

Table 5-7. A Comparison of the Percentage of Time that USEPA Temperature Benchmarks for Salmonid Life Stage Protective Conditions Are Attained Each Month on the Tuolumne River Under the Modeled Scenarios.

Temperature Effects		Confluence (RM 0)					1/4 River (RM 13.2)					IGD (RM 23.54)					IGU (RM 28.1)					3/4 River (RM 38.29)				
			Scenario					Scenario					Scenario					Scenario					Scenario			
Life Stage	Month/ USEPA Benchmark (°C)	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA
AM	Sep (18)	**2%**	2%	2%	2%	2%	**3%**	3%	5%	5%	3%	**16%**	12%	27%	26%	14%	**18%**	13%	29%	29%	15%	**36%**	29%	38%	37%	32%
AM	Oct (18)	**24%**	22%	30%	30%	24%	**34%**	32%	40%	39%	33%	**61%**	59%	62%	62%	60%	**68%**	65%	68%	68%	66%	**84%**	83%	83%	83%	83%
R	Oct (13)	**0%**	0%	0%	0%	0%	**0%**	0%	0%	0%	0%	**0%**	0%	0%	0%	0%	**0%**	0%	0%	0%	0%	**0%**	0%	0%	0%	0%
R	Nov (13)	**27%**	27%	28%	27%	27%	**34%**	33%	34%	33%	33%	**23%**	21%	24%	22%	23%	**24%**	22%	24%	21%	23%	**30%**	26%	26%	23%	28%
R	Dec (13)	**99%**	99%	99%	99%	99%	**100%**	100%	99%	99%	100%	**96%**	96%	96%	96%	96%	**96%**	96%	95%	96%	95%	**95%**	94%	94%	94%	94%
R	Jan (13)	**100%**	98%	98%	98%	99%	**100%**	99%	99%	99%	100%	**99%**	98%	98%	98%	99%	**99%**	98%	98%	98%	99%	**100%**	99%	99%	99%	100%
R	Feb (13)	**73%**	74%	74%	77%	69%	**77%**	79%	80%	82%	75%	**74%**	79%	81%	85%	72%	**74%**	79%	81%	85%	72%	**80%**	84%	88%	91%	78%
R	Mar (13)	**39%**	37%	36%	39%	36%	**53%**	51%	52%	54%	52%	**57%**	62%	68%	76%	60%	**58%**	63%	69%	77%	61%	**60%**	70%	81%	88%	66%
CR	Mar (16)	**68%**	74%	83%	90%	75%	**74%**	81%	91%	94%	79%	**82%**	97%	99%	99%	89%	**83%**	98%	99%	99%	91%	**91%**	100%	100%	100%	99%
CR	Apr (16)	**52%**	60%	74%	86%	59%	**55%**	75%	86%	92%	63%	**67%**	95%	96%	98%	71%	**69%**	96%	97%	98%	72%	**81%**	97%	99%	100%	82%
CR	May (16)	**24%**	39%	58%	65%	31%	**36%**	65%	79%	85%	48%	**50%**	87%	96%	99%	69%	**51%**	89%	97%	100%	70%	**66%**	98%	100%	100%	84%
S	Apr (14)	**27%**	29%	30%	35%	30%	**40%**	43%	48%	59%	46%	**55%**	70%	84%	91%	62%	**56%**	74%	86%	93%	63%	**64%**	91%	95%	96%	68%
S	May (14)	**4%**	4%	5%	7%	3%	**18%**	20%	29%	43%	18%	**37%**	61%	76%	81%	50%	**38%**	66%	78%	83%	52%	**47%**	84%	91%	96%	64%
S	Jun (14)	**0%**	0%	0%	0%	0%	**3%**	4%	4%	10%	2%	**20%**	29%	36%	43%	18%	**21%**	32%	38%	46%	19%	**31%**	54%	66%	72%	23%
CR	Jun (16)	**5%**	7%	11%	16%	4%	**19%**	32%	40%	52%	17%	**31%**	62%	70%	74%	24%	**31%**	64%	72%	75%	25%	**33%**	74%	77%	85%	31%
SR	Jun (18)	**26%**	40%	55%	65%	21%	**30%**	58%	67%	74%	23%	**33%**	75%	78%	85%	32%	**33%**	75%	79%	87%	32%	**36%**	83%	90%	91%	35%
SR	Jul (18)	**8%**	6%	7%	6%	7%	**19%**	17%	19%	15%	16%	**24%**	22%	38%	38%	20%	**24%**	22%	39%	40%	21%	**28%**	26%	41%	41%	24%
SR	Aug (18)	**0%**	0%	0%	0%	0%	**2%**	2%	2%	2%	2%	**8%**	7%	9%	8%	7%	**8%**	7%	9%	8%	7%	**12%**	10%	20%	18%	12%

AM = Adult Migration.
R = Reproduction (Spawning, Egg Incubation, and Fry Emergence).
CR = Core Rearing (*O. mykiss* only in June).
S = Smoltification.
SR = Summer Rearing.
IGD = Infiltration Gallery Downstream.
IGU = Infiltration Gallery Upstream.

Table 5-8. A Comparison of the Percentages of Time That the 20° Celsius Harmful Temperature Benchmark for Salmonids Is Attained Each Month in the Tuolumne River Under the Modeled Scenarios.

Tuolumne River		Confluence (RM 0)					1/4 River (RM 13.2)					IGD (RM 23.54)					IGU (RM 28.1)					3/4 River (RM 38.29)				
			Scenario					Scenario					Scenario					Scenario					Scenario			
USEPA Benchmark (°C)	Month	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA
20	Sep	**7%**	7%	14%	13%	7%	**10.5%**	9%	19.5%	19%	10%	**31%**	25%	36%	36%	28%	**35%**	29%	38%	38%	31%	**50%**	47%	47%	47%	50%
20	Oct	**58%**	58%	62%	62%	58%	**64%**	63%	68%	67%	64%	**82%**	80%	82%	81%	82%	**85%**	85%	85%	85%	85%	**93%**	92%	92%	92%	92%
20	Nov	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
20	Dec	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
20	Jan	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
20	Feb	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
20	Mar	**98%**	100%	100%	100%	99%	**98%**	100%	100%	100%	99%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
20	Apr	**81%**	97%	98%	99%	82%	**86%**	98%	99%	100%	86%	**95%**	100%	100%	100%	97%	**96%**	100%	100%	100%	99%	**100%**	100%	100%	100%	100%
20	May	**57%**	91%	99%	100%	75%	**62%**	96%	100%	100%	80%	**80%**	100%	100%	100%	97%	**81%**	100%	100%	100%	99%	**93%**	100%	100%	100%	100%
20	Jun	**31%**	65%	74%	76%	25%	**31%**	71%	76%	80%	26%	**35%**	80%	89%	91%	36%	**36%**	82%	91%	91%	37%	**49%**	92%	93%	96%	42%
20	Jul	**20%**	19%	22%	18%	16%	**20%**	20%	26%	24%	16%	**26%**	25%	43%	44%	23%	**27%**	26%	42%	43%	24%	**34%**	35%	44%	45%	30%
20	Aug	**5%**	4%	4%	3%	4%	**7%**	7%	7%	6%	7%	**11%**	9%	16%	15%	10%	**12%**	10%	19%	18%	12%	**39%**	36%	42%	41%	38%

IGD = Infiltration Gallery Downstream.
IGU = Infiltration Gallery Upstream.

Table 5-9. A Comparison of the Percentages of Time That the 25° Celsius Lethal Temperature Benchmark for Salmonids Is Attained Each Month in the Tuolumne River Under the Modeled Scenarios.

Tuolumne River		Confluence (RM 0)					1/4 River (RM 13.2)					IGD (RM 23.54)					IGU (RM 28.1)					3/4 River (RM 38.29)				
			Scenario					Scenario					Scenario					Scenario					Scenario			
USEPA Benchmark (°C)	Month	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA	Existing Conditions	30% UF Objective	40% UF Objective	50% UF Objective	TVA
25	Sep	**59%**	56%	60%	60%	58%	**62%**	59%	62%	62%	62%	**81%**	80%	80%	80%	81%	**83%**	82%	82%	82%	83%	**90%**	90%	90%	90%	90%
25	Oct	**98%**	98%	98%	98%	98%	**98%**	98%	98%	98%	98%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
25	Nov	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
25	Dec	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
25	Jan	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
25	Feb	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
25	Mar	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
25	Apr	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
25	May	**96%**	100%	100%	100%	100%	**96%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%	**100%**	100%	100%	100%	100%
25	Jun	**50%**	88%	94%	96%	53%	**53%**	91%	95%	96%	54%	**72.5%**	97%	98%	99%	81.8%	**72%**	97%	98%	99%	87%	**77%**	98%	99%	100%	100%
25	Jul	**27%**	29%	46%	47%	24%	**29%**	31%	46%	47%	25%	**48%**	59%	61%	61%	47%	**48%**	58%	60%	61%	48%	**52%**	61%	62%	63%	59%
25	Aug	**19%**	16%	26%	25%	18%	**23%**	20%	31%	30%	22%	**50%**	50%	50%	50%	50%	**52%**	51%	51%	51%	51%	**62%**	61%	60%	60%	61%

IGD = Infiltration Gallery Downstream.
IGU = Infiltration Gallery Upstream.

Temporal and Spatial Life Stage Assessments

The results in the sections below provide greater detail regarding conditions fish could experience between the modeling scenarios according to time period, life stage, and location.

Figure 5-1 shows the running 7DADM temperatures for all modeling scenarios at La Grange Dam year-round. At this location, variation in temperatures is minimal throughout the year with temperatures averaged over all water year types only ranging between nine and thirteen degrees Celsius. These temperatures primarily remain below seasonal USEPA benchmark temperatures, except for periods in October–December of the years 1983, 1991, 1992, 1995, and 1998 for various scenarios, where the USEPA benchmark for reproduction of 13°C is exceeded. Generally, when compared to Existing Conditions all the other scenarios exhibit lower temperatures during February through June and higher temperatures during the remaining time of the year at this location.

The temperature modeling indicates adequate cold-water storage would be expected to be available from upstream reservoirs year-round to provide suitable salmonid habitat at this location based on historical operations. However, depending on environmental conditions like ambient air temperature, flow rates, and solar radiance, the water temperature could change as it flows downstream, which would subsequently impact different life stages down the river. The potential temperature impacts of the scenarios on different life stages of salmonids are discussed below.

Because annual operations for the Tuolumne River flow requirements begin updating in February of each year and extend through the following January, the flows and temperatures seen in the October through January period are more dependent on the previous year's water year type than the water year type designation that is determined at the end of the water year (i.e., the designation determined after the end of September). Therefore, the averaging period for water year type in the temperature figures is shifted to apply from February through January rather than October through September. For example, October 1975 through January 1976 is officially part of a Critically Dry water year (1976), but for this report, is assigned the designation for water year 1975, which was a Wet Year.

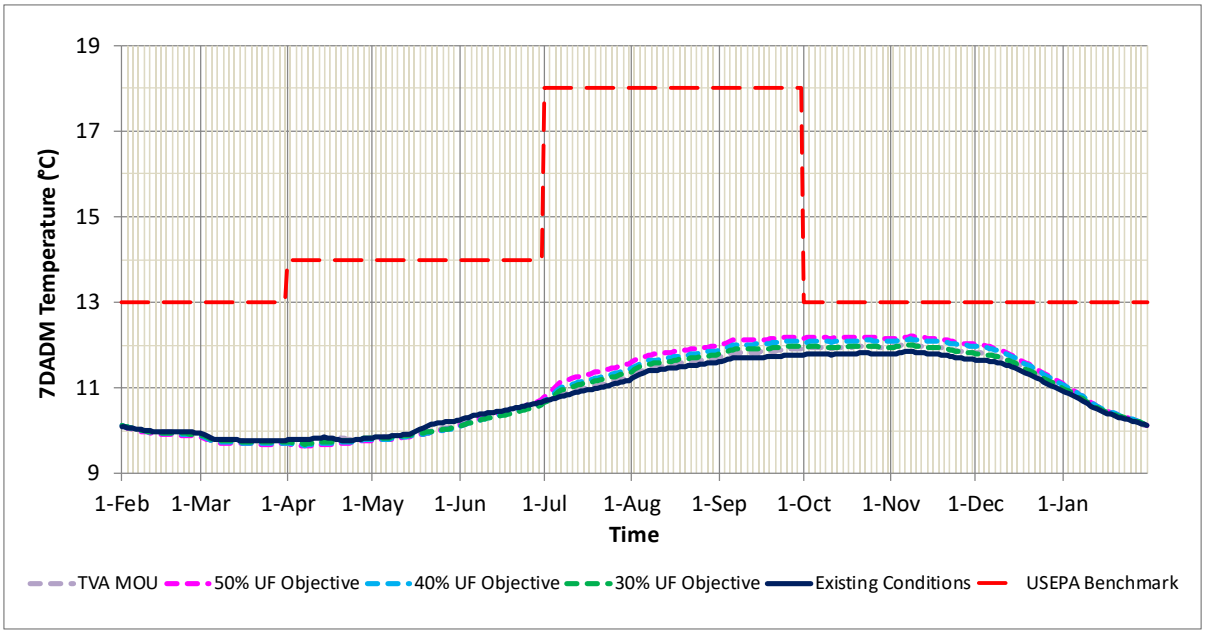


Figure 5-1. Tuolumne River Running 7DADM Water Temperatures Downstream of La Grange Dam (RM 53.5) Averaged Across All Water Years from 1970 to 2003. The USEPA Benchmark Line Represents the Life Stage with the Lowest Temperature Threshold for Each Month.

Results presented below use monthly longitudinal graphs using the average temperatures over all water year types, as well as the average temperatures over specific year water year types (including Wet and Critical) to show a range of potential conditions that fish may experience in the river. The graphics display the USEPA guidance benchmarks for protective conditions for each life stage to compare against the scenarios predicted water temperatures. For Chinook salmon, the graphics also display the ranges for supportive, stressful, and detrimental temperatures from Cain et al. (2019). *O. mykiss* has a higher tolerance for warm water temperatures, so the *O. mykiss* ranges are less than 21.5°C for supportive, 21.5°C to 26.5°C for stressful, and above 26.5°C for detrimental conditions. However, these ranges are not displayed in the graphics.

Adult Migration September 1–October 31

Adult migration was assessed for the months of September and October using 18°C as the USEPA temperature benchmark for the entire reach downstream of La Grange Dam. All modeling scenarios exhibit suitable temperatures at La Grange Dam (RM 53.5) during September and October reflecting the release of cold water from the reservoirs, which never exceed 15° Celsius. Modeled water temperatures would increase downstream, entering the stressful range at approximately RM 49 (Figure 5-2). Temperatures in all scenarios would exceed the USEPA benchmark temperature between RM 45 and 46 and enter the detrimental range between RM 37 and 38. Water temperatures would increase down the river incrementally from wetter water year types to drier water year types due to a decrease in water availability and decreasing flow releases. The range in predicted water temperatures can be seen in Figure 5-3 (Wet Years) and Figure 5-4 (Critical Years). Consistently, wetter water years result in lower water temperatures and increase the number of river miles with suitable temperatures.

For the month of September, there is only minor variability across the various scenarios because the flow regimes modeled are consistent with the Existing Conditions; however, different flow

management during the January through June period could impact reservoir carryover storage,[28] cold-water pool, and water availability during summer and fall which results in some variability in temperatures during September. For example, the release of more water during the spring for the 30% UF Objective scenario reduces the availability of cold water in the upstream reservoirs compared to the Existing Conditions scenario, thus resulting in a slight increase in water temperatures during September. Alternatively, the 40% and 50% UF Objective scenarios exhibit the use of allowable adaptive methods to shift[29] water budgets to time periods outside of the February through June period to prevent adverse effects to fisheries, which would result in reduced temperatures compared to the other scenarios. The benefits of the flow shifting to September is noticeable in Wet Years, where water temperatures would be reduced for the 40% UF Objective scenario up to 1.5° Celsius (Figure 5-3). Consistent with the modeling of adaptive methods for the 2018 SED, flow shifting was modeled for Wet Years and for 40% and 50% UF Objective scenarios only.

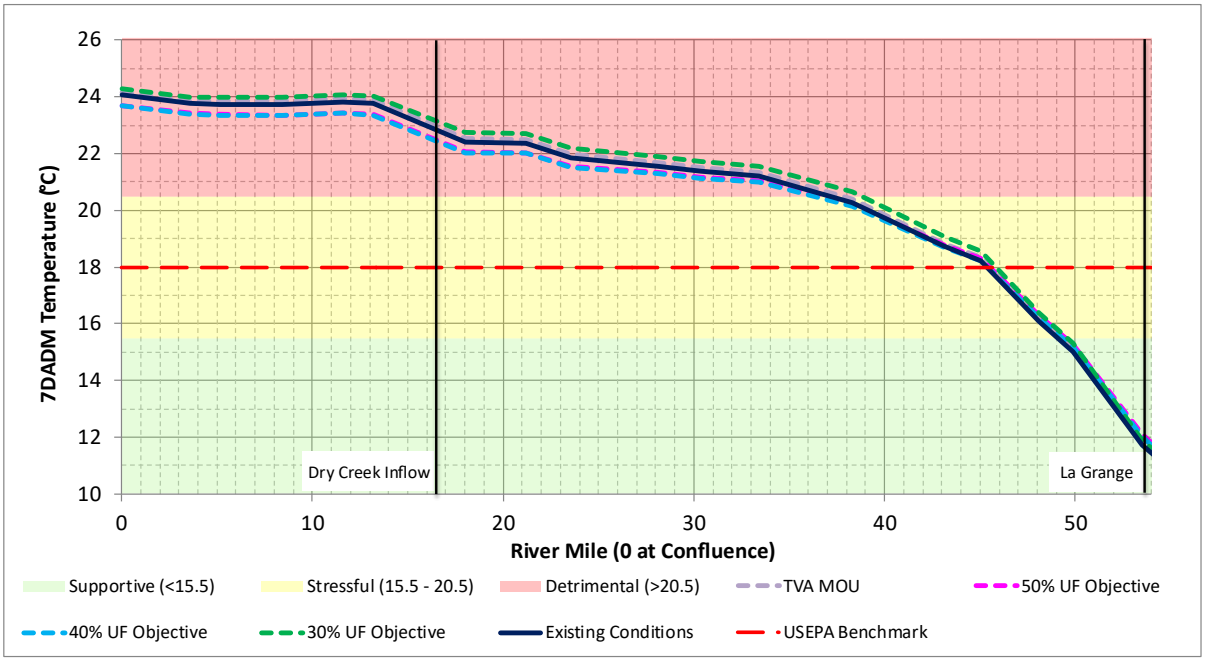


Figure 5-2. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration during September Averaged Across All Water Year Types from 1970 to 2003.

[28] Carryover, or carryover storage, is a term used to describe the reservoir storage level at the end of the water year in September, which indicates how much water is being carried over from one water year to the next.

[29] The application of flow shifting is described in Appendix F.1 of the 2018 Final SED on the State Water Board website.

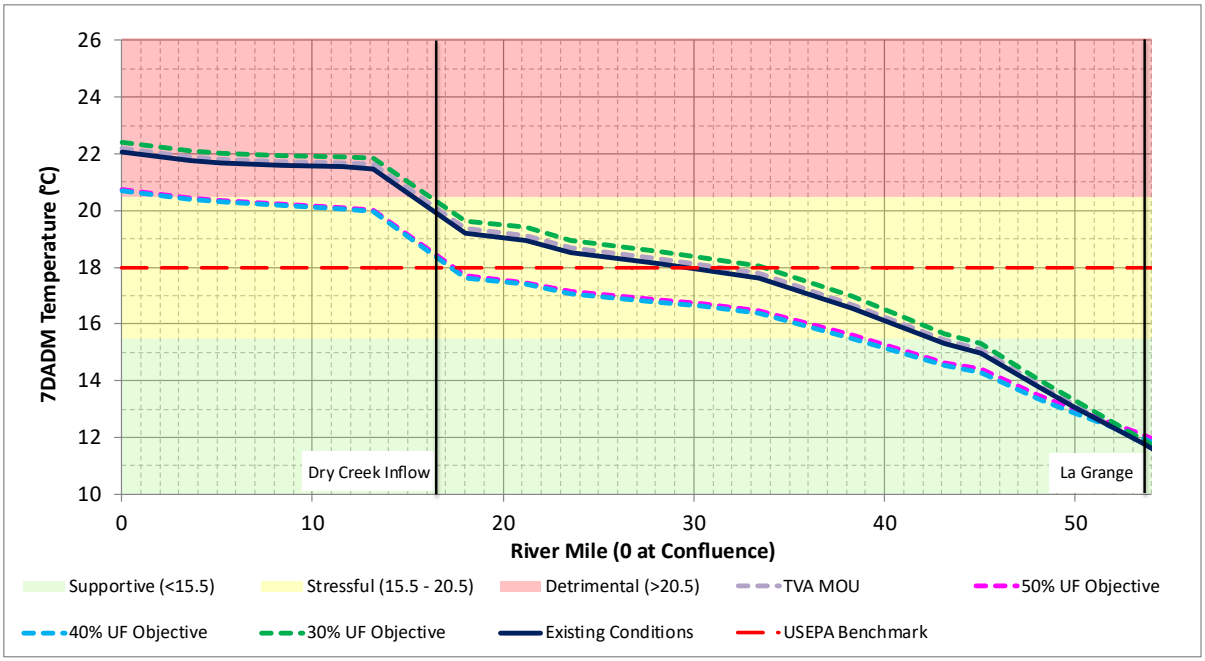


Figure 5-3. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration During September Averaged Across Wet Water Year Types from 1970 to 2003. The 40% and 50% UF Objective Scenarios Reflect Temperature Improvements Due to Flow Shifting Through Allowable Adaptive Methods of the Bay-Delta Plan.

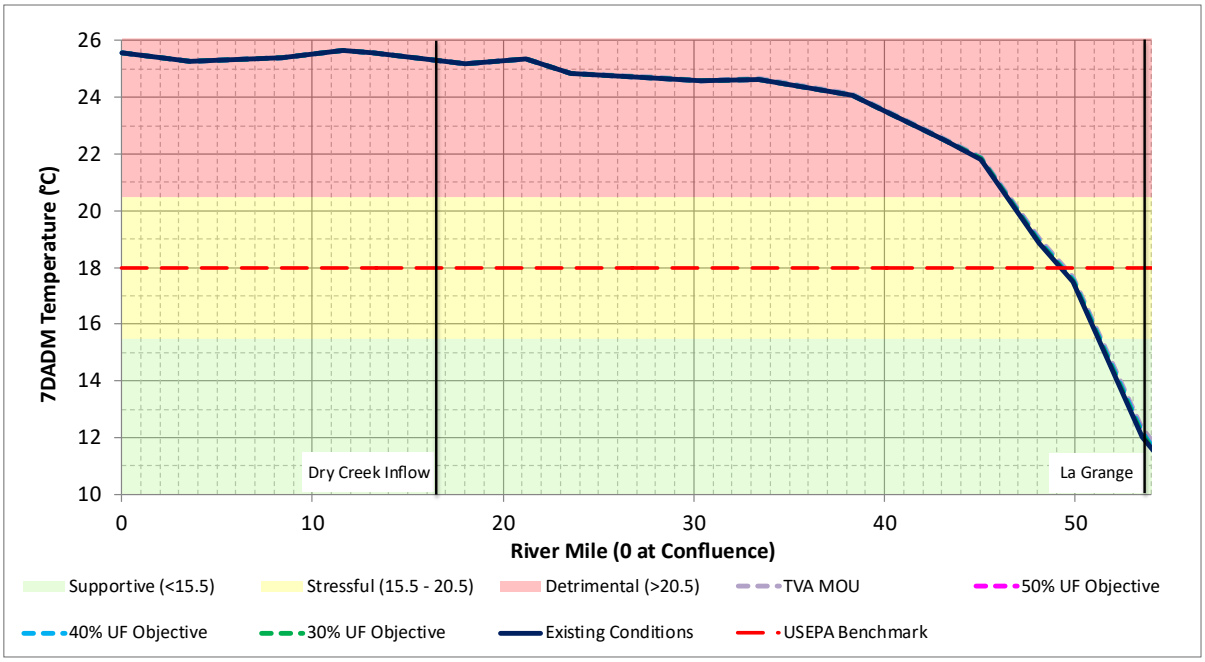


Figure 5-4. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration During September Averaged Across Critical Water Year Types from 1970 to 2003.

October water temperatures would typically be cooler compared to September due to cooler ambient air temperatures (Figure 5-5). October water temperatures would largely remain below detrimental conditions for all the scenarios and water year types,[30] except for Critical Years, where water temperatures would be detrimental from near RM 22 to the confluence with the LSJR (Figure 5-5 to Figure 5-7). While temperatures at La Grange Dam (RM 53.5) would be suitable for adult migration in all scenarios, temperatures averaged over all water year types would enter the stressful range at approximately RMs 41–43 and cross the USEPA benchmark temperature of 18°C upstream of the Dry Creek inflow[31] (RM 16). On average, temperatures in the TVA, 30% UF Objective, 40% UF Objective and 50% UF Objective scenario would be within 0.5 degree Celsius above or below the Existing Conditions, and the patterns are similar to those predicted in September.

Similar to September, the potential benefits to water temperatures from flow shifting into October can be seen in Figure 5-6. The flow shifting for the 40% and 50% UF Objective scenarios would allow the water temperatures to avoid exceeding the USEPA benchmark temperature for adult migration of 18°C throughout the entire reach of the Tuolumne River. Distinct reductions in water temperatures can be seen as a result of designed October fall flow pulses for the Existing Conditions and other scenarios in Figure 5-8. The fall flow pulse would be expected to allow water temperatures at the confluence with the LSJR (RM 0) to drop below detrimental temperatures slightly sooner than would have occurred without the pulse. The fall flow pulse is an example of a management action that can have multiple benefits. For example, fall flow pulses can reduce water temperatures, flush fine sediments from spawning gravels, and trigger behavioral responses (migration or spawning activities) in salmon.

The month of November is a primary period for adult migration on the Tuolumne River, and November water temperatures would usually be below the USEPA benchmark for adult migration. The maximum predicted water temperature at RM 0 in November is 18.4°C, and the benchmark would be exceeded less than 2% of November days from 1970 to 2003. While November is a primary period of adult migration, this report contains a limited discussion of adult migration because the spawning, egg incubation, and fry emergence benchmark is lower, thus a more appropriate benchmark to evaluate impacts to salmonid populations during the month of November.

[30] As noted previously, in graphs summarizing specific water year type information, October through January use the previous year's water year type designation to better reflect the water supply conditions that inform October through January flow and reservoir management, and related water temperature conditions.

[31] Dry Creek is tributary in the lower watershed that joins the river around the city of Modesto and contributes to flow in the Tuolumne River.

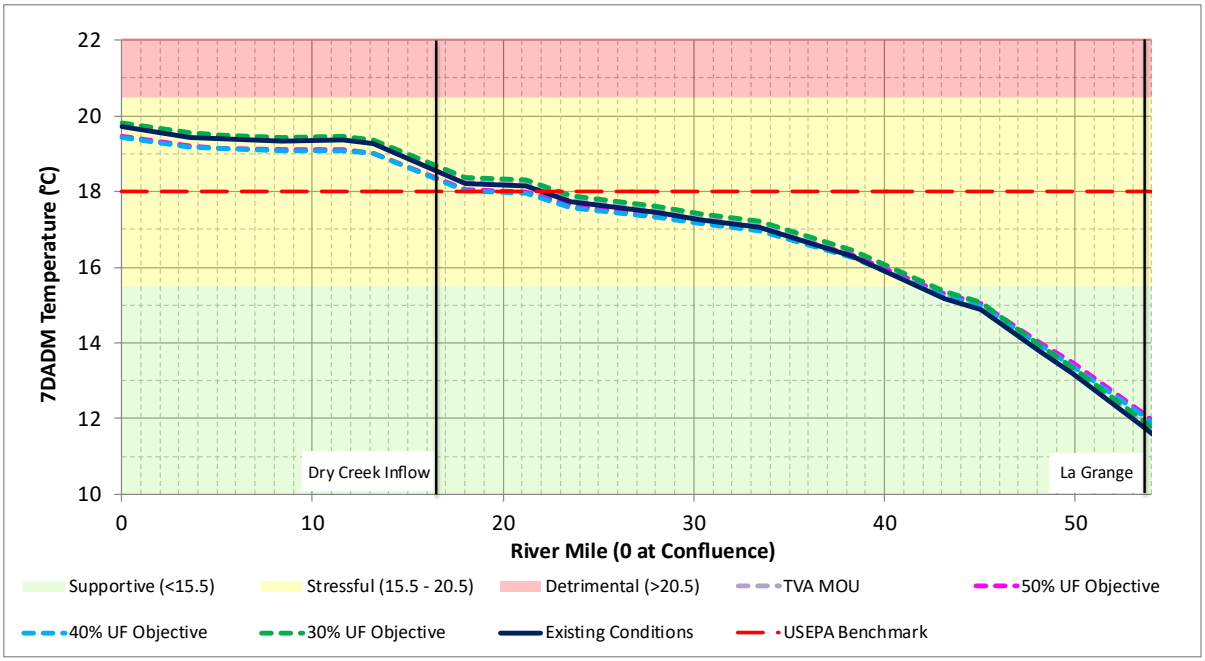


Figure 5-5. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration During October Averaged Across All Water Year Types from 1970 to 2003.

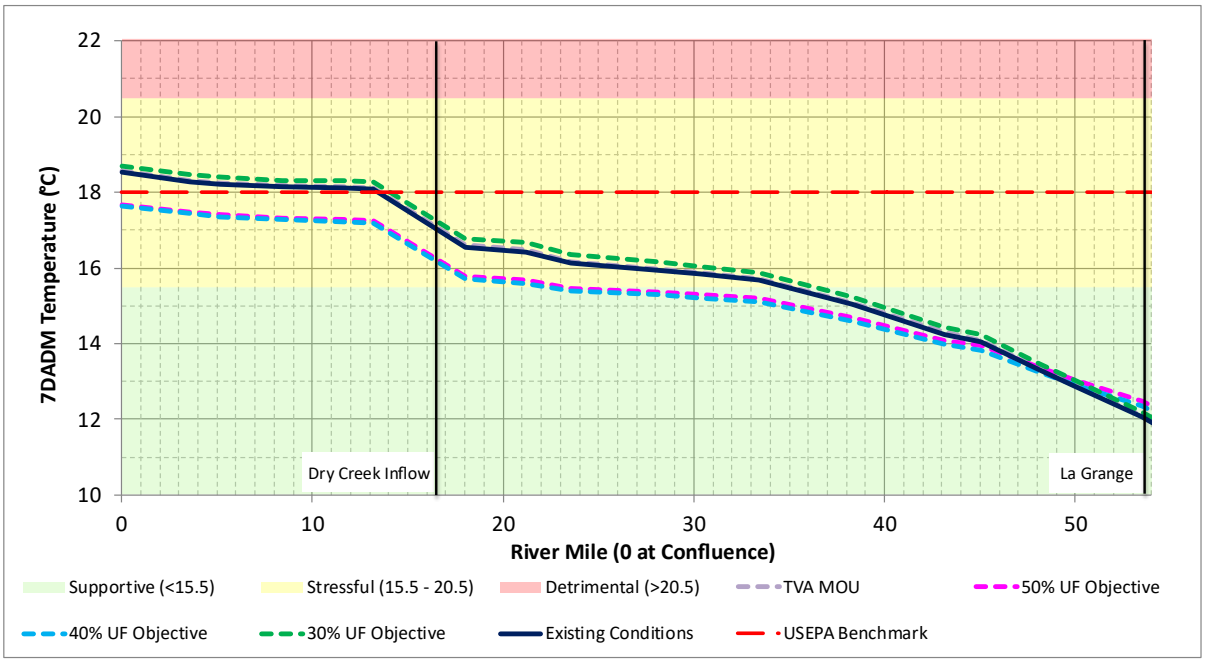


Figure 5-6. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration During October Averaged Across Wet Water Year Types from 1970 to 2003. The 40% and 50% UF Objective Scenarios Reflect Temperature Improvements Due to Flow Shifting Through Allowable Adaptive Methods of the Bay-Delta Plan.

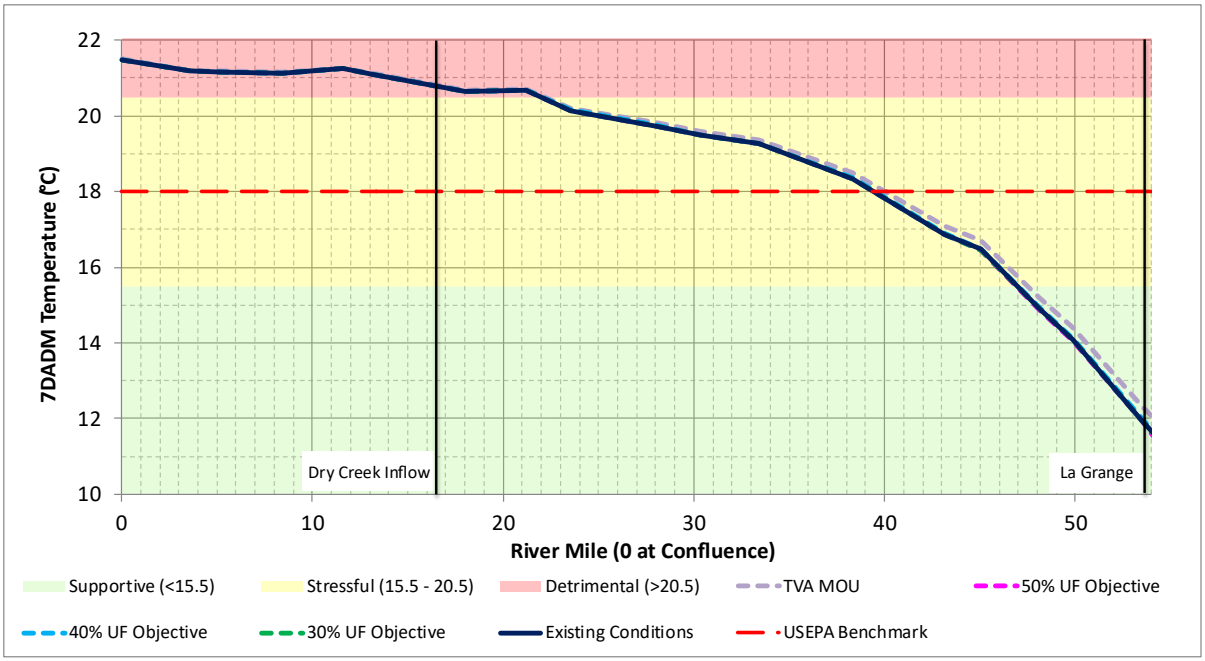


Figure 5-7. Tuolumne River Longitudinal Water Temperature Profile for Adult Migration during October Averaged Across Critical Water Year Types from 1970 to 2003.

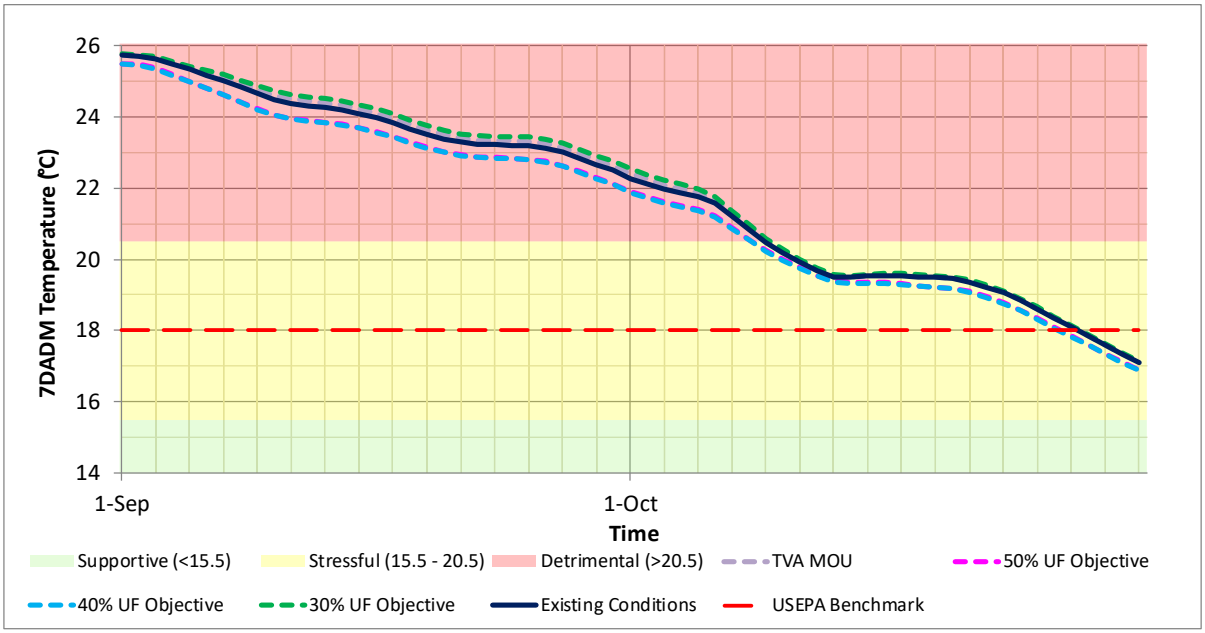


Figure 5-8. Tuolumne River Running 7DADM Water Temperatures at RM 0 for Adult Migration in September and October Averaged Across All Water Year Types from 1970 to 2003.

Spawning, Egg Incubation, and Fry Emergence October 1–March 31

Temperatures for spawning, egg incubation, and fry emergence were assessed using the USEPA benchmark temperature of 13°C in the approximate spawning reach from RM 23.54 upstream to La Grange Dam (RM 53.5). In October, the water temperature for all modeled scenarios would be suitable at La Grange Dam, (averaged over all water year types, Figure 5-9). Temperatures in all scenarios would enter the detrimental range at approximately river mile 48 and remain in the detrimental range through the rest of the spawning reach. Water year type showed minimal impact to suitable habitat in October, where in Wet Years 13°C is exceeded at RM 49 and in Critical Years at RM 52 (Figure 5-10 and Figure 5-11).

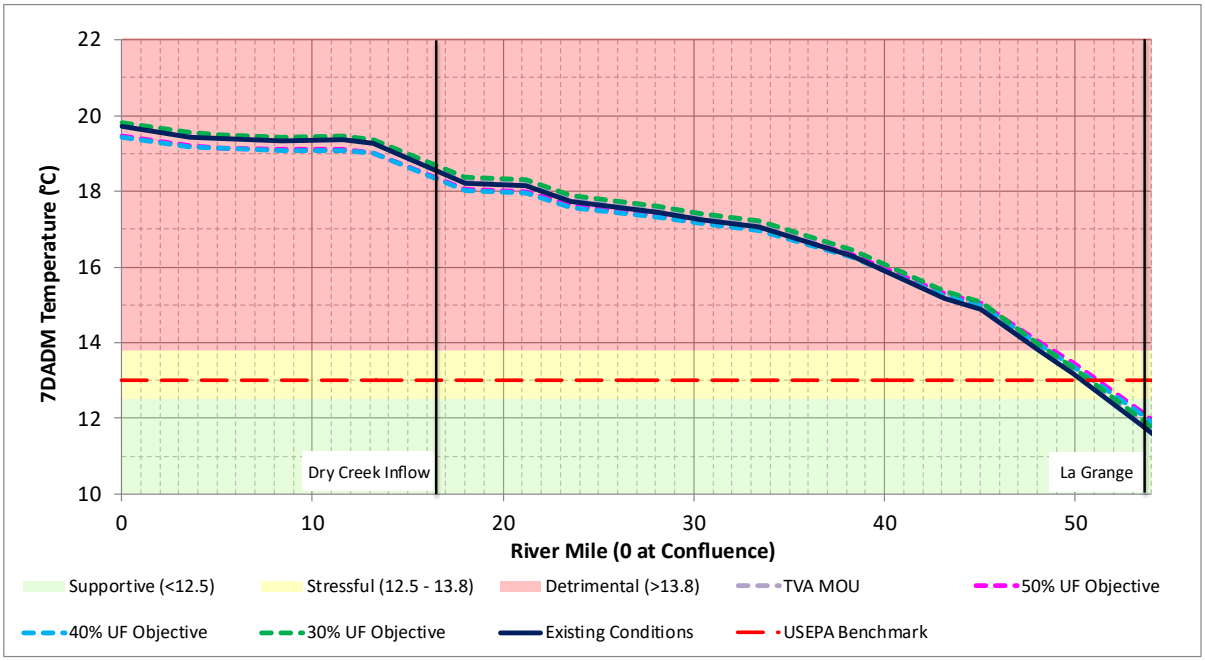


Figure 5-9. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During October Averaged Across All Water Year Types from 1970 to 2003.

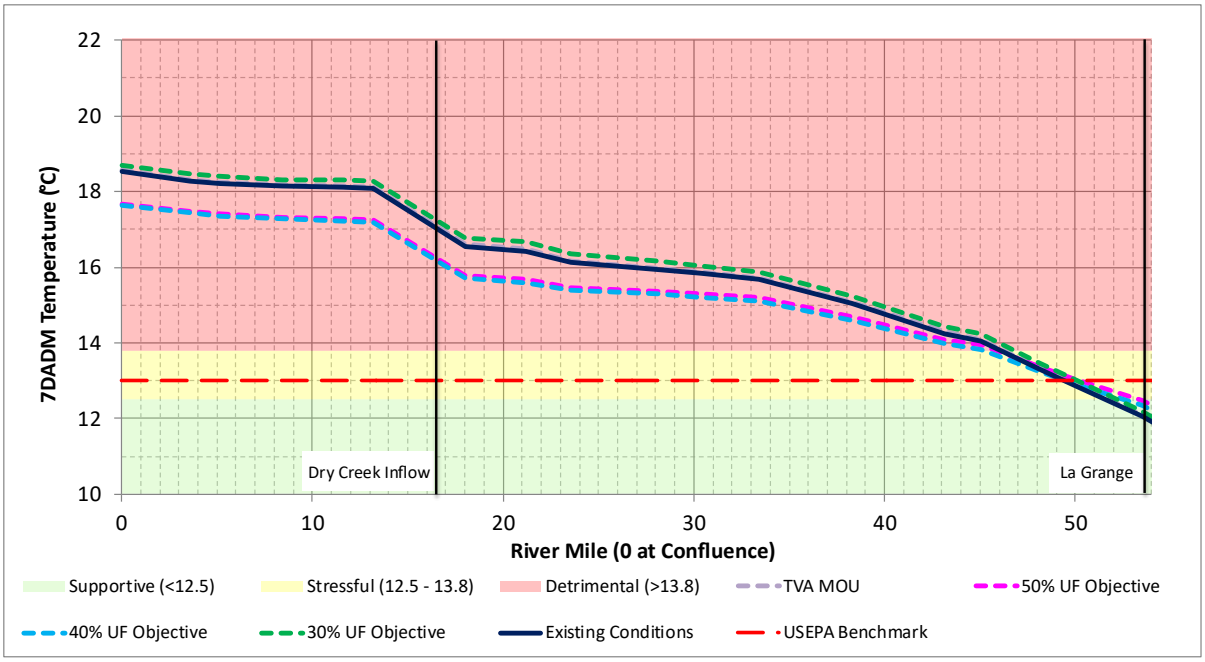


Figure 5-10. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During October Averaged Across Wet Water Year Types from 1970 to 2003.

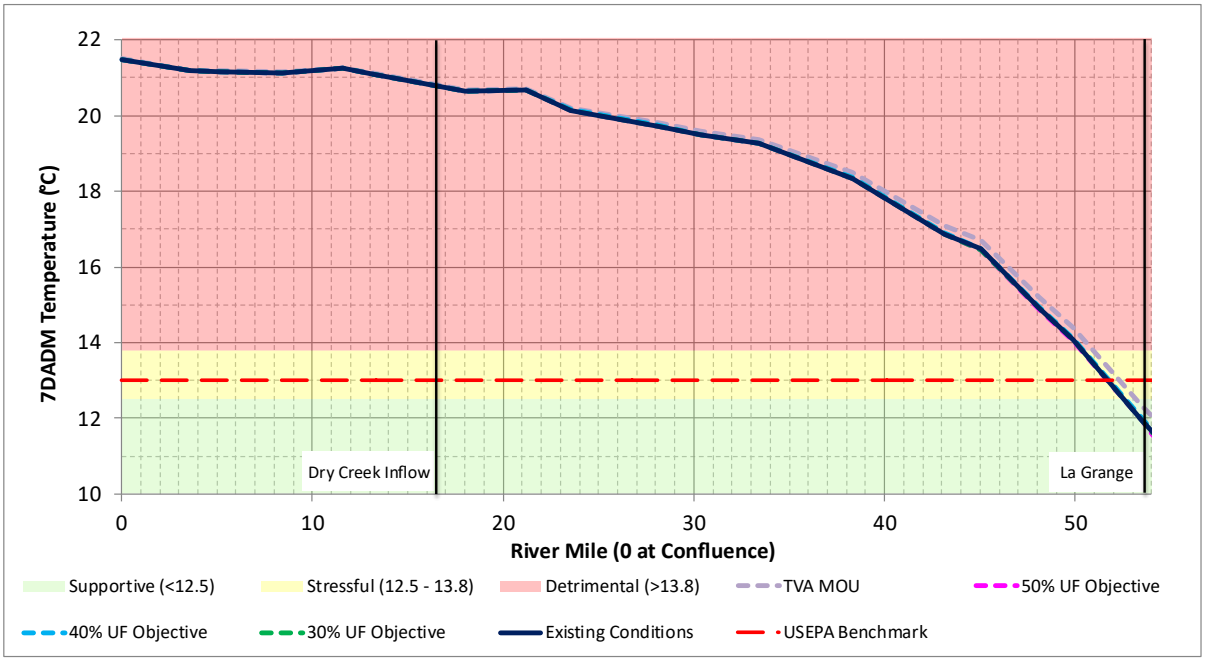


Figure 5-11. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During October Averaged Across Critical Water Year Types from 1970 to 2003.

In November, temperatures for all scenarios would be within the supportive range at La Grange Dam but exceed the USEPA benchmark temperature of 13°C between approximately river mile 45–48 when averaged across all years (Figure 5-12). Temperatures in all scenarios would enter the detrimental range between approximately RM 33 to 38 depending on the scenario (Figure 5-12).

Wet Years exhibit more miles available for spawning below detrimental temperatures and Critical Years exhibit fewer miles (Figure 5-13 and Figure 5-14). Compared to October, ambient air temperatures in November are typically lower, so river water temperatures do not increase as much as the water flows downstream.

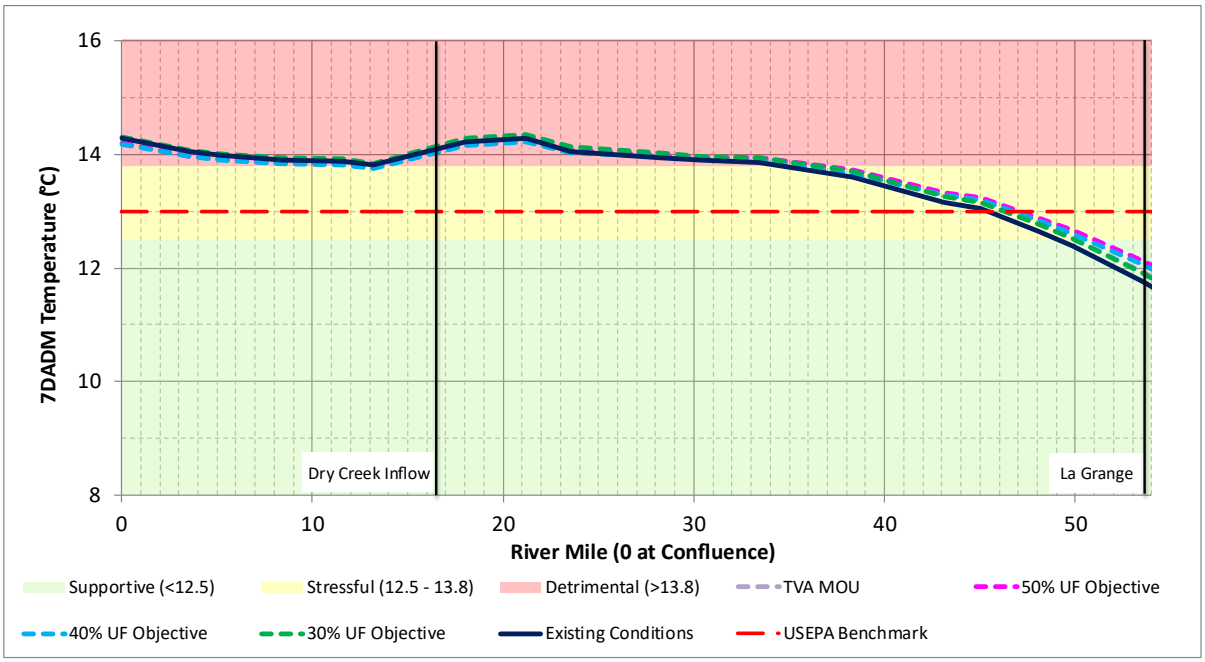


Figure 5-12. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence during November Averaged Across All Water Year Types from 1970 to 2003.

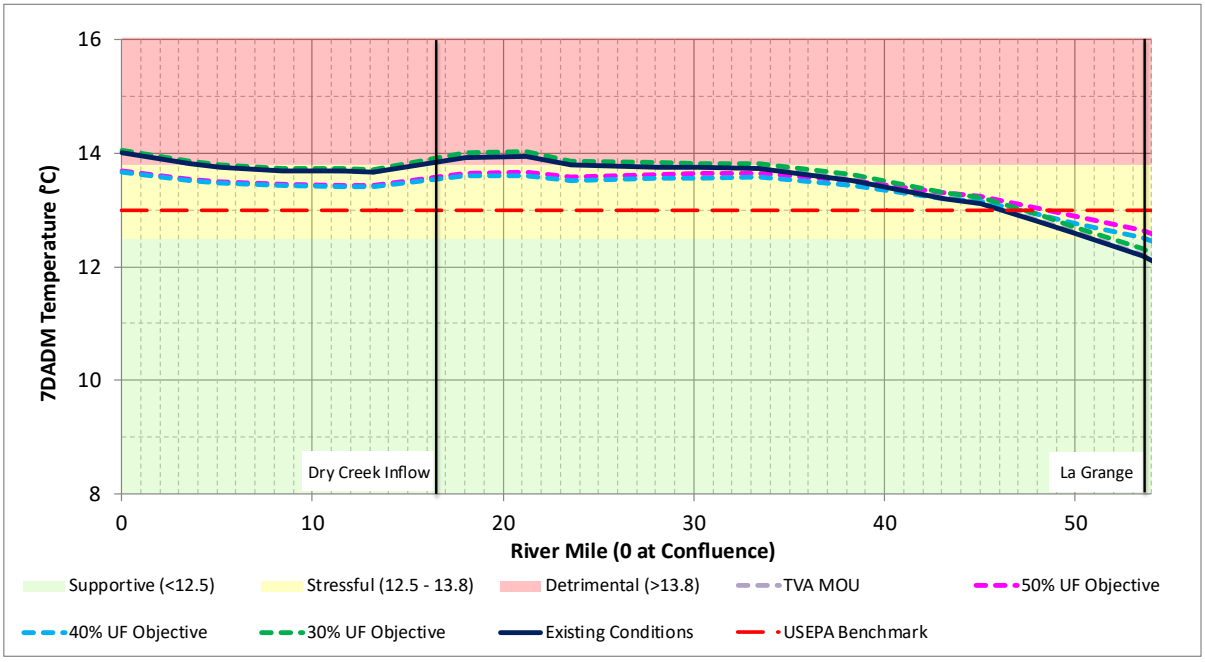


Figure 5-13. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence during November Averaged Across Wet Water Year Types from 1970 to 2003.

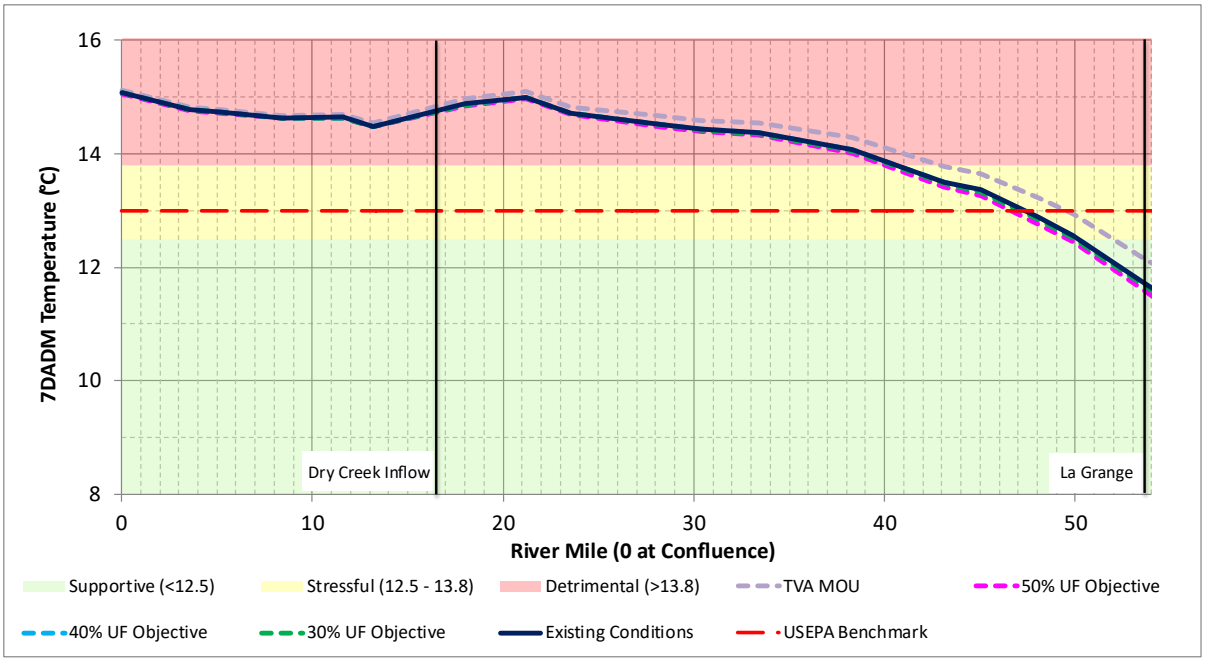


Figure 5-14. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During November Averaged Across Critical Water Year Types from 1970 to 2003.

In December and January, river temperatures under all modeled scenarios would be in the supportive range throughout the Tuolumne River spawning reach (Figure 5-15 and Figure 5-16). Ambient air temperatures in December and January are typically low enough to result in an overall reduction of water temperatures as the water flows downstream.

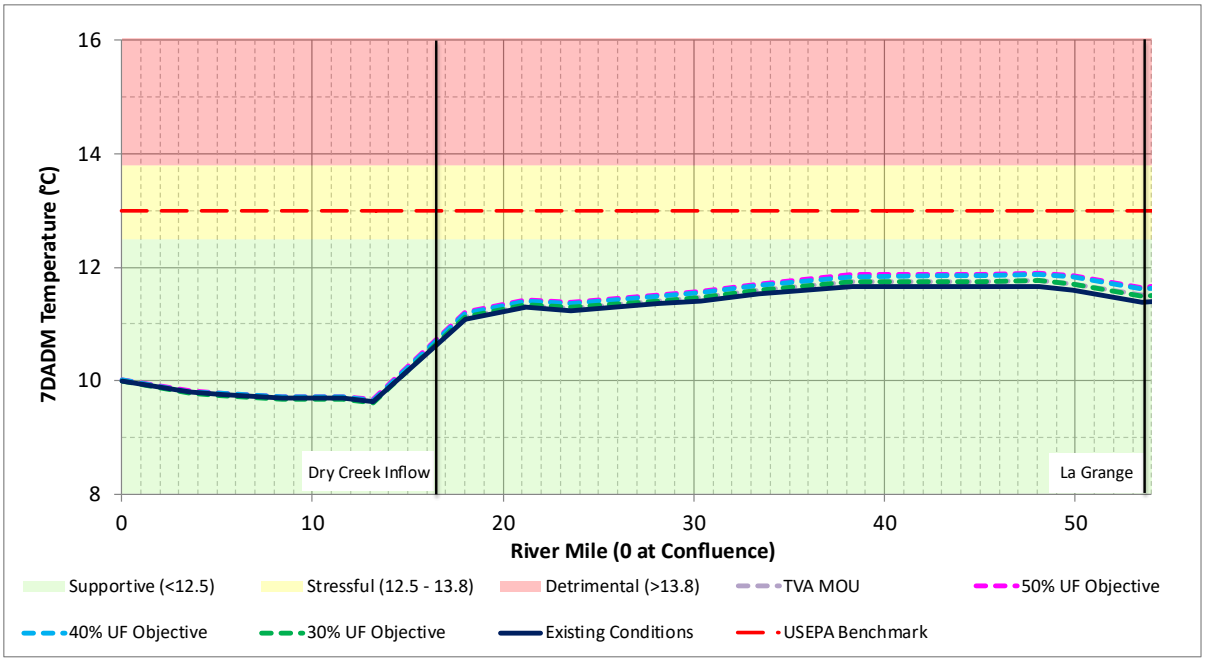


Figure 5-15. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During December Averaged Across All Water Year Types from 1970 to 2003.

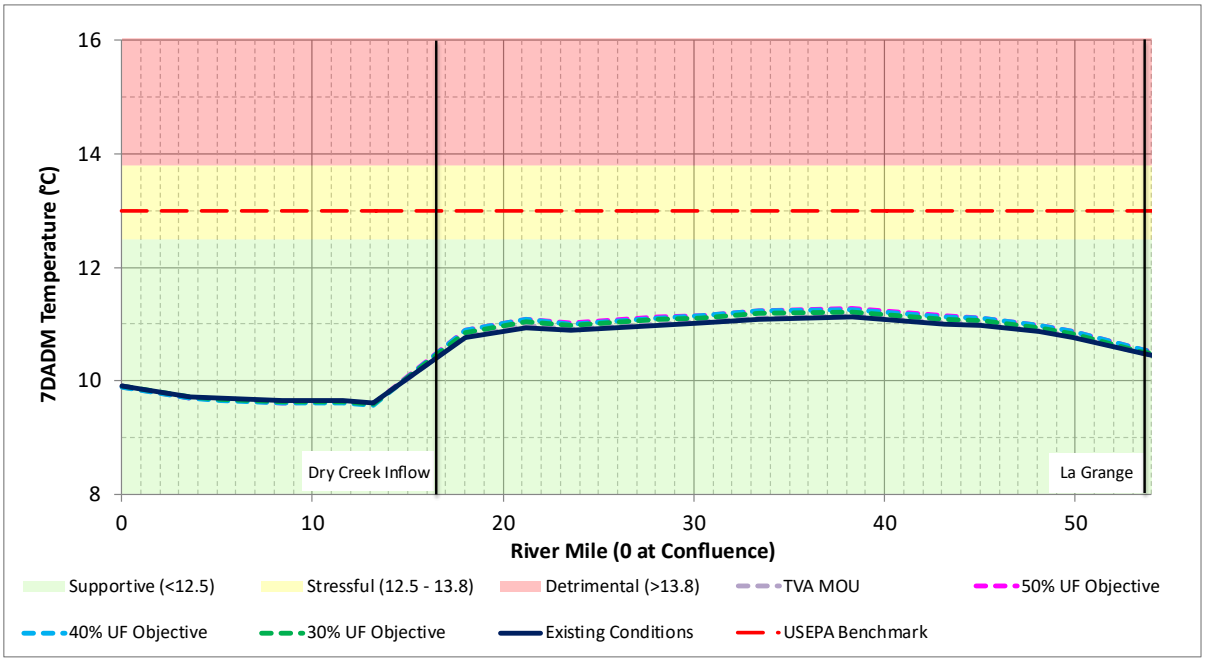


Figure 5-16. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During January Averaged Across All Water Year Types from 1970 to 2003.

In February, modeling of temperatures averaged across all water year types in all scenarios would be within the supportive range for the entire length of the spawning reach (Figure 5-17). Average temperatures in the scenarios would only exceed the USEPA benchmark during Critical Years

(Figure 5-18 at approximately RM 36 to 39), except for the 50% UF Objective scenario which would remain below the benchmark throughout the spawning reach.

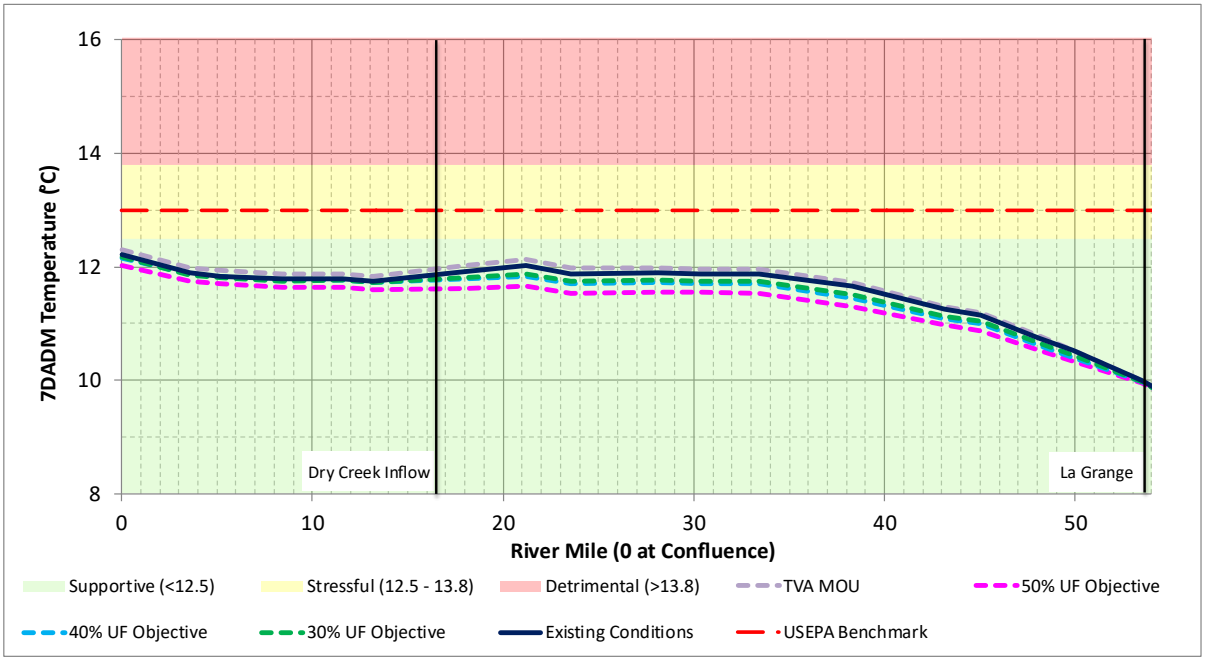


Figure 5-17. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During February Averaged Across All Water Year Types from 1970 to 2003.

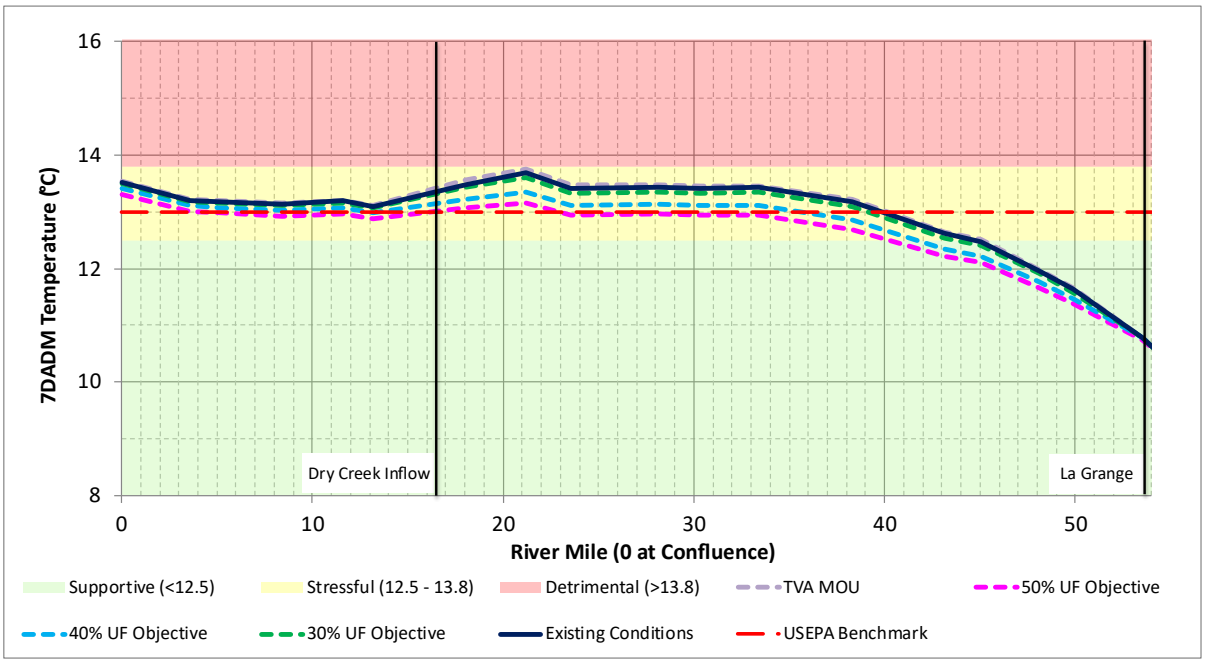


Figure 5-18. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During February Averaged Across Critical Water Year Types from 1970 to 2003.

In March, temperatures in all scenarios would be suitable at La Grange Dam but increase moving downstream. Temperatures averaged over all years under Existing Conditions would be the warmest among all of the scenarios and rise above the USEPA benchmark temperature of 13°C at approximately river mile 30 (Figure 5-19). All other scenarios exhibit significant improvements in average temperatures compared to Existing Conditions, and temperatures would remain below the benchmark throughout the spawning reach. In addition, during March the scenarios that increase flows would begin to have more influence on downstream river temperatures, especially in drier years (Figure 5-22 and Figure 5-23). All scenarios exhibit similar suitable average temperatures in Wet and Above Normal Years (Figure 5-20 and Figure 5-21). However, in Below Normal Years portions of the spawning reach would begin seeing more stressful or detrimental temperatures (Figure 5-22), and in Critical Years conditions become progressively warmer (Figure 5-23).

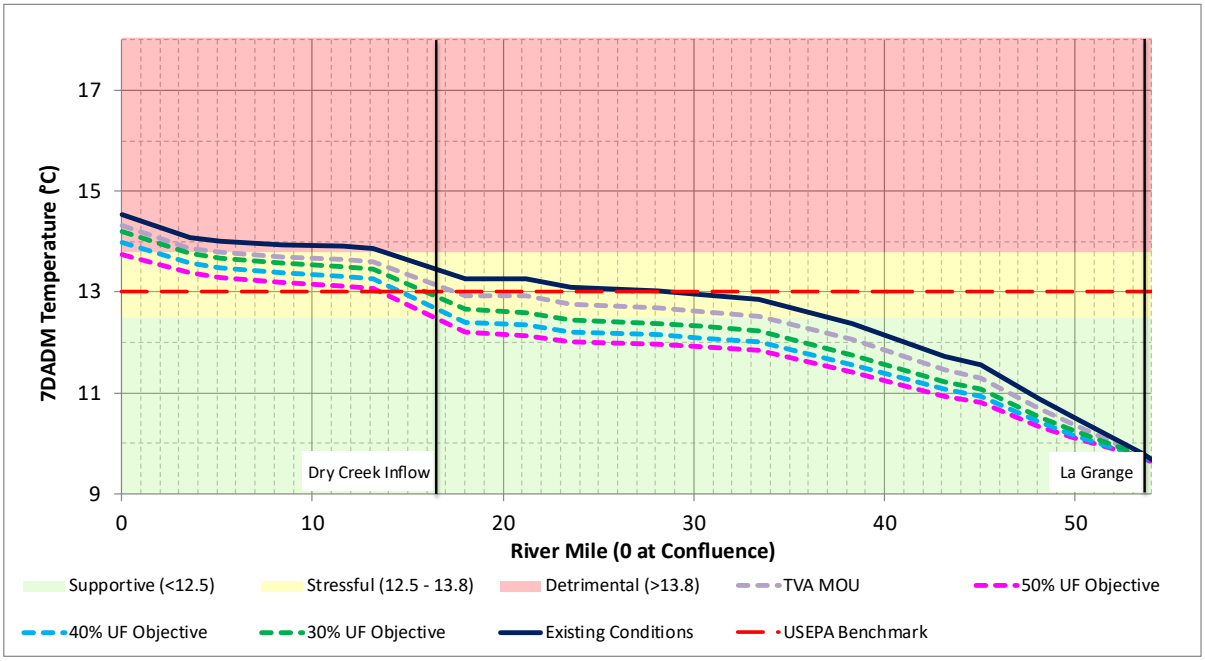


Figure 5-19. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During March Averaged Across All Water Year Types from 1970 to 2003.

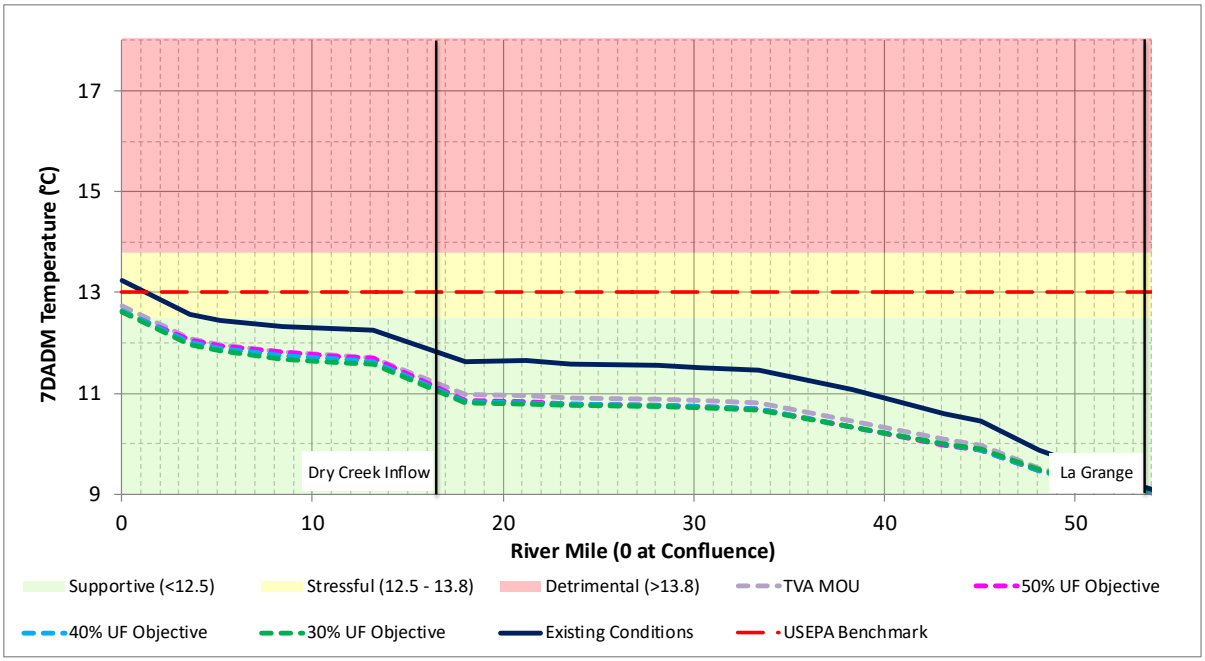


Figure 5-20. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During March Averaged Across Wet Water Year Types from 1970 to 2003.

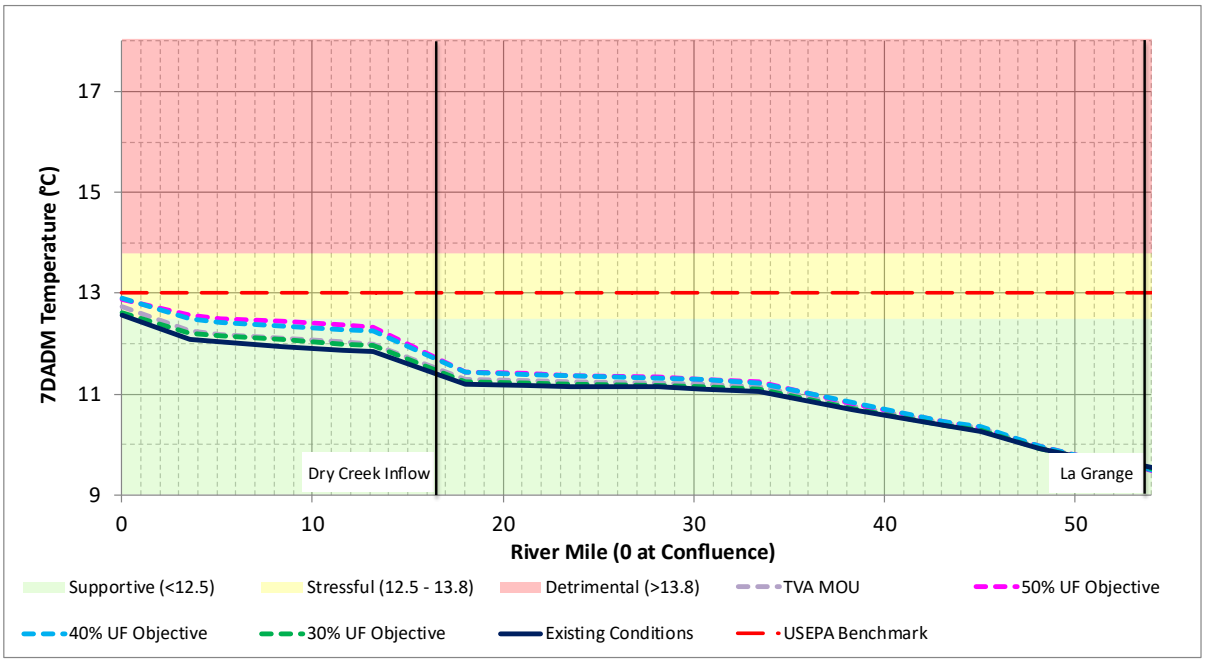


Figure 5-21. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During March Averaged Across Above Normal Water Year Types from 1970 to 2003.

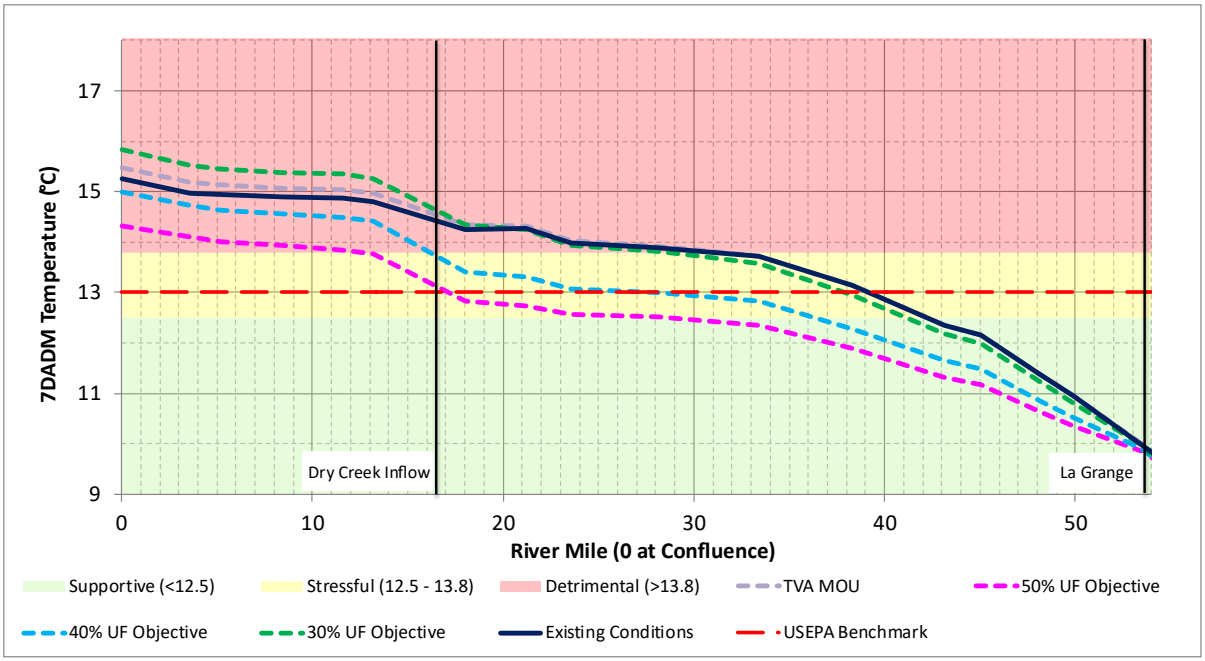


Figure 5-22. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During March Averaged Across Below Normal Water Year Types from 1970 to 2003.

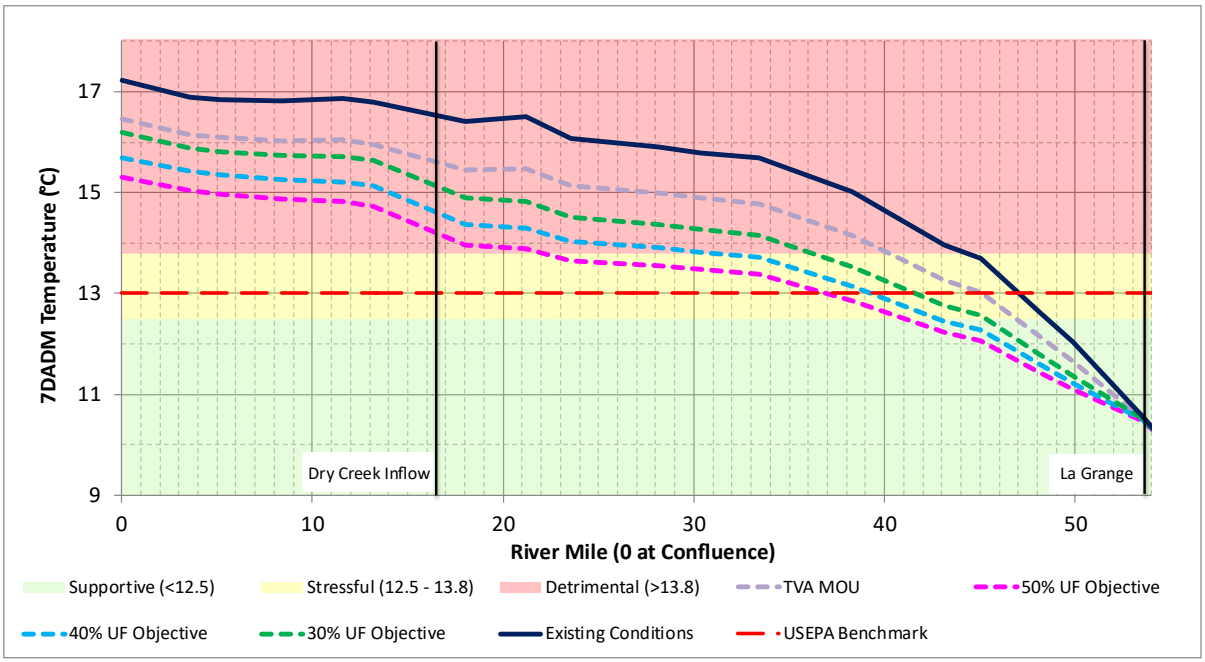


Figure 5-23. Tuolumne River Longitudinal Water Temperature Profile for Spawning, Incubation, and Fry Emergence During March Averaged Across Critical Water Year Types from 1970 to 2003.

On a seasonal basis, modeling indicates that temperatures would exceed the USEPA benchmark temperature of 13°C for a majority of the spawning reach until late November. For example, the lower end of the spawning reach between RM 23.54 and RM 38.29 exhibit temperatures in the detrimental range until approximately mid-November and would be above the benchmark until near the last week of November (Figure 5-24 and Figure 5-25). There would be only about 8 river miles on average (from RM 45 to La Grange Dam) that exhibit suitable temperatures during the entire month of November (Figure 5-12). The late timing of suitable temperatures for spawning for the majority of the spawning reach could truncate the spawning, egg incubation, and fry emergence period because elevated temperatures are exhibited in Dry and Critical Years at RM 38.29 by mid-February (Figure 5-18, Figure 5-26, and Figure 5-27). This truncated period may not be long enough for the fish to complete this life stage (i.e., spawning to fry emergence). In March, the USEPA benchmark temperature of 13°C would be exceeded in a large portion of the spawning reach beginning in Below Normal Years for most scenarios (Figure 5-22 and Figure 5-23) with Critical Years exhibiting the least amount of suitable habitat for emerging fry. Water temperatures typically remain below the benchmark through the month of March at RM 49.87 (Figure 5-28), which suggests that about 4 miles of the river could provide adequate water temperatures to complete the spawning, egg incubation, and fry emergence period.

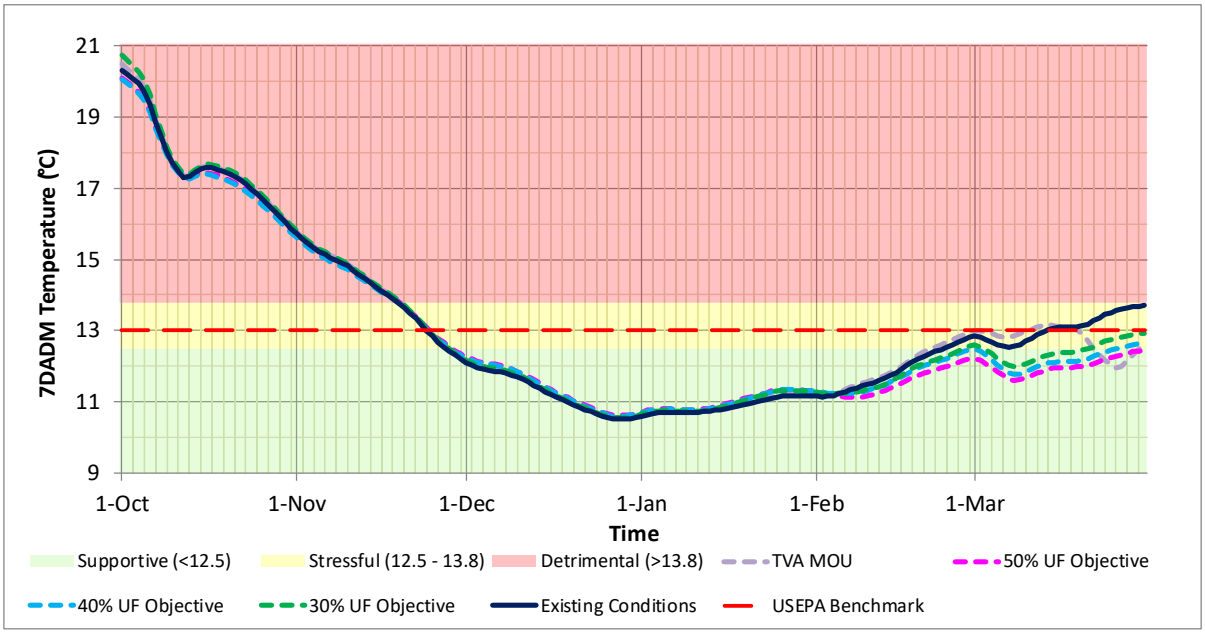


Figure 5-24. Tuolumne River Running 7DADM Water Temperatures at RM 23.54 Averaged Across All Water Year Types from 1970 to 2003 for Spawning, Egg Incubation, and Fry Emergence.

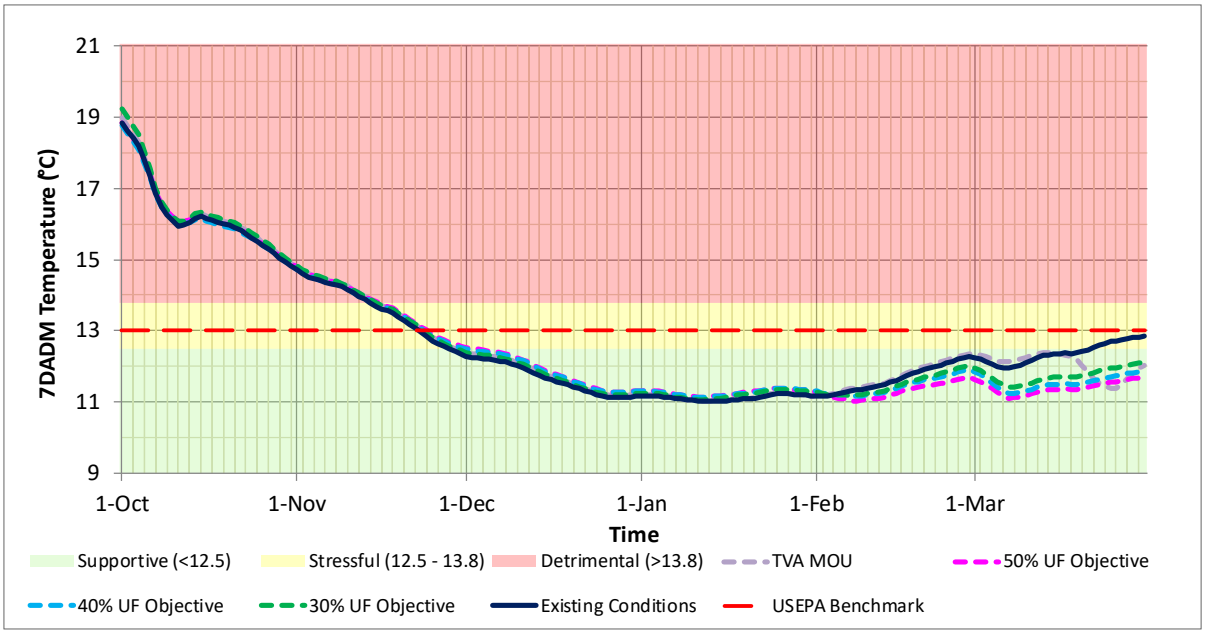


Figure 5-25. Tuolumne River Running 7DADM Water Temperatures at RM 38.29 Averaged Across All Water Year Types from 1970 to 2003 for Spawning, Egg Incubation, and Fry Emergence.

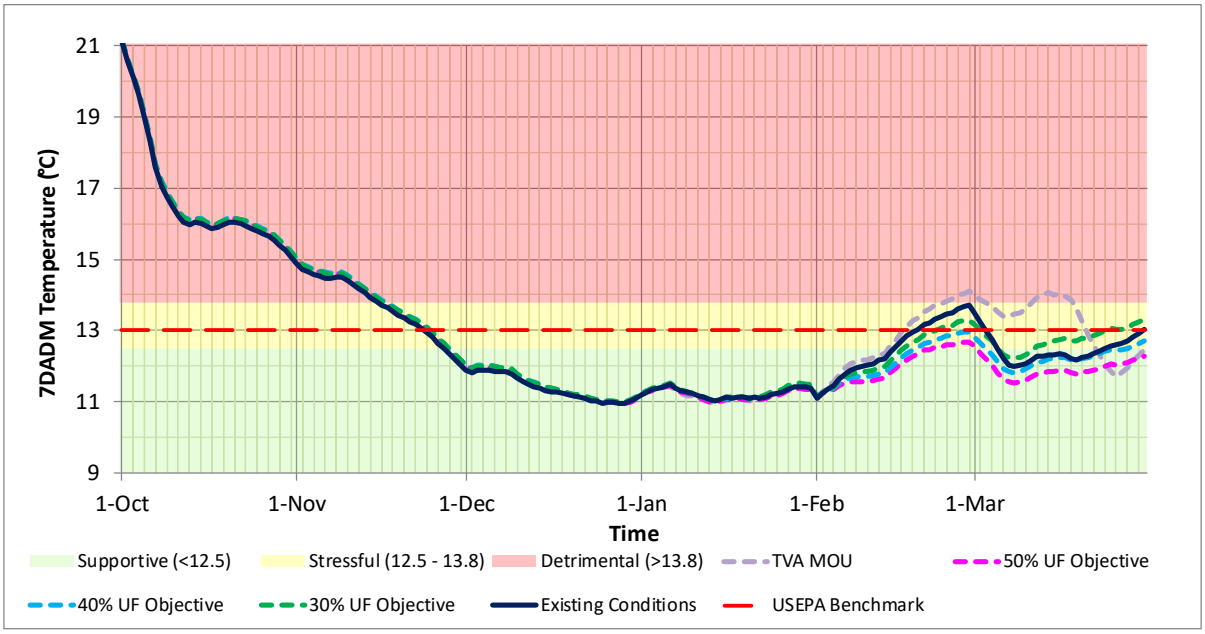


Figure 5-26. Tuolumne River Running 7DADM Water Temperatures at RM 38.29 Averaged Across Dry Water Year Types from 1970 to 2003 for Spawning, Egg Incubation, and Fry Emergence.

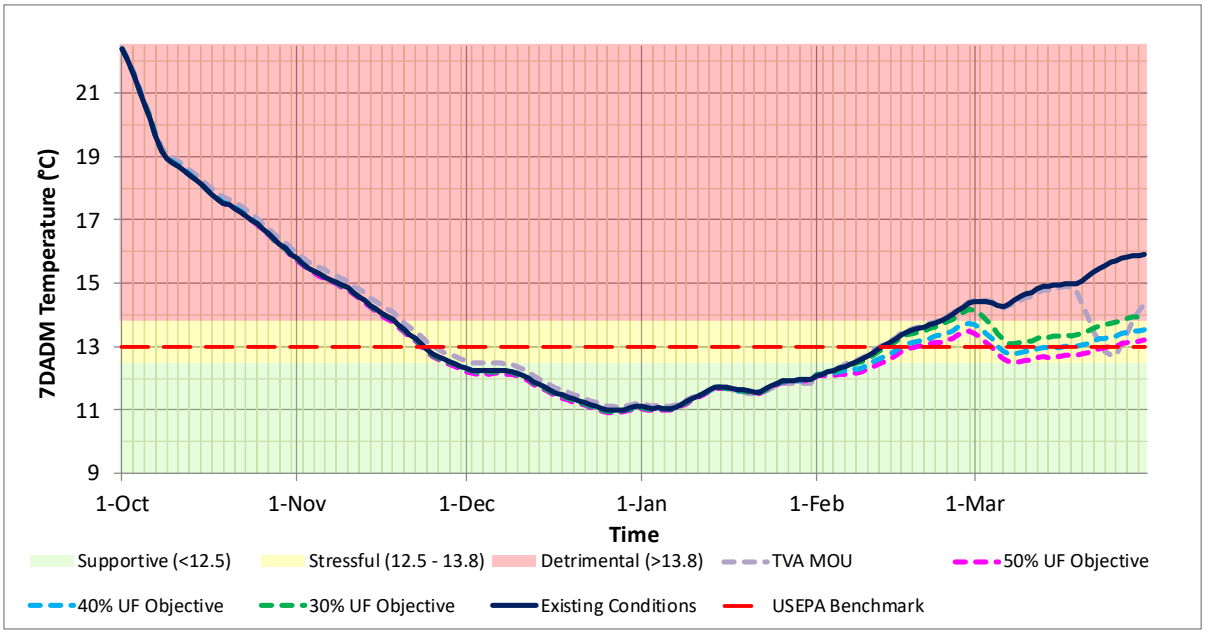


Figure 5-27. Tuolumne River Running 7DADM Water Temperatures at RM 38.29 Averaged Across Critical Water Year Types from 1970 to 2003 for Spawning, Egg Incubation, and Fry Emergence.

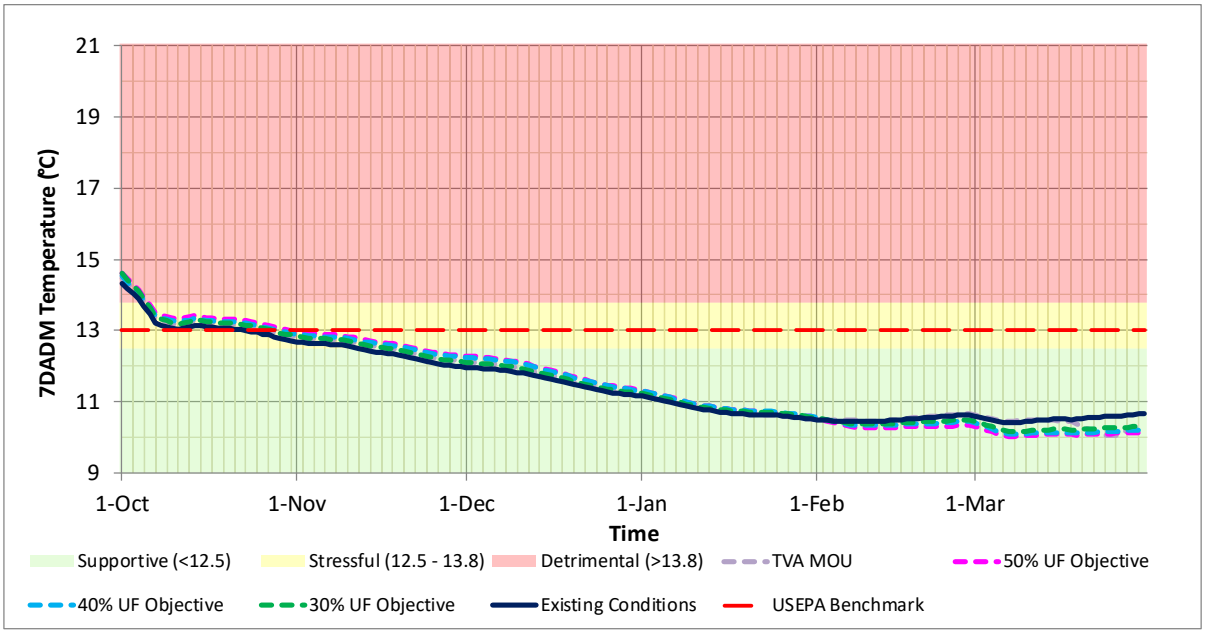


Figure 5-28. Tuolumne River Running 7DADM Water Temperatures at RM 49.87 Averaged Across All Water Year Types from 1970 to 2003 for Spawning, Egg Incubation, and Fry Emergence.

Core Juvenile Rearing March 1–May 31

Temperatures were assessed for core juvenile rearing from March through May throughout the Tuolumne River from La Grange Dam downstream to the confluence with the LSJR using the USEPA benchmark temperature of 16°C. Temperatures averaged over all water year types would be suitable throughout the Tuolumne River in March with all scenarios exhibiting temperatures in the supportive range (Figure 5-29). Furthermore, in all water year types, except Critical Years, all scenarios exhibited supportive temperatures. In Critical Years the TVA would increase the amount of river miles that attain the 16°C benchmark compared to the Existing Conditions, increasing the suitable river miles from near RM 24 for the Existing Conditions scenario to near RM 12 for the TV (Figure 5-30).

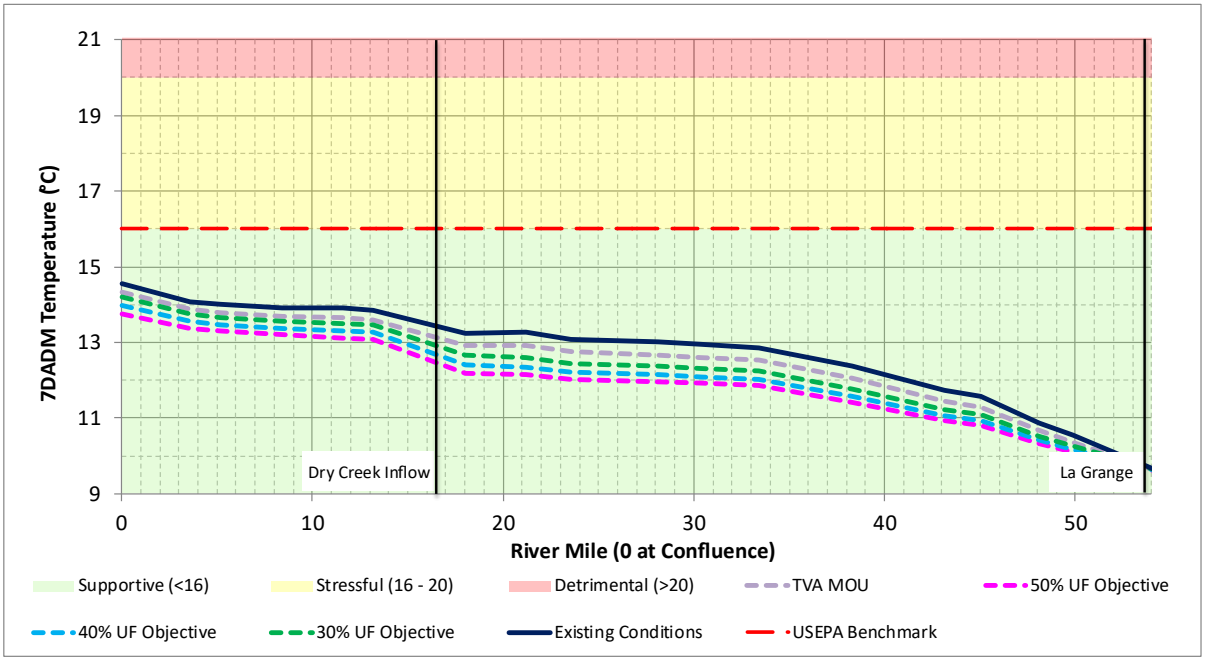


Figure 5-29. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During March Averaged Across All Water Year Types from 1970 to 2003.

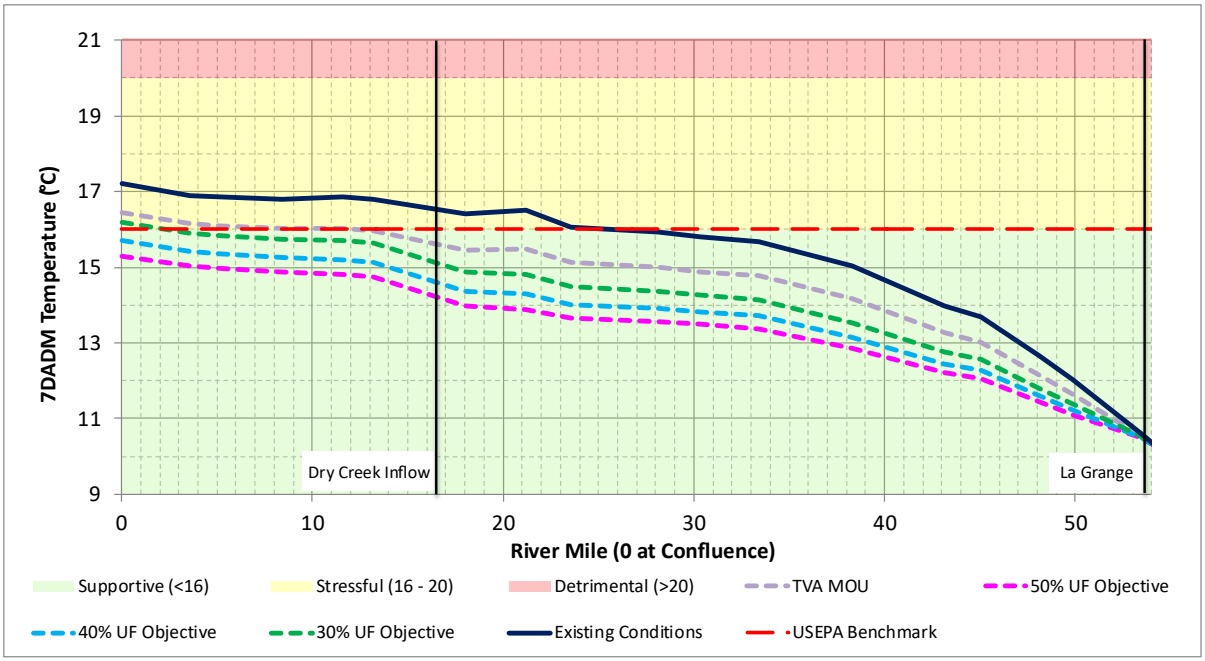


Figure 5-30. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During March Averaged Across Critical Water Year Types from 1970 to 2003.

In April, temperatures averaged over all water year types would generally remain suitable for all scenarios, and TVA scenario exhibits lower temperatures than the Existing Conditions throughout the river (Figure 5-31). In Dry Years, the TVA would be similar to the Existing Conditions, and they would exceed the benchmark between near RM 16 (Figure 5-32). The 40% and 50% UF Objective temperatures would remain suitable to the confluence with the LSJR, but the 30% UF Objective would exceed the benchmark near RM 13 (Figure 5-32). In Critical Years, more of the core juvenile rearing habitat is predicted to experience unsuitable temperatures (Figure 5-33).

At the confluence during Critical Years, the Existing Conditions and TVA scenarios would exceed detrimental temperatures by mid-April and primarily remain at 20°C and above through the month of May (Figure 5-34). The 30%, 40%, and 50% UF Objective scenarios would enter into the stressful temperature range at the confluence during April but remain below 20°C through May during Critical Years (Figure 5-34).

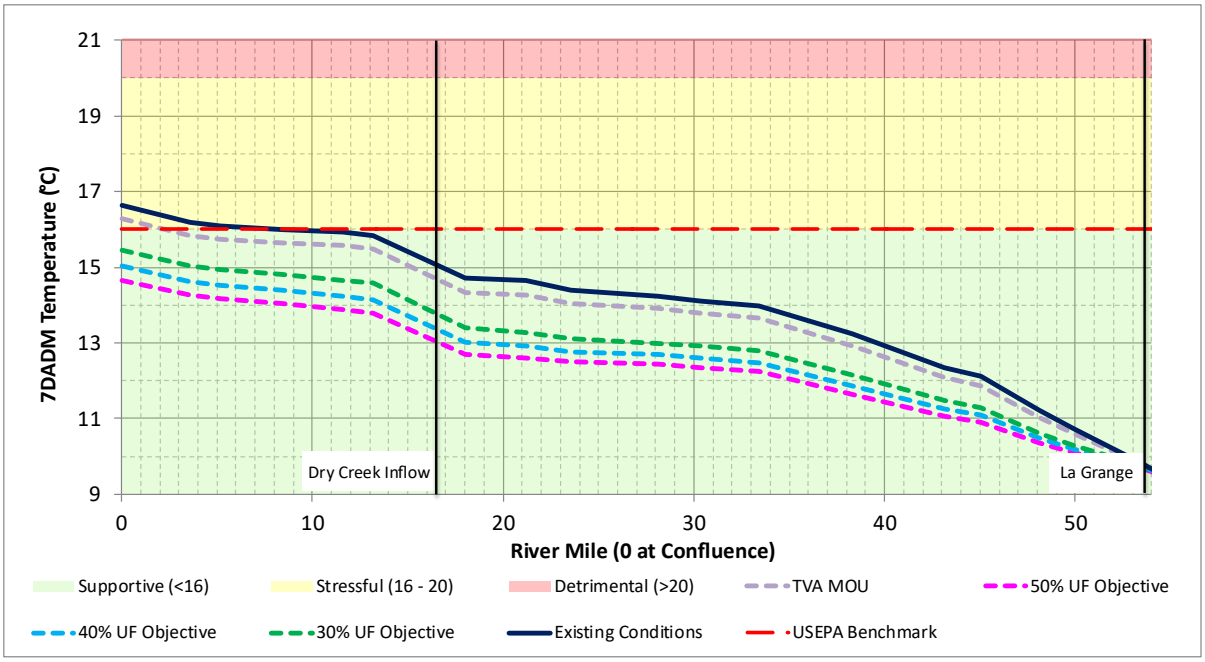


Figure 5-31. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across All Water Year Types from 1970 to 2003.

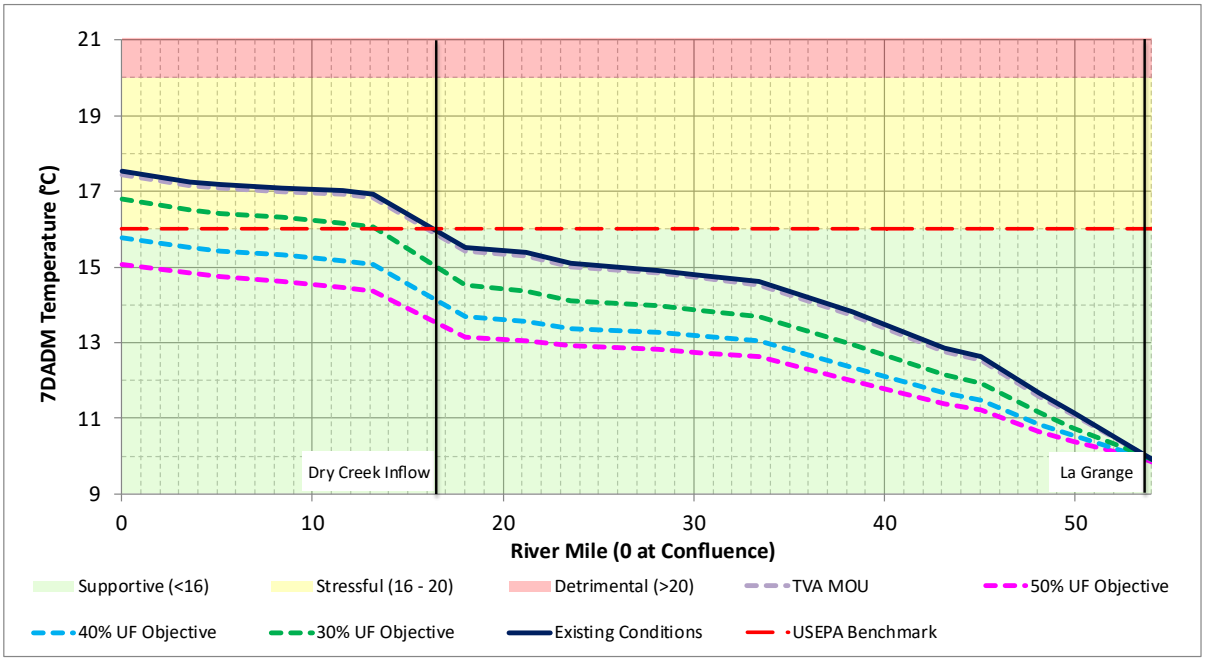


Figure 5-32. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across Dry Water Year Types from 1970 to 2003.

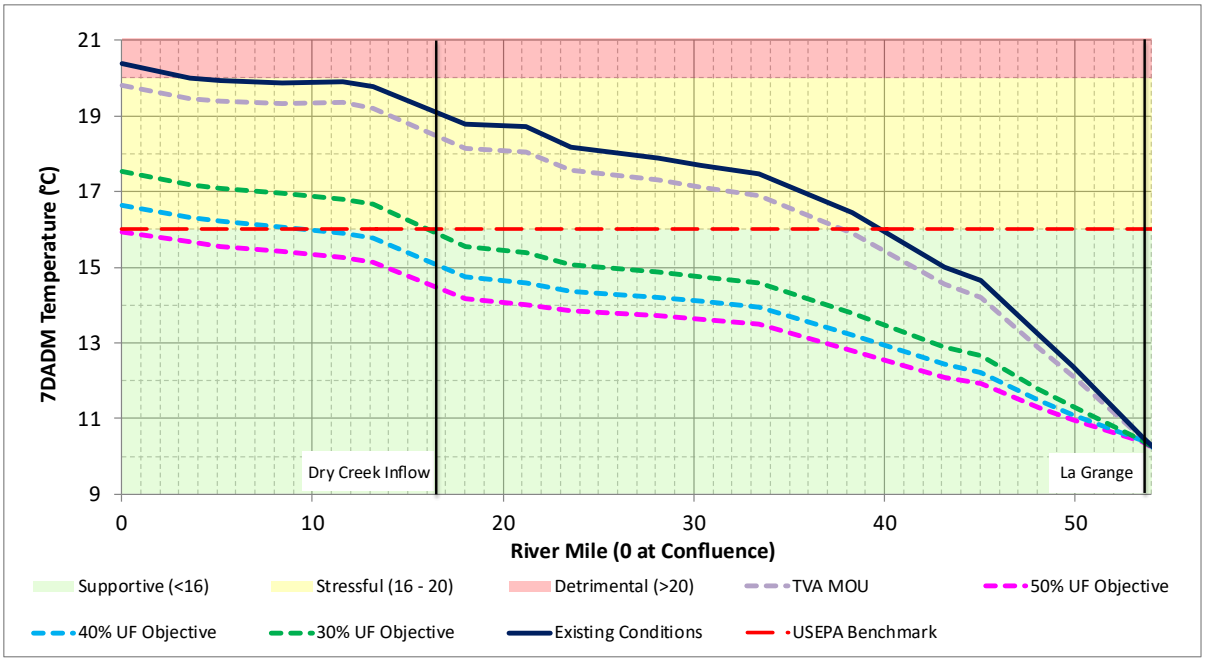


Figure 5-33. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across Critical Water Year Types from 1970 to 2003.

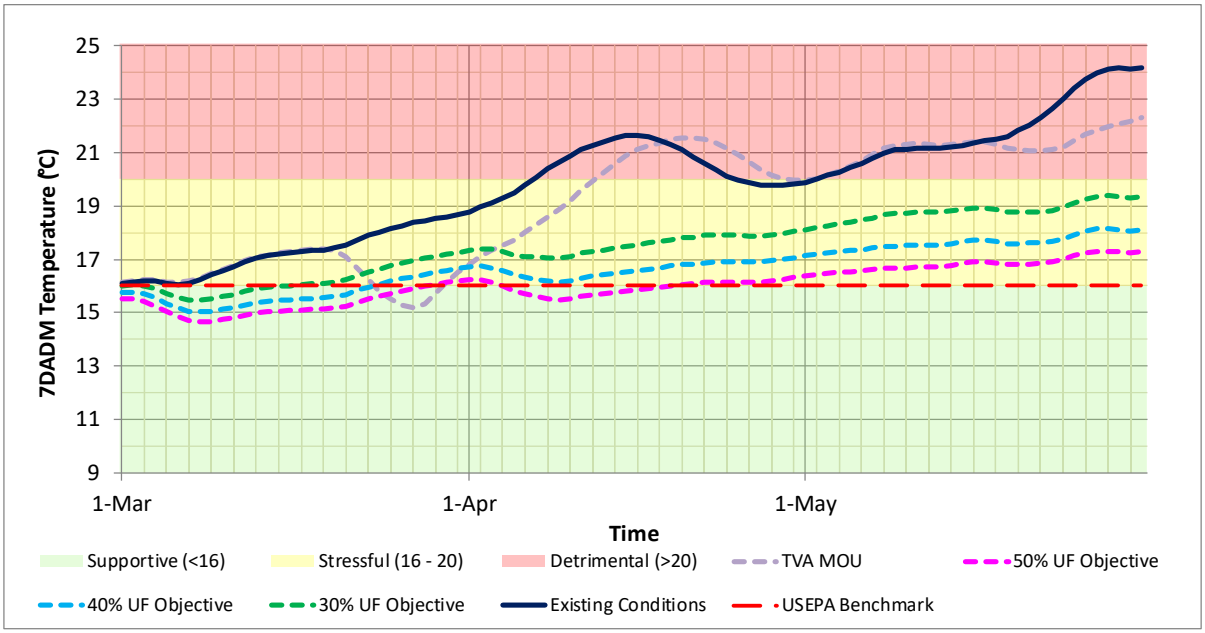


Figure 5-34. Tuolumne River Running 7DADM Water Temperatures at RM 0 Averaged Across Critical Water Year Types from 1970 to 2003 for Core Juvenile Rearing.

Temperatures in May are characterized as warmer than in April for all scenarios, and stressful temperatures are experienced further upstream (Figure 5-35). Temperatures would generally be suitable throughout the river in Wet through Above Normal Years, except for Existing Conditions (Figure 5-36 and Figure 5-37), but Dry and Critical Years would be characterized by large regions of stressful and detrimental temperatures (Figure 5-38 and Figure 5-39). The warm temperatures exhibited by the Existing Conditions scenario are mainly due to a large and rapid increase in temperatures in mid-May that would coincide with a precipitous reduction in the scenario's flow regime which can be seen in the time series graphs (Figure 5-40). A similar rapid increase in temperatures would occur with the TVA scenario; however, the increase would not start until the last week of May. Similar to the increase in frequency in meeting benchmarks shown in Section 5.2.2.1, *Tuolumne River*, the TVA scenario exhibits considerably lower temperatures than the Existing Conditions during May.

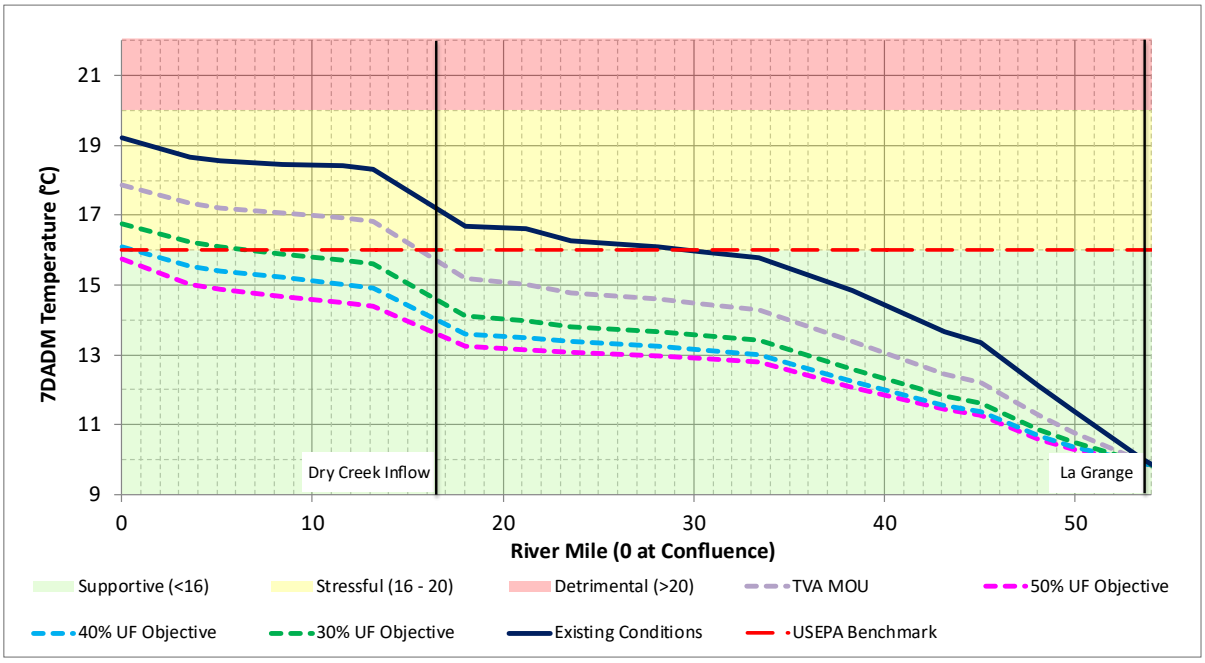


Figure 5-35. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across All Water Year Types from 1970 to 2003.

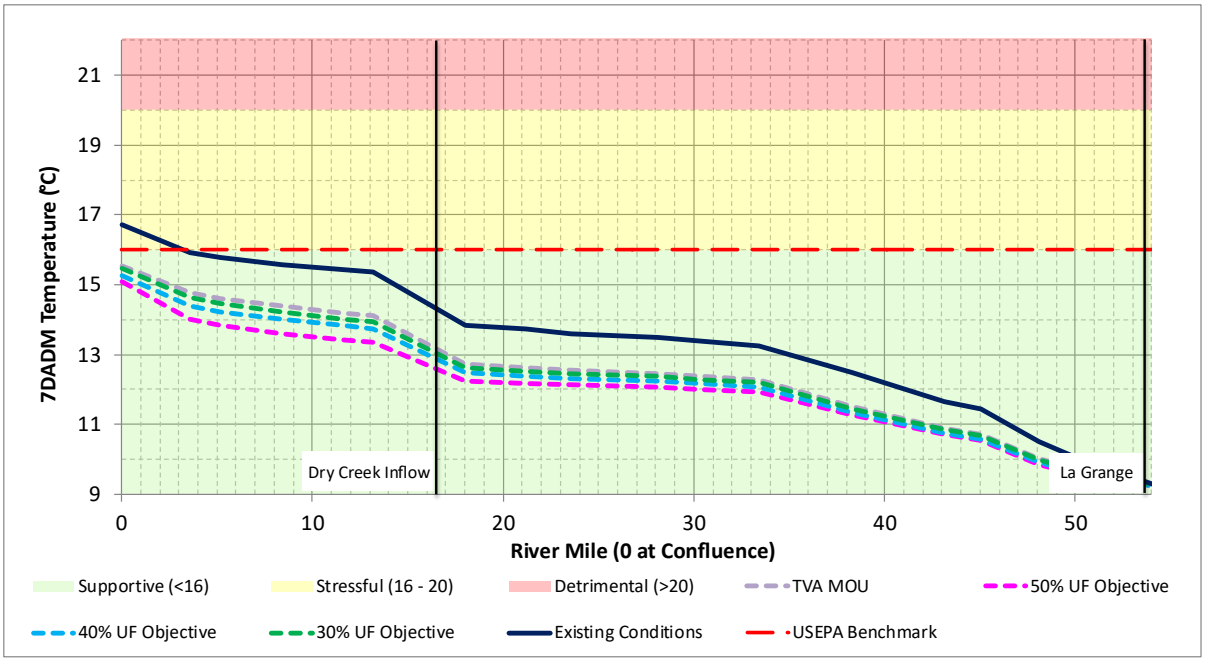


Figure 5-36. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Wet Water Year Types from 1970 to 2003.

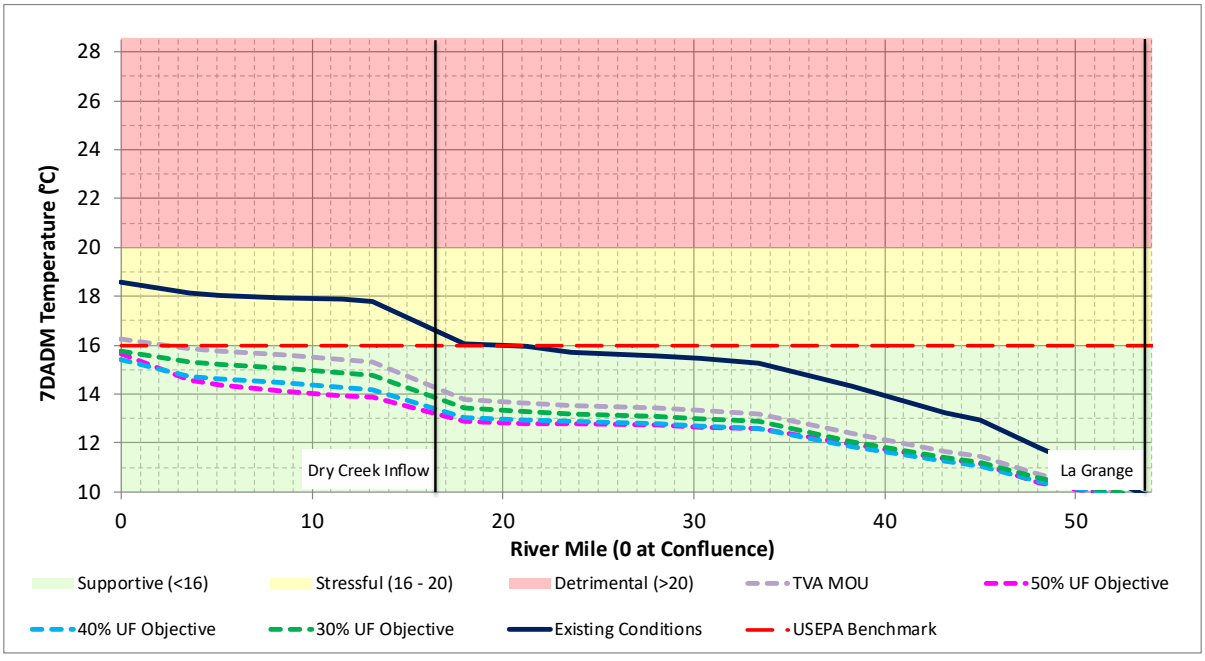


Figure 5-37. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Above Normal Water Year Types from 1970 to 2003.

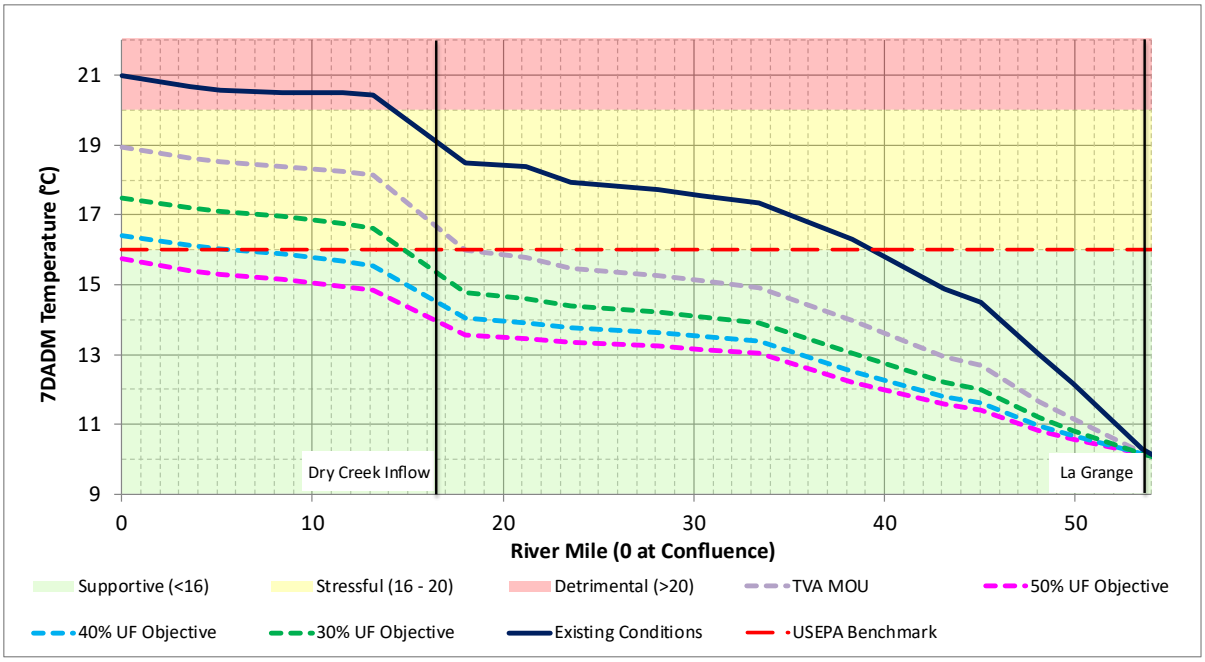


Figure 5-38. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Dry Water Year Types from 1970 to 2003.

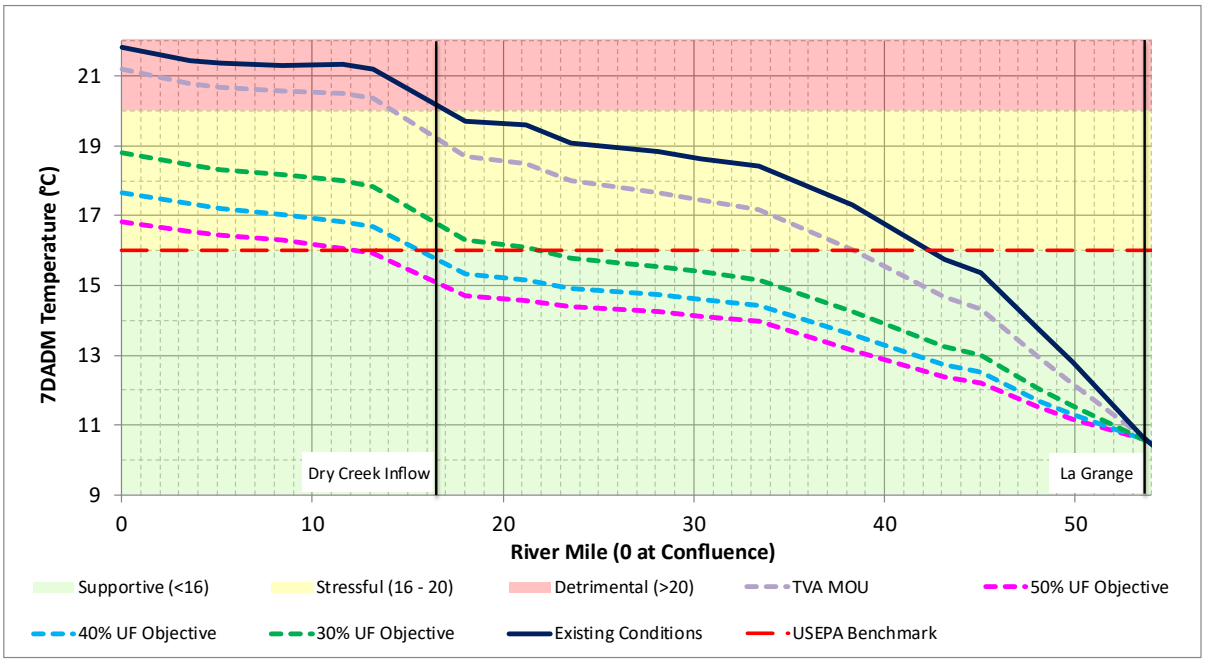


Figure 5-39. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Critical Water Year Types from 1970 to 2003.

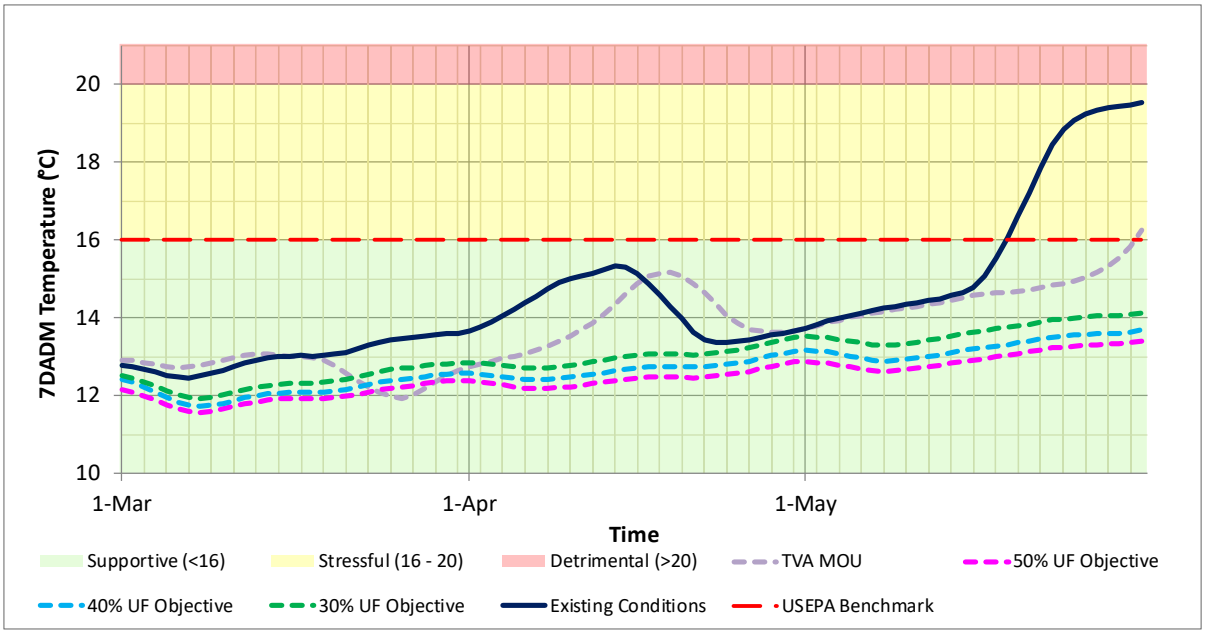


Figure 5-40. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 Averaged Across All Water Year Types from 1970 to 2003 for Core Juvenile Rearing.

Smoltification April 1–June 30

Smoltification was assessed using the USEPA benchmark temperature of 14°C for the months of April, May, and June.

Temperatures averaged over all water year types in April would be suitable for smoltification at La Grange Dam in all scenarios with all scenarios showing warming downstream (Figure 5-41). The Existing Conditions scenario exhibited the highest water temperatures, followed by the TVA scenario, which would be slightly cooler. Temperatures in the Existing Conditions scenario would exceed the USEPA benchmark temperature of 14°C at approximately river mile 33, while the TVA scenario would exceed this benchmark at approximately river mile 23. Temperature for the 50% UF Objective would be lowest and would exceed the USEPA benchmark temperature near river mile 10.

During Wet Years, April water temperatures primarily would remain below the USEPA benchmark temperature of 14°C throughout the Tuolumne River, except for the Existing Conditions scenario (Figure 5-42). Temperatures would increase incrementally from wetter years to drier years with all scenarios exceeding the benchmark by the confluence with the LSJR (Figure 5-43). The TVA scenario exhibits lower water temperatures than the Existing Conditions, and the TVA would remain below detrimental temperatures throughout the river.

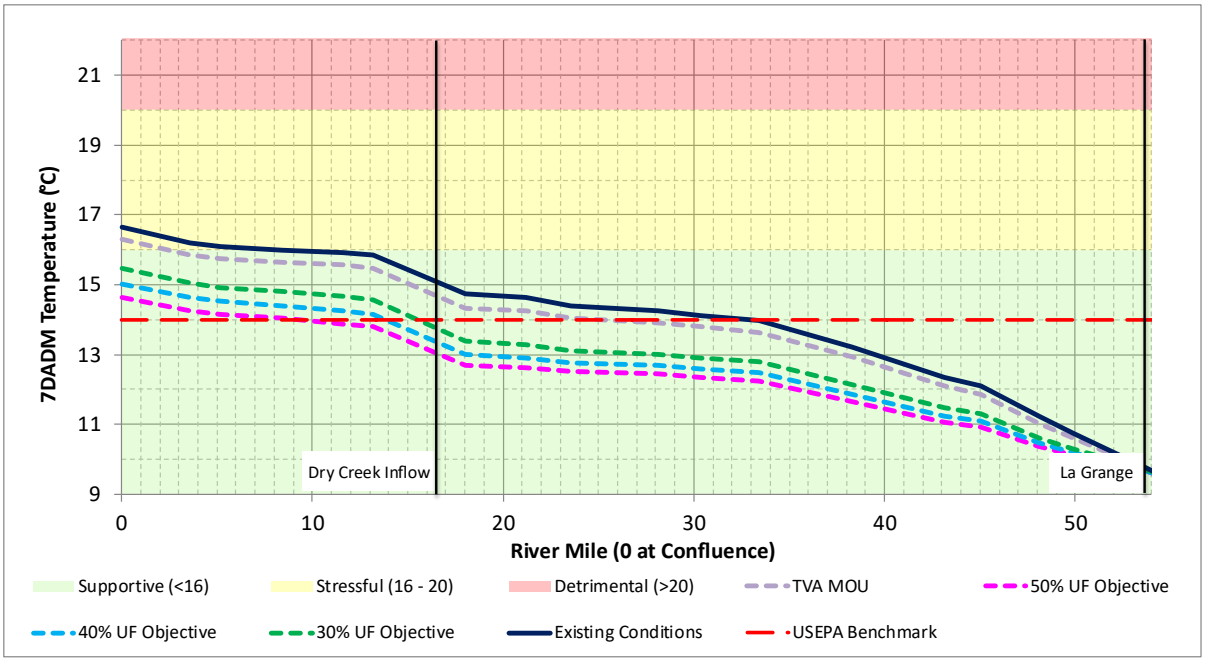


Figure 5-41. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During April Averaged Across All Water Year Types from 1970 to 2003.

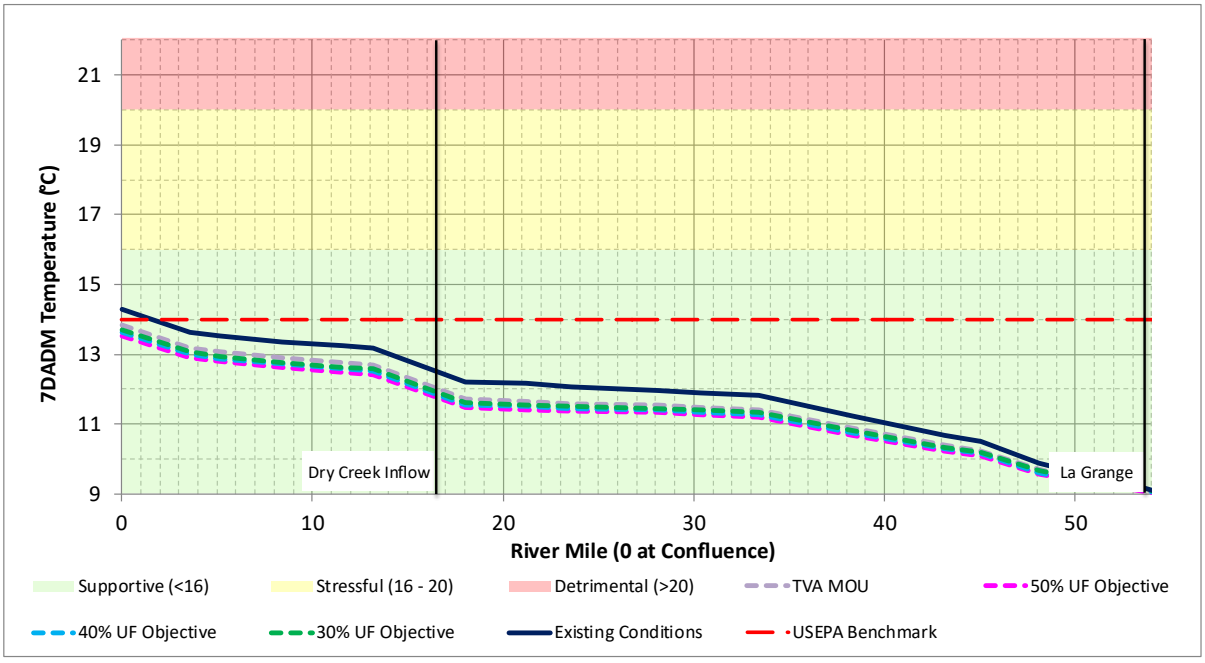


Figure 5-42. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During April Averaged Across Wet Water Year Types from 1970 to 2003.

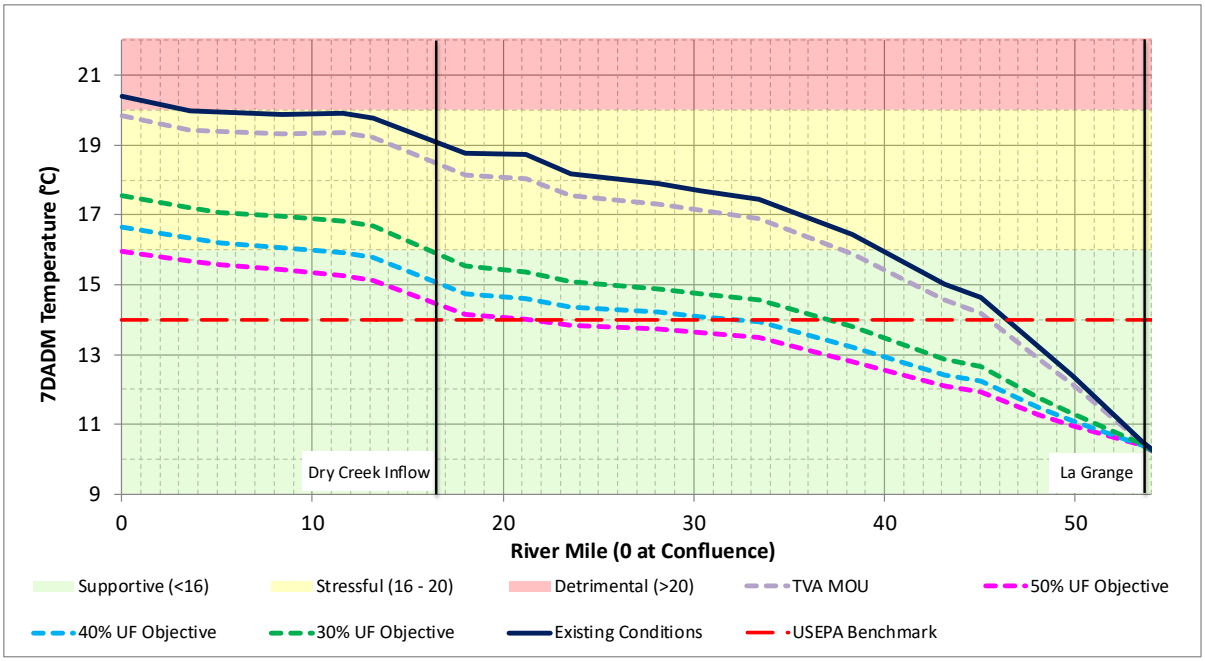


Figure 5-43. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During April Averaged Across Critical Water Year Types from 1970 to 2003.

In May, temperature trends are similar to April, except temperatures would be 1–2°C warmer depending on the scenario (Figure 5-44). In addition, the range between the different scenarios was larger in May than in April. Temperatures averaged across all water year types would exceed the USEPA benchmark of 14°C for all scenarios. The TVA scenario exhibits lower temperatures than the Existing Conditions throughout the river during May over the range of water year types (Figure 5-45 and Figure 5-46).

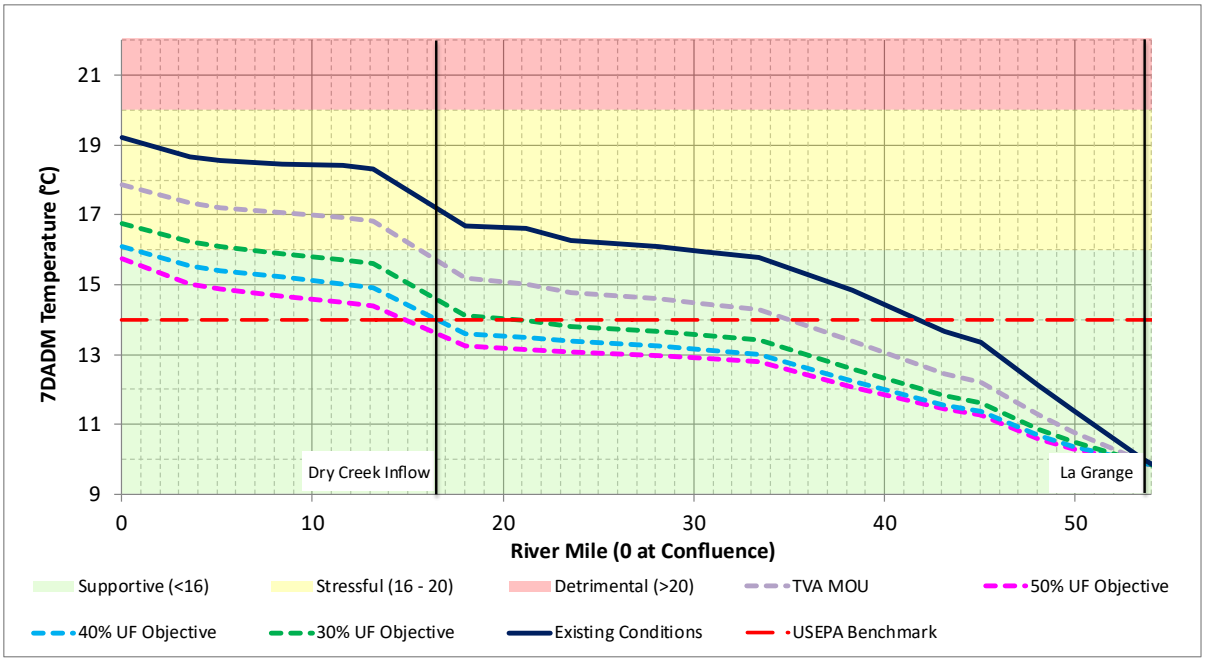


Figure 5-44. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During May Averaged Across All Water Year Types from 1970 to 2003.

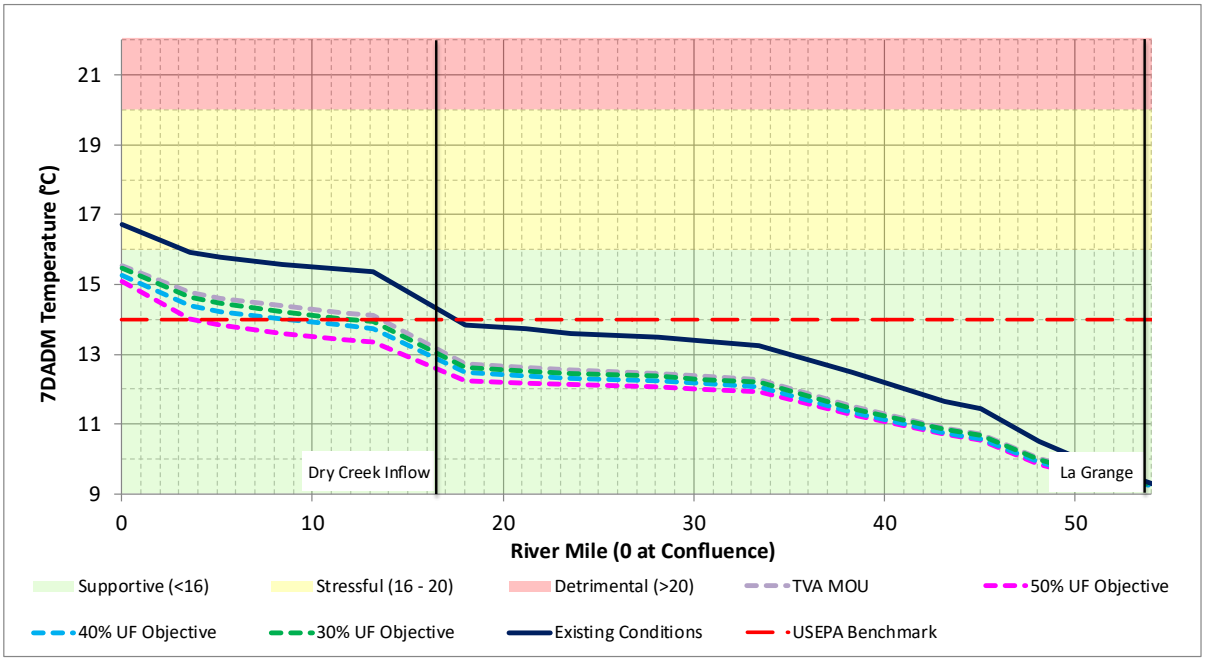


Figure 5-45. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During May Averaged Across Wet Water Year Types from 1970 to 2003.

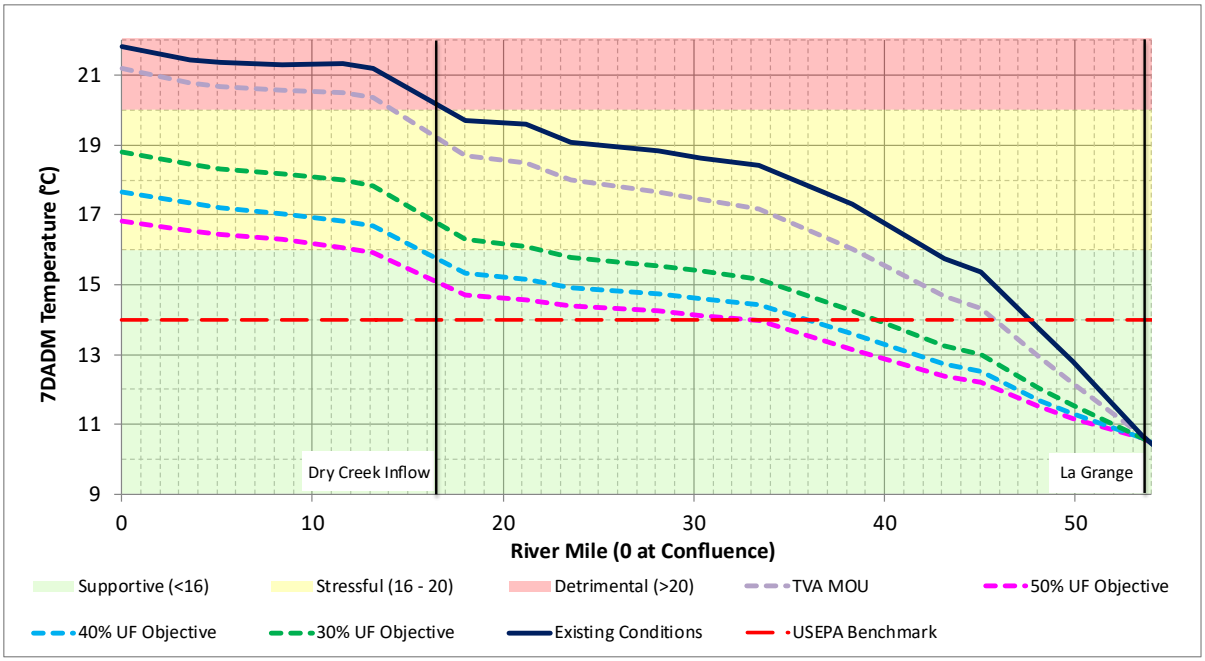


Figure 5-46. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During May Averaged Across Critical Water Year Types from 1970 to 2003.

In June, temperatures continue to rise increasing 2–6°C from May temperatures, depending on the scenario (Figure 5-47). All scenarios exhibit temperatures above the USEPA benchmark of 14°C for smoltification. The TVA scenario exhibits similar water temperatures as the Existing Conditions when averaged over all water year types; however, in June, the TVA exhibits warmer water temperatures than the Existing Conditions during wetter year types and cooler water temperatures during drier year types (Figure 5-48 to Figure 5-51). The Existing Conditions and TVA scenarios would exceed the 20°C detrimental benchmark through much of the river, except in Wet Years. In Dry and Critical Years, the 30%, 40%, and the 50% UF Objective scenarios would exceed the 20°C detrimental benchmark in the lower half of the Tuolumne River (Figure 5-50 and Figure 5-51).

On a seasonal basis, all scenarios would exceed the USEPA benchmark of 14°C for smoltification during April through June when averaged across all water year types at RM 0 (Figure 5-52) The 14°C benchmark would be met upstream variably by each of the scenarios depending on river mile and water year type (Figure 5-53). The rapid rise in temperature that starts at the end of May for the TVA scenario (Figure 5-53) and continues into June (Figure 5-52) corresponds to a reduction in flow (i.e., ending of the pulse flow) in that scenario. In Above Normal Years and drier years, the Existing Conditions and TVA scenarios exhibit lethal temperatures in early to mid-June in the lower reaches of the Tuolumne River (Figure 5-53).

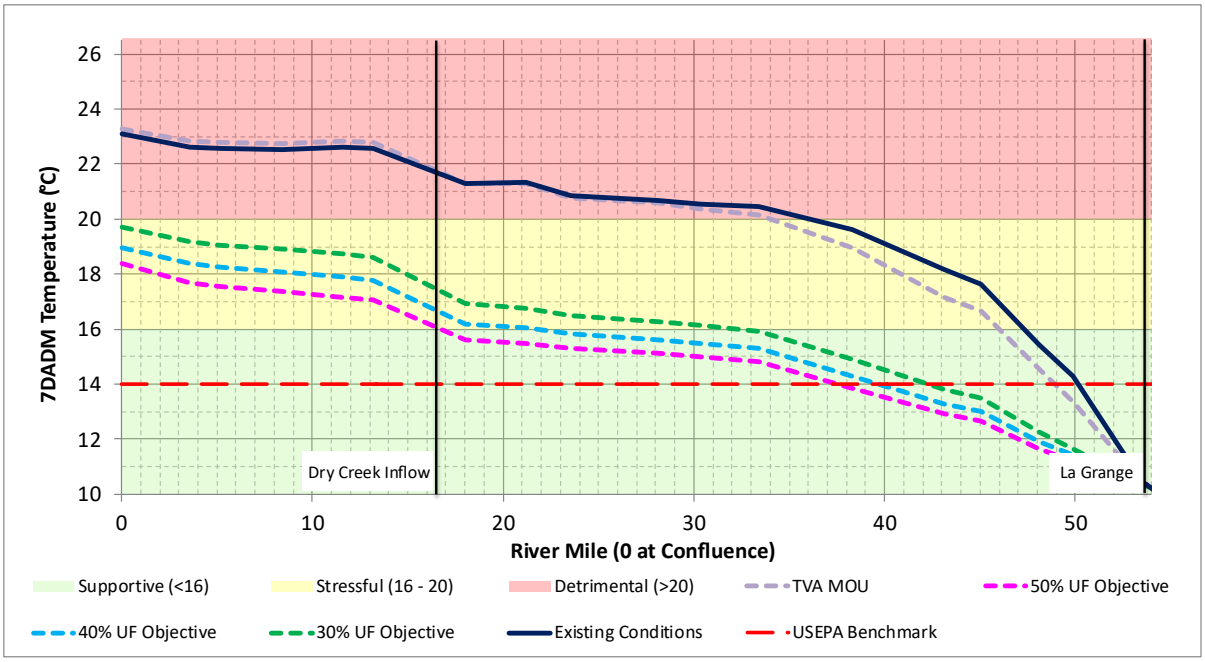


Figure 5-47. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During June Averaged Across All Water Year Types from 1970 to 2003.

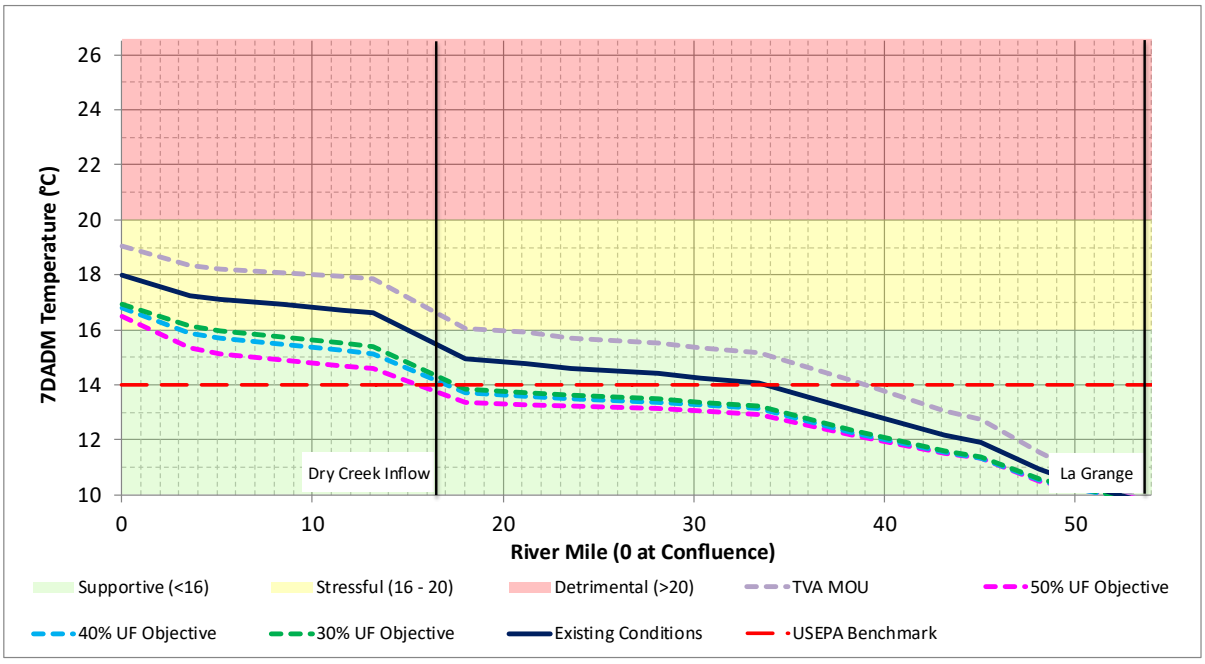


Figure 5-48. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During June Averaged Across Wet Water Year Types from 1970 to 2003.

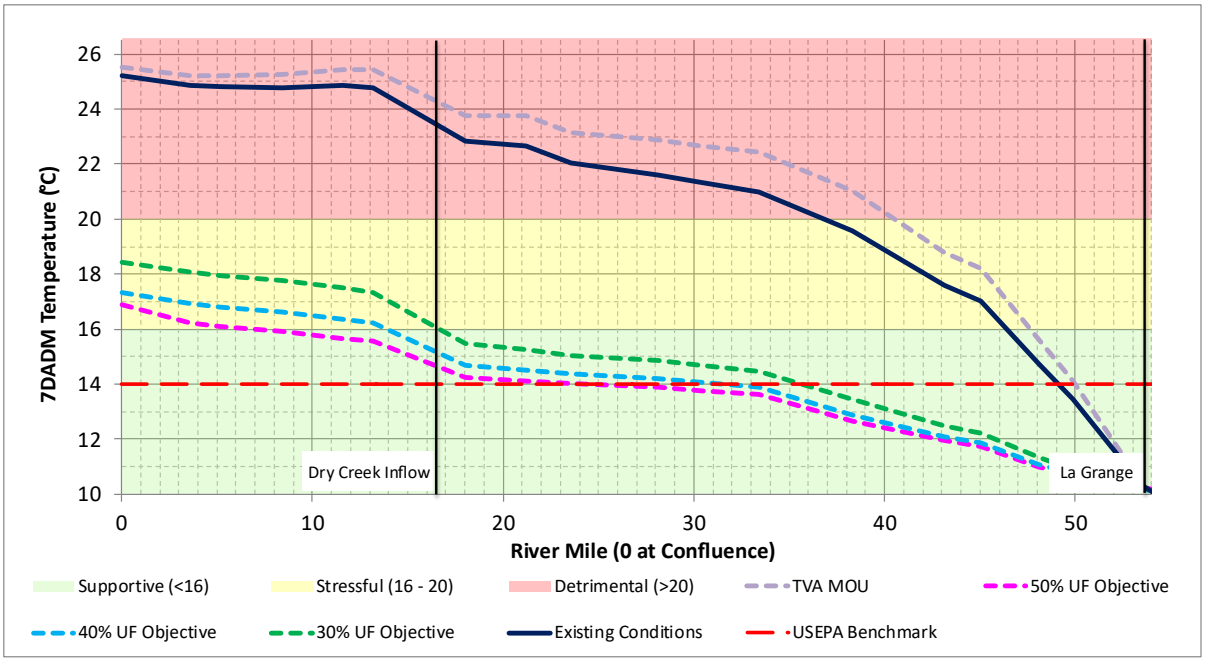


Figure 5-49. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During June Averaged Across Above Normal Water Year Types from 1970 to 2003.

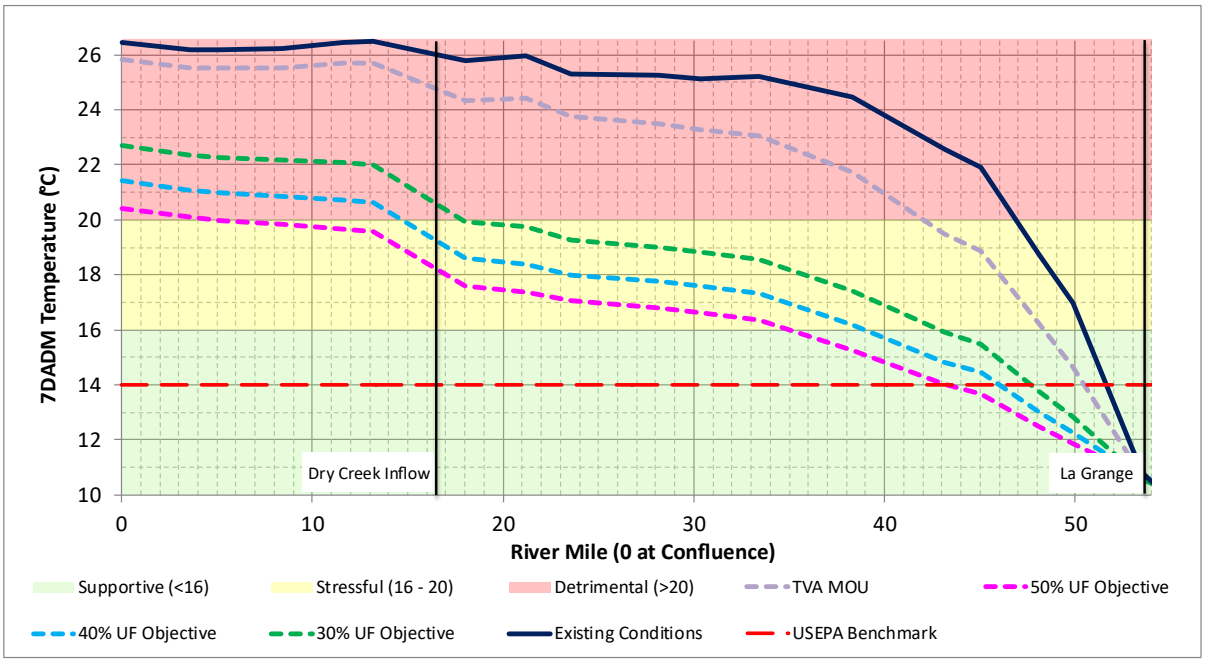


Figure 5-50. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During June Averaged Across Dry Water Year Types from 1970 to 2003.

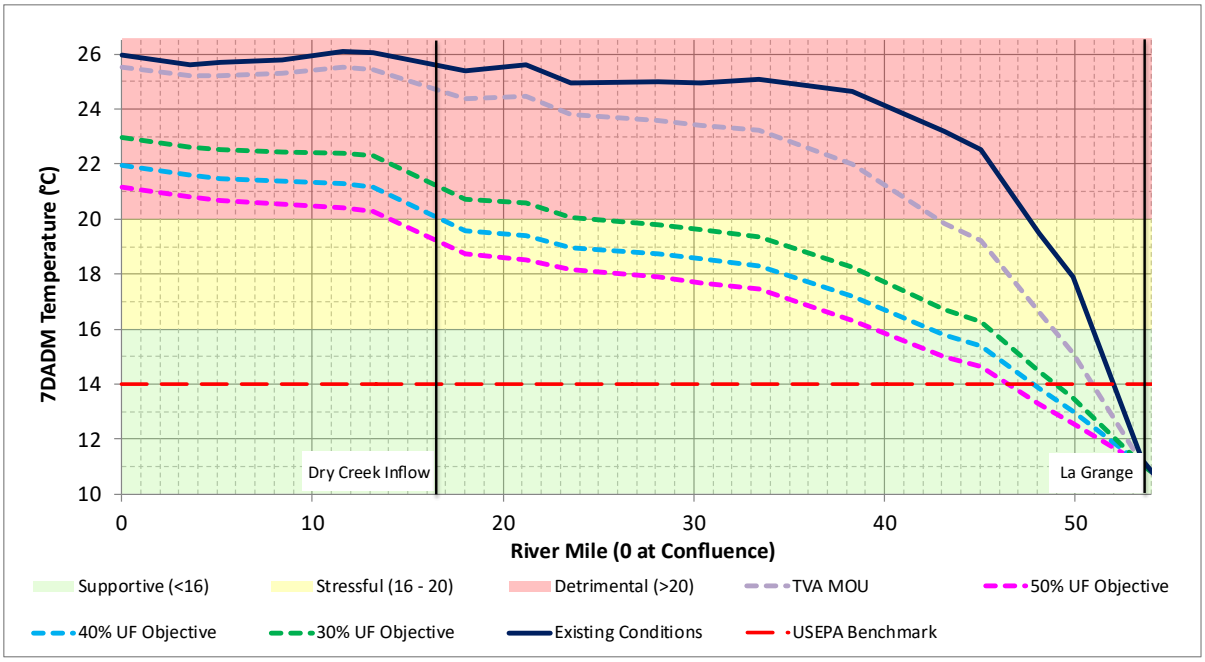


Figure 5-51. Tuolumne River Longitudinal Water Temperature Profile for Smoltification During June Averaged Across Critical Water Year Types from 1970 to 2003.

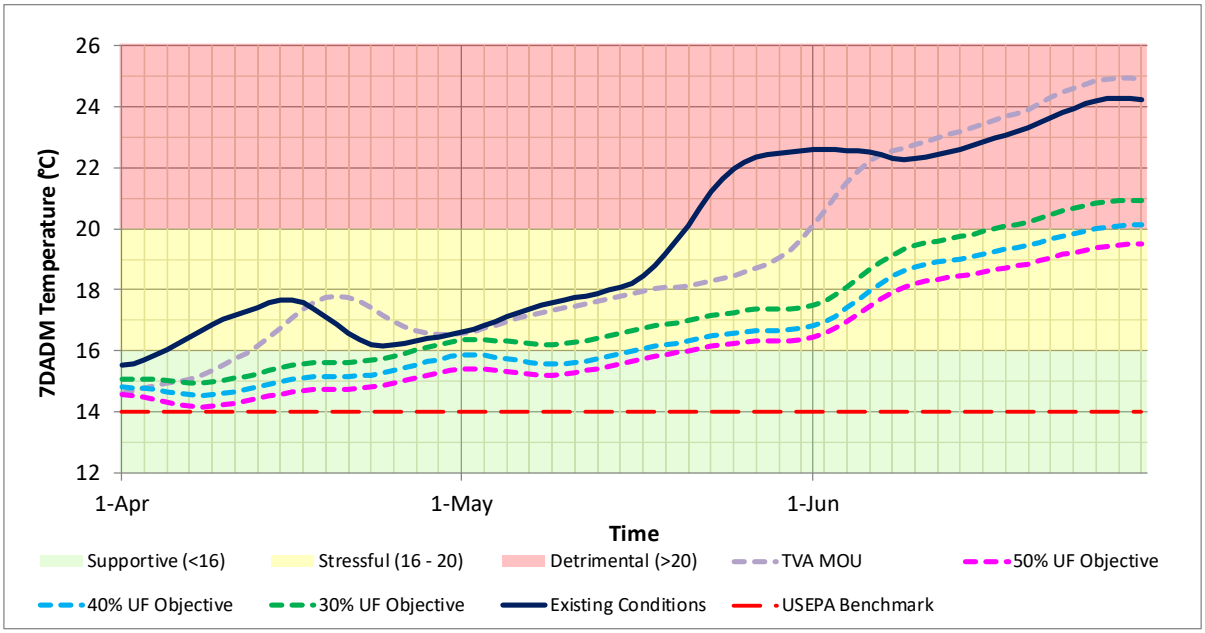


Figure 5-52. Tuolumne River Running 7DADM Water Temperatures at RM 0 Averaged Across All Water Year Types from 1970 to 2003 for Smoltification.

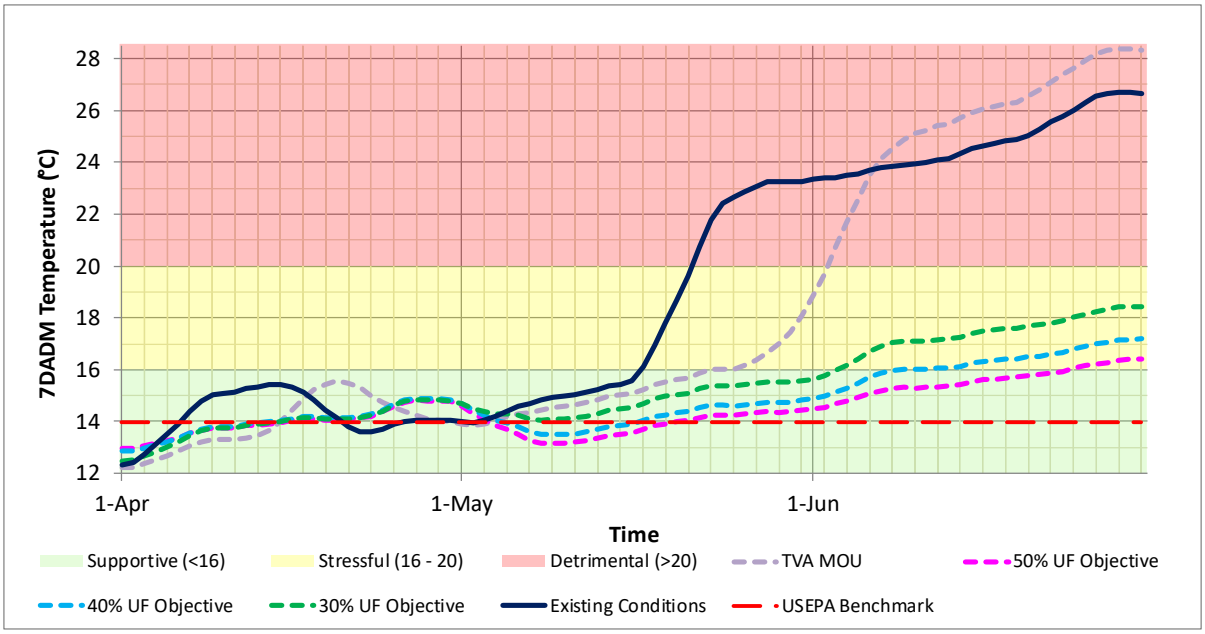


Figure 5-53. Tuolumne River Running 7DADM Water Temperatures at RM 13.2 Averaged Across Above Normal Water Year Types from 1970 to 2003 for Smoltification.

Core Juvenile Rearing (*O. mykiss*) June 1–June 30

Temperatures for core rearing *O. mykiss* were assessed in June using the USEPA benchmark temperature of 16^0C from La Grange Dam at RM 53.5 downstream to RM 28.1.

During June, temperatures averaged over all water year types at La Grange Dam would be suitable for core juvenile rearing *O. mykiss* for all scenarios. The Existing Conditions and TVA scenarios would exceed the USEPA benchmark of 16°C near RM 45–47 (Figure 5-54). The 40% and 50% UF Objective scenarios exhibit suitable temperatures below the benchmark throughout the *O. mykiss* core rearing reach; however, the 30% UF Objective scenario would exceed the benchmark near RM 30 but remains near 16°C through the core rearing reach. During Wet Years, all scenarios would be expected to remain below the USEPA benchmark for *O. mykiss* core rearing throughout the rearing reach (Figure 5-55). Starting with Above Normal Years, the Existing Conditions and TVA scenarios would exceed the benchmark as far upstream as RM 45 (Figure 5-56) and farther upstream during drier years (Figure 5-57 to Figure 5-59). The % UF Objective scenarios continue to exhibit temperatures below 16°C throughout the *O. mykiss* core rearing reach in Above Normal and Below Normal Years; however, the 30%, 40%, and 50% UF Objective scenarios would exceed the benchmark between RM 35 and RM 43 in Dry Years (Figure 5-58) and RM 46 and RM 39 in Critical Years (Figure 5-59).

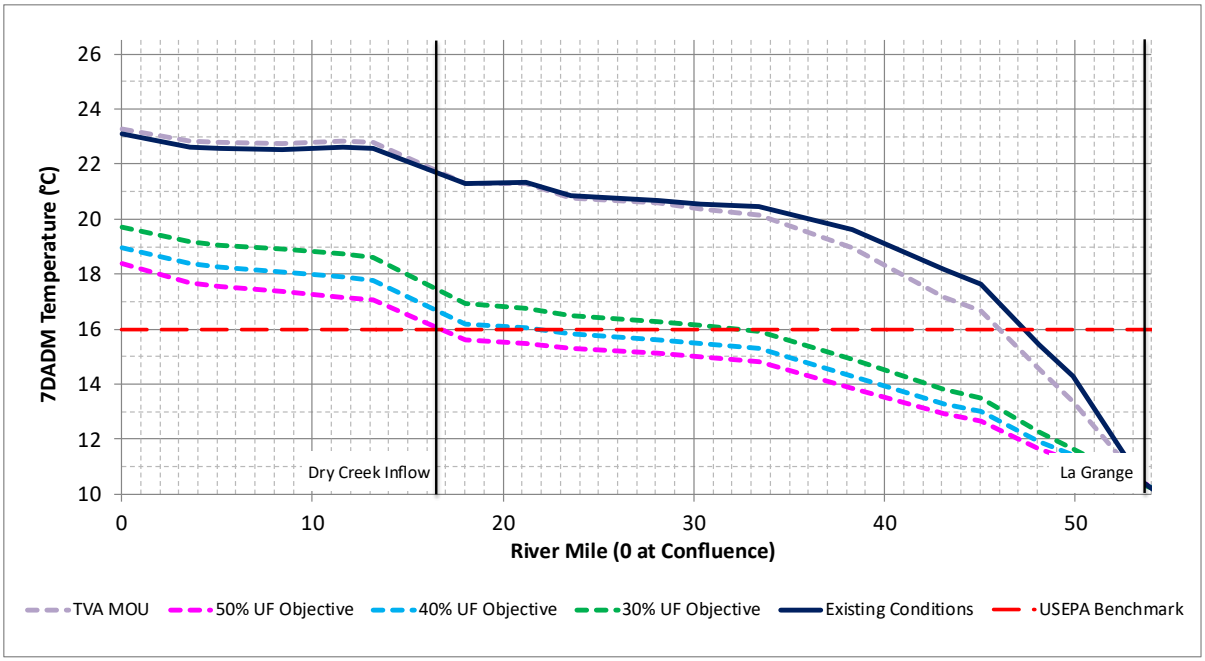


Figure 5-54. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across All Water Year Types from 1970 to 2003.

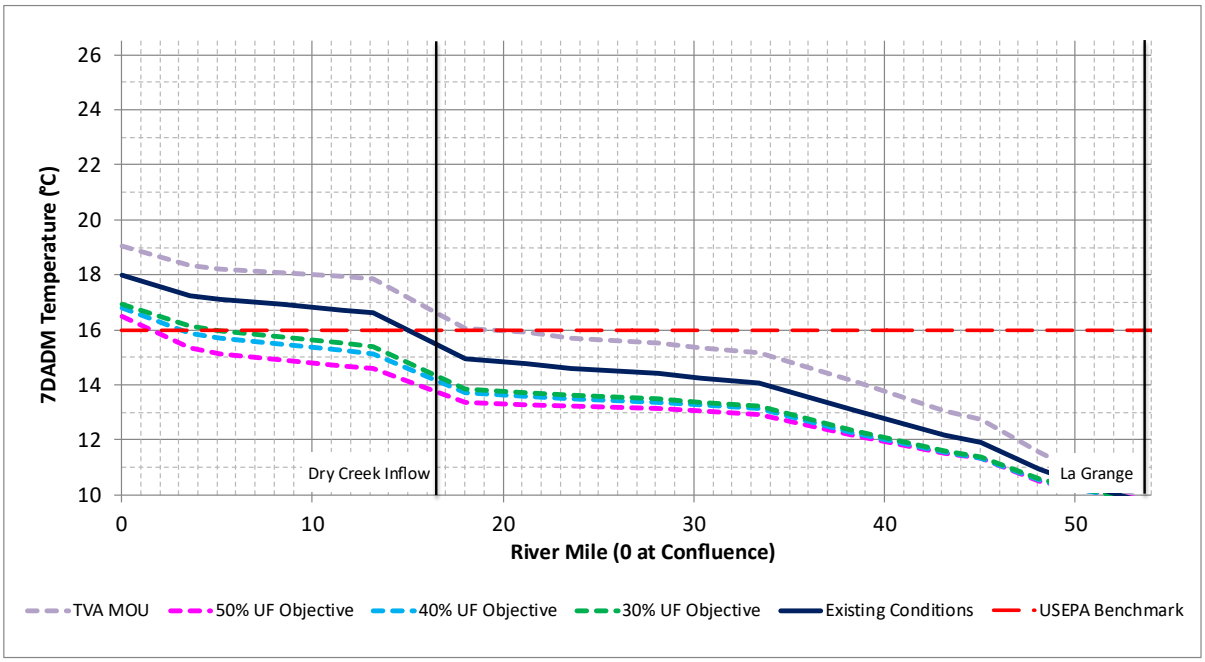


Figure 5-55. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Wet Water Year Types from 1970 to 2003.

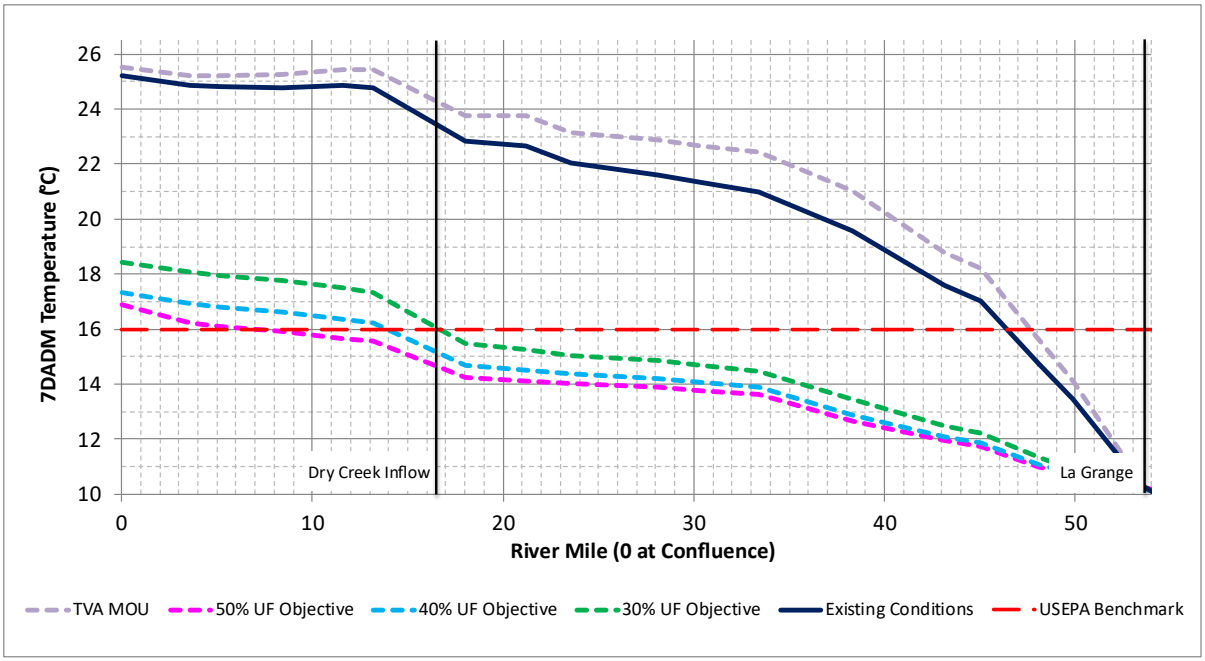


Figure 5-56. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Above Normal Water Year Types from 1970 to 2003.

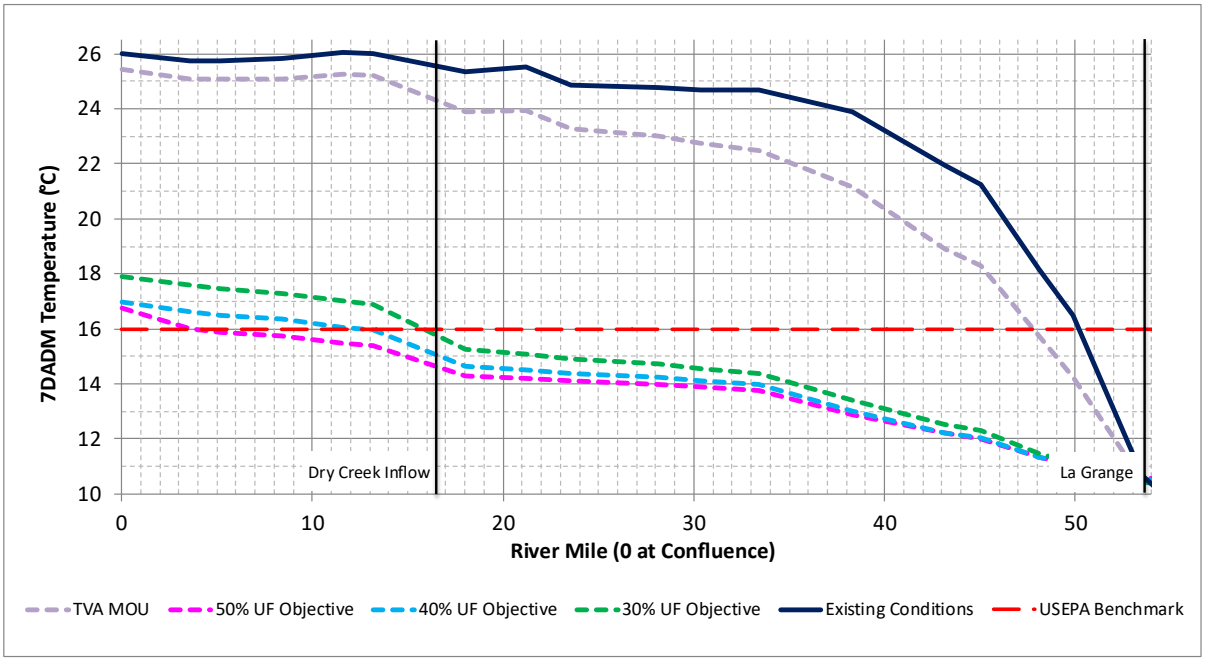


Figure 5-57. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Below Normal Water Year Types from 1970 to 2003.

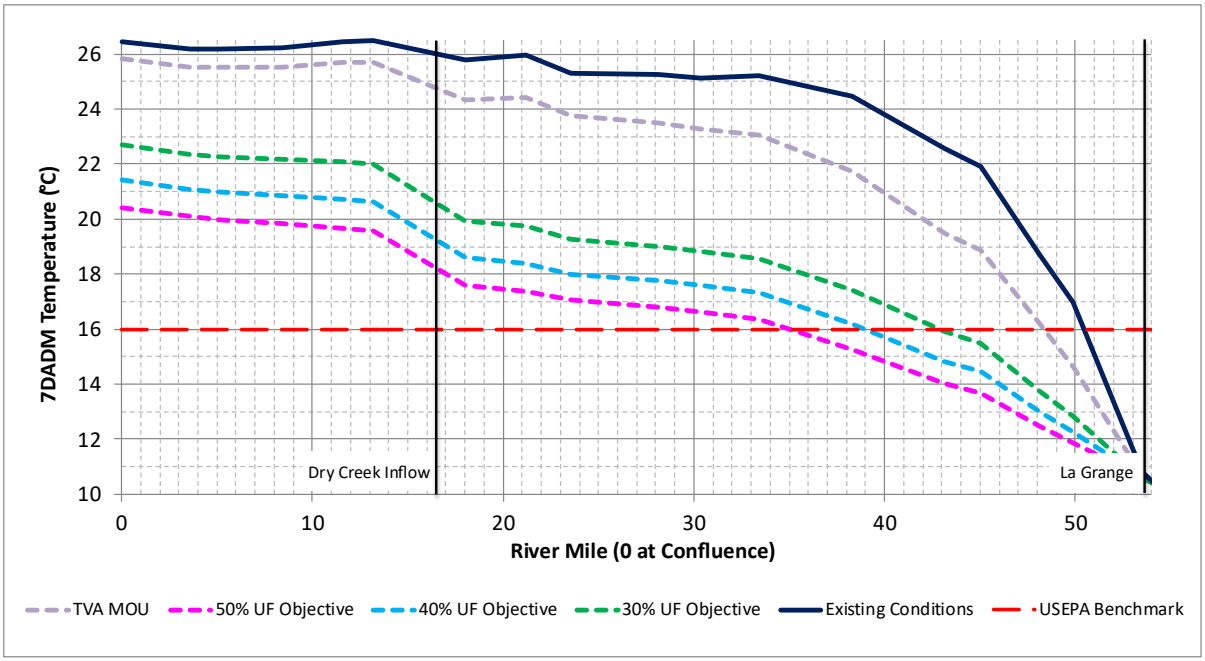


Figure 5-58. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Dry Water Year Types from 1970 to 2003.

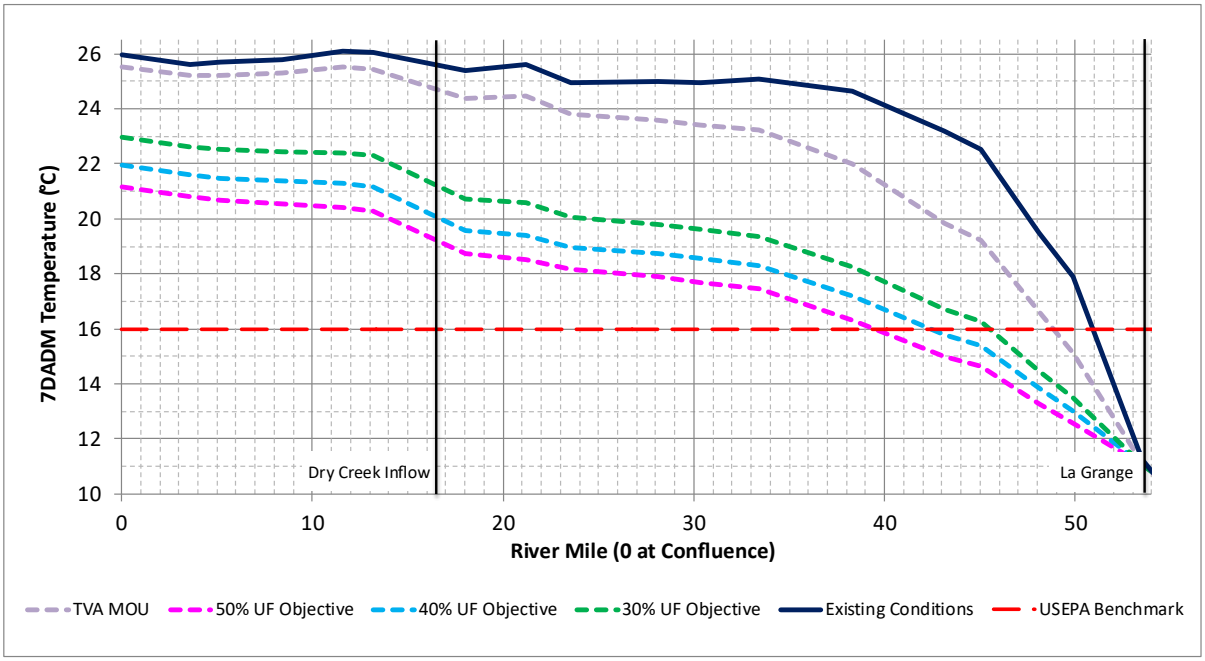


Figure 5-59. Tuolumne River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Critical Water Year Types from 1970 to 2003.

Figure 5-60 shows the general trend in water temperatures over the *O. mykiss* core rearing season at RM 38, approximately in the middle of the rearing reach. The Existing Conditions and TVA scenarios would generally exceed the USEPA benchmark of 16°C for core juvenile rearing for nearly the entire June period.

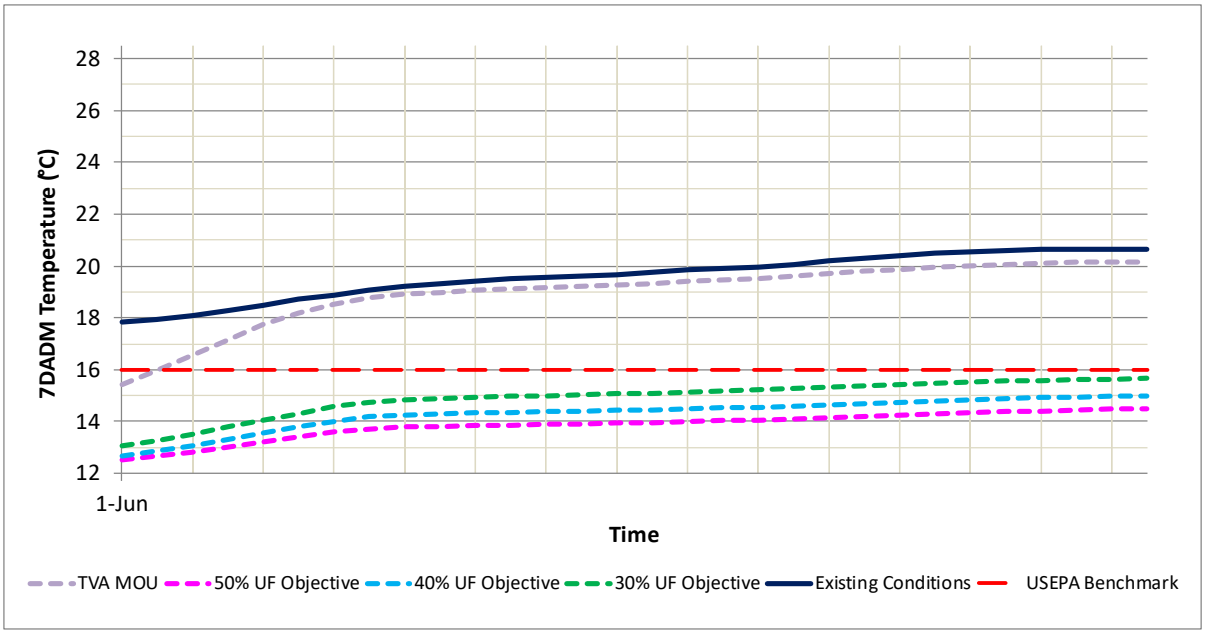


Figure 5-60. Tuolumne River Running 7DADM Water Temperatures at RM 38.29 Averaged Across All Water Year Types from 1970 to 2003 for *O. mykiss* Core Juvenile Rearing.

Non-Core Rearing (*O. mykiss*) June 1–June 30

Temperatures for non-core juvenile rearing *O. mykiss* were assessed in June using the USEPA benchmark temperature of 18°C from RM 28.1 downstream to the confluence with the LSJR.

During June, the Existing Conditions and TVA scenarios would exceed the USEPA benchmark of 18°C throughout the non-core rearing reach, except in Wet Years (Figure 5-54 to Figure 5-59, 18°C benchmark not shown[32]). Both the Existing Conditions and TVA scenarios would exceed lethal temperatures from Above Normal Years, with increasing temperatures in drier year types (Figure 5-56 to Figure 5-59, 18°C benchmark not shown). The % UF Objective scenarios would largely remain below the benchmark throughout the non-core rearing reach in Wet, Above Normal, and Below Normal Years (Figure 5-55 to Figure 5-57, 18°C benchmark not shown); however, in Dry and Critical Years, these scenarios would exceed 18°C through a majority of the non-core river reach but remain below lethal temperatures (Figure 5-58 and Figure 5-59, 18°C benchmark not shown).

Summer Rearing (*O. mykiss*) June 1–August 31

Summer rearing was assessed using the USEPA benchmark temperature of 18°C for the months of June, July, and August. The primary evaluation location is from RM 53.5 downstream to RM 23.54; however, the most efficient metric to compare scenarios is the number of river miles downstream from La Grange Dam that are suitable. From 1982 to 2021 *O. mykiss* have been observed as far downstream as RM 35 during June to September (TID and MID 2022). This temperature evaluation considers over-summering young-of-the year juvenile *O. mykiss* as well as resident *O. mykiss*.

[32] The June graphs in the previous Temporal and Life Stage Assessment section (Core Juvenile Rearing *O. mykiss* June 1–June 30) were reused here due to overlapping time periods.

During June, the scenarios exhibit distinctive patterns in water temperatures averaged across all water year types, and the Existing Conditions and TVA scenarios would exceed the 18°C benchmark within 10–15 miles downstream of La Grange Dam (Figure 5-54, 18°C benchmark not shown[33]). The % UF Objective scenarios generally exhibit suitable temperatures throughout the entire summer rearing reach. The Existing Conditions and TVA modeling scenarios exhibit suitable temperatures throughout the 30-mile summer rearing reach in Wet Years, but from Above Normal to Critical Years, the scenarios only exhibit temperatures below 18°C for about 4–11 miles below La Grange Dam (Figure 5-55 to Figure 5-59, 18°C benchmark not shown[34]). During June, the % UF Objective scenarios exhibit temperatures below the benchmark throughout the 30 mile summer rearing reach from Wet through Below Normal Years, and the 30%, 40%, and 50% UF Objective scenarios would be expected to provide 10–15 miles, 15–30, and 25–30 miles of suitable temperatures in Critical and Dry Years, respectively (Figure 5-56 to Figure 5-59, 18°C benchmark not shown).

In July[35] and August, all scenarios have similar flow regimes, and thus they exhibit similar temperatures (Figure 5-61 and Figure 5-67, respectively). The exception to this is during Wet Years where the 40% and 50% UF Objective scenarios use adaptive methods to shift flow from the spring to the summer and fall to address temperature impacts, which results in a reduction in water temperature of about 1°C (Figure 5-62 for July and Figure 5-68 for August). In all water year types, except Wet Years, suitable habitat below 18°C would be constrained to less than 10 miles from La Grange Dam (Figure 5-63 to Figure 5-66 for July and Figure 5-69 to Figure 5-72 for August), with large portions of the summer rearing reach expected to exceed lethal temperatures, especially in drier years.

[33] The June graphs in the previous Temporal and Life Stage Assessment section (Core Juvenile Rearing *O. mykiss* June 1-June 30) were reused here due to overlapping time periods.

[34] The June graphs in the previous Temporal and Life Stage Assessment section (Core Juvenile Rearing *O. mykiss* June 1-June 30) were reused here due to overlapping time periods.

[35] The 30% to 50% UF Objective Flow scenarios include requirements until June 30; however, the modeling includes many days of flow ramping starting July 1 down to the flows required in the Existing Conditions scenario. These elevated flows during the down-ramping period result in lower water temperature values, which is reflected in the average monthly temperatures in July. As a result, the difference in water temperatures between the % UF Objective scenarios and the Existing Conditions scenarios depicted in Figure 5-63 to Figure 5-66 may be larger at the beginning of July compared to the end of July.

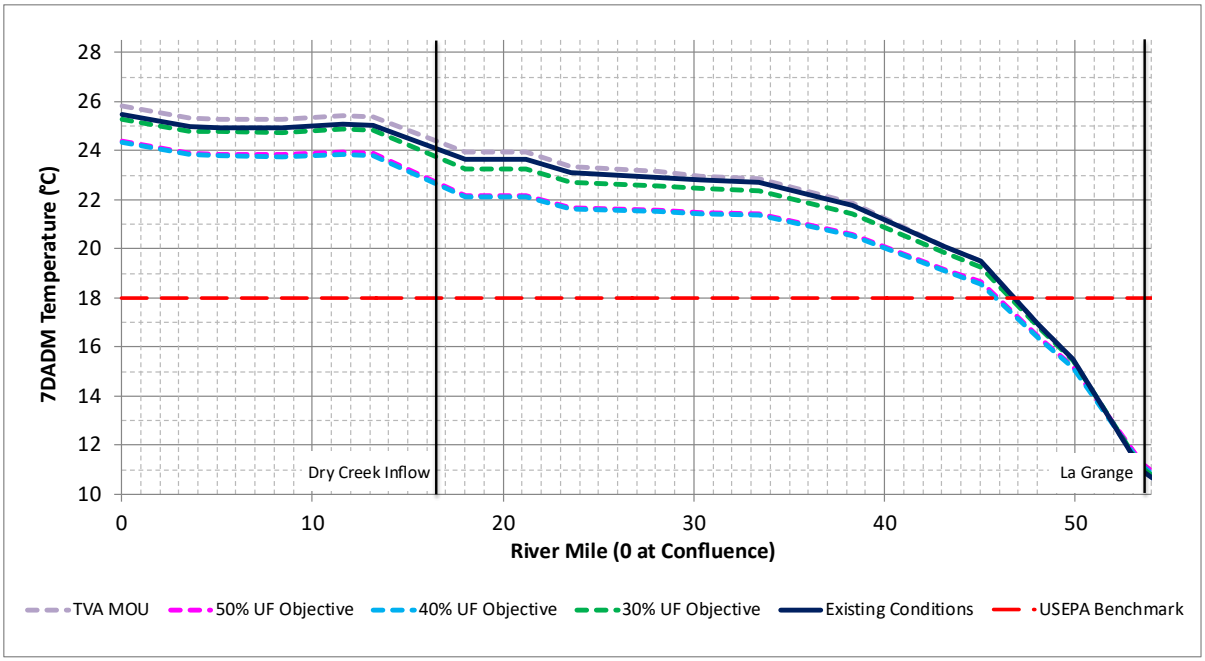


Figure 5-61. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across All Water Year Types from 1970 to 2003.

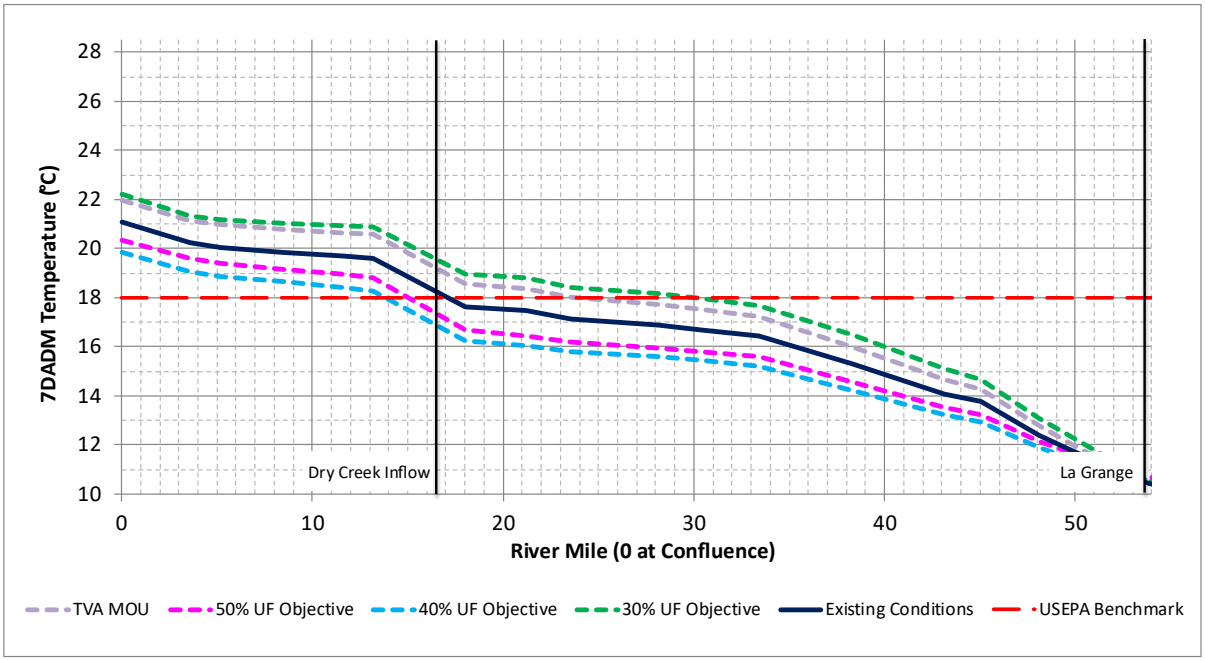


Figure 5-62. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across Wet Water Year Types from 1970 to 2003. The 40% and 50% UF Objective Scenarios Reflect Temperature Improvements Due to Flow Shifting Through Allowable Adaptive Methods of the Bay-Delta Plan.

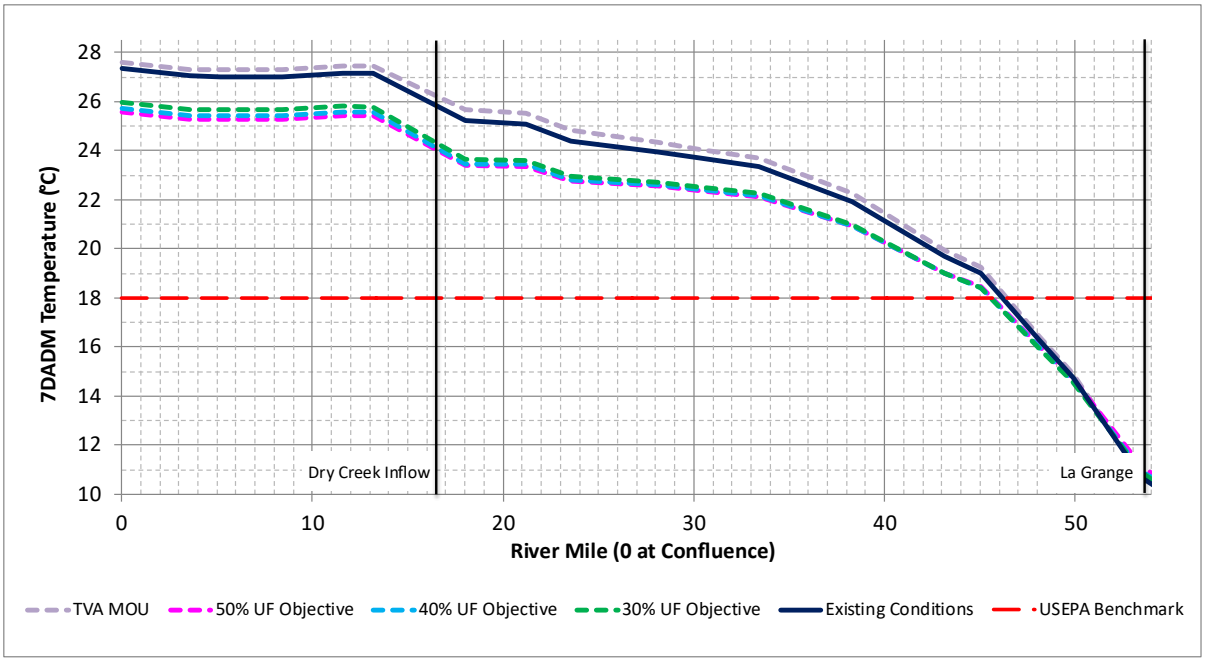


Figure 5-63. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across Above Normal Water Year Types from 1970 to 2003.

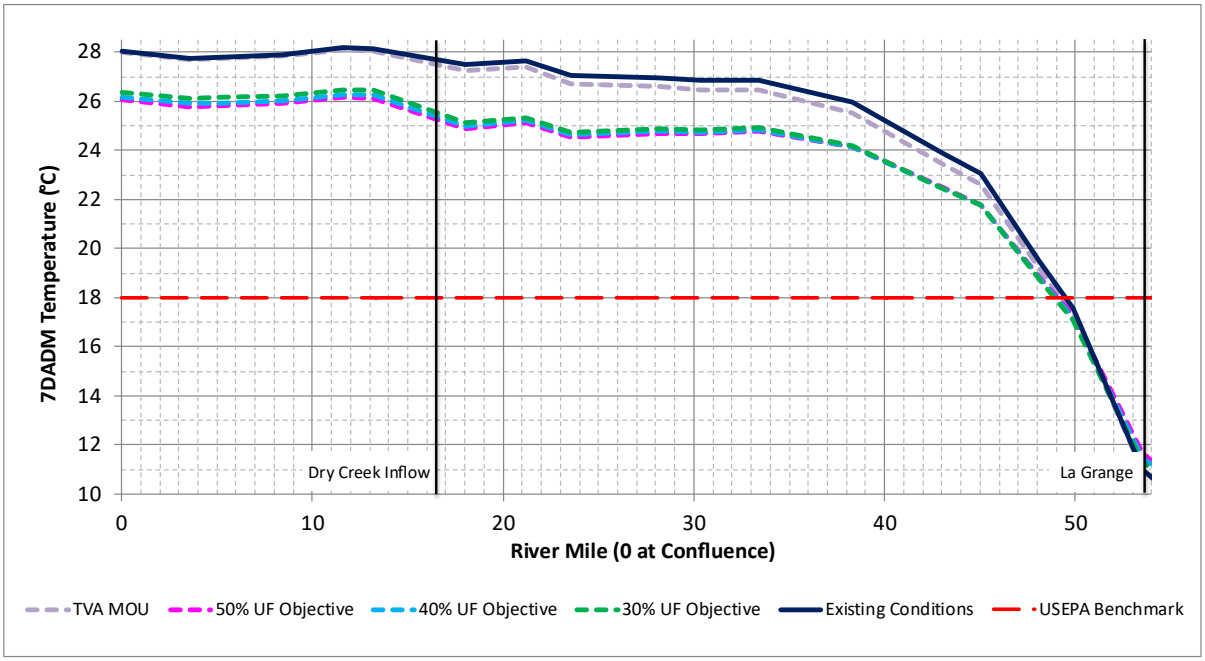


Figure 5-64. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across Below-Normal Water Year Types from 1970 to 2003.

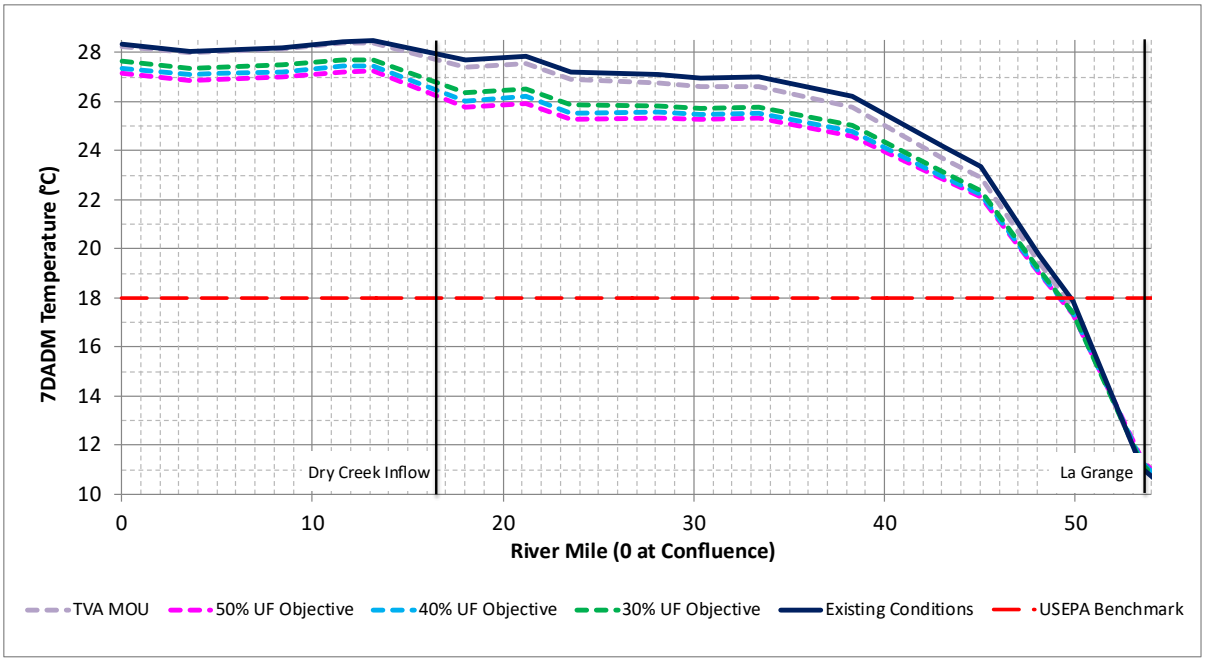


Figure 5-65. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across Dry Water Year Types from 1970 to 2003.

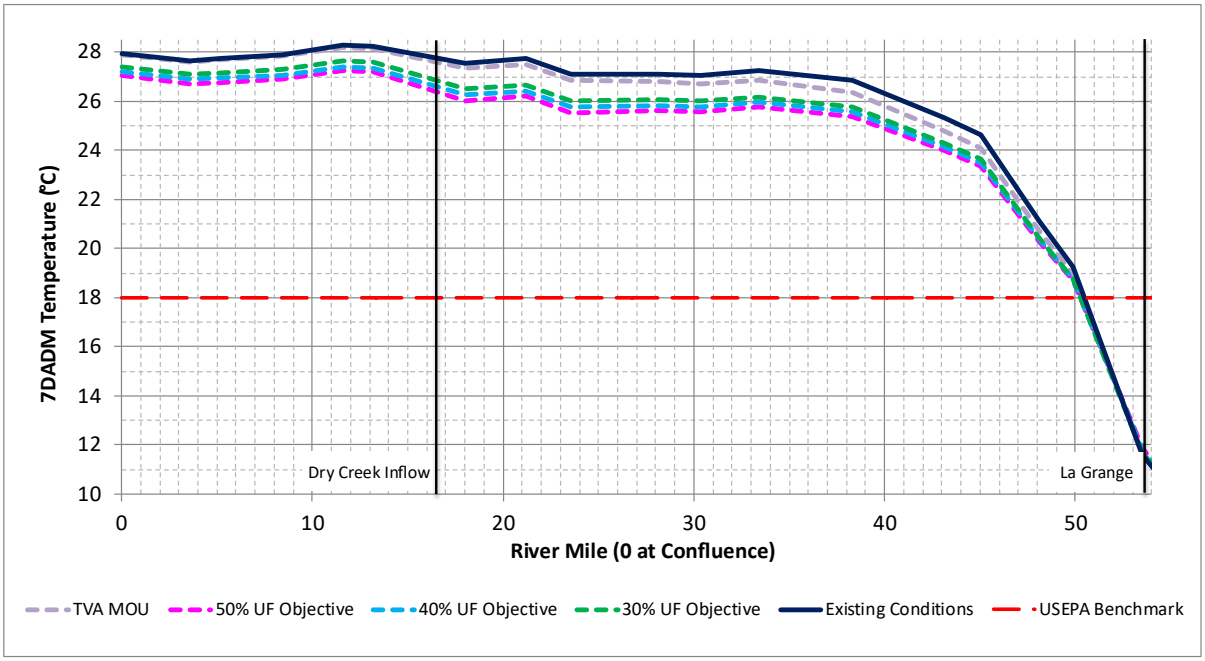


Figure 5-66. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During July Averaged Across Critical Water Year Types from 1970 to 2003.

Water temperatures in the Tuolumne River during August exhibit similar temperature patterns as July, except temperatures are typically slightly warmer, thus reducing available habitat by about 1–10 miles (Figure 5-67 to Figure 5-72). Suitable summer rearing habitat with temperatures below the 18°C benchmark would range from about 20 miles in Wet Years to about 3 miles in Critical Years.

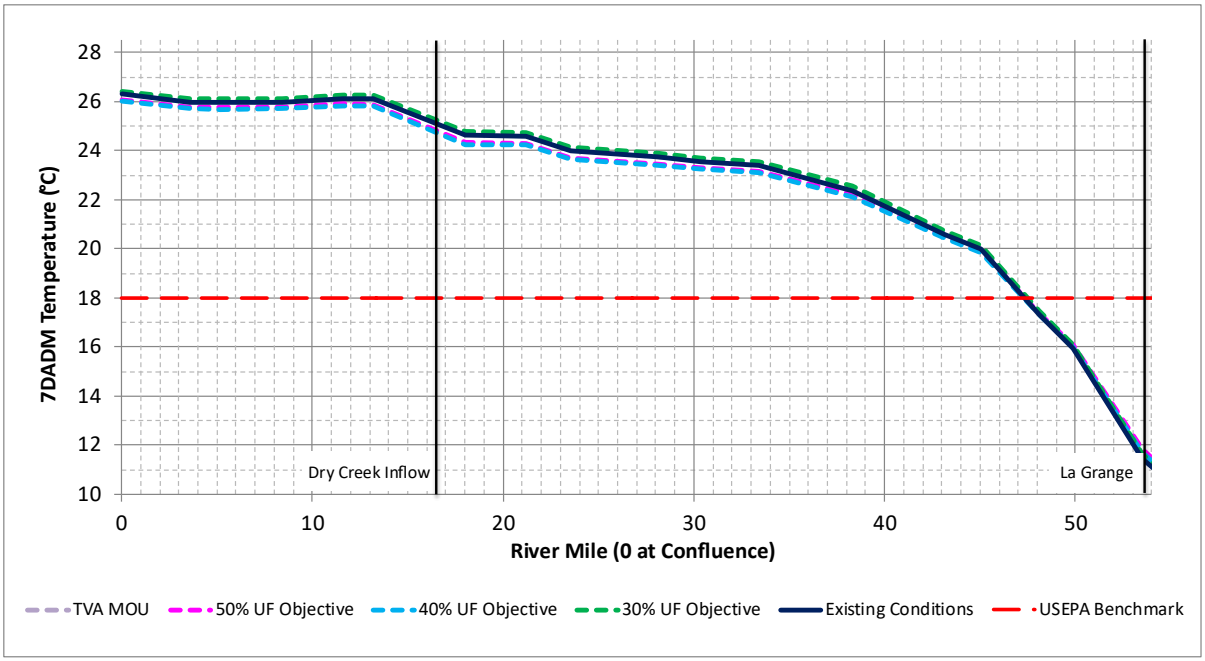


Figure 5-67. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across All Water Year Types from 1970 to 2003.

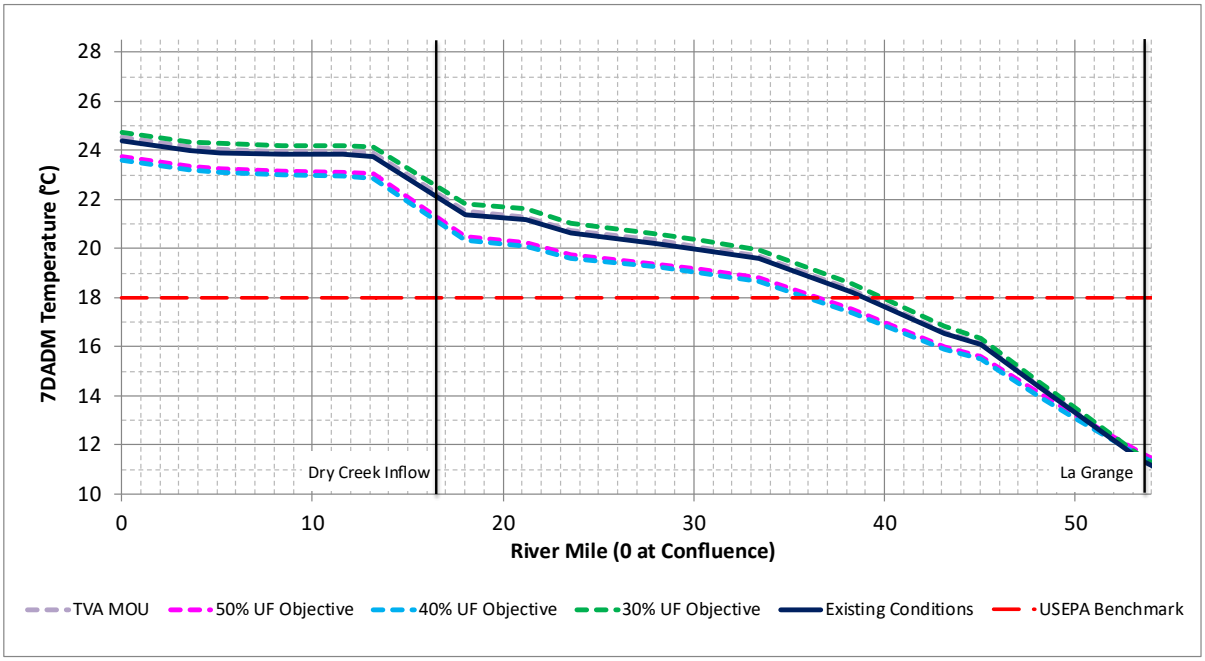


Figure 5-68. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across Wet Water Year Types from 1970 to 2003. The 40% and 50% UF Objective Scenarios Reflect Temperature Improvements Due to Flow Shifting Through Allowable Adaptive Methods of the Bay-Delta Plan.

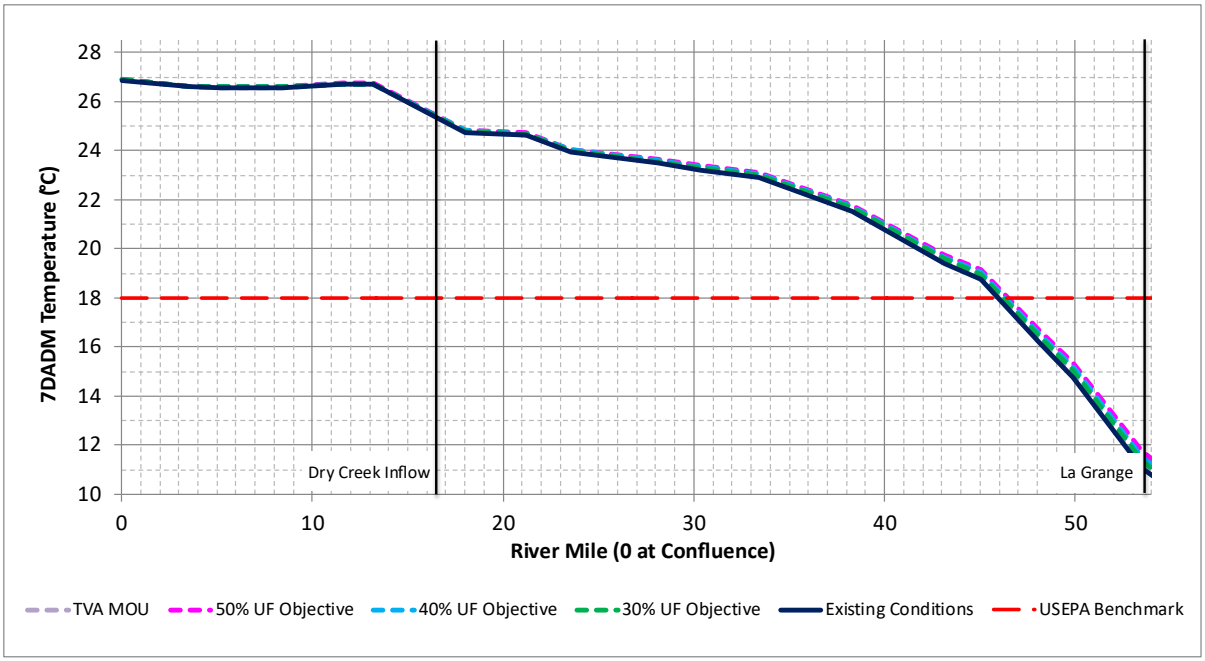


Figure 5-69. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across Above Normal Water Year Types from 1970 to 2003.

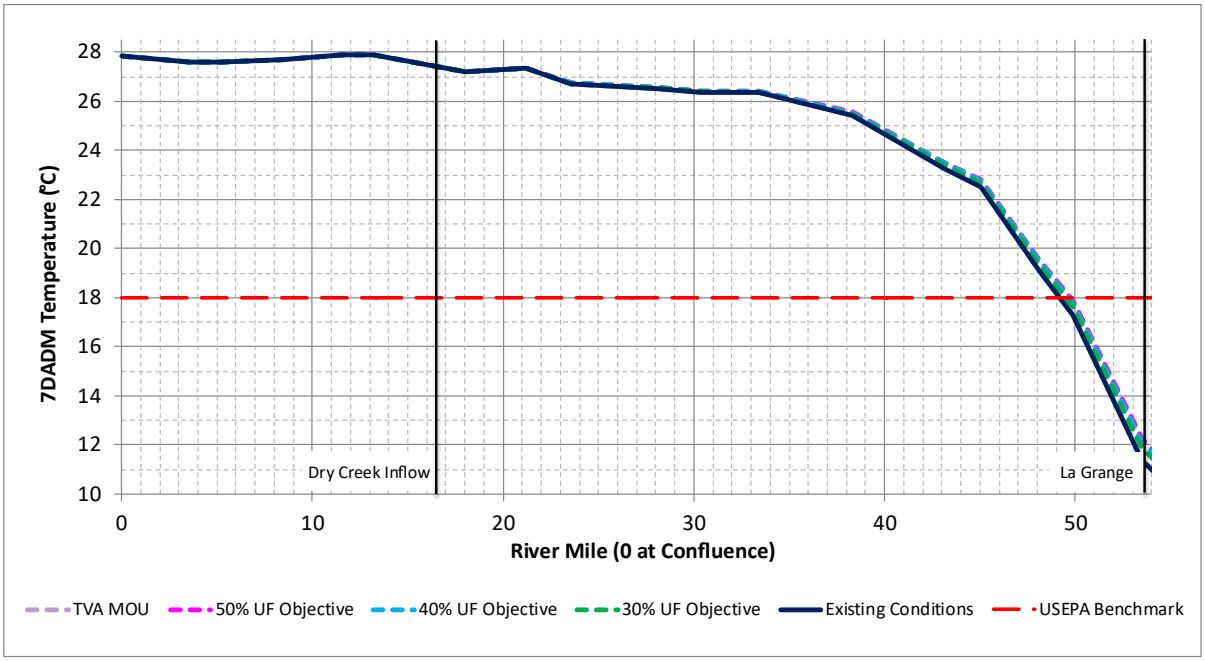


Figure 5-70. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across Below Normal Water Year Types from 1970 to 2003.

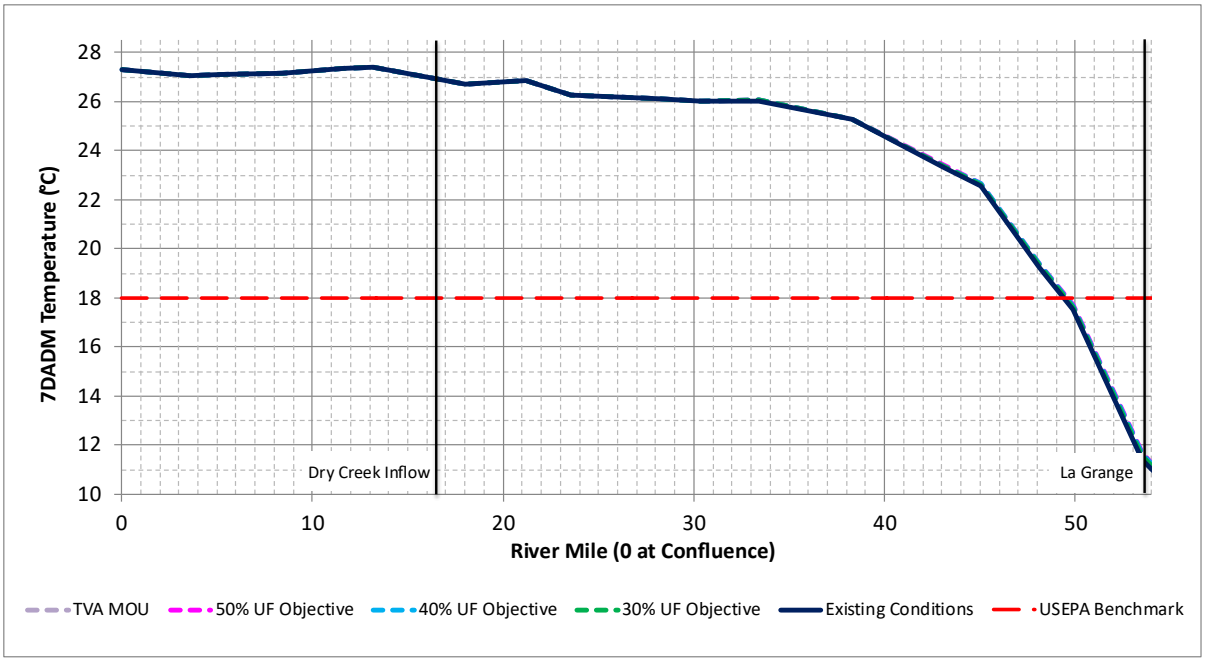


Figure 5-71. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across Dry Water Year Types from 1970 to 2003.

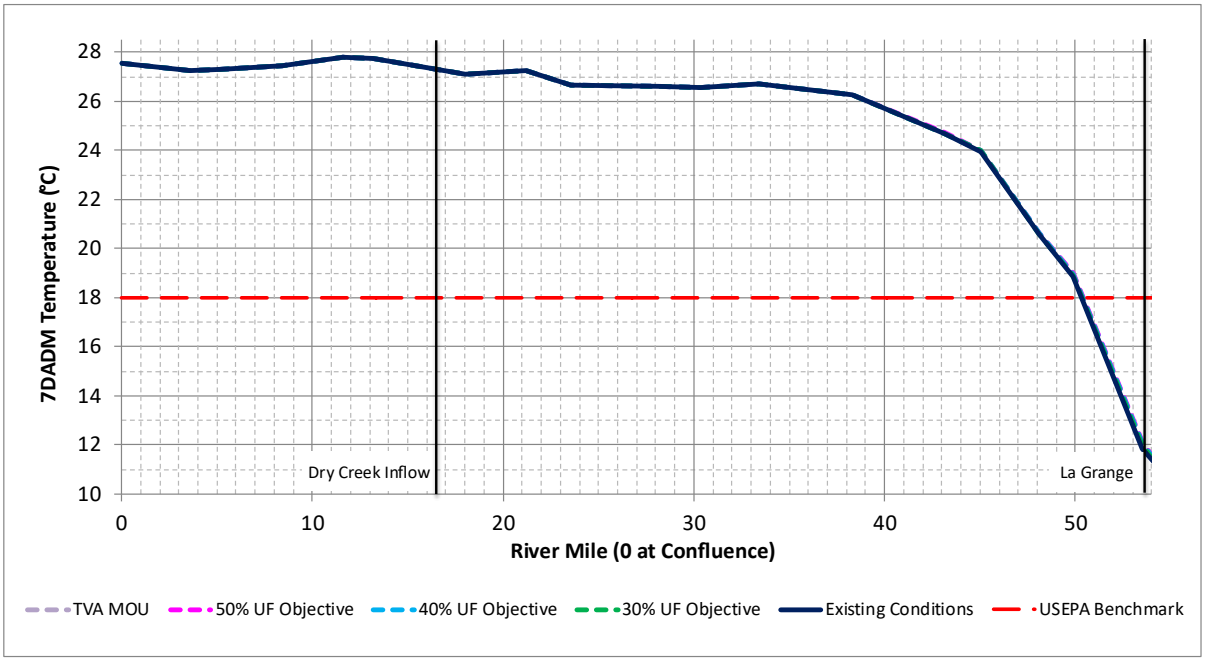


Figure 5-72. Tuolumne River Longitudinal Water Temperature Profile for Summer Rearing During August Averaged Across Critical Water Year Types from 1970 to 2003.

Sequential Dry Year Off-Ramps

To conserve water during multi-year drought conditions, the TVA includes flow requirement off-ramps that reduce pulse flows during sequential dry years. The off-ramp for the floodplain inundation pulse (typically proposed during March–April, but variable within March through June) is applied each year during any sequence of Critical, Dry, or Below Normal Years that follow a Critical or Dry Year. The off-ramp for the outmigration pulse (proposed during April–May) is applied each year during a sequence of Critical or Dry years that follow a Critical or Dry year. The dry year off-ramps do not impact baseflows, but they do reduce the March–April floodplain and April–May outmigration pulse flows (see Chapter 4 for specific differences in flow quantity and timing). The effect of the TVA during off-ramp years on river temperatures was assessed on a seasonal basis for core juvenile rearing during March through May at RM 28.1, which is approximately in the middle of the core rearing reach. River temperatures were compared during two different off-ramp sequences. First, 1987–1992 consisted of six years of consecutive Critical Years. Second, 2001–2002 consisted of two consecutive Dry Years.

TVA Critical Years are scheduled to contain an 18-day floodplain inundation pulse flow from March 20 to April 6 in the first nonconsecutive Critical Year, but sequential Critical Years are scheduled to contain a 3-day floodplain inundation pulse from March 20 through March 22. The outmigration pulse flow is scheduled for 44 days from April 17 through May 30 for all years including off-ramp years, but the pulse flow volume is reduced to 11,000 acre-feet (AF) in off-ramp Critical Years from 35,000 AF in nonconsecutive Critical Years. Figure 5-73 to Figure 5-78 show the modeled temperature profiles for the TVA, Existing Conditions, and 40% UF Objective scenarios at RM 28.1 from March through May for years 1987–1992. The Existing Conditions scenario is shown to assess the ability of the TVA to improve conditions compared to baseline conditions, and the 40% UF Objective scenario is shown as a reference for ambient inter-annual and intra-annual variability influences on water temperature.

As seen in Figure 5-73, water temperatures would be considerably reduced in 1987 for the TVA with the implementation of the 18-day floodplain pulse flow in March–April compared to the Existing Conditions, and temperatures are expected to be maintained below the USEPA benchmark of 16°C for core juvenile rearing. The TVA outmigration pulse flow in April–May also exhibits a considerable reduction in temperatures compared to the Existing Conditions, especially in the second half of May. In contrast, the years that include the TVA sequential dry year off-ramps exhibit short, 3-day drops in temperatures in March only, and the TVA temperatures generally would exceed 16°C throughout the month of April (Figure 5-74 to Figure 5-78). In addition, the TVA temperatures would exceed the Existing Conditions scenario from mid-April through mid-May when the off-ramps are being implemented.

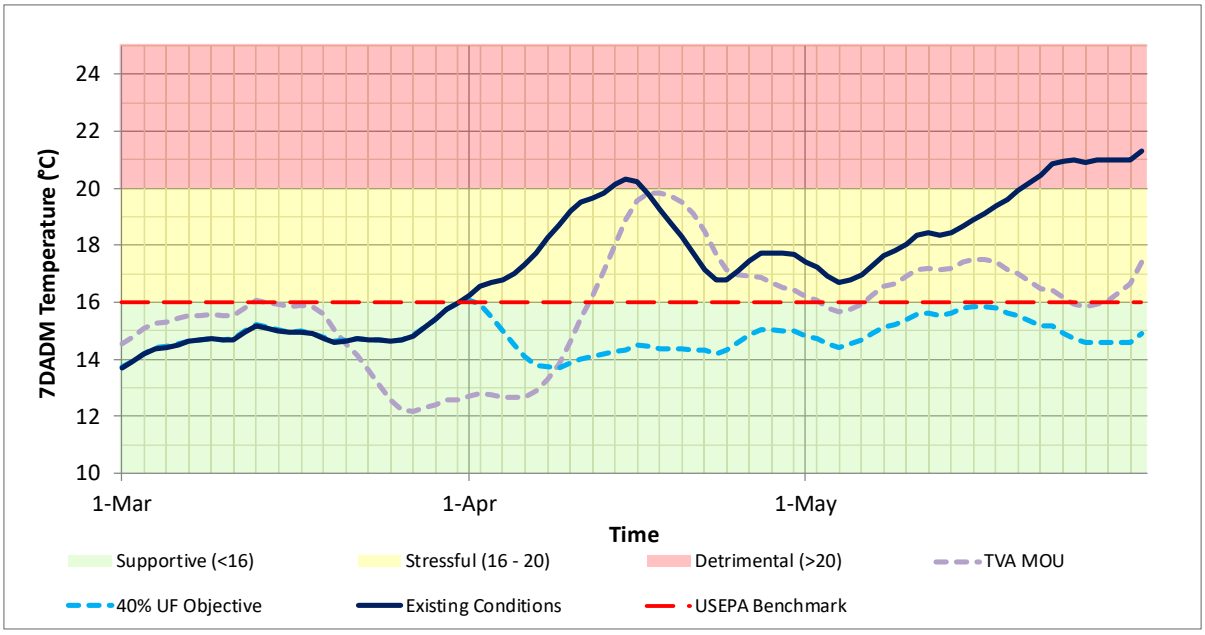


Figure 5-73. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1987 Which Is the First Critical Water Year Type in a Sequence of Critical Years and Is Not an Off-Ramp Year.

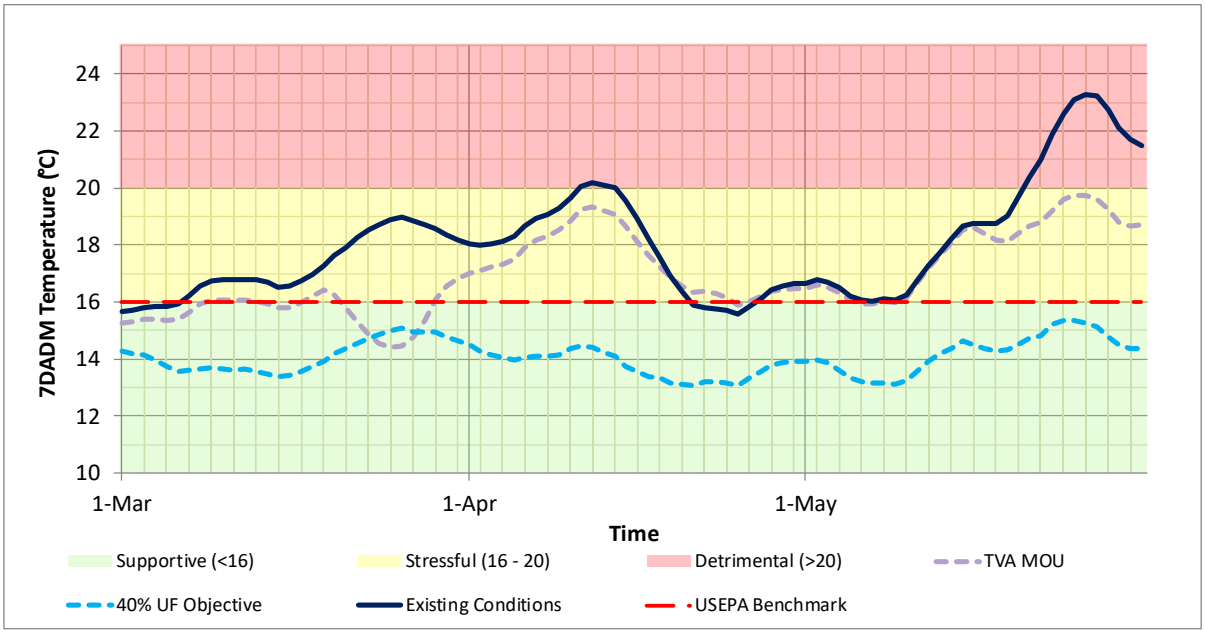


Figure 5-74. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1988 Which Is the Second Critical Water Year Type in a Sequence of Critical Years and Is an Off-Ramp Year.

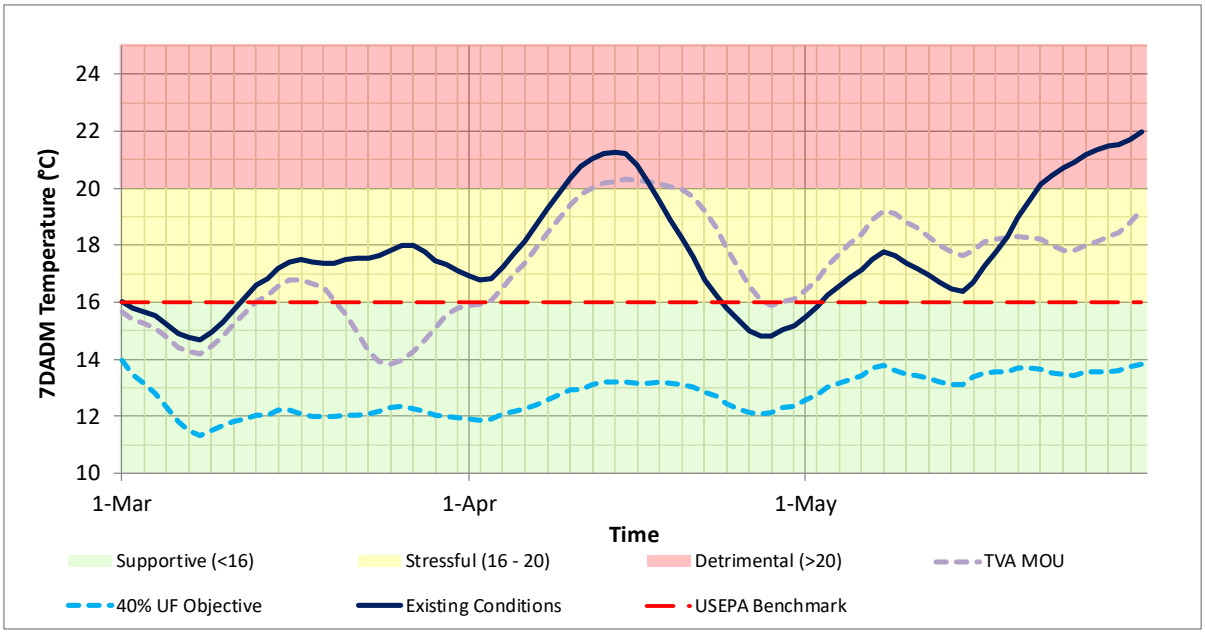


Figure 5-75. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1989 Which Is the Third Critical Water Year Type in a Sequence of Critical Years and Is an Off-Ramp Year.

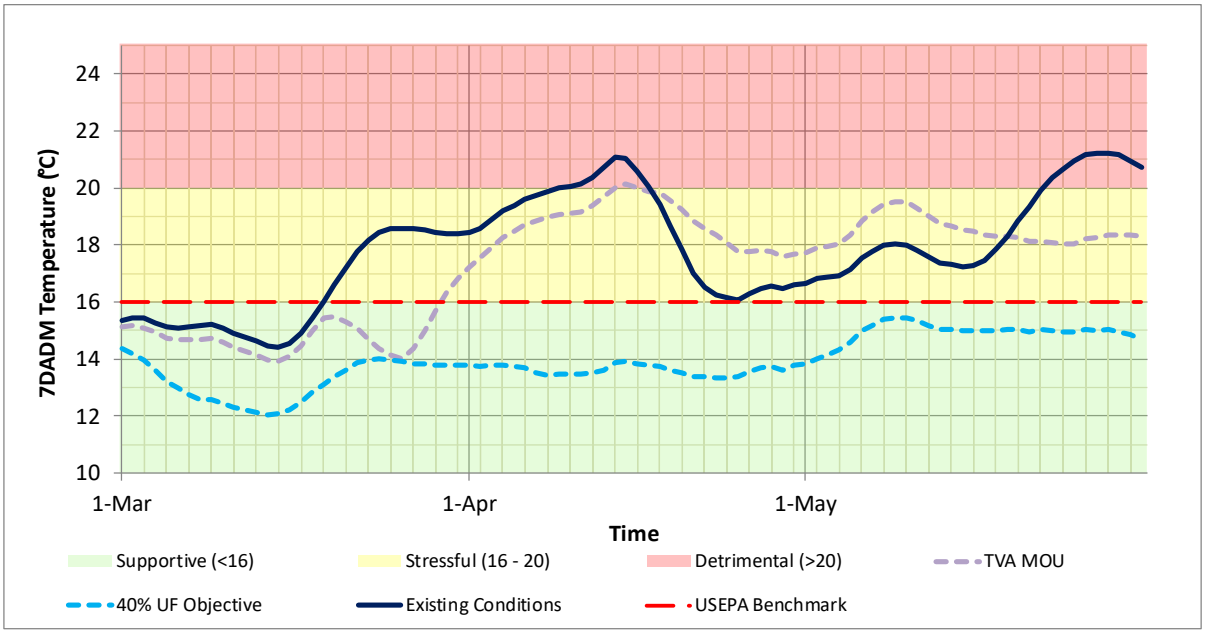


Figure 5-76. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1990 Which Is the Fourth Critical Water Year Type in a Sequence of Critical Years and Is an Off-Ramp Year.

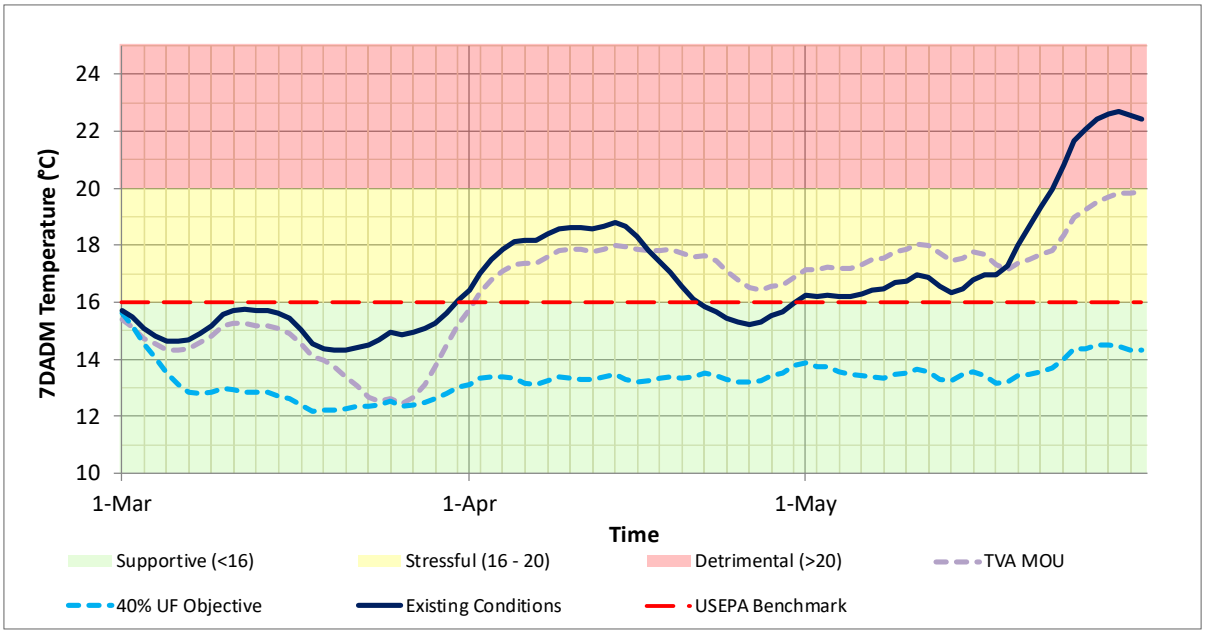


Figure 5-77. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1991 Which Is the Fifth Critical Water Year Type in a Sequence of Critical Years and Is an Off-Ramp Year.

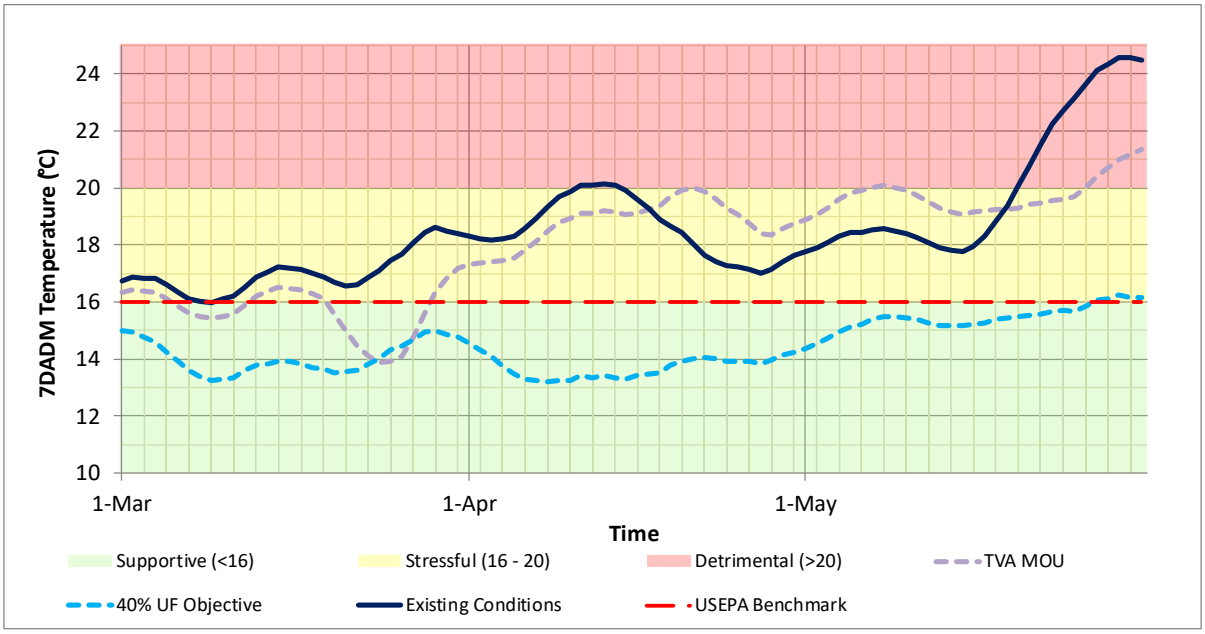


Figure 5-78. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 1992 Which Is the Sixth Critical Water Year Type in a Sequence of Critical Years and Is an Off-Ramp Year.

The TVA flow commitments during Dry Years, such as 2001 and 2002, are scheduled to contain a 27-day floodplain inundation pulse flow from March 15 through April 10 in the first nonconsecutive Dry Year, but in sequential Dry Years, the off-ramp schedule has a 3-day floodplain inundation pulse from March 20 through March 22. The outmigration pulse flow is scheduled for 44 days from April 17 through May 30 for all non-off-ramp years, but the pulse flow volume is reduced to 45,000 AF in off-ramp Dry Years from 75,000 AF. Consistent with the previously discussed drought period, the 2001 TVA floodplain pulse flow in March–April would expect to maintain temperatures below 16°C and then exhibited a rise in water temperatures once the pulse flow ended (Figure 5-79). Similarly, in the 2002 off-ramp Dry Year (Figure 5-80), a drop in water temperature is exhibited around March 20, but temperatures would be expected to increase rapidly to exceed the benchmark by the end of March and into April when the flow pulse was absent. This rapid rise in April water temperatures is also observed when the flow pulses are absent from 1987 to 1992 (Figure 5-73 to Figure 5-78).

The TVA sequential dry year off-ramps have the potential to increase water temperatures in the Tuolumne River during the primary core juvenile rearing period. As seen in Figure 5-75 to Figure 5-78, the TVA water temperatures are expected to be warmer than the Existing Conditions scenario from mid-April to mid-May. From 1970 to 2024, 17 out of the 55 years would have included sequential dry year off-ramps which is a frequency of 1 out of every 3 years.

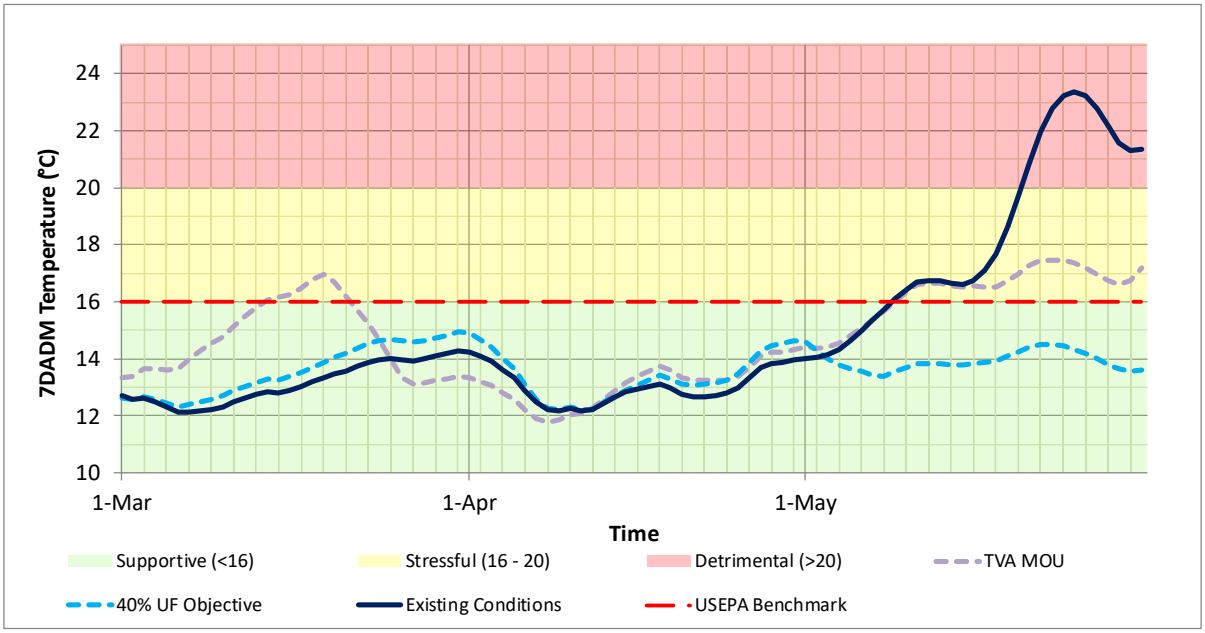


Figure 5-79. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 2001 Which Is the First Dry Water Year Type in a Sequence of Dry Years and Is Not an Off-Ramp Year.

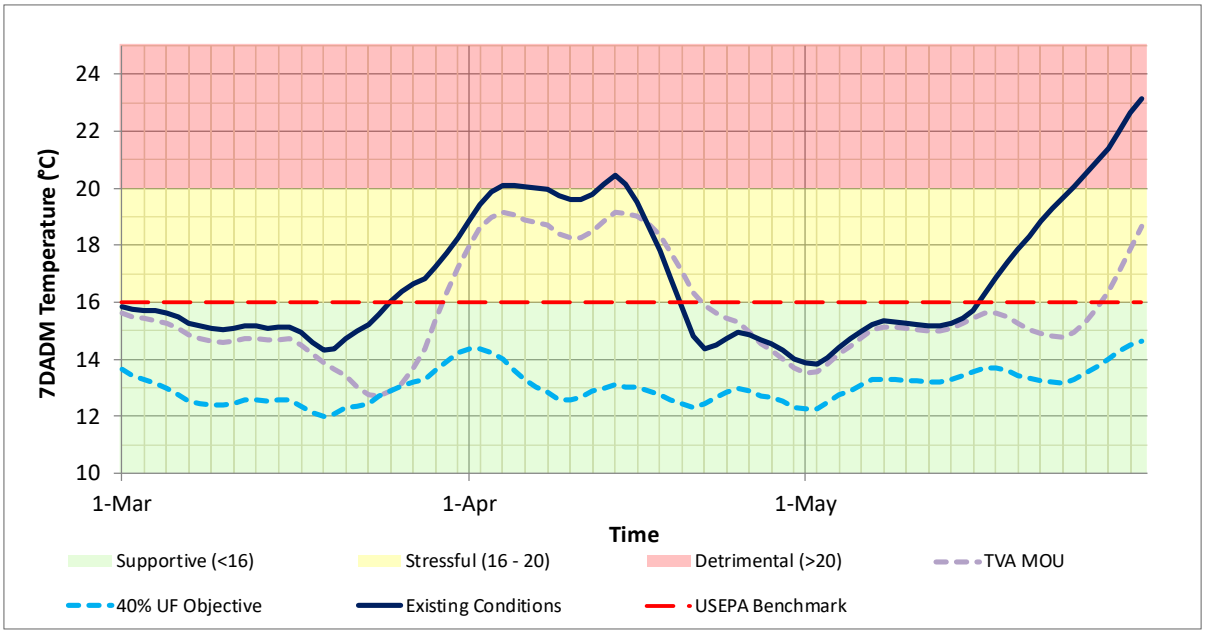


Figure 5-80. Tuolumne River Running 7DADM Water Temperatures at RM 28.1 During 2002 Which Is the Second Dry Water Year Type in a Sequence of Dry Years and Is an Off-Ramp Year.

5.2.2.2 Lower San Joaquin River

The results presented here follow the same format of results in Section 5.2.2.1, *Tuolumne River*, above. The results presented in tabular format in the *Percentage of Time USEPA Benchmarks are Achieved* and *Percentage of Time Detrimental and Lethal Temperature are Avoided* sections are a comparative overview meant to be interpreted as a broad view of the occurrences of temperatures suitable[36] for fall-run Chinook salmon and *O. mykiss* between scenarios. Results are also presented in figures in the *Temporal and Life Stage Assessments* section and are organized according to evaluation time period, life stage, and location.[37] These results are more granular such that the difference between the modeled scenarios can be tracked in more detail through space and time.

[36] Refers to temperatures that are at or below USEPA's recommended numeric criteria for protective conditions. See Section 5.2.1.3, *Temperature Benchmarks.*

[37] Adult Migration September 1-December 31, Core Juvenile Rearing February 1-June 30, and Smoltification February 1-June 30. Non-Core juvenile Rearing June 1–June 30 (*O. mykiss*).

Frequency of Benchmark Attainment or Exceedance

In this section, the frequency[38] of meeting temperature benchmarks based on USEPA guidance (7DADM unit of measurement; see Section 5.2.1.3, *Temperature Benchmarks*) in the LSJR is compared between the Existing Conditions and the TVA or 40% UF Objective scenarios. The 30% and 50% UF requirements are not used in this analysis (see Section 5.2.1.2, *Modeling Scenarios*, and Table 5-1 for a description of scenarios). In addition to the influence that the Tuolumne River has on water temperature conditions in the LSJR, the Stanislaus, Merced, and upper San Joaquin rivers also influence LSJR water temperature conditions. Accordingly, for the TVA scenario, the Stanislaus and Merced rivers were modeled either with the Existing Conditions or with the implementation of the 40% UF Objective on those rivers. Including both scenarios for the other tributaries allows for an evaluation of a range of potential outcomes from the TVA. The frequencies of attainment are displayed at four locations in the LSJR and for different life stage seasons and water temperature benchmarks. The interpretation of results is the same as above for the Tuolumne River (Section 5.2.2.1, *Tuolumne River*). All of the values in these tables are the percentages that benchmarks are attained. The increases and decreases (relative to Existing Conditions) of frequency that are 10% or greater are considered significant.

The interpretation of these modeling results in terms of temperature benefits to fall-run Chinook salmon and *O. mykiss* (rainbow trout/steelhead) is discussed in Section 5.2.3.2, *Lower San Joaquin River*.

Percentage of Time USEPA Benchmarks Are Achieved

Table 5-10 shows the percentage of time on the LSJR that USEPA temperature benchmarks for protective conditions (14°C, 16°C, and 18°C) are expected to be attained for each scenario. Changes between scenarios are not as noticeable on the LSJR due to multiple tributaries contributing flow in the watershed. There are no expected changes relative to Existing Conditions that are greater than 10% in the amount of time that these most protective criteria are met. However, Table 5-11 and Table 5-12 indicate that reductions in harmful and lethal temperatures are possible under some of the scenarios as discussed in the following sections. For reference, the LSJR reach most directly influenced by the TVA flow and temperature is labeled Above the Stanislaus Confluence. Above the Merced River represents riverine inputs and temperature conditions from the upper San Joaquin River, which the 2018 Bay-Delta Plan and the TVA have negligible effect on.

Percentage of Time Harmful and Lethal Temperature are Avoided

Table 5-11 and Table 5-12 show the percentage of time in the LSJR that USEPA temperature benchmarks for harmful and lethal effect are attained for each modeling scenario. A 10% or greater increase in frequency that the USEPA benchmarks are attained compared to Existing Conditions is considered a significant increase in the amount of time that protective conditions are achieved. None of the scenarios exhibited a significant (i.e., 10% or greater) decrease in the frequency of attaining the benchmarks compared to the Existing Conditions.

[38] The frequency of meeting the benchmarks in this analysis is the percentage of days during each month over the modeled 34-year period (1970–2003; n= number of days per specific month multiplied by 34 years).

Harmful

Harmful water temperature conditions (i.e., >20°C) are expected to be avoided throughout the LSJR from November to March for all scenarios, although water temperatures would frequently be harmful during July and August (i.e., >95%, Table 5-11). The TVA exhibits a significant increase in the frequency of avoiding harmful temperature conditions during May in the river reach between the Tuolumne River and the Stanislaus River, but harmful temperature conditions would occur slightly more frequently during April, June, and July under the TVA in this same river reach. The TVA + 2018 BDP scenario exhibit significant reductions of harmful temperature throughout all of the LSJR reaches below the Merced River confluence during May, when the Stanislaus and Merced rivers contribute 40% UF. The 40% UF Objective all tribs scenario exhibits significant improvement relative to Existing Conditions in June, more than doubling the frequency that harmful temperatures are avoided downstream of the Tuolumne River.

Lethal

Lethal water temperature conditions (i.e., >25°C) are primarily expected to be avoided in the LSJR from October to May for all scenarios (Table 5-12). From June through September, the TVA does not exhibit any appreciable change in the frequency of avoiding lethal water temperatures relative to Existing Conditions. The 40% UF Objective all tribs scenario exhibits significant increases in the frequency that lethal water temperatures are would be avoided during June and July in the LSJR reaches between the Stanislaus and Merced rivers. All scenarios are expected to avoid lethal temperatures at Vernalis more than 90% of the time during June, although temperature conditions are expected to be much warmer during July and August.

Table 5-10. A Comparison of the Percentages of Time That USEPA Temperature Benchmarks for Salmonid Life Stage Protective Conditions Are Attained Each Month on the San Joaquin River Under the Modeled Scenarios.

Lower San Joaquin River		Vernalis				Above the Stanislaus Confluence				Above the Tuolumne Confluence				Above the Merced Confluence			
			Scenario				Scenario				Scenario				Scenario		
Life Stage	Month/USEPA Benchmark (°C)	Existing Conditions 2023	40% UF Objective all tribs	TVA	TVA + 2018 BDP	Existing Conditions 2023	40% UF Objective all tribs	TVA	TVA + 2018 BDP	Existing Conditions 2023	40% UF Objective all tribs	TVA	TVA + 2018 BDP	Existing Conditions 2023	40% UF Objective all tribs	TVA	TVA + 2018 BDP
AM	Sep (18)	**3%**	2%	3%	2%	**1%**	1%	1%	1%	**0%**	0%	0%	0%	**0%**	0%	0%	0%
AM	Oct (18)	**54%**	62%	54%	62%	**30%**	35%	30%	32%	**24%**	26%	24%	26%	**8%**	8%	8%	8%
AM	Nov (18)	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**99%**	99%	99%	99%
AM	Dec (18)	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
CR	Feb (16)	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
CR	Mar (16)	**82%**	86%	84%	87%	**76%**	81%	80%	80%	**53%**	53%	53%	53%	**52%**	52%	52%	52%
CR	Apr (16)	**28%**	32%	33%	33%	**19%**	20%	23%	23%	**3%**	3%	3%	3%	**1%**	1%	1%	1%
CR	May (16)	**1%**	6%	2%	3%	**0%**	1%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%
CR	Jun (16)	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%
S	Feb (14)	**95%**	94%	95%	94%	**91%**	91%	91%	90%	**85%**	84%	85%	84%	**82%**	82%	82%	82%
S	Mar (14)	**41%**	41%	41%	41%	**34%**	32%	32%	33%	**10%**	9%	10%	9%	**3%**	3%	3%	3%
S	Apr (14)	**3%**	4%	4%	4%	**2%**	2%	3%	3%	**0%**	0%	0%	0%	**0%**	0%	0%	0%
S	May (14)	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%
S	Jun (14)	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%
NCR	Jun (18)	**1%**	7%	1%	2%	**0%**	3%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%
AM	Sep (18)	**3%**	2%	3%	2%	**1%**	1%	1%	1%	**0%**	0%	0%	0%	**0%**	0%	0%	0%
AM	Oct (18)	**54%**	62%	54%	62%	**30%**	35%	30%	32%	**24%**	26%	24%	26%	**8%**	8%	8%	8%
AM	Nov (18)	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**99%**	99%	99%	99%

AM = Adult Migration.
CR = Core Rearing.
S = Smoltification.
NCR = Non-Core Rearing (O. mykiss).
Vernalis is at river mile 69.31.
Above the Stanislaus River Confluence is at river mile 72.501.
Above the Tuolumne River Confluence is at river mile 81.401.
Above the Merced River Confluence is at river mile 116.001.

Table 5-11. A Comparison of the Percentages of Time That the 20° Celsius Harmful Temperature Benchmark for Salmonids Is Attained Each Month on the San Joaquin River Under the Modeled Scenarios.

Lower San Joaquin River		Vernalis				Above the Stanislaus Confluence				Above the Tuolumne Confluence				Above the Merced Confluence			
			Scenario				Scenario				Scenario				Scenario		
USEPA Benchmark (°C)	Month	Existing Conditions	40% UF Objective all tribs	TVA	TVA + 2018 BDP	Existing Conditions	40% UF Objective all tribs	TVA	TVA + 2018 BDP	Existing Conditions	40% UF Objective all tribs	TVA	TVA + 2018 BDP	Existing Conditions	40% UF Objective all tribs	TVA	TVA + 2018 BDP
20	Sep	**10%**	13%	10%	11%	**5%**	6%	5%	5%	**3%**	3%	3%	3%	**0%**	0%	0%	0%
20	Oct	**81%**	85%	80%	84%	**67%**	69%	67%	67%	**62%**	63%	62%	63%	**45%**	45%	45%	45%
20	Nov	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
20	Dec	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
20	Jan	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
20	Feb	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
20	Mar	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
20	Apr	**95%**	99%	95%	97%	**89.2%**	98.5%	88%	92%	**72%**	81%	72%	81%	**75%**	75%	75%	75%
20	May	**69%**	92%	75%	81%	**51%**	87%	64%	68%	**14%**	26%	14%	26%	**10%**	10%	10%	10%
20	Jun	**23%**	46%	22%	22%	**12%**	37%	8%	8%	**0%**	0%	0%	0%	**0%**	0%	0%	0%
20	Jul	**5%**	5%	4%	4%	**4%**	4%	3%	3%	**0%**	0%	0%	0%	**0%**	0%	0%	0%
20	Aug	**2%**	2%	2%	2%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%

Table 5-12. A Comparison of the Percentage of Time That the 25° Celsius Lethal Temperature Benchmark for Salmonids Is Attained Each Month on the San Joaquin River Under the Modeled Scenarios.

Lower San Joaquin River		Vernalis				Above the Stanislaus Confluence				Above the Tuolumne Confluence				Above the Merced Confluence			
			Scenario				Scenario				Scenario				Scenario		
USEPA Benchmark (°C)	Month	Existing Conditions	40% UF Objective all tribs	TVA	TVA + 2018 BDP	Existing Conditions	40% UF Objective all tribs	TVA	TVA + 2018 BDP	Existing Conditions	40% UF Objective all tribs	TVA	TVA + 2018 BDP	Existing Conditions	40% UF Objective all tribs	TVA	TVA + 2018 BDP
25	Sep	**96%**	96%	96%	96%	**90%**	89%	90%	88%	**89%**	87%	89%	87%	**55%**	55%	55%	55%
25	Oct	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
25	Nov	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
25	Dec	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
25	Jan	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
25	Feb	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
25	Mar	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
25	Apr	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%	**100%**	100%	100%	100%
25	May	**100%**	100%	100%	100%	**99%**	100%	100%	100%	**96%**	100%	96%	100%	**97%**	97%	97%	97%
25	Jun	**93%**	96%	92%	93%	**78%**	94%	78%	86%	**67%**	81%	67%	81%	**46%**	46%	46%	46%
25	Jul	**55%**	63%	54%	58%	**37%**	50%	37%	40%	**28%**	30%	28%	30%	**2%**	2%	2%	2%
25	Aug	**66%**	68%	66%	66%	**51%**	49%	51%	47%	**45%**	40%	45%	40%	**0%**	0%	0%	0%

Temporal and Spatial Life Stage Assessments

The results in the sections below provide graphical depictions of the temperature conditions fish may experience across the modeling scenarios according to evaluation time period, life stage, and location. Results use monthly longitudinal water temperature graphs averaged over all water year types, and during Wet and Critical years, to show the range of potential conditions that fish may experience in the river. Benchmarks on the graphics are for USEPA guidance for protective conditions and for supportive, stressful, and detrimental temperature ranges (SEP) for fall-run Chinook salmon (see Section 5.2.1.3, *Temperature Benchmarks*).

The discussions of the results place little emphasis on the LSJR reaches above the confluence with the Tuolumne River because that reach of the LSJR is unaffected by the TVA; however, the water temperature of the LSJR upstream of the confluence with the Tuolumne River may vary depending on whether the 2018 Bay-Delta Plan UF objectives are being implemented by the other tributaries. Consequently, the influence of the Tuolumne River on water temperatures in the LSJR may be impacted by these variations, and this information is used to assess the overall resulting condition in the LSJR. For each of the longitudinal profiles below, in most cases, the lines depicting the modeling scenarios show a discernible decrease in temperature at the confluence of each tributary due to colder water entering the San Joaquin River.

Adult Migration September 1–December 31

Longitudinal river temperatures were assessed for each month from September through December using the USEPA benchmark of 18°C for adult migration. During the adult migration period, the flow regimes are similar, so temperature conditions are not expected to vary considerably.

The water temperatures for salmonids in the LSJR averaged across all water year types are typically expected to be in the detrimental range at Vernalis during September and into the first week of October (Figure 5-81). Only in Wet Years would the water temperatures drop below the detrimental range at Vernalis during September (Figure 5-82). The evaluated scenarios tend to exhibit a minimal temperature effect in the LSJR during this time period because these scenarios do not substantially change the flows during September through December. However, the scenarios that included 2018 Bay-Delta Plan flow contributions, i.e., 40% UF Objective all tribs and TVA + 2018 BDP, would exhibit lower temperatures through the entire LSJR reach due to adaptive methods flow shifting in Wet Years.

During September, temperatures for all scenarios are expected to be in the detrimental range through the entire assessed reach of the LSJR (Figure 5-83). Temperatures are similar between scenarios with less than 0.5°C difference between scenarios. Similarly, while there is some difference between water year types, Wet Years are expected to be only about 2°C cooler than Critical Years, and all water year types exhibit detrimental temperatures during September (Figure 5-84 and Figure 5-85).

Water temperatures in October would decrease compared to September and move out of the detrimental range into the stressful range throughout the LSJR reach below the Tuolumne River confluence in all water year types (Figure 5-86). In November and December, water temperatures throughout the LSJR are expected to be supportive and well below the USEPA benchmark of 18°C for adult migration (Figure 5-87 and Figure 5-88). Neither month exhibited much variability across scenarios or water year types.

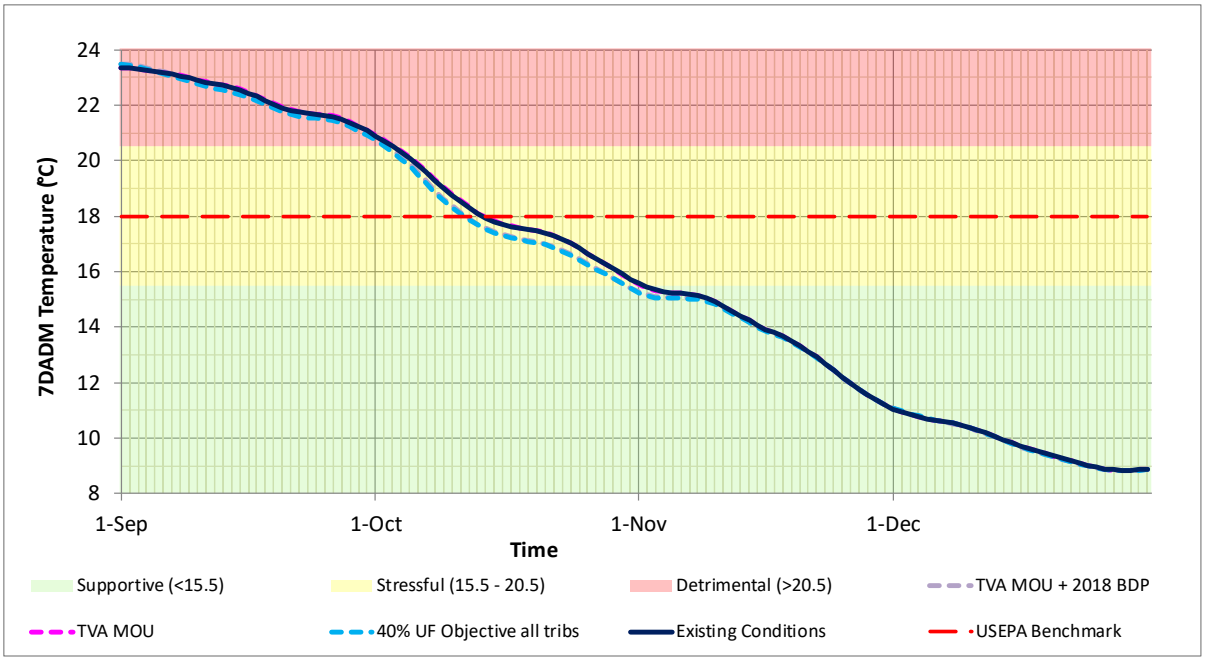


Figure 5-81. Lower San Joaquin River Running 7DADM Water Temperatures at RM 69.31 (Vernalis) Averaged Across All Water Year Types from 1970 to 2003 for Adult Migration.

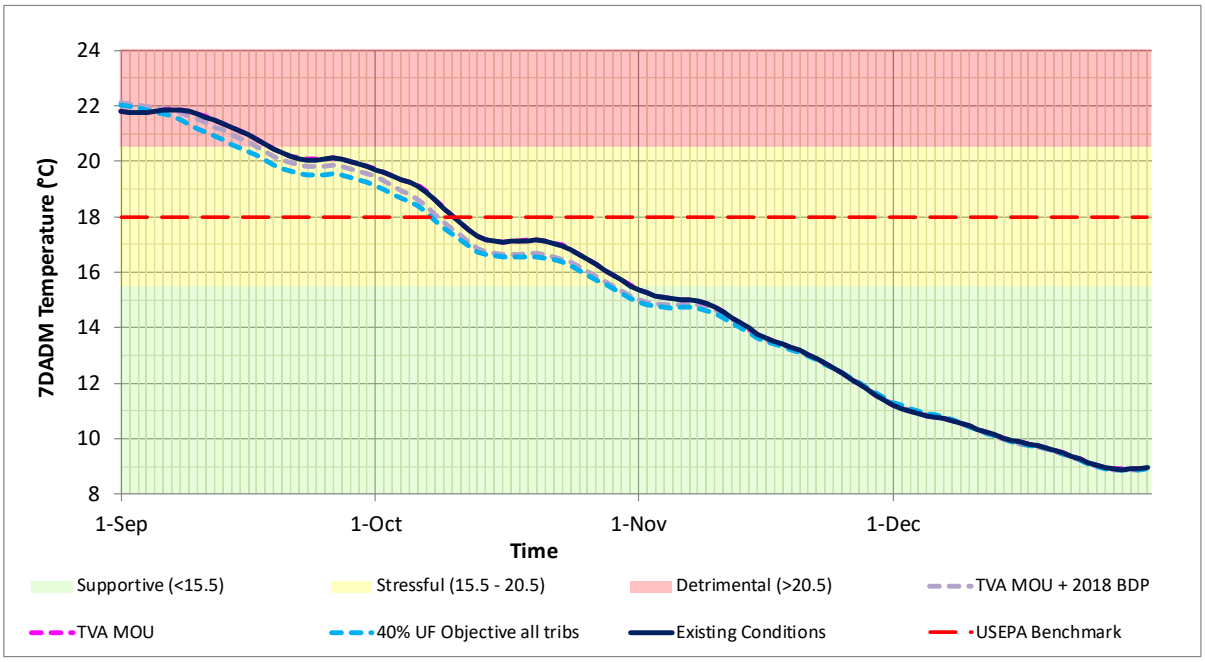


Figure 5-82. Lower San Joaquin River Running 7DADM Water Temperatures at RM 69.31 (Vernalis) Averaged Across Wet Water Year Types from 1970 to 2003 for Adult Migration.

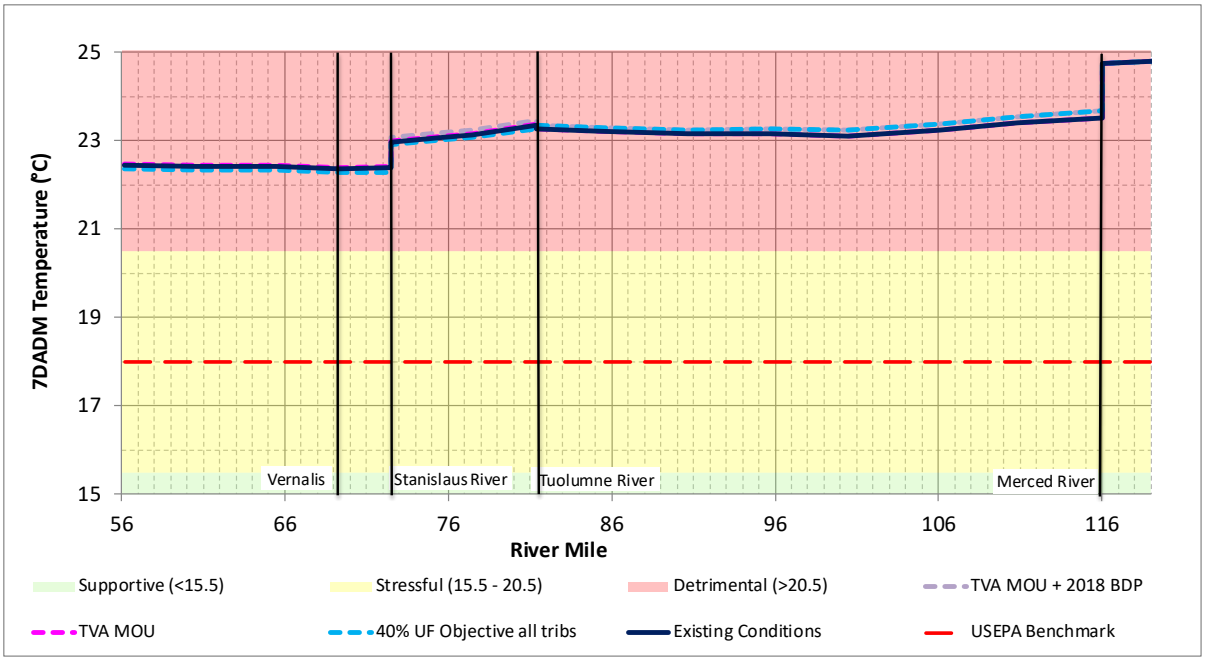


Figure 5-83. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During September Averaged Across All Water Year Types from 1970 to 2003.

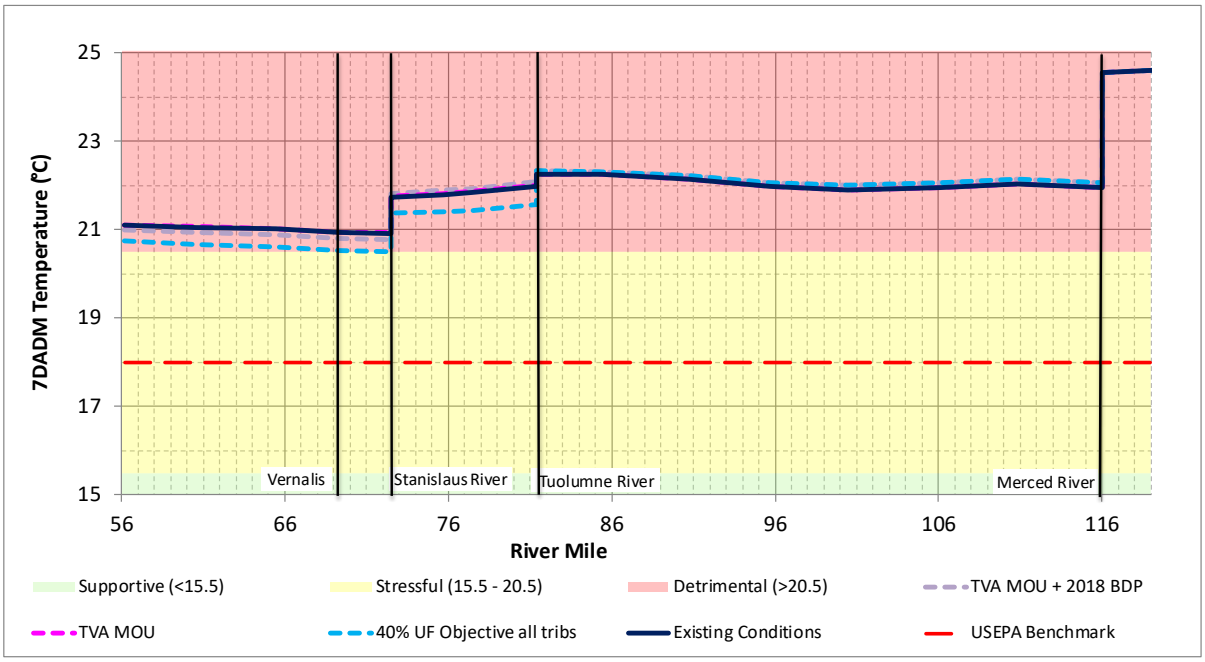


Figure 5-84. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During September Averaged Across Wet Water Year Types from 1970 to 2003.

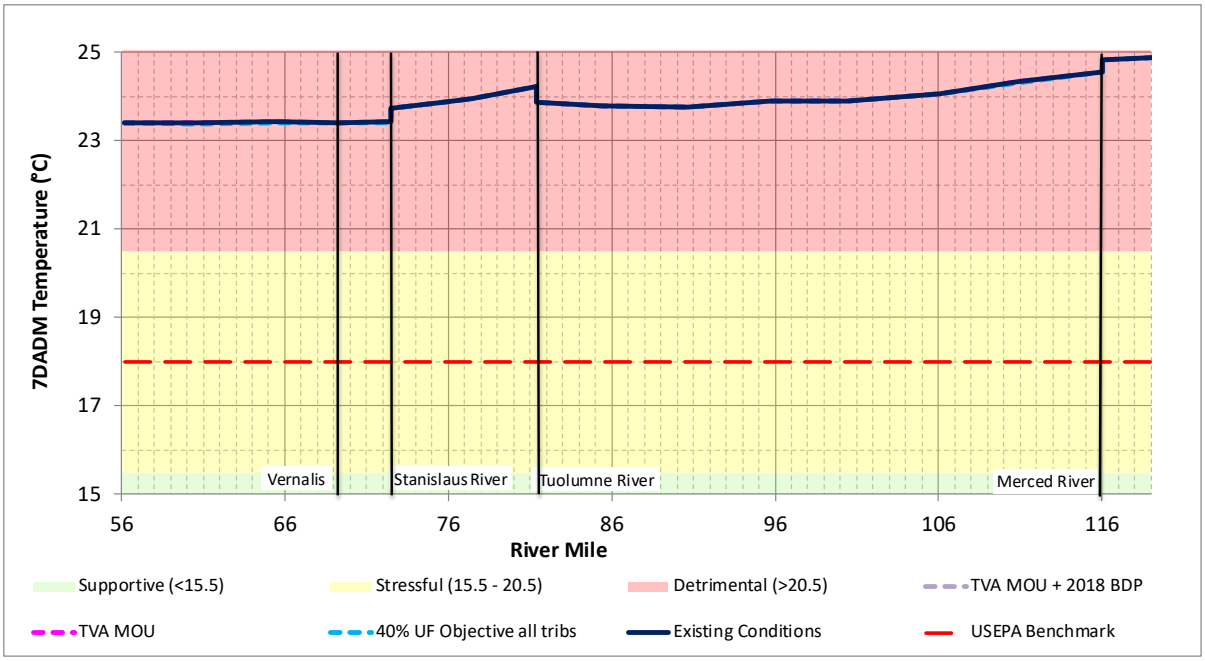


Figure 5-85. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During September Averaged Across Critical Water Year Types from 1970 to 2003.

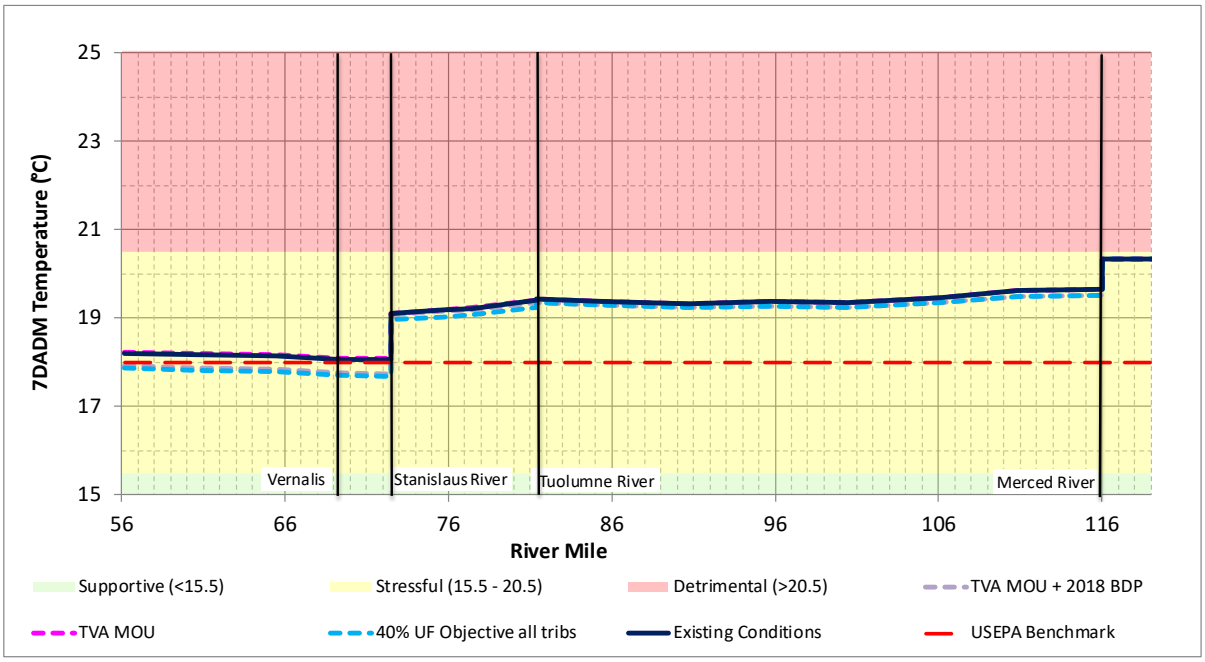


Figure 5-86. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During October Averaged Across All Water Year Types from 1970 to 2003.

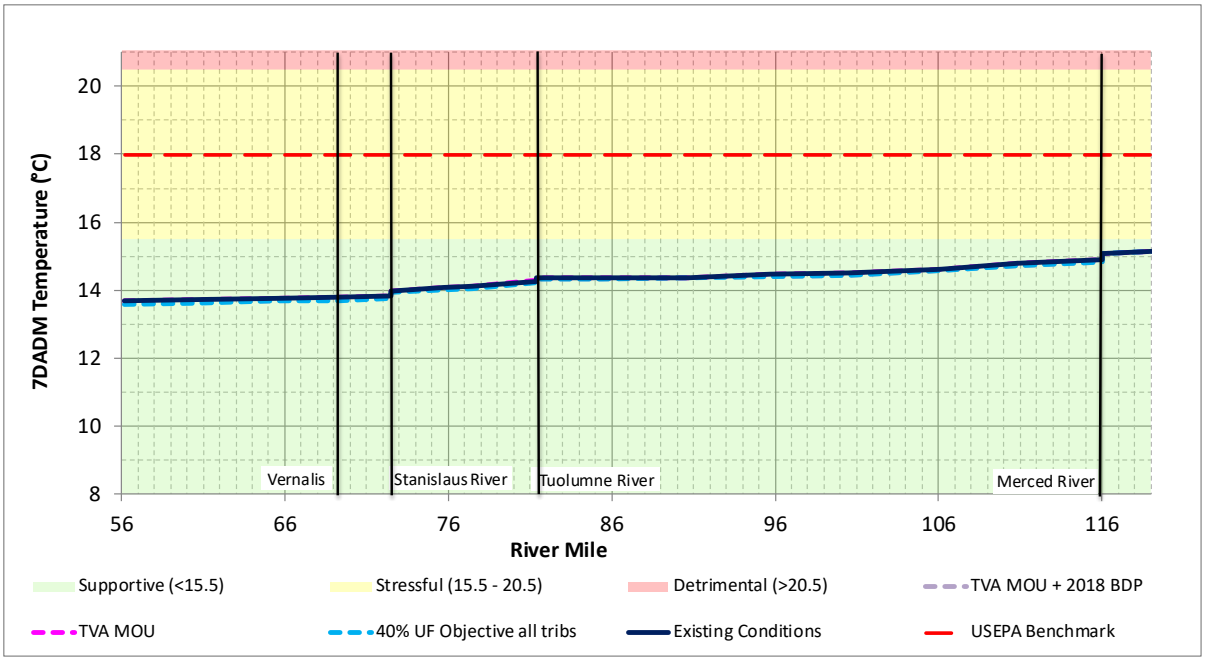


Figure 5-87. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During November Averaged Across All Water Year Types from 1970 to 2003.

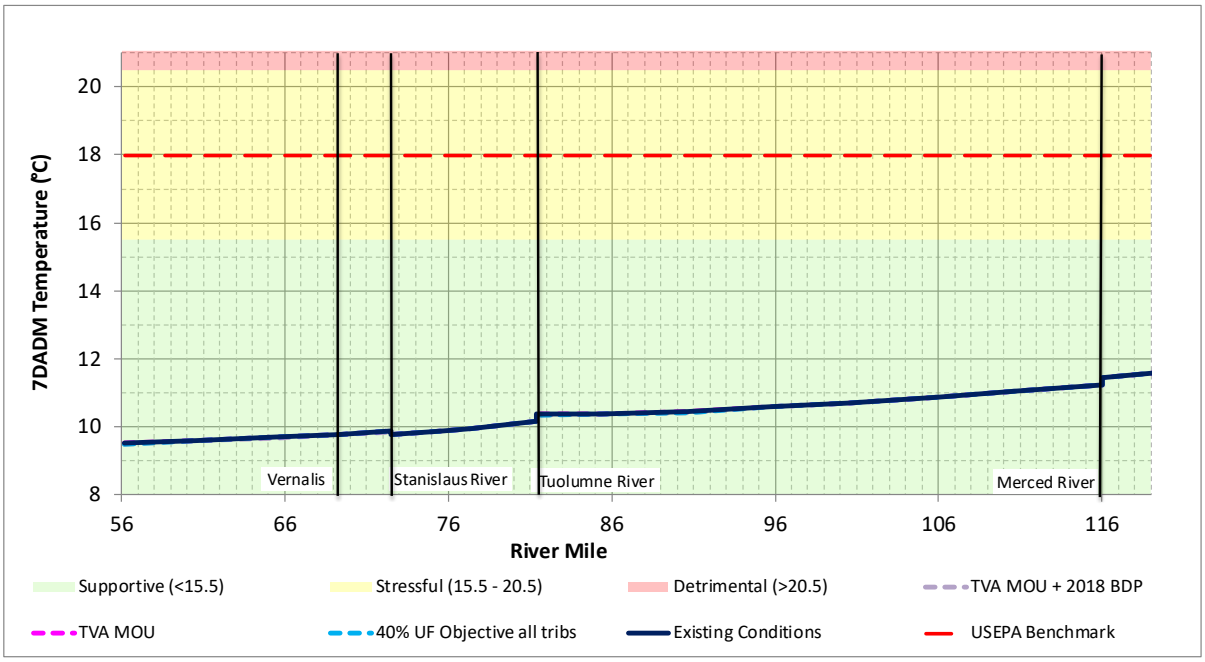


Figure 5-88. Lower San Joaquin River Longitudinal Water Temperature Profile for Adult Migration During December Averaged Across All Water Year Types from 1970 to 2003.

Core Juvenile Rearing February 1–June 30

LSJR water temperature for core juvenile rearing was assessed from February 1 through June 30 using the USEPA benchmark temperature of 16°C for core juvenile rearing. Water temperatures averaged across all water year types would typically be suitable in the LSJR until the beginning of April (Figure 5-89). Water temperatures would generally remain in the stressful range during April to the end of May before becoming detrimental during June. In May, the variability across scenarios would increase, and the 40% UF Objective all tribs scenario exhibits cooler temperatures than the others. The TVA would not appreciably vary from the Existing Conditions, but there is some indication of reduced temperatures during flow pulse periods.

In Wet Years, water temperatures in the LSJR are expected to remain suitable and below 16°C until mid-April and generally stay below detrimental temperatures until the beginning or end of June depending on the scenario (Figure 5-90). Water temperatures in the LSJR are expected to increase incrementally in drier year types, and during Critical Years, water temperatures would exceed the 16°C benchmark in March and detrimental conditions in early May to early June, depending on the scenario (Figure 5-91). The variability in temperature across scenarios would increase with drier years; however, the 40% UF Objective all tribs scenario most consistently exhibits the lowest water temperature of all the scenarios.

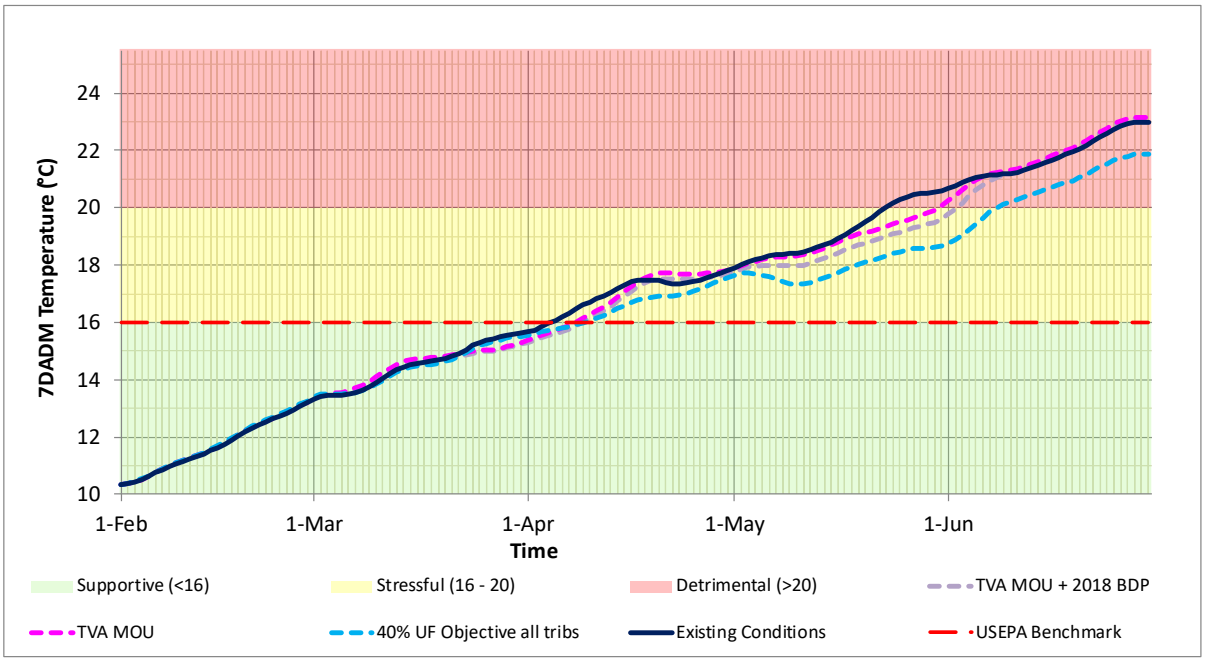


Figure 5-89. Lower San Joaquin River Running 7DADM Water Temperatures at RM 69.31 (Vernalis) Averaged Across All Water Year Types from 1970 to 2003 for Core Juvenile Rearing.

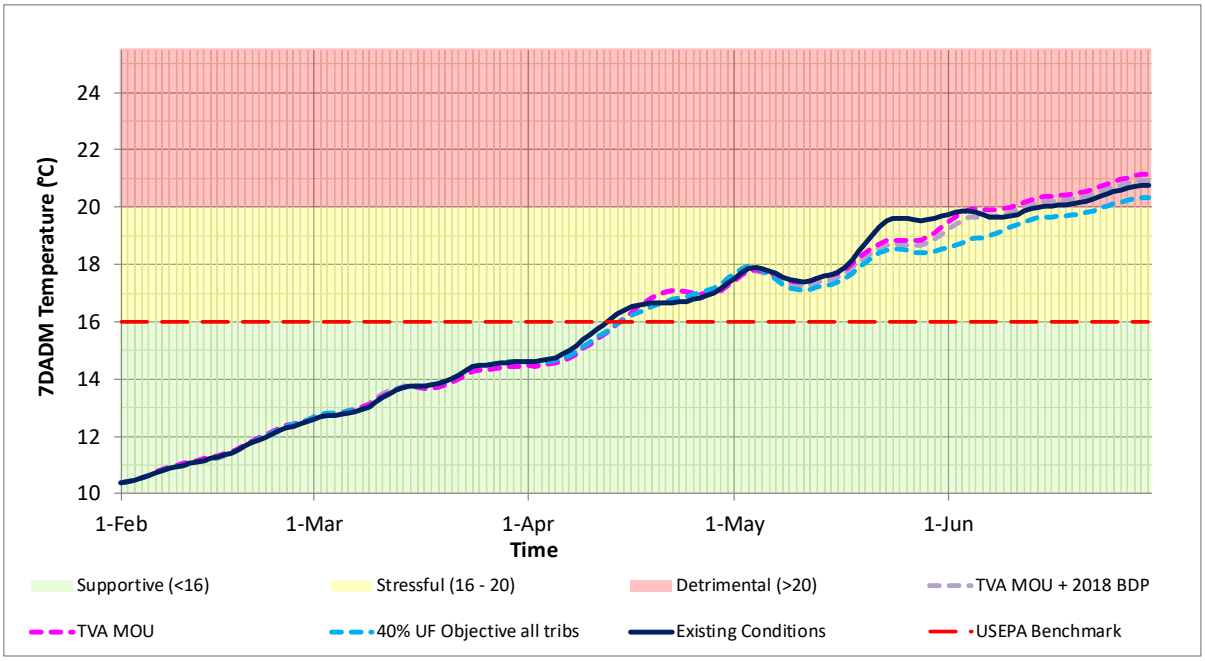


Figure 5-90. Lower San Joaquin River Running 7DADM Water Temperatures at RM 69.31 (Vernalis) Averaged Across Wet Water Year Types from 1970 to 2003 for Core Juvenile Rearing.

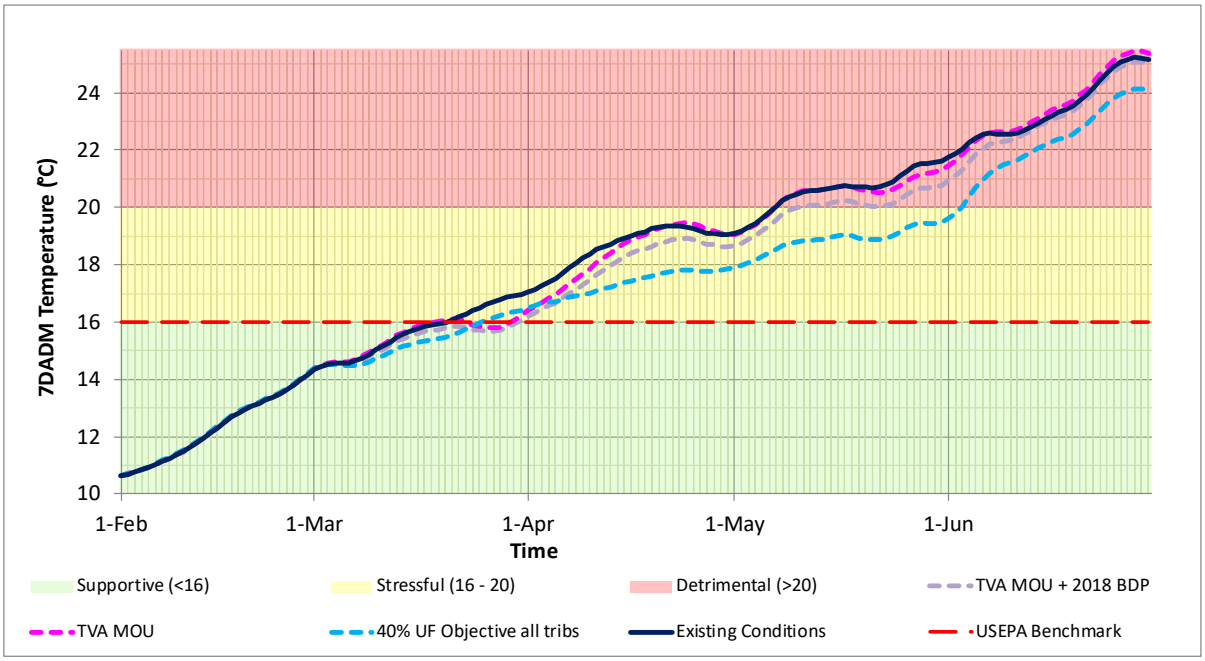


Figure 5-91. Lower San Joaquin River Running 7DADM Water Temperatures at RM 69.31 (Vernalis) Averaged Across Critical Water Year Types from 1970 to 2003 for Core Juvenile Rearing.

During February water temperature are expected to be in the supportive range and below the USEPA benchmark for all scenarios and water year types at all locations assessed on the San Joaquin River (Figure 5-92). During March, water temperatures in the LSJR downstream of the confluence with the Tuolumne River would primarily below the 16°C benchmark in all water year types (Figure 5-93 to Figure 5-95).

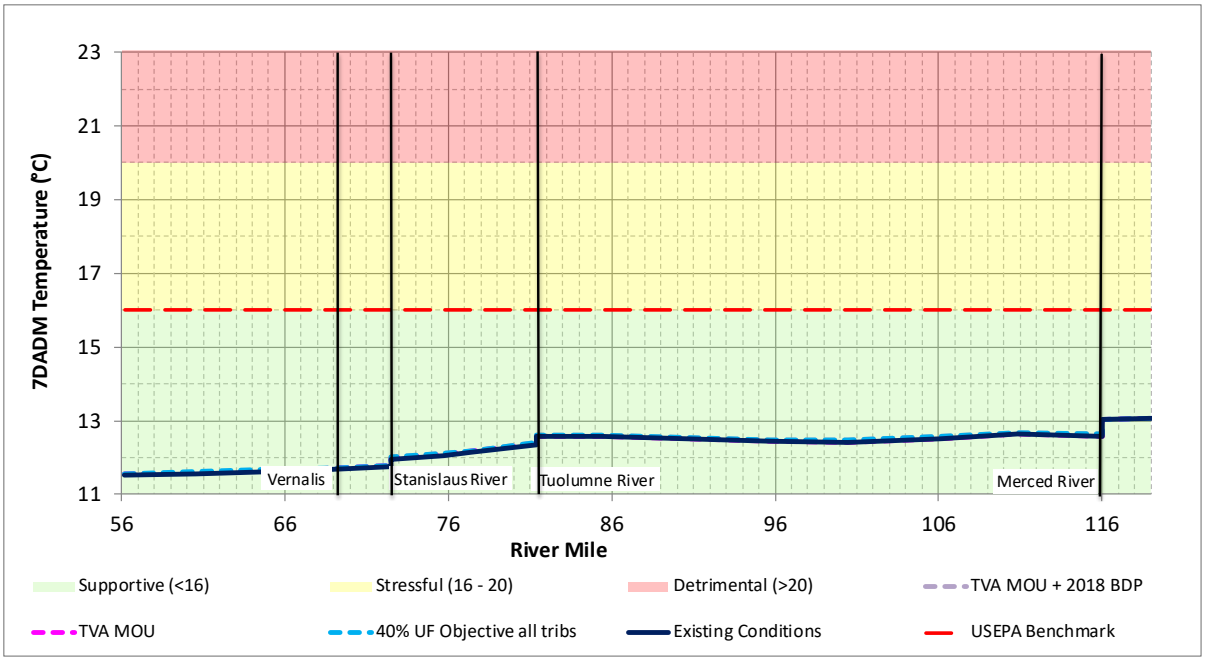


Figure 5-92. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During February Averaged Across All Water Year Types from 1970 to 2003.

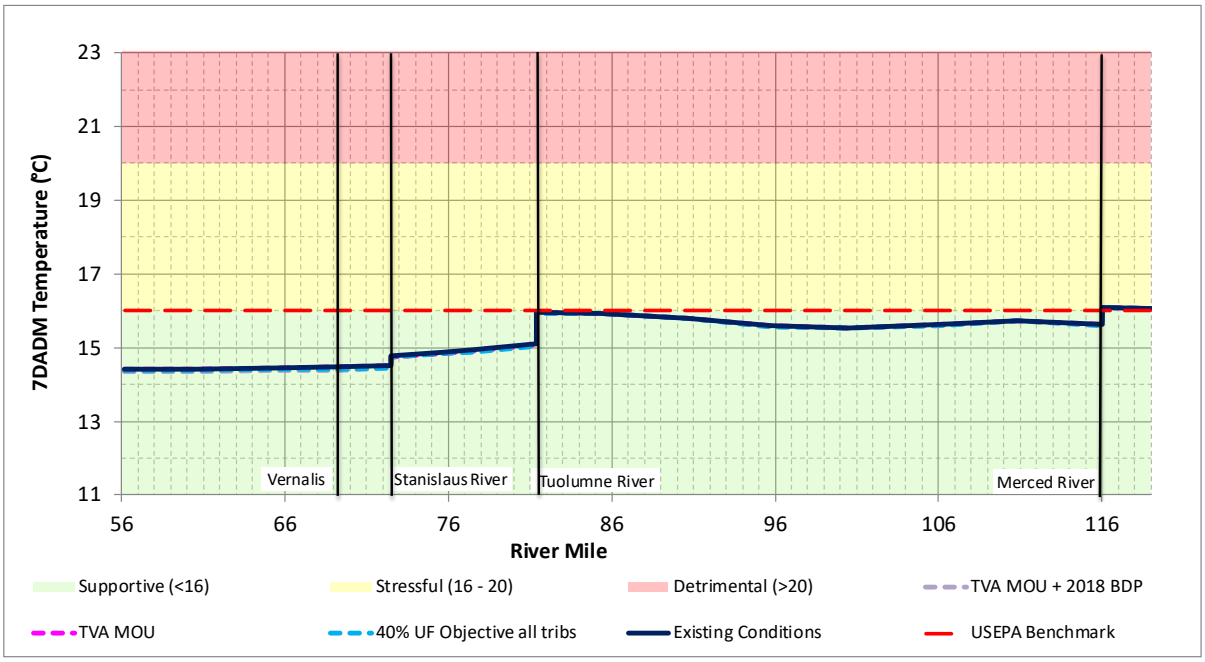


Figure 5-93. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During March Averaged Across All Water Year Types from 1970 to 2003.

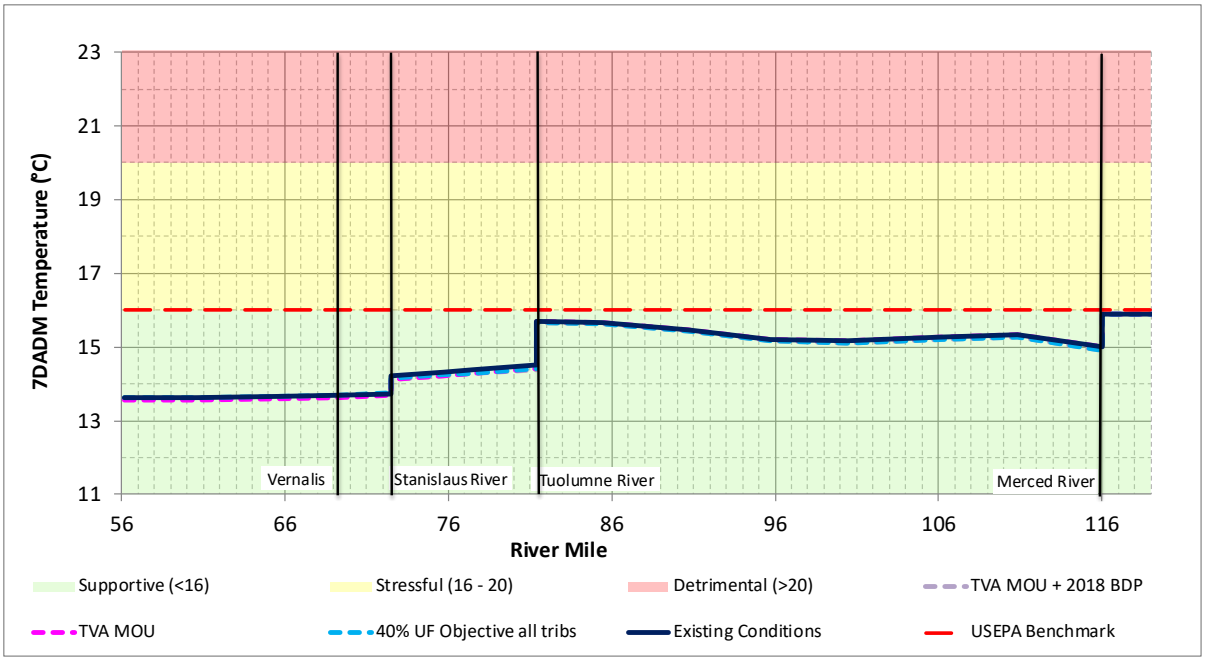


Figure 5-94. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During March Averaged Across Wet Water Year Types from 1970 to 2003.

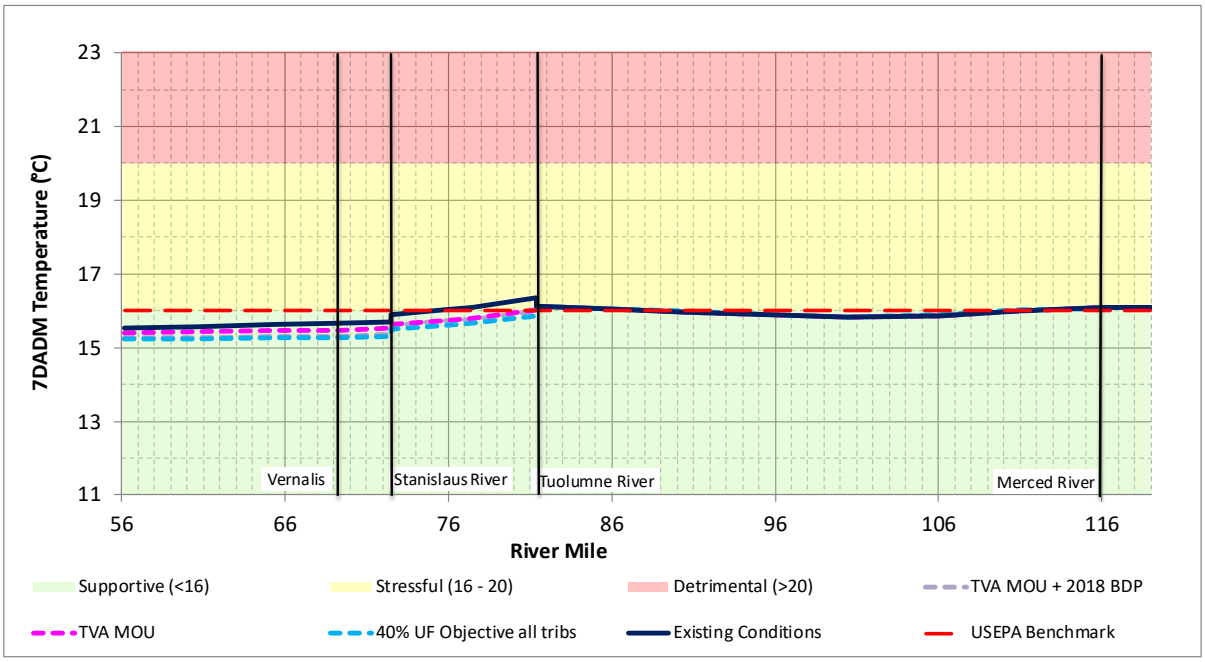


Figure 5-95. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During March Averaged Across Critical Water Year Types from 1970 to 2003.

During April, flows from the Tuolumne River are expected to considerably reduce the water temperatures in the LSJR below the confluence; however, water temperatures in the LSJR are would still be within the stressful range for all scenarios and water year types, except for downstream of Vernalis during Wet Years (Figure 5-96 to Figure 5-98). In Wet and Above Normal Years, all the scenarios would perform similarly and reduce the water temperatures in the LSJR between 1.5° and 2°C (Figure 5-97, only Wet Years shown). In the drier years, the TVA, TVA + 2018 BDP, and 40% UF Objective all tribs scenarios would improve temperature conditions in the LSJR compared to the Existing Conditions scenario (Figure 5-98).

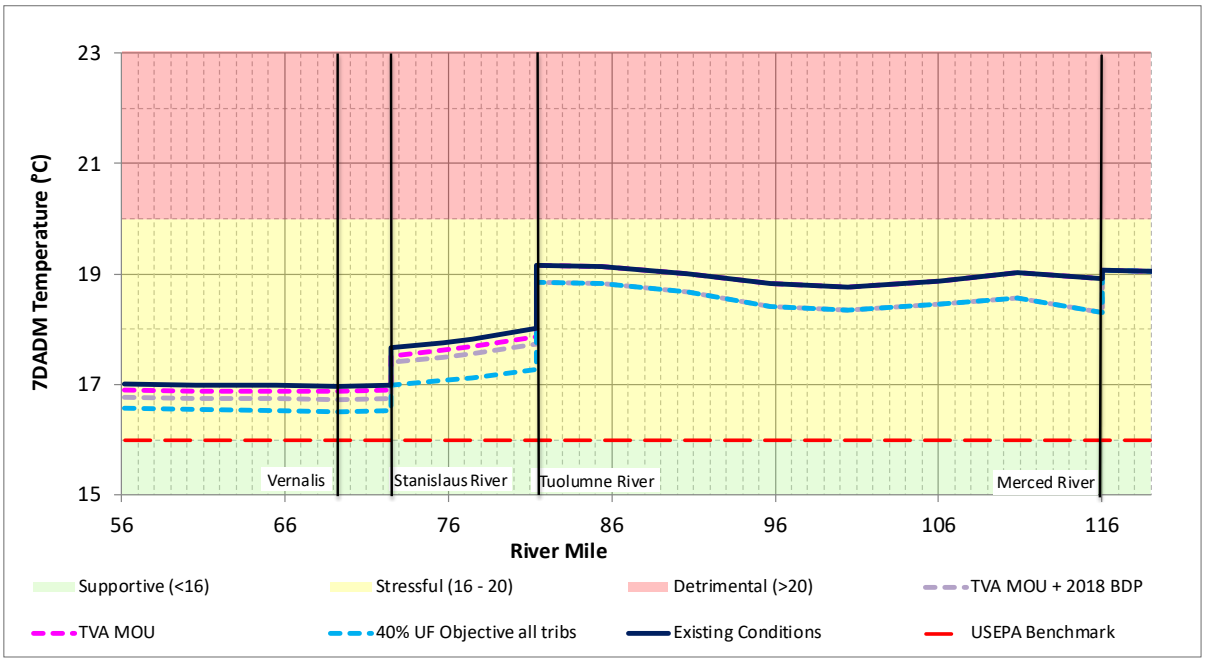


Figure 5-96. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across All Water Year Types from 1970 to 2003.

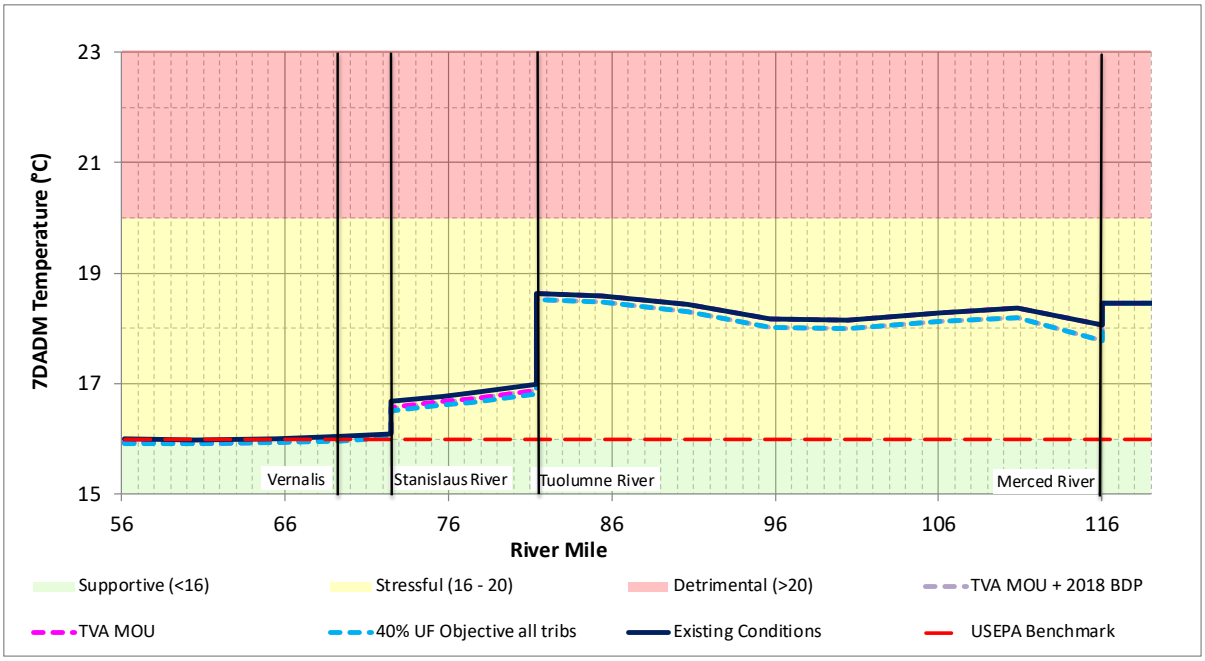


Figure 5-97. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across Wet Water Year Types from 1970 to 2003.

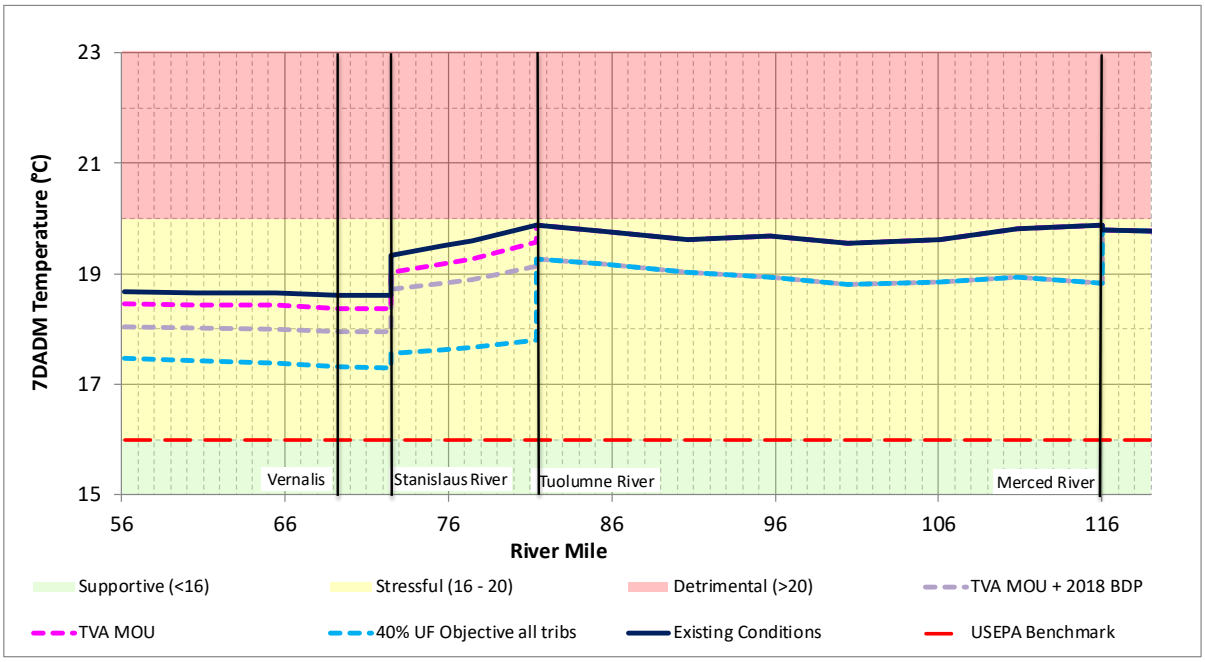


Figure 5-98. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During April Averaged Across Critical Water Year Types from 1970 to 2003.

During May, water temperatures in the LSJR upstream of the Tuolumne River confluence are expected to be in the detrimental range for all water year types; however, the water temperature would decreased considerably by the inflow from the Tuolumne River, and all scenarios, except Existing Conditions, would reduce the water temperatures into the stressful range when averaged across all water year types (Figure 5-99). The TVA, TVA + 2018 BDP, and 40% UF Objective all tribs scenarios would reduce temperatures from the Existing Conditions scenario below the Tuolumne River confluence by 0.8°C, 0.9°C, and 2.0°C, respectively, on average across all water year types. Improvements to LSJR water temperatures relative to Existing Conditions below the confluence with the Tuolumne River under the TVA, TVA + 2018 BDP, and 40% UF Objective all tribs scenarios range from 0.3–1.3°C, 0.6–1.5°C, and 0.8–3.2°C, respectively, when averaged by each water year type (Figure 5-100 and Figure 5-101, only Critical and Wet Years shown)..

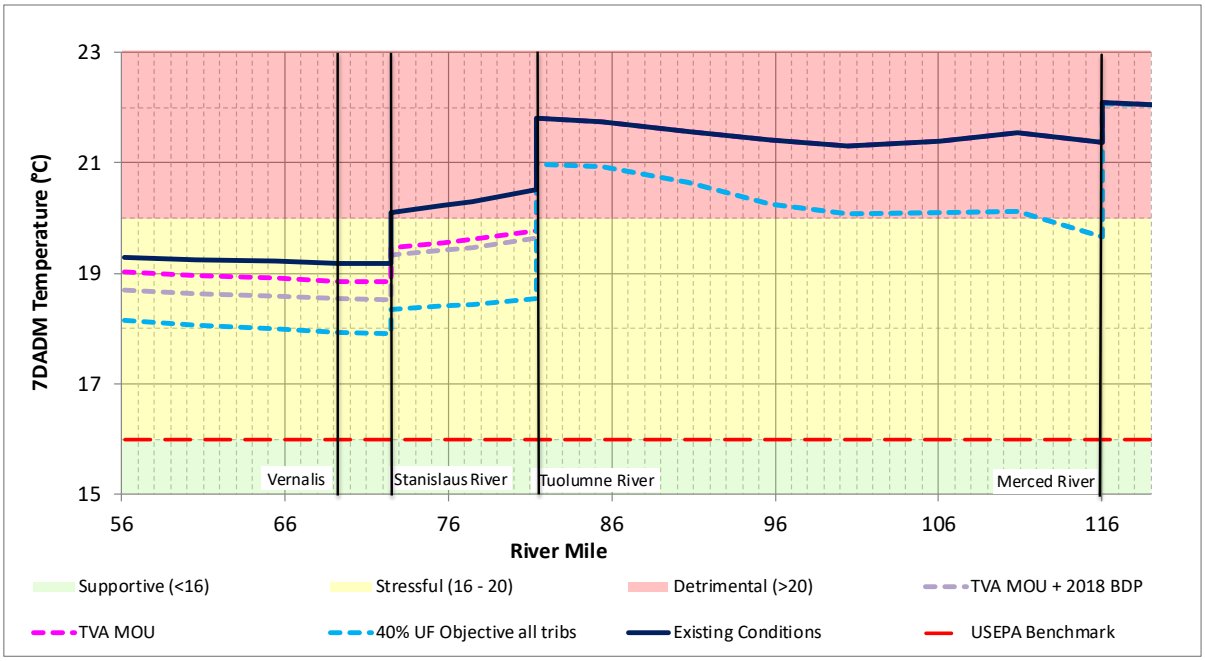


Figure 5-99. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across All Water Year Types from 1970 to 2003.

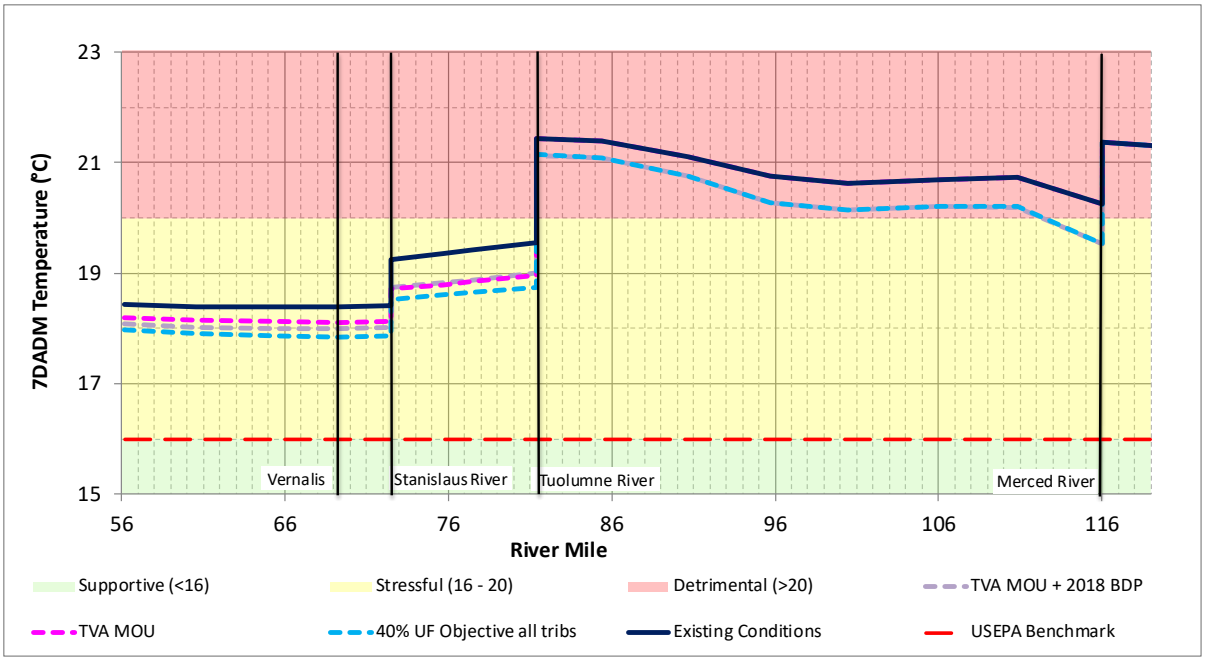


Figure 5-100. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Wet Water Year Types from 1970 to 2003.

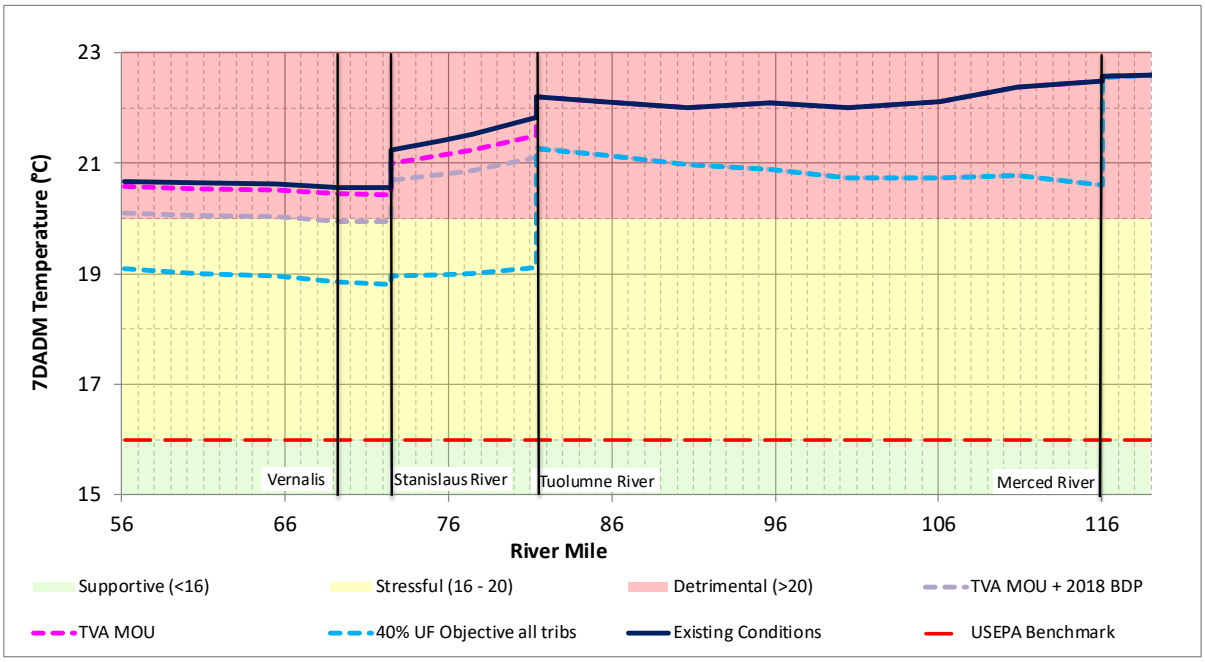


Figure 5-101. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During May Averaged Across Critical Water Year Types from 1970 to 2003.

During June, water temperatures in LSJR are expected to be in the detrimental range through the entire assessed reach of the San Joaquin River, except for the 40% UF Objective all tribs scenario in wetter water year types (Figure 5-102 to Figure 5-104). The TVA exhibits warmer temperatures compared to Existing Conditions during June on average. The TVA + 2018 BDP exhibits overall cooler temperatures than the Existing Conditions in June because of the contributions from the Merced and Stanislaus rivers. The 40% UF Objective all tribs scenario water temperatures would be reduced in the LSJR, on average across all water year types, by 2.4°C with a range of 0.6°–5.6°C when averaged by each water year type.

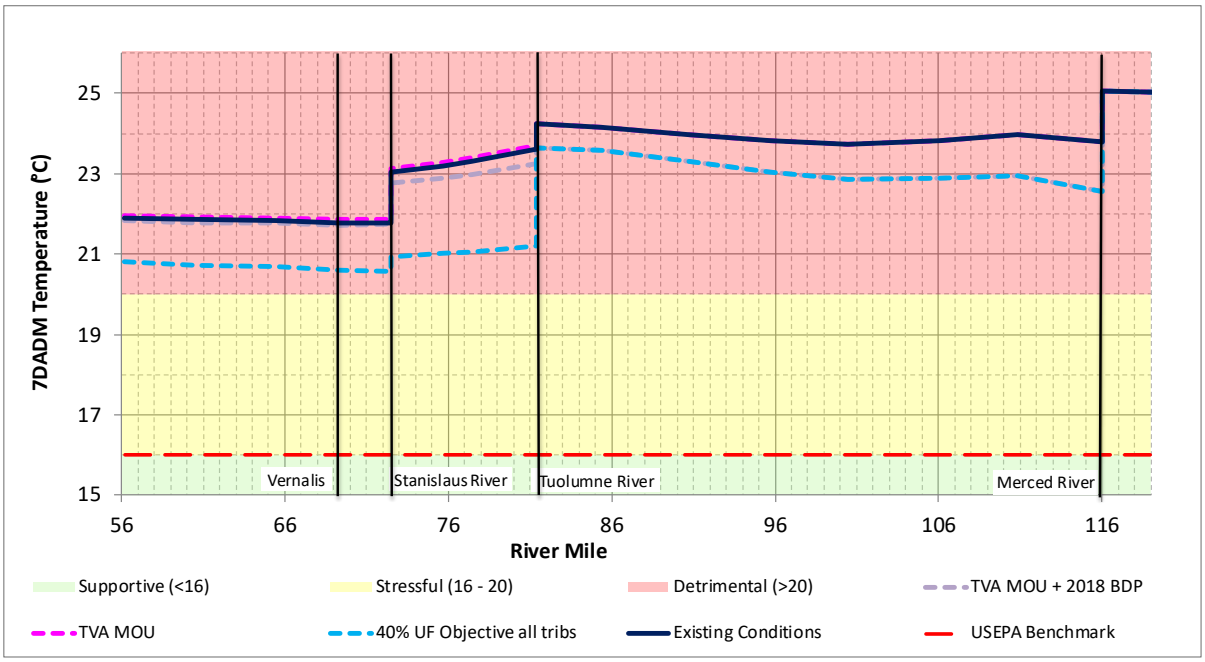


Figure 5-102. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across All Water Year Types from 1970 to 2003.

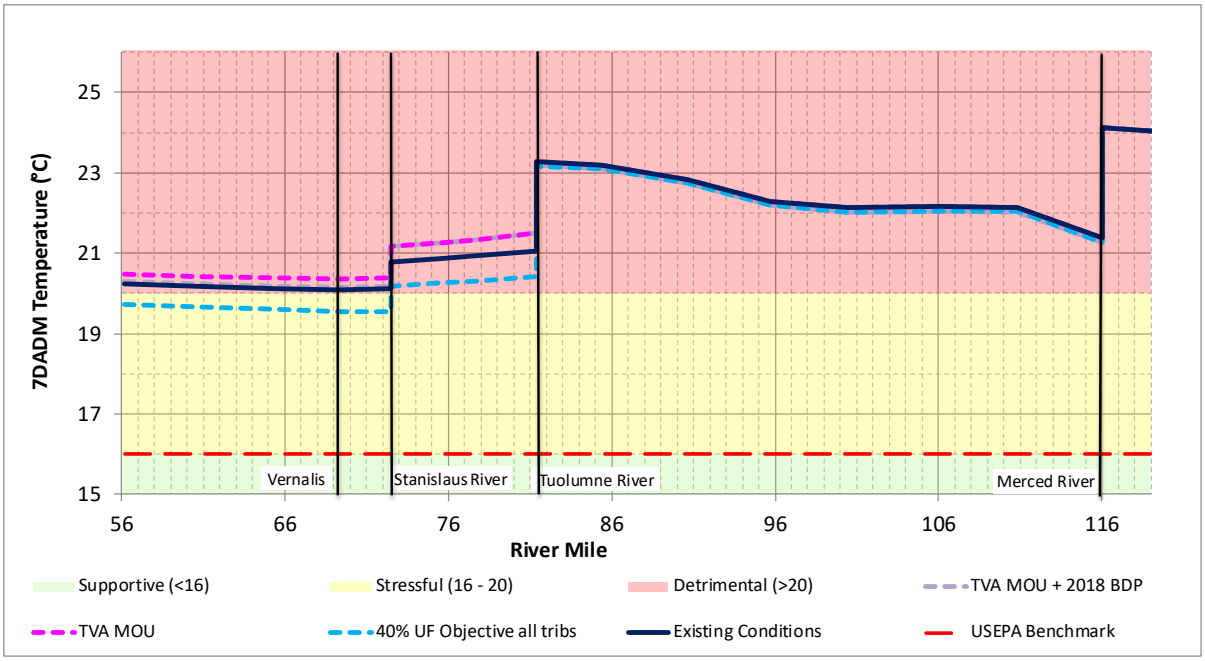


Figure 5-103. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Wet Water Year Types from 1970 to 2003.

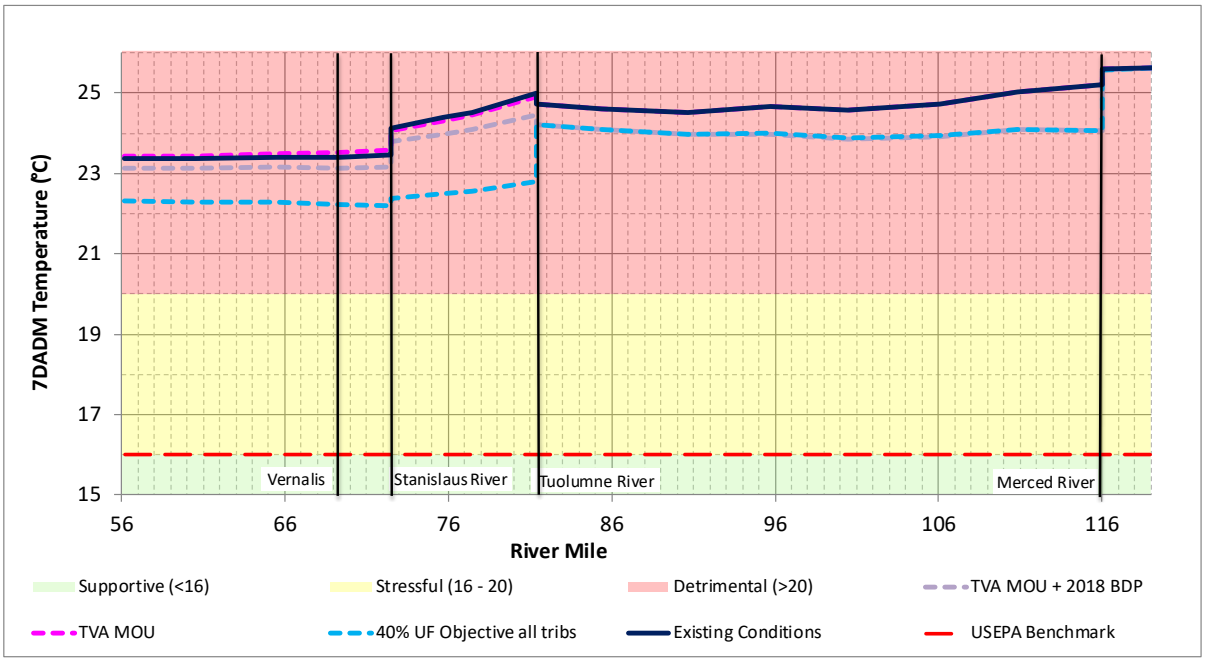


Figure 5-104. Lower San Joaquin River Longitudinal Water Temperature Profile for Core Juvenile Rearing During June Averaged Across Critical Water Year Types from 1970 to 2003.

Smoltification February 1–June 30

Water temperatures for smoltification were assessed in the LSJR from February 1 through June 30 using the USEPA benchmark of 14°C. The smoltification assessment period overlaps the core juvenile rearing period[39] to cover the range of possible smoltification timing, though the actual timing of cohorts smolting will depend on spawn timing and environmental conditions, e.g., temperature and food availability.

During February, water temperature for all scenarios are expected to be similar and within the supportive range for smoltification for the entire reach of the LSJR (Figure 5-92). The USEPA benchmark of 14°C is would typically be exceeded starting between late February/early March in Critical Years, and around mid-March in Wet Years, in the LSJR at Vernalis for all scenarios (Figure 5-90 and Figure 5-91). The 16°C supportive benchmark would be exceeded about a month later with some variability across scenarios (Figure 5-96 to Figure 5-98). During April through June, neither the USEPA benchmark of 14°C for smoltification nor the supportive range of 16°C are expected to be maintained for any scenario; however, the Tuolumne River inflow into the LSJR is expected to help to reduce water temperatures to varying degrees depending on the scenario (Figure 5-96 to Figure 5-104).

Non-Core Juvenile Rearing *(O. mykiss*) June 1–June 30

Temperatures for non-core juvenile rearing *O. mykiss* were assessed in June using the USEPA benchmark temperature of 18°C. As discussed in the core juvenile rearing section,[40] June water temperatures are characterized as detrimental throughout the majority of the LSJR, and the 18°C benchmark would be exceeded by all scenarios in all water year types (Figure 5-102 to Figure 5-104 [18°C benchmark not show] and Table 5-10). The 40% UF Objective scenario would provide improvement in temperatures when compared to the Existing Conditions, and the TVA and TVA + 2018 BDP would be similar to the Existing Conditions scenario.

5.2.3 Discussion

This section summarizes the potential water temperature effects of the proposed TVA, and how those effects may benefit salmonids during critical life stages.

5.2.3.1 Tuolumne River

The water temperature results for the Existing Conditions scenario indicate impaired water temperatures in the Tuolumne River are likely limiting salmonid populations, which is consistent with information considered in the Chapter 2, *Limiting Factors Analysis* (e.g., CDFG 2010; SWRCB 2022), including the stock recruitment analyses (Chapter 2, Section 2.8, *Limiting Factors Analysis*), where spring temperatures were the covariates best able to predict Chinook salmon juvenile productivity. All freshwater life stages of Chinook salmon and *O. mykiss* are expected to experience stressful, harmful, or lethal temperature conditions during some portion of their temporal range of habitation in the Tuolumne River. This results in narrowed time windows for these salmonids to successfully complete their respective life stages as well as truncating the overall time for the fishes

[39] This section refers to figures in the Core Juvenile Rearing February 1–June 30 section. The 14°C Celsius benchmark for smoltification is not shown in those graphs,

[40] This section refers to figures in the Core Juvenile Rearing February 1–June 30 section. The 18°C Celsius benchmark for non-core rearing is not shown in those graphs,

to successfully complete the freshwater portion of the life cycle, i.e., from adult immigration to juvenile emigration. Improvements to Tuolumne River water temperatures are crucial to improve the survival and success of the freshwater life stages of Chinook salmon and anadromous *O. mykiss* in the Tuolumne River, except during December and January which are expected to have adequate temperature conditions.

During the July through January period, the TVA scenario has a flow schedule similar to Existing Conditions, so it is not expected that water temperatures will change much relative to Existing Conditions. The modeling primarily confirms this assumption, except the TVA scenario's water operations during the January through June period would result in a reduction in summer and fall Don Pedro Reservoir storage volumes and thus a reduction in cold-water pool volume from late summer through the fall, when compared to the Existing Conditions. A consequence of the reduction of cold-water pool in the reservoir would be warmer river water temperature during the late summer and fall when the flow schedule is consistent with the Existing Conditions scenario.

Generally, the TVA scenario would show improvements in water temperatures during February through June when compared to the Existing Conditions, but the improvements were highly variable across the different water year types. The TVA would show improvements to water temperatures during the late March and May flow pulses; but, these benefits to water temperature would greatly be reduced during off-ramp years as discussed in *Sequential Dry Year Off-Ramps* in Section 5.2.2.1, *Tuolumne River*. Additionally, during April when there are no pulse flows, Tuolumne River water temperatures under the TVA scenario could reach levels that are stressful and detrimental to salmonids (e.g., Figure 5-73 through Figure 5-80). As mentioned above, from 1970 to 2024, 17 out of the 55 years would have included sequential dry year off-ramps which is a frequency of 1 out of every 3 years.

The 30%–50% UF Objective scenarios consistently would provide substantial improvements in water temperature compared to the Existing Conditions during February through June. The % UF Objective scenarios would significantly increase the frequency of maintaining temperatures below important temperature benchmarks and the frequency of avoiding harmful and lethal temperatures compared to the Existing Conditions.

5.2.3.2 Lower San Joaquin River

The LSJR is an important corridor for migrating and rearing salmonids from the Tuolumne River and other tributaries, so adequate temperatures to promote survival and productivity are necessary to maintain viable populations of salmonids in the LSJR. Like the Tuolumne River, the LSJR is currently experiencing elevated temperature levels that are limiting salmonid populations (SWRCB 2022).

The TVA scenario generally expected to result in LSJR water temperatures slightly cooler than the Existing Conditions but fluctuated both cooler and warmer than the Existing Conditions. The TVA consistently would performed better than the Existing Conditions during May flow pulses, where the Tuolumne River would contribute enough flow of cooler water to reduce water temperatures in the LSJR. May is the only month that the TVA exhibited a significant increase in the percentage of time that harmful water temperatures (20°C) were avoided in the LSJR reach just downstream of the Tuolumne River. As discussed in Chapter 2, Section 2.8, *Limiting Factors Analysis*, May water temperatures are important for Chinook salmon juvenile productivity.

The 40% UF Objective all tribs scenario exhibited substantial improvements in water temperature in the LSJR compared to the Existing Conditions starting in April and extending through June. The greatest improvements to water temperature the 40% UF Objective all tribs scenario are expected in drier water year types, where water temperatures would be up to 5°C cooler than the Existing Conditions. The 40% UF Objective all tribs scenario would significantly reduce the time that harmful temperatures occur during May in all LSJR reaches downstream of the Merced River. Additional reductions of harmful and lethal temperatures would occur under the 40% UF Objective all tribs scenario during June in various LSJR reaches as shown in Table 5-11 and Table 5-12.

5.3 References

5.3.1 Printed References

Brown, L.R., and M.L. Bauer. 2009. Effects of hydrologic infrastructure on flow regimes of California's central valley rivers: implications for fish populations. *River Research and Applications*. DOI: 10.1002/rra.1293.

Brown, L. R., and J. T. May. 2006. Variation in spring nearshore resident fish species composition and life histories in the lower Sacramento–San Joaquin Watershed and Delta. *San Francisco Estuary and Watershed Science* 4(2):1–15.

CALFED. 2009. San Joaquin River Basin Water Temperature Modeling and Analysis. Prepared for CALFED ERP-06D-S20. Prepared by AD Consultants, Resource Management Associates, Inc. and Watercourse Engineering, Inc.

Cain J., J. Ferguson, E. Greene, M. L. Ratliff, J. Rosenfield, A. Weber-Stover, S. Louie, J. Shelton, T. Heyne, B. Elrott, S. Franks, M. Gutierrez, R. Reed, D. Swank, S. Edmundson, K. Schmidt, R. Johnson, J. Howard, J. Zimmerman, C. Carr, D. Worth, R. Henery, J. Israel, P. Cadrett, R. Martin, and J. D. Wikert. 2019. Conservation Planning Foundation for Restoring Chinook Salmon (Oncorhynchus Tshawytscha) and *O. mykiss* in the Stanislaus River. Prepared by Anchor QEA, LLC (Seattle, Washington).

California Department of Fish and Game (CDFG). 2010. *Effects of Water Temperature on Anadromous Salmonids in the San Joaquin River Basin.* Fresno, CA. Prepared for the Informational Proceeding to Develop Flow Criteria for the Delta Ecosystem Necessary to Protect Public Trust Resources Before the State Water Resources Control Board (Sacramento, CA).

California Department of Fish and Wildlife (CDFW). 2013. *San Joaquin River Basin-Wide Water Temperature and EC Model.* Prepared by AD Consultants, Resource Management Associates, Inc. and Watercourse Engineering, Inc.

Carlisle, D. M., M. R. Meador, T. M. Short, C. M. Tate, M. E. Gurtz, W. L. Bryant, J. A. Falcone, and M. D. Woodside. 2013. *The Quality of our Nation's Waters – Ecological Health in the Nation's streams, 1993–2005.* U.S. Geological Survey Circular 1391. Reston, Virginia.

Federal Energy Regulatory Commission (FERC). 2020. Final Environmental Impact Statement for Hydropower Licenses. Don Pedro Hydroelectric Project, FERC Project No. 2299-082; La Grange Hydroelectric Project, FERC Project No. 14581-002. Division of Hydropower Licensing. Washington, D.C. July.

Hallock, R. J. 1989. *Upper Sacramento River Steelhead (Oncorhynchus mykiss), 1952–1988.* Report to the U.S. Fish and Wildlife Service.

McBain & Trush, Inc. (eds.). 2002. *San Joaquin River Restoration Study Background Report.* Prepared for Friant Water Users Authority (Lindsay, CA) and Natural Resources Defense Council (San Francisco, CA).

McCullough, D. A., S. Spaulding, D. Sturdevant, and M. Hicks. 2001. *Issue Paper 5: Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids.* EPA-910-D-01-005. Prepared for the U.S. Environmental Protection Agency as part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project.

McEwan, D. 2001. Central Valley Steelhead. In Brown, R. L. Fish Bulletin 179–*Contributions to the Biology of Central Valley Salmonids*, Volume 1 of 2.

Moyle, P. B. 2002. *Inland Fishes of California.* Revised and Expanded. Berkeley and Los Angeles, Ca; London, England: University of California Press.

Myrick, C. A., and J. J. Cech Jr. 2001. *Temperature Effects on Chinook Salmon and Steelhead: A Review Focusing on California's Central Valley Populations.* Bay-Delta Modeling Forum Technical Publication 01-1.

National Marine Fisheries Services (NMFS). 2009. Endangered Species Act Section 7 Consultation. Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project. Southwest Region.

Richter, B.D. and G.A. Thomas. 2007. Restoring Environmental Flows by Modifying Dam Operations. *Ecology and Society* 12(1).

Rosenfield, J. A., and R. D. Baxter. 2007. Population dynamics and distribution patterns of longfin smelt in the San Francisco estuary. *Transactions of the American Fisheries Society* 136(36):1577–1592.

State Water Resources Control Board (State Water Board). 2018. Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: San Joaquin River Flows and Southern Delta Water Quality. Final. State Clearinghouse #2012122071. Division of Water Rights. Sacramento, CA.

State Water Resources Control Board (SWRCB) 2022. 2020–2022 Integrated Report for Clean Water Act Sections 303(d) and 305(b). Final Staff Report. Surface Water Quality Assessment.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2022. Annual Report for 2021 pursuant to Article 58 of the license for FERC Project No. 2299.

U. S. Bureau of Reclamation (USBR) and Department of Water Resources (DWR). 2011. Draft Program Environmental Impact Statement/Environmental Impact Report. SCH #2007081125. Prepared for the San Joaquin River Restoration Program.

U.S. Environmental Protection Agency (USEPA). 2003. USEPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water. Seattle, WA.

U.S. Fish and Wildlife Service (USFWS). 1996. Recovery Plan for the Sacramento/San Joaquin Delta Native Fishes. U.S. Fish and Wildlife Service. Portland, OR.

Wang, J. C. S., and R. L. Brown. 1993. *Observations of Early Life Stages of Delta Smelt, Hypomesus transpacificus, in the Sacramento-San Joaquin Estuary in 1991, with a Review of its Ecological Status in 1988 to 1990.* Technical Report 35. Prepared for the Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary.

Williams, J. G. 2006. Central valley salmon: a perspective on chinook and steelhead in the central valley of California. *San Francisco Estuary and Watershed Science* 4(3).

Chapter 6
Predator Control

6.1 Introduction

Survival of out-migrating fall-run Chinook (*Oncorhynchus tshawytscha*) from the Tuolumne River is low in most years with high rates of mortality in the lower Tuolumne River (TID and MID 2020a). Predation of juvenile salmonids by introduced species (e.g., largemouth bass (*Micropterus nigricans*), smallmouth bass (*Micropterus dolomieu*), and striped bass (*Morone saxatilis*) may be a dominant source of mortality under low-flow conditions in the Tuolumne River. The largemouth bass population has been estimated to be large enough that, if they were only preying on fall-run Chinook, they could consume the entire out-migrating population (FISHBIO 2013). However, multiple agencies consider the predator rate estimates in FISHBIO (2013) to be unreliable due to concerns[1] with the methodology used in the predator abundance estimates and digestion rates. In addition, in-channel aggregate extraction pits, maintained by reservoir operation flows and sediment retention, may provide ideal habitat for predators (McBain & Trush 2004; See Chapter 2, *Aquatic Ecosystem Stressors in the Tuolumne River*).

The Tuolumne River Voluntary Agreement (TVA) proposed in a Memorandum of Understanding (MOU)[2] includes implementation of a Predator Control and Suppression Plan (Predator Control Plan). A Predator Control and Suppression Plan was also developed for the Federal Energy Regulatory Commission (FERC) relicensing of the Don Pedro Hydroelectric Project and included in the Amended Final License Application (AFLA) submitted to FERC in October of 2017 (TID and MID 2017). The Predator Control Plan considered here is based on descriptions provided by the TVA Parties[3] in relation to the Voluntary Agreement MOU and is described somewhat differently[4] than the Predator Control and Suppression Plan included in the AFLA.

The Predator Control Plan is designed to target an annual reduction in predation rates of 10% below river mile (RM) 25.5 and 20% upstream of RM 25.5. It also includes a fish counting and barrier weir (hereafter referred to as barrier weir) at RM 25 coupled with annual predator suppression activities throughout the Tuolumne River. Predator suppression activities may include removal or isolation methods such as electrofishing, fyke netting, seining, or other collection methods. The barrier weir is intended to prevent striped bass and other predators from moving upstream past RM 25. In addition, this would provide a location to monitor adult salmonids and other fishes as they move

[1] A detailed description of concerns with FISHBIO (2013) is found in Master Response 3.1 of the 2018 Final SED.

[2] In March 2022, the State Water Board received a Memorandum of Understanding Advancing a Term Sheet for the Voluntary Agreements to Update and Implement the Bay-Delta Water Quality Control Plan, and Other Related Actions. Subsequently, in November 2022, the State Water Board received a Revised MOU with additional proposals for voluntary agreements including for the Tuolumne River.

[3] Turlock Irrigation District (TID), Modesto Irrigation District (MID), and the San Francisco Public Utilities Commission (SFPUC), a department of the City and County of San Francisco (CCSF).

[4] Both plans have the same program objectives but the Predator Control and Suppression Plan for the FERC relicensing process is fully developed and includes removal methods, timelines, and monitoring metrics while the Predator Control Plan for the TVA is much less developed and includes provisions for details of the project to be developed in consultation with CDFW, such as the location and design of the barrier and counting weir as well as development of a scientific study and monitoring plan.

upstream. The barrier weir is expected to congregate striped bass immediately downstream for capture and removal from the Tuolumne River. Overall, the barrier weir is envisioned to improve rearing and migration conditions for salmonids by reducing the number of predators entering the reach between the barrier weir and La Grange Dam, approximately 27 miles. The barrier weir is proposed to be in place by year 3. Predator suppression activities are proposed for implementation in years 4 to 6 after the barrier weir is installed and continue through year eight of the TVA. The description of this non-flow asset does not include any details about how many predators will need to be removed to achieve the desired reduction in predation rates, or how changes in predation rates will be measured to determine if the goals are achieved. The asset as described does not include any design information for the fish counting and barrier weir. Regular monitoring and assessment would need to be implemented to gauge the effectiveness of the Predator Control Plan in reducing predation rates and achieving goals.

6.1.1 2018 Bay-Delta Plan's Recommendations to Other Agencies

The Program of Implementation (Chapter IV) in the 2018 Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary (2018 Bay-Delta Plan)[5] sets forth Recommendations to Other Agencies (Section C), consistent with the Porter Cologne Water Quality Control Act, for implementation by agencies other than the State Water Board. These actions include improvements to habitat conditions both inside and outside of the Estuary, many of which are under the authorities of other agencies. The State Water Board recognizes and incorporates recommendations to other agencies, in the Program of Implementation, as part of the overall effort to comprehensively address Delta and tributary ecosystem needs. The non-flow asset addressing predator control included in the TVA is similar to the recommendation specific to the lower San Joaquin River (LSJR) watershed identified in the excerpt below.

6.1.1.1 Reduce Predation and Competition by Non-Native Fish

California Department of Fish and Wildlife (CDFW), National Marine Fisheries Service (NMFS), USFWS, FERC, FERC licensees, local water districts, conservation groups, landowners, water users and other appropriate entities should reduce impacts that non-native predators and competitors have on native fish and modify habitats that currently favor non-native fish over native fish in the LSJR and its tributaries to favor native fish. Actions include but are not limited to the following:

a) Study and report the effects that predators and non-native fish have on native fish.

b) Identify gravel pits, scour pools, ponds, weirs, diversion dams, and other structures or areas that harbor significant numbers of non-native fish and predatory fish that may currently reduce native fish survival.

c) Modify priority structures and areas to reduce predation and non-native fish effects and to improve native fish success.

d) Evaluate and implement changes to fishing regulations to reduce the impact that non-native competitor and predator fish have on native fish.

[5] Available on the State Water Board website at 2018 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary.

6.2 Methods

The State does not have predation or life-cycle population models to quantitatively assess the effectiveness of this program. Instead, the potential efficacy of the Predator Control Plan was qualitatively evaluated by conducting a literature review of other predator removal or control projects, studies, and small barrier weirs.

As part of the FERC relicensing process, the TVA Parties developed a suite of physical and biological models to analyze management scenarios for the Tuolumne River (TID and MID 2017). Models include a Tuolumne River Operation Model, temperature models for both Don Pedro Reservoir and the lower Tuolumne River, a floodplain hydraulic model for the lower Tuolumne River, and population models for both Chinook salmon and *Oncorhynchus mykiss* (*O. mykiss*). Many of these models are interconnected, with the results of one model feeding into another. For example, results from the Tuolumne River Operation Model can be used as input into the Lower Tuolumne River Temperature Model (TID and MID 2017). These models were developed with input from licensing parties and reports on model development were issued (TID and MID 2017). In the years since the AFLA was submitted, there have been updates to the fish population models and possibly other models. However, new documentation is unavailable (TID and MID 2020b), and it is unclear what has been updated or changed.

The validity of the Chinook salmon and *O. mykiss* population models for the lower Tuolumne River is highly uncertain and has been criticized by multiple agencies, including the State Water Board, the California Department of Fish and Wildlife, NMFS and the United States Fish and Wildlife Service (CDFW 2014; NMFS 2014; State Water Board 2013; USFWS 2014). NMFS disagrees with several aspects of the models, and the studies and literature that pertain to model development, application, and preliminary conclusions (NMFS 2014). Criticisms from all agencies include, but are not limited to, concerns that the models do not recognize existing rearing and spawning habitat limitations or accurately represent temperature sensitivity, predation, and the effect of flow in establishing rearing and floodplain habitat benefits (CDFW 2014; NMFS 2014; SWRCB 2013; USFWS 2014).

In 2020 a third party, Anchor QEA, reviewed the lower Tuolumne River Chinook salmon and *O. mykiss* population models and identified multiple strengths and weaknesses of the models. Specifically, they noted that the models have a high priority assigned to predation and the effectiveness of predator suppression methods (Anchor QEA 2020), meaning the model is highly sensitive to changes in predation and may overestimate the influence of predation controls. The results of predator suppression activities are not modeled directly but instead are represented in the model by changing predation rates (TID and MID 2017). For the reasons discussed above, this Draft TVA Scientific Basis Report does not rely on the models developed in the relicensing process to analyze the effectiveness of predator controls but includes a discussion of the results as part of its literature review below.

6.3 Literature Review

A Northern Pikeminnow Sport Reward Program (NPMSRP) implemented on the Columbia and Snake Rivers is designed to reduce the population of Northern pikeminnow by anglers through monetary rewards based on the number of fish harvested (Winther et al. 2022). The NPMSRP was developed to reduce predation on juvenile salmonids by Northern pikeminnow based on simulation modeling that found that a sustained reduction of 10–20% of the Northern pikeminnow population larger than 275 mm could result in an annual reduction in predation of 50% or more (Nigro 1990; Rieman and Beamesderfer 1990). Since 1990, over 5.3 million Northern pikeminnow have been removed by the NPMSRP (Winther et al. 2022). With high levels of removal, the NPMSRP is believed to have reduced predation on juvenile salmonids; however, estimates vary widely and accompanying increases in salmonid population abundance have been difficult to detect (Carey et al. 2012). The lack of positive juvenile salmonid population-level responses may be a result of compensatory responses by other predators such as Caspian terns (*Hydroprogne caspia*) and marine mammals such as California sea lions (*Zalophus californianus*) (Carey et al. 2012).

Zipkin et al. (2008) investigated the response of non-native smallmouth bass from an intensive seven-year removal program of adults, sub-adults and juveniles in a lake in New York State. Smallmouth bass removals were achieved through targeted shoreline boat electrofishing in the spring and fall over the seven-year removal period. The authors found that the program had success in reducing the overall biomass of smallmouth bass in the lake as well as subsequent increases in native fish populations but also found an increase in the relative abundance of juvenile bass (<200mm). These results show that in a closed system there may be benefits to native fish populations from predator removal but there also may be an unintended increase in predator populations. Zipkin et al. (2008) notes that the relative increase in juvenile bass may result in the necessity to continue intensive removals indefinitely to maintain benefits for native species.

More locally, there have been several predator removal studies in California Central Valley streams. A predator removal study on the Mokelumne River paired predator removal with juvenile Chinook salmon tracking and flow manipulation (Cavallo et al. 2012). In the study, predators were experimentally removed from one reach to determine the impact of the removals on juvenile Chinook salmon survival. The researchers performed two predator removal events and evaluated juvenile Chinook salmon survival before and after each event. The researchers found an increase in juvenile salmon survival at the removal site after the first removal event, but they found no survival increases after the second removal event (Cavallo et al. 2012). The researchers suggested that, for predator removal to be beneficial to juvenile salmon survival, a sustained removal effort may be needed over time (with daily rather than weekly removals).

Researchers from the National Oceanic and Atmospheric Administration (NOAA) Southwest Fisheries Science Center and University of Washington performed a suite of studies in the LSJR to investigate the relationships between predator densities and environmental variables on juvenile salmonid survival in 2014 and 2015 (Hayes et al. 2017; Michel et al. 2019). Michel et al. (2019) artificially manipulated predator densities in three reaches of the LSJR. Predators were removed from one reach and relocated to another, while densities in a third reach were not manipulated for use as a control. The researchers used acoustically tagged salmon smolts and predation event recorders baited with salmon smolts to compare survival through each reach before and after predator relocations. The researchers estimated they were able to remove 40–70% of all predators in their removal reaches but found the effects to only be temporary, with evidence of predators

returning to their original reach by the next electrofishing effort, which occurred 2–3 weeks later (Michel et al. 2019). Overall, even with large scale removals and relocations, the researchers found no statistically significant evidence that these predator manipulations influenced salmonid survival.

Michel et al. (2019) used genetic techniques to analyze the gut contents to better understand the diet of select predators including striped bass, largemouth bass, channel catfish (*Ictalurus punctatus*), and white catfish (*Ameiurus catus*) in the LSJR. Overall, the researchers found all four predators consumed Chinook salmon but also consumed non-native fish species at greater frequencies. Similarly, a 2012 predation study on the Tuolumne River found that Chinook salmon occurred in 12% of the non-empty stomach samples, but Chinook salmon only made up about 10% of the fish observed in predator stomach samples (FISHBIO 2013). These findings suggest that predator removals may result in the unintended consequence of increasing non-native competition for Chinook salmon or other trophic interaction impacts.

As indicated earlier, the Predator Control Plan includes the installation of a new barrier weir in the lower Tuolumne River at RM 25.5. This barrier weir is proposed to allow passage for native fishes while blocking non-native predator species, mainly striped bass, from moving upstream. A similar structure which has been observed as an effective method to block striped bass migration, currently exists on the Mokelumne River, the Woodbridge Irrigation District Dam (WIDD). Sabal et al. (2016) sought to determine the impacts of striped bass predation on juvenile salmonids downstream of the WIDD through a study that coupled juvenile Chinook salmon survival, striped bass removals, and diet contents over three years. They found that juvenile Chinook salmon survival at WIDD increased by 25–29% after the removal of striped bass from the WIDD. However, the authors also found that striped bass immediately downstream of the WIDD consumed more Chinook salmon than in other altered or unaltered locations in the Mokelumne River.

Sabal et al. (2016) supports the hypothesis that a barrier weir in combination with predator removal may be effective in controlling predation in the immediate area. However, there is currently no barrier weir in the lower Tuolumne River, and the installation of such a barrier may result in a new predation hot spot with potential to increase predation in the lower Tuolumne River if predators are not removed. Sabal et al. (2016) did not investigate how long the increase in juvenile salmon survival would last in relation to predator removals; however, based on the results of Cavallo et al. (2012) and Michel et al. (2019), predator removals downstream of the barrier weir may have short term effects unless predator removal occurs at an appropriate frequency. The lethal removal or relocation of predators to a disconnected water body may slow the recolonization of predators to the lower Tuolumne River, but with an open migration corridor with the San Joaquin River, it is likely that recolonization will eventually occur (Moyle 2002; Zipkin 2008; Moyle and Bennett 2010; Cavallo et al. 2012; Grossman et al. 2013; Grossman 2016; Michel et al. 2019).

There are other ongoing studies or projects that could potentially inform the Tuolumne River Predator Control Plan in the near future. There is an ongoing effort to remove smallmouth bass on the Coquille River Basin in Oregon. Smallmouth bass are recent invaders in the Coquille River, with fish first identified in 2011. The salmon population in the Coquille River basin experienced a crash in 2018 that was attributed to predation by smallmouth bass. Consequently, a smallmouth bass removal effort was initiated in 2020. However, no results are available currently (personal communication G. Vonderhoe). A predation study was conducted on the nearby Stanislaus River from 2018–2021 by NMFS and Oakdale and South San Joaquin Irrigation Districts (NOAA Fisheries 2021). The study was designed to research non-native predation by electrofishing throughout the juvenile fall-run Chinook salmon outmigration period to determine predator abundance and

predation rates on fall-run Chinook salmon. The study also included efforts to remove or relocate predator fishes to determine if there was a change in Chinook salmon survival (FISHBIO n.d.). The predator removal part of the study was not fully implemented due to permitting challenges; however, once available, the results from the dietary portion of the study could be used to investigate the likely impacts of a Tuolumne River Predator Control Program on both target and non-target species.

6.4 Discussion

The predation of juvenile salmonids by non-natives may be a large source of mortality such that the population is negatively impacted. Predator suppression may facilitate increases in abundances of prey fish populations, but this requires intensive and sustained removal efforts (Beamesderfer 2000). In general, there is a lack of evidence in the literature for predator removal as a successful management strategy for recovery of target species. Findings further suggest that inherent challenges exist in eliminating predator populations in systems with complex population dynamics (Grossman 2016).

Although a barrier weir is proposed to reduce or stop immigration of predators into the Tuolumne River upstream of RM 25.5, the lower portion of the river would still have an open migration corridor and repopulation of predator species is likely. The design and location of the barrier weir have not yet been determined, and it is unclear how a proposed structure would accommodate the passage of all native species migrating into the Tuolumne River. Chinook salmon, *O. mykiss*, Pacific lamprey (*Entosphenus tridentatus*), green sturgeon (*Sinosturio medirostris*), and white sturgeon (*Sinosturio transmontanus*) among other native migratory species, will all need access into and out of the Tuolumne River at various times. The design of the structure needs to accommodate passage for native species while also blocking target non-native species.

Predation by non-native fish is one of many ecosystem stressors (See Chapter 2) affecting juvenile salmonid populations in the Tuolumne River. Other stressors such as physical habitat alteration, hydromodification, and elevated water temperatures favor non-native species and thus intensify interspecific competition and predation. All of the ecosystem stressors must be addressed in coordination for the recovery of native salmonids.

The importance of a natural flow regime to the native flora and fauna, function, and resilience of lotic ecosystems is widely accepted (Grossman et al. 1982; Poff et al. 1997). However, in some cases restoration of natural hydrologic cycles alone is unlikely to benefit native fishes without concurrent management of invasive predators (Tyus and Saunders 2000; Propst et al. 2008). The State Water Board, in the 2018 Bay-Delta Plan and the supporting environmental document (SWRCB 2018), recognizes that predator control projects such as those proposed should be part of the overall effort to comprehensively address tributary aquatic ecosystem needs (See Section 6.1.1, *2018 Bay-Delta Plan's Recommendations to Other Agencies*). Salmonid conservation efforts in the Tuolumne River cannot focus on habitat restoration alone because (1) the physical structure of the system is highly constrained by domestic and agricultural water demands, and (2) non-native species, including predators, will continue to pose a threat to salmonid persistence. Predator control is not likely to be effective on a broad scale without considering the habitat conditions that make non-native predators successful. The cumulative effect of flow and other non-flow measures in the TVA, such as habitat restoration, along with predator reduction strategies, is intended to increase juvenile salmonid survival and abundance.

6.5 References

6.5.1 Printed References

Anchor QEA. 2020. Third Party Review of Tuolumne River Chinook Salmon and *Oncorhynchus mykiss* Population Models. Prepared for NOAA Fisheries. E-Filed with FERC August 26,2020. Ascension #20200827-5055.

Beamesderfer, R.C., D.L. Ward, and A.A. Nigro. 1996. Evaluation of the Biological Basis for a Predator Control Program on Northern Squawfish (P*tychocheilus oregonesis*) in the Columbia and Snake Rivers. *Canadian Journal of Fish and Aquatic Science* (53) pp 2898–2908. https://cdnsciencepub.com/doi/10.1139/f96-225.

California Department of Fish and Wildlife (CDFW). 2014. Comments in Response to Draft License Application Don Pedro Hydroelectric Project (Project) Federal Energy Regulatory Commission (Commission) No. 2299-075 Tuolumne River. February 26. eLibrary# 20140228-5015.

Carey M.P., Sanderson B.L., Barnas K.A., Olden J.D. 2012. Native invaders—challenges for science, management, policy, and society. Front Eco Environ 10:373–381. doi: http://dx.doi.org/10.1890/110060.

Cavallo, B., J. Merz, and J. Setka. 2012. Effects of Predator and Flow Manipulation on Chinook Salmon (*Oncorhynchus tshawytscha*) Survival in and Imperiled Estuary. Environmental Biology of Fishes. https://www.noaa.gov/sites/default/files/legacy/document/2020/Oct/07354626322.pdf.

FISHBIO. n.d. Stanislaus Native Fish Plan. Available online: https://fishbio.com/projects/stanislaus-native-fish-plan/ accessed 4/8/2024.

FISHBIO. 2013. Predation Study Report Don Pedro Project FERC No. 2299. Prepared for Turlock Irrigation District and Modesto Irrigation District. https://donpedro-relicensing.com/study-reports/.

Grossman, G.D., T. Essington, B. Johnson, J. Miller., N. E. Monsen, and T.N. Pearsons. 2013. Effects of Fish Predation on Salmonids in the Sacramento River- San Joaquin Delta and Associated Ecosystems. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=73874.

Grossman, G.D. 2016. Predation on Fishes in the Sacramento–San Joaquin Delta: Current Knowledge and Future Directions. San Francisco Estuary and Watershed Science, 14(2).

Grossman, G.D., P.B. Moyle, and J.R. Whitaker Jr. 1982. Stochastic in structural and functional characteristics of and Indiana stream fish assemblage: a test of community theory. American Naturalist 120: 423–454.

Hayes, S., D. Huff, D. Demer, C. Michel, G. Cutter, N. Demetras, B. Lehman, S. Manugian, S. Lindley, J. Smith, T. Quinn. 2017. Testing the Effects of Manipulated Predator Densities and Environmental Variables on Juvenile Salmonid Survival in the Lower San Joaquin River. Prepared for the California Department of Water Resources, Agreement No. 4600010100.

McBain and Trush. 2004. Coarse Sediment Management Plan for the Lower Tuolumne River, Revised Final. Prepared for the Tuolumne River Technical Advisory Committee, Turlock and Modesto Irrigation Districts, USFWS Anadromous Fish Restoration Program, and California Bay-Delta Authority.

Michel, C.J., J.M. Smith, B.M. Lehman, N.J. Demetras, D.D. Huff, P.L. Brandes, J.A. Israel, T.P. Quinn, and S.A. Hayes. 2019. Limitations of Active Removal to Manage Predatory Fish Populations. North American Journal of Fishers Management. https://afspubs.onlinelibrary.wiley.com/doi/full/10.1002/nafm.10391.

Moyle, P.B. 2002. Inland Fishes of California Revised and Expanded. University of California Press, Berkley California.

Moyle, P.B. and Bennett, W.A. 2010. Striped bass predation on listed fishes: can a control program be justified? Letter to Jim Kellogg, President, Fish and Game Commission. August 26, 2010.

National Marine Fisheries Service (NMFS). 2014a. Comments on the Draft License Application for the Don Pedro Hydroelectric Project, P-2299. March 3. eLibrary: 20140303-5136.

Nigro, A.A. 1990. Development of a System-Wide Predator Control Program: Stepwise Implementation of a Predation Index Predator Control Fisheries and Evaluation Plan in the Columbia River Basin. Prepared for the Bonneville Power Administration. https://www.pikeminnow.org/wp-content/uploads/2017/03/1990-Pikeminnow-AR.pdf.

NOAA Fisheries. 2021. California Central Valley Water Operations: Stanislaus Nonnative Predator Research Program. Available online: https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/california-central-valley-water-operations-stanislaus-nonnative-predator-research.

Poff, N.L., J.D. Allen, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The Natural Flow Regime: A Paradigm for River Conservation and Restoration. Bioscience 47(11): 769–784.

Propst, D.L., K.B. Gido, and J.A. Stefferud. 2008. Natural Flow Regimes, Nonnative Fishes, and Native Fish Persistence in Arid-land River Systems. Ecological Applications 18(5):1236–1252.

Rieman, B.E. and R.C. Beamesderfer. 1990. Dynamics of a Northern Squawfish Population and the Potential to Reduce Predation on Juvenile Salmonids in a Columbia River Reservoir. North American Journal of Fisheries Management. Issue 10, pp 228–241. https://www.tandfonline.com/doi/abs/10.1577/1548-8675%281990%29010%3C0228%3ADOANSP%3E2.3.CO%3B2?journalCode=ujfm20.

Sabal, M., S. Hayes, J. Merz, and J. Setka. 2016. Habitat Alterations and a Nonnative Predator, the Striped Bass, Increase Native Chinook Salmon Mortality in the Central Valley, California. North American Journal of Fisheries Management. Issue 36, pp 309–320. https://www.tandfonline.com/doi/abs/10.1080/02755947.2015.1121938.

State Water Resources Control Board (SWRCB). 2013. Comments on Initial Study Report for Don Pedro Hydroelectric Project, Federal Energy Regulatory Commission Project No. 2299. eLibrary: 20130320-001.

State Water Resources Control Board (SWRCB). 2018. Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: San Joaquin River Flows and Southern Delta Water Quality. Final. State Clearinghouse #2012122071. Division of Water Rights. Sacramento, CA.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2017. Don Pedro Hydroelectric Project FERC No. 2299 Amendment of Application Exhibit E- Environmental Report. Accession # 20171011-5067.

Turlock Irrigation District and Modesto Irrigation District (TID and MID) 2020a. Turlock and Modesto Irrigation Districts Project No. 2299- Article 58 Annual Report for 2019. E-filed with FERC March 30, 2020.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2020b. Turlock Irrigation District and Modesto Irrigation District Don Pedro Hydroelectric Project No. 2299 Revised Fish Population Model Results. E-filed with FERC June 17,2020. Ascension # 20200317-5109.

Tyus. H.M. and J.F. Sanders. 2000. Nonnative Fish Control and Endangered Fish Recovery: Lessons from the Colorado River. Fisheries 25(9):17–24.

U.S. Fish and Wildlife Service (USFWS). 2014. U.S. Fish and Wildlife Service Comments on Updated Study Report and Draft License Application, Don Pedro Hydroelectric Project, FERC Project #P-2299 on the Tuolumne River; Tuolumne and Stanislaus Counties, California. February 26. eLibrary: 20140227-5120.

Winther, E., G. Waltz, and A. Martin. 2022. Report on the Predation Index, Predator Control Fisheries and Program Evaluation for the Columbia River Basin Northern Pikeminnow Sport Reward Program 2021 Annual Report. Prepared for the Bonneville Power Administration. https://www.pikeminnow.org/wp-content/uploads/2023/04/2021-Pikeminnow-AR.pdf.

Zipkin, E.F., P.J. Sullivan, E.G. Cooch, C.E. Kraft, B.J. Shuter, and B.C. Weidel. 2008. Overcompensatory Response of a Smallmouth Bass (*Micropterus dolomieu*) Population to Harvest: Release from Competition? Canadian Journal of Fish and Aquatic Science Issue 65 Pg 2279–2292. https://cdnsciencepub.com/doi/10.1139/F08-133.

6.5.2 Personal Communications

Vonderhoe, Gary. Assistant Fish District Biologist Oregon Department of Fish and Wildlife. Personal Communication March 17, 2023.

Chapter 7
Spawning and Rearing Habitat

7.1 Introduction

The Tuolumne River Voluntary Agreement (TVA) includes flow and non-flow assets (see Chapter 3, *Description of Flow and Non-flow Assets*) that are intended to provide for and improve spawning and rearing habitat. Flows would be provided in January through June, and non-flow assets include rearing/floodplain[1] habitat that would be inundated at the proposed flows. This chapter evaluates potential benefits to salmonids by quantifying the frequency and magnitude of suitable spawning and juvenile rearing habitat predicted to result from the TVA with non-flow commitments and compares those results to Existing Conditions and the 30-50% UF Objective scenarios without the addition of non-flow assets (see Section 7.3.1.1, *Analytical Approach to Evaluating Non-Flow Assets*, for more detail). For additional information and support, see the analogous evaluations conducted in the Draft Scientific Basis Report Supplement in Support of Proposed Voluntary Agreements for the Sacramento River, Delta, and Tributaries Update to the San Francisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan (State Water Board 2023) and in the Final Substitute Environmental Document (SED)[2] for the 2018 Bay-Delta Plan Update (State Water Board 2018).

This chapter also contains a literature review of habitat restoration actions and qualitatively evaluates potential benefits from the TVA non-flow commitments (Section 7.2, *Habitat Restoration*). Non-flow activities evaluated include floodplain construction and gravel and large woody debris (LWD) augmentation. The State Water Board, in the 2018 Bay-Delta Plan update and the supporting environmental document (State Water Board 2018, Appendix K), recognizes that habitat enhancement projects such as those proposed should be part of the overall effort to comprehensively address tributary aquatic ecosystem needs (See Section 7.1.3, *2018 Bay-Delta Plan's Recommendations to Other Agencies*, of this chapter).

7.1.1 Habitat Effects on Aquatic Species

The survival of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) is affected by the spatial and temporal availability of suitable habitat, as well as nutritional opportunities. Extensive seasonal floodplains and wetlands historically supported significant production of native fish species (Ahearn et al. 2006). Improving habitat availability, including floodplain inundation regimes to which native fish species are adapted, is critical for juvenile salmon rearing (Herbold et al. 2018; Sturrock et al. 2022), as well as other native fishes (Sommer et al. 2002). Dynamic connectivity between rivers and their floodplains improves nutrient and organic matter mobilization and exchange (Junk et al. 1989), and inundation of floodplain areas creates access to foraging habitat and provides refuge from high velocities during high-flow events (Moyle et al. 2007). Fish yields have also been found to increase with water surface area in floodplains (Jeffres et al. 2008; USFWS 2013). Life history

[1] For this chapter, rearing/floodplain projects refers to those projects in floodplain areas adjacent to the channel.

[2] Several chapters in the 2018 Final SED include descriptions of modeling and floodplain evaluations that were used to support the Bay-Delta Plan Update including: Chapters 4, 5, 7, 19; Appendix C; and Master Response 3.1. As applicable, information in this chapter summarizes or references those descriptions.

diversity in salmonids is also enhanced with access to floodplain habitat (Goertler et al. 2018) and is recognized as a critical component of population viability (Carlson and Satterthwaite 2011).

Multiple studies have documented widespread benefits from floodplain habitat at multiple levels ranging from individual organisms to ecosystems (Junk et al. 1989; Moyle et al. 2007). Floodplain inundation provides flood peak attenuation and promotes exchange of nutrients, organic matter, organisms, sediment, and energy between the terrestrial and aquatic systems (Cain et al. 2003; Mesick 2009). Access to floodplain habitat improves juvenile fish survival by improving prey availability which leads to higher growth rates of juvenile Chinook salmon using floodplain habitat for rearing (Sommer et al. 2001; Jeffres et al. 2008; Katz et al. 2017; Jeffres et al. 2020; Cordoleani et al. 2022). In addition, floodplain habitat may provide refuges from predators during the critical rearing and migration times (Mesick 2009). Splittail is another native fish species that is dependent on floodplains as an obligate floodplain spawner (Opperman 2012), with population dynamics closely associated with annual patterns of flow and floodplain inundation (Moyle et al. 2004).

7.1.2 Habitat Degradation

Since California's gold rush, manipulation of channel morphology has caused large-scale changes to the Tuolumne River corridor (McBain and Trush 2000). The three largest dams,[3] aggregate extraction, agricultural and urban encroachment, and other land uses have caused sediment imbalances in the channel and have had a deleterious impact on the ecosystem of the lower Tuolumne River. All coarse sediment historically supplied from unregulated portions of the upper watershed to the lower Tuolumne River is trapped and not transported downstream; and the frequency, magnitude, and duration of bed-mobilizing flows that influence bedload transport capacity in the lower Tuolumne River has been irrevocably altered and facilitated the accumulation of fine sediment in the river (Stillwater Sciences 2013; McBain and Trush 2000). Habitats in the Tuolumne River downstream from La Grange Dam have also been influenced and altered by former gold mining activities and gravel mining (McBain and Trush 2000). Dredge tailings from gravel mining activities combined with the armoring and stabilizing of channel banks with rip-rap from human manipulation has constrained the channel and restricted channel meander and reduced delivery of gravel to the river (MacBain and Trush 2000; Moyle 2002; Stillwater Sciences n.d.). As a result, there is limited suitable spawning habitat downstream of the dams which results in redd superimposition and egg mortality (Stillwater Sciences n.d.). Dams have also blocked the transport of LWD from the upper watershed. Additionally, the lack of channel migration has halted critical processes needed for riparian regeneration and the input of LWD. The functional riparian corridor has also been reduced as land was reclaimed to increase farmable areas (McBain and Trush 2000). For more detail, see Chapter 2, *Aquatic Ecosystem Stressors in the Tuolumne River*, Section 2.2, *Physical Habitat Loss or Alteration*.

Multi-year research programs[4] have identified several limiting factors to Chinook salmon production and survival which include but are not limited to reduced spawning gravel quantity and quality, egg mortality from redd superimposition, and low egg survival-to-emergence; and reduced and degraded fry and juvenile rearing habitat (McBain and Trush 2000). The effects of degraded in-channel habitat on Chinook salmon are listed below (Table 7-1).

[3] La Grange Dam (constructed in 1893), Old Don Pedro Dam (completed in 1923) and New Don Pedro Dam (completed in 1971; located downstream, and results in submergence, of Old Don Pedro Dam).

[4] Conducted by Tuolumne and Modesto Irrigation Districts, the U.S. Fish and Wildlife Service, and the California Department of Fish and Wildlife (then California Department of Fish and Game).

Table 7-1. Habitat Stressors from Human Manipulation of Habitat in the Tuolumne River, and Their Effects on Chinook Salmon.

Habitat Stressors	Effects
Loss of coarse sediment supply and transport	• Reduced spawning habitat quantity and quality. • Reduced exposed bars, reducing rearing habitat along lateral bar features. • Coarsening of bed surface, reducing spawning habitat quality.
In-channel gravel extraction and gold dredger mining	• Reduced spawning and rearing habitat area. • Increased habitat availability for non-native fish species that prey on juvenile salmon, reducing smolt out migration success. • Reduced ability of river to route coarse sediment through reaches, decreasing spawning and rearing habitat.
Loss of fine sediment transport capacity	• Accumulation of in-channel fine sediment storage, reduced adult holding habitat and emergence success. • Infiltration of fine sediments into spawning gravels decreases emergence success. • Increased embeddedness of surface particles degrades fry rearing habitat.
Loss of large woody debris	• Reduced nutrients supply and habitat structural diversity.

Source: Adapted from McBain and Trush (2000).

The amount of floodplain habitat, and the frequency with which inundation occurs under contemporary flow regimes, have been greatly reduced from the historic extent. On the Tuolumne River, over a century of habitat degradation from human activities has transformed the river from a dynamic, alluvial river to a fossilized channel between man-made dikes, or agricultural fields, or fossilized within riparian vegetation that has encroached into the low water channel (McBain and Trush 2000). The channel banks have become armored and stabilized with rip-rap which confines the river, and land has been reclaimed to increase farmable areas and for other urban uses. This confining does not allow stream-energy and nutrients from flows to naturally distribute onto adjacent floodplains and riparian vegetation, which causes a reduction in spawning and rearing habitat (McBain and Trush 2000). The resulting loss of lateral connectivity means a decrease in seasonal wetlands and riparian areas, which results in diminished productivity and a decrease in aquatic habitat quality associated with the communities that depend on these habitats (Cain et al. 2003; McBain and Trush 2002). For more detail, see Chapter 2, *Aquatic Ecosystem Stressors in the Tuolumne River*, Section 2.2, *Physical Habitat Loss or Alteration* and Section 2.4, *Predation*.

7.1.3 2018 Bay-Delta Plan's Recommendations to Other Agencies

The Program of Implementation (Chapter IV) in the 2018 Bay-Delta Plan[5] sets forth Recommendations to Other Agencies (Section C), consistent with the Porter-Cologne Water Quality Control Act, for implementation by agencies other than the State Water Board. These actions include improvements to habitat conditions both inside and outside of the Bay-Delta Estuary, many of which are under the authorities of other agencies. The State Water Board recognizes and incorporates recommendations to other agencies, in the Program of Implementation, as part of the overall effort

[5] Available on the State Water Board website at 2018 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary.

to comprehensively address Delta and tributary ecosystem needs. The non-flow assets addressing spawning and rearing habitat that are included in the proposed TVA are similar to several of the recommendations in the 2018 Bay-Delta Plan below.

7.1.3.1 Expand the Gravel Replacement and Maintenance Programs for Salmonid Spawning Habitat

Action 5. from the Recommendations to Other Agencies is excerpted below.

> The presence of dams on the major tributaries of the Delta blocks the movement of gravel eroding from upstream areas and causes fine sediments to infiltrate the remaining gravels. Reduction in the riverbed gravels required for salmonid spawning limits the success of chinook salmon and steelhead trout reproduction in the watershed of the Bay-Delta Estuary.
>
> Under the AFRP,[6] and other gravel replacement and maintenance programs, the DWR, the USBR, and other agencies that currently conduct gravel replacement and spawning habitat improvement programs on the Sacramento and San Joaquin River systems should continue and, where possible, increase their efforts in the reaches where salmonids are likely to spawn.

7.1.3.2 San Joaquin River Non-Flow Actions

Recommendations to other agencies for non-flow actions specific to the lower San Joaquin River watershed are described.

Restore, Enhance, and Protect Floodplain and Riparian Habitat

> The USCOE, USBR, DFW, USFWS, FERC licensees, water districts, local landowners, and other appropriate entities should undertake, participate in, fund or authorize riparian and floodplain habitat corridor restoration, enhancement and protection actions along the LSJR and its tributaries, including but not limited to the following:
>
> a) Obtain easements or acquire land for riparian and floodplain habitat restoration.
>
> b) Reduce salmon stranding events in ponds, pits, and other unnatural features by physically modifying problem areas within river corridors.
>
> c) Facilitate the establishment and maintenance of self-sustaining native riparian and floodplain vegetation.
>
> d) Restore, enhance, and protect secondary/side-channel habitats to increase habitat diversity and function within the Stanislaus, Tuolumne, and Merced Rivers.
>
> e) Import silt or fine sediment onto floodplain restoration projects to improve soil moisture properties and encourage riparian vegetation success.
>
> f) Identify locations in the LSJR and its tributaries that are appropriate for levee modification (e.g., rip-rap removal and levee set back or removal) for the purpose of improving native fish and wildlife habitat.

Provide and Maintain Coarse Sediment for Salmonid Spawning and Rearing

Action 10.iii. from the Recommendations to Other Agencies is excerpted below.

[6] Anadromous Fish Restoration Program.

Provide and Maintain Coarse Sediment for Salmonid Spawning and Rearing: DWR, USBR, DFW, USFS, NMFS, FERC, FERC licensees and other entities performing or otherwise participating in habitat restoration, enhancement and protection projects should provide and maintain an adequate supply of coarse sediment for salmonid spawning and rearing habitat. In addition, entities that can control contributions of fine sediment in the Stanislaus, Tuolumne, and Merced River watersheds should reduce the input of fine sediment in spawning areas. These actions include but are not limited to the following:

a) Develop and maintain coarse sediment management plans for the major LSJR tributaries that consist of two temporal stages: (1) short-term restoration and gravel augmentation to re-build spawning habitat and to restore functional processes important to native fish and wildlife; and (2) long-term course sediment augmentation program to maintain the functioning of the restored habitat and to compensate for the blockage, by dams, of the natural gravel supply.

b) Develop and implement erosion control measures including the construction of sediment retention basins within the Stanislaus, Tuolumne, and Merced River watersheds.

c) Identify and remediate unpaved roads or other disturbed areas that may be contributing to fine sediment input.

Enhance In-Channel Complexity

Action 10.iv. from the Recommendations to Other Agencies is excerpted below.

Enhance In-Channel Complexity: The DFW, USFWS, NMFS, FERC, FERC licensees, conservation groups, water districts and other appropriate entities should enhance in-channel complexity within the LSJR tributaries by adding instream structures, including but not limited to the following:

a) Add boulders, large woody debris, or other structures where appropriate in river channels, taking human safety into consideration.

b) If large woody debris or coarse sediment is removed from upstream reservoirs, it should be transported downstream and placed into the Stanislaus, Tuolumne, and Merced Rivers due to that reservoir's contribution to deficits of large woody debris and coarse sediment supply in these rivers.

7.2 Habitat Restoration

Stream enhancement techniques targeting spawning and rearing habitat (in-channel and floodplain), such as those included as non-flow assets in the TVA proposal, are designed to mitigate degraded river conditions by improving habitat lost to human manipulation of the river corridor. For spawning habitat restoration (used interchangeably with enhancement) specific to the Tuolumne River, McBain and Trush (2000) recommended course sediment supply be increased and fine sediment supply be reduced. In-channel augmentation with wood, boulders, gravel, and other structures increases habitat complexity by altering channel morphology and provides cover and habitat for fish and other biota (Roni et al. 2013). The non-flow assets include 77 acres of newly constructed habitat which will be inundated at the proposed flows and include rearing/floodplain projects (see Section 3.1.2, *Non-flow Assets*). The construction of floodplain habitats is a common restoration technique that can be an important component of habitat enhancement to replace natural floodplain channels that have been degraded (Beechie et al. 2001). The addition of specific acreages at specific locations in fulfillment of the rearing/floodplain non-flow assets under the TVA is uncertain currently; however, this qualitative evaluation applies generally to the construction of floodplain habitats.

The section below describes some supporting studies that show the expected benefits from the enhancement techniques in the TVA proposal. Literature regarding habitat enhancement techniques and their effects is extensive, therefore only a small number of papers are presented as examples. The studies described below largely were performed in the Central Valley or Pacific Northwest and include salmonid(s)[7] as a group of interest. Methodologies include, but are not limited to, pre and post monitoring of restoration areas, habitat type comparisons, treatment vs. paired reference comparisons, literature reviews and meta-analyses.

7.2.1 Spawning Habitat

7.2.1.1 Gravel Augmentation

Salmonids have historically (i.e., post dam construction) used the 25-mile reach of the Tuolumne River between La Grange Dam and the town of Waterford for spawning (USFWS 1995); however, spawning studies have shown spawning preferences generally decrease from upstream to downstream (for more detail see Chapter 2, *Aquatic Ecosystem Stressors*, Section 2.1, *Physical Habitat Loss or Alteration*). A comparison of spawning habitat area from 1999–2001 to historical estimates showed a potential loss of 1.8 million ft^2 or 73% decrease in habitat area (McBain and Trush 2004). The loss of course sediment supply to the lower Tuolumne River (i.e., downstream of La Grange Dam) can be mitigated by gravel augmentation which is a common restoration technique implemented where dams or other obstructions have cut off gravel transport and sediment supply. In the Central Valley, regular gravel supplementation in spawning areas has become a significant component of salmonid spawning habitat restoration projects (TID and MID 2007). It is used to temporarily improve or create spawning habitat for salmon, trout, or other species that require gravel substrate to complete reproduction (Roni et al. 2013; Wheaton et al. 2004). Studies described below have shown that the addition of spawning gravel can benefit salmonids and macroinvertebrates.

On the Mokelumne River, Merz and Setka (2004) evaluated the effectiveness of a project to enhance spawning habitat for Chinook salmon. The authors tested the hypothesis that gravel augmentation would attract spawning adult Chinook salmon due to improved physical characteristics, specifically depths, water velocities, and intergravel water quality. Physical measurements were taken before and after gravel augmentation by employing topographic channel surveys, pebble counts, hydrologic data analysis, and redd surveys. Results indicated Chinook salmon responded immediately to the enhanced site, began spawning within 2 months after gravel augmentation, and continued to use the site during the three spawning seasons encompassed by the study. Several habitat features known to influence habitat suitability were all positively affected by the enhancement. Stream velocity, gravel permeability, and dissolved oxygen all increased; and conversely, depths, intergravel water temperature, turbidity, and total suspended solids all decreased. While the authors concluded that gravel enhancement can be an effective means for improving salmon spawning habitat in rivers where upstream dams affected gravel recruitment, they cautioned that its usefulness in restoring salmon populations is poorly understood. Additionally, while augmentation can provide immediate physical improvements to specific sites, the longevity and effects of this type of enhancement to the entire system is unknown. The authors acknowledged salmon production can also be greatly influenced by annual variation in other factors, such as precipitation, ocean conditions, water diversion rates, and predation rates.

[7] Studies with Chinook salmon were included when available.

In another study on the Mokelumne River, Merz and Chan (2005) evaluated the effects of gravel augmentation on macroinvertebrate assemblages. The authors tested the hypothesis that density, biomass, species richness, diversity, and evenness will be influenced post-augmentation. Physical and biological measurements were taken before and after gravel augmentation by employing topographic channel surveys, pebble counts, and the collection of benthic macroinvertebrates. Results indicated new gravel was quickly incorporated into the stream ecosystem and exploited by the resident macroinvertebrate community. At four weeks post-augmentation, macroinvertebrate richness, diversity, and evenness were similar to adjacent unenhanced gravel areas; and at 12 weeks post-augmentation, the macroinvertebrate assemblage density and biomass were significantly higher than in adjacent unenhanced gravel areas.

On the Tuolumne River, the Bobcat Flat restoration project pre- and post-restoration monitoring evaluation results showed a significant positive change in habitat for fall-run Chinook salmon spawning (Figure 7-1). The Bobcat Flat restoration project began in 2001 as part of the Central Valley Project Improvement Act (CVPIA) Instream Flow and Fisheries Investigations, which included gravel augmentation that focused on in-channel restoration. USFWS (2013) stage-discharge relationship analyses indicated positive increases in post-restoration habitat quantity for steelhead trout spawners at higher flows and an increase for steelhead trout rearing fish at lower flows. The stage-discharge relationships for fall-run Chinook salmon rearing did not show such a significant positive change, but they were expected to improve in the long-term once riparian vegetation regrew from construction (not shown.)

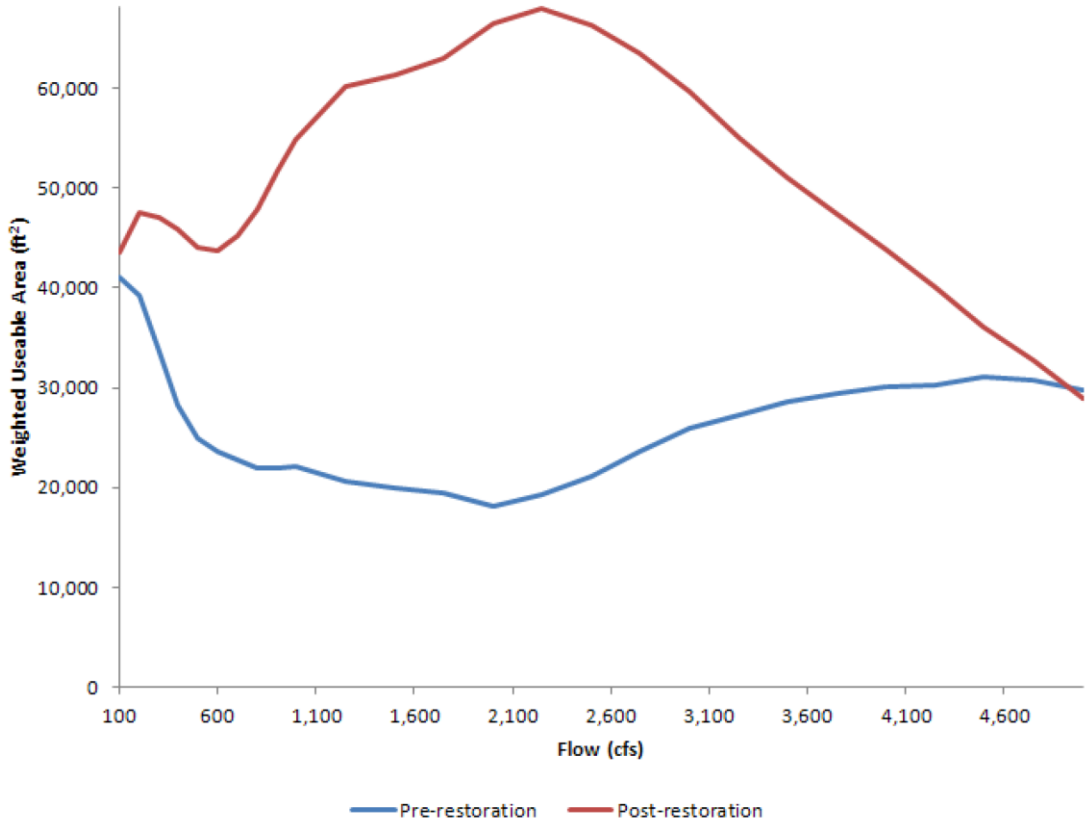


Figure 7-1. Fall-Run Chinook Salmon Fish-Habitat Relationships at the Bobcat Flat Restoration Site on the Tuolumne River (Source: USFWS 2013).

In three Norway rivers, Pulg et al. (2022) evaluated the functioning of gravel additions in a long-term study over a period of 18 years. The authors hypothesized that gravel augmentation would improve sedimentologic spawning conditions and increase both egg survival and fry densities for Atlantic salmon (*Salmo salar*) and Brown trout (*Salmo trutta*). In eight of the oldest known gravel augmentation sites, changes in sediment quality, egg survival, and juvenile abundance were measured to capture the effect on the target fish species. After gravel additions, measurements of interstitial oxygen concentrations indicated good incubation conditions. In total, all gravel sites on all three rivers had an average egg survival of 90.2% after gravel augmentation in all monitored years. Additionally, juvenile fish densities increased after spawning habitats were established. Spawning activity, high egg survival, and the significant increase in fry densities after gravel augmentation indicated the in-channel restoration functioned as hypothesized.

7.2.1.2 Gravel Cleaning

Gravel quality is an influencing factor on the success of incubation and emergence of salmonid eggs and alevins. Poor gravel quality due to the infiltration of fine sediments can reduce survival by decreasing the availability of oxygen and the removal of metabolic wastes and entrap emerging fry (Cooper 1965; Kondolf 2000). In 2001, Stillwater Sciences completed a survey to estimate the volume of fine sediment deposits within the Tuolumne River channel and found that, in general, all streambed surface and subsurface substrates contained a large volume of fine sediments (McBain and Trush 2004, Appendix E). The reduced quality of spawning habitat has in turn reduced the productive capacity of spawning reaches and concentrated Chinook salmon in a smaller spawning reach which has reduced the survival of salmonid embryos (McBain and Trush 2000; McBain and Trush 2004). In the Central Valley, gravel cleaning has been implemented as a habitat restoration technique in Putah Creek (Coastal Conservancy 2016; Davis 2016) and recommended on the Tuolumne River (TID and MID 1992; McBain and Trush 2000; McBain and Trush 2004, Appendix F) to improve spawning gravel quality.

In a review relating sediment quality to egg-to-fry survival for steelhead trout (*Oncorhynchus mykiss*), Chinook salmon, Chum salmon (*Oncorhynchus keta*), and coho salmon (*Oncorhynchus kisutc*) in the Pacific Northwest, Jensen et al. (2009) evaluated the importance of fine sediment deposition to early salmonid survival and found that increasing amounts of fine sediments in stream substrates reduced egg-to-fry survival for salmonids. The authors found statistically significant linear relationships between the proportion of fine sediment and egg-to-fry survival. Of the various sizes of fine sediments evaluated, fine sediment at the smallest size class (<0.85 mm) had the largest impact on survival with survival dropping rapidly when redds contained greater than 10% <0.85 mm sized fractions.

A same type of meta-analysis performed by Kemp et al. (2011) showed similar results. A compilation of published data was evaluated on the range of survival to hatching stage of Atlantic salmon (*Salmo salar*) eggs in relation to the amount of fine sediment within spawning gravels. Results indicated a decrease in survival as the amount of fine sediment increased (Figure 7-2).

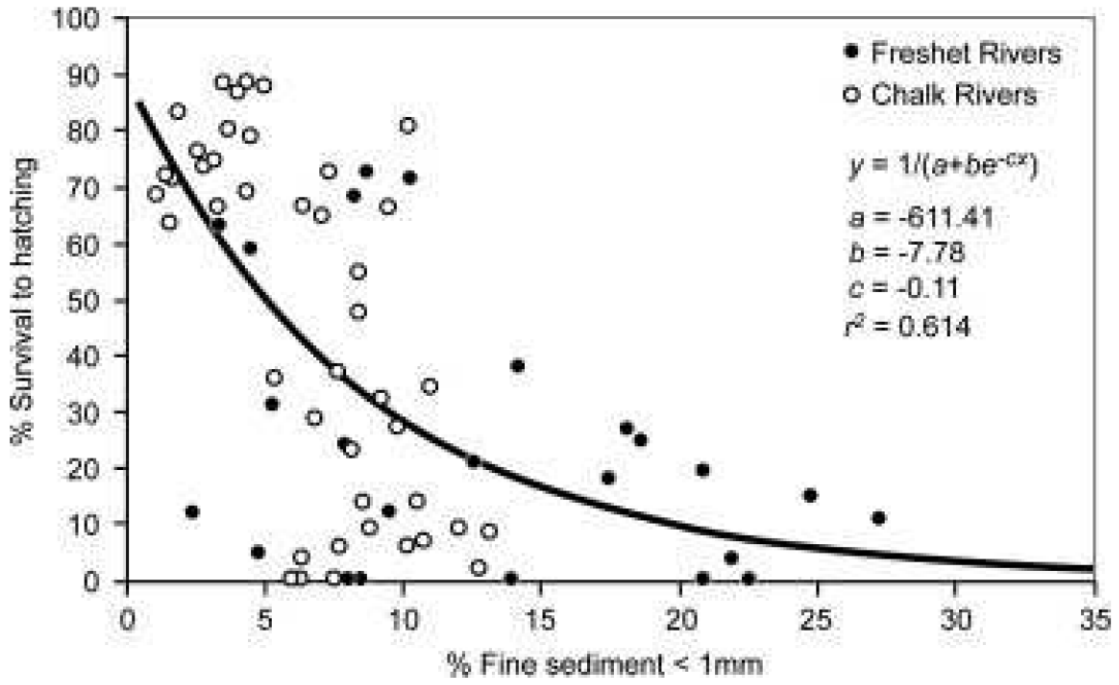


Figure 7-2. Atlantic Salmon Embryo Survival Rate as Fine Sediment Increases (Source: Kemp et al. 2011).

Sternecker et al. (2013) evaluated effects on the biotic and abiotic environmental parameters from excavating substratum in a highly impacted gravel bar. The authors hypothesized removal of fine sediment at the restored area would increase the hatching success of brown trout (*Salmo trutta*) eggs due to improved hydraulic exchange of the interstitial zone. Additionally, authors expected macroinvertebrate composition to be affected. The abiotic physiochemical parameters monitored included dissolved oxygen, temperature, redox potential, specific conductance, pH, and concentrations of nitrate, nitrite, and ammonium which were measured 18 days before, as well as one day and three months post-restoration. Biotic parameters monitored included the composition of benthic macroinvertebrates and brown trout egg abundance. Results indicated the reduction of fine sediment caused an increase in exchange rates between surface water and the hyporheic zone which had positive effects on salmonid hatching success and macroinvertebrate composition. After excavation: the substratum composition at the restoration site had a significantly lower fraction of fines and the proportion of fines decreased even further three months post-restoration; physiochemical habitat conditions had the greatest change from pre-restoration conditions at three months post-restoration; the hatching success of brown trout eggs increased from 0% in the spawning season one year before the restoration to 77% after the restoration and the number of macroinvertebrate taxa doubled at three months post-restoration.

The TVA proposal includes cleaning selected gravel patches for two to three weeks for 5 years to expand the availability of high-quality gravel which would improve spawning success and egg-to-emergence survival for fall-run Chinook salmon. In a technical memorandum from Stillwater Sciences in 2001 (McBain and Trush 2004, Appendix F), staff asserted that cleaning interstitial deposits (and source control) may be the most effective means of improving productivity of the available spawning habitat. However, any entity implementing a gravel cleaning project needs to

consider there are various cleaning techniques available (i.e. hydraulic and mechanical) which may have varying negative ecological impacts such as a temporary decline in spawning use and disturbance of the invertebrate community due to the disruption of gravel and interstitial spaces (McBain and Trush 2004, Appendix F; TID and MID 1992).

7.2.1.3 Large Woody Debris Augmentation

The Don Pedro and La Grange dams have cut off the supply of LWD from the upper Tuolumne River Basin such that only local riparian sources, which are severely degraded themselves, provide inputs (FERC 2020; McBain and Trush 2000; Stillwater Sciences 2017). LWD functions to enhance the quality of fish habitat and plays an important role in the creation and maintenance of fish habitat throughout entire rivers. The beneficial functions that LWD provides include the creation of pools, increase in habitat complexity, reduction in sediment transport, trapping of gravel needed for spawning, stabilization of stream channels, food provisions for aquatic invertebrates, stream nutrient enhancement, and cover from predators (Bisson et al. 1987; Dolloff and Warren, Jr. 2003). A common restoration technique to offset the loss of LWD is augmenting the river channel with wood substrates[8] (Roni et al. 2013; Roni et al. 2015). Studies described below have shown that the addition of LWD can benefit salmonids, invertebrates, and periphyton.[9]

In various Oregon and Washington streams, Roni and Quinn (2001) evaluated the responses of juvenile salmonid populations to LWD augmentation. The objectives of the study were to determine whether the artificial placement of LWD would produce a significant change in physical habitat and juvenile abundances of Coho salmon, Cutthroat trout (*Oncorhynchus clarki*), and steelhead trout. The authors compared differences in habitat, LWD, and fish abundance between treatment and reference reaches in 30 streams after restoration during the summer and winter. Results indicated that the physical habitat features of the treatment sites responded as expected to LWD placement: the total number of pieces of LWD and the total number of functional pieces[10] of LWD was significantly higher in treatment sites. Treatment sites had higher wetted area, total number of habitat units, total pool area, and total number of pools during both summer and winter. Results also indicated a beneficial effect on salmonid densities. Coho salmon densities were higher in summer and there was a positive linear relationship between the response of those densities and the number of pieces of functioning LWD. In the winter, Coho salmon, cutthroat and steelhead trout densities were higher in treatment sites.

In a meta-analysis of 51 different studies encompassing 211 projects, Whiteway et al. (2010) tested the effectiveness of using different types of instream structures (LWD will be the only type discussed) on changes in salmonid abundance and physical habitat characteristics including percent pool and riffle areas, mean stream width, number of pieces of LWD, percent cover, and mean stream depth. Augmentation with LWD had significant effects on the physical habitat characteristics of the streams including an increase in pool area with increased number of pieces of LWD. In addition, salmonid numbers significantly increased from augmentation efforts: 73% of projects resulted in increased local salmonid densities and 87% of projects increased in biomass. However, studies that involved monitoring for five or more years after restoration showed a significant lower salmonid

[8] Methods of augmentation range from falling, pushing, or hauling trees from the riparian zone into the active stream channel to construction of highly engineered structures such as log weirs or logjams.

[9] A community found on submerged surfaces in aquatic systems which consists of algae, cyanobacteria, heterotrophic microbes and detritus.

[10] Primary factor contributing to pool formation.

density increase. The authors acknowledged that long-term monitoring on the effect of in-stream structures is needed (Kondolf and Micheli 1995; Roni et al. 2008). To allow for the evaluation and tracking of physical changes (i.e., geomorphological adjustments) in the river channel after restoration is completed. Kondolf and Micheli (1995) recommend no less than ten years of monitoring post-restoration.

In two large river systems in Western Washington, Coe et al. (2009) evaluated the role of wood in providing habitat for lower trophic levels by measuring periphyton biomass and invertebrate density and community structure by collecting 3 years of logjam data after placement. The authors considered both direct and indirect effects of wood by sampling wood and cobble substrates in reaches with introduced logjams and by sampling cobble substrates in reaches without introduced or naturally occurring logjams. The authors hypothesized that the direct effects would include higher periphyton biomass and invertebrate density on wood than on cobble substrates and that invertebrate community composition would differ on cobbles and wood. The authors also hypothesized that an indirect effect would be greater periphyton biomass and increased invertebrate density on cobbles in reaches with wood compared to cobbles in reaches without wood. Results indicated periphyton biomass and invertebrate densities were significantly higher on logjams than on cobbles within the same reach: periphyton were as much as 1.5 to 8 times higher on wood (depending on sample and river) and invertebrates were 2 to 5 times higher (depending on sample and river). Invertebrate community composition also differed: meiofauna[11] dominated the community on wood substrates whereas chironomids dominated cobble substrates. The authors did not find significant indirect effects.

In a literature review of the current knowledge from LWD augmentation studies, Roni et al. (2015) addressed several topics which have been the subject of controversy regarding the efficacy and success of restoration projects and studies employing LWD augmentation. Among the topics addressed are the physical response of stream channels to augmentation and, acknowledged by the authors as perhaps the most important, the biological response to augmentation. The literature showed augmentation typically leads to improvements in physical habitat attributes including increased pools, cover, habitat complexity, and other measures of aquatic habitat important for fish. Of the 83 papers reporting a physical response (other than structural stability) post-augmentation, 77 papers indicated a positive response for at least one habitat attribute. The literature also showed positive responses in salmonid abundances following augmentation. Of the 96 papers reporting biological responses to LWD augmentation, 81 included changes in fish abundance, biomass, species diversity or richness, or survival; and of those, 68 reported positive responses. According to Roni et al. (2015), the most thorough meta-analysis, of papers reviewed, was conducted by Whiteway et al (2010) which showed positive results for salmonids[12] post-augmentation (Figure 7-3).

[11] Includes cyclopoid and harpacticoid copepods, ostracods, mites, oligochaetes, nematodes and tardigrades,

[12] Whiteway et al. (2010) meta-analysis considered Chinook salmon, as well as the other salmonids listed in Figure 7-3, however, of the studies reviewed fewer than 10 included data on Chinook salmon responses and therefore were not included in the comparison of individual species.

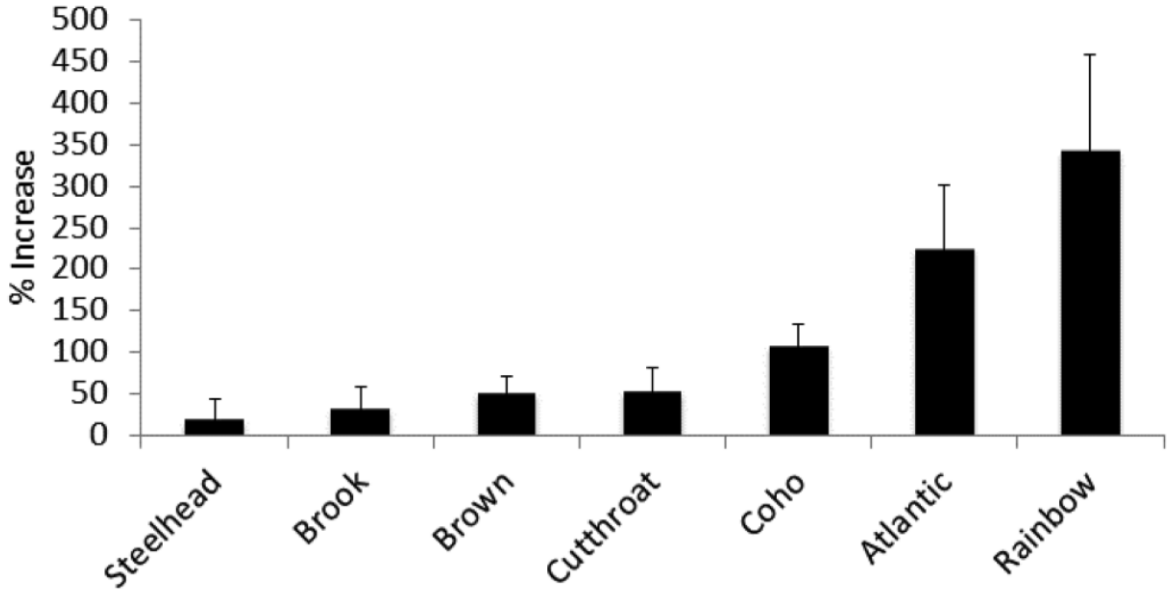


Figure 7-3. Fish Responses to LWD Augmentation and Other Instream Habitat Improvement Projects Shown as Percent Increases of Various Salmonid Species (Original Examination by Whiteway et al. 2010).

While LWD augmentation can provide important benefits to salmonid species including habitat complexity and cover from predators, it does not address the underlying process that delivers wood to stream channels. To provide high quality habitat in the long-term will require a sustained input of natural wood by combining LWD augmentation with restoration of riparian and upslope processes that are natural sources of woody debris (Roni et al. 2015). There is also a potential for LWD to negatively impact salmonid species by providing feeding habitat for predators. During periods of low flows, toppled trees and subsequent pools created by LWD may provide habitat to predator species such as racoons, herons, and water snakes (Dolloff and Warren, Jr. 2003). Long term post-restoration monitoring is also necessary to evaluate possible structure failure over time and physical changes in the river channel (Kondolf and Micheli 1995).

7.2.2 Rearing Habitat

7.2.2.1 Constructed Habitat

This section describes supporting studies that show the expected benefits from constructing floodplain. Roni et al. (2005; 2008; 2013) performed literature reviews on various floodplain enhancement techniques and found numerous studies supporting that constructed floodplains can be particularly effective at both providing habitat for and increasing the survival of juvenile salmonids. Literature regarding habitat enhancement techniques and their effects is extensive, therefore only a small number of papers are presented as examples.

On two Oregon streams, Solazzi et al. (2000) evaluated the effects of increasing winter rearing habitat on the abundance of salmonids.[13] Prior investigations suggested the amount and complexity of winter habitat was limiting coho salmon populations in Oregon. The authors used a before-after-control-impact experimental methodology to look at the effects of excavating off-channel rearing ponds (alcoves), creating large dam pools in-channel, and adding LWD. The study design included four streams, with two treatment streams being compared to two reference streams, thus allowing the authors to assess changes in habitat and fish population parameters. Summer and winter habitat surveys were used to estimate the amount of available habitat; snorkeling and electrofishing was used to estimate fish abundance; and plane traps were used to estimate the number of downstream migrants. The study showed that the creation of new off-channel habitats, marginal in-channel improvements and the addition of LWD[14] resulted in increased winter rearing habitat by 7 to 13-fold depending on treatment stream. Post habitat enhancement, the abundance of coho salmon smolts increased by two-fold in the treatment streams when compared to the reference streams. The increase in winter habitat not only benefited coho salmon smolt abundance, but steelhead and cutthroat trout as well, most likely due to the increase in habitat parameters that provide suitable depths, velocities, and cover.

In the Chilliwack River watershed in British Columbia, Ogston et al. (2015) evaluated the effectiveness of restoring floodplain habitat on increasing coho salmon smolts. Objectives for this study included determining production from restored habitat and to investigate the degree to which large-scale restoration increased overall production of coho salmon smolts at the watershed scale. The watershed has a history of impacts from logging activities resulting in reduced channel complexity and degradation of off-channel habitat. Consequently, off-channel enhancement became a common tool in aquatic rehabilitation in the early 1990s (Cleary 2001). Seven major off-channel habitat restoration projects[15] consisting of construction and reconnection of floodplain habitats to the mainstem (two projects also included construction of extensive spawning habitat[16]), added a total of 157,000 m^2 of new habitat between 1996 and 2000. In 2002, two methods of population sampling were employed to estimate smolt production from restored habitats and total watershed production: a marking program using weir traps were installed at the outlets of five of the restoration sites, and a rotary screw trap was installed downstream on the mainstem of the Chilliwack River. Trap capture efficiency was estimated from the downstream rotary screw trap, which in conjunction with capture of unmarked smolts, allowed for an estimate of population size of outmigrants from the entire upper watershed. Total coho smolt production supported by restored habitat was in the range of 27–34% which was a significant increase when considering the size of the watershed (600 km^2) and total upper watershed outmigrants (247,200). This study indicated the construction of off-channel habitat at multiple sites throughout the floodplain of a large river can result in a considerable increase in salmonids.

[13] Study species include juvenile coho salmon, age-0 trout (*Oncorhynchus spp.*), steelhead, and coastal cutthroat trout. The study was originally designed to examine changes in abundance of coho salmon smolts. However, the authors also collected information on two sympatric but less abundant species, steelhead and coastal cutthroat trout.

[14] For more detail on the benefits of large woody debris augmentation, see Section 7.2.1.3, *Large Woody Debris Augmentation*.

[15] Initiated by Fisheries and Oceans Canada in conjunction with the BC Ministry of Environment Watershed Restoration Program.

[16] For a discussion of the benefits of in-channel habitat enhancement projects anticipated to improve spawning habitat, see Section 7.2.1, *Spawning Habitat*.

In western Washington, numerous floodplain habitat enhancement projects have been completed with the intent of increasing salmonid production (Roni et al. 2006). Studies suggest such floodplain projects have been successful at creating rearing habitat for coho salmon and other fishes (Morley et al. 2005; Giannico and Hinch 2003); however, the relationships between smolt productivity and floodplain habitat quality lacked evaluation. Roni et al. (2006) evaluated existing data[17] (1987 - 2000) at 30 sites on coho salmon smolts in the Skagit, Stillaguamish, Quillayute, and Hoh River basins to compare smolt production, density, and mean length among different types of floodplain habitats which were categorized based on morphology (pond or channel) and type (natural or constructed). The authors also evaluated how project size influenced smolt production and how smolt size and density was correlated with physical parameters including: distance from saltwater, perimeter, shoreline irregularity, mean depth, percent littoral habitat, and percent cover. For the comparison of different habitat types, results indicated a pond morphology (i.e., off-channel) produced larger smolts than a channel morphology. Also, results indicated that constructed floodplain habitats produced coho salmon smolts of similar size and density when compared to natural floodplain habitats. For the comparison of project sizes, total wetted area explained much of the variation in smolt density and production among project sites. The physical parameters with the most influence on the data were: shoreline irregularity was positively correlated with smolt density and negatively correlated with smolt length among project sites.

7.2.2.2 Growth Benefits in Floodplains

Among the many benefits (see Section 7.1.1, *Habitat Effects on Aquatic Species*) that floodplains provide are enhanced rearing opportunities (i.e., prey availability) and increased growth to juvenile salmonids. Studies supporting these findings have been conducted in the Delta watershed tributaries (Sacramento and Cosumnes Rivers) and are summarized below.

On the Sacramento River and adjacent Yolo Bypass,[18] Sommer et al. (2001) evaluated the relative importance of floodplain habitat[19] versus riverine habitat to juvenile chinook salmon by comparing indicators of habitat quality: salmon growth, feeding success, and survival. Beach seines were used at multiple locations in both habitats to collect data on salmon fork lengths to determine if there were major differences in salmon sizes. This study did not provide definitive evidence of growth differences; therefore, individuals from paired releases of coded-wire-tagged fish were captured at Chipps Island (from releases upstream in both habitats) thus allowing comparisons of growth differences and a relative estimate of migration time and survival. Temperature and flow data were collected and invertebrates were also sampled for information on whether variation in salmon diets between the river and floodplain was consistent with gross differences in prey type and relative abundance.

Results indicated that floodplain habitat provides important rearing opportunities for Chinook salmon. The mean length of juveniles captured in beach seines increased faster in the Yolo Bypass when compared to the Sacramento River. For the paired coded-wire-tagged releases, individuals were larger and had higher apparent growth rates for fish released in the Yolo Bypass when

[17] Monitored by the Washington Department of Fish and Wildlife and Skagit River System Cooperative.

[18] A 24,000-hectare agricultural floodplain basin that conveys excess flow from the Sacramento Valley, including the Sacramento River, Feather River, American River, Sutter Bypass, and westside streams.

[19] It should be noted that the floodplain in this study was the Yolo Bypass which has different conditions (i.e., dominated by agricultural uses) than overbank areas adjacent to the Tuolumne River. However, the Yolo Bypass probably provides similar functions to more "natural" floodplains (Sommer et al. 2001).

compared to Sacramento River releases. Additionally, survival estimates were somewhat higher for Yolo Bypass releases; however, recoveries were too few for any differences to be statistically significant. The Yolo Bypass had significantly higher temperatures (around 5 to 10°C; due to the shallower depths on the broad floodplain) and one to two orders of magnitude greater drift invertebrates which explained the differences between apparent growth rates in the two habitats. The higher prey availability, measured as prey biomass (see Figure 7-4a), in the Yolo Bypass led to juveniles consuming significantly more prey items which resulted in increased feeding success. Using prey biomass as a measure of feeding success is limited due to temperature affecting how consumption alters growth rate; therefore, the authors used bioenergetic modeling to incorporate the metabolic effects of temperature to produce a wet weight ration index (Figure 7-4b) as another measure of feeding success. Bioenergetic modeling indicated increased prey availability was sufficient to offset increased metabolic requirements from the higher water temperatures.

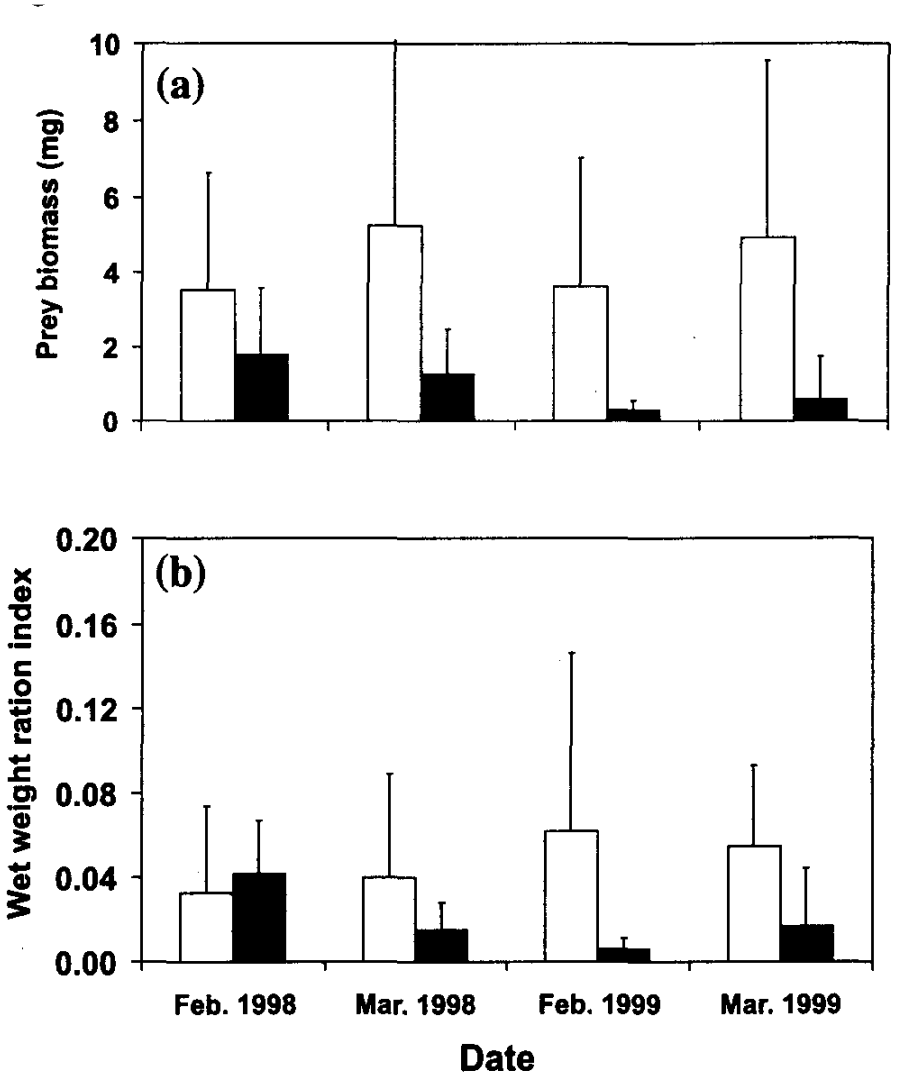


Figure 7-4. Feeding Success Compared Between Sacramento River (Closed Bars) and Yolo Bypass (Open Bars) (Source: Sommer et al. 2001).

On the Cosumnes River, Jeffres et al. (2008) built on the evaluation performed by Sommer et al. (2001) to further assess juvenile Chinook salmon growth differences in the river and floodplain. Unlike Sommer et al., 2001, the authors placed juveniles in enclosures in a permanent pond and two ephemeral habitats on the floodplain, and two locations in the river. For this growth study, fork lengths were measured at various intervals after deployment of the enclosures, diet analysis was performed on selected individuals to determine potential prey items, and temperature and flow data were collected. Results indicated that juveniles grew largest in ephemeral floodplain habitats (see Figure 7-5). The diets of juveniles were dependent on rearing habitat: juveniles consumed benthic macroinvertebrates (river), or zooplankton and benthic macroinvertebrates (floodplain). Although differences in prey abundances were not evaluated in this study, Grosholz and Gallo (2006) performed a study in the same area which indicated zooplankton biomass was 10 to 100 times greater in floodplain habitat when compared to river habitat. From the findings in this study and Sommer et al. (2001), Jeffres et al. concluded that restoring floodplain habitats should have major benefits to Chinook salmon populations.



Figure 7-5. Fork Length and Overall Health Condition Differences in Fish Reared for 54 Days in River Habitat (Length) and Floodplain Habitat (Right) (Source: Jeffres et al. 2008).

7.2.3 Summary of Potential Benefits

The three different techniques of in-channel habitat enhancement (i.e., gravel augmentation, gravel cleaning, and LWD augmentation) and the construction of floodplain habitats in combination with the flow assets (see Chapter 3, *Description of Flow and Non-Flow Assets*) in the TVA proposal are intended to improve spawning and rearing conditions for fall-run Chinook salmon and *O. mykiss*. Studies were presented in this section showing supportive evidence that in-channel habitat enhancement actions will benefit the target species, other native fishes, and lower trophic levels. The addition of gravel is anticipated to provide greater spawning opportunities, increase spawning habitat suitability, improve incubation conditions and egg survival, increase salmonid juvenile densities, and increase habitat and density and biomass of the resident macroinvertebrate

community. The cleaning of gravel to remove fine sediment is anticipated to increase spawning opportunities, improve spawning habitat suitability and invertebrate composition, and improve hatching success. The addition of LWD is anticipated to increase habitat complexity, increase survival and densities of salmonids, increase invertebrate densities, and increase periphyton biomass.

Studies were also presented showing supportive evidence that additional floodplain habitat through off-channel construction projects will benefit juvenile salmonids. The additional floodplain habitat is anticipated to increase the amount of useable rearing area and the abundance and production of juvenile outmigrants. Studies also show that floodplain habitats are important for providing rearing opportunities through greater prey availability which can result in growth benefits to juveniles. Floodplain habitats are anticipated to increase the production and availability of drift invertebrates and increase the growth rates and sizes of outmigrating juveniles leading to potentially higher survival rates.

7.3 Habitat Modeling

7.3.1 Methods

7.3.1.1 Analytical Approach to Evaluating Non-Flow Assets

The effects of non-flow assets on habitat for fall-run Chinook salmon on the Tuolumne River during spawning and rearing were analyzed using daily flows produced representing flow under Existing Conditions, TVA commitments (TVA), and 30%, 40%, and 50% Unimpaired Flow (UF) Objective scenarios. Modeled flows were produced by the Water Supply Effects model. Hydraulic modeling to support effects of habitat restoration was conducted using the System for Environmental Flow Analysis model for eight (8) subreaches encompassing RM 52.2 - RM 0 (Stillwater Sciences 2012) and the two-dimensional TUFLOW floodplain model (HDR and Stillwater Sciences 2017). The modeled extents included in the hydraulic models are mapped in Figure 7-6 along with the locations of the simulated temperatures generated by the San Joaquin River Basin-wide HEC5Q model and the simulated flows generated by the Water Supply Effects model.[20] The outputs from the flow modelling were combined with flow-to-suitable habitat area relationships developed for spawning and rearing life stages of Chinook salmon generated using habitat suitability criteria and the hydraulic models. The effects of temperature on habitat availability were then applied by calculating the proportion of river miles on a given day that had suitable temperatures using output from the temperature models and multiplying the daily total habitat by that proportion.

[20] See Chapter 5, *Water Temperature*, for an evaluation of potential benefits to river temperatures from the TVA.

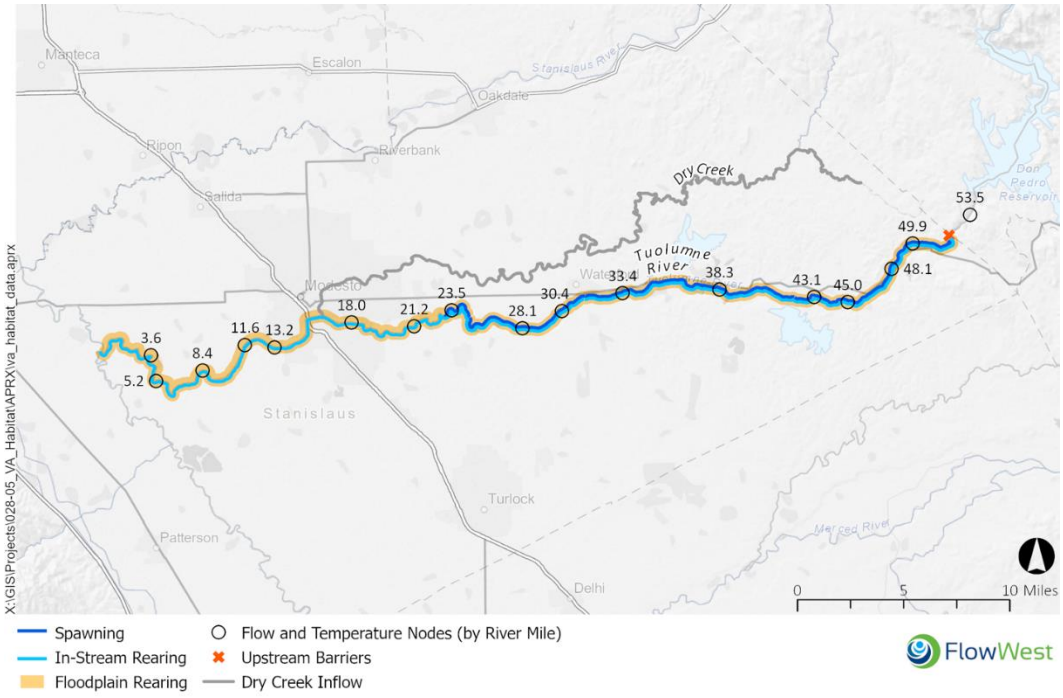


Figure 7-6. Map of Hydraulic Model Extents for Spawning (Dark Blue), Instream Rearing (Light Blue), and Floodplain Rearing (Gold) for the Existing Habitat Quantification. Flow and Temperature Nodes (Open Circles) Represent River Mile (RM) Locations of Simulated.

Spawning and Rearing Habitat Modeling Evaluation

This section explains the source of and the process used to acquire input data for the analysis of non-flow assets conducted to support the TVA process. Non-flow assets include constructed spawning, in-channel rearing, and floodplain rearing habitat for fall-run Chinook salmon and were evaluated under different flow scenarios. The analysis estimates the quantity of spawning and juvenile rearing habitat predicted to result from the TVA, Existing Conditions, and 30–50% UF Objective scenarios.

On the Tuolumne River, the fall-run rearing period was defined as January through June and the spawning period was defined as October through December, so these time periods were evaluated to determine potential habitat benefits of the scenarios for rearing juvenile and adult spawning salmonids, respectively. Spawning, in-channel rearing, and floodplain rearing flow-to-suitable-habitat area relationships (i.e., weighted usable area [WUA]) were developed using the TVA Habitat Suitability Criteria (Hume and Baker 2024). These analyses produced flow-to-suitable-habitat relationships for both existing conditions (Existing) and under the hypothetical TVA conditions (Existing + VA) which incorporate TVA non-flow habitat improvement (Figure 7-7 through Figure 7-9). The Existing Conditions and 30–50% UF Objective scenarios use the Existing flow-to-suitable-habitat relationship to estimate resulting suitable habitat acreage, while the TVA scenario used the Existing + VA flow-to-suitable-habitat relationship. Using the flow-to-suitable habitat relationships, modeled flow was converted into total suitable area (acres) for spawning, in-channel rearing, and floodplain rearing for each day from 1970–2003 for each scenario and summarized annually.

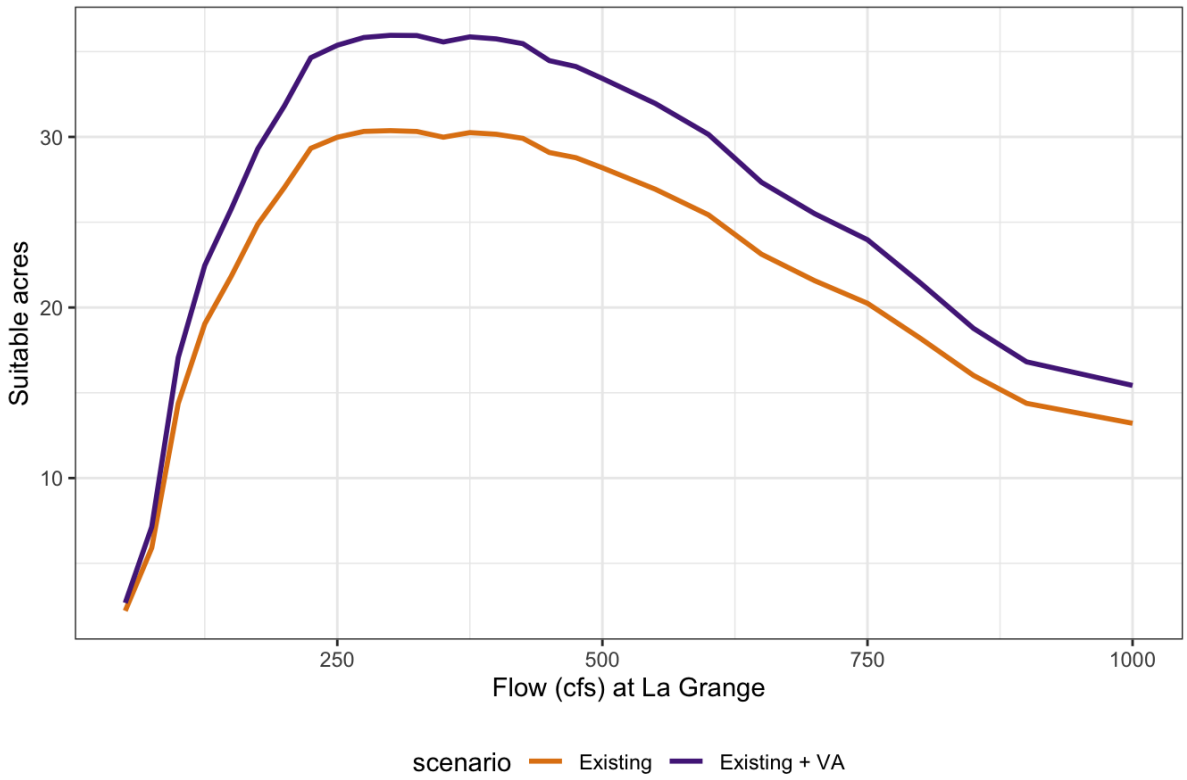


Figure 7-7. Flow-to-Suitable Spawning Habitat Relationships for the Tuolumne River Under Existing (Orange) and Existing + VA Conditions (Purple) (Hume and Baker 2024).

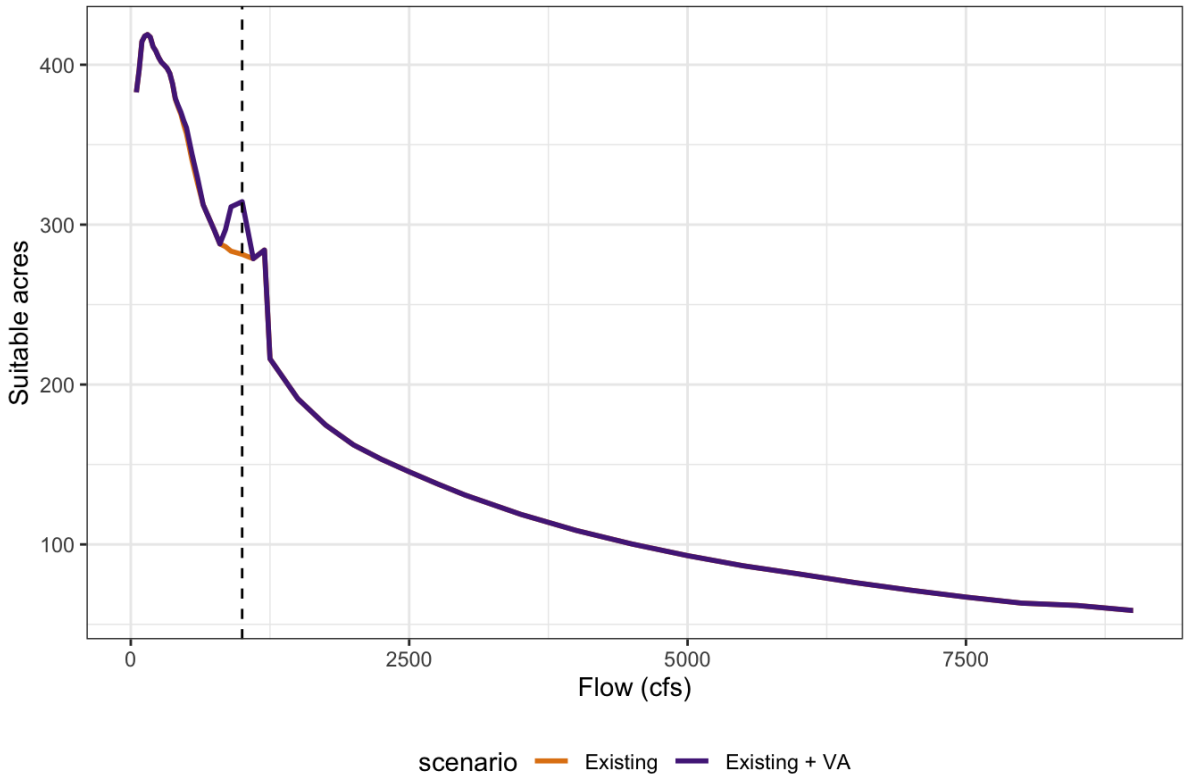


Figure 7-8. Flow-to-Suitable In-Channel Rearing Habitat Relationships for the Tuolumne River Under Existing (Orange) and Existing + VA Conditions (Purple). The Dotted Vertical Line Represents the Floodplain Inundation Threshold Value of 1,000 CFS (Hume and Baker 2024).

The scenarios were evaluated in terms of providing measurable, biologically important benefits of additional suitable spawning, instream rearing, and floodplain rearing habitat to fall-run Chinook salmon consistent with the suitable habitat quantification for the CVPIA (Peterson and Duarte 2020). Analyses are focused on habitat for fall-run Chinook salmon, and it is expected that habitat created for fall-run will also provide ancillary benefits to other runs and other native fish populations because of similar habitat suitability. For comparing TVA assets to existing and potential future conditions, the habitat needed to support the doubling goal population established in the CVPIA, Anadromous Fish Restoration Program (AFRP) were also estimated. These estimates were calculated using assumptions from the Emigrating Salmonoid Habitat Estimation model as applied in the Central Valley Flood Protection Plan Conservation Strategy (SJRRP 2012).

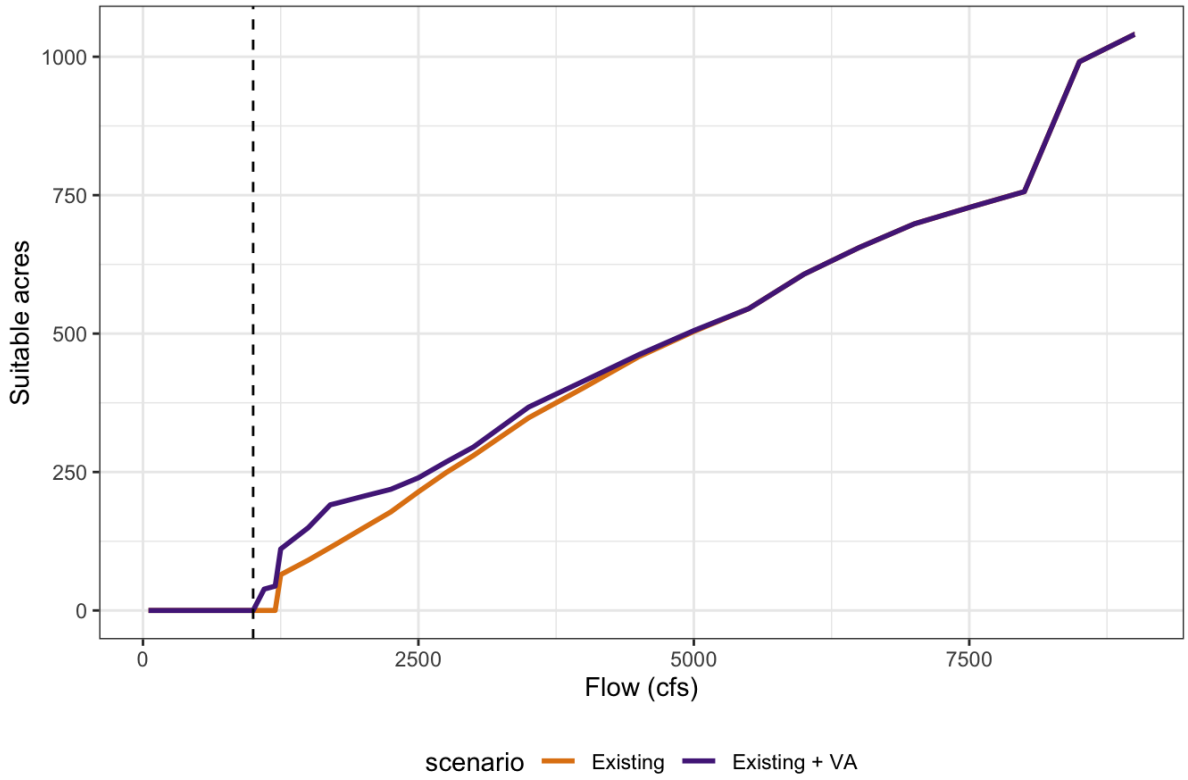


Figure 7-9. Flow-to-Suitable Floodplain Habitat Relationships for the Tuolumne River Under Existing (Orange) and Existing + VA Conditions (Purple). The Dotted Vertical Line Represents the Floodplain Inundation Threshold Value of 1,000 CFS (Hume and Baker 2024).

The TVA Habitat Suitability Criteria (Hume and Baker 2024) characterizes the suitability of habitat using physical characteristics, e.g., depth and velocity, but does not consider the usability of habitat as impacted by water temperatures. As described in Chapter 5, *Water Temperature*, the different scenarios are expected to provide considerably different water temperature conditions temporally and spatially, and the variability in water temperature conditions are likely to impact the quantity of usable rearing and spawning habitat. Therefore, the habitat evaluation included a step to filter out the quantity of habitat acreage that is predicted to be unsuitable due to elevated water temperatures. A similar type of temperature filtering for habitat in the Tuolumne River has been conducted previously (Stillwater Sciences 2017).

To filter the modeled habitat to account for temperature, the proportion of life stage-specific river miles where the temperature met USEPA benchmark for spawning (13°C) or rearing (16°C) was calculated, producing a value between 0 and 1 for each day (or proportion suitable). Modeled daily water temperatures were provided on each day for river miles spanning RM 53.5 (below Don Pedro dam) to RM 0.0 using the San Joaquin River Basin-wide HEC5Q model (Chapter 5). Daily modeled rearing and spawning habitat acreages were then multiplied by the calculated daily proportion suitable (by temperature) to produce a daily time series of suitable habitat accounting for suitable temperature benchmarks for 30 years. Ultimately this produced a time series of suitable (i.e., both physical and temperature) rearing and spawning habitat for each flow scenario. This process is outlined in Figure 7-10.

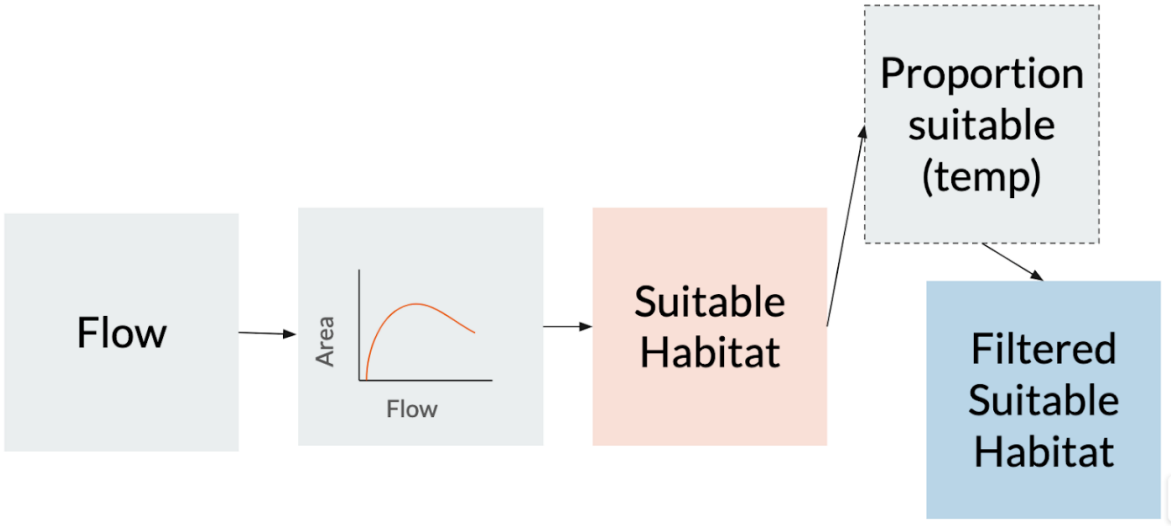


Figure 7-10. Workflow for Combining Modeled Flow, Flow-to-Suitable Area Relationships, and Modeled Temperature.

Calculating Habitat Needed to Support Doubling Goal Population

To evaluate how existing and proposed habitat meet the AFRP doubling goal, the amount of habitat needed to support the doubling goals was calculated. The doubling goal (referred to as the Narrative Salmon Objective in the TVA Term Sheet) is the doubled (average) natural (ocean) production during the 1967 to 1991 time period. Natural production is defined as the portion of production that is not produced in hatcheries. The doubling goal, along with values for escapement (or spawner abundance), harvest (both instream and ocean), and production (natural and total) are provided in the United States Fish and Wildlife Service (USFWS) Working Paper on Restoration Needs Volume 3 Table 3-Xa-1 (1995). Using spawner abundance allows the translation of the doubling goal to habitat area needed to support natural production based on the calculations and parameters described below. The escapement values associated with the Tuolumne River natural production estimates in Table 3-Xa-1 (USFWS 1995) were multiplied by 2 to approximate the escapement needed to support the attainment of the target doubling goal, assuming a 1:1 relationship between escapement and natural production (Table 7-2).

The total area of suitable spawning habitat required to meet the needs of the doubling goal population size is based on the doubled adult population size (doubled escapement, described above) and the assumed static input parameters for spawner sex ratio and redd size (Table 7-3). The suitable rearing habitat area required to meet the territory size needs of the doubling goal population is based on the total number of fry expected to be produced by the doubled adult population calculated using the assumed static input parameters for spawner sex ratio, fecundity, egg-to-fry survival, and the individual fry territory requirement (Table 7-3). Input parameters were developed from Tuolumne River-specific monitoring information, where available; however, when not available from the Tuolumne River, the best available information from the literature was used.

The spawning habitat need (acres, H_s) is calculated as the product of the spawner sex ratio (0.515) and redd size (9.29 square-meters [m^2]) equaling 4.65 m^2 and the doubled escapement (E), divided by 4,047 (to convert m^2 to acres).

$$Hs = \frac{0.515 * 9.29 * E}{4047}$$

The number of juveniles (J) is calculated as the product of the spawner sex ratio (0.515), fecundity (5,335), egg-to-fry survival (0.32), and target escapement (E).

$$J = 0.515 * 5{,}335 * 0.32 * E$$

The suitable rearing habit need (acres, H_r) is calculated as the product of the number of juveniles (J) and the territory requirement (0.05423379 m^2) divided by 4,047 (to convert m^2 to acres).

$$H_r = \frac{0.05423379 * J}{4047}$$

To inform the uncertainty associated with the estimated habitat needed to support the doubling goal, ranges of the input parameters were included, wherever possible, and input parameter distributions were parameterized based on data from the literature and Tuolumne River monitoring data. The input parameter distributions were randomly sampled (n = 1,000,000 draws) to generate 1,000,000 estimates of the doubling goal suitable habitat area needs which provides a range of habitat need estimates which to compare to the estimate using the static input parameters. Comparison of the mean, median, and other summary statistics of the 1,000,000 estimates are shown in Appendix D, *Doubling Goal Habitat Estimate and Input Parameter Uncertainty Analysis*.

The range of territory size used to determine habitat needed to support the doubling goal was based on Grant and Kramer (1990) and Keeley and McPhail (1998). The equations below show how territory size was calculated, where A_T is territory size in square meters, L is fork length in centimeters, and S is a binary variable describing if fork length is greater than five centimeters. Territory size distributions from these sources were combined by equal random draws from both.

Grant and Kramer (1990):

$$log_{10} A_T = 2.61 * log_{10} L - 2.83$$

Keeley and McPhail (1998):

$$log_{10} A_T = 2.47 * log_{10} L - 2.26 - 0.48S$$

In addition to using the two equations, the range in the territory size input parameter was developed using a beta distribution developed for fry fork lengths (between 37.5 and 42 millimeters) as inputs into the equations. The individual fry-rearing territory size requirement (Table 7-3) applies to all fry produced by the doubled number of adults before any growth, movement, or juvenile mortality. Previous analyses found that in other watersheds the range of habitat needed to support all fry produced by the doubled number of adults overlaps a majority of the range of habitat to support the predicted number to survive to smolt-sized fish (State Water Board et al. 2023), and this is consistent with Tuolumne River Chinook salmon when the fry-to-smolt survival is less than 58%. This current analysis assumes that the range of habitat needs for the doubled population is adequately represented by use of fry-sized fish; however, the range of habitat needs may underestimate the actual need if fry-to-smolt survival exceeds 58%. Growth, movement, and juvenile mortality factors are not included because they vary significantly in data quality and availability across the TVA watershed. To adequately incorporate these dynamics would require a lifecycle model, which is unavailable.

The egg-to-fry survival parameter (Table 7-3) was developed using data from a study conducted on the Lower Tuolumne River (TID and MID 1991), where egg survival was measured through emergence traps in 1988 and 1989. A beta distribution was parameterized using the empirical data.

The eggs per female or fecundity parameter (Table 7-3) was developed using data from fall-run spawning surveys conducted on the Tuolumne River from 1971–2008. A normal distribution was parameterized using the empirical data. The sex ratio of 0.515 was also documented in this same data source.

The redd size parameter (Table 7-3) was developed based on methods outlined in Reynolds et al. (1990) to account for the possibility of multiple redds occurring in the same area over the entire spawning season. According to this paper, the same area could be used to build 3–4 redds within a season, and the territory required for a spawning pair spans between 200–650 square feet (Reynolds et al. 1990). To account for this, the redd size parameter first draws from a beta distribution bounded between 3 and 4 with a mean of 3.5 “times utilized per season”. The spawning territory requirement per female was developed as a bounded beta distribution ranging from 200–650 square feet. The final redd size is then calculated as spawning territory requirement divided by times utilized per season, which produces a distribution with a mean of 100 square feet or 9.29 square meters.

Distributions generated for juvenile territory requirement, juvenile fork length, egg-to-fry survival rate, eggs-per-female, and redd size are shown in Appendix D.

Table 7-2. Summary of the Doubled Escapement of Fall-Run on the Tuolumne River, Number of Juveniles, and Rearing and Spawning Habitat Needed to Support the Doubled Escapement. Values Are Shown for Calculations Using Fixed Parameters and for the Mean and Median.

Watershed	Doubled Escapement	Juveniles Produced			Rearing Area (acres)			Spawning Area (acres)	
		Median	Mean	Fixed	Median	Mean	Fixed	Median	Mean
Tuolumne River	17,800	18,720,476	19,910,300	240	405	638	21	21	21

Table 7-3. Input parameters Used to calculate the Rearing and Spawning Habitat Area Needed to Support the Doubling Goal Population.

Parameter	Static	Distribution (Q25–75)	Citation
Juvenile territory	0.062 m^2	0.05–0.17m^2	Static: Stillwater Sciences (2017) Distribution: Grant and Kramer (1990), Keeley and McPhail (1998)
Juvenile fork length	39.75 mm	39.26–40.24 mm	Static: CVPIA SIT Fall Run DSM Distribution: San Joaquin River Restoration Program (2012)
Egg-to-fry survival rate	0.32	0.26–0.54	TID and MID 1991, Appendix 8
Eggs per female	5335	4632–6039	Lower Tuolumne River Annual Report 2008-2 (Table 7-3)
Sex ratio: proportion female	0.515		Lower Tuolumne River Annual Report 2008-2 (Table 7-1)
Redd size	9.29 m^2		Reynolds et al. 1990

Meaningful Floodplain Event

In addition to the annual habitat acreage evaluation, floodplain habitat was analyzed using the Meaningful Floodplain Event (MFE) approach, which incorporates hydrological conditions, including the frequency of floodplain flows and their duration and magnitude. The MFE was developed to evaluate the scenarios based on the need for longer and repetitive (both inter- and intra-annually) inundation periods (Grosholz and Gallo 2006; Opperman 2012; Takata et al. 2017). Longer periods of floodplain inundation contribute to increased juvenile Chinook salmon growth in the Central Valley (Takata et al. 2017) driven by enhanced organic matter and nutrient recycling leading to high prey densities (Sommer et al. 2001; Sommer et al. 2004; Grosholz and Gallo 2006). Repeated flood pulses of sufficient duration have also been found to support native fishes (Grosholz and Gallo 2006).

The MFE analysis evaluates floodplains in terms of magnitude, inter-annual frequency, intra-annual frequency, and duration.

- Magnitude is the area inundated by a floodplain event based on hydrology.
- Inter-annual frequency is the long-term average in which cohorts are exposed to floodplains. The targeted inter-annual frequency is a desired inundated area occurring 2 out of every 3 years. Inter-annual frequency is important to account for natural variation in population size, as salmon cohorts may vary between years.
- Intra-annual frequency is the number of distinct floodplain events in a given rearing season. The targeted intra-annual frequency is a desired inundated area occurring in at least two months during the rearing season. Intra-annual frequency ensures that habitat is available throughout the rearing season to support life history diversity.
- Duration is the number of days the area is inundated during a floodplain event. Based on the literature, to provide optimal benefits, floodplain must be inundated for sufficient time to allow food web to activate and reach peak productivity.
    - Floodplain productivity peaks after 21 days of inundation (Grosholz and Gallo 2006; Yarnell et al. 2015). Salmon spend 30–56 days on the floodplain on average (Sommer et al. 2005) and longer inundation provides greater benefits for life history diversity and growth (Goertler et al. 2018).
    - For the purposes of modeling MFEs, it is assumed that an event will last at least 30 days (i.e., an entire month) because this is a more conservative metric for floodplain benefit. Flows were provided at a daily timestep, so flow time series were aggregated to a monthly timestep for the MFE analysis by taking the average flow by month.

The MFE is calculated for four given areas (i.e., magnitudes): the area needed to support 25%, 50%, 75%, and 100% of the doubling goal population. The proportion of MFE occurrence throughout the model period is estimated for the scenarios. A 10% difference or greater between the Existing Conditions and alternative scenario is considered significant. The parameters chosen for MFE are somewhat conservative, so actual benefits may be greater than model results suggest.

While the MFE addresses the multidimensionality of floodplain events while still retaining interpretability, the calculation does involve multiple steps summarized below:

1. Define floodplain magnitude criteria:
    - e.g., 50% of the habitat needed (acres) to support the doubling goal juvenile population.
2. Determine if the intra-annual floodplain frequency is met.
    - Is the floodplain magnitude met during at least 2 of the 5 months of the rearing period (February–June)?
3. Determine if the inter-annual floodplain frequency is met.
    - Is the floodplain magnitude met during at least 2 of the 5 months of the rearing period and at least 2 out of every 3 years?
4. Determine the proportion of MFE event occurrence.
    - What proportion of years were the MFE criteria met during the modeled hydrology period? This is calculated using a center-aligned, rolling 3-year window, meaning that there will be a window for each year except the first (1970) and last (2003) year.

7.3.2 Results

The results of the habitat analysis predict that the TVA scenario (combined flow and non-flow assets) produces an increase in suitable habitat for fall-run Chinook salmon during both rearing and spawning seasons on the Tuolumne River as compared to the Existing Conditions scenario. Much of the increase in rearing habitat can be attributed to improvements in floodplain suitable habitat. Spawning habitat estimates for all scenarios, including the Existing Conditions scenario, exceeds the amount of habitat required to support approximately 50% of the offspring of the doubling goal populations (see Section 7.3.2.1, *Spawning Habitat*). For all scenarios, in-channel and floodplain rearing habitat estimates exceed 70% and 35%, respectively, of the doubling goal habitat need and combined exceed the 100% doubling goal habitat need (see Section 7.3.2.2, *In-channel Rearing Habitat*, Section 7.3.2.3, *Floodplain Rearing Habitat*, and Section 07.3.2.3, *Combined Rearing Habitat*).

Spawning is limited by the availability of suitable habitat because a finite number of redds can be constructed in a given area. The development of additional spawning habitat, through constructed habitat and habitat restoration, provides more opportunities for spawning (Merz 2004; Roni et al. 2008; McManamay et al. 2010), which should result in an increase in the number of juveniles.

Juvenile salmon and steelhead require access to suitable rearing habitat and suitable food resources during rearing. Expanding habitat availability, both spatially and temporally, for juvenile salmon is expected to improve abundance, productivity, diversity, and spatial structure of Central Valley salmon populations, and it may also lead to incidental benefits for other native fish species (SWRCB 2018). Suitable rearing habitat for juvenile fall-run Chinook salmon supports growth and survival during outmigration (Maslin et al. 1997; Limm and Marchetti 2009).

7.3.2.1 Spawning Habitat

The proposed habitat restoration commitments identified in the TVA Term Sheet for spawning habitat on the Tuolumne River include 75,000 tons of new gravel between RM 52 and RM 39 and approximately 25,000 tons of new gravel between RM 39 and RM 24.5 to create additional spawning/rearing habitat. Figure 7-11 shows the predicted median of annual mean temperature filtered spawning habitat across all modeled years (1970–2003) under the Existing Conditions, TVA, and 30%, 40%, and 50% UF Objective scenarios. The predicted median of annual mean temperature filtered spawning habitats for all scenarios exceed 60% of the habitat needed to support the doubling goal (DG Ac, 21 acres). All the modeled scenarios exceed the suitable physical spawning habitat (i.e., WUA[21]) needed to meet the doubling goal on average (Table 7-4); however, the estimated suitable habitat is decreased when temperature is considered. For all scenarios, approximately one half of the physically suitable habitat does not meet suitable temperatures. The TVA is predicted to provide the largest quantity of spawning habitat.

Figure 7-12 shows the predicted median of annual mean temperature filtered spawning habitat for the scenarios by water year type.

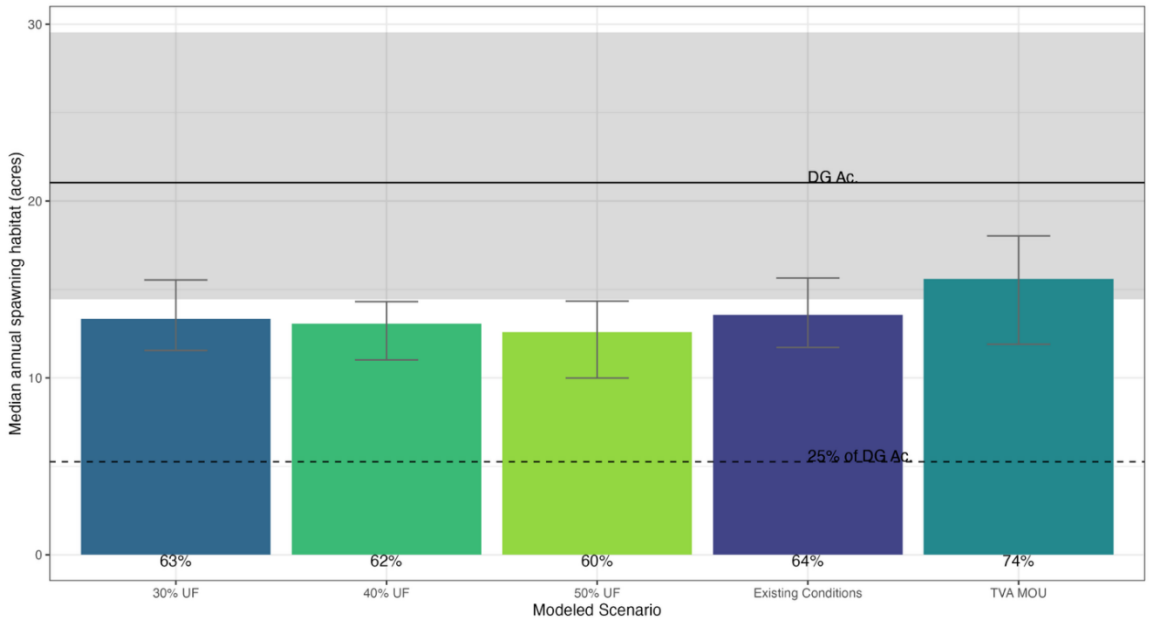


Figure 7-11. Median of Annual Mean Temperature Filtered Spawning Habitat (Acres) Across All Modeled Years (1970–2003) Under the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Line Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles.

[21] A method used to estimate the amount of suitable salmonid habitat available in rivers and streams, particularly for spawning and rearing.

Table 7-4. Median of Annual Mean Spawning Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses.

			No temperature filter		Temperature filter	
Scenario	Habitat Type	Doubling goal acreage	Median estimated acres	Percent of doubling goal acreage	Median estimated acres	Percent of doubling goal acreage
30% UF	Spawning	21 (14, 30)	28 (23, 30)	135%	13.3 (12, 16)	63%
40% UF	Spawning	21 (14, 30)	28 (19, 30)	133%	13.1 (11, 14)	62%
50% UF	Spawning	21 (14, 30)	28 (19, 30)	133%	12.6 (10, 14)	60%
Existing Conditions	Spawning	21 (14, 30)	28 (23, 30)	133%	14 (12, 16)	64%
TVA	Spawning	21 (14, 30)	33 (27, 35)	157%	16 (12, 18)	74%

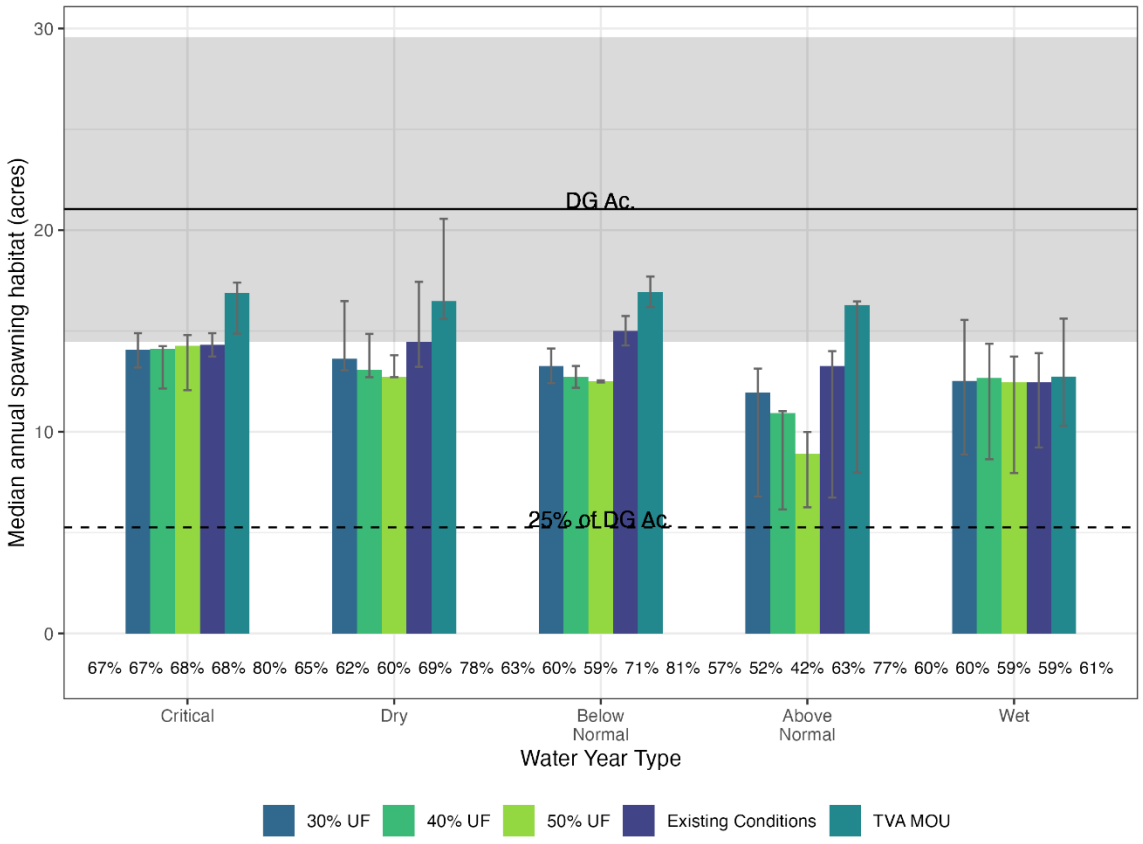


Figure 7-12. Median of Annual Mean Temperature Filtered Spawning Habitat (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios by Water Year Type. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. Across All Water Year Types, the TVA Offers More Spawning Habitat (October Through December) Than the Existing Conditions and UF Objective Scenarios. Across Critical to Wet Water Year Types, the TVA Offers 9–12% More Spawning Habitat in the Tuolumne River.

7.3.2.2 In-channel Rearing Habitat

The proposed habitat restoration commitments identified in the TVA term sheet included 77 acres of newly constructed rearing/floodplain habitat. Rearing habitat was evaluated for in-channel habitat alone, floodplain habitat alone, and for the combination of in-channel and floodplain habitat. Figure 7-13 shows the predicted median of annual mean temperature filtered in-channel rearing habitat area across all modeled years (1970–2003) under the Existing Conditions, the TVA, and 30%, 40%, and 50% UF Objective scenarios. The predicted median temperature filtered in-channel rearing habitats for all scenarios exceed 70% of the habitat needed to support the doubling goal (DG Ac, 240 acres). The TVA and Existing Conditions scenarios exceed the suitable physical habitat (i.e., WUA) needed to meet the doubling goal on average (Table 7-5); however, the estimated suitable habitat is decreased when temperature is considered. This is consistent with Stillwater Science's (2017) analysis of suitable *O. mykiss* habitat in the Tuolumne River, where the authors found that the effective useable habitat (i.e., habitat meeting both WUA and temperature benchmarks) was lower than the standard WUA estimate when temperatures are unsuitable. The 30% and 40% UF Objective scenarios are predicted to provide the most temperature filtered in-channel rearing habitat, followed by the 50% UF Objective and the TVA, and then by the Existing Conditions; however, all the scenarios are comparable considering the uncertainty in the estimates.

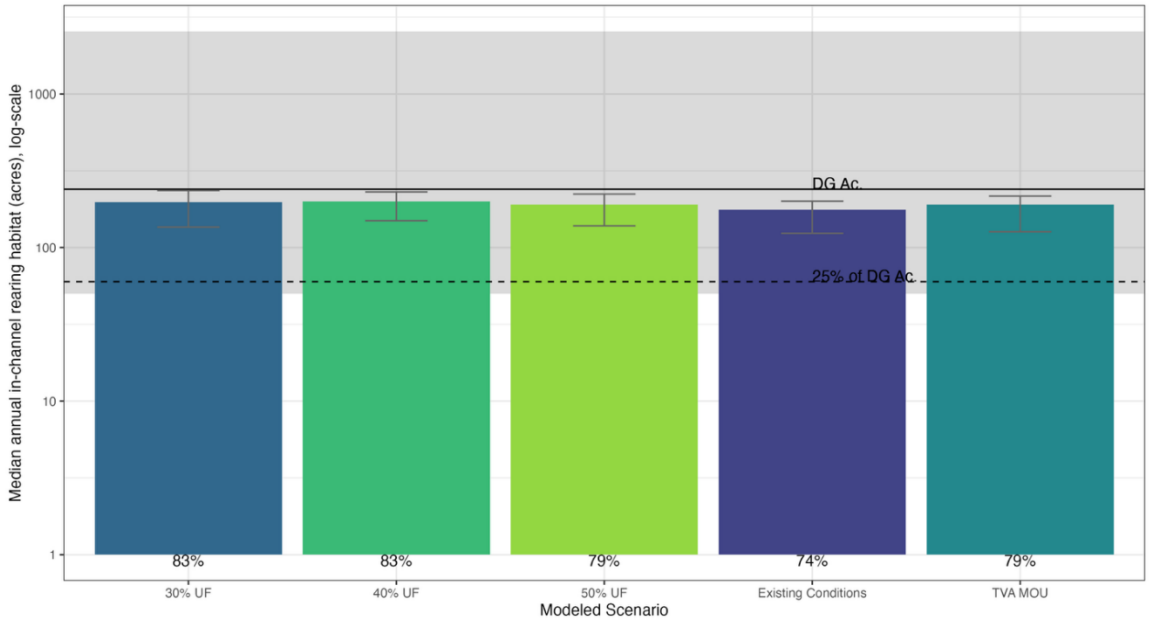


Figure 7-13. Median of Annual Mean Temperature Filtered In-Channel Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. The TVA Shows a 4% Increase Over Existing Conditions, and the 30% and 40% UF Objective Scenarios Show a 4% Increase Over the TVA Conditions.

Table 7-5. Median of Annual Mean In-Channel Rearing Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses.

			No temperature filter		Temperature filter	
Scenario	**Habitat Type**	**Doubling goal acreage**	**Median estimated acres**	**Percent of doubling goal acreage**	**Median estimated acres**	**Percent of doubling goal acreage**
30% UF	Rearing	240 (50, 2,563)	202 (146, 297)	84%	198 (136, 235)	83%
40% UF	Rearing	240 (50, 2,563)	205 (157, 277)	85%	199 (149, 230)	83%
50% UF	Rearing	240 (50, 2,563)	195 (140, 251)	81%	190 (138, 223)	79%
Existing Conditions	Rearing	240 (50, 2,563)	271 (168, 366)	113%	176 (124, 200)	74%
TVA	Rearing	240 (50, 2,563)	259 (170, 349)	108%	190 (127, 216)	79%

Figure 7-14 shows the predicted median of annual mean temperature filtered in-channel rearing habitat for the scenarios by water year type. These analyses show reductions in in-channel rearing habitat in the wetter year types, which highlights a mechanism whereby velocities and depths become less suitable in the channels when using weighted usable area analyses. For example, the predicted temperature filtered suitable in-channel rearing habitat for Critical, Dry, and Below Normal years is approximately the quantity needed to support the doubling goal population, whereas the Above Normal and Wet years are predicted to provide significantly less.

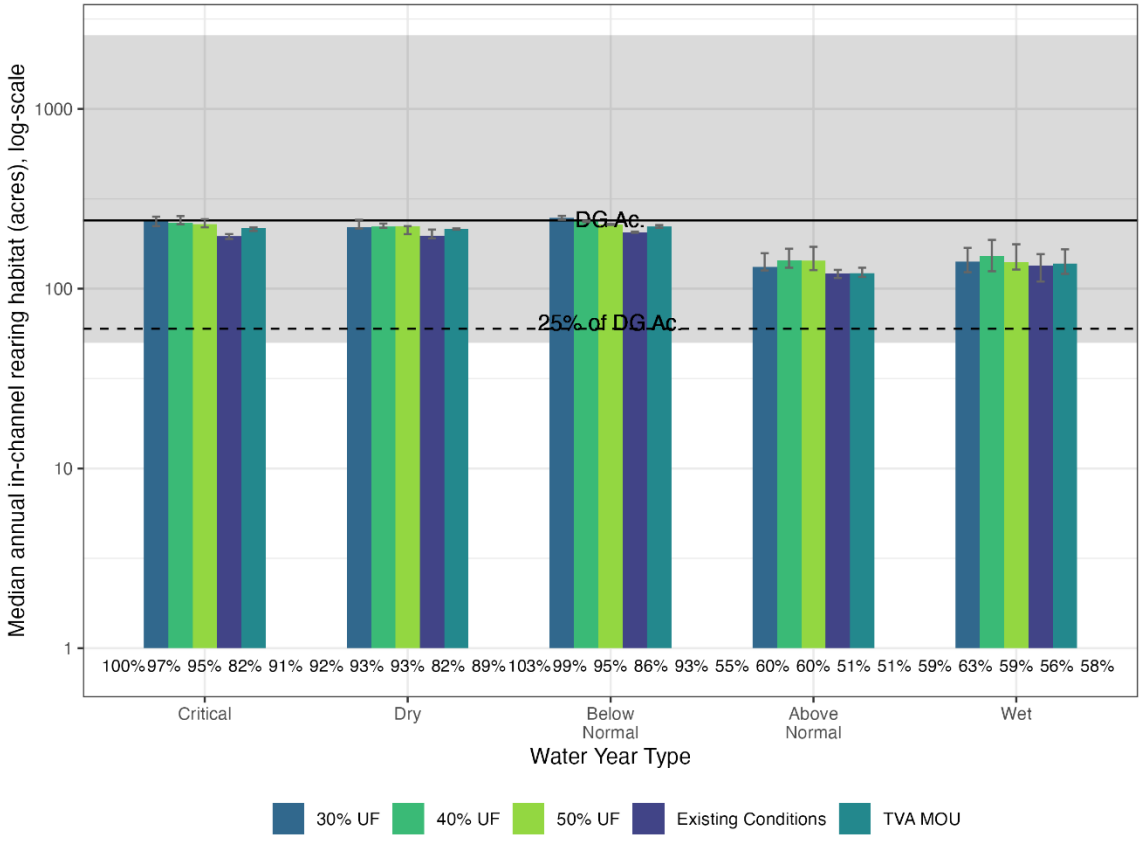


Figure 7-14. Median of Annual Mean Temperature Filtered In-Channel Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios by Water Year Type. The Solid Line Represents the Acreage of Habitat Required To Support the Doubling Goal Population, the Gray Band Represents Area of Habitat Required to Support the Doubling Goal Population, the Grey Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. Across All Water Year Types the TVA Conditions Represent an Increase in In-Channel Rearing Habitat Over Existing Conditions.

7.3.2.3 Floodplain Rearing Habitat

Floodplain and off-channel habitat provide lower-velocity refugia habitat during high flow events. Figure 7-15 shows the predicted median of annual mean temperature filtered floodplain rearing habitat area across all modeled years (1970–2003) under the Existing Conditions, the TVA, and 30%, 40%, and 50% UF Objective scenarios. The predicted median temperature filtered floodplain rearing habitats for all scenarios exceed 35% of the habitat needed to support the doubling goal (DG Ac, 240 acres). The Existing Conditions scenario is predicted to provide the lowest quantity of floodplain rearing habitat at 35% of the acreage needed for the doubling goal population (Table 7-6). The TVA and UF Objective scenarios are all predicted to increase the floodplain rearing habitat over the Existing Conditions by providing 41%, 54%, 58%, and 80% of the required habitat for the doubling goal population, respectively.

Floodplain inundation occurs at higher flows, i.e., >1,000 cfs, so the water temperatures are predicted to remain cooler as the water travels downstream. Consequently, few acres of floodplain rearing habitat exceed the USEPA benchmark for juvenile rearing, which results in minimal reductions (i.e., <3%) in suitable floodplain rearing habitat between unfiltered and temperature filtered acreages for all scenarios (Table 7-6). This analysis does not adjust the temperature benchmark for rearing in floodplain habitats. The temperature model incorporates river geometry in its estimation, and the potential for water to warm when on floodplains (see Appendix B, *Hydrologic and Water Quality Modeling*, Section B.4, *HEC-5Q Temperature Modeling – Updates*, for more information on the temperature modeling).

Figure 7-16 shows the predicted median of annual mean temperature filtered floodplain rearing habitat for the scenarios by water year type. Floodplain rearing habitat increases incrementally from drier to wetter water year types. While all the scenarios exceed 25% of the doubling goal population acreage when evaluated across all years (Figure 7-15), only the 40% and 50% UF Objective scenarios exceed 25% of the doubling goal acreage for the majority of water year types (Figure 7-16). The median floodplain rearing acreages in Critical Years for Existing Conditions and the 30% UF Objective scenarios are zero.

The TVA and 30%–50% UF Objective scenarios increase the proportion of MFE occurrence over Existing Conditions (Figure 7-17 and Table 7-7). The TVA increases the frequency by 3% and 9% compared to the Existing Conditions at the 25% and 50% of doubling goal supported levels. The 30% UF Objective scenario is modeled to increase the frequency by 3% for 25%–75% doubling goal levels. The 40% and 50% UF Objective scenarios increase the frequency of MFE occurrence at all doubling goal levels, and the increase is significant (i.e., >10%) for the 25% and 50% doubling goal levels for the 40% UF Objective scenario and for the 25%–75% doubling goal levels for 50% UF Objective scenario. None of the scenarios are expected to result in a proportion of MFE occurrence to support the TVA doubling goal population acreage in 100% of years.

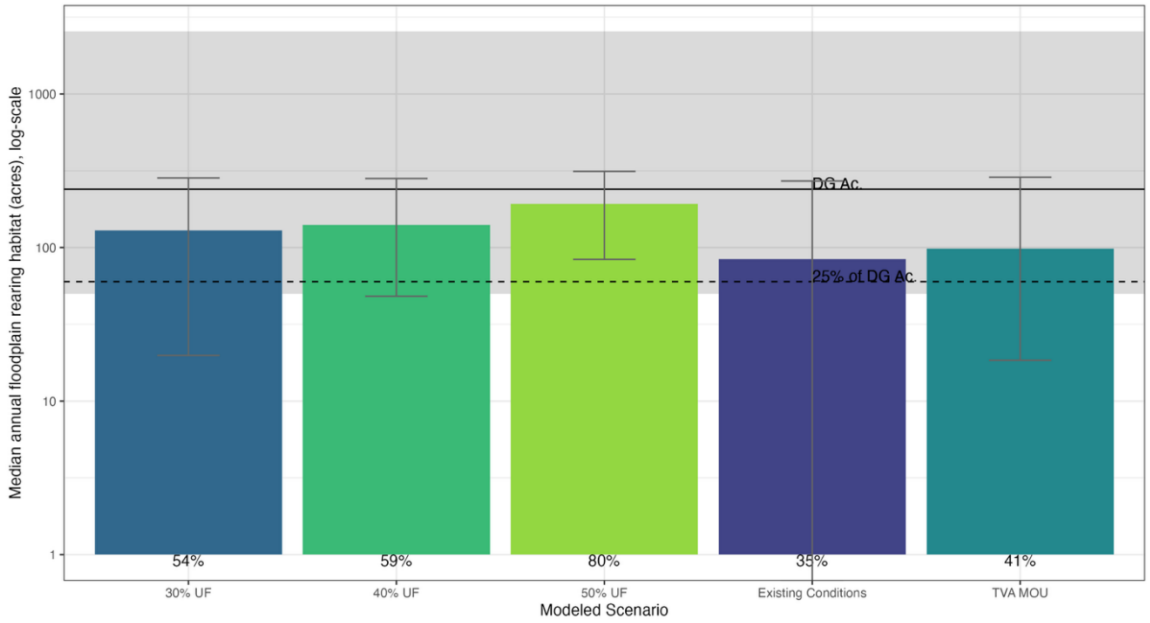


Figure 7-15. Median of Annual Mean Temperature Filtered Floodplain Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. The TVA Shows a 14% Increase Over Existing Conditions, and the 40% and 50% UF Objective Scenarios Show a 10–14% Increase Over the TVA.

Table 7-6. Median of Annual Mean Floodplain Rearing Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses.

			No temperature filter		Temperature filter	
Scenario	Habitat Type	Doubling goal acreage	Median estimated acres	Percent of doubling goal acreage	Median estimated acres	Percent of doubling goal acreage
30% UF	Rearing	240 (50, 2,563)	133 (27, 294)	55%	129 (20, 284)	54%
40% UF	Rearing	240 (50, 2,563)	143 (55, 289)	60%	140 (48, 282)	58%
50% UF	Rearing	240 (50, 2,563)	194 (91, 320)	81%	192 (84, 314)	80%
Existing Conditions	Rearing	240 (50, 2,563)	84 (0, 274)	35%	84 (0, 271)	35%
TVA	Rearing	240 (50, 2,563)	101 (19, 295)	42%	98 (18, 287)	41%

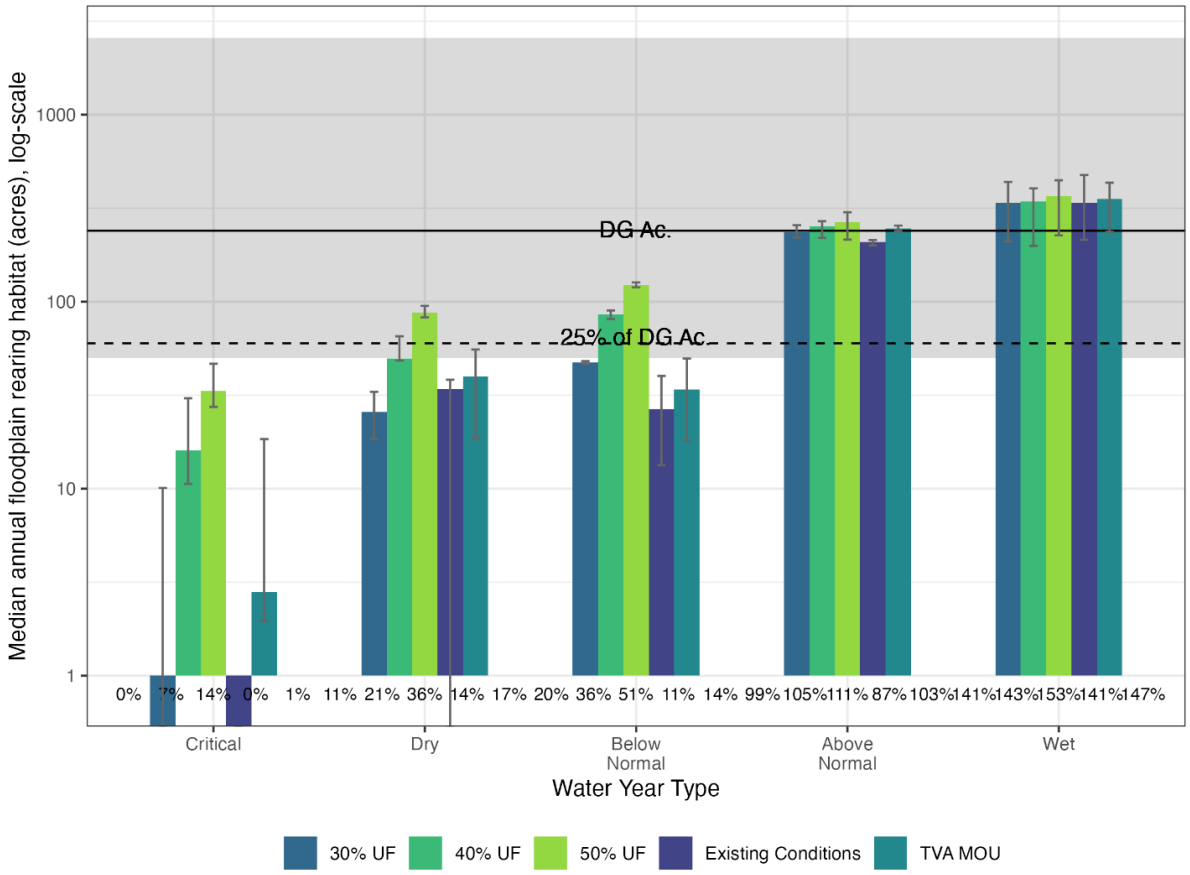


Figure 7-16. Median of Annual Mean Temperature Filtered Floodplain Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios by Water Year Type. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. The TVA and the 40% and 50% UF Objective Scenarios Are Predicted to Provide an Increase in Floodplain Rearing Habitat Over Existing Conditions in All Water Year Types. The Appearance of Negative Values Are an Artifact of the Log Scale, and Median of Annual Mean Suitable Habitat for Existing Conditions and 30% UF Objective Scenarios Are 0 Acres for Critical Years.

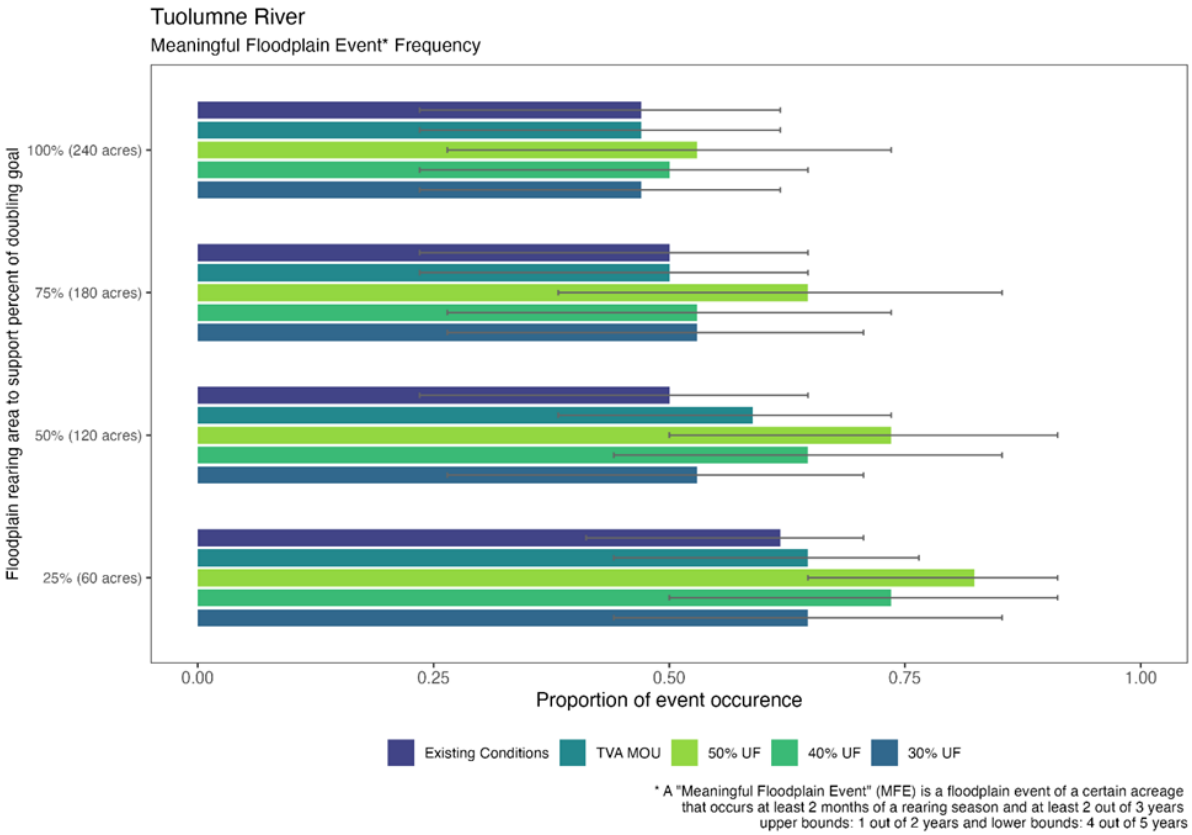


Figure 7-17. The Proportion of MFE Occurrence for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios on the Tuolumne River. This Bar Chart Is Oriented Horizontally. The X-Axis Represents Proportion of Event Occurrence, and the Y-Axis Represents Floodplain Rearing Area Needed to Support the Percentage of the Doubling Goal Acreage. The Lower Bounds of the Error Bars Represent the Proportion of Event Occurrence When MFE Criteria Are Restricted to Require Floodplain Events 4 out of 5 Years. The Upper Bounds of the Error Bars Represent the Proportion of Event Occurrence When MFE Criteria Are Reduced Only to Require Floodplain Events 1 out of 2 Years.

Table 7-7. The Proportion of MFE Occurrence for the Existing Conditions, TVA, and 30%–50% UF Objective Scenarios on the Tuolumne River, Calculated with and without the Temperature Filter Applied. Values Shown Are the Proportion of Floodplain Event Occurrence Delineated by Floodplain Rearing Area Needed to Support Percent of Doubling Goal (25%, 50%, 75%, and 100%) with Lower and Upper Bounds Shown in Parentheses. The Lower Bound Represents the Proportion of Event Occurrence When MFE Criteria Are Restricted to Require Floodplain Events 4 out of 5 Years, and Upper Bound Represents the Proportion of Event Occurrence When MFE Criteria Are Loosened to Require Floodplain Events 1 out of 2 Years.

	No temperature filter				Temperature filter			
	Percentage of Doubling Goal Supported				Percentage of Doubling Goal Supported			
Scenario	**25%**	**50%**	**75%**	**100%**	**25%**	**50%**	**75%**	**100%**
30% UF	0.74 (0.47, 0.91)	0.53 (0.32, 0.71)	0.53 (0.26, 0.71)	0.47 (0.24, 0.62)	0.65 (0.44, 0.85)	0.53 (0.26, 0.71)	0.53 (0.26, 0.71)	0.47 (0.24, 0.62)
40% UF	0.76 (0.56, 0.91)	0.65 (0.44, 0.85)	0.53 (0.26, 0.74)	0.5 (0.24, 0.65)	0.74 (0.5, 0.91)	0.65 (0.44, 0.85)	0.53 (0.26, 0.74)	0.5 (0.24, 0.65)
50% UF	0.88 (0.76, 0.94)	0.74 (0.5, 0.91)	0.71 (0.44, 0.91)	0.53 (0.26, 0.74)	0.82 (0.65, 0.91)	0.74 (0.5, 0.91)	0.65 (0.38, 0.85)	0.53 (0.26, 0.74)
Existing Conditions	0.65 (0.44, 0.76)	0.5 (0.24, 0.65)	0.5 (0.24, 0.65)	0.47 (0.24, 0.62)	0.62 (0.41, 0.71)	0.5 (0.24, 0.65)	0.5 (0.24, 0.65)	0.47 (0.24, 0.62)
TVA	0.65 (0.44, 0.76)	0.62 (0.41, 0.74)	0.53 (0.26, 0.71)	0.47 (0.24, 0.62)	0.65 (0.44, 0.76)	0.59 (0.38, 0.74)	0.5 (0.24, 0.65)	0.47 (0.24, 0.62)

7.3.2.4 Combined Rearing Habitat

In-channel rearing habitat and floodplain rearing habitat both provide important, but different, benefits for juvenile salmon, and including both types of habitats increase habitat diversity and resilience for the population as a whole. The predicted median of annual mean in-channel and floodplain combined rearing habitat estimates for all the scenarios exceed the doubling goal acreage (Figure 7-18 and Table 7-8). The Existing Conditions scenario provides the least quantity of temperature filtered combined rearing habitat (271 acres), and the combined rearing habitat acreage increases with the alternative scenarios starting with the TVA (298 acres) followed by the 30% UF Objective (327 acres), 40% UF Objective (344 acres), and the 50% UF Objective (376 acres).

The predicted median of annual mean temperature filtered combined rearing habitat estimates for the 30%–50% UF Objective scenarios exceed the quantity needed to support the doubling goal population in all water year types (Figure 7-19). The TVA scenario estimate meets the quantity to support the doubling goal population in all water year types, except Critical Years, but the Existing Conditions scenario is predicted to only meet the required acreage during Wet and Above Normal Years.

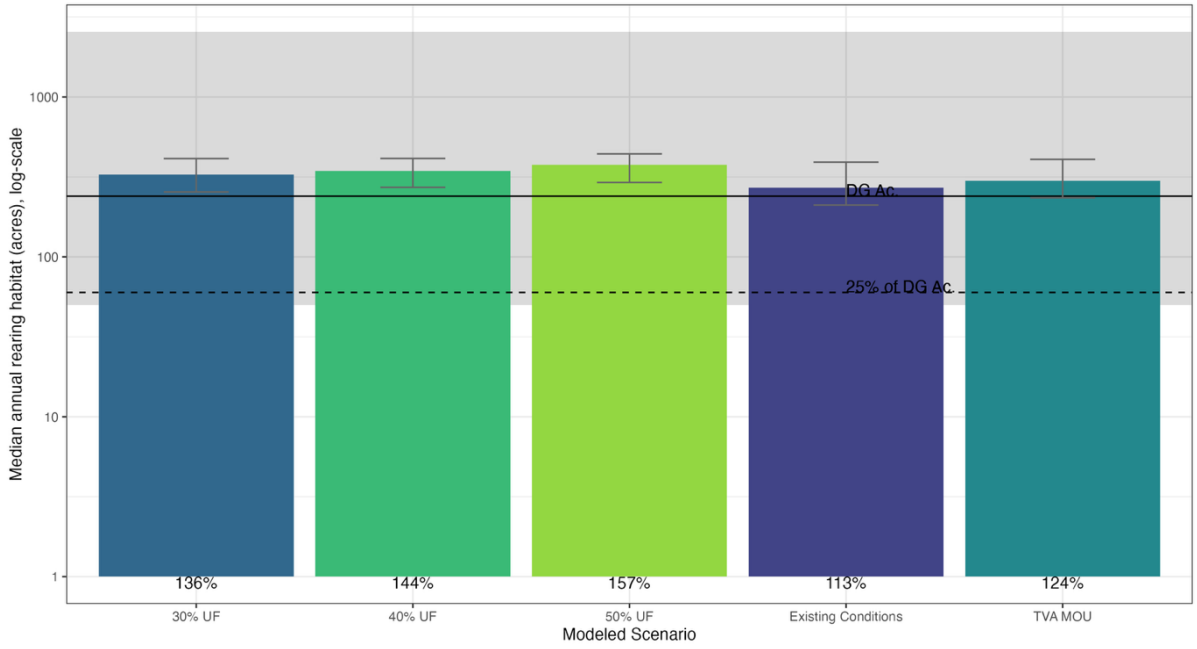


Figure 7-18. Median of Annual Mean Total Temperature Filtered Rearing (In-Channel and Floodplain Combined) Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Scenarios. The Solid Line Represents Area of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Area. Error Bars Represent the 25% and 75% Quartiles. Combined Rearing Habitat for The TVA Shows an 18% Increase Over Baseline Conditions. All Flow Scenarios Reach the Doubling Goal Target for Rearing Habitat with In-Channel and Floodplain Habitat Combined.

Table 7-8. Median of Annual Mean Combined (In-Channel and Floodplain) Rearing Habitat for Each Scenario Calculated with and without the Temperature Filter Applied, Shown Alongside 25% and 75% Quartiles in Parentheses. Doubling Goal Acreage Is Shown Alongside the 2.5% and 97.5% Probability Intervals Calculated with Uncertainty in Parentheses.

			No temperature filter		Temperature filter	
Scenario	Habitat Type	Doubling goal acreage	Median estimated acres	Percent of doubling goal acreage	Median estimated acres	Percent of doubling goal acreage
30% UF	Rearing	240 (50, 2,563)	359 (326, 429)	150%	327 (255, 412)	136%
40% UF	Rearing	240 (50, 2,563)	358 (325, 422)	149%	344 (272, 412)	144%
50% UF	Rearing	240 (50, 2,563)	379 (333, 448)	158%	376 (292, 440)	157%
Existing Conditions	Rearing	240 (50, 2,563)	389 (371, 439)	162%	271 (211, 391)	113%
TVA	Rearing	240 (50, 2,563)	386 (365, 463)	161%	298 (234, 407)	124%

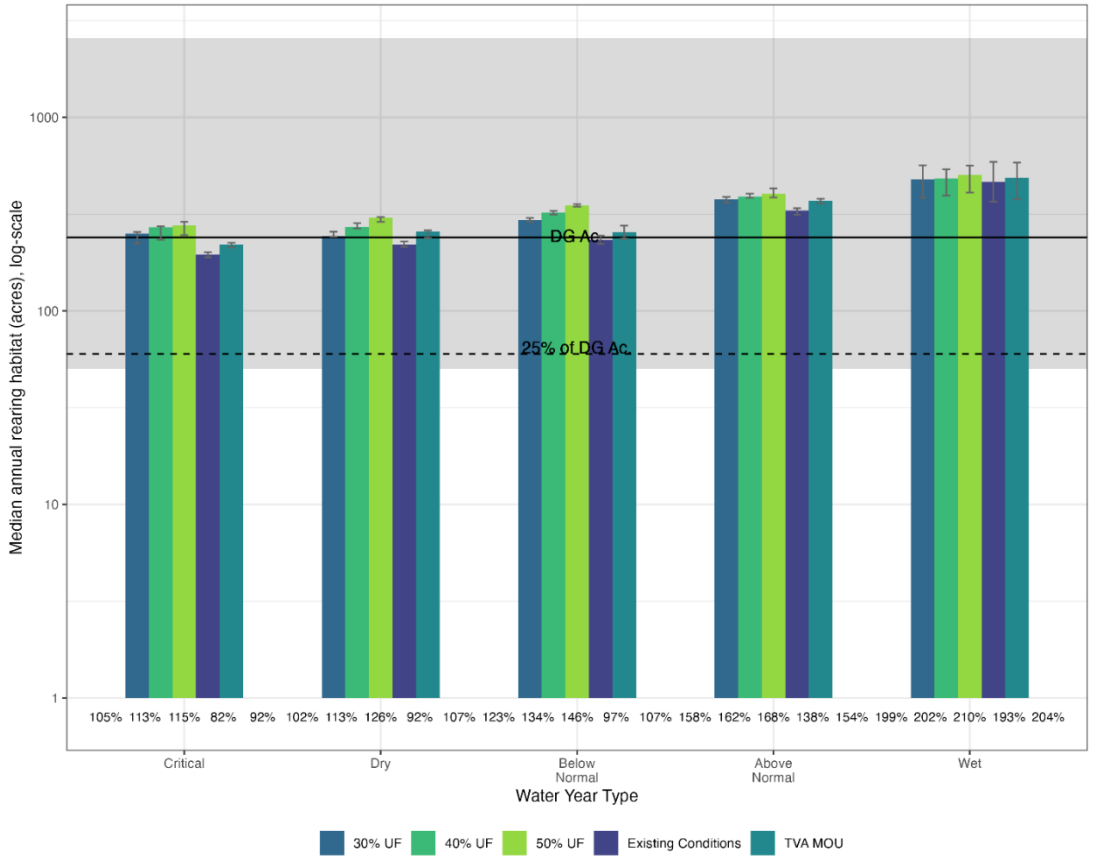


Figure 7-19. Median of Annual Mean Total Temperature Filtered Rearing (In-Channel and Floodplain Combined) Habitat Area (Acres) for the Existing Conditions, TVA, and 30%–50% UF Scenarios by Water Year Type. The Solid Line Represents the Acreage of Habitat Required to Support the Doubling Goal Population, the Gray Band Represents the 2.5% and 97.5% Probability Intervals of This Estimate, and Dashed Lines Represent 25% of the Doubling Goal Acreage. Error Bars Represent the 25% and 75% Quartiles. In All Water Year Types, the TVA Scenario Shows an Increase in Rearing Habitat Over Existing Conditions.

7.4 Discussion

The TVA is intended to increase the quantity and quality of spawning and rearing habitat for native salmonids by implementing a combination of flow and non-flow actions. The TVA scenario is predicted to provide 14% and 10% more spawning habitat and combined rearing habitat, respectively, than the Existing Conditions scenario. The TVA modeled spawning habitat is not expected to support 100% of the doubling goal population (Table 7-4), but the modeled combined in-channel and floodplain rearing habitat are expected to support 100% of the doubling goal population (Table 7-8).

The TVA increases in habitat are likely the result of different actions for spawning habitat and rearing habitat. For example, the flow schedules across the scenarios during the spawning season are similar, so the increased spawning habitat of the TVA will largely be due to the physical restoration actions that increase the flow-to-suitable spawning habitat relationships depicted in Figure 7-7. In contrast, during the January through June rearing period, the TVA flow schedule is considerably different from the Existing Conditions (Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*), which results in improved temperatures (Chapter 5, *Water Temperature*) and increased frequency of floodplain activation flows. The TVA increase in rearing habitat is a result of the change in flow schedule combined with the physical restoration actions to change the flow-to-suitable in-channel and floodplain rearing habitat relationships (Figure 7-8 and Figure 7-9).

The unfiltered temperature spawning habitat for the 30%–50% UF Objective scenarios is equivalent to the Existing Conditions because the flow schedules are the same. The 30%–50% UF Objective scenarios are expected to reduce the quantity of temperature filtered spawning habitat (7% less than Existing Conditions, Figure 7-11 and Table 7-4). However, as discussed in Chapter 5, the Bay-Delta Plan requires development of minimum reservoir carryover storage targets or other requirements to help ensure that providing flows in the February through June period does not have significant adverse temperature or other impacts on fisheries. Also, potential adaptive implementation methods described in the Bay-Delta Plan allow for shifting[22] of a portion of the February through June unimpaired flow to time periods outside of the February through June period when the unimpaired flow requirement is greater than 30%. This analysis applied flow shifting under the 40% and 50% UF Objective scenarios. The adaptive methods resulted in considerable reductions in temperature compared to the Existing Conditions during the fall spawning period. If implemented in water years other than just Wet Years and with minimum carryover storage targets, then it is likely that the 40% and 50% UF Objectives would not result in reductions in spawning habitat compared to the Existing Conditions.

The 30%–50% UF Objective Scenarios are predicted to increase the quantity of temperature filtered in-channel, floodplain, and combined rearing habitat over the Existing Conditions (Table 7-5, Table 7-6, and Table 7-8). The 30%, 40%, and 50% UF Objective scenarios are predicted to provide 21%, 27%, and 39%, respectively, more rearing habitat than the Existing Conditions. All the habitat increases predicted for the UF Objective scenarios compared to the Existing Conditions are the result of changes to flow patterns or reductions to water temperatures because the flow-to-habitat relationships were the same for all of these scenarios. Combined with non-flow restoration actions, the UF Objective scenarios could provide more suitable habitat. Like the other scenarios, all the UF

[22] The application of flow shifting is described in Appendix F.1 of the 2018 Final SED on the State Water Board website.

Objective flow scenarios are predicted to provide enough temperature filtered combined rearing habitat to support 100% of the doubling goal population.

Water temperature greatly influences the quantity of suitable habitat. For example, the modeled amount of physically suitable spawning habitat exceeds the quantity needed to support 100% of the doubling goal population for all scenarios; however, it is expected that much of that physical habitat may be unsuitable due to elevated temperatures, and it is estimated that the scenarios will only support 62%–76% of the doubling goal population (Table 7-4). Table 7-9 shows the percentage of habitat that meets both physical suitability criteria using WUA and USEPA temperature benchmarks for each Chinook salmon life stage. As discussed in Chapter 2, *Aquatic Ecosystem Stressors in the Tuolumne River*, Section 2.8, *Limiting Factors Analysis*, the stock-recruitment analyses determined that spring water temperatures were the strongest predictor of juvenile abundance variability in the Tuolumne River. This supports the concept that water temperature influences Chinook salmon's ability to use habitat successfully. This interaction between temperature and habitat suitability emphasizes the need to coordinate the flow and non-flow actions to maximize habitat benefits for salmonids.

Floodplain habitats are necessary to provide enough rearing habitat because in-channel habitats are inadequate alone. The TVA and UF Objective scenarios, while providing more than Existing Conditions, are predicted to provide only enough in-channel rearing habitat to support approximately 80% of the doubling goal population. In addition to providing more physical space to rear in the river, floodplains are well documented to provide increased primary and secondary productivity, refugia from predators, and refugia from high velocities. The TVA and UF Objective scenarios are predicted to increase the proportion of time that meaningful floodplain events occur on an annual basis, which should provide benefits to rearing salmonids.

The need for more floodplain rearing habitat is supported by the stock-recruitment analysis (Chapter 2, Section 2.8, *Limiting Factors Analysis*). The analysis found evidence that estimated annual floodplain quantity in the Tuolumne River is an important factor in explaining juvenile productivity variability. This analysis suggests actions that increase the activation of floodplain acreage on the Tuolumne River could also increase juvenile productivity in the river. However, floodplain activation in the Tuolumne River is not independent of flow and water temperature variability. Flow and water temperature were both found to have stronger relationships with juvenile productivity than floodplain. Juvenile productivity likely benefited from all three of the factors, but additional studies may be necessary to better understand their inter-relationships with juvenile productivity. Additional information supporting the importance of floodplains in the Tuolumne River can be found in the 2018 Final SED, Chapter 19, *Analyses of Benefits to Native Fish Populations from Increased Flow between February 1 and June 30*, Section 19.3, *Floodplain Inundation*.

Further uncertainty exists within the estimates of habitat acreage needed to support the doubling goal population. For example, there is a 50-fold difference in the 2.5% and 97.5% probability estimates of the rearing habitat needed to support the doubling goal population. Furthermore, estimates of the Existing Conditions rearing habitat suggest that the combined rearing habitat currently supports over 100% of the doubling goal population and is not limiting. The Existing Conditions estimates of spawning habitat suggest that the population may be limited to 67% of the doubling goal; however, the current annual mean abundance of fall-run Chinook salmon (2006–2022) is approximately 800 spawners and 170,000 juveniles (Appendix A, *Stock-Recruitment Modeling*), which are equivalent to approximately 4% of the doubling goal number of spawners and 0.9% of juveniles. Far fewer fish are being supported in the Tuolumne River than suggested by the acres of available existing suitable habitat. The suitability criteria or number of organisms supported by an area of habitat may need to be calibrated for the Tuolumne River, or it is possible that some other factor independent of habitat acreage is impacting Chinook salmon abundance numbers.

The incorporation of water temperature into the quantity of acreage of suitable habitat in this analysis is simplistic, so there is uncertainty in the adjustment of acres of suitable habitat. This analysis used a binary approach for temperature, i.e., river miles above a specific USEPA benchmark for a life stage or river miles below a specific benchmark. Temperature has incremental influences on biology that are more complex, and temperature impacts are not independent of other environmental factors, e.g., food availability and predator interactions. However, as discussed in the 2018 Final SED, Master Response 3.1, *Fish Protection*, WUA considers the habitat variables of depth, velocity, and substrate (or cover) to define the amount of usable or suitable physical habitat for different life stages and does not consider the effects of other physical, chemical, and biological factors on life stage success. This analysis does not attempt to evaluate specific biological impacts of suitable acreage and temperature interactions but instead provides for a quantifiable and repeatable index of the influence of the flow, suitable habitat, and water temperature interactions.

Table 7-9. The Percentage of Temperature Filtered Habitat to Total (Unfiltered) Habitat. Temperature Filtered Habitat Uses Temperature Benchmarks and WUA Physical Criteria to Evaluate Habitat Suitability Versus Total (Unfiltered) Habitat Using WUA Only.

Scenario	Spawning	In-channel Rearing	Floodplain Rearing	Combined Rearing
30% UF	48%	98%	97%	91%
40% UF	47%	97%	98%	96%
50% UF	45%	97%	99%	99%
Existing Conditions	50%	65%	100%	70%
TVA	48%	73%	97%	77%

7.5 References

7.5.1 Printed References

Ahearn, D. S., J. H. Viers, J. F. Mount, and R. A. Dahlgren. 2006. Priming the productivity pump: flood pulse driven trends in suspended algal biomass distribution across a restored floodplain. Freshwater Biology 51:1417–1433. https://doi.org/10.1111/j.1365-2427.2006.01580.x.

Beechie, T.J., B.D. Collins, G.R. Pess. 2001. Holocene and recent geomorphic processes, land use, and salmonid habitat in two north Puget Sound River basins. *Water Science and Application* 4: 37–54.

Bisson, P. A., R. E. Bilby, M. D. Bryant, C. A. Dolloff, G. B. Grette, R. A. House, M. L. Murphy, K. V, Koski, and J. R. Sedell. 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, and future. In: Salo, Ernest O.; Cundy, Terrance W., eds. Streamside management: forestry and fishery interactions. Seattle, WA: Institute of Forest Resources.

Cain, J.R., R.P. Walkling, S. Beamish, E. Cheng, E. Cutter, M. and Wickland. 2003. San Joaquin Basin Ecological Flow Analysis. National Heritage Institute. 247 pages.

Carlson, S. M., and W. H. Satterthwaite. 2011. Weakened portfolio effect in a collapsed salmon population complex. Canadian Journal of Fisheries and Aquatic Sciences 68(9):1579–1589. https://doi.org/10.1139/f2011-084.

Cleary, J.S. 2001. "Increasing Coho Productivity in the Chilliwack River Watershed." *Streamline.* Available: https://a100.gov.bc.ca/pub/eirs/finishDownloadDocument.do?subdocumentId=1284. Accessed April 11, 2024.

Coastal Conservancy. 2016. Staff Recommendation. Lower Putah Creek Spawning Habitat Enhancement. Project No. 16-041-01.

Coe, H. J., P. M. Kiffney, G. R. Pess, K. K. Kloehn, and M. L. Mchenry. 2009. Periphyton and invertebrate response to wood placement in large pacific coastal rivers. River Research and Applications. DOI: 10.1002/rra.1201 (published online).

Cooper, A. C. 1965. The effect of transported stream sediment on the survival of sockeye and pink salmon eggs and alevin. Bulletin 18. International Pacific Salmon Fisheries Commission, New Westminster, British Columbia.

Cordoleani, F., E. Holmes, M. Bell-Tilcock, R.C. Johnson, and C. Jeffres. 2022. Variability in foodscapes and fish growth across a habitat mosaic: implications for management and ecosystem restoration. *Ecological Indicators* 136 (2022) 108681.

Davis, K.W. 2016. *Gravelbed Scarification and Salmon Report.* Report 5604. Sacramento. CA. Prepared for Putah Creek Streamkeeper.

Dolloff A.C., M.L. Warren, Jr. 2003. Fish relationship with large wood in small streams. *American Fisheries Society Symposium* 37: 179-193.

Federal Energy Regulatory Commission (FERC). 2020. Final Environmental Impact Statement for Hydropower Licenses. Don Pedro Hydroelectric Project Project No. 2299-082—California. La Grange Hydroelectric Project No. 14581-002—California. FERC/EIS-029F. Office of Energy Projects, Division of Hydropower Licensing. Washington D.C., NE.

Giannico, G. R., and S. G. Hinch. 2003. The effect of wood and temperature on juvenile coho salmon winter movement, growth, density and survival in side-channels. *River Research and Applications* 19: 219–231.

Goertler, P., K. Jones, J. Cordell, B. Schreier, and T. Sommer. 2018. Effects of Extreme Hydrologic Regimes on Juvenile Chinook Salmon Prey Resources and Diet Composition in a Large River Floodplain. Transactions of the American Fisheries Society 147(2):287–299. https://doi.org/10.1002/tafs.10028.

Grant, J.W.A., and D.L. Kramer. 1990. Territory size as a predictor of the upper limit to population density of juvenile salmonids in streams. Can. J. Fish. Aquat. Sci. 47: 1724-1737.

Grosholz E, Gallo E. 2006. The influence of flood cycle and fish predation on invertebrate production on a restored California floodplain. *Hydrobiologia* 568: 91–109.

HDR Inc. and Stillwater Sciences. 2017. Lower Tuolumne River Floodplain Hydraulic Assessment. FERC Project Number 2299. Prepared for Turlock and Modesto Irrigation Districts. 387 pages.

Herbold, B., S. M. Carlson, R. Henery, R. Johnson, N. Mantua, M. McClure. 2018. Managing for Salmon Resilience in California's Variable and Changing Climate. San Francisco Estuary and Watershed Science 16(2). https://doi.org/10.15447/sfews.2018v16iss2art3.

Hume, N. and Baker, P. Stillwater Sciences. 2024. *Healthy Rivers and Landscapes Proposal – Methods for Quantifying Existing and Future Suitable Habitat for Fall-run Chinook salmon*. Final. Prepared for the Tuolumne River Technical Advisory Committee.

Jeffres, C. A., J. J. Opperman, and P. B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. *Environmental Biology of Fishes* 83: 449–458.

Jeffres, C.A., E.J. Holmes, T.R. Sommer, J.V.E. Katz, R.A. Hovel. 2020. Detrital food web contributes to aquatic ecosystem productivity and rapid salmon growth in a managed floodplain. PLoS One 15 (9), e0216019. https://doi.org/10.1371/journal.pone.0216019.

Jensen, D. W., E. A. Steel, A.H. Fullerton, and G.R. Pess. 2009. Impact of fine sediment on egg-to-fry survival of Pacific salmon: a meta-analysis of published studies. Revies in Fisheries Sciences. 17(3): 348–359.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Special publication. *Canadian Journal of Fisheries and Aquatic Science* 106:110–127.

Katz, J.V.E., C. Jeffres, J.L. Conrad, T.R. Sommer, J. Martinez, S. Brumbaugh, N. Corline, P.B. Moyle, J.M. Dias. 2017. Floodplain farm fields provide novel rearing habitat for Chinook salmon. PLoS One 12 (6), e0177409. https://doi.org/10.1371/journal.pone.0177409.

Keeley, E.R., and McPhail, J.D. 1998. Food abundance, intruder pressure, and body size as determinants of territory size in juvenile steelhead trout (*Oncorhynchus mykiss*). Behavior 135:65:82.

Kemp, P., D. Sear, A. Collins, P. Naden, and I. Jones. 2011. The impacts of fine sediment on riverine fish. Hydrological Processes. 25: 1800–1821.

Kondolf, G.M. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society 129: 262-281.

Kondolf, G.M., and E.R., Micheli. 1995. Evaluating stream restoration projects. Environmental Management. 19(1): 1–15.

Limm, M. P., and M. P. Marchetti. 2009. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) growth in off-channel and main-channel habitats on the Sacramento River, CA using otolith increment widths. *Environmental Biology of Fishes* 85(2):141–151. https://doi.org/10.1007/s10641-009-9473-8.

Maslin, P., M. Lennox, J. Kindopp, and W. McKinney. 1998. Intermittent streams as rearing habitat for Sacramento River chinook salmon (*Oncorhynchus tshawytscha*). California State University, Chico, Chico, California.

McBain and Trush, 2000. *Habitat Restoration Plan for The Lower Tuolumne River Corridor.* Final. Prepared for the Tuolumne River Technical Advisory Committee.

McBain and Trush. editor. 2002. *San Joaquin River Restoration Study Background Report.* Prepared for Friant Water Users Authority (Lindsay, CA) and Natural Resources Defense Council (San Francisco CA).

McBain and Trush. 2004. Coarse Sediment Management Plan for the lower Tuolumne River. Revised Final. Prepared for Tuolumne River Technical Advisory Committee, Turlock and Modesto Irrigation Districts, U.S. Fish and Wildlife Service Anadromous Fish Restoration Program, and California Bay-Delta Authority.

McManamay, R., C.A. Dolloff, D.J. Orth, and M.A. Cantrell. 2010. Gravel addition as a habitat restoration technique for tailwaters. North American Journal of Fisheries Management 30: 1238-1257.

Merz, J. E., and L. K. O. Chan. 2005. Effects of gravel augmentation on macroinvertebrate assemblages in a regulated California river. River Research and Applications 21: 61–74.

Merz, J. E., and J. D. Setka. 2004. Evaluation of a spawning habitat enhancement site for Chinook salmon in a regulated California River. North American Journal of Fisheries Management 24(2): 397–407.

Mesick, C.F. 2009. *The High Risk of Extinction for the Natural Fall-Run Chinook Salmon Population in the Lower Tuolumne River due to Insufficient Instream Flow Releases.* U.S. Fish and Wildlife Service, Energy and Instream Flow Branch, Sacramento, CA. Exhibit No. FWS-50.

Morley, S. A., P. S. Garcia, T. R. Bennett, and P. Roni. 2005. Juvenile salmonid (Oncorhynchus spp.) use of constructed and natural side channels in Pacific Northwest rivers. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 2811–2821.

Moyle, P. B. 2002. Inland Fishes of California. Revised and Expanded. Berkeley and Los Angeles, Ca; London, England: University of California Press.

Moyle P. B., R. D. Baxter, T. R. Sommer, T. C. Foin, and S. A. Matern. 2004. Biology and population dynamics of Sacramento splittail (Pogonichthys macrolepidotus) in the San Francisco Estuary: a review. *San Francisco Estuary and Watershed Science* 2(2).

Moyle, P.B., P.K. Crain, and K. Whitener. 2007. Patterns in the Use of a Restored California Floodplain by Native and Alien fishes. San Francisco Estuary and Watershed Science 5:1–27.

Ogston, L., S. Gidora, M. Foy, and J. Rosenfeld. 2015. Watershed scale effectiveness of floodplain habitat restoration for juvenile coho salmon in the Chilliwack River, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 72: 479-490.

Opperman, J. J. 2012. A conceptual model for floodplains in the Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science* 10(3).

Pulg, U., R. J. Lennox, S. Stranzi, E. O. Espedel, S. E. Gabrielsen, T. Wiers, G. Velle, C. Hauer, B. O. Donnum, and B. T. Barlaup. 2022. Long-term effects and cost-benefit analysis of eight spawning gravel augmentations for Atlantic salmon and Brown trout in Norway. Hydrobiologia. 849: 485–507.

Peterson, J.T. and Duarte, A. 2020. Decision analysis for greater insights into the development and evaluation of Chinook salmon restoration strategies in California's Central Valley. Restoration Ecology 28-6: 1596-1609. https://doi.org/10.1111/rec.13244. GitHub repository available at https://github.com/CVPIA-OSC/fallRunDSM.

Reynolds, F.L., Reavis R.L., and Schuler, J. 1990. Central Valley Salmon and Steelhead Restoration and Enhancement Plan. State of California Resources Agency Department of Fish and Game.

Roni, P., and T.P. Quinn, 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58: 282-292.

Roni, P., T. Beechie, G. Pess, and K. Hanson. 2015. Wood placement in river restoration: fact, fiction, and future direction. Canadian Journal of Fisheries and Aquatic Sciences 72: 466–478.

Roni, P., C. Dietrich, D. King, S. Morley, and P. Garcia. 2006. Coho salmon smolt production from constructed and natural floodplain habitats. *Transactions of the American Fisheries Society* 135:1398–1408.

Roni, P., Hanson, K. & Beechie, T.J. 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. *North American Journal of Fisheries Management* 28: 856–890.

Roni, P., K. Hanson, T. J. Beechie, G. R. Pess, M. M. Pollock, and D. M. Bartley. 2005. Habitat Rehabilitation for Inland Fisheries. Global Review of Effectiveness and Guidance for Rehabilitation of Freshwater Ecosystems. FAO Fisheries Technical Paper 484. Prepared for the Food and Agriculture Organization of the United Nations (Rome).

Roni, P., G. Pess, K. Hanson, and M. Pearsons. 2013. Chapter 5: Selecting appropriate stream and watershed restoration techniques. In P. Roni and T. Beechie (eds.), Stream and watershed restoration: A guide to restoring riverine processes and habitats. John Wiley & Sons, Ltd.

San Joaquin River Restoration Program. 2012. Minimum Floodplain Habitat Area for Spring and Fall-Run Chinook Salmon.

Solazzi, M.F., T.E. Nickelson, S.L Johnson, and J.D Rodgers. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 906–914.

Sommer, T., M. L. Nobriga, W.C. Harrell, W. Batham, and W. Kimmerer. 2001. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 325–333.

Sommer, T. R., L. Conrad, G. O'Leary, F. Feyrer, and W. C. Harrell. 2002. Spawning and Rearing of Splittail in a Model Floodplain Wetland. Transactions of the American Fisheries Society 131(5):966–974. https://doi.org/10.1577/1548-8659(2002)131%3C0966:SAROSI%3E2.0.CO;2.

Sommer, T. R., W. C. Harrell, A. M. Solger, B. Tom, and W. Kimmerer. 2004. Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA. *Aquatic Conservation: Marine and Freshwater Ecosystems* 14: 247–261.

Sommer, T. R., W. C. Harrell, M. L. Nobriga. 2005. Habitat use and stranding risk of juvenile Chinook salmon on a seasonal floodplain. *North American Journal of Fisheries Management* 25: 1493–1504.

State Water Resources Control Board (State Water Board). 2018. Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: San Joaquin River Flows and Southern Delta Water Quality. Final. State Clearinghouse #2012122071. Division of Water Rights. Sacramento, CA.

State Water Resources Control Board (State Water Board), California Department of Water Resources, and California Department of Fish and Wildlife. 2023. Final Draft Scientific Basis Report Supplement in Support of Proposed Voluntary Agreements for the Sacramento River, Delta, and Tributaries Update to the San Francisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan. September. (ICF 103625.0.002.01.004.01.) Sacramento, CA.

Sternecker, K., R. Wild, and J. Geist. 2013. Effects of substratum restoration on salmonid habitat quality in a subalpine stream. Environmental Biology of Fishes 96: 1341–1351.

Stillwater Sciences. 2012. Lower Tuolumne River Instream Flow Studies: Pulse Flow Study Report. Final. Prepared by Stillwater Sciences, Berkeley, California for Turlock Irrigation District and Modesto Irrigation District, California. June.

Stillwater Sciences. 2013. Spawning Gravel in the Lower Tuolumne River. Updated Study Report. W&AR-04. Don Pedro Project, Federal Energy Regulatory Commission No. 2299. Prepared for Turlock Irrigation District (Turlock, CA) and Modesto Irrigation District (Modesto, CA).

Stillwater Sciences. 2017. Oncorhynchus Mykiss Habitat Survey. Amended study report. W&AR-12. Don Pedro Project, Federal Energy Regulatory Commission No. 2299. Prepared for Turlock Irrigation District (Turlock, CA) and Modesto Irrigation District (Modesto, CA).

Stillwater Sciences. 2017. Lower Tuolumne River Instream Flow Study—Evaluation of effective usable habitat area for over-summering *O. mykiss*. Final Report. Prepared by Stillwater Sciences, Davis, California for Turlock Irrigation District, Turlock California and Modesto Irrigation District, Modesto, California.

Stillwater Sciences. n.d. Tuolumne River Restoration Program Summary Report. AFRP/CALFED Adaptive Management Forum. Supplement Report. Tuolumne River Restoration Program. Prepared by Stillwater Sciences with Tuolumne River Technical Advisory Committee (Berkeley,R CA).

Sturrock, A. M., M. Ogaz, K. Neal, N. J. Corline, R. Peek, D. Myers, et al. 2022. Floodplain trophic subsidies in a modified river network: managed foodscapes of the future? Landscape Ecology 37:2991–3009. https://doi.org/10.1007/s10980-022-01526-5.

Takata, L., T. R. Sommer, J. L. Conrad, B. M. Schreier. 2017. Rearing and migration of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in a large river floodplain. *Environmental Biology of Fishes* 100: 1105–1120.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 1991. Lower Tuolumne River Spawning Gravel Studies Report. Don Pedro Hydroelectric Project FERC No. 2299. Prepared by EA Engineering, Science, and Technology.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 1992. Volume IV. Appendices 6 through 11 of Fisheries Studies Report Pursuant to Article 39. Don Pedro Hydroelectric Project FERC No. 2299.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2007. 2006 Lower Tuolumne River Annual Report. Report 2006-10. Tuolumne River La Grange Gravel Addition, Phase II Annual Report. Don Pedro Hydroelectric Project FERC No. 2299. Prepared by California Department of Fish and Wildlife.

U.S. Fish and Wildlife Service (USFWS). 1995. Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California. Volume 3. Prepared for the U.S. Fish and Wildlife Services under the direction of the Anadromous Fish Restoration Program Core Group. Stockton, CA.

U.S. Fish and Wildlife Service (USFWS). 2013. Identification of the Instream Flow Requirements for Anadromous Fish in the Streams within the Central Valley of California and Fisheries Investigations. Annual Progress Report. Prepared by staff of the Restoration and Monitoring Program.

Wheaton, J. M., G. B. Pasternack, and J. E. Merz. 2004. Spawning habitat rehabilitation – I. Conceptual approach and methods. International Journal of River Basin Management. 2(1): 3-20.

Whiteway, S. L., P. M. Biron, A. Zimmermann, O. Venter, and J. W. A. Grant. 2010. Do in-stream restoration structures enhance salmonid abundance? A meta-analysis. Canadian Journal of Fisheries and Aquatic Sciences 67: 831–841.

Chapter 8

Traditional Ecological Knowledge of California Native American Tribes

8.1 Introduction

The purpose of this chapter is to describe the centrality of traditional stewardship of the Bay-Delta watershed in sustainably managing water resources, the role of traditional ecological knowledge in informing science and management, and the harm that aquatic ecosystem stressors have inflicted to tribes. This chapter provides an overview of the traditional ecological knowledge (TEK) of California Native American Tribes within the Bay-Delta watershed and more broadly of tribal communities with a strong cultural connection to salmon and other native fish species whose traditional lands are within northern California. In this chapter, the term "traditional ecological knowledge" means a way of knowing that is passed down through generations. This includes knowledge of and understanding of traditional land stewardship practices, and practices involving natural resources like plants, animals, ecosystems, and seasons. TEK is also developed and maintained through generations of Indigenous people observing the environment and developing science through those observations.

This chapter begins with this Introduction (Section 8.1), Section 8.2 then describes traditional ecological knowledge of northern California tribes, including benefits of integrating TEK with western science and resource management to improve scientific knowledge, management, and stewardship of aquatic resources. Section 8.2 also connects TEK and traditional stewardship practices with the flow and habitat restoration actions being considered for updating the Bay-Delta Plan.

8.2 Traditional Ecological Knowledge

8.2.1 Consideration of Traditional Ecological Knowledge in the Bay-Delta Plan

During public outreach and engagement activities in support of the Sacramento/Delta Update to the Bay-Delta Plan, the State Water Board received requests from California Native American Tribes to incorporate TEK into the Bay-Delta Plan to inform reasonable protection of beneficial uses. As a result of these requests, State Water Board staff have engaged in efforts to document TEK and traditional stewardship practices of federally recognized and non-federally recognized tribes whose historical lands fall within the Bay-Delta watershed, including its tributaries, and more broadly of tribal communities with a strong cultural connection to salmon whose traditional lands are within northern California. Part of these efforts include a literature review of TEK. However, the availability of TEK in the literature is limited because tribes are often hesitant to share their knowledge for fear that they will lose their data sovereignty, thus threatening their tribal sovereignty (Huntington 2000; Carroll et al. 2021). Board staff acknowledge the limitations of literature review and are currently developing with tribes, other avenues for documenting, considering and incorporating TEK.

8.2.2 Description of Traditional Ecological Knowledge

TEK is often defined in academic literature as "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes et al. 2000). TEK can be considered a form of adaptive management. From published sources, Yurok tribal members have described TEK as a "way of life" that includes aspects of science, spirituality, and cultural traditions. Yurok TEK includes knowing how and when to gather, hunt, harvest, and how to prepare traditional foods. From conversations with California Native American tribal members and representatives, Board staff have learned more about what TEK is; it may be described as knowledge of lived experiences in the environment, passed down through many generations.

Whereas Western ecological knowledge is often considered quantitative, TEK may be qualitative, incorporating knowledge, teaching, practices, and spiritual beliefs (Tolowa Dee-ni' Nation et al. 2017). TEK is also place-based; TEK from one tribe is not representative of TEK from all tribes in a region. In addition, all types of ecological knowledge are interconnected (e.g., fire, fish, rivers, estuaries, and more). Therefore, the parceling of management categories among U.S. state and federal agencies can be in direct conflict with how tribes conceptualize these vital ecological and cultural resources (Save California Salmon Series on TEK). The Western conservation perspective of limited human involvement with the environment is problematic for many Indigenous communities because, for them, Indigenous landscape stewardship practices necessarily include Indigenous people. Indigenous people have stewarded landscapes since time immemorial; the landscapes were not pristine and untouched (Ramos 2021).

8.2.3 Benefits of Incorporating TEK in the Bay-Delta Plan

When incorporated with Western ecological knowledge, TEK can improve the spatial and temporal resolution of environmental monitoring data and provide knowledge that predates that obtained by practitioners of western science. For example, TEK can provide knowledge about native fish species like Chinook salmon and native vegetation that are culturally significant to tribes and were prevalent prior to the arrival of European settlers (Tolowa Dee-ni' Nation et al. 2017), as well as information about environmental conditions prior to and during human development of the landscape (Usher 2000). Indigenous knowledge may also provide historical information about geographic distributions of native species (Tolowa Dee-ni' Nation et al. 2017) and how they are influenced by environmental conditions.

TEK is complementary to Western ecological knowledge, and the two approaches together can provide a more holistic and effective approach to adaptive resource management (Zedler and Stevens 2018). Traditionally, native Californians tended the landscape, observing and applying different practices to improve yield of culturally important plant species; these principles can be applied to adaptively managing habitat restoration sites. Zedler and Stevens proposed a process of including TEK in restoration and adaptive management that they term "ecocultural restoration" (Zedler and Stevens 2018). They developed a framework for the ecocultural restoration of floodplains in the Sacramento-San Joaquin Delta and suggested establishing a network of ecocultural restoration sites throughout the region. Their framework includes restoring culturally significant plant species during the floodplain restoration process and incorporating Indigenous land stewardship practices into the adaptive management of the restored sites. They suggested that

Indigenous people should be engaged during the planning and decision-making to combine TEK and traditional stewardship practices with the adaptive management of floodplain restoration sites.

In their framework, Western ecological knowledge would provide hydrological modeling and TEK would provide the knowledge about assemblages of culturally significant native plant species that would improve the restoration sites. Culturally significant plants could include plants that are more likely to establish successfully and outcompete nonnative plant species. Once the initial restoration activities are complete, traditional stewardship practices could guide adaptive management of restoration sites. For example, tending plantings and prescribing selective burns can favor ecoculturally important species in plant assemblages. Several restoration sites in the Bay-Delta watershed already incorporate Native American heritage, such as Cache Creek Nature Preserve, which includes a tending and gathering garden created by the California Indian Basketweaving Association (Zedler and Stevens 2018).

8.2.4 Tribal Connections to Native Fish and Plant Species

Native fish species are culturally significant to many tribes in Northern California and the Bay-Delta watershed. For the Plains Valley Miwok, Delta smelt, Chinook salmon, and green sturgeon are important food species (Hankins 2018). In addition to fish species, tribes likely harvested over 500 plant species from the Delta region (Zedler and Stevens 2018). Along the San Joaquin River and its tributaries, Native Americans gathered near oak groves abundant with acorns. The Northern Valley Yokuts, for example, gathered acorns and established territories around these areas for fishing, hunting, and gathering. The Northern Valley Yokuts' diet was diverse, including fish, fowl, acorns, tule roots, freshwater bivalves, small mammals, and corms, bulbs, grass, and forb seeds.

Plants hold profound significance for California Native American Tribes and are harvested for medicinal, spiritual, and ceremonial purposes (Zedler and Stevens 2018). In the Delta, mugwort (*Artemisia douglasiana*) is an important medicinal plant. Riparian plant species, including white root (*Carex barbarae*), willow (*Salix spp.*), deergrass (*Muhlenbergia rigens*), California hazelnut (*Corylus cornuta*), and western red bud (*Cercus occidentalis*) are used as basketweaving materials. Other plants such as milkweed (*Asclepias californica*) and Indian hemp (*Apocynum cannabinum*) are used to make fish and deer nets and for ceremonial regalia. Tule (*Schoenoplectus acutus*) is particularly culturally significant; every part of the plant is utilized, serving a variety of purposes, including food, building boats, and making duck decoys for fishing and hunting.

8.2.5 Traditional Land Stewardship Practices

Before modern development, California's grasslands, wetlands, oak chapparals, old growth forests, and other environments were not untouched wilderness, as they were tended for millennia by Native Americans through practices such as selective burning, planting, harvesting, and hunting (Claire and Surprise 2021). Traditional land stewardship improved landscape diversity and biodiversity, favoring the growth of culturally important species (Zedler and Stevens 2018). Traditional land stewardship practices also improved stream flows. For instance, before 1850, the lower Cosumnes River watershed was managed through planned burning to achieve more open riparian woodlands, reducing evapotranspiration and thereby prolonging stream flow during the wet season (Zedler and Stevens 2018). This practice improved the availability of water in natural springs in the upper watershed and enabled more water to flow into tributaries.

Traditional land stewardship practices also improved food yield. Indigenous People selectively harvested fish based on their developmental stage or time of year, such as restricting harvests during spawning, to manage fish populations (Zedler and Stevens 2018). In the Delta, Plains Miwok land stewardship is believed to have managed the fishery in the lower Cosumnes River streams and sloughs to increase production and abundance of native fishes to supply up to one-third of Plains Miwok diet (Zedler and Stevens 2018).

8.2.6 Importance of Flow and Water Quality to Tribal Uses of Water

Tribal uses of water are connected to the hydrology and ecology of Northern California and the Bay-Delta watershed. California Native American Tribes rely on functional flows that resemble natural patterns of flow variability to sustain cultural uses of water (Moloney 2023). Flows support geomorphic, chemical, and biological processes that contribute to water quality and tribal subsistence fishing and other tribal cultural uses of water. For example, Native Americans rely on cottonwood (*Populus* spp.) for building materials and medicine, and cottonwood tree seed germination relies on natural riverine processes . In addition, peak river flows help to support tribal cultural and subsistence fishing by benefiting salmon populations through floodplain inundation and cueing salmon migration (Moloney 2023). Tribes in the Bay-Delta watershed need access to clean water as a spiritual and cultural resource and to protect human health (Moreno 2023). The Buena Vista Rancheria of Me-Wuk Indians of Amador County, California, inhabited the Mokelumne River watershed, the lower San Joaquin River watershed, and the southern Delta (Moloney 2023). The river's name "Mokelumne" is a Miwok term meaning "people of the fish net" derived from "mok" meaning "fish net" and "-umne," meaning "people of" (Moloney 2023, page ref. n/a). The Me-Wuk call water "Ki-ku" and to the Me-Wuk, "Ki-ku is life, Ki-ku is a relation," (Moloney 2023). Ki-ku connects their people to the past, present, and future. The Me-Wuk consider all water to be connected as "an entity with a life of its own, a relative who connects all things," a teacher and a guide, and a cleaning agent; therefore, water itself is a significant resource (Moloney 2023). Cultural uses of water include sustenance and maintenance of basic needs, for use as a material, to maintain health, provide medicine, hold ceremonies, and produce food. Water also sustains species that the Me-Wuk rely upon to meet their cultural needs. For example, willow is an important riparian plant that is used in basket weaving and building sweat lodges. Tribal uses of water are the historical human use and management of water in California; these uses have been disrupted by colonization, genocide, and other aquatic ecosystem stressors (Moloney 2023).

8.2.7 Effects of Aquatic Ecosystem Stressors on Tribal Uses of Water

Land development, water management infrastructure, flow alteration, climate change, nonnative species, and harmful algal blooms are some of the aquatic ecosystem stressors affecting aquatic species and ecosystems in the Bay-Delta watershed and throughout Northern California, with profound impacts on California Native American Tribes. These stressors have in turn affected the physical, cultural, and spiritual health and well-being of tribal communities. Drained wetlands, diverted streams, and decimated fisheries have disrupted not only the ecology of the region but also the traditional ways of life of tribal communities (Claire and Surprise 2021).

Water management infrastructure such as channelization, levees, dams, and hydrologic alteration of streams has impacted tribes across Northern California and in the Bay-Delta watershed. These and other ecosystem stressors have degraded the abundance, accessibility, and quality of freshwater mussels, salmonids, lamprey, and sturgeon (Long and Lake 2018). Anadromous fish species, a staple of traditional tribal diets, have declined substantially. For example, in the Klamath region, salmon and tanoak traditionally provided half of the diet among members of the Karuk tribe. However, consumption of salmon has dropped from an average of 200 kilograms per person per year to 2.25 kilograms per person per year. The reduction in salmon harvest has resulted in low food security and poor health of tribal members, disrupted social relationships, and an overall decline in quality of life. Other aquatic ecosystem stressors such as climate change, invasive species, extirpations of culturally important animals, and contamination of streams by toxins have also reduced the availability of ecoculturally important resources (Long and Lake 2018).

Shasta and Friant Dams, part of the Central Valley Project (CVP), flooded the land of the Winnemem Wintu and North Fork Mono Indians, respectively (Claire and Surprise 2021; Mulcahy 2023). The Friant Dam blocked the migration of Chinook salmon to the upper San Joaquin River watershed, and CVP operations contributed to the dewatering of the San Joaquin River and extirpation of spring-run Chinook salmon from the San Joaquin River (McBain& Trush 2002). Middleton-Manning et al. (2018) review how three Indian nations, the Pit River, Winnemem Wintu, and Mountain Maidu, have advocated for restoration and preservation of their homelands, as hydrologic alteration of rivers has significantly affected the tribal resources of these Northern California Native American Tribes. In 1947, Shasta Reservoir flooded over 90% of the Winnemem Wintu's homelands and prevented salmon from returning to their natal spawning sites in the McCloud River (Mulcahy 2023). Shasta Reservoir also affected traditional lives of the Pit River, Shasta, Modoc, and other tribal nations, who relied on salmon that historically migrated upstream past the dam location and whose homelands were flooded by the reservoir (Middleton-Manning et al. 2018).

Climate change has exacerbated these challenges for California Native American Tribes through increased reliance on groundwater, decreases in native vegetation and wildlife, and degraded aquatic habitat (OEHHA 2022). Sea level rise has limited access to traditional sites along shorelines. Warm temperatures have increased toxins due to harmful algal blooms in lakes, rivers, and streams, threatening tribal communities' access to clean water and food. Elevated temperatures along with reduced stream flows have harmed native fish, including salmon, that are of cultural and spiritual importance to many tribes. Invasive plants, such as water primrose (*Ludwigia spp.*), have increased in abundance due to climate change and have outcompeted culturally significant native plant species (OEHHA 2022).

8.3 References

8.3.1 Printed References

Berkes, F., J. Colding, and C. Folke. 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecol Appl 10:1251-1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROT EKA]2.0.CO;2

Carroll S. R., E. Herczog, M. Hudson, K., Russell, and S. Stall. 2021. Operationalizing the CARE and FAIR Principles for Indigenous data futures. *Scientific Data* 8:108.

Claire, T. and K. Surprise. 2021. Moving the Rain: Settler Colonialism, the Capitalist State, and the Hydrologic Rift in California's Central Valley. Antipode Vol. 0 No. 0 2021 ISSN 0066-4812, pp. 1–21.

Hankins, D. K. 2018. Ecocultural Equality in the Miwko? Waali?. San Francisco Estuary and Watershed Science. 16(3): 1–9.

Howard University School of Law (Howard). 2023. A Brief History of Civil Rights in the United States: Indigenous Peoples' Civil Rights. January 6. Available: https://library.law.howard.edu/civilrightshistory/indigenous. Accessed: September 17, 2023.

Huntington, H. P. 2000. Using Traditional Ecological Knowledge in Science: Methods and Applications. Ecological Applications 10(5):1270–1274.

Long, J. W. and F. K. Lake. 2018. Escaping social-ecological traps through tribal stewardship on national forest lands in the Pacific Northwest, United States of America. Ecology and Society 23(2):10.

McBain & Trush, Inc. (eds.), 2002. San Joaquin River Restoration Study Background Report, prepared for Friant Water Users Authority, Lindsay, CA, and Natural Resources Defense Council, San Francisco, CA.

Middleton-Manning, B. R., M. S. Gali, and D. Houck. 2018. Holding the Headwaters: Northern California Indian Resistance to State and Corporate Water Development. Decolonization: Indigeneity, Education & Society. 7(1):174–198.

Office of Environmental Health Hazard Assessment (OEHHA). 2022. Indicators of Climate Change in California, Fourth Edition, California Environmental Protection Agency.

Ramos, S. C. 2021. Understanding Yurok Traditional Ecological Knowledge and Wildlife Management. The Wildlife Society DOI: 10.1002/jwmg.22140.

Tolowa Dee-ni' Nation, InterTribal Sinkyone Wilderness Council, Cher-Ae-Heights Indian Community of the Trinidad Rancheria, and Wiyot Tribe. 2017. Informing the North Coast MPA Baseline: Traditional Ecological Knowledge of Keystone Marine Species and Ecosystems. May. Available; https://caseagrant.ucsd.edu/sites/default/files/39-Rocha-Final.pdf. Accessed: September 20, 2023.

Usher, Peter J. 2000. Traditional Ecological Knowledge in Environmental Assessment and Management. Arctic 53(2):183–193.

Zedler, J., M. L. Stevens. 2018. Western and Traditional Ecological Knowledge in Ecocultural Restoration. San Francisco Estuary and Watershed Science. 16 (3):2–15.

8.3.2 Personal Communications

Moreno, K. 2023. Testimony for an Informational Item on Consideration of addition of tribal beneficial uses to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta a at State Water Resources Control Board (State Water Board) Meeting, July 6-7 Board Meeting Transcript.

Mulcahy, G. 2023. Testimony for an Informational Item on Consideration of addition of tribal beneficial uses to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta a at State Water Resources Control Board (State Water Board) Meeting, July 6-7 Board Meeting Transcript.

Chapter 9
Conclusions and Uncertainties

Native aquatic species have been declining in the Tuolumne River due to anthropogenic stressors. These stressors include physical habitat loss or alteration, reduced floodplain habitat, elevated water temperatures, predation, inadequate flows, hatchery-origin strays, and direct take. The Tuolumne River Voluntary Agreement (TVA) Memorandum of Understanding (MOU) proposes a combination of flow and restoration commitments to improve conditions for native species under the hypothesis that habitat restoration in combination with higher flows would provide enhanced benefits (TVA MOU 2022[1]). These actions would occur initially for an 8-year period in lieu of implementing the flow and related actions required in the 2018 updates to the Bay-Delta Plan. As previously described, the TVA flow and non-flow habitat contributions were analyzed in comparison to existing environmental conditions and the 30–50% of unimpaired flow objective adopted pursuant to the 2018 Bay-Delta Plan amendments (See Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*, Section 4.4.1.1, *Description of Tuolumne River Modeling Alternatives*).

The TVA proposes that a combination of flow and non-flow restoration commitments would improve conditions for native species to: (1) implement the Bay-Delta Plan's narrative Lower San Joaquin River Flows objective to "Maintain inflow conditions from the San Joaquin River watershed to the Delta at Vernalis sufficient to support and maintain the natural production of viable native San Joaquin River watershed fish populations migrating through the Delta..." and (2) provide the participating parties' share, during implementation of the TVA, to contribute to achieving the existing Narrative Salmon Protection Objective (doubled salmon population relative to the reference population of 1967 to 1991) by 2050 (TVA MOU 2022).

To evaluate the scientific support for the expectation of achieving these dual objectives, this Draft TVA Scientific Basis Report evaluates the proposed flow and restoration commitments toward increasing suitable habitat for salmonids. The analysis uses quantitative modeling that coupled hydrodynamic models to flow-dependent habitat and water temperature models. A qualitative literature review was used where no quantitative models exist (e.g., predator control). Other factors and regulatory actions outside of the February through June time period may also contribute to salmon population dynamics.

By design, the TVA is expected to provide an increase in flow in the Tuolumne River during the drier water year types and a reduction of flow during wetter water years compared to the existing conditions (Table 4-40, in Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*). This shift in the timing of instream flows could improve conditions during dry periods when the ecosystem is stressed. The TVA is also expected to provide an overall increase in Delta outflow with similar water year patterns (Table 4-41, in Chapter 4). The changes in hydrology are expected to impact habitat and water temperature conditions described below.

The quantitative habitat modeling analyses for the TVA predict increases in the suitable spawning and juvenile rearing habitat for salmonids compared to the existing conditions. The TVA's predicted

[1] Available on the State Water Board website at Proposals for Voluntary Agreements to Update and Implement the Bay-Delta Plan.

salmonid spawning (Figure 7-11, Figure 7-12, and Table 7-4, in Chapter 7, *Spawning and Rearing Habitat*), in-channel rearing (Figure 7-13, Figure 7-14, and Table 7-5, in Chapter 7, Spawning and Rearing Habitat), floodplain rearing (Figure 7-15, Figure 7-16, and Table 7-6, in Chapter 7), and combined rearing (Figure 7-18, Figure 7-19, and Table 7-8, in Chapter 7) habitats should contribute toward the narrative objectives described above.

The water temperature modeling analyses for the TVA predict improved water temperature conditions during the juvenile Chinook salmon rearing months March through May (Table 5-7 and Section 5.2.2, Results, in Chapter 5, *Water Temperature*); however, these water temperature benefits would be reduced upon implementation of sequential dry-year off-ramps proposed by the TVA. The TVA is predicted to result in increased water temperatures compared to existing conditions for juvenile Chinook salmon rearing or *O. mykiss* core rearing and summer rearing during June and July (Table 5-7 and Section 5.2.2, Results, in Chapter 5).

The incorporation of predator control actions, along with the other flow and non-flow actions of the TVA, may contribute toward the narrative objective (Chapter 6, *Predator Control*).

The proposed TVA may also help protect Tribal Beneficial Uses through increased springtime flows and related habitat and temperature improvements. Incorporation of traditional ecological knowledge and effective tribal consultation may improve environmental understanding and restoration outcomes (Chapter 8, *Traditional Ecological Knowledge of California Native American Tribes*).

As is the case with all modeling analyses, the results involve a degree of uncertainty arising from assumptions and simplifications. The science program for the TVA and the Healthy Rivers and Landscapes program as a whole will help to address some of the uncertainties described below. These assumptions and simplifications include:

1. The proposed TVA habitat does not include a site location or engineering design, so the actual outcome will likely deviate from the modeled results included in this Draft TVA Scientific Basis Report. The habitat modeling uses adjusted flow-to-habitat curves developed by the Tuolumne Parties for hypothetical restoration sites. Different locations for these restoration projects could affect the actual outcomes, both positively and negatively.
2. Accounting methods have yet to be finalized for the TVA flow and non-flow habitat commitments. This Draft TVA Scientific Basis Report therefore makes assumptions for how those commitments would be accounted for, based in part on their suitability, to quantify the resulting flow, acres of suitable habitat, and other potential benefits of the proposed TVA. The draft non-flow habitat accounting methods do not fully align with the assumptions in this Draft TVA Scientific Basis Report because there is flexibility in those requirements that were not possible to model. Therefore, the amount of suitable habitat may differ from the values presented here. When the TVA accounting procedures are finalized, and if they are changed to include additional specificity in the implementation of TVA commitments, they would provide additional certainty in how the commitments would be provided and therefore in the benefits these commitments would be expected to provide.
3. Flow accounting methods are still being developed, which once available, would inform the total volume of new additive Delta outflow resulting from implementation of the TVA (Chapter 4, Section 4.4.3.2, *Delta Throughflow Protection and Net Delta Outflow*).

4. Analysis of habitat restoration benefits is based on the assumption that restoration sites will replicate natural ecosystem functions and that restoration sites would be maintained such that species benefits do not diminish over time.
5. The Meaningful Floodplain Event approach was designed conservatively so suitable habitat would be guaranteed. This method likely underestimates the amount of floodplain habitat that would be available, assuming the restored habitat is accessible and suitable.
6. There is considerable uncertainty around the estimated rearing habitat necessary to support the doubling goal population (e.g., there is a 50-fold difference in the 2.5% and 97.5% probability estimates of the rearing habitat needed). The habitat modeling estimates that the median annual combined juvenile salmon rearing habitat is enough to support 100% of the doubling goal population, even though far fewer Chinook salmon are being supported in the Tuolumne River than suggested by the modeled acres of available existing suitable habitat. The suitability criteria or number of organisms supported by an area of habitat may need to be calibrated for the Tuolumne River.
7. There is a general lack of evidence in the literature for predator control as a management strategy for recovery of strong, positive, population-level responses in target species. It is unclear how effective the predator control program will be at increasing salmon abundance.
8. Analyses were focused on a couple at-risk species with the expectation that the benefits for those species would apply more generally to all native aquatic species, natural ecosystem functions, and other natural processes fundamental to beneficial uses of water resources. For salmonids in particular, modeling was primarily conducted based on needs of fall-run Chinook salmon and *O. mykiss* in the Tuolumne River, but needs of other species will vary.

The TVA, if adopted, would include a set of implementation criteria and habitat suitability and utilization criteria, along with a monitoring program, to ascertain the actual benefits realized and overall program success.

Appendix A

Stock-Recruitment Modeling

Contents

Appendix A Stock-Recruitment Modeling A-1

A.1 Introduction A-1

A.2 Background A-1

A.2.1 Model Formulation A-2

A.3 Methods A-3

A.3.1 Spawner and Juvenile Abundance Estimates A-4

A.3.2 Environmental Covariates A-5

A.3.3 Modeling Approach A-6

A.4 Model Interpretation A-7

A.5 Results and Discussion A-7

A.5.1 Temperature Effects A-8

A.5.2 Flow Effects A-9

A.5.3 Habitat Size and Availability A-10

A.6 References A-18

A.6.1 Printed References A-18

Appendix A
Stock-Recruitment Modeling

A.1 Introduction

This appendix describes in detail the background, data sources, methods, and results of stock-recruitment modeling that is summarized in Chapter 2, *Aquatic Ecosystem Stressors*, Section 2.8, *Limiting Factors Analysis.*

A.2 Background

Stock-recruitment models are commonly used in fisheries management to describe the relationship between the number of adult spawners (the stock) and the total number of adult or juvenile recruits they produce (Quinn II and Deriso 1999) and to inform fisheries management decisions. Satterthwaite (2023) modeled stock-recruitment relationships of Sacramento River fall-run Chinook salmon to evaluate the probability that meeting spawning escapement goals will achieve goals for hatchery and natural production. Stock-recruitment models can also be used to evaluate the effects of environmental factors and local management actions (e.g., flow, water temperature, or habitat restoration) on long-term trends in productivity and abundance of salmon (Adkison 2022). For example, Sturrock et al. (2020) used stock-recruitment modeling to assess how regulated flow has influenced production of fall-run Chinook salmon on the Stanislaus River, and Munsch et al. (2020) evaluated how flow and habitat restoration have affected Chinook salmon fry density in the Sacramento-–San Joaquin Delta.

The use of stock-recruitment modeling to evaluate effects of environmental factors on salmon production was recommended in a report to the State Water Resources Control Board (State Water Board or Board) by an Independent Scientific Advisory Panel (ISAP) convened by the Delta Stewardship Council's Delta Science Program[1] for the development of biological goals pursuant to the 2018 Bay-Delta Plan[2] (Dahm et al. 2019). The ISAP report included stock-recruitment modeling for the Stanislaus River by examining the relationship between spawner abundance and juvenile recruits of fall-run Chinook salmon, and the effects of environmental covariates, including flow, temperature, and habitat, on the stock-recruitment relationship. State Water Board staff subsequently developed stock-recruitment modeling to examine the relationship between adult fall-run Chinook salmon spawners and juvenile recruits for the Stanislaus and Tuolumne Rivers and inform the development of quantitative biological goals. (ICF 2023; 2023 Biological Goals Report). The 2023 Biological Goals Report included the use of density-independent, and Ricker and Beverton-Holt (density-dependent) stock-recruitment models describing the relationship between fall-run Chinook salmon spawner abundance and juvenile recruitment in the Tuolumne River. Flow and water temperature were evaluated as environmental covariates in the models.

[1] Established to provide scientific information and syntheses for the state of scientific knowledge on issues critical for managing the Bay-Delta system.

[2] Available on the State Water Board website at 2018 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary.

In February 2024, the State Water Board received the peer review report for the Final Draft Scientific Basis Report in Support of Proposed Voluntary Agreements for the Sacramento River, Delta, and Tributaries Update to the San Francisco Bay/Sacramento–San Joaquin Delta Water Quality Control Plan (SWRCB 2024; 2024 Draft Supplement Report for the Sacramento/Delta). Peer reviewers recommended that the report be revised with a quantitative analysis of limiting factors for salmon production, especially whether habitat was limiting salmon abundance. Board staff considered commonly used modeling approaches, including life-cycle modeling and stock-recruitment modeling, to quantitatively evaluate the effects of limiting factors. Life-cycle models were deemed too complex and reliant on sub-models to be useful. Life-cycle models would have required updates to relationships between the environment, transitions among different life stages, and other biological rates; recalibration to newer hydrologic and temperature modeling; and they could not be applied to Bay-Delta tributaries for which temperature models are not yet developed. Moreover, the models largely rely on relationships derived from literature, rather than monitoring data collected in the system.

Through their relative simplicity and reliance on monitoring data, stock-recruitment models circumvent many of the limitations of life-cycle models. These models can be fit using temperature, flow, and other environmental gage data, and measures of adult and juvenile salmon abundance collected from carcass surveys, rotary screw traps, and other monitoring approaches already employed within the tributaries to the Bay-Delta. Therefore, following the recommendations of the peer reviewers on the 2024 Draft Supplement Report for the Sacramento/Delta, recommendations in the ISAP report, and the approach used in the 2023 Biological Goals Report, stock-recruitment models were developed for this Draft TVA Scientific Basis Report to evaluate potential environmental factors limiting the production of juvenile fall-run Chinook salmon in the Tuolumne River, including flow, temperature, and spawning and rearing habitat area.

A.2.1 Model Formulation

The simplest of the stock-recruitment models is the density-independent model which predicts that the number of juvenile recruits increases at a constant rate with an increasing number of adult spawners. The density-independent model does not typically reflect the population dynamics of most natural populations because the model does not consider the effects of density-dependence on growth, mortality, fecundity, and recruitment (Wootton 1990). Density-dependent effects refer to intrinsic processes that are either positively or negatively affected by increasing population density.

The more complex Beverton-Holt and Ricker models build upon the simple density-independent model by incorporating density-dependence. The models predict that at low spawner abundances, density-independent factors (e.g., environmental stressors and background birth and death rates) exert a relatively greater influence on population dynamics than density-dependent factors (e.g., competition for habitat area). However, as the number of spawners increases, density-dependent factors become more influential on population dynamics (Subbey et al. 2014). The Beverton-Holt and Ricker models can produce different results and line curvature due to differences in underlying assumptions. The Beverton-Holt model assumes a high mortality rate of recruits at larger population sizes due to juvenile competition and predation. The Beverton-Holt model is usually selected when it is hypothesized that recruitment is limited by food availability or habitat space, and that predators can rapidly adjust their feeding rates based on changes in prey abundance. The Ricker model assumes egg and juvenile mortality is proportional to the initial juvenile cohort size. This model is generally selected if it is hypothesized that cannibalism of juveniles by adults is high,

redd superimposition is significant, and the effects of predators are not immediate and display a time-lag response (Wootton 1990). Nonetheless, both models lead to less per capita recruitment as spawning stock size increases (i.e., fewer juveniles are produced per adult spawner at higher spawner densities).

The following three stock-recruitment model forms were considered for the Tuolumne River:

$R_t = \alpha * S_t + \gamma * F_t$, Density-independent (1)

Here, R_t represents the total annual number of juvenile recruits for year t, S_t is the annual estimate of adult spawner abundance, and α is intrinsic productivity (i.e., the slope near the origin). F_t is an environmental covariate (flow, temperature, or habitat area), and γ is the coefficient value for the covariate effect (i.e., estimate of the effect of flow, temperature, or habitat area on juvenile abundance).

$R_t = (\alpha * S_t / 1 + \beta * S_t) + \gamma * F_t$, Beverton-Holt (2)

$R_t = \alpha * S_t * \exp(-\beta * S_t) + \gamma * F_t$, Ricker (3)

In the Beverton-Holt (eqn. 2) and Ricker model forms (eqn. 3), β is the density-dependent term, expressing the effect of diminishing numbers of juvenile recruits per adult spawner as the number of spawners increases.

A.3 Methods

Data used in modeling were compiled from a variety of sources across the Tuolumne River watershed covering the years 2007–2022, excluding 2010 and 2020 due to gaps in data collection. Juvenile salmonid outmigrant abundance estimates were sourced from Rotary Screw Trap (RST) monitoring surveys at Waterford, CA, with juvenile abundance estimates presented in Turlock and Modesto Irrigation Districts 2022 Lower Tuolumne Annual Report to the Federal Energy Regulatory Commission (TID and MID 2023). Adult salmonid spawner abundance estimates were sourced from California Department of Fish and Wildlife carcass surveys with results presented in GrandTab (CDFW 2023). Environmental covariate data (flow and temperature) were sourced from USGS gage 11290000 at Modesto, CA (Figure A-1).

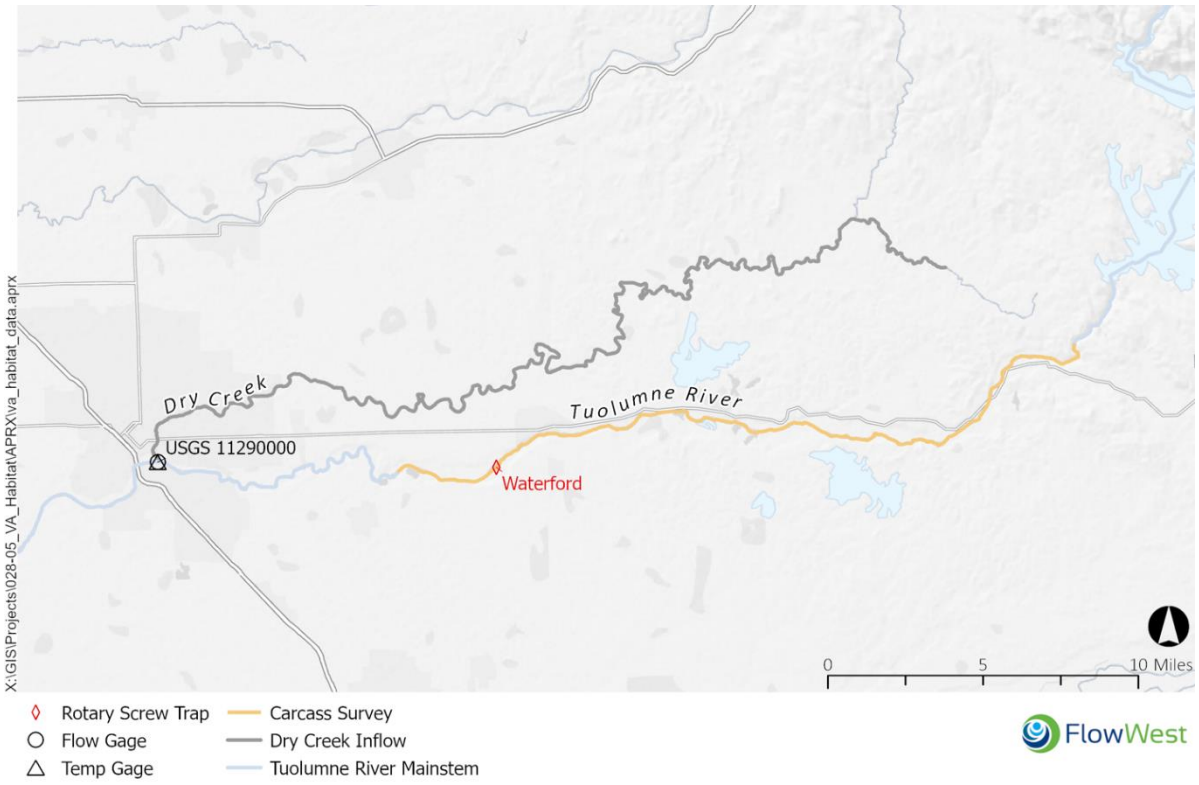


Figure A-1. A map of the juvenile and adult salmonid monitoring data sources, flow gages, and temperature gages used in the Tuolumne stock-recruitment analysis.

A.3.1 Spawner and Juvenile Abundance Estimates

Adult spawner abundance estimates used in stock-recruitment modeling were sourced from GrandTab escapement estimates. GrandTab describes the escapement estimates as the number of adult Chinook salmon "that successfully migrated upstream to a natural spawning area or hatchery" (CDFW 2023). Personal communication with California Department of Fish and Wildlife revealed that the estimates reported in GrandTab for the Tuolumne River were from carcass survey counts as described in the 2022 Spawning Survey Summary Update attached to the 2022 Federal Energy Regulatory Commission (FERC) Report (TID and MID 2023).

For juvenile abundance estimates, staff used estimates of total passage from the Waterford RST site reported in the Outmigrant Trapping report attached to the 2022 FERC Report. Data from the Waterford site were used because the Grayson RST has had very low efficiency since 2015 due to clogging with water hyacinth. Data collected in 2006 at the Waterford RST were excluded due to large sampling gaps resulting in underestimation of smolt outmigration due to high flows. In addition, 2020 was excluded because sampling was suspended due to the COVID-19 pandemic. In addition, the 2022 FERC report identifies that fry abundance was likely underestimated during 2017 because of a sampling gap from mid-February to March during flood control releases. Finally, during 2013–2016, and 2021–2022, RST monitoring ceased during May, and in some cases earlier in the spring, due to high river temperatures. For this reason, the environmental covariates used in stock-recruitment modeling are calculated through the end of May rather than the full rearing period. The modeling therefore likely underestimates juvenile production and the impacts of warm temperatures in June due to not accounting for the full rearing period.

A.3.2 Environmental Covariates

All analyses were performed using R Statistical Software (v4.4.1; R Core Team).[3] Historical flow data for the Tuolumne River were read and processed for analysis from the USGS gage 11290000 at Modesto, CA, using the read NWISdv R package.[4] Data were available as mean daily flows and were aggregated into two annual covariates: annual mean of daily mean flow between January 1 and May 31 and flow variation measured as the mean of daily moving 7-day window of weekly maximum minus weekly minimum flow from January 1 through May 31 (Table A-1; Sturrock et al. 2020; Munsch et al. 2020). These time frames represented the rearing period for juvenile fall-run Chinook salmon on the Tuolumne River. The rearing period for fall-run Chinook salmon also includes June, but data for June were excluded when calculating environmental covariates due to gaps in operation of the Waterford RST used to estimate juvenile abundance (described above). Temperature data were read from the same USGS gage and processed into three different annual covariates: mean daily maximum temperature from January 1 through May 31, May 1 through May 31, and October 1 through November 30. Mean temperature estimates could not be calculated for the year 2010 due to missing data values during the spring period of that year. The spring timeframes represent portions of the rearing period while the October through November values represent part of the spawning period. Different subsets of the rearing period were calculated for temperature consistent with the 2023 Biological Goals Report which demonstrated that temperature later in spring, especially during May, was more predictive of stock-recruitment relationships.

Habitat acreage estimates were included in the analysis to assess whether the availability of rearing and spawning habitat affects the stock-recruitment relationship. Multiple habitat data covariates were estimated using flow-to-weighted usable area curves (WUA) or flow-to-wetted area curves for total wetted area (Table A-2), as described in Chapter 7, *Spawning and Rearing Habitat*, Section 7.3, *Habitat Modeling*. For the stock-recruitment modeling, the habitat covariates were estimated using historical flow data and the Existing Conditions flow-to-habitat area curves to provide an estimate of the habitat acreages that corresponded with the environmental conditions experienced by populations of fish being modeled. Spawning habitat data were filtered to the period of October through December and summarized as the annual mean. The in-channel, floodplain, and combined rearing WUA habitat covariate data were filtered to the period of January through May and summarized as the annual mean. For wetted area covariates, flow-to-wetted area curves were provided for in-channel and floodplain wetted area separately. In-channel wetted area was used for spawning and in-channel rearing covariates, and floodplain wetted area was used for floodplain covariates. Combined wetted area was produced by summing in-channel and floodplain wetted area. Wetted area covariates do not incorporate habitat suitability criteria.

The habitat covariates were organized by life stage (spawning or rearing time frames) and by total wetted area or WUA. Ten habitat covariates (Table A-2) were evaluated in the stock-recruitment models.

[3] R Core Team (2024). _R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

[4] Available at readNWISdv: Daily Value USGS NWIS Data Retrieval.

Table A-1. Summary of the Temperature and Flow Covariates Processed for Analysis in the Tuolumne Stock-Recruitment Modeling. Model Type, Covariate Name, Chinook Salmon Life Stage, and the Examined Timeframe Used Are Delineated.

Covariate	Life Stage	Timeframe
Temperature mean	Rearing	Jan-May
Temperature mean	Rearing	May
Temperature mean	Spawning	Oct-Nov
Flow mean	Rearing	Jan-May
Flow variation	Rearing	Jan-May

Table A-2. Summary of the Habitat Covariates Processed for Analysis in the Tuolumne River Stock-Recruitment Modeling. Covariate Name, Habitat Type, the Flow-to-Habitat Relationship Used, and the Examined Timeframe Are Delineated.

Covariate	Habitat type	Flow-to-habitat relationship	Timeframe
Mean spawning wetted area	Spawning	Total wetted area	Oct-Dec
Mean spawning area	Spawning	Weighted usable area	Oct-Dec
Mean inundated wetted area	Floodplain rearing	Total wetted area	Jan-May
Total acre days wetted area	Floodplain rearing	Total wetted area	Jan-May
Mean inundated area	Floodplain rearing	Weighted usable area	Jan-May
Total acre days	Floodplain rearing	Weighted usable area	Jan-May
Total acre days wetted area	In-channel rearing	Total wetted area	Jan-May
Mean rearing area	In-channel rearing	Weighted usable area	Jan-May
Mean combined wetted area	In-channel and floodplain rearing	Total wetted area	Jan-May
Mean combined rearing area	In-channel and floodplain rearing	Weighted usable area	Jan-May

A.3.3 Modeling Approach

Stock-recruitment models were fit using nonlinear least squares regression using the 'nlstools' package in R[5] to evaluate how fall-run Chinook salmon juvenile production in the Tuolumne River is influenced by adult spawner abundance and environmental covariates. Three model forms were considered: a density-independent model (Eq. 1) and two density-dependent model forms, Beverton-Holt (Eq. 2) and Ricker (Eq. 3). Results are presented below for density-independent and Ricker models, as models parameterized using the Beverton-Holt models would not converge on a solution. Models were fitted with a multiplicative error structure by taking the natural logarithm of both sides of the stock-recruitment equation (Eq. 1-3; Quinn II and Deriso 1999). Density-independent and Ricker models were fit separately to estimate the effects of spawner abundance (density-independent and Ricker), density-dependence (Ricker), and additive effects of individual environmental covariates (density-independent and Ricker), including temperature, flow, and habitat (Table A-1 and Table A-2), to identify which factors best explain interannual variation in juvenile production (Table A-3). Environmental covariate values were natural log or natural log (x+1) transformed prior to model fitting.

[5] Available at nlstools: Tools for Nonlinear Regression Analysis.

We fit thirty-two stock-recruitment models and assessed model performance using Akaike's Information Criterion (AIC). AIC is one of the most applied statistical tools for comparing the level of empirical support for different models fit to the same set of data (Cavanaugh and Neath 2019). A model that has a lower AIC value provides a relatively better fit to the data than a model with a higher AIC value, meaning that models with lower AIC have a more appropriate structure given the observed data. In addition, models with lower AIC values are less likely to be overly simplistic or complex (i.e., they are less likely to contain too many or too few parameters) and are more likely to include parameters that explain patterns in the data well. By contrast, models with higher AIC values may contain parameters with lower explanatory power and have less ability to predict future outcomes. The difference among AIC values ($AIC_i - AIC_{min} = \Delta AIC$) between a given model under consideration (AIC_i) and the best-fitting model (model with the lowest AIC value, AIC_{min}) indicates the relative level of support. ΔAIC = 0-2 indicates that the model is substantially supported, ΔAIC = 4-7 indicates substantially less support, and ΔAIC > 10 indicates essentially no support (Cavanaugh and Neath 2019). Therefore, ΔAIC was used to compare the relative performance of each model for explaining the stock-recruitment relationship. Estimated temperature, flow, and habitat covariate effects from models were considered statistically significant if $p < 0.05$. Covariate values were natural log-transformed prior to fitting models. In addition, Pearson's correlation coefficient (Pearson's r) was calculated for all covariate combinations to evaluate their inter-relationships (Section A.3.3, *Modeling Approach*, in Appendix A). All model estimates in Table A-3 are presented on the natural log scale.

A.4 Model Interpretation

This limiting factors analysis is intended to describe the general direction (positive or negative) and magnitude of effects of historical flow, temperature, and modeled habitat area on juvenile fall-run Chinook salmon recruitment. Because environmental covariates are based on historical data, the stock-recruitment models do not evaluate the effects of the specific flow or habitat actions analyzed in other chapters of this report. In addition, the models should not be used to predict the effects of flow, temperature, and habitat area on juvenile salmon abundance; rather, the models can be used to understand whether covariates likely had positive or negative effects on past abundance. Because the covariate values were not standardized prior to analysis, the estimated effects of the covariates from Table 2-6 below should not be directly compared as effect sizes. Rather, the ΔAIC should be used to interpret the overall model performance for explaining the stock-recruitment relationship, and the p-value associated with each parameter estimate should be used to evaluate whether that parameter (e.g., habitat area) strongly influenced juvenile abundance.

A.5 Results and Discussion

Density-independent models generally outperformed density-dependent Ricker models (e.g., see Density-Independent and Density-Dependent May Temperature models in Table A-3), suggesting that due to low population size, density-dependence does not strongly affect juvenile Chinook salmon abundance in the Tuolumne River. Estimated effects of spawner abundance and density-dependence from the top-performing Ricker models were generally not significant ($p > 0.05$). Estimated effects of environmental covariates during the juvenile rearing period were generally significant, suggesting that juvenile abundance is more strongly driven by environmental conditions than by intrinsic population dynamics (Table A-3).

Overall, models including environmental covariates of flow, temperature, or floodplain habitat area during the juvenile rearing period had more support than models that included only an effect of spawner abundance or included a covariate effect of spawning habitat, spawning temperature, in-channel rearing habitat, or total rearing habitat (Table A-3).z However, spawning area, in-channel wetted area, and total rearing habitat area were estimated to have positive effects on juvenile recruitment, even though models including an effect of those covariates had higher ΔAIC values (ΔAIC > 10; see further discussion below). Stock-recruitment modeling identified key limiting factors to juvenile recruitment in the Tuolumne River. The best-fitting temperature models, with the lowest ΔAIC values, were the Density-Independent + May Temperature (ΔAIC = 0), Density-Independent + January–May Temperature (ΔAIC = 0.94), and Density-Dependent + May Temperature models (ΔAIC = 2). ΔAIC values for these models were between 0 and 2, indicating substantial support for these models. The best-fitting flow model was the Density-Independent + Mean January-May Flow model (ΔAIC = 4.21); and the top habitat model was the Density-Independent + Floodplain WUA model (ΔAIC = 6.52) (Table A-3). Because the ΔAIC value of the top flow and habitat models was between 4 and 7, these models are less supported (i.e., more uncertainty) than the top temperature models.

A.5.1 Temperature Effects

Temperature emerged as the most influential environmental factor affecting recruitment, with the Density-Independent May Temperature model identified as the best-fitting model overall (Figure A-2; ΔAIC = 0), followed closely by the Density-Independent January through May Temperature model (ΔAIC = 0.94) (Table A-3). Both models revealed strong negative effects of temperature during the rearing period on juvenile recruitment, with γ values of -3.19 ($p < 0.01$) and -4.69 ($p < 0.01$), for the May and January-May Temperature models, respectively. These results suggest that higher temperatures during the rearing period (January through May) significantly reduce juvenile survival.

In contrast, temperature models that focused on the adult spawning period (October through November) were not as strongly supported according to ΔAIC and had non-significant parameter estimates, suggesting that temperatures during spawning are less influential on recruitment (Table A-3). The consistently strong and negative relationship between rearing temperature and recruitment across the top models suggests that thermal conditions during the juvenile life stage are a key limiting factor in the Tuolumne River (see also Chapter 2, Section 2.4, *Temperature*).

Water temperature and low dissolved oxygen, which decreases with increasing water temperature, are primary contributors to salmon embryo mortality (Quinn 2018). The 2023 Biological Goals Report found that warmer temperatures during the rearing period (Feb-June) were negatively correlated with juvenile abundance for Chinook salmon in the Stanislaus River, and temperatures during the end of the rearing period (May-June) had the strongest negative relationship with juvenile abundance on the Tuolumne River. The ISAP report's stock-recruitment modeling showed that warmer temperatures during spawning and early egg incubation (Oct.-Nov.) had negative effects on recruitment of Stanislaus River Chinook salmon, but that report did not examine effects of rearing temperature. Fitzgerald and Martin (2022) used thermal performance curves to demonstrate that through effects on metabolism, higher temperature increases pre-spawn mortality, embryonic mortality, and juvenile mortality of fall-run Chinook salmon on the Tuolumne River, especially during warm and dry years. Developing salmon embryos and juveniles face thermal stress due to an increased metabolic rate requiring more prey to be consumed, a higher oxygen

demand, yet lower dissolved oxygen in river, and higher predation rates during smolt outmigration (Martin et al. 2017; Nobriga et al. 2021; Fitzgerald 2025; see also Chapter 2, Section 2.4).

Overall, these results indicate that warmer water temperatures during the spring recession flow in the Tuolumne River correspond with a decrease in juvenile production. Within the present-day Tuolumne River fall-run Chinook population, our modeling shows that lethal temperatures during juvenile rearing are a stronger contributing factor on recruitment than during adult spawning. Temperature contributes more to the loss of potential recruitment than other environmental variables, including flow and habitat.

A.5.2 Flow Effects

Flow conditions during the juvenile rearing period explained significant variation in annual juvenile recruitment. Models containing a mean flow covariate were among the most strongly supported of all models considered, second only to models including an effect of rearing temperature (Figure A-3; Table A-3). The best-performing flow model was the Density-Independent January through May Flow model (ΔAIC = 4.21). This model had a highly significant positive effect of flow (γ =0.62, p < 0.01), indicating that higher flow during the rearing period is positively associated with juvenile production. Models that included an effect of flow variation were not as well supported according to AIC, but effects of flow variation on juvenile abundance were nevertheless strongly, significantly positive (Table A-3). These findings strengthen the discussion in Chapter 2, Section 2.5, *Flow*, about the importance of rearing-period hydrology in determining juvenile recruitment success, likely due to improved habitat connectivity, food availability, and reduced predation at higher flows. Flow may also affect juvenile survival in part through its effects on temperature. Mean flow and temperature on the Tuolumne River during the rearing period (Jan-May) are strongly negatively correlated (Figure A-5; Pearson r = -0.99), with higher spring temperatures during years with lower flow.

In the Tuolumne River, the volume and timing of winter–spring flows exert a strong influence on juvenile Chinook salmon survival. From 1996 to 2005, sustained late-winter and spring discharges of 1,200 cfs increased smolt outmigration through the Delta by 17.5%, whereas low winter flows below 350 cfs, as occurred in 1996, drove high juvenile mortality and poor adult returns (Mesick 2009). Due to the benefits of flow for juvenile salmon, Mesick (2009) suggests late-winter flow pulses are needed on the Tuolumne River to increase fry survival, which is supported by stock-recruitment modeling. The 2023 Biological Goals Report stock-recruitment modeling found that years with higher and more variable stream flow on the Tuolumne River were associated with higher juvenile outmigrant abundance (p. 3–18). Comparable patterns emerge for the Stanislaus and Sacramento Rivers; on the Stanislaus River, Sturrock et al. (2020) linked lower, less variable flows to diminished fall-run Chinook production and recruitment. Similarly, the ISAP report stock-recruitment modeling for the Stanislaus River found that higher mean flow was positively associated with juvenile fall-run Chinook salmon abundance.

Higher flows activate floodplain rearing habitat for juvenile Chinook salmon. Mean flow and floodplain habitat area on the Tuolumne River during the rearing period (Jan-May) are strongly positively correlated (Figure A-5), with higher spring flow resulting in more floodplain habitat. Higher annual flows that activate floodplains are associated with higher diversity and abundance of prey like aquatic macroinvertebrates, leading predictably to higher salmon growth rates (Goertler et al. 2017).

A.5.3 Habitat Size and Availability

Models incorporating measures of floodplain inundation also provided strong support for the role of floodplain habitat availability in influencing stock-recruitment relationships. The Density-Independent + Floodplain WUA model (ΔAIC = 6.52) was the best-performing habitat model (Figure A-4; Table A-3). This model featured statistically significant, positive effects of spawner abundance ($\alpha = 67.05$, $p < 0.01$) and floodplain WUA (acres) ($\gamma = 0.29$, $p < 0.01$), suggesting that higher spawner abundance and larger floodplain habitat area are associated with higher juvenile recruitment. Although modeling results indicate that floodplain habitat effects are secondary to temperature and flow, these results nevertheless highlight the ecological value of floodplain inundation during the rearing period, which may offer increased access to high-quality foraging habitat and refuge from predators.

Other habitat-related models, including Density-Independent + Floodplain Wetted Area, Density-Dependent (Ricker) + Floodplain WUA, Density-Dependent (Ricker) + Floodplain Wetted Area, Density-Independent + Total Rearing Wetted Area, Density-Independent + Total Acre-Days Wetted Area, and Density-Independent + Floodplain WUA Acre-Days models also showed statistically significant, positive covariate effects but had higher ΔAIC values compared to the top habitat model (Table 2-6). Models incorporating covariate effects of spawning and in-channel rearing habitat area consistently had high ΔAIC values and non-significant parameter estimates. For example, the Density-Independent + Spawning WUA model had a ΔAIC value of 21.51, with positive but nonsignificant effects of spawner abundance ($\alpha = 7.24$, $p = 0.9$) and spawning WUA ($\gamma = 0.87$, $p = 0.71$) on juvenile recruitment. Similarly, the Density-Independent + In-Channel WUA model had a ΔAIC value of 21.68, a positive but nonsignificant effect of spawner abundance ($\alpha = 128.72$, $p = 0.71$), and in-channel WUA was estimated to have no effect on juvenile recruitment ($\gamma = 0$, $p = 1$). These findings suggest that spawning habitat and instream rearing habitat are not as limiting to recruitment as temperature, flow, and floodplain habitat during the rearing period in the Tuolumne River (Table A-3).

Floodplain habitat provides substantial benefits to juvenile Chinook salmon by supporting faster growth and higher survival through improved access to drift invertebrate prey, greater feeding success, and refuge from predators (Sommer et al., 2001; Jeffres et al. 2008). Floodplain habitats are generally shallower and warmer than in-channel wetted areas. Although elevated temperatures can sometimes reduce survival, warm floodplain waters are rich in prey, including terrestrial invertebrates and aquatic macroinvertebrates and zooplankton. See also Chapter 7, Section 7.2.2.2, *Growth Benefits in Floodplains*.

Table A-3. Summary Results of Fall-Run Chinook Salmon Stock-Recruitment Models, Comparing Density-Dependent (Ricker) and Density-Independent Models with Different Environmental Covariates. The Table Includes Columns Describing the Model Considered, the Stock-Recruitment Equation Used to Fit the Model, and the Parameters Included in the Model (α for Spawner Abundance, β for Density-Dependence, and γ for the Environmental Covariate). The 'Estimate' Column Is the Estimated Direction (+ or -) and Magnitude of the Effects of Spawner Abundance, Density-Dependence, and Environmental Covariates (Flow, Temperature, and Habitat Area) on Juvenile Abundance Along with the Standard Error, T-Value, and P-Value Associated with Each Parameter Estimate. Significant Estimates of Covariate Effects (P < 0.05) Are in Bold. Estimates Are on the Natural Log Scale. Models Are Ranked by AIC and ΔAIC Value. Models with a Lower ΔAIC Have More Empirical Support.

Model	Equation	Parameter	Estimate	Standard Error	t-value	p-value	AIC	Δ AIC
Density-Independent + May Temperature	1	α (spawner abundance)	1.63E+06	2.32E+06	0.7	0.5	20.46	0.00
		γ (covariate effect)	**-3.19**	**0.48**	**-6.67**	**<0.01**		
Density-Independent + January-May Temperature	1	α (spawner abundance)	4.31E+07	8.60E+07	0.5	0.63	21.4	0.94
		γ (covariate effect)	**-4.69**	**0.73**	**-6.39**	**<0.01**		
Density-Dependent (Ricker) + May Temperature	3	α (spawner abundance)	1.63E+06	2.57E+06	0.63	0.54	22.46	2.00
		β (density-dependence)	1.47E-06	2.51E-04	0.01	1		
		γ (covariate effect)	**-3.19**	**0.51**	**-6.21**	**<0.01**		
Density-Dependent (Ricker) + January-May Temperature	3	α (spawner abundance)	5.97E+07	1.33E+08	0.45	0.66	23.19	2.73
		β (density-dependence)	1.05E-04	2.63E-04	0.4	0.7		
		γ (covariate effect)	**-4.78**	**0.8**	**-6.01**	**<0.01**		
Density-Independent + Mean January-May Flow	1	α (spawner abundance)	2.17	1.65	1.31	0.21	24.67	4.21
		γ (covariate effect)	**0.62**	**0.11**	**5.46**	**<0.01**		
Density-Dependent (Ricker) + Mean January-May Flow	3	α (spawner abundance)	2.1	1.65	1.27	0.23	26.33	5.87
		β (density-dependence)	1.56E-04	2.98E-04	0.52	0.61		
		γ (covariate effect)	**0.65**	**0.12**	**5.16**	**<0.01**		
Density-Independent + Floodplain WUA	1	**α (spawner abundance)**	**67.05**	**13.41**	**5**	**<0.01**	26.98	6.52
		γ (covariate effect)	**0.29**	**0.06**	**4.84**	**<0.01**		
Density-Independent + Floodplain Wetted Area	1	**α (spawner abundance)**	**64.41**	**13.44**	**4.79**	**<0.01**	27.31	6.85
		γ (covariate effect)	**0.27**	**0.06**	**4.75**	**<0.01**		
Density-Dependent (Ricker) + Floodplain WUA	3	**α (spawner abundance)**	**68.77**	**19.19**	**3.58**	**<0.01**	28.96	8.50
		β (density-dependence)	4.38E-05	3.21E-04	0.14	0.89		
		γ (covariate effect)	**0.29**	**0.07**	**4.49**	**<0.01**		

Model	Equation	Parameter	Estimate	Standard Error	t-value	p-value	AIC	Δ AIC
Density-Dependent (Ricker) + Floodplain Wetted Area	3	**α (spawner abundance)**	**64.25**	**18.5**	**3.47**	**<0.01**	29.31	8.85
		β (density-dependence)	-4.14E-06	3.22E-04	-0.01	0.99		
		γ (covariate effect)	**0.27**	**0.06**	**4.41**	**<0.01**		
Density-Independent + Total Rearing Wetted Area	1	α (spawner abundance)	0.1	0.28	0.35	0.73	31.01	10.55
		γ (covariate effect)	**1.04**	**0.41**	**2.55**	**0.03**		
Density-Independent + Floodplain WUA Acre Days	1	**α (spawner abundance)**	**54.87**	**16.03**	**3.42**	**<0.01**	31.70	11.24
		γ (covariate effect)	**0.15**	**0.04**	**3.64**	**<0.01**		
Density-Independent + Floodplain Wetted Acre Days	1	**α (spawner abundance)**	**54.49**	**16.35**	**3.33**	**<0.01**	32.08	11.62
		γ (covariate effect)	**0.14**	**0.04**	**3.55**	**<0.01**		
Density-Dependent (Ricker) + Floodplain WUA Acre Days	3	**α (spawner abundance)**	**44.81**	**17.03**	**2.63**	**0.02**	32.82	12.36
		β (density-dependence)	-3.00E-04	-3.54E-04	-0.85	0.42		
		γ (covariate effect)	**0.15**	**0.04**	**3.56**	**<0.01**		
Density-Dependent (Ricker) + Floodplain Wetted Acre Days	3	**α (spawner abundance)**	**43.51**	**16.94**	**2.57**	**0.03**	33.05	12.59
		β (density-dependence)	-3.27E-04	-3.57E-04	-0.92	0.38		
		γ (covariate effect)	**0.14**	**0.04**	**3.51**	**<0.01**		
Density-Independent + Flow Variation	1	α (spawner abundance)	2.98	3.75	0.79	0.44	34.19	13.73
		γ (covariate effect)	**0.66**	**0.22**	**3.03**	**0.01**		
Density-Dependent (Ricker) + Flow Variation	3	α (spawner abundance)	2.5	3.24	0.77	0.46	35.40	14.94
		β (density-dependence)	-3.10E-04	3.90E-04	-0.8	0.44		
		γ (covariate effect)	**0.65**	**0.22**	**2.95**	**0.01**		
Density-Independent + Total Rearing WUA	1	α (spawner abundance)	0.1	0.47	0.21	0.84	36.94	16.48
		γ (covariate effect)	1.18	0.78	1.52	0.16		
Density-Independent + In-Channel Wetted Area	1	α (spawner abundance)	0.1	0.99	0.1	0.92	37.61	17.15
		γ (covariate effect)	1.07	1.47	0.73	0.48		
Density-Dependent (Ricker) + Total Rearing WUA	3	α (spawner abundance)	0.1	0.52	0.19	0.85	38.89	18.43
		β (density-dependence)	-9.11E-05	4.75E-04	-0.19	0.85		
		γ (covariate effect)	1.17	0.88	1.34	0.21		

Model	Equation	Parameter	Estimate	Standard Error	t-value	p-value	AIC	Δ AIC
Density-Dependent (Ricker) + In-Channel Wetted Area	3	α (spawner abundance)	0.1	1.06	0.09	0.93	39.30	18.84
		β (density-dependence)	-2.23E-04	4.71E-04	-0.47	0.65		
		γ (covariate effect)	1.04	1.6	0.65	0.53		
Density-Independent	1	**α (spawner abundance)**	**128.72**	**31.4**	**4.1**	**<0.01**	40.14	19.68
Density-Independent + Spawning Wetted Area	1	α (spawner abundance)	0.1	2.85	0.04	0.97	40.91	20.45
		γ (covariate effect)	1.08	4.3	0.25	0.81		
Density-Dependent (Ricker)	3	**α (spawner abundance)**	**100.21**	**43.02**	**2.33**	**0.04**	41.55	21.09
		β (density-dependence)	-3.56E-04	4.97E-04	-0.72	0.49		
Density-Independent + October-November Temperature	1	α (spawner abundance)	4.20E+05	4.96E+06	0.08	0.93	41.6	21.14
		γ (covariate effect)	-2.9	4.23	-0.68	0.51		
Density-Independent + Spawning WUA	1	α (spawner abundance)	7.24	54.42	0.13	0.9	41.97	21.51
		γ (covariate effect)	0.87	2.28	0.38	0.71		
Density-Independent + In-Channel WUA	1	α (spawner abundance)	128.72	339.28	0.38	0.71	42.14	21.68
		γ (covariate effect)	0	0.46	0	1		
Density-Dependent (Ricker) + Spawning Wetted Area	3	α (spawner abundance)	0.1	2.95	0.03	0.97	42.37	21.91
		β (density-dependence)	-3.27E-04	5.03E-04	-0.65	0.53		
		γ (covariate effect)	1.05	4.45	0.23	0.82		
Density-Dependent (Ricker) + Mean Oct-Nov Temperature	3	α (spawner abundance)	2.12E+05	2.98E+05	0.07	0.94	43.37	22.91
		β (density-dependence)	-2.50E-05	5.86E-04	-0.43	0.68		
		γ (covariate effect)	-1.89	4.98	-0.38	0.71		
Density-Dependent (Ricker) + Spawning WUA	3	α (spawner abundance)	34.65	283.11	0.12	0.91	43.53	23.07
		β (density-dependence)	-3.29E-04	5.58E-04	-0.59	0.57		
		γ (covariate effect)	0.33	2.52	0.13	0.9		
Density-Dependent (Ricker) + In-Channel WUA	3	α (spawner abundance)	100.21	300.72	0.33	0.75	43.55	23.09
		β (density-dependence)	-3.56E-04	5.50E-04	-0.65	0.53		
		γ (covariate effect)	0	0.5	0	1		

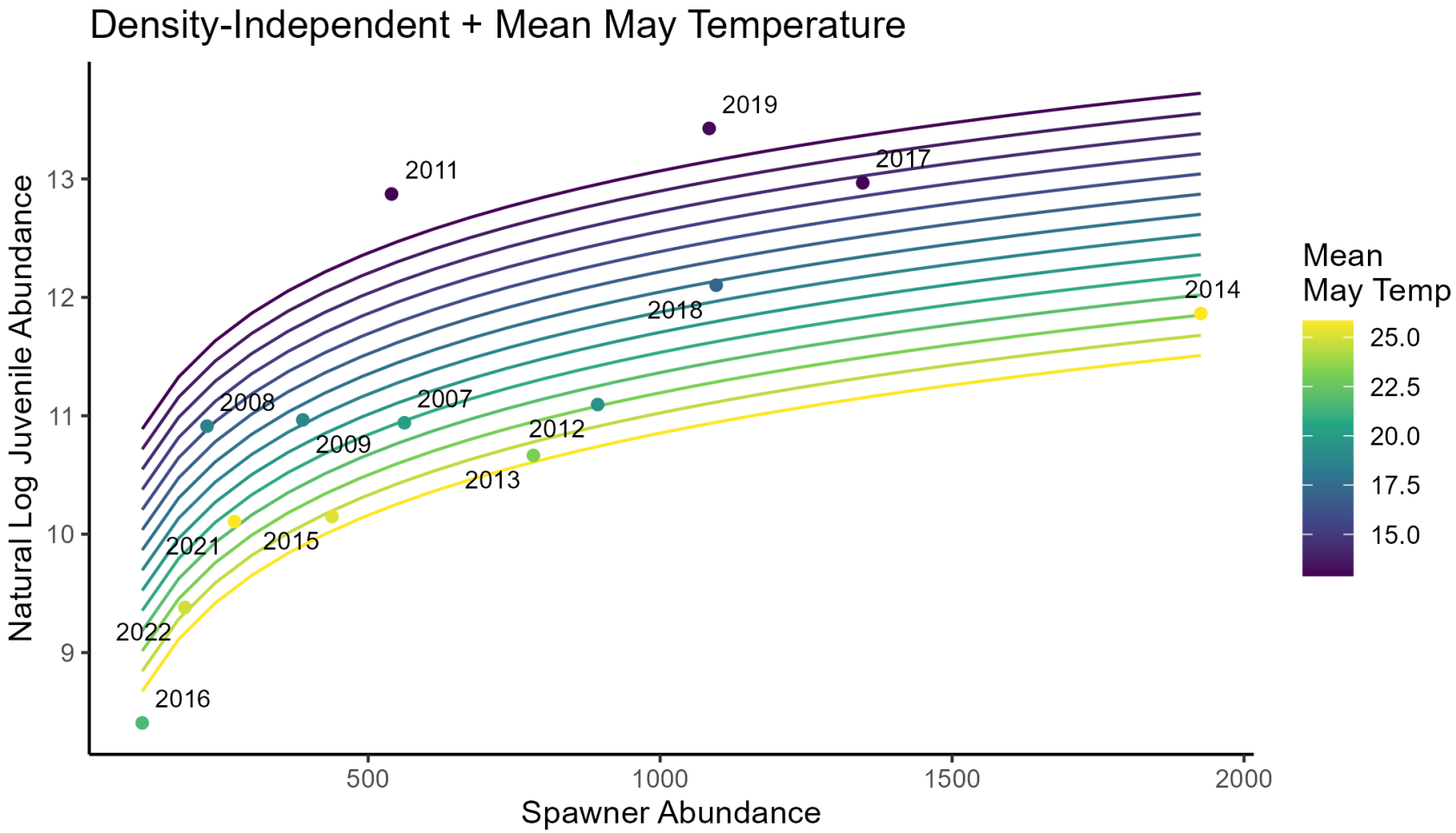


Figure A-2. Density-Independent + Mean May Temperature. This Was the Top Model Overall (ΔAIC = 0.00), Describing the Relationship Between Spawner Abundance and the Natural Log of Juvenile Abundance, Modeled as a Density-Independent Function with an Additive Effect of Mean May Temperature (in Celsius). Points Represent Annual Observed Spawner and Juvenile Abundance; Point and Line Colors Represent Mean May Temperature; Solid Lines Show the Predicted Stock-Recruitment Relationship Based on the Fitted Model.

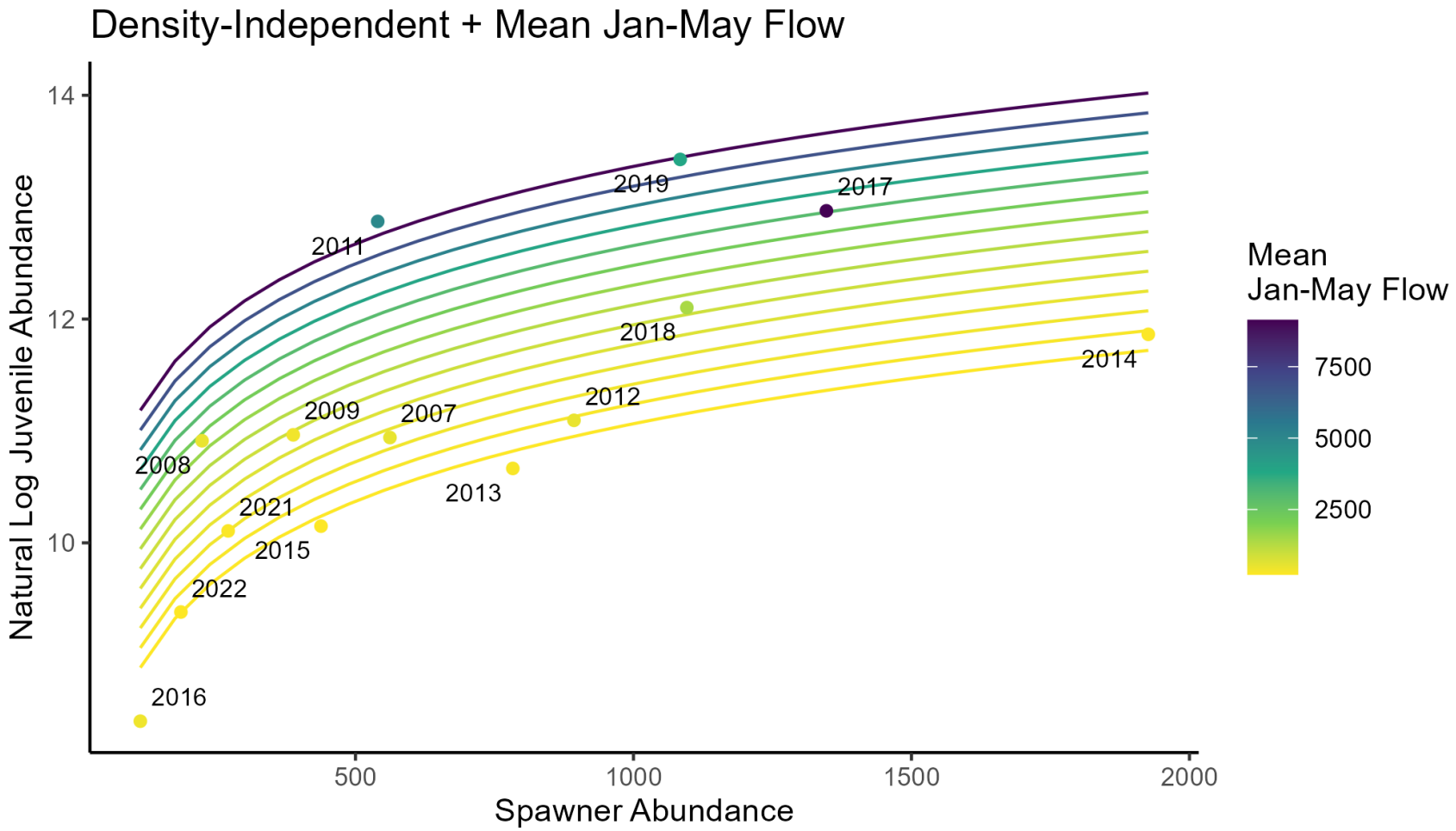


Figure A-3. Density-Independent + Mean Jan-May Flow. This was the Top Model That Included a Flow Covariate (Δ AIC = 4.21), Describing the Relationship Between Spawner Abundance and the Natural Log of Juvenile Abundance, Modeled as a Density-Independent Function with an Additive Effect of Mean Jan–May Flow (cfs). Points Represent Annual Observed Spawner and Juvenile Abundance; Point and Line Colors Represent Mean Jan-May Flow; Solid Lines Show the Predicted Stock-Recruitment Relationship Based on the Fitted Model.

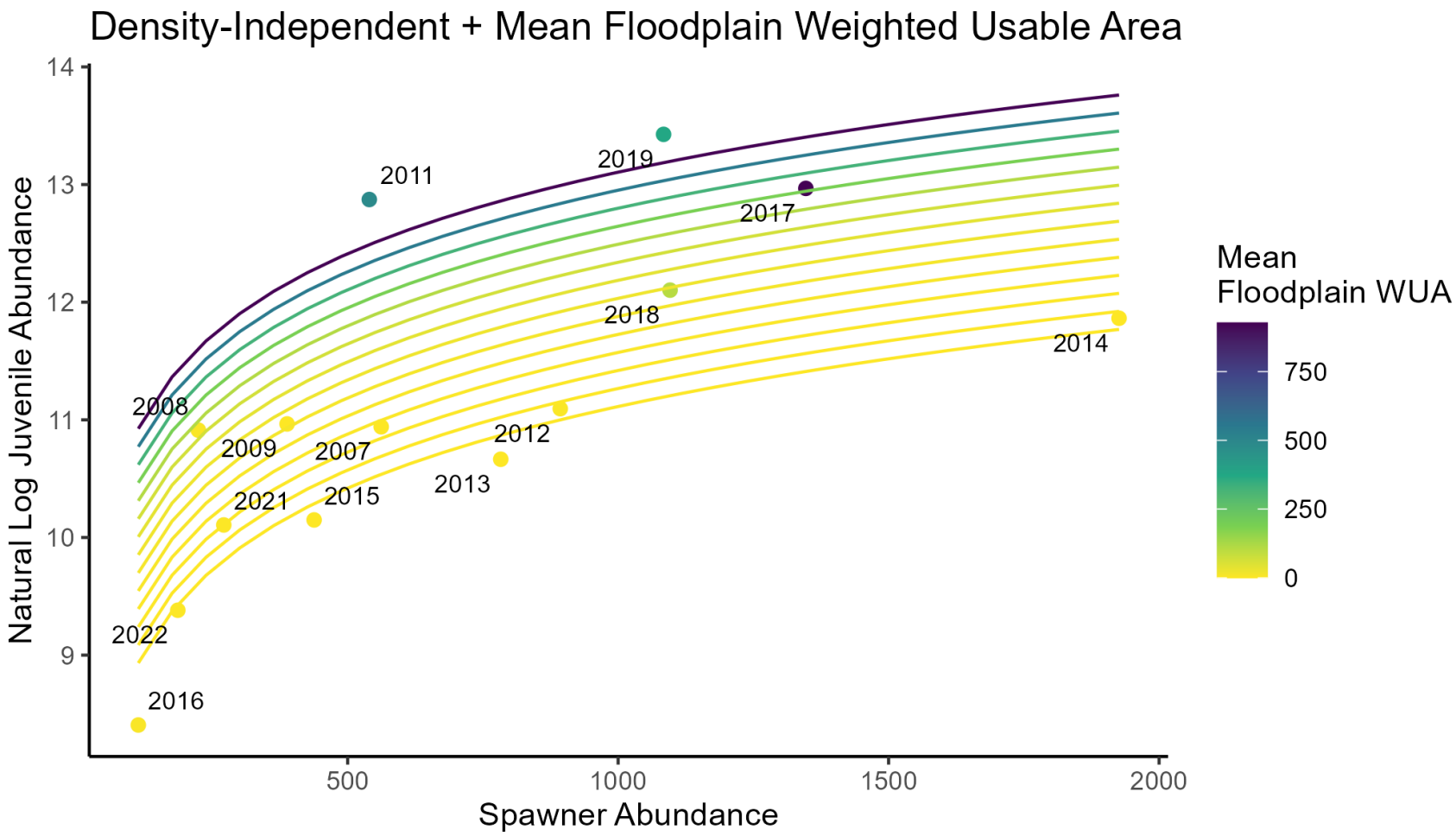


Figure A-4. Density-Independent + Mean Floodplain Weighted Usable Area. This Was the Top Model That Included a Habitat Covariate (Δ AIC = 6.52), Describing the Relationship Between Spawner Abundance and the Natural Log of Juvenile Abundance, Modeled as a Density-Independent Function with an Additive Effect of Mean Floodplain Weighted Usable Area (acres). Points Represent Annual Observed Spawner and Juvenile Abundance; Point and Line Colors Represent Floodplain Weighted Usable Area Modeled Using Observed Flows; Solid Lines Show the Predicted Stock-Recruitment Relationship Based on the Fitted Model.

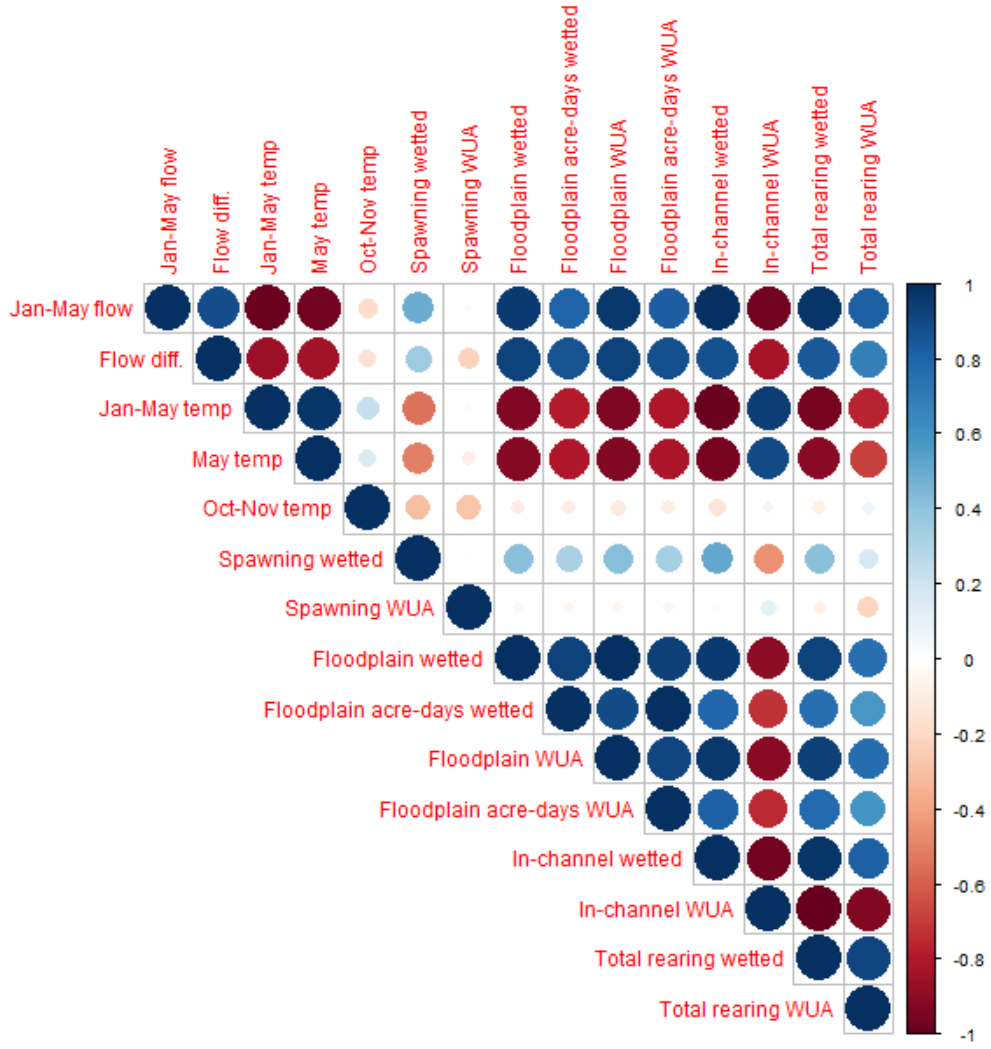


Figure A-5. Correlation Plot Depicting the Pearson Correlation Coefficient (Pearson r) for All Environmental Covariates Considered in Stock-Recruitment Models. Dark Blue Colors with Large Circles Indicate a Strongly Positive Correlation (e.g., r = 1), and Dark Red Colors with Large Circles Indicate a Strongly Negative Correlation (e.g., r = -1) Among Paired Covariates.

A.6 References

A.6.1 Printed References

Adkison, M.D. 2022. A Review of Salmon Spawner–Recruitment Analysis: The Central Role of the Data and Its Impact on Management Strategy. Reviews in Fisheries Science & Aquaculture 30:391–427. https://doi.org/10.1080/23308249.2021.1972086.

California Department of Fish and Wildlife (CDFW). 2023. GrandTab 2023.06.26. California Central Valley Chinook Escapement Database Report. Compiled by J. Azat.

Cavanaugh JE, Neath AA. 2019. The Akaike information criterion: Background, derivation, properties, application, interpretation, and refinements. WIREs Computational Stats. 11:e1460. https://doi.org/10.1002/wics.1460.

Dahm, C., W. Kimmerer, J. Korman, P.B. Moyle, G.T. Ruggerone, and C.A Simenstad. 2019. Final. *Developing Biological Goals for the Bay-Delta Plan: Concepts and Ideas from an Independent Scientific Advisory Panel.*

Fitzgerald, A.M. 2025. Incorporating local information to predict thermal stress for diverse species. *Canadian Journal of Fisheries and Aquatic Sciences* 81:1–21. https://cdnsciencepub.com/doi/10.1139/cjfas-2024-0189.

Fitzgerald, A.M. and B. J. Martin. 2022. Quantification of thermal impacts across freshwater life stages to improve temperature management for anadromous salmonids. *Conservation Physiology* 10(1): coac013; doi:10.1093/conphys/coac013.

Goertler P., K. Jones, J. Cordell, B. Schreier, and T. Sommer. 2017. Effects of extreme hydrologic regimes on juvenile chinook salmon prey resources and diet composition in a large river floodplain. *Transactions of the American Fisheries Society.* DOI: 10.1002/tafs.10028.

ICF. 2023. California Environmental Protection Agency Final Initial Biological Goals For The Lower San Joaquin River. September. Prepared for the State Water Resources Control Board, California Environmental Protection Agency.

Jeffres, C. A., J. J. Opperman, and P. B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environmental Biology of Fishes 83(4):449–458. https://doi.org/10.1007/s10641-008-9367-1.

Martin, B.T., A. Pike, S.N. John, N. Hamda, J. Roberts, S.T. Lindley, and E.M. Danner. 2017. Phenomenological vs. biophysical models of thermal stress in aquatic eggs. Ecology Letters 20:50–59.

Mesick, C. 2009. The high risk of extinction for the natural Fall-Run Chinook salmon population in the lower Tuolumne River due to insufficient instream flow releases. U.S. Fish and Wildlife Service, Energy and Instream Flow Branch, Sacramento, CA. 4 September 2009. Exhibit No. FWS-50.

Munsch, S.H., C.M. Greene, R.C. Johnson, W.H. Satterthwaite, H. Imaki, P.L. Brandes, and M.R. O'Farrell. 2020. Science for integrative management of a diadromous fish stock: interdependencies of fisheries, flow, and habitat restoration. Canadian Journal of Fisheries and Aquatic Sciences 77:1487–1504. https://doi.org/10.1139/cjfas-2020-0075

Nobriga, M.L., C.J. Michel, R.C. Johnson, and J.D. Wikert. 2021. Coldwater fish in a warm water world: Implications for predation of salmon smolts during estuary transit. Ecology and Evolution 11(15):10381–10395. https://doi.org/10.1002/ece3.7840

Quinn, T.J. II, and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press, Oxford.

Quinn, T.P. 2018. *The Behavior and Ecology of Pacific Salmon and Trout.* Second Edition. University of Washington Press.

Satterthwaite, W.H. 2023. An Approach to Defining a Sacramento River Fall Chinook Escapement Objective Considering Natural Production, Hatcheries, and Risk Tolerance. San Francisco Estuary and Watershed Science 21(3):Art 3 [accessed 2024 Mar 29]. https://doi.org/10.15447/sfews.2023v21iss3art3.

Sommer, T., M. L. Nobriga, W.C. Harrell, W. Batham, and W. Kimmerer. 2001. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 325–333.

State Water Resources Control Board (SWRCB). 2024. Peer Review Package for the Final Draft Scientific Basis Report Supplement in Support of Proposed Voluntary Agreements for the Sacramento River, Delta, and Tributaries Update to the San Francisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan. 74 pages.

Sturrock, A.M., S.M. Carlson, J.D. Wikert, T. Heyne, S. Nusslé, J.E. Merz, H.J.W. Sturrock, and R.C. Johnson. 2020. Unnatural selection of salmon life histories in a modified riverscape. Global Change Biology 26:1235–1247. https://doi.org/10.1111/gcb.14896.

Subbey, S., J.A. Devine, R. Schaarschmidt, and D.M. Nash. 2014. Modelling and forecasting stock–recruitment: current and future perspectives. ICES Journal of Marine Science 71:2307–2322. http://doi.org/10.1093/icesjms/fsu148.

Turlock Irrigation District and Modesto Irrigation District (TID and MID). 2023. Turlock and Modesto Irrigation Districts Project No. 2299- Article 58 Annual Report for 2022.

Wootton, R.J. 1990. Ecology of Teleost Fishes. Springer Netherlands.

Appendix B

Hydrologic and Water Quality Modeling

Contents

Appendix B Hydrologic and Water Quality Modeling B-1

B.1 Introduction B-1

B.2 Water Supply Effects Modeling - Updates B-2

B.2.1 Updated CALSIM II Model Baseline B-2

B.2.2 Updated WSE Model Baseline B-9

B.2.3 Pre-Defined Alternatives modeled in WSE B-49

B.3 Water Supply Effects Modeling – Summary Results B-63

B.3.1 Flow on the Tuolumne River at La Grange B-63

B.3.2 New Don Pedro Reservoir Storage B-71

B.3.3 Tuolumne River Surface Water Diversions B-78

B.4 HEC-5Q Temperature Modeling – Updates B-79

B.4.1 Temperature Model Preprocessing B-80

B.4.2 Temperature Model Modifications B-87

B.5 HEC-5Q Temperature Modeling – Summary Results B-88

B.5.1 Tuolumne River Longitudinal Temperature Profiles B-88

B.5.2 The Tuolumne River Below La Grange Diversion Dam (RM 53.5) B-101

B.5.3 The Tuolumne River Between Turlock State Park and Waterford (RM 38.3) B-115

B.5.4 The Tuolumne River Between Waterford and Santa Fe Avenue Bridge (RM 28.1) B-129

B.5.5 The Tuolumne River Below Modesto (RM 13.2) B-143

B.5.6 The Tuolumne River at the Confluence with the SJR (RM 0) B-157

B.6 References B-171

B.6.1 Printed References B-171

B.6.2 Personal Communications B-173

Appendix B
Hydrologic and Water Quality Modeling

B.1 Introduction

This appendix includes a description of the hydrologic, water supply, and water quality modeling methods and assumptions used to analyze the effects of the Tuolumne River Voluntary Agreement (TVA) in this Draft TVA Scientific Basis Report. The primary models used were the Water Supply Effects (WSE) spreadsheet model and the San Joaquin River (SJR) Basin-Wide Water Temperature Model,[1] or HEC-5Q model. These models were used for the TVA analysis because they were already designed to analyze the impacts of new flow requirements on the Tuolumne River, and they allow for the most direct method to compare the effects of the TVA flows with current flow requirements. Summary results from WSE and HEC-5Q characterizing the effects of the TVA are presented below in Sections B.3 and B.5, respectively. Model results are also shown in other chapters of this Draft TVA Scientific Basis Report, including Chapter 4, *Tuolumne River Hydrology and Operations Modeling Methods and Results*, and Chapter 5, *Water Temperature*.

WSE is a spreadsheet-based, hydrologic water balance model for the Lower San Joaquin River (LSJR) and its tributaries, the Stanislaus, Tuolumne, and Merced Rivers. The model domain extends from each tributary's rim reservoir (New Melones on the Stanislaus, New Don Pedro on the Tuolumne, and Lake McClure on the Merced) down to its confluence with the SJR and on the mainstem SJR from Mud Slough above the Merced confluence down to Vernalis. Output is generated on a monthly timestep from 1922 to 2003, using historical inflows from the CALSIM II model, but assuming a current level of development (demands, infrastructure). The primary results output from WSE are the flows, reservoir storage levels, and diversions by major irrigation districts on each tributary.

The WSE model was developed by the State Water Resources Control Board (State Water Board or SWRCB) to support its efforts for updating the Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary in 2018 (2018 Bay-Delta Plan). The original version of the model used for the 2018 Bay-Delta Plan is fully described in Appendix F.1 to the Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary San Joaquin River Flows and Southern Delta Water Quality, or 2018 Final SED (SWRCB 2018). In the 2018 Final SED, WSE was used to analyze potential changes in flow and water supplies on the Stanislaus, Tuolumne, and Merced Rivers that could result from adding unimpaired flow (UF) requirements at the confluence of each river. Since 2018, WSE has received several updates to improve its representation of the LSJR system, the accuracy of its results, and its usability, which are documented in the sections below.[2] In addition, output data from WSE serves as the primary input to the HEC-5Q model, which is used to analyze the temperature effects of the TVA.

[1] The San Joaquin River Basin-Wide Water Temperature Model developed using the U.S. Army Corps of Engineers Hydrologic Engineering Center's HEC-5Q water quality model.

[2] The updated version of WSE is titled "WSE_TVA_Model_Sep2025.xlsm."

B.2 Water Supply Effects Modeling - Updates

This section describes the updates made to the WSE model since release of the 2018 Final SED. Part of this effort included updating the representation of the baseline modeling scenario in WSE to reflect conditions as of 2023. Other refinements focused on the sources of input data to the model, the creation of new pre-defined alternatives for analyzing the TVA, and some minor error corrections. Though this document is concerned primarily with results on the Tuolumne River, this chapter also describes updates made to WSE's representation of the Stanislaus and Merced Rivers for completeness. For further details on WSE, please review Appendix F.1 to the 2018 Final SED. The underlying calculations and operations of the WSE model have not changed from those in Appendix F.1, except as described below in this section.

The changes described here represent those updates that affect the calculation of model results. In addition, other non-computational changes have been made to WSE since release of the 2018 Final SED that do not affect the actual calculations. These changes were made primarily to improve the usability of the model or to remove redundant or unused information, e.g., reorganizing the model control tabs and the addition of new tabs to organize input data.

B.2.1 Updated CALSIM II Model Baseline

Updating the WSE representation of baseline to represent conditions from 2023 requires first identifying or developing a CALSIM II model run that represents those conditions. As described in Appendix F.1 of the 2018 Final SED, the WSE model was developed using the CALSIM II model as a framework, incorporating many of the same node-link designations to identify locations in WSE. In addition, various CALSIM II timeseries serve as inputs and boundary conditions for WSE, representing parameters that are not dynamically modeled, and WSE reservoir operations parameters are calibrated based on CALSIM II storage and diversion results. For the 2018 version of WSE, the SWRCB CALSIM II baseline model was developed based on a CALSIM II model run provided by the United States Bureau of Reclamation (Reclamation) in 2013, with some modifications applied by the State Water Board to Stanislaus River operations and Vernalis pulse flow requirements.

Since 2013 there have been multiple version updates to the CALSIM II SJR module, with the latest (at the time of this analysis) being in 2021 (USBR 2021). Some of the major model updates to the representation of the LSJR in CALSIM II between 2013 and 2021 include:

- Dynamic representation of the Tuolumne and Merced flow requirements (Prior versions specified Tuolumne and Merced flow requirements using input timeseries for target flows)
- Suspension of the Davis-Grunsky contract flow requirement on the Merced to reflect that it expired in 2017 (DWR 1967)
- Significant updates to the representation of the Tuolumne River, such as adjusted inflow patterns to New Don Pedro, new district demand estimates, updated parameters representing district losses, and changes to New Don Pedro reservoir operations
- Addition of the 2019 Biological Opinion (BiOp) Stepped Release Plan (SRP) flow requirements and updated allocation logic for Central Valley Project (CVP) contractors on the Stanislaus River
- Suspension of Stanislaus River release requirements to meet D-1641 baseflow and water quality requirements at Vernalis

- Removal of the Vernalis Adaptive Management Plan (VAMP) flow requirements, reflecting that it expired in 2012
- Addition of the San Joaquin River Restoration Program (SJRRP) rediversion points on the LSJR, with the rediversion capacities representing a future level of development.

To develop a new CALSIM II baseline model for updating WSE, herein referred to as *SWRCB CALSIM II 2023 baseline*, the State Water Board began with Reclamation's 2021 version of CALSIM II and, similar to the process performed in the 2018 Final SED, applied a series of adjustments. A summary of the differences between the SWRCB CALSIM II model used in the 2018 Final SED, the 2021 CALSIM II model produced by Reclamation, and the SWRCB CALSIM II 2023 baseline are presented in Table B-1 at the end of this section.

The first adjustment was to turn on New Melones release requirements to meet D-1641 baseflow standards from February 1 through April 14 and from May 16 through June 30 (Table B-10, Section B.2.2.2) and D-1641 annual salinity requirements at Vernalis. These requirements function as backstops should the flow released by the Stanislaus SRP plus the flow provided by upstream tributaries on the San Joaquin be insufficient to meet the D-1641 standards. During the April 15 through May 15 pulse flow period, D-1641 flow standards are not applied and the SRP governs releases from the Stanislaus River.[3] The second adjustment related to D-1641 was to implement the D-1641 Vernalis October pulse flow requirement (Table B-10, Section B.2.2.2) in CALSIM II based on its representation in CALSIM 3.[4]

The third adjustment was to reduce SJRRP rediversion for Patterson Irrigation District (PID), Banta-Carbona Irrigation District (BCID), and West Stanislaus Irrigation District (WSID) to current levels. Figure B-1 1 shows the monthly SJRRP rediversion capacities for PID, BCID, and WSID at the future level modeled in the 2021 version of CALSIM II and at the level modeled in the SWRCB CALSIM II 2023 baseline. The diversion capacities for PID and BCID used for the SWRCB CALSIM II 2023 baseline represent the current level of rediversion capacity available to the districts (SJRRP 2017). WSID diversion is set to 0 cubic feet per second (cfs) because SJRRP rediversion is currently allowed by the State Water Board through approval of annual temporary change petitions submitted by Reclamation that only add points of rediversion at PID and BCID facilities and do not include WSID (SWRCB 2022).[5]

[3] Since CALSIM is a monthly model, the final required flow for D-1641 in April and May is the baseflow target multiplied by the number of days it is applied (14 in April, 16 in May) and divided by the number of days in the month.

[4] The D-1641 flow and salinity requirements were turned on by editing the files: *vernalis_min.wresl*, *vernalis_wqmin_Disag.wresl*, and *vernalis_wqpulse_Disag.wresl*.

[5] SJRRP rediversion capacities used in CALSIM II are found in the file *SRRP_Recapture_Pot.table*.

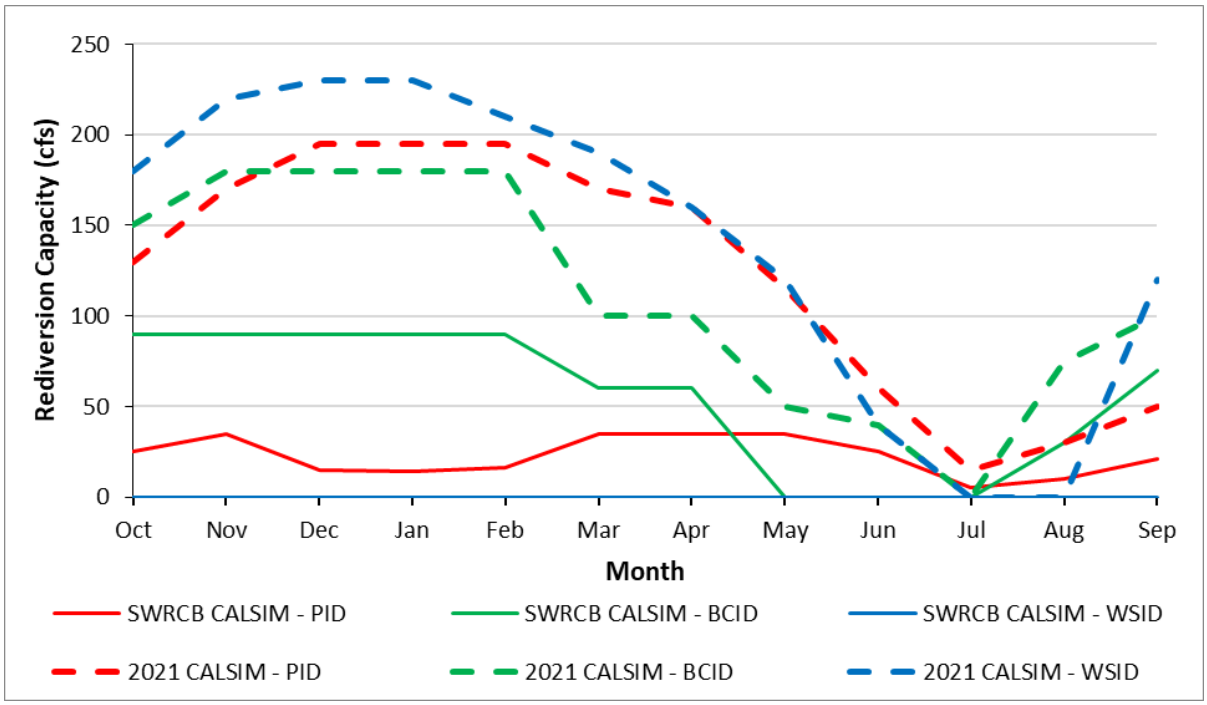


Figure B-1. SJRRP Rediversion Capacities on the Lower San Joaquin River Modeled in CALSIM II.

Finally, the Tuolumne diversion allocation file[6] from Reclamation's 2021 model version was replaced with the corresponding file from the SWRCB CALSIM II baseline model run used in the 2018 Final SED, since the newer version assumes significantly higher allocations than what historical data shows. Figure B-2 graphs the minimum allocation schemes used in CALSIM II for both the 2018 Final SED and the 2021 Reclamation version. Here the allocation is a percentage of district demand, and the available water is the sum of End of March Storage in New Don Pedro reservoir plus inflow to the reservoir from April through July. The allocations in the 2021 version are much higher than those in the 2018 Final SED version, particularly at lower estimates of available water. The lowest allocation the districts can receive in the 2021 version is set to 75% of their demand occurring when available water is less than 1,090 thousand acre-feet (TAF). On the other hand, in the 2018 Final SED version the minimum allocation was 50% of the demand occurring when available water was less than 1,400 TAF.

[6] The Tuolumne diversion allocations used in CALSIM II are found in the file *TuolAllocNormal.table*

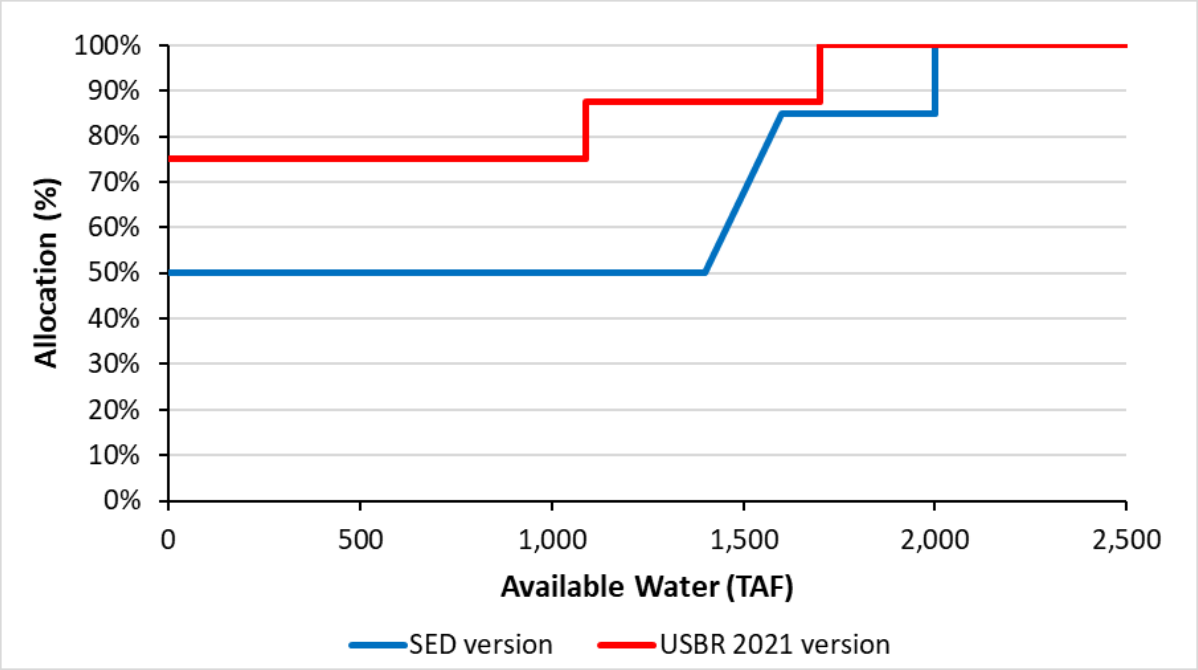


Figure B-2. Tuolumne District Water Allocation Schemes Modeled in CALSIM II (Available Water = End of March Storage + Inflow April through July and Allocation Is a % of Demand).

Allowing for such high diversion allocations, even when the available water supply is severely reduced, will result in significant draw down of reservoir storage, which is not consistent with observed past behavior. Severely drawing down or draining reservoirs to maximize water deliveries today will increase the risk of water supply shortage in the future if the following year or following several years are dry. Instead, reservoir operators work to balance the current demands with the need to retain water in the reservoir for future use, considering the uncertainty of future inflows and the risk of drought. Historical observations of reservoir volumes and supply allocations show that water suppliers operate reservoirs and allocate water more conservatively than assumed in the 2021 Reclamation version. For example, in drought years 2014 and 2015, Turlock Irrigation District (TID) limited supply allocations to 20 and 18 inches per acre, respectively, compared to a normal 48 inches, with reservoir carryover supply cited as an important consideration (Holland 2014; 2015). This is corroborated with information from the Agricultural Water Management Plans (AWMPs) for TID and Modesto Irrigation District (MID), irrigation districts that divert from the Tuolumne River, which show that actual allocations on the river have fallen below 50% (TID 2021; MID 2015).

Figure B-3 shows the exceedance distribution of resulting end-of-September storage in New Don Pedro from 1921 to 2003 for the 2021 CALSIM II model both before and after replacing the Tuolumne allocation file with the 2018 Final SED version, along with the exceedance distribution of historical end-of-September storage for 1996 to 2023 from the California Data Exchange Center (DWR n.d.).[7] Compared to historical observations, the end-of-September storage levels produced using the 2018 Final SED allocation scheme better represent carryover storage levels over the last 28 years. Using the CALSIM II 2021 allocations, New Don Pedro storage is drawn down more often to lower levels, falling below 1,000 TAF over 20% of the time and below 600 TAF 10% of the time. The two lowest end-of-September storage values (294 TAF in 1992 and 287 TAF in 1977) even fall below New Don Pedro's minimum operating pool or dead pool, which is 309 TAF. On the other hand, the allocations from the 2018 Final SED CALSIM II model maintain higher storage, only allowing it to fall below 1,000 TAF a little over 10% of the time and draining it below 600 TAF once. In reality, since 1996, New Don Pedro reservoir storage has rarely fallen below 1,000 TAF, except during the 2014–2015 drought, and the minimum storage it has been reduced to in that period is only 628 TAF.

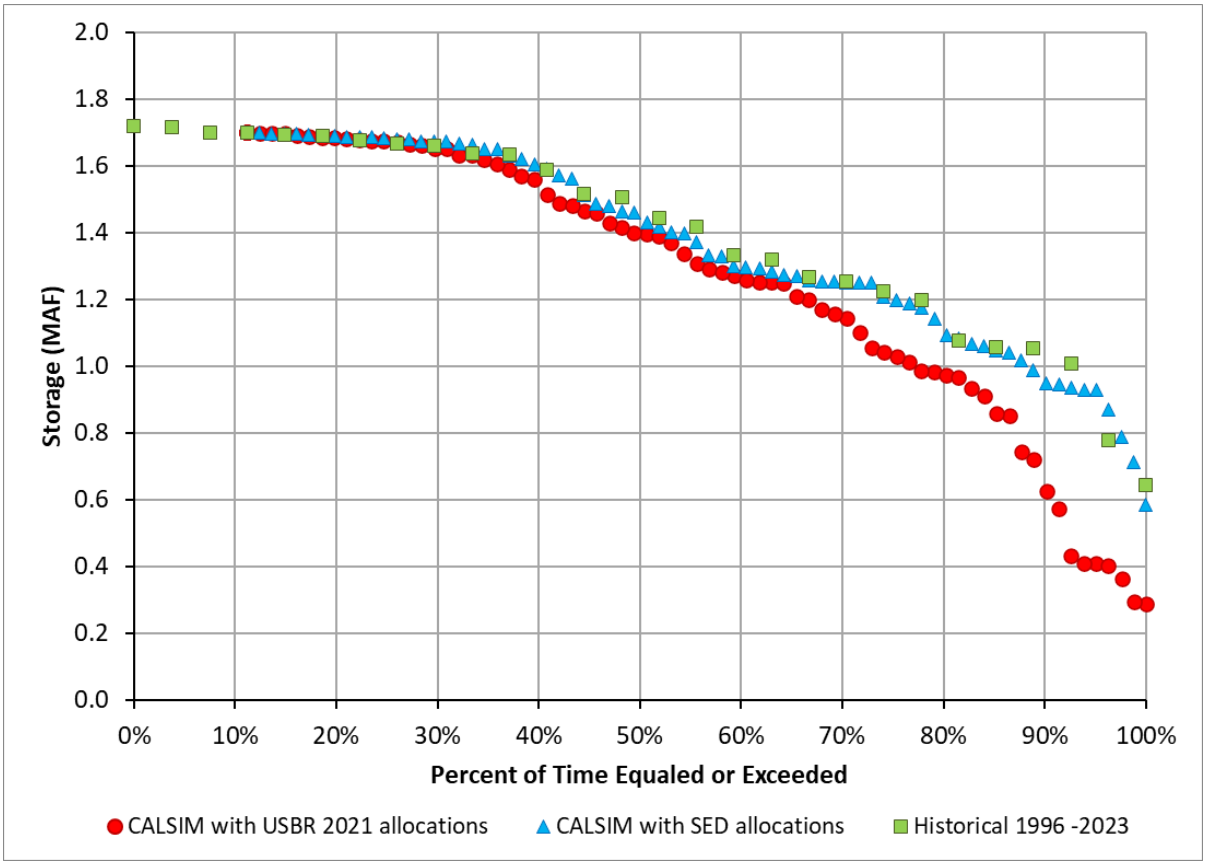


Figure B-3. Exceedance Chart of End-of-September Storage in New Don Pedro Reservoir.

[7] The period of 1996 to 2023 is displayed for historical results as prior years in the historical record will be operating to a different flow standard than the 1995 Federal Energy Regulatory Commission (FERC) settlement requirements modeled in CALSIM II.

Table B-1. Summary of Differences Between the SWRCB CALSIM II Baseline from the 2018 Final SED, Reclamation's 2021 CALSIM II Model, and the New SWRCB CALSIM II 2023 Baseline.

CALSIM II Representation	SWRCB CALSIM II from 2018 Final SED	Reclamation CALSIM II 2021	SWRCB CALSIM II 2023
SJRRP	Not Included	Included, with future potential recapture capacity	Included, with current recapture capacity
VAMP	Included	Not Included	Not Included
D-1641 Baseflow (Feb 1 - Apr 14 and May 16 -June 30)	Included	Not Included	Included
D-1641 Pulse Flow (Apr 15 - May 15)	Not Included (VAMP instead)	Not Included	Not Included
D-1641 October Pulse	Not Included	Not Included	Included
D-1641 Vernalis Electrical Conductivity	Included	Not Included	Included
New Melones Starting Storage	1000 TAF	1700 TAF	1700 TAF
Stanislaus Minimum Flow	2009 BiOp, DO requirement	New Melones SRP (2019 BiOp), DO requirement	New Melones SRP (2019 BiOp), DO requirement
CVP Contractor Allocation	Based on NMI	Based on WYT	Based on WYT
Stanislaus Minimum District Groundwater Pumping	• SSJID+OID North = 52 TAF/year • OID South = 20 TAF/year	• SSJID+OID North = 51 TAF/year • OID South = 20 TAF/year	• SSJID+OID North = 51 TAF/year • OID South = 20 TAF/year
Stanislaus Annual Irrigation Year (Mar–Feb) Demand from 1922 to 2003	• 2020 level of development • Max Diversion ~590 TAF SSJID/OID • + Max ~155 TAF SEWD/CSJWCD • + ~20 TAF Riparian	• 2030 level of development • Max Diversion ~591 TAF SSJID/OID • + Max ~155 TAF SEWD/CSJWCD • + ~18 TAF Riparian	• 2030 level of development • Max Diversion ~591 TAF SSJID/OID • + Max ~155 TAF SEWD/CSJWCD • + ~18 TAF Riparian
New Melones September Carryover	• Avg = 1,171 TAF • Min = 80 TAF	• Avg = 1,412 TAF • Min = 184 TAF	• Avg = 1,291 TAF • Min = 80 TAF
Tuolumne Minimum Flow	1995 FERC (timeseries inputs)	1995 FERC, with interpolation water release in Apr-May (dynamically modeled)	1995 FERC, with interpolation water release in Apr-May (dynamically modeled)
Minimum District Allocations	50% when Water Supply is less than 1,400 TAF	75% when Water Supply is less than 1,090 TAF	50% when Water Supply is less than 1,400 TAF

CALSIM II Representation	SWRCB CALSIM II from 2018 Final SED	Reclamation CALSIM II 2021	SWRCB CALSIM II 2023
Tuolumne Minimum District Groundwater Pumping	• MID = 39 TAF/year • TID = 158 TAF/year	• MID = 38 TAF/year • TID = 108 TAF/year	• MID = 38 TAF/year • TID = 108 TAF/year
Tuolumne Operating Reservoir Losses	• Modesto Reservoir Losses = 55 TAF/year • Turlock Reservoir Losses = 92 TAF/year	• Modesto Reservoir Losses = 31 TAF/year • Turlock Reservoir Losses = 52 TAF/year	• Modesto Reservoir Losses = 31 TAF/year • Turlock Reservoir Losses = 52 TAF/year
Tuolumne Annual Irrigation Year (Mar–Feb) Demand from 1922 to 2003	• 2020 level of development • Max Diversion ~1,107 TAF MID/TID • + ~7 TAF Riparian	• 2030 level of development • Max Diversion ~ 996 TAF MID/TID • + ~7 TAF Riparian	• 2030 level of development • Max Diversion ~ 996 TAF MID/TID • + ~7 TAF Riparian
New Don Pedro September Carryover	• Avg = 1,311 TAF • Min = 396 TAF	• Avg = 1,296 TAF • Min = 287 TAF	• Avg = 1,395 TAF • Min = 584 TAF
Merced Minimum Flow	Davis-Grunsky/1996 FERC/October Pulse/Cowell Agreement (timeseries inputs)	1996 FERC/October Pulse/Cowell Agreement (dynamically modeled)	1996 FERC/October Pulse/Cowell Agreement (dynamically modeled)
Merced Minimum District Groundwater Pumping	Merced ID = 54 TAF/year	Merced ID = 34 TAF/year	Merced ID = 34 TAF/year
Merced Annual Irrigation Year (Mar–Feb) Demand from 1922 to 2003	• 2020 level of development • Max Diversion ~528 TAF Merced ID • + ~25 TAF Cowell • + ~41 TAF Riparian	• 2030 level of development • Max Diversion ~528 TAF Merced ID • + ~25 TAF Cowell • + ~41 TAF Riparian	• 2030 level of development • Max Diversion ~528 TAF Merced ID • + ~25 TAF Cowell • + ~41 TAF Riparian
Lake McClure September Carryover	• Avg = 507 TAF • Min = 103 TAF	• Avg = 565 TAF • Min = 125 TAF	• Avg = 565 TAF • Min = 125 TAF

B.2.2 Updated WSE Model Baseline

This section contains the assumptions and methods used to update the WSE-CALSIM and the WSE-SWRCB baselines (the WSE-SWRCB baseline was referred to as the WSE-CEQA baseline in the 2018 Final SED).[8] The WSE-CALSIM baseline is the WSE model run developed for direct comparison with the SWRCB CALSIM II 2023 baseline model. This comparison is used to 1) establish reservoir operations in WSE, and 2) demonstrate the efficacy of the WSE model by showing that, when given a similar set of assumption and input data, the WSE model results corroborate the results produced by CALSIM II. The WSE-SWRCB baseline, on the other hand, is the model run that best represents the existing conditions as of 2023, taking into account more recent information than may be incorporated in CALSIM II. This run will serve as the baseline of comparison for analyzing the effects of the TVA.

B.2.2.1 CALSIM II Input Data

In the 2018 Final SED version of WSE, CALSIM II data timeseries were pasted into different tabs, making it cumbersome to update the model. In the current version of the model, all the data timeseries from CALSIM II used in WSE are now stored in the new "CALSIM Data" tab. Table B-2 lists the CALSIM II timeseries imported into WSE from the SWRCB CALSIM II 2023 baseline, along with a description of what the timeseries represented in CALSIM II and how they are applied in WSE. The CALSIM II data primarily represents boundary conditions for WSE, such as inflows, or parameters that WSE cannot directly calculate, including reservoir evaporation rates and agricultural consumptive use demands. Some of the CALSIM II timeseries in Table B-2 are not used for specific calculations in WSE but are instead imported to characterize the CALSIM II water balance and for comparison with final WSE results. Finally, a few of the timeseries are used only to represent parameters under CALSIM mode.

[8] The user can choose which baseline is active in WSE by selecting the "Baseline" alternative as the active alternative and then using the "Switch Mode" button on the *USER_Controls* tab to set the model to be in either "CALSIM" or "SWRCB" mode.

Table B-2. CALSIM II Timeseries Imported into WSE.

Data Type	CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE?
Return Flow	R564A	Return flow from local/riparian Merced diverters back to the Merced River	Local inflow to the Merced River
Return Flow	R564B	Return flow from Merced ID to the Merced River	Component of Merced ID demand Local inflow to the Merced River
Return Flow	R620	Return flow from Stevinson ID to the San Joaquin River	Local inflow to the San Joaquin River
Return Flow	R545A	Return flow from TID to the Tuolumne River	Component of TID demand Local inflow to the Tuolumne River
Return Flow	R545C	Return flow from MID to the Tuolumne River	Component of MID demand Local inflow to the Tuolumne River
Return Flow	R630J	Return flow from local/riparian Tuolumne diverters to the San Joaquin River	Local inflow to the San Joaquin River
Return Flow	R630K	Return flow from non-district lands on the south side of the Tuolumne River to the San Joaquin River	Local inflow to the San Joaquin River
Return Flow	R630L	Return flow from TID to the San Joaquin River	Component of TID demand Local inflow to the San Joaquin River
Return Flow	R566	Return flow from TID to the Merced River	Component of TID demand Local inflow to the Merced River
Return Flow	R636A	Return flow from MID to the San Joaquin River	Component of MID demand Local inflow to the San Joaquin River
Return Flow	R636B	Return flow from non-district lands on the north side of the Tuolumne River to the San Joaquin River	Local inflow to the San Joaquin River
Return Flow	R636C	Return flow from MID to the San Joaquin River	Component of MID demand Local inflow to the San Joaquin River
Return Flow	R637A	Return flow from MID to the San Joaquin River	Component of MID demand Local inflow to the San Joaquin River
Return Flow	R637B	Return flow from non-district lands on the north side of the Tuolumne to the San Joaquin River	Local inflow to the San Joaquin River

Data Type	CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE?
Return Flow	R528C	Return flow from MID to the Stanislaus River	Component of MID demand Local inflow to the Stanislaus River
Return Flow	R528A	Return flow from OID south to the Stanislaus River	Component of OID south demand Local inflow to the Stanislaus River
Return Flow	R528B	Return flow from SSJID/OID north to the Stanislaus River	Component of SSJID/OID north demand Local inflow to the Stanislaus River
Return Flow	R637C	Return flow from local/riparian Stanislaus diverters to the San Joaquin River	Local inflow to the San Joaquin River
Return Flow	R534B	Return flow from OID south to non-district lands on the north side of the Tuolumne River	Component of OID south demand
Return Flow	R545B	Return flow from OID south to the Tuolumne River	Component of OID south demand Local inflow to the Tuolumne River
Return Flow	R532	Return flow from OID south to MID	Component of OID south demand Component of MID demand
Return Flow	R526	Return flow from SSJID to non-district lands east of SSJID	Component of SSJID/OID north demand
Return Flow	R630M	Return flow from local San Joaquin diverters back to the San Joaquin River	Local inflow to the San Joaquin River
Return Flow	R630WEST	Return flow from the west side of the San Joaquin River	Local inflow to the San Joaquin River
Return Flow	R637D	Return flow from local San Joaquin diverters back to the San Joaquin River	Local inflow to the San Joaquin River
Return Flow	R639A	Return flow from local San Joaquin diverters back to the San Joaquin River	Local inflow to the San Joaquin River
Return Flow	R639WEST	Return flow from the west side of the San Joaquin River	Local inflow to the San Joaquin River
Diversion	D561	Merced ID surface water diversion from the Merced River	Calibration of Merced ID diversions (*CALSIM* mode only)
Diversion	D562	Local/Riparian surface water diversions from the Merced River	Cowell Agreement diversion demand (*CALSIM* mode only)
Diversion	D566	Stevinson ID, El Nido, riparian surface water diversions from the Merced River	Riparian diversion demand on the Merced River

Data Type	CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE?
Diversion	D562A	Delivery to Local/Riparian Lands on the Merced River	Characterizing CALSIM II water delivery in the Merced River watershed
Diversion	D574	Delivery to Stevinson ID, El Nido, and riparian lands	Characterizing CALSIM II water delivery in the Merced River watershed
Diversion	D571	Delivery to Merced ID	Characterizing CALSIM II water delivery in the Merced River watershed
Diversion	D572	Delivery to Merced National Wildlife Refuge from Merced ID	Characterizing CALSIM II water delivery in the Merced River watershed
Diversion	D540A	MID surface water diversions from the Tuolumne River	Calibration of TID and MID diversions (*CALSIM* mode only)
Diversion	D540B	TID surface water diversions from the Tuolumne River	Calibration of TID and MID diversions (*CALSIM* mode only)
Diversion	D545	Local/Riparian surface water diversions from the Tuolumne River	Riparian diversion demand on the Tuolumne River
Diversion	D551	Delivery to non-district lands south of the Tuolumne River	Characterizing CALSIM II water delivery in the Tuolumne River watershed
Diversion	D549	Delivery to TID	Characterizing CALSIM II water delivery in the Tuolumne River watershed
Diversion	D545A	Delivery to Local/Riparian Lands on the Tuolumne River	Characterizing CALSIM II water delivery in the Tuolumne River watershed
Diversion	D79_SEEP	Turlock regulating reservoir groundwater seepage	Turlock reservoir seepage (*CALSIM* mode only)
Diversion	D535	Delivery to non-district lands north of the Tuolumne River	Characterizing CALSIM II water delivery in the Tuolumne River watershed
Diversion	D533	Delivery to MID	Characterizing CALSIM II water delivery in the Tuolumne River watershed
Diversion	D78_SEEP	Modesto regulating reservoir groundwater seepage	Modesto reservoir seepage (*CALSIM* mode only)
Diversion	D78A	Surface water delivery to Modesto M&I	Modesto M&I diversion demand (*CALSIM* mode only)
Diversion	D520A	SEWD and CSJWCD surface water diversion from the Stanislaus River	Characterizing CALSIM II water delivery in the Stanislaus River watershed

Data Type	CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE?
Diversion	D520A1	OID and SSJID water sales to SEWD	Characterizing CALSIM II water delivery in the Stanislaus River watershed
Diversion	D520B	SSJID/OID north surface water diversion from the Stanislaus River	Calibration of OID and SSJID diversions (*CALSIM* mode only)
Diversion	D520C	OID south surface water diversion from the Stanislaus River	Calibration of OID and SSJID diversions (*CALSIM* mode only)
Diversion	D528	Local/Riparian surface water diversions from the Stanislaus River	Riparian diversion demand on the Stanislaus River
Diversion	D528A	Delivery to Local/Riparian Lands on the Stanislaus River	Characterizing CALSIM II water delivery in the Stanislaus River watershed
Diversion	D531	Delivery to OID south	Characterizing CALSIM II water delivery in the Stanislaus River watershed
Diversion	D530_VAMP	Transfer of water from OID to MID in exchange for MID meeting OID's Vernalis Adaptive Management Plan (VAMP) requirement	Characterizing CALSIM II water delivery in the Stanislaus River watershed
Diversion	D75_SEEP	Woodward regulating reservoir groundwater seepage	Woodward reservoir seepage (*CALSIM* mode only)
Diversion	D523	Delivery to SSJID/OID north	Characterizing CALSIM II water delivery in the Stanislaus River watershed
Diversion	D620C	Stevinson ID, El Nido, riparian surface water diversions from the San Joaquin River	San Joaquin River baseline diversion
Diversion	D620A	Non-district diversion from the San Joaquin River on the south side of the Tuolumne River	San Joaquin River baseline diversion
Diversion	D620B	Local surface water diversion from the San Joaquin River between the Merced and Tuolumne Rivers	San Joaquin River baseline diversion
Diversion	D620D	San Joaquin River Restoration water recapture for Patterson Irrigation District	San Joaquin River baseline diversion
Diversion	D630A	Non-district diversion from the San Joaquin River on the north side of the Tuolumne River	San Joaquin River baseline diversion
Diversion	D630B	Local surface water diversion from the San Joaquin River between the Tuolumne and Stanislaus Rivers	San Joaquin River baseline diversion

Data Type	CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE?
Diversion	D630C	San Joaquin River Restoration water recapture for West Stanislaus Irrigation District	San Joaquin River baseline diversion
Diversion	D637	Local surface water diversion from the San Joaquin River downstream of the Stanislaus River	San Joaquin River baseline diversion
Diversion	D639	Non-Project surface water diversions near Vernalis	San Joaquin River baseline diversion
Diversion	D639A	San Joaquin River Restoration water recapture for Banta-Carbona Irrigation District	San Joaquin River baseline diversion
Diversion	D639B	Remainder of San Joaquin River Restoration water after recapture	San Joaquin River baseline diversion
Reservoir Storage	S20	Lake McClure storage	Calibration of WSE Reservoir Operations Parameters
Reservoir Storage	S81	New Don Pedro reservoir storage	Calibration of WSE Reservoir Operations Parameters
Reservoir Storage	S79	Turlock regulating reservoir storage	Characterizing CALSIM II water storage on the Tuolumne River
Reservoir Storage	S78	Modesto regulating reservoir storage	Characterizing CALSIM II water storage on the Tuolumne River
Reservoir Storage	S10	New Melones reservoir storage	Calibration of WSE Reservoir Operations Parameters
Reservoir Storage	S76	Tulloch reservoir storage	Tulloch reservoir storage
Reservoir Storage	S75	Woodward regulating reservoir storage	Characterizing CALSIM II water storage on the Stanislaus River
Reservoir Evaporation	E20	Lake McClure evaporation	Estimate of evaporative losses from Lake McClure to determine water available for diversion
Reservoir Evaporation	E81	New Don Pedro reservoir evaporation	Estimate of evaporative losses from New Don Pedro to determine water available for diversion
Reservoir Evaporation	E10	New Melones reservoir evaporation	Estimate of evaporative losses from New Melones to determine water available for diversion
Reservoir Evaporation	E76	Tulloch reservoir evaporation	Evaporative loss from Tulloch
Groundwater Pumping	GP573	Stevinson ID, El Nido, riparian groundwater pumping	Characterizing CALSIM II groundwater use in the Merced River watershed

Data Type	CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE?
Groundwater Pumping	GP570	Merced ID groundwater pumping	Characterizing CALSIM II groundwater use in the Merced River watershed
Groundwater Pumping	GP550	Non-district groundwater pumping on the south side of the Tuolumne River	Characterizing CALSIM II groundwater use in the Tuolumne River watershed
Groundwater Pumping	GP548	TID groundwater pumping	Characterizing CALSIM II groundwater use in the Tuolumne River watershed
Groundwater Pumping	GP534	Non-district groundwater pumping on the north side of the Tuolumne River	Characterizing CALSIM II groundwater use in the Tuolumne River watershed
Groundwater Pumping	GP532	MID groundwater pumping	Characterizing CALSIM II groundwater use in the Tuolumne River watershed
Groundwater Pumping	GP78A	Groundwater pumping for Modesto M&I	Characterizing CALSIM II groundwater use in the Tuolumne River watershed
Groundwater Pumping	GP530	OID south groundwater pumping	Characterizing CALSIM II groundwater use in the Stanislaus River watershed
Groundwater Pumping	GP522	SSJID/OID north groundwater pumping	Characterizing CALSIM II groundwater use in the Stanislaus River watershed
Groundwater Pumping	GP528A	Riparian groundwater pumping	Characterizing CALSIM II groundwater use in the Stanislaus River watershed
Streamflow	C20	Lake McClure release	Characterizing CALSIM II Flow on the Merced River
Streamflow	C561	Crocker Huffman release	Characterizing CALSIM II Flow on the Merced River
Streamflow	C562	Merced River Crocker Huffman to Snelling, after riparian diversions	Characterizing CALSIM II Flow on the Merced River
Streamflow	C564	Merced River from Snelling to Cressy	Characterizing CALSIM II Flow on the Merced River
Streamflow	C566	Merced River above the confluence with the San Joaquin River	Characterizing CALSIM II Flow on the Merced River
Streamflow	C81	New Don Pedro reservoir release	Characterizing CALSIM II Flow on the Tuolumne River
Streamflow	C540	Tuolumne River from La Grange to Modesto	Characterizing CALSIM II Flow on the Tuolumne River

Data Type	CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE?
Streamflow	C545	Tuolumne River above the confluence with the San Joaquin River	Characterizing CALSIM II Flow on the Tuolumne River
Streamflow	C10	New Melones reservoir release	Characterizing CALSIM II Flow on the Stanislaus River
Streamflow	C76	Tulloch reservoir release	Characterizing CALSIM II Flow on the Stanislaus River
Streamflow	C520	Stanislaus River from Goodwin to Ripon	Characterizing CALSIM II Flow on the Stanislaus River
Streamflow	C528	Stanislaus River above the confluence with the San Joaquin River	Characterizing CALSIM II Flow on the Stanislaus River
Streamflow	C611	Lander Avenue to Mud/Salt Slough	Boundary flow for HEC-5Q Temperature model
Streamflow	C614	San Joaquin River above Salt Slough	Boundary flow on the mainstem San Joaquin River for WSE
Streamflow	C619	Westside return flows to the San Joaquin River near the Merced River confluence	Local Inflow to the San Joaquin River
Streamflow	C620	San Joaquin River between the Merced and Tuolumne Rivers	Characterizing CALSIM II Flow on the San Joaquin River
Streamflow	C630	San Joaquin River between the Tuolumne River and Maze	Characterizing CALSIM II Flow on the San Joaquin River
Streamflow	C636	San Joaquin River between Maze and the Stanislaus River	Characterizing CALSIM II Flow on the San Joaquin River
Streamflow	C637	San Joaquin River between the Stanislaus River and Vernalis	Characterizing CALSIM II Flow on the San Joaquin River
Streamflow	C639	San Joaquin River below Vernalis	Characterizing CALSIM II Flow on the San Joaquin River
Streamflow	C644	San Joaquin River below Mossdale	Used to calculate depletions/accretions on the SJR between Vernalis and Mossdale in the HEC-5Q Temperature model
Vernalis Water Quality	VERNWQFINAL	Vernalis Electrical Conductivity	Determining flow needed to meet D-1641 salinity requirements
Tributary Inflow	I20	Inflow to Lake McClure	Inflow to Lake McClure

Data Type	CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE?
Tributary Inflow	I561	Merced River accretions between New Exchequer dam and Crocker Huffman	Local inflow to the Merced River
Tributary Inflow	I562	Merced River accretions between Crocker Huffman and Cressy	Local inflow to the Merced River
Tributary Inflow	I566	Merced River accretions between Cressy and Stevinson	Local inflow to the Merced River
Tributary Inflow	I81	Inflow to New Don Pedro reservoir	Inflow to New Don Pedro reservoir
Tributary Inflow	I545	Tuolumne River accretions between La Grange and Modesto	Local inflow to the Tuolumne River
Tributary Inflow	I10	Inflow to New Melones reservoir	Inflow to New Melones reservoir
Tributary Inflow	I76	Stanislaus River accretions between New Melones reservoir and Tulloch	Local inflow to the Stanislaus River
Tributary Inflow	I520	Stanislaus River accretions between Tulloch and Goodwin	Local inflow to the Stanislaus River
Tributary Inflow	I528	Stanislaus River accretions between Goodwin and Ripon	Local inflow to the Stanislaus River
Tributary Inflow	I636	San Joaquin River accretions between the Tuolumne River and Maze	Local inflow to the San Joaquin River
Tributary Inflow	I637	Stanislaus River accretions below Ripon	Local inflow to the San Joaquin River
Water Demand	CUAW_562A_PAG	CUAW demand for local/riparian diverters on the Merced River	Characterizing CALSIM II demands in the Merced River watershed
Water Demand	CUAW_571_ND	CUAW demand for non-district lands in Merced ID	Characterizing CALSIM II demands in the Merced River watershed
Water Demand	CUAW_571_PAG	CUAW demand for Merced ID	Component of Merced ID demand
Water Demand	CUAW_574_PAG	CUAW demand for Stevinson, El Nido, and riparian lands on the Merced River	Characterizing CALSIM II demands in the Merced River watershed
Water Demand	DEMAND_D572	Bear Creek Refuge demand	Bear Creek Refuge demand
Water Demand	CUAW_545A_PAG	CUAW demand for local/riparian diverters on the Tuolumne River	Characterizing CALSIM II demands in the Tuolumne River watershed
Water Demand	CUAW_549_ND	CUAW demand for non-district lands in TID	Characterizing CALSIM II demands in the Tuolumne River watershed

Data Type	CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE?
Water Demand	CUAW_533_PAG	CUAW demand for MID	Component of MID demand
Water Demand	CUAW_535_PAG	CUAW demand for non-district lands on the north side of the Tuolumne River	Characterizing CALSIM II demands in the Tuolumne River watershed
Water Demand	CUAW_549_PAG	CUAW demand for TID	Component of TID demand
Water Demand	CUAW_551_PAG	CUAW demand for non-district lands on the south side of the Tuolumne River	Characterizing CALSIM II demands in the Tuolumne River watershed
Water Demand	CUAW_511_ND	CUAW demand for non-district lands in SEWD	Characterizing CALSIM II demands in the Stanislaus River watershed
Water Demand	CUAW_511_PAG	CUAW demand for SEWD	Characterizing CALSIM II demands in the Stanislaus River watershed
Water Demand	CUAW_512_PAG	CUAW demand for CSJWCD	Characterizing CALSIM II demands in the Stanislaus River watershed
Water Demand	DEMAND_D523_MI_A	M&I demand in SSJID	Component of SSJID demand (*CALSIM* mode only)
Water Demand	CUAW_528A_PAG	CUAW demand for local/riparian diverters on the Stanislaus River	Characterizing CALSIM II demands in the Stanislaus River watershed
Water Demand	CUAW_523OID_PAG	CUAW demand for OID north	Component of OID north demand
Water Demand	CUAW_523SSJ_PAG	CUAW demand for SSJID	Component of SSJID demand
Water Demand	CUAW_531_ND	CUAW demand for non-district lands in OID south	Component of OID south demand
Water Demand	CUAW_531_PAG	CUAW demand for OID south	Component of OID south demand
Reservoir Parameters	EVAP_S20	Lake McClure evaporation rate	Lake McClure evaporation rate
Reservoir Parameters	EVAP_S81	New Don Pedro evaporation rate	New Don Pedro evaporation rate
Reservoir Parameters	S81LEVEL4	New Don Pedro CALSIM storage zone 4	New Don Pedro flood storage curve
Reservoir Parameters	EVAP_S10	New Melones evaporation rate	New Melones evaporation rate

Merced ID = Merced Irrigation District; TID = Turlock Irrigation District; MID = Modesto Irrigation District; OID = Oakdale Irrigation District; SSJID = South San Joaquin Irrigation District; SEWD = Stockton East Water District; CSJWCD = Central San Joaquin Water Conservation District; M&I = Municipal and Industrial; CUAW = Consumptive use of applied water

Note: Timeseries for Tributary Inflow, Water Demand, and Reservoir Parameters are extracted from the file *2020D09ESV.dss* of the SWRCB CALSIM II 2023 model run. Timeseries for all other data types are extracted from the file *CSII_SWRCB_05252023.dss* of the SWRCB CALSIM II 2023 model run.

B.2.2.2 Calculation of Flow Targets

For the most part, monthly instream flow releases in WSE are still calculated the same way as they were in the 2018 Final SED. However, the calculation of flow targets has been improved, giving the user greater control over where the baseline flow requirements are applied. In addition, there are several updates to the baseline flow requirements applied on each of the Eastside tributaries, which are covered in the following subsections.

In the 2018 Final SED version of WSE, flow requirements on each tributary, apart from the UF and flow shifting requirements, were modeled as being required at the tributary diversion dams, Goodwin Dam on the Stanislaus; La Grange Dam on the Tuolumne; and Crocker Huffman Dam on the Merced. However, these requirements were also translated to the confluence of each tributary using CALSIM II estimates of the accretions and depletions between the dams and the tributary confluences to produce expected flow downstream. The expected flows were used to gauge how much water should reach the confluence to guarantee that the instream flow requirements were met at the upstream compliance points. This assumed that the instream flow releases at the diversion dams were protected from being diverted by downstream riparian diverters on each tributary (but were not protected from downstream depletions).

In WSE-SWRCB, flow requirements can now be applied at other locations besides the diversion dams, or at multiple locations. Flow requirements can be modeled at Goodwin and/or Ripon on the Stanislaus, at La Grange and/or Modesto on the Tuolumne, and at Crocker Huffman, Cressy, and/or Stevinson on the Merced (these locations correspond to nodes represented in the CALSIM II model). Instead of calculating the expected flows for downstream locations based on the accretions and depletions as in the previous version, each location has a target flow that can be turned on or off depending on where the flow requirements are desired. In addition, the assumption of protection for the instream flows has been separated out from the calculations, and a switch was added to allow it to be turned on or off. By turning the switch off,[9] releases to meet target flows for upstream locations can be diverted by downstream riparian diverters on each tributary (denoted by CALSIM II links D528 on the Stanislaus, D545 on the Tuolumne, and D566 on the Merced). However, if there is a flow target active downstream of the riparian diverters, the model will first bypass enough flow to meet the target before calculating the amount of water available for riparian diverters.

Merced River Flow Requirements

For the Merced River, the first change to the baseline representation was to remove flows resulting from the Davis-Grunsky contract, a 1967 agreement between DWR and Merced Irrigation District under which Merced Irrigation District agreed to release additional flow for recreation and fish enhancement (DWR 1967). This agreement ended in 2017 and is thus no longer reflected in the baseline alternative. The second change was to update the implementation of the current FERC Project Number 2179 license flow requirements to represent both the normal and dry year flow schedules (FERC 1964).[10] In the 2018 Final SED, representation of this requirement was simplified and only the normal year flow schedule was modeled. The normal year schedule is now applied

[9] Note, that this switch does not affect diversions by Cowell Agreement Diverters on the Merced or diverters on the mainstem SJR in WSE.

[10] A similar update was made to implement the dry year flow schedule for the Davis-Grunsky agreement, if it was active.

when the April through July unimpaired inflow to Lake McClure is greater than 450 TAF and the dry year schedule is applied when the April through July unimpaired inflow is less than 450 TAF. The active schedule is determined annually beginning in April of each year and applied through the following March. See Table B-3 for the monthly flows required under the Merced FERC license for Project Number 2179 in the latest version of WSE.

Another modification to the Merced FERC requirement was to move the target location from Crocker Huffman to Cressy. In the 2018 Final SED modeling, the FERC requirements were treated as release targets at Crocker Huffman diversion dam, which is similar to how CALSIM II models these requirements. However, the actual compliance point for these flows is at Shaffer Bridge, about 19.2 miles downstream of Crocker Huffman (FERC 2015). Since the node framework structure of CALSIM II that WSE is based on does not represent Shaffer Bridge as a separate location, the requirement is modeled at Cressy, which is a few miles downstream of Shaffer Bridge.

Table B-3. 1964 FERC Minimum Flow Requirements on the Merced River at Shaffer Bridge (in cfs).

Calendar Month	Normal Year	Dry Year [a]
1	75	60
2	75	60
3	75	60
4	75	60
5	75	60
6	25	15
7	25	15
8	25	15
9	25	15
10	50	38
11	100	75
12	100	75

[a] A dry year occurs when the forecasted April through July unimpaired inflow is less than 450 TAF (FERC 1964).

Tuolumne River Flow Requirements

For the Tuolumne River, the baseline requirements modeled in WSE are the current New Don Pedro FERC license minimum flow requirements established in the 1995 FERC settlement agreement, which are shown in Table B-5. Compared to the 2018 Final SED, the representation of these requirements has been updated with the option to include “interpolation water.” Under the 1995 FERC settlement agreement there are ten year type classifications defined by the San Joaquin River 60-20-20 index (SJR Index) that determine the annual minimum flow schedule for the Tuolumne River, which are shown in Table B-4. When the actual value of the SJR index falls between the specific values that define the year type classifications, the precise volume of flow to be released each fish flow year (April 15 to April 14 of the following year) is to be determined using interpolation between index values (FERC 1995). Interpolation water is only applied when the year type classification is between “Median Critical” and “Intermediate Below Normal-Above Normal” or when the SJR index falls between 1441 and 3073. Based on input provided by the TVA parties, the volume of the interpolation water is determined using linear interpolation between SJR index values and is modeled as a fall pulse flow in October. However, in reality, interpolation water will be

managed in real time to provide releases when they would be most beneficial over the fall through early spring. For the WSE-SWRCB baseline, interpolation water release requirements are not applied, consistent with the TVA draft accounting spreadsheet provided by the TVA parties (TID, MID, CCSF 2025). In the WSE-CALSIM baseline the interpolation water release is active and is divided equally between April and May to be consistent with CALSIM II.

In addition, the index values that define the year type classifications under the 1995 FERC settlement agreement have been updated based on the 2022 lower Tuolumne River annual FERC report (TID and MID 2023). Appendix A to the New Don Pedro 1995 Settlement Agreement states that "the 60-20-20 index numbers used each year shall be updated to incorporate subsequent water years … so as to maintain approximately the same frequency distribution of water year types" (FERC 1995). The index values used currently in WSE are shown in Table B-4.

Table B-4. Tuolumne Year Type Classifications Under the 1995 Settlement Agreement.

SJR Index [a]	Year Type Classification	Frequency of Occurrence
>=4773	Median Wet/Maximum	13.30%
>=3903	Intermediate AN-W	15.40%
>=3669	Median Above Normal	5.10%
>=3073	Intermediate BN-AN	15.50%
>=2642	Median Below Normal	10.30%
>=2352	Intermediate D-BN	9.10%
>=2061	Median Dry	10.80%
>=1955	Intermediate C-D	6.10%
>=1441	Median Critical	8.00%
> 0	Critical	6.40%

[a] SJR Index values used in WSE were updated from the values used in the 2018 Final SED based on the 2022 lower Tuolumne River Annual FERC report (TID and MID 2023).

Table B-5. Minimum Monthly Flow Requirements at La Grange Dam on the Tuolumne River per the 1995 FERC Settlement Agreement (in TAF).

Year Type Classification	Intermediate BN-AN *and above* [a]	Median Below Normal	Intermediate D-BN	Median Dry	Intermediate C-D	Median Critical	Critical
January	18.4	10.8	11.1	9.2	9.2	9.2	9.2
February	16.7	9.7	10	8.3	8.3	8.3	8.3
March	18.4	10.8	11.1	9.2	9.2	9.2	9.2
April [b]	62.8	40.4	28.7	27.5	25.2	19.0	14.5
May [b]	63.4	40.8	29.0	27.8	25.5	19.3	14.8
June	14.9	4.5	4.5	4.5	3	3	3
July	15.4	4.6	4.6	4.6	3.1	3.1	3.1
August	15.4	4.6	4.6	4.6	3.1	3.1	3.1
September	14.9	4.5	4.5	4.5	3	3	3
October	24.4	13.2	12.7	9.2	9.2	7.7	7.7
November	17.9	10.4	10.7	8.9	8.9	8.9	8.9
December	18.4	10.8	11.1	9.2	9.2	9.2	9.2
Annual Total	**300.9**	**165**	**142.5**	**127.5**	**117**	**103**	**94**

[a] The 1995 FERC settlement agreement defines 10 water year classifications, but this table only shows information for 7 of them because the 4 wettest classifications (Intermediate BN-AN, Median Above Normal, Intermediate AN-W, and Median Wet/Maximum) under the Tuolumne 1995 FERC settlement agreement require the same minimum flows. (FERC 1995).

[b] April and May flow requirements include both the required baseflow and required spring pulse flow under the 1995 FERC settlement agreement. These values were slightly updated from the values used in the 2018 Final SED to make sure the pulse flow was divided equally between the two months. Based on the TVA party modeling, the April/May pulse flow is released between April 15 and May 15 (TID, MID, CCSF 2024).

Another update to representation of the 1995 FERC requirements is the option to calculate the required flow based on monthly forecasting of the SJR 60-20-20 index. Forecasted SJR index values at the 90% and 75% exceedance levels for each month from February through May over the modeling period (1922 to 2003) were extracted from the CALSIM II Allocation Model (CAM) and provided by the Department of Water Resources (DWR). The CAM is a CALSIM II support tool that uses forecasted monthly reservoir and local inflows as inputs to derive seasonal delivery targets (DWR 2003; Yin et al. 2012). The forecasted index values and the corresponding forecasted water year type (WYT) used in WSE at the 90% and 75% exceedance levels are presented in Table B-6 and Table B-7, respectively. When using forecasting for the 1995 FERC license, April flow requirements are determined by April 90% exceedance forecast of the SJR index, while May through March flow requirements are determined by the May 75% exceedance forecast of the SJR index. For the 1995 FERC April/May pulse flow, WSE also includes an option to determine the entire spring pulse flow volume based on the April forecast without updating the volume in May. For the WSE-SWRCB baseline, forecasting is applied and the Spring pulse volume is determined by the April forecast. For the WSE-CALSIM baseline, forecasting is not applied.

Table B-6. CAM Data for February, March, April, and May 90% Exceedance Forecasts of SJR 60-20-20 Index (million acre-feet or MAF) and WYT from 1922 to 2003.

Year	Feb SJR Index	Mar SJR Index	Apr SJR Index	May SJR Index	Feb SJR WYT	Mar SJR WYT	Apr SJR WYT	May SJR WYT	Final SJR WYT
1922	2.24	2.67	2.91	2.97	D	BN	BN	BN	W
1923	2.84	2.56	2.29	3.05	BN	BN	D	BN	AN
1924	1.45	1.31	1.36	1.53	C	C	C	C	C
1925	1.81	2.42	2.64	3.06	C	D	BN	BN	BN
1926	1.57	2.01	1.72	2.52	C	C	C	BN	D
1927	2.19	2.99	2.98	3.44	D	BN	BN	AN	AN
1928	2.13	2.14	2.68	2.94	D	D	BN	BN	BN
1929	1.49	1.45	1.58	1.97	C	C	C	C	C
1930	1.50	1.59	1.66	2.00	C	C	C	C	C
1931	1.39	1.34	1.18	1.43	C	C	C	C	C
1932	2.52	3.10	2.87	2.96	BN	AN	BN	BN	AN
1933	2.05	1.83	1.85	2.00	C	C	C	C	D
1934	1.79	1.95	1.68	1.77	C	C	C	C	C
1935	2.27	2.17	2.46	3.68	D	D	D	AN	AN
1936	2.16	3.72	3.55	3.80	D	AN	AN	W	AN
1937	2.39	3.39	3.59	3.72	D	AN	AN	AN	W
1938	2.58	3.96	5.23	5.68	BN	W	W	W	W

Year	Feb SJR Index	Mar SJR Index	Apr SJR Index	May SJR Index	Feb SJR WYT	Mar SJR WYT	Apr SJR WYT	May SJR WYT	Final SJR WYT
1939	2.08	2.11	2.15	2.37	C	D	D	D	D
1940	2.61	3.31	3.70	3.75	BN	AN	AN	AN	AN
1941	2.91	3.58	3.67	4.09	BN	AN	AN	W	W
1942	3.17	3.23	3.26	3.92	AN	AN	AN	W	W
1943	3.33	3.25	3.97	4.22	AN	AN	W	W	W
1944	1.93	2.31	2.17	2.49	C	D	D	D	BN
1945	2.00	2.68	3.05	3.09	C	BN	BN	BN	AN
1946	2.70	2.67	3.14	3.18	BN	BN	AN	AN	AN
1947	2.28	2.23	2.32	2.43	D	D	D	D	D
1948	1.26	1.27	1.57	2.35	C	C	C	D	BN
1949	1.63	1.73	2.11	2.26	C	C	D	D	BN
1950	2.04	2.07	2.13	2.59	C	C	D	BN	BN
1951	3.21	3.29	3.61	3.72	AN	AN	AN	AN	AN
1952	3.74	3.68	4.39	4.70	AN	AN	W	W	W
1953	2.65	2.24	2.22	2.64	BN	D	D	BN	BN
1954	1.80	1.98	2.45	2.80	C	C	D	BN	BN
1955	2.08	2.04	1.80	2.16	C	C	C	D	D
1956	4.36	4.13	4.16	4.45	W	W	W	W	W
1957	1.94	2.14	2.18	2.42	C	D	D	D	BN
1958	2.12	2.72	3.56	4.36	D	BN	AN	W	W
1959	1.89	2.35	2.03	2.29	C	D	C	D	D
1960	1.20	1.56	1.60	1.94	C	C	C	C	C
1961	1.42	1.34	1.40	1.62	C	C	C	C	C
1962	1.30	2.67	2.83	3.02	C	BN	BN	BN	BN
1963	2.11	2.35	2.66	3.40	D	D	BN	AN	AN
1964	2.16	1.86	1.95	2.14	D	C	C	D	D
1965	3.47	3.16	3.38	3.83	AN	AN	AN	W	W
1966	2.76	2.68	2.47	2.73	BN	BN	D	BN	BN
1967	2.90	2.60	3.55	4.67	BN	BN	AN	W	W
1968	2.09	2.12	2.04	2.17	C	D	C	D	D
1969	4.66	5.65	5.66	6.18	W	W	W	W	W
1970	3.30	3.06	3.16	3.22	AN	BN	AN	AN	AN
1971	2.63	2.38	2.47	2.52	BN	D	D	BN	BN
1972	2.01	1.85	1.54	1.86	C	C	C	C	D
1973	2.31	2.86	3.08	3.04	D	BN	BN	BN	AN
1974	3.10	2.75	3.46	3.81	BN	BN	AN	W	W
1975	2.02	2.60	3.14	3.48	C	BN	AN	AN	W
1976	1.65	1.79	1.69	1.85	C	C	C	C	C
1977	0.93	0.84	0.83	0.86	C	C	C	C	C

Year	Feb SJR Index	Mar SJR Index	Apr SJR Index	May SJR Index	Feb SJR WYT	Mar SJR WYT	Apr SJR WYT	May SJR WYT	Final SJR WYT
1978	2.67	3.24	3.94	4.62	BN	AN	W	W	W
1979	2.50	2.92	3.25	3.33	D	BN	AN	AN	AN
1980	3.47	4.32	4.53	4.61	AN	W	W	W	W
1981	2.18	2.06	2.31	2.53	D	C	D	BN	D
1982	3.17	3.34	4.44	5.56	AN	AN	W	W	W
1983	4.24	5.20	6.44	7.06	W	W	W	W	W
1984	3.23	3.37	3.52	3.54	AN	AN	AN	AN	AN
1985	2.12	2.10	2.40	2.56	D	D	D	BN	D
1986	2.23	4.09	4.61	4.61	D	W	W	W	W
1987	1.50	1.64	1.71	1.92	C	C	C	C	C
1988	1.85	1.58	1.34	1.70	C	C	C	C	C
1989	1.47	1.46	1.84	2.07	C	C	C	C	C
1990	1.50	1.56	1.46	1.74	C	C	C	C	C
1991	0.87	0.80	1.83	1.92	C	C	C	C	C
1992	1.46	1.86	1.87	2.00	C	C	C	C	C
1993	3.30	3.74	4.03	4.06	AN	AN	W	W	W
1994	1.68	1.94	1.69	2.05	C	C	C	C	C
1995	3.64	3.17	4.95	5.45	AN	AN	W	W	W
1996	2.51	3.27	3.38	3.75	BN	AN	AN	AN	W
1997	5.20	4.32	4.49	4.35	W	W	W	W	W
1998	2.88	4.33	4.62	4.88	BN	W	W	W	W
1999	2.42	2.86	2.76	3.03	D	BN	BN	BN	AN
2000	2.24	3.13	2.96	3.28	D	AN	BN	AN	AN
2001	1.78	2.03	2.02	2.49	C	C	C	D	D
2002	2.30	2.11	2.26	2.46	D	D	D	D	D
2003	2.15	2.04	2.03	2.70	D	C	C	BN	BN

Note: SJR WYT designations are W if SJR index >= 3.8 MAF, AN if index <3.8 MAF and >3.1 MAF, BN if index <=3.1 MAF and >2.5 MAF, D if index <=2.5 MAF and >2.1 MAF, and C if index <=2.1 MAF (SWRCB 2000).

Table B-7. CAM Data for February, March, April, and May 75% Exceedance Forecasts of SJR 60-20-20 Index (MAF) and WYT from 1922 to 2003.

Year	Feb SJR Index	Mar SJR Index	Apr SJR Index	May SJR Index	Feb SJR WYT	Mar SJR WYT	Apr SJR WYT	May SJR WYT	Final SJR WYT
1922	2.48	2.89	3.05	2.99	D	BN	BN	BN	W
1923	3.11	2.76	2.42	3.07	AN	BN	D	BN	AN
1924	1.64	1.46	1.42	1.54	C	C	C	C	C
1925	2.03	2.63	2.78	3.08	C	BN	BN	BN	BN
1926	1.77	2.19	1.83	2.54	C	D	C	BN	D
1927	2.43	3.22	3.13	3.46	D	AN	AN	AN	AN
1928	2.36	2.34	2.81	2.97	D	D	BN	BN	BN

Year	Feb SJR Index	Mar SJR Index	Apr SJR Index	May SJR Index	Feb SJR WYT	Mar SJR WYT	Apr SJR WYT	May SJR WYT	Final SJR WYT
1929	1.68	1.60	1.69	1.99	C	C	C	C	C
1930	1.71	1.76	1.77	2.02	C	C	C	C	C
1931	1.58	1.50	1.28	1.44	C	C	C	C	C
1932	2.78	3.34	3.02	2.98	BN	AN	BN	BN	AN
1933	2.27	1.99	1.96	2.01	D	C	C	C	D
1934	2.01	2.14	1.80	1.78	C	D	C	C	C
1935	2.53	2.38	2.60	3.71	BN	D	BN	AN	AN
1936	2.40	3.97	3.70	3.83	D	W	AN	W	AN
1937	2.62	3.63	3.74	3.75	BN	AN	AN	AN	W
1938	2.84	4.22	5.38	5.72	BN	W	W	W	W
1939	2.29	2.29	2.27	2.38	D	D	D	D	D
1940	2.88	3.55	3.85	3.78	BN	AN	W	AN	AN
1941	3.18	3.82	3.82	4.12	AN	W	W	W	W
1942	3.45	3.46	3.40	3.94	AN	AN	AN	W	W
1943	3.63	3.49	4.12	4.24	AN	AN	W	W	W
1944	2.15	2.50	2.29	2.51	D	D	D	BN	BN
1945	2.23	2.91	3.20	3.12	D	BN	AN	AN	AN
1946	2.97	2.89	3.28	3.20	BN	BN	AN	AN	AN
1947	2.52	2.43	2.46	2.45	BN	D	D	D	D
1948	1.45	1.43	1.68	2.37	C	C	C	D	BN
1949	1.83	1.89	2.23	2.28	C	C	D	D	BN
1950	2.28	2.26	2.26	2.61	D	D	D	BN	BN
1951	3.52	3.56	3.77	3.75	AN	AN	AN	AN	AN
1952	4.06	3.93	4.54	4.73	W	W	W	W	W
1953	2.91	2.43	2.35	2.66	BN	D	D	BN	BN
1954	2.01	2.16	2.59	2.82	C	D	BN	BN	BN
1955	2.31	2.22	1.91	2.18	D	D	C	D	D
1956	4.71	4.42	4.32	4.48	W	W	W	W	W
1957	2.15	2.33	2.30	2.43	D	D	D	D	BN
1958	2.36	2.94	3.71	4.39	D	BN	AN	W	W
1959	2.11	2.54	2.14	2.30	D	BN	D	D	D
1960	1.38	1.73	1.71	1.96	C	C	C	C	C
1961	1.62	1.50	1.51	1.63	C	C	C	C	C
1962	1.50	2.89	2.98	3.04	C	BN	BN	BN	BN
1963	2.35	2.57	2.80	3.42	D	BN	BN	AN	AN
1964	2.39	2.04	2.07	2.16	D	C	C	D	D
1965	3.79	3.41	3.53	3.86	AN	AN	AN	W	W
1966	3.03	2.89	2.60	2.75	BN	BN	BN	BN	BN
1967	3.18	2.83	3.70	4.70	AN	BN	AN	W	W

Year	Feb SJR Index	Mar SJR Index	Apr SJR Index	May SJR Index	Feb SJR WYT	Mar SJR WYT	Apr SJR WYT	May SJR WYT	Final SJR WYT
1968	2.31	2.30	2.16	2.19	D	D	D	D	D
1969	5.02	5.95	5.81	6.22	W	W	W	W	W
1970	3.61	3.30	3.31	3.25	AN	AN	AN	AN	AN
1971	2.90	2.59	2.60	2.54	BN	BN	BN	BN	BN
1972	2.24	2.04	1.66	1.88	D	C	C	C	D
1973	2.57	3.10	3.23	3.07	BN	BN	AN	BN	AN
1974	3.39	2.97	3.61	3.83	AN	BN	AN	W	W
1975	2.24	2.81	3.28	3.50	D	BN	AN	AN	W
1976	1.85	1.96	1.80	1.86	C	C	C	C	C
1977	1.10	0.96	0.85	0.86	C	C	C	C	C
1978	2.95	3.48	4.10	4.66	BN	AN	W	W	W
1979	2.75	3.14	3.40	3.35	BN	AN	AN	AN	AN
1980	3.79	4.61	4.69	4.64	AN	W	W	W	W
1981	2.40	2.24	2.43	2.55	D	D	D	BN	D
1982	3.47	3.61	4.59	5.59	AN	AN	W	W	W
1983	4.58	5.50	6.59	7.10	W	W	W	W	W
1984	3.54	3.63	3.67	3.57	AN	AN	AN	AN	AN
1985	2.35	2.29	2.53	2.58	D	D	BN	BN	D
1986	2.48	4.37	4.77	4.64	D	W	W	W	W
1987	1.67	1.80	1.82	1.93	C	C	C	C	C
1988	2.08	1.75	1.45	1.72	C	C	C	C	C
1989	1.68	1.62	1.97	2.09	C	C	C	C	C
1990	1.70	1.73	1.57	1.75	C	C	C	C	C
1991	1.03	0.89	1.95	1.93	C	C	C	C	C
1992	1.66	2.05	1.99	2.01	C	C	C	C	C
1993	3.60	3.99	4.18	4.09	AN	W	W	W	W
1994	1.87	2.11	1.79	2.06	C	D	C	C	C
1995	3.96	3.41	5.11	5.48	W	AN	W	W	W
1996	2.76	3.52	3.53	3.78	BN	AN	AN	AN	W
1997	5.59	4.61	4.65	4.38	W	W	W	W	W
1998	3.15	4.59	4.77	4.91	AN	W	W	W	W
1999	2.67	3.10	2.90	3.05	BN	BN	BN	BN	AN
2000	2.49	3.37	3.10	3.30	D	AN	BN	AN	AN
2001	1.99	2.21	2.14	2.51	C	D	D	BN	D
2002	2.56	2.31	2.39	2.48	BN	D	D	D	D
2003	2.39	2.24	2.16	2.72	D	D	D	BN	BN

Note: SJR WYT designations are W if SJR index >= 3.8 MAF, AN if index <3.8 MAF and >3.1 MAF, BN if index <=3.1 MAF and >2.5 MAF, D if index <=2.5 MAF and >2.1 MAF, and C if index <=2.1 MAF (SWRCB 2000).

Stanislaus River Flow Requirements

For the Stanislaus River, the baseline minimum instream flow requirements have been updated to reflect changes to the coordinated operations of the CVP and the State Water Project and the BiOp released in 2019 by the National Marine Fisheries Service (NMFS) (NMFS 2019). Stanislaus flow requirements in WSE are now based on the New Melones SRP, which provides default daily hydrographs of required flow at Goodwin for each of the WYTs defined in D-1641 (USBR 2019). However, since WSE is a monthly model, the SRP flows are implemented as total monthly flow volumes, as shown in Table B-8. These requirements are similar to those set forth in Table 2E of the previous BiOp released in 2009, which defined the baseline flow requirements on the Stanislaus in the 2018 Final SED version of WSE (NMFS 2009). For critically dry, dry, and below normal WYTs, the requirements are the same as those in Table 2E. In above normal and wet years the minimum requirements are reduced such that releases in above normal years would match below normal year releases in Table 2E and releases in wet years would match above normal year releases in Table 2E. The requirements in wetter years were reduced from the previous operations to promote storage for potential future droughts and preserve cold-water pool. Another difference is that WYTs in the NM SRP are determined based on the SJR index rather than the New Melones Index which was previously used for the Table 2E requirements.

Table B-8. Minimum Monthly Flow Required by WYT on the Stanislaus River at Goodwin Under the 2019 BiOp Stepped Release Plan (in TAF).

Month	Critically Dry	Dry	Below Normal	Above Normal	Wet
January	13	13	14	14	14
February	12	12	13	13	13
March	12	12	12	12	94
April	27	46	91	91	83
May	25	39	76	76	96
June	9	12	22	22	56
July	9	12	15	15	18
August	9	12	15	15	18
September	9	12	15	15	18
October	36	39	48	48	49
November	12	12	12	12	12
December	12	12	12	12	12
Total	**185**	**234**	**346**	**346**	**484**

Finally, the proxy flow requirement from CALSIM II representing flows needed to meet the Water Right Decision 1422 (D-1422) dissolved oxygen (DO) objective below Goodwin was added to WSE. According to D-1422, in an agreement with the Central Valley Regional Water Quality Control Board, Reclamation planned to release up to 70,000 acre-feet (AF) annually to maintain a mean monthly total dissolved solids (TDS) concentration in the SJR below the mouth of the Stanislaus at 500 parts per million maximum and to maintain DO in the Stanislaus River at the level specified in the 1971 Interim Water Quality Control Plan for the SJR Basin, or whatever plan amended or superseded it (SWRCB 1973). Through Order WR 98-09, the San Joaquin TDS objective was replaced with the Vernalis salinity objective in the 1995 Bay-Delta Plan (SWRCB 2000), but the Stanislaus DO objective still applies. Neither WSE nor CALSIM II model DO concentrations in the Stanislaus River,

but CALSIM II has established surrogate flows that represent release requirements that would maintain DO levels. In the latest version of CALSIM II, the surrogate flows are released during June through September and are reduced in critically dry years, as shown in Table B-9 (USBR 2021). Note that these flows represent the total flow that must be achieved to meet the DO requirement; if monthly releases from Goodwin for other requirements meet or exceed these values, no additional release is needed for DO.

Table B-9. Stanislaus Dissolved Oxygen Surrogate Flow Requirement Below Goodwin Dam from CALSIM II (in TAF).

Calendar Month	Non-Critically Dry Years	Critically Dry Years
January	0	0
February	0	0
March	0	0
April	0	0
May	0	0
June	15.2	11.9
July	16.3	12.3
August	17.4	12.3
September	14.8	11.9
October	0	0
November	0	0
December	0	0

San Joaquin River Flow Requirements

For the San Joaquin River, the calculation of D-1641 February through June flow requirements was updated to better reflect its representation in CALSIM II. Table B-10 shows the D-1641 flow requirements that can be modeled in WSE. The baseflow and pulse flow targets depend on the location of X2;[11] if it is at or west of Chipps Island then the higher flow targets apply and if it is east the lower targets apply (SWRCB 2000). The 2018 version of WSE used a simplifying approach to determine the targets, relying on CALSIM II output for the average monthly location of X2 (when X2's location was less than 75 kilometers, the location of Chipps Island upstream from the Golden Gate Bridge, the higher flow requirement was used for the entire month). In the current version of WSE, the monthly flow target is determined by averaging the higher and lower targets weighted by the number of days each target would apply, which is based on the CALSIM II estimate of monthly "Chipps Days," or the number of days that X2 is at or west of Chipps Island in each month.[12]

[11] The X2 standard, introduced in the 1995 Bay-Delta Plan, refers to the position (in kilometers) relative to the Golden Gate Bridge at which 2 parts per thousand salinity occurs in the Delta estuary. The X2 standard is designed to improve shallow-water fish habitat in the spring of each year and can limit export pumping.

[12] Values taken from the "chs_days" column of the CALSIM II file *x2days.table*

For the months of April and May, D-1641 flow requirements are split between the baseflow (April 1 to April 14 and May 16 to May 31) and pulse flow (April 15 to May 15) periods. This results in 14 days of baseflow and 16 days of pulse flow during April and 16 days of baseflow and 15 days of pulse flow during May. If the D-1641 pulse flow is turned on in WSE, the April and May baseflow and pulse flow targets are averaged together to produce the final monthly target flow, this time weighted by the number of days that the baseflow and pulse flow apply. Otherwise, if the pulse flow is turned off, then the D-1641 monthly baseflow volume is multiplied by 14/30 in April and 16/31 in May to produce the final D-1641 baseflow target. For both the WSE-CALSIM and WSE-SWRCB baselines the D-1641 pulse flow is not active.

Table B-10. D-1641 Minimum Monthly Flow Requirements in the SJR at Airport Way Bridge near Vernalis (in cfs).

60-20-20 WYT [a]	Baseflow if X2 is East of Chipps Island [b]	Baseflow if X2 is West of Chipps Island [b]	Pulse Flow if X2 is East of Chipps Island [c]	Pulse Flow if X2 is West of Chipps Island [c]	October (cfs) [d]
Wet	2,130	3,420	7,330	8,620	2,000
Above Normal	2,130	3,420	5,730	7,020	2,000
Below Normal	1,420	2,280	4,620	5,480	2,000
Dry	1,420	2,280	4,020	4,880	2,000
Critically Dry	710	1,140	3,110	3,540	2,000

[a] SJR Index as defined by D-1641 (SWRCB 2000).

[b] Baseflow period is from Feb 1–April 14 and from May 16–June 30.

[c] Pulse flow period is from April 15–May 15.

[d] October pulse requirement is 1,000 cfs in consecutive critically dry years.

B.2.2.3 Calculation of Monthly Surface Water Demand

In WSE-SWRCB, the agricultural surface water demands for South San Joaquin, Oakdale, Turlock, Modesto, and Merced Irrigation Districts (SSJID, OID, TID, MID, and Merced ID, respectively) are still calculated the same way as described in Appendix F.1 of the 2018 Final SED. However, several parameters that make up those demand estimates have been updated. In particular, values for deep percolation, distribution system losses, and groundwater pumping within the modeled irrigation districts have been updated using the most recent AWMPs. Refinements were also made to the calculation of riparian diversions on all the tributaries and Cowell diversions on the Merced River. Finally, a new method of calculating CVP contractor allocations on the Stanislaus River using WYT was implemented based on information from CALSIM II.

Deep Percolation and Distribution Losses

WSE represents district field and canal losses using deep percolation and distribution loss factors (DP and DL factors, respectively). These factors are multipliers that increase district diversion demands based on the other components of the demand. The DP factor multiplies each district's CUAW demand, while the distribution loss factor is applied to the total district demand (not including M&I demand or regulating reservoir losses). Table B-11 shows the updated loss factors and how they were calculated based on the AWMP information. In the 2018 Final SED, these factors were calculated using district data from AWMPs released in 2012/2013. For WSE-SWRCB, these factors are primarily based on data from 2020 AWMPs, which were released in 2021. The factors for TID and Merced ID also incorporated information from their 2015 AWMPs so that the averaging period would span at least 10 years. The factors for MID were calculated using only year 2018 data because that is the only year included in MID's 2020 AWMP with a complete water balance breakdown. Compared with the 2018 Final SED values (see Table F.1.2-11, Appendix F.1), the DP factors for SSJID and Merced ID and the DL factor for Merced ID increased while the DL factor for OID decreased. The other factors were relatively unchanged compared to the values from the 2018 Final SED.

Table B-11. Calculation of Deep Percolation and Distribution Loss Factors for Irrigation Districts Represented in WSE.

AWMP parameter	Unit	Calculation	SSJID [a, b, c]	OID	MID [d]	TID	Merced ID [e]
Consumptive Use of Applied Water (CUAW)	AF/y	-	132,475	152,200	215,700	322,771	318,592
Deep Percolation of Applied Water (DP)	AF/y	-	60,764	25,100	79,700	150,670	144,343
Distribution System inflow (DI)	AF/y	-	189,308	224,400	232,824	517,556	481,439
Conveyance Evaporation (CEV)	AF/y	-	1,217	1,800	2,400	1,531	9,854
Conveyance Seepage (CS)	AF/y	-	30,805	27,700	11,900	36,595	144,679
Deep Percolation Factor (DPF)	-	(DP)/(CUAW)	0.46	0.16	0.37	0.47	0.45
Distribution Loss Factor (DLF)	-	(CEV+CS)/(DI-CEV-CS)	0.20	0.15	0.07	0.08	0.47

Sources: SSJID 2020; OID 2020; MID 2020; TID 2020; TID 2015; Merced ID 2020; Merced ID 2015.

AF/y = acre feet per year.

[a] SSJID Distribution System Inflows are the sum of Woodward Reservoir Releases (181,576 AF), OID Spills to Main Canal (3,061 AF), and District Pumping (4,671 AF) (see Table 5-1, SSJID 2020).

[b] SSJID conveyance seepage is the sum of Main Distributary Canal Seepage (25,745 AF) and lateral Seepage (5,060 AF) (see Table 5-1, SSJID 2020).

[c] SSJID conveyance evaporation is the sum of Main Distributary Canal EVAP (516 AF) and District Lateral EVAP (701 AF) (see Table 5-1, SSJID 2020).

[d] MID Distribution System Inflows is the sum of Surface Water – Irrigation (238,900 AF), Groundwater Pumping – Irrigation (Agency Wells) (19,800 AF), and Spill Inflows: Oakdale Irrigation District (7,824 AF) minus Seepage – Reservoirs (24,500 AF) and Evaporation – Reservoirs & Recharge Basins (9,200 AF) (see Table 47, MID 2020).

[e] In the 2020 AWMP, Merced ID deep percolation is separated into Deep Percolation of Surface Water, Deep Percolation of GW on Direct Delivery Land, and Deep Percolation of GW on non-Delivery Land (Table 24, Merced ID 2020). These values are summed annually and then averaged with the annual estimates of total Deep Percolation from the 2015 AWMP (see Table 5-16, Merced ID 2015).

Minimum Groundwater Pumping

District minimum groundwater pumping estimates represent the amount of groundwater pumping that is assumed to occur every year regardless of surface water availability and are applied in WSE as a reduction for each district's overall water demand. Table B-12 shows the annual value for each irrigation district's minimum groundwater pumping currently used in the WSE-CALSIM baseline (on the left) and the WSE-SWRCB baseline (on the right); this table is analogous to Table F.1.2-13 from Appendix F.1 of the 2018 Final SED. For CALSIM mode, CALSIM II estimates of Merced ID and TID minimum pumping decreased (54.0 and 157.5 TAF/y in the 2018 Final SED, respectively), while the values for SSJID, OID, and MID changed only slightly. For SWRCB mode, the values in Table B-12 for SSJID, OID, TID, and Merced ID are the minimums of the annual total pumping values reported from 2010 to 2020 in the district AWMPs; for TID and Merced ID this period spans the data reported from both their 2015 and 2020 AWMPs. Based on the AWMP data, SSJID's and OID's minimum pumping increased a little (35.6 and 18.3 TAF/y in the 2018 Final SED, respectively), Merced ID's minimum pumping increased significantly (37 TAF/y in the 2018 Final SED), and TID's minimum pumping decreased (80.6 TAF/y in the 2018 Final SED). Since MID only reports groundwater use for a single year in its AWMPs, MID's minimum pumping was not changed from the 2018 Final SED value, which was acquired from the district in response to an information request in 2015.

Table B-12. Annual Minimum Groundwater Pumping Estimates for Each Irrigation District.

Irrigation District	CALSIM Mode Annual Total (TAF/y)	Source	SWRCB Mode Annual Total (TAF/y)	Sources
SSJID	51.0 [a]	CALSIM	41.8	SSJID 2020
OID	19.9 [a]	CALSIM	22.1	OID 2020
MID	38.3	CALSIM	12.0	2015 MID Info Request (Salyer pers. comm.)
TID	108.3	CALSIM	63.6	TID 2020
Merced ID	34.0	CALSIM	116.0	Merced ID 2015

[a] SSJID minimum groundwater pumping to CALSIM district node 522 includes minimum groundwater pumping for the portion of OID on the north side of the Stanislaus, and OID CALSIM represents only OID south minimum groundwater pumping to CALSIM district node 530 on the south side of the Stanislaus.

Other Surface Water Demands

As in the 2018 Final SED, the other surface water demands accounted for in WSE include Woodward, Modesto, and Turlock Reservoir losses; SSJID deliveries to the Degroot Water Treatment Plant (WTP); Modesto City M&I demands; and Merced ID Sphere of Influence (SOI) demands. Table B-13 shows the annual value of these demands currently used for the WSE-CALSIM baseline (on the left) and the WSE-SWRCB baseline (on the right); this table is analogous to Table F.1.2-12 from Appendix F.1 of the 2018 Final SED.

For CALSIM mode, the values for Modesto and Turlock Reservoir losses decreased from what they were in the 2018 Final SED (55 and 92 TAF/y, respectively), while Woodward Reservoir losses, Modesto M&I demand, and Merced ID SOI deliveries did not change. In the 2018 Final SED version of WSE, Degroot WTP M&I demand in CALSIM mode was incorrectly modeled using the value from the 2012 SSJID AWMP (15.7 TAF/y) instead of the estimate of SSJID M&I demand from CALSIM II. This has been corrected in the current version and SSJID M&I demand for the WSE-CALSIM baseline is now based on the CALSIM II input timeseries "DEMAND_D523_MI_A."

For SWRCB mode, most of the values only had relatively small changes from the 2018 Final SED. Woodward losses decreased (29.5 TAF/y in the 2018 Final SED), while Modesto losses, Modesto M&I demand, and Degroot WTP M&I demand increased (31.2, 30.0, and 15.7 TAF/y in the 2018 Final SED, respectively). The estimate of Turlock Reservoir losses was not updated from the 2018 Final SED because TID's 2020 AWMP focuses on the distribution system downstream of the reservoir and has no estimate of losses from the reservoir or the upstream canal system. Merced ID SOI demands increased overall to 79.5 TAF/y (68 TAF/y in the 2018 Final SED), with outside water sales rising from 16 to 30.3 TAF/y, with deliveries to the Merced National Wildlife Refuge decreasing from 15 to 6.3 TAF/y, and with the addition of 5.9 TAF/y of demand for other commitments. In WSE, these other commitments are grouped with Merced ID deliveries to Stevinson Water District.

Table B-13. Other Annual Demands for Each Irrigation District.

Parameters	Irrigation District	CALSIM Mode Annual Total (TAF/y)	Source	SWRCB Mode Annual Total (TAF/y)	Sources
Woodward Reservoir Losses [a]	SSJID	62	CALSIM	24.0	SSJID 2020
Modesto Reservoir Losses [b]	MID	31	CALSIM	33.7	MID 2020
Turlock Reservoir Losses	TID	52	CALSIM	46.8	2015 TID Info Request (Hashimoto pers. Comm)
Modesto M&I Demand	MID	65	CALSIM	30.6	MID 2020
Degroot WTP M&I Demand	SSJID	44.0	CALSIM	22.5	SSJID 2022
Merced SOI Demands [c]	Merced ID	81.4	CALSIM	79.5	Merced ID 2015; Merced ID 2020

[a] Woodward Reservoir Losses includes losses from Woodward and losses upstream in the main supply canal from the Stanislaus River. Value represents 2005–2019 average and is estimated from Table 5-1 of the SSJID 2020 AWMP. Estimate includes Reservoir Seepage (16,476 AF) + Reservoir Evap (8,500 AF) + Main Supply Canal Seepage (458 AF) + Main Supply Canal Evap (76 AF) + U3 Ranch Deliveries (3,514 AF) - Reservoir Precip (1,389 AF) - Main Supply Canal Precip (18 AF) - Tributary Inflow (3,628 AF).

[b] Modesto Reservoir Losses are estimated from Table 47 of the MID 2020 AWMP. Estimate includes Seepage – Reservoirs (24,500 AF) + Evaporation – Reservoirs & Recharge Basins (9,200 AF).

[c] Merced SOI demands include Merced National Wildlife Refuge (15 TAF/y CALSIM, 6.3 TAF/y SWRCB), Stevinson (26.4 TAF/y CALSIM, 24 TAF/y SWRCB), El Nido (40 TAF/y CALSIM, 13 TAF/y SWRCB), Other Commitments (0 TAF/y CALSIM, 5.9 TAF/y SWRCB), and other SOI demand (0 TAF/y CALSIM, 30.3 TAF/y SWRCB).

Stanislaus CVP Contractor Allocations

WSE's allocation scheme for Stanislaus CVP contractors, Stockton East Water District (SEWD) and Central San Joaquin Water Conservation District (CSJWCD), was modified to include the option to determine allocations using SJR 60-20-20 WYT. Table B-14 presents the new allocation scheme for the CVP contractors, which is based on information from Reclamation's 2021 version of CALSIM II.[13] In previous versions of CALSIM II, the Stanislaus CVP contractor received water based on the New Melones Index (NMI), which is an estimate of the available water on the Stanislaus for the growing season (see Table F.1.2-1 of Appendix F.1 from the 2018 Final SED). However, with the implementation of the 2019 BiOp, in the more recent versions of CALSIM II the allocations shifted away from relying on NMI in favor of the SJR 60-20-20 WYT. A switch has been included in the latest version of WSE that controls the Stanislaus CVP allocation scheme and it can be set to the following options:

1. Allocations determined by WSE's estimate of water availability (see Section F.1.2.5 of Appendix F.1 from the 2018 Final SED),
2. Allocations determined by NMI and Table F.1.2-1 of Appendix F.1 from the 2018 Final SED,
3. Allocations determined by SJR 60-20-20 WYT and Table B-14 below,
4. Allocations determined by taking the minimum of option 1 and 2 (how it was done in the 2018 Final SED),
5. Allocations determined by taking the minimum of option 1 and 3 (current default).

In addition, another constraint was added to WSE's representation of the Stanislaus CVP contractor deliveries. Whenever New Melones storage falls below 300 TAF, CVP deliveries to SEWD and CSJWCD are reduced to 0 until the storage rises above that threshold. This constraint is also based on information from the Reclamation 2021 version of CALSIM II and is intended to protect hydropower operations in the event of low storage levels.

Table B-14. Stanislaus CVP Contractor (SEWD/CSJWCD) Allocation Scheme Using SJR 60-20-20 WYT from CALSIM II (in TAF).

SJR 60-20-20 WYT	SEWD	CSJWCD	Total
Critically Dry	0	0	0
Dry	0	49	49
Below Normal	75	80	155
Above Normal	75	80	155
Wet	75	80	155

The monthly demand pattern for the CVP contractors, used in WSE to distribute their annual allocation by month over the irrigation year, was also updated slightly based on results of the SWRCB CALSIM II 2023 model run. The demand pattern used in the 2018 Final SED is shown in Table F.1.2-19 of Appendix F.1 from the 2018 Final SED and its replacement is shown in Table B-15 below. The new pattern is based on the monthly average diversion shown in the CALSIM result timeseries for diversion link D520A (Stanislaus Contractor diversion).

[13] Stanislaus contractor allocations are defined in the CALSIM file *Stanislaus_dems.wresl*

Table B-15. CVP Contractor (SEWD/CSJWCD) Monthly Diversion Schedule.

Calendar Month	Monthly Demand Pattern (% of Annual)	Modeled Demand (TAF)
January	3%	4
February	2%	3
March	3%	4
April	5%	8
May	12%	18
June	18%	28
July	21%	32
August	16%	24
September	9%	13
October	5%	8
November	4%	6
December	3%	5
Total	**100%**	**155**

Riparian and Cowell Agreement Diversion Demands

The Cowell Agreement is an adjudicated settlement from 1926 establishing that Merced ID must release minimum flows at Crocker Huffman for diversion by senior riparian diverters (Merced ID 2013). In the 2018 Final SED, for the WSE-CEQA baseline it was assumed that the full volume of the Cowell minimum flow releases would be diverted upstream of Shaffer Bridge. However, based on analysis of reported use by water rights that indicate they are part of the Cowell Agreement, this may be an overestimate of their diversion. To update the estimate in WSE, annual diversion reports from 2017 to 2022 for Cowell Agreement water rights were reviewed and totaled to estimate annual Cowell Agreement diversions, as shown in Table B-16. The annual diversions ranged from 49.6 TAF in 2018 to 65.7 TAF in 2021, with an average annual diversion of 58.7 TAF/y. For use in WSE, the 58.7 TAF/y estimate was distributed monthly based on the pattern of Cowell Agreement flow releases, as shown in Table B-17. It is assumed that the undiverted portion of the Cowell Agreement releases can contribute to meeting downstream flow requirements or be diverted for other downstream riparian demands on the Merced River.

Table B-16. Annual Reported Diversion from 2017 to 2022 by Cowell Agreement Water Rights (in AF).

Water Right ID	2017	2018	2019	2020	2021	2022
S017517	4,740	4,260	4,260	4,260	4,254	3,863
S017523	33	242	383	424	562	541
S018779	21,751	15,979	20,245	20,247	20,767	18,450
S002055 [a]	0	0	0	0	0	0
S017509	6,360	6,180	6,360	6,360	6,360	6,360
S018929 [b]	0	0	0	0	0	0
S020055	18,265	15,952	14,870	12,544	20,525	22,158
S020517	0	0	0	0	0	0
S021809	2,416	2,267	2,325	2,260	2,182	2,200

Water Right ID	2017	2018	2019	2020	2021	2022
S020054	4,290	4,513	6,060	10,240	10,362	10,486
S023348 [c]	0	0	0	0	0	0
S021177 [d]	2,989	0	0	0	0	0
S020053	0	0	0	0	0	0
S020244	447	195	404	381	357	372
S021166	13	0	0	1	1	0
Total	**61,303**	**49,588**	**54,906**	**56,716**	**65,371**	**64,431**

Source: Diversion volumes were extracted from annual reports submitted for each water right to the State Water Board. These reports are available to the public through the Electronic Water Rights Information Management System (eWRIMS) (SWRCB 2024).

[a] Annual reports from 2017, 2018, and 2019 for S002055indicate that the claimant has replaced riparian water with groundwater. These reports include an amount directly diverted, but nothing beneficially used. In addition, no reports were available for 2020, 2021, and 2022.

[b] No annual reports have been submitted for Water Right S018929.

[c] Annual reporting for S023348 indicates that water usage is reported under water right S020054.

[d] Annual reporting for S021177 from 2018 through 2022 indicates that the claimant's water usage is reported under water right S020054. However, the 2017 report does not indicate that water usage was reported under S020054 and monthly totals are at times higher than the monthly value shown in S020054. For this analysis, it is assumed that water diverted under S021177 is included with S020054 for years 2018 through 2022 and separate for 2017.

Table B-17. Monthly Cowell Agreement Diversion on the Merced River Between Crocker Huffman Dam and Shaffer Bridge.

Calendar Month	Required Cowell Agreement Release (cfs)	Required Cowell Agreement Release (TAF)	Cowell Agreement Diversion for WSE-SWRCB Baseline (TAF)
January	50	3.1	1.9
February	50	2.8	1.7
March	100	6.1	3.8
April	175	10.4	6.5
May	225	13.8	8.7
June	250	14.9	9.3
July	225	13.8	8.7
August	175	10.8	6.7
September	150	8.9	5.6
October	50	3.1	1.9
November	50	3.0	1.9
December	50	3.1	1.9
Annual	NA	93.8	58.7

As in the 2018 Final SED, downstream riparian demands on the tributaries are still based on the resulting CALSIM II diversion timeseries D528 on the Stanislaus, D545 on the Tuolumne, and D566 on the Merced. However, the steps for allocating water to these demands have changed. In the 2018 Final SED, it was assumed that the rim reservoirs would release enough water to fully meet the riparian demands, but in the latest version of WSE, the steps for calculating the diversions have been updated as follows:

1. If inflows are available that enter the river below the rim dams, either from accretions or a local tributary inflow, the riparian diverters may take that flow, unless there is a downstream flow requirement, in which case they must bypass enough to satisfy the requirement,
2. On the Merced only, if Cowell Agreement diversions are less than the full release for the Cowell Agreement, the downstream riparians may divert the abandoned portion,
3. If instream flows are not protected, then downstream riparians may divert up to the amount released at the diversion reservoir to satisfy the upstream requirement,
4. Otherwise, any remaining riparian demand must be satisfied by bypassing inflow to the rim reservoir; if inflow to the rim reservoir is less than the remaining demand, then there will be a shortage.

B.2.2.4 Other Updates

Some other minor updates and corrections from the 2018 Final SED version of WSE include:

- The Cowell Agreement implementation was updated during October through February so that the required release at Crocker Huffman would be the minimum between 50 cfs and the inflow to Lake McClure; in the 2018 Final SED these requirements were set to 50 cfs (FERC 2015).
- The required release at Crocker Huffman to satisfy the fall pulse flow requirement in October was corrected to 12.5 TAF (FERC 2015; MID 2020); this requirement was previously set slightly too high at about 14.1 TAF in the 2018 Final SED.
- On the Tuolumne, a minor reference error was corrected related to the New Don Pedro evaporation rates used in WSE. In the 2018 version of WSE, the monthly evaporation rate from CALSIM II was applied one month later than it should have been (i.e., October 1921 evaporation rate was applied to determine November 1921 evaporation).
- A minor error was corrected in application of the Stanislaus CVP contractor allocation scheme from CALSIM II based on NMI. In the 2018 Final SED, for NMI between 0 and 1400, SEWD's allocation was set to 15.5 TAF (10% of 155 TAF) instead of 10 TAF as it should have been.
- A minor error was corrected in the calculation of CUAW demand for OID south, which incorrectly included non-district CUAW demands from CALSIM II.
- SJRRP rediversion points on the SJR for PID, WSID, and BCID were added to WSE's representation of the LSJR using the resulting diversion timeseries from the SWRCB CALSIM II 2023 model run (D620D, D630C, D639A, and D639B).
- On all the tributaries, district diversion of local inflows (tributary inflows that do not occur above the rim dams) was changed so that the local inflows can only be diverted if there is more than enough local inflow to fully satisfy the non-Cowell riparian demands downstream and meet downstream flow targets.
- The maximum annual district diversion for TID/MID on the Tuolumne was reduced from 1100 TAF/y to 1000 TAF/y based on the results of the SWRCB CALSIM II 2023 model run.
- The maximum annual district diversion for Merced ID on the Merced was increased from 525 TAF/y to 600 TAF/y based on Merced ID's reported annual diversion for year 2011 in the 2015 AWMP (Merced ID 2015).

- The method for distributing the maximum annual district diversion by month over the irrigation year for the Tuolumne and Merced Rivers was changed to be consistent with how it was done for the Stanislaus River. In the 2018 Final SED version of WSE, the annual maximum district diversion for the Tuolumne and Merced Rivers was distributed monthly using a repeating yearly pattern of typical monthly diversion fractions from CALSIM II. In WSE-SWRCB, the annual maximum district diversions are distributed monthly based on the actual monthly demands in WSE. (see Section F.1.2.6 of Appendix F.1 from the 2018 Final SED)

B.2.2.5 WSE Baseline Calibration

Once the above updates were made to WSE, a similar process was performed as in the 2018 Final SED to calibrate and finalize the baseline model runs. For the WSE-CALSIM baseline, the storage and diversion results on each tributary were compared directly with CALSIM II results for the same values to determine how well WSE's representation of reservoir operations and diversion demands matched with CALSIM II. This comparison showed that for Lake McClure and New Melones the reservoir operations parameters (end-of-September storage guidelines, maximum draw from storage parameters, and minimum allocations; see Section F.1.2.5 of Appendix F.1) set in the 2018 Final SED still yielded a good match with CALSIM II (see Figure B-4, Figure B-7, and Figure B-11 below for Stanislaus River calibration comparison with CALSIM II; see Figure B-6, Figure B-9, and Figure B-13 below for Merced River calibration comparison with CALSIM II). For New Don Pedro, storage levels were underestimated during dry periods using the 2018 Final SED operations parameters. To adjust this, the "Maximum Draw from Storage" value for New Don Pedro was reduced from 65% to 50%. The New Don Pedro end-of-September storage guideline was unchanged from the 2018 Final SED value. Table B-18 summarizes the reservoir operations parameters for each tributaries rim reservoir. As in the 2018 Final SED, adjustment factors were then applied to district CUAW demands on each tributary to scale total district surface water demands to the levels seen in CALSM II; these factors are shown in Table B-19. After setting the CUAW adjustment factors, the storage comparisons were revisited, but the match was still good and no further changes were necessary (see Figure B-5, Figure B-8, and Figure B-12 below for Tuolumne River final calibration comparison with CALSIM II).

For the WSE-SWRCB baseline, the reservoir operations parameters determined from the calibration with CALSIM II were still applied. However, the tributary diversion demands were instead calibrated to the level of demand seen in the results of the tributary operations models, as was done in the 2018 Final SED. The final CUAW adjustment factors from this calibration are also shown in Table B-19.

Table B-18. Baseline End-of-September Storage Guidelines, Maximum Draw from Storage, and Minimum Diversion Variables for the Eastside Tributaries.

Variable	Stanislaus River	Tuolumne River	Merced River
End-of-September Storage Guideline (TAF)	85	800	115
Maximum Draw from Storage (% of available storage)	80%	50%	80%
Minimum District Diversion (% of Max Demand)	0%	50%	0%

Table B-19. Adjustment Factors Applied to CUAW Demands.

CUAW Multiplier	SSJID	OID	MID	TID	Merced ID
WSE-CALSIM Mode Adjustment Factor [a]	1.09	1.09	1.02	1.02	0.82
WSE-SWRCB Mode Adjustment Factor [b]	1.20	1.20	0.97	0.97	1.09

[a] Adjustment factors were developed during corroboration with the SWRCB CALSIM II 2023 baseline as a final step to better match diversion demands between CALSIM II and WSE.

[b] Adjustment factors were developed to match WSE annual diversions under WSE-SWRCB baseline conditions to the annual diversions as seen in the baseline runs for the tributary operations models.

WSE-CALSIM Baseline Comparison to SWRCB CALSIM II 2023

Figure B-4 through Figure B-13 present some of the results used in the calibration comparison of the WSE-CALSIM baseline with the SWRCB CALSIM II 2023 model. Figure B-4 through Figure B-6 show the monthly timeseries from Oct 1985 to Sep 2003 of (a) flow near the confluence and (b) rim reservoir storage for the Stanislaus, Tuolumne, and Merced Rivers, respectively. Figure B-7 through Figure B-9 compare the exceedance distributions of (a) annual Feb–Jun flow near the confluence, (b) carryover storage in the rim reservoirs, (c) annual surface water diversions, and (d) annual Feb–Jun flow near the confluence as a % of Feb–Jun UF for each of the tributaries. Figure B-10 presents exceedance distributions comparing (a) annual district diversions over all three tributaries, (b) annual Feb–Jun flow at Vernalis, and (c) annual Feb–Jun flow at Vernalis as a % of Feb–Jun UF. Finally, Figure B-11 through Figure B-13 show the annual timeseries from 1922 to 2003 for (a) total diversion, (b) Feb–Jun flow near the confluence, and (c) carryover storage on each tributary. As these comparisons show, there is a close match between the CALSIM II and WSE results for flow, storage, and diversion on all three tributaries.

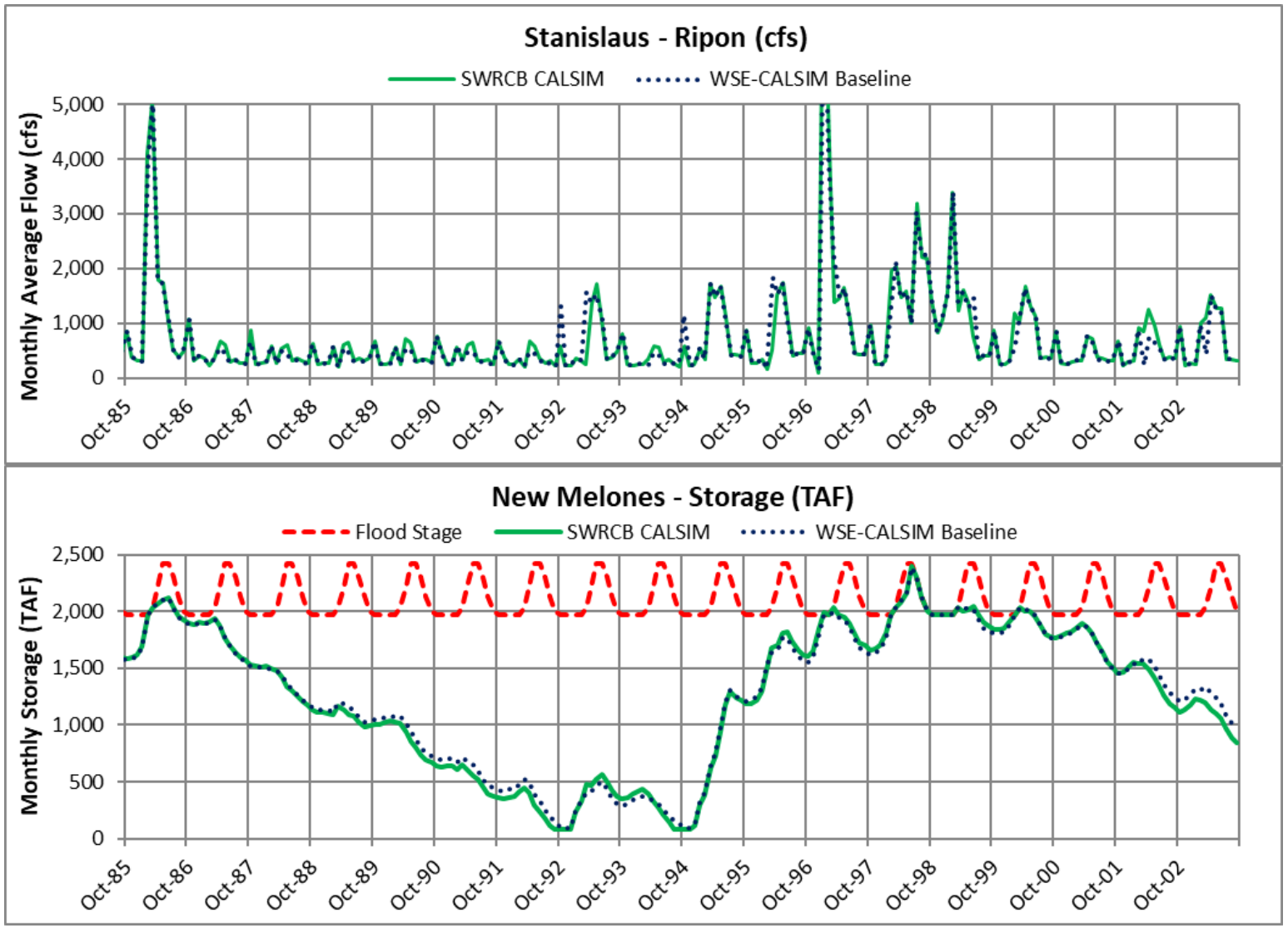


Figure B-4. Monthly Timeseries of WSE-CALSIM Baseline Results Compared with SWRCB CALSIM II 2023 Results on the Stanislaus River from Oct 1985 to Sep 2003 for (a) Flow at Ripon and (b) Storage in New Melones.

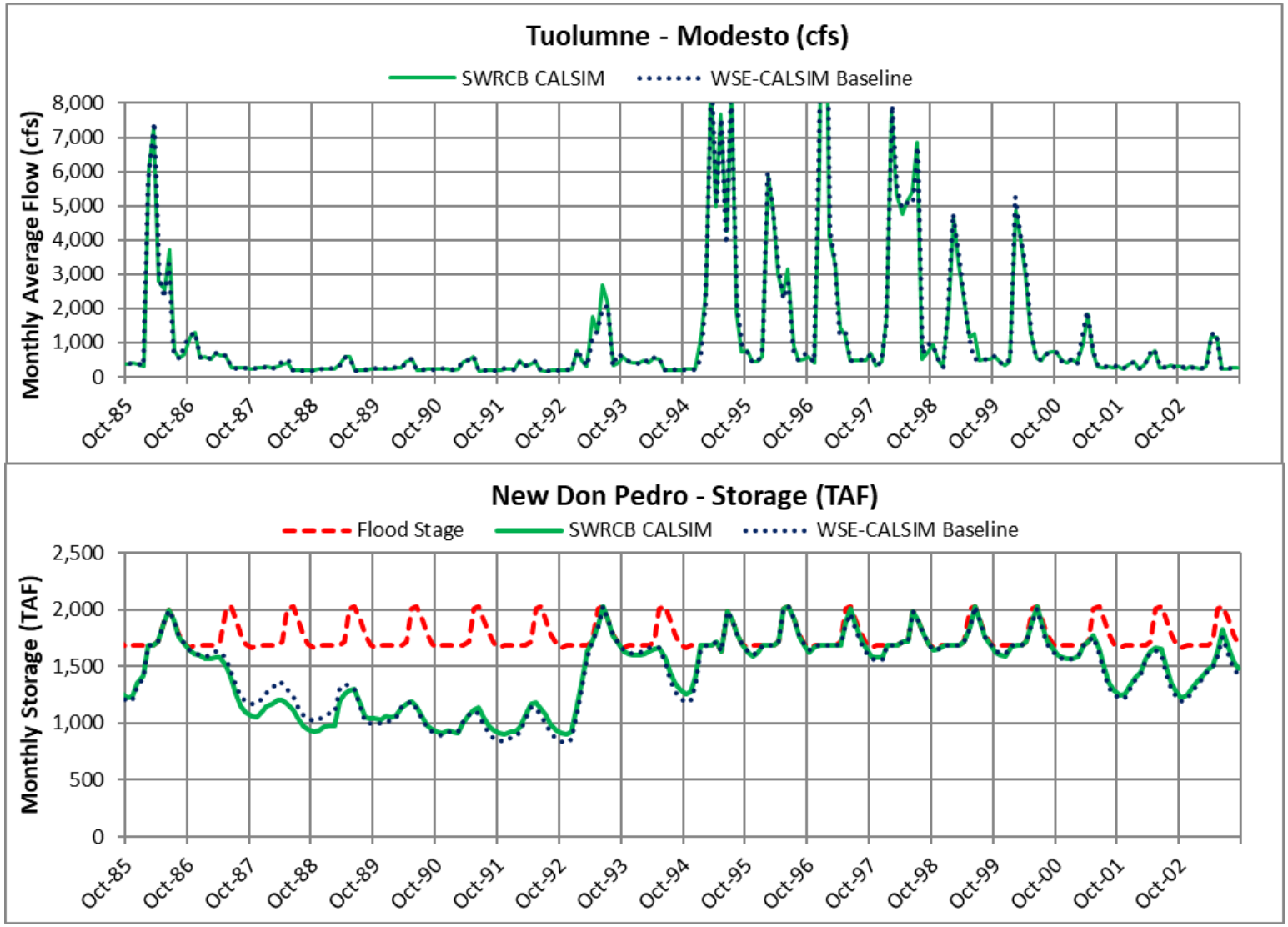


Figure B-5. Monthly Timeseries of WSE-CALSIM Baseline Results Compared with SWRCB CALSIM II 2023 Results on the Tuolumne River from Oct 1985 to Sep 2003 for (a) Flow at Modesto and (b) Storage in New Don Pedro.

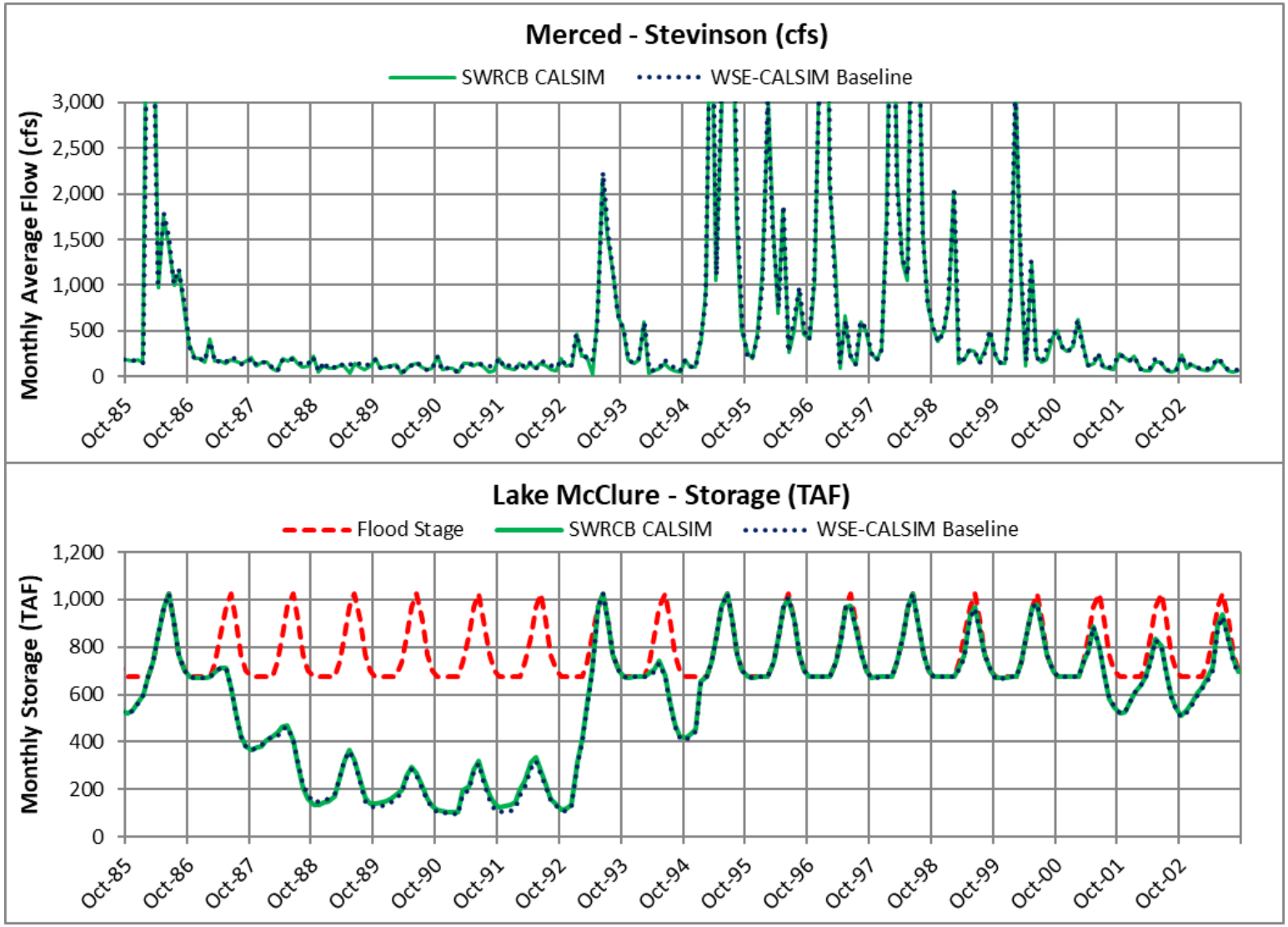


Figure B-6. Monthly Timeseries of WSE-CALSIM Baseline Results Compared with SWRCB CALSIM II 2023 Results on the Merced River from Oct 1985 to Sep 2003 for (a) Flow at Stevinson and (b) Storage in Lake McClure.

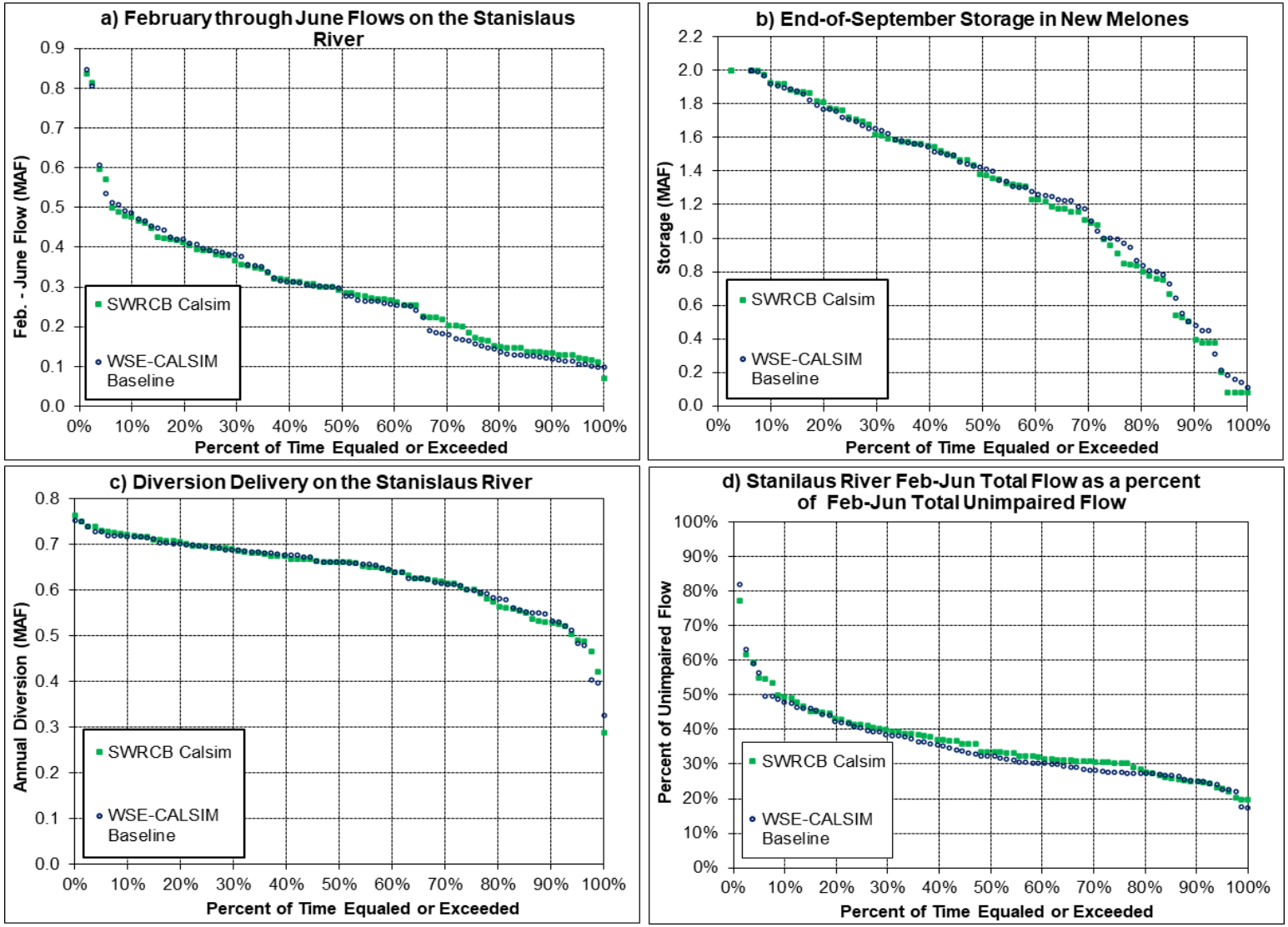


Figure B-7. Exceedance Charts of WSE-CALSIM Baseline Results Compared with SWRCB CALSIM II 2023 Results on the Stanislaus River for (a) Annual Feb–Jun Flow at Ripon, (b) End-of-September Storage, (c) Annual Diversion Delivery, (d) Annual Feb–Jun Flow at Ripon as a % of UF.

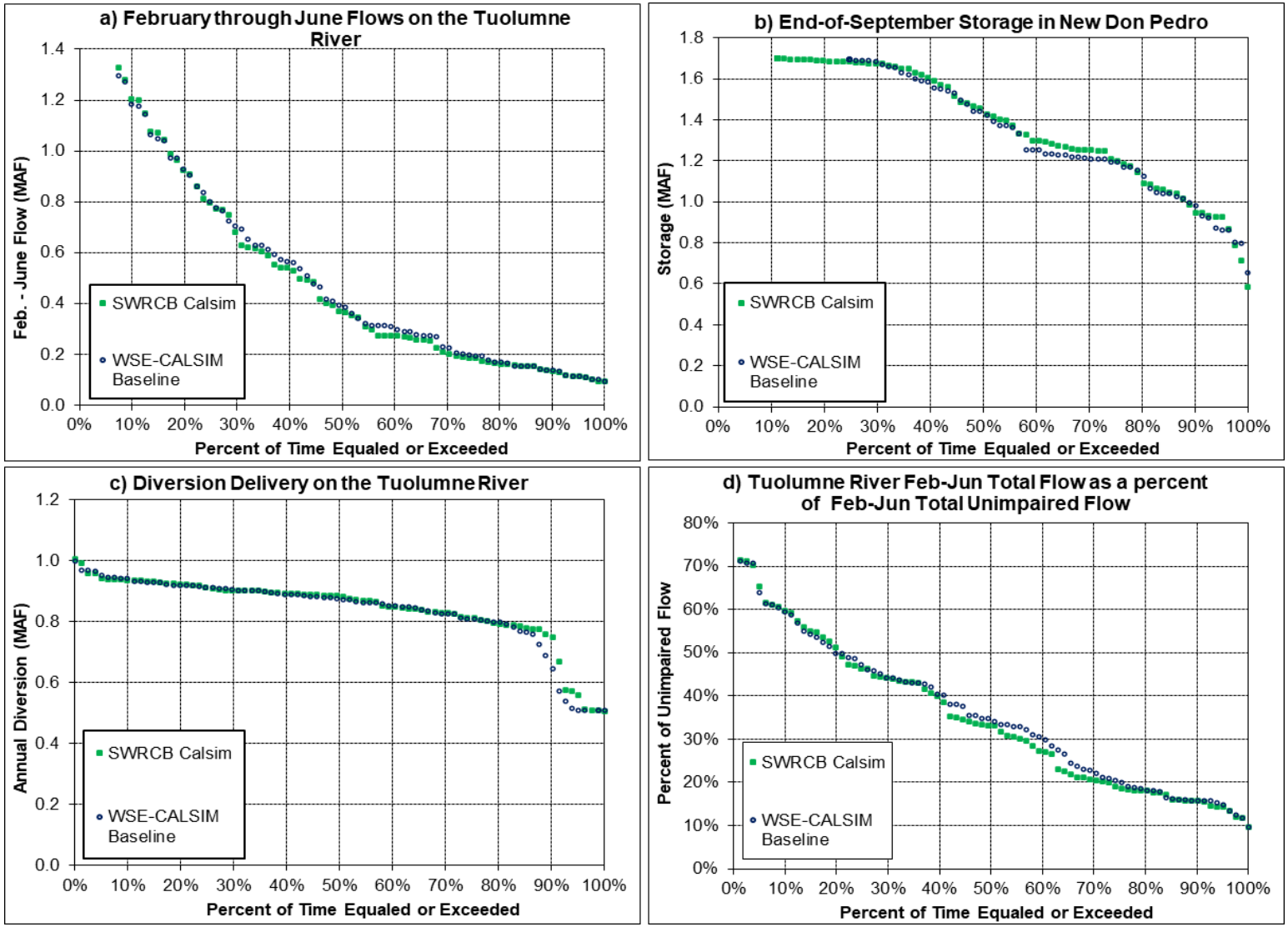


Figure B-8. Exceedance Charts of WSE-CALSIM Baseline Results Compared with SWRCB CALSIM II 2023 Results on the Tuolumne River for (a) Annual Feb–Jun Flow at Modesto, (b) End-of-September Storage, (c) Annual Diversion Delivery, (d) Annual Feb–Jun Flow at Modesto as a % of UF.

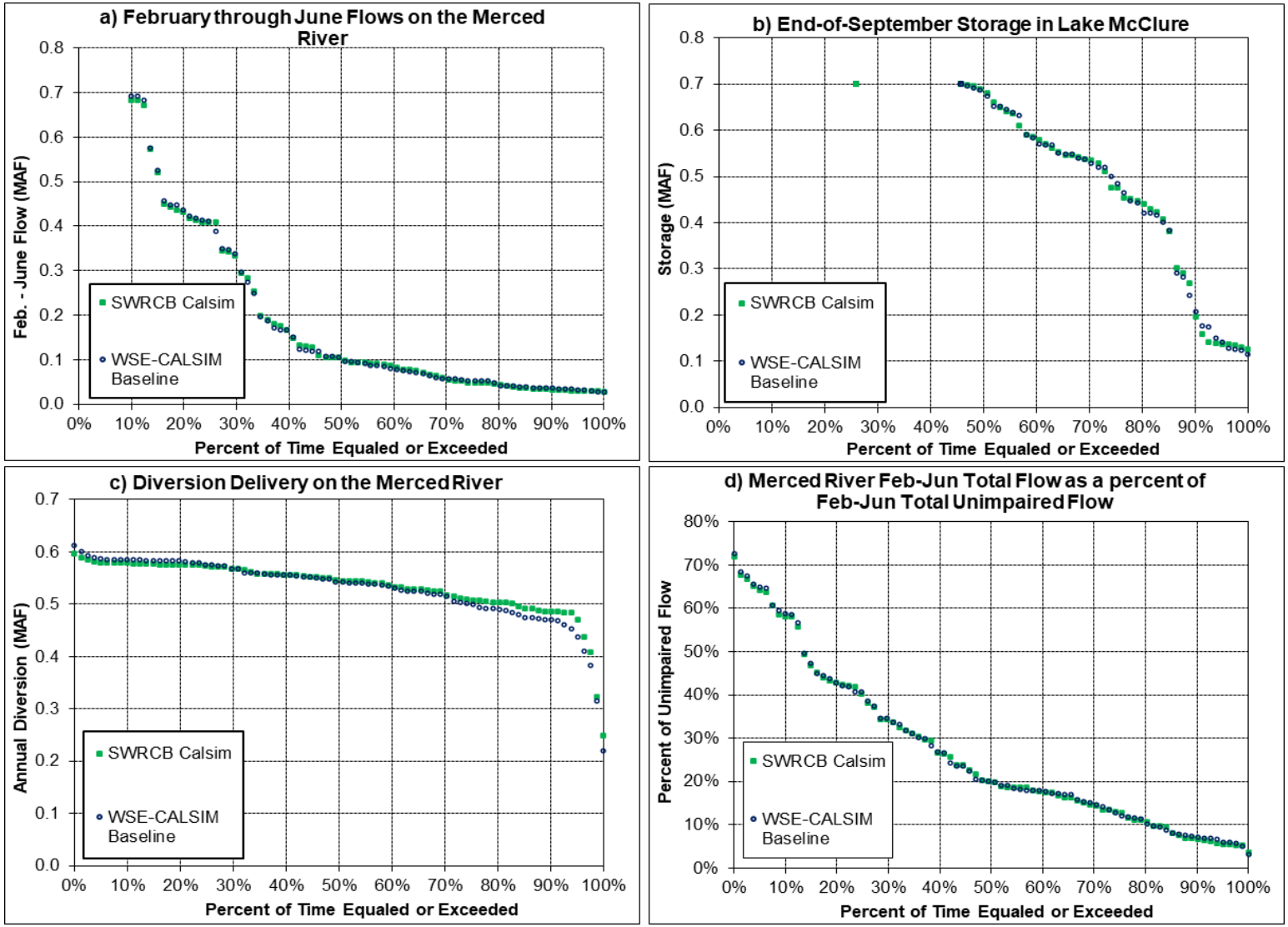
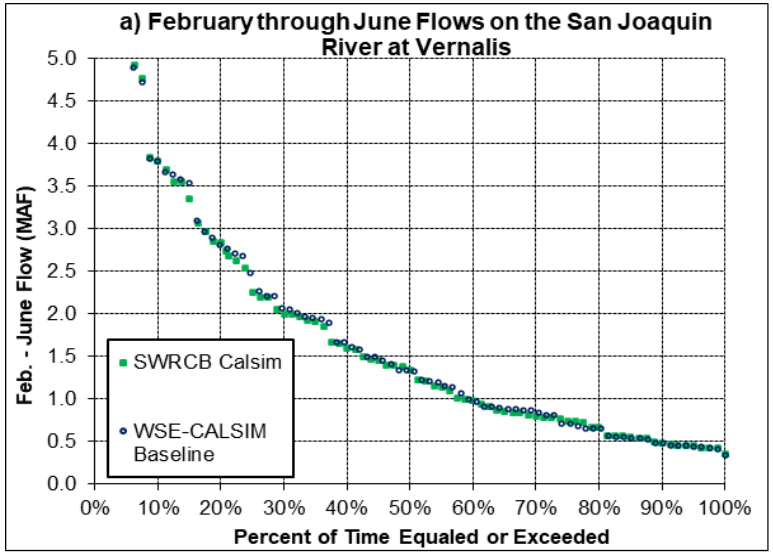
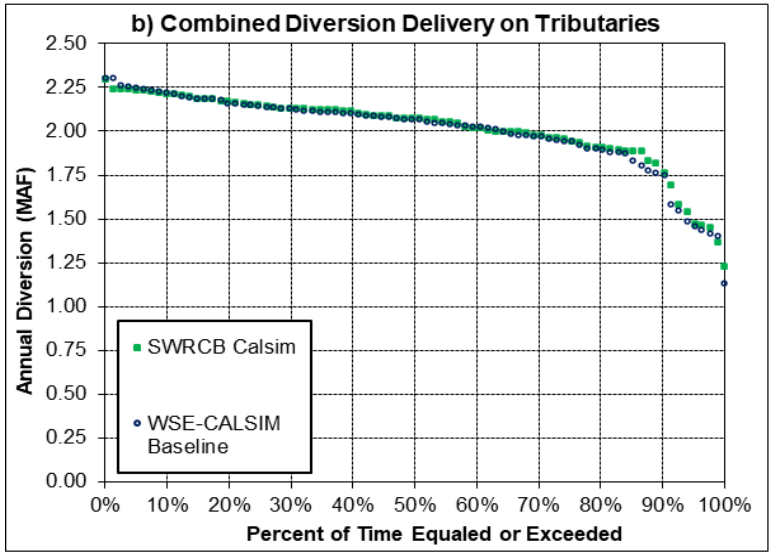


Figure B-9. Exceedance Charts of WSE-CALSIM Baseline Results Compared with SWRCB CALSIM II 2023 Results on the Merced River for (a) Annual Feb–Jun Flow at Stevinson, (b) End-of-September Storage, (c) Annual Diversion Delivery, (d) Annual Feb–Jun Flow at Stevinson as a % of UF.





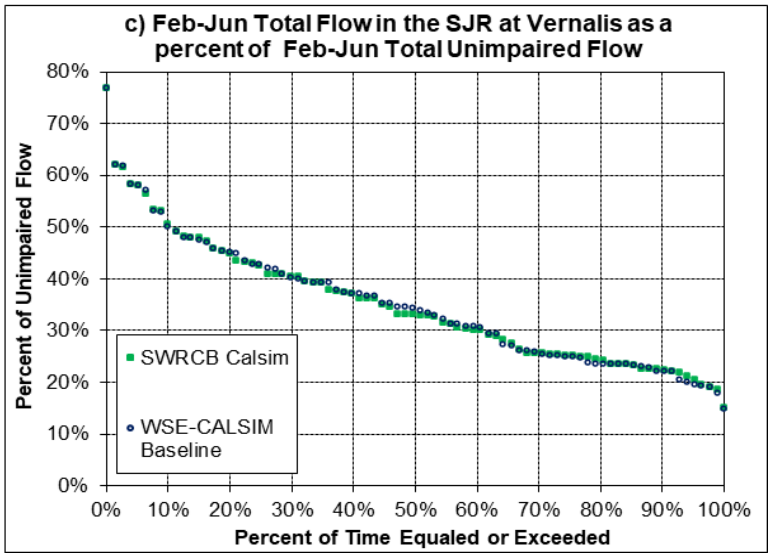


Figure B-10. Exceedance Charts of WSE-CALSIM Baseline Results Compared with SWRCB CALSIM II 2023 Results for (a) Annual Feb–Jun Flow at Vernalis, (b) Annual Diversion Delivery from All Three Major Tributaries, (c) Annual Feb–Jun Flow at Vernalis as a % of UF.

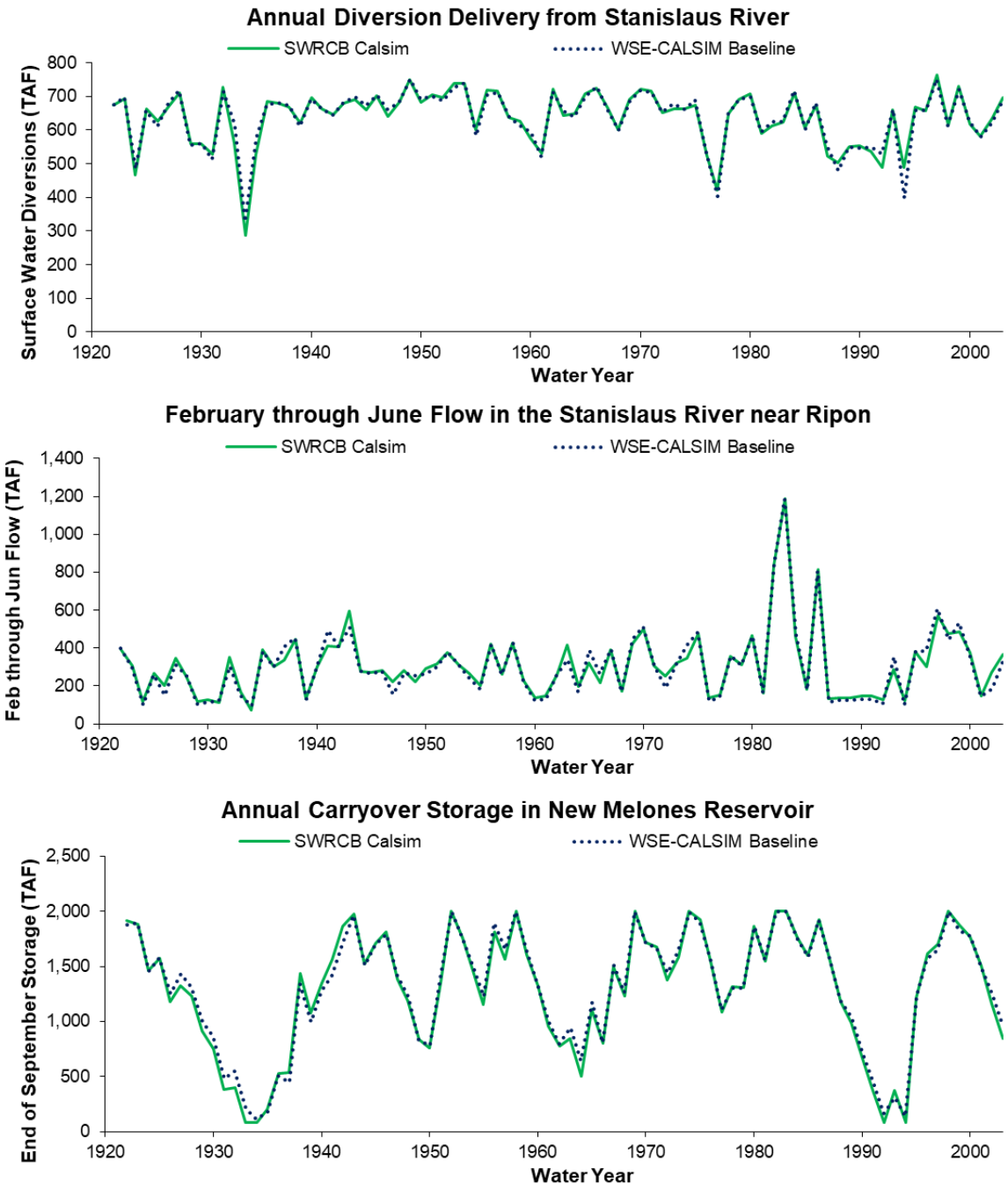


Figure B-11. Annual Timeseries of WSE-CALSIM Baseline Results Compared with SWRCB CALSIM II 2023 Results on the Stanislaus River from 1922 to 2003 for (a) Diversion Delivery and (b) Total Feb–Jun Flow near Ripon, and (c) End-of-September Storage in New Melones.



Figure B-12. Annual Timeseries of WSE-CALSIM Baseline Results Compared with SWRCB CALSIM II 2023 Results on the Tuolumne River from 1922 to 2003 for (a) Diversion Delivery and (b) Total Feb–Jun Flow near Modesto, and (c) End-of-September Storage in New Don Pedro.

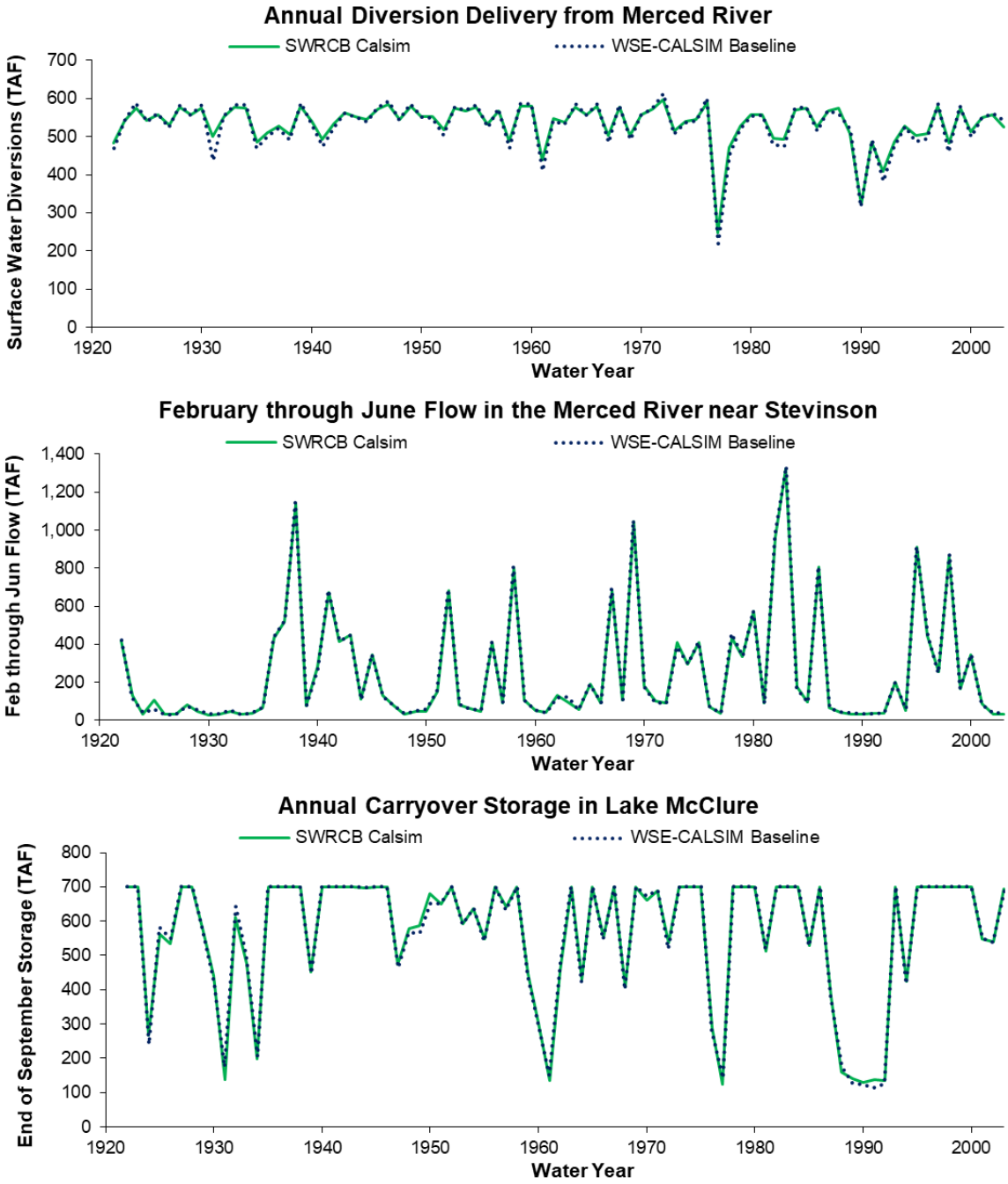


Figure B-13. Annual Timeseries of WSE-CALSIM Baseline Results Compared with SWRCB CALSIM II 2023 Results on the Merced River from 1922 to 2003 for (a) Diversion Delivery and (b) Total Feb–Jun Flow near Stevinson, and (c) End-of-September Storage in Lake McClure.

B.2.3 Pre-Defined Alternatives modeled in WSE

The current version of WSE comes with a set of pre-defined alternatives that can be selected from the model control tabs. These include all the % UF alternatives modeled in the 2018 Final SED version of WSE, as well as several new options for the Tuolumne River. The sections below describe the assumptions made to model the pre-defined alternatives; other assumptions not described are assumed to be the same as in the WSE-SWRCB baseline.

B.2.3.1 Unimpaired Flow Alternatives

As in the 2018 Final SED, WSE includes pre-defined UF alternatives, ranging from 20% to 60% UF in increments of 5%, where the instream flow from February to June at the confluence of the Merced, Tuolumne, and Stanislaus Rivers must equal the % UF. However, for this report only the results of the 30%, 40%, and 50% UF alternatives are presented for scenario comparisons because 30% to 50% UF represents the potential range of UF requirements adopted in the 2018 Bay-Delta Plan. Most of the baseline modifications described above also apply to the UF alternatives, including, but not limited to, the updated CALSIM II input data, AWMP demand parameters, Stanislaus CVP contractor allocations, and Riparian/Cowell diversions. In addition, for these alternatives the updated baseline flow requirements function as backstops for the UF requirements in the February through June period and generally govern instream flows for the rest of the year (unless flow shifting is applied; See Section F.1.2.7 of Appendix F.1 of the 2018 Final SED). On the Tuolumne, forecasting is still applied as it was in the WSE-SWRCB baseline when calculating the required flow under the 1995 FERC license in the UF alternatives.

Relative to the 2018 Final SED version of WSE, there were slight adjustments to some of the reservoir operations parameters for the Merced and Tuolumne Rivers under the UF alternatives. On the Merced, because the maximum diversion increased from 525 to 600 TAF/y, the minimum allocation in the UF alternatives increased from 79 to 90 TAF/y (the % minimum allocation stayed the same at 15% of the maximum diversion for all UF alternatives). On the Tuolumne, the maximum draw from storage for the 20% and 30% UF alternatives was reduced from 60% and 55%, respectively, to 50% so that they would not exceed the value set in the WSE-CALSIM baseline calibration. In addition, since the Tuolumne River maximum diversion decreased from 1100 to 1000 TAF/y, the minimum allocation in the UF alternatives decreased from 363 to 333 for the 20%, 30%, and 40% UF alternatives and from 220 TAF to 200 TAF/y for the 50% and 60% UF alternatives (the % minimum allocation stayed the same). See Table B-20 for a summary of the reservoir operations parameters for all three tributaries under the UF alternatives.

Table B-20. Assumptions under the Pre-Defined UF Alternatives Compared to Baseline.

Parameter	Baseline	20% & 25% UF	30% & 35% UF	40% & 45% UF	50% & 55% UF	60% UF
Stanislaus Minimum District Diversion (% of Max Diversion ~ 600 TAF)	0%	35% (210 TAF)	35% (210 TAF)	35% (210 TAF)	30% (180 TAF)	30% (180 TAF)
NML End-of-September Storage Guideline (TAF)	85	700	700	700	700	700
NML Max Draw from Storage [a]	80%	80%	70%	50%	45%	35%
Stanislaus Flow Shifting [b]	NA	None	None	Yes	Yes	Yes

Parameter	Baseline	20% & 25% UF	30% & 35% UF	40% & 45% UF	50% & 55% UF	60% UF
NML End-of-Drought Storage Refill Parameter [c]	NA	100%	100%	70%	50%	50%
Tuolumne Minimum District Diversion (% of Max Diversion ~ 1,000 TAF)	50% (500 TAF)	33% (333 TAF)	33% (333 TAF)	33% (333 TAF)	20% (200 TAF)	20% (200 TAF)
NDP End-of-September Storage Guideline (TAF)	800	800	800	800	800	800
NDP Max Draw from Storage [a]	50%	50%	50%	50%	45%	35%
Tuolumne Flow Shifting [b]	NA	None	None	Yes	Yes	Yes
NDP End-of-Drought Storage Refill Parameter [c]	NA	100%	100%	70%	50%	50%
Merced Minimum District Diversion (% of Max Diversion ~ 600 TAF)	0%	15% (90 TAF)	15% (90 TAF)	15% (90 TAF)	15% (90 TAF)	15% (90 TAF)
NEX End-of-September Storage Guideline (TAF)	115	300	300	300	300	300
NEX Max Draw from Storage [a]	80%	70%	60%	50%	45%	35%
Merced Flow Shifting [b]	NA	None	None	Yes	Yes	Yes
NEX End-of-Drought Storage Refill Parameter [c]	NA	100%	100%	100%	50%	50%
Vernalis Minimum Flow Feb–Jun (cfs) [d, e]	D-1641	1,000	1,000	1,000	1,000	1,000

NML = New Melones; NDP = New Don Pedro; NEX = New Exchequer.

[a] The "Max Draw from Storage" represents the maximum % of the March 1 storage minus the End-of-September Storage Guideline that can be released over the growing season (March–September).

[b] The target flow rates used for flow shifting are the same as in the 2018 Final SED.

[c] The "End-of-Drought Storage Refill Parameter" represents an additional cut to diversion (applied as 1 minus the parameter) to allow reservoir storage to refill when the preceding October storage was low (less than the End-of-September Storage Guideline plus 10%) and the growing season inflow is projected to be higher than average.

[d] For UF alternatives, the Stanislaus, Tuolumne, and Merced must provide 29%, 47%, and 24%, respectively, of additional releases necessary to meet the 1,000 cfs Vernalis requirement. Percentages are based on the average fraction of UF that each tributary contributes to the basin relative to the total UF from all three tributaries.

[e] Compared to the 2018 Final SED version of WSE, VAMP requirements are not included in the baseline for the current version of WSE.

B.2.3.2 2020 FERC FEIS Flow Requirements

On July 7, 2020, the Final Environmental Impact Statement (FEIS) for the FERC relicensing of the New Don Pedro and La Grange hydroelectric projects (2020 FERC FEIS) was released. Though the process to complete the FERC relicensing for New Don Pedro is still ongoing, an alternative was added to WSE, the "Tuol*2020FERC*" alternative, to simulate the FERC staff recommended flow requirements. The requirements added to WSE are described in Appendix B of the 2020 FERC FEIS including the baseflow and pulse flow recommendations in articles 409 and 410, respectively (FERC 2020). In WSE, this alternative can only be selected for the Tuolumne River and does not change any of the assumptions for the other tributaries.

Table B-21 below presents the monthly baseflow requirements from the 2020 FERC FEIS, which are required at La Grange Diversion Dam and determined based on SJR 60-20-20 WYT. For the 2020 FERC requirements in WSE, WYT can be represented either with perfect foresight using the historical record of actual WYTs or with monthly forecasted WYT determinations based on the CAM model data (see Table B-6 and Table B-7 in Section B.2.2.2). If using forecasting, the preliminary WYT for the flow requirements will be determined starting in February using a 90% exceedance forecasted WYT, with updates in March and April also based on the monthly 90% exceedance forecasts. The final WYT is determined in May based on the 75% exceedance forecasted WYT and governs flows from May through January of the following calendar year. If using perfect foresight, WSE applies each year's WYT starting in February through the following January when calculating the baseflows. Since the baseflow requirements for April, May, and October are defined on a half-month basis and the WSE model uses a monthly timestep, average monthly flow targets are produced based on the number of days in each period of Table B-21. Over a month, the average cfs targets will result in the same total volume released as the original half-month flow requirements.

As described in the 2020 FERC FEIS, during the period from June through October 15, TID and MID plan to operate two in-river infiltration galleries (IGs) at approximately River Mile (RM) 25.9. The IGs will allow TID and MID to move a portion of their summer diversions from La Grange dam (RM 53.5) downstream. The additional release for the downstream diversion would then be incorporated into the upstream baseflow requirement at La Grange, providing more water between RM 53.5 and 25.9 to benefit cold-water fisheries during the summer, while at the same time maintaining TID and MID's water supplies. Until the IGs are fully operational, the FEIS includes interim baseflow requirements to be used in the period between final FERC licensing and implementation of the IGs, which are shown in parentheses in Table B-21.

Though the 2020 FERC FEIS does not directly provide the monthly IG diversion values, it does include the expected monthly instream flows just below the IGs, which are shown in Table B-22 for the months when the IGs would be in operation. These flows do not indicate a flow requirement at the IG locations and assume that there are no other diversions or losses (e.g., seepage to groundwater or evaporation) between the La Grange release and the IG diversions. Although the flows past the IGs are not required, they can be used to estimate the monthly IG diversion assumed in the FEIS by subtracting Table B-22 from Table B-21 for June through October, which is shown in Table B-23. For the *Tuol2020FERC* alternative in WSE, it is assumed that the IGs are active and the non-interim baseflows are applied.[14] If the IGs are applied, then Table B-23 is used to represent the downstream diversion. It is assumed that the IG diversion does not represent an increase in district demand, but rather a shift in where the diversion is taken; therefore, the district diversion allocation at La Grange is reduced by the amount diverted at the IGs.

[14] Should the user wish to see results without the IG diversions, there is a switch on the control tab that can turn it off and automatically change the baseflow requirements to the interim baseflows.

Table B-21. 2020 FERC FEIS Baseflow Requirements at La Grange Dam (in cfs).

Period	Days in Period	Critically Dry	Dry	Below Normal	Above Normal	Wet
January	31	175	200	225	225	225
February	28/29	175	200	225	225	225
March	31	200	225	250	250	250
April 1 - 15	15	200	225	250	250	250
April 16 - 30	15	200	250	275	275	275
May 1 - 15	15	200	250	275	275	275
May 1 - 31	16	225	275	300	300	300
June [a]	30	200 (125)	200 (125)	200 (150)	200 (150)	200 (150)
July [a]	31	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
August [a]	31	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
September [a]	30	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
October 1–15 [a]	15	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
October 16–31	16	200	225	275	275	275
November	30	200	225	275	275	275
December	31	200	225	275	275	275

Source: Table 1 in Appendix B of FERC 2020.

[a] Values in Parentheses are the interim release requirements at La Grange to be provided until both IGs are operational.

Table B-22. Potential Flow Downstream of the Infiltration Galleries at RM 25.9 During the Period of IG Operation (in cfs).

Period	Days in Period	Critically Dry	Dry	Below Normal	Above Normal	Wet
June [a]	30	125 (125)	125 (125)	100 (150)	100 (150)	100 (150)
July [a, b]	31	125 (150)	137 (175)	158 (225)	158 (225)	158 (225)
August [a, b]	31	125 (150)	130 (175)	153 (225)	153 (225)	153 (225)
September [a, b]	30	125 (150)	133 (175)	155 (225)	155 (225)	155 (225)
October 1–15 [a]	15	125 (150)	125 (175)	150 (225)	150 (225)	150 (225)
October 16–31	16	200	225	275	275	275

Source: Table 1 in Appendix B of FERC 2020.

[a] Values in parentheses are the interim release requirements at La Grange to be provided until both IGs are operational.

[b] Non-interim flow values for July, August, and September of all but critically dry year types incorporate a 200 cfs minimum release requirement for 10 total days during the summer to provide boating opportunities on the Tuolumne River downstream of the IGs. The spreadsheet provided by the TVA parties assumed that 5 of these boating days will be in July, 2 in August, and 3 in September.

Table B-23. Assumed Infiltration Gallery Diversion Used in WSE (in cfs).

Period	Days in Period	Critically Dry	Dry	Below Normal	Above Normal	Wet
June	30	75	75	100	100	100
July	31	175	163	142	142	142

Period	Days in Period	Critically Dry	Dry	Below Normal	Above Normal	Wet
August	31	175	170	147	147	147
September	30	175	168	145	145	145
October 1–15 [a]	15	175	175	150	150	150
October 16–31 [a]	16	0	0	0	0	0

[a] For use in the WSE model with its monthly timestep, the October values are averaged based on the number of days in each period. The average October IG diversion is approximately 85 cfs for critically dry and dry years and is approximately 73 cfs for below normal, above normal, and wet years.

Table B-24 and Table B-25 describe the outmigration and floodplain pulse flows associated with the 2020 FERC FEIS, including the duration, volume, and assumed modeling period in WSE. As with the baseflows, the pulse flow requirements are dependent on SJR 60-20-20 WYT. The spring outmigration pulse is intended to encourage outmigration and increase survival of parr and smolt salmon during the spring. The outmigration pulse generally has decreasing pulse volumes as the WYT gets drier. The floodplain inundation pulse is designed to provide floodplain habitat for juvenile Chinook salmon during the rearing life stage by maintaining flows at about 2,750 cfs for a continuous period of 9 to 20 days. The floodplain pulse generally has a decreasing pulse length as WYT gets drier. The 2020 FERC FEIS also includes an additional 1000 cfs fall flushing pulse for 3 days (about 5,950 AF) in every WYT, intended for maintenance to clean gravels of built-up algae, debris, and surface fines prior to the start of substantial spawning. In WSE, the flushing pulse is applied in October on top of the baseflows above.

Both the outmigration and floodplain pulses also include dry year relief off-ramps to conserve water supply during drought periods. For the outmigration pulse, in any sequence of consecutive critically dry (C) and/or dry (D) years, all but the first year will have an off-ramp. For example, if there was a sequence of five WYTs of D-D-C-D-C, the second and third D and both C water years would have reduced outmigration pulse flow volumes. If there was a sequence of six WYTs of C-D-BN-C-D-C, both D water years and the third C water year would have a reduced outmigration pulse flow volume. The off-ramp condition for the floodplain pulse is similar, except that an off-ramp will also be applied in a below normal (BN) year following a C or D year. For example, in the same sequence of six WYTs of C-D-BN-C-D-C, the off-ramp would be applied in all years except for the first C year. Note that a BN year will not have an off-ramp applied or trigger off-ramps in the following year unless it is preceded by a C or D year, so the sequence W-BN-BN-C-W would not have any off-ramp years.

In WSE, the pulse flow requirements can be calculated with either perfect foresight of WYT or with forecasting based on the CAM model data. If using forecasting, the inundation pulse volume and timing will be determined based on the March 90% exceedance forecast of SJR WYT. For the outmigration pulse, the April flow volume will be determined by the April 90% exceedance forecasted WYT, while the May volume will be determined by the May 75% exceedance forecasted WYT. WSE also includes an option to determine the entire spring outmigration pulse flow volume based on the April forecast without updating the volume in May. For both pulses, if forecasting is applied, off-ramps will be triggered by comparing the forecasted WYT in the current month to the previous year's final WYT. Table B-26 and Table B-27 show the years that trigger off-ramps in WSE for the outmigration and inundation pulses, respectively, based on historical WYT and when using forecasted WYTs.

Because the 2020 FERC FEIS pulse periods do not match the monthly timestep of WSE, the pulses are modeled as total volumes of water released in each month or months with no shaping. The intent of WSE is to understand the overall system water balance, focusing on the total water released for instream flow, how it will affect the water available for diversions, and what will be left in storage. When river flows are reported as cfs in WSE, they represent the monthly average flow rate. In practice, flow rates are not expected to be constant over an entire month. Both TVA pulses would include up ramping and down ramping rates at their beginning and end that would occur on the order of hours to prevent sudden large shifts in flow rate. For the outmigration pulse, adaptive management may be applied to optimize the pulse for the timing, duration, and flow rate, rather than maintaining a single, constant release. For the floodplain pulse, the start date will be determined annually to coincide with Chinook salmon rearing rather than starting on March 1 every year.

Table B-24. Representation of the 2020 FERC FEIS Outmigration Pulse Flow in WSE.

Water Year Type	Pulse Period Start Date [a]	Pulse Period End Date [a]	Pulse Length (Days)	Total Pulse Volume (AF) [b]	April Pulse Volume (AF) [c]	May Pulse Volume (AF) [c]
Wet	17-Apr	30-May	44	150,000	44,000	106,000
Above Normal	17-Apr	30-May	44	150,000	44,000	106,000
Below Normal	17-Apr	30-May	44	100,000	29,333	70,667
Dry	17-Apr	30-May	44	75,000	22,000	53,000
Critically Dry	17-Apr	30-May	44	35,000	10,267	24,733
Dry Year Off-Ramp	17-Apr	30-May	44	45,000	13,200	31,800
Critically Dry Year Off-Ramp	17-Apr	30-May	44	11,000	3,227	7,773

[a] Includes 6 days of up ramping in April (17 to the 22) and 7 days of down ramping in May (24 to the 30).

[b] Pulse volumes in this table are in addition to 2020 FERC FEIS baseflows.

[c] The April and May Pulse Volumes represent how the Total Pulse Volume is divided between the two months, based on the information provided by the TVA Parties (TID, MID, CCSF 2024).

Table B-25. Representation of the 2020 FERC FEIS Floodplain Inundation Pulse Flow in WSE.

Water Year Type	Pulse Period Start Date	Pulse Period End Date	Pulse Length (Days)	Target Flow Rate (cfs) [a]	Pulse Volume (AF) [b]
Wet	1-Mar	20-Mar	20	2,750	99,174
Above Normal	1-Mar	20-Mar	20	2,750	99,174
Below Normal	1-Mar	20-Mar	18	2,750	89,256
Dry	1-Mar	16-Mar	14	2,750	70,116
Critically Dry	1-Mar	9-Mar	9	2,750	45,521
Below Normal Year Off-Ramp	1-Mar	14-Mar	14	2,750	69,421
Dry Year Off-Ramp	NA	NA	0	NA	0
Critically Dry Year Off-Ramp	NA	NA	0	NA	0

[a] Target flow rate is inclusive of the baseflow, which in March is 200 cfs for critical years, 225 cfs for dry years, and 250 cfs for below normal, above normal, and wet years.

[b] The pulse volume is the release needed to meet the target flow rate minus the 2020 FERC FEIS baseflows over the pulse length.

Table B-26. Years with Dry Year Off-Ramps in WSE for 2020 FERC FEIS Outmigration Pulse Flow.

Year	Final SJR WYT	April Forecasted WYT (90% Exceedance)	May Forecasted WYT (75% Exceedance)	Off-Ramps with Perfect Foresight	April Off-Ramp with Forecasting	May Off-Ramp with Forecasting
1922	W	BN	BN	No	No	No
1923	AN	D	BN	No	No	No
1924	C	C	C	No	No	No
1925	BN	BN	BN	No	No	No
1926	D	C	BN	No	No	No
1927	AN	BN	AN	No	No	No
1928	BN	BN	BN	No	No	No
1929	C	C	C	No	No	No
1930	C	C	C	Yes	Yes	Yes
1931	C	C	C	Yes	Yes	Yes
1932	AN	BN	BN	No	No	No
1933	D	C	C	No	No	No
1934	C	C	C	Yes	Yes	Yes
1935	AN	D	AN	No	Yes	No
1936	AN	AN	W	No	No	No
1937	W	AN	AN	No	No	No
1938	W	W	W	No	No	No
1939	D	D	D	No	No	No
1940	AN	AN	AN	No	No	No
1941	W	AN	W	No	No	No
1942	W	AN	W	No	No	No
1943	W	W	W	No	No	No
1944	BN	D	BN	No	No	No
1945	AN	BN	AN	No	No	No
1946	AN	AN	AN	No	No	No
1947	D	D	D	No	No	No
1948	BN	C	D	No	Yes	Yes
1949	BN	D	D	No	No	No
1950	BN	D	BN	No	No	No
1951	AN	AN	AN	No	No	No
1952	W	W	W	No	No	No
1953	BN	D	BN	No	No	No
1954	BN	D	BN	No	No	No
1955	D	C	D	No	No	No
1956	W	W	W	No	No	No
1957	BN	D	D	No	No	No
1958	W	AN	W	No	No	No
1959	D	C	D	No	No	No
1960	C	C	C	Yes	Yes	Yes
1961	C	C	C	Yes	Yes	Yes
1962	BN	BN	BN	No	No	No

Year	Final SJR WYT	April Forecasted WYT (90% Exceedance)	May Forecasted WYT (75% Exceedance)	Off-Ramps with Perfect Foresight	April Off-Ramp with Forecasting	May Off-Ramp with Forecasting
1963	AN	BN	AN	No	No	No
1964	D	C	D	No	No	No
1965	W	AN	W	No	No	No
1966	BN	D	BN	No	No	No
1967	W	AN	W	No	No	No
1968	D	C	D	No	No	No
1969	W	W	W	No	No	No
1970	AN	AN	AN	No	No	No
1971	BN	D	BN	No	No	No
1972	D	C	C	No	No	No
1973	AN	BN	BN	No	No	No
1974	W	AN	W	No	No	No
1975	W	AN	AN	No	No	No
1976	C	C	C	No	No	No
1977	C	C	C	Yes	Yes	Yes
1978	W	W	W	No	No	No
1979	AN	AN	AN	No	No	No
1980	W	W	W	No	No	No
1981	D	D	BN	No	No	No
1982	W	W	W	No	No	No
1983	W	W	W	No	No	No
1984	AN	AN	AN	No	No	No
1985	D	D	BN	No	No	No
1986	W	W	W	No	No	No
1987	C	C	C	No	No	No
1988	C	C	C	Yes	Yes	Yes
1989	C	C	C	Yes	Yes	Yes
1990	C	C	C	Yes	Yes	Yes
1991	C	C	C	Yes	Yes	Yes
1992	C	C	C	Yes	Yes	Yes
1993	W	W	W	No	No	No
1994	C	C	C	No	No	No
1995	W	W	W	No	No	No
1996	W	AN	AN	No	No	No
1997	W	W	W	No	No	No
1998	W	W	W	No	No	No
1999	AN	BN	BN	No	No	No
2000	AN	BN	AN	No	No	No
2001	D	C	BN	No	No	No
2002	D	D	D	Yes	Yes	Yes
2003	BN	C	BN	No	Yes	No

Table B-27. Years with Dry Year Off-Ramps in WSE for 2020 FERC FEIS Inundation Pulse Flow.

Year	Final SJR WYT	March forecasted WYT (90% Exceedance)	April Forecasted WYT (90% Exceedance)	Off-Ramps with Perfect Foresight	March Off-Ramp with Forecasting	April Off-Ramp with Forecasting
1922	W	BN	BN	No	No	No
1923	AN	BN	D	No	No	No
1924	C	C	C	No	No	No
1925	BN	D	BN	Yes	Yes	Yes
1926	D	C	C	Yes	Yes	Yes
1927	AN	BN	BN	No	Yes	Yes
1928	BN	D	BN	No	No	No
1929	C	C	C	No	No	No
1930	C	C	C	Yes	Yes	Yes
1931	C	C	C	Yes	Yes	Yes
1932	AN	AN	BN	No	No	Yes
1933	D	C	C	No	No	No
1934	C	C	C	Yes	Yes	Yes
1935	AN	D	D	No	Yes	Yes
1936	AN	AN	AN	No	No	No
1937	W	AN	AN	No	No	No
1938	W	W	W	No	No	No
1939	D	D	D	No	No	No
1940	AN	AN	AN	No	No	No
1941	W	AN	AN	No	No	No
1942	W	AN	AN	No	No	No
1943	W	AN	W	No	No	No
1944	BN	D	D	No	No	No
1945	AN	BN	BN	No	No	No
1946	AN	BN	AN	No	No	No
1947	D	D	D	No	No	No
1948	BN	C	C	Yes	Yes	Yes
1949	BN	C	D	Yes	Yes	Yes
1950	BN	C	D	Yes	Yes	Yes
1951	AN	AN	AN	No	No	No
1952	W	AN	W	No	No	No
1953	BN	D	D	No	No	No
1954	BN	C	D	No	No	No
1955	D	C	C	No	No	No
1956	W	W	W	No	No	No
1957	BN	D	D	No	No	No
1958	W	BN	AN	No	No	No
1959	D	D	C	No	No	No
1960	C	C	C	Yes	Yes	Yes
1961	C	C	C	Yes	Yes	Yes
1962	BN	BN	BN	Yes	Yes	Yes

Year	Final SJR WYT	March forecasted WYT (90% Exceedance)	April Forecasted WYT (90% Exceedance)	Off-Ramps with Perfect Foresight	March Off-Ramp with Forecasting	April Off-Ramp with Forecasting
1963	AN	D	BN	No	Yes	Yes
1964	D	C	C	No	No	No
1965	W	AN	AN	No	No	No
1966	BN	BN	D	No	No	No
1967	W	BN	AN	No	No	No
1968	D	D	C	No	No	No
1969	W	W	W	No	No	No
1970	AN	BN	AN	No	No	No
1971	BN	D	D	No	No	No
1972	D	C	C	No	No	No
1973	AN	BN	BN	No	Yes	Yes
1974	W	BN	AN	No	No	No
1975	W	BN	AN	No	No	No
1976	C	C	C	No	No	No
1977	C	C	C	Yes	Yes	Yes
1978	W	AN	W	No	No	No
1979	AN	BN	AN	No	No	No
1980	W	W	W	No	No	No
1981	D	C	D	No	No	No
1982	W	AN	W	No	No	No
1983	W	W	W	No	No	No
1984	AN	AN	AN	No	No	No
1985	D	D	D	No	No	No
1986	W	W	W	No	No	No
1987	C	C	C	No	No	No
1988	C	C	C	Yes	Yes	Yes
1989	C	C	C	Yes	Yes	Yes
1990	C	C	C	Yes	Yes	Yes
1991	C	C	C	Yes	Yes	Yes
1992	C	C	C	Yes	Yes	Yes
1993	W	AN	W	No	No	No
1994	C	C	C	No	No	No
1995	W	AN	W	No	No	No
1996	W	AN	AN	No	No	No
1997	W	W	W	No	No	No
1998	W	W	W	No	No	No
1999	AN	BN	BN	No	No	No
2000	AN	AN	BN	No	No	No
2001	D	C	C	No	No	No
2002	D	D	D	Yes	Yes	Yes
2003	BN	C	C	Yes	Yes	Yes

B.2.3.3 WSE TVA Alternatives

The TVA flow measures are largely based on the flow requirements proposed in the 2020 FERC FEIS described above, with some modifications. The TVA updates relate to the details of the floodplain inundation pulse flow and a small change to assumed diversion by the IGs during June. The TVA representation used in WSE relies on information from the FEIS and from three spreadsheets provided by the TVA parties in April of 2023 (TID, MID, CCSF 2023), June of 2024 (TID, MID, CCSF 2024), and April of 2025 (TID, MID, CCSF 2025). With regards to the floodplain inundation pulse, the TVA adds about 10 TAF to the pulse volumes described in Table B-25 for below normal years without off-ramps and for all dry and critical years, both with and without off-ramps.[15] In addition, the TVA parties also redefined the target flow for the inundations pulse to be 1,700 cfs, instead of 2,750 cfs, so that the release duration could be increased as shown in Table B-28.[16] The second update applied by the TVA was to increase expected June flows below the IGs in the non-interim flow schedule from 100 to 150 cfs in below normal, above normal, and wet year types, in effect reducing the estimate of IG diversions for June from 100 to 50 cfs. Figure B-14 through Figure B-18 compare the January through June requirements proposed under the 2020 FERC license and under the TVA for each SJR WYT.

Table B-28. Representation of the Floodplain Inundation Pulse Flow Under the TVA in WSE.

Water Year Type	Pulse Period Start Date	Pulse Period End Date	Pulse Length (Days)	Target Flow Rate (cfs) [a]	Pulse Volume (AF) [b]	Ramping Volume (AF) [c]	Total Volume (cfs)
Wet	10-Mar	12-Apr	34	1,700	97,785	1,389	99,174
Above Normal	10-Mar	12-Apr	34	1,700	97,785	1,389	99,174
Below Normal	10-Mar	12-Apr	34	1,700	97,785	1,389	99,174
Dry	15-Mar	10-Apr	27	1,700	78,992	1,124	80,116
Critically Dry	20-Mar	6-Apr	18	1,700	53,554	1,967	55,521
Below Normal Year Off-Ramp	21-Mar	12-Apr	23	1,700	66,149	3,272	69,421
Dry Year Off-Ramp	20-Mar	22-Mar	3	1,700	8,777	1,223	10,000
Critically Dry Year Off-Ramp	20-Mar	22-Mar	3	1,700	8,926	1,074	10,000

[a] Target flow rate is inclusive of the baseflow, which from March 1 through April 15 is 200 cfs for critical years, 225 cfs for dry years, and 250 cfs for below normal, above normal, and wet years.

[b] The Pulse volume is the release needed to meet the target flow rate minus the baseflow over the pulse length.

[c] The ramping volume is assumed to be divided in half to provide 1 day of up ramping the day before the pulse period start date and 1 day of down ramping the day after the pulse period end date.

[15] For below normal years without off-ramps, the TVA added 9.918 TAF so that the total pulse volume would be equal to the pulse volume for wet and above normal years.

[16] There are two options in WSE for applying forecasting with the inundation pulse in the TVA alternatives: either to use the March 90% exceedance forecasted WYT for the entire pulse period or to update the pulse target flows and end date in April based on the April 90% exceedance forecasted WYT.

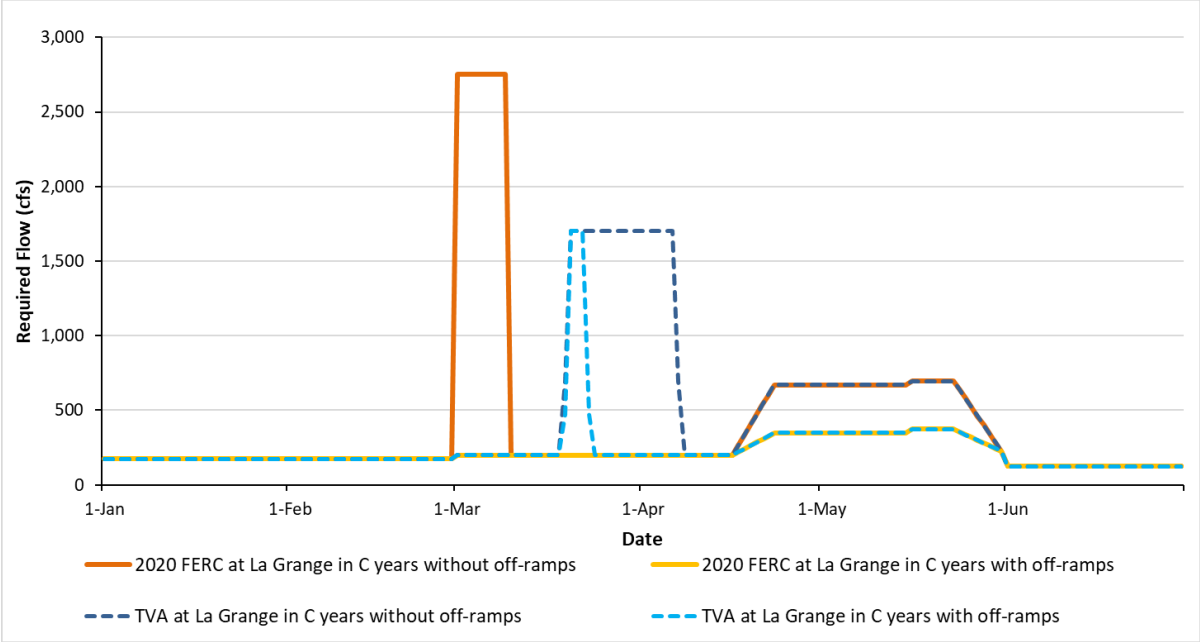


Figure B-14. January through June Required Flows on the Tuolumne Proposed Under the 2020 FERC License and the TVA MOU Alternative in Critical (C) Years.

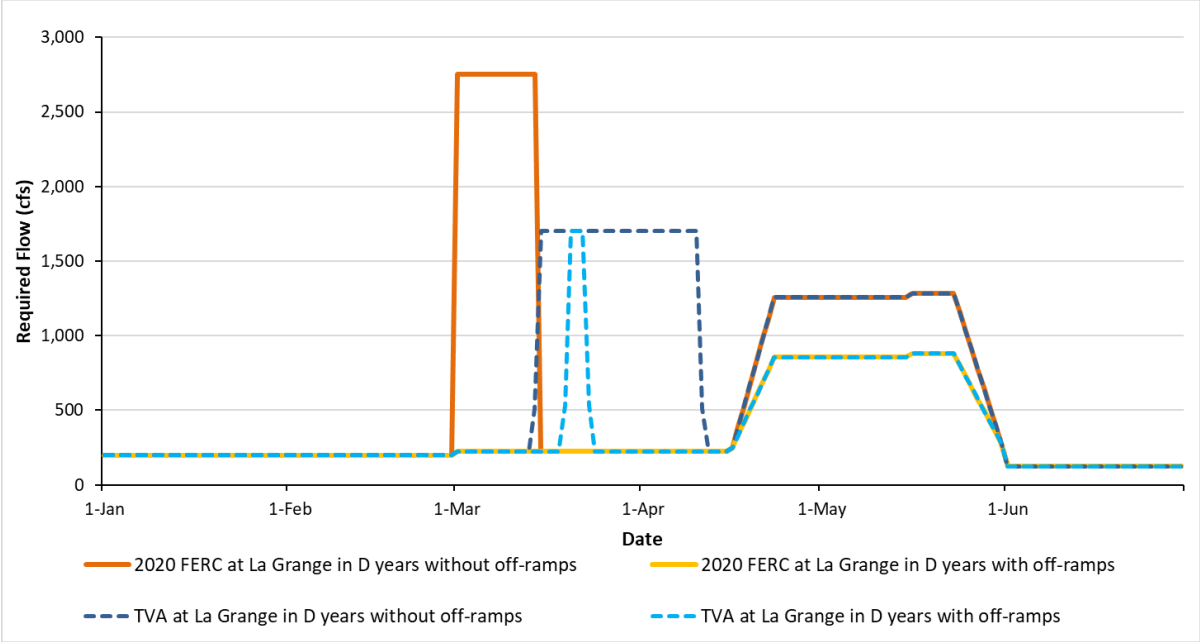


Figure B-15. January through June Required Flows on the Tuolumne Proposed Under the 2020 FERC License and the TVA MOU Alternative in Dry (D) Years.

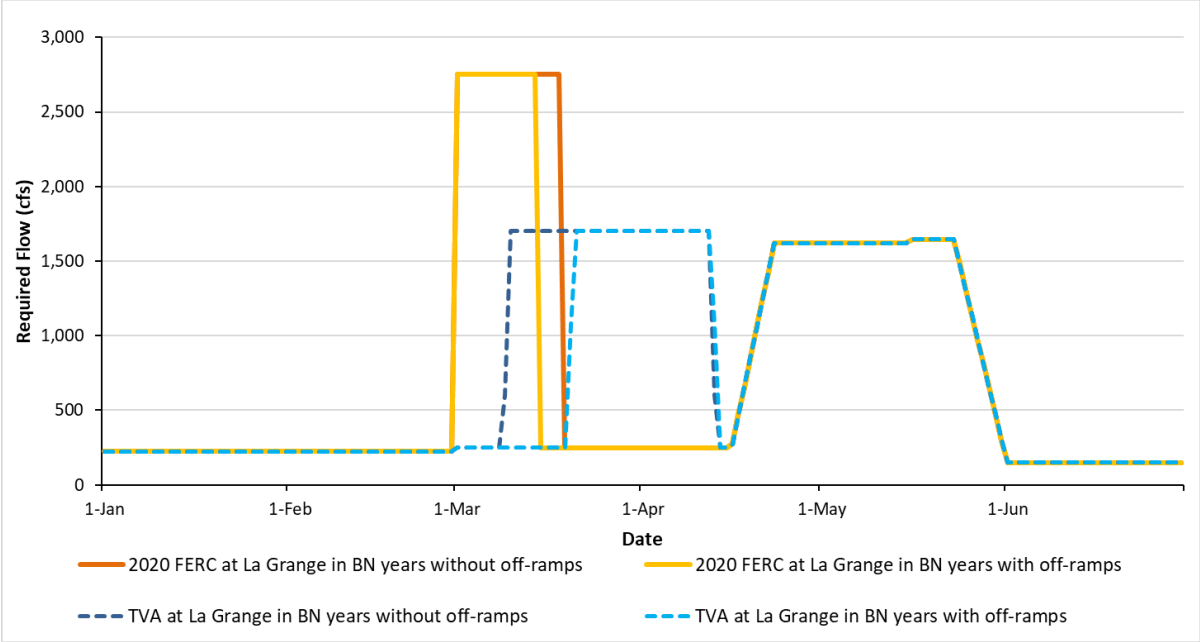


Figure B-16. January Through June Required Flows on the Tuolumne Proposed Under the 2020 FERC License and the TVA MOU Alternative in Below Normal (BN) Years.

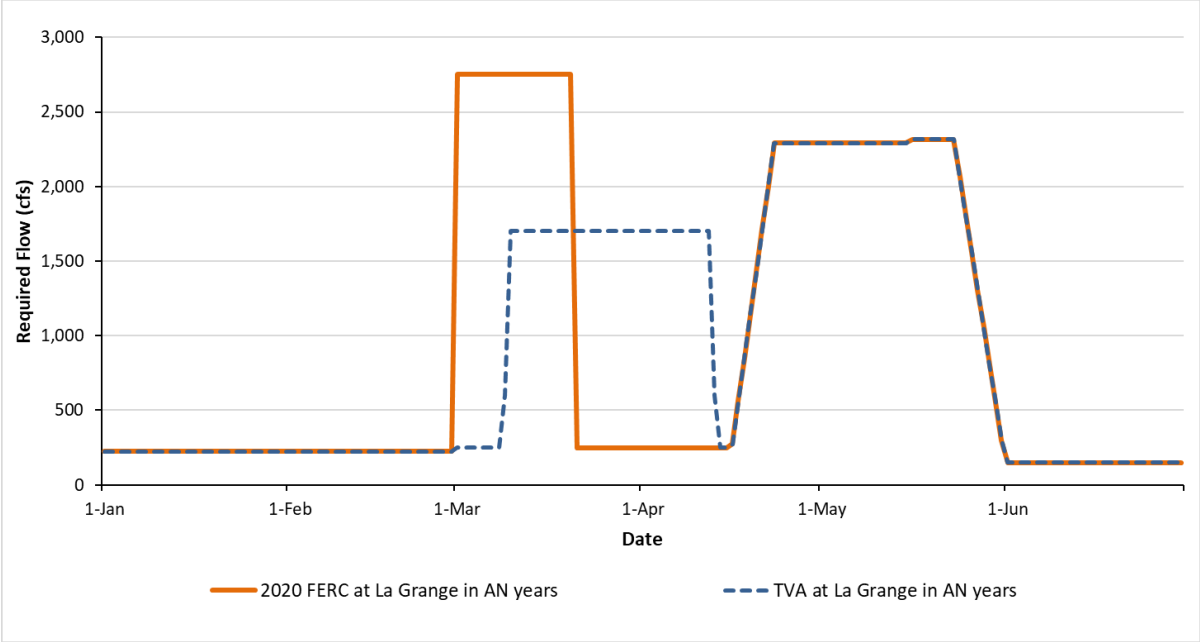


Figure B-17. January Through June Required Flows on the Tuolumne Proposed Under the 2020 FERC License and the TVA MOU Alternative in Above Normal (AN) Years.

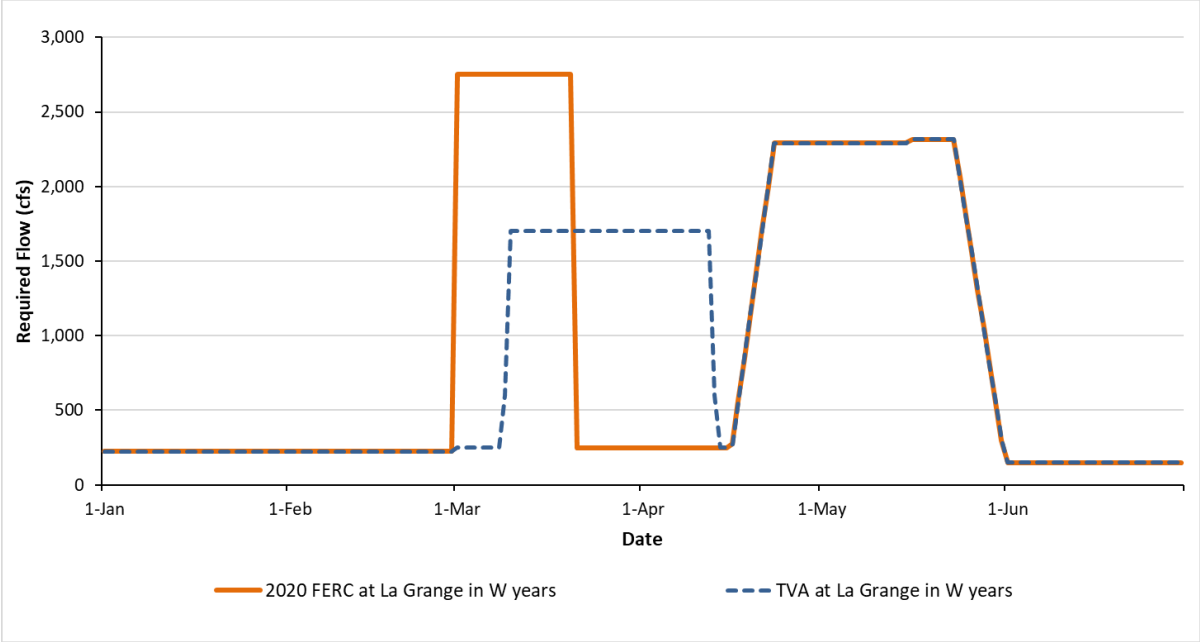


Figure B-18. January Through June Required Flows on the Tuolumne Proposed Under the 2020 FERC License and the TVA MOU Alternative in Wet (W) Years.

A description of the TVA was also released on November 9, 2022, in the "Memorandum of Understanding Advancing a Term Sheet for the Voluntary Agreements to Update and Implement the Bay-Delta Water Quality Control Plan, and Other Related Actions - Revised" (MOU).[17] The MOU presents a summary of the flows to be provided under the TVA but lacks the modeling detail needed to implement it in WSE and was therefore not used in updating the model. However, it should be noted that the MOU presents the TVA as only applying from January through June, while the 2020 FERC FEIS and the TVA draft accounting spreadsheet present flow requirements year-round (the TVA draft accounting spreadsheet uses 2020 FERC FEIS flow requirements for July–December). Therefore, two TVA alternatives[18] were added to WSE, including:

1. **TVAMOU –** Models the 2020 FERC FEIS flow requirements with the TVA updates from January through June and the 1995 FERC baseline flow requirements from July through December. This alternative does not include IG diversions or interpolation water and uses the FEIS interim baseflow requirements at La Grange.
2. **TVA+2020FERC –** Models the 2020 FERC FEIS flow requirements year-round with the TVA updates. This alternative includes IG diversions and uses the non-interim baseflow requirements at La Grange.

[17] Available at https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/2023/revised-TVA-mou-swrcb-copy.pdf.

[18] These two pre-defined alternatives only apply to the Tuolumne River. For both, forecasting is applied to determine flow requirements and pulse volumes/timing are determined by the forecasted WYT in the pulse's starting month. In addition, based on assumptions in the TVA draft accounting spreadsheet (TID, MID, CCSF 2025), it is also assumed for the TVA alternatives that there will be no reduction in Tuolumne River diversion compared to baseline. Other assumptions in these alternatives related to the representation of the Tuolumne River (reservoir operations, demands, etc.) are the same as in the baseline.

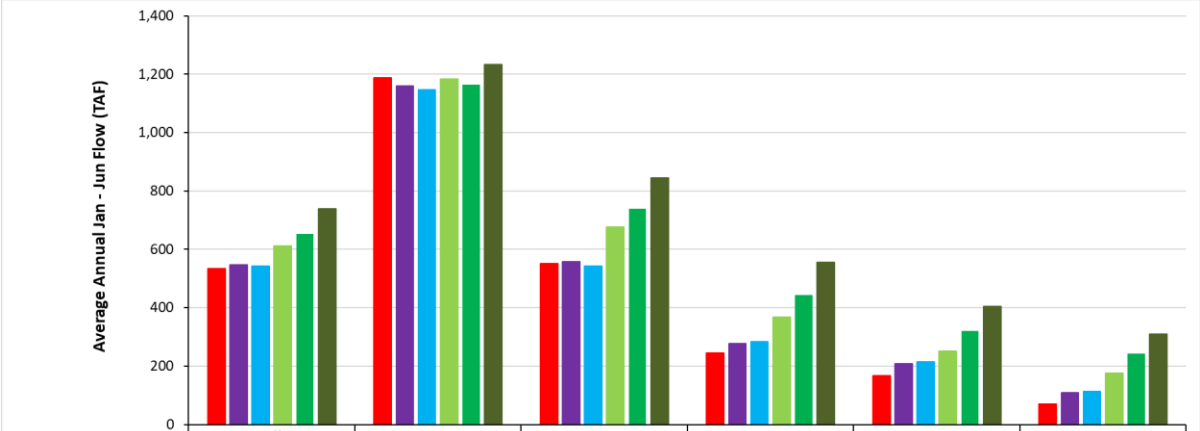
B.3 Water Supply Effects Modeling – Summary Results

This section compares WSE results on the Tuolumne River for the TVA MOU and TVA+2020FERC alternatives with the results of the existing conditions baseline and with alternatives representing the potential implementation of the 2018 Bay-Delta Plan, which is the 40% UF alternative plus the 30% and 50% UF alternatives to represent adaptive implementation. The comparison here focuses on flow, storage, and diversion results for the Tuolumne River.

B.3.1 Flow on the Tuolumne River at La Grange

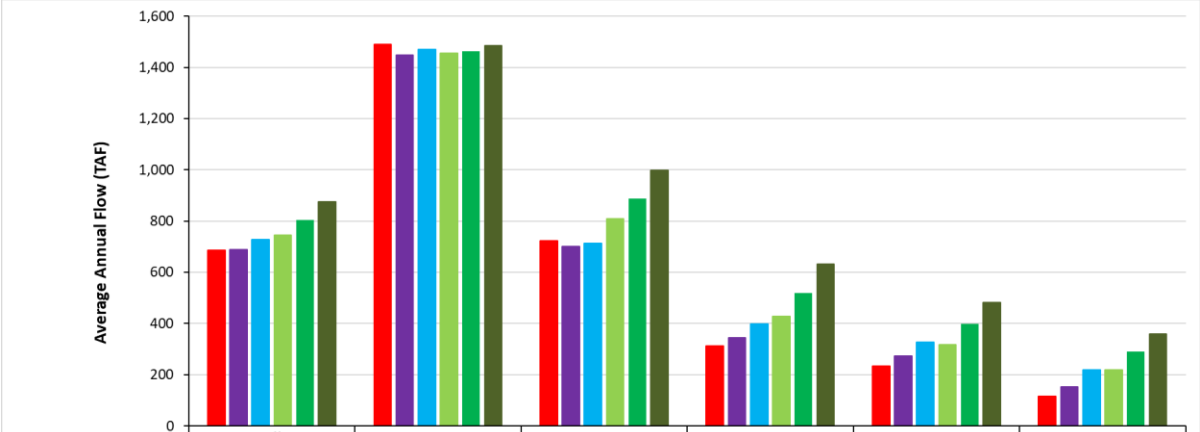
Figure B-19 and Figure B-20 present bar charts of WSE results for January through June and annual total flow at La Grange, respectively, averaged over 1922 to 2003 for all years and by WYT. From January through June, the total flow released at La Grange under the TVA MOU and TVA+2020FERC alternatives exceed those released under the existing conditions baseline during drier year types, are generally reduced in wetter years due to reservoir reoperation and reduced flood spills, and are always less than the volume provided under a 30% UF requirement. When accounting for the entire year, the TVA+2020FERC alternative results in more flow at La Grange on average than the 30% UF alternative in some year types, while the TVA MOU alternative is still less than 30% UF. However, there are some caveats when considering the TVA+2020FERC alternative and the UF alternatives. First, the UF alternatives assume the 1995 FERC license requirements are in effect from July through January as a backstop since the UF requirement is only applied from February through June. If the 2020 FERC license requirements were used as the backstop from July through January instead, the 30% UF alternative would likely provide more water than the TVA+2020FERC alternative. Second, some of the flow provided at La Grange under the TVA+2020FERC will be diverted downstream at the IGs.

Figure B-21 through Figure B-32 present monthly exceedance charts of WSE output for the total monthly flow at La Grange over the period of 1922 to 2003. Each figure provides the range of resulting flows that occurred in the WSE alternatives for the given month over the 82-year record, ordered with the highest values on the left to the lowest values on the right. Generally, flows at lower exceedance percentages correspond to wetter conditions (years with large flood spills will be exceeded less often) and flows at the higher exceedance percentages correspond to drier conditions when the only releases at La Grange are the minimum flow requirements.



	All	W	AN	BN	D	C
Existing Conditions	534	1,187	551	245	166	71
TVA MOU	546	1,159	557	277	208	109
TVA+2020FERC	543	1,147	543	284	215	114
30% UF Objective	611	1,184	676	368	251	176
40% UF Objective	653	1,163	738	443	319	242
50% UF Objective	738	1,233	844	557	404	310

Figure B-19. Average Total January through June Flow in the Tuolumne River at La Grange Under the WSE Alternatives.



	All	W	AN	BN	D	C
Existing Conditions	686	1,489	723	312	234	115
TVA MOU	689	1,449	702	344	274	154
TVA+2020FERC	727	1,469	713	399	326	219
30% UF Objective	745	1,456	810	429	317	219
40% UF Objective	803	1,463	888	519	398	291
50% UF Objective	877	1,486	999	633	482	359

Figure B-20. Average Annual Flow in the Tuolumne River at La Grange Under the WSE Alternatives.

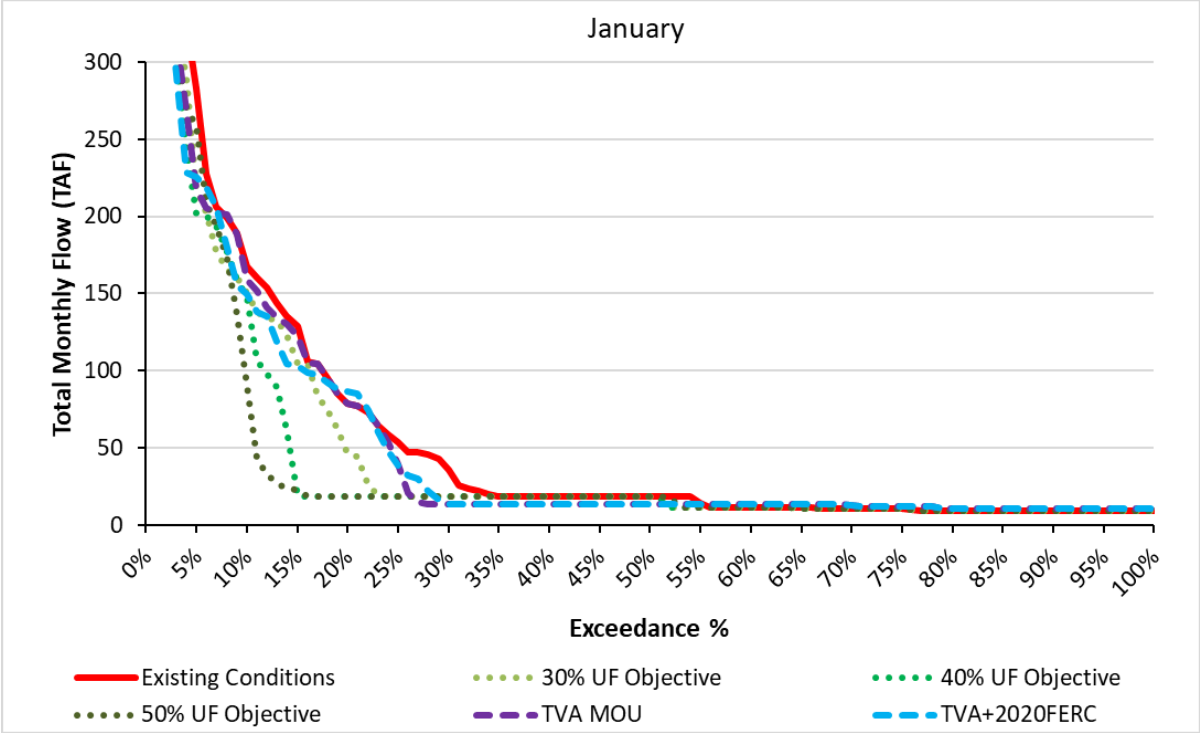


Figure B-21. Exceedance Chart of Total January Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

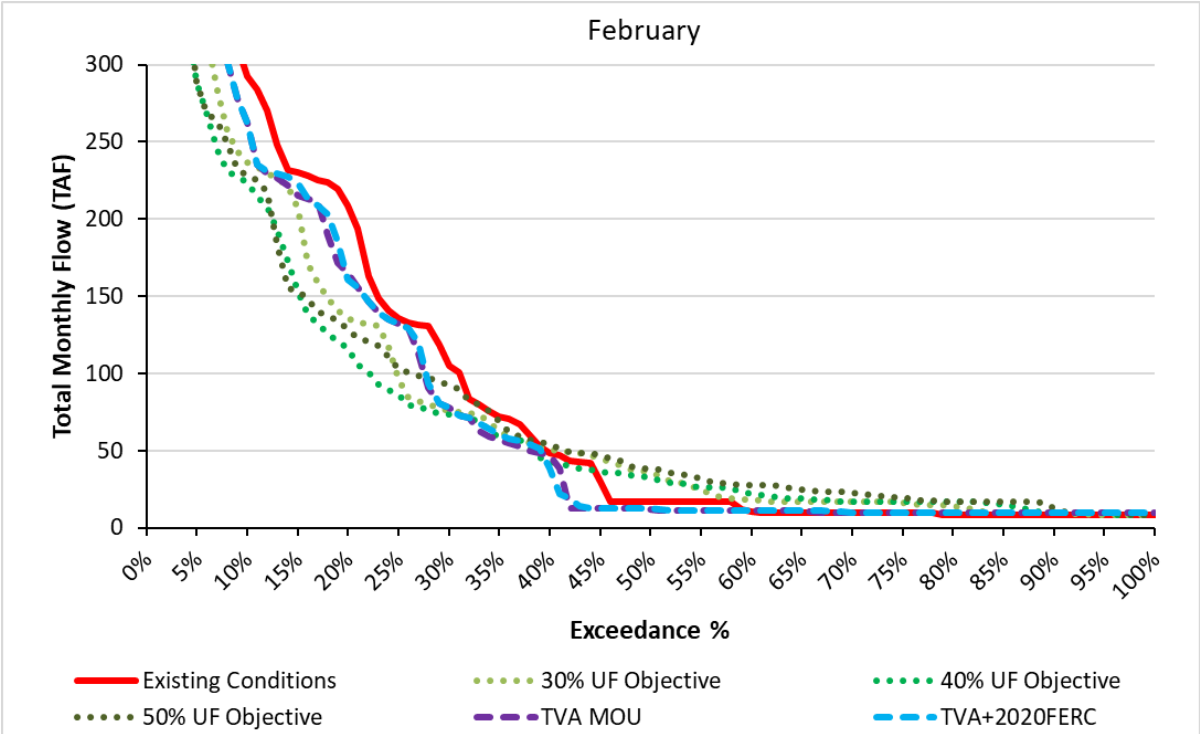


Figure B-22. Exceedance Chart of Total February Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

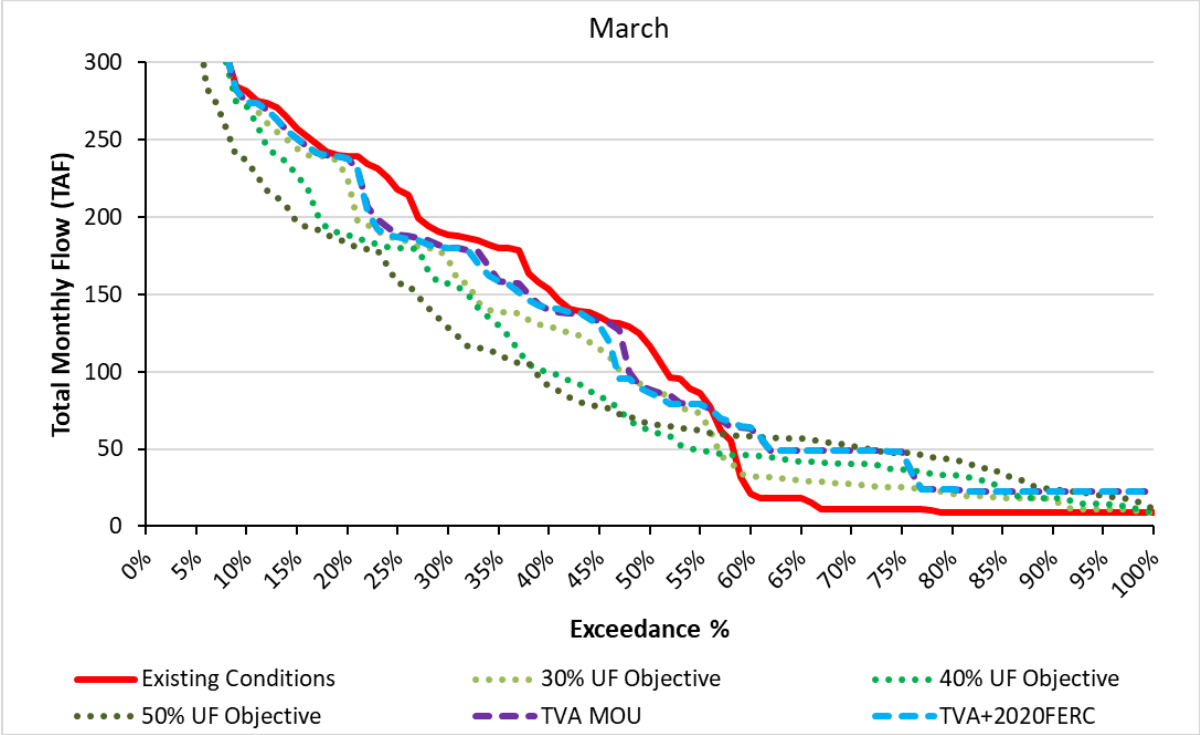


Figure B-23. Exceedance Chart of Total March Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

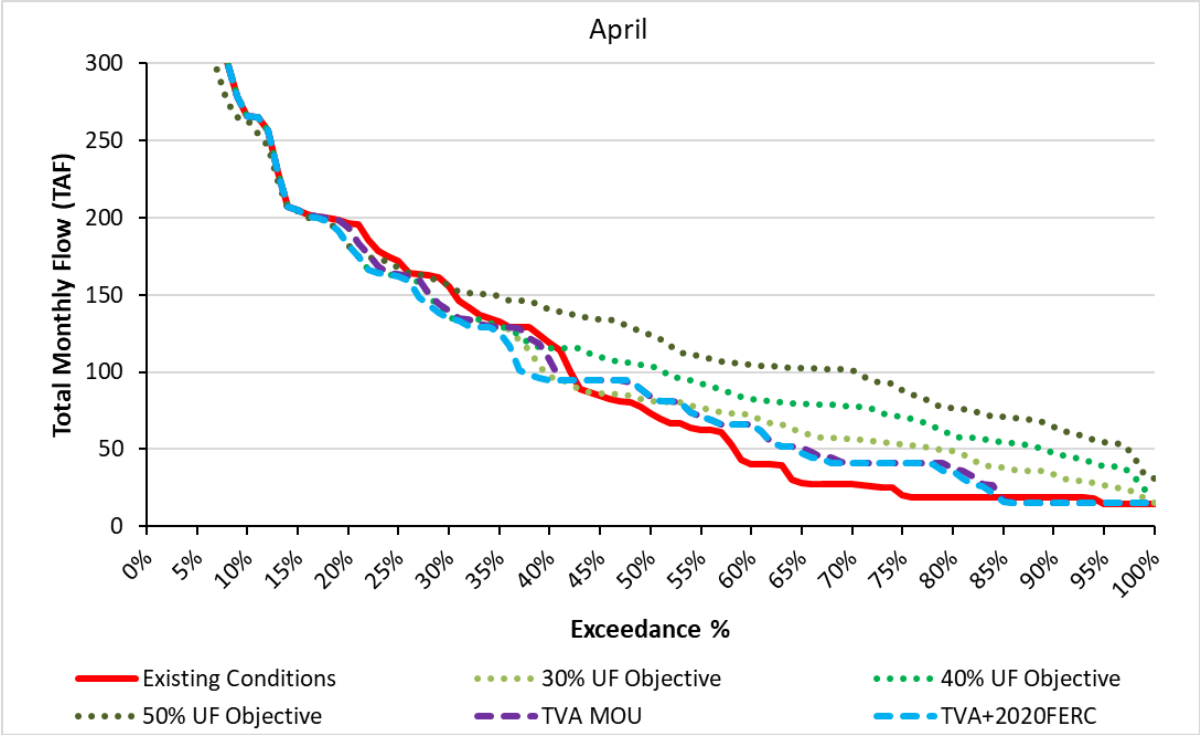


Figure B-24. Exceedance Chart of Total April Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

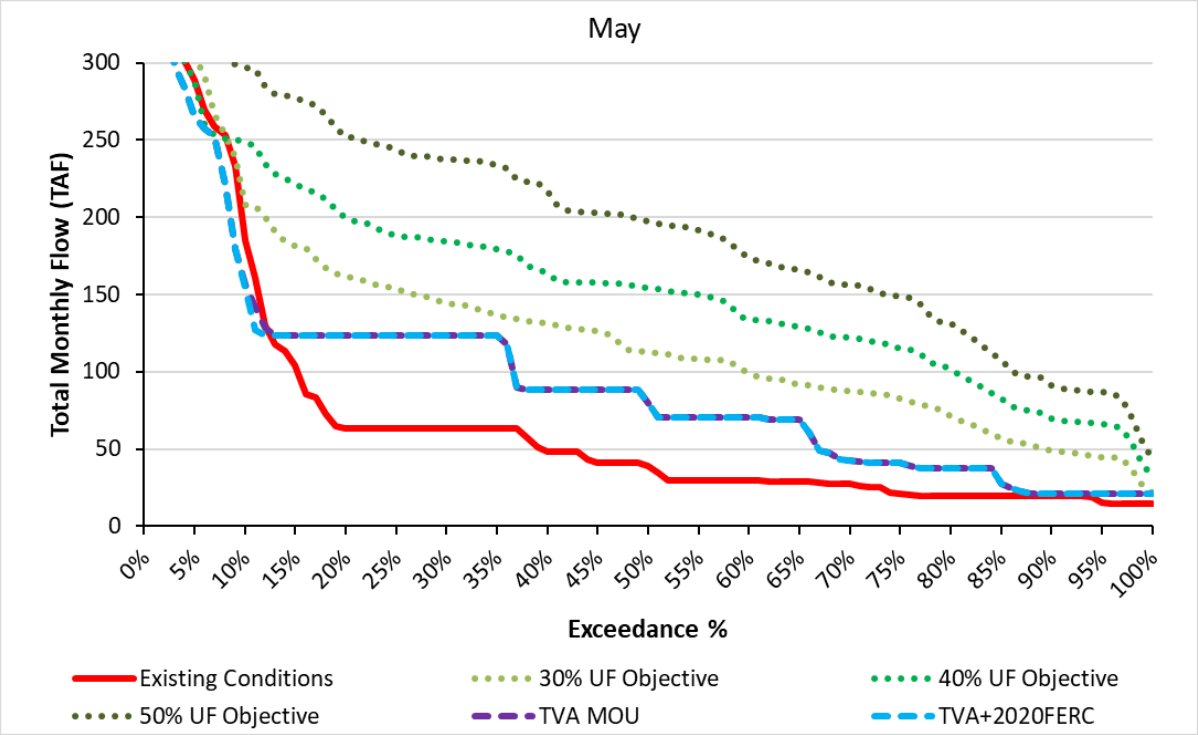


Figure B-25. Exceedance Chart of Total May Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

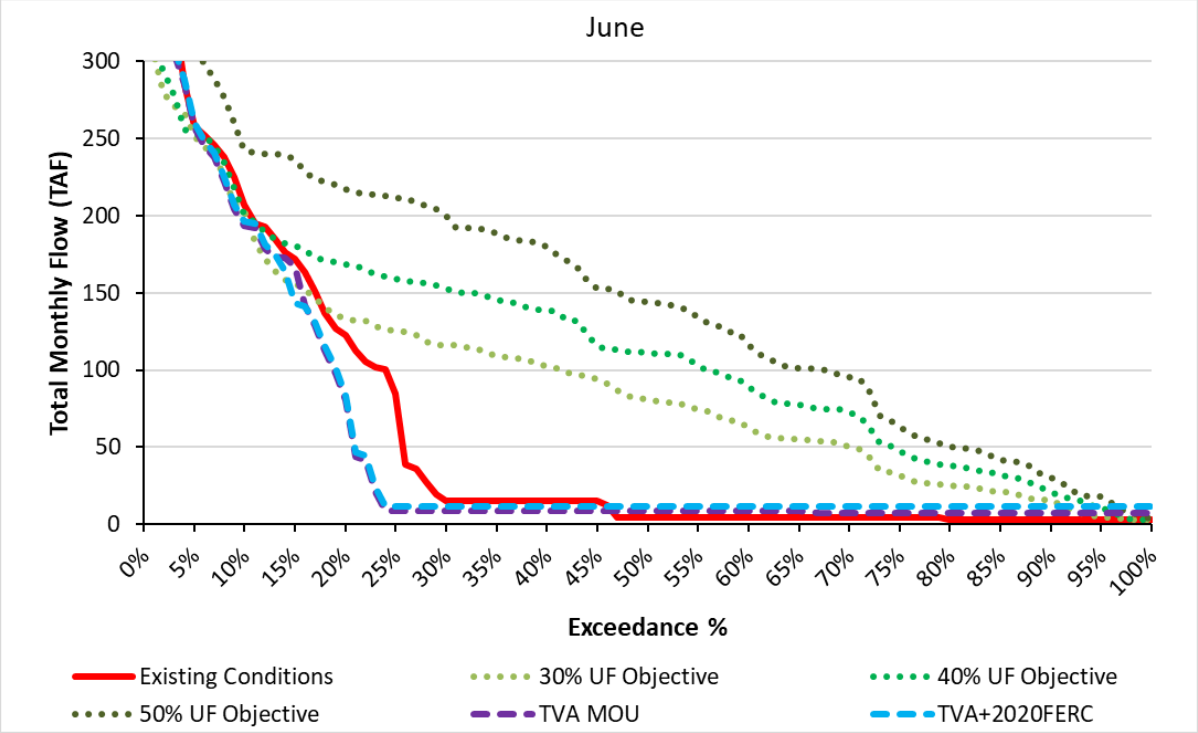


Figure B-26. Exceedance Chart of Total June Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

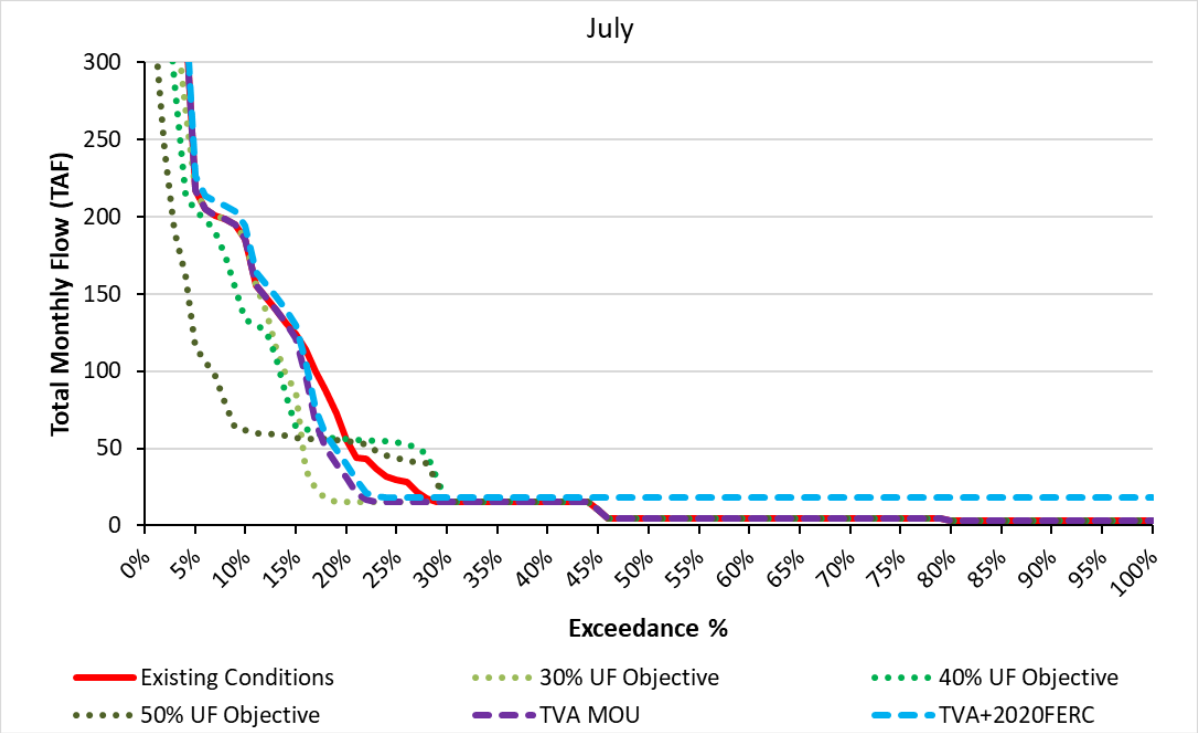


Figure B-27. Exceedance Chart of Total July Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

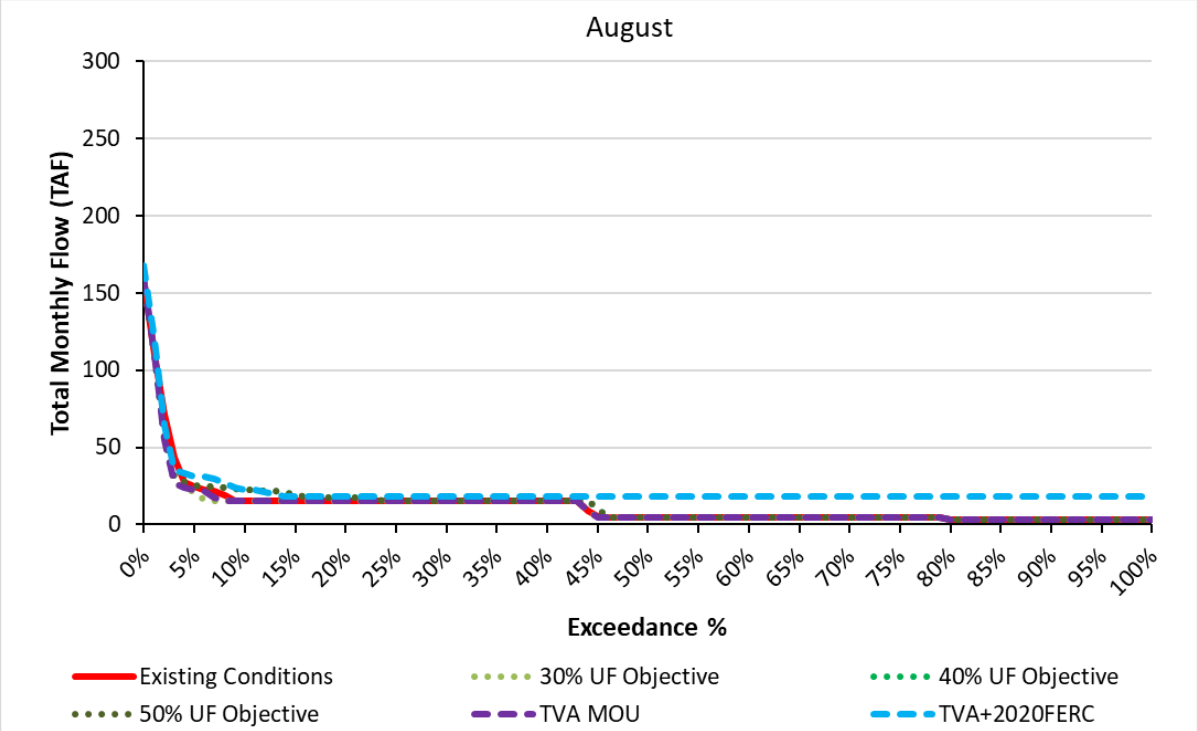


Figure B-28. Exceedance Chart of Total August Resulting Flow at La Grange from 1922 to 2003 under the WSE Alternatives.

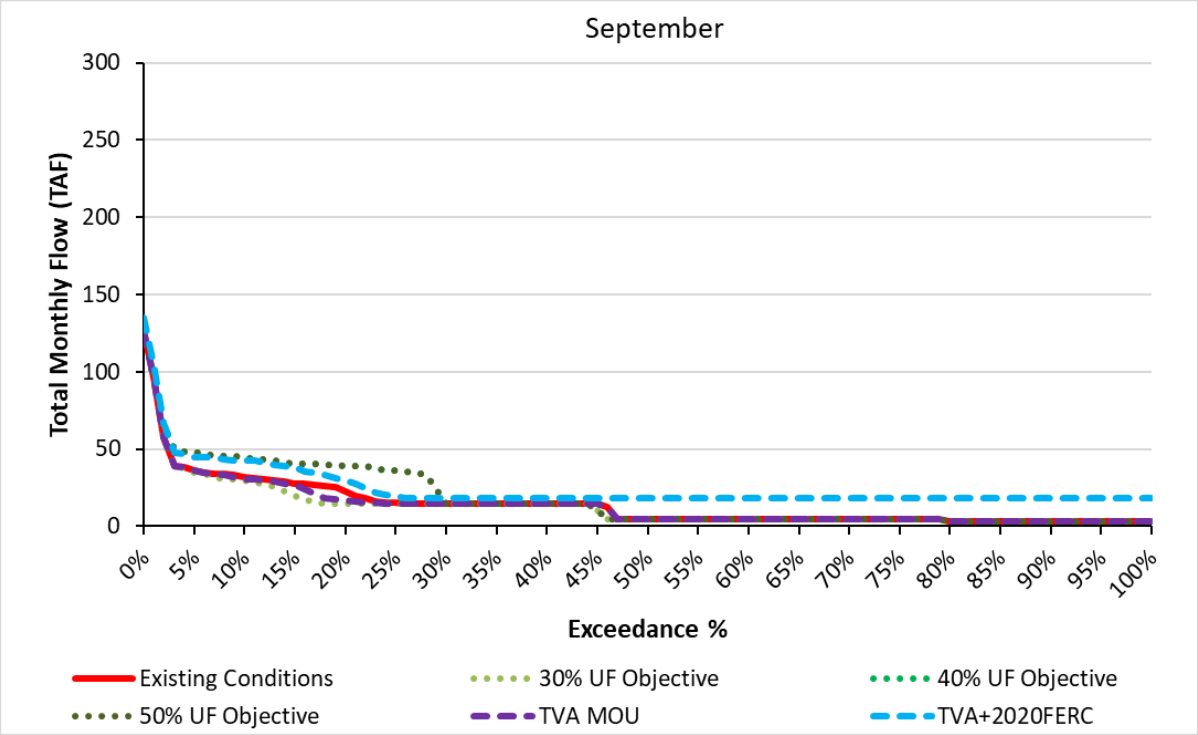


Figure B-29. Exceedance Chart of Total September Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

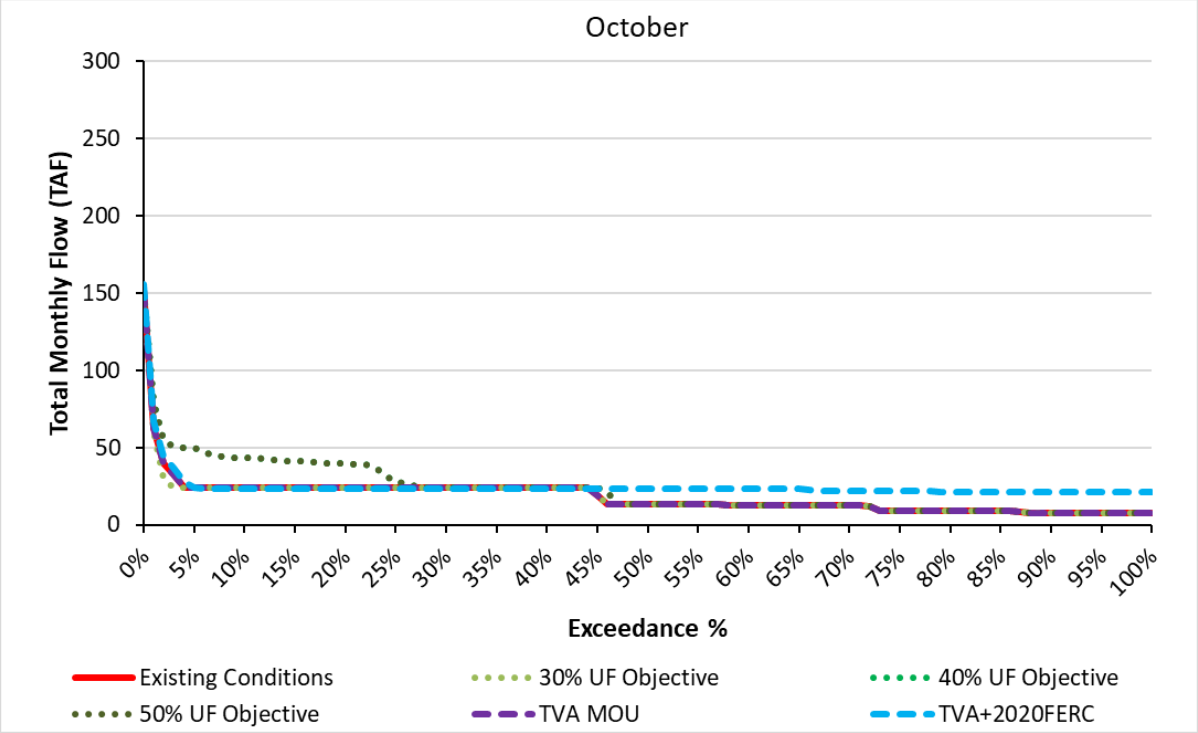


Figure B-30. Exceedance Chart of Total October Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

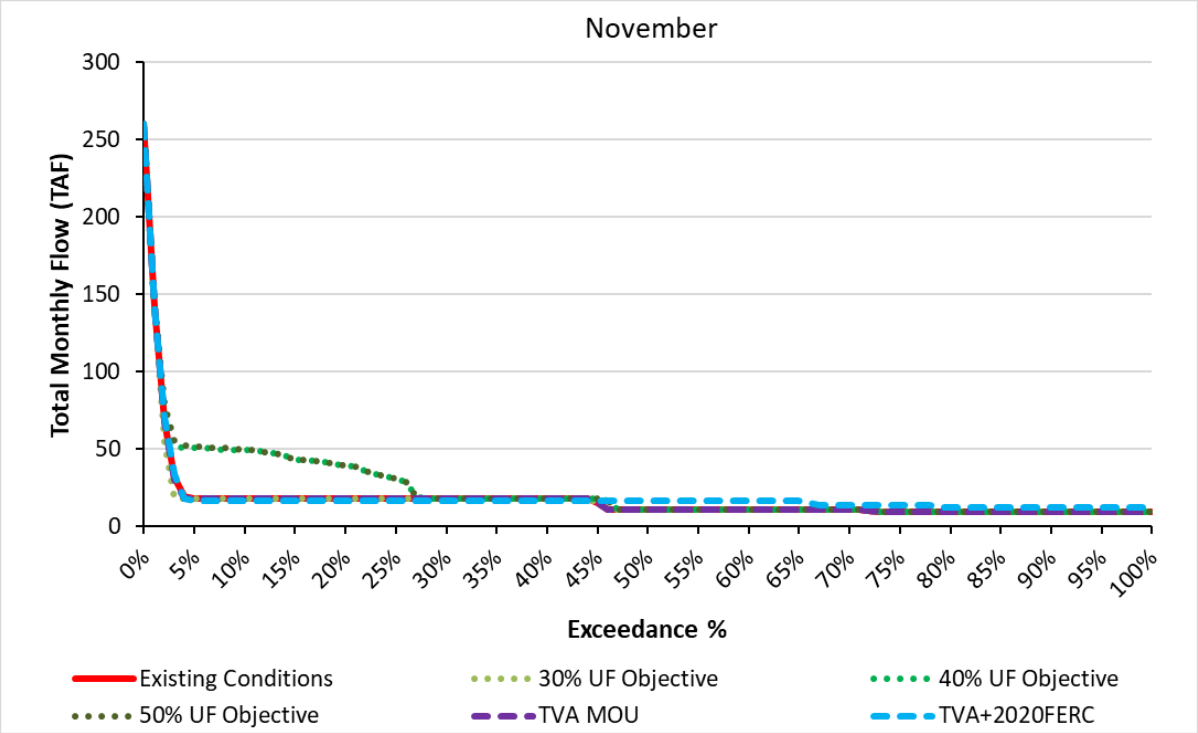


Figure B-31. Exceedance Chart of Total November Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

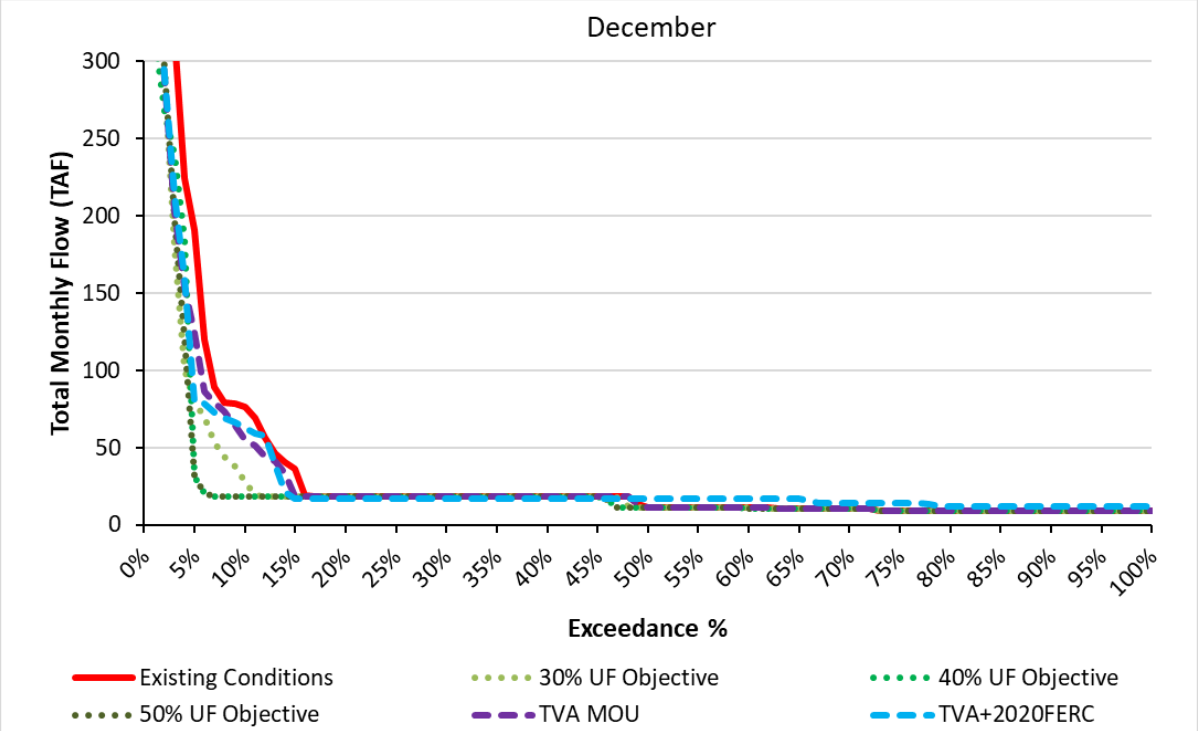


Figure B-32. Exceedance Chart of Total December Resulting Flow at La Grange from 1922 to 2003 Under the WSE Alternatives.

B.3.2 New Don Pedro Reservoir Storage

Reservoir storage level is an important factor in both maintaining temperature control to protect fish and wildlife and to preserve water supply for future dry conditions. Under the alternatives, as the instream flow requirements increase, it results in less water available for storage compared to the baseline. Figure B-33 shows the average end-of-month storage in New Don Pedro over all months for each of the alternatives modeled in WSE. Figure B-34 through Figure B-45 present monthly exceedance charts of WSE output for New Don Pedro end-of-month storage levels over the period of 1922 to 2003. Each figure shows the range of storage levels that occurred in the WSE alternatives for the given month over the 82-year record, ordered with the highest levels on the left to the lowest levels on the right. Average end-of-month storage levels under the TVA alternatives generally fall below the existing conditions baseline and between those seen in the 30% and the 40% UF alternatives, except during May through September when storage conditions are similar to those in the 30% UF alternative. Based on the monthly figures, the TVA alternatives tend to have a greater range in monthly storage levels, with the lowest monthly storage values falling well below those seen under baseline and the 50% UF alternative. Due to the assumption that Tuolumne River diversions will not be reduced under the TVA compared to baseline levels, storage is impacted more than it otherwise would have been.

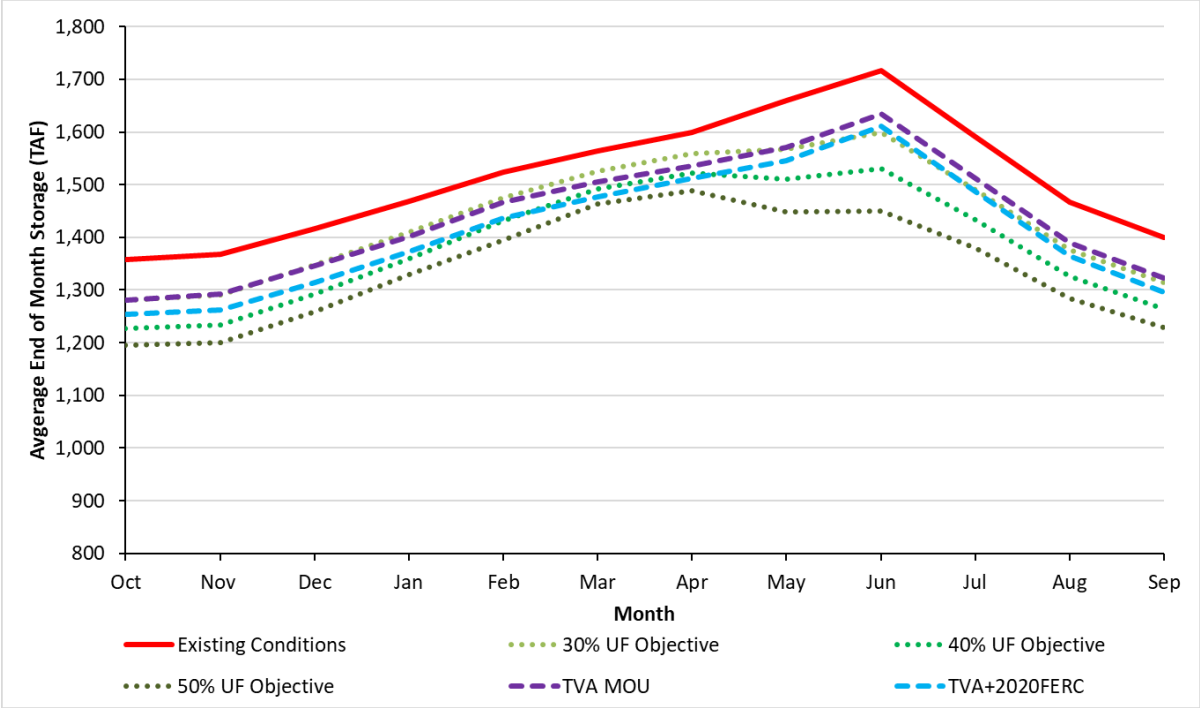


Figure B-33. Average End-of-Month Storage in New Don Pedro Under the WSE Alternatives.

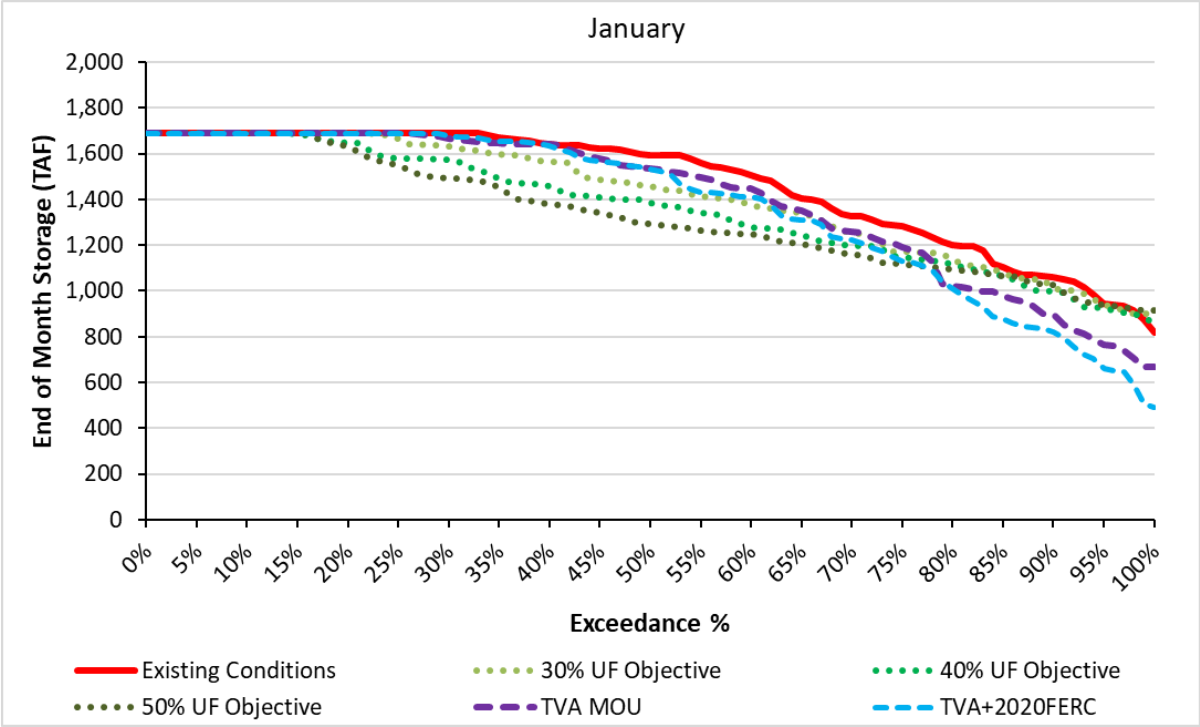


Figure B-34. Exceedance Chart of January Storage Levels in New Don Pedro from 1922 to 2003 Under the WSE Alternatives.

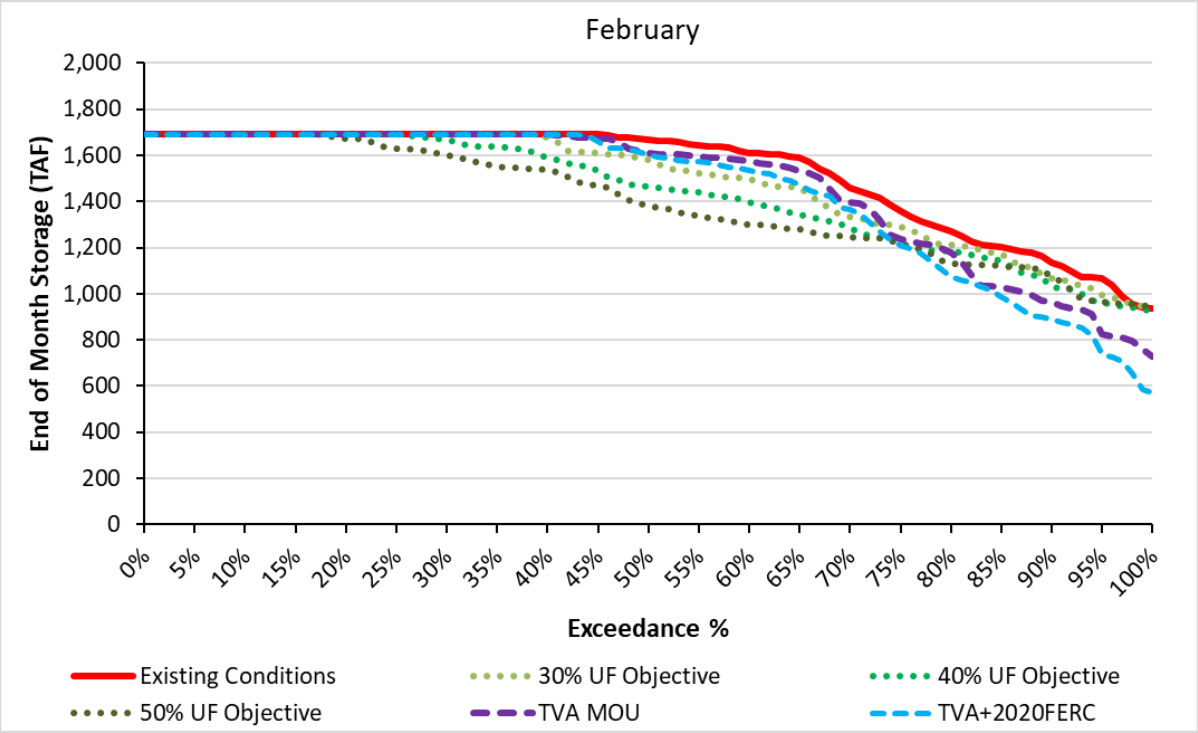


Figure B-35. Exceedance Chart of February Storage Levels from 1922 to 2003 Under the WSE Alternatives.

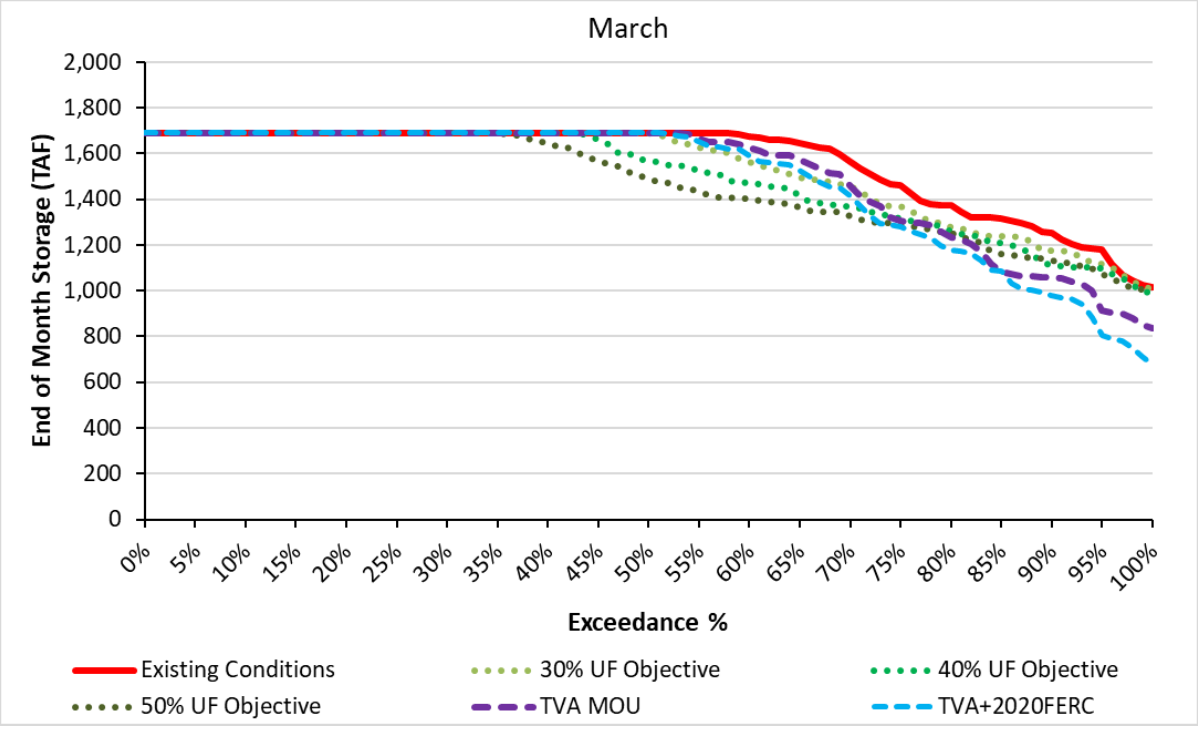


Figure B-36. Exceedance Chart of March Storage Levels from 1922 to 2003 Under the WSE Alternatives.

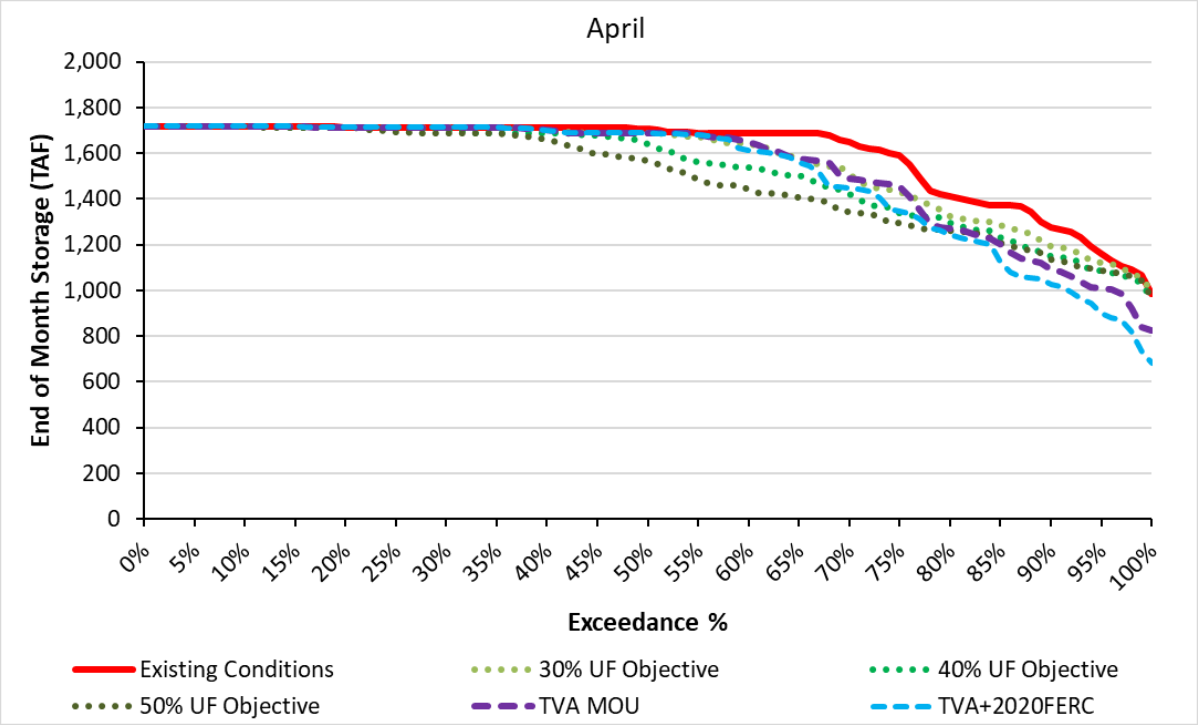


Figure B-37. Exceedance Chart of April Storage Levels from 1922 to 2003 Under the WSE Alternatives.

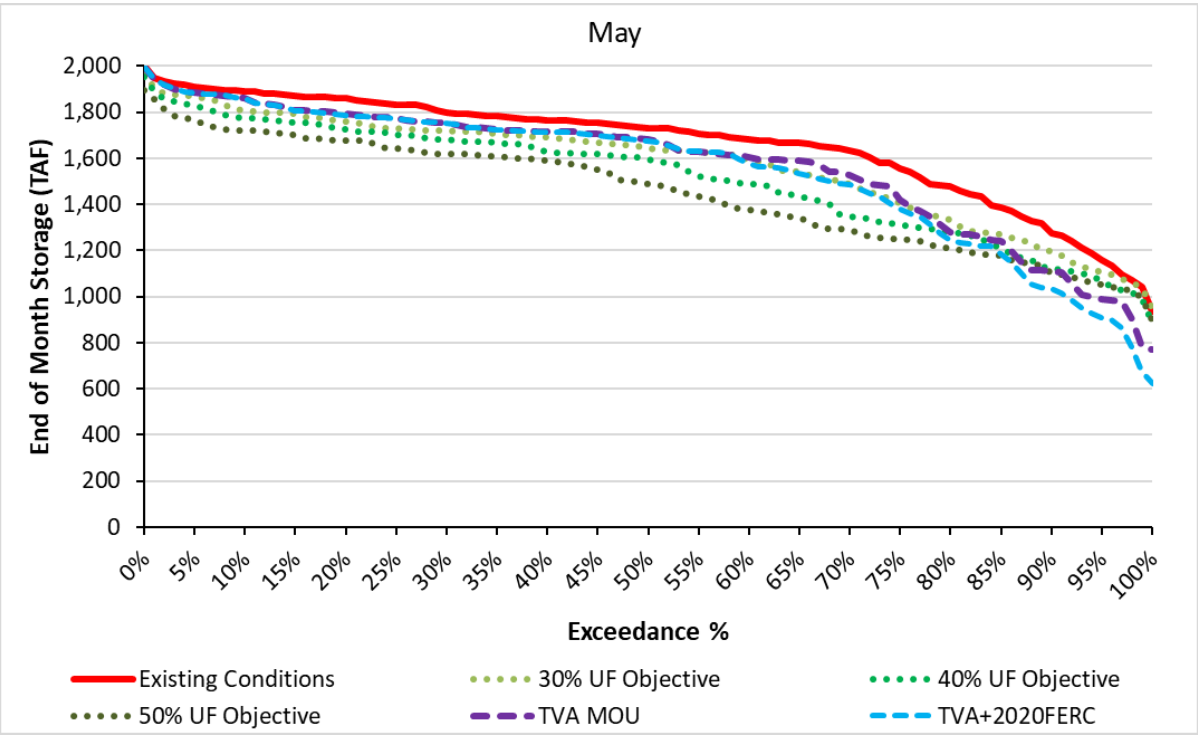


Figure B-38. Exceedance Chart of May Storage Levels from 1922 to 2003 Under the WSE Alternatives.

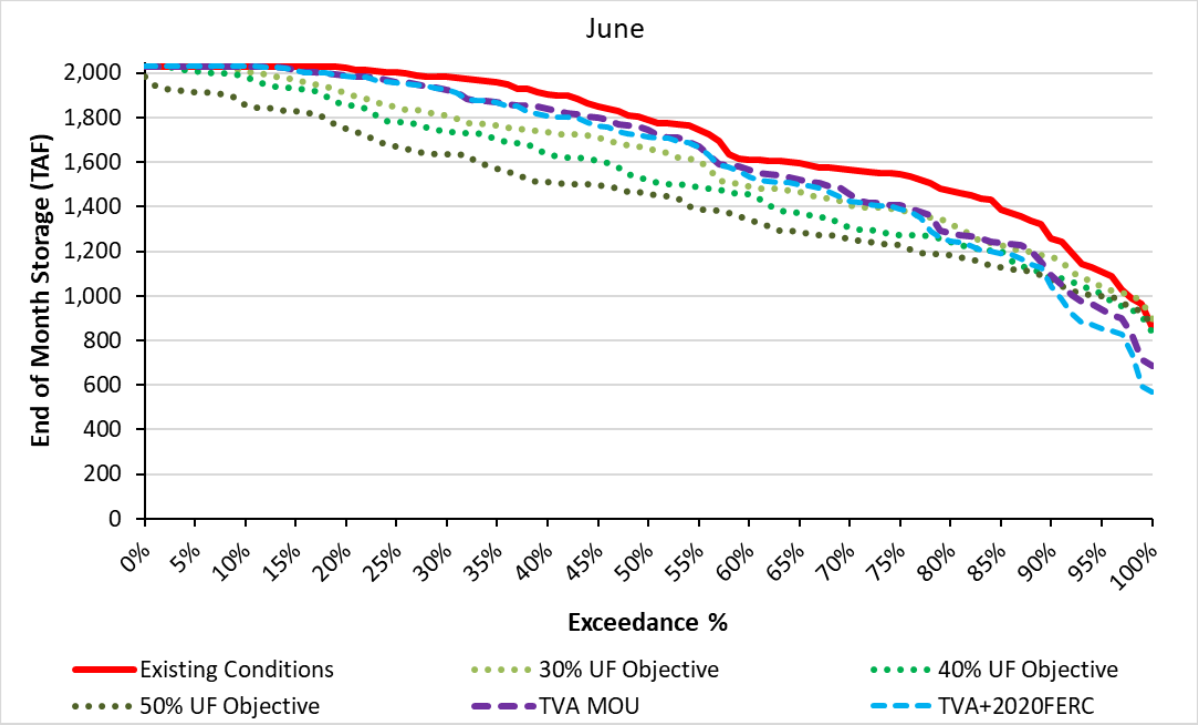


Figure B-39. Exceedance Chart of June Storage Levels from 1922 to 2003 Under the WSE Alternatives.

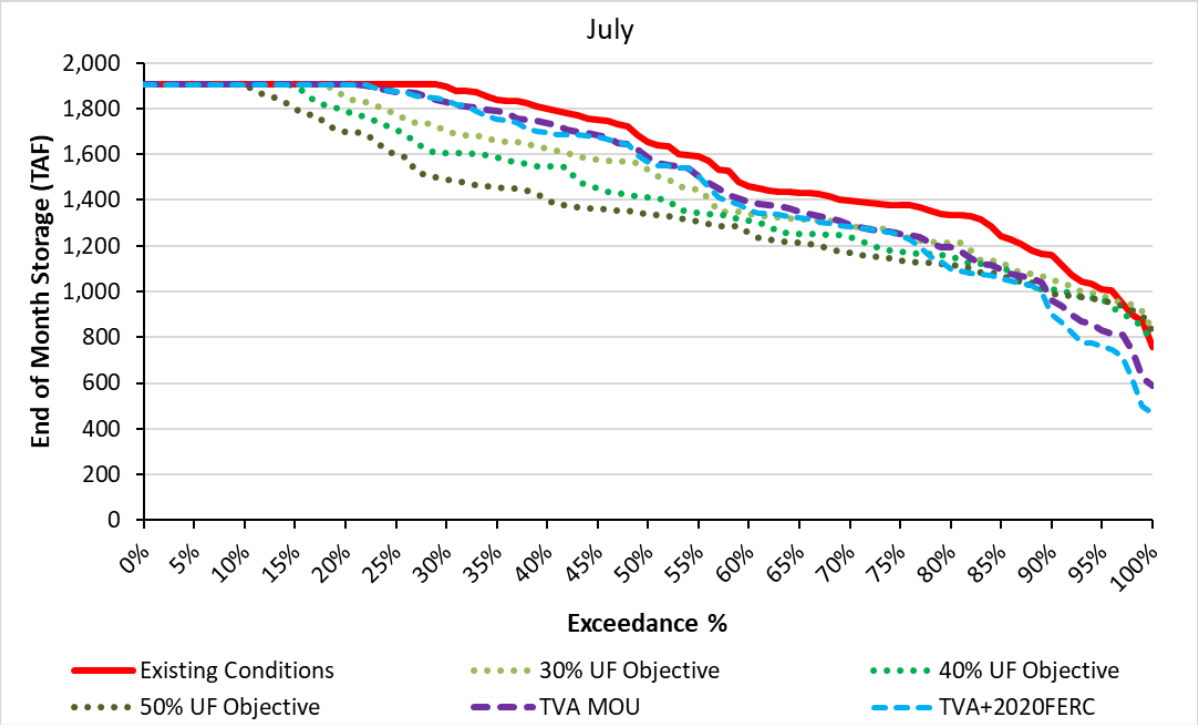


Figure B-40. Exceedance Chart of July Storage Levels from 1922 to 2003 Under the WSE Alternatives.

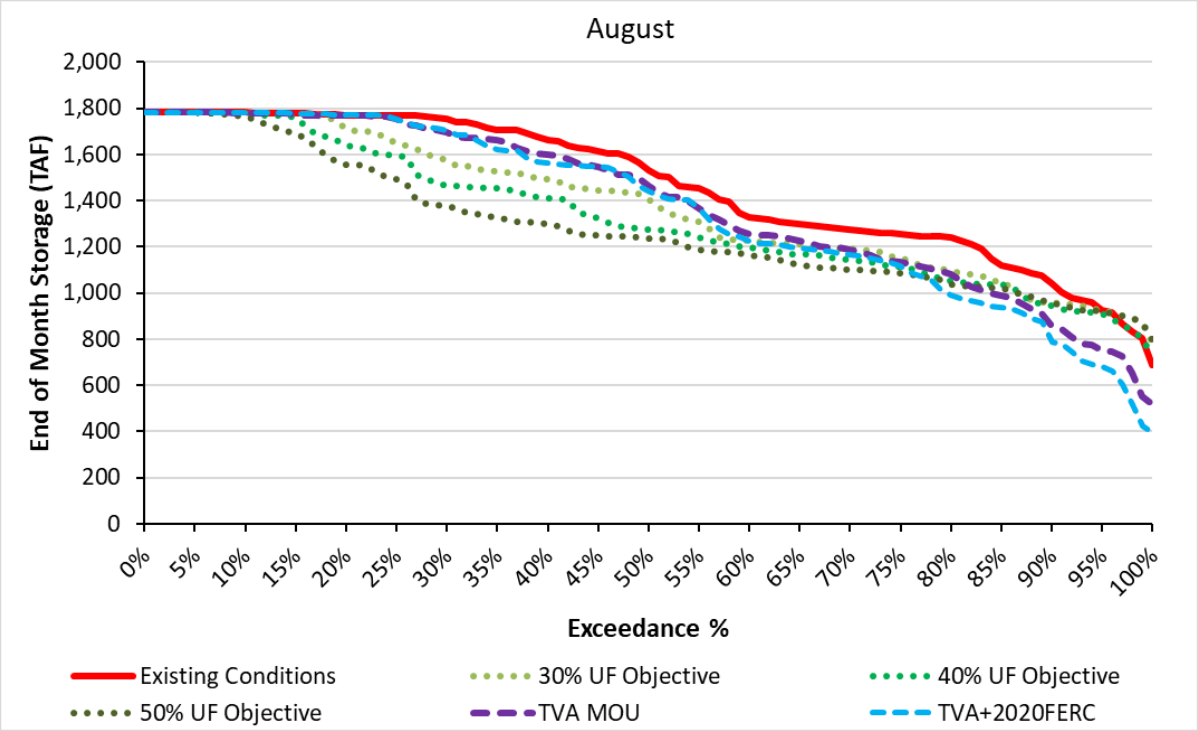


Figure B-41. Exceedance Chart of August Storage Levels from 1922 to 2003 Under the WSE Alternatives.

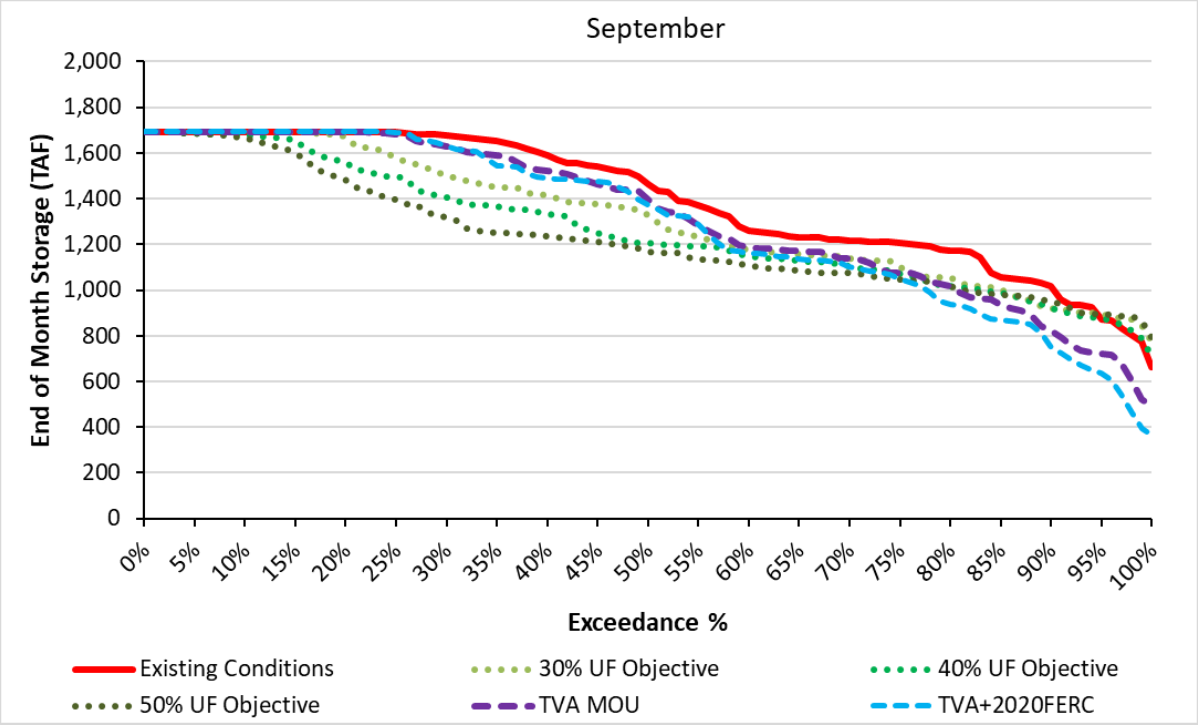


Figure B-42. Exceedance Chart of September Storage Levels from 1922 to 2003 Under the WSE Alternatives.

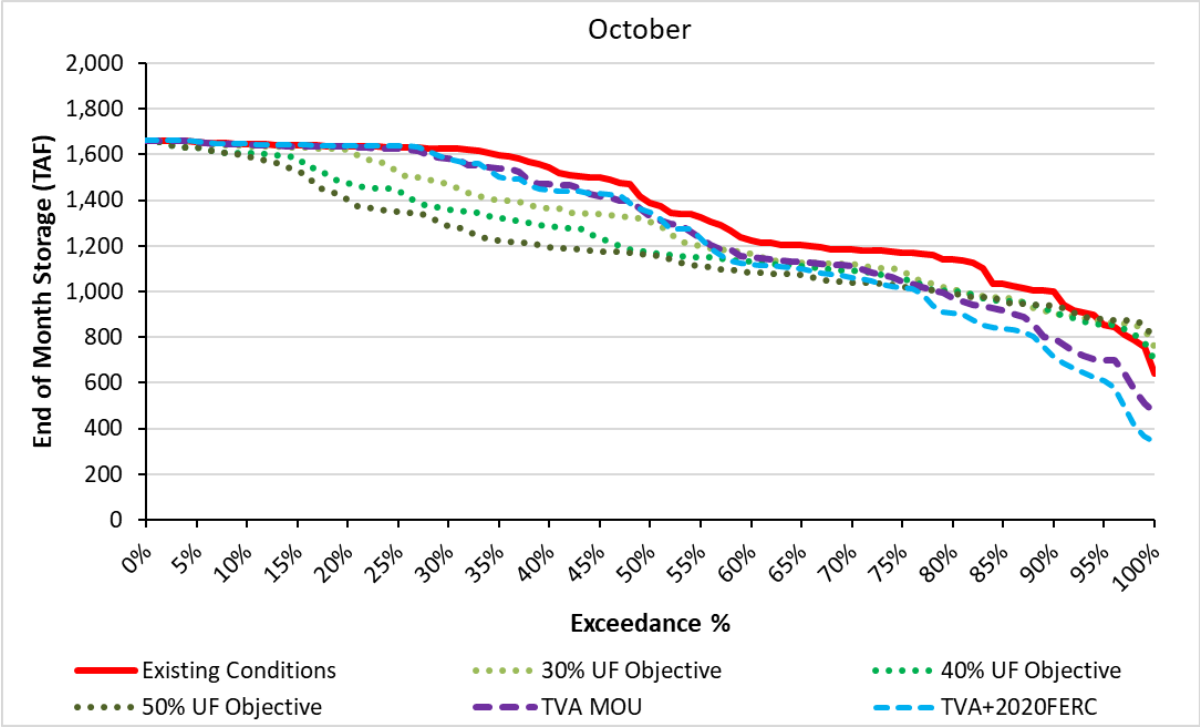


Figure B-43. Exceedance Chart of October Storage Levels from 1922 to 2003 Under the WSE Alternatives.

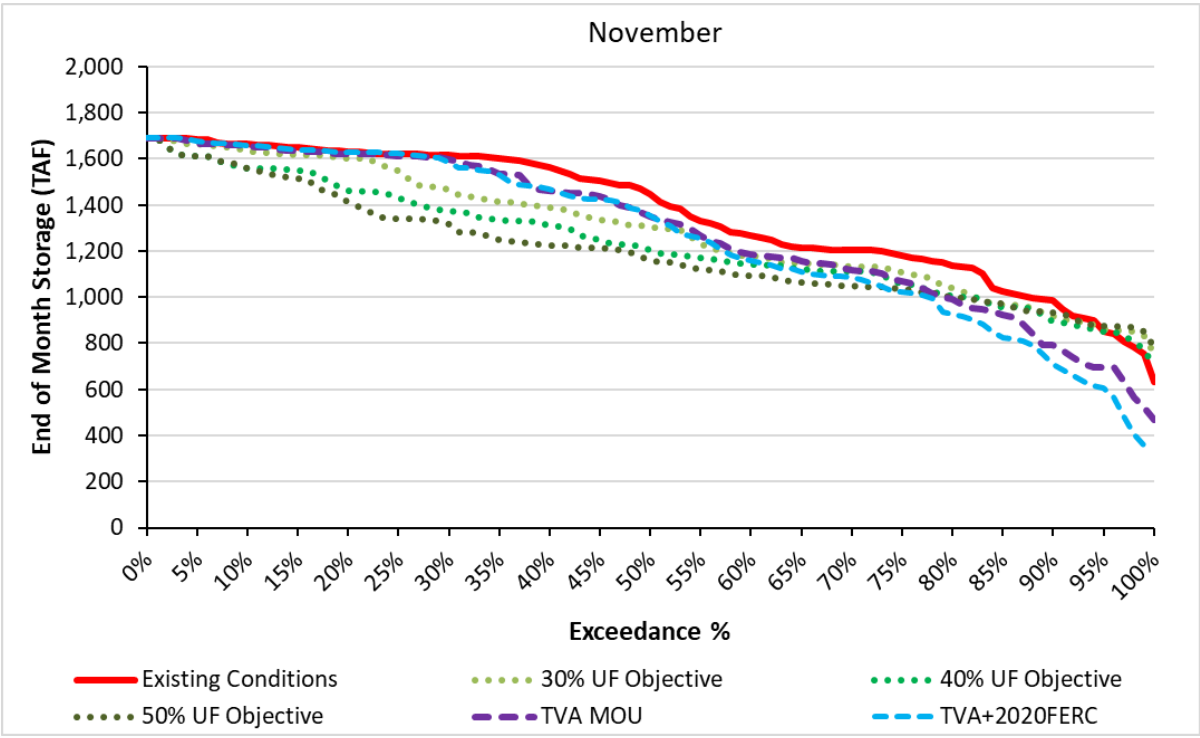


Figure B-44. Exceedance Chart of November Storage Levels from 1922 to 2003 Under the WSE Alternatives.

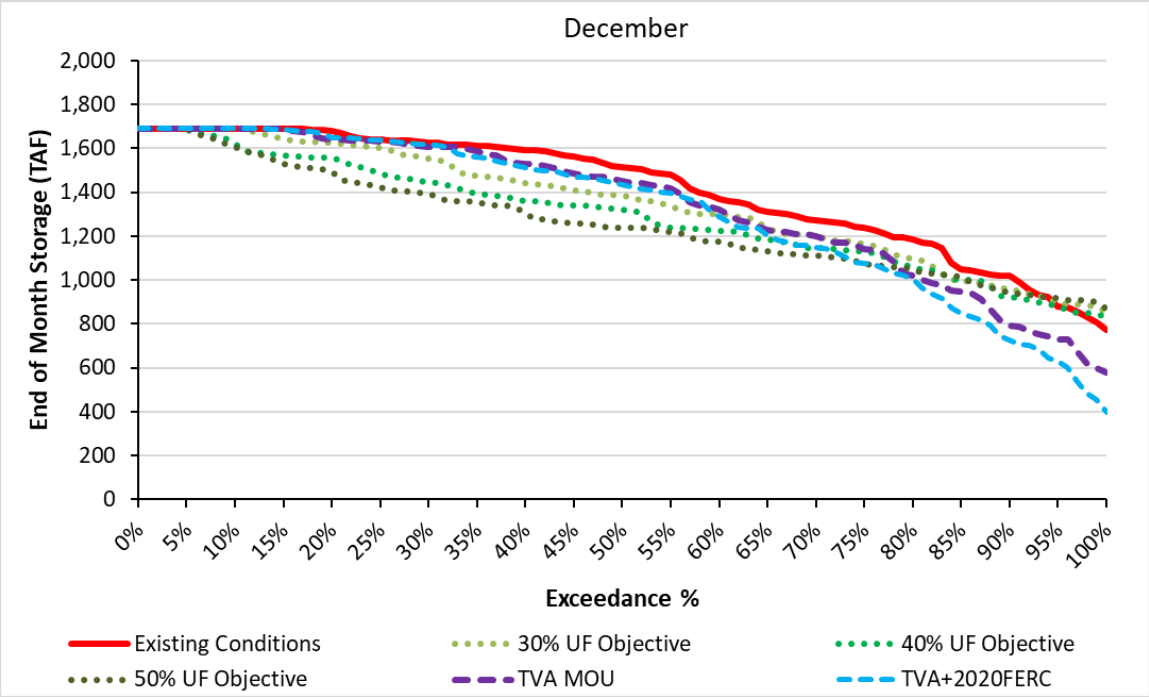


Figure B-45. Exceedance Chart of December Storage Levels from 1922 to 2003 Under the WSE Alternatives.

B.3.3 Tuolumne River Surface Water Diversions

Table B-29 summarizes average annual diversions from the Tuolumne River modeled in WSE and the change under the TVA and UF alternatives relative to the existing conditions baseline. Figure B-46 presents an exceedance chart of annual Tuolumne River diversion results from the WSE model, showing the range of annual diversion values. Overall diversions decrease in the UF alternatives relative to the baseline, with a gradually larger reduction in diversions as the % UF requirement increases. There is no change in diversions under the TVA alternatives since the model was manually set up to maintain baseline diversion levels under the TVA to be consistent with the assumptions in the TVA draft accounting spreadsheet (TID, MID, CCSF 2025). However, maintaining diversion levels under the TVA alternatives results in a trade off, with greater demand being placed on reservoir storage, which could reduce drought resiliency and the cold-water pool.

Table B-29. Average Annual Baseline Water Supply and Difference from Baseline Conditions on the Tuolumne River over the 82-Year Modeling Period.

Alternative	Tuolumne Diversion (TAF)	Difference from Baseline (TAF)	Difference from Baseline (% of Baseline)
Existing Conditions Baseline	839	0	0%
30% UF Objective	788	-52	-6%
40% UF Objective	732	-108	-13%
50% UF Objective	660	-180	-21%
TVA MOU	839	0	0%
TVA+2020FERC [a]	839	0	0%

[a] Annual Diversions under the TVA+2020FERC alternative include diversions at the IGs.

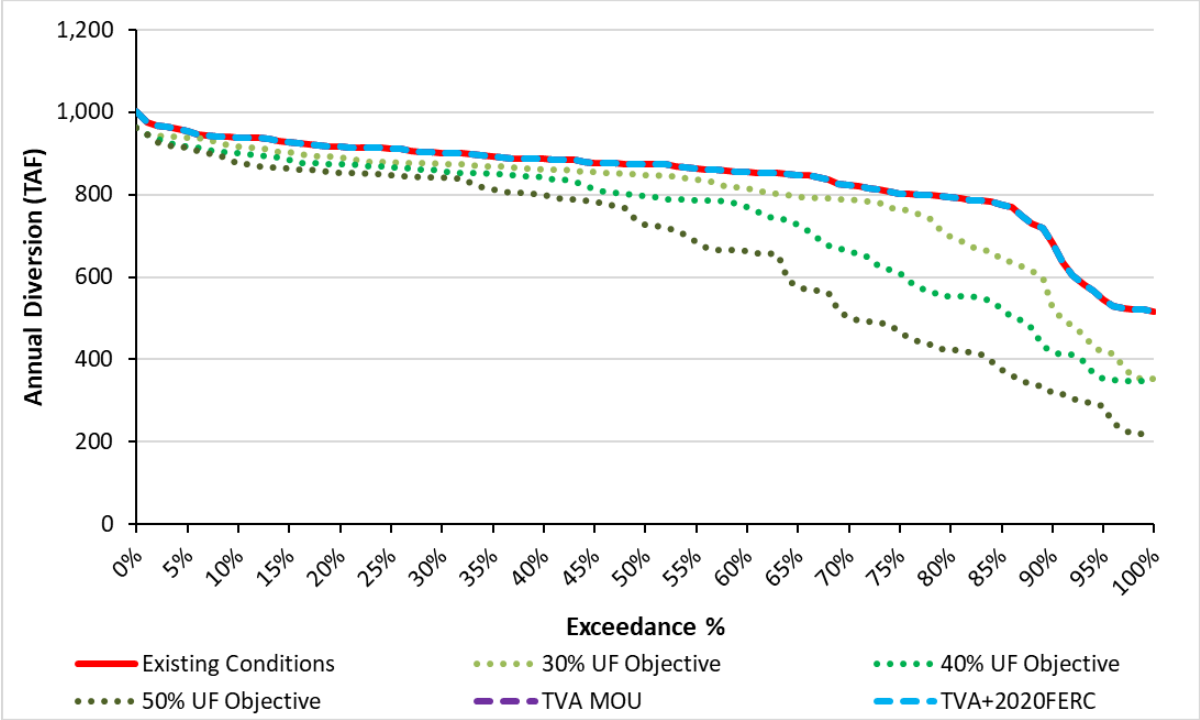


Figure B-46. Exceedance Chart of Annual Tuolumne River Surface Water Diversions from 1922 to 2003 Under the WSE Alternatives.

B.4 HEC-5Q Temperature Modeling – Updates

This section describes the updates made to the HEC-5Q temperature model for the analysis of the TVA. The current version of the HEC-5Q temperature model is mostly the same as the version used to analyze temperature effects for the 2018 Bay-Delta Plan (see Appendix F.1.6 Temperature Modeling), which in turn was based on the SJR Basin-Wide Water Temperature and EC Model released by California Department of Fish and Wildlife (CDFW) in June of 2013 (CDFW 2013). The updates made to the HEC-5Q temperature model for the TVA analysis include the addition of the IG diversion point on the Tuolumne and a correction to where Dry Creek flows enter the Tuolumne. Once the temperature model is finished, the results are postprocessed in an excel workbook to produce temperature summary figures and tables similar to those from the 2018 Final SED. The temperature results are discussed in greater detail in Chapter 5 of this report.

To operate the temperature model, the State Water Board used the Hydrologic Water Quality Modeling System (HWMS), a graphical user interface that provides run management and model result visualization for HEC-5Q. The extent of the HEC-5Q temperature model includes the Merced, Tuolumne, and Stanislaus River systems from their LSJR confluences to the upstream end of the major reservoirs (i.e., Lake McClure, New Don Pedro, and New Melones, respectively). On the SJR, the upstream extent of the model is Salt Slough above the Merced River confluence and the downstream boundary is the SJR at Mossdale. The model simulates reservoir stratification, release temperatures, and downstream river temperatures as a function of the inflow temperatures, reservoir geometry and outlets, flow, meteorology, and river geometry and produces output in 6-hour increments. As in the 2018 Final SED, given the large quantity of data produced by the temperature model, only the results for the 1970–2003 period were postprocessed.

B.4.1 Temperature Model Preprocessing

Before WSE results are input to the temperature model, a preprocessing routine, originally designed so that CALSIM II scenarios could be analyzed with the HEC-5Q model (i.e.,CALSIM to HEC-5Q preprocessor), is used to convert the monthly WSE output to a daily format compatible with the HEC-5Q model. Since the WSE model was developed such that it would output flows at each location corresponding to the CALSIM II nodes it allows for a nearly seamless replacement of CALSIM flow values used in the CALSIM to HEC-5Q preprocessor by the WSE alternative results. However, this preprocessing routine does not account for the Tuolumne IG diversion. Furthermore, the TVA alternatives include flow requirements that operate on a sub-monthly timestep that would not be represented by the results of the preprocessor. Therefore, additional preprocessing steps were included in setting up the temperature model for this analysis.

To set up the TVA alternatives, the CALSIM to HEC-5Q preprocessor was still used, but with the IG diversion temporarily removed. In a separate spreadsheet, a daily IG diversion timeseries was produced assuming a uniform daily diversion rate equal to the monthly diversion rates shown in Table B-23; for October, IG diversion was only included for the first 15 days of the month. For WSE alternatives that did not have the IGs active, a placeholder timeseries representing the IG diversion with all values set to 0 was added to the input file for HEC-5Q instead. Updates were made to the temperature modeling files to account for the IG diversion timeseries as described in the next section.

In addition, a timeseries for daily New Don Pedro outflow under the TVA scenarios was created to model the TVA flow requirements with the daily patterns provided by the TVA parties (TID, MID, CCSF 2024). For the floodplain pulse, the total pulse volume is allocated so that total flow, when including the baseflow, will reach 1700 cfs for the maximum number of days possible given the available water for the pulse. Any remainder is used to provide 1 day of up ramping at the beginning and 1 day of down ramping at the end of the pulse period. Daily target cfs values for the floodplain pulse are shown in Table B-31. For the outmigration pulse, the volume is released to meet a target flow rate that varies by WYT, shown in Table B-30, for a period of 31 days from April 23rd to May 23rd. The pulse also includes 6 days of up ramping from April 17 to April 22 that have a total volume equal to 3 days at the target flow rate and 7 days of down ramping from May 24 to May 30 that have a total volume equal to 3.5 days at the target flow rate. Daily target cfs values for the outmigration pulse are shown in Table B-32. Finally, for the TVA+2020FERC alternative, the fall pulse was allocated from October 4 to October 8 as shown in Table B-33.

Other releases made in WSE from New Don Pedro, including the TVA baseflows, flood spills, and releases for diversions, were assumed to be distributed uniformly over each day of the month. The final daily timeseries for New Don Pedro outflow was created by adding all the individual releases together. The final timeseries was then imported to the HEC-5Q input file produced by the CALSIM to the HEC-5Q preprocessor (this overwrote the New Don Pedro outflow timeseries produced by the preprocessor). Similarly, the Don Pedro outflow timeseries for the existing conditions baseline was adjusted to allocate the April/May outmigration pulse and fall pulse volumes of the 1995 FERC requirements to be released from April 16 to May 15 (without any ramping) and October 5 to 7, respectively.[19]

Table B-30. Representation of the Outmigration Pulse Flow Under the TVA for HEC-5Q.

Water Year Type	Pulse Period Start Date	Pulse Period End Date	Pulse Length (Days)	Target Flow Rate (cfs) [a]	Pulse Volume (AF) [b]	Ramping Volume (AF) [c]	Total Volume (cfs)
Wet	23-Apr	23-May	31	2,017	124,000	26,000	150,000
Above Normal	23-Apr	23-May	31	2,017	124,000	26,000	150,000
Below Normal	23-Apr	23-May	31	1,344	82,667	17,333	100,000
Dry	23-Apr	23-May	31	1,008	62,000	13,000	75,000
Critically Dry	23-Apr	23-May	31	471	28,933	6,067	35,000
Dry Year Off-Ramp	23-Apr	23-May	31	605	37,200	7,800	45,000
Critically Dry Year Off-Ramp	23-Apr	23-May	31	148	9,093	1,907	11,000

[a] Target flow rate for the outmigration pulse without including baseflow. Values are determined from the 2024 spreadsheet provided by the TVA parties (TID, MID, CCSF 2024).

[b] The Pulse volume is the release made to meet the target flow rate over the pulse length.

[c] The ramping volume is divided proportionally to provide 6 days of up ramping before the pulse period start date and 7 days of down ramping after the pulse period end date.

It should also be noted that the CALSIM to HEC-5Q preprocessor and the temperature model do not account for the SJRRP rediversions by PID, WSID, or BCID that have been added to CALSIM II and WSE since the 2018 Bay-Delta Plan update. To avoid incorrectly representing the rediversions in the temperature model, they were removed from the WSE model input for the preprocessor. Flow in the San Joaquin may be slightly overestimated than would be expected if the diversions were included in the temperature model; however, the error should be minimal since the rediversions are generally small (averages 52 cfs a month in WSE) compared to the total flow of the SJR (averages 4,282 cfs per month at Vernalis in WSE). These diversions may be incorporated into the temperature model as part of a future analysis.

[19] The adjustment to the Don Pedro outflow timeseries for the 1995 FERC fall pulse is also applied to temperature modeling for the UF alternatives.

Table B-31. Daily Flow Breakdown for the TVA Floodplain Inundation Pulse Used in the HEC-5Q Temperature Model (in cfs).

Date	Wet Year Pulse	Above Normal Year Pulse	Below Normal Year Pulse	Dry Year Pulse	Critical Year Pulse	Below Normal Year Pulse with Off-Ramp	Dry Year Pulse with Off-Ramp	Critical Year Pulse with Off-Ramp
1-Mar	0	0	0	0	0	0	0	0
2-Mar	0	0	0	0	0	0	0	0
3-Mar	0	0	0	0	0	0	0	0
4-Mar	0	0	0	0	0	0	0	0
5-Mar	0	0	0	0	0	0	0	0
6-Mar	0	0	0	0	0	0	0	0
7-Mar	0	0	0	0	0	0	0	0
8-Mar	0	0	0	0	0	0	0	0
9-Mar	350	350	350	0	0	0	0	0
10-Mar	1,450	1,450	1,450	0	0	0	0	0
11-Mar	1,450	1,450	1,450	0	0	0	0	0
12-Mar	1,450	1,450	1,450	0	0	0	0	0
13-Mar	1,450	1,450	1,450	0	0	0	0	0
14-Mar	1,450	1,450	1,450	283	0	0	0	0
15-Mar	1,450	1,450	1,450	1,475	0	0	0	0
16-Mar	1,450	1,450	1,450	1,475	0	0	0	0
17-Mar	1,450	1,450	1,450	1,475	0	0	0	0
18-Mar	1,450	1,450	1,450	1,475	0	0	0	0
19-Mar	1,450	1,450	1,450	1,475	496	0	308	271
20-Mar	1,450	1,450	1,450	1,475	1,500	825	1,475	1,500
21-Mar	1,450	1,450	1,450	1,475	1,500	1,450	1,475	1,500
22-Mar	1,450	1,450	1,450	1,475	1,500	1,450	1,475	1,500
23-Mar	1,450	1,450	1,450	1,475	1,500	1,450	308	271
24-Mar	1,450	1,450	1,450	1,475	1,500	1,450	0	0
25-Mar	1,450	1,450	1,450	1,475	1,500	1,450	0	0
26-Mar	1,450	1,450	1,450	1,475	1,500	1,450	0	0

Date	Wet Year Pulse	Above Normal Year Pulse	Below Normal Year Pulse	Dry Year Pulse	Critical Year Pulse	Below Normal Year Pulse with Off-Ramp	Dry Year Pulse with Off-Ramp	Critical Year Pulse with Off-Ramp
27-Mar	1,450	1,450	1,450	1,475	1,500	1,450	0	0
28-Mar	1,450	1,450	1,450	1,475	1,500	1,450	0	0
29-Mar	1,450	1,450	1,450	1,475	1,500	1,450	0	0
30-Mar	1,450	1,450	1,450	1,475	1,500	1,450	0	0
31-Mar	1,450	1,450	1,450	1,475	1,500	1,450	0	0
1-Apr	1,450	1,450	1,450	1,475	1,500	1,450	0	0
2-Apr	1,450	1,450	1,450	1,475	1,500	1,450	0	0
3-Apr	1,450	1,450	1,450	1,475	1,500	1,450	0	0
4-Apr	1,450	1,450	1,450	1,475	1,500	1,450	0	0
5-Apr	1,450	1,450	1,450	1,475	1,500	1,450	0	0
6-Apr	1,450	1,450	1,450	1,475	1,500	1,450	0	0
7-Apr	1,450	1,450	1,450	1,475	496	1,450	0	0
8-Apr	1,450	1,450	1,450	1,475	0	1,450	0	0
9-Apr	1,450	1,450	1,450	1,475	0	1,450	0	0
10-Apr	1,450	1,450	1,450	1,475	0	1,450	0	0
11-Apr	1,450	1,450	1,450	283	0	1,450	0	0
12-Apr	1,450	1,450	1,450	0	0	1,450	0	0
13-Apr	350	350	350	0	0	825	0	0
14-Apr	0	0	0	0	0	0	0	0
15-Apr	0	0	0	0	0	0	0	0

Table B-32. Daily Flow Breakdown for the TVA Outmigration Pulse Used in the HEC-5Q Temperature Model (in cfs).

Date	Wet Year Pulse	Above Normal Year Pulse	Below Normal Year Pulse	Dry Year Pulse	Critical Year Pulse	Dry Year Pulse with Off-Ramp	Critical Year Pulse with Off-Ramp
16-Apr	0	0	0	0	0	0	0
17-Apr	288	288	192	144	67	86	21
18-Apr	576	576	384	288	134	173	42
19-Apr	864	864	576	432	202	259	63
20-Apr	1,152	1,152	768	576	269	346	85
21-Apr	1,440	1,440	960	720	336	432	106
22-Apr	1,729	1,729	1,152	864	403	519	127
23-Apr	2,017	2,017	1,344	1,008	471	605	148
24-Apr	2,017	2,017	1,344	1,008	471	605	148
25-Apr	2,017	2,017	1,344	1,008	471	605	148
26-Apr	2,017	2,017	1,344	1,008	471	605	148
27-Apr	2,017	2,017	1,344	1,008	471	605	148
28-Apr	2,017	2,017	1,344	1,008	471	605	148
29-Apr	2,017	2,017	1,344	1,008	471	605	148
30-Apr	2,017	2,017	1,344	1,008	471	605	148
1-May	2,017	2,017	1,344	1,008	471	605	148
2-May	2,017	2,017	1,344	1,008	471	605	148
3-May	2,017	2,017	1,344	1,008	471	605	148
4-May	2,017	2,017	1,344	1,008	471	605	148
5-May	2,017	2,017	1,344	1,008	471	605	148
6-May	2,017	2,017	1,344	1,008	471	605	148
7-May	2,017	2,017	1,344	1,008	471	605	148
8-May	2,017	2,017	1,344	1,008	471	605	148
9-May	2,017	2,017	1,344	1,008	471	605	148
10-May	2,017	2,017	1,344	1,008	471	605	148
11-May	2,017	2,017	1,344	1,008	471	605	148
12-May	2,017	2,017	1,344	1,008	471	605	148

Date	Wet Year Pulse	Above Normal Year Pulse	Below Normal Year Pulse	Dry Year Pulse	Critical Year Pulse	Dry Year Pulse with Off-Ramp	Critical Year Pulse with Off-Ramp
13-May	2,017	2,017	1,344	1,008	471	605	148
14-May	2,017	2,017	1,344	1,008	471	605	148
15-May	2,017	2,017	1,344	1,008	471	605	148
16-May	2,017	2,017	1,344	1,008	471	605	148
17-May	2,017	2,017	1,344	1,008	471	605	148
18-May	2,017	2,017	1,344	1,008	471	605	148
19-May	2,017	2,017	1,344	1,008	471	605	148
20-May	2,017	2,017	1,344	1,008	471	605	148
21-May	2,017	2,017	1,344	1,008	471	605	148
22-May	2,017	2,017	1,344	1,008	471	605	148
23-May	2,017	2,017	1,344	1,008	471	605	148
24-May	1,765	1,765	1,176	882	412	529	129
25-May	1,513	1,513	1,008	756	353	454	111
26-May	1,260	1,260	840	630	294	378	92
27-May	1,008	1,008	672	504	235	303	74
28-May	756	756	504	378	176	227	55
29-May	504	504	336	252	118	151	37
30-May	252	252	168	126	59	76	18
31-May	0	0	0	0	0	0	0

Table B-33. Daily Flow Breakdown for the 2020 FERC Fall Pulse Used in the HEC-5Q Temperature Model (in cfs).

Date	Wet Year Pulse	Above Normal Year Pulse	Below Normal Year Pulse	Dry Year Pulse	Critical Year Pulse
1-Oct	0	0	0	0	0
2-Oct	0	0	0	0	0
3-Oct	0	0	0	0	0
4-Oct	450	450	450	450	450
5-Oct	700	700	700	700	700
6-Oct	700	700	700	700	700
7-Oct	700	700	700	700	700
8-Oct	450	450	450	450	450
9-Oct	0	0	0	0	0
10-Oct	0	0	0	0	0
11-Oct	0	0	0	0	0
12-Oct	0	0	0	0	0
13-Oct	0	0	0	0	0
14-Oct	0	0	0	0	0
15-Oct	0	0	0	0	0

B.4.2 Temperature Model Modifications

All updates to the temperature model were applied in the 3R_CS_5.dat and 3R_CS_5Q.dat files. For the temperature model, each river is made up of reaches that are separated by control points (CPs) defined in the 3R_CS_5.dat file. The control points that make up the Tuolumne from upstream to downstream are: CP 450 (La Grange, RM 53.5), CP 448 (Don Pedro Control, RM 52.8), CP 440 (Turlock State Park, RM 42.9), CP 430 (Waterford, RM 33.1), CP 420 (Santa Fe Ave Bridge, RM 22.5), 410 (Modesto, RM 16.1), and CP 405 (confluence with the SJR, RM 0). Diversions are implemented in a reach by adding a "DR record" for the downstream CP that specifies what percentage of the diversion occurs between that downstream CP and the closest upstream CP. However, each CP can only have one DR record. In addition, diversions default to being distributed over the length of the reach rather than at a specific point. Additional information on how the HEC-5Q model works is available in the HEC-5 model documentation (USACE 1998) and the HEC-5Q input parameter documentation (Smith 2013).

The IG diversion is located at RM 25.9, between CPs 430 and 420. In the base version of the model there was already a DR record between CPs 430 and 420, which represented 30% of the total depletion/losses on the Tuolumne between La Grange and the confluence. The other 70% of the losses were distributed over the other reaches, with 10% between CP 448 to 440, 20% between CP 440 to 430, and 40% between CP 420 to 410. To add a DR record for the IG diversion in the correct location, the loss term between CPs 430 and 420 was redistributed over the other reaches, assigning 10% extra to each of them.[20] A new "QD record" for CP 420 was also added to the 3R_CS_5.dat file to read in the IG diversion timeseries from the DSS input file for the temperature model. Finally, in the 3R_CS_5Q.dat file a second "SI record" was added following the "S2 record" for the reach from CP 430 to 420 which identifies that the diversion should be withdrawn at a specific point (in this case reference point 107.2, which corresponds to RM 25.9).

One additional change was made to the 3R_CS_5Q.dat file to correct the inflow location of Dry Creek, a tributary on the north side of the Tuolumne River. The Dry Creek confluence is located in downtown Modesto at about RM 16.5 on the Tuolumne; however, in the base version of the temperature model it was placed about 5 miles upstream at RM 21.7. Both RM 21.7 and RM 16.5 are part of the reach between CPs 420 and 410. To correct the error, the reference location identified in the SI record following the S2 record for the reach from CP 430 to 420 was changed from 103.0 to 97.8.

[20] The input timeseries to the temperature model for Tuolumne River losses is 0 in all months except February 1984 (average monthly losses equal 145.42) and December 1998 (average monthly losses equal 11.21 cfs), so this change should have minimal effect on model results for runs that do not include IG diversions under the TVA.

B.5 HEC-5Q Temperature Modeling – Summary Results

This section compares HEC-5Q temperature model results on the Tuolumne River for the TVA MOU and TVA+2020FERC alternatives with the results of the existing conditions baseline and with alternatives representing the potential implementation of the 2018 Bay-Delta Plan, which is the 40% UF alternative plus the 30% and 50% UF alternatives to represent adaptive implementation. The results shown here are created by postprocessing the temperature model output (produced in 6-hour increments) to identify average daily and maximum daily temperatures over the 1970 to 2003 period. Results are further postprocessed to determine the 7-day average of daily maximum (7DADM) temperatures for each day, which is an important metric used by the U.S. Environmental Protection Agency (USEPA) to estimate the suitability of temperature conditions for fish as it describes the maximum temperatures that fish are exposed to over the past week. Subsection B.5.1 below presents longitudinal profiles of average monthly 7DADM temperatures along the length of the Tuolumne River, while Subsections B.5.2 through B.5.6 present more detailed temperature results for specific locations, starting at La Grange Diversion dam followed by downstream locations roughly at quarter markers along the river. Further analysis and discussion of temperature model results is presented in Chapter 5, which compares the temperature model results against USEPA temperature benchmarks for different fish life stages.

B.5.1 Tuolumne River Longitudinal Temperature Profiles

Figure B-47 through Figure B-58 present longitudinal profiles of average monthly 7DADM temperatures over 1970 to 2003 along the length of the Tuolumne River from La Grange to the confluence with the SJR. Figure B-59 through Figure B-70 present similar longitudinal profiles of average monthly 7DADM temperatures to the previous 12 figures, but only averaging results over critical years.[21] During November through February, temperatures are relatively constant along the length of the river, varying by about 1 or 2 degrees between La Grange and the confluence, and there is little difference between the alternatives. Starting in March, temperatures begin to rise as water flows downriver, gradually from March to May and more quickly from June onwards through the summer. For the TVA MOU alternative, the greatest effects come in March through May, corresponding to pulse flow periods, with average monthly 7DADM temperatures reduced below existing condition levels along the length of the river (but still higher than in the UF alternatives). The TVA + 2020 FERC alternative shares the same improvements as the TVA MOU alternative during March through May, but also shows much lower temperatures in the upper half of the river over the summer as IG operation allows greater instream flow release at La Grange.

[21] There are 9 critical years from 1970 to 2003: 1976, 1977, 1987-1992, and 1994. Since annual operations for the TVA flow requirements begin updating in February of each year and extend through the following January, the flows and temperatures seen in the October through January period are more dependent on the previous year's WYT than the current one. Therefore, the averaging period for WYT in the temperature figures is shifted forward to apply from February through January rather than October through September. For example, October 1975 through January 1976 are officially part of a C water year (1976), but in this averaging they are assigned the designation for water year 1975 which was W.

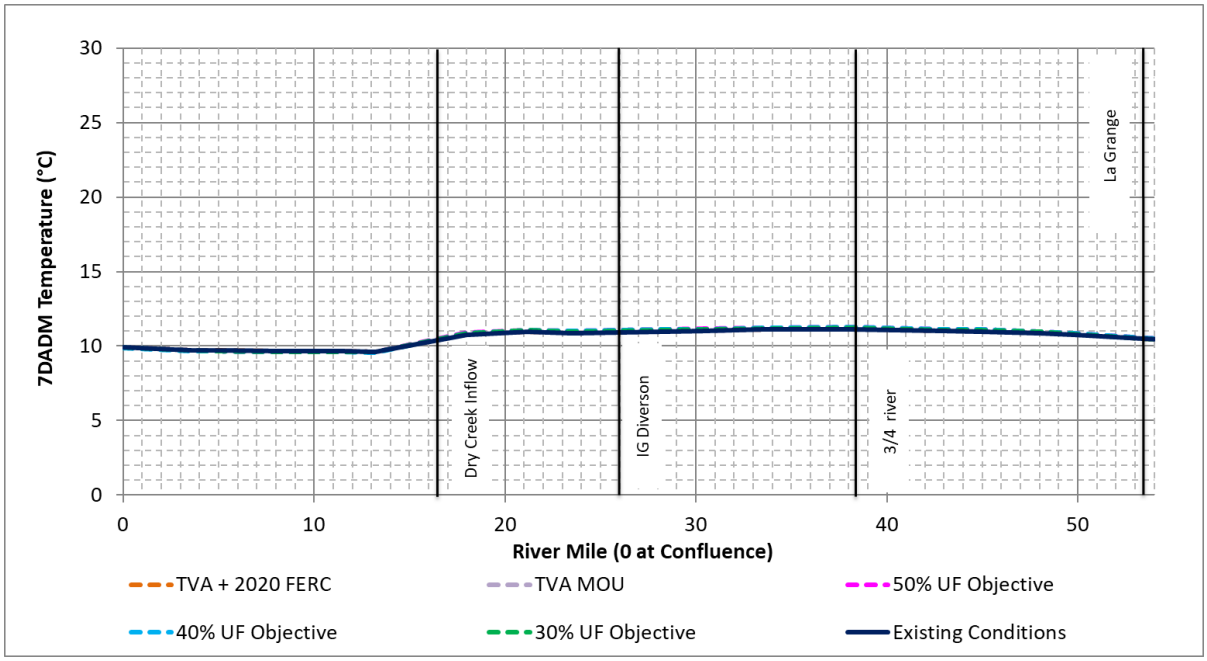


Figure B-47. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in January (Averaged over All Years from 1970 to 2003).

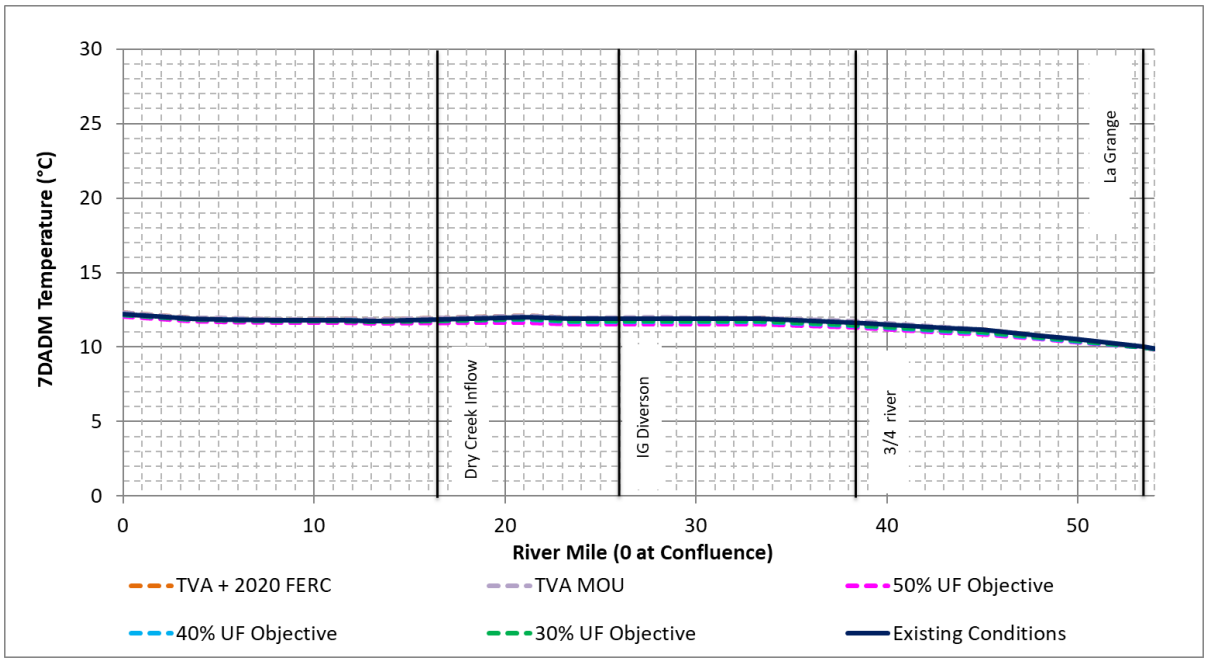


Figure B-48. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in February (Averaged over All Years from 1970 to 2003).

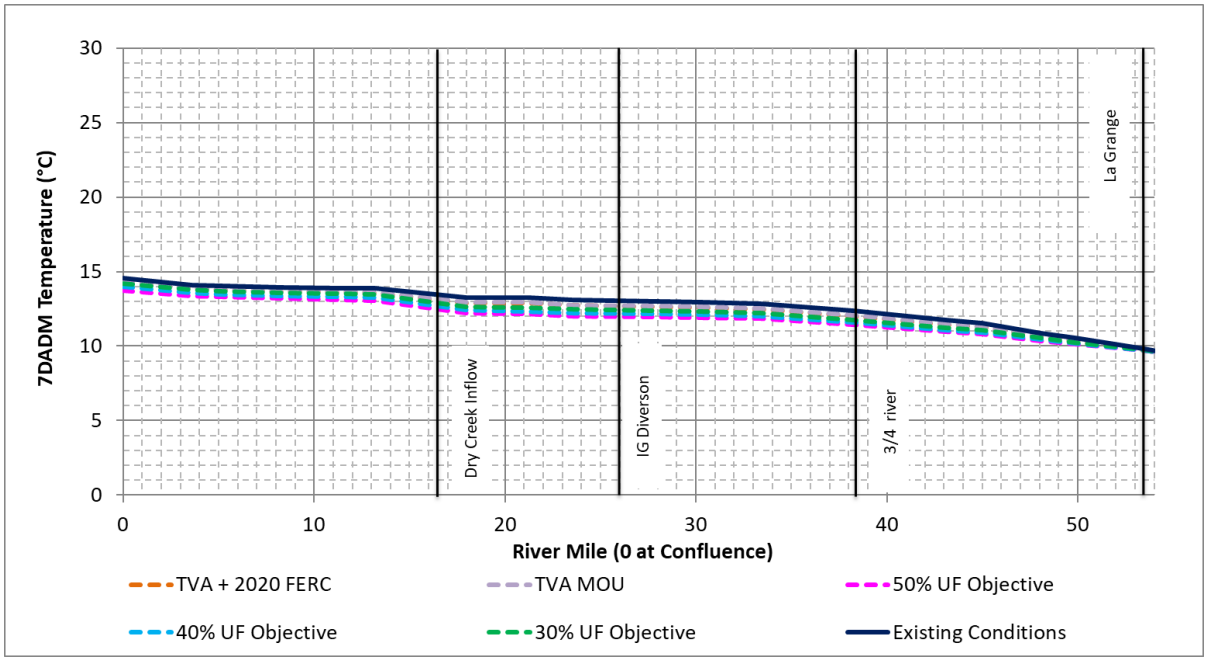


Figure B-49. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in March (Averaged over All Years from 1970 to 2003).

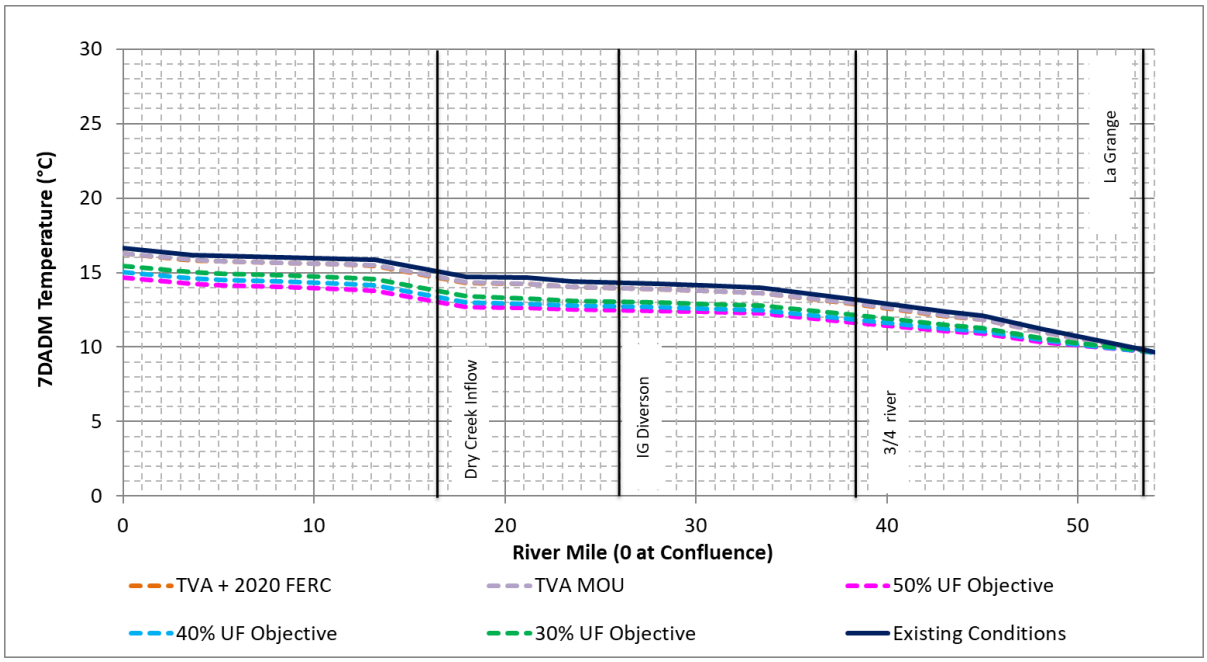


Figure B-50. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in April (Averaged over All Years from 1970 to 2003).

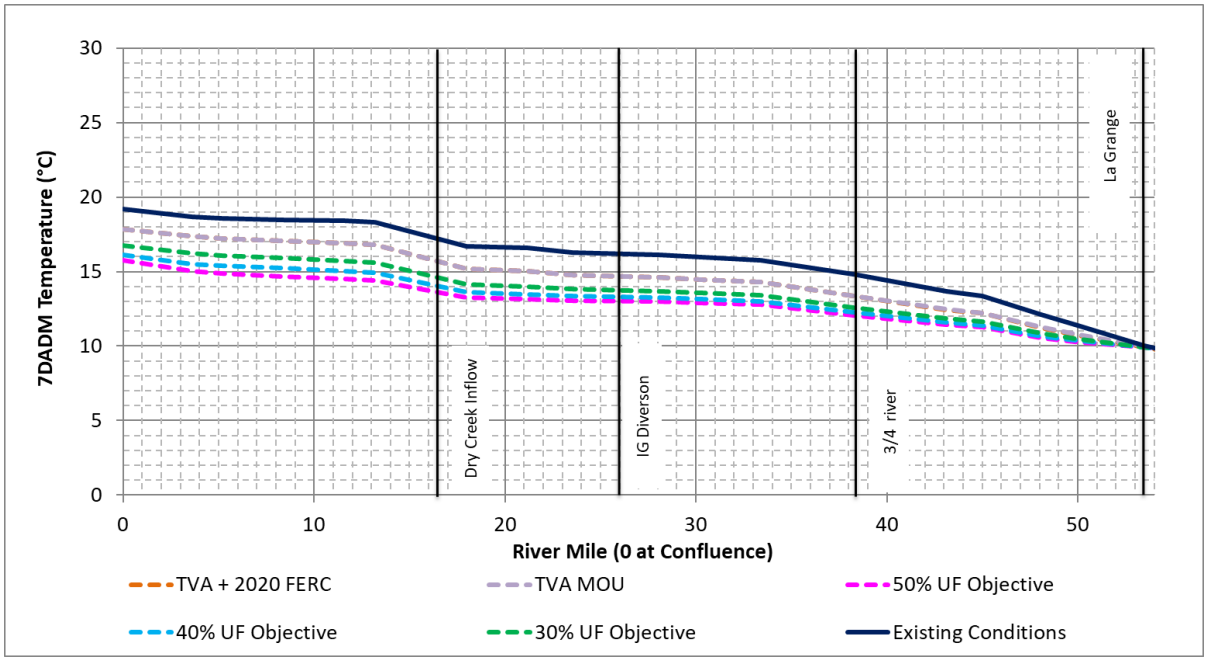


Figure B-51. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in May (Averaged over All Years from 1970 to 2003).

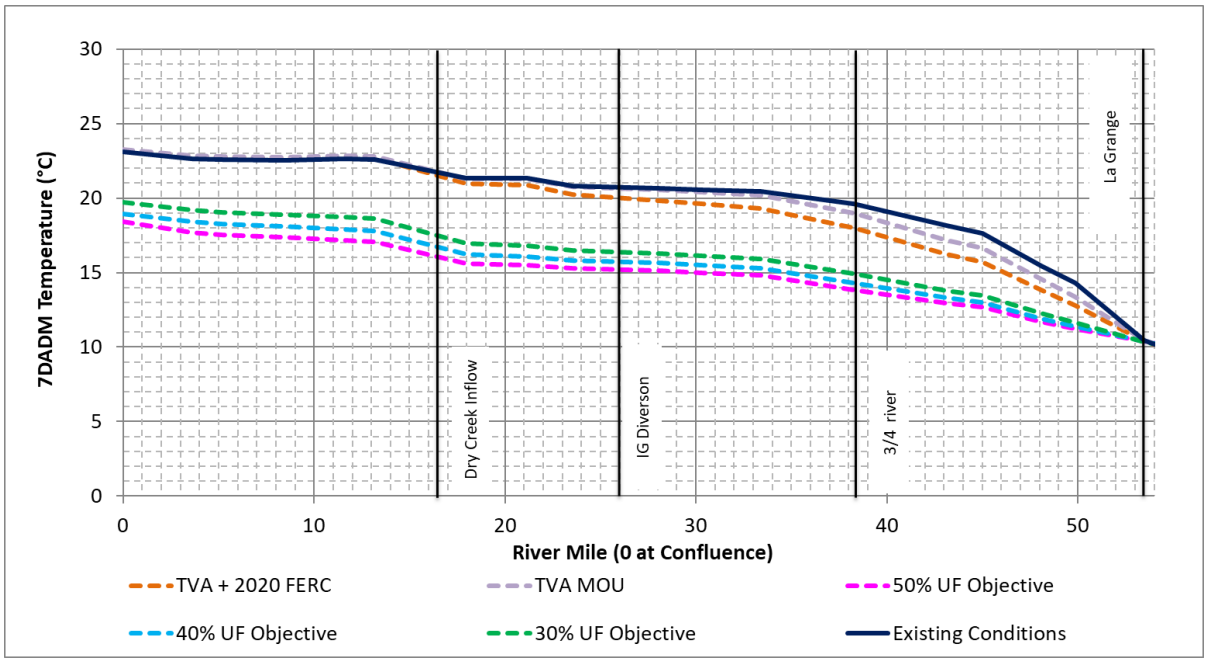


Figure B-52. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in June (Averaged over All Years from 1970 to 2003).

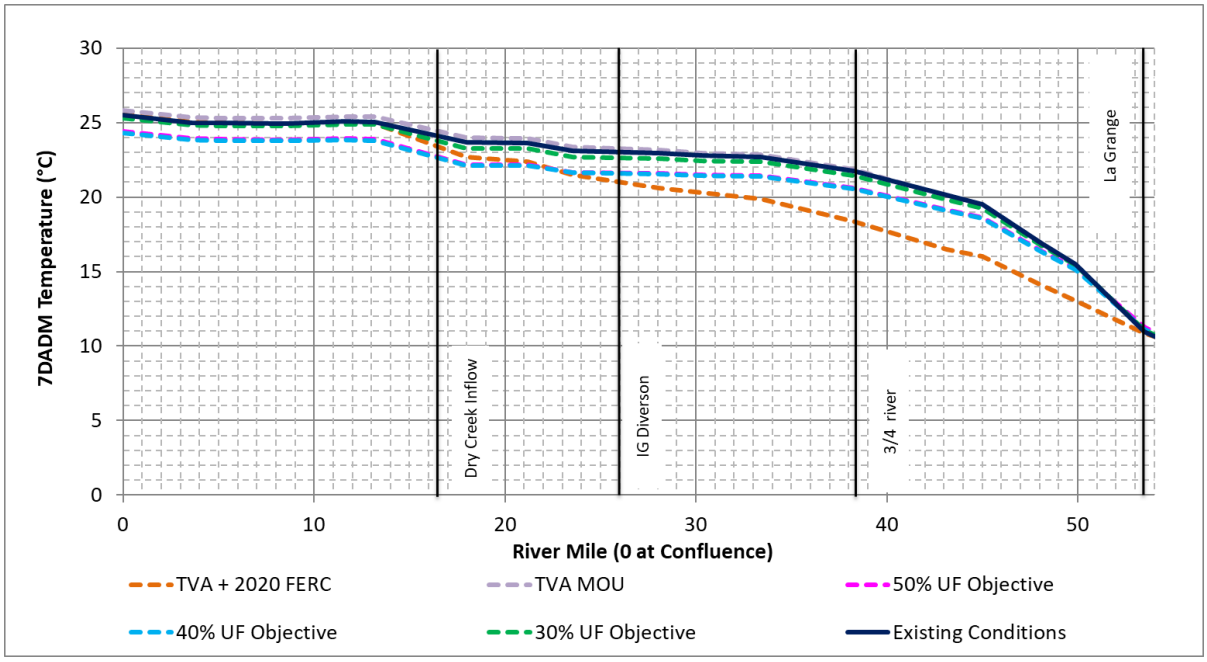


Figure B-53. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in July (Averaged over All Years from 1970 to 2003).

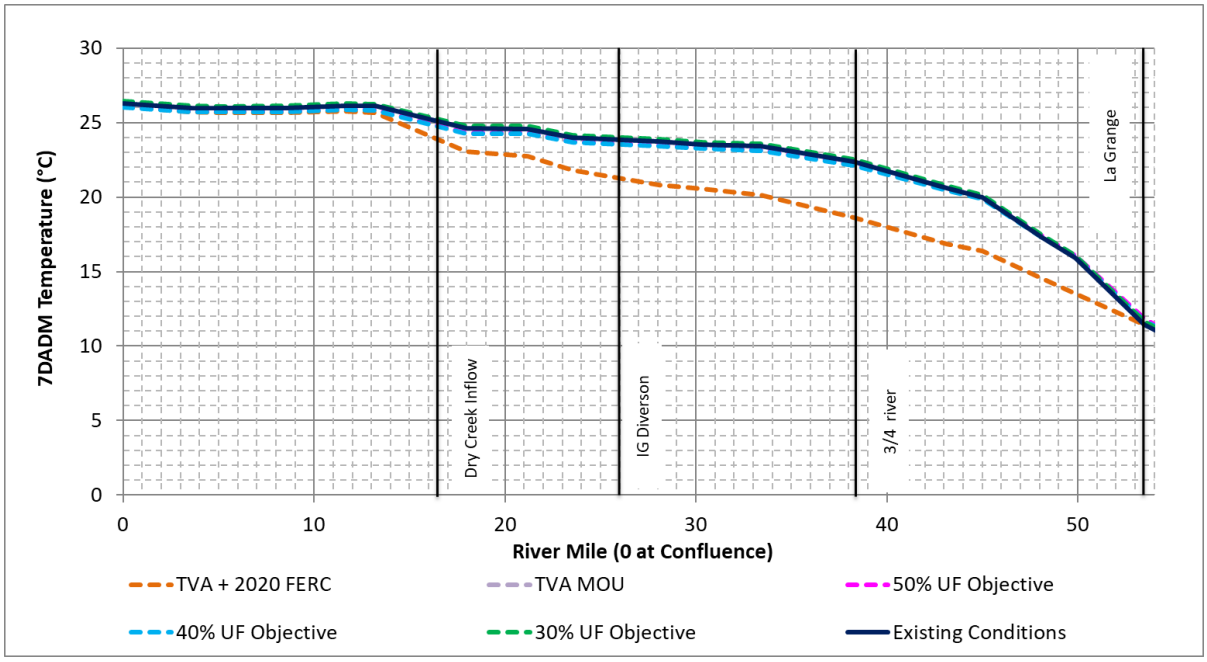


Figure B-54. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in August (Averaged over All Years from 1970 to 2003).

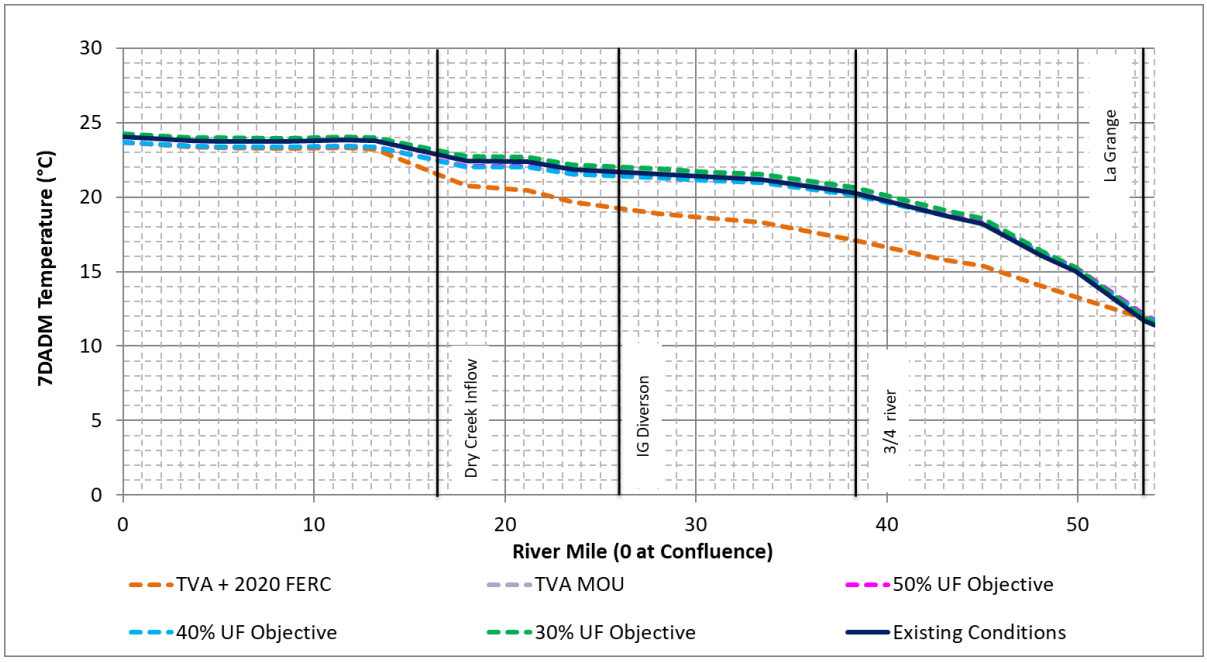


Figure B-55. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in September (Averaged over All Years from 1970 to 2003).

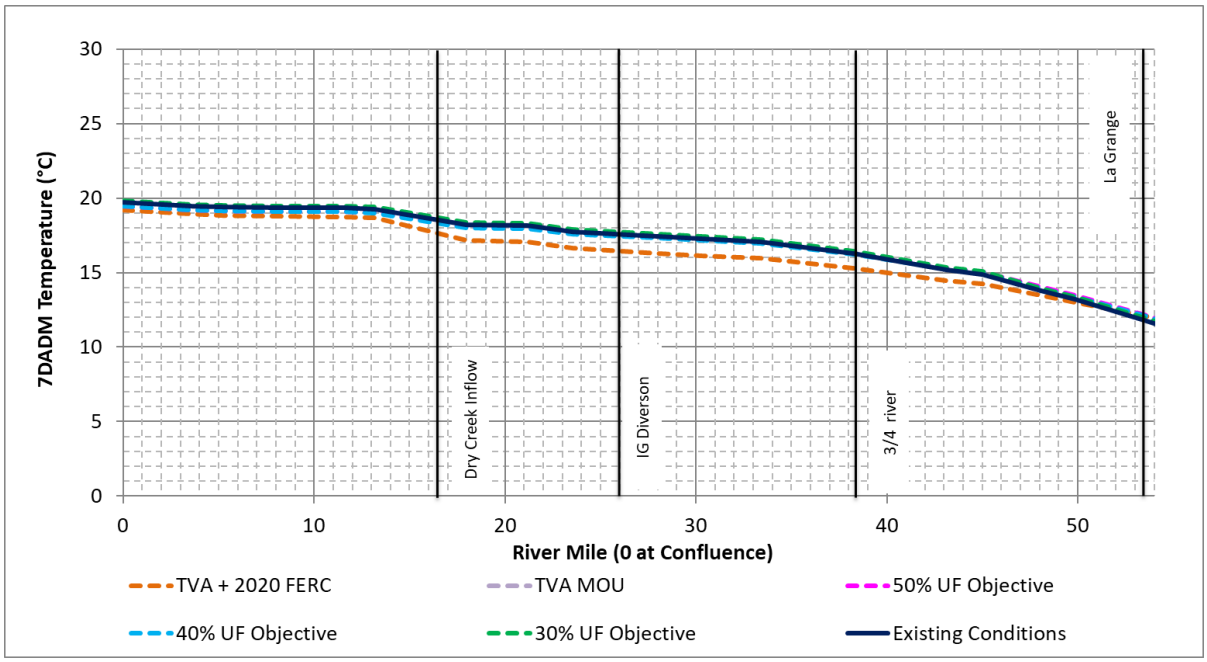


Figure B-56. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in October (Averaged over All Years from 1970 to 2003).

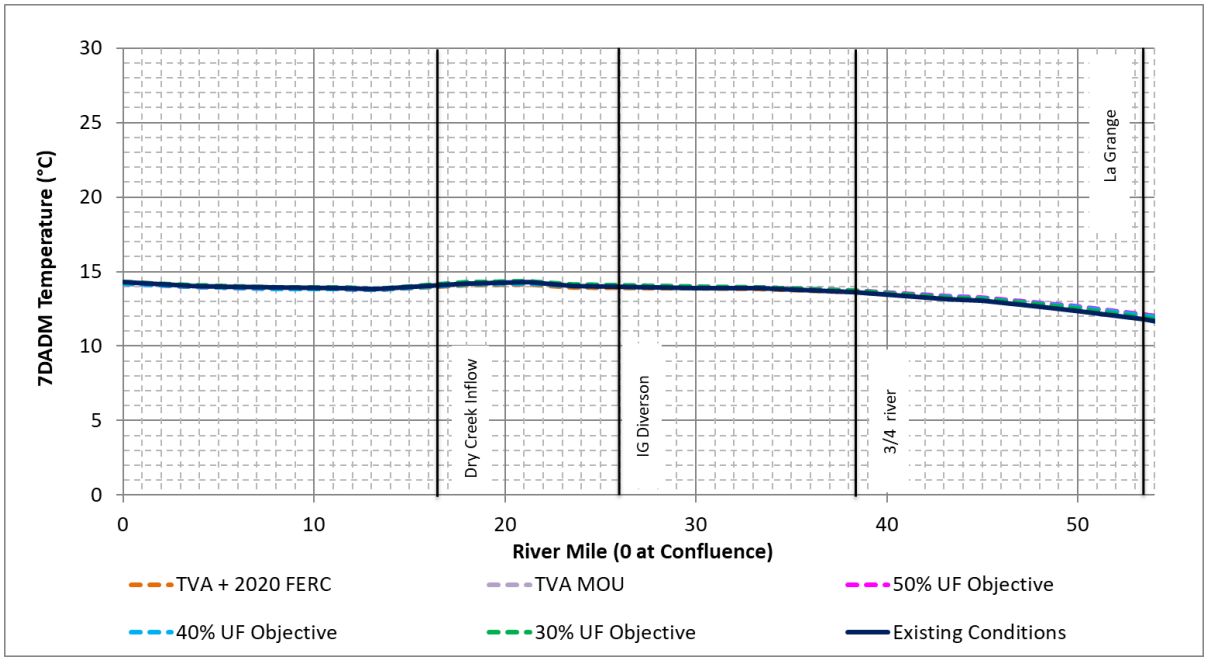


Figure B-57. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in November (Averaged over All Years from 1970 to 2003).

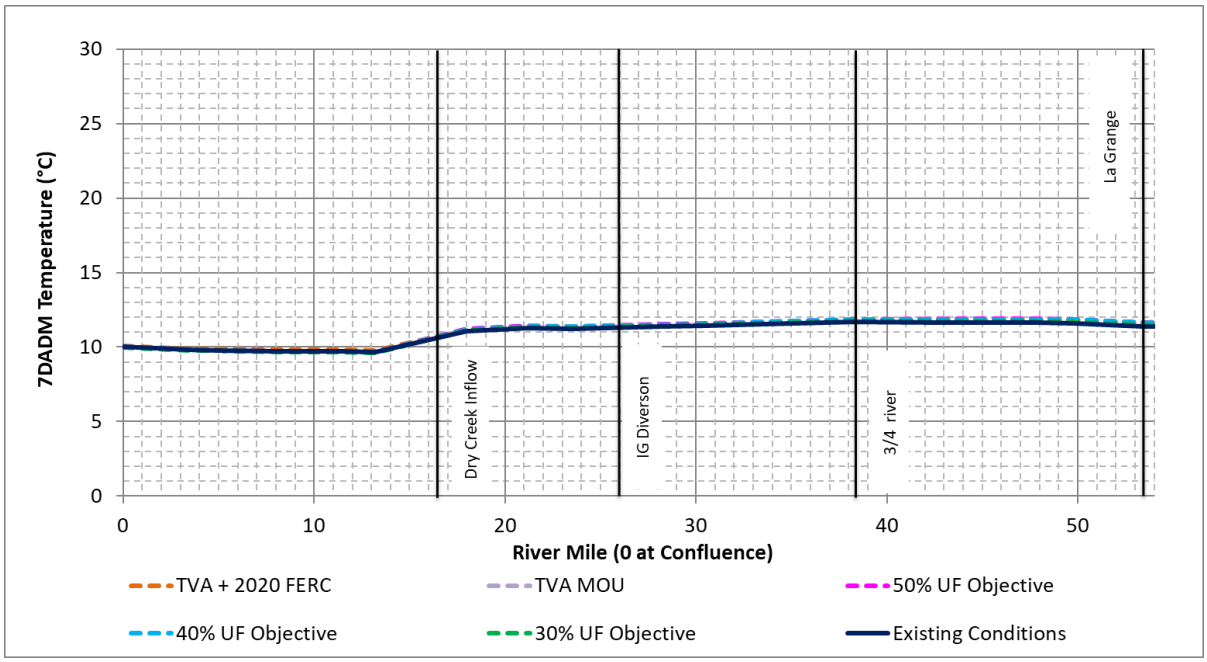


Figure B-58. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in December (Averaged over All Years from 1970 to 2003).

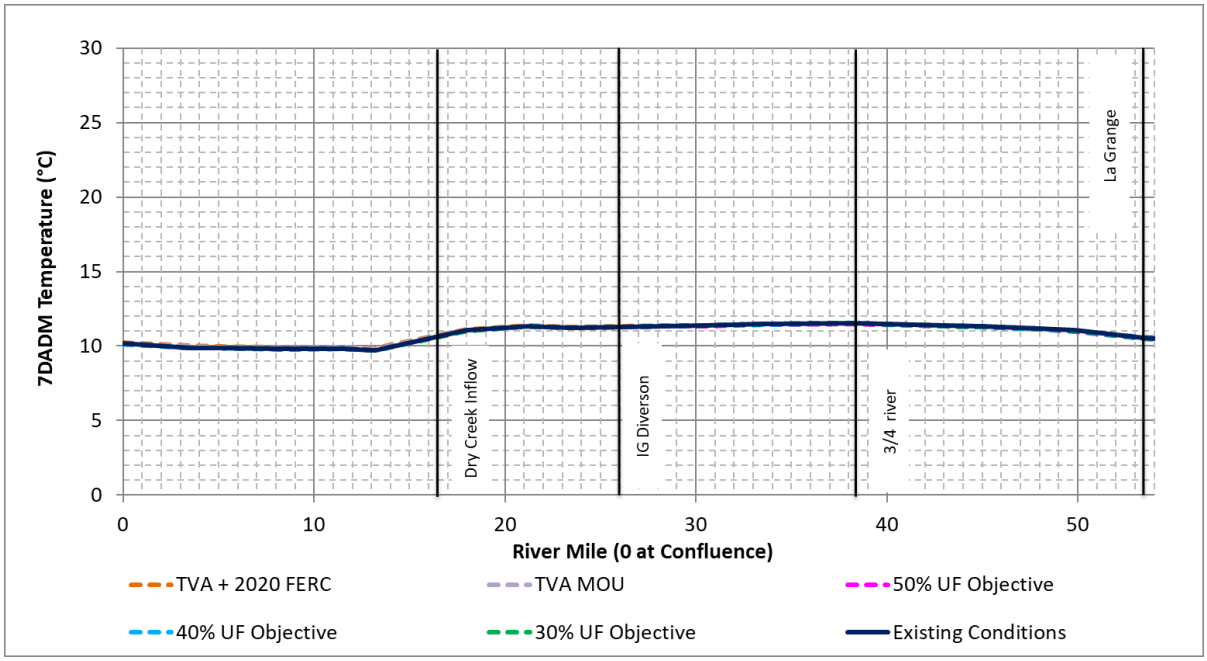


Figure B-59. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in January (Averaged over Critical Years from 1970 to 2003).

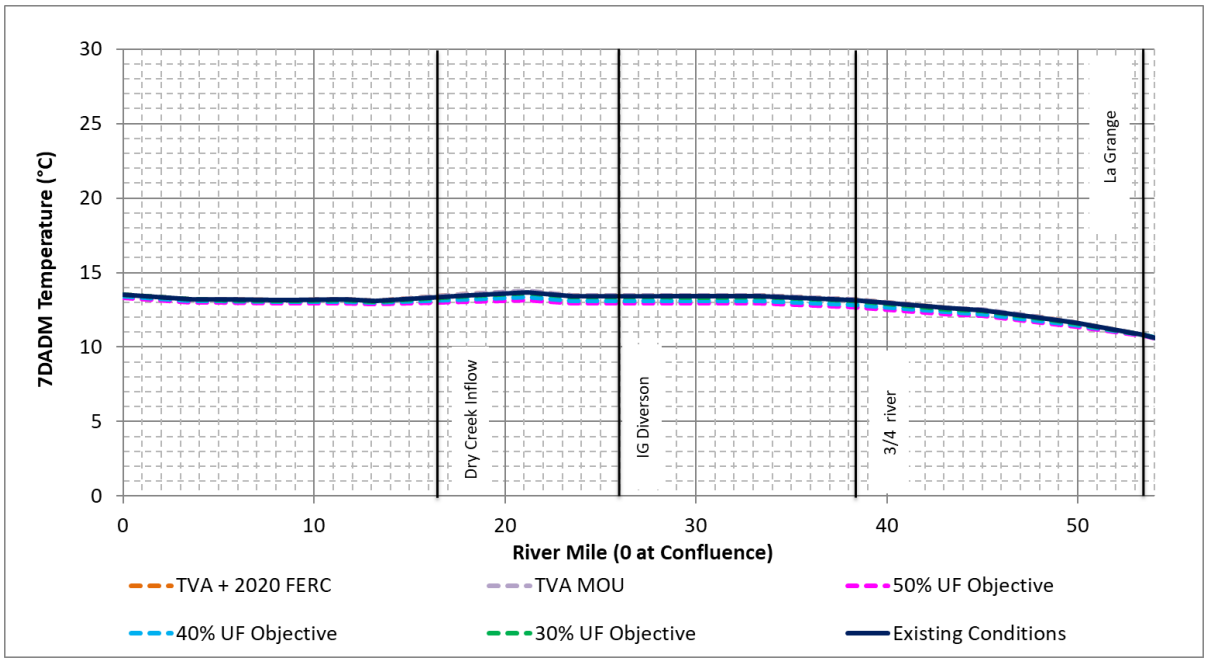


Figure B-60. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in February (Averaged over Critical Years from 1970 to 2003).

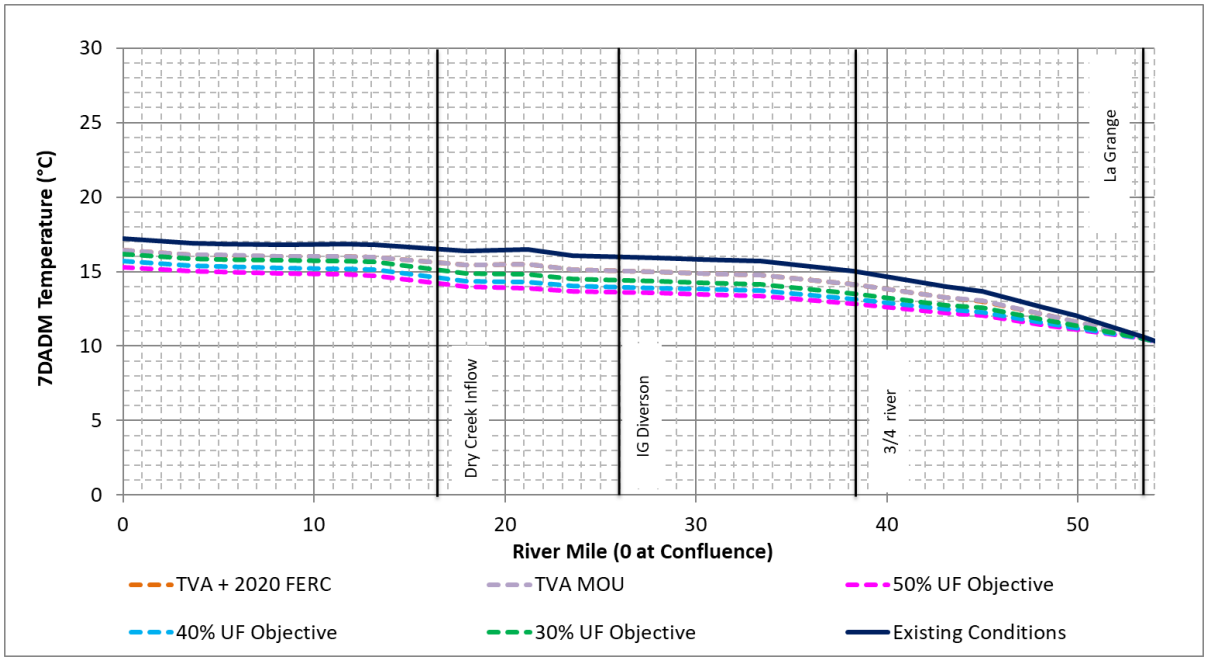


Figure B-61. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in March (Averaged over Critical Years from 1970 to 2003).

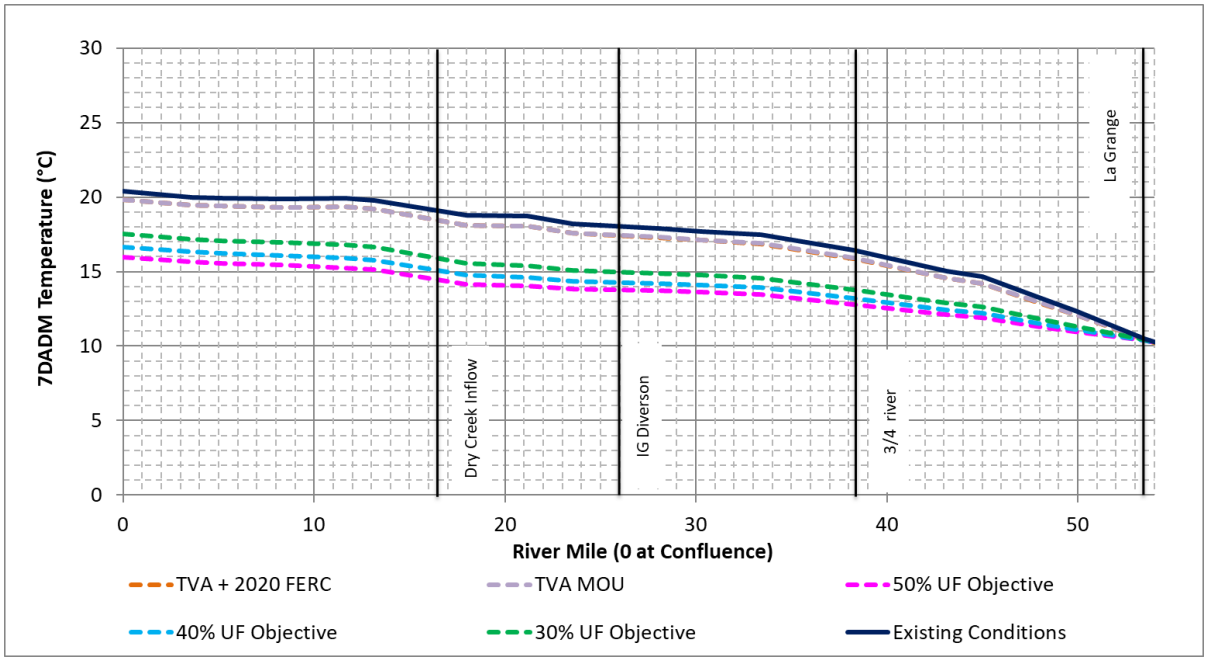


Figure B-62. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in April (Averaged over Critical Years from 1970 to 2003).

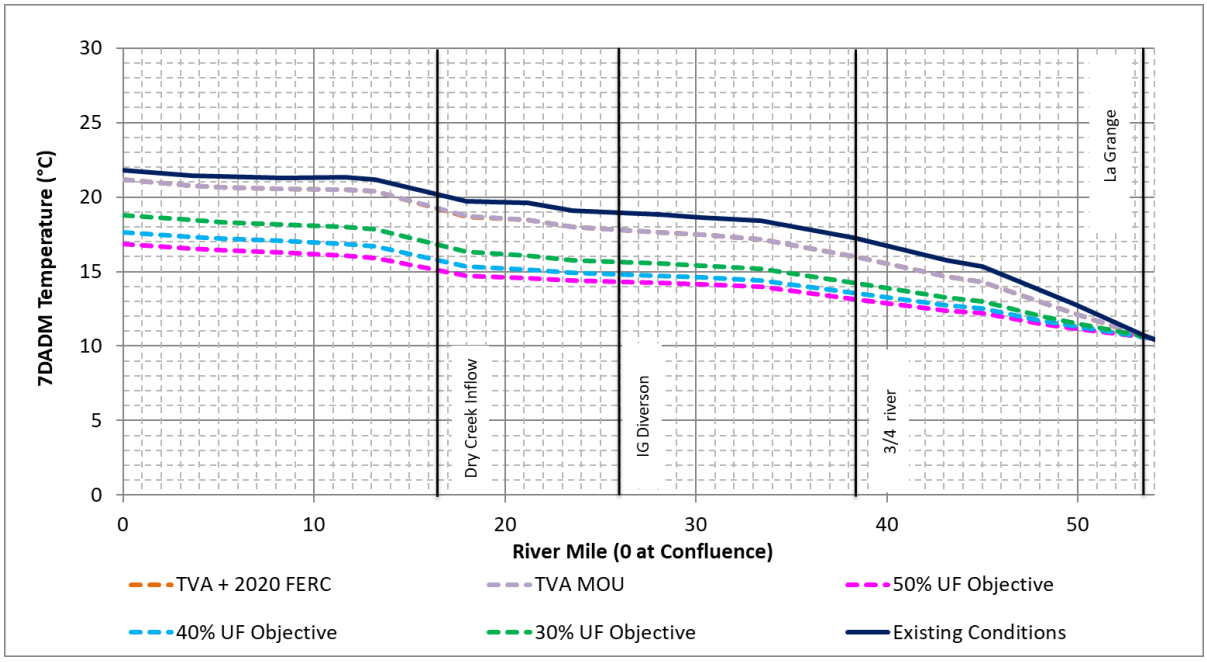


Figure B-63. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in May (Averaged over Critical Years from 1970 to 2003).

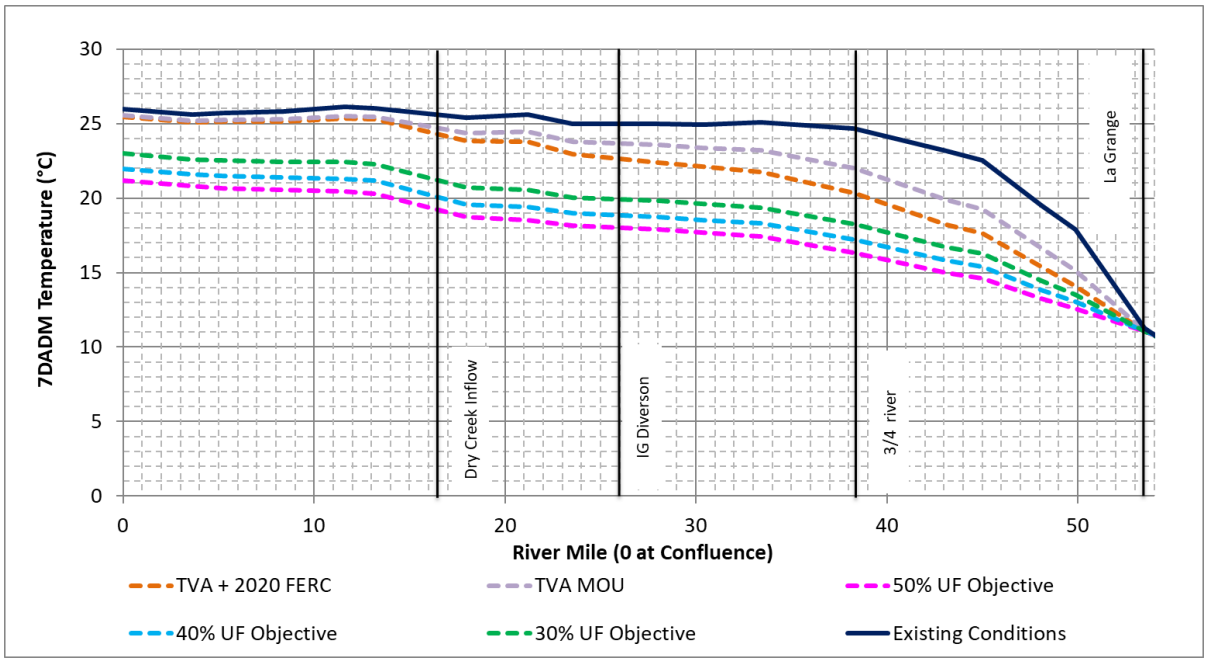


Figure B-64. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in June (Averaged over Critical Years from 1970 to 2003).

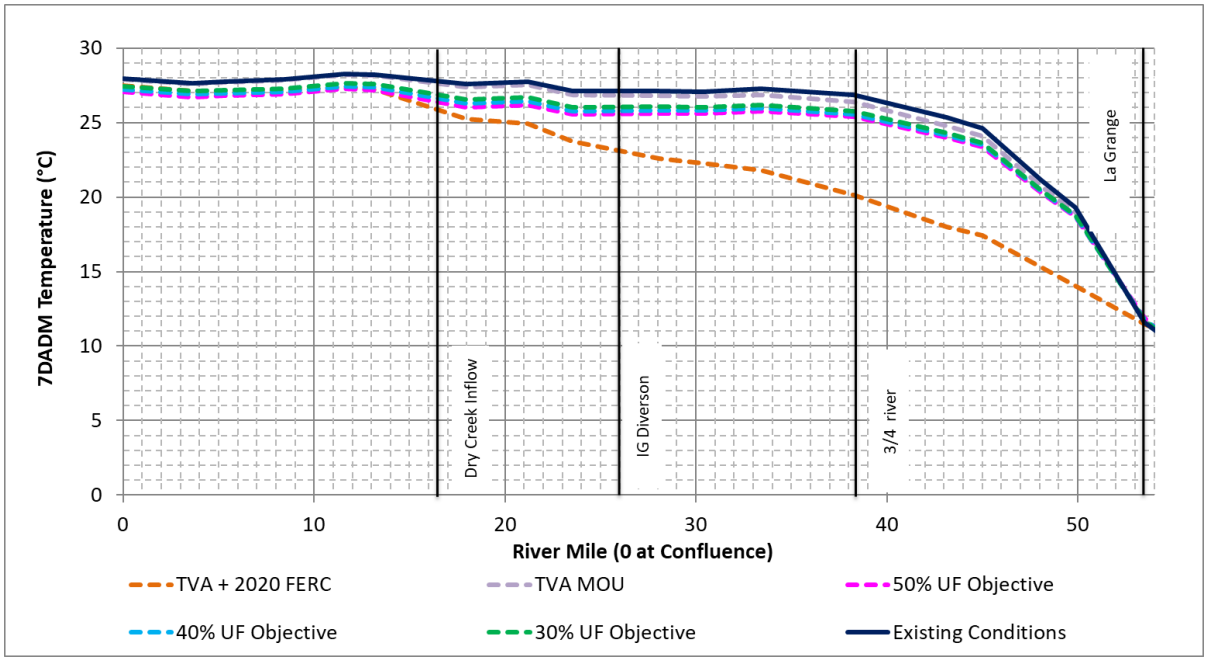


Figure B-65. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in July (Averaged over Critical Years from 1970 to 2003).

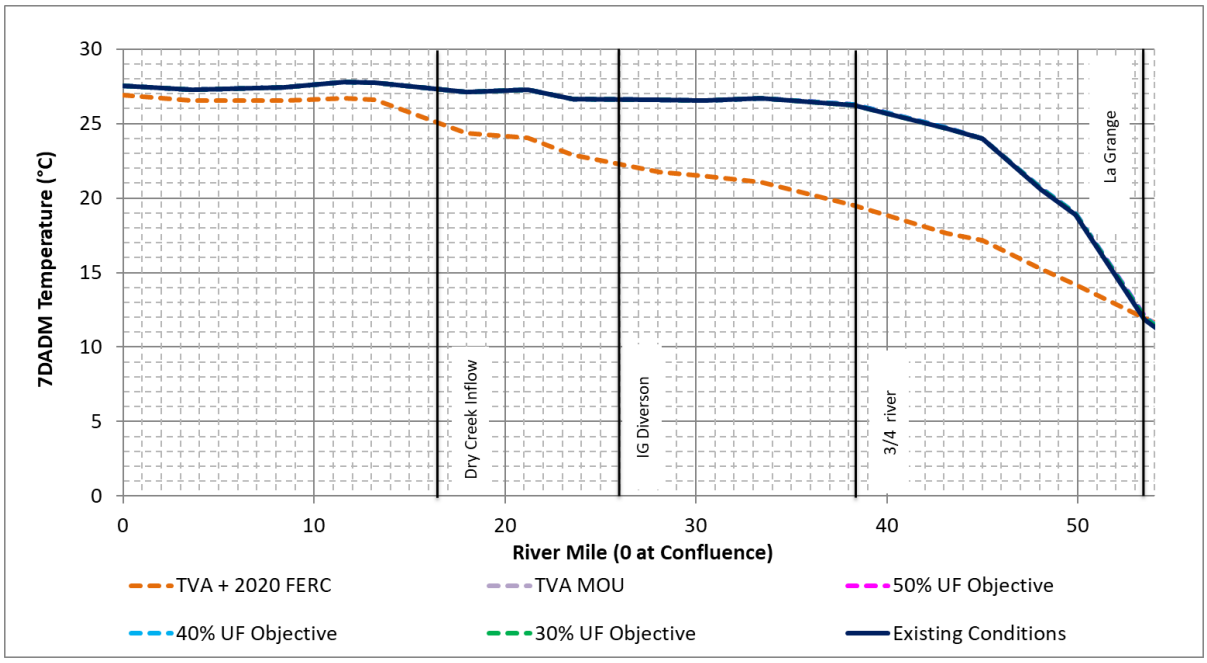


Figure B-66. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in August (Averaged over Critical Years from 1970 to 2003).

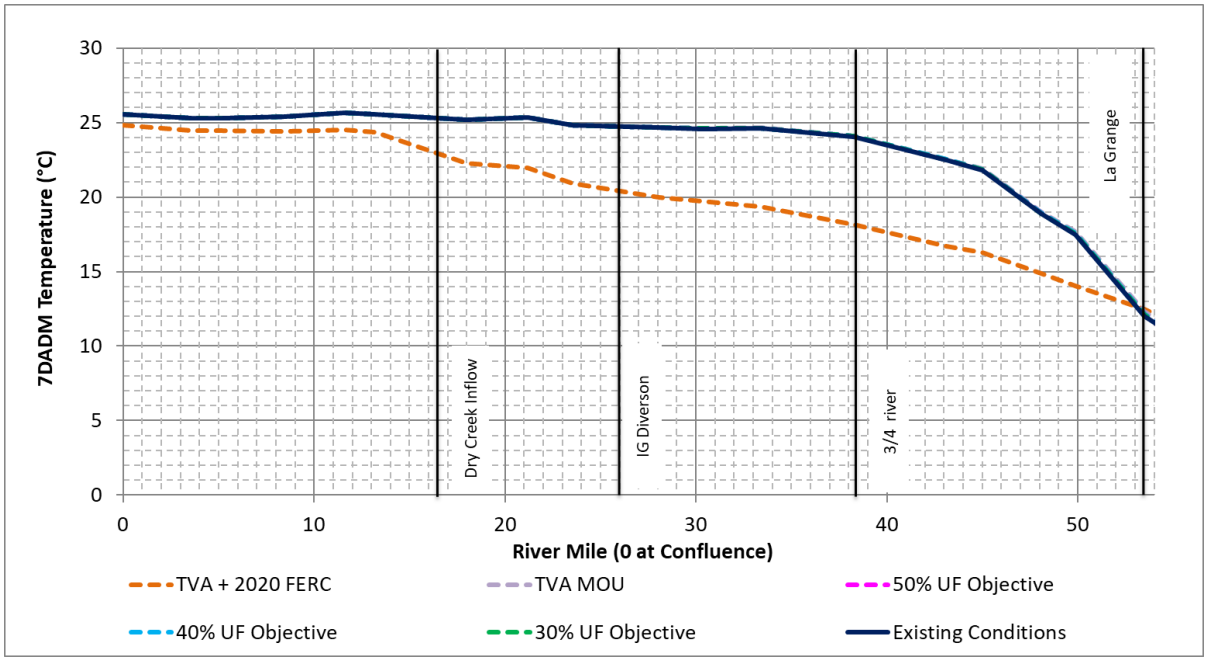


Figure B-67. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in September (Averaged over Critical Years from 1970 to 2003).

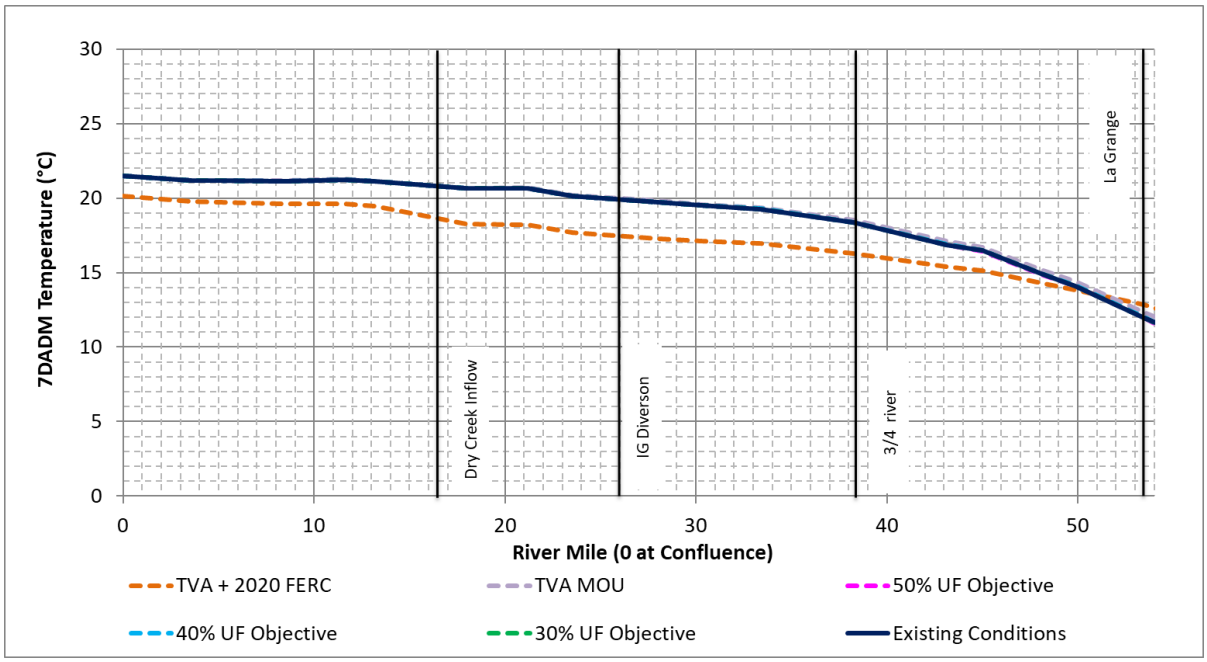


Figure B-68. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in October (Averaged over Critical Years from 1970 to 2003).

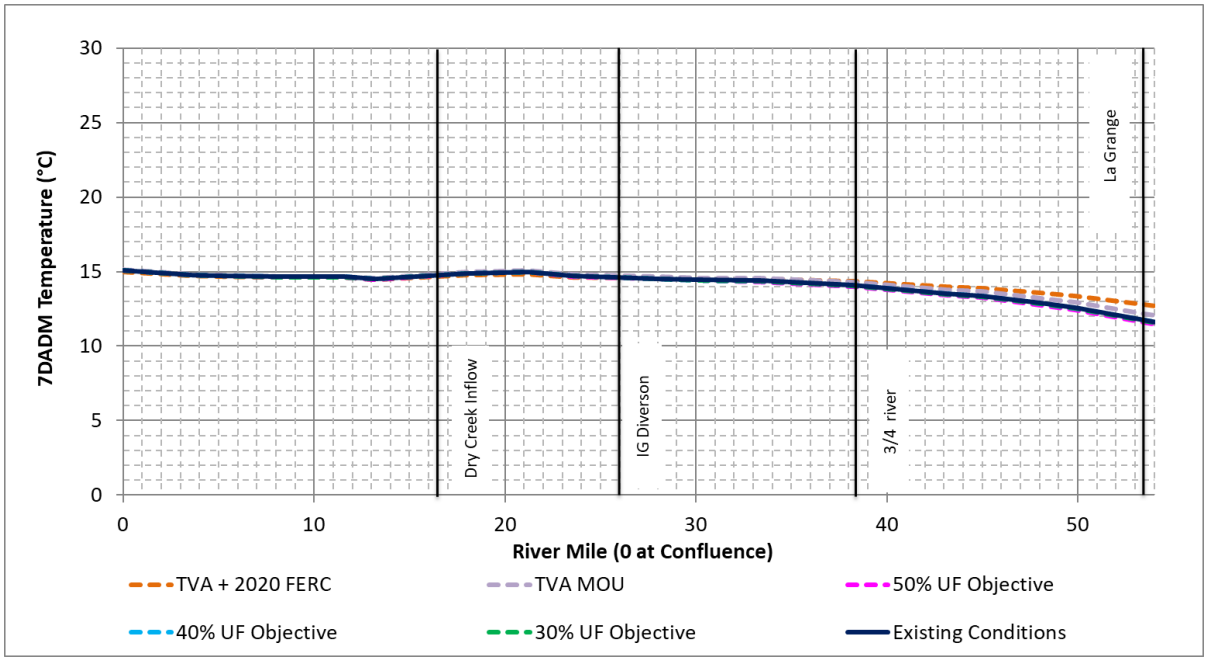


Figure B-69. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in November (Averaged over Critical Years from 1970 to 2003).

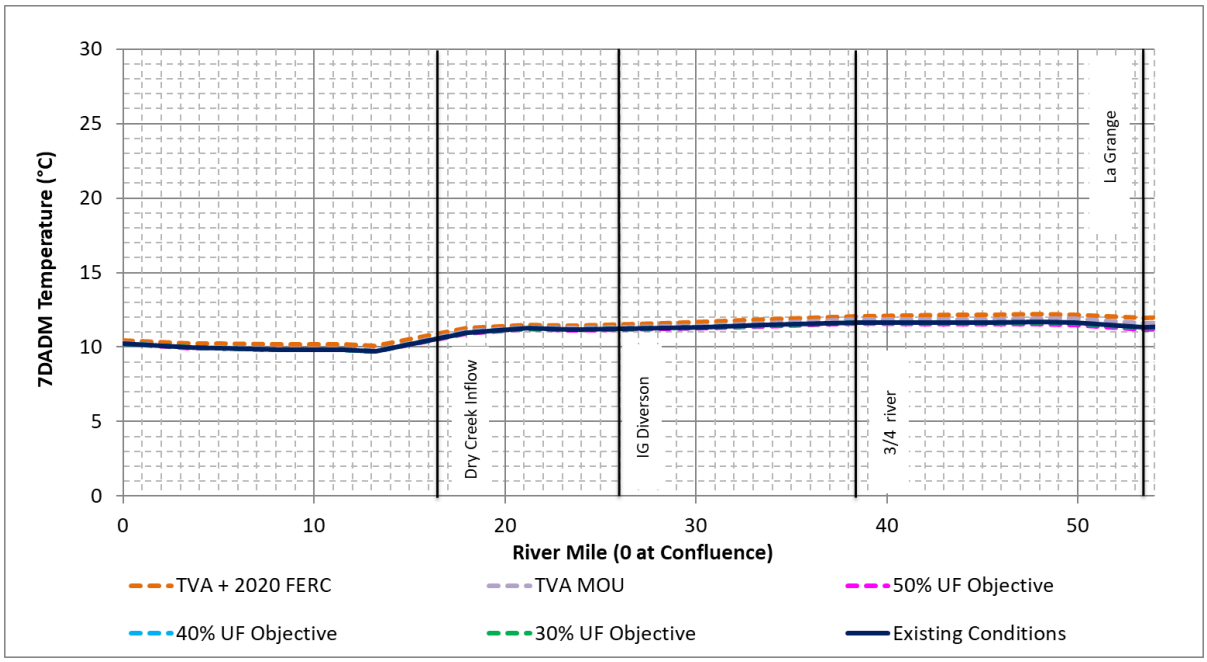


Figure B-70. Tuolumne River Longitudinal Profile of Average Monthly 7DADM Temperatures in December (Averaged over Critical Years from 1970 to 2003).

B.5.2 The Tuolumne River Below La Grange Diversion Dam (RM 53.5)

Figure B-71 and Figure B-72 present timeseries of average daily 7DADM temperatures at RM 53.5 over a year, the first being averaged over all years from 1970 to 2003 and the second only averaged over critical year types in that period.[22] The span of the figures is from February through January, which coincides with the operational year under the TVA (annual requirements under the TVA update in February). On average, there is little change in temperature over the year and little difference between the alternatives. Critical years are mostly the same except the TVA alternatives show slight increases in temperature during the winter due to reduced reservoir storage. Figure B-73 through Figure B-96 present exceedance charts and box plots of daily maximum temperatures for each month at RM 53.5, intended to show the range of maximum daily temperatures that occur each month in the model run.

[22] Since annual operations for the TVA flow requirements begin updating in February of each year and extend through the following January, the flows and temperatures seen in the October through January period are more dependent on the previous year's WYT than the current one. Therefore, the averaging period for WYT in the temperature figures is shifted forward to apply from February through January rather than October through September.

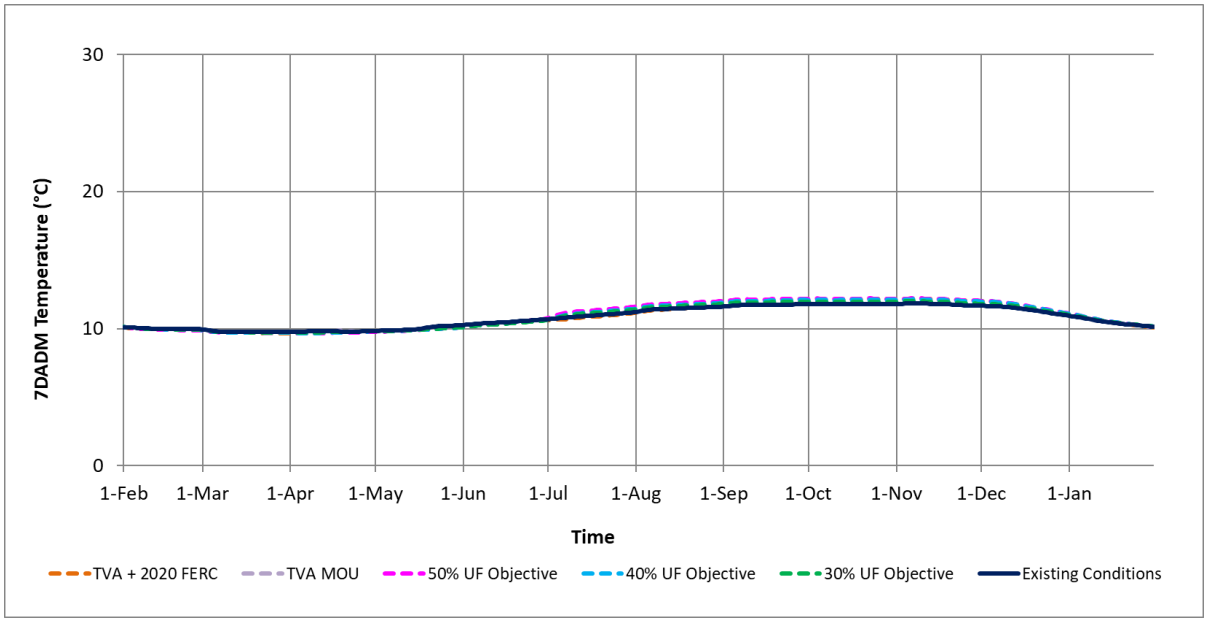


Figure B-71. Average Daily Tuolumne Running 7DADM Temperatures at RM 53.5 (Averaged over All Years from 1970 to 2003).

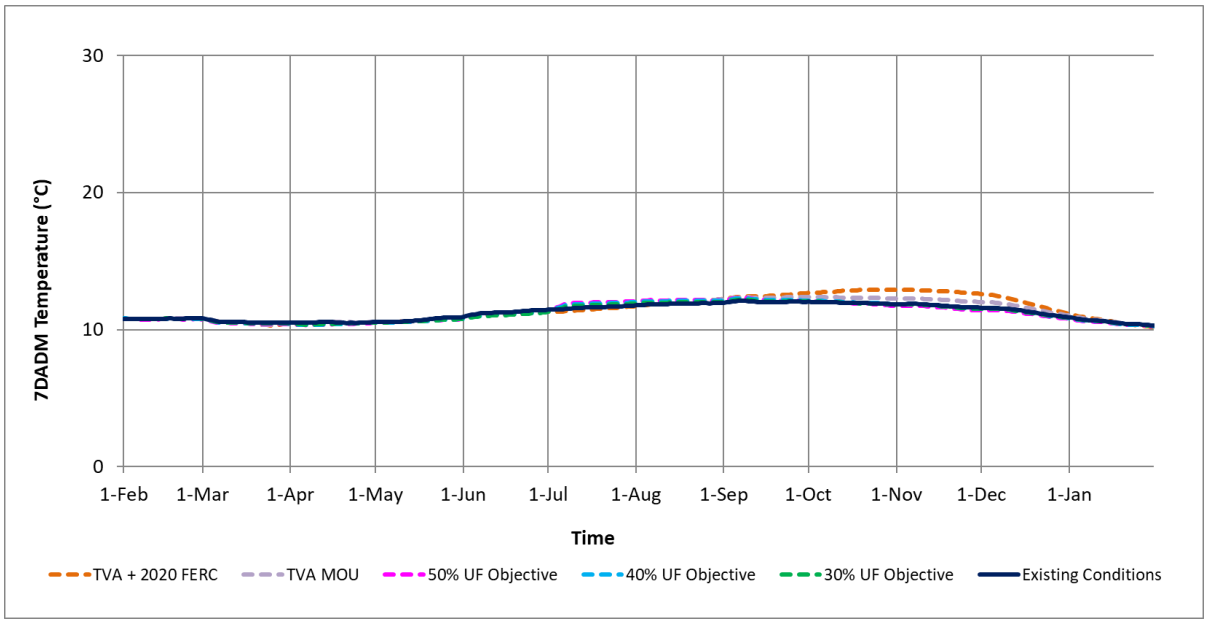


Figure B-72. Average Daily Tuolumne Running 7DADM Temperatures at RM 53.5 (Averaged over Critical Years from 1970 to 2003).

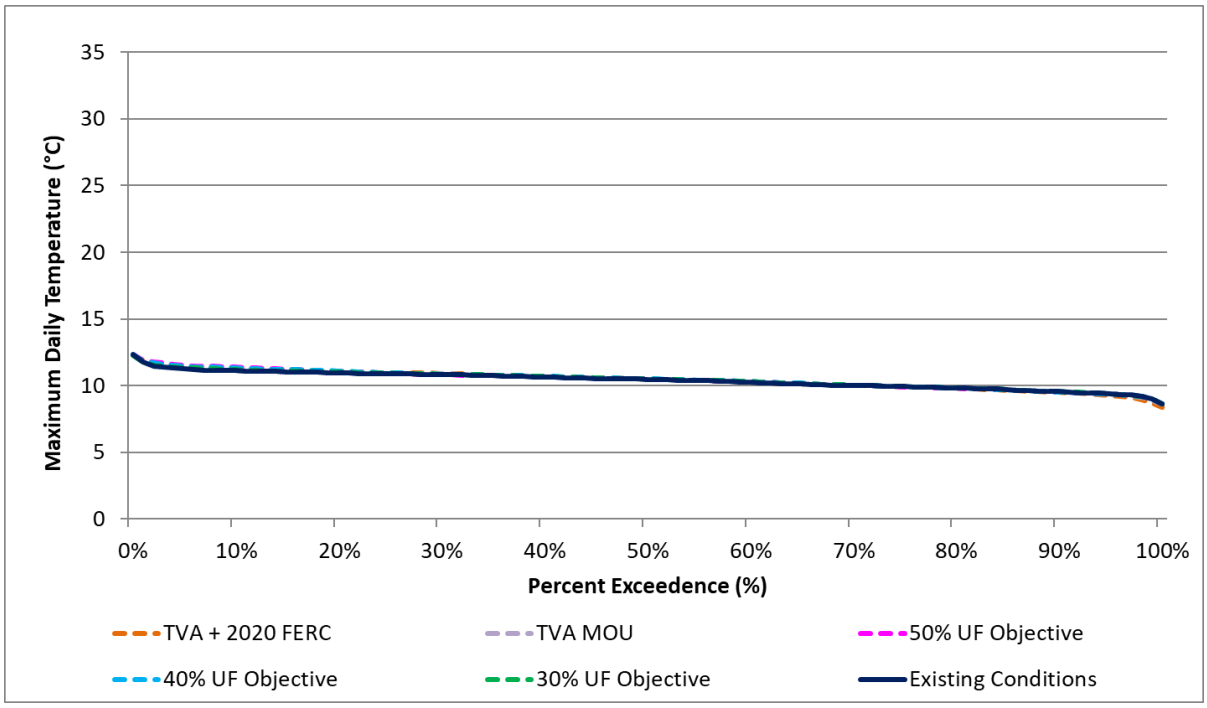


Figure B-73. Exceedance Chart of Daily Maximum Temperatures in January at RM 53.5 from 1970 to 2003.

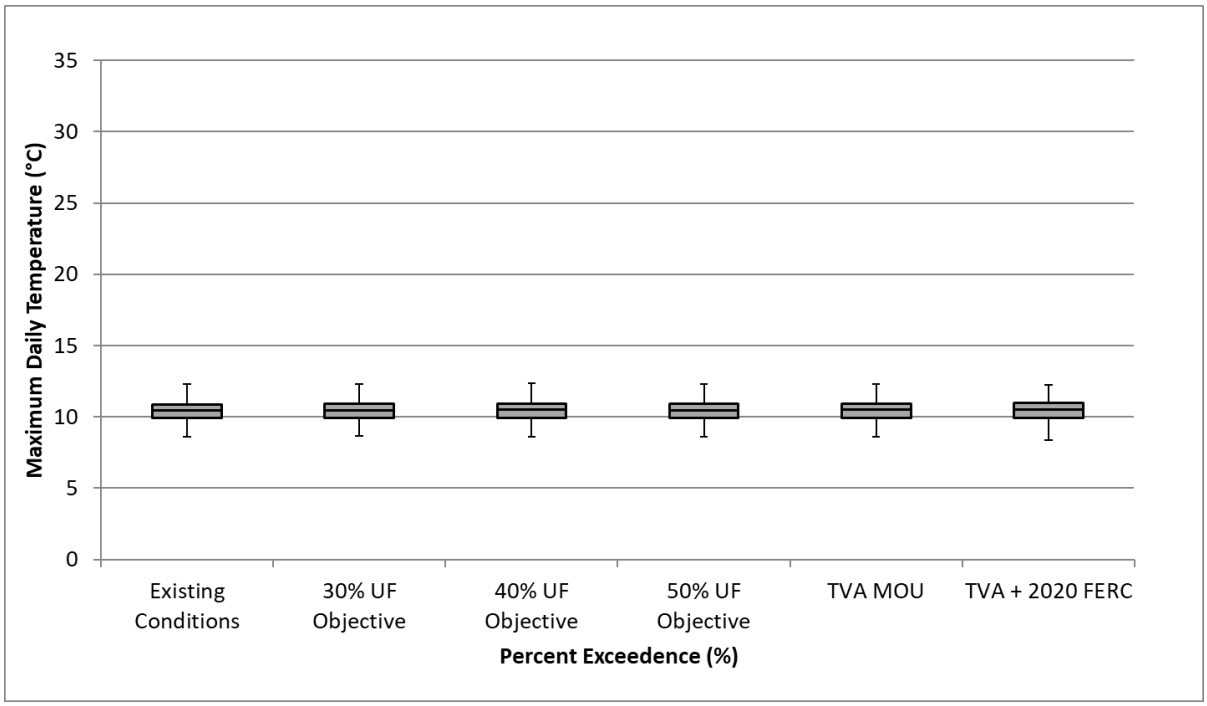


Figure B-74. Box Plot of Daily Maximum Temperatures in January at RM 53.5 from 1970 to 2003.

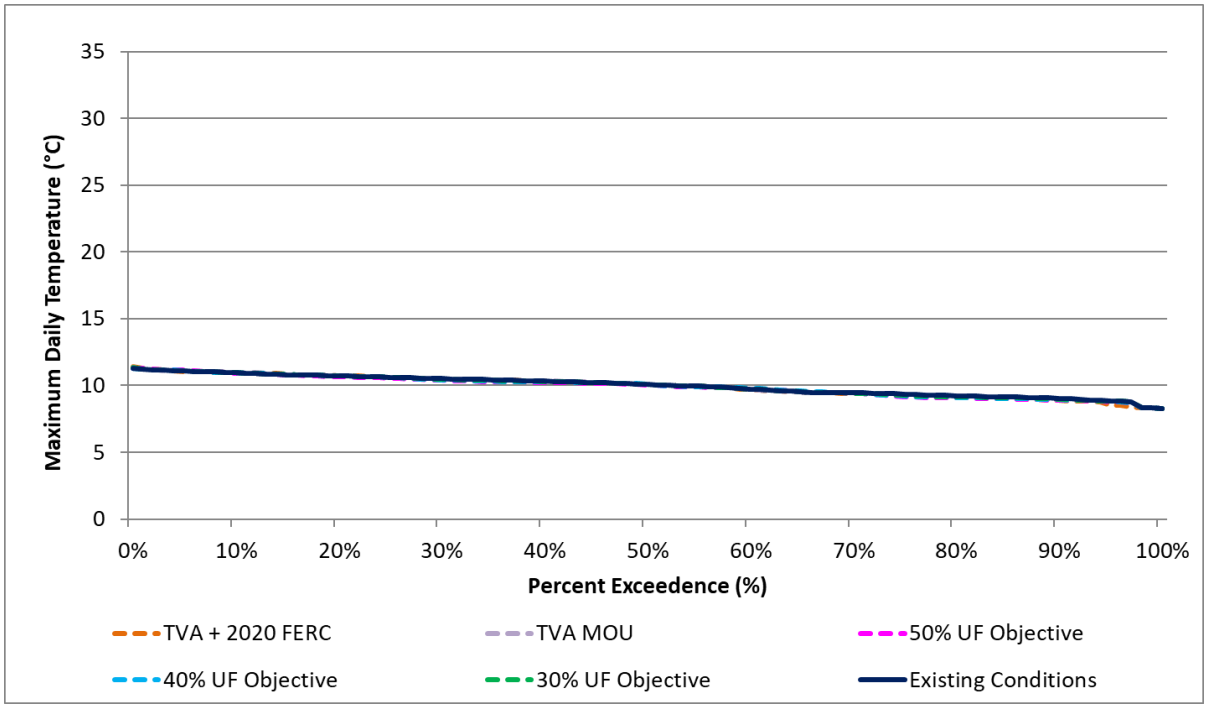


Figure B-75. Exceedance Chart of Daily Maximum Temperatures in February at RM 53.5 from 1970 to 2003.

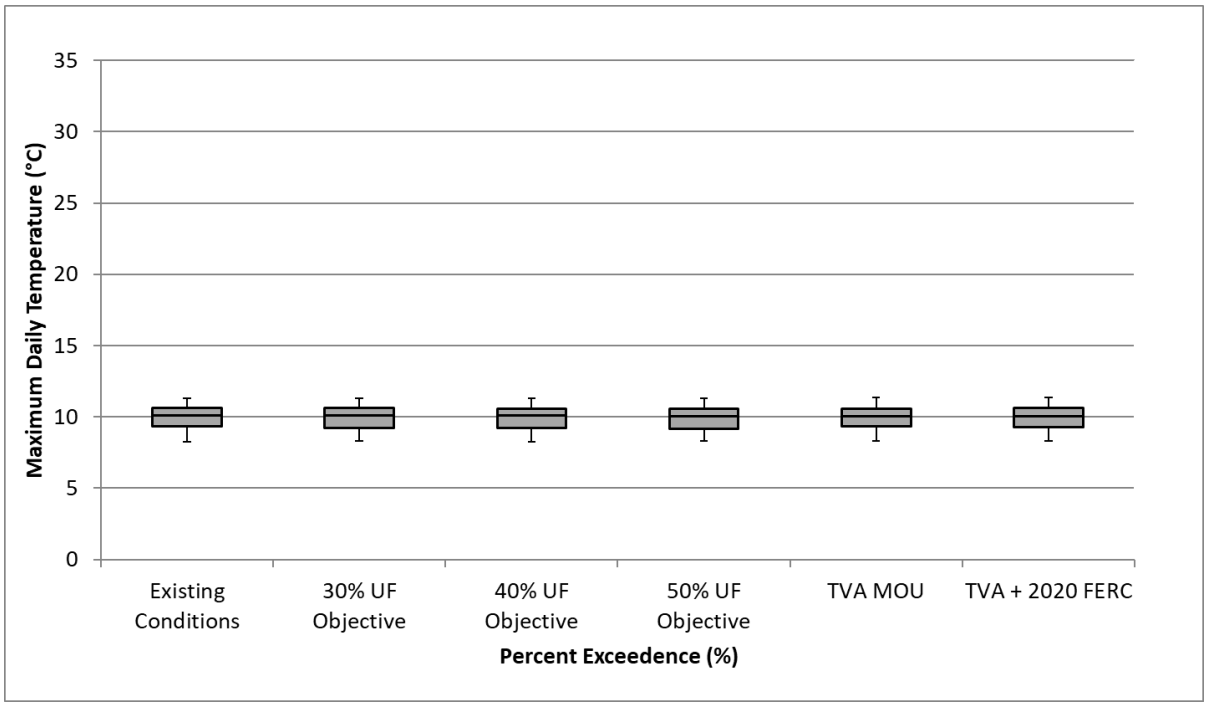


Figure B-76. Box Plot of Daily Maximum Temperatures in February at RM 53.5 from 1970 to 2003.

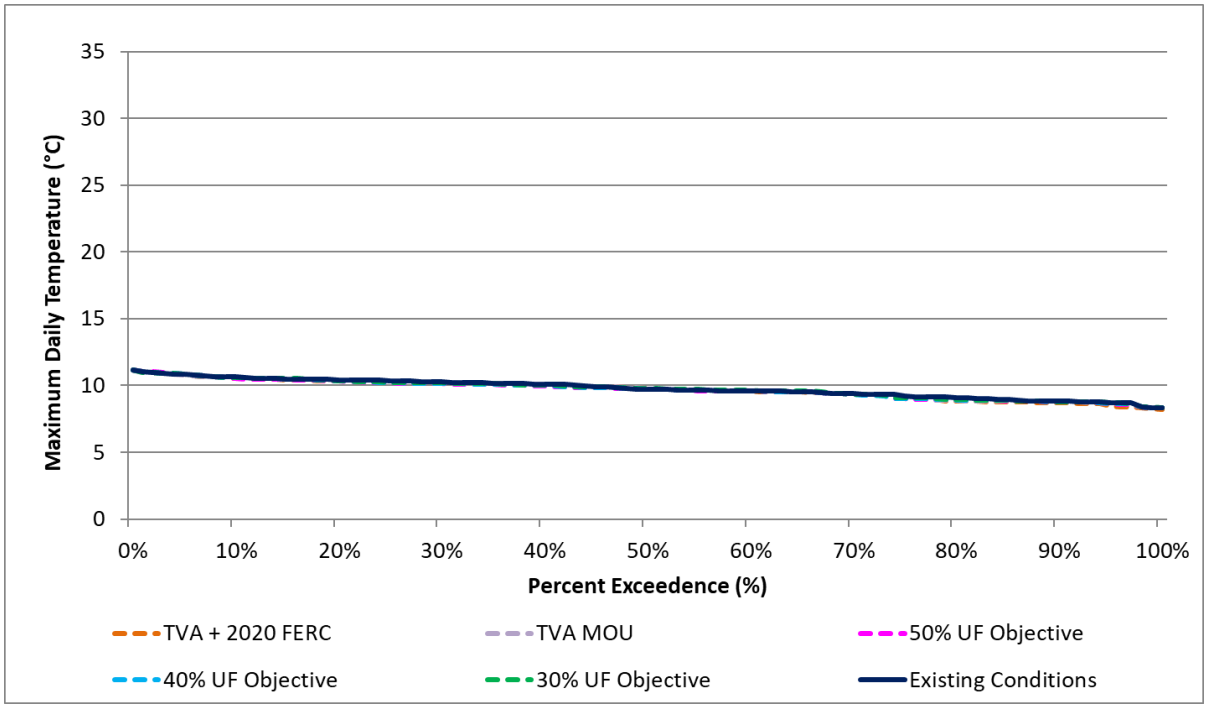


Figure B-77. Exceedance Chart of Daily Maximum Temperatures in March at RM 53.5 from 1970 to 2003.

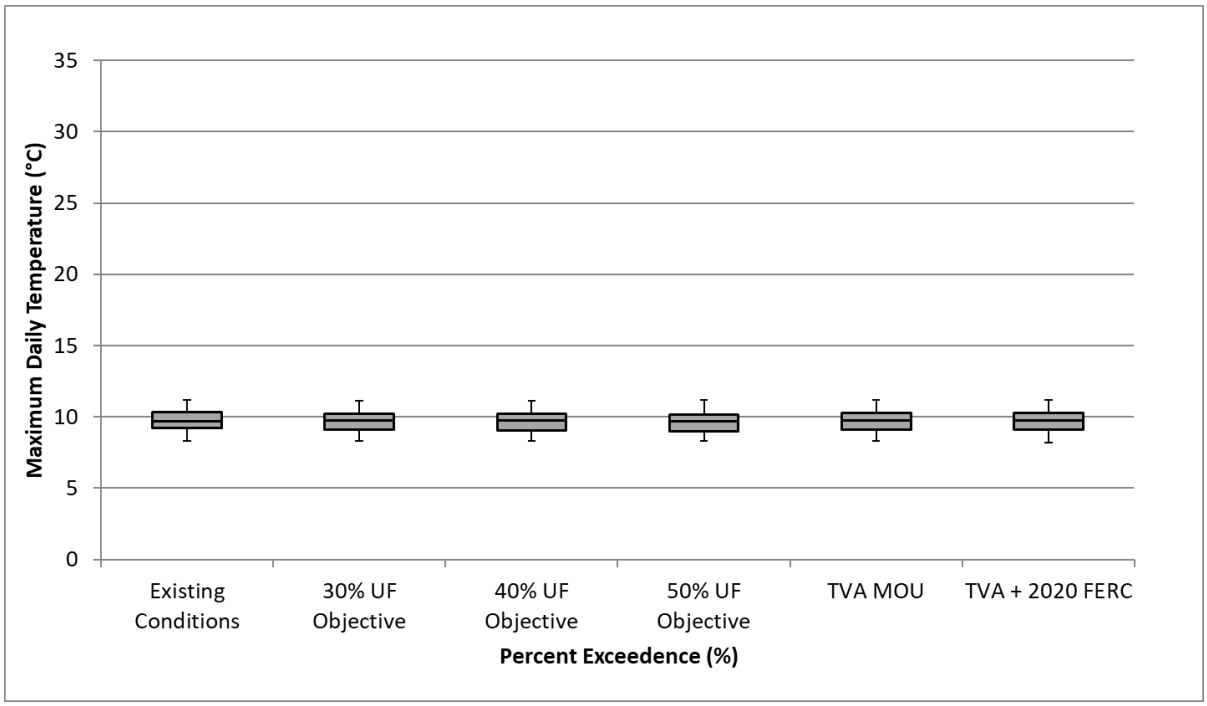


Figure B-78. Box Plot of Daily Maximum Temperatures in March at RM 53.5 from 1970 to 2003.

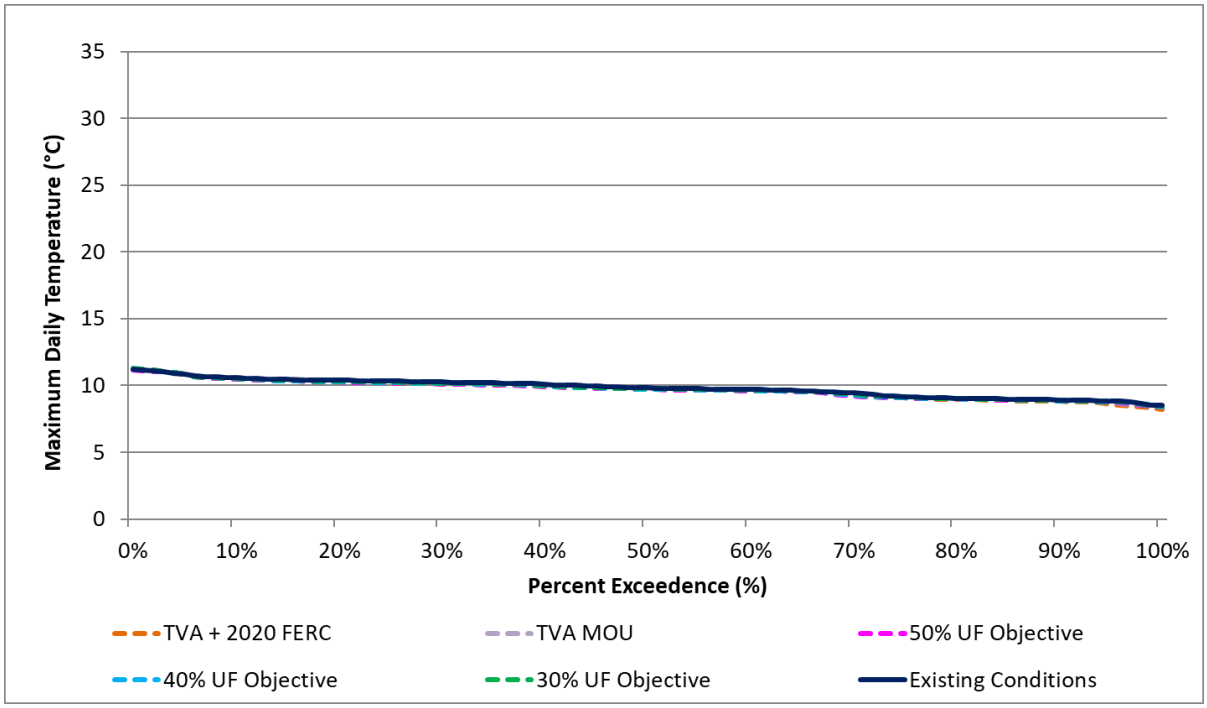


Figure B-79. Exceedance Chart of Daily Maximum Temperatures in April at RM 53.5 from 1970 to 2003.

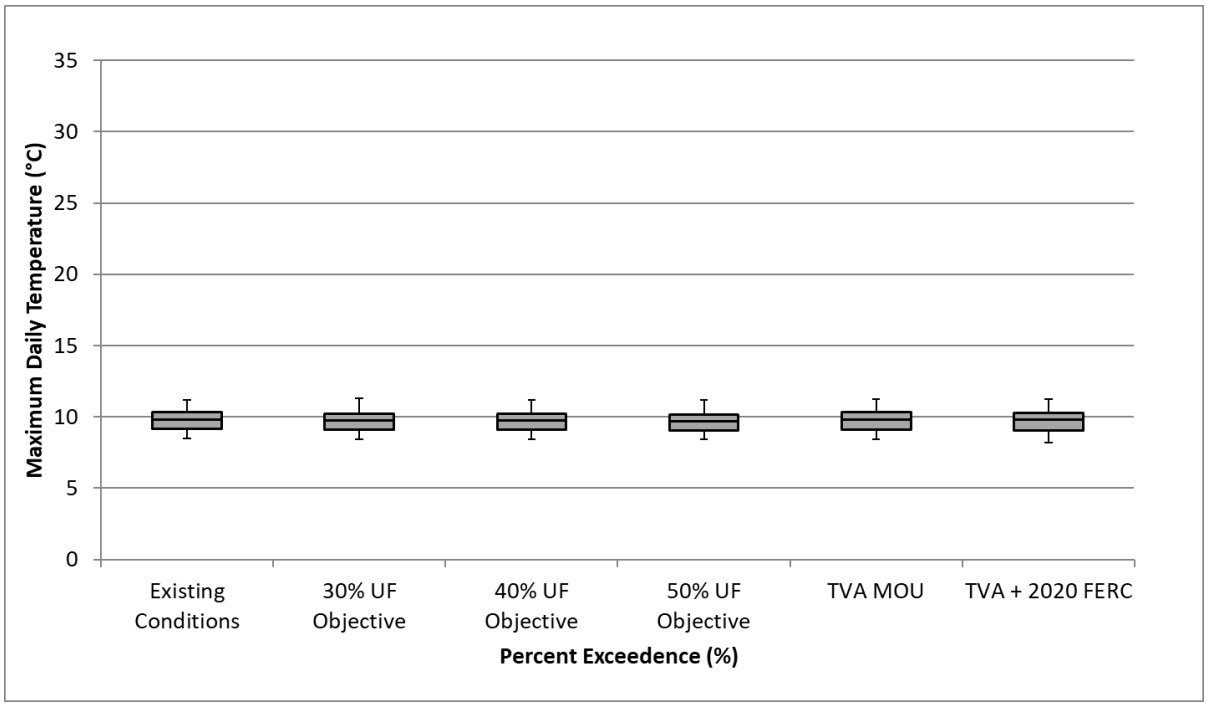


Figure B-80. Box Plot of Daily Maximum Temperatures in April at RM 53.5 from 1970 to 2003.

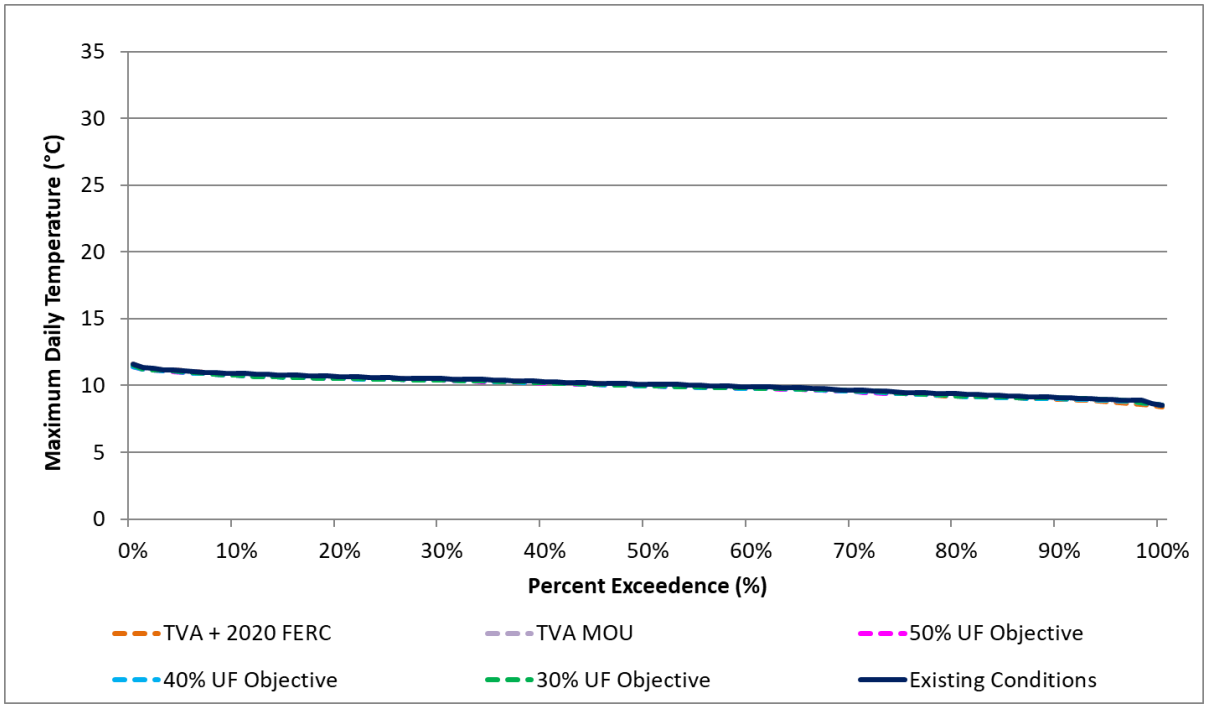


Figure B-81. Exceedance Chart of Daily Maximum Temperatures in May at RM 53.5 from 1970 to 2003.

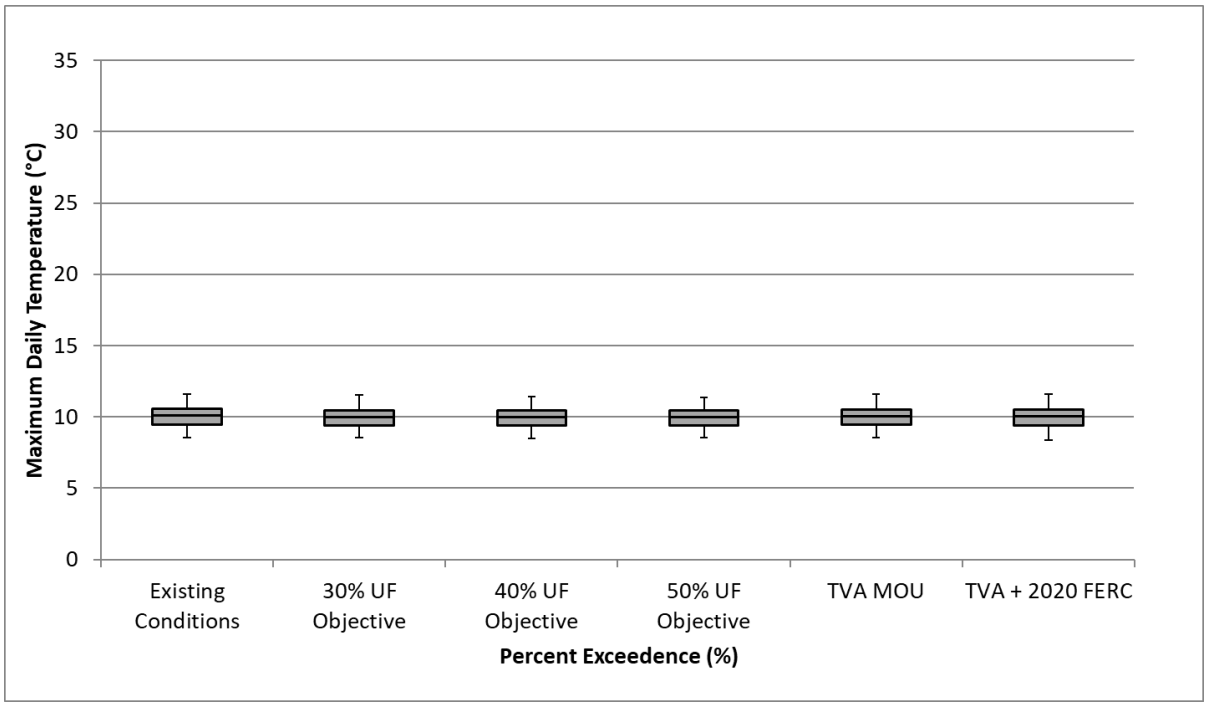


Figure B-82. Box Plot of Daily Maximum Temperatures in May at RM 53.5 from 1970 to 2003.

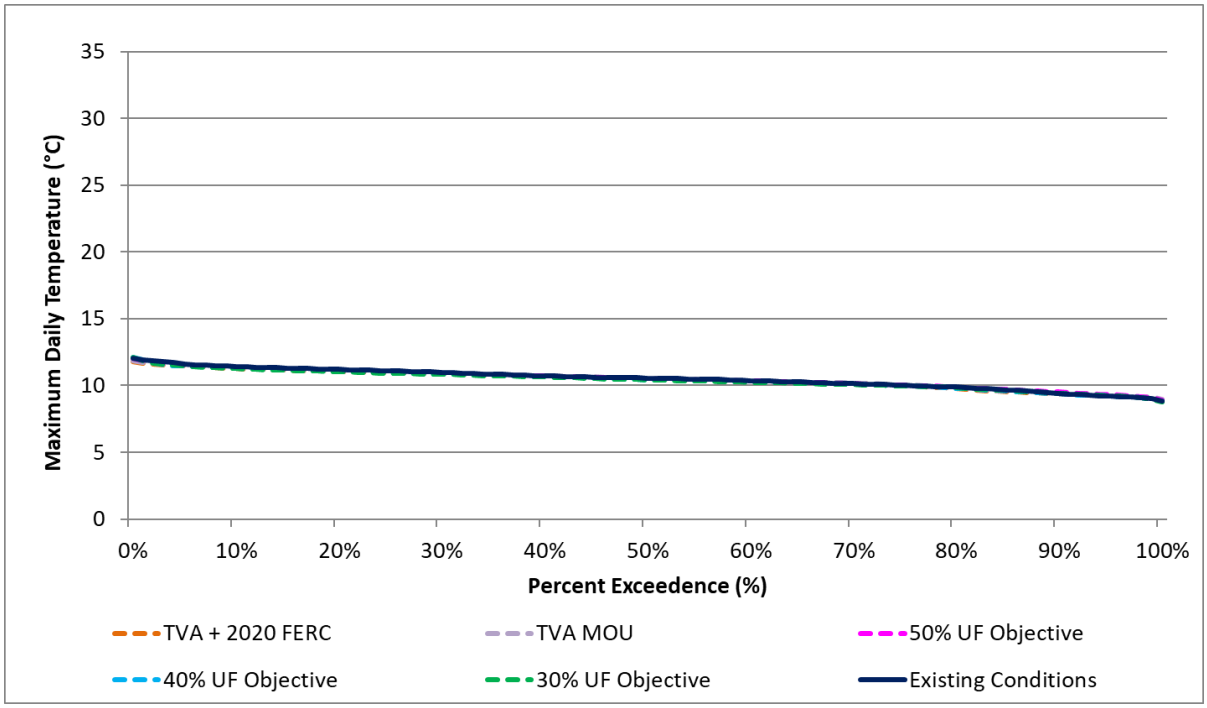


Figure B-83. Exceedance Chart of Daily Maximum Temperatures in June at RM 53.5 from 1970 to 2003.

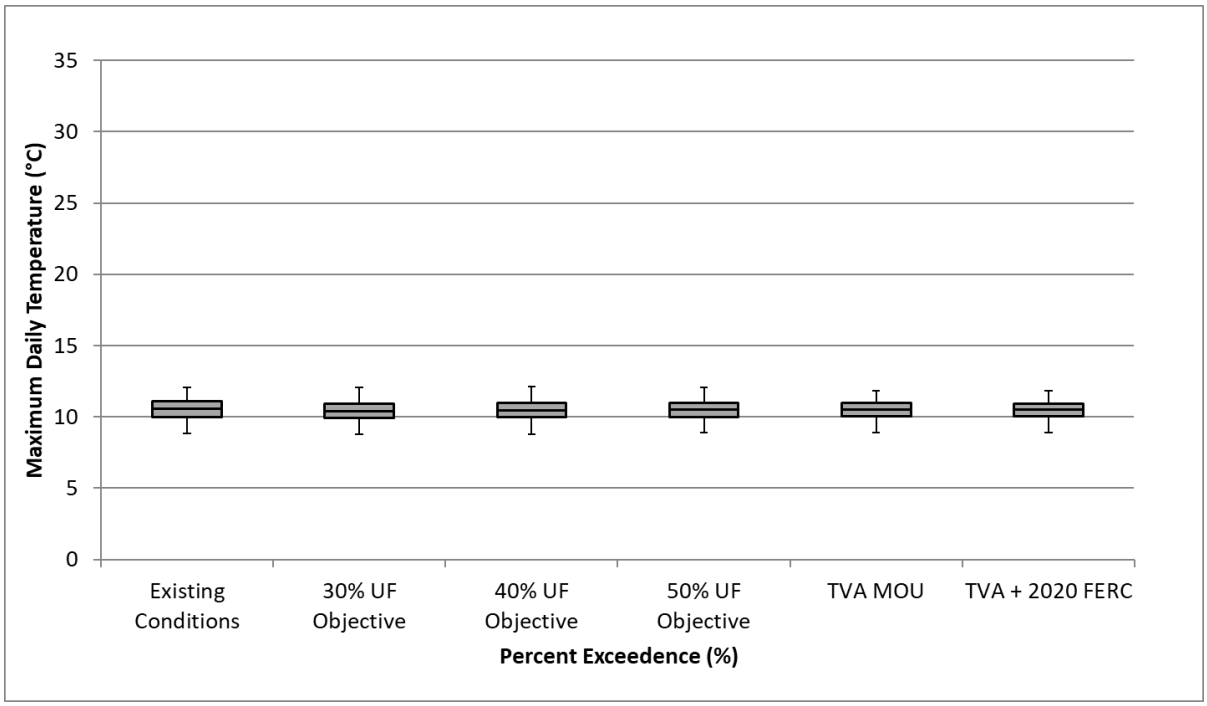


Figure B-84. Box Plot of Daily Maximum Temperatures in June at RM 53.5 from 1970 to 2003.

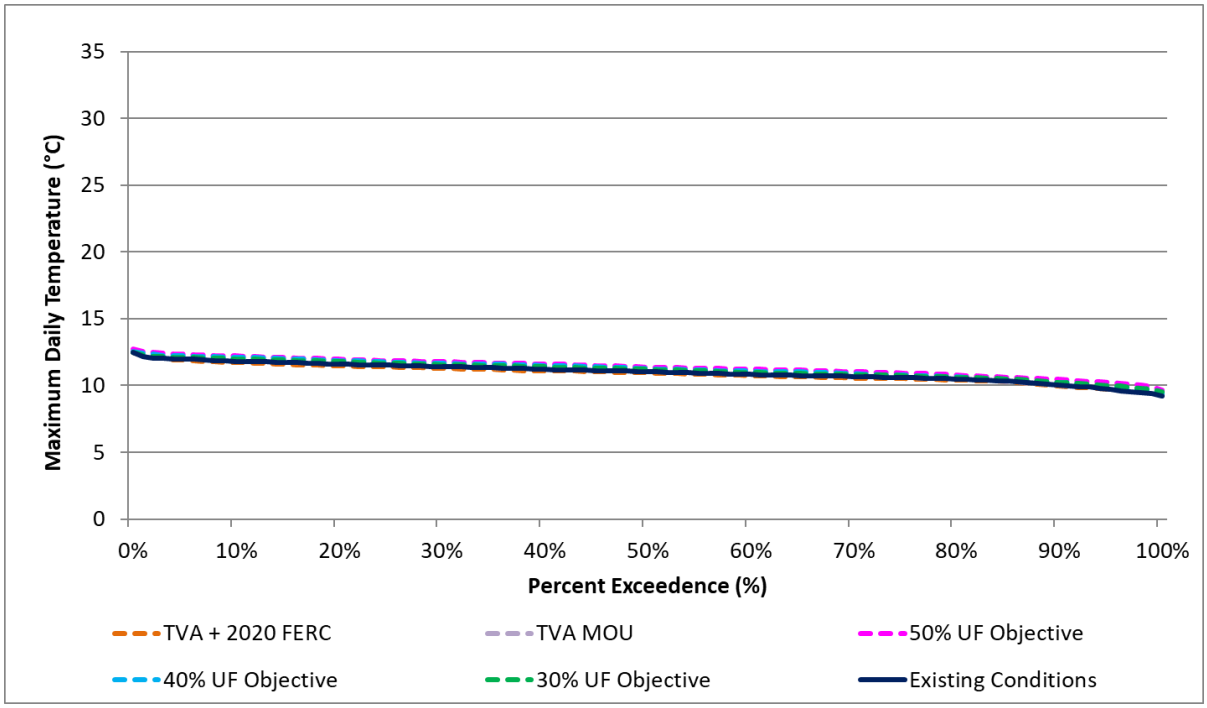


Figure B-85. Exceedance Chart of Daily Maximum Temperatures in July at RM 53.5 from 1970 to 2003.

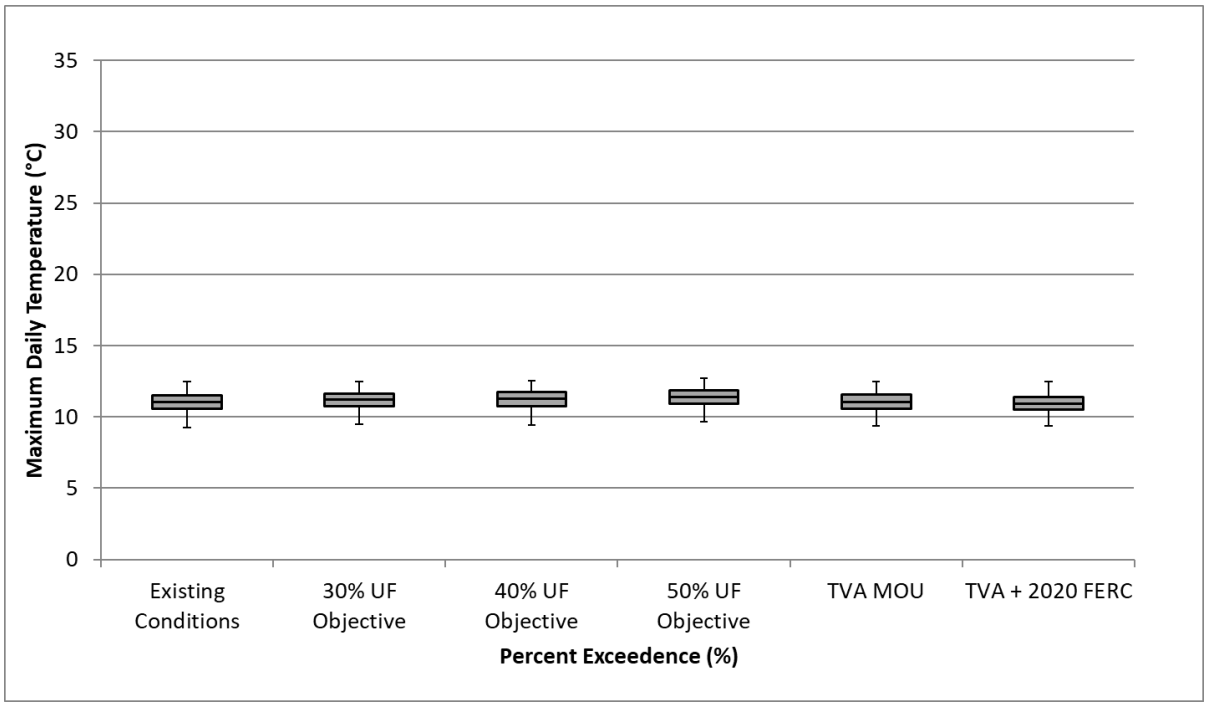


Figure B-86. Box Plot of Daily Maximum Temperatures in July at RM 53.5 from 1970 to 2003.

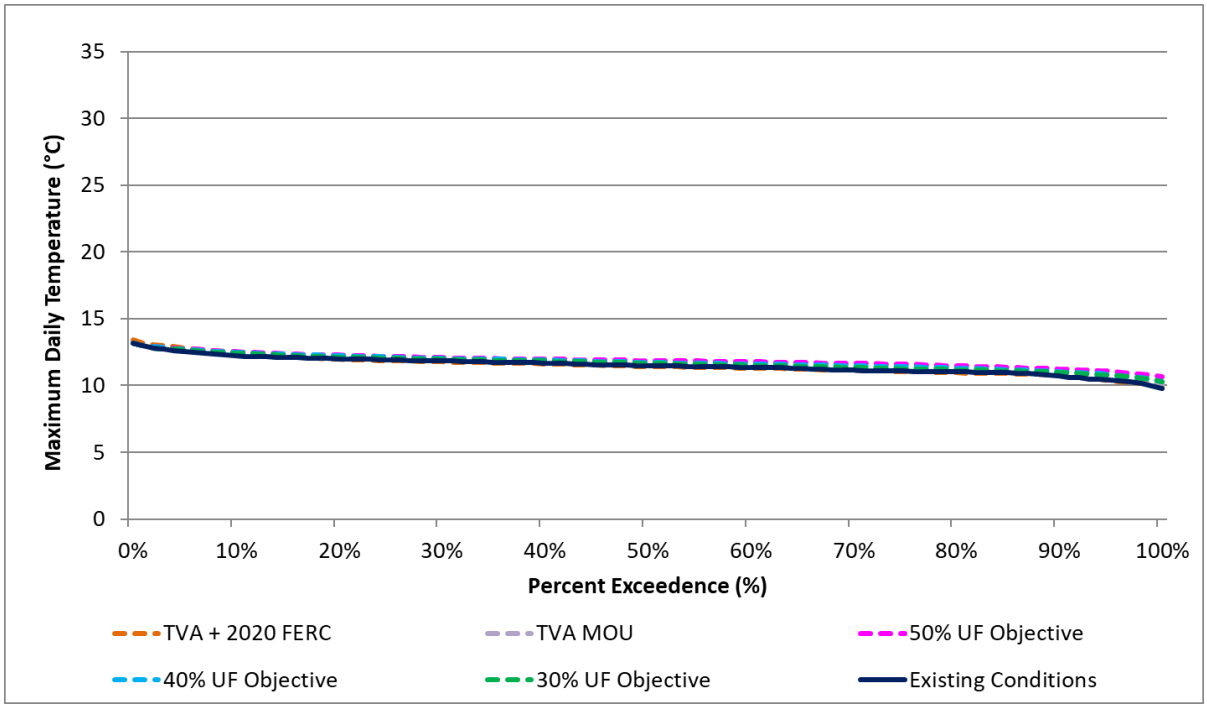


Figure B-87. Exceedance Chart of Daily Maximum Temperatures in August at RM 53.5 from 1970 to 2003.

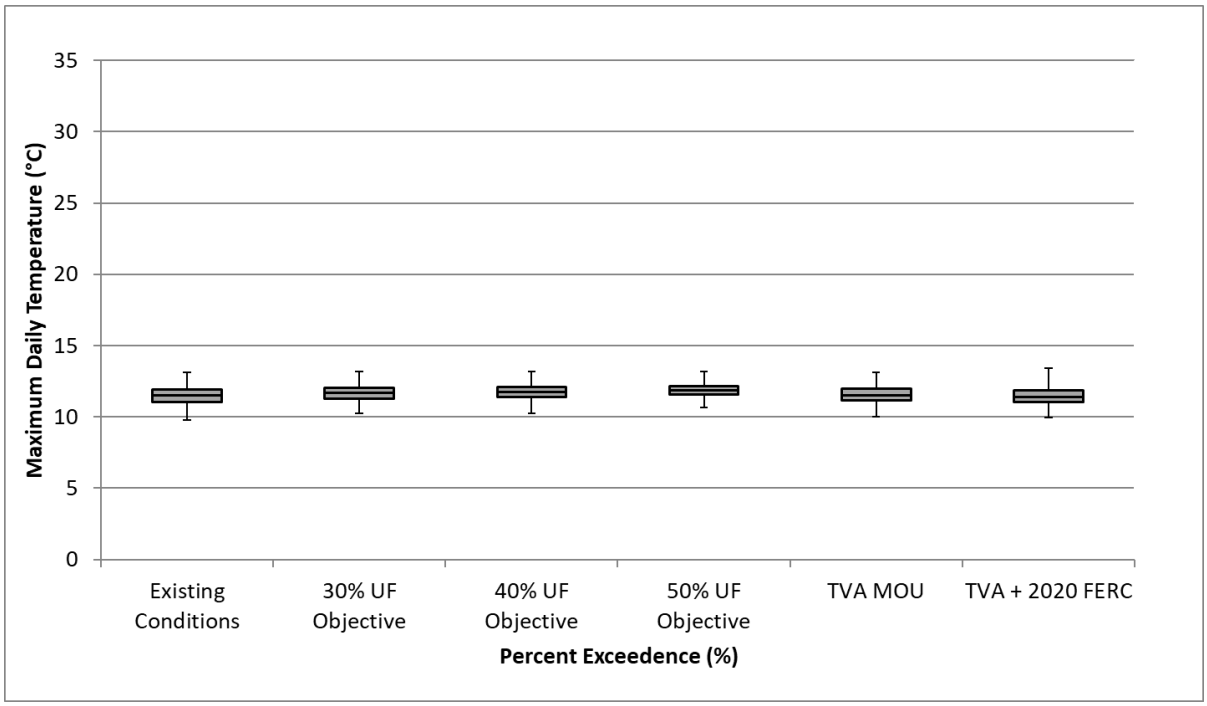


Figure B-88. Box Plot of Daily Maximum Temperatures in August at RM 53.5 from 1970 to 2003.

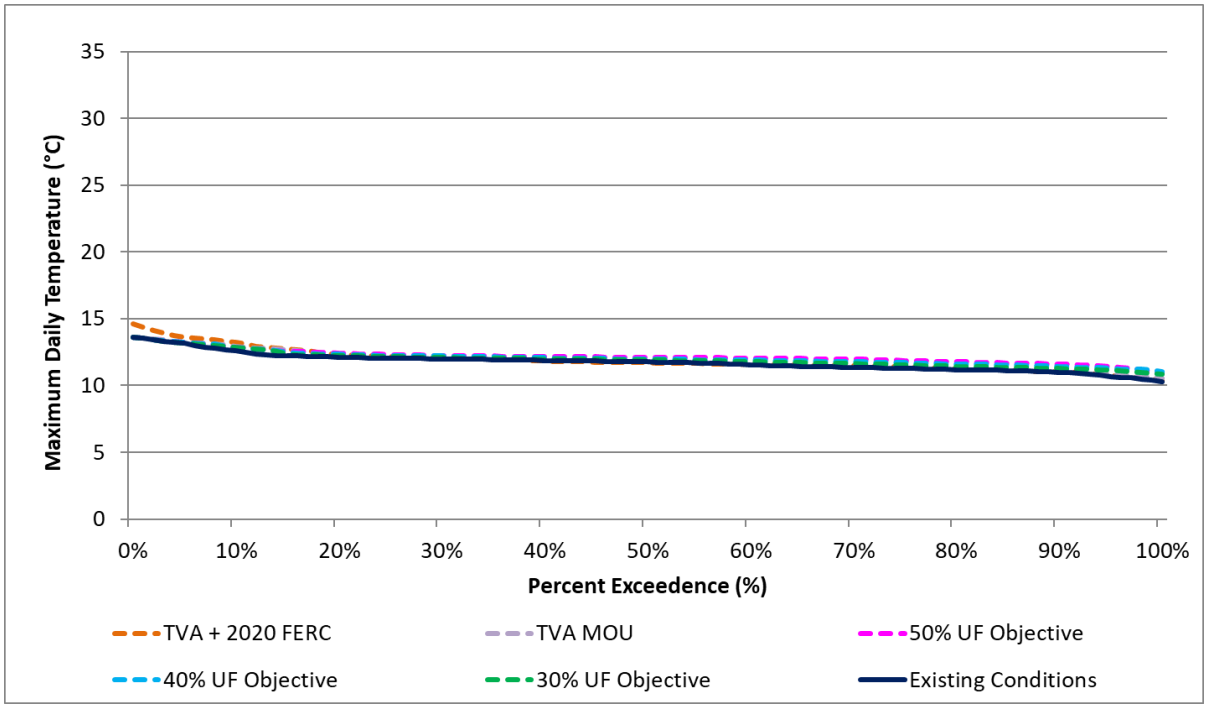


Figure B-89. Exceedance Chart of Daily Maximum Temperatures in September at RM 53.5 from 1970 to 2003.

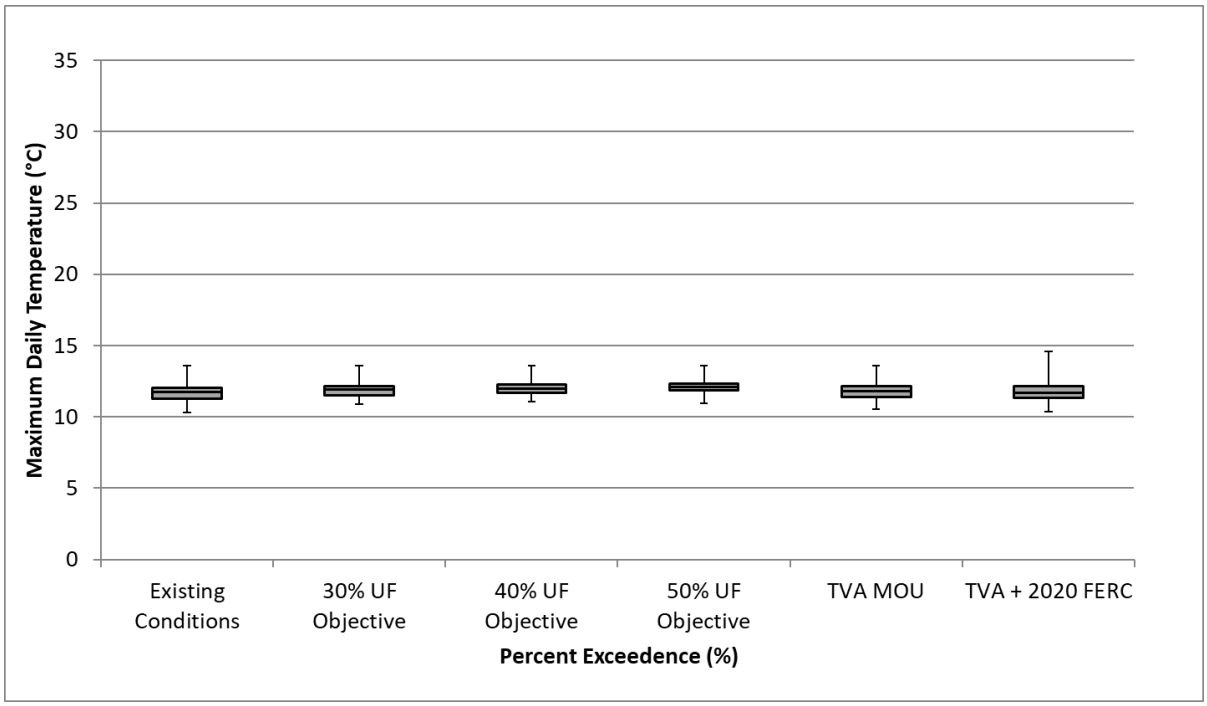


Figure B-90. Box Plot of Daily Maximum Temperatures in September at RM 53.5 from 1970 to 2003.

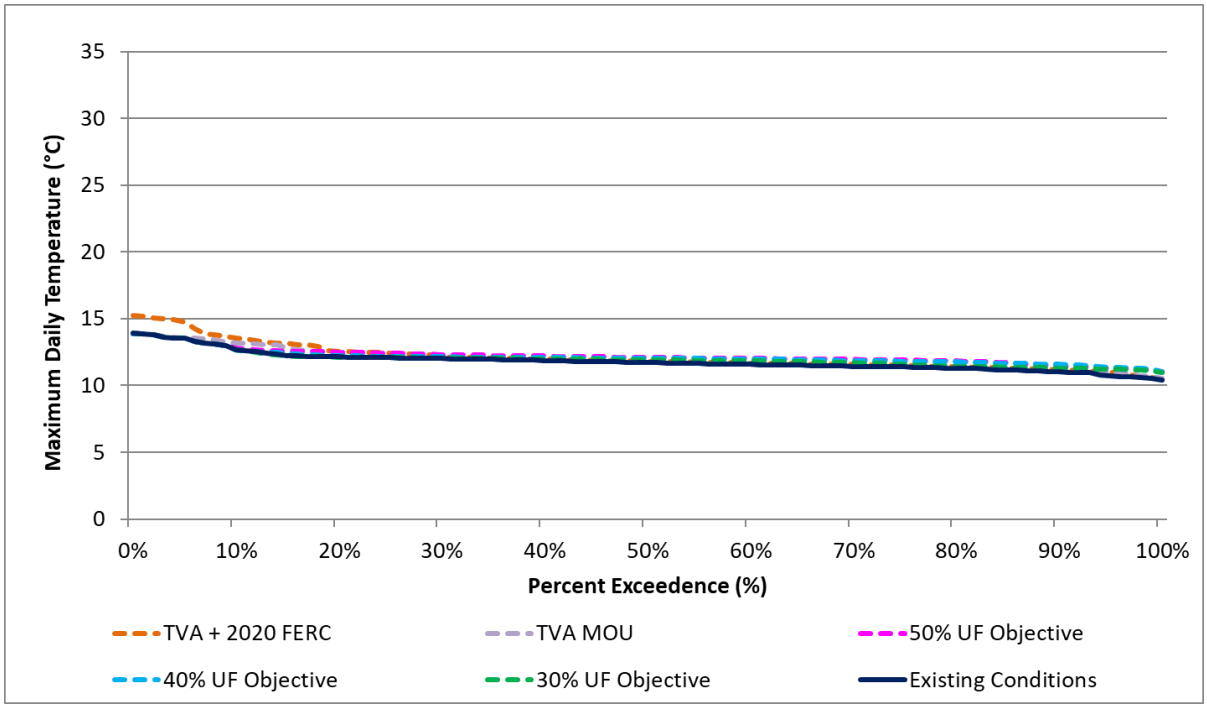


Figure B-91. Exceedance Chart of Daily Maximum Temperatures in October at RM 53.5 from 1970 to 2003.

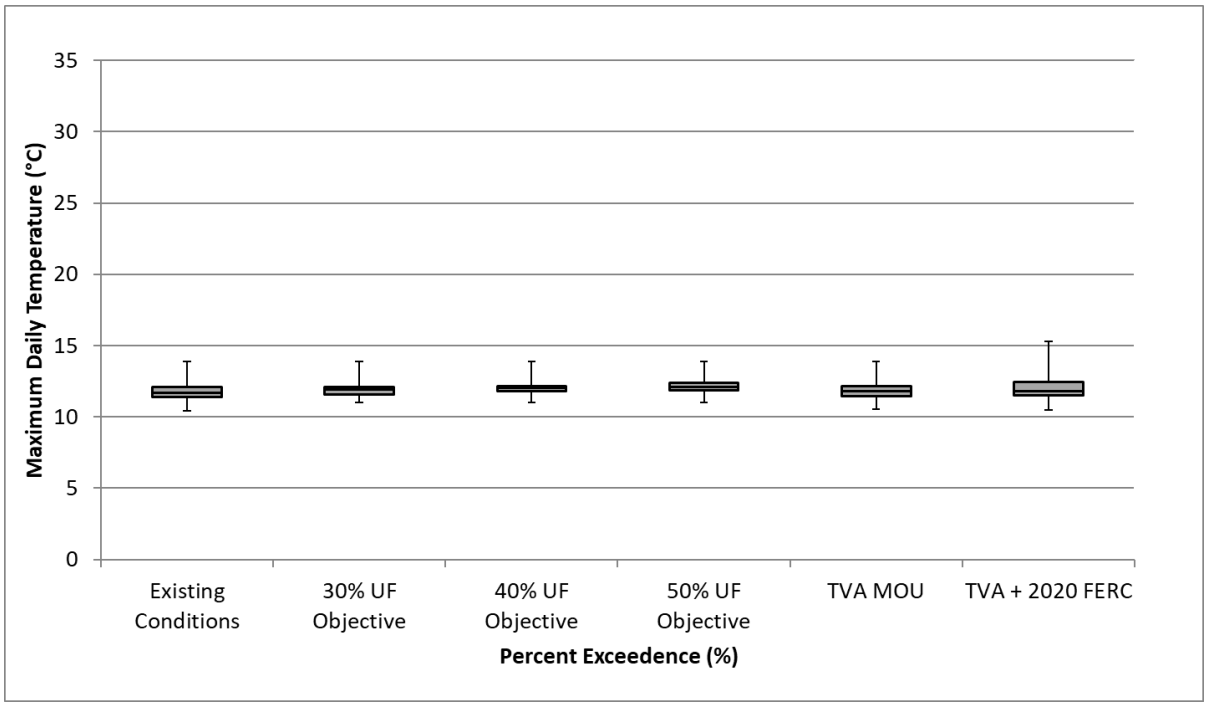


Figure B-92. Box Plot of Daily Maximum Temperatures in October at RM 53.5 from 1970 to 2003.

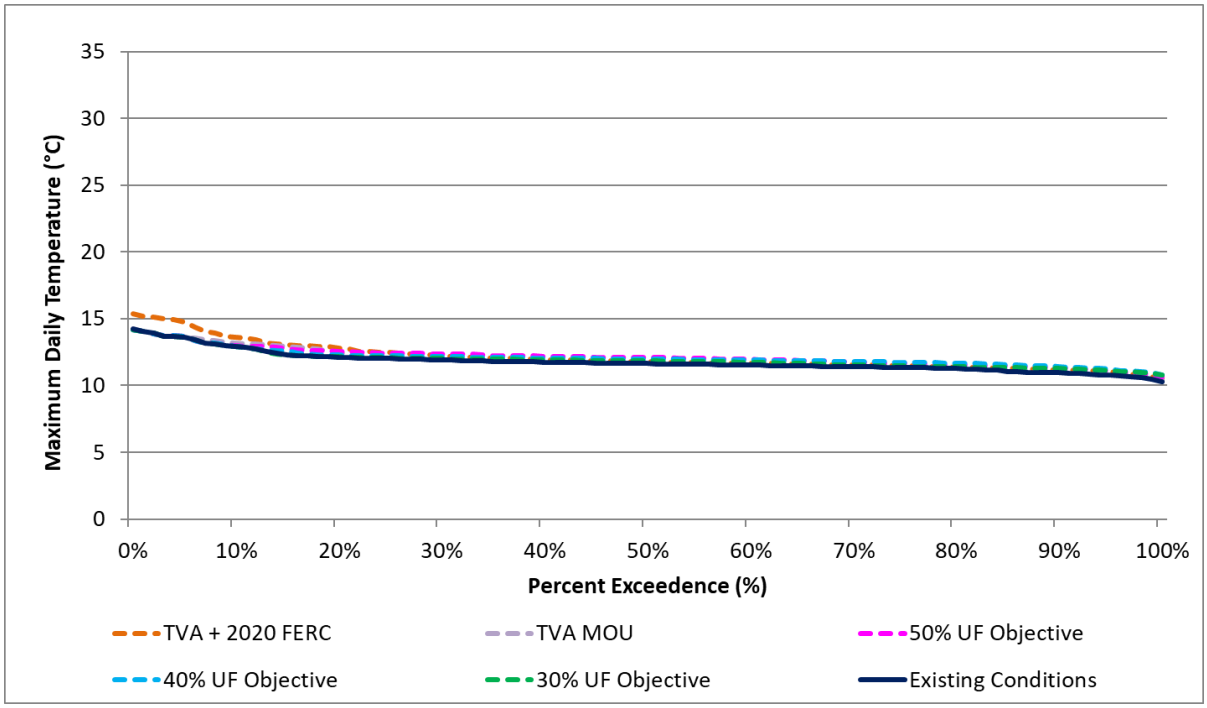


Figure B-93. Exceedance Chart of Daily Maximum Temperatures in November at RM 53.5 from 1970 to 2003.

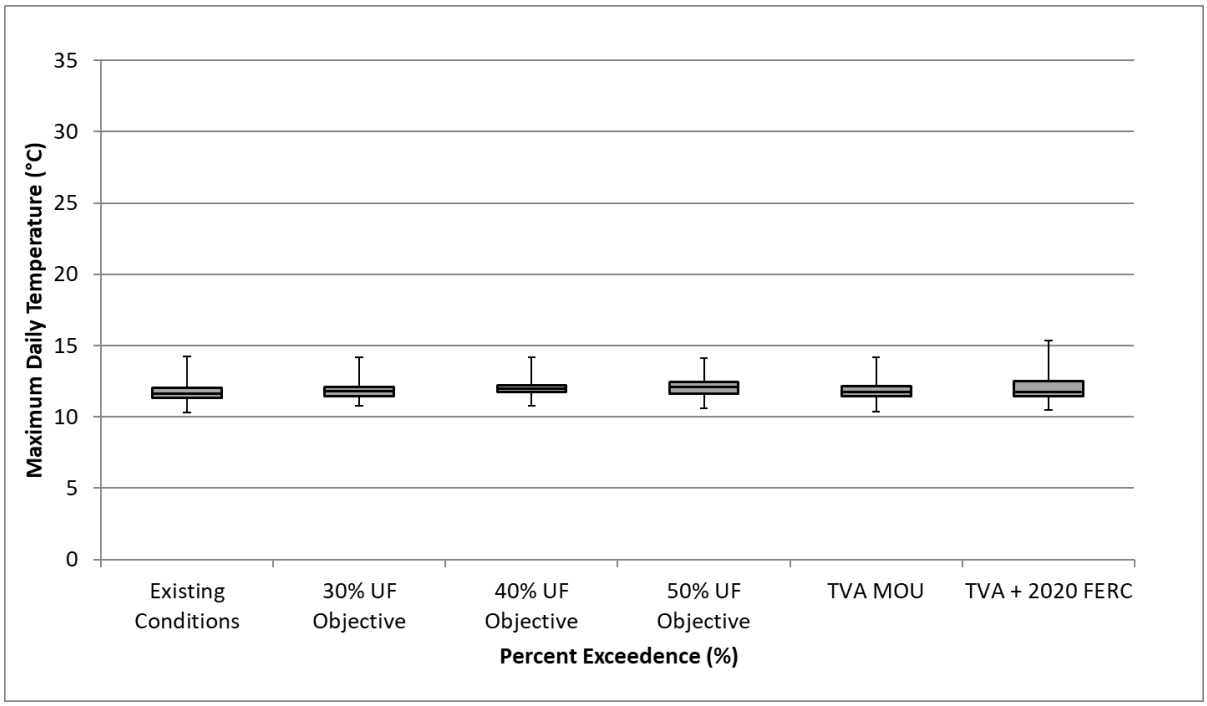


Figure B-94. Box Plot of Daily Maximum Temperatures in November at RM 53.5 from 1970 to 2003.

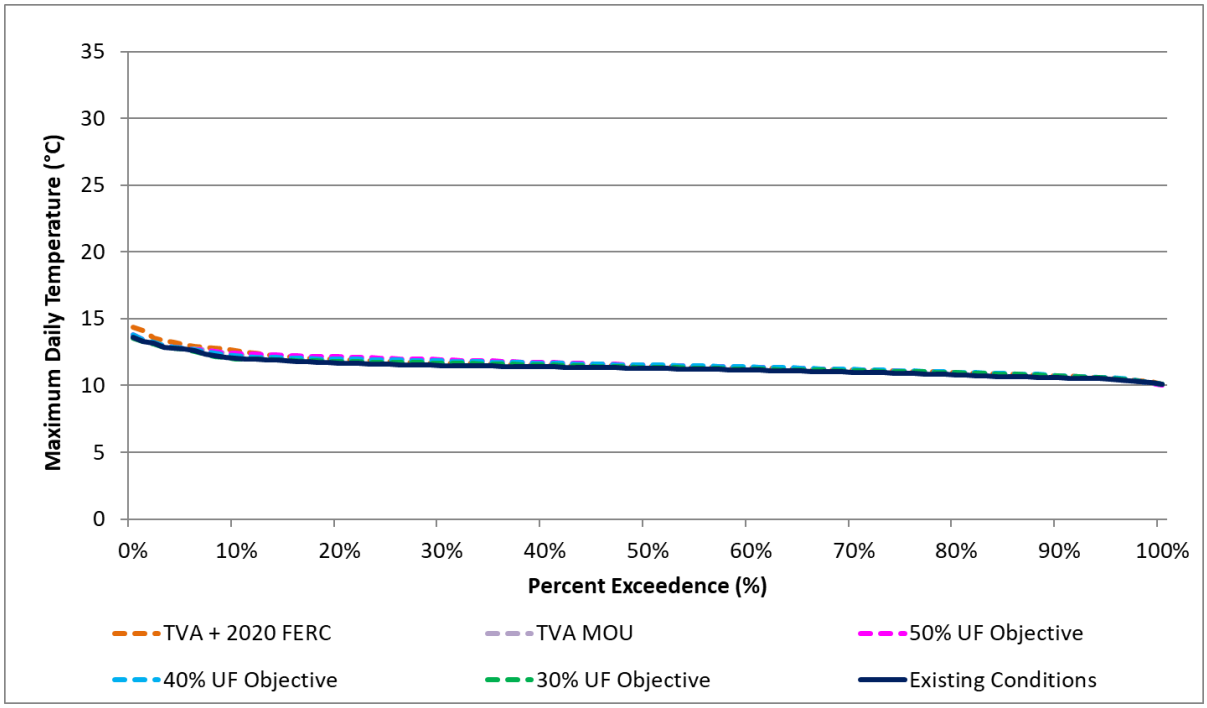


Figure B-95. Exceedance Chart of Daily Maximum Temperatures in December at RM 53.5 from 1970 to 2003.

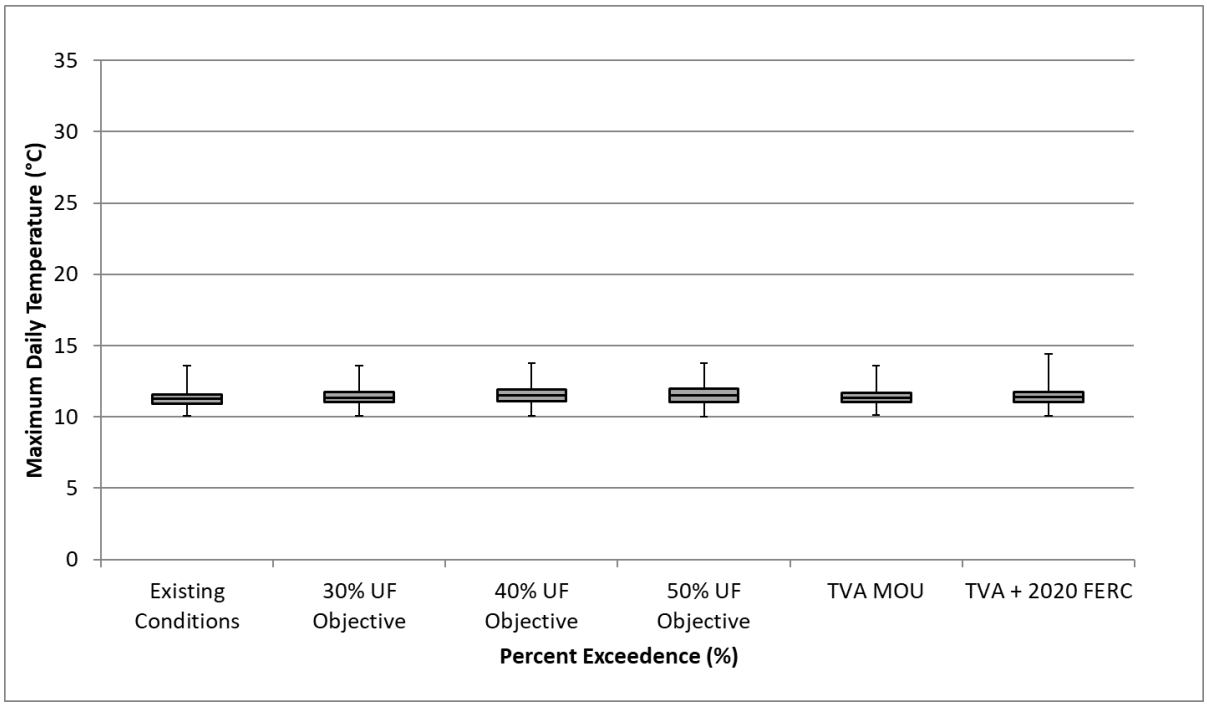


Figure B-96. Box Plot of Daily Maximum Temperatures in December at RM 53.5 from 1970 to 2003.

B.5.3 The Tuolumne River Between Turlock State Park and Waterford (RM 38.3)

Figure B-97 and Figure B-98 present timeseries of average daily 7DADM temperatures at RM 38.3 over a year, the first being averaged over all years from 1970 to 2003 and the second only averaged over critical year types in that period.[23] The span of the figures is from February through January, which coincides with the operational year under the TVA (annual requirements under the TVA update in February). Figure B-99 through Figure B-122 present exceedance charts and box plots of daily maximum temperatures for each month at RM 38.3, intended to show the range of maximum daily temperatures that occur each month in the model run. The TVA MOU alternative shows lower temperatures compared to existing conditions during the end of March through the beginning of April, which corresponds to the floodplain inundation pulse period, and then at the end of May, since the outmigration pulse under the TVA is longer than under existing conditions. June under the TVA MOU is generally similar to the existing conditions, but temperatures are improved during critical years. Temperatures under all three UF alternatives are generally lower than in the existing conditions at this location throughout the February through June period. The TVA + 2020 FERC alternative provides the same benefit from March through May as the TVA MOU alternative but also results in lower temperatures over the summer with operation of the IGs allowing greater instream flow in this portion of the river.

[23] Since annual operations for the TVA flow requirements begin updating in February of each year and extend through the following January, the flows and temperatures seen in the October through January period are more dependent on the previous year's WYT than the current one. Therefore, the averaging period for WYT in the temperature figures is shifted forward to apply from February through January rather than October through September.

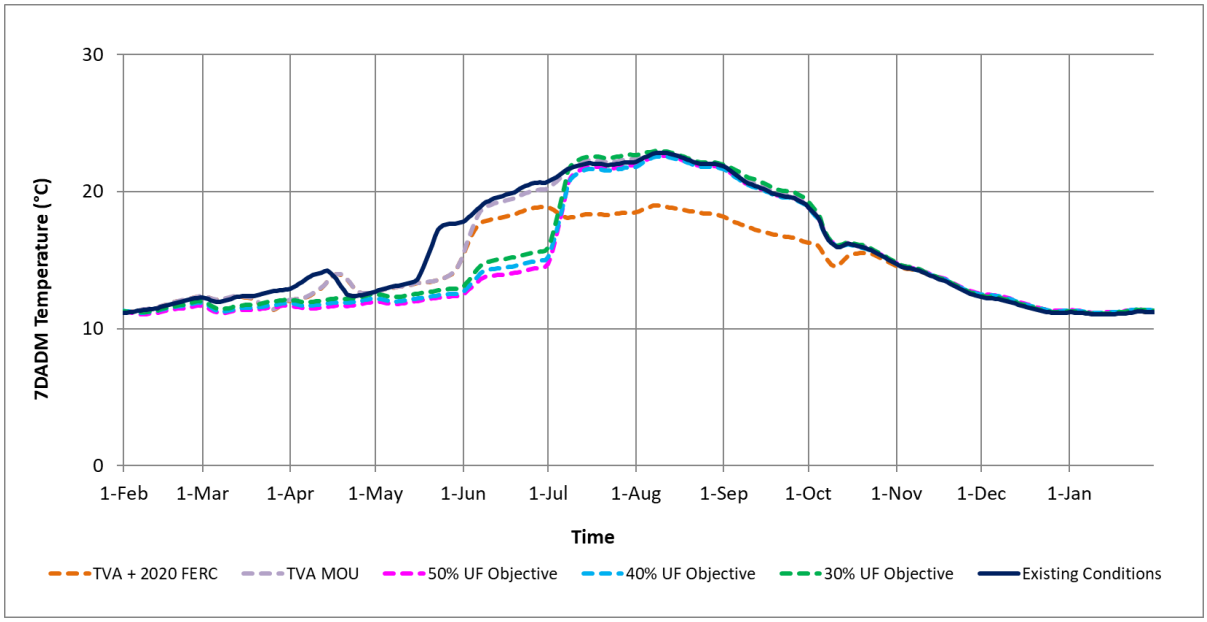


Figure B-97. Average Daily Tuolumne Running 7DADM Temperatures at RM 38.3 (Averaged over All Years from 1970 to 2003).

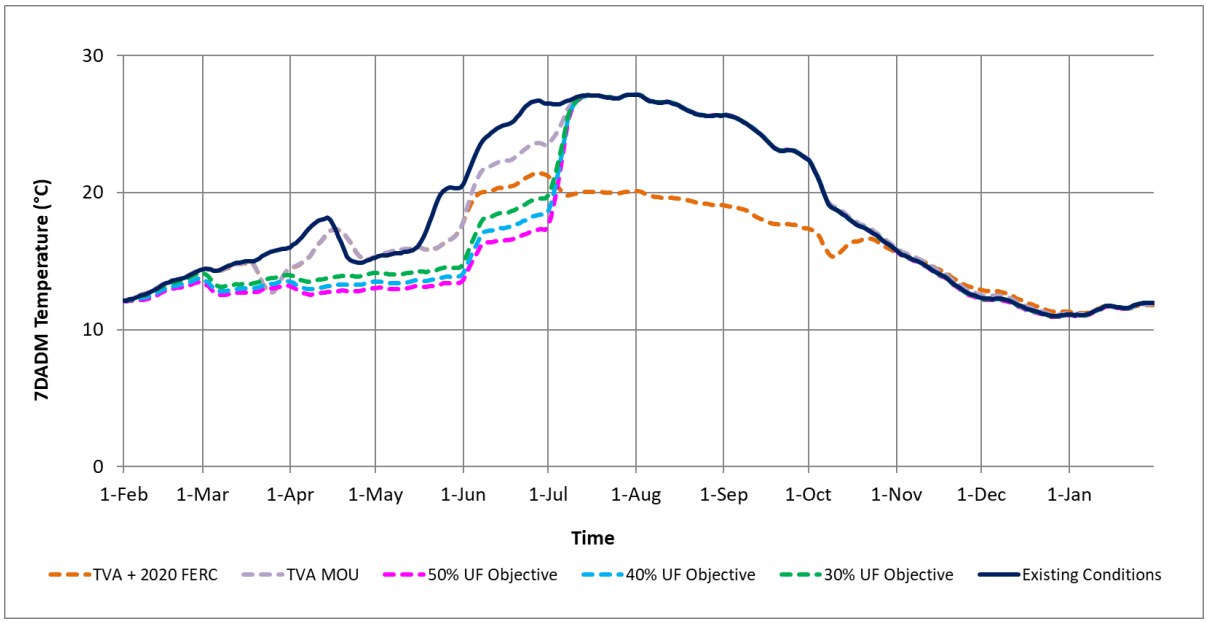


Figure B-98. Average Daily Tuolumne Running 7DADM Temperatures at RM 38.3 (Averaged over Critical Years from 1970 to 2003).

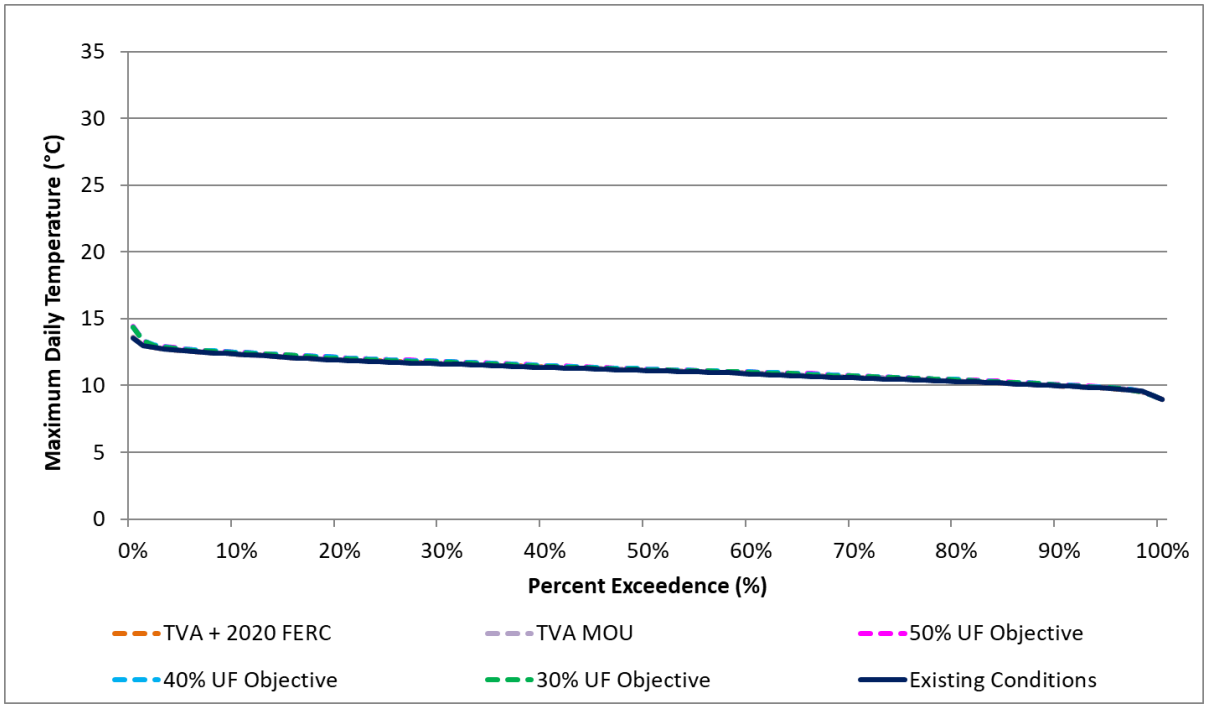


Figure B-99. Exceedance Chart of Daily Maximum Temperatures in January at RM 38.3 from 1970 to 2003.

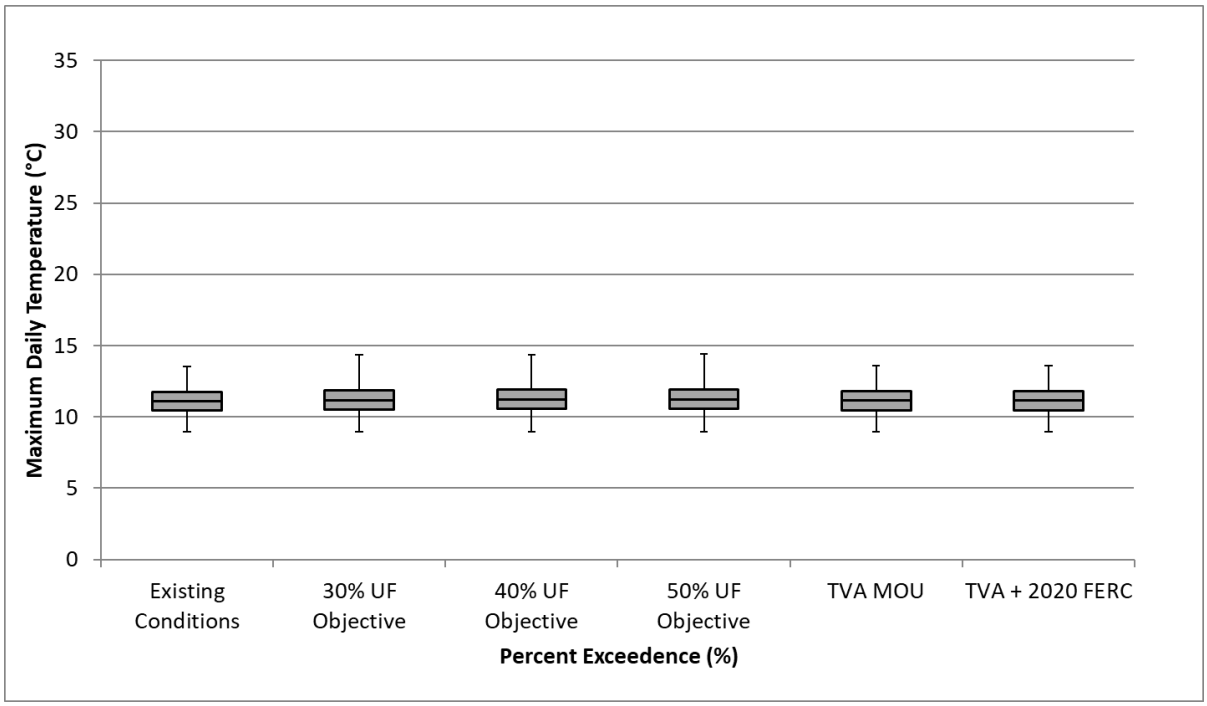


Figure B-100. Box Plot of Daily Maximum Temperatures in January at RM 38.3 from 1970 to 2003.

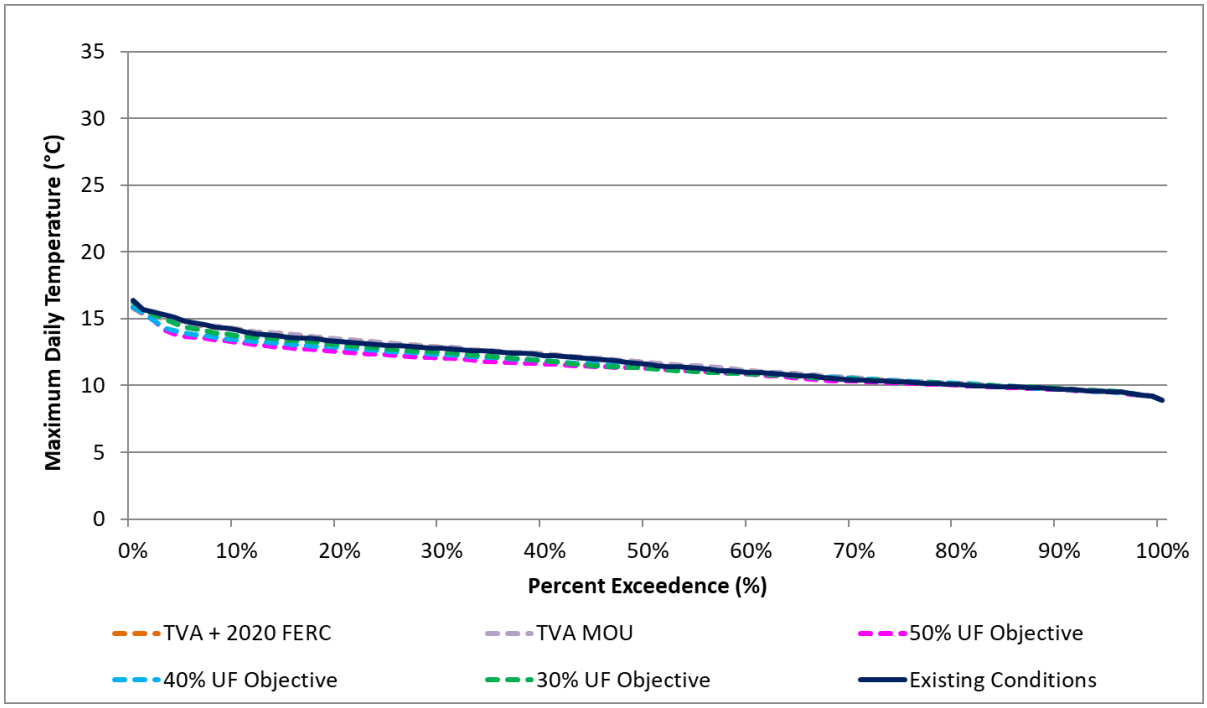


Figure B-101. Exceedance Chart of Daily Maximum Temperatures in February at RM 38.3 from 1970 to 2003.

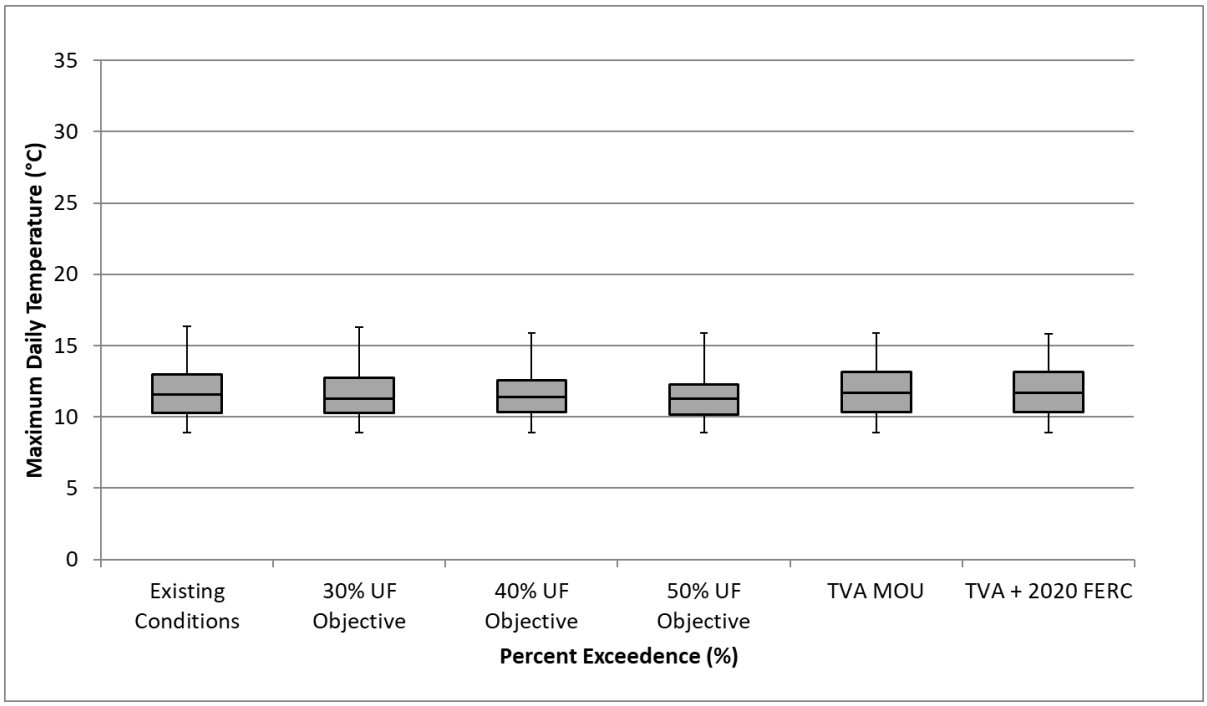


Figure B-102. Box Plot of Daily Maximum Temperatures in February at RM 38.3 from 1970 to 2003.

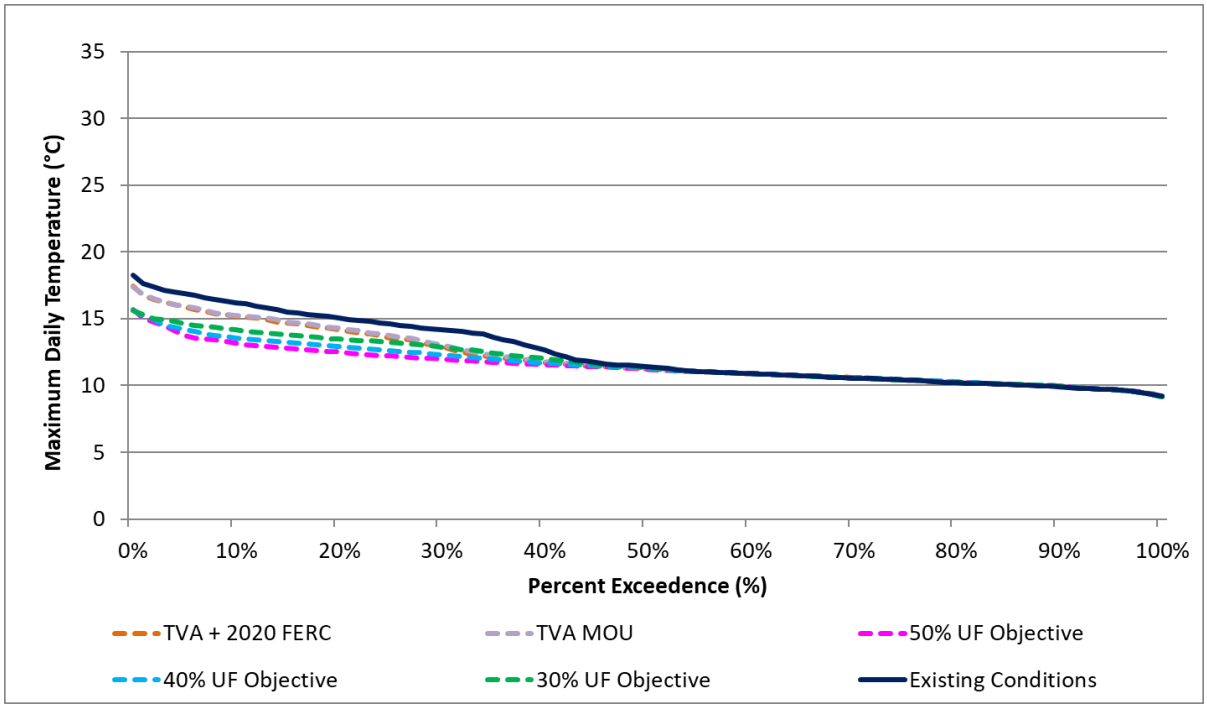


Figure B-103. Exceedance Chart of Daily Maximum Temperatures in March at RM 38.3 from 1970 to 2003.

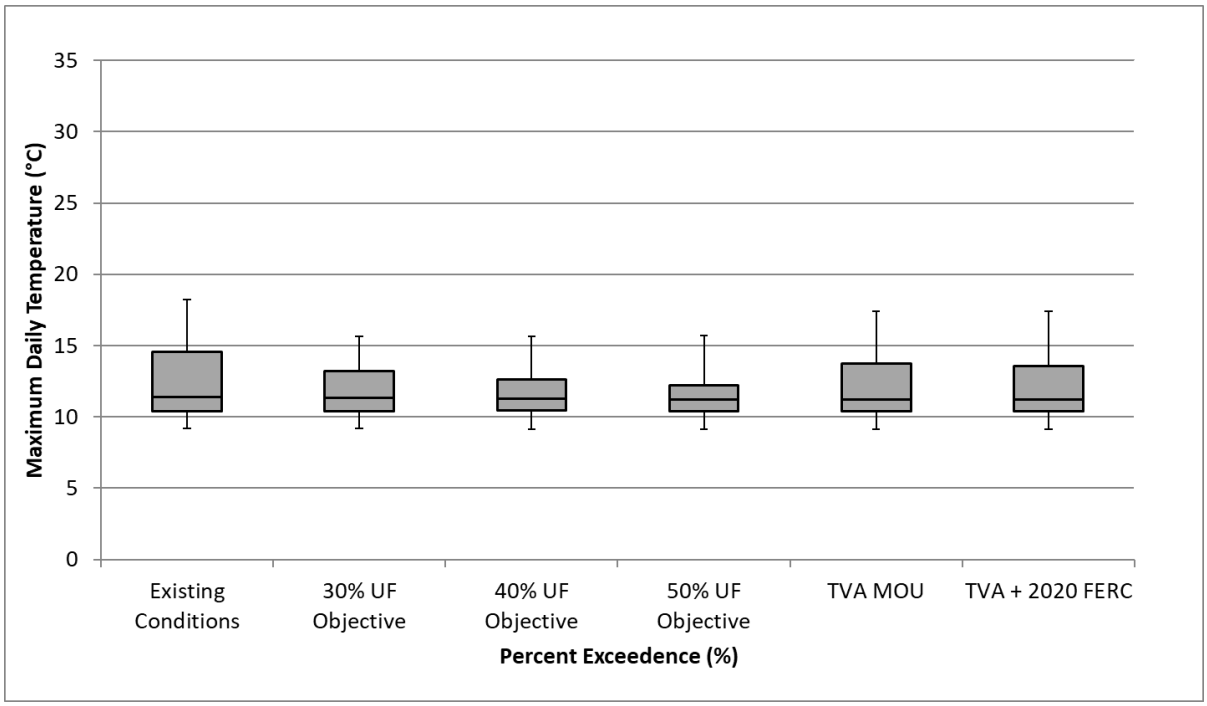


Figure B-104. Box Plot of Daily Maximum Temperatures in March at RM 38.3 from 1970 to 2003.

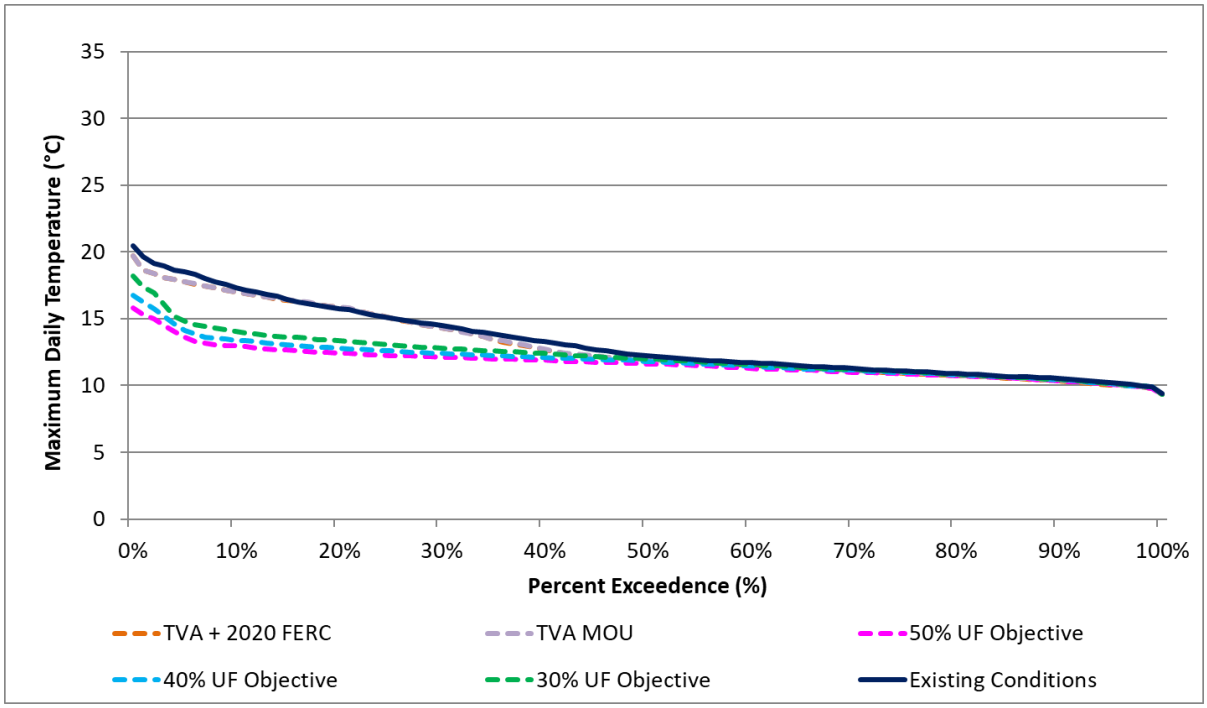


Figure B-105. Exceedance Chart of Daily Maximum Temperatures in April at RM 38.3 from 1970 to 2003.

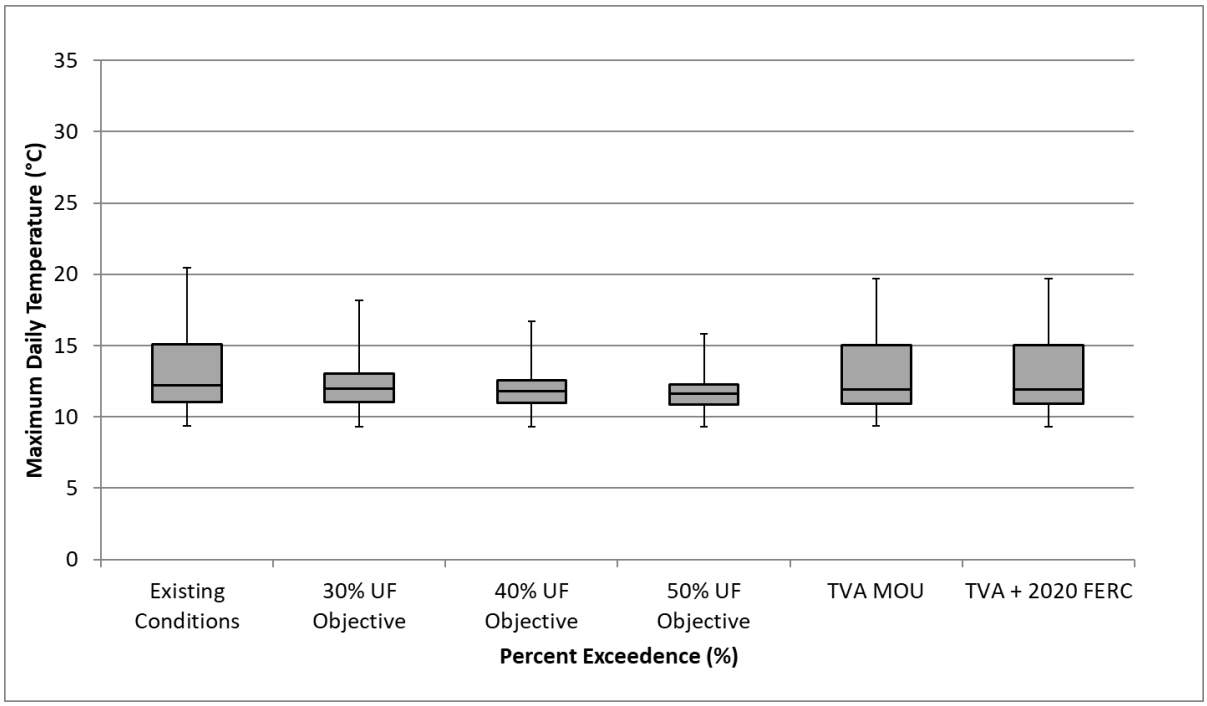


Figure B-106. Box Plot of Daily Maximum Temperatures in April at RM 38.3 from 1970 to 2003.

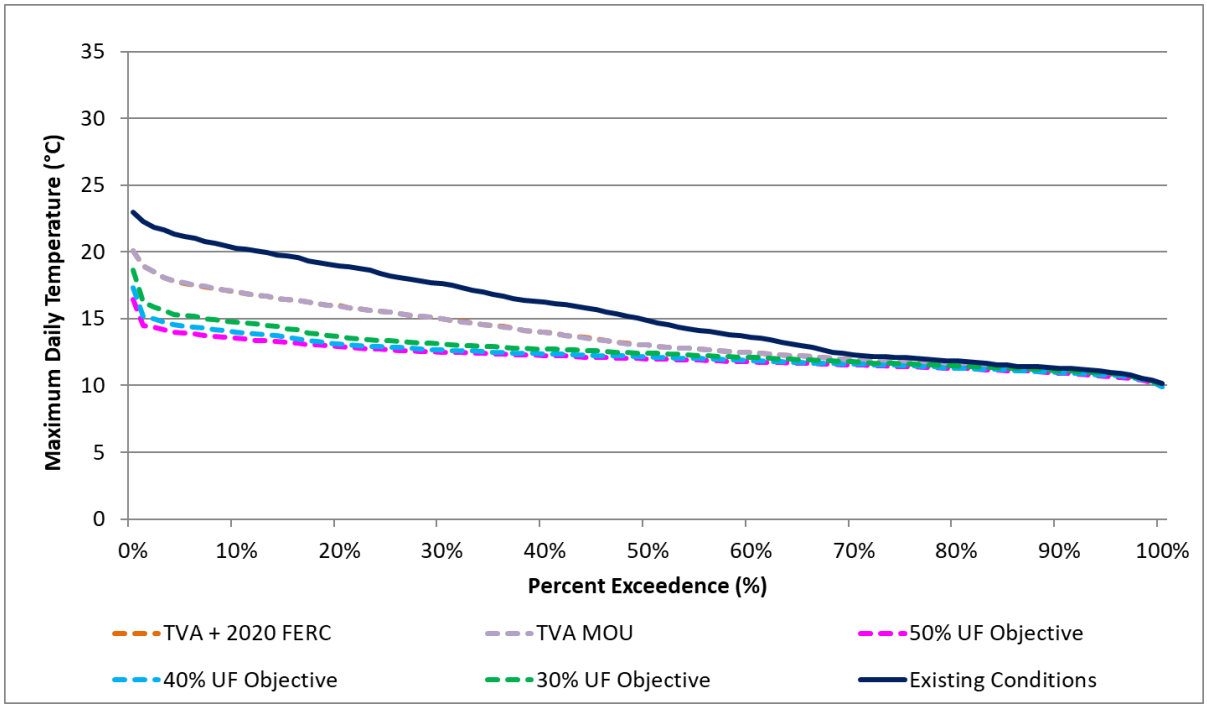


Figure B-107. Exceedance Chart of Daily Maximum Temperatures in May at RM 38.3 from 1970 to 2003.

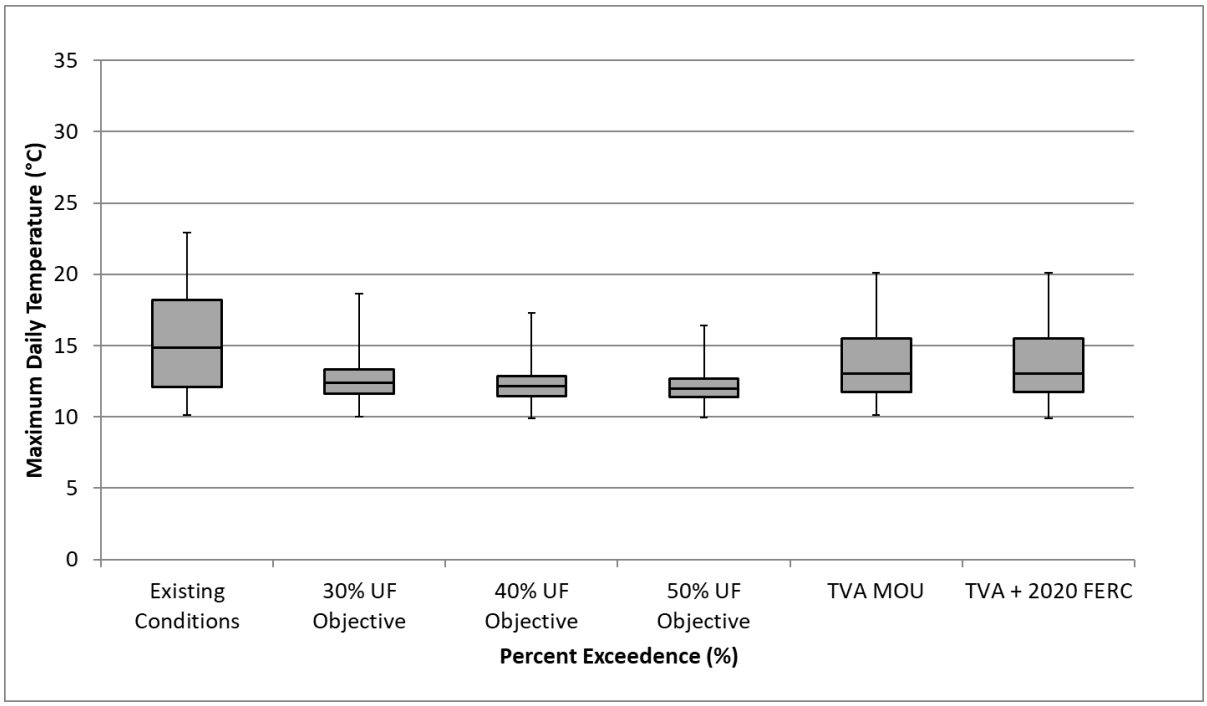


Figure B-108. Box Plot of Daily Maximum Temperatures in May at RM 38.3 from 1970 to 2003.

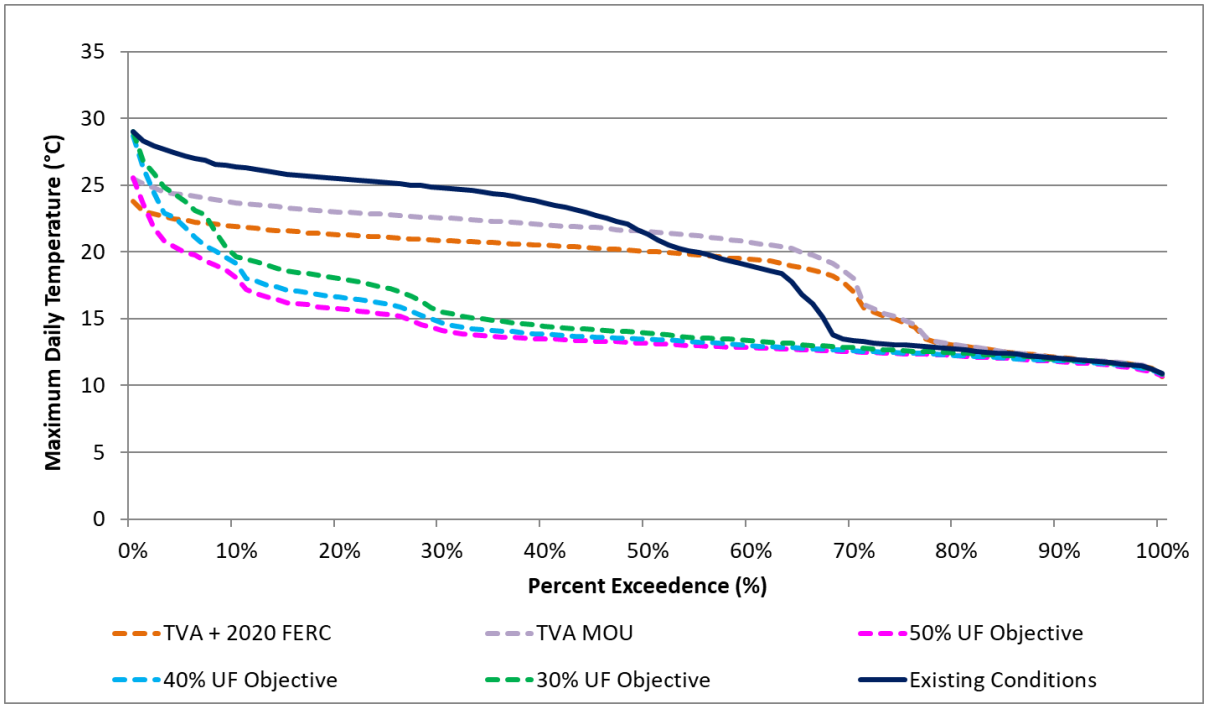


Figure B-109. Exceedance Chart of Daily Maximum Temperatures in June at RM 38.3 from 1970 to 2003.

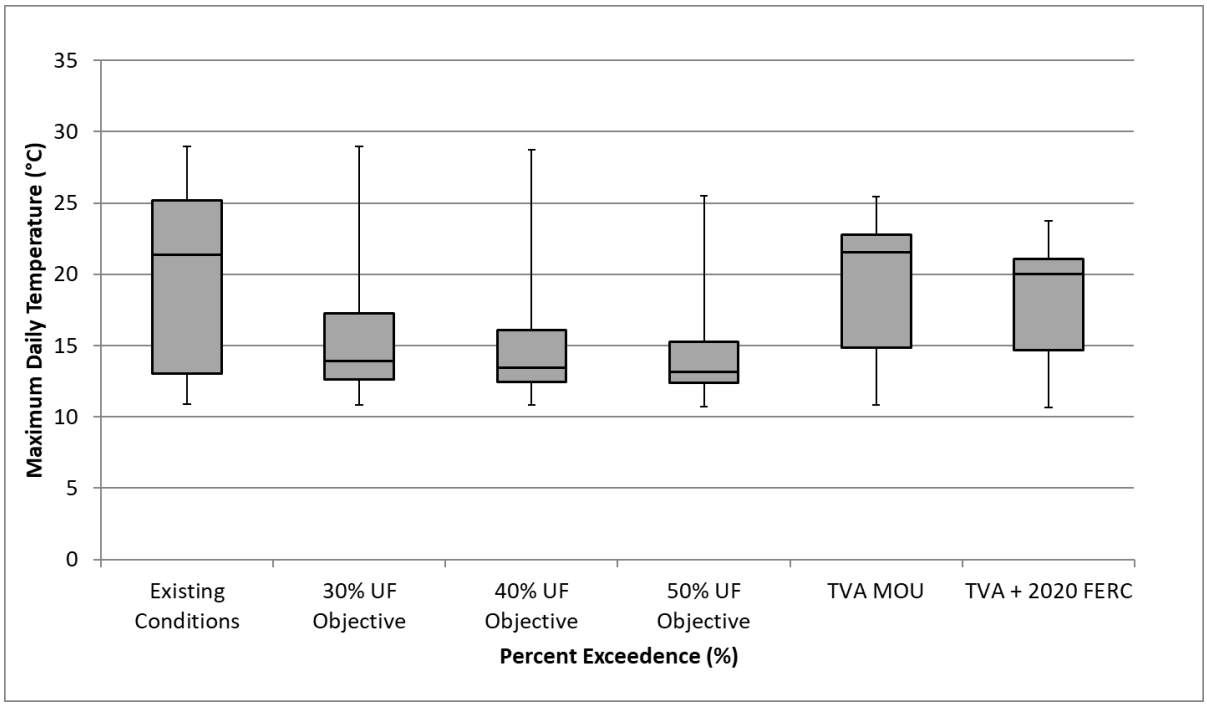


Figure B-110. Box Plot of Daily Maximum Temperatures in June at RM 38.3 from 1970 to 2003.

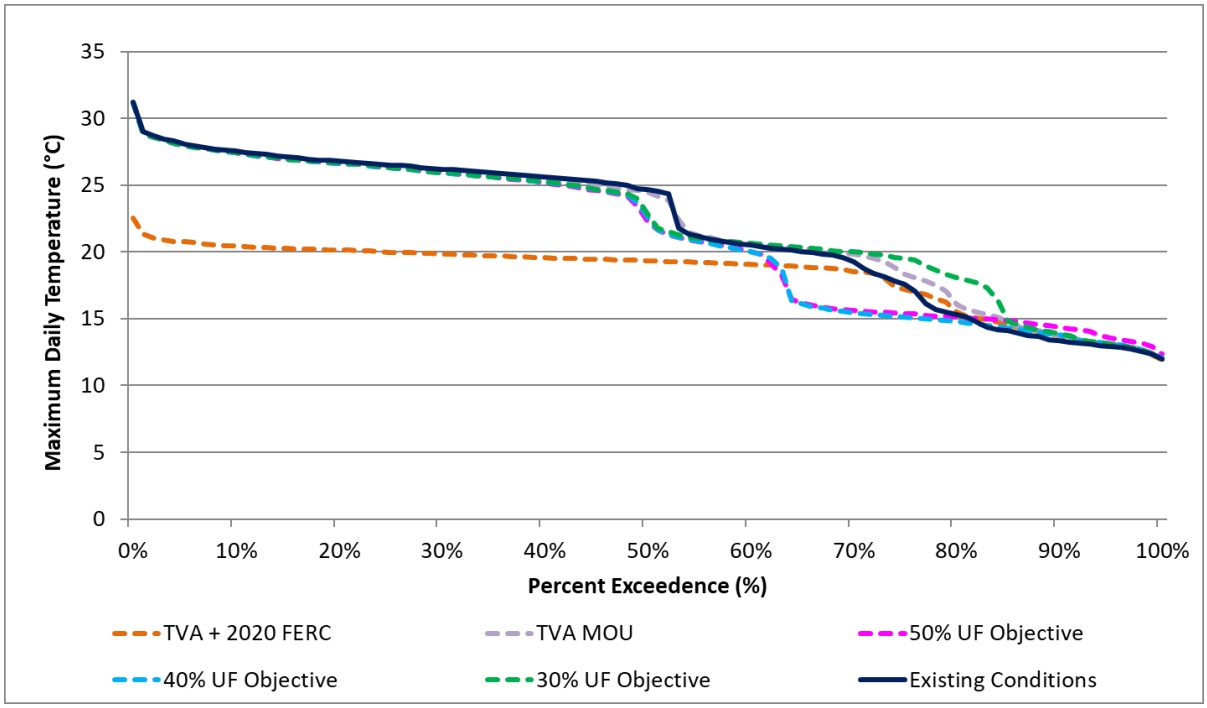


Figure B-111. Exceedance Chart of Daily Maximum Temperatures in July at RM 38.3 from 1970 to 2003.

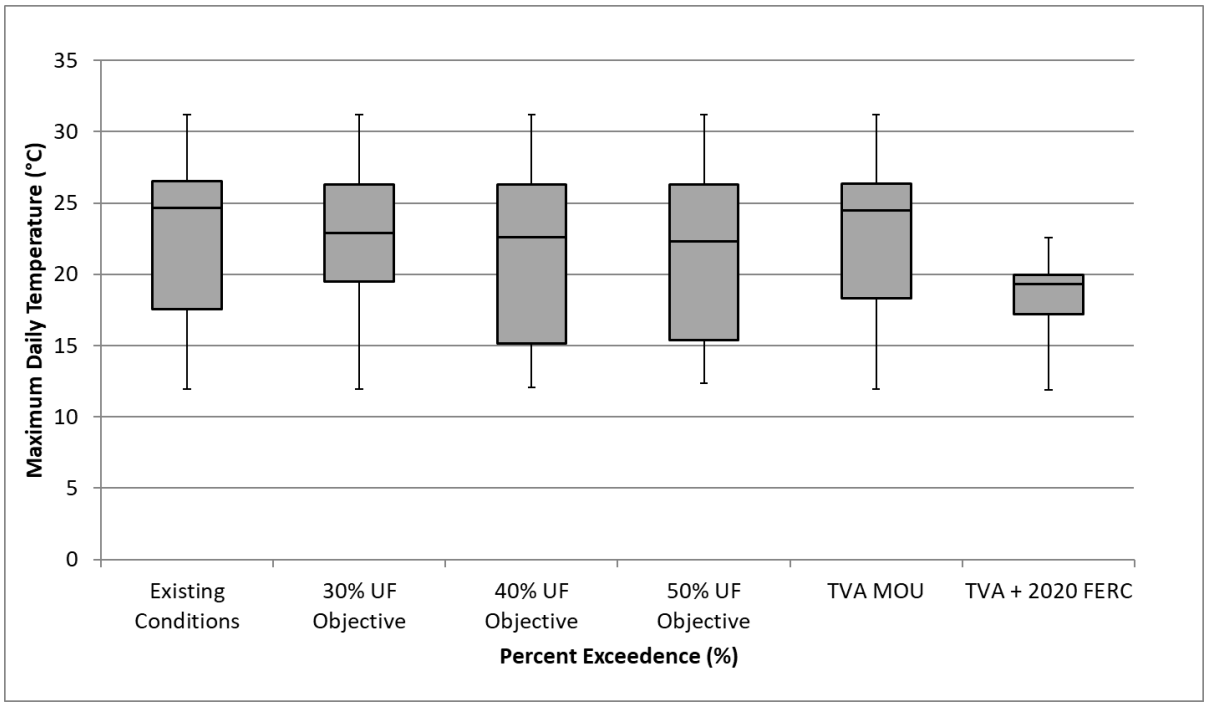


Figure B-112. Box Plot of Daily Maximum Temperatures in July at RM 38.3 from 1970 to 2003.

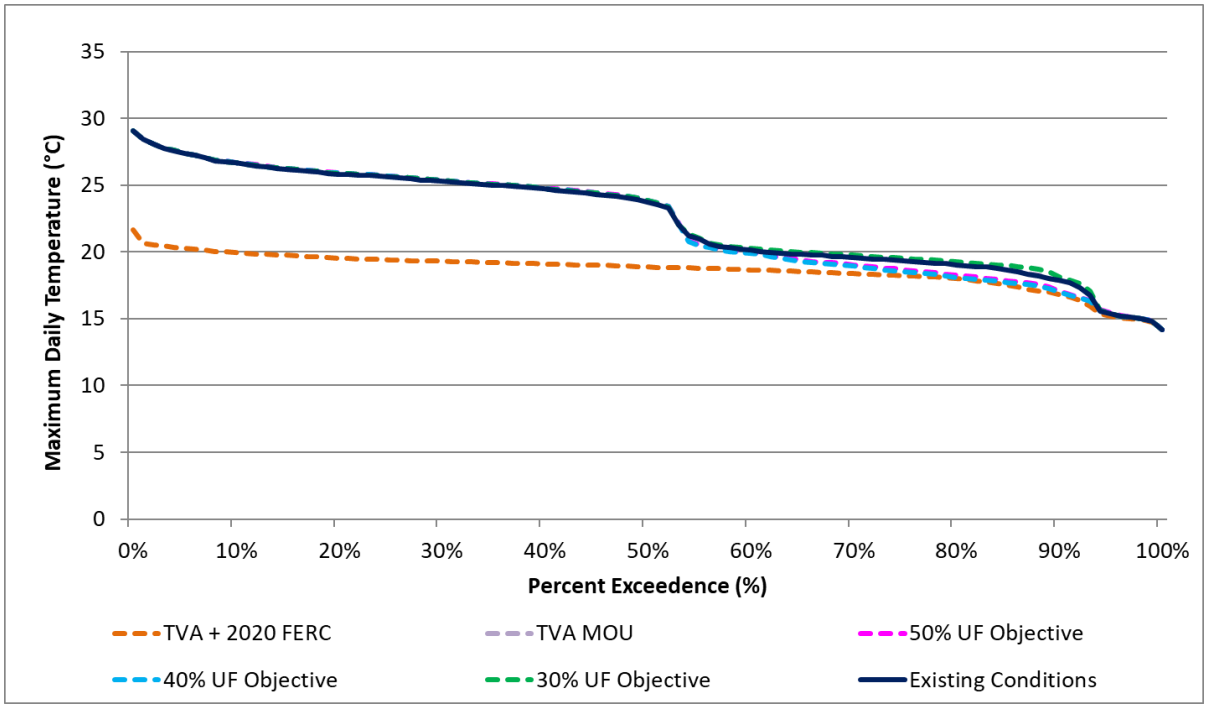


Figure B-113. Exceedance Chart of Daily Maximum Temperatures in August at RM 38.3 from 1970 to 2003.

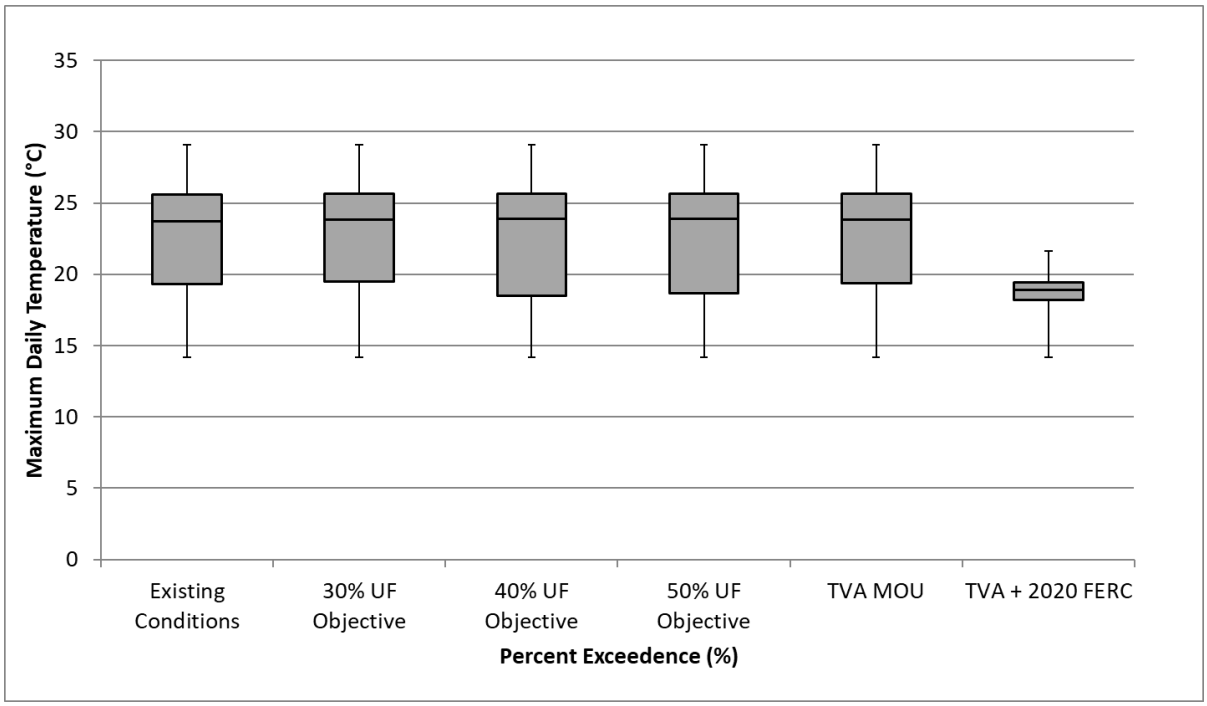


Figure B-114. Box Plot of Daily Maximum Temperatures in August at RM 38.3 from 1970 to 2003.

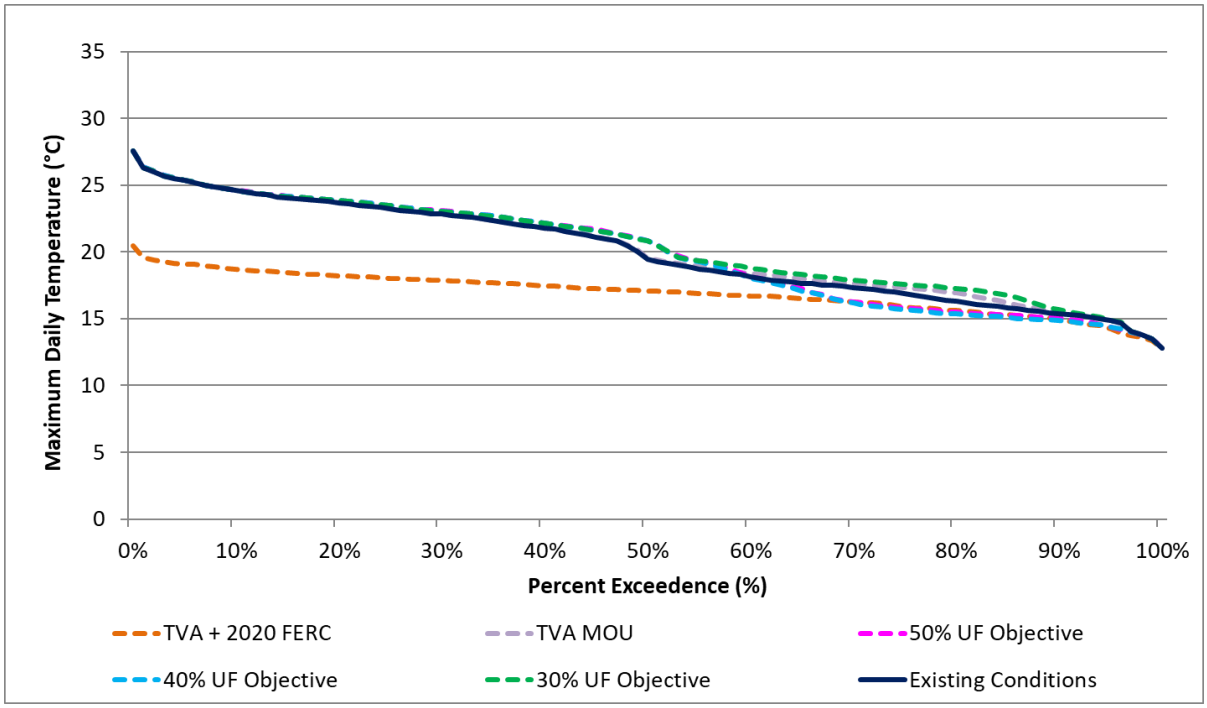


Figure B-115. Exceedance Chart of Daily Maximum Temperatures in September at RM 38.3 from 1970 to 2003.

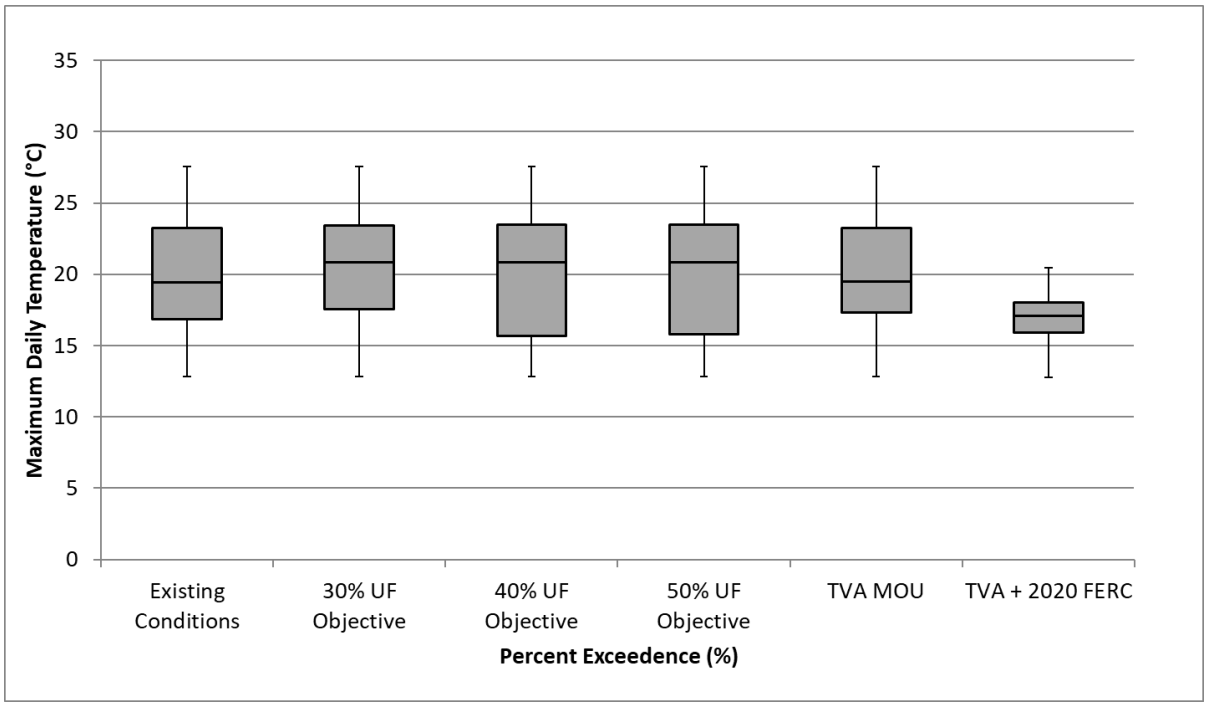


Figure B-116. Box Plot of Daily Maximum Temperatures in September at RM 38.3 from 1970 to 2003.

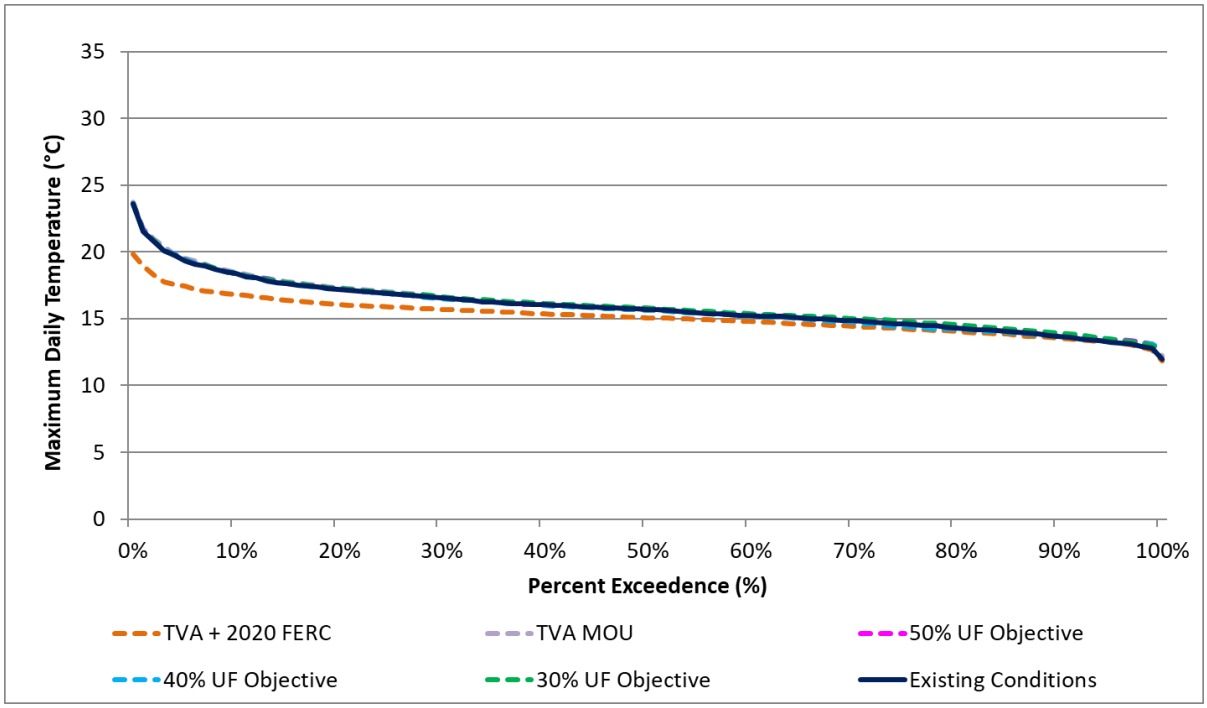


Figure B-117. Exceedance Chart of Daily Maximum Temperatures in October at RM 38.3 from 1970 to 2003.

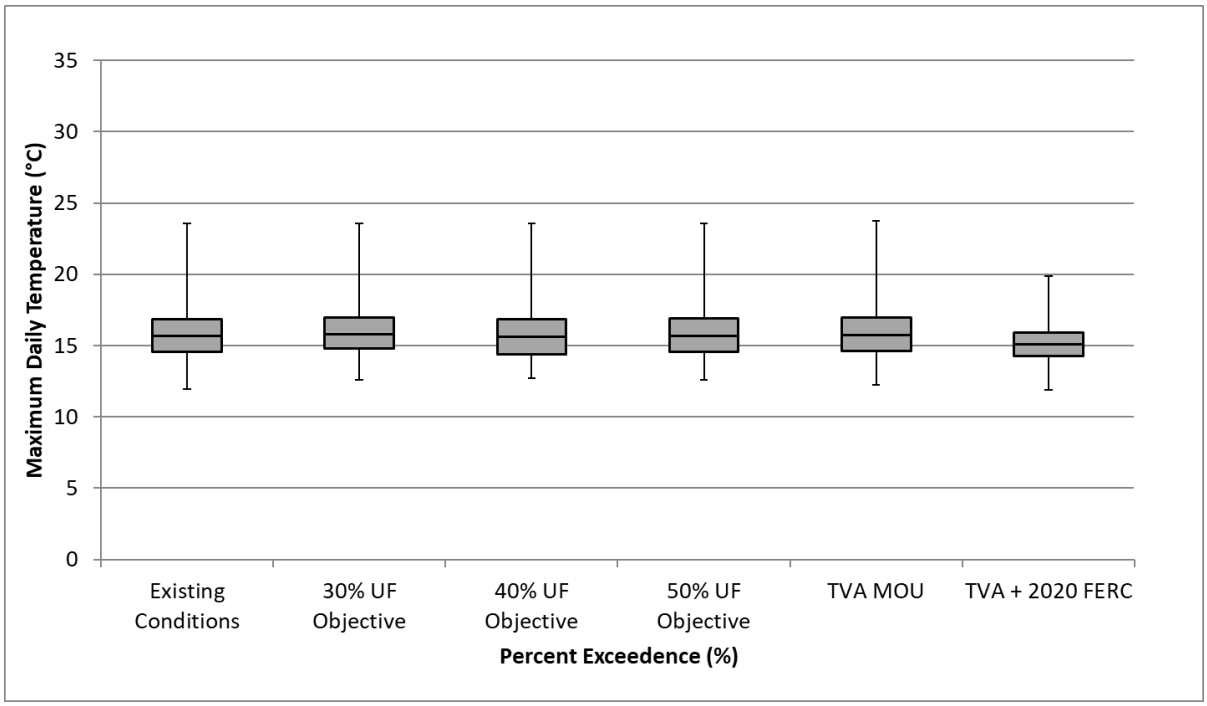


Figure B-118. Box Plot of Daily Maximum Temperatures in October at RM 38.3 from 1970 to 2003.

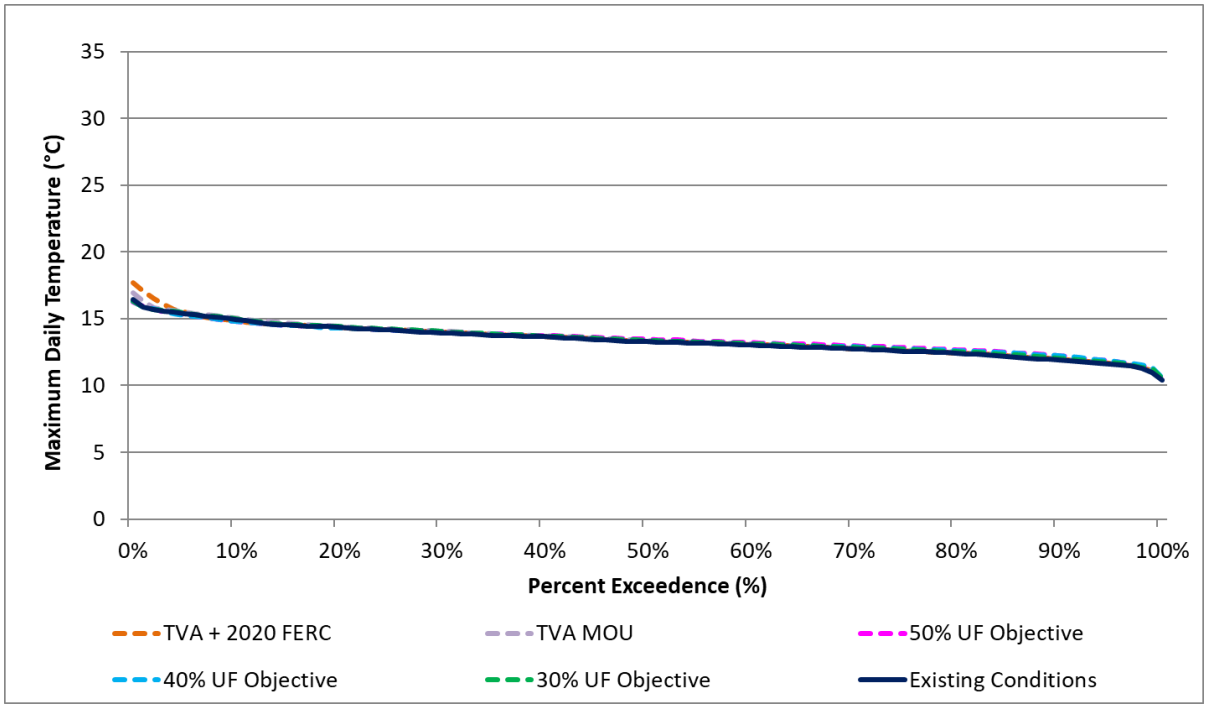


Figure B-119. Exceedance Chart of Daily Maximum Temperatures in November at RM 38.3 from 1970 to 2003.

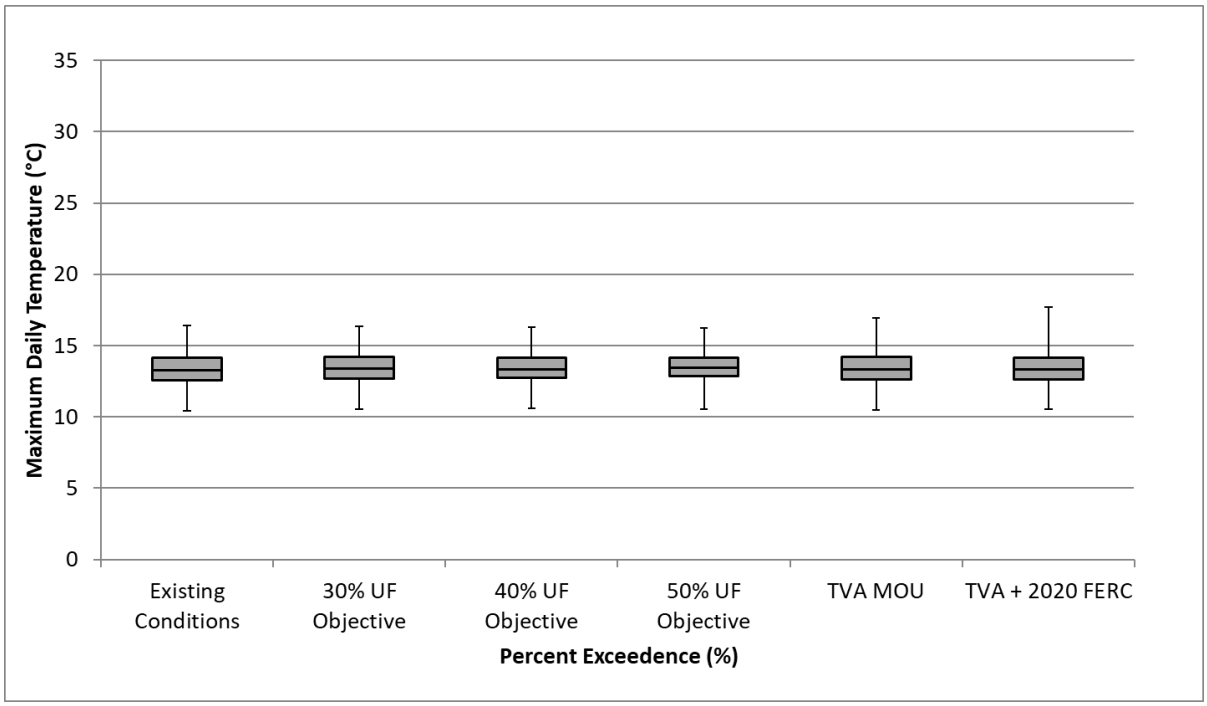


Figure B-120. Box Plot of Daily Maximum Temperatures in November at RM 38.3 from 1970 to 2003.

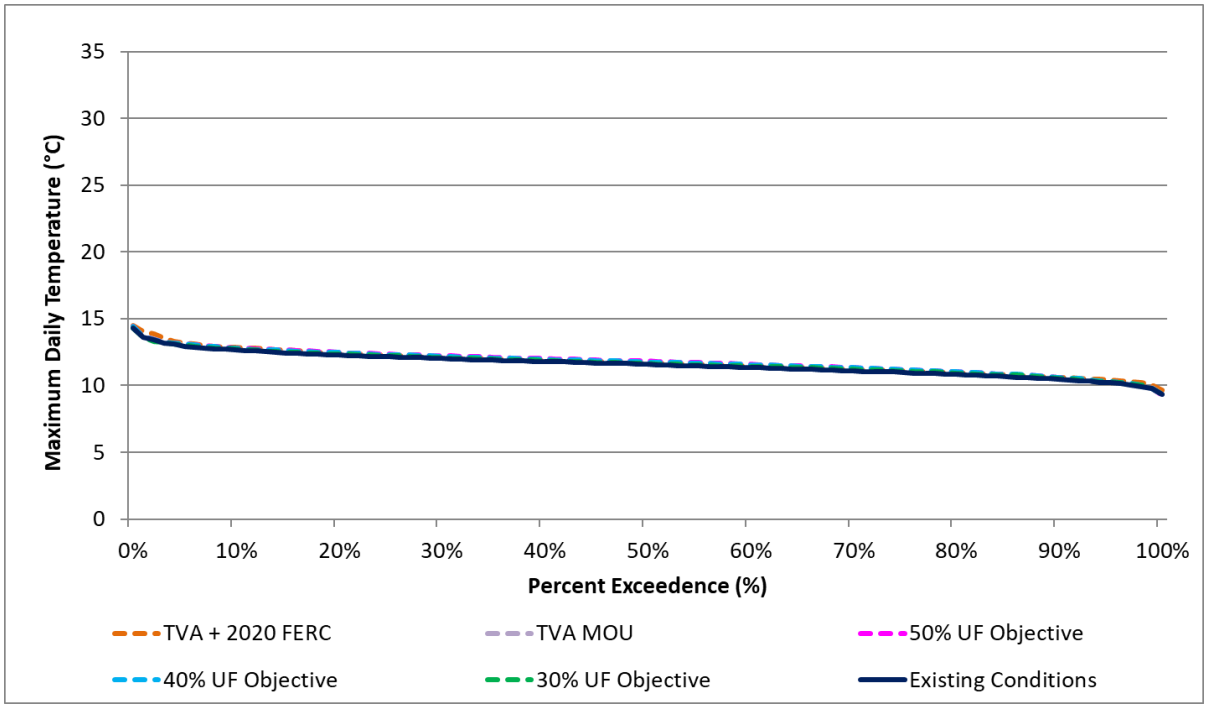


Figure B-121. Exceedance Chart of Daily Maximum Temperatures in December at RM 38.3 from 1970 to 2003.

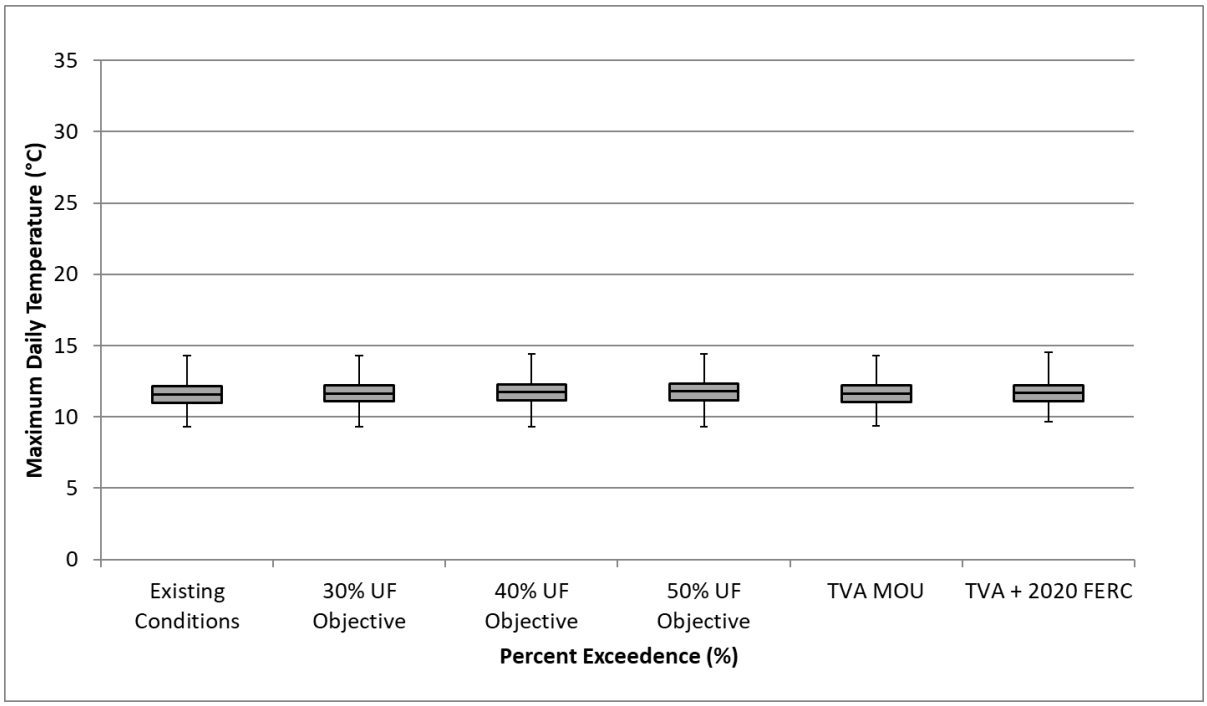


Figure B-122. Box Plot of Daily Maximum Temperatures in December at RM 38.3 from 1970 to 2003.

B.5.4 The Tuolumne River Between Waterford and Santa Fe Avenue Bridge (RM 28.1)

Figure B-123 and Figure B-124 present timeseries of average daily 7DADM temperatures at RM 28.1 over a year, the first being averaged over all years from 1970 to 2003 and the second only averaged over critical year types in that period.[24] The span of the figures is from February through January, which coincides with the operational year under the TVA (annual requirements under the TVA update in February). Figure B-125 through Figure B-148 present exceedance charts and box plots of daily maximum temperatures for each month at RM 28.1, intended to show the range of maximum daily temperatures that occur each month in the model run. Results at this location show similar effects to those seen at RM 38.3, but temperatures in all alternatives at RM 28.1 are slightly higher than at RM 38.3.

[24] Since annual operations for the TVA flow requirements begin updating in February of each year and extend through the following January, the flows and temperatures seen in the October through January period are more dependent on the previous year's WYT than the current one. Therefore, the averaging period for WYT in the temperature figures is shifted forward to apply from February through January rather than October through September.

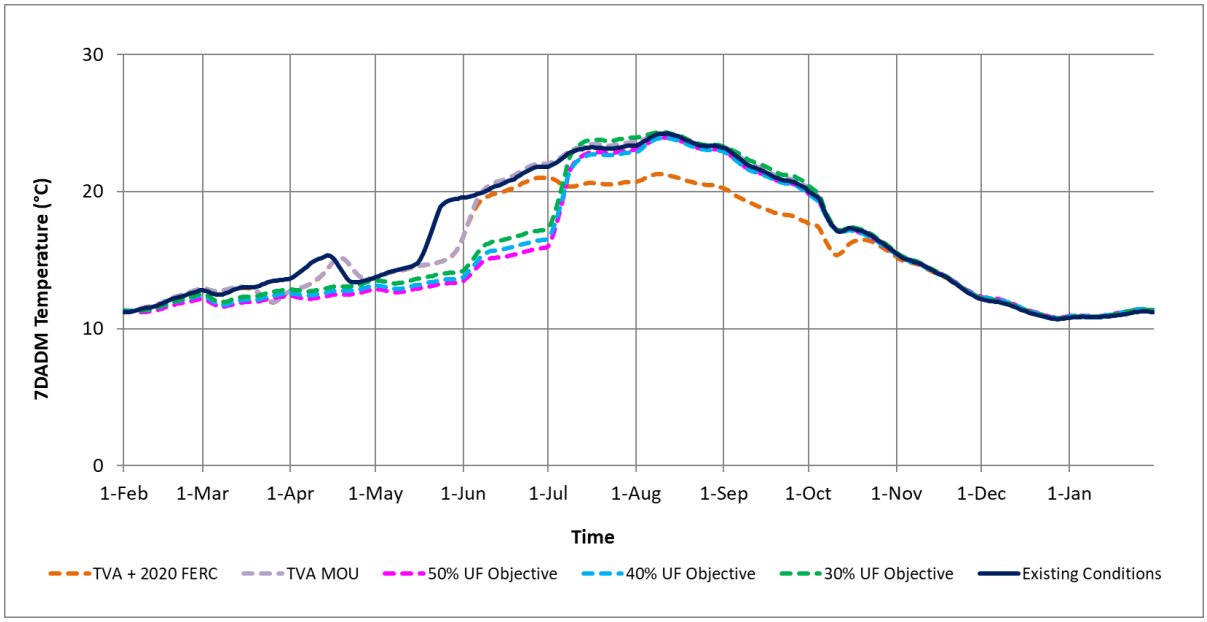


Figure B-123. Average Daily Tuolumne Running 7DADM Temperatures at RM 28.1 (Averaged over All Years from 1970 to 2003).

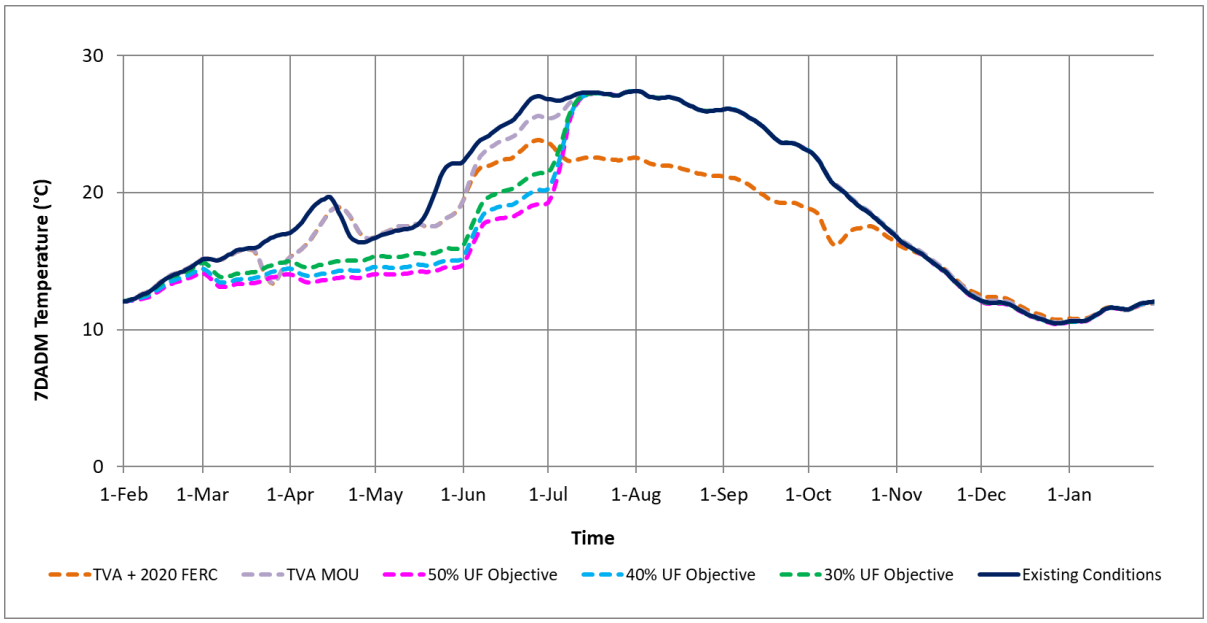


Figure B-124. Average Daily Tuolumne Running 7DADM Temperatures at RM 28.1 (Averaged over Critical Years from 1970 to 2003).

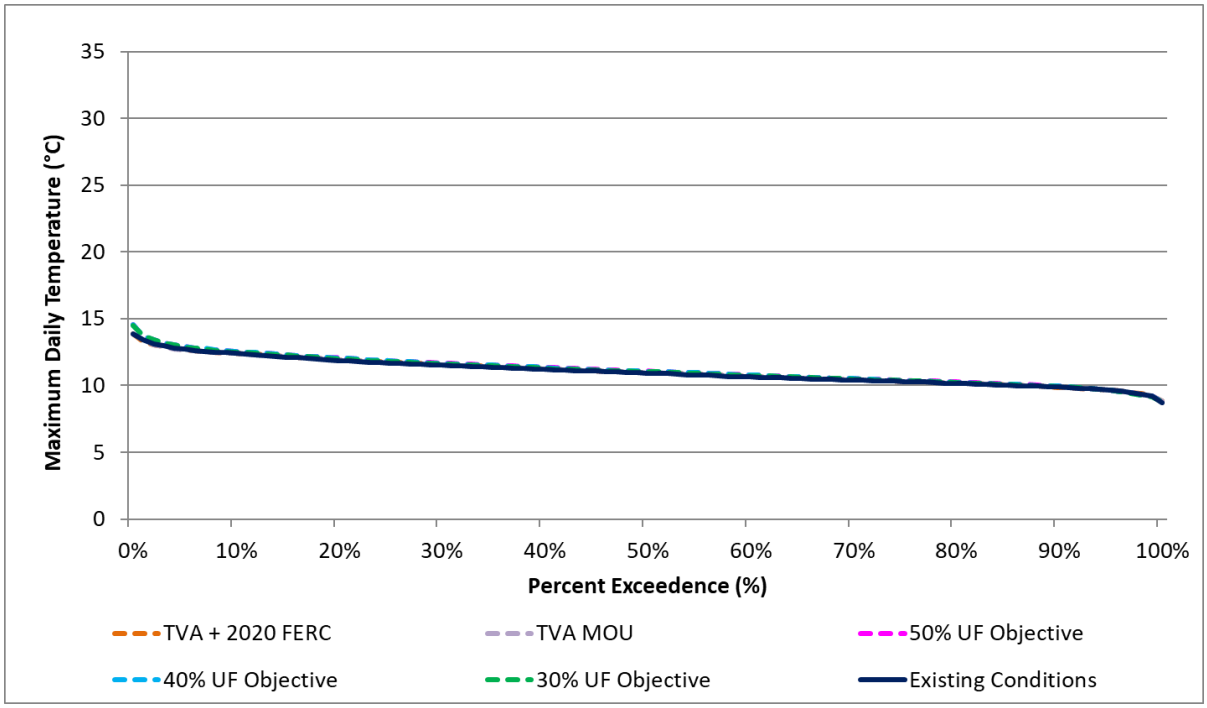


Figure B-125. Exceedance Chart of Daily Maximum Temperatures in January at RM 28.1 from 1970 to 2003.

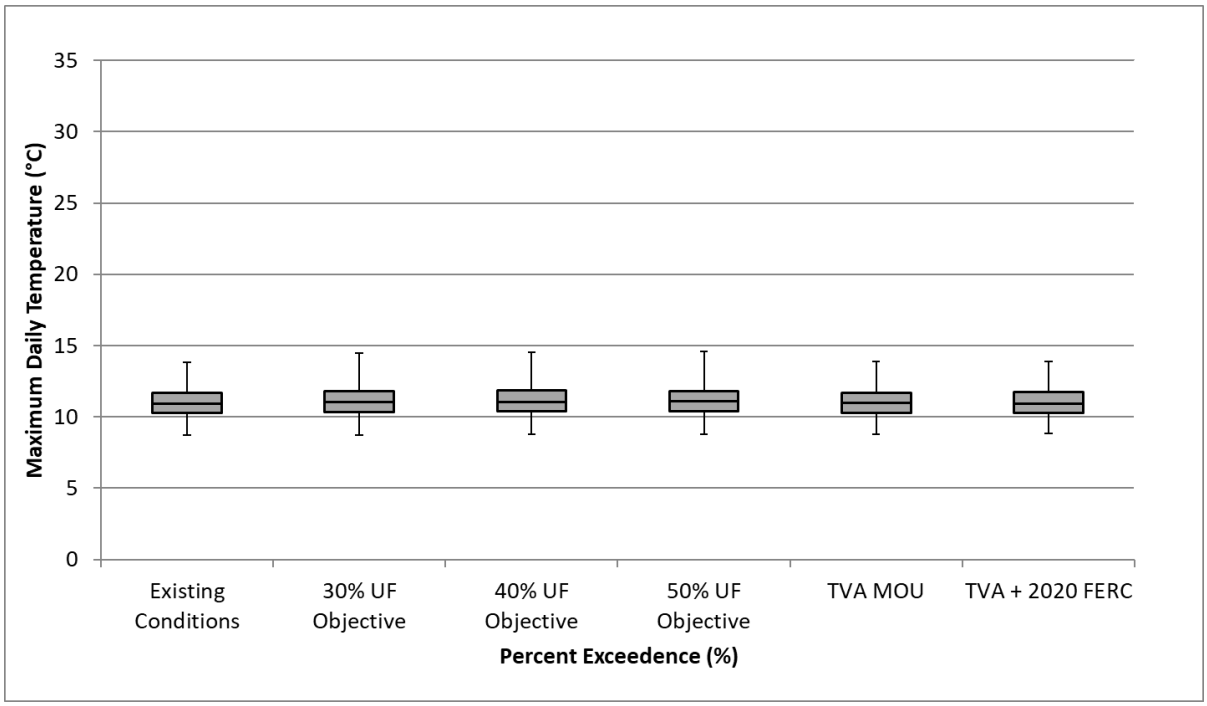


Figure B-126. Box Plot of Daily Maximum Temperatures in January at RM 28.1 from 1970 to 2003.

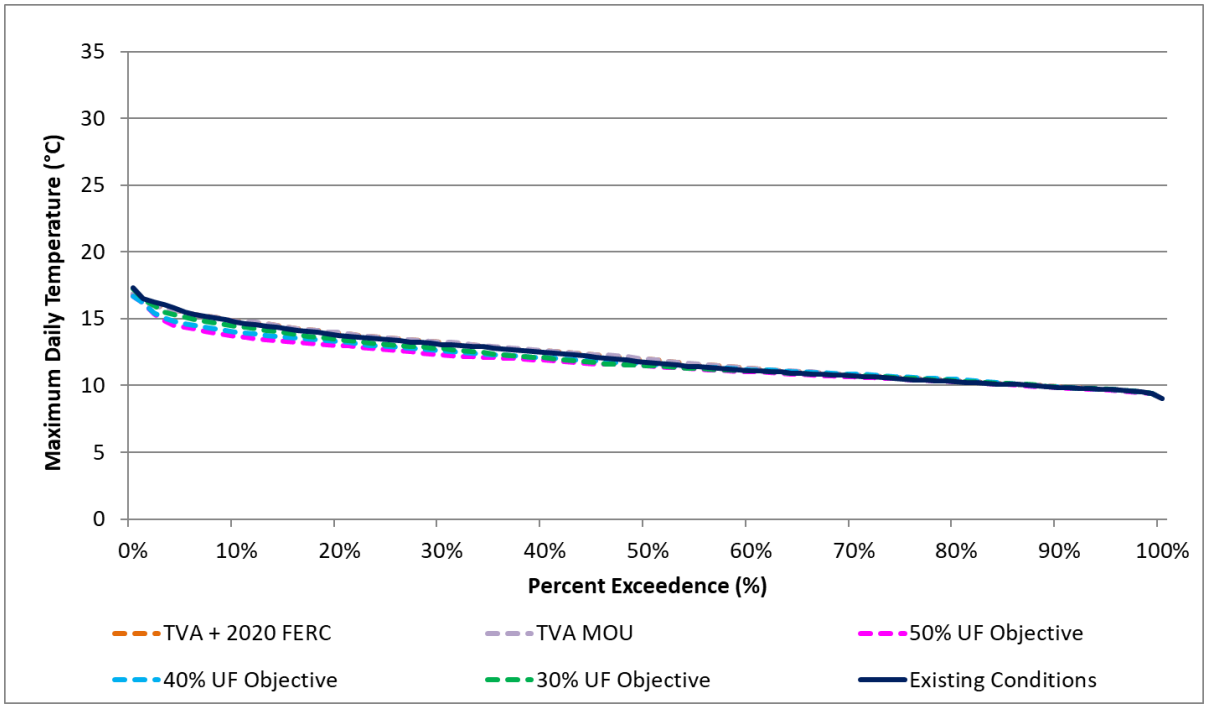


Figure B-127. Exceedance Chart of Daily Maximum Temperatures in February at RM 28.1 from 1970 to 2003.

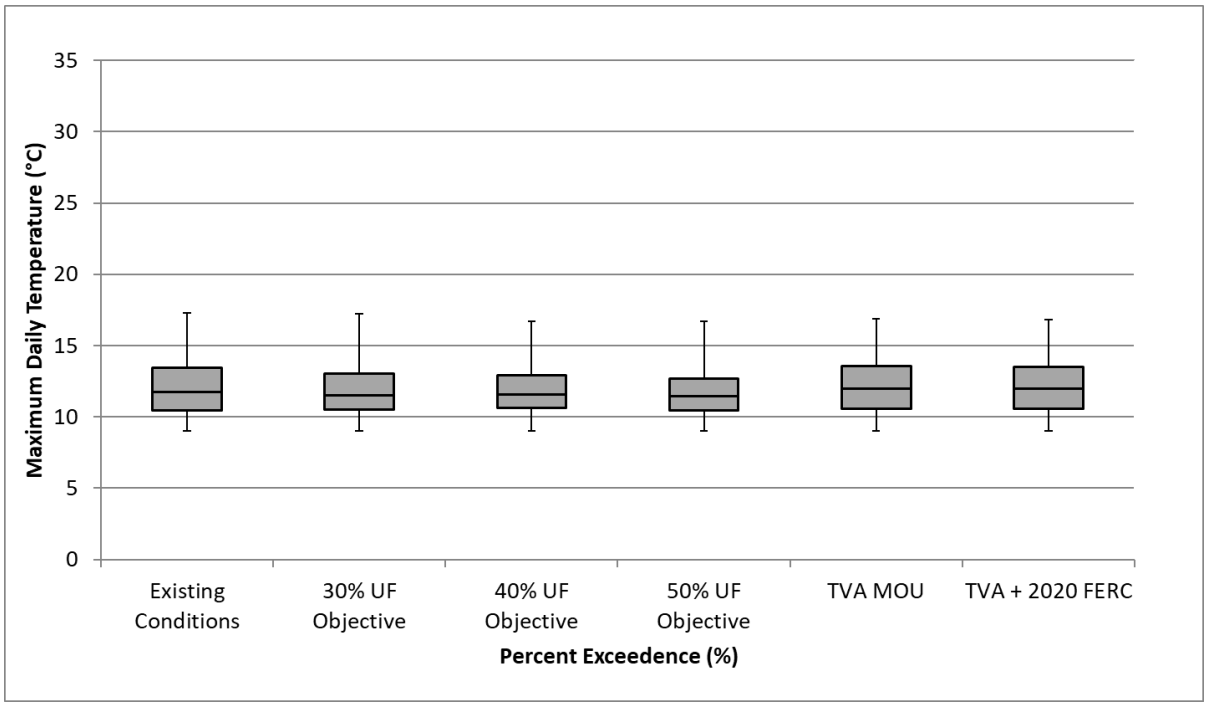


Figure B-128. Box Plot of Daily Maximum Temperatures in February at RM 28.1 from 1970 to 2003.

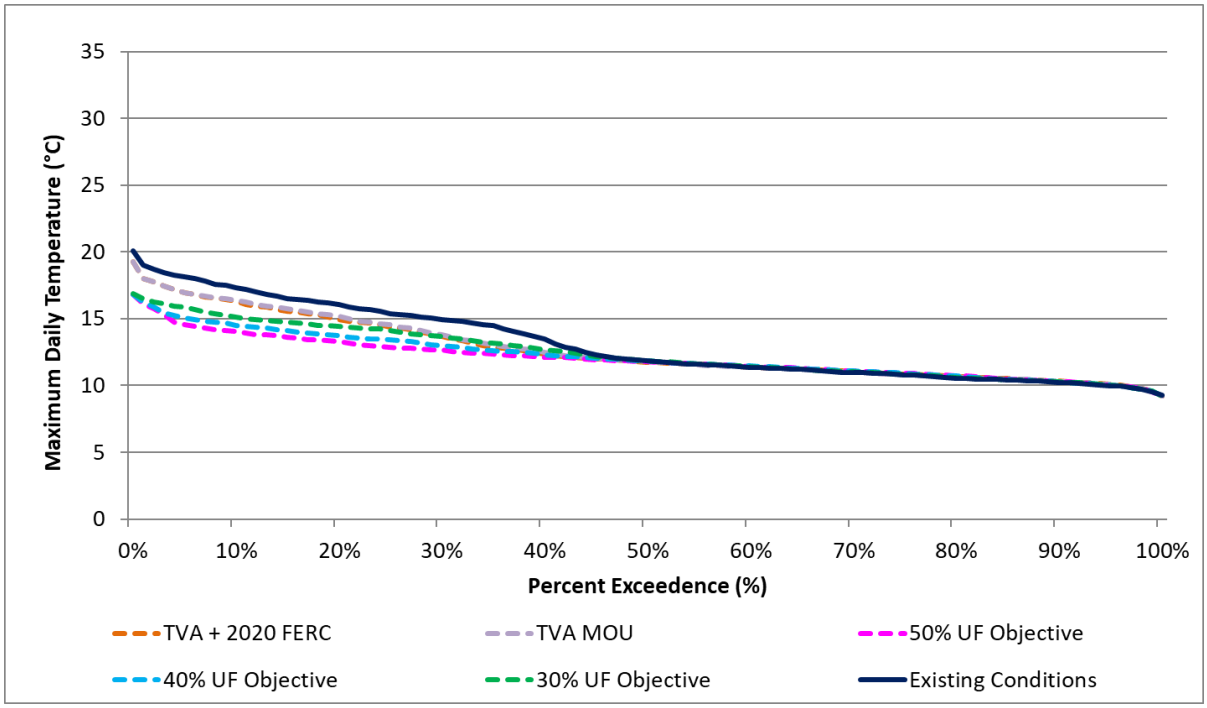


Figure B-129. Exceedance Chart of Daily Maximum Temperatures in March at RM 28.1 from 1970 to 2003.

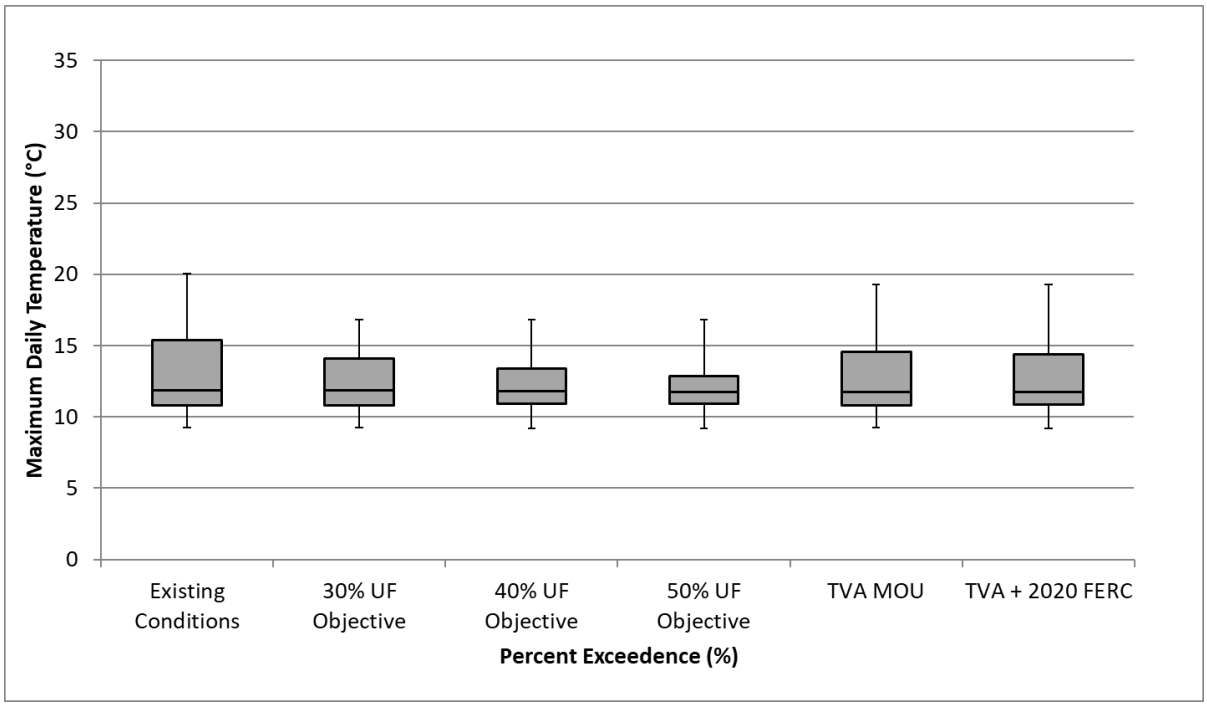


Figure B-130. Box Plot of Daily Maximum Temperatures in March at RM 28.1 from 1970 to 2003.

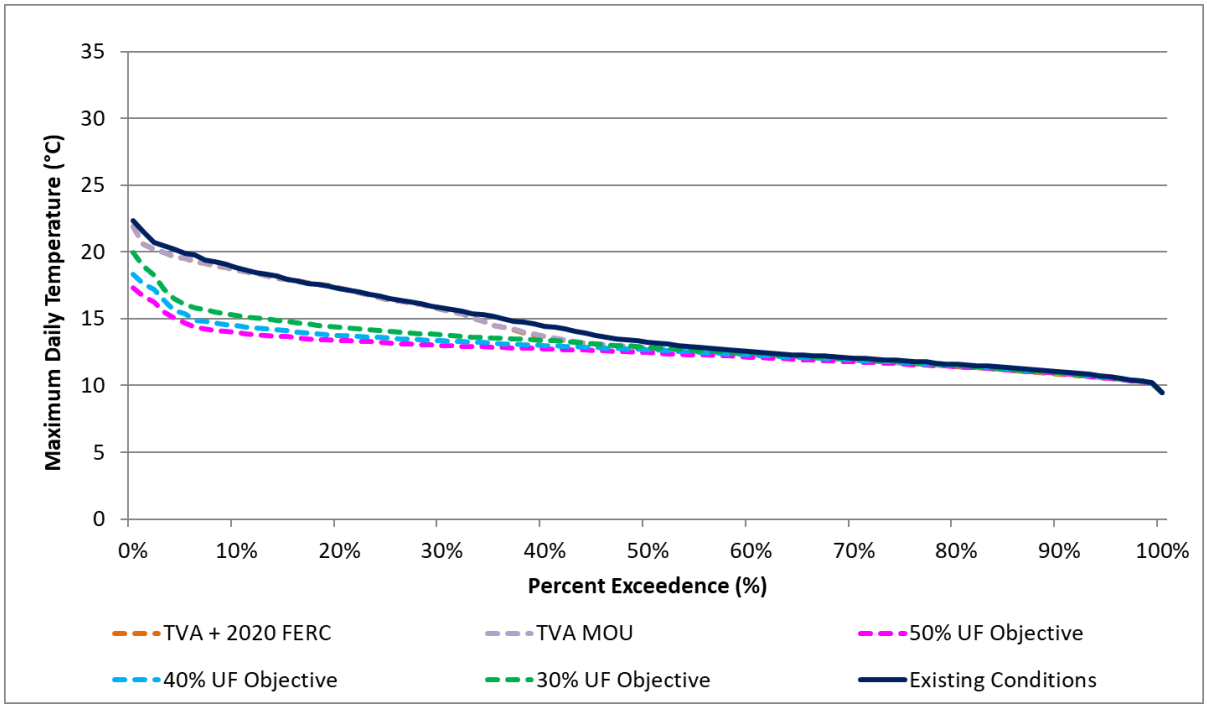


Figure B-131. Exceedance Chart of Daily Maximum Temperatures in April at RM 28.1 from 1970 to 2003.

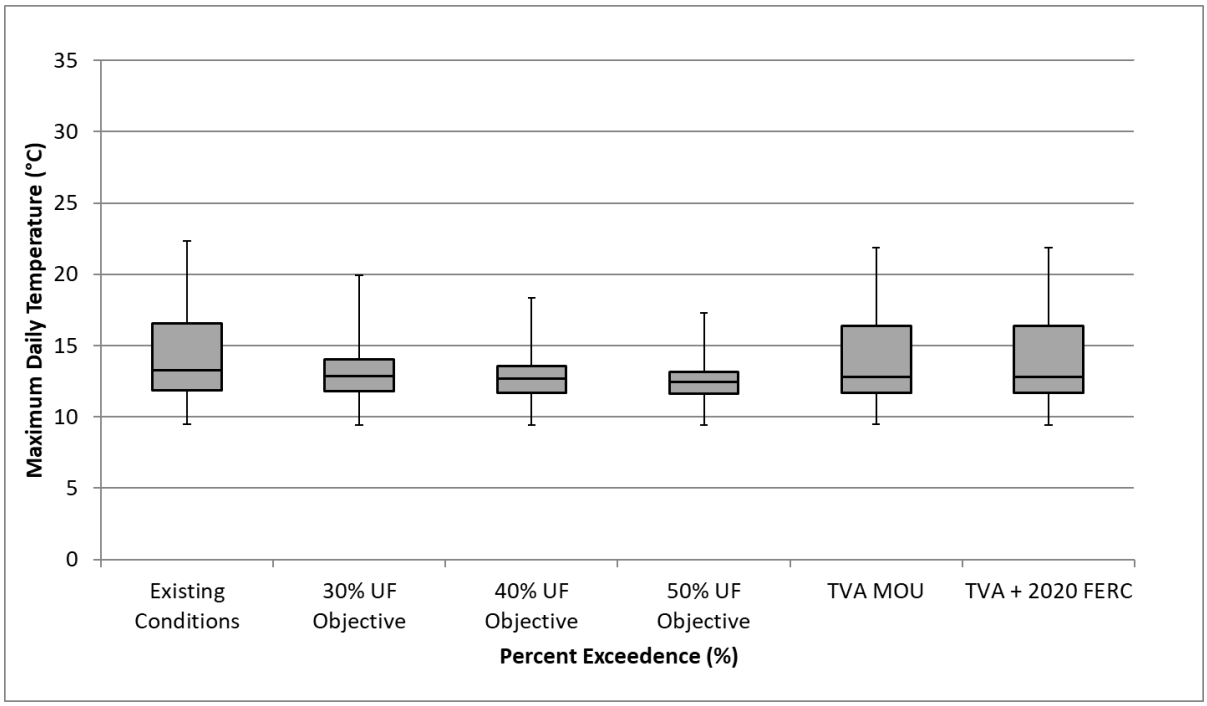


Figure B-132. Box Plot of Daily Maximum Temperatures in April at RM 28.1 from 1970 to 2003.

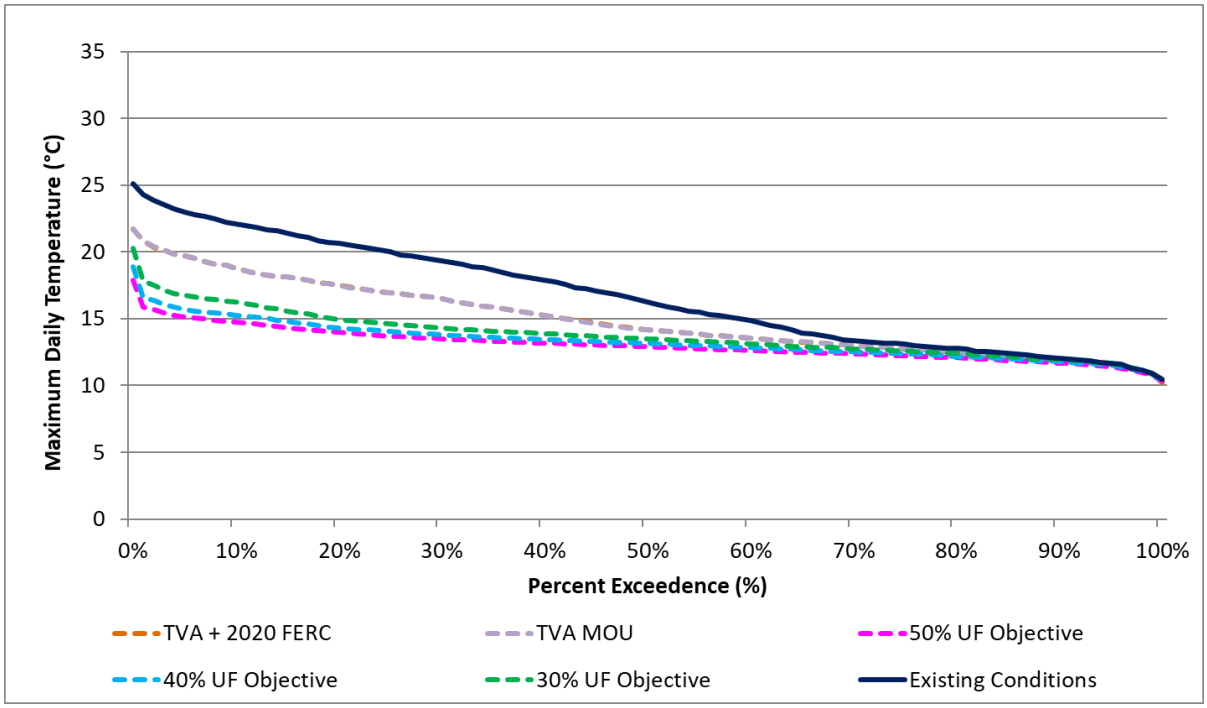


Figure B-133. Exceedance Chart of Daily Maximum Temperatures in May at RM 28.1 from 1970 to 2003.

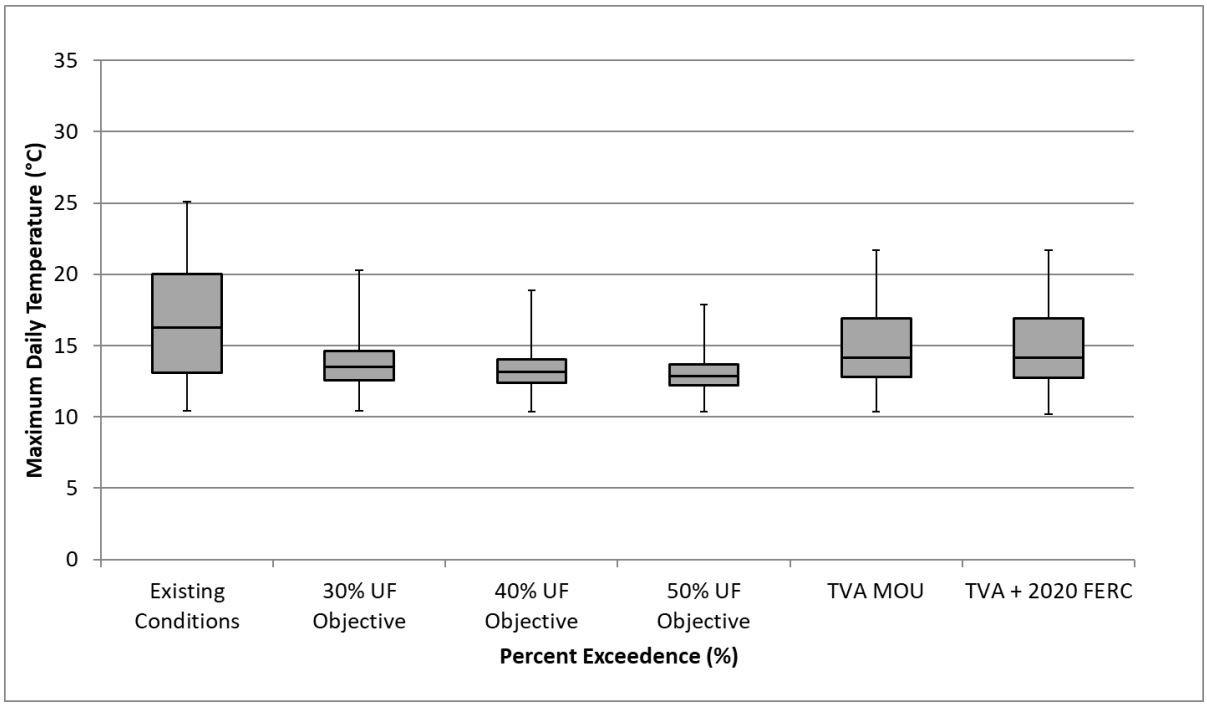


Figure B-134. Box Plot of Daily Maximum Temperatures in May at RM 28.1 from 1970 to 2003.

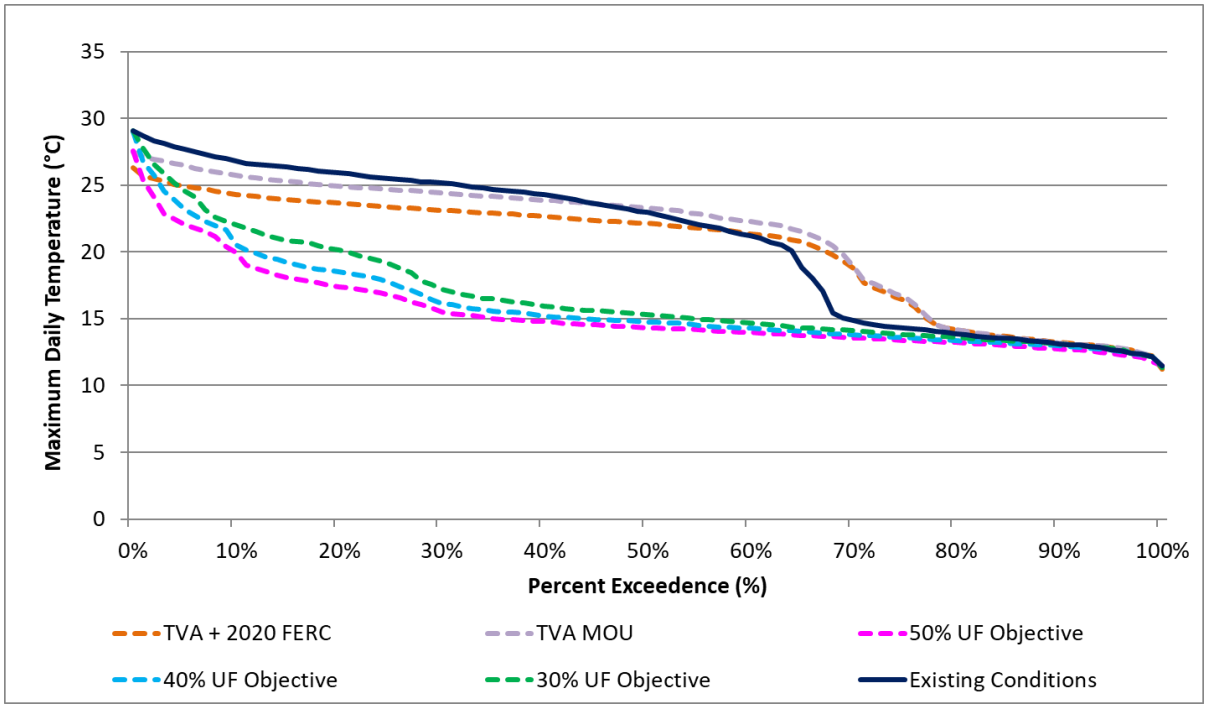


Figure B-135. Exceedance Chart of Daily Maximum Temperatures in June at RM 28.1 from 1970 to 2003.

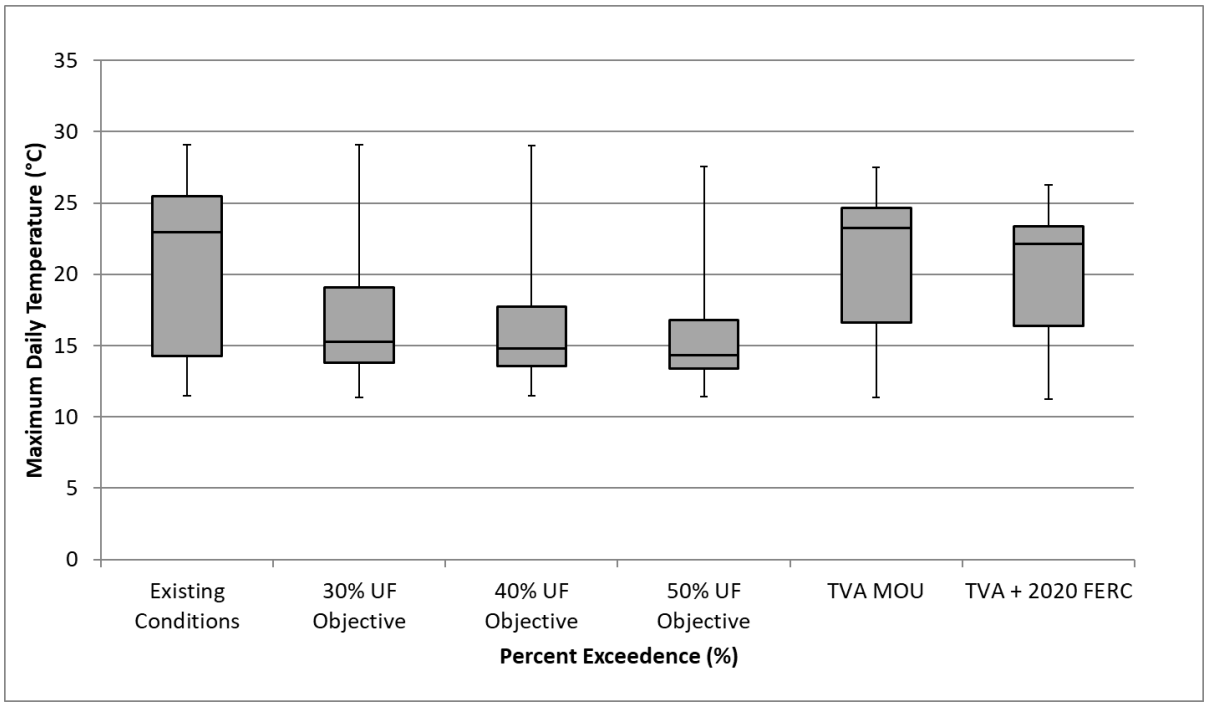


Figure B-136. Box Plot of Daily Maximum Temperatures in June at RM 28.1 from 1970 to 2003.

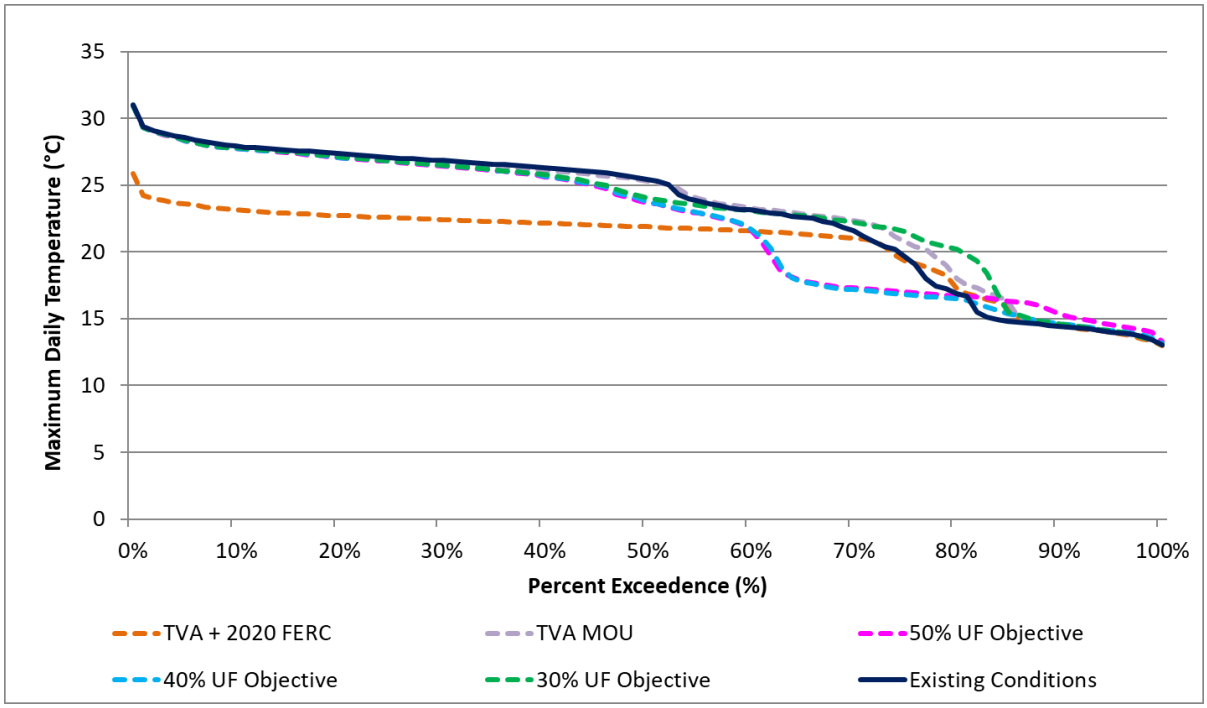


Figure B-137. Exceedance Chart of Daily Maximum Temperatures in July at RM 28.1 from 1970 to 2003.

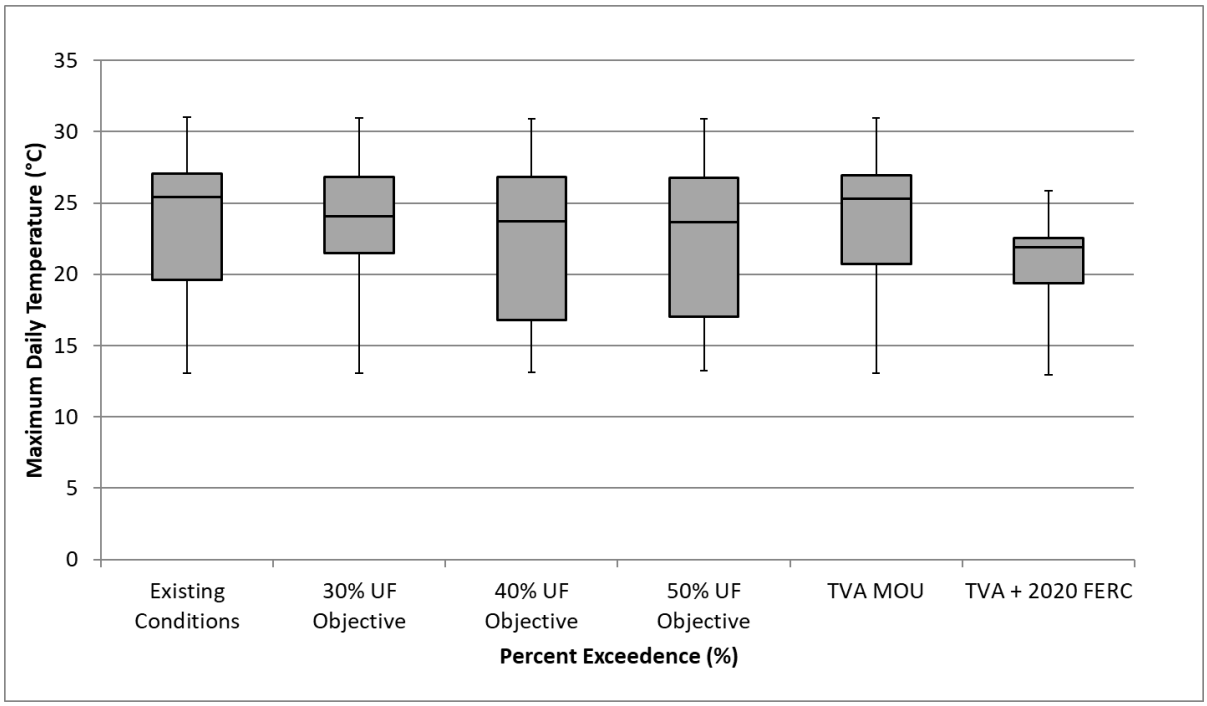


Figure B-138. Box Plot of Daily Maximum Temperatures in July at RM 28.1 from 1970 to 2003.

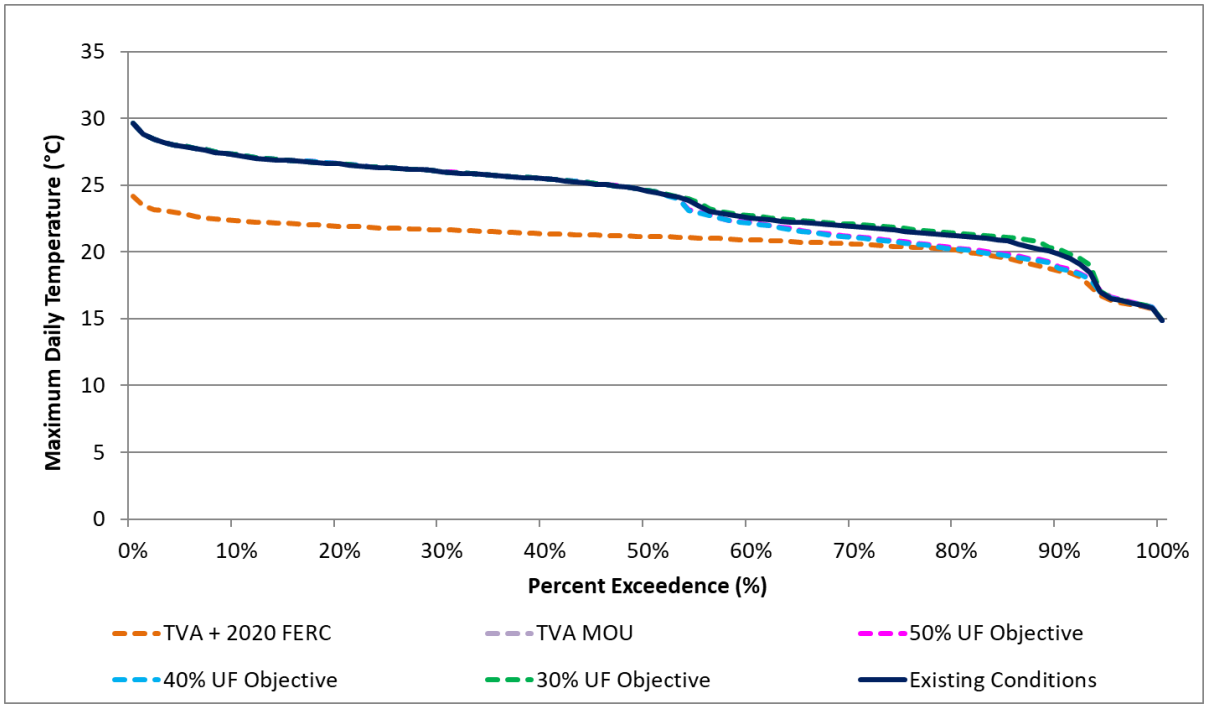


Figure B-139. Exceedance Chart of Daily Maximum Temperatures in August at RM 28.1 from 1970 to 2003.

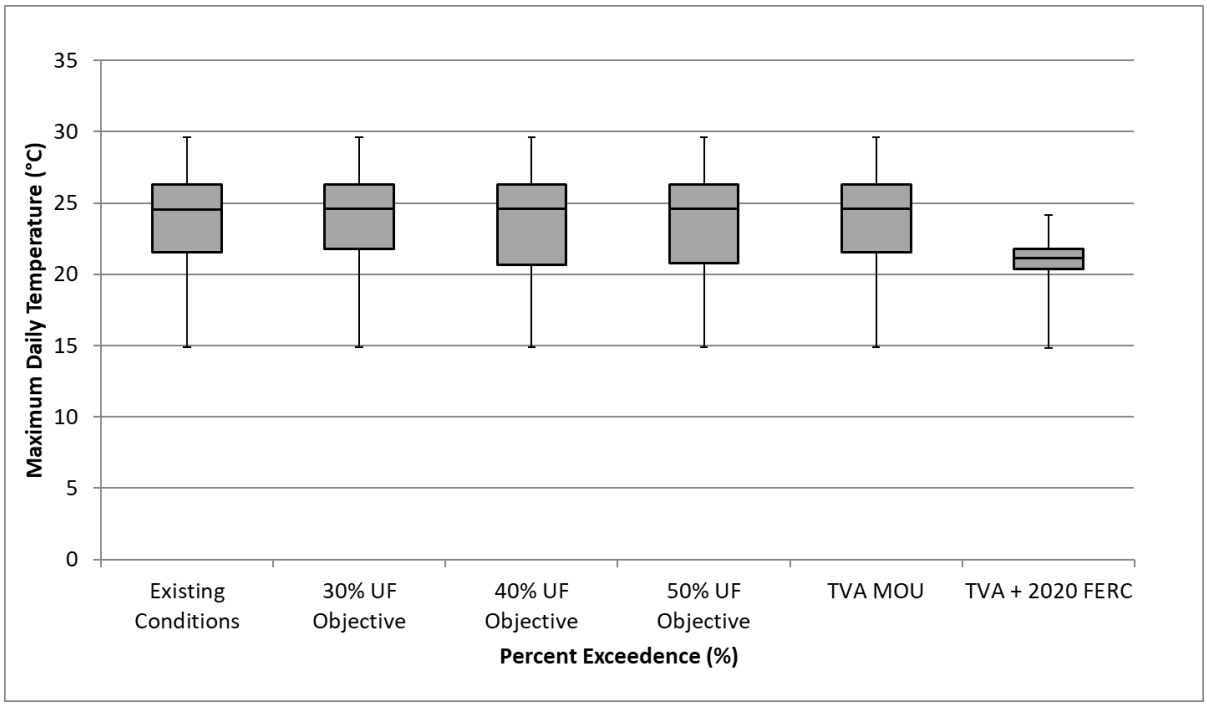


Figure B-140. Box Plot of Daily Maximum Temperatures in August at RM 28.1 from 1970 to 2003.

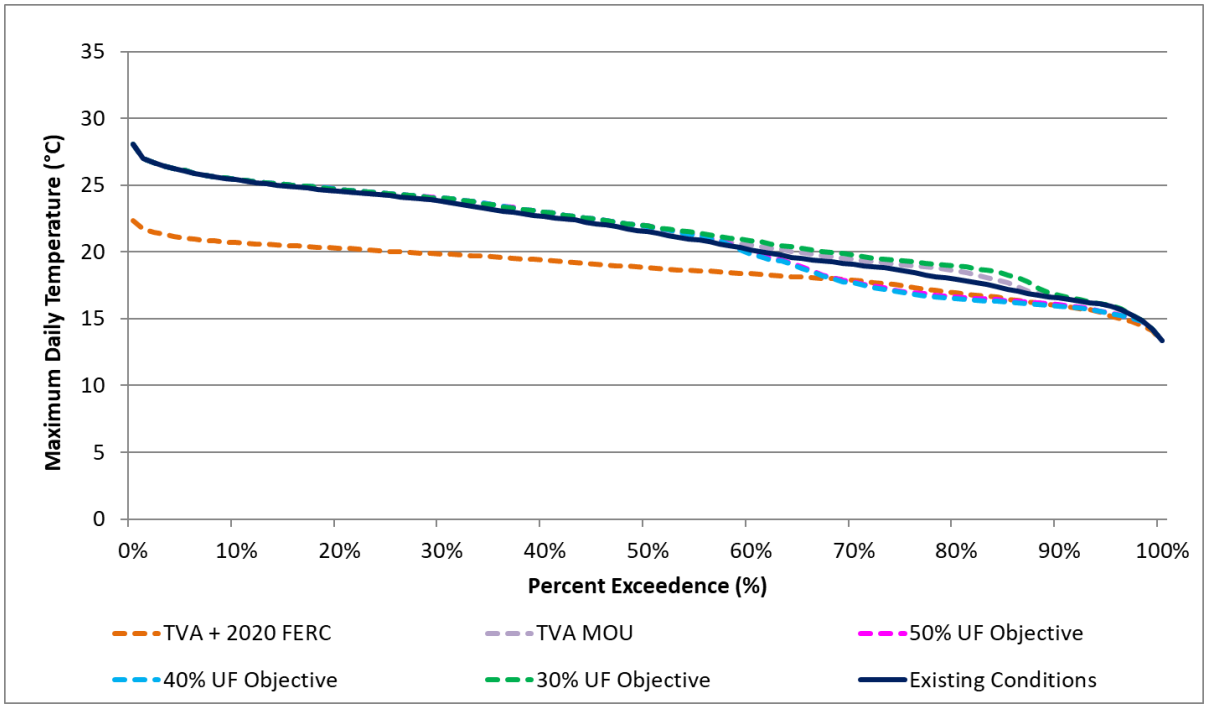


Figure B-141. Exceedance Chart of Daily Maximum Temperatures in September at RM 28.1 from 1970 to 2003.

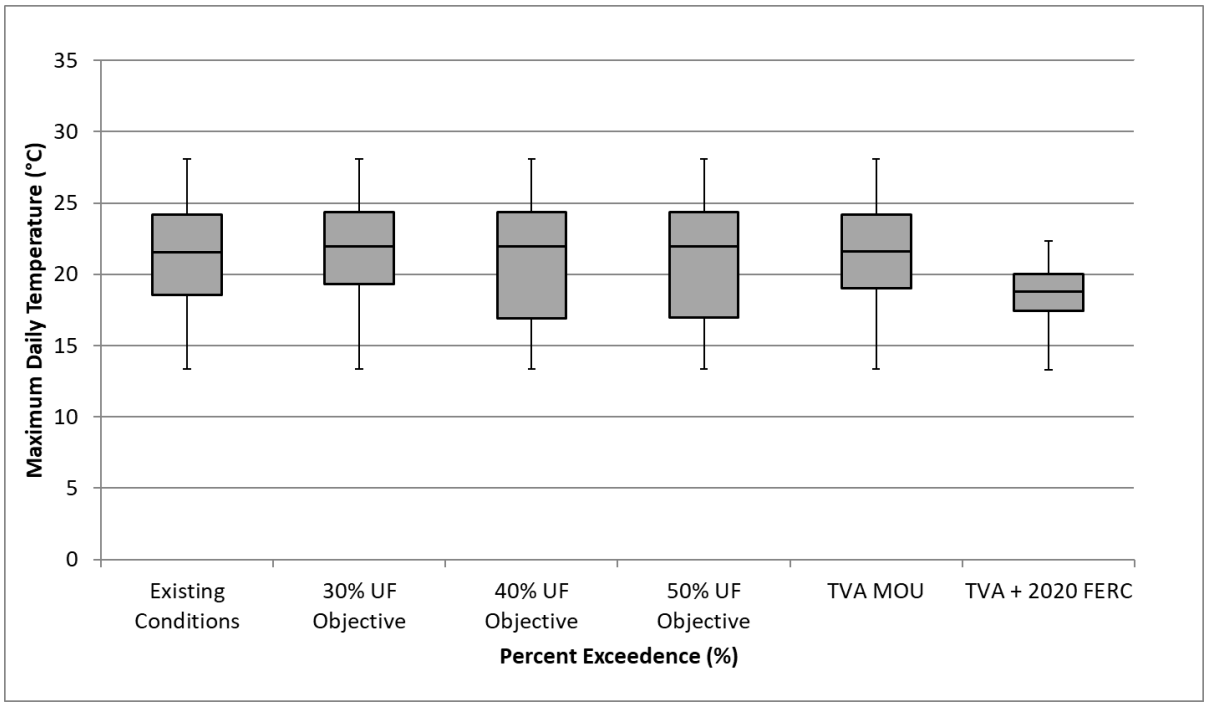


Figure B-142. Box Plot of Daily Maximum Temperatures in September at RM 28.1 from 1970 to 2003.

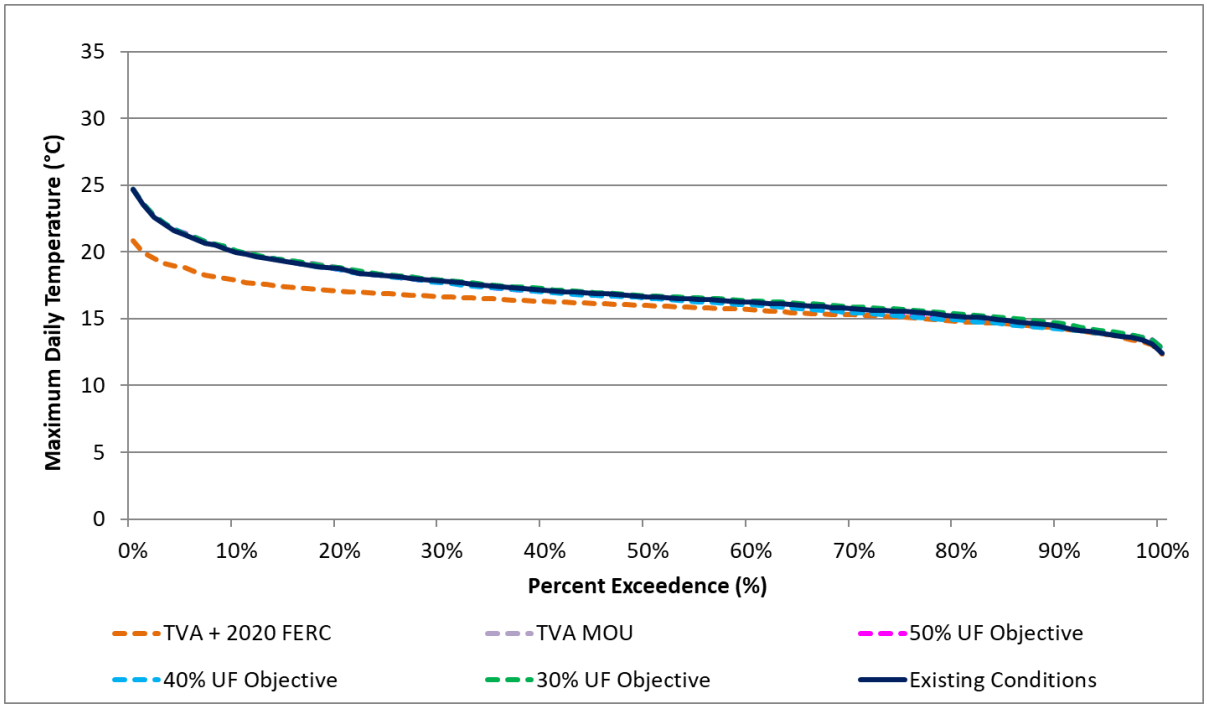


Figure B-143. Exceedance Chart of Daily Maximum Temperatures in October at RM 28.1 from 1970 to 2003.

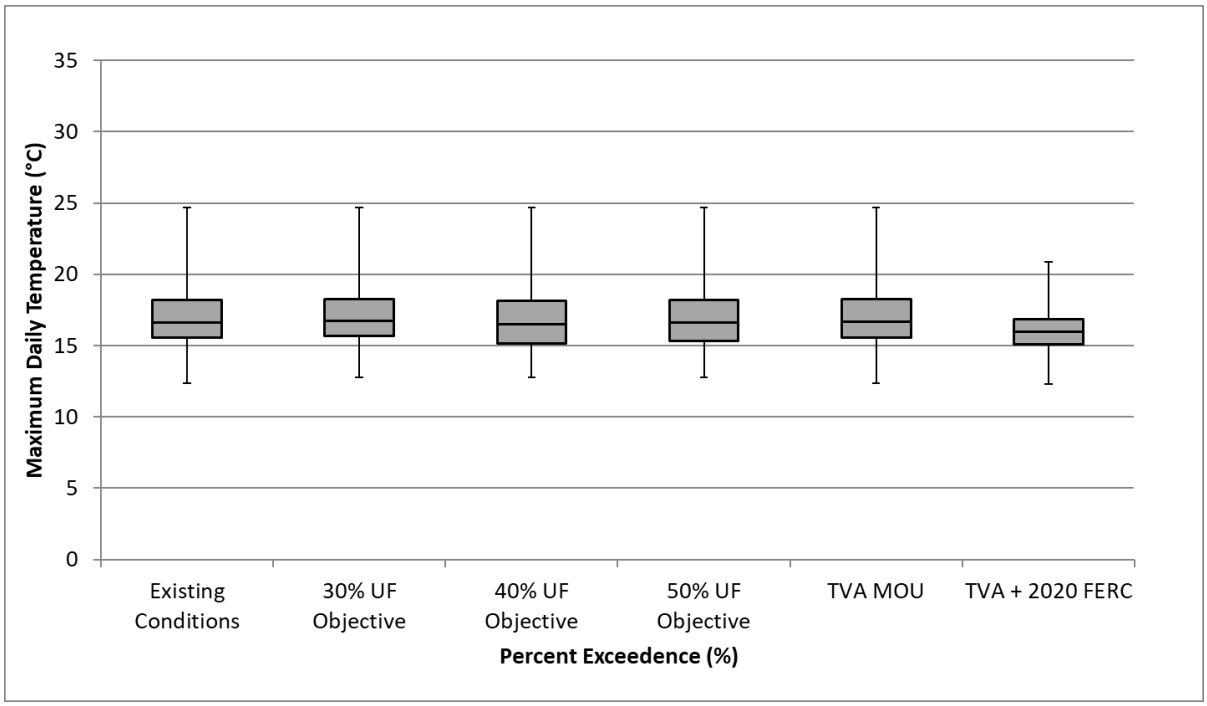


Figure B-144. Box Plot of Daily Maximum Temperatures in October at RM 28.1 from 1970 to 2003.

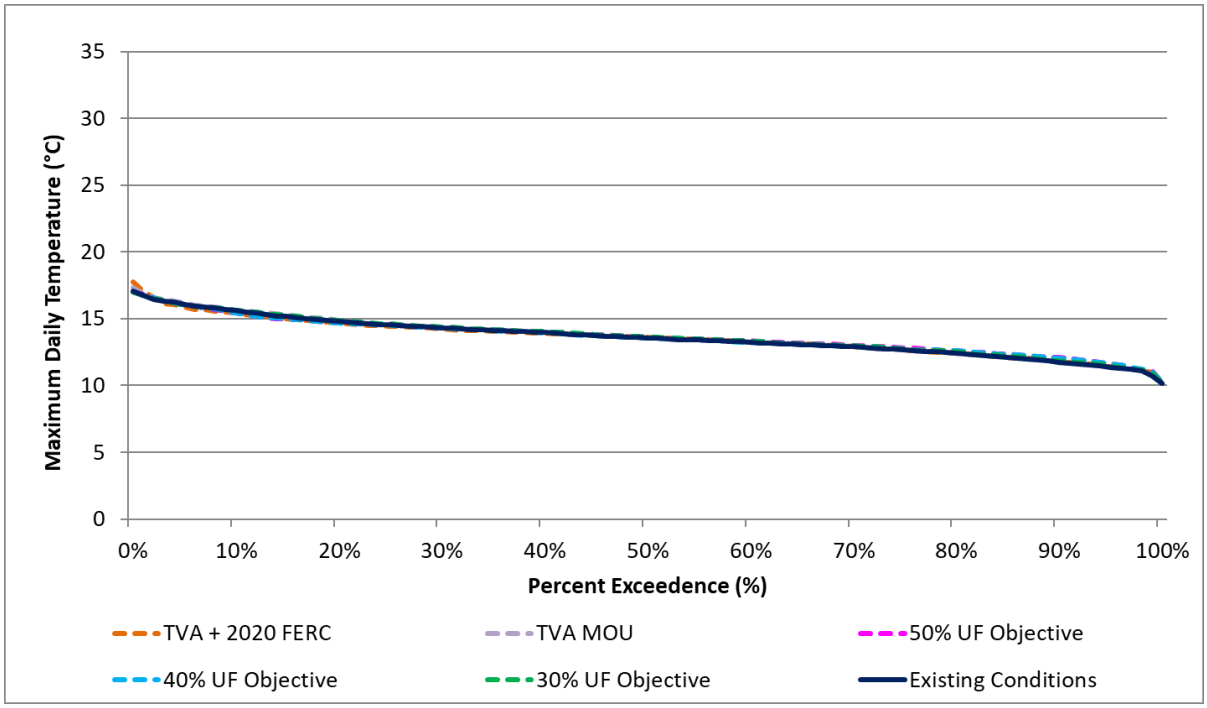


Figure B-145. Exceedance Chart of Daily Maximum Temperatures in November at RM 28.1 from 1970 to 2003.

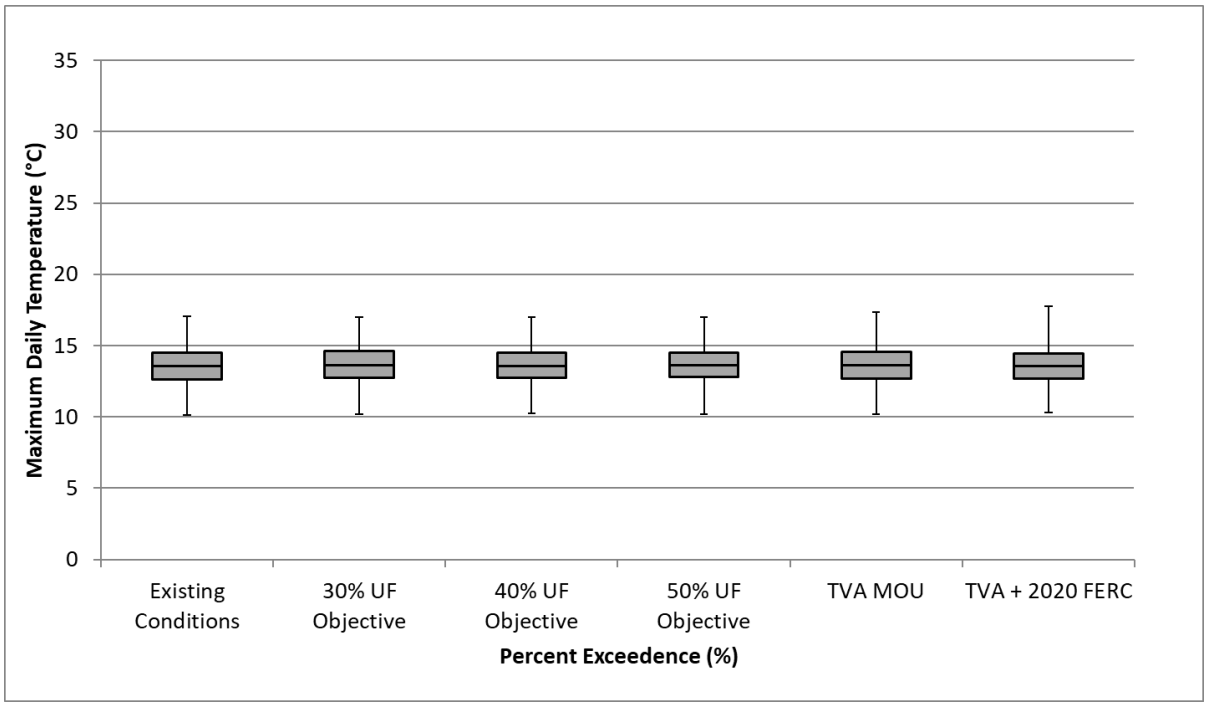


Figure B-146. Box Plot of Daily Maximum Temperatures in November at RM 28.1 from 1970 to 2003.

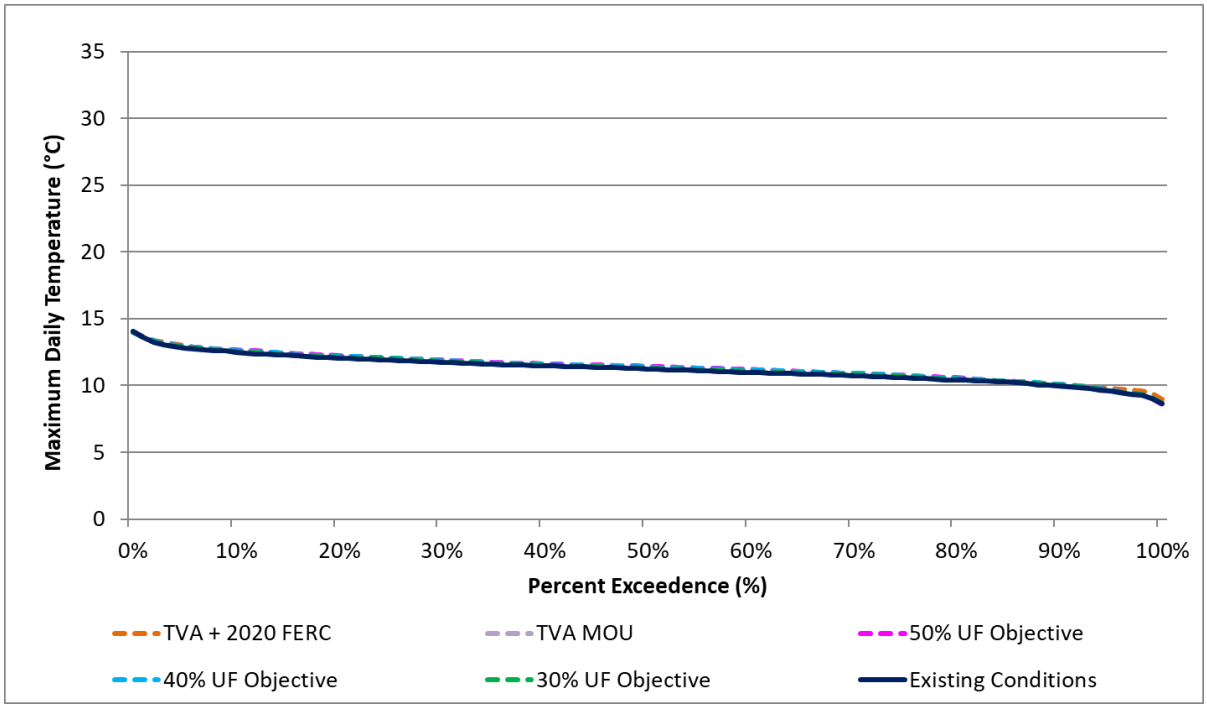


Figure B-147. Exceedance Chart of Daily Maximum Temperatures in December at RM 28.1 from 1970 to 2003.

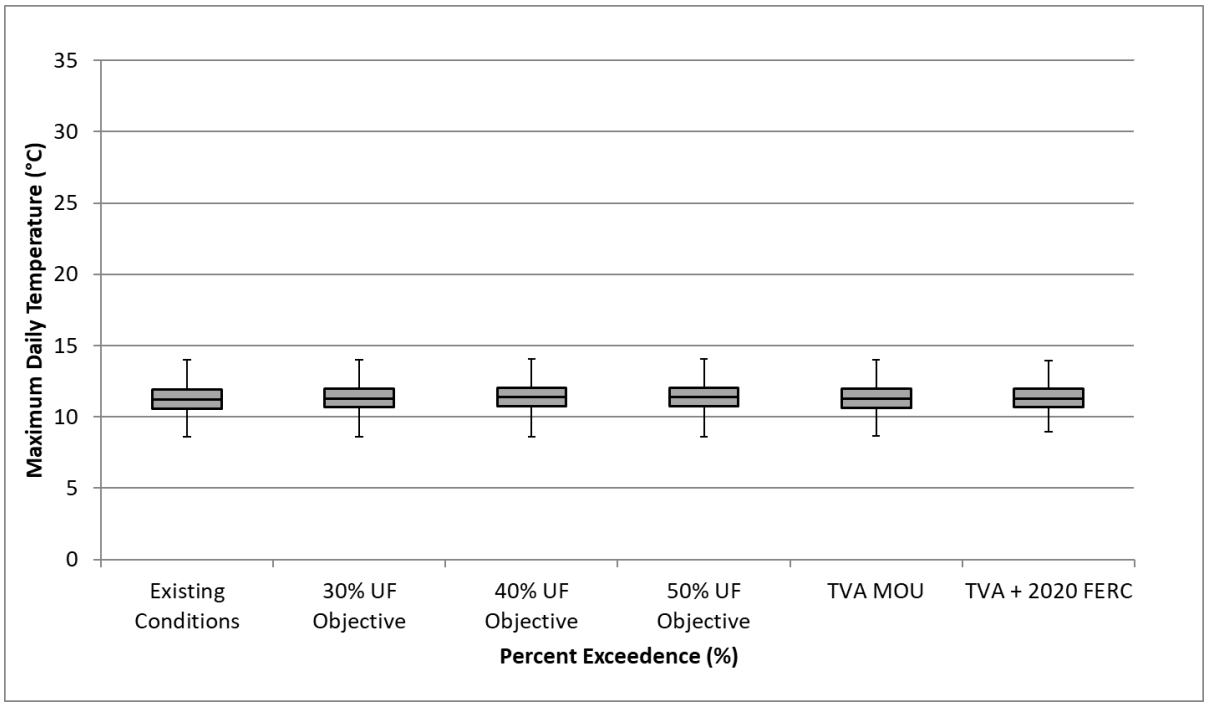


Figure B-148. Box Plot of Daily Maximum Temperatures in December at RM 28.1 from 1970 to 2003.

B.5.5 The Tuolumne River Below Modesto (RM 13.2)

Figure B-149 and Figure B-150 present timeseries of average daily 7DADM temperatures at RM 13.2 over a year, the first being averaged over all years from 1970 to 2003 and the second only averaged over critical year types in that period.[25] The span of the figures is from February through January, which coincides with the operational year under the TVA (annual requirements under the TVA update in February). Figure B-151 through Figure B-174 present exceedance charts and box plots of daily maximum temperatures for each month at RM 13.2, intended to show the range of maximum daily temperatures that occur each month in the model run. The TVA MOU alternative shows lower temperatures compared to existing conditions during the end of March through the beginning of April, which corresponds to the floodplain inundation pulse period, and then at the end of May, since the outmigration pulse under the TVA is longer than under existing conditions. Temperatures under all three UF alternatives are generally lower than the existing conditions at this location throughout the February through June period. Unlike its modeled temperature effects at upstream locations, the TVA + 2020 FERC alternative does not produce lower temperatures at RM 13.2 during the summer, as this location is past the point of the IG diversion.

[25] Since annual operations for the TVA flow requirements begin updating in February of each year and extend through the following January, the flows and temperatures seen in the October through January period are more dependent on the previous year's WYT than the current one. Therefore, the averaging period for WYT in the temperature figures is shifted forward to apply from February through January rather than October through September.

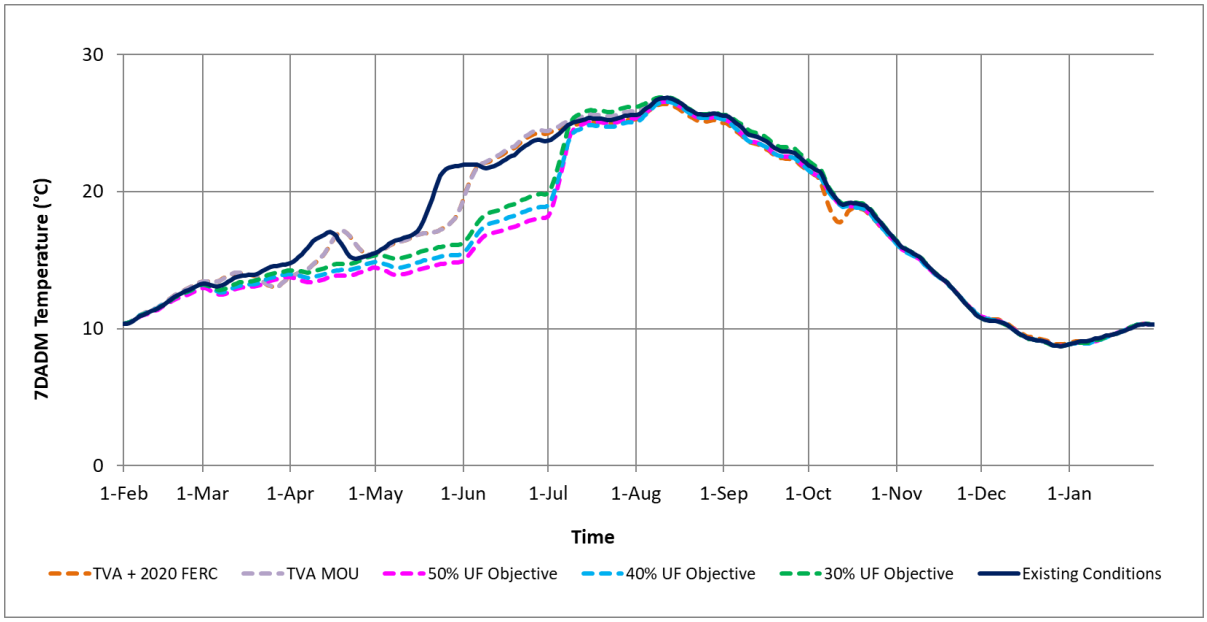


Figure B-149. Average Daily Tuolumne Running 7DADM Temperatures at RM 13.2 (Averaged over All Years from 1970 to 2003).

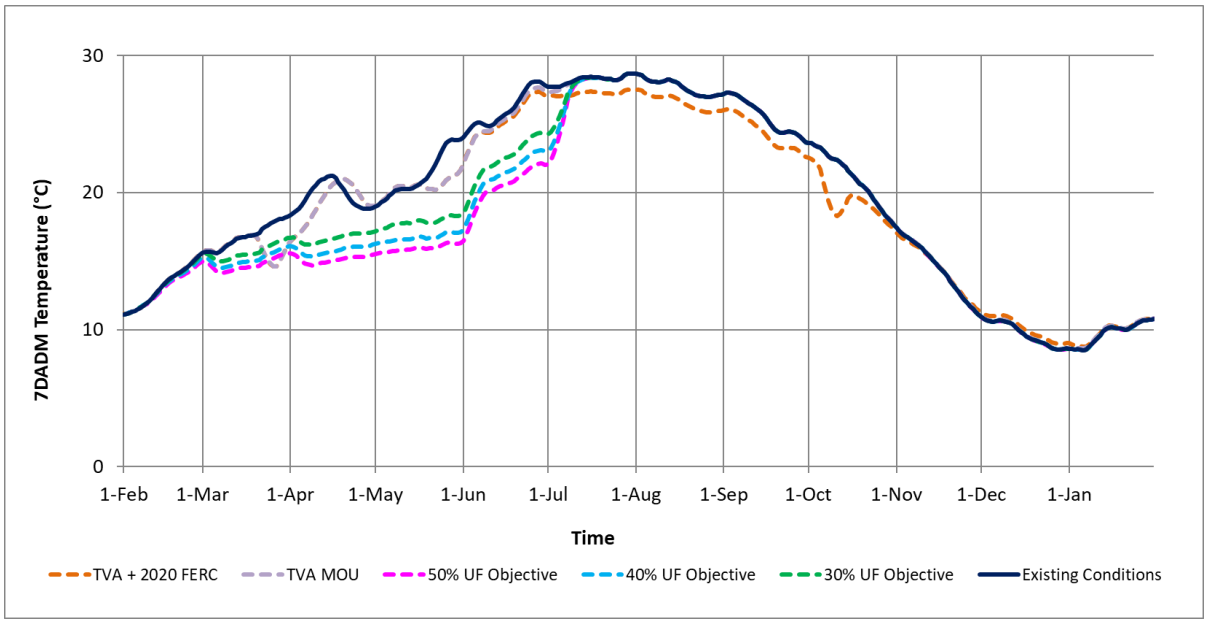


Figure B-150. Average Daily Tuolumne Running 7DADM Temperatures at RM 13.2 (Averaged over Critical Years from 1970 to 2003).

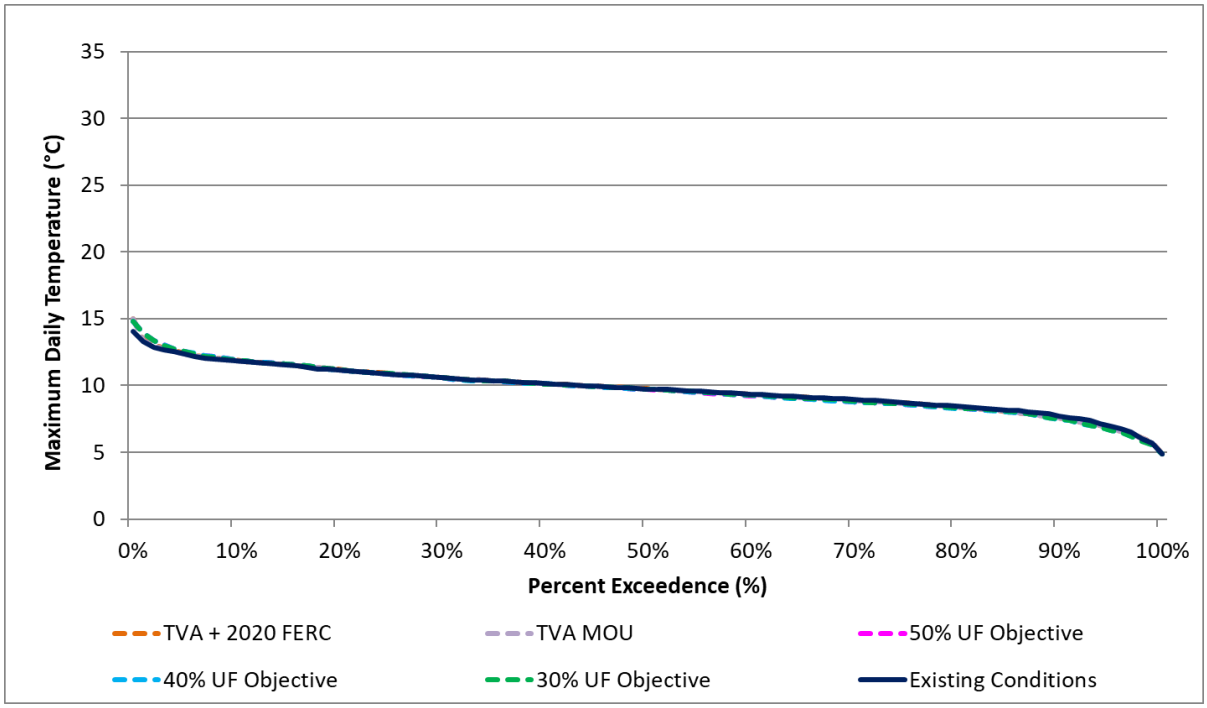


Figure B-151. Exceedance Chart of Daily Maximum Temperatures in January at RM 13.2 from 1970 to 2003.

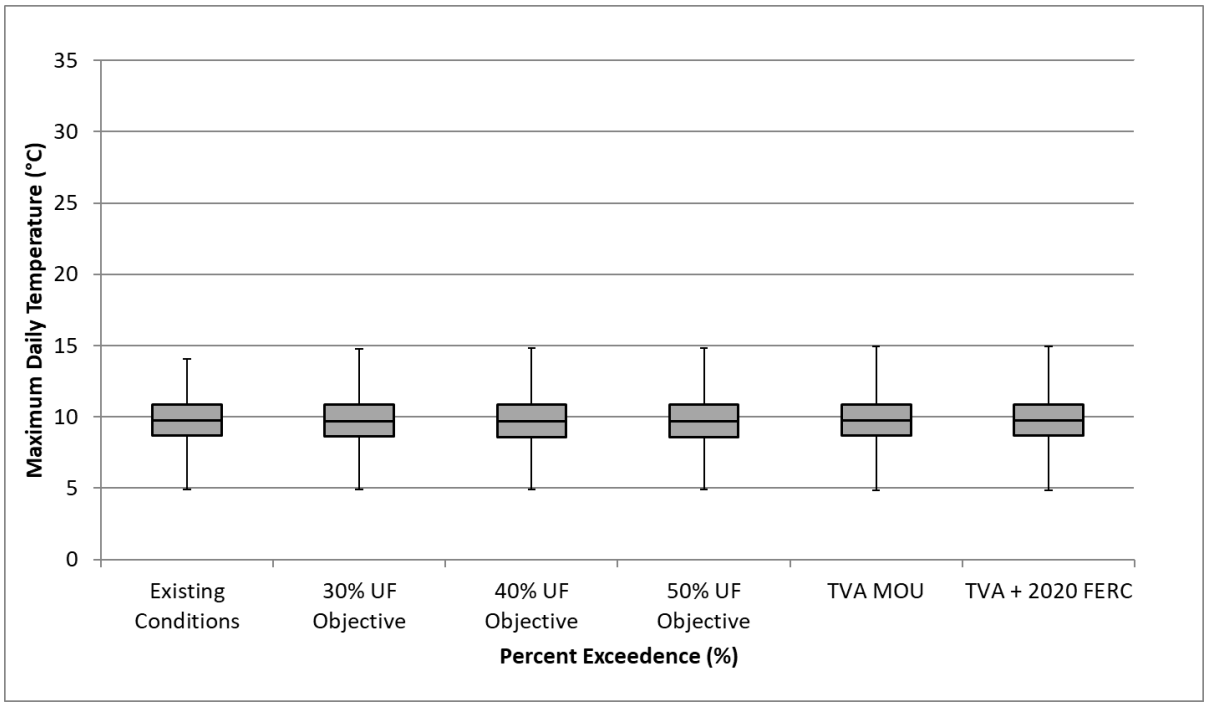


Figure B-152. Box Plot of Daily Maximum Temperatures in January at RM 13.2 from 1970 to 2003.

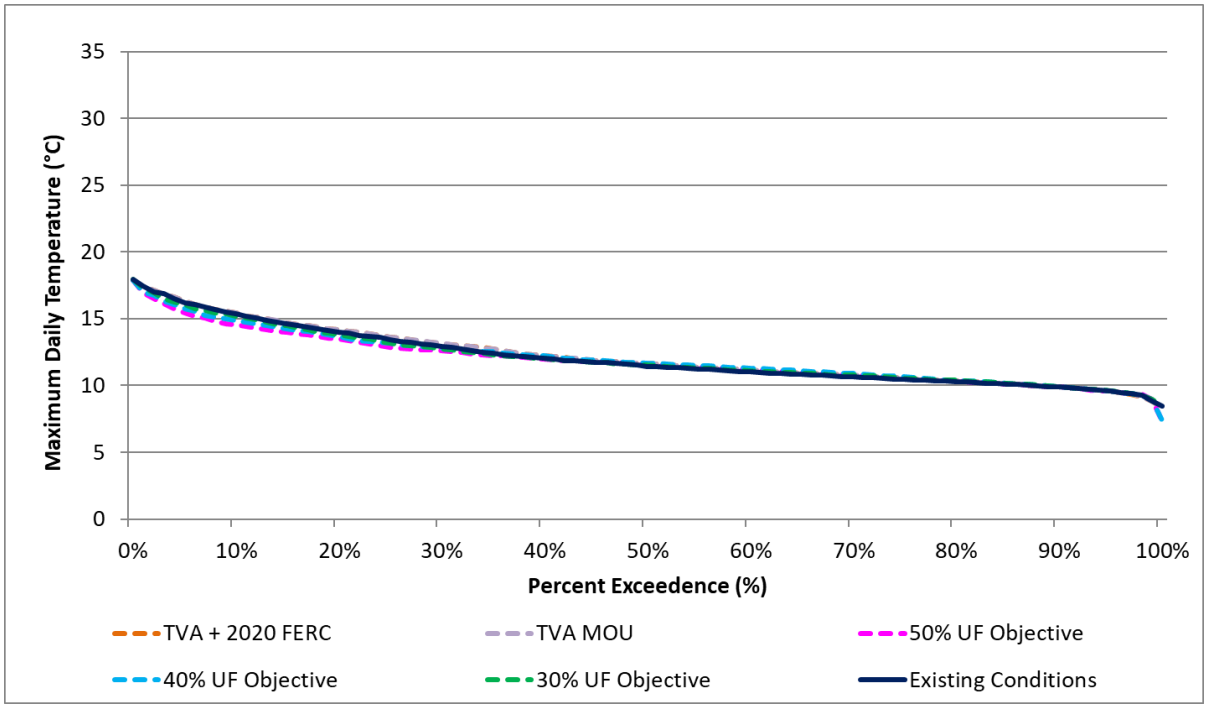


Figure B-153. Exceedance Chart of Daily Maximum Temperatures in February at RM 13.2 from 1970 to 2003.

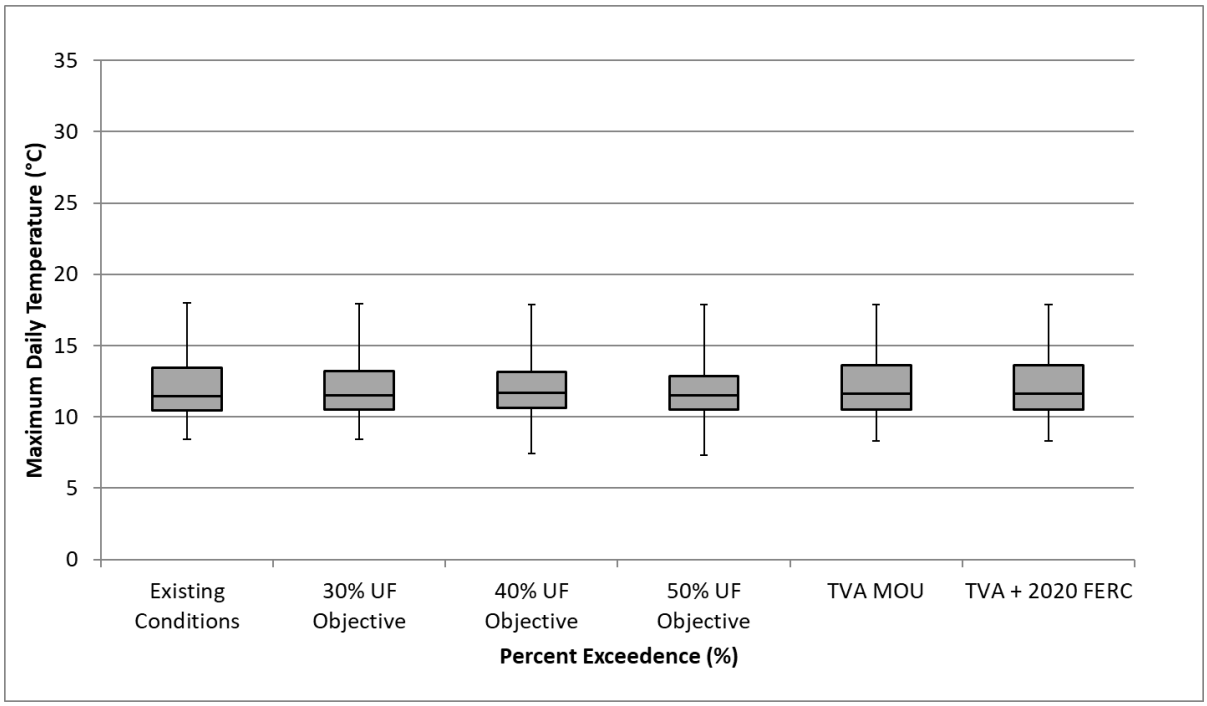


Figure B-154. Box Plot of Daily Maximum Temperatures in February at RM 13.2 from 1970 to 2003.

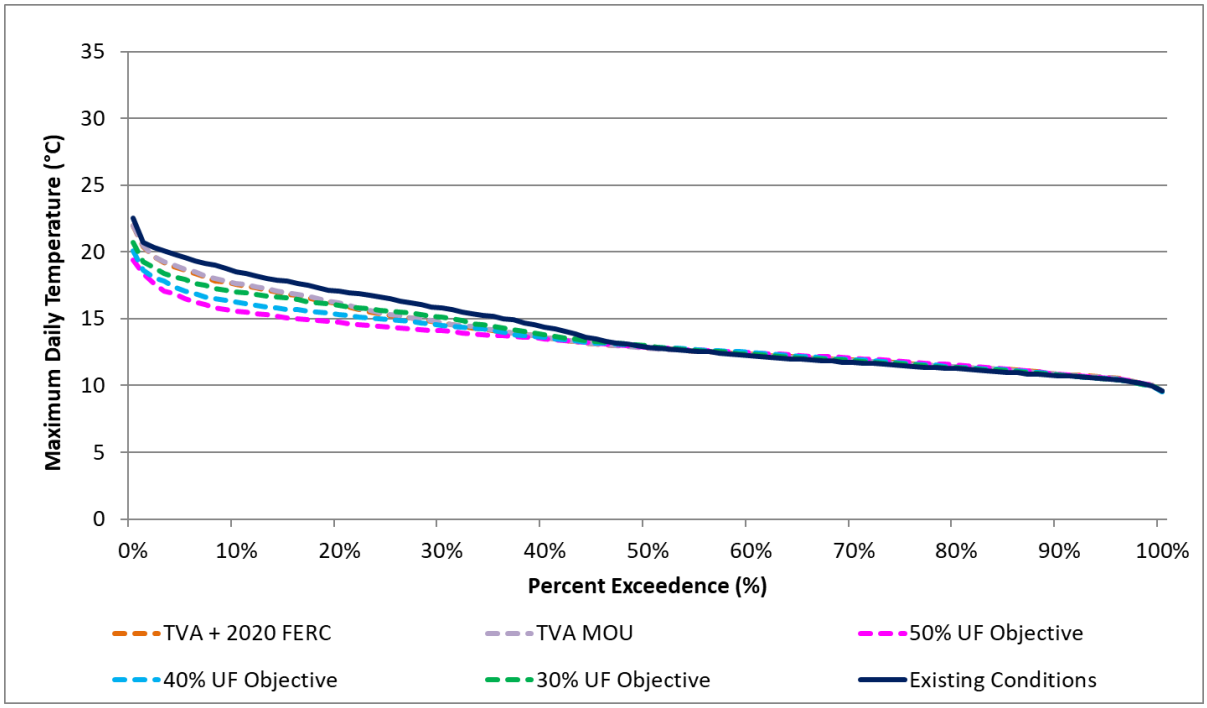


Figure B-155. Exceedance Chart of Daily Maximum Temperatures in March at RM 13.2 from 1970 to 2003.

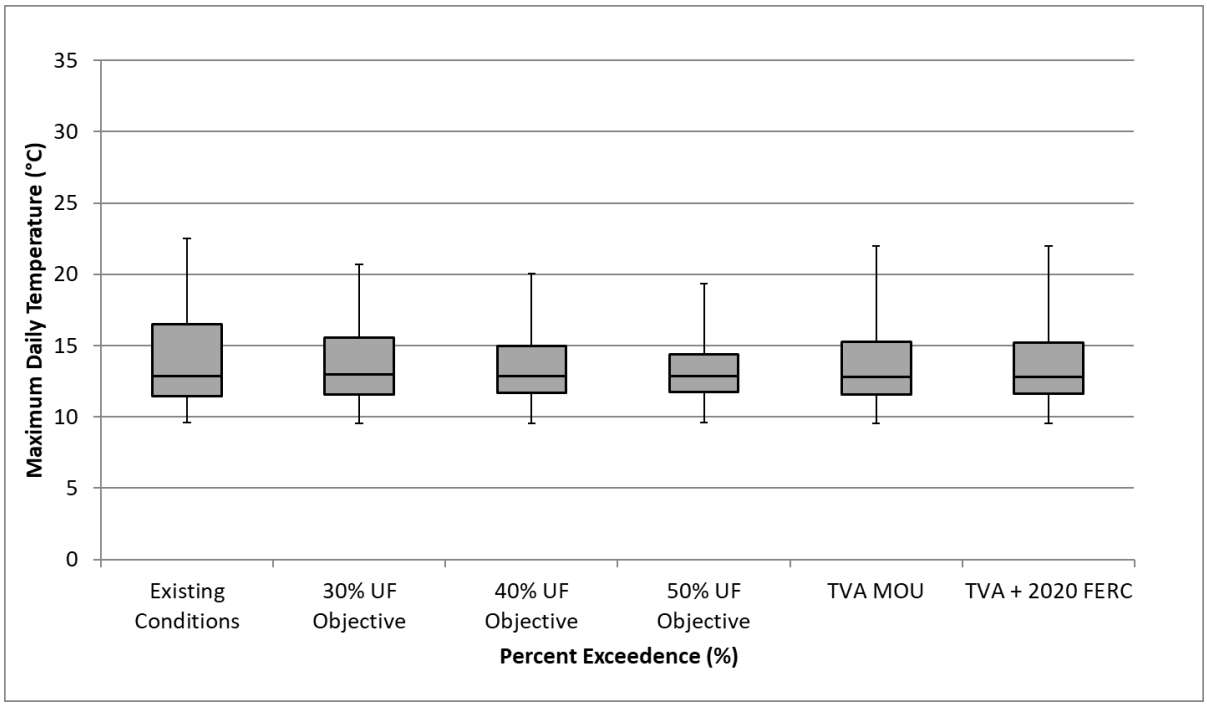


Figure B-156. Box Plot of Daily Maximum Temperatures in March at RM 13.2 from 1970 to 2003.

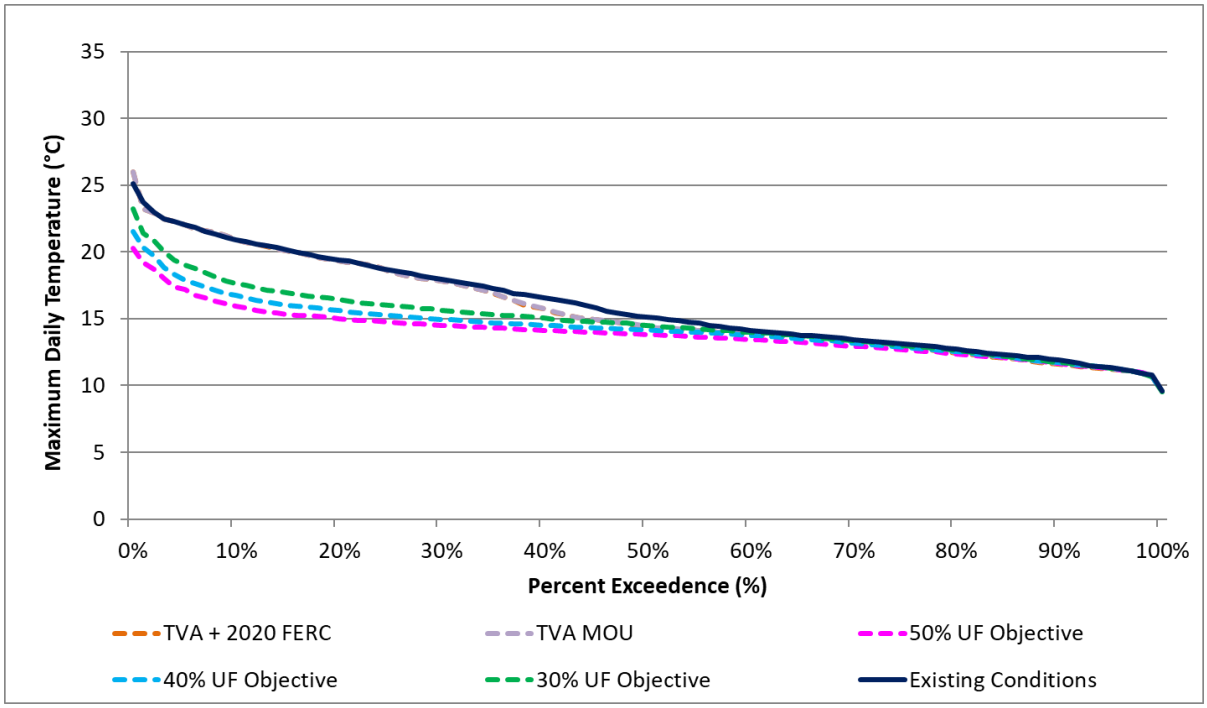


Figure B-157. Exceedance Chart of Daily Maximum Temperatures in April at RM 13.2 from 1970 to 2003.

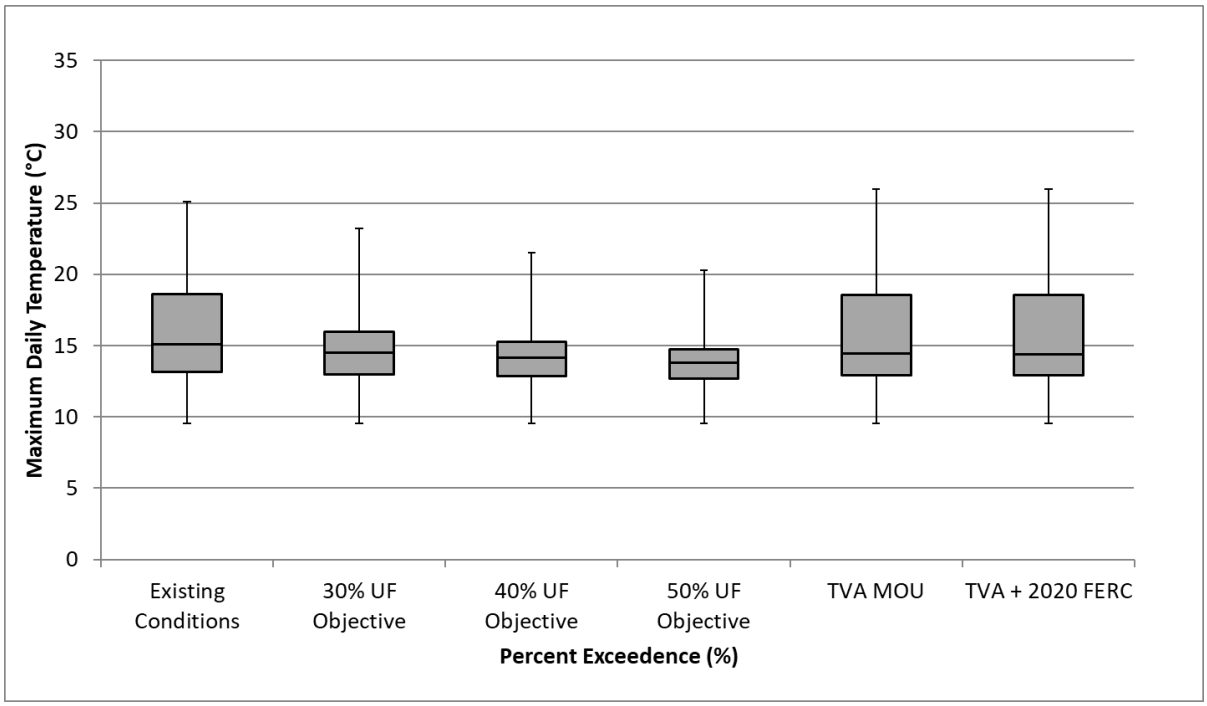


Figure B-158. Box Plot of Daily Maximum Temperatures in April at RM 13.2 from 1970 to 2003.

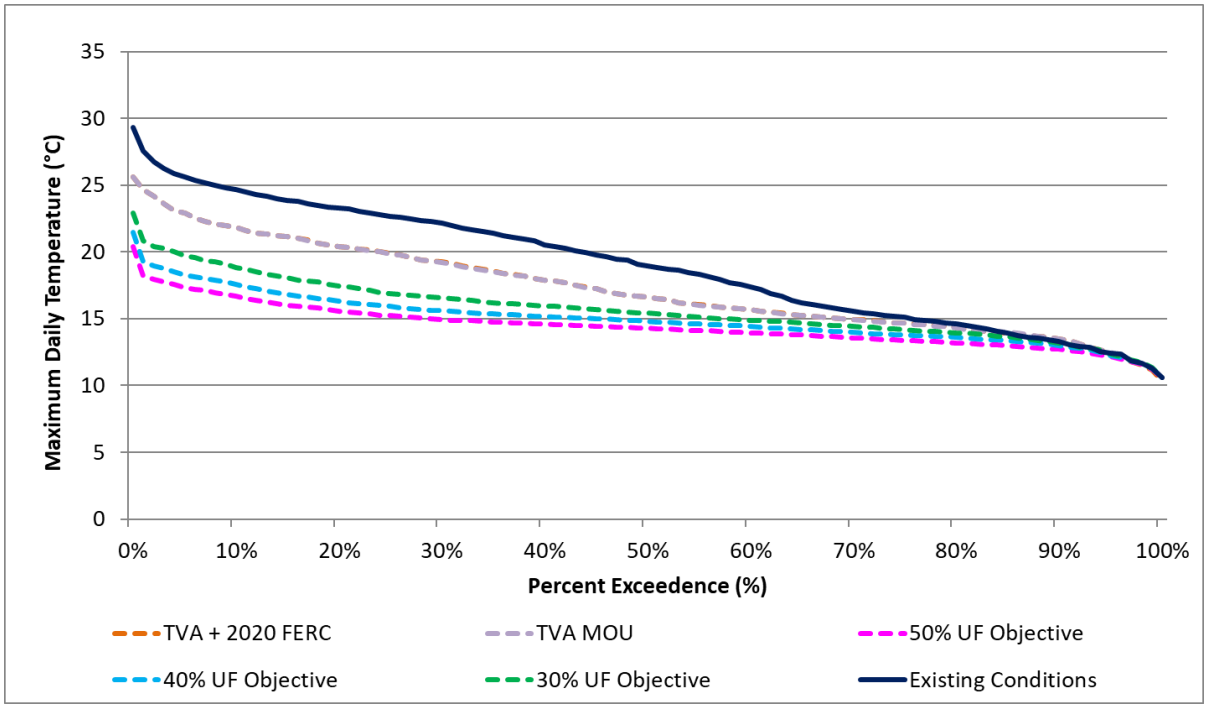


Figure B-159. Exceedance Chart of Daily Maximum Temperatures in May at RM 13.2 from 1970 to 2003.

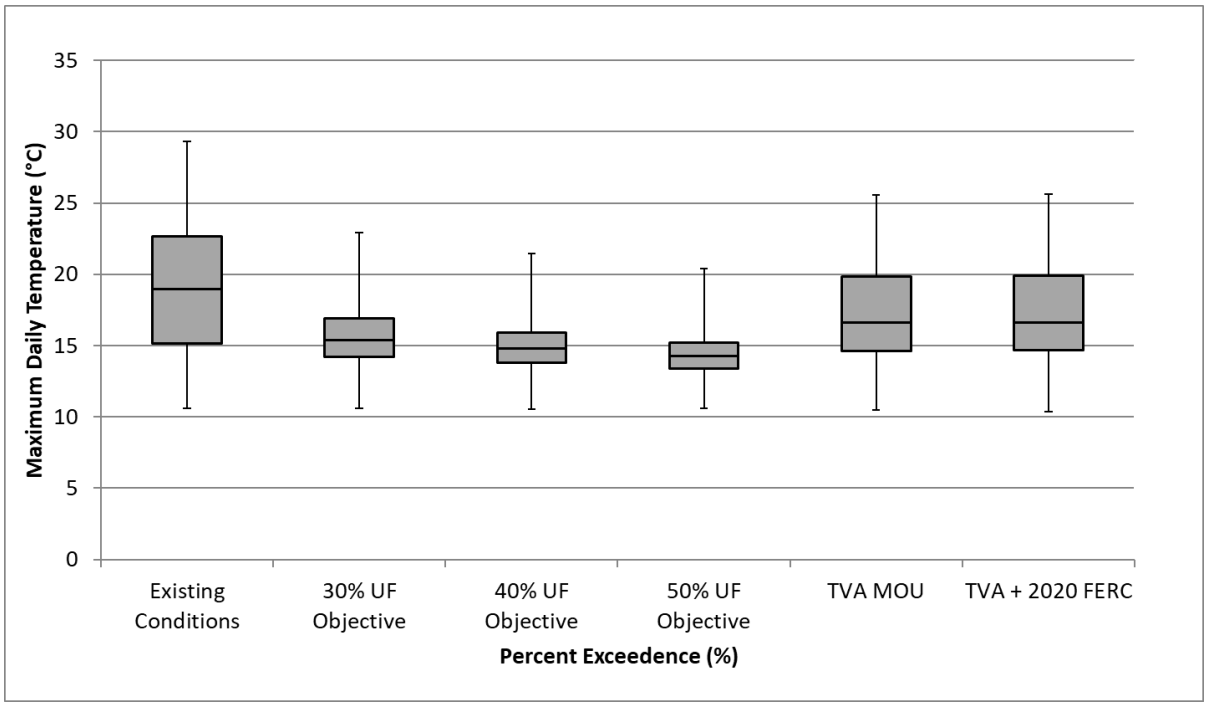


Figure B-160. Box Plot of Daily Maximum Temperatures in May at RM 13.2 from 1970 to 2003.

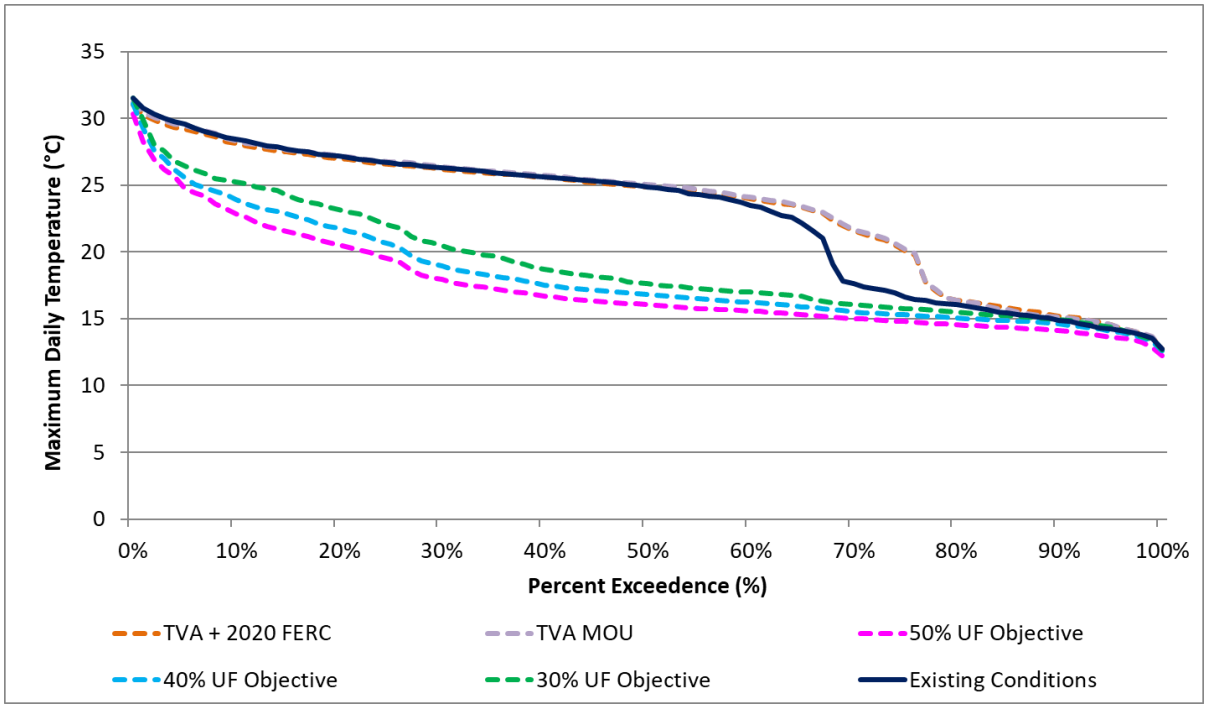


Figure B-161. Exceedance Chart of Daily Maximum Temperatures in June at RM 13.2 from 1970 to 2003.

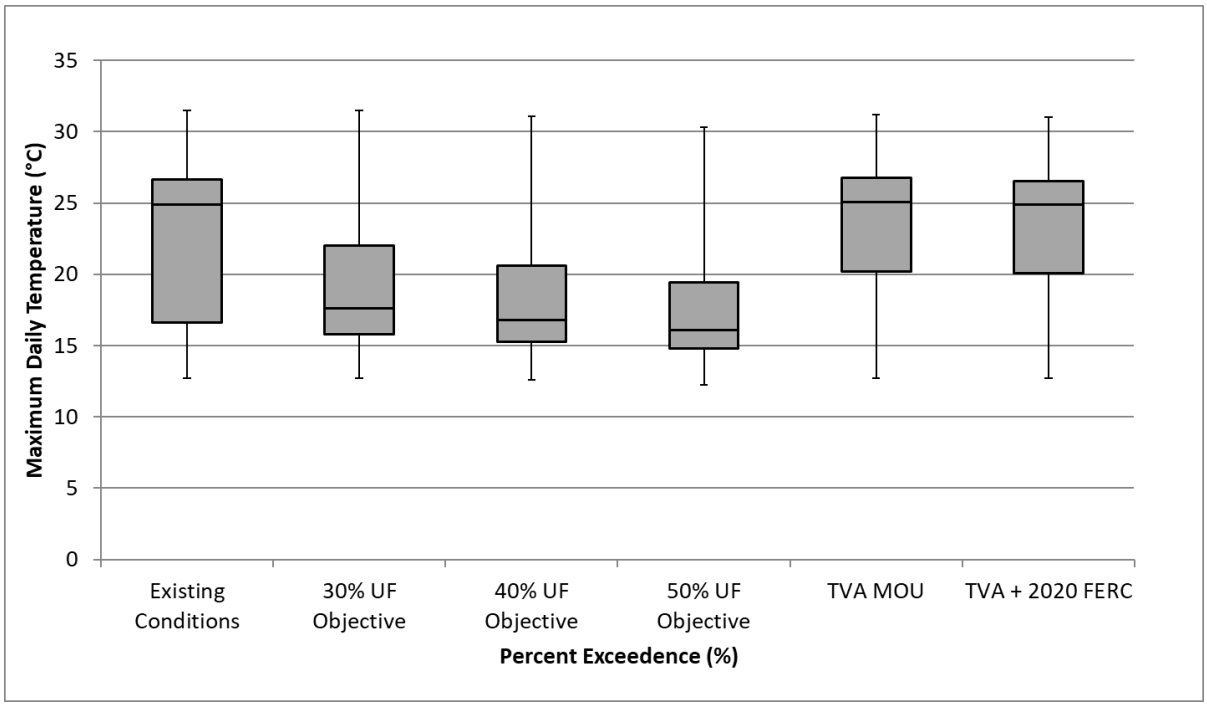


Figure B-162. Box Plot of Daily Maximum Temperatures in June at RM 13.2 from 1970 to 2003.

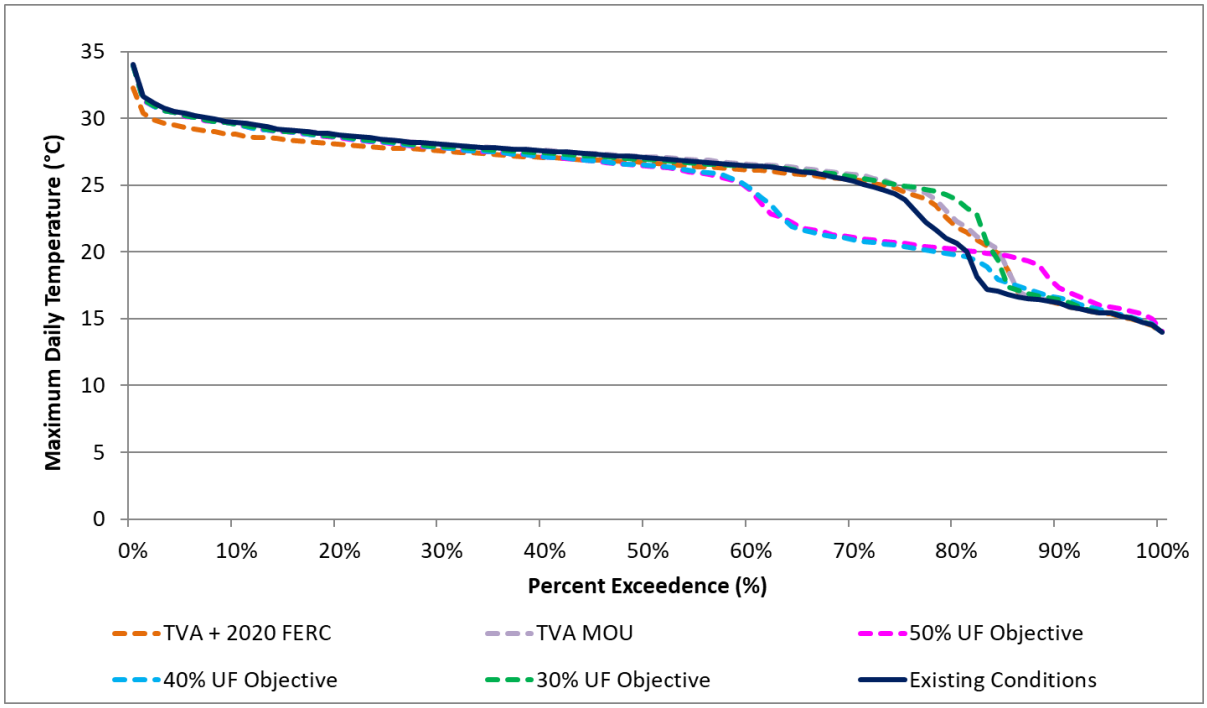


Figure B-163. Exceedance Chart of Daily Maximum Temperatures in July at RM 13.2 from 1970 to 2003.

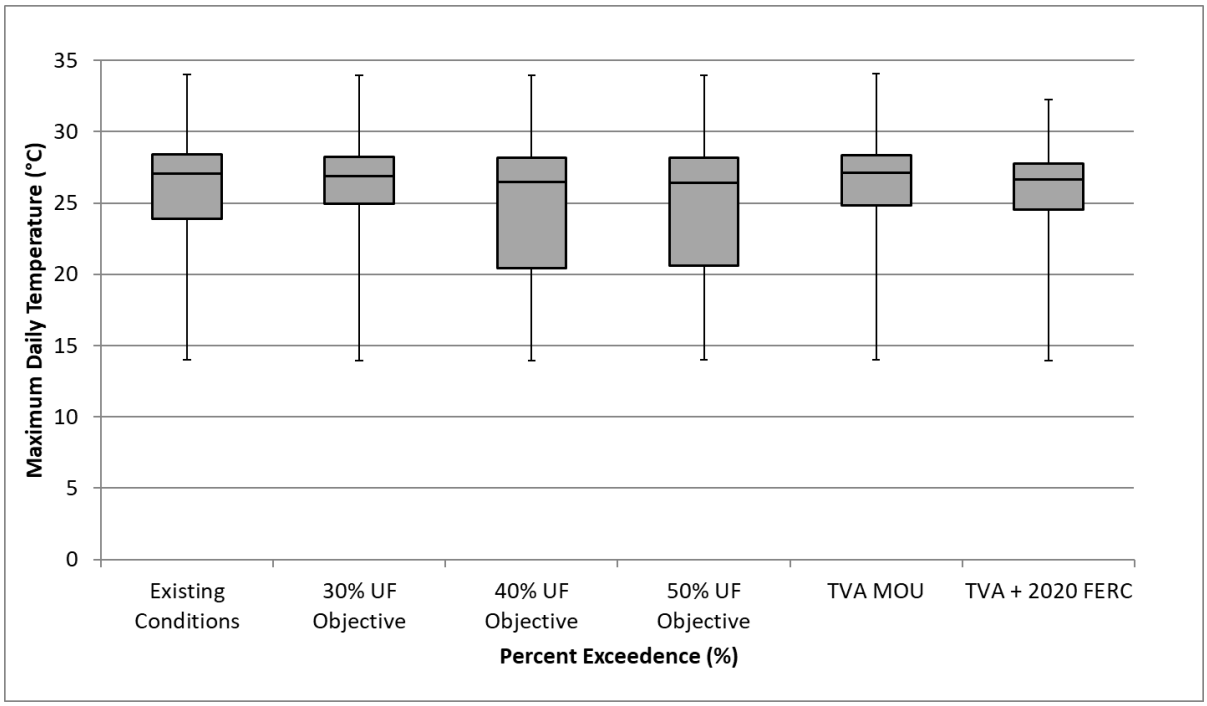


Figure B-164. Box Plot of Daily Maximum Temperatures in July at RM 13.2 from 1970 to 2003.

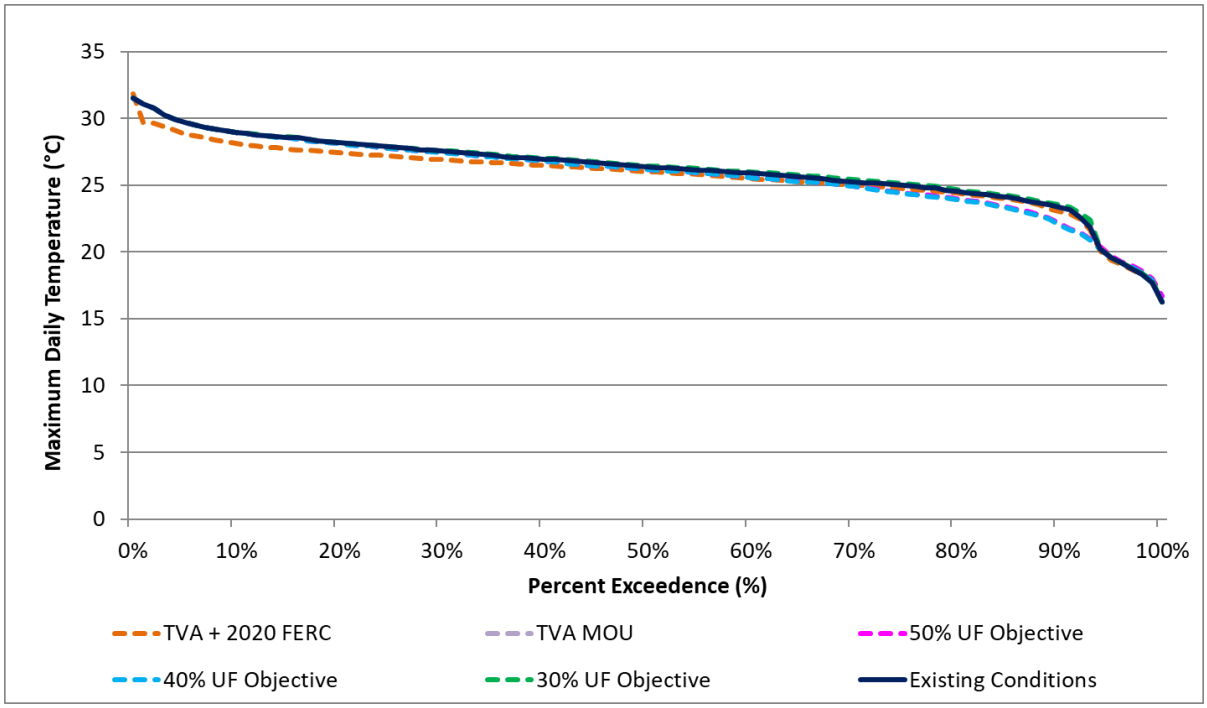


Figure B-165. Exceedance Chart of Daily Maximum Temperatures in August at RM 13.2 from 1970 to 2003.

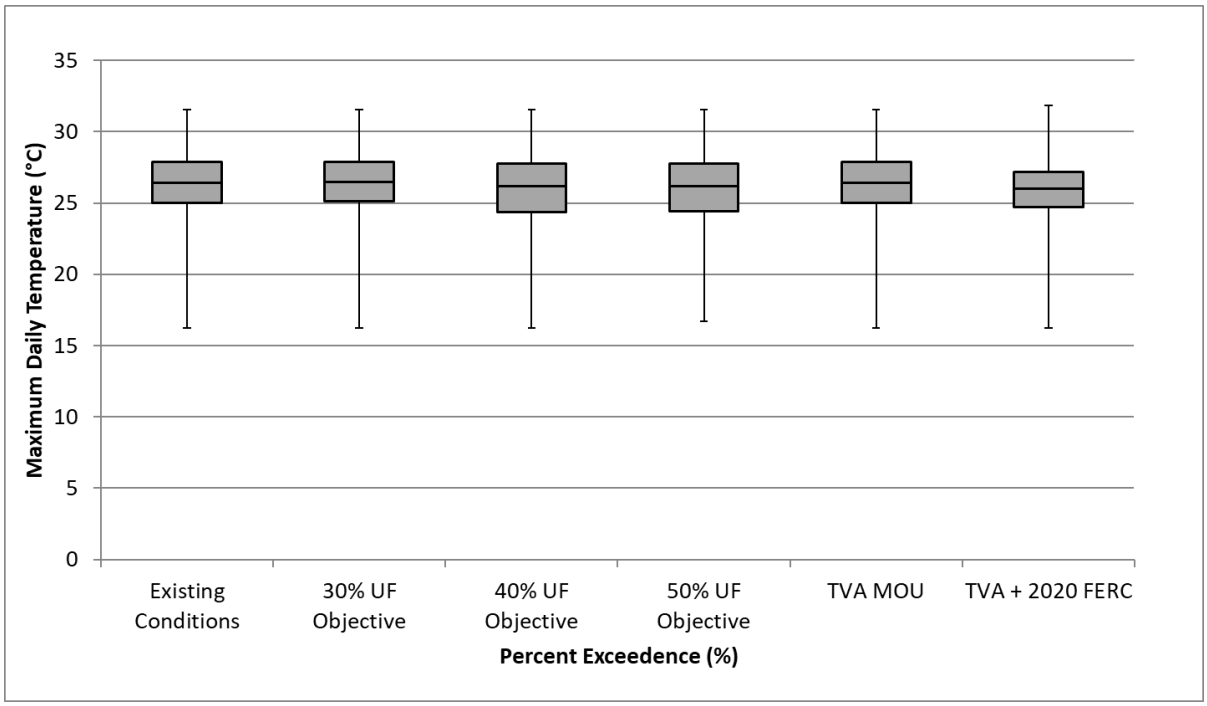


Figure B-166. Box Plot of Daily Maximum Temperatures in August at RM 13.2 from 1970 to 2003.

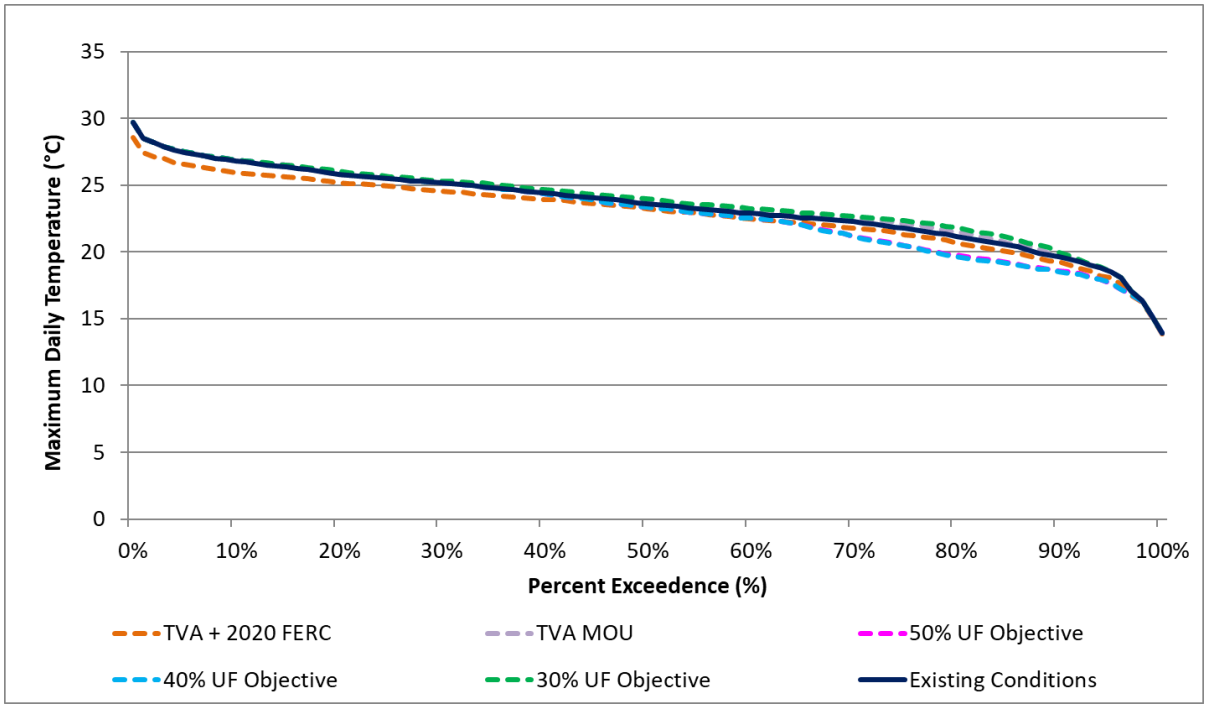


Figure B-167. Exceedance Chart of Daily Maximum Temperatures in September at RM 13.2 from 1970 to 2003.

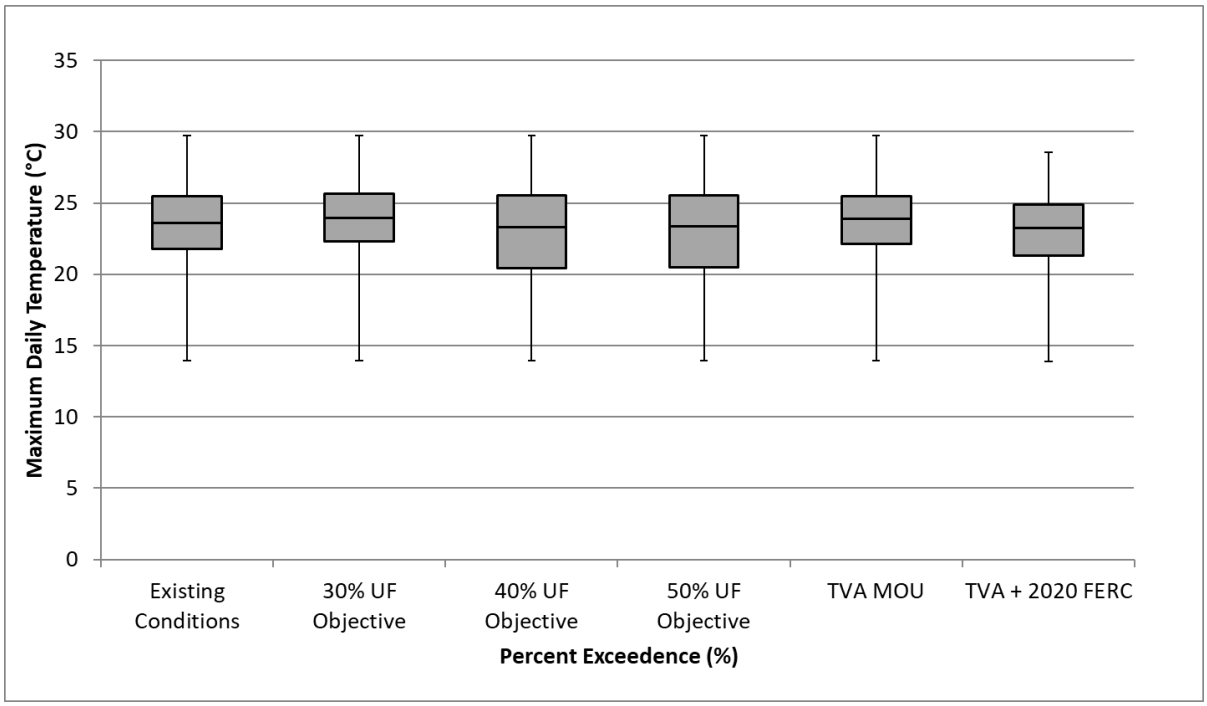


Figure B-168. Box Plot of Daily Maximum Temperatures in September at RM 13.2 from 1970 to 2003.

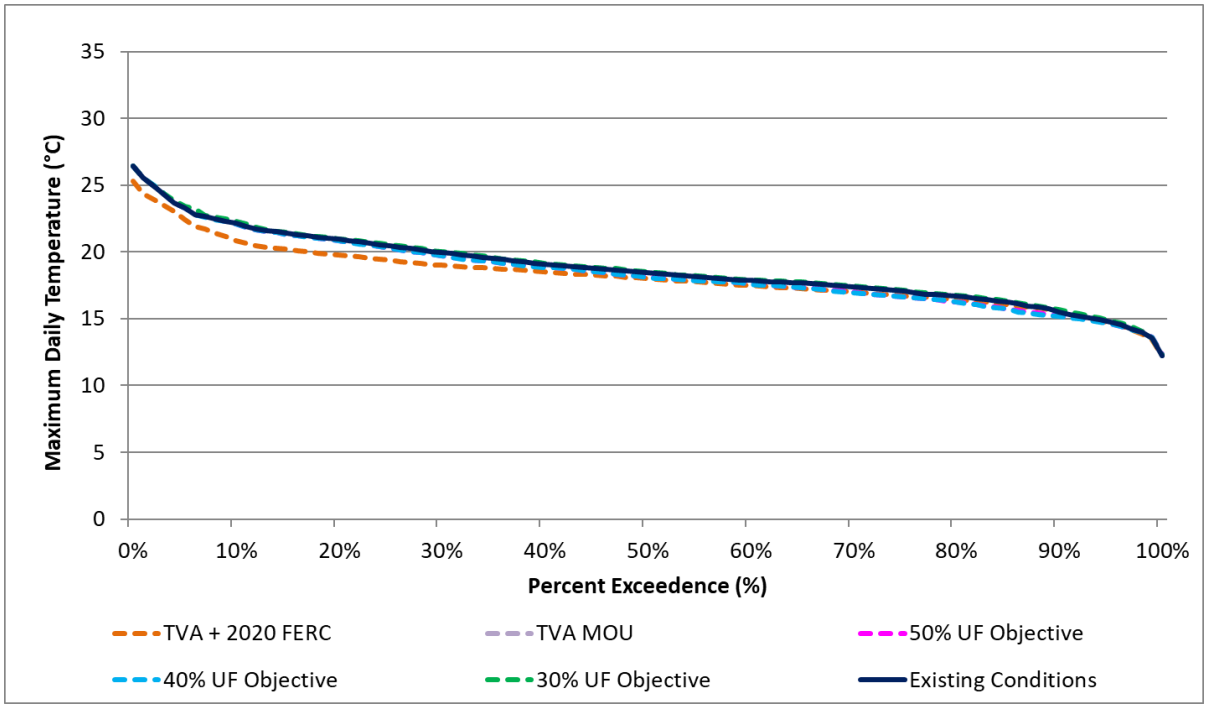


Figure B-169. Exceedance Chart of Daily Maximum Temperatures in October at RM 13.2 from 1970 to 2003.

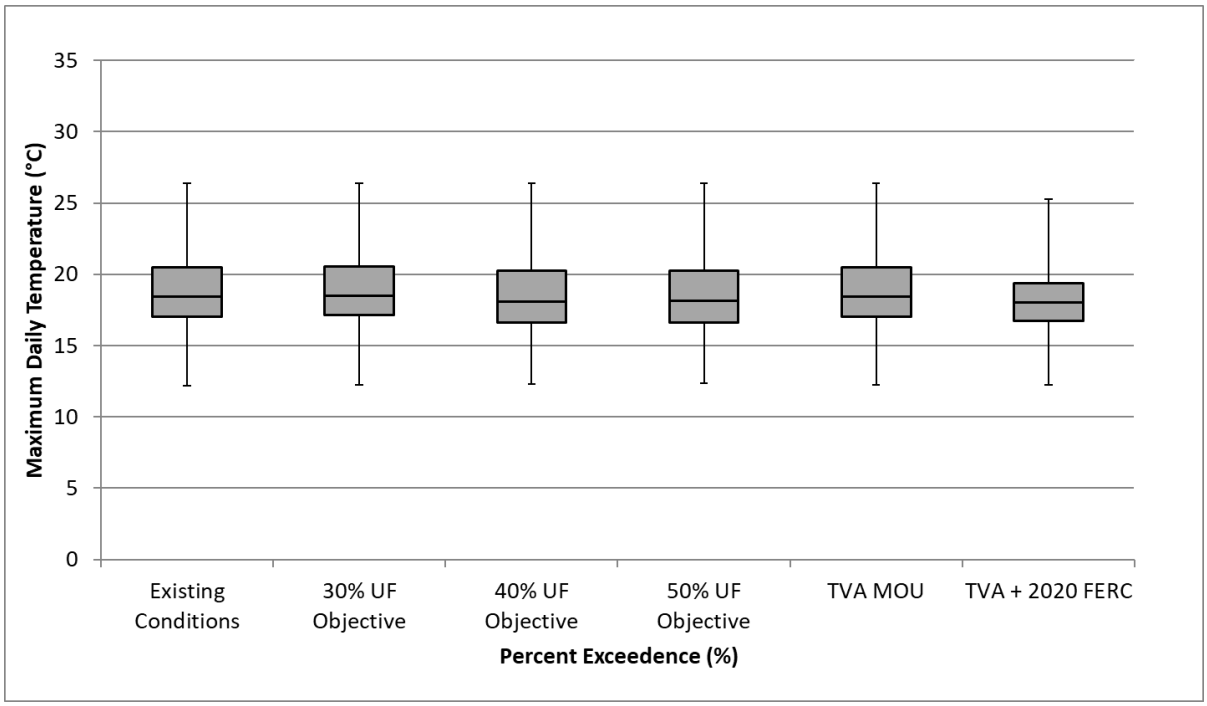


Figure B-170. Box Plot of Daily Maximum Temperatures in October at RM 13.2 from 1970 to 2003.

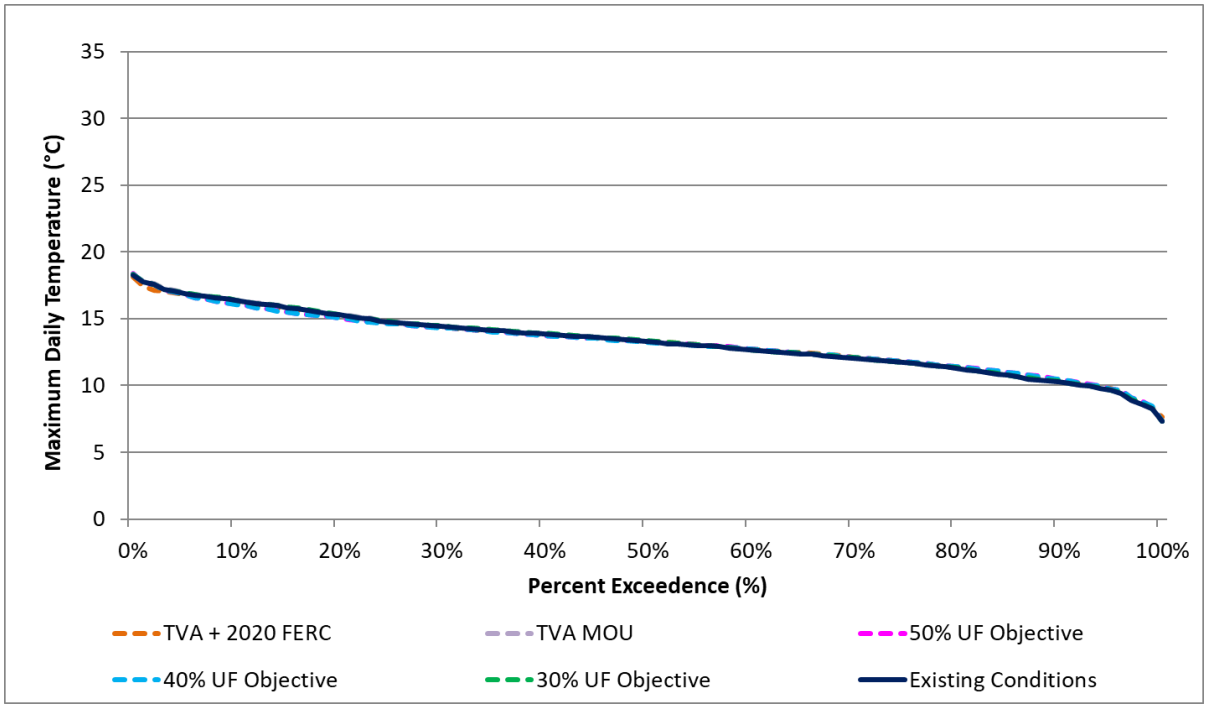


Figure B-171. Exceedance Chart of Daily Maximum Temperatures in November at RM 13.2 from 1970 to 2003.

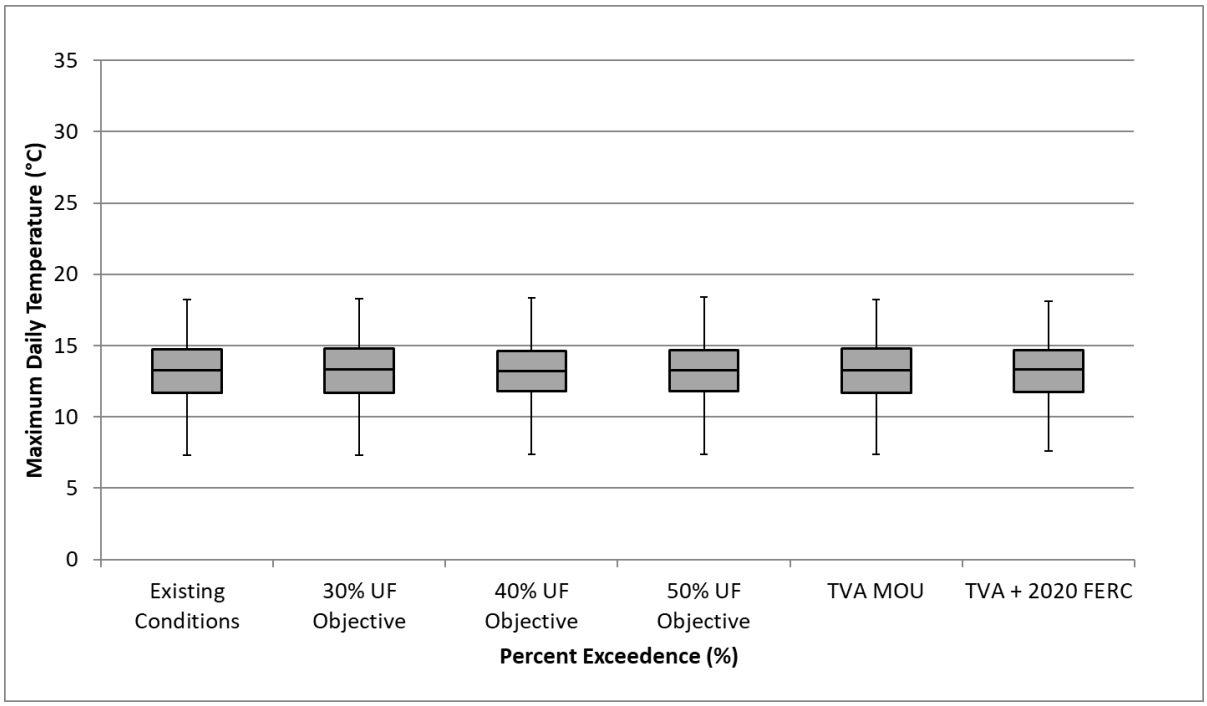


Figure B-172. Box Plot of Daily Maximum Temperatures in November at RM 13.2 from 1970 to 2003.

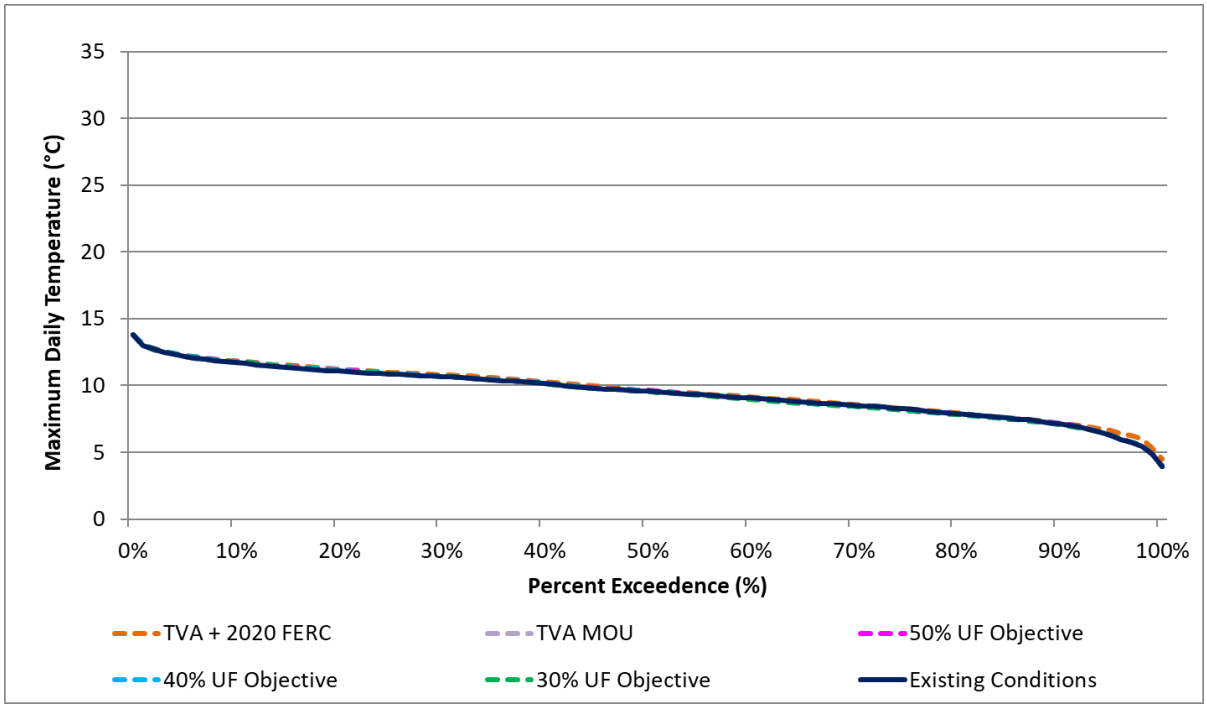


Figure B-173. Exceedance Chart of Daily Maximum Temperatures in December at RM 13.2 from 1970 to 2003.

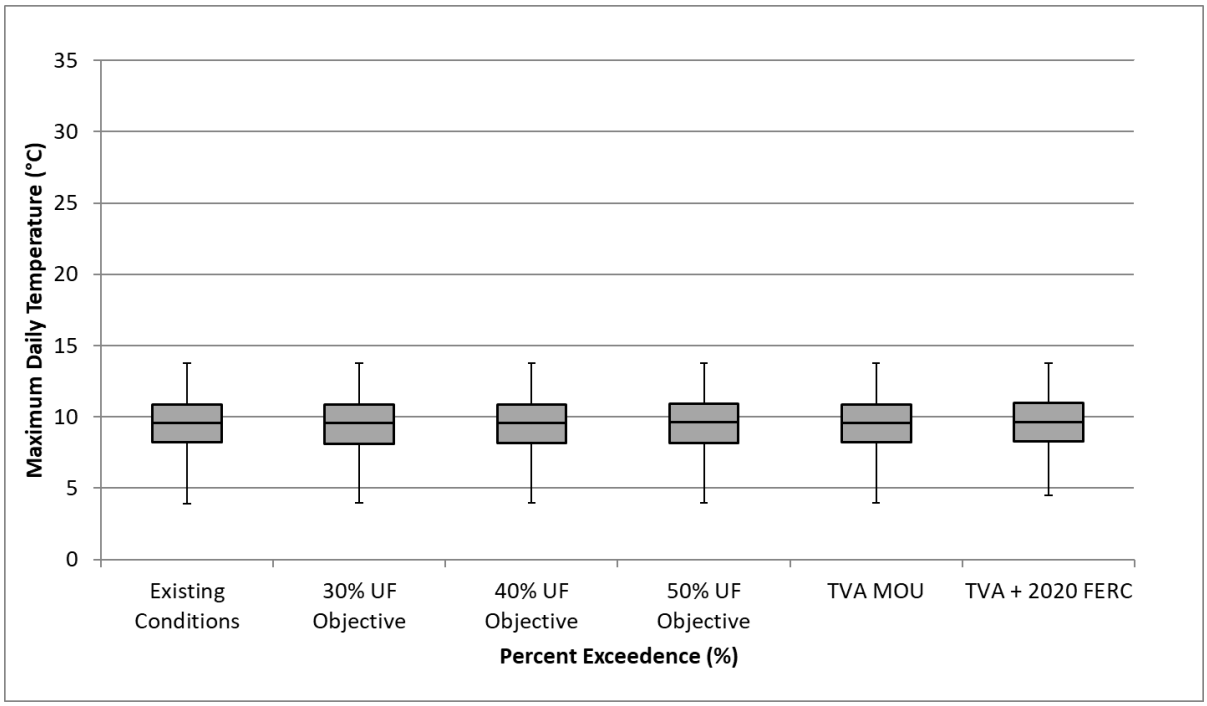


Figure B-174. Box Plot of Daily Maximum Temperatures in December at RM 13.2 from 1970 to 2003.

B.5.6 The Tuolumne River at the Confluence with the SJR (RM 0)

Figure B-175 and Figure B-176 present timeseries of average daily 7DADM temperatures at the confluence with the SJR over a year, the first being averaged over all years from 1970 to 2003 and the second only averaged over critical year types in that period.[26] The span of the figures is from February through January, which coincides with the operational year under the TVA (annual requirements under the TVA update in February). Figure B-177 through Figure B-200 present exceedance charts and box plots of daily maximum temperatures for each month at the confluence with the SJR, intended to show the range of maximum daily temperatures that occur each month in the model run. Results at this location show similar effects to those seen at RM 13.2.

[26] Since annual operations for the TVA flow requirements begin updating in February of each year and extend through the following January, the flows and temperatures seen in the October through January period are more dependent on the previous year's WYT than the current one. Therefore, the averaging period for WYT in the temperature figures is shifted forward to apply from February through January rather than October through September.

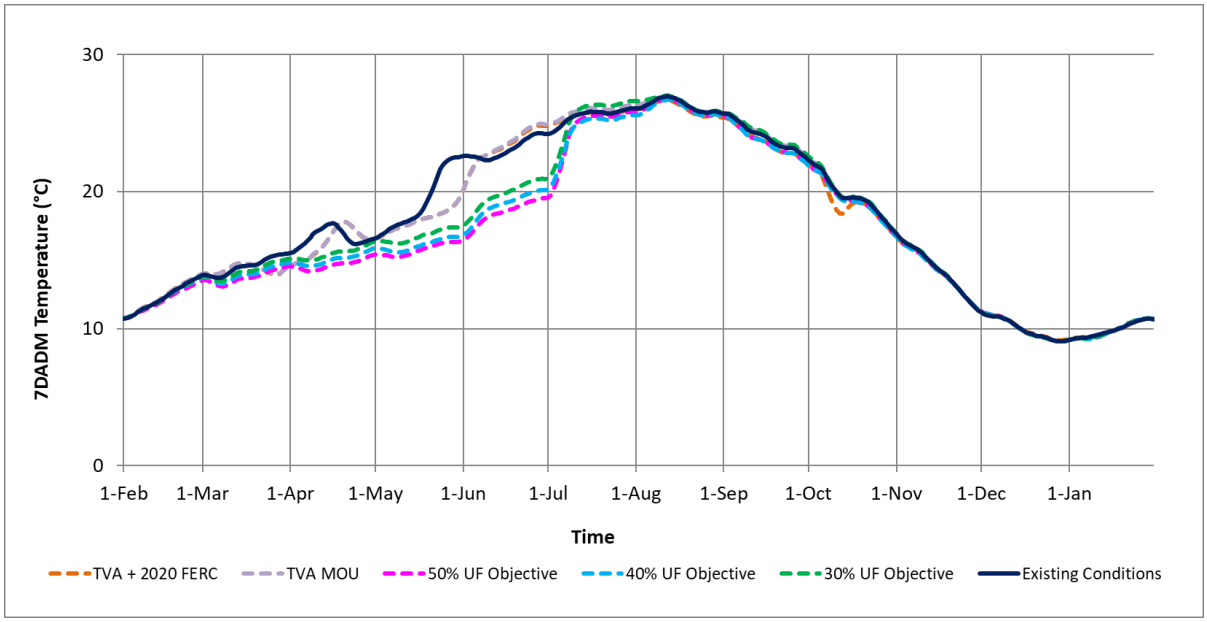


Figure B-175. Average Daily Tuolumne Running 7DADM Temperatures at the Confluence with the SJR (Averaged over All Years from 1970 to 2003).

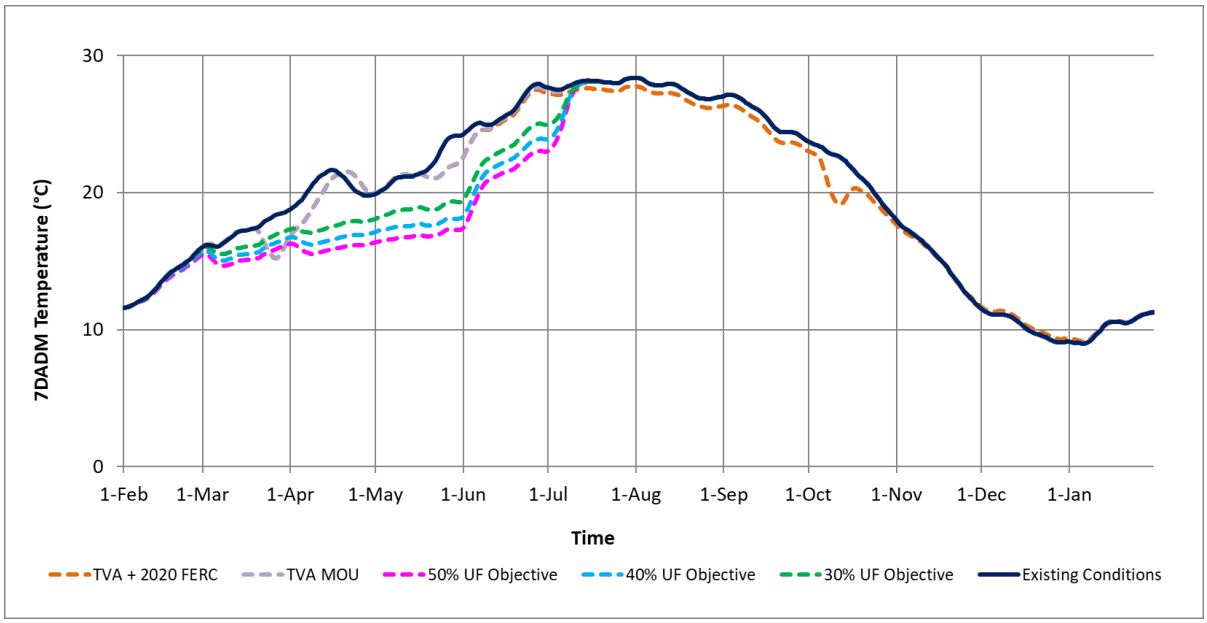


Figure B-176. Average Daily Tuolumne Running 7DADM Temperatures at the Confluence with the SJR (Averaged over Critical Years from 1970 to 2003).

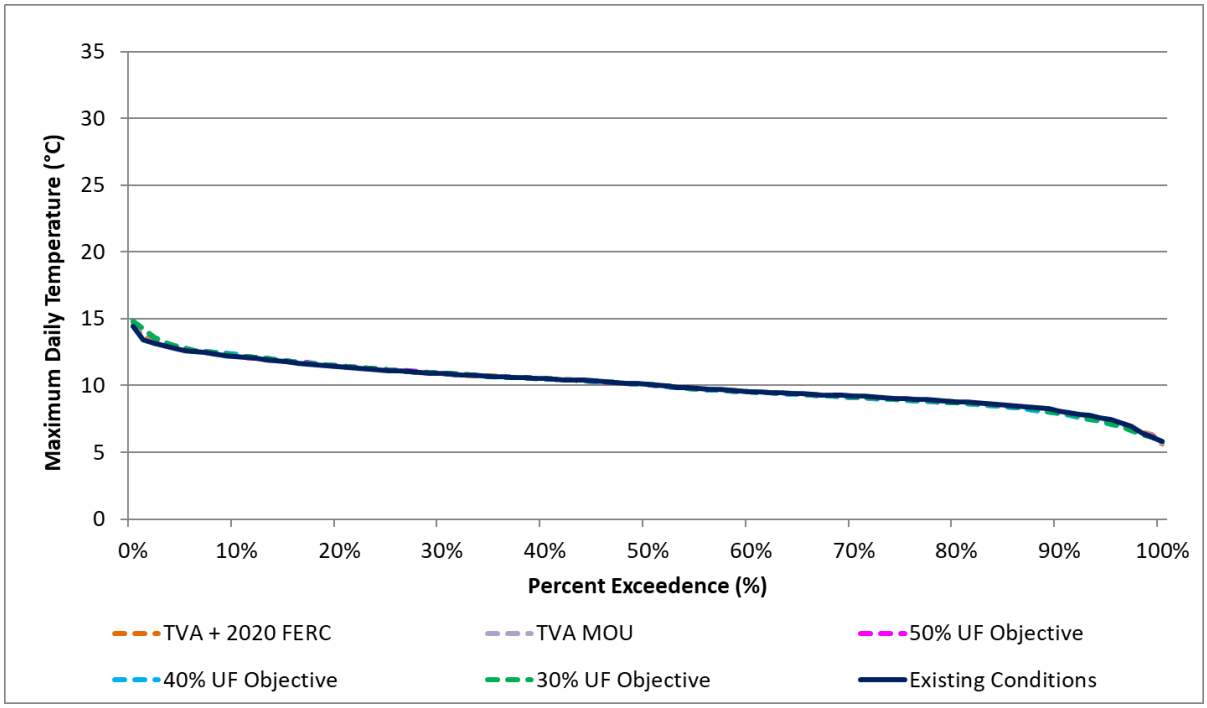


Figure B-177. Exceedance Chart of Daily Maximum Temperatures in January at the Confluence with the SJR from 1970 to 2003.

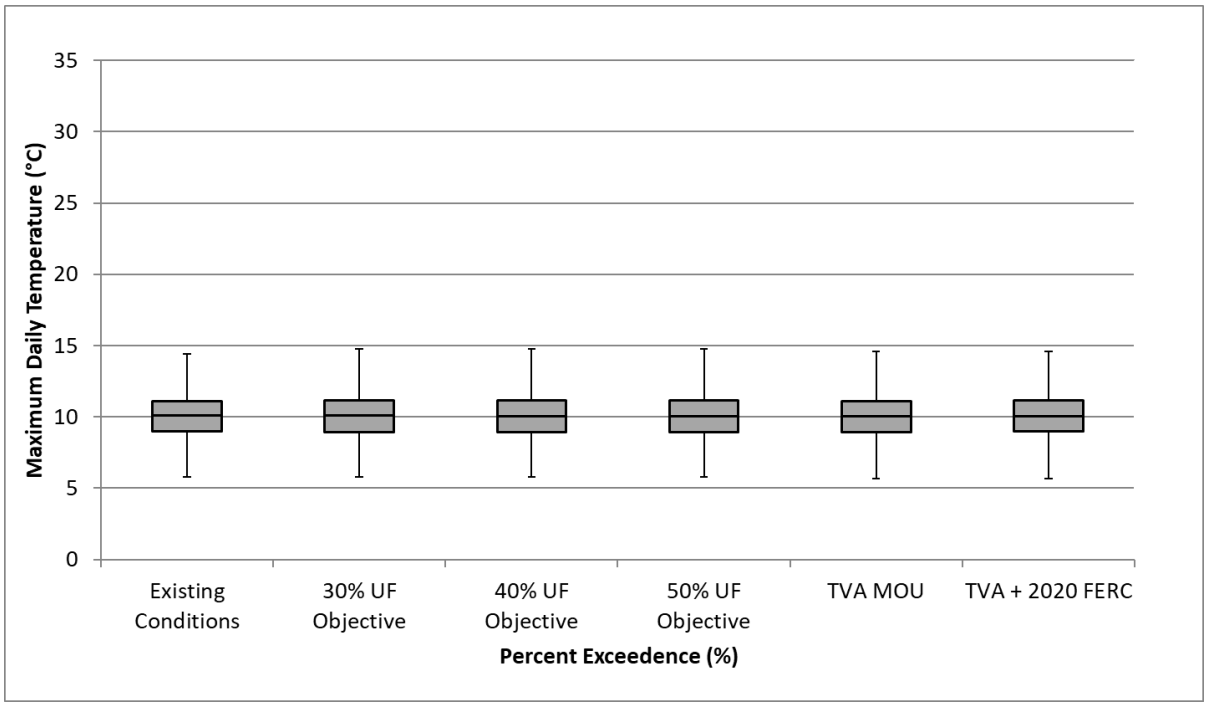


Figure B-178. Box Plot of Daily Maximum Temperatures in January at the Confluence with the SJR from 1970 to 2003.

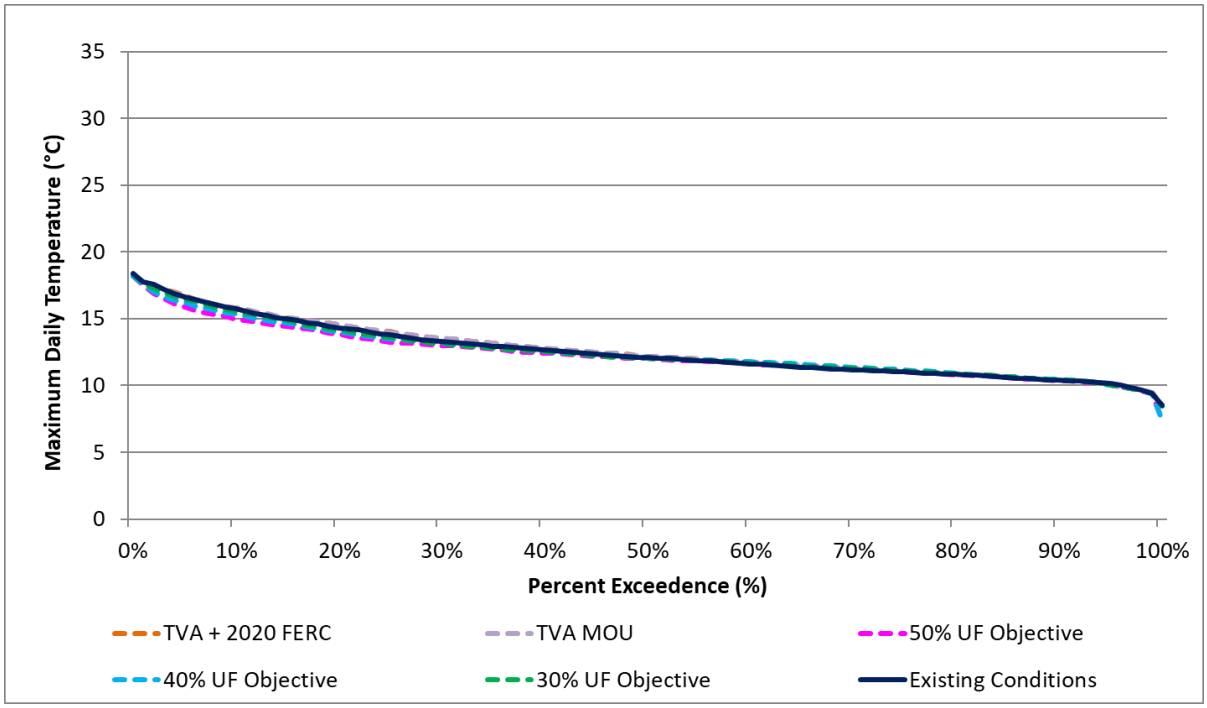


Figure B-179. Exceedance Chart of Daily Maximum Temperatures in February at the Confluence with the SJR from 1970 to 2003.

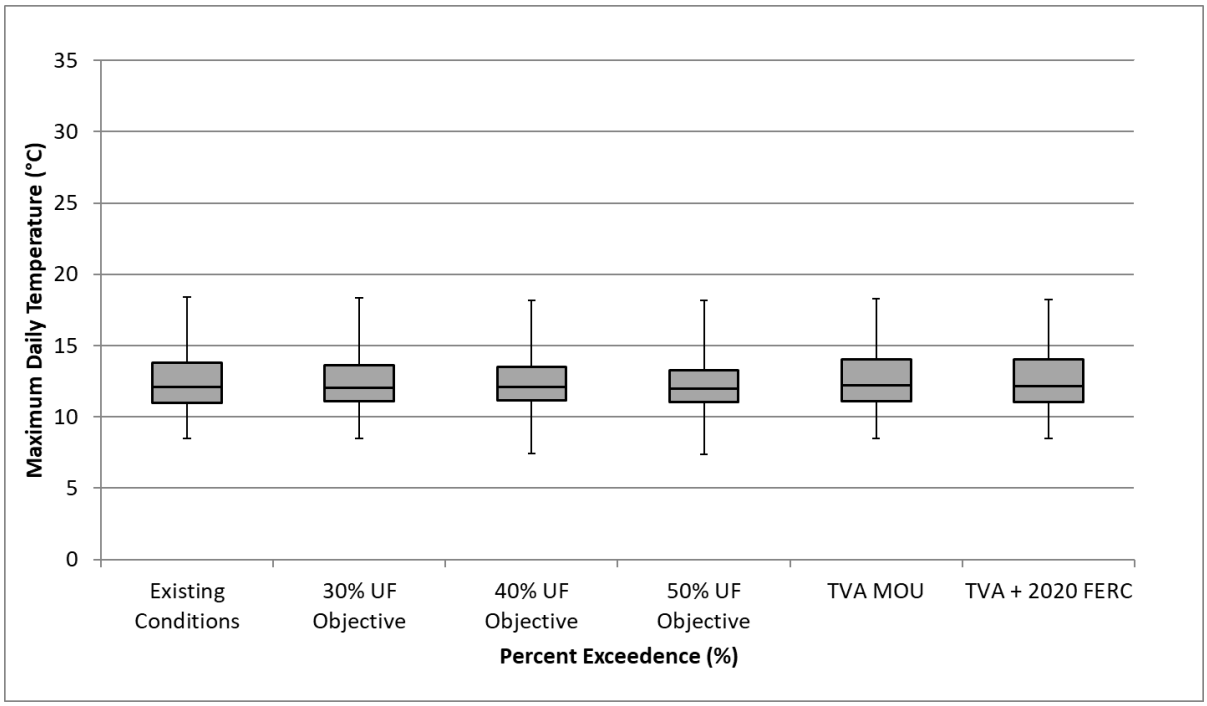


Figure B-180. Box Plot of Daily Maximum Temperatures in February at the Confluence with the SJR from 1970 to 2003.

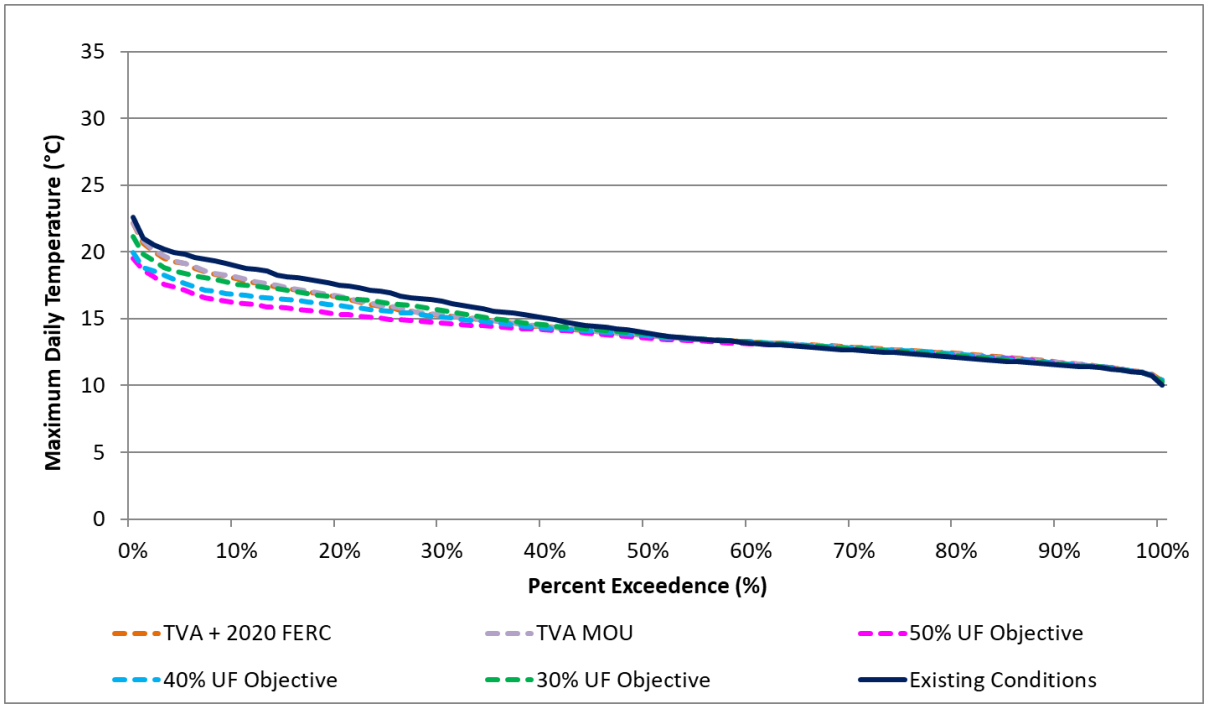


Figure B-181. Exceedance Chart of Daily Maximum Temperatures in March at the Confluence with the SJR from 1970 to 2003.

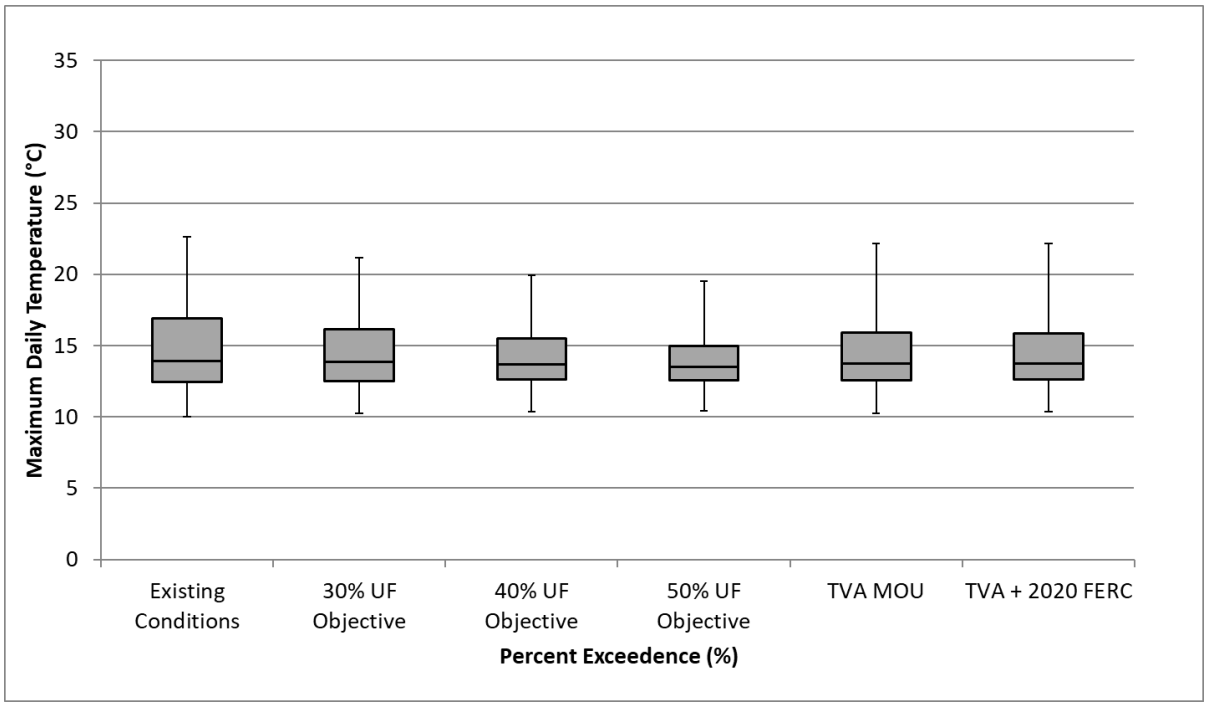


Figure B-182. Box Plot of Daily Maximum Temperatures in March at the Confluence with the SJR from 1970 to 2003.

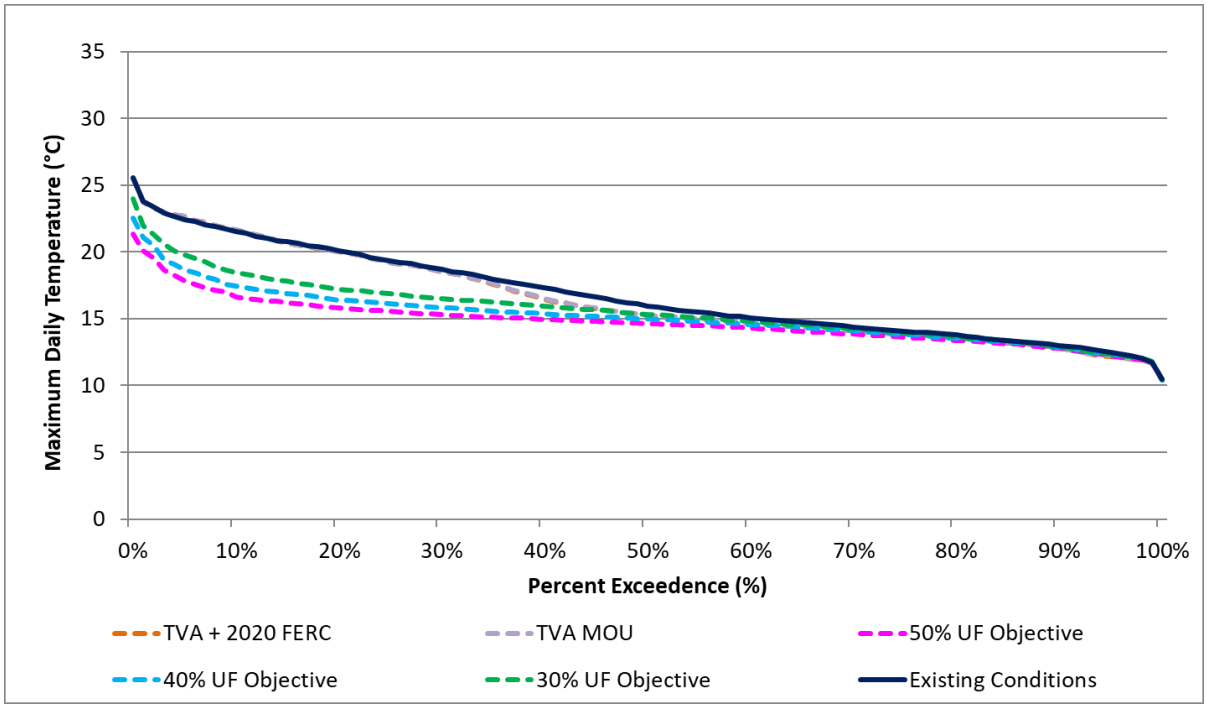


Figure B-183. Exceedance Chart of Daily Maximum Temperatures in April at the Confluence with the SJR from 1970 to 2003.

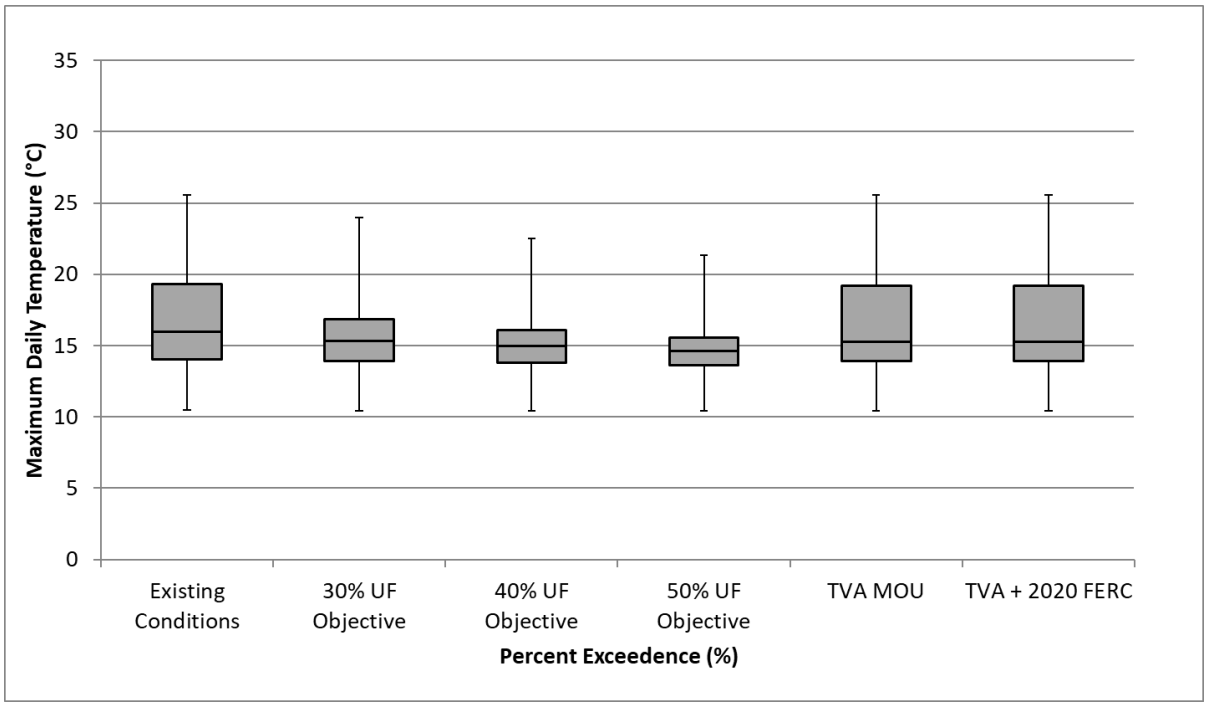


Figure B-184. Box Plot of Daily Maximum Temperatures in April at the Confluence with the SJR from 1970 to 2003.

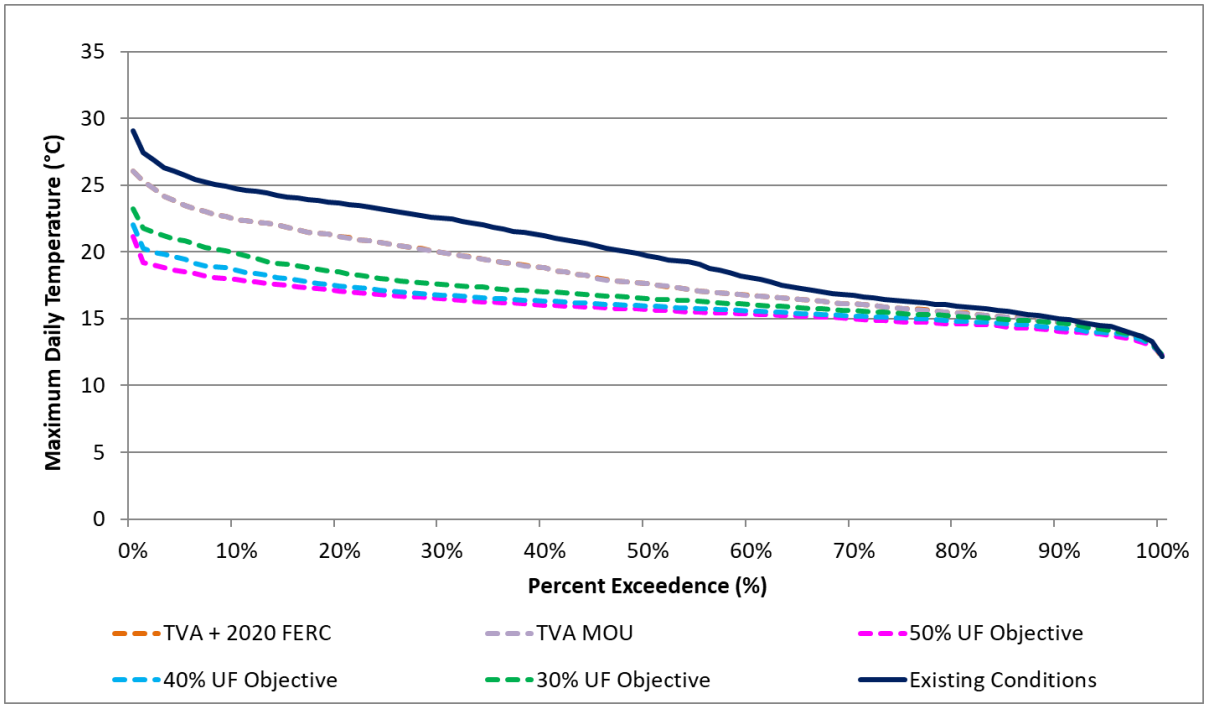


Figure B-185. Exceedance Chart of Daily Maximum Temperatures in May at the Confluence with the SJR from 1970 to 2003.

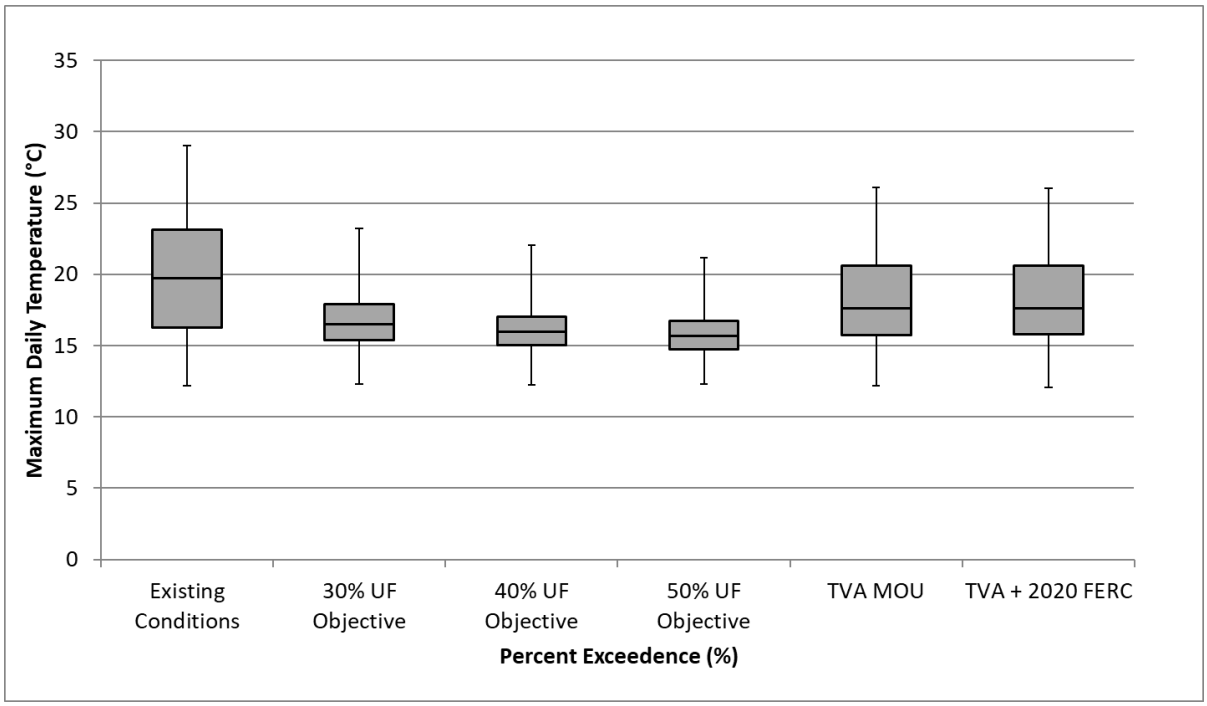


Figure B-186. Box Plot of Daily Maximum Temperatures in May at the Confluence with the SJR from 1970 to 2003.

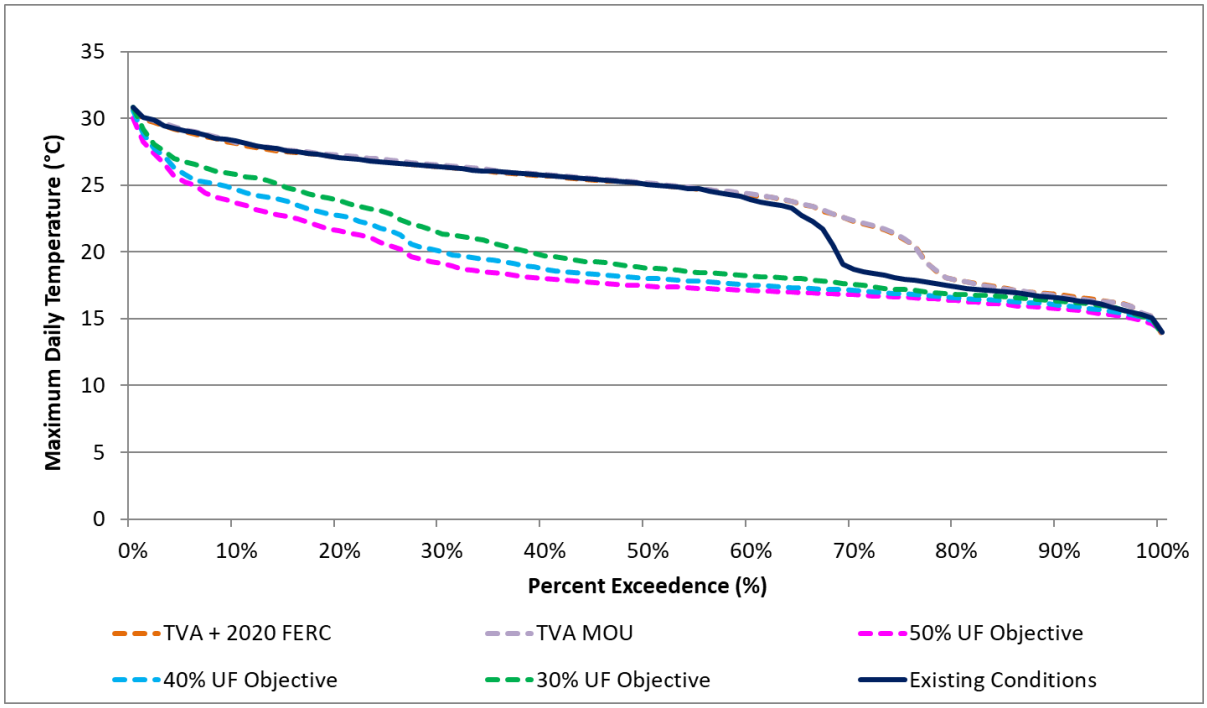


Figure B-187. Exceedance Chart of Daily Maximum Temperatures in June at the Confluence with the SJR from 1970 to 2003.

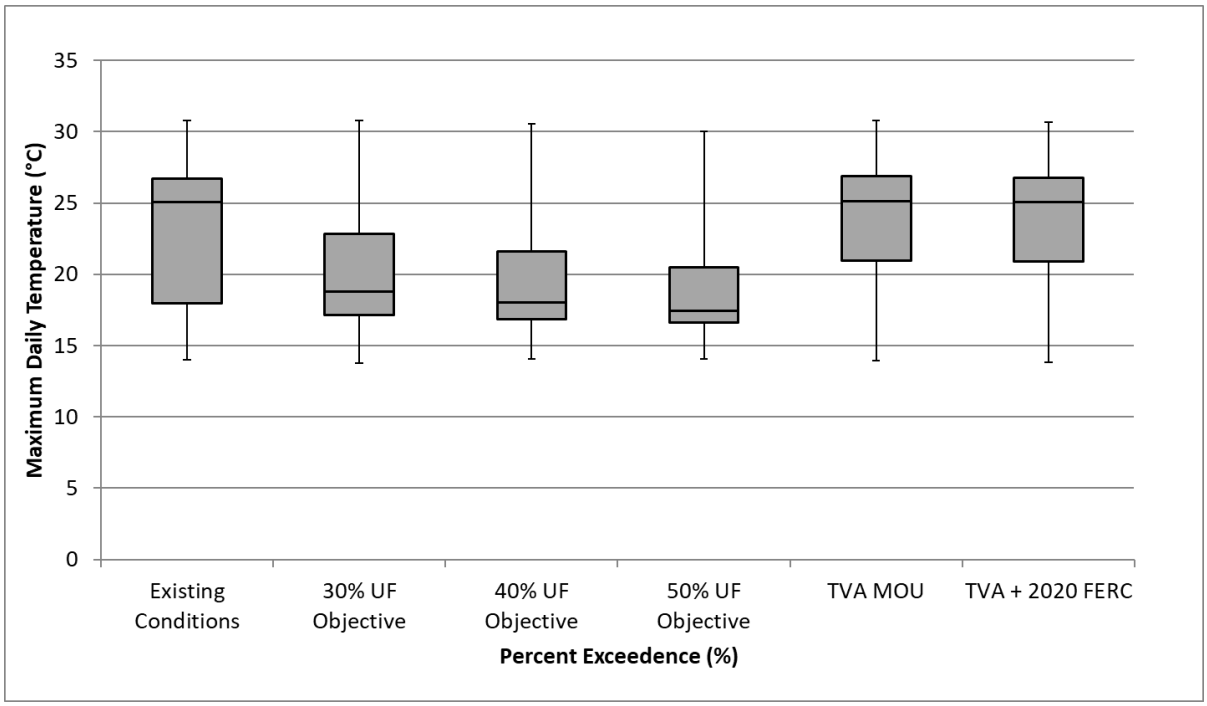


Figure B-188. Box Plot of Daily Maximum Temperatures in June at the Confluence with the SJR from 1970 to 2003.

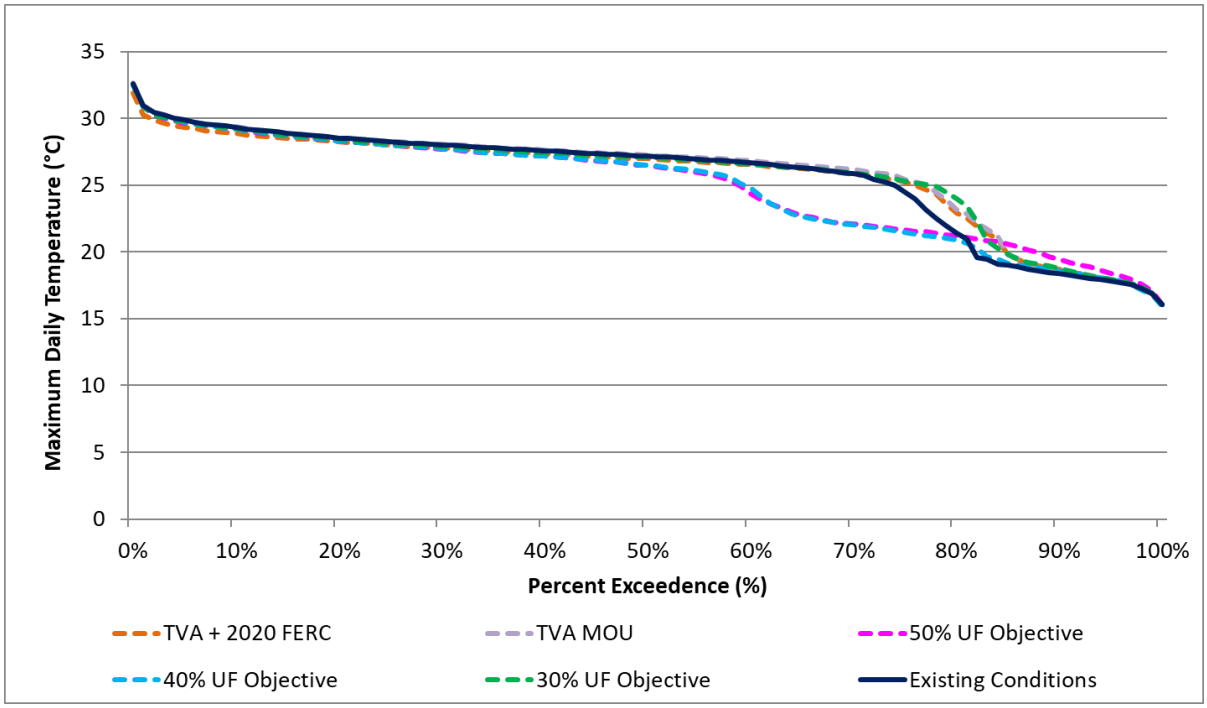


Figure B-189. Exceedance Chart of Daily Maximum Temperatures in July at the Confluence with the SJR from 1970 to 2003.

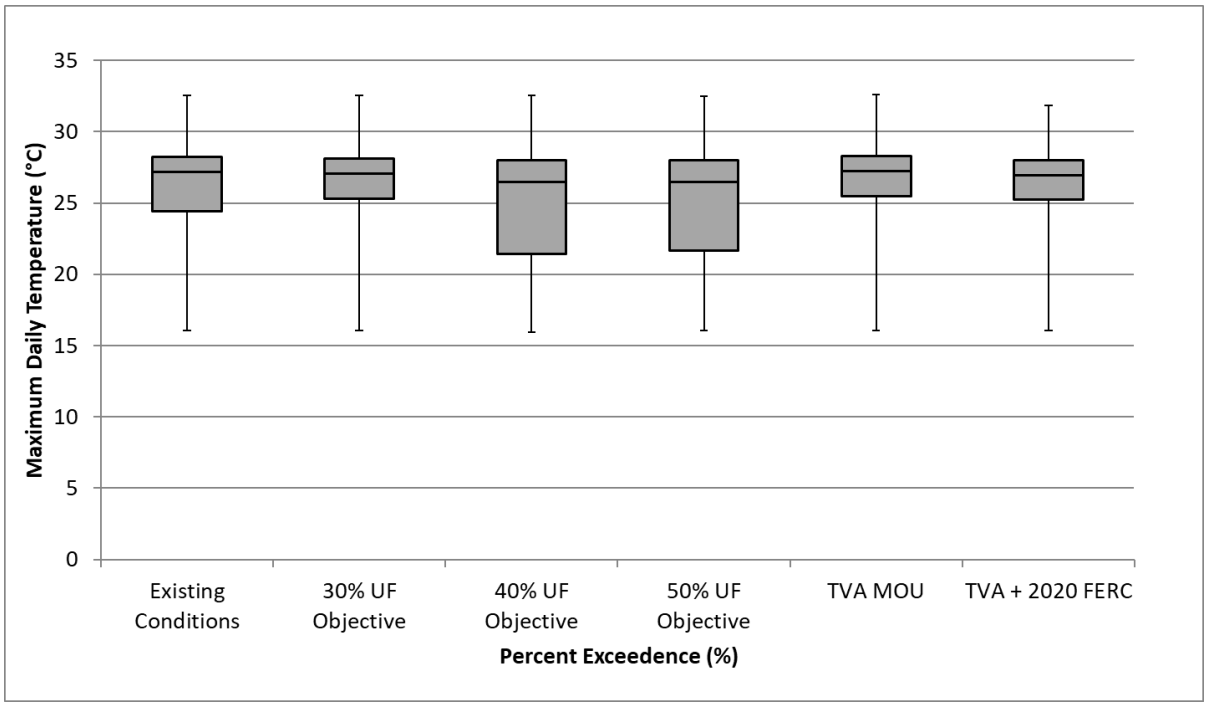


Figure B-190. Box Plot of Daily Maximum Temperatures in July at the Confluence with the SJR from 1970 to 2003.

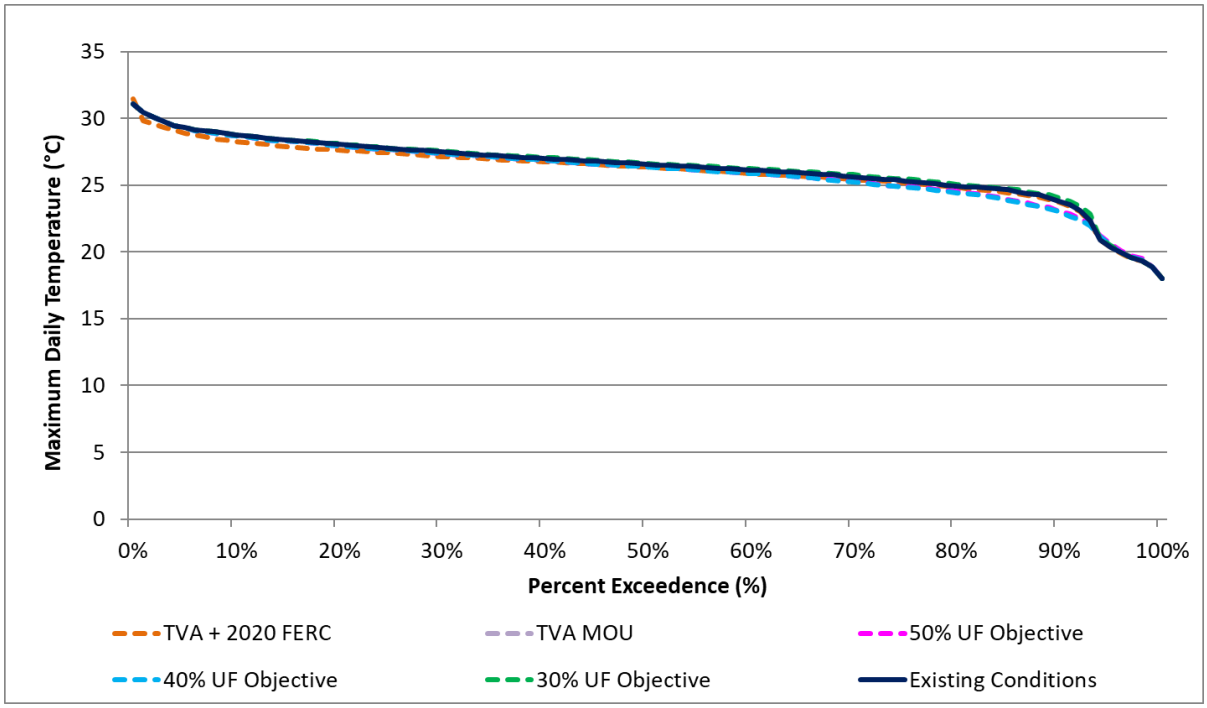


Figure B-191. Exceedance Chart of Daily Maximum Temperatures in August at the Confluence with the SJR from 1970 to 2003.

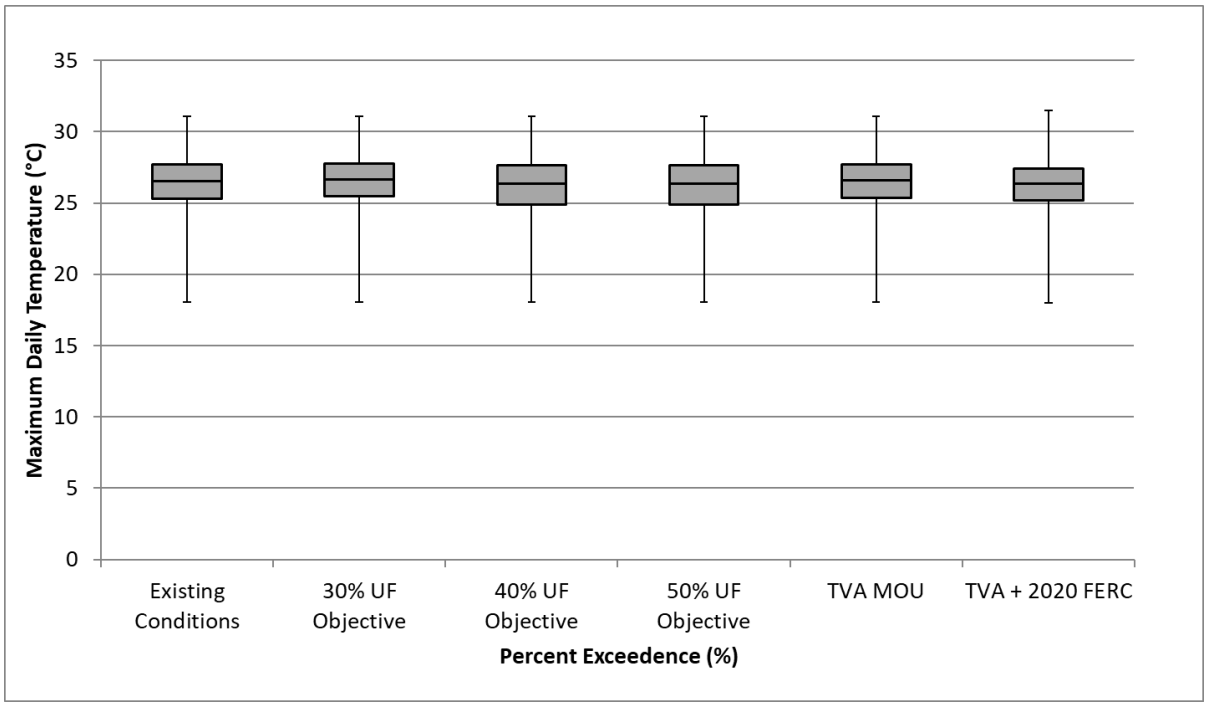


Figure B-192. Box Plot of Daily Maximum Temperatures in August at the Confluence with the SJR from 1970 to 2003.

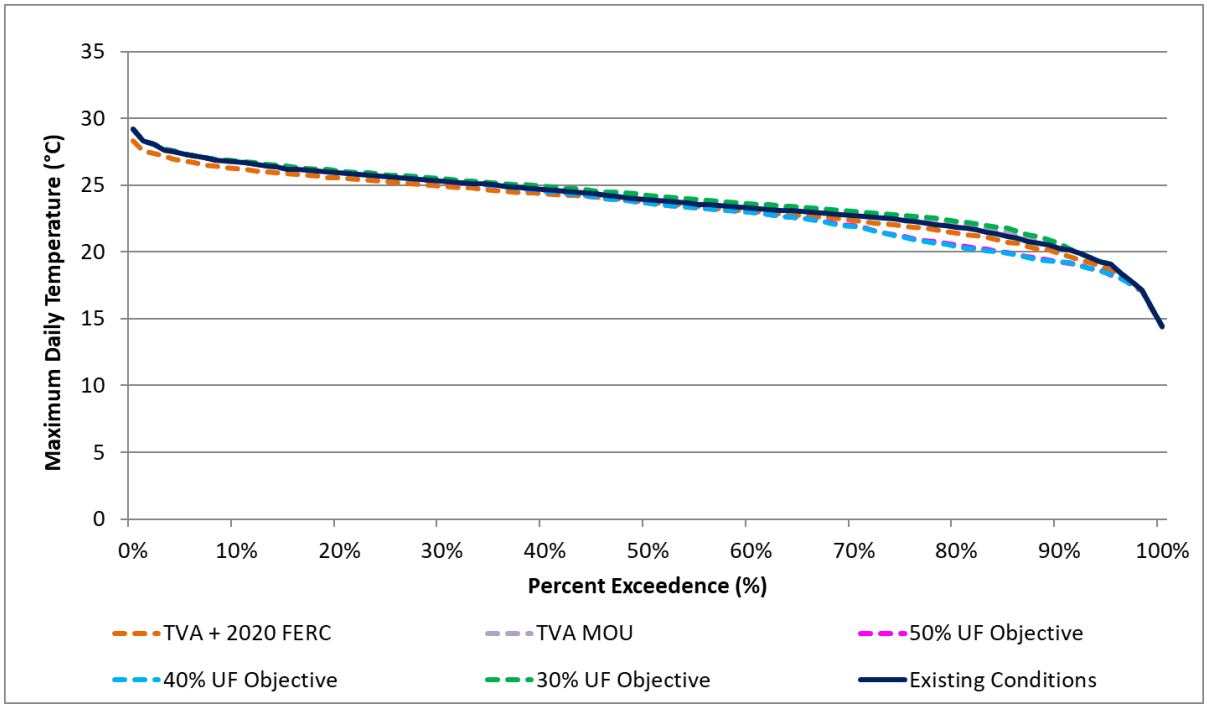


Figure B-193. Exceedance Chart of Daily Maximum Temperatures in September at the Confluence with the SJR from 1970 to 2003.

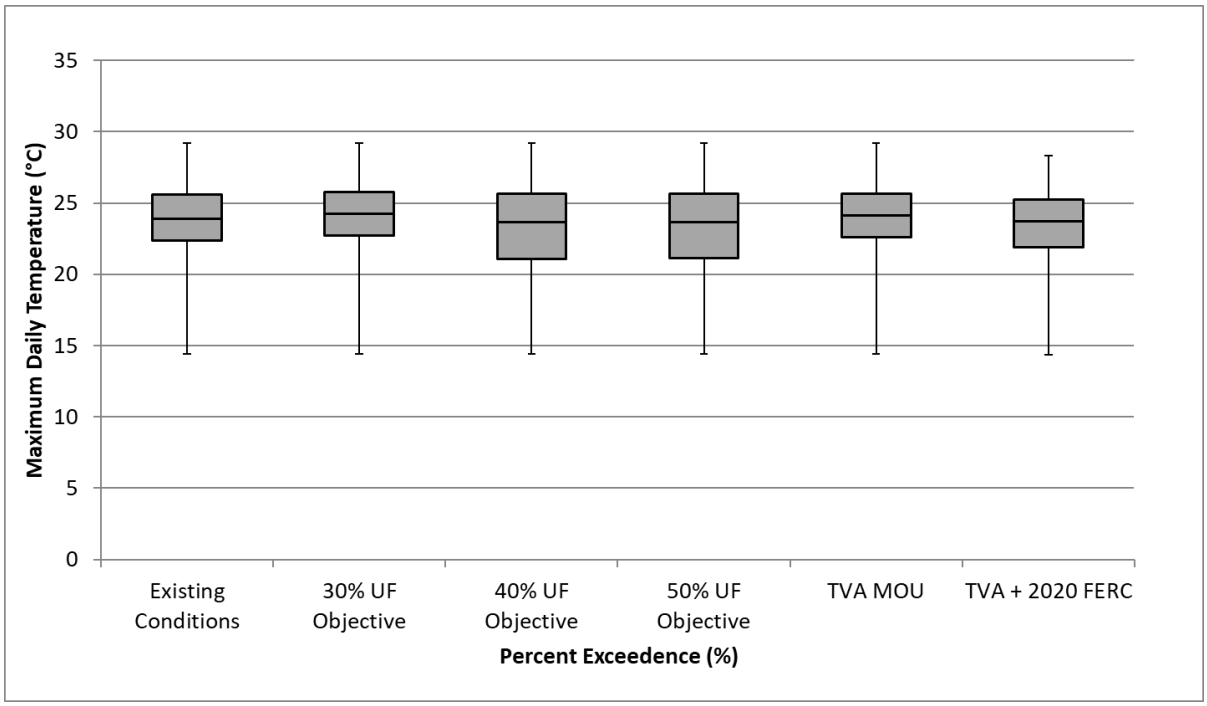


Figure B-194. Box Plot of Daily Maximum Temperatures in September at the Confluence with the SJR from 1970 to 2003.

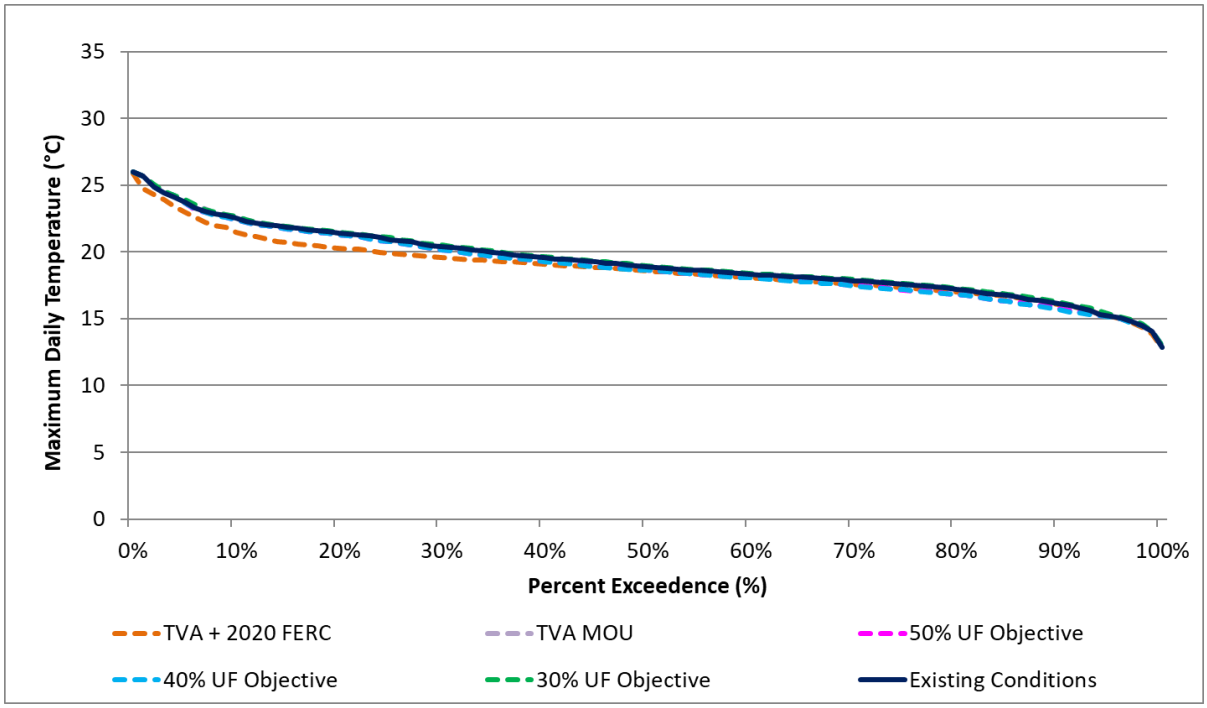


Figure B-195. Exceedance Chart of Daily Maximum Temperatures in October at the Confluence with the SJR from 1970 to 2003.

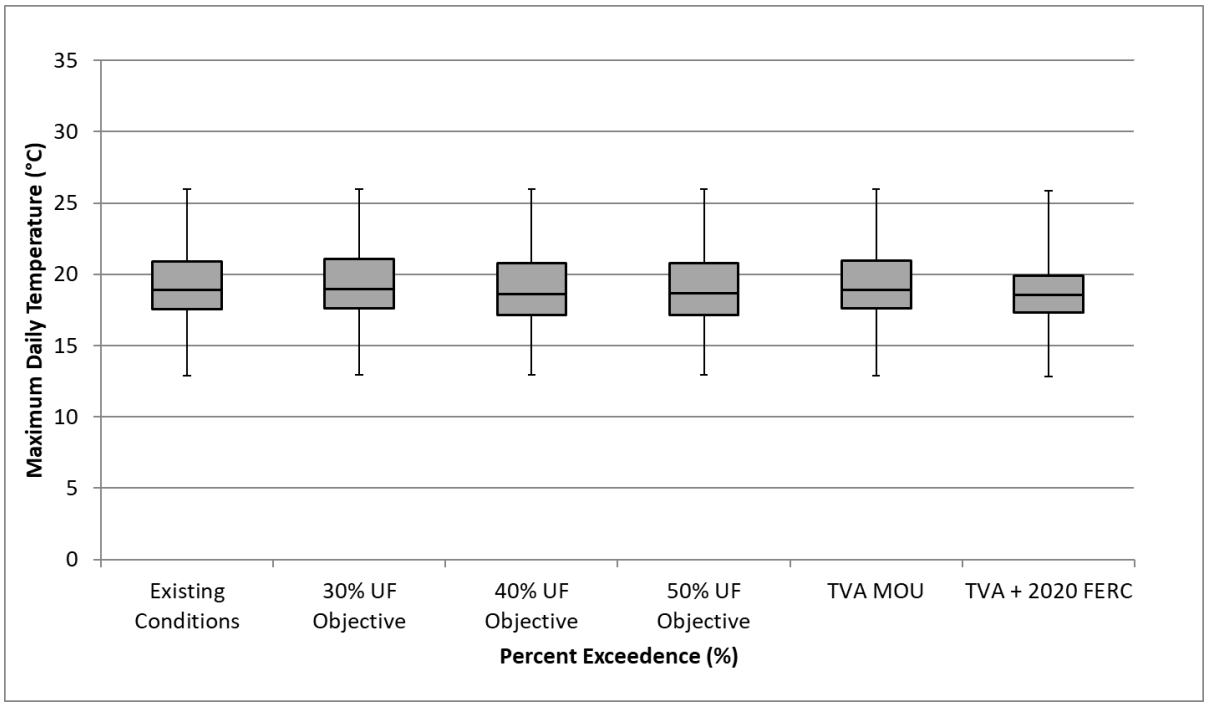


Figure B-196. Box Plot of Daily Maximum Temperatures in October at the Confluence with the SJR from 1970 to 2003.

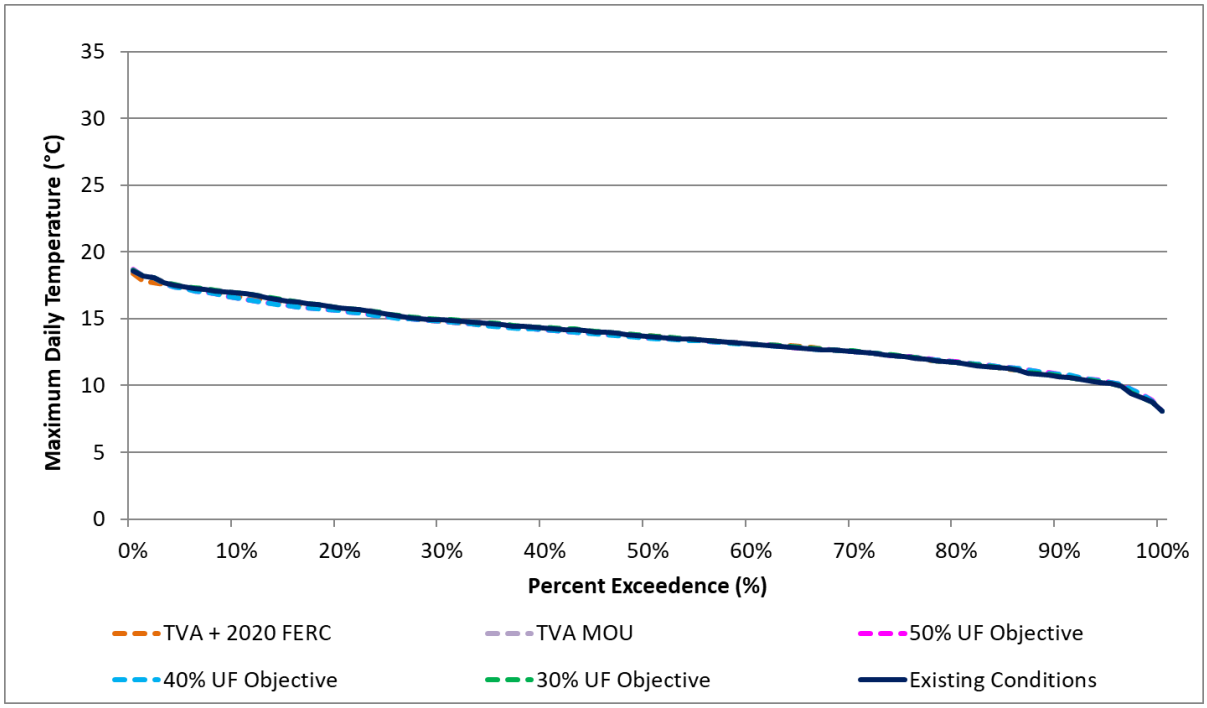


Figure B-197. Exceedance Chart of Daily Maximum Temperatures in November at the Confluence with the SJR from 1970 to 2003.

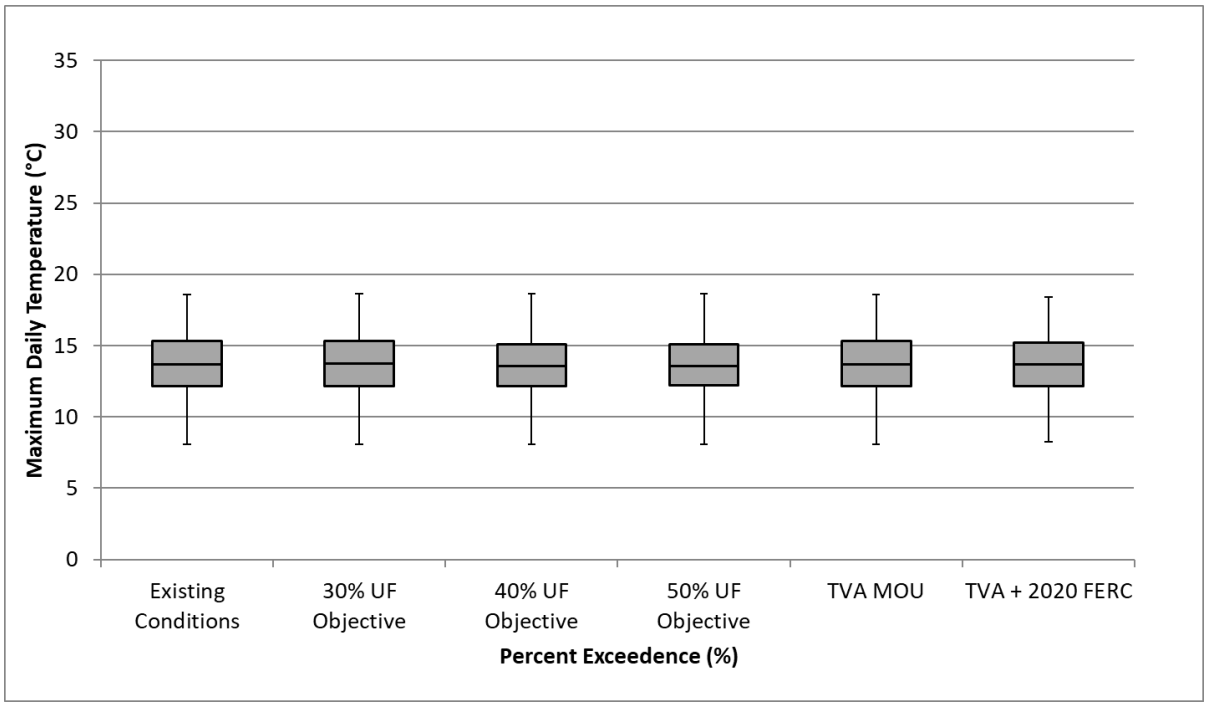


Figure B-198. Box Plot of Daily Maximum Temperatures in November at the Confluence with the SJR from 1970 to 2003.

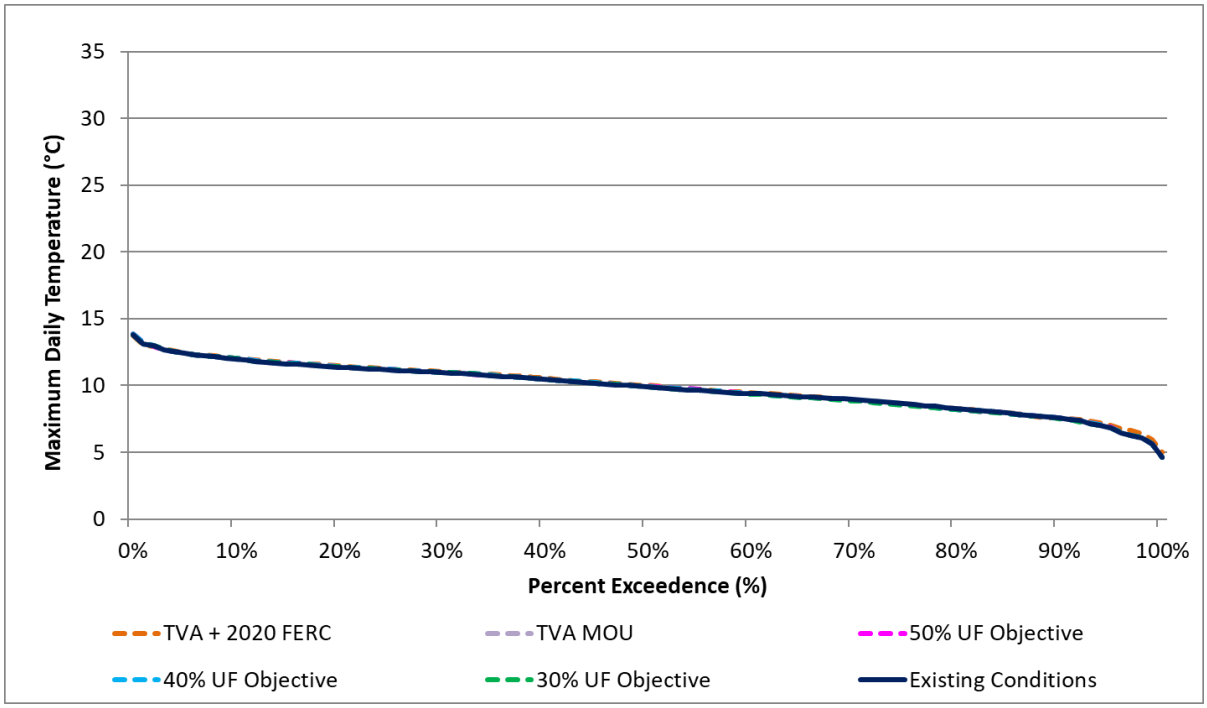


Figure B-199. Exceedance Chart of Daily Maximum Temperatures in December at the Confluence with the SJR from 1970 to 2003.

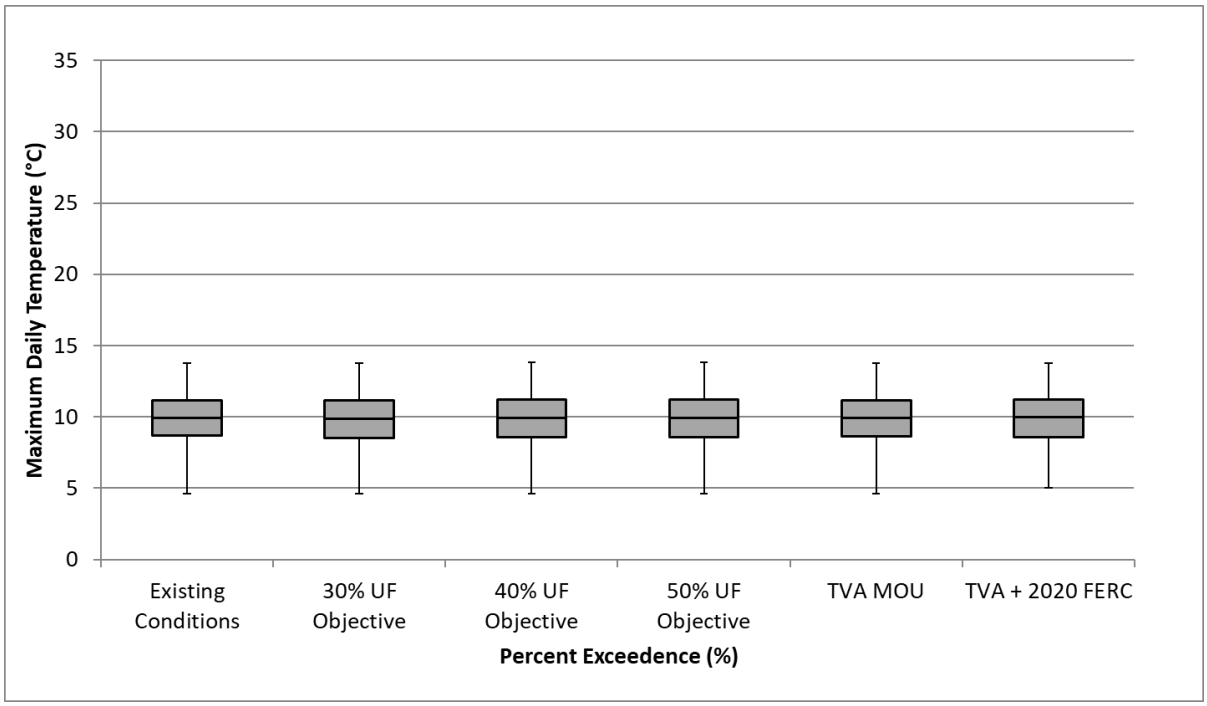


Figure B-200. Box Plot of Daily Maximum Temperatures in December at the Confluence with the SJR from 1970 to 2003.

B.6 References

B.6.1 Printed References

California Department of Fish and Wildlife (CDFW). 2013. San Joaquin River Basin-Wide Water Temperature and EC Model. June. Prepared by AD Consultants, Resource Management Associates, and Watercourse Engineering, Inc.

California Department of Water Resources (DWR). 1967. Contract between State of California and Merced Irrigation District for Recreation and Fish Enhancement Grants under the Davis-Grunsky Act.

California Department of Water Resources (DWR). 2003. Monthly Hydrologic Forecasts for Use in CALSIM II Allocation Model (CAM), Preliminary Draft. November.

California Department of Water Resources (DWR). n.d. Don Pedro reservoir Daily Storage, gage DNP. Available: https://cdec.water.ca.gov/dynamicapp/wsSensorData. Accessed: April 16, 2024.

Federal Energy Regulatory Commission (FERC). 1964. Merced Irrigation District, Project No. 2179 order issuing License (Major). April 8.

Federal Energy Regulatory Commission (FERC). 1995. New Don Pedro Proceeding: P-2299-024. Settlement Agreement.

Federal Energy Regulatory Commission (FERC). 2015. Final Environmental Impact Statement for Hydropower Licenses. Merced River Hydroelectric Project, FERC Project No. 2179-043; Merced Falls Hydroelectric Project, FERC Project No. 2467-020. Division of Hydropower Licensing. Washington, D.C. December.

Federal Energy Regulatory Commission (FERC). 2020. Final Environmental Impact Statement for Hydropower Licenses. Don Pedro Hydroelectric Project, FERC Project No. 2299-082; La Grange Hydroelectric Project, FERC Project No. 14581-002. Division of Hydropower Licensing. Washington, D.C. July.

Holland, J. 2014. "Turlock Irrigation District Votes to Cut in Half its Water Deliveries to Farms." *The Modesto Bee.* May 2, 2014. Available: http://www.modbee.com/news/local/turlock/article3161121.html. Accessed March 28, 2024.

Holland, J. 2015. "Turlock Irrigation District Caps Water Deliveries at 40 Percent of Normal." *The Modesto Bee.* March 31, 2015. Available: http://www.modbee.com/news/local/turlock/article17010653.html. Accessed March 28, 2024.

Merced Irrigation District (Merced ID). 2013. *Agricultural Water Management Plan.* September 3. Developed for the Department of Water Resources by Merced ID.

Merced Irrigation District (Merced ID). 2015. *Merced Water Operations Model.* Version 5. Excel Spreadsheet (MercedID_2015_Merced_Ops_Model.xlsx).

Merced Irrigation District (Merced ID). 2016. *Agricultural Water Management Plan.* July 5. Developed for the Department of Water Resources by Merced ID.

Merced Irrigation District (Merced ID). 2021. *Agricultural Water Management Plan.* July 13. Developed for the Department of Water Resources by Merced ID.

Modesto Irrigation District (MID). 2015. *Agricultural Water Management Plan 2015 Update.* December. Prepared by Provost & Pritchard Consulting Group.

Modesto Irrigation District (MID). 2021. *Agricultural Water Management Plan 2020 Update.* March 23. Prepared for MID.

National Marine Fisheries Service (NMFS). 2009. Appendix 2-E: Stanislaus River Minimum Flows for Fish Needs. Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project. ESA Section 7 Consultation Southwest Region. June 4.

National Marine Fisheries Service (NMFS). 2019. Biological Opinion on Long-term Operation of the Central Valley Project and the State Water Project. ESA Section 7 Consultation. West Coast Region. October 21.

Oakdale Irrigation District (OID). 2021. *Agricultural Water Management Plan.* Final. March. Prepared by Davids Engineering, Inc.

San Joaquin River Restoration Program (SJRRP). 2017. *San Joaquin River Restoration Program Long-term Recapture and Recirculation of Restoration Flows EIS/EIR, Project Description Technical Memorandum.* September.

Smith, D. 2013. *HEC5Q Input Description.*

South San Joaquin Irrigation District (SSJID). 2021. *2020 Agricultural Water Management Plan.* Final Draft. March 23. Prepared by Davids Engineering, Inc.

South San Joaquin Irrigation District (SSJID). 2022. *2022 Water Master Plan.* December. Prepared by Jacobs.

State Water Resources Control Board (SWRCB). 1973. Water Right Decision 1422. April.

State Water Resources Control Board (SWRCB). 2000. Revised Water Right Decision 1641. Revised March 15.

State Water Resources Control Board (SWRCB). 2018. Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: San Joaquin River Flows and Southern Delta Water Quality. Final. State Clearinghouse #2012122071. Division of Water Rights. Sacramento, CA.

State Water Resources Control Board (SWRCB). 2023. Order Approving Temporary Changes to Permits 11885, 11886, and 11887 of the U.S. Bureau of Reclamation for the Temporary Transfer or Exchange of Up To 45,000 Acre-Feet of Water for Instream Flow Dedication and Rediversion. November 17. Division of Water Rights.

State Water Resources Control Board (SWRCB). 2024. Electronic Water Rights Information Management System (eWRIMS) public query. Available: https://ciwqs.waterboards.ca.gov/ciwqs/ewrims/EWServlet?Redirect_Page=EWWaterRightPublicSearch.jsp&Purpose=getEWAppSearchPage. Accessed: May 7, 2024.

Turlock Irrigation District (TID). 2015. *2015 Agricultural Water Management Plan.* Turlock, CA. November. Prepared by TID.

Turlock Irrigation District (TID). 2021. *2020 Agricultural Water Management Plan.* Final. Turlock, CA. March. Prepared by TID.

Turlock and Modesto Irrigation District (TID and MID). 2023. *2022 Lower Tuolumne River Annual Report.* March 30. Prepared for the Federal Energy Regulatory Commission.

Turlock Irrigation District, Modesto Irrigation District, and The City and County of San Francisco (TID, MID, and CCSF). 2023. *TVA party responses to SWRCB technical questions.* Excel Spreadsheet (TIDMIDCCSF_2023_TVA_Modeling). April.

Turlock Irrigation District, Modesto Irrigation District, and The City and County of San Francisco (TID, MID, and CCSF). 2024. *TVA party modeling of daily flows under the FERC base case and updated TRVA hydrology.* Excel Spreadsheet (TIDMIDCCSF_2024_Daily_TVA_Flows). June.

Turlock Irrigation District, Modesto Irrigation District, and The City and County of San Francisco (TID, MID, and CCSF). 2025. *Draft Tuolumne Accounting spreadsheet model.* Excel Spreadsheet (Tuol_Accounting_Model_Apr2025). April.

U.S. Army Corps of Engineers (USACE). 1998. HEC-5 Simulation of Flood Control and Conservation Systems. User's Manual Version 8.0. Hydrologic Engineering Center, Davis, CA. October.

U.S. Bureau of Reclamation (USBR). 2019. Appendix B New Melones Stepped Release Plan Daily Hydrographs for Critical, Dry, Below Normal, Above Normal and Wet Year Type. Reinitiation of Consultation on the Coordinated Long-Term Operation of the Central Valley Project and State Water Project, Final Biological Assessment. Central Valley Project, California Mid-Pacific Region. October.

U.S. Bureau of Reclamation (USBR). 2021. Attachment 1 Model Assumptions. Reclamation Benchmark Model Documentation. July

Yin, H., L. Zhong, and M. Lui. 2012. *Office Memo regarding the Development of San Joaquin River Hydrologic Forecast and Fortran Callable Library for CAM.* Department of Water Resources (DWR). August 23.

B.6.2 Personal Communications

Hashimoto, Casey P. E. Turlock Irrigation District General Manager. Letter submitted via email Re: Response to "Information request related to preparing the substitute environmental document for the update to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary." Date: October 6, 2015.

Salyer, Greg. Modesto Irrigation District Interim General Manager. Letter Re: Modesto Irrigation District – Response to Information Request Related to Preparing the Substitute Environmental Document for the Update to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. Dated October 2, 2015.

Appendix C

Draft Tuolumne Accounting Spreadsheet Model

Contents

Appendix C Draft Tuolumne Accounting Spreadsheet Model 1

C.1 Overview 1

C.1.1 Background and Purpose of Accounting Model 1

C.1.2 Organization of this Document 1

C.2 Model Tabs 2

C.2.1 1995 2

C.2.2 HRL 4

C.2.3 1995 and HRL comparison 5

C.3 Input Tabs 7

C.3.1 Storage_req 7

C.3.2 1995 flow req 7

C.3.3 HRL flow req 7

C.3.4 Evap_calc 8

C.4 Plots 8

C.4.1 Model plots 8

Appendix C

Draft Tuolumne Accounting Spreadsheet Model

*[State Water Board staff note: This appendix and the version of the accounting spreadsheet model described (**Tuol_Accounting_Model_Jul2025.xlsx**) were received from the TVA parties in July of 2025. The model version described here is slightly different from the version used in the analysis shown in Chapter 4, Tuolumne River Hydrology and Operations Modeling Methods and Results, which was received in April of 2025 (**Tuol_Accounting_Model_Apr2025.xlsx**). The April version did not include interpolation water in the calculation of the 1995 Settlement Agreement required flows, which informed the decision to not include interpolation water in the WSE modeling described in Chapter 4 and Appendix B, Hydrologic and Water Quality Modeling. In addition, the July accounting spreadsheet does not include several result summary tabs shown in the April version that provided modeling results for comparison and discussion in Chapter 4. Finally, column headings on several tabs in the July version of the spreadsheet have been changed from those presented in the April version. The Draft TVA Scientific Basis Report will be revised, as necessary, once the Tuolumne HRL Accounting Model is finalized.]*

C.1 Overview

C.1.1 Background and Purpose of Accounting Model

The Tuolumne HRL Accounting Model (Accounting Model) has been developed using historical hydrology and operational records to demonstrate how flow accounting will be performed for the Tuolumne Healthy Rivers and Landscapes (THRL) program. This example includes historical hydrology and operation data from the Tuolumne River water storage projects from 1999 to 2023.

During implementation, the same accounting approach will be used to track and quantify the T-HRL flow assets. Some inputs that are estimated or generalized for the historical accounting example may be replaced with actual known values during real-time implementation.

C.1.2 Organization of this Document

The Tuolumne HRL Accounting Model is an Excel spreadsheet with multiple tabs. Each tab is described in the following sections of this documentation. The content of the tab as developed for the historical accounting model is described, and the intended future use for flow accounting during implementation of the Tuolumne HRL is also described. The content of each tab in the worksheet is described by column, moving from left to right within each tab.

C.2 Model Tabs

C.2.1 1995

The 1995 tab contains a simulation of the total resulting flow in the Tuolumne River at La Grange with the 1995 FERC Settlement Agreement for the Don Pedro Project in place. Each component of the simulation is described here:

The date range included in the historical version of the T-HRL Accounting Model is January 1999 through September 2023. The model uses a daily timestep.

The water year types used in the 1995 Settlement Agreement are based on the value of the San Joaquin Index (SJI), also known as the 60:20:20 index. There are 10 water year types included in the 1995 Settlement Agreement. In the 1995 simulation, the water year type is updated on April 16 and May 16 of each year, based on the 90% exceedance value of the April SJI and the 75% exceedance value of the May SJI, respectively.

Full natural flow at La Grange (FNF) is a calculated value of total unimpaired flow at La Grange. FNF is used to represent total inflow to Tuolumne River storage. FNF values are available on CDEC at station TLG.

Storage in the Accounting Model represents the sum of water in storage at four water storage reservoirs on the Tuolumne River: Don Pedro Reservoir, Hetch Hetchy Reservoir, Cherry Lake and Lake Eleanor. The storage in these reservoirs is calculated at each timestep based on the water balance of inflow and outflows. Inflow is represented as FNF. Outflows include evaporation, San Francisco diversion to the SFPUC service area, diversion by Modesto Irrigation District and Turlock Irrigation District, and releases to the Tuolumne River at La Grange. The storage estimate is calculated initially here (column I), and is then re-calculated based on adjusted outflows (column S). The adjusted value is considered the final daily estimate of reservoir storage.

Surface area of Tuolumne River reservoir storage is estimated for each timestep based on the storage value for that timestep; the relationship between storage and surface area is included on tab “evap_calc.”

City and County of San Francisco (CCSF) diversion is the delivery of water from Hetch Hetchy Reservoir to the SFPUC service area. Irrigation diversion is the delivery of water through the Modesto Canal and the Turlock Canal. The values are based on historical meter records in the historical version of the Accounting Model; current meter records will be used during implementation of the T-HRL program.

Evap is the estimated evaporation from reservoir storage. These values are calculated based on the daily value of surface area and estimates of the evaporation rate; the estimated evaporation rates are included on tab “evap_calc.”

Minimum flow represents the daily value of the instream flow requirement at La Grange on the Tuolumne River in the 1995 Settlement Agreement. These are determined for each timestep based on the date and the water year type; daily minimum flow values are included on tab “1995 flow req.” Interpolation flows are an additional component of the required flows in the 1995 Settlement Agreement. The historical volumes of the interpolation flows that have been required during the 1999 – 2023 period are include, and are added to the minimum flow.

River flow is the calculated value of total flow in the Tuolumne River at La Grange. The calculation includes the minimum flow for the instream flow requirement, and flood control releases that include an estimate of spills from reservoir storage and releases from reservoir storage that are made to manage reservoir storage at seasonal targets. Releases to manage reservoir storage levels are assumed to occur at 9,700 cfs, which is typically a flow rate that is considered within channel capacity (which is defined as stage 55ft at 9th street Modesto). Spills are estimated as flows equivalent to 9,700 cfs plus any increase in daily reservoir storage that is greater than the total reservoir storage capacity. Seasonal targets for reservoir storage are included in tab "Storage_req." These seasonal targets include formal flood control requirements for Don Pedro Reservoir and unofficial operational drawdown targets for Don Pedro and the San Francisco reservoirs. Historical modifications to these targets have been included where possible in the values on tab "Storage_req" and if future modifications occur, they will be included in the Accounting Model during implementation of the T-HRL program.

Flood control release is calculated daily as any river flow that is in excess of minimum flow, and is an initial estimate of this value. Adjusted flood is a forward-looking 16-day rolling average of the daily calculation of flood control release. The value of adjusted flood is used in the Accounting Model to estimate river flow. This rolling average is used in the historical estimate the use of weather and inflow forecasts in actual reservoir operation. The flood control operations represented in this spreadsheet model are designed to estimate flood control volumes with respect to standard U.S. Army Corps of Engineers (USACE) regulations. However, the tool does not perfectly replicate real-time flood control operations on a day-to-day basis. Due to the dynamic nature of hydrologic conditions during flood events and real-time operational decision-making, the tool's outputs should not be interpreted as a precedent or a prescriptive guide for real-time flood control operations. If USACE guidance changes during implementation, those changes will be included in updates to the real-time accounting for the HRL.

Adjusted river is a calculated value of river flow that incorporates the value of adjusted flood instead of the initial value of flood control release. Adjusted storage is calculated using the adjusted river values.

A component of typical river operations not included in the model is buffer flow. Buffer flow is flow that is released from reservoir storage in addition to the minimum instream flow requirement when no spills or flood control releases are being made. The buffer flow ensures that the minimum required flow is met continuously while operational changes (such as changes in generation or water supply delivery rate changes) are made. Buffer flow is not included in the Accounting Model as it is can be highly variable depending on the outlet structure used to make river releases. The release of buffer flows will continue with the implementation of the T-HRL. The Accounting Model relies on comparison of required flows between the 1995 and T-HRL simulations to identify flow assets of the T-HRL program. The buffer flow is not included in this spreadsheet model and will not be included in flow accounting used to identify Tuolumne HRL flow assets.

C.2.2 HRL

The HRL tab contains a simulation of the total resulting flow in the Tuolumne River at La Grange with the T-HRL program in place. The HRL tab is organized similarly to the 1995 tab and contains the same model calculations. To avoid repetition, only the columns of the HRL tab that differ from the 1995 tab are described here:

The water year types used in the T-HRL program are based on the value of the San Joaquin Index (SJI), also known as the 60:20:20 index. The five SJI water year types developed for D1641 are used for the T-HRL. In the T-HRL simulation, the water year type is updated on February 16, March 16 and April 16 and based on the 90% exceedance value of the monthly SJI forecast; on May 16, the T-HRL water year type is updated based on the 75% exceedance value of the May SJI forecast.

Minimum flow represents the daily value of the instream flow requirement at La Grange on the Tuolumne River in the Tuolumne Healthy Rivers and Landscapes program. These are determined for each timestep based on the date and the water year type; daily minimum flow values are included on tab "HRL flow req." Default timing of pulse flows in the T-HRL program are used in the historical version of the Accounting Model; pulse flow timing and shaping may be modified during implementation of the T-HRL and the actual pulse flow releases will be reflected in the Accounting Model.

Cell U2 of the HRL tab is set up as a switch within the Accounting Model that is used to select either the current FERC license (1995 Settlement Agreement) or the expected future FERC license for the Don Pedro Project. Setting the value of this cell to 1 selects the current license. Setting the value to 2 selects the future license. These settings do not make any changes to required flows at La Grange in the T-HRL simulation from January through June, because the T-HRL required flows are the same as the required flows in the expected future FERC license. The selection of FERC license does change required flow at La Grange in the period from July through December. The current FERC license is expected to be in effect when implementation of the T-HRL begins.

The expected future FERC license for the Don Pedro Project includes a provision to use infiltration galleries (IGs) on the lower Tuolumne River to recapture some of the releases made at La Grange. When implemented, this operation will allow for higher flows in the portion of the Tuolumne River between La Grange and the IGs at certain times of year without creating additional water supply impact at Don Pedro. The IGs and associated instream flow requirements are not included in the current version of the Accounting Model; the Accounting Model will be updated to include the IGs and associated flow schedule prior to start of operation of the IGs.

Additional Maximum Tuolumne Flows have been included in the simulation of the Tuolumne HRL. These volumes have been coordinated with CA Department of Water Resources (DWR) based on the hydrology and changes in Delta inflows that are estimated in the simulations included in this spreadsheet model. Similar coordination with DWR will occur during implementation of the Tuolumne HRL. The additional maximum Tuolumne flows are not included in the Tuolumne HRL flow assets and are not expected to be protected through the Delta. The specific timing of release of any Additional Maximum Tuolumne Flows will be coordinated with DWR and other parties and may also be timed to optimize ecological benefit. By definition, the Tuolumne HRL flows are regulatory flows, not a transfer, and therefore there are no compensable redirected impacts. Nonetheless, the Tuolumne River Parties have offered Additional Maximum Tuolumne Flows that may be deployed upon the occurrence of certain conditions that Tuolumne River Parties agree upon with DWR and other parties.

C.2.3 1995 and HRL comparison

The 1995 and HRL comparison tab uses simulated river flows that are calculated in the 1995 and HRL tabs as inputs for accounting to identify the flow assets of the T-HRL program. This tab also identifies T-HRL flow assets that are expected to be protected as new Delta outflow and includes estimates of the effects of the T-HRL program on Delta outflow and water exports from the Delta. The columns in the 1995 and HRL comparison tab are described here:

The Delta protection flag is used to indicate the time period for which T-HRL flow assets will be protected if they occur. The date range for protection is entered in cells C3:D4. In column D, a 1 indicates that protection through the Delta will be applied for any T-HRL flow assets, and a 0 indicates that protection will not be applied.

Difference in required flow is the required instream flow at La Grange in the T-HRL simulation minus the required flow at La Grange in the 1995 simulation. Difference in total flow at La Grange is the adjusted river flow in the T-HRL simulation minus the adjusted river flow in the 1995 simulation.

Estimated total flow at Vernalis in 1995 scenario, applying 10% loss factor is the adjusted river flow at La Grange from the 1995 simulation with a 10% loss factor applied. This represents the flow from the Tuolumne River simulations that reaches Vernalis. Estimated difference in total flow at Vernalis, applying 10% loss factor is the difference in adjusted river flow (T-HRL minus 1995) with a 10% loss factor applied. This represents the difference in flow from the Tuolumne River that reaches Vernalis when the T-HRL simulation is compared to the 1995 simulation.

HRL water to be protected, including period indicated by Delta protection flag is an accounting of water from the T-HRL flow assets that is expected to be protected as Delta outflow. The T-HRL flow assets are the increment of increased flows at Vernalis that occur when the adjusted river flow in the HRL simulation is greater than the adjusted river flow in the 1995 simulation, with the following additional requirements:

- the Delta protection flag must be equal to 1 (determined by dates in cells C3:D4);
- the difference (HRL minus 1995) must be positive;
- there can be no spill or flood control release in the HRL simulation (meaning only the required minimum flow of the T-HRL is being released at La Grange);
- the date must be within the period of January through June.

Difference in total flow at Vernalis minus HRL water to be protected is estimated T-HRL flow at Vernalis minus estimated 1995 flow at Vernalis minus the T-HRL water to be protected. Note that these flows do not represent all flow estimated to occur at Vernalis; instead, they represent the portion of flow at Vernalis that originates in the Tuolumne River.

DWR estimate of balanced, restricted, excess are indications of Delta status that are used by the state and federal water export projects. Balanced and excess refer to Delta status relative to the objectives in D1641, and restricted refers to Delta status relative to the requirements in the federal Biological Opinions. These values were provided by DWR for the historical period from 1999 – 2023. They will be updated in coordination with DWR during implementation of the T-HRL.

HRL resulting flow minus protected HRL water minus 1995 resulting flow during balanced or restricted conditions shows the full value during balanced conditions and the value divided by 2 during restricted conditions. During excess conditions, the value is set to zero.

Cell O4 of the 1995 and HRL comparison tab is used to input the assumed loss factor for surface water flows between La Grange and Vernalis. Per DWR, the current best estimate of this value is 10%.

The Jan-Jun flag indicates whether each daily timestep is within the period from January through June (indicated by a value of 1) or outside that period (indicated by a value of 0).

The following calculations to estimate potential effects on Project exports and Delta outflow were provided by DWR.

This calculation for potential decrease in project exports compares two simulated values of total flow from the Tuolumne River as they reach Vernalis: HRL implementation minus the protected portion of T-HRL flow, and the 1995 FERC Settlement Agreement. This calculation assumes that, during balanced conditions, if the total flows for the T-HRL case minus the protected portion are less than total flows for the 1995 case, then total exports from the Delta by the Projects will be reduced by the same amount, and that if this occurs during restricted conditions, Delta exports will be reduced by half the amount of the difference.

The calculation for potential increase in Project exports is also based on a comparison of two simulated values of total flow from the Tuolumne River as they reach Vernalis: HRL implementation minus the protected portion of T-HRL flow, and the 1995 FERC Settlement Agreement (the same flows that are used in the calculation of potential decrease in exports). The calculation of increase in exports assumes that, during balanced conditions, if the total flows for the T-HRL case minus the protected portion are greater than total flows for the 1995 case, then total exports from the Delta by the Projects will be increased by the same amount, and that if this occurs during restricted conditions, Delta exports will be increased by half the amount of the difference.

Total additional Delta outflow is calculated based on several factors: If the total flow at Vernalis that originates from the Tuolumne River is greater in the T-HRL simulation than in the 1995 simulation, then additional Delta outflow is equal to the difference minus the concurrent increase in Delta exports. If the total flow at Vernalis originating from the Tuolumne River is less in the T-HRL case than the 1995 case, then the Vernalis reduction is equivalent to an outflow reduction in excess conditions; there is no change in Delta outflow in balanced conditions; and in restricted conditions the change in Delta outflow is estimated to be half the change at Vernalis.

Total additional outflow Jan-Jun is the calculated values for total additional Delta outflow multiplied by the Jan-Jun flag.

C.3 Input Tabs

C.3.1 Storage_req

The storage_req tab contains a table of values that represent the maximum storage capacity of the water supply reservoirs on the Tuolumne River. The values in this table are described here:

Don Pedro Flood Control Curve is the formal flood control requirement determined by Army Corps of Engineers (ACOE) for Don Pedro. These values include default storage limit for each day of the year. The default value may be modified by ACOE to account for snowpack in the watershed, or other factors that can lead to modified values.

Don Pedro Unofficial Operational Drawdown includes additional drawdown values that reflect the seasonal preference of Don Pedro operators for optimal reservoir performance. These are shown as negative values.

CCSF combined storage is the maximum combined storage capacity of Hetch Hetchy Reservoir, Cherry Lake and Lake Eleanor.

CCSF Unofficial Operational Drawdown includes drawdown values that reflect the seasonal preference of CCSF reservoir operators for optimal reservoir performance. These are shown as negative values.

Combined Reservoir Operations Curve is the sum of Don Pedro Flood Control Curve, Don Pedro Unofficial Operational Drawdown, CCSF Combined Storage and CCSF Unofficial Operational Drawdown. This is an approximation of the maximum storage target for the combined Tuolumne River reservoirs. This value is used to indicate when flood control releases from storage would be needed in the historical simulation.

C.3.2 1995 flow req

The 1995 flow req tab includes a table of instream flow requirements for each day of the year for the 10 water year types that are used in the 1995 FERC Settlement Agreement.

Default timing and shapes are included in this schedule for the spring outmigration pulse and the fall pulse. During implementation, the timing and shape of these pulses is determined each year to optimize ecosystem benefit. During implementation of the T-HRL, the timing and shape will be estimated for these pulse flows in the Accounting Model.

C.3.3 HRL flow req

The HRL flow req tab includes a table of instream flow requirements for each day of the year for the 5 water year types that are used in the T-HRL. Three additional sets of daily flow requirements are included for the three water year types that include an “off-ramp” schedule: Critical, Dry and Below Normal water year types.

Default timing and shapes are included in this schedule for the March floodplain pulse, the spring outmigration pulse and the fall pulse. During implementation, the timing and shape of these pulses will be determined each year to optimize ecosystem benefit. During implementation of the T-HRL, the timing and shape of these pulsed will be reflected in the Accounting Model.

C.3.4 Evap_calc

The Evap_calc tab includes a lookup table of storage and area. This is used by the model to estimate surface area for values of combined reservoir storage that are calculated by the model.

This tab also includes a lookup table of monthly evap factors, in units of cfs per acre per day. These factors are applied to the calculated reservoir surface area values to estimate evaporation from the reservoir surfaces.

C.4 Plots

C.4.1 Model plots

Two plots are included to visualize the accounting model output:

- A plot of total storage shows the estimated value of Tuolumne River storage in the 1995 simulation and the HRL simulation. The default flood control limit on storage is also shown on this plot.
- A plot of flow at La Grange shows required flow at La Grange in the 1995 simulation and the HRL simulation, and also shows estimated total flow in the two simulations.

Appendix D

Habitat Modeling Methods

Contents

Appendix D Habitat Modeling Methods D-1
D.1 Doubling Goal Habitat Estimate and Input Parameter Uncertainty Analysis D-1
D.1.1 Parameter distributions D-1
D.1.2 Doubling Goal Habitat Need Distributions D-6

Appendix D
Habitat Modeling Methods

D.1 Doubling Goal Habitat Estimate and Input Parameter Uncertainty Analysis

To estimate uncertainty around the habitat acreage estimates, distributions were generated for several parameters that factor into calculating the amount of habitat required to support doubling of the spawning population (see Section 7.3, *Habitat Modeling*). This appendix provides more information on these distributions and the estimates of uncertainty for spawning and rearing habitat by the resampling analyses using the habitat model and parameter distributions (1,000,000 draws).

D.1.1 Parameter distributions

The following figures show distributions of parameter values for juvenile fork length, juvenile territory requirement, proportion female, fecundity, egg-to-fry survival, and redd size compared to the static value for that parameter. Input parameter ranges and distributions were parameterized based on data from the literature and Tuolumne River monitoring data (see Chapter 7, *Spawning and Rearing Habitat*, for references). The input parameter data were randomly sampled (n = 1,000,000 draws) to generate the distributions for each parameter (Figure D-1 through Figure D-5). Additional details on the parameterization of each distribution can be found in Section 7.3.1.1, *Analytical Approach to Evaluating Non-Flow Assets*.

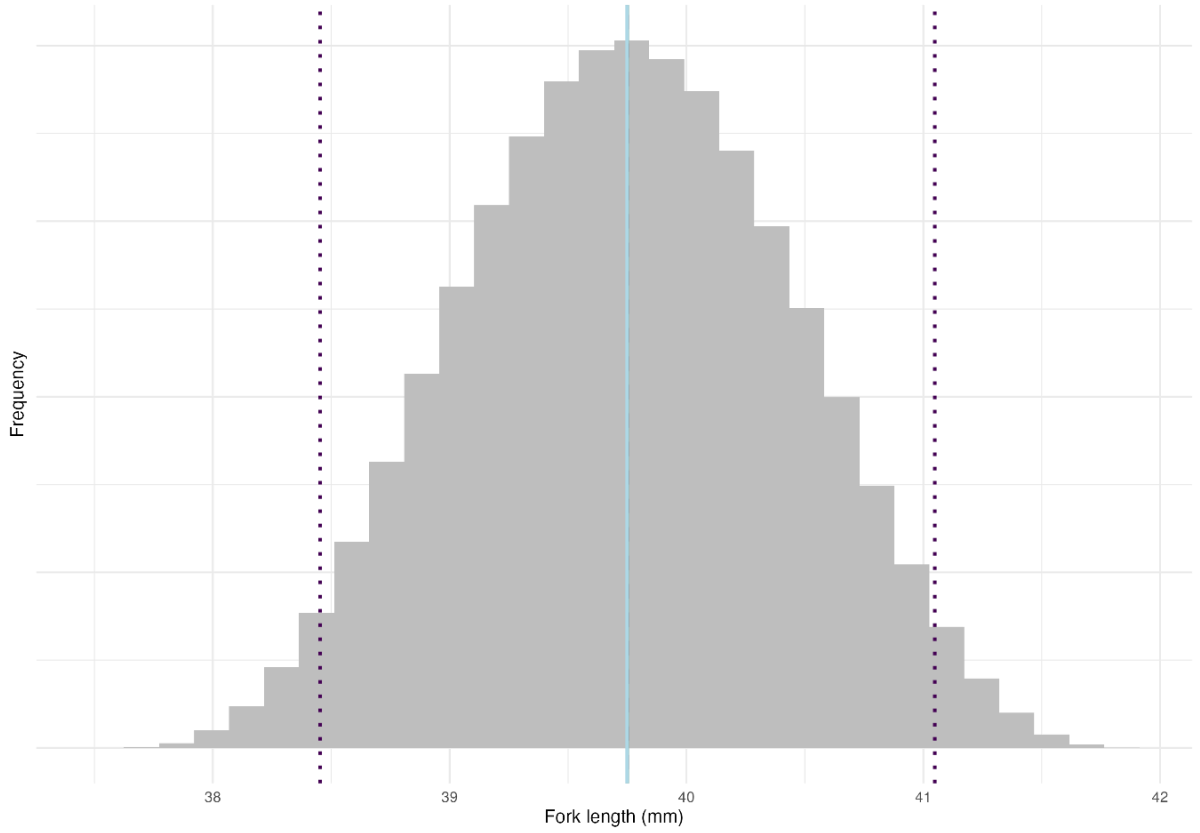


Figure D-1. Histogram of 1,000,000 Random Draws from a Distribution Parameterizing Juvenile Fork Length in Millimeters. The Mean, Median, and Static Value Are Equal (39.75mm) and Are Shown by the Light Blue Line. The 2.5% and 97.5% Confidence Intervals Are Shown as Dotted Purple Lines.

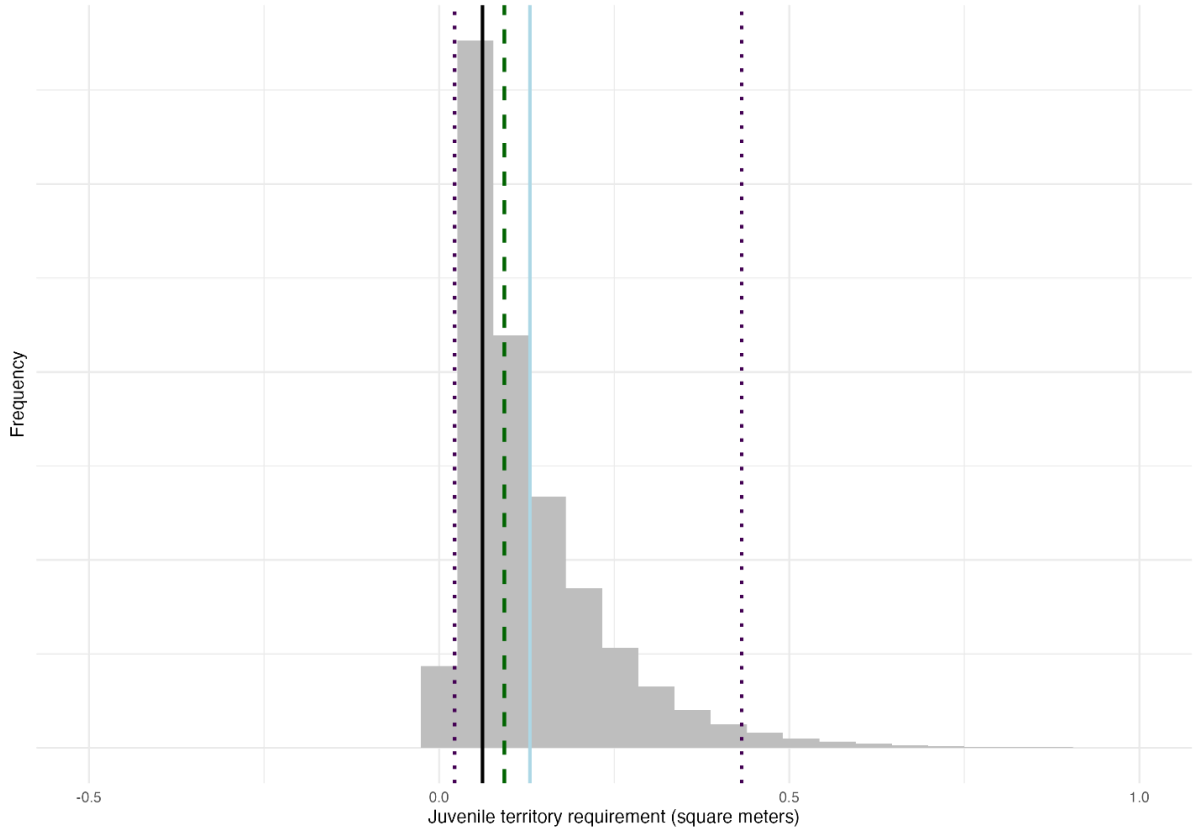


Figure D-2. Histogram of 1,000,000 Random Draws from a Distribution Parameterizing Juvenile Territory Requirement in Square Meters. The Mean Is Shown in Light Blue, the Median in Dashed Green, and the Static Value (0.062 m^2) Is Shown as a Solid Black Line. The 2.5% and 97.5% Confidence Intervals Are Shown as Dotted Purple Lines.

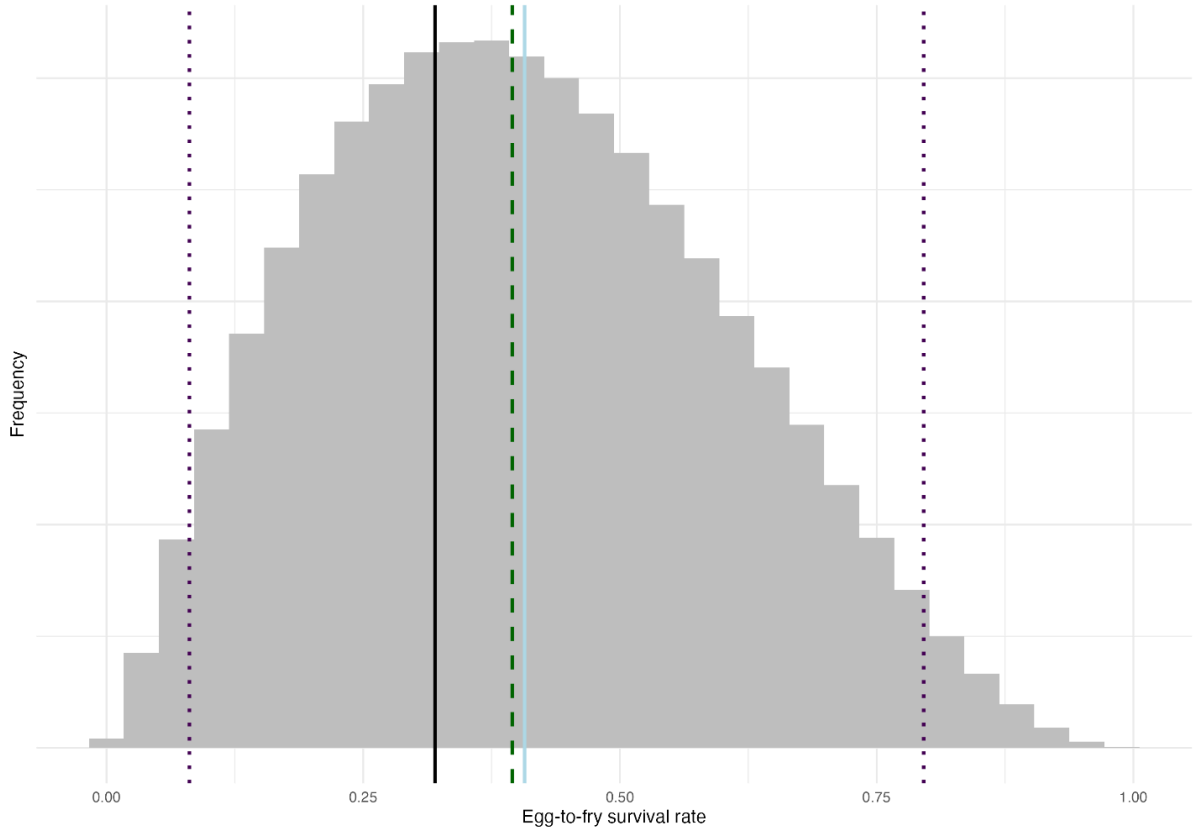


Figure D-3. Histogram of 1,000,000 Random Draws from a Distribution Parameterizing Egg-to-Fry Survival Rate. The Mean Is Shown in Light Blue, the Median in Dashed Green, and the Static Value (0.32) Is Shown as a Solid Black Line. The 2.5% and 97.5% Confidence Intervals Are Shown as Dotted Purple Lines.

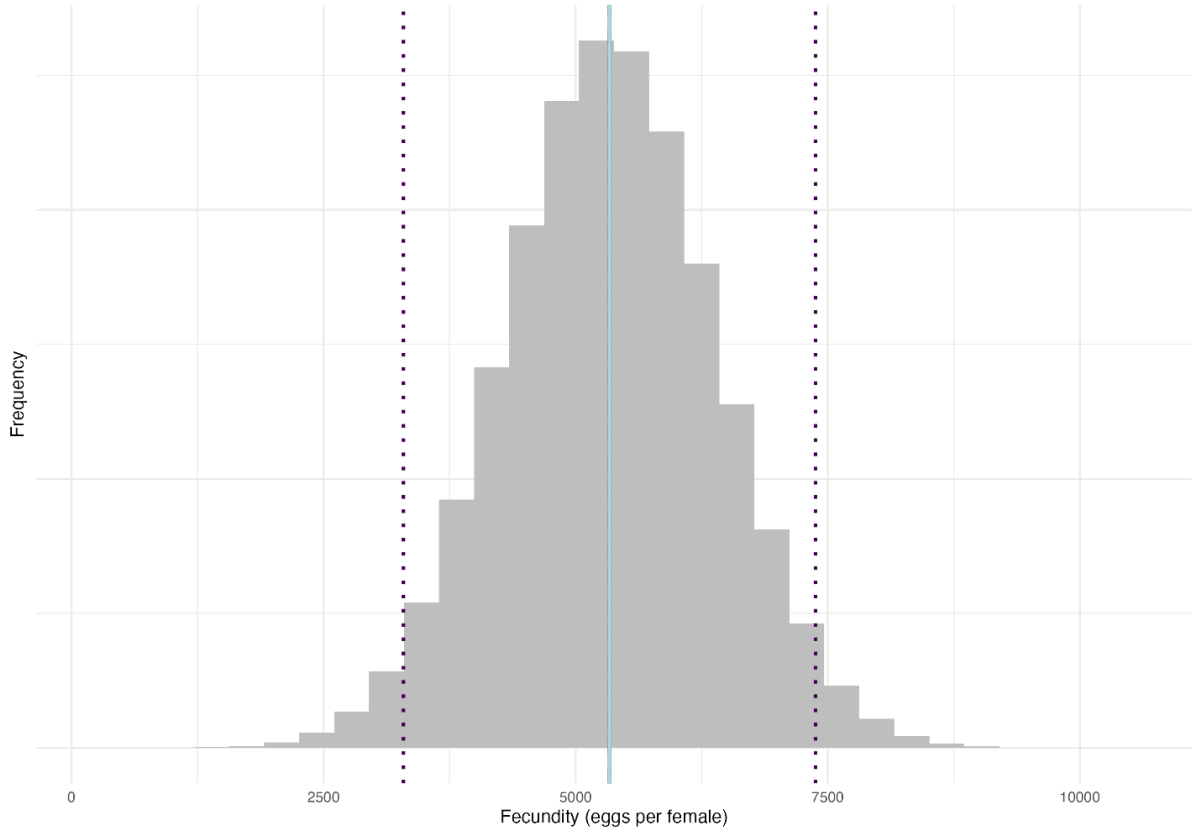


Figure D-4. Histogram of 1,000,000 Random Draws from a Distribution Parameterizing Fecundity Represented as Eggs per Female. The Mean, Median, and Static Value (5335 Eggs per Female) Are Equal and Represented on the Plot by a Light Blue Line. The 2.5% and 97.5% Confidence Intervals Are Shown as Dotted Purple Lines.

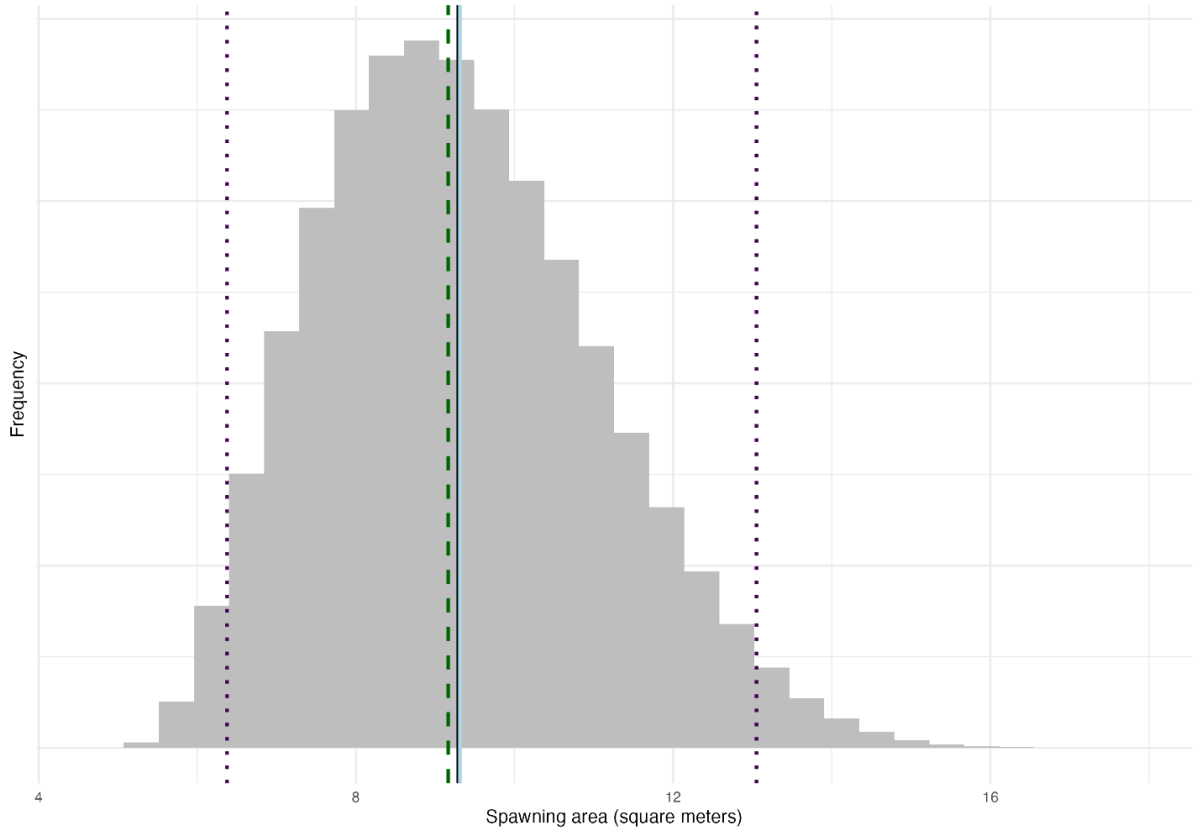


Figure D-5. Histogram of 1,000,000 Random Draws from a Distribution Parameterizing Redd Size in Square Meters. The Mean Is Shown in Light Blue, the Median in Dashed Green, and the Static Value (9.29 m^2) Is Shown as a Solid Black Line. The 2.5% and 97.5% Confidence Intervals Are Shown as Dotted Purple Lines.

D.1.2 Doubling Goal Habitat Need Distributions

The following figures show distributions of spawning and rearing habitat need estimates, calculated from 1,000,000 random draws of parameters: juvenile territory requirement, juvenile fork length, egg-to-fry survival rate, eggs-per-female, and redd size. Sex ratio is the only parameter where no uncertainty was incorporated.

The differences in spawning habitat need (i.e., one calculated using static parameter values versus one calculated using random draws of parameter values) are minimal because only two parameters are used in these calculations: sex ratio and redd size (Figure D-6). As well, only the one static value was used for the sex ratio parameter, which reduced the potential for variability in the habitat estimate. Summary statistics for spawning habitat need estimates are displayed in Table D-1.

The variability in the rearing habitat need estimate is greater using resampling approach compared to the static estimate (i.e., estimates not incorporating variability for input parameters), and the static estimate is considerably lower than the estimate using resampling (Figure D-7). These differences are primarily due to the territory size and egg-to-fry survival parameters (see Figure D-2 and Figure D-3). The static parameters for these two parameters are on the low-end of the simulated distribution developed using the resampling approach. The resampling approach utilizes a range of fork lengths to determine the territory size and also draws on multiple models of the territory size-fork length relationship resulting in a distribution that is more representative than the static approach that relied on a single fork length. Similarly, the resampling approach develops a distribution of egg-to-fry survival using data collected in the Lower Tuolumne River rather than relying on a single survival value. Summary statistics for rearing habitat need estimates are displayed in Table D-2.

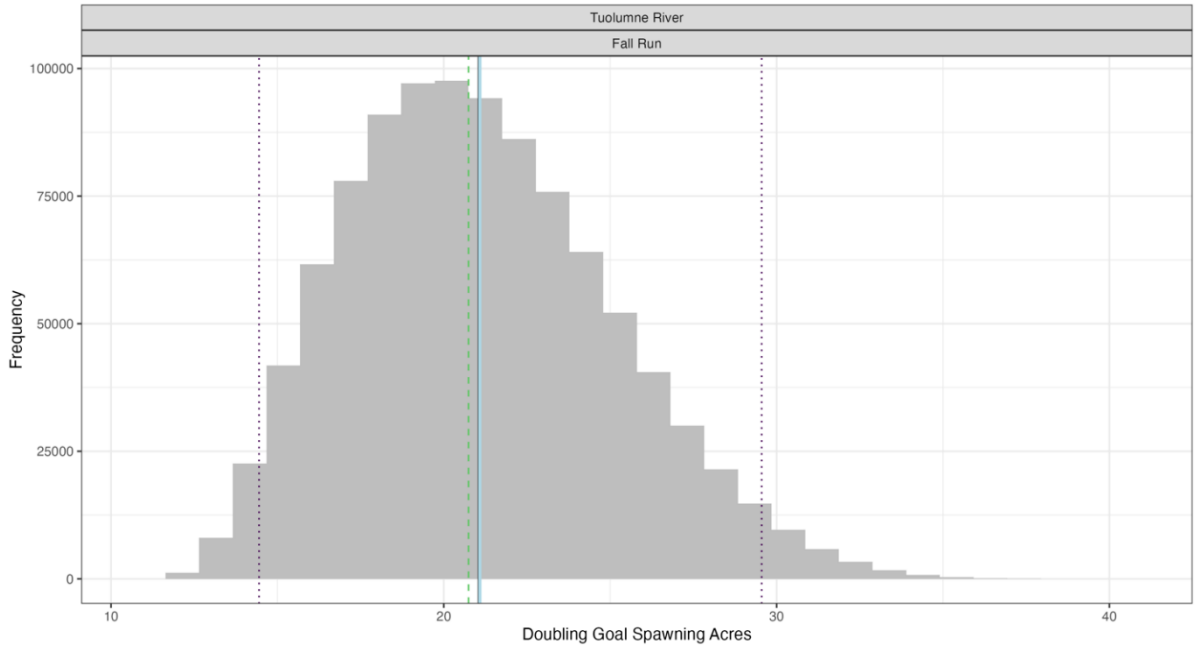


Figure D-6. Simulated Spawning Habitat Distributions in Acres Based on the Target Escapement from the Anadromous Fish Restoration Program (AFRP) Doubling Goal and Parameter Distributions. The Solid Black Line Represents the Habitat Need Estimated Using Static Parameters. The Dashed Green Line and Light Blue Line Are the Median and Mean Habitat Need Estimated Using the Resampling Approach, Respectively, and the Dotted Purple Lines Are the 97.5% Intervals of the Simulated Distribution. The Mean Estimate (Light Blue Line) Slightly Overlaps the Static Value (Black Line).

Table D-1. Spawning Doubling Goal Acreages Calculated for the Tuolumne River. The Doubling Goal Calculated Using Static Parameter Values Is Shown Alongside the Mean, Median, and 95% Confidence Intervals from the Doubling Goal Acreage Estimated Using Resampling.

Watershed	Species	Static Acreage	Mean Estimated Acreage	Median Estimated Acreage	Lower 95th Percentile	Upper 95th Percentile
Tuolumne River	Fall-run	21.04	21.08	20.74	14.45	29.55

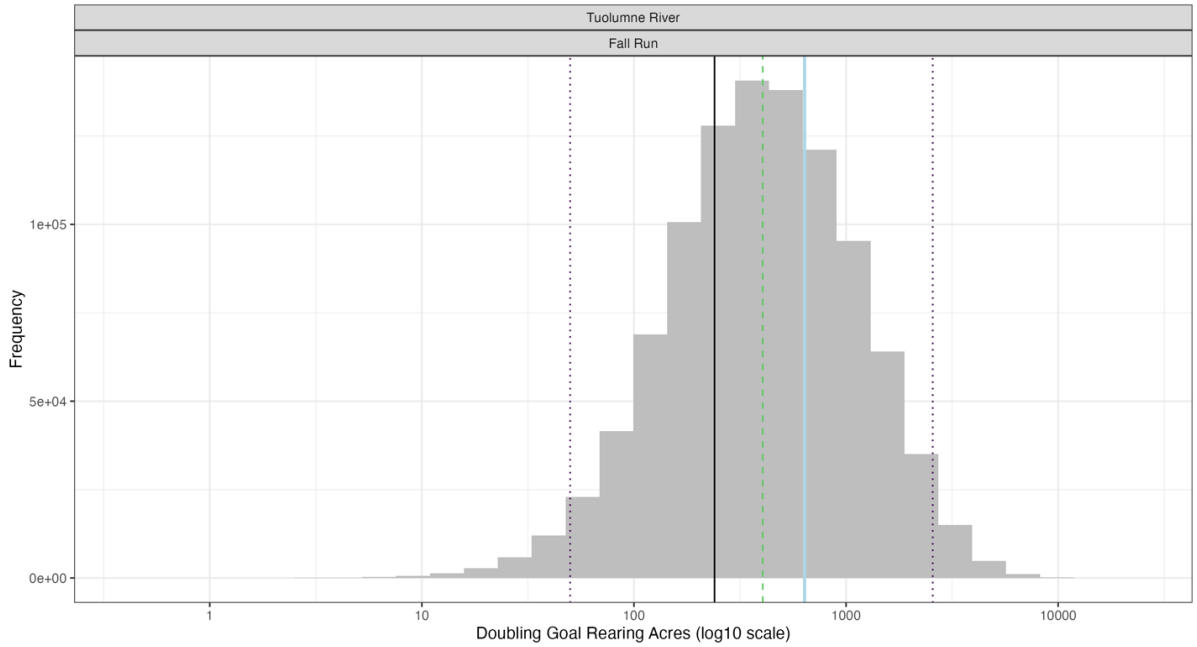


Figure D-7. Simulated Rearing Habitat Distributions in Acres (log10 scale) Based on the Target Escapement from the AFRP Doubling Goal and Parameter Distributions. The Solid Black Line Represents the Habitat Need Estimated Using Static Parameters. The Dashed Green Line and Light Blue Line Are the Median and Mean Habitat Need Estimated Using the Resampling Approach, Respectively, and the Dotted Lines Are the 97.5% Intervals of the Simulated Distribution.

Table D-2. Rearing Doubling Goal Acreages Calculated for the Tuolumne River. The Doubling Goal Calculated Using Static Parameter Values Is Shown Alongside the Mean, Median, and 95% Confidence Intervals from the Doubling Goal Acreage Estimated Using Resampling.

Watershed	Species	Static Acreage	Mean Estimated Acreage	Median Estimated Acreage	Lower 95th Percentile	Upper 95th Percentile
Tuolumne River	Fall-run	239.76	637.52	404.62	50.02	2562.65