Appendix G2

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

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

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ICF

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Acronyms and Abbreviations

Acronym or Abbreviation	Definition
2017 Scientific Basis Report	*Scientific Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflows, Cold Water Habitat, and Interior Delta Flows*
AFRP	Anadromous Fish Restoration Program
Bay-Delta	San Francisco Bay/Sacramento-San Joaquin River Delta Estuary
Bay-Delta Plan	Water Quality Control Plan for the Bay-Delta
BiOp	Biological Opinion
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife
cfs	cubic feet per second
CPU	central processing unit
CVP	Central Valley Project
CVFED	Central Valley Floodplain Evaluation and Delineation
CVPIA	Central Valley Project Improvement Act
cyanoHAB	cyanobacterial bloom
D-1641	Water Right Decision 1641
Delta	Sacramento-San Joaquin River Delta
DG	doubling goal
Draft Supplement Report	*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*
DSC	Delta Stewardship Council
DSM2	DWR's Delta Simulation Model 2
DWR	California Department of Water Resources
EBMUD	East Bay Municipal Utility District
EC	electrical conductivity
FLOAT-MAST	Flow Alteration - Management Analysis and Synthesis Team
GAM	generalized additive model
HAB	harmful algal bloom
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HSC	habitat suitability criteria
ISB	Independent Science Board
JSA	Joint Settlement Agreement
LiDAR	light detection and ranging
m^2	square meters
MFE	Meaningful Floodplain Event
MOU	Memorandum of Understanding
NMFS	National Marine Fisheries Service
OEHHA	Office of Environmental Health Hazard Assessment

Acronym or Abbreviation	Definition
PHABSIM	Physical Habitat Simulation
ppt	parts per thousand
PWA	public water agency
Reclamation	U.S. Bureau of Reclamation
RMA	Resource Management Associates
Sacramento/Delta Update to the Bay-Delta Plan	process to update the Sacramento River and Delta tributary inflow and cold-water habitat, Delta outflow, and interior Delta flow components of the Bay-Delta Plan
SacWAM	Sacramento Water Allocation Model
SFEI	San Francisco Estuary Institute
State Water Board	State Water Resources Control Board
SWP	State Water Project
TAF	thousand acre-feet
TBUs	Tribal Beneficial Uses
TDC	thiamine deficiency complex
TEK	Traditional Ecological Knowledge
Tidal Wetlands PWT	IEP Tidal Wetland Monitoring Project Work Team
USEPA	U.S. Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
VA	Voluntary Agreement
VA Term Sheet	*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*
YWA	Yuba Water Agency

Executive Summary

The State Water Resources Control Board (State Water 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). In 2022, the State Water Board received a Memorandum of Understanding (MOU; hereafter referred to as the VA Term Sheet) signed by state and federal agencies and water users proposing Voluntary Agreements (VAs) for updating and implementing the Bay-Delta Plan. The State Water Board is in the process of evaluating and considering the VAs, including preparing necessary environmental documentation and other technical analyses. This *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* (Draft Supplement Report) is part of that process and has been prepared to document the science supporting the proposed provisions included in the VAs.

This Draft Supplement Report was developed by State Water Board staff in collaboration with staff from the California Department of Fish and Wildlife (CDFW) (lead for aquatic ecosystem stressors analysis and description of VA assets on the Sacramento River and tributaries) and the California Department of Water Resources (DWR) (lead for aquatic ecosystem stressors in the San Francisco Bay/Sacramento-San Joaquin River Delta Estuary (Bay-Delta), and support for hydrology and modeling, analytical approach, and anticipated VA outcomes). This Draft Supplement Report was made available for public comment from January 5 to February 8, 2023, including a Board Workshop on January 19, 2023. Following receipt of public comments, the draft was revised as appropriate (see Chapter 1, *Introduction*, for an overview of how comments were addressed) and this final Draft Supplement Report will be submitted for 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 adoption.

The State Water Board initiated a process to update the Sacramento River and Sacramento-San Joaquin River Delta (Delta) tributary inflow and cold water habitat, Delta outflow, and interior Delta flow components of the Bay-Delta Plan (referred to as the Sacramento/Delta Update to the Bay-Delta Plan) in 2012. In 2017, the State Water Board finalized the *Scientific Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflows, Cold Water Habitat, and Interior Delta Flows* (2017 Scientific Basis Report), documenting the science supporting a possible Sacramento/Delta Update to the Bay-Delta Plan. The lower San Joaquin River flow and southern Delta salinity components of Bay-Delta Plan were updated separately in 2018. The VAs are proposed as an alternative pathway to update and implement the Bay-Delta Plan.

This Draft Supplement Report serves as an addendum to the 2017 Scientific Basis Report that documents the science supporting the anticipated benefits of the proposed VAs in support of their consideration as part of the Sacramento/Delta Update to the Bay-Delta Plan (see Chapter 1, *Introduction*, for details on the report background). This report builds on the 2017 Scientific Basis Report, particularly with additional scientific information supporting specific flow and non-flow habitat restoration actions in the tributaries, flood bypasses, and Delta outlined in the VAs.

This report evaluates Delta outflows with and without potential VA flow contributions from the Tuolumne River and Friant VA Parties. The Tuolumne River portion of the VAs are under consideration separately due to their nature and extent. Accordingly, a separate scientific basis report and Staff Report are under development to evaluate the effects of a potential Tuolumne River VA on the Tuolumne River and lower San Joaquin River. With respect to the Friant portions of the VA that involve reducing the recapture of San Joaquin River Restoration Program flows in the Delta, these effects are fully considered in this report and Staff Report; however, the Friant VA Parties have indicated that they may not participate in the VAs. Accordingly, the scenario without Tuolumne River and Friant evaluated in this report addresses the potential low-end range of Delta outflows that may occur under the VAs if the Tuolumne River and Friant portions of the VAs are not approved or advanced.

In addition to documenting possible benefits of the VAs for native fish species, this Draft Supplement Report provides information on Traditional Ecological Knowledge (TEK) from California Native American tribes within the Bay-Delta watershed to inform reasonable protection of beneficial uses, including the possible addition of Tribal Beneficial Uses (TBUs) of Tribal Traditional Culture, Tribal Subsistence Fishing, and Subsistence Fishing (State Water Board 2020), in the event that these beneficial uses are incorporated into the Bay-Delta Plan. TEK could also inform adaptive management of the VAs if they are approved, through engagement by the State Water Board and VA Parties with California Native American tribes.

As described further in this report and the 2017 Scientific Basis Report, native aquatic species have been declining in the Sacramento River, its tributaries, and the Bay-Delta due to anthropogenic stressors, including degradation of habitat and changes in flows. These aquatic ecosystem stressors have also affected the physical well-being and spiritual and cultural uses of water by California Native American tribes (see Chapter 2, *Aquatic Ecosystem Stressors*, for details on stressors affecting native species that are culturally significant to tribes). The VAs propose a combination of assets (Table ES-1) to address these stressors over 8 years (with the possibility of extension), including varying amounts of increased flows, depending on water year type, and non-flow habitat restoration actions targeted at improving spawning and rearing capacity for juvenile salmonids and other native fishes (see Chapter 3, *Description of Flow and Non-Flow Assets*, for details on VA assets).

Table ES-1. Proposed VA Assets as Modeled

	Flows (thousand acre-feet) by Water Year Type					Restoration (acres)		
Location	C	D	BN	AN	W	Spawning	Instream Rearing	Floodplain
Sacramento		100	100	100		113.5	137.5	20,000
American[3]	30	40	10	10		25	75	
Yuba		50	50	50			50	100
Feather		60	60	60		15	5.25	1,655
Putah[4]	7	6	6	6		1.4		
Mokelumne[5] (by Mokelumne Water Year Type)		5	5	7			1	25
Delta		125[1]	125[1]	175[1]				5,227.5[2]
PWA Fixed Price Purchases	3	63.5	84.5	99.5	27			
PWA Market Price Purchases		50	60	83				
Permanent State Water purchases	65	108	9	52	123			
Friant (by San Joaquin Water Year Type)[6]		0-50	0-50	0-50				
Tuolumne (by San Joaquin Water Year Type)	37	62	78	27				

Flow assets are proposed to be additive to the Delta outflows resulting from State Water Board Revised Water Right Decision 1641 (D-1641) and implementation of the 2019 Biological Opinions for operations of the State Water Project and Central Valley Project. Blank cells indicate no proposed assets in that category. Water year types are based on Sacramento Valley Index unless otherwise noted. C = Critical, D = Dry, BN = Below Normal, AN = Above Normal, W = Wet, PWA = public water agency

1 Forgone exports.
2 Includes tidal wetland habitat.
3 These flows proposed to be deployed in 3 out of 8 years of the VA in AN, BN, D, or C years.
4 Flow contributions anticipated to result from modified operations and would not be protected as Delta outflow, as discussions for these VAs are still underway.
5 Flow contributions anticipated to result from modified operations and not be protected as Delta outflow, as discussions for these VAs are still underway. Mokelumne VA reflects updated volumes from the Mokelumne VA Term Sheet addendum (August 2022); Mokelumne VA based on Joint Settlement Agreement water year types.
6 Flow contributions originally proposed to result from forgone recapture of up to 50 thousand acre-feet of San Joaquin River Restoration Program flows and provided based on San Joaquin water year type. VA participation by Friant Parties is uncertain at the time of this writing.

The VA habitat and flow actions are proposed as implementation measures for an existing and a new water quality objective in the Bay-Delta Plan. Specifically, the VAs propose: (1) a new narrative objective to achieve the viability of native fish populations (Narrative Viability Objective; Box ES-1); and (2) to provide the participating parties' share, during implementation of the VAs, to contribute to achieving the existing Narrative Salmon Protection Objective (Box ES-1), and propose doing so by 2050.

Box ES-1. Objectives for the VAs Proposed in the VA Term Sheet (Voluntary Agreements Parties 2022)

The proposed new Narrative Viability Objective states:

> Maintain water quality conditions, including flow conditions in and from tributaries and into the Delta, together with other measures in the watershed, sufficient to support and maintain the natural production of viable native fish populations. Conditions and measures that reasonably contribute toward maintaining viable native fish populations include, but may not be limited to, (1) flows that support native fish species, including the relative magnitude, duration, timing, temperature, and spatial extent of flows, and (2) conditions within water bodies that enhance spawning, rearing, growth, and migration in order to contribute to improved viability. Indicators of viability include population abundance, spatial extent, distribution, structure, genetic and life history diversity, and productivity. Flows provided to meet this objective shall be managed in a manner to avoid causing significant adverse impacts to fish and wildlife beneficial uses at other times of the year.

The existing Narrative Salmon Protection Objective (also referred to as the salmon doubling goal, or the Narrative Salmon Objective in the VA Term Sheet) states:

> Water quality conditions shall be maintained, together with other measures in the watershed, sufficient to achieve a doubling of natural production of chinook salmon from the average production of 1967–1991, consistent with provisions of State and federal law.

This Draft Supplement Report includes quantitative evaluations of the projected changes in suitable habitat provided for native species from VA proposed flows and non-flow habitat restoration actions compared to the reference condition. The reference condition represents the flows resulting from implementing the State Water Board Revised Water Right Decision 1641 (D-1641) and the Central Valley Project (CVP) and State Water Project (SWP) federal Endangered Species Act Biological Opinions (BiOps) issued in 2008/2009 for long-term CVP/SWP operations, as modeled. Suitable habitat for spawning and rearing habitat was defined by velocity, depth, temperature, and cover criteria, while suitable habitat for estuarine species was defined by salinity, temperature, and turbidity criteria. Habitat acreage that does not meet all applicable criteria is not quantified in these results, but it may provide some partial benefits. Quantitative habitat analyses were not performed for Putah Creek because no existing suitable habitat data were available for comparison. This report also includes quantitative evaluations of projected changes in native species abundance indices and the frequency of meeting ecological flow thresholds with VA proposed flows compared to the reference condition. In addition, a qualitative literature review was conducted to evaluate possible benefits of the VAs where no quantitative models exist (see Chapter 4, *Hydrology and Operations Modeling Methods and Results*, for details on hydrological modeling and Chapter 5, *Analytical Approach to Evaluating Assets*, for details on the analytical approach to evaluating the benefits of the VAs). The quantitative analyses indicate expected increases in suitable spawning and rearing habitat for salmonids and increases in suitable habitat and population abundance indices for estuarine species. Chinook salmon fall-run and spring-run (only analyzed for the Sacramento River) spawning (Figure ES-1), instream rearing (Figure ES-2), and floodplain (Table ES-2) habitats are expected to contribute toward the narrative objectives described above. However, the magnitude of increase varies with water year type and tributary such that not all habitat categories will have increases in all water year types.

The VAs and reference condition are projected to surpass the spawning habitat needed to support 25 percent of the doubling goal (the target for the VAs) in all tributaries except the American River (Figure ES-1, Table ES-2). The combination of instream rearing and floodplain habitat needed to support 25 percent of the doubling goal population is projected to be met in the Mokelumne, Sacramento (for spring run), and Yuba Rivers in both the reference condition and VA scenarios, and in the Feather River in the VA scenario, but not in any scenario in the American and Sacramento (for fall run) Rivers (Figure ES-2, Table ES-3). Sacramento River rearing habitat would surpass the habitat needed to support 25 percent of the doubling goal population with the addition of 20,000 acres of floodplain enhancement on the Sutter Bypass, provided that juvenile fish passage issues can be addressed. Floodplain habitat in watersheds with VA floodplain assets is expected to be provided to support 25 percent of the doubling goal population in 51 to 72 percent of years in each of the Feather (66 percent), Mokelumne (51 percent), and Yuba (72 percent) Rivers (Table ES-3).

Habitat areas for estuarine species are also expected to increase in the Bay-Delta (Table ES-4), contributing toward the Narrative Viability Objective proposed in the VAs. However, increases would be small relative to total region size and vary by species. Abundance indices based on flows under the VAs of four native indicator species (California Bay shrimp [*Crangon franciscorum*], Sacramento splittail [*Pogonichthys macrolepidotus*], longfin smelt [*Spirinchus thaleichthys*], and starry flounder [*Platichthys stellatus*]) are expected to increase in all water year types except wet years (in which they are expected to decrease) (Figure ES-3). Possible higher bookends of Delta outflow resulting from the VAs could result in greater increases in abundance indices. The frequency of achieving ecological flow thresholds associated with benefits to species or with important X2[1] thresholds would generally increase under the VAs, although in some cases there are slight decreases (Table ES-1). Qualitatively, the synergy of flow and non-flow habitat restoration assets proposed in the VAs is expected to improve conditions for salmonids and estuarine species toward achieving the proposed new Narrative Viability Objective and existing Narrative Salmon Protection Objective (see Chapter 6, *Anticipated Biological and Environmental Outcomes*, for details on the anticipated biological and environmental outcomes).

[1] X2 is the location in the Bay-Delta where the tidally averaged bottom salinity is 2 parts per thousand. It is expressed as the distance in kilometers from the Golden Gate Bridge.

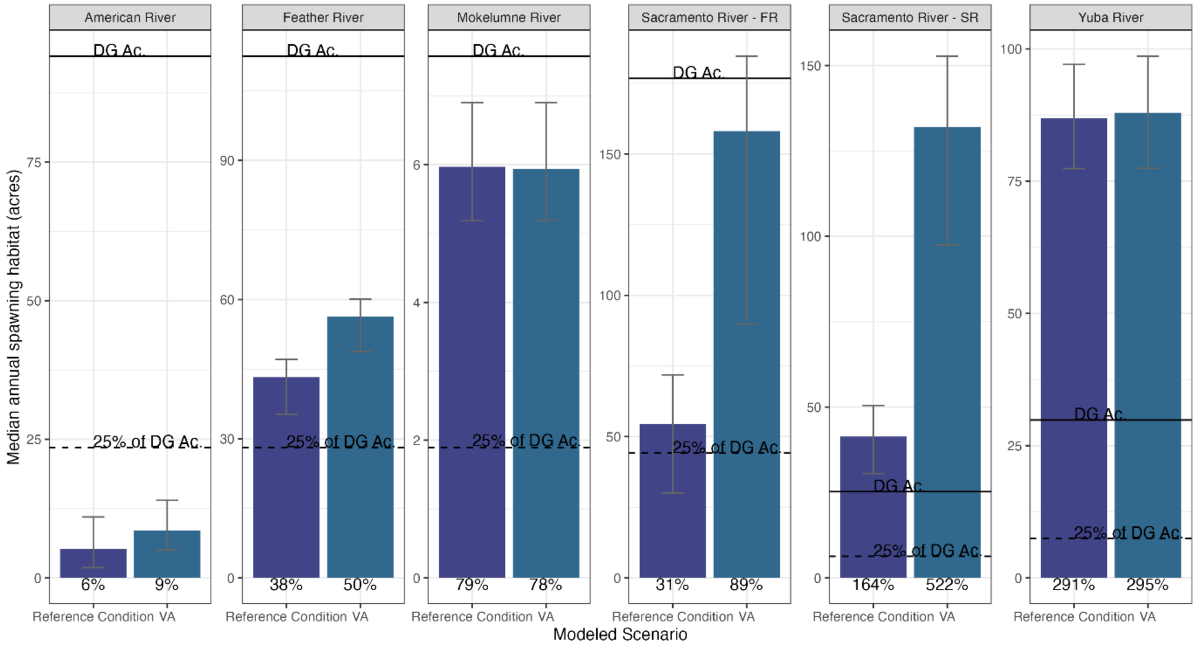

Figure ES-1. Median (across All Years) Spawning Habitat (Acres) under Reference Condition and VA Scenarios for Each Watershed
Results are presented for fall run in all tributaries and for spring run in the Sacramento River. Solid lines represent area of habitat required to support the doubling goal (DG) population, and dashed lines represent 25 percent of the doubling goal area. The amount of habitat as a percentage of the habitat needed to support the doubling goal is printed below each bar. Error bars represent the upper and lower quartiles. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes.

Table ES-2. Spawning Habitat Results Compared to the VA Term Sheet Commitments and the Habitat Required to Support 25 Percent of the Doubling Goal

Watershed	Acres Proposed in VA Term Sheet	Modeled Results (Habitat Suitable by Depth, Velocity, and Temperature Criteria)			
		Acres to support 25% of Doubling Goal	Median Acres Reference Condition	Acres Added by VA	Median Total Acres with VA
American River	25	23.5	5.22	3.35	8.57
Feather	15	28	43.26	13.13	56.39
Mokelumne	0	2	5.97	-0.04	5.93
Sacramento River - FR	113.5	44.25	54.4	103.7	158.1
Sacramento River - SR		6.25	41.4	90.53	131.93
Yuba	0	7.5	86.85	1.06	87.91

FR= fall run, SR = spring run

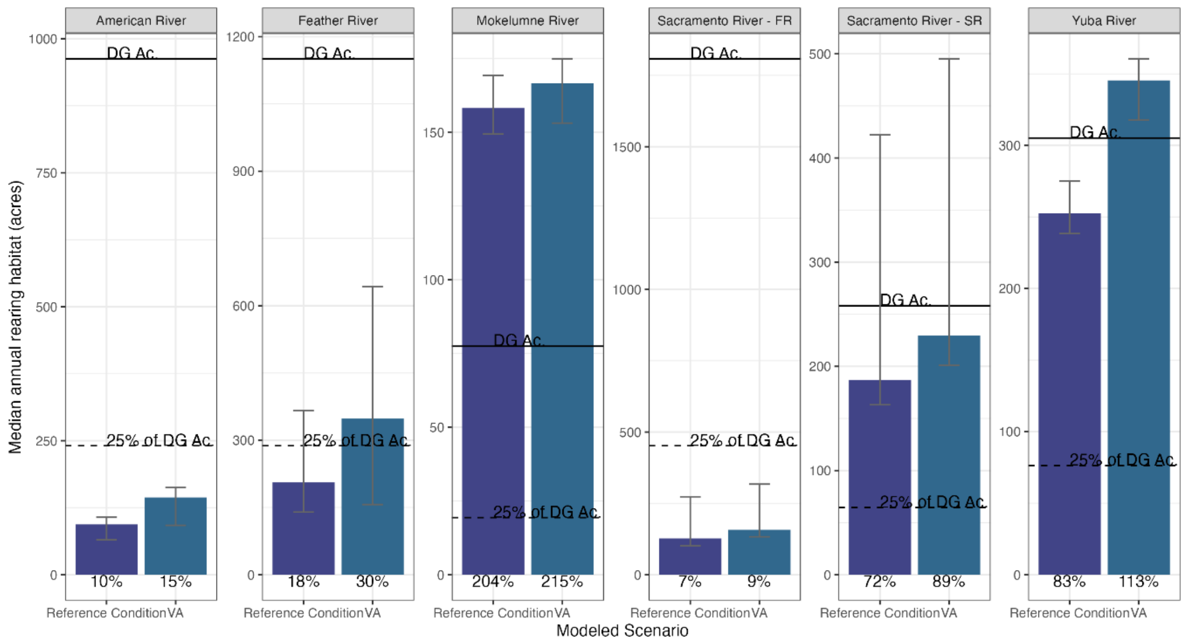

Figure ES-2. Median (across All Years) Rearing Habitat (Acres) under Reference Condition and VA Scenarios for Each Watershed, including Both Floodplain and In-Channel Rearing Habitat
Results are presented for fall run in all tributaries and for spring run in the Sacramento River. The amount of habitat as a percentage of the habitat needed to support the doubling goal (DG) is printed below each bar. Solid lines represent area of habitat required to support the doubling goal population, and dashed lines represent 25 percent of the doubling goal area. Error bars represent the upper and lower quartiles. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes. Note that the Sacramento and Feather River results do not include the 20,000 acres of floodplain enhancement on the Sutter Bypass that may be available as rearing habitat for fish from the Feather and Sacramento Rivers during times when this floodplain is inundated and fish have access.

Table ES-3. Rearing Habitat (Combined In-Channel and Floodplain) Results Compared to the VA Term Sheet Commitments and the Habitat Required to Support 25 Percent of the Doubling Goal

		Modeled Results (Habitat Suitable by Depth, Velocity, Cover, and Temperature Criteria)					
Watershed	Acres Proposed in VA Term Sheet	Acres to Support 25% of Doubling Goal	Median Acres Reference Condition	Acres Added by VA	Median Total Acres with VA	MFE[1] Reference Condition (%)	MFE[1] VA (%)
American	75	240.5	93.91	50.16	144.07		
Feather	1660.25	287.5	206	142.22	348.22	46	66
Mokelumne	26	19.25	158.23	8.43	166.66	51	51
Sacramento River: FR[2]	137.5	452	127.19	30.44	157.63		
Sacramento River: SR[2]		64.5	186.97	42.7	229.67		
Yuba	150	76.25	252.51	92.91	345.42	11	72

1 Meaningful Floodplain Event (MFE) results represent the expected percent of years with floodplain events that would support salmonid rearing.
2 Numbers for the Sacramento River do not include the 20,000 acres of proposed floodplain habitat enhancements on the Sutter Bypass that may be available as rearing habitat for fish from the Feather and Sacramento Rivers during times when this floodplain is inundated and fish have access.
FR = fall run, SR = spring run

Table ES-4. Projected Increases in Habitat Area for Delta Smelt, Longfin Smelt, and Salmonids within Relevant Seasons for Each Species

Species and Life Stage	Season	Scenario	VA Change From Reference Condition (acres)	VA Change From Reference Condition (%)
Longfin Smelt Larvae	Jan–Apr	VA	635–1,600	2–5
		VA w/o SJ	635–1580	2–5
Longfin Smelt Juveniles	Mar–Aug	VA	-166–3,547	0–7
		VA w/o SJ	-241–3,238	0–7
Delta Smelt Larvae	Mar–Jun	VA	-3,184–2,260	-11–13
		VA w/o SJ	-3,204–1,993	-11–11
Delta Smelt Juveniles	Jul–Nov	VA	1,694–7,917	5–19
		VA w/o SJ	1,555–7,634	4–18
Salmonid Rearing	Oct–Jun	VA	475–578	2–3
		VA w/o SJ	476–581	2–3

The VA w/o SJ contributions scenario excludes Friant and Tuolumne VA flows because the Friant VA is uncertain and the Tuolumne VA would be subject to State Water Board decision-making under a separate process. Results are provided as ranges across water year types. The VA Term Sheet proposes 5,227.5 acres of tidal wetland and floodplain habitat restoration, but only 4,074 acres were included in the modeling.
SJ = San Joaquin; w/o = without

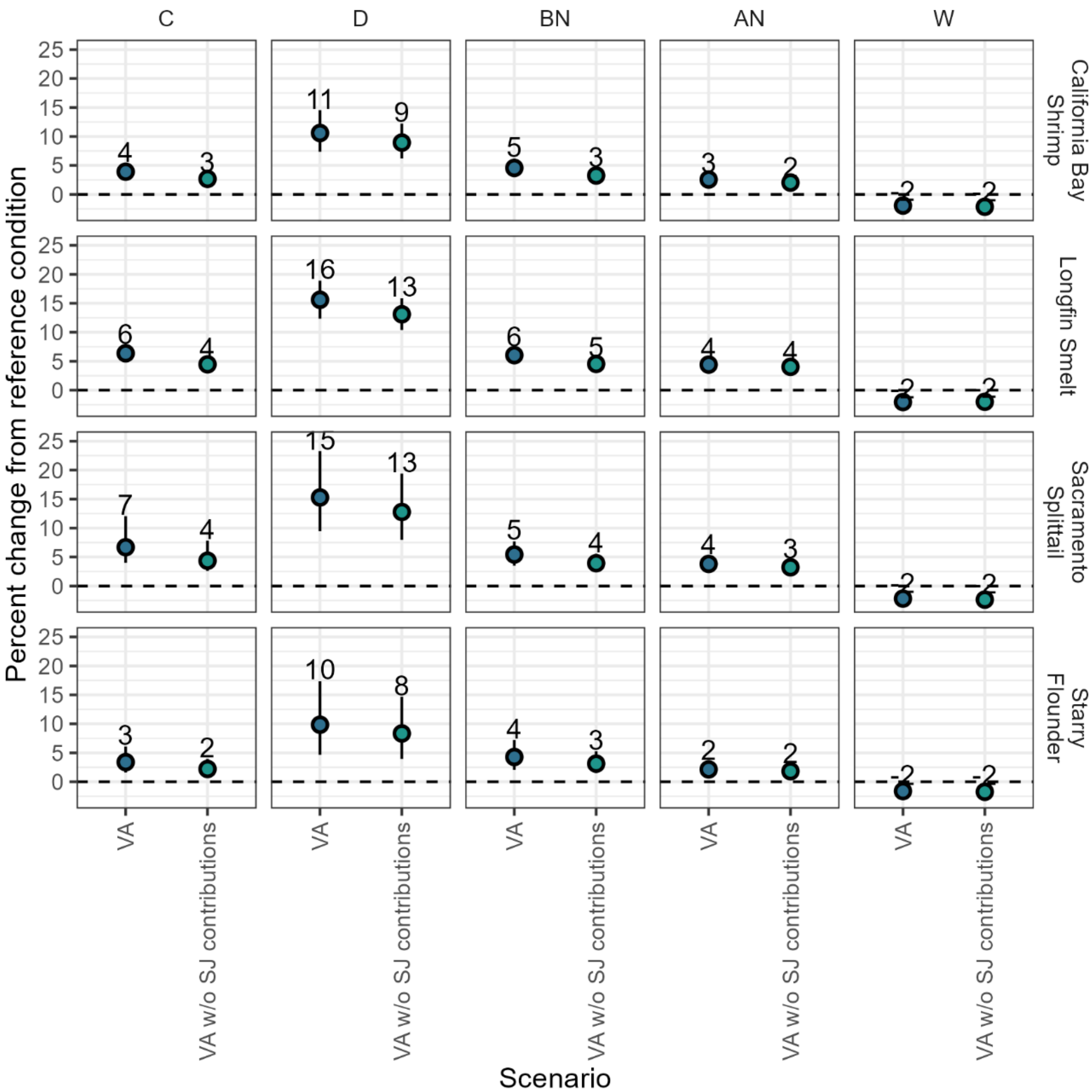

Figure ES-3. Potential Percent Change (Median Prediction ± 95 Percent Confidence Intervals) in Abundance Indices Relative to Reference Condition

The median predictions (rounded to a whole number) are also printed above each point. The VA without San Joaquin contributions scenario excludes Friant and Tuolumne VA flows because the Friant VA is uncertain and the Tuolumne VA would be subject to State Water Board decision-making under a separate process.

Table ES-5. Frequency of Exceeding Ecological Flow Thresholds within the Seasons Specified in Section 5.4

Threshold (cfs)	Reference Condition (%)	VA (%)	VA w/o SJ Contributions (%)
Georgiana Slough Flow Reversal Low (17,000)	53	52	52
Georgiana Slough Flow Reversal High (20,000)	43	44	44
Fall Run Outmigration (20,000)	26	26	26
Winter Run Outmigration (20,000)	57	60	60
Bay Shrimp low (20,000)	51	55	52
Bay Shrimp high (25,000)	41	45	44
Longfin Smelt (43,000)	29	29	29
Sacramento Splittail low (30,000)	39	43	41
Sacramento Splittail high (47,000)	26	25	25
Starry Flounder (21,000)	42	46	46
Green and White Sturgeon (37,000)	15	15	15
Collinsville X2 (7,100)	99	99	99
Chipps Island X2 (11,400)	81	87	87
Port Chicago X2 (29,200)	41	43	43

The Georgiana Slough flow reversal threshold represents monthly flows while the other thresholds represent seasonally averaged flows. The VA interior Delta flows used for the Georgiana Slough flow reversal and the fall- and winter-run outmigration thresholds do not include any unspecified water purchases (market price and permanent state water purchases) because the origin of that water is unknown. Thresholds for Collinsville, Chipps Island, and Port Chicago represent the flows that correspond to an average X2 location downstream of the specified location.
cfs = cubic feet per second; SJ = San Joaquin; w/o = without

While the quantitative and qualitative analyses described in this report indicate expected benefits from the VAs, the actual outcomes of the VAs are not certain at this time. As with all modeling analyses, the quantitative results have uncertainty arising from assumptions and simplifications, unexpected events, unanticipated consequences, and unknown unknowns in the system. Additional uncertainties in VA outcomes arise from the timing of non-flow habitat restoration action completion; assumptions of the suitability of VA 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 7, *Conclusions and Uncertainties*, for details on the uncertainty and a summary of the findings). The VA Parties are developing accounting procedures for flow and non-flow assets that, when finalized, would provide additional certainty in how the assets would be provided and therefore in the benefits they would be expected to provide. The VAs, 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.

Chapter 1
Introduction

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

The State Water Resource Control Board's (State Water Board's) mission is to preserve, enhance, and restore the quality of California's water resources and drinking water for the protection of the environment, public health, and all beneficial uses, and to ensure proper water resource allocation and efficient use, for the benefit of present and future generations. The State Water Board protects water quality that affects beneficial uses of water in the San Francisco Bay/Sacramento-San Joaquin River Delta Estuary (Bay-Delta) in part through its Water Quality Control Plan for the Bay-Delta (Bay-Delta Plan). The State Water Board is responsible for adopting and updating the Bay-Delta Plan, which establishes water quality control measures and flow requirements needed to provide reasonable protection of beneficial uses of water in the watershed.

The current Bay-Delta Plan identifies various beneficial uses of water in the Bay-Delta watershed and establishes water quality objectives designed to reasonably protect those uses. Water quality objectives can be numerical or narrative in form. Certain numerical objectives are expressed as flows and others as salinity (electrical conductivity [EC] or chloride) and dissolved oxygen levels that are largely achieved through flows and project operations. The Bay-Delta Plan also includes narrative fish and wildlife protection objectives for salmon and the Suisun Marsh. The Bay-Delta Plan includes a program of implementation identifying how the objectives will be achieved, including a description of actions necessary to achieve the objectives; a time schedule for taking the actions; and monitoring, evaluation, and reporting measures to determine compliance with the objectives and evaluate the effectiveness of implementation measures.

The State Water Board has been engaged in a process since 2008 to update the 2006 Bay-Delta Plan to ensure that beneficial uses of water in the Bay-Delta watershed are reasonably protected. In 2018, the State Water Board updated the Bay-Delta Plan water quality objectives and the program of implementation to address San Joaquin River flows for the protection of fish and wildlife beneficial uses and southern Sacramento-San Joaquin River Delta (Delta) salinity for the protection of agricultural beneficial uses. The State Water Board is currently in the process of updating other components of the Bay-Delta Plan to protect native fish and wildlife in the Sacramento River, Delta, and associated tributaries (Sacramento/Delta Update to the Bay-Delta Plan). In support of that work, in 2017 the State Water Board prepared a final *Scientific Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflows, Cold Water Habitat, and Interior Delta Flows* (2017 Scientific Basis Report) (State Water Board 2017). The 2017 Scientific Basis Report described the science supporting possible changes to the Bay-Delta Plan being considered at the time. Based on the 2017 Scientific Basis Report, in July 2018, the State Water Board released a framework (State Water Board 2018) for a possible Sacramento/Delta Update to the Bay-Delta Plan for the reasonable protection of fish and wildlife, including Sacramento River and tributary and Delta eastside tributary (including Calaveras, Cosumnes, and Mokelumne Rivers) inflows and cold water habitat measures, Delta outflows, and interior Delta flows (State Water Board 2018).

Since completion of the 2017 Scientific Basis Report and the 2018 updates to the Bay-Delta Plan, the State Water Board received proposed Voluntary Agreements (VAs) proposing updates to the Bay-Delta Plan and its implementation on March 29, 2022 (and amended on August 11, 2022, and November 10, 2022) titled *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* (Voluntary Agreements Parties 2022; MOU; hereafter referred to as the VA Term Sheet). The VAs included signatories from state and federal agencies, local water agencies, private companies, and a nonprofit mutual benefit corporation (collectively referred to in the VA documents as "Parties," "public water agencies," or "PWAs"). The Parties submitted the VAs as a Bay-Delta Plan alternative that is proposed as a voluntary pathway to achieve reasonable protection of fish and wildlife beneficial uses.

1.2 Background on the 2017 Scientific Basis Report

In October 2017, the State Water Board released its final Scientific Basis Report in support of the possible Sacramento/Delta Update to the Bay-Delta Plan (State Water Board 2017). The 2017 Scientific Basis Report documents the science upon which possible changes to the Bay-Delta Plan are based, including documentation of the prolonged and severe decline in numerous native species, such as spring-run and winter-run Chinook salmon (*Oncorhynchus tshawytscha*), longfin smelt (*Spirinchus thaleichthys*), Delta smelt (*Hypomesus transpacificus*), Sacramento splittail (*Pogonichthys macrolepidotus*), and other species. The 2017 Scientific Basis Report discusses the impacts that non-flow stressors like habitat loss are having on the ecosystem and the importance of addressing these stressors to protect the Bay-Delta ecosystem. Additionally, the 2017 Scientific Basis Report acknowledges that habitat restoration and other non-flow actions can potentially reduce the needs for flows. The 2017 Scientific Basis Report also presents evidence indicating that native fish and other aquatic species require more flow of a more natural pattern than is currently required under the Bay-Delta Plan to provide appropriate quantities of quality habitat and to support specific functions needed to protect these species.

A working draft version of the 2017 Scientific Basis Report was released on October 19, 2016, to receive public input prior to the submittal of the 2017 Scientific Basis Report for external peer review. The 2017 Scientific Basis Report builds upon the priorities and science in the State Water Board's 2008 Bay-Delta Strategic Workplan, 2009 Periodic Review Staff Report, and 2010 Report on the Development of Flow Criteria for the Bay-Delta Ecosystem required by the Sacramento-San Joaquin Delta Reform Act of 2009 (Wat. Code, §§ 85000–85350); three informational workshops held in September, October, and November 2012; an additional three independent science workshops held in collaboration with the Delta Science Program, National Marine Fisheries Service (NMFS), and California Department of Fish and Wildlife (CDFW); and the public comments submitted on those processes.

A public workshop on the draft 2017 Scientific Basis Report was held on December 7, 2016. Part of the input on the draft 2017 Scientific Basis Report included consultation and input from the Delta Independent Science Board (ISB). The Delta ISB's Final Review Document was provided to the State Water Board in February 2017 (Delta ISB 2017).

Based on public and agency input—including input received at the December 2016 workshop, associated public comment letters, and the Delta ISB's Final Review Document—the 2017 Scientific

Basis Report was refined, and a final draft 2017 Scientific Basis Report was prepared for independent peer review, as required by Health and Safety Code section 57004. Through the external peer review process, the final version of the 2017 Scientific Basis Report was reviewed by five independent external scientific peer reviewers with a broad range of expertise; these reviewers determined that the report is based on sound science.

1.3 Draft Scientific Basis Report Supplement

This report, 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* (Draft Supplement Report), was developed as a supplement to the 2017 Scientific Basis Report. The Draft Supplement Report was developed by State Water Board staff in collaboration with staff from CDFW (lead for aquatic ecosystem stressors analysis and description of VA assets on the Sacramento and tributaries) and the California Department of Water Resources (DWR) (lead for aquatic ecosystem stressors in the Bay-Delta, and support for analytical approach and anticipated VA outcomes) to document the science supporting the proposed flow and non-flow habitat provisions included in the VAs (Voluntary Agreements Parties 2022). This Draft Supplement Report builds on the 2017 Scientific Basis Report, particularly with additional scientific information supporting specific flow and non-flow habitat restoration actions in the tributaries, flood bypasses, and Delta outlined in the VAs.

This report also documents Traditional Ecological Knowledge (TEK) from California Native American tribes within the Bay-Delta watershed to provide a record of how aquatic ecosystem stressors have affected tribal physical well-being and spiritual and cultural uses of water and to inform reasonable protection of beneficial uses, including the Tribal Beneficial Uses (TBUs) of Tribal Traditional Culture, Tribal Subsistence Fishing, and Subsistence Fishing (State Water Board 2020), that are being considered by the State Water Board for inclusion in the Bay-Delta Plan (State Water Board Resolution 2016-0011). TEK could also inform adaptive management of the VAs if they are approved.

While the Draft Staff Report for the Sacramento/Delta updates to the Bay-Delta Plan contains analyses of both the impacts and benefits of all evaluated alternatives, this Draft Supplement Report only analyzes the benefits of the VA alternatives. This Draft Supplement Report was made available for public comment from January 5 to February 8, 2023, including a Board Workshop on January 19, 2023. Following receipt of public comments, the Draft Supplement Report was revised as appropriate and this final Draft Supplement Report will be submitted for 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 adoption.

1.3.1 Response to Comments on the Draft Supplement Report

The State Water Board received written comments on the January 2023 draft version of this Draft Supplement Report and held a technical workshop on January 19, 2023, to receive oral comments and answer questions from the public and other agencies. Below is a summary of the primary topics raised by commenters on the draft and how these comments have been addressed in this version of the Draft Supplement Report or will be addressed in upcoming related processes.

1.3.1.1 Tribal Beneficial Uses and Traditional Ecological Knowledge

The State Water Board received comments expressing concerns about omission of TEK from the Draft Supplement Report and a lack of recognition of TBUs in the Bay-Delta Plan. In response to these comments, State Water Board staff held two tribal listening sessions and other meetings with coalitions of Bay-Delta tribes during spring of 2023 to hear feedback on proposed updates to the Bay-Delta Plan and to document TEK. At its meeting on June 7, 2023, the State Water Board held an Informational Item on consideration of incorporating TBUs into the Bay-Delta Plan. During the Informational Item, a panel of California Native American tribes addressed the State Water Board on the significance of including TBUs in the Bay-Delta Plan. The panel also shared its TEK related to flow, water quality, and cultural uses of water in the Bay-Delta watershed. Following the presentations, the State Water Board received public comment on consideration of TBUs in the Bay-Delta Plan. The State Water Board is considering addition of TBUs and subsistence fishing beneficial uses to the Plan, including Tribal Traditional Culture, Tribal Subsistence Fishing, and Subsistence Fishing (State Water Board 2020). The State Water Board will decide on incorporation of TBUs when Plan amendments are considered for adoption.

In response to comments requesting inclusion of TEK in the report, State Water Board staff have engaged in efforts to document TEK of federally recognized and non-federally recognized tribes whose historical lands fall within the Bay-Delta watershed, including its tributaries. Part of these efforts included a literature review of TEK and documentation of TEK shared during the State Water Board's June 7, 2023, Informational Item on consideration of incorporating TBUs in the Bay-Delta Plan. Section 2.5, *Impacts of Aquatic Ecosystem Stressors on Tribal Uses of Water in the Bay-Delta*, in Chapter 2, *Aquatic Ecosystem Stressors*, describes TEK recorded through these efforts. However, the availability of TEK in the literature is limited, and State Water Board staff are currently pursuing other avenues for documenting TEK. The State Water Board is committed to ongoing engagement with California Native American tribes to incorporate TEK into the State Water Board's Bay-Delta planning and implementation efforts to inform the reasonable protection of beneficial uses.

1.3.1.2 Descriptions of Assets from the VA Term Sheet

Several commenters expressed concern with the terms and structure of the VAs specified in the VA Term Sheet. For example, some commenters suggested that the assets were not enough to achieve the benefits necessary to improve protection of fish and wildlife beneficial uses, that the flow or restoration assets were unlikely to materialize, that the enforceability of the VAs has not yet been defined, or that the adaptive management program of the VAs could use improvement and refinement. Other commenters expressed support for the VAs as a better way to achieve the desired outcomes than what has been tried in the past, and that its combination of flow and habitat restoration assets are likely to achieve the desired benefits. The Draft Supplement Report only analyzes the potential benefits of the VA Term Sheet that was provided to the State Water Board. The public will have the opportunity to provide comments on the VA alternative through review of the Draft Staff Report for the Sacramento/Delta updates to the Bay-Delta Plan. Furthermore, following receipt of comments on the Draft Staff Report and receipt of peer review comments on this report expected in late 2023, proposed specific changes to the Bay-Delta Plan will be developed. Those draft changes will be the subject of additional public input before the State Water Board develops a final Draft Staff Report and proposed changes to the Bay-Delta Plan for consideration by the State Water Board at a public State Water Board meeting anticipated in late 2024.

1.3.1.3 Climate Change and Drought

Several commenters requested that the Draft Supplement Report include more consideration of the effects of climate change and long-term drought. To address these comments, the discussion in this report of the potential effects of climate change (Section 6.3.2, *Limitations to Benefits with Climate Change*) and long-term drought (Section 6.3.1, *Limitations to Benefits During Multi-Year Droughts*) on the benefits of the VAs has been supplemented. Climate change will likely degrade the long-term benefits of the VA assets but may not have large impacts over the 8-year term of the VAs. A long-term drought during the term of the VAs could reduce their benefits, but the expected benefits under such a drought should be similar to those represented in results for critical or dry water year types.

1.3.1.4 Water Temperature

The State Water Board received comments that the Draft Supplement Report did not account for water temperatures for habitat suitability or carryover storage needs, or did not do so appropriately. In response to these comments, the report now includes temperature suitability as a criterion in the tributary habitat analyses. In addition, the temperature criteria have also been modified for the estuarine habitat analysis to better reflect the latest research on the temperature tolerance of the identified estuarine species.

1.3.1.5 Harmful Algal Blooms

Comments indicated that the Draft Supplement Report did not contain a thorough discussion of the status of harmful algal blooms (HABs) in the Delta or analyze the effects of the VAs on HABs. This report includes additional discussion of the current status and drivers of HABs in Chapter 2, *Aquatic Ecosystem Stressors*, as well as the potential effects of the VAs on HABs (Section 6.2.1, *Benefits of Increased Flow*). However, the Draft Supplement Report is only analyzing the potential benefits of the VAs, while the Draft Staff Report analyzes both the benefits and impacts. We do not expect the VAs to prove a significant a benefit in reducing HABs due to the primarily spring timing of the VA flow assets given that HABs largely occur during the summer and fall.

1.3.1.6 Flow versus Non-Flow Habitat

Several commenters suggested that either flow or non-flow habitat is more important for sustaining native fish species, and that the Draft Supplement Report overly emphasizes the benefits of one over the other. Some commenters stated that habitat is not limiting for native fish species and that habitat cannot be substituted for flow, while other commenters stated that there was an over-emphasis on benefits of flow. There were also suggestions that the report did not cite the best available science on habitat benefits for species. To address these comments, this report includes additional cross-references to the best available scientific evidence and adds references to the scientific literature where necessary.

1.3.1.7 Additional Stressors

Some commenters suggested additional stressors that should be considered in the analysis, such as thiamine deficiency, hatchery genetic effects, direct (fishery) take, predation, and the cumulative impact of multiple stressors. This report now includes a discussion of thiamine deficiency as an aquatic ecosystem stressor in Section 2.4.3, *Thiamine Deficiency*, and discussion of the cumulative impacts of multiple stressors in Section 2.4.5, *Cumulative Effects*. Hatchery effects, direct take, and predation are already covered in the Draft Supplement Report (throughout Chapter 2, Section 2.4.1, and Section 2.3.6, respectively) or in the 2017 Scientific Basis Report (Sections 4.5.2, 4.5.1, and 4.4.1, respectively).

1.3.1.8 Hydrology and Operations Modeling

The State Water Board received comments on various issues related to the hydrology and operations modeling. There was general confusion about the baseline used in the report and statements either that the federal Endangered Species Act Biological Opinions for long-term Central Valley Project (CVP)/State Water Project (SWP) operations (BiOps) issued in 2008/2009 were the correct baseline, or that the 2019 BiOps baseline from the VA Term Sheet should have been used instead. In response to these comments, this report now uses the term "reference condition" to distinguish the point of comparison for the VAs in this report, which is consistent with the 2017 Scientific Basis Report, from others (e.g., the accounting baselines in the VA Term Sheet or the baseline used in the Draft Staff Report for environmental impact determinations). Furthermore, we now use a consistent reference condition in all analyses: flows resulting from State Water Board Revised Water Right Decision 1641 (D-1641) and the 2008/2009 BiOps, as modeled. We use this reference condition rather than the accounting baseline in the VA Term Sheet for consistency with the 2017 Scientific Basis Report, to which this report is a supplement.

Some commenters also expressed confusion or questions about the assumptions of CalSim 2 (used for the estuarine habitat analyses) and CalSim 3 (used for all other analyses). This report changes from use of CalSim to the Sacramento Water Allocation Model (SacWAM) for all hydrology and operations modeling to ensure internal consistency in this report and consistency with the Draft Staff Report. Although it was computationally infeasible to rerun the estuarine habitat analyses with SacWAM inputs instead of CalSim 2 inputs, this report includes post-processed results based on SacWAM-modeled flows.

Some commenters requested improved documentation of the hydrology and operations modeling. Chapter 4, *Hydrology and Operations Modeling Methods and Results*, has been rewritten to document assumptions of SacWAM and incorporate requests for clarifying details. Lastly, some comments suggested that the monthly timestep of the hydrology and operations modeling was not sufficient to capture sub-monthly benefits of the VA assets. However, the intent of this analysis was to use one modeling tool for the full area of the Bay-Delta Plan update to ensure consistency in modeling approach across tributaries. No model with finer temporal resolution than monthly was available that encompassed this full area.

1.3.1.9 Flexibility in VA Assets and Accounting Measures

Several commenters expressed concern that the VA assets would not materialize or that the flexibility in the timing of their deployment in the VA Term Sheet would degrade their benefits. To ensure the materialization of the VA assets, the VA Parties are producing accounting procedures that would be used to verify compliance with the flow and non-flow habitat commitments. A summary of the proposed draft non-flow habitat accounting methods and the areas where they differ from the assumptions in this report is included in Chapter 5, *Analytical Approach to Evaluating Assets*. The proposed VA flow accounting methodology is still under development, but a summary of the proposed flow flexibility brackets has been provided by the VA Parties and is analyzed in this report. These flow flexibility scenarios are intended to encompass the range of possible benefits that could result from the proposed flexibility in timing of flow asset deployment.

1.3.1.10 Tributary Details

Several VA Parties recommended incorporation of additional details about their tributary in Chapter 2, *Aquatic Ecosystem Stressors* (formerly *Limiting Factors*), in the flow modeling described in Chapter 4, *Hydrology and Operations Modeling Methods and Results*, and in the description of the VA assets in Chapter 5, *Analytical Approach to Evaluating Assets*. We carefully considered each of these comments and incorporated changes where appropriate. These comments were assessed to determine if the requested level of detail was within the scope of the report and if the requested modeling changes were applicable after the transition to SacWAM; where feasible, changes to this report were made if they improved the ability to represent the VA assets as described by the VA Term Sheet.

Some parties from other tributaries that are not reflected in the VA Term Sheet requested that the Draft Supplement Report include their proposals for VAs in the analysis. This report does not include analyses of provisions that are not part of the VA Term Sheet.

1.3.1.11 Flow Abundance Analyses

The State Water Board received several comments on the flow-abundance analyses requesting that the uncertainty in those relationships be disclosed or expressing that the relationships were not modeled appropriately. For consistency, the flow-abundance relationships in the Draft Scientific Basis Report Supplement are identical to those in the peer-reviewed 2017 Scientific Basis Report. The only change made to these calculations from the 2017 Scientific Basis Report was the estimation of uncertainty in the reported results. However, to address these comments, the report now directs readers to the 2017 Scientific Basis Report for additional documentation of these relationships and their underlying uncertainty.

The State Water Board also received comments requesting that the Draft Scientific Basis Report Supplement evaluate the frequency of achieving the ecological flow thresholds identified in the 2017 Scientific Basis Report. To address these comments, this report now reproduces those flow threshold analyses using SacWAM flows for the reference condition and VA scenarios.

1.3.1.12 Habitat Modeling

The State Water Board received several comments on the habitat modeling approach. Some commenters requested additional documentation or changes to the doubling goal habitat area. In response to these comments, this report includes expanded documentation of the methods for this calculation, including explanations for the reasoning behind each assumption and how the required habitat area would change if different assumptions were used. Comments were also received from the Yuba Water Agency (YWA) and Regional Water Authority that the habitat data for the Yuba and American Rivers respectively were outdated. This report incorporates these revisions, which resulted in increased reference condition habitat area (and VA habitat area because VA assets are additive to the reference condition) in the Yuba River, and increased VA habitat area in the American River.

Several commenters suggested that all the appropriate metrics of habitat suitability were not incorporated into habitat analyses. To address this comment, this report adds temperature criteria (see Section 1.3.1.4, *Water Temperature*) and assumptions of cover criteria for salmonid rearing habitat in the tributaries. However, the treatment of cover in the draft VA non-flow habitat accounting methods contains flexibility that was not possible to model and cover categories of uncertain suitability. Therefore, the extent to which the implemented non-flow habitat assets would contain fully suitable cover is unknown. Further discussion of this can be found in Section 5.1.3.2, *VA Habitat Quantification*. Additional suitability criteria were not included due to a lack of data. However, this report adds caveats acknowledging the assumptions of the analytical approach. Lastly, a comment was received from the Delta ISB that the projections of habitat gains are overly optimistic because they focus on just Delta smelt and fall-run Chinook salmon. This report now adds spring run in the Sacramento River to the tributary habitat analyses.

1.3.1.13 Other Approaches

Some commenters suggested using other modeling approaches such as lifecycle or mechanistic models. However, these approaches were not feasible within the timeframe and would not have been consistent with the methods used in the 2017 Scientific Basis Report. Evaluation of the expected benefits of the VA flow assets were designed to mirror the methodology in the 2017 Scientific Basis Report for consistency and comparability. Therefore, application of a different methodology for evaluating the benefits of the flow assets than the peer-reviewed methods used in the 2017 Scientific Basis Report would have detracted from that comparability. Furthermore, life cycle models are not available for fall run and spring run (the two runs analyzed in this report) that could accommodate our inputs without modification and recalibration, and it is unclear whether the existing models could be modified to accommodate our inputs, or how long that modification would take if possible.

1.3.1.14 Impacts of the VAs

Some commenters asked for various analyses of the impacts of the VAs, such as on groundwater, drinking water, agriculture, or salinity. These impacts are analyzed in the Draft Staff Report, while the Draft Supplement Report only analyzes the benefits of the VAs.

1.4 Description of the Proposed Voluntary Agreements

The VAs propose that the State Water Board update the Bay-Delta Plan to include a new Narrative Viability Objective as well as a combination of voluntary flow and non-flow habitat restoration actions. Specifically, the VAs propose: (1) a new narrative objective to achieve the viability of native fish populations (Narrative Viability Objective); and (2) to provide the participating parties' share, during implementation of the VAs, to contribute to achieving the existing Narrative Salmon Protection Objective, and propose doing so by 2050 (Voluntary Agreements Parties 2022).

The proposed Narrative Viability Objective states:

> Maintain water quality conditions, including flow conditions in and from tributaries and into the Delta, together with other measures in the watershed, sufficient to support and maintain the natural production of viable native fish populations. Conditions and measures that reasonably contribute toward maintaining viable native fish populations include, but may not be limited to, (1) flows that support native fish species, including the relative magnitude, duration, timing, temperature, and spatial extent of flows, and (2) conditions within water bodies that enhance spawning, rearing, growth, and migration in order to contribute to improved viability. Indicators of viability include population abundance, spatial extent, distribution, structure, genetic and life history diversity, and productivity. Flows provided to

> meet this objective shall be managed in a manner to avoid causing significant adverse impacts to fish and wildlife beneficial uses at other times of the year.

The existing Narrative Salmon Protection Objective (also referred to as the salmon doubling objective, or the Narrative Salmon Objective in the VA Term Sheet) states:

> Water quality conditions shall be maintained, together with other measures in the watershed, sufficient to achieve a doubling of natural production of chinook salmon from the average production of 1967–1991, consistent with provisions of State and federal law.

The VAs propose an 8-year term and a set of flow and non-flow habitat restoration actions, or assets, in selected tributaries, flood bypasses, and the Delta, which are described in more detail in Chapter 3, *Description of Flow and Non-Flow Assets*. Flow assets are expected to be concentrated in January through June, with some flexibility outside of this period (currently encapsulated in a draft Flow Measures Description submitted to the State Water Board on February 28, 2023), with more limited flow assets also planned for fall months (Mokelumne and Putah systems). Priority months include April through May, and priority water year types include Dry, Below Normal, and Above Normal water years. Flows during these time periods and water year types are intended to benefit spawning and rearing habitats for salmonids in the tributaries and provide benefits for more estuarine native species such as longfin smelt. Proposed restoration actions target spawning and rearing capacity for juvenile salmonids, as well as other native fishes. Tributary restoration actions are intended to restore spawning and rearing habitats sufficient to support approximately 25 percent of the offspring of the salmon doubling goal populations for each tributary. Restoration actions are also intended to improve regional aquatic food supply and improve connectivity between the in-channel and the new and existing floodplains. Where appropriate, restoration actions are intended to be integrated with and complementary to VA flow assets. While the VAs are in part intended to avoid temperature impacts, the VAs do not include an explicit commitment to cold water temperature benefits.

When the 2017 Scientific Basis Report was developed, it used—for comparison when evaluating expected Delta outflow from changes to the Bay-Delta Plan—a regulatory baseline that included the flows resulting from implementing the State Water Board's Revised D-1641 and the CVP and SWP federal Endangered Species Act BiOps issued in 2008/2009 for long-term CVP/SWP operations, as modeled (hereafter referred to as the reference condition). In contrast, the VA proposal, as submitted, accounts for environmental flows relative to flows resulting from D-1641 and BiOps for CVP/SWP long-term operations issued in 2019, as modeled (hereafter referred to as the 2019 BiOps condition). Because this report is a supplement to the 2017 Scientific Basis Report, the expected benefits of the VAs are analyzed relative to the same reference condition as the 2017 Scientific Basis Report to provide a consistent basis of evaluation. This approach analyzes VA flows and habitat above flows resulting from D-1641 and the 2008/2009 BiOps as modeled, and above habitat required by the 2008/2009 BiOps (i.e., the reference condition, including assuming completion of the 8,000 acres of tidal wetland restoration required by the BiOps).

Analyses of the benefits of Delta outflow resulting from the VAs are conducted under two VA scenarios: (1) VA flows from the Sacramento, Feather, American, Mokelumne, and Tuolumne Rivers; Putah Creek; and Delta outflow contributions, including from Friant water users identified in the VA Term Sheet (hereafter referred to as the VA scenario), and (2) the VA flows without Tuolumne River flows and Friant contributions (hereafter referred to as the VA without San Joaquin). These two scenarios are meant to encompass the potential range of VA flows given uncertainties with the San Joaquin contributions. Friant VA flows are excluded from the VA without San Joaquin scenario due to a recent decision to withdraw from the VA proposal. Contributions are included in the VA scenario in recognition that Friant may rejoin the VA pending ongoing negotiations (Friant Water Authority 2023). The Tuolumne VA flows are excluded from the VA without San Joaquin scenario because the Tuolumne VA is being evaluated under a separate process to consider whether changes should be made to the 2018 amendments to the Bay-Delta Plan that established updated Lower San Joaquin River Flows and Southern Delta Salinity objectives. To illustrate the combined effects of the Tuolumne River VA with the other VA components, the Tuolumne River VA contributions are reflected in the VA scenario. The November 2022 VA Term Sheet identified other possible San Joaquin River contributions from the Merced and Stanislaus Rivers that are not included in either scenario because VA contributions have not been identified from either tributary.

The VAs include 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 VA program, and Tributary/Delta Governance Entities that would oversee implementing the agreements for which that entity is responsible. The VA Science Program is proposed to "(A) inform decision-making by the Systemwide Governance Committee, Tributary/Delta Governance Entities, and VA Parties; (B) track and report progress relative to the metrics and outcomes stated in Appendix 4; (C) reduce management-relevant uncertainty; and (D) provide recommendations on adjusting management actions to the Systemwide Governance Committee, Tributary/Delta Governance Entities and VA Parties" (Voluntary Agreements Parties 2022). The framework for the VA Science Program is proposed to be collaboratively developed by the VA Parties in coordination with the State Water Board.

On the eighth year of the VAs, the State Water Board would consider the reports, analyses, information, and data from the VA Science Program as well as recommendations from the VA Governance Committee and the Delta ISB to decide the future of the VA program. If the VAs are substantially achieving the stated objectives, the VA Parties would continue implementation of the VAs without any substantial modification in terms. If the VAs are expected to achieve the stated objectives with some modifications, the VA Parties would continue implementation with substantive modifications in terms. However, if the VAs are not expected to achieve the stated objectives, then either (1) new agreements may be negotiated or (2) the State Water Board would impose regulations to implement the Bay-Delta Plan (Voluntary Agreements Parties 2022).

1.5 Overview of Chapters

The following is a summary of the components of this Draft Supplement Report:

- **Chapter 1, *Introduction*,** provides an overview of the Bay-Delta Plan Update process, background on the 2017 Scientific Basis Report, the purpose of the Draft Supplement Report, an overview of revisions to the Draft Supplement report in response to public comments, and the stated objectives of the VAs.
- **Chapter 2, *Aquatic Ecosystem Stressors*,** summarizes the best available science related to flow and non-flow aquatic ecosystem stressors in both the tributaries and Delta and documents relevant TEK from California Native American tribes in the Bay-Delta watershed.

- **Chapter 3, *Description of Flow and Non-Flow Assets*,** presents assets outlined in Appendices 1 and 2 of the VA Term Sheet, including assets for the Sacramento River, American River, Yuba River, Feather River, Putah Creek, Friant system, Mokelumne River, and Bay-Delta.
- **Chapter 4, *Hydrology and Operations Modeling Methods and Results*,** presents modeling assumptions and an evaluation of changes in Bay-Delta hydrology that would result from implementation of the VAs.
- **Chapter 5, *Analytical Approach to Evaluating Assets*,** describes the analytical approach to evaluating assets, including the use of flow:area relationships to quantify tributary and off-stream habitats, two-dimensional hydrodynamic analysis for the Bay-Delta, and flow-abundance relationships for certain native species occupying the estuary.
- **Chapter 6, *Anticipated Biological and Environmental Outcomes*,** presents the anticipated outcomes that implementation of the VAs' assets is expected to provide.
- **Chapter 7, *Conclusions and Uncertainties,*** presents the findings of this Draft Supplement Report and includes a characterization of uncertainties associated with anticipated outcomes.
- **Chapter 8, *References*,** includes bibliographical information for sources cited in this Draft Supplement Report.

Chapter 2
Aquatic Ecosystem Stressors

The 2017 Scientific Basis Report (State Water Board 2017) describes a variety of aquatic ecosystem stressors that are negatively affecting native fish species in the Delta and its tributaries. The Sacramento/Delta Update to the Bay-Delta Plan is primarily focused on providing reasonable protection for native fish and other aquatic species rearing or residing in or migrating through the Delta, and the State Water Board is also considering inclusion of TBUs in the Bay-Delta Plan. The main focal species are Chinook salmon, Central Valley steelhead (*Oncorhynchus mykiss*), longfin smelt, green sturgeon (*Acipenser medirostris*), white sturgeon (*Acipenser transmontanus*), Sacramento splittail (*Pogonichthys macrolepidotus*), Delta smelt, starry flounder (*Platichthys stellatus*), and California Bay shrimp (*Crangon franciscorum*). The life histories and other information regarding each of these species, as well as native and nonnative zooplankton upon which many of them feed, are described in Chapter 3 of the 2017 Scientific Basis Report. This chapter briefly summarizes an updated review of the best available science on aquatic ecosystem stressors related to flow and non-flow habitat in both the tributaries and Delta. Table 2-1 provides hypotheses for how the VA proposal may address the most important of these stressors. For the purposes of this report, an aquatic ecosystem stressor is any factor that negatively affects native species' individual health, population abundance, or viability.

Table 2-1. Aquatic Ecosystem Stressors Affecting Fishes in the Tributaries and Delta, along with Qualitative Hypotheses of How the VA Proposal May Address these Factors

Stressor	Subfactor	Hypothesized Flow Benefit	Hypothesized Habitat Restoration Benefit
Food supply/ ecosystem productivity		May move food from high-density to low-density areas (Sections 6.1.4 and 6.2.4)	Wetlands and floodplains may provide greater primary productivity and increased foraging opportunities (Sections 6.1.2 and 6.2.3).
Physical habitat loss/ alteration	Spawning habitat	Higher flows and correct flow timing may increase spawning habitat area and reduce redd dewatering (Section 6.1.4).	Restoration increases habitat quantity and quality (Section 6.1.1).
	Rearing habitat	Higher flows transport fish between rearing habitat patches and increase access to off-channel habitat (Section 6.1.4).	Restoration increases habitat quantity and quality (Section 6.1.2).
	Tidal marsh	Higher flows transport fish to marsh habitat and superimpose the low-salinity zone over regions with large areas of tidal marsh habitat (Section 6.2.4).	Restoration increases habitat quantity and quality (Section 6.2.2).
	Floodplain and wetland habitat	Higher flows increase frequency of floodplain inundation (Section 6.1.3).	Restoration increases habitat area and allows inundation at lower flow rates (Section 6.1.2).

Stressor	Subfactor	Hypothesized Flow Benefit	Hypothesized Habitat Restoration Benefit
Water quality	Contaminants	High flows increase loading of contaminants but also increase dilution of contaminants (Section 2.3.3).	Wetland plants can remove contaminants (Section 2.2.3). Transitioning from managed wetland to tidal wetlands may reduce mercury methylation (Sections 2.2.3 and 6.2.4).
	Harmful algal blooms	Higher flow in the summer reduces potential for cyanobacterial growth, but VA flows in the spring are unlikely to affect HABs (Sections 2.3.4 and 6.2.1).	
	Dissolved oxygen	Higher flows keep water circulating, raising dissolved oxygen, but flow pulses can also increase biological oxygen demand from agricultural drainage or managed wetlands (Sections 6.1.4, 6.2.3, and 6.2.4).	Replacing managed wetlands with tidal wetlands may increase dissolved oxygen (Section 6.2.3).
	Sediment and turbidity	Higher flows increase turbidity in the Delta if there is sufficient upstream sediment supply (Section 6.2.1).	
	Temperature	Higher flows decrease temperatures in downstream reaches below dams, when managed appropriately, although temperatures just below dams are most affected by the temperature of released water (Section 3.2.1 of the 2017 Scientific Basis Report [State Water Board 2017). Higher flows in the Delta are correlated with lower temperature, but cause-effect relationship is unclear (Section 2.3.3).	There is a potential for increased nighttime cooling in tidal wetlands during summertime spring tides (Sections 2.3.3 and 6.2.3).

Stressor	Subfactor	Hypothesized Flow Benefit	Hypothesized Habitat Restoration Benefit
Movement/ migration/ passage/ connectivity	Juvenile outmigration and rearing habitat connectivity	Higher flows may transport anadromous fishes to ocean or different habitats faster. More sustained flows during the full outmigration window support diverse timings and sizes of fish, which in turn support life history diversity (Sections 6.1.3 and 6.1.4).	Habitat restoration may provide access to more habitat and resting points along migration routes and may also allow fish to reach destinations in better condition and across a broader distribution of body sizes, improving life history diversity (Sections 6.1.2 and 6.1.4).
	Floodplain connectivity	Higher winter/spring flows may increase floodplain inundation and connectivity between the main channel and habitat on the floodplain (Sections 2.2.4 and 6.1.4).	Habitat restoration may provide increased access to highly productive off-channel habitat for growth and rearing (Sections 2.2.1 and 6.1.2).
	Adult upstream migration and passage	Increased flow may restore migration cues and reduce straying (Section 2.2.4).	Some actions may reduce or resolve adult fish passage impediments, providing improved access to spawning areas (Section 3.1.1).
Invasive species	Fish—as predators and competitors	Flow moves fish through high-predation areas more quickly. Higher springtime flows may favor native species (Sections 2.2.5, 6.1.3, and 6.2.1).	Habitat restoration may provide refugia from predation if sites are not dominated by submerged aquatic vegetation (Sections 2.3.1 and 2.3.6).
	Aquatic vegetation	Flood flows may discourage establishment of submerged aquatic vegetation and flush out invasive floating vegetation, but more research is needed (Section 2.3.6).	
	Invertebrates	Higher flows may restrict the brackish clam *Potamocorbula amurensi*s from moving into upstream regions of the Delta (Section 2.3.6).	
Direct take	Diversions and exports	Entrainment risk can decrease with increased flow. Increased flow also reduces travel time, routing fish into corridors with increased survival rates, etc. (Section 2.4.1).	

Stressor	Subfactor	Hypothesized Flow Benefit	Hypothesized Habitat Restoration Benefit
	Stranding	Increased flow can reduce the incidence of juvenile Chinook stranding when habitat becomes disconnected from the main channel during low flows (Section 6.1.2).	Habitat restoration may minimize stranding if volitional movement is included in project design (Sections 2.2.4 and 6.1.2.2).
Disease		Increased flow may reduce temperatures and thereby reduce susceptibility to disease (Section 2.4.2).	
Climate change		Providing higher springtime flows will help increase ecosystem resiliency (Sections 2.4.3 and 6.3).	Restoring additional habitat may increase overall ecosystem resiliency to stressors, including climate change (Section 2.4.3 and 6.3).

Blank cells indicate no expected benefit.

2.1 Bay-Delta Tributaries

2.1.1 Sacramento River

2.1.1.1 Physical Habitat Loss or Alteration

Loss and alteration of physical habitat on the Sacramento River is covered in detail in the 2017 Scientific Basis Report (State Water Board 2017). The majority of Chinook salmon spawning in the Sacramento River occurs between Keswick Dam and Red Bluff Diversion Dam. Water temperature and flow in this reach must be carefully managed to support egg and embryo development and not dewater completed redds before fry emergence. Redd dewatering is both a flow and non-flow habitat issue. The earliest life history stages of salmonids (egg incubation to emergence from the gravel) are particularly sensitive. These life stages require suitable water temperature regimes and stable and continuous river flows to prevent redds from being dewatered or exposed to warm, deoxygenated water so incubating eggs and larval fish may survive. Dewatering can occur anytime a streamflow reduction occurs and is of concern on a managed river system such as the Sacramento River. Redds constructed in shallow areas (less than or equal to a depth of 2 feet) are susceptible to dewatering by flow reduction actions undertaken by the U.S. Bureau of Reclamation (Reclamation) as operations transition from high summer export regimes to low winter storage flow regimes (Revnak et al. 2017). Late spawning winter-run Chinook (mid-July to mid-August) are of concern because of the time required for embryos to fully develop and fry to escape the redd, and the need for cool water temperatures during this summer period. Reclamation is required to limit the number of dewatered winter-run Chinook redds to 1 percent or less (NMFS 2019). Other Chinook salmon runs (such as spring-run Chinook salmon and fall-run Chinook salmon) can be affected as well because they tend to be actively spawning prior to and during the flow reduction period from fall to winter base flows in October.

2.1.1.2 Ecosystem Productivity and Food Supply

As discussed in the *Habitat Connectivity* sections below as well as in the 2017 Scientific Basis Report (State Water Board 2017), the disconnection and destruction of rearing habitat are considered stressors for salmonids on the Sacramento River. Losses of riparian habitat, floodplains, and side channels have reduced the amount and quality of rearing habitat available to native fishes. The productivity of these habitats has been well documented (Feyrer et al. 2006b; Grosholz and Gallo 2006; State Water Board 2017; Sturrock et al. 2022) and it is therefore reasonable to assume that this habitat reduction has led to an overall decrease in ecosystem productivity. However, it is uncertain whether food supply is currently limiting salmonid populations on the Sacramento River, as it is difficult to disentangle effects of primary and secondary productivity from other components of rearing habitat (water temperature, cover, water velocity, and predator refuge).

2.1.1.3 Water Quality

Aquatic ecosystem stressors related to water quality are discussed in the 2017 Scientific Basis Report (State Water Board 2017).

2.1.1.4 Habitat Connectivity

The importance of a natural flow regime to the native flora and fauna, function, and resilience of lotic ecosystems is covered in the 2017 Scientific Basis Report (State Water Board 2017), and newer studies (Rolls and Bond 2017; Yarnell et al. 2020; Grantham et al. 2022) have added to existing knowledge.

One significance of the water management infrastructure and altered flow regimes in the Sacramento River is the reduction in spring outmigration (i.e., seaward) survival of juvenile salmon (Kjelson and Brandes 1989; Notch et al. 2020). Survival bottlenecks at this critical life stage have significant repercussions throughout the Chinook salmon lifecycle (Michel 2018). Most juvenile Chinook salmon in the Sacramento River rear and out-migrate during the winter or spring months, with winter-run Chinook rearing and leaving the system the earliest (Fisher 1994). Except for drought years, historically these seasons provided adequate flows and cool water temperatures for juveniles to rear in and successfully transit through downstream regions. At present, except for very wet years, flows are only occasionally adequate for outmigration or off-channel rearing due to reduced reservoir releases to store water for use in the summer months (Sturrock et al. 2019a). In California's Central Valley, studies have found that increased streamflow can improve survival of imperiled juvenile salmon populations during their oceanward migration (Michel et al. 2021).

All natural-origin spring run Chinook salmon in the Sacramento River basin can be affected by low flows during smolt outmigration. Natural-origin spring run salmon have been particularly affected by low reservoir releases and spring agricultural diversions due to their slow embryonic development in high-elevation tributaries (e.g., Deer and Mill Creeks), which result in late emergence, rearing, and outmigration timing in downstream reaches (Johnson and Merrick 2012). The hydrograph of the Sacramento River is highly regulated and can result in a mismatch between the ideal outmigration conditions the smolts experience as they leave their natal creeks and the altered outmigration conditions they encounter as they enter the mainstem Sacramento River.

Hatchery managers recognize the relationship between survival and flow in the mainstem Sacramento River and to the best of their ability release hatchery-origin smolts immediately prior to or during storm events. When in-river conditions (flow and water temperature) in the mainstem Sacramento River in April and May are exceptionally poor, hatchery managers historically truck all or a percentage of this economically important species to the Delta or Bay systems to improve survival and maximize ocean recruitment (Sturrock et al. 2019b).

Extensive acoustic tagging studies on the mainstem Sacramento River over the last decade show that flow was the most important environmental covariate in predicting outmigration success, with increased levels of flow correlating with increasing smolt survival (Michel et al. 2015; Notch et al. 2020; Henderson et al. 2018). A synthesis of the survival estimates of several thousand acoustically tagged Chinook smolts released into the Sacramento River March through May identified key flow-survival thresholds based on river stage at Wilkins Slough (Michel et al. 2021). Greater than 50 percent survival of Chinook smolts was achieved when flows at Wilkins were 10,700 cubic feet per second (cfs) or greater, and survival was near zero when flows were less than 4,000 cfs at Wilkins.

2.1.1.5 Invasive Species

See Section 4.4 of the 2017 Scientific Basis Report for a description of nonnative species (State Water Board 2017).

2.1.2 Feather River

2.1.2.1 Physical Habitat Loss or Alteration

Impacts from dams, water operations, levees, and channelization as described in the 2017 Scientific Basis Report (State Water Board 2017) similarly apply to the Feather system below Oroville Dam, affecting and reducing spawning and rearing habitat, natural flow regimes, floodplain connectivity, and water quality (NMFS 2016).

Although pathogens occur naturally in the Feather River, the operations of Oroville Dam facilities may have produced environmental conditions where fish are more susceptible to disease (NMFS 2016), and outbreaks of the salmonid parasite *Ceratonova shasta* have been documented in recent years (Lehman et al. 2020). Susceptibility of fishes to disease is related to several factors that occur in the environment, including fish species and their densities, water quality conditions, decreased flows, and number of pathogens in the environment (Foott 2017). Impediments to upstream migration and lack of sufficient flow can alter the exposure of fish by delaying downstream migration and decreasing survival by increasing residence time to certain pathogens.

Downstream water diversions along the lower Feather River have the potential to entrain fish, change water flow and hydrology in the vicinity of the facility, or create an environment hospitable to fish species that prey on anadromous fishes (Moyle and White 2002; Mussen et al. 2013). Unscreened diversions can entrain juveniles, which can be either killed or injured by the pump or transported to a canal where their survival is greatly diminished (Poletto et al. 2015).

2.1.2.2 Ecosystem Productivity and Food Supply

As discussed in the *Habitat Connectivity* sections as well as in the 2017 Scientific Basis Report (State Water Board 2017), the disconnection and destruction of rearing habitat are considered limiting factors for salmonids on the Feather River. Losses of riparian habitat, floodplains, and side channels have affected the food supply available to native fishes because the productivity of these habitats has been well documented (Feyrer et al. 2006b; Grosholz and Gallo 2006; State Water Board 2017; Sturrock et al. 2022). However, it is uncertain whether food supply in and of itself is currently limiting salmonid populations on the Feather River, as it is difficult to disentangle effects of primary and secondary productivity from other components of rearing habitat (water temperature, cover, water velocity, and predator refuge).

2.1.2.3 Water Quality

Water quality issues are discussed in Section 5.4.2.3 of the 2017 Scientific Basis Report (State Water Board 2017) and references therein.

2.1.2.4 Habitat Connectivity

As described in the 2017 Scientific Basis Report (State Water Board 2017), 3,600 square miles of the 4,400-square-mile Feather River watershed is above Oroville Dam. Oroville Dam is a barrier to fish passage, blocking anadromous fishes from accessing historical spawning and rearing habitat, likely making it the single largest stressor to native fishes in the Feather River.

Downstream of Oroville Dam, the Fish Barrier Dam acts as a guidance weir for adult Chinook salmon and steelhead to reach the Feather River Fish Hatchery and, as such, is the true terminus of anadromous fish upstream accessibility. Farther downstream near the town of Live Oak, California, the Sutter Extension Water District operates a pumping facility that includes a boulder weir that stretches across the river to raise the water surface elevation. The boulder weir does not have an engineered fish ladder designed for anadromous fish passage; at low to moderate flows in the Feather River, the weir imposes a passage impediment to those fish species. The Sunset Weir is a 10-foot-tall boulder weir originally constructed in the 1920s on the Feather River approximately 2 miles southeast of the town of Live Oak. The weir represents a significant barrier for adult fish passage, particularly for Chinook salmon and sturgeon.

2.1.2.5 Invasive Species

See Section 4.4 of the 2017 Scientific Basis Report (State Water Board 2017) for a description of nonnative species.

2.1.3 Yuba River

2.1.3.1 Physical Habitat Loss or Alteration

Impacts from reduced flows, dams, barriers, levees, and channelization as described in the 2017 Scientific Basis Report (State Water Board 2017) similarly apply to the Yuba River (NMFS 2019), affecting and reducing spawning and rearing habitat, natural flow regimes, floodplain, and water quality (NMFS 2016). Additionally, the Yuba River was heavily affected by hydraulic mining in the nineteenth century (Nakamura 2017). Three barriers (Daguerre Point, New Bullards Bar, and Englebright Dams) and the 15 miles of 20- to 75-foot-high training walls 4.5 miles upstream of Daguerre Point Dam to 2.5 miles downstream are key pieces of infrastructure diminishing natural river processes in the Yuba River. Although Daguerre Point Dam has two fish ladders for upstream fish passage, Englebright Dam is a complete barrier to salmonid passage with no fish ladder, while the ladder designs at Daguerre Point Dam are an impediment to sturgeon upstream passage.

All three barriers prevent the physical transport and recruitment of large woody materials to the lower Yuba River. Large woody material is important for maintaining habitat complexity and creating refuge hospitable to adult and juvenile fish. The creation of training walls along the river prevents natural river processes from occurring and has reduced lateral movement of the river, resulting in a more channelized river. This has confined the corridor, particularly in the Dry Creek and Daguerre Dam Reaches (Wyrick and Pasternack 2012). It has also diminished habitat processes necessary for salmonid productivity, including inundation of the natural floodplain, formation of fine sediment and organic matter deposition, and sediment benches that encourage riparian vegetation recruitment necessary for overhanging cover for fish, stream shading, and as a source of terrestrial and aquatic invertebrate food sources for fish. There are also several unscreened diversions on the Yuba River; they likely will result in loss of juvenile salmonids and should be considered an ecosystem stressor (Moyle and White 2002; NMFS 2019).

2.1.3.2 Ecosystem Productivity and Food Supply

As discussed in the previous section as well as in the 2017 Scientific Basis Report (State Water Board 2017), the disconnection and destruction of rearing habitat are considered ecosystem stressors for salmonids on the Yuba River. Losses of riparian habitat, floodplains, and side channels have affected the food supply available to native fishes, and the productivity of these habitats has been well documented (Feyrer et al. 2006b; Grosholz and Gallo 2006; State Water Board 2017; Sturrock et al. 2022). However, it is uncertain whether food supply is currently limiting salmonid populations on the Yuba River, as it is difficult to disentangle effects of primary and secondary productivity from other components of rearing habitat (water temperature, cover, water velocity, and predator refuge).

2.1.3.3 Water Quality

There is an abundance of mercury in the sediment-laden tailings piles that currently make up the lower Yuba floodplain and are stored behind the Englebright and New Bullards Bar Dams. In the northwestern Sierra Nevada, the highest average levels of bioaccumulation occur in the Bear River and South Yuba River watersheds (Slotton et al. 1997). Further water quality issues are discussed in Section 5.4.2.4 of the 2017 Scientific Basis Report (State Water Board 2017) and references therein.

2.1.3.4 Habitat Connectivity

High winter and spring storm flows from rain and snowmelt inundate the riparian and floodplain habitat vital for prolonged juvenile salmonid rearing. These flows also provide outmigration cues in which juvenile salmonids have evolved and mobilize and clean spawning gravels (State Water Board 2017). The current flow regime on the Yuba River does not allow for floodplain inundation during the winter and spring juvenile growth periods. This limits habitat diversity and complexity necessary for juvenile refugia. The habitat that does become inundated dewaters rapidly, disconnecting habitat availability and diminishing the amount of time available for a meaningful growth period. In addition, some regulated flow fluctuations under current conditions have dewatered redds and created isolated pools, thereby stranding juveniles (ICF Jones & Stokes 2009; Larrieu and Pasternack 2021).

The dams on the Yuba River directly affect longitudinal fish passage by either delaying (Daguerre Point Dam) or completely blocking (Englebright and New Bullards Bar Dams) the movement of native fishes. The 15 miles of 20- to 75-foot-high training walls in the lower Yuba River limit lateral connectivity by confining the river channel to a narrow corridor and separating the Yuba River from its original floodplain. These floodplains and other off-channel habitats provide refuge from increased high flows and sediment loads, extend rearing habitat to reduce competition between individuals, increase prey availability for growth, and potentially reduce encounters with piscivorous predators, all of which can improve rearing conditions and increase growth and survival rates (Sommer et al. 2001b; Limm and Marchetti 2003, 2009; Moyle et al. 2007; Jeffres et al. 2008). Available information indicates that fry and juvenile rearing physical habitat structure (complexity, sinuosity, diversity, instream objects, and overhanging cover) is an ongoing stressor and limiting factor for anadromous salmonids in the lower Yuba River (Wyrick and Pasternack 2012).

2.1.3.5 Invasive Species

See Section 4.4 of the 2017 Scientific Basis Report (State Water Board 2017) for a description of nonnative species.

2.1.4 American River

2.1.4.1 Physical Habitat Loss or Alteration

Along with flow alterations stemming from Folsom Dam operations, physical transport of gravel and large woody materials has also been inhibited by the construction of both Folsom and Nimbus Dams. Gravel and woody material transport is important for creation of favorable spawning and rearing habitat and maintenance of habitat complexity and refuge hospitable to juvenile anadromous fish species in the lower American River. Without the dams, gravel and large woody material typically can be transported downstream during high-flow events. However, with the dams in place, recruitment of spawning gravel and woody material habitat features are diminished in the lower American River.

Stable and continuous river flows are important to the early life history (egg incubation to emergence from the gravel) of salmonids. Reductions in flow during the early life stages can completely dewater incubating eggs and/or larval fish or expose them to warm, deoxygenated water, affecting their survival (NMFS 2019). Dewatering redds has the potential to occur anytime a flow reduction occurs.

With respect to flow and water temperatures along the lower American River, the current operating regime is often not reliable for the protection of aquatic resources during various life stage periods. Low flows and elevated water temperatures in the fall can lead to stressful conditions and increased susceptibility to disease for holding adult Chinook salmon, which may affect survival of early-run prespawning adults. Early spawning adult Chinook during periods of increased water temperatures can expose eggs and larvae to unfavorable warmer, deoxygenated water and decrease the likelihood of surviving these conditions. Flow decreases following the peak of Chinook salmon spawning in December and January also can lead to dewatered redds, exposing eggs and larvae to lower dissolved oxygen levels and increasing mortality from stranding (Reclamation 2021). Low-flow conditions or flow fluctuations from January through April provide suboptimal conditions for adult steelhead spawning, increasing the risk of redd dewatering and of stranding and isolating rearing juvenile salmonids. Lower flows may also affect downstream juvenile migration and survival through increased travel time.

The lower section of the American River is highly leveed and shallow, with fewer deep pools and limited off-channel habitats and riparian vegetation necessary for rearing juveniles and promoting salmonid production. Floodplains and other off-channel habitats provide refuge from increased high flows and sediment loads, extend rearing habitat to reduce competition between individuals, increase prey availability for growth, and potentially reduce encounters with piscivorous predators, all of which can improve rearing conditions and increase growth and survival rates (Sommer et al. 2001a; Limm and Marchetti 2003, 2009; Moyle et al. 2007; Jeffres et al. 2008).

2.1.4.2 Ecosystem Productivity and Food Supply

As described above, the physical changes on the American River prevent natural movement of flows through the river channel and inhibit interactions with the surrounding landscape, which in turn limit the biophysical processes that create rearing habitat and enhance foodweb dynamics (NMFS 2016; State Water Board 2017). The dynamic shallow-water habitats that historically provided rearing habitat for salmonids have been diminished through levee construction in all but the wettest years (NMFS 2019). Losses of riparian habitat, floodplains, and side channels have affected the food supply available to native fishes; the productivity of these habitats has been well documented (Feyrer et al. 2006b; Grosholz and Gallo 2006; State Water Board 2017; Sturrock et al. 2022). However, it is uncertain whether food supply is currently limiting salmonid populations on the American River, as it is difficult to disentangle effects of primary and secondary productivity from other components of rearing habitat (water temperature, cover, water velocity, and predator refuge).

2.1.4.3 Water Quality

Specific effects attributed to elevated water temperatures during juvenile rearing, over summering, and outmigration include increased mortality, increased susceptibility and exposure to diseases, impaired ability to avoid predators, altered migration timing, and changes in fish community structure that favor competitors of salmonids. Water temperatures during the summer months can become unsuitable for juvenile steelhead rearing, and increased water temperature is believed to be one of the limiting factors for steelhead production in the lower American River (NMFS 2019). Warm temperatures can extend into the fall, leading to elevated pre-spawn mortality for adult fall-run Chinook salmon holding and spawning until meteorological conditions create cooler temperatures, typically after mid-November (Kaiser and Phillips 2019; Kelly and Phillips 2020; Grimes and Galinat 2021). On March 23, 2022, the State Water Board adopted Resolution No. 2022-0006, which identified the lower American River as an impaired waterbody for temperature. Warm water temperatures observed in the lower American River during summer were identified as impairing cold freshwater habitat, a beneficial use identified for the lower American River. HABs, which may be transported downstream, can also occur during the summer in the American River, particularly in Lake Natoma (State Water Board 2023). See Section 5.4.2.2 of the 2017 Scientific Basis Report (State Water Board 2017) for more detail on water quality issues on the American River.

2.1.4.4 Habitat Connectivity

Impacts on connectivity caused by dams, water operations, and levees are described more generally in State Water Board 2017 and in the previous three sections. The current flow in the lower American River regime does not allow for floodplain inundation during the winter and spring juvenile growth period, limiting lateral connectivity. The habitat that does become inundated dewaters rapidly, disconnecting habitat availability and diminishing the amount of time available for a meaningful growth period. In addition, regulated flow fluctuations under current conditions dewater redds and create isolated pools that strand juvenile fish (CDFG 2001; Snider et al. 2001; NMFS 2019). Stranding can lead to direct mortality when these areas drain or dry up. Indirect mortality can result through increased susceptibility to predation or water quality deterioration in shallow or stagnant stranding locations (Revnak et al. 2017). A delay in migration to the Delta has the potential to reduce any benefits from water operation protection measures, which are intended to minimize entrainment from south of Delta operations.

2.1.4.5 Invasive Species

See Section 4.4 of the 2017 Scientific Basis Report (State Water Board 2017) for a description of nonnative species.

2.1.5 Mokelumne River

2.1.5.1 Physical Habitat Loss or Alteration

Impacts from dams, water operations, levees, and channelization as described in the 2017 Scientific Basis Report (State Water Board 2017) similarly apply to the Mokelumne River below Camanche Dam, affecting and reducing spawning and rearing habitat, natural flow regimes, floodplain connectivity, and water quality. Descriptions of stressors and physical changes to the Mokelumne River can be found in Sections 2.2.7.1 and 5.4.2.5 of the 2017 Scientific Basis Report (State Water Board 2017).

Limited spawning substrate because of available suitable spawning substrates that have been dewatered or diminished through lower flows can result in competition for space and lead to redd superimposition. While the returning adult escapement population for in-river and hatchery returns has recently been at or above that of the 1992–2016 Anadromous Fish Restoration Program (AFRP) doubling goal, Johnson et al. (2012) found that approximately 90 percent of the returning adults in 2004–2005 were hatchery stock. Data from Calfish.org show that the hatchery proportion of returning salmon ranged between 64 percent and 94 percent for in-river spawning salmon between 2010 and 2019. Most of the available spawning habitat in the lower Mokelumne River is limited to a 9.8-mile section of river directly downstream of Camanche Dam (Setka and Bishop 2003). However, most of the spawning occurs upstream of Mackville Road up to Camanche Dam, a stretch of roughly 4 miles.

Along with flow alterations stemming from Camanche Dam operations, physical transport of gravel and large woody materials has also been inhibited by the construction of Camanche Dam. Gravel and woody material transport is important for creation of favorable spawning habitat and maintenance of habitat complexity and refuge hospitable to juvenile anadromous fish species in the lower Mokelumne River. Without the dam, gravel and large woody material typically can be transported downstream during high-flow events. However, with the dam in place, recruitment of spawning gravel and woody material habitat features are diminished in the lower Mokelumne River.

2.1.5.2 Ecosystem Productivity and Food Supply

Lateral movement of the Mokelumne River has been reduced, along with the frequency of floodplain inundation, which severely limits the biophysical processes that create rearing habitat. Losses of riparian habitat, floodplains, and side channels have affected the food supply available to native fishes; the productivity of these habitats has been well documented (Feyrer et al. 2006b; Grosholz and Gallo 2006; State Water Board 2017; Sturrock et al. 2022). However, it is uncertain whether food supply is currently limiting salmonid populations on the Mokelumne River because it is difficult to disentangle effects of primary and secondary productivity from other components of rearing habitat (water temperature, cover, water velocity, and predator refuge).

2.1.5.3 Water Quality

Early-season water temperatures can approach the upper limits for adult Chinook salmon spawning. Specific effects attributed to increased temperatures include delay in spawning and increased susceptibility and exposure of eggs to diseases. Specific effects attributed to elevated water temperatures during juvenile rearing and outmigration include increased mortality, increased susceptibility and exposure to diseases, impaired ability to avoid predators, altered migration timing, and changes in fish community structure that favor competitors of salmonids (State Water Board 2017). Low flow rates can cause the water temperature to rise above the preferred range for outmigrant fry and juvenile salmonids downstream of Woodbridge Diversion Dam and can persist into the summer months during dry and critically dry water year types. The abundance of salmonids could increase if water temperatures and flows for juvenile rearing and migration were improved, particularly in dry years (NMFS 2014).

2.1.5.4 Habitat Connectivity

Springtime flows below Woodbridge Diversion Dam are often a small proportion of the inflow, particularly in the drier years, and are inadequate to effectively convey juvenile salmonids downstream and through the Delta. There is the potential for stranding of juvenile salmonids due to elevated flow fluctuations in several reaches downstream of Camanche Dam, based on predicted changes in wet surface area over a range of flows. The stranding potential increased at flows below 400 cfs (USFWS 1995).

Current stressors to salmonids from low flows on the Mokelumne River can delay attraction and migratory cues to adults and inhibit juvenile emigration. Often, adult Chinook salmon returning to the Mokelumne River stray to other river systems or experience increased travel time. This is believed to be caused by insufficient attraction flows, elevated water temperature during the summer–early fall period, and operations of the Delta Cross Channel gates in the summer and early fall when adult Chinook salmon are migrating upstream (McKibbin 2022). Minimum flows below the Woodbridge Diversion Dam range from 15 to 300 cfs (EBMUD 1998) and can range from 15 to 25 cfs in the late summer and from 45 to 100 cfs in October, depending on water year type. Elevated water temperatures due to low flows during the summer and early fall may block or delay migrating adults moving upstream or cause them to stray to other river systems in the Central Valley.

Reservoir operations and diversions on the Mokelumne River have reduced the current flows to below 24 percent of the unimpaired January–June average flows, and lower in drier years. Adequate flows during outmigration are necessary for juveniles to reach parts of the Delta with tidal influence. Reduced flow duration or magnitude, along with tidal cycles, can cause the lower Mokelumne River forks to be difficult to navigate for juveniles during outmigration and delay their migration through increased travel times. Juveniles are therefore subject to lethal or sublethal water quality effects, thus reducing successful outmigration. Additionally, they may be subject to predation.

Among the many restoration actions reviewed by the Mokelumne River Technical Advisory Committee, screening of diversions was rated the second highest priority behind gravel augmentation. A Central Valley Project Improvement Act (CVPIA) Charter was developed in 2017 (CVPIA 2017) to identify and reduce impacts of riparian water diversions, and three high-priority screening projects were completed in 2021. Water diversions can entrain juvenile fish, change water flow and hydrology in the vicinity of the facility, or create an environment hospitable to fish species that prey on anadromous fishes (Moyle 2002; Mussen et al. 2013).

2.1.6 Putah Creek

2.1.6.1 Physical Habitat Loss or Alteration

Gravel quantity and quality in lower Putah Creek are considered limiting factors for salmonid spawning and incubation (Wildlife Survey and Photo Service 2015). Completion of Monticello Dam and the Putah Creek Diversion Dam have blocked sediment supply, causing lower Putah Creek to become “sediment starved” (EDAW 2005). Erosion and down-cutting have occurred as a result of the sediment-starved river, and streamflow has increased due to channelization and levees (EDAW 2005). In lower Putah Creek, gravel generally occurs in small patches, often only in a thin layer over the underlying clay (Small et al. 2004). Sections of lower Putah Creek have 60 to 90 percent of the spawning gravels embedded with or covered by sediment (Wildlife Survey and Photo Service 2015), which has made it difficult for trout and salmon to dig into the gravel to create a redd. When spawning does occur in this embedded gravel, eggs can be washed away (Wildlife Survey and Photo Service 2015), likely resulting from scouring shallow redds. Scouring of redds due to high flows released from Lake Berryessa has also occurred (Small et al. 2004). Regardless of the cause of redd scour, whether poor gravel quality or high flows, redd scour reduces the number of offspring produced in Putah Creek. The limited quantity and poor quality of gravel in Putah Creek likely have also caused detrimental impacts on spawning Pacific lamprey because they dig nests in gravel for spawning (Moyle 2002).

Recently, a project has been implemented to rehabilitate some of the embedded gravel through scarification, a process of loosening gravel with large equipment (Wildlife Survey and Photo Service 2015). Redds in scarified sections have been found to be deeper and of better quality than in control sections (Wildlife Survey and Photo Service 2015). Salmon have also begun building redds in areas along the margins of the scarified sections, such as the gravel areas between Putah Diversion Dam and Scarification Site 6 that were used by salmon for redds in 2014, 1 year after the scarification (Wildlife Survey and Photo Service 2015). Salmon redd construction in these areas expands the area of loosened and potentially suitable gravel. Rainbow trout have been found building redds in the scarified sections (Wildlife Survey and Photo Service 2015). Sculpins have also been found to use for cover the larger cobbles that were made available through scarification (Wildlife Survey and Photo Service 2015).

2.1.6.2 Water Quality

Temperature in Putah Creek below the Putah Diversion Dam is consistently cool, in the range of 12 to 15 degrees Celsius (°C) (53-59 degrees Fahrenheit [°F]) throughout the year (Jones & Stokes

Associates 1996; EDAW 2005). Temperature begins to increase downstream as ambient heat is gained by the relatively small flow released from the Putah Diversion Dam, resulting in approximately 11°C (19°F; from 12°C [53°F] to 22°C [72°F]) of warming between the Putah Diversion Dam and Stevenson Bridge (EDAW 2005). In addition to this natural warming, further warming may be occurring in several wide areas of the channel degraded by a history of gravel mining (EDAW 2005). Although there are limited temperature data available, water temperature in April generally reaches or exceeds the upper range of suitable spawning conditions for Pacific lamprey, hitch, and Sacramento sucker (EDAW 2005). Temperatures in the lower parts of Putah Creek can be as high as 22°C (72°F) by mid-May (Small et al. 2004), barring late migrants from leaving the system in many years. Groundwater may also affect temperatures in Putah Creek; in some years it can contribute up to a quarter of total flow (EDAW 2005).

Other water quality stressors in Putah Creek include mercury, aquatic toxicity, and gross pollutants (trash) (EDAW 2005). One fish contamination study conducted by the Agency for Toxic Substances and Disease Registry found that all largemouth bass samples contained mercury, and some contained concentrations that are a health concern to pregnant or nursing women (EDAW 2005). Another study conducted by the University of California, Davis confirmed that many of the Putah Creek fish species contained mercury concentrations at levels of potential concern (Slotton et al. 1999). Larger individuals of the top predatory species exhibited the highest contaminant concentrations. Additionally, contaminated crayfish may be a hazard for both human and wildlife consumption and certain small or juvenile fish may be a chronic hazard to wildlife (Slotton et al. 1999). HABs can also occur during the summer in Putah Creek, particularly in Lake Solano (State Water Board 2023).

2.1.6.3 Habitat Connectivity

Fish passage into Putah Creek is blocked for much of the year due the presence of the Los Rios Check Dam, a 12-foot-high, 30-foot-wide concrete structure fitted with wooden boards about 23 miles downstream of the Diversion Dam and 1.2 miles upstream of the Yolo Bypass (EDAW 2005; Yolo Basin Foundation and CDFW 2016). The Los Rios Check Dam blocks free passage of salmonids and other native species from entering Putah Creek (StreamWise 2021). Each year the flashboards must be manually removed to allow fish, mainly Chinook salmon, to move into the creek. Removal of the flashboards generally occurs once adult Chinook are observed in the Toe Drain (Small et al. 2004) and is timed to coincide with a 5-day attraction flow of approximately 50 cfs in late November or early December (Small et al. 2004; EDAW 2005). Due to the presence of this flashboard dam, fish that arrive early or in a different season do not have access to the spawning grounds on Putah Creek. At least one large fish kill has occurred after heavy rains and runoff attracted adult Chinook salmon to the area of the Los Rios Check Dam, which had the flashboards installed and resulted in fish congregating downstream of the check dam in water with low dissolved oxygen (Rabidoux et al. 2022). Habitat downstream of the Los Rios Check Dam is not suitable for salmonid spawning and consists of a straightened ditch and a deep excavated channel (Yolo Basin Foundation and CDFW 2016). The flashboard dam can block migrating juvenile salmonids as well as adults. The flashboards are generally installed in the spring, during the juvenile outmigration season. The installation of the flashboards can strand the young of that year above the dam (Small et al. 2004). Once the flashboards are installed, it is unlikely that young of that year would make it past the dam due to low flows and a drop of approximately 15 feet between the upstream and downstream water levels (Small et al. 2004). There is potential for successful downstream passage at the flashboard dam in years with higher flows, but under low or normal flows the dam represents a significant barrier to outmigration (Small et al. 2004).

At Road 106A, a seasonal earthen road crossing is installed annually in the spring for farm operations, and then the culverts are removed in the fall to allow for fish passage upstream (EDAW 2005). The crossing at Road 106A has the potential to be a barrier to fish passage when it is in place (EDAW 2005). The Winters percolation dam—a 100-foot-wide concrete structure that was built in 1936 and collapsed during a flood in 1951—partially obstructs fish passage, especially during low flows or when debris clogs the passageways through the dam (EDAW 2005). In addition to the human-constructed passage barriers, beaver dams can be a barrier to fish passage in Putah Creek. Beaver dams are typically broken up and washed downstream during high-flow events, but during dry or more moderate periods the dams can persist for years (EDAW 2005). When flows are insufficient to overtop or bypass the beaver dams, fish may have difficulty in passing over or around them (EDAW 2005).

2.1.6.4 Invasive Species

There are numerous invasive species in the Putah Creek watershed. Arundo, eucalyptus, Himalayan blackberry, Eurasian watermilfoil, perennial pepperweed, tamarisk, tree-of-heaven, and yellow star thistle are the most abundant weed species in the riparian corridor (EDAW 2005). These invasive plants can restrict flows along waterways, resulting in channel scouring, increased water temperatures, interrupted sediment transport, and increased levee erosion (EDAW 2005). Given poor connectivity and low velocity, it is likely that invasive aquatic weeds are also an ecosystem stressor in some reaches of Putah Creek; however, this has not been comprehensively assessed.

2.2 Off-Stream: Bypasses, Side Channels

This section builds upon the description of the flood basins and floodplain/wetland habitat in the 2017 Scientific Basis Report (State Water Board 2017) and focuses specifically on how the flood basins provide off-channel habitat and the associated ecosystem stressors, with an emphasis on Chinook salmon but with consideration to other native species. There is an emphasis on the Yolo Bypass and Sutter Bypass (flood bypasses), as most of the research in the historical flood basins has been conducted there, particularly as it relates to floodplain habitat. However, the ecosystem stressors described below apply somewhat or fully to other off-channel habitat in the project area such as the Butte Sink and Colusa basin.

The extensive loss of seasonal floodplain habitat has contributed to the decline of Central Valley Chinook salmon (NMFS 2014). California's Central Valley was once characterized by extensive seasonal flooding; however, only 3 percent of historical freshwater wetland habitat remains in the Sacramento-San Joaquin Delta (Whipple et al. 2012). Widespread levee construction for flood control and agricultural development now prevents inundation of most of the historical floodplain except under extreme flooding (Opperman 2012). The loss of this seasonal habitat has likely had drastic ecosystem impacts, as seasonal floodplains drive key biological processes that maintain biodiversity in river ecosystems (Junk et al. 1989). Multiple studies have highlighted the benefits of off-channel habitat for many native Central Valley fishes, including Chinook salmon (Sommer et al. 2001a, 2001b; Feyrer et al. 2006a; Jeffres et al. 2008).

The largest remaining floodplain-like habitats in the Central Valley are the flood bypasses, designed to divert floodwaters from the Sacramento, Feather, and American Rivers away from downstream population centers (Sommer et al. 2001b; Feyrer et al. 2006a). As such, the flood bypasses mimic some aspects of biologically defined floodplain habitat (e.g., seasonal inundation, shallow inundation, increased water residence time, productive foodwebs, rearing and spawning habitat for native fishes) but diverge in other aspects due to anthropogenic changes to the landscape. The bypasses are designed and maintained as flood conveyance channels, which severely limits hydrological and geomorphic processes as well as lateral connectivity to the rivers (Williams et al. 2009). Additionally, land use in the bypasses affects both hydrology, habitat types, and ecological processes normally associated with floodplains.

The Yolo Bypass floods, at least partially, in approximately 70 percent of years and can divert up to four times the flow of the Sacramento River, most of which flows over the Fremont Weir at the northern extent of the Yolo Bypass. Outside of the flood season, most land in the Yolo Bypass supports seasonal agriculture (e.g., sugar beets, rice, wild rice), while approximately one-third is maintained as wetland, riparian, and upland habitat for avian and wildlife species (Sommer et al. 2001b).

The Sutter Bypass floods, at least partially, in approximately 95 percent of years and receives water from Butte Creek, Feather River, and Sacramento River. The primary connection point to Sacramento River is Tisdale Weir, which on average spills 43 days per year (DWR 2020). Like in Yolo Bypass, land use in Sutter Bypass is a mix of agriculture (primarily rice farming), managed wetlands, and wildlife areas/refuges. Unlike the Yolo Bypass, Sutter Bypass is a primary migration corridor for Chinook salmon; Butte Creek fall-run Chinook salmon and spring-run Chinook salmon pass through the bypass on their journey to and from the ocean.

Emigrating juvenile Chinook salmon from the Sacramento River and Feather River can access the flood bypasses during the flood stage, when flood weirs or levees are spilling, or through the southern terminus of both bypasses, which are permanently connected to the Sacramento River. Studies have shown that the flood bypasses provide suitable juvenile Chinook salmon rearing habitat with higher prey densities than the adjacent Sacramento River (Sommer et al. 2001b, 2001c, 2005; Henery et al. 2010). While it has been hypothesized that juvenile Chinook salmon rearing in the bypasses incur survival benefits during outmigration and in the ocean due to higher growth rates, this has yet to be proven (Sommer et al. 2001b; Takata et al. 2017). Nonetheless, juvenile Chinook salmon rearing in the Yolo Bypass supports increased life history diversity, providing resilience for Central Valley Chinook salmon populations in the face of variable and uncertain environmental conditions (Takata et al. 2017; Goertler et al. 2018b).

2.2.1 Physical Habitat Loss or Alteration

Sacramento splittail are obligate floodplain spawners, and splittail spawning and rearing has been documented in the flood bypasses (Feyrer et al. 2006a). Splittail recruitment has been documented to correlate with inundated habitat in Yolo Bypass (Feyrer et al. 2006b). However, there is still uncertainty whether certain micro-habitat types within the flood bypasses are preferred for spawning and rearing (Moyle et al. 2004).

Relatively little is known about micro-habitat use or preference of juvenile salmonids rearing in the flood bypasses. Using purse seine sampling, Sommer et al. (2005) found juvenile salmon across all habitat types (“natural,” “riparian,” and “agricultural”) in Yolo Bypass, but they only caught juvenile salmon in what was characterized as "low velocity areas." More recent work has shown that flooded agricultural fields in Yolo Bypass provide for high productivity of food resources (Corline et al. 2017; Jeffres et al. 2020) and rapid growth of hatchery fish released into the fields (Katz et al. 2017). It is reasonable to assume that restoring more natural floodplain habitat types in the flood bypasses would provide benefits to a suite of native aquatic and terrestrial species. However, it is unknown whether the current composition of habitat types is a limiting factor for juvenile salmon at present inundation regimes.

Due to the direct relationship between flow, connectivity, and fish access to the bypasses and inundated habitat, it is questionable whether physical rearing habitat (as opposed to inundating flows) within the bypasses is a limiting factor, as flow creates both access and habitat (DWR and Reclamation 2012).

2.2.2 Ecosystem Productivity and Food Supply

When inundated, the flood bypasses are extremely productive and support both in-situ rearing of juvenile fish and foodweb exports to downstream habitats (Sommer et al. 2001c; Benigno and Sommer 2008; Cordoleani et al. 2022; Sturrock et al. 2022). Ecosystem productivity is therefore not considered a limiting factor within the flood bypasses themselves. However, the productivity of the bypasses is affected by the lack of connectivity to the river, which is discussed in more detail below in Section 2.2.4, *Habitat Connectivity*.

2.2.3 Water Quality

Temperature and dissolved oxygen are primarily determined by season and flow, but drainage of rice fields and managed wetlands can exacerbate conditions, causing dissolved oxygen to decrease and water temperatures to increase (DWR 2019a). Optimal ranges for temperature and dissolved oxygen for salmonids (State Water Board 2017) are regularly exceeded when salmonids are present in the bypasses.

Presence of contaminants in Yolo Bypass is well documented in the literature (Smalling et al. 2007; Orlando et al. 2020), and bioaccumulation of methylmercury (Henery et al. 2010) and pesticide residues have been discovered in juvenile Chinook salmon in the Yolo Bypass (Anzalone et al. 2022). Contaminant loading in the Sutter Bypass and Butte Sink is largely unknown and should be explored. Research in Yolo Bypass showed an increase in methylmercury concentration in water, foodwebs, and fishes in agricultural wetlands as compared to permanent and seasonal wetlands, suggesting that water management within the bypass plays an important role in mercury cycling (Windham-Myers et al. 2014) as higher water temperatures and increased water residence time increases methylation. DWR (2019b) expects increased methylmercury production in Yolo Bypass because of Fremont Weir notch operations that would increase the extent and duration of shallow inundation. Conversely, increased Sacramento flow is expected to decrease concentrations of current use pesticides through dilution and degradation, while potentially increasing mobilization of legacy contaminants (DWR 2019b). The potential impacts of elevated contaminant levels are discussed in Section 4.3.1 of the 2017 Scientific Basis Report.

2.2.4 Habitat Connectivity

The primary ecosystem stressor in the flood bypasses is connectivity, both onto and off of the flood bypasses but also within the flood bypasses (Feyrer et al. 2006a; DWR and Reclamation 2012; DWR 2019b). Connectivity between the rivers and the flood bypasses is limited by dam operations, levees, and flood control weirs that all reduce the inundation frequency and duration, as well as inhibit fish passage into and out of the bypasses. This lack of lateral connectivity prevents juvenile Chinook salmon from accessing approximately 75,000 acres of productive rearing habitat in Yolo Bypass and Sutter Bypass alone. Therefore, it is not necessarily a lack of floodplain-like habitat that is the limiting factor in terms of rearing habitat, but rather access to that habitat. Improving connectivity by increasing both the frequency and magnitude of flow entering the flood bypasses will also directly facilitate increased frequency and duration of inundated habitat, which is a secondary ecosystem stressor.

For adult salmon and other native migratory species, the lack of lateral connectivity means that individuals can become stranded or experience migratory delays when entering the flood bypasses. Adult salmon have been observed in Yolo Bypass from August to June and in Sutter Bypass from September to June. Stranding or migratory delays are risks during both low-flow conditions and flood events. As both flood bypasses are connected to the Sacramento River at their southern terminus, fish can enter dead-end sloughs in the flood bypasses during low-flow conditions when the weirs are not spilling. The exceptions to this are Butte Creek salmon in Sutter Bypass and, to a lesser extent, Putah Creek salmon in Yolo Bypass, as they rely on the bypasses as primary migration corridors to reach their native streams. During high-flow events, migratory fishes can become stranded as floodwaters recede and the flood control weirs stop spilling. Sturgeons have difficulty navigating the weirs, and the altered hydraulics and presence of barriers throughout the bypasses result in the stranding of both native and nonnative fish species (CDFW 2016a).

The lack of connectivity between the bypasses and the river prevents juvenile Chinook salmon from accessing rearing habitat and causes fish passage delays and stranding of all life stages for multiple species (CDFW 2016a, 2017). Water operations and water management infrastructure within the bypasses can also affect fish passage either by (1) directly impeding fish passage because of infrastructure or low flows, or (2) creating unnatural attraction flows, resulting in fish stranding in canals, fields, or wetlands (CDFG 2012; CDFW 2022a; Gahan 2016). Several projects have been or are being implemented to increase fish passage at Fremont Weir and Sacramento Weir in Yolo Bypass and at Tisdale Weir in Sutter Bypass. However, it is not likely that these projects alone will eliminate the connectivity and fish passage issues in the flood bypasses. Significant resources have been allocated to prevent adult migratory fishes from straying into the Colusa basin since 2012, primarily by constructing a fish exclusion barrier at Knights Landing Outfall Gates and a migration barrier and fish salvage facility at Wallace Weir. CDFW is conducting fish rescues in the flood bypasses in most years and is operating a permanent fish salvage facility at Wallace Weir in the northwestern end of Yolo Bypass. Fish rescued or salvaged in the flood bypasses are relocated back to the river. The survival, fitness, and reproductive success of rescued salmonids and sturgeons are subject to ongoing investigation (CDFW 2016a, 2022b).

The primary ecosystem stressor for fish once they enter the bypasses is reduced connectivity caused by physical infrastructure (e.g., weirs, berms, rice checks, drainage canals), water management, invasive aquatic weeds, and water quality. Stranding is primarily observed around human-made infrastructure (Sommer et al. 2005; CDFG 2012; CDFW 2016a, 2022a; Gahan 2016), but data collection is limited by access and timely surveys of the expansive areas of the bypasses. It is reasonable to assume that the documented fish stranding is a small proportion of the true number of fish that are lost in the bypasses. Studies investigating movement of adult fall-run Chinook salmon and white sturgeon (Johnston et al. 2020) determined that although a majority of fall-run Chinook salmon entering the Yolo Bypass exited the bypass again volitionally, white sturgeon were less likely to do so. Even when fish successfully exit the flood bypasses, it is unknown how the migratory delay affects their survival, fitness, and reproductive success. It is therefore critical that improvement, enhancement, or restoration actions in the bypasses account for both juvenile and adult life stages, particularly for Chinook salmon, Central Valley steelhead, green sturgeon, white sturgeon, splittail, and Pacific lamprey.

Reduced frequency and inundation of the flood bypasses also affect primary and secondary productivity, thereby reducing not only aquatic ecosystem foodweb productivity within the bypasses but also export of energy to downstream habitats (Lehman et al. 2008a). Numerous research studies are investigating the potential to increase transport of productivity from floodplains and agricultural areas to downstream habitat (Sommer et al. 2020b; Frantzich et al. 2021; Sturrock et al. 2022), but these are still in pilot phases and have yet to be proven effective at scale.

2.2.5 Invasive Species

Water hyacinth (*Eichhornia crassipes*) and water primrose (*Ludwigia peploides*) are rapidly expanding in both bypasses, clogging perennial canals and fish passage infrastructure, thereby limiting or blocking fish passage. The issue of nonnative plants is discussed in more detail in Section 4.4.3, *Aquatic Plants*, of the 2017 Scientific Basis Report (State Water Board 2017).

It is currently unknown if or to what extent predation by native (chiefly Sacramento pikeminnow) and nonnative (chiefly striped bass, catfishes, and black bass) fishes is an ecosystem stressor in the flood bypasses. Sommer et al. (2001b) hypothesized that predator encounters may be lower in the Yolo Bypass during flood conditions. Unpublished data suggest that as flow decreases and temperature increases, survival of juvenile Chinook salmon decreases, probably due to some combination of, or even interaction between, reduced connectivity, increased predation, and poor water quality conditions. Predation is likely situational and dependent on environmental conditions (Ward and McReynolds 2004). This ecosystem stressor warrants further investigation.

2.3 San Francisco Bay/Sacramento-San Joaquin Delta Estuary

Native species in the Bay-Delta are affected by numerous anthropogenic stressors that limit their population viability (State Water Board 2017).

2.3.1 Physical Habitat Loss or Alteration

As discussed in the 2017 Scientific Basis Report (State Water Board 2017), loss of habitat is a major stressor on all species within the Bay-Delta. The Delta historically had complex water channels with 450,000 acres of expansive wetland habitat, formed over time as floodwaters met the tides (Whipple et al. 2012; Robinson et al. 2014). These wetlands were bordered by riparian forests and grasslands, with transitional zones connecting the aquatic and terrestrial habitats. These habitats are important pieces in the Bay-Delta's ecology, as they provide myriad functions for wildlife including shelter, foodweb productivity, and landscape resiliency in the face of climate change and other anthropogenic changes (Lehman et al. 2010; Whipple et al. 2012; Brown et al. 2016a; Frantzich et al. 2018).

These expansive wetlands and connected terrestrial and riverine habitats have been mostly lost in the modern Delta. Major alterations include land conversion, subsidence, altered hydrology, channelization, and many other stressors. Tidal wetlands have experienced a 98-percent loss, dendritic channels a 93-percent loss, and seasonal wetlands an 85-percent loss (Robinson et al. 2014). The San Francisco Estuary Institute's *Delta Transformed* (Robinson et al. 2014) describes the historical state of the Delta and the changes it has undergone in detail.

Loss of non-flow habitat is intertwined with all the other stressors, including flow, because habitat is defined as the suite of environmental parameters in which a species can live. Loss of habitat includes not only the destruction of physical habitat features—including through draining wetlands, channelizing sloughs, stabilizing banks, and cutting off floodplains—but also the alteration of natural processes that result in optimal water quality conditions. Reduction in flow disconnects patches of habitat from each other, limiting transport of food and sediment to downstream habitats as well as preventing migrating species from finding appropriate refuge habitats (Keeley et al. 2022). Removal of vegetation increases water temperatures (Crepeau and Miller 2014), changes topographic heterogeneity (Morzaria-Luna et al. 2004), and alters substrate characteristics (Baldwin et al. 2001; Sloey et al. 2015). Chinook salmon and steelhead rearing and foraging in the Bay-Delta use cover (e.g., vegetation, woody debris) to avoid detection by and contact with predators. For example, emigrating Chinook salmon juveniles' use of natural shorelines compared with shorelines consisting primarily of rock revetment is significantly higher (Hellmair et al. 2018). Shoreline development has reduced juvenile Chinook salmon and steelhead access to floodplain rearing habitat in the Bay-Delta (Boughton and Pike 2013).

Restoration of habitat in other systems has had measurable effects on populations of native fish species, though results vary widely (Roni 2019). For example, an intensive program of wetland and off-channel habitat restoration in the Colombia River estuary resulted in increased juvenile salmonid abundance, increased food resources, and increased growth (Diefenderfer et al. 2016). Watershed restoration in Puget Sound has resulted in 2 to 5 times higher density of salmon and steelhead parr and smolts; however, with limited restoration area, this has only resulted in an estimated 5- to 7-percent increase in population (Roni et al. 2010)

Since 2017, there has been significant progress on tidal wetland restoration. The 2008 BiOp for the SWP and CVP operations required 8,000 acres of tidal wetland to be built in the Delta to address the decreased productivity (USFWS 2008). To date, 4,074 acres of tidal wetland restoration have been completed and an additional 2,975 acres are under construction. Monitoring associated with these restoration sites is starting to evaluate the benefits of these sites for native fish species, including invertebrate production, physical habitat, and refuge from predation (Tidal Wetlands PWT 2017; Contreras et al. 2018; Hartman et al. 2019, 2022a). Recent research has identified that tidal wetland channels are used by longfin smelt as spawning and rearing habitat (Grimaldo et al. 2017). Spawning of longfin smelt can occur in tidal wetlands—including tributaries of the San Francisco Bay, Suisun Marsh, wetlands bordering Suisun Bay, the Cache Slough Complex, and the central and western Delta—when conditions are appropriate (Rosenfield and Baxter 2007; Merz et al. 2013; Grimaldo et al. 2017).

Estuarine wetlands are particularly important for rearing Chinook salmon. In the Pacific Northwest there is a long history of wetland restoration to benefit salmon, where wetland restoration has been conclusively linked to increased salmon population resiliency (Simenstad and Cordell 2000; Gray et al. 2002), mostly through increased foraging ability in tidal wetlands (David et al. 2016; Diefenderfer et al. 2016). In the Bay-Delta, the Delta was previously thought to have relatively low survival rates compared to other parts of the Central Valley, so moving juvenile salmonids through the Delta as fast as possible was preferred (Baker and Morhardt 2001). However, recent research has found it is an important rearing habitat in a variety of water year types (Phillis et al. 2018), particularly in tidal slough complexes (Goertler et al. 2018a, 2018b). Use of wetland habitat provides important foraging opportunities for these fishes and increases the life history diversity of the population (Goertler et al. 2018b; Sommer et al. 2001c), and survival in the freshwater portion of the Delta may be higher than in the mainstem Sacramento River or the brackish water reaches of the Bay-Delta (Michel et al. 2015). Increasing habitat heterogeneity and life history diversity are important components in increasing the resiliency of Central Valley Chinook salmon populations, especially in the face of climate change (Goertler et al. 2017; Herbold et al. 2018). For example, during the 2012–2015 extreme drought, tidal sloughs of lower Yolo Bypass and the Cache Slough Complex supported large numbers of rearing salmon, which benefited from abundant food resources and higher feeding success (Goertler et al. 2018a). Similarly, using otolith analyses, Miller et al. (2010) suggested that estuary rearing was more important than originally thought, with evidence of prolonged rearing in brackish water in parr, smolt, and fry.

2.3.2 Ecosystem Productivity and Food Supply

Decreased food supply has been identified as a major stressor on fish populations. Primary productivity within the Bay-Delta has declined from historical levels, leading to declines in secondary production, including zooplankton and other key sources of fish food (Kimmerer et al. 1994; Orsi and Mecum 1996; Cloern et al. 2016). The Pelagic Organism Decline of the early 2000s had numerous interacting causes, but limited food supply was identified as one of the major factors causing the decline (Sommer et al. 2007; Mac Nally et al. 2010). Delta smelt are food-limited across much of their range (Hammock et al. 2015), and the copepods and mysids that Delta smelt eat may also be food-limited (Orsi and Mecum 1996; Kimmerer et al. 2005; Gearty et al. 2021).

Primary productivity within the Bay-Delta is subject to greater seasonal and interannual variability than in other estuarine and coastal systems (Cloern and Jassby 2010), and productivity in the Bay-Delta is much lower than in other estuaries with similar nutrient regimes (Cloern 2001). It is likely that phytoplankton production within the Delta has always been low in comparison to other estuaries, with much of the primary productivity coming from the historically extensive tidal wetlands (Whipple et al. 2012; Cloern et al. 2016). After the draining and conversion of most of the tidal wetlands within the Delta, this source of primary productivity was cut off, and the highly variable phytoplankton chlorophyll productivity was limited by the high turbidity of Delta waters. Productivity in Suisun Bay and the low-salinity zone further declined after arrival of the invasive overbite clam *Potamocorbula amurensis* in 1986, which has been linked to numerous phytoplankton and zooplankton declines (Kimmerer et al. 1994; Greene et al. 2011; Kimmerer and Lougee 2015; Lucas et al. 2016).

Much of the tidal wetland restoration being undertaken in the Delta is designed to reverse these trends by restoring high-productivity shallow-water habitat that was hypothesized to provide a subsidy of production to surrounding deep-water habitats (Cloern 2007; USFWS 2008). Research on tidal wetlands has evolved since this restoration was mandated, and the current conceptual model focuses more on increased opportunities for fishes to access wetlands and forage within the tidal excursion of the sites (Sherman et al. 2017), because net export of production from wetlands is highly variable (Lehman et al. 2010; Kimmerer et al. 2018a; Yelton et al. 2022). However, even with this caveat, wetland habitat restoration may overall restore a modest portion of net primary productivity, with recent estimates of 12-percent recovery of historical primary productivity rates if planned habitat restoration goals are fully implemented (Cloern et al. 2021).

2.3.3 Water Quality

Estuarine fish habitat has two components. The first is the *stationary habitat* described in Section 2.3.1, *Physical Habitat Loss or Alteration*, such as tidal wetlands, channels, and off-channel habitat. The second is *dynamic habitat*, variable water quality parameters that allow optimal growth and survival within a given area of stationary habitat (Peterson 2003) (Figure 2-1). Variable habitat characteristics such as water temperature, turbidity, dissolved oxygen, pH, water velocity, food supply, and contaminant load influence the quality of habitat for fish (Sommer and Mejia 2013; Bever et al. 2016).

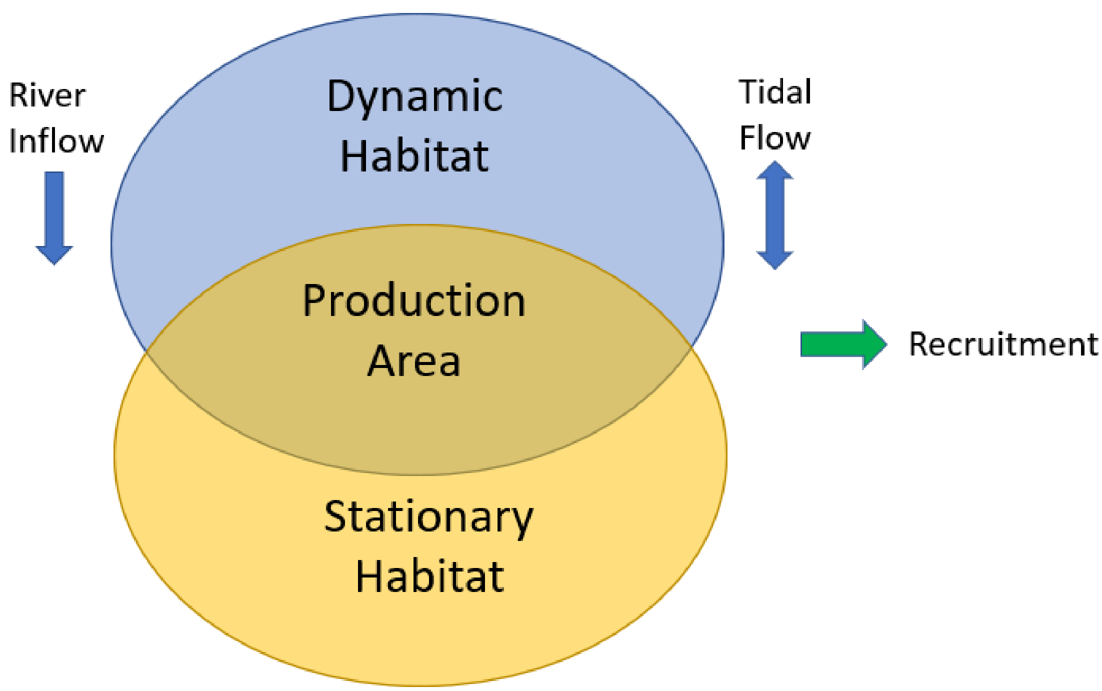

Figure 2-1. Conceptual Model of Dynamic Habitat (Water Quality) and Stationary Habitat (Physical Features) Coinciding to Produce Optimal Fish Production in an Estuary
Modified from Peterson (2003). Two overlapping circles show the production area, which is the intersection of stationary habitat (bottom circle) and dynamic habitat (top circle). An arrow on the left side shows decreasing unidirectional river inflow, an arrow on the top right side shows bidirectional tidal flow, and an arrow on the middle right side shows recruitment.

In the Delta, a declining trend in turbidity has limited the amount of optimal dynamic habitat available for native pelagic fishes (Schoellhamer 2011; Hestir et al. 2016; Work et al. 2020). Delta smelt prefer moderate-turbidity habitat, which allows them to forage efficiently and avoid predation (Hasenbein et al. 2013; Ferrari et al. 2014; Komoroske et al. 2016). Salmon also may use turbidity to avoid predation (Gregory and Levings 1998). However, the freshwater reaches of the Delta have become increasingly clear over time, which is attributed to a combination of decreased sediment supply due to upstream dams and increased coverage of submersed aquatic vegetation (Schoellhamer 2011; Hestir et al. 2016; Work et al. 2020). Turbidity is highly correlated with Delta outflow, with increasing water clarity under low-flow conditions (Livsey et al. 2021), and the decrease in turbidity has occurred most strongly in low-flow years (Stern et al. 2016). Extended shallow areas with high wind-wave activity, such as Grizzly Bay, also typically have higher-turbidity habitat than wide, deep channels (Bever et al. 2018). Modeling of climate scenarios suggests that an increased frequency and magnitude of large flow events (precipitation and precipitation variability) in the future may increase sediment transport into the Delta, increasing turbidity and habitat for native fishes (Stern et al. 2020).

Water temperature may be one of the crucial concerns for native aquatic species in the future. Climate change has increased the amount of time that the Bay-Delta is above the optimal temperature for many native fishes (Brown et al. 2016b; Bashevkin et al. 2022). For example, the high-flow year of 2017 was expected to provide good conditions for Delta smelt; however, their population continued to decline despite high flows, most likely due to high water temperatures (FLOAT-MAST 2021). Similarly, the area of Bay-Delta habitat exceeding the Delta smelt critical thermal maximum temperature increased by 1.5 square kilometers per year during 1985 to 2019 (Halverson et al. 2022). Under most climate change scenarios, droughts will become more severe and more frequent (Swain et al. 2018). While Delta inflow and water temperatures are negatively correlated most of the year (Bashevkin and Mahardja 2022), the extent to which inflow has a causal influence on water temperatures in the Bay-Delta is unknown. If inflow has a significant causal effect on water temperatures in the Bay-Delta, or if the causal driver of droughts is linked to water temperatures, more frequent droughts could lead to more frequent high temperatures, resulting in direct temperature stress and other temperature-related effects such as interactions with other stressors (Ghalambor et al. 2021; Herbold et al. 2022).

Water temperature conditions and salmonids' ability to access refuge in the Delta have impacts on rearing and migrating. Increases in water temperature increase the bioenergetic needs of the Delta fish community assemblage, and temperature thresholds play a role in establishing metabolic rates (reviewed by Richter and Kolmes 2005). For example, growth and consumption rates of striped bass, a widely distributed salmonid predator, increase with increasing temperatures within their thermal tolerance (Person-Le Ruyet et al. 2004). Largemouth bass have been shown to tolerate higher water temperatures than native fishes like Delta smelt (Davis et al. 2019a), and salmonids are sensitive to increasing water temperature conditions (review by Richter and Kolmes 2005). Largemouth bass consume Chinook salmon at significantly higher rates with increasing temperature, and when temperatures exceed 20°C (68°F), juvenile Chinook salmon survival in the Delta declines rapidly (Nobriga et al. 2021). Refuge habitats that provide relief from extreme temperatures will become more integral for a population's overall success. Occasional stratification may provide some refuge to fishes that can inhabit cooler bottom waters during these periods. For example, stratification was detected at levels that could be protective of Delta smelt in the Sacramento Deepwater Ship Channel (Mahardja et al. 2022).

As discussed in Section 4.3.1 of the 2017 Scientific Basis Report (State Water Board 2017), contaminant loading from urban and agricultural pesticides likely influences both fish and invertebrate health and abundance (Hammock et al. 2015; Hasenbein et al. 2018; Teh et al. 2019), but the extent to which this translates to population-level limitation remains unknown (Fong et al. 2016; Hasenbein et al. 2018; Connon et al. 2019). Concentration of contaminants is usually highest during high-flow events when runoff from urban and agricultural sources transport contaminants into the waterways (Weston et al. 2015).

2.3.4 Harmful Algal Blooms

Along with anthropogenic contaminants, toxins produced by harmful cyanobacterial blooms (cyanoHABs) may be limiting native aquatic species. As discussed in the 2017 Scientific Basis Report (State Water Board 2017), cyanoHABs have been occurring in the Delta with increasing frequency and severity since the turn of the century. Cyanobacteria are photosynthetic bacteria that occur as components of phytoplankton communities in all the world's waterbodies. Many taxa are harmless, but some species may produce harmful chemicals (cyanotoxins), and some can form toxic blooms in freshwater and brackish ecosystems. Many cyanobacteria genera can form cyanoHABs, including *Anabaena*/*Dolichospermum*, *Aphanizomenon, Cylindrospermopsis, Oscillatoria*, *Microcystis*, and *Planktothrix*.

Environmental conditions favoring the formation of cyanoHABs typically include calm and stratified water, warm water temperatures, high availability of light, and an ample supply of nutrients (Paerl et al. 2011; Huber et al. 2012; Lehman et al. 2013, 2018; Berg and Sutula 2015). In the Delta, cyanoHABs are found most frequently in dry years (Hartman et al. 2022b; Lehman et al. 2022). The most successful strategies for mitigating cyanoHABs have focused on these environmental factors, including increasing the flow of water, promoting mixing of the water column, and reducing the supply of nutrients (Paerl et al. 2011).

Blooms of the toxin-producing cyanobacteria *Microcystis* sp. have been observed in the Delta since the late 1990s by researchers from DWR and other agencies. These blooms were first documented visually as small, lettuce-like flakes in the water (Lehman and Waller 2003). The blooms were initially classified as *Microcystis aeruginosa*; however, this morphospecies has since been found to comprise multiple strains, so it is referred to here by genus rather than by species (Otten et al. 2017; Pérez-Carrascal et al. 2019). Studies of these blooms demonstrated that they contain multiple variants of microcystin, which act as liver toxins (Lehman et al. 2005), and the presence of low concentrations in the Delta is a cause for concern. Investigations have found that the blooms frequently are composed of a mix of *Aphanizomenon* sp., *Microcystis* sp., *Dolichospermum* (formerly *Anabaena*) sp., *Planktothrix* sp., and *Pseudoanabaena* sp. (Lehman et al. 2010; Mioni et al. 2012); however, research to date has focused primarily on *Microcystis*.

Regionally, the central and south Delta have historically had the highest surface concentrations of *Microcystis* and *Aphanizomenon* (Lehman et al. 2008b, 2013, 2018; Mioni et al. 2012; Berg and Sutula 2015). Starting in 2012, very high abundances of *Microcystis* colonies were observed in the south-east Delta region in the Turning basin of the Stockton Shipping Channel, in Discovery Bay, and at Rough and Ready Island (Spier et al. 2013; Lehman et al. 2018). *Microcystis* abundance is typically much lower in Suisun Bay west of Antioch and north of Collinsville on the Sacramento River (Lehman et al. 2005, 2008b, 2013, 2018; Mioni et al. 2012).

Since the 2017 Scientific Basis Report, there has been increased monitoring of cyanobacteria in the Delta, including regular visual assessments by fish and water quality monitoring surveys, Fluoroprobe data collection, regular monitoring for cyanotoxins at cyanoHAB hot spots (e.g., East Bay Regional Parks at Big Break and Restore the Delta in Stockton), and the expansion of the State Water Board's Freshwater and Estuarine HAB Program to coordinate cyanoHAB monitoring.[2] It is still unknown whether cyanoHABs are having significant population-level effects on fish and wildlife in the Delta (though there is extensive evidence for effects at the individual level; see Acuña et al. 2012a, 2012b; Kurobe et al. 2018; Ger et al. 2018). However, cyanoHABs are a serious problem for residents of and visitors to the Delta. CyanoHABs regularly occur at the boat launch at Big Break Regional Shoreline (a popular recreation area), the Port of Stockton waterfront, Discovery Bay, and other local parks and marinas (State Water Board 2022). These occurrences impact recreational use of the Delta, human and pet health, and the health of fish and wildlife. Regular cyanotoxin monitoring at the State Water Project facilities ensures dangerous levels of cyanotoxins do not enter the water supply, however many smaller water intakes are not monitored. CyanoHABs during 2021 and 2022 in the central Delta also caused taste and odor issues for Contra Costa Water District, causing them to change their intake points (Hartman et al. 2022b).

2.3.5 Habitat Connectivity

The Sacramento River watershed's riverine habitat has become highly modified and simplified, influenced by water withdrawals and an expanding human footprint both in the Central Valley and elsewhere in California. Construction of levees and maintenance projects have disconnected rivers from the floodplain, an important habitat for outmigrating Chinook salmon and steelhead that provides habitat connectivity and complexity between the river and the Bay-Delta. Over time, this modification has created a degraded and simplified aquatic habitat for all life stages of Chinook salmon and steelhead. As Chinook salmon and steelhead migrate from the upper watershed through the middle Sacramento River, they experience unidirectional riverine flows. However, once they enter the Delta, bidirectional flows created by tidal influence make the relationship between flow and migration (and subsequently routing and survival) more complex (Zabel et al. 1998; Smith et al. 2002; Perry et al. 2018).

For anadromous and semi-anadromous species, the loss of habitat combined with changes in flow has resulted in altered habitat connectivity (Keeley et al. 2022). The remaining wetland habitat is highly fragmented, meaning migratory species have few opportunities to rest and grow on their way to the ocean. Migrating through the main channels of the Delta, which are mostly lined with rip-rap, provides opportunities for predators to prey upon juvenile salmonids.

Changes in the Central Valley have decreased habitat connectivity for Chinook salmon and steelhead. Historical records from monitoring locations indicate winter-run Chinook salmon juveniles begin entering the Delta in October, continuing until April. The timing of smolt outmigration to the Delta is correlated with pulse flows that occur in the Sacramento River (del Rosario et al. 2013). Fry and smolt that are cued to migrate by traveling downstream may spend time foraging and rearing in the Bay-Delta before entering the ocean (Sturrock et al. 2015), including in the tidal sloughs of the Yolo Bypass (Sommer et al. 2001c, 2005; Goertler et al. 2017). Changes to flows through the upper and middle Sacramento River alter migration cues, which are dampened by a decrease in flow. Additionally, decreased flow may shift the timing of Delta and ocean entry, causing some proportion

[2] https://www.waterboards.ca.gov/water_issues/programs/swamp/freshwater_cyanobacteria.html

of a population to be exposed to poor environmental conditions (e.g., when entry does not correspond with peak productivity or corresponds to times when temperatures in the Delta are too high), which can change population-level mortality rates (Weitkamp et al. 2015; Notch et al. 2020; Singer et al. 2020). By using flow actions to connect wetland and floodplain restoration sites within the Sacramento basin, North Delta, and Suisun March, fish will have greater access to highly productive rearing habitat that may increase their likelihood of survival.

2.3.6 Invasive Species

Invasive fishes, zooplankton, benthic invertebrates, aquatic vegetation, and phytoplankton are all sources of stress for native species in the Bay-Delta. For example, invasive fishes make up 60 percent to 90 percent of individual fishes in the freshwater Delta (Brown 2003). Many of these introduced, invasive fishes are from the southeastern United States and have been thriving in the Bay-Delta where flows have been altered, water temperatures are warming, and vegetation is spreading (Conrad et al. 2016; Young et al. 2018). This topic is covered extensively in the 2017 Scientific Basis Report, but there are a few notable updates.

The degree to which predation by invasive fishes has a population-level effect on salmonids and smelt remains contentious, but additional research is helping to determine locational and water quality predictors of predation events. Michel et al. (2020a) identified several areas along the lower San Joaquin River, Mildred Island, and Old River as particularly hazardous for juvenile salmon. Temperature, turbidity, and presence of invasive weeds are still considered major factors in probability of predation events (Michel et al. 2020a; Nobriga et al. 2021), and more study is needed on the impact of artificial structures and lighting in altering predation dynamics (Lehman et al. 2019). Restoration of tidal wetlands and riparian areas may help to mitigate the effects of predatory fishes, but only if these areas do not become filled with submerged aquatic vegetation. An increase in flows may provide relief from predation pressures by mobilizing increased sediment load into and within the Delta and decreasing the number of fish routing through the central Delta and south Delta, where temperatures are higher, turbidity is lower, and predation is higher (Perry et al. 2018; Michel et al. 2020a).

Section 4.4.1 of the 2017 Scientific Basis Report recommends assessing the cost-effectiveness of not salvaging nonnative species from fish rescue facilities at the CVP and SWP (State Water Board 2017). Mahardja and Sommer (2017) found that removing nonnative striped bass at the salvage facilities was not likely to have an impact on the population. Experimental removal of predatory fishes has also been relatively ineffective on the large scale (Michel et al. 2020b), though more effective in closed systems such as the Tracy Fish Collection Facility (Bridges et al. 2019).

Mahardja et al. (2020) also documented an invasive fish that has recently become established in the Delta, the bluefin killifish (*Lucania goodei*). However, it is currently unknown what effect this invasive fish might have on native fishes.

Nonnative aquatic vegetation has remained high since the 2017 Scientific Basis Report and continues to alter water quality for pelagic fishes (Hestir et al. 2016); provide habitat for nonnative fishes, including black bass and striped bass (Conrad et al. 2016); increase predation risk by decreasing turbidity (Ferrari et al. 2014; Hestir et al. 2016; Work et al. 2020; Michel et al. 2020a); and block waterways (Caudill et al. 2021). Previous research hypothesized that the increase of submerged aquatic vegetation between 2014 and 2016 was caused by drought conditions

(Kimmerer et al. 2019), but wet years of 2017 and 2019 did not reduce submerged aquatic vegetation coverage (Hartman et al. 2022b; Khanna et al. 2022).

Nonnative invertebrates continue to dominate the zooplankton community. The nonnative mysid *Hyperacanthomysis longirostris* is smaller and therefore less nutritious than the native mysid *Neomysis mercedis*, but it has dominated over the past 20 years potentially due to its smaller size at maturity and higher temperature tolerances (Avila and Hartman 2020). Other nonnative zooplankters, such as the copepod *Pseudodiaptomus forbesi*, have replaced native copepods in the diets of Delta smelt (Slater et al. 2019; Jungbluth et al. 2021), though *Eurytemora affinis* is still important in diets of longfin smelt in the south San Francisco Bay (Jungbluth et al. 2021; Barros et al. 2022).

The invasive clams *Potamocorbula amurensis* and *Corbicula fluminea* still dominate the benthic community, and abundances of *Potamocorbula* in the brackish regions of the Bay-Delta (Suisun Bay and Suisun Marsh) have increased dramatically since 2000 (Crauder et al. 2016). However, *Potamocorbula* is much less abundant in the smaller sloughs in Suisun Marsh than in the larger sloughs (Baumsteiger et al. 2017), providing hope that restoration in smaller sloughs may be more effective at increasing primary productivity without that productivity being consumed by clams.

2.4 Systemwide Stressors

Native fish species are affected by some stressors throughout the Central Valley within the tributaries and the Bay-Delta. These stressors affect fishes across life stages to varying degrees. Four such stressors are direct take, disease, thiamine deficiency, and climate change.

2.4.1 Direct Take

Direct take of native fish species occurs chiefly through fishing (salmonids and sturgeon) and entrainment in water diversions (all species). Flow actions may transport fish past areas where they are subject to entrainment, thereby reducing entrainment risk. Creation of habitat in the form of restoration sites may provide resting areas for rearing and foraging fish away from diversions. The 2017 Scientific Basis Report (State Water Board 2017) discussed factors affecting entrainment both at unscreened, smaller diversions upstream of the Bay-Delta and at the major SWP and CVP facilities in the Delta.

The degree to which these sources of direct take are ecosystem stressors limiting fish population growth is the topic of debate, and likely varies by species. Kimmerer and Rose (2018) found that Delta smelt population growth rates could be increased by as much as 39 percent if entrainment-related mortality was removed. However, a recent model of longfin smelt found that entrainment-related mortality only accounted for up to 1.5 percent of the population (Kimmerer and Gross 2022). A separate study estimated that proportional entrainment was negligible in extreme wet years, and approximately 2 percent in a moderately dry year (Gross et al. 2022). Changes to water project operations to be more protective of native fishes has reduced salmonid take considerably and use of improved modeling has the potential for reducing entrainment still further (Tillotson et al. 2022).

Varying levels of flow can cause juvenile salmonids migrating down the mainstem Sacramento River to be routed through different pathways, some more optimal than others for fish survival and eventual entrainment (Perry et al. 2018; Hance et al. 2022; Singer et al. 2020). Entry into the interior Delta increases with decreasing Sacramento River flow (Perry et al. 2018; Hance et al. 2022). Entry into the Delta Cross Channel and Georgiana Slough routes salmonids into the central and interior Delta, an area with decreased survival rates compared to the mainstem Sacramento River and the Delta (Brandes and McLain 2001; Newman and Brandes 2010). Sacramento River origin fish entering the interior Delta have greater potential to move into the hydrodynamic footprint of the SWP Banks and CVP Jones pumping plants and will experience net reverse flows if entering the Old and Middle River corridor. Reverse flows in this corridor may result in an increased travel time, indirect mortality through predation, and mortality through direct loss at the Delta fish collection facilities (see summary by Vogel 2011:103–105).

2.4.2 Disease

Disease is a growing concern in the Sacramento River and its tributaries, particularly for Chinook salmon (Foott 2014, 2016, 2017; Lehman et al. 2020). Susceptibility of fishes to disease is related to several factors that occur in the environment, including fish species and their densities, water quality conditions, decreased flows, and densities of pathogens in the environment (Foott 2017). Although pathogens occur naturally in the environment, the operations of dams may have produced environmental conditions where fish are more susceptible to disease (NMFS 2016). Impediments to upstream migration and lack of sufficient flow can delay upstream migration and increase residence time, thereby increasing pathogen exposure and decreasing survival.

The National Wild Fish Health Survey is a program conducted by the U.S. Fish and Wildlife Service (USFWS) Fish Health Center to assess the prevalence and distribution of major fish pathogens in wild fish populations. One focus of the California/Nevada Fish Health Center's National Wild Fish Health Survey efforts was with juvenile fall-run Chinook pathogens (particularly *Ceratonova shasta* and *Parvicapsula minibicornis*), smolt development (gill sodium-plus-potassium adenosine triphosphatase [Na,K-ATPase] activity), and response to organophosphates (brain acetylcholinesterase [AChE] activity) in the Sacramento River. In 2013, 2014, 2015, and 2016, *Ceratonova shasta* infection was detected in juvenile Chinook salmon collected from the lower Sacramento River. In 2014, 74 percent of Chinook juveniles examined were infected with *Ceratonova shasta* (Foott 2014). Research in the Klamath River has documented significant juvenile Chinook mortality in some years (Foott et al. 2004) and yielded a better understanding of the complex interaction of the parasite's life cycle (fish and polychaete worm hosts) with environmental factors such as temperature, flow, and nutrients (Stocking et al. 2006). The prognosis of myxosporean infections in natural Chinook and their effect on survival should be evaluated.

2.4.3 Thiamine Deficiency

Thiamine deficiency has emerged as a new stressor to California Central Valley Chinook salmon, resulting in significant early life stage mortality of salmon stocks (Mantua et al. 2021; NMFS 2021). Thiamine deficiency complex (TDC) was first discovered in California's Central Valley in early 2020 when hatcheries reported an increase in mortality of fall-run Chinook fry as well as unusual behaviors such as loss of appetite, lethargy, corkscrew swimming, impaired coordination, inability to remain upright, and excitability. Prior to 2020, TDC had not been diagnosed in California salmon.

Thiamine (also called vitamin B1) is an essential vitamin necessary for converting food into energy. Salmon cannot produce thiamine on their own and must acquire the compound through diet.

Thiamine deficiency, or a lack of thiamine, occurs when an organism cannot retain or take in enough of this vitamin through its typical diet to power vital body functions. In addition to the behavioral aberrations attributed to TDC, other physical abnormalities seen in fry include hydrocephalus (built-up fluid in the ventricles deep within the brain), vascular congestion, diminished yolk sac conversion efficiency, large yolk sacs with opacities, edema, and hemorrhaging (Fisher et al. 1995; Fitzsimmons et al. 2005; Harder et al. 2018). The impacts of these physical and behavioral defects lead to reduced disease resistance (Ottinger et al. 2012), growth (Fitzsimons et al. 2009), prey capture (Fitzsimons et al. 2009), and predator avoidance (Fitzsimons et al. 2009) that all influence survival. Fry with TDC can replenish their thiamine levels via their diet; however, survivors may have these ongoing sub-lethal effects. Lethal and sub-lethal effects of TDC have also been identified in adult salmonids that may cause unusual swimming patterns (Amcoff et al. 1998), reduced fitness (Houde et al. 2015), or reduced ability to ascend cascades during migration (Ketola et al. 2005).

In addition to being caused by a lack of thiamine in the diet, TDC can be caused by a diet of fishes high in thiaminase, an enzyme that destroys or inactivates thiamine in the gut of consumers. High thiaminase is common in fishes in the herring family (*Clupeidae*) (Lepak et al. 2013). Thiaminase was identified as the primary cause for the onset of TDC in Great Lakes and Baltic Sea salmonids (Brown 1998). It is hypothesized that TDC in California's Central Valley Chinook salmon is caused by consumption of prey fish with thiaminase I (NMFS 2021). Surveys in 2019 and 2020 found record-high abundances of northern anchovy (*Engraulis mordax*), a species that produces thiaminase I in its tissue, off the southern and central California coast (NMFS 2021). Early results suggest that Chinook salmon beginning in 2018 and continuing through 2020 had narrow diets dominated by anchovies that were high in thiaminase and lipids but low in thiamine relative to other prey species (Mantua et al. 2021).

While increased consumption of anchovies is currently thought to be the proximate cause, changes in the availability of environmental thiamine may also be involved. For example, environmental conditions in the marine foodweb producing less thiamine (Sanudo-Wilhelmy et al. 2012; Suffridge et al. 2018, 2020), adults experiencing conditions of oxidative stress (Vouri and Nikinmaa 2007), diets rich in fats causing perioxidation (Mikkonen et al. 2011; Keinanen et al. 2018), or additional toxicants (Lundström et al. 1999) could all be influencing thiamine pathways for salmon.

Since the diagnosis of TDC in Central Valley systems, thiamine treatments have been used at different life stages in hatcheries to increase egg thiamine concentrations and reduce both direct mortality and latent developmental effects. Thiamine injection treatments are given to returning adults before spawning and at fertilization, and eggs and fry are soaked in thiamine baths (Kwak 2019, 2022a; Foott 2020). For the spring-run Chinook salmon program at Feather River Hatchery, returning fish are tagged as spring-run Chinook salmon and released back into the river (Kwak 2022b). This tagging period provides an opportunity to inject these fish with thiamine prior to their spawning. Female winter-run salmon have also been treated with thiamine prior to spawning, which has resulted in significant improvements to egg thiamine concentration and survival of progeny (Bell 2022). In Central Valley fall-run Chinook salmon hatcheries, fish are spawned almost immediately upon entering the hatcheries so thiamine treatments have been given to eggs at fertilization to elevate egg thiamine levels, which has been shown to improve survival (Mantua et al. 2021; Reed et al. 2023).

Although treatments are now available to remedy and even prevent TDC in hatcheries, research into the causes of low overall thiamine levels for Chinook salmon is ongoing. Samples of eggs collected at the Central Valley hatcheries over the past few years have found that the impacts of TDC seem to vary between stocks (NMFS 2021) and potentially between years (Ward et al. 2022). There are currently little data on TDC presence in natural-origin salmonids in the Central Valley. Studies are ongoing to assess TDC in natural-origin fish in the ocean as well as the potential for treatment. In addition, studies of adult Chinook salmon in the ocean could provide some insight into the future of thiamine levels for returning adults (NOAA Fisheries 2020).

2.4.4 Climate Change

The effects of climate change will exacerbate all the above stressors in a variety of ways. Physical changes to ocean, river, and stream environments along the West Coast are predicted, including warmer atmospheric temperatures, diminished snowpack resulting in altered streamflow volume and timing, lower late-summer flows, a continued rise in stream temperatures, and increased sea-surface temperatures and ocean acidity, resulting in altered marine and freshwater food-chain dynamics (Herbold et al. 2022). Increased sea level-driven salinity intrusion may cause increased reservoir releases, reduced reservoir storage, depleted cold water pool, and higher riverine temperatures. Experts predict these changes in the hydrology and water temperature in the Central Valley, including the Bay-Delta, will have negative effects on future Chinook salmon populations (NMFS 2014; Lindley et al. 2009) and Delta smelt populations (Brown et al. 2016b; Halverson et al. 2022), as well as many other native California fishes (Moyle et al. 2013). Increases in air temperature directly affect water temperature, and with increased water temperature fish will have increased food needs. Food limitation may become more severe and predation pressure may also increase.

Drought years are predicted to occur with greater frequency in the Sacramento Valley with climate change (Swain et al. 2018). In the San Francisco estuary, the effects of recurring drought and drought-managed flows are likely to have outsized impacts on pelagic fishes, which have already seen marked declines, because these species do not recover from drought-managed flows in all years and littoral fishes are more resistant to conditions resulting from drought management (Mahardja et al. 2021).

Some effects of climate change are already being observed. Median annual freshwater flow in the Bay-Delta has not significantly changed over the past 100 years, though seasonal patterns have changed and there has been increased variability in current Delta outflow conditions compared with predevelopment flow conditions (Hutton et al. 2021). Bashevkin et al. (2022) reported a general warming pattern in water temperature for most months and areas modeled in the Bay-Delta over the past 50 years, noting spatio-seasonal variability in that pattern. Providing higher springtime flows and restoring physical habitats may be important components of increasing resiliency to these changes.

2.4.5 Cumulative Effects

Cumulative impacts on aquatic ecosystems can have profound and long-lasting effects on species and the environment. A study by Crain et al. (2008) found that the cumulative effects of multiple stressors will often be worse due to synergistic interactions between the stressors. These impacts can have cascading effects down the food chain and can manifest at multiple ecological levels, such as the individual, population, or ecosystem level, and responses can be additive, multiplicative, non-linear, or even delayed (Hodgson and Halpern 2019; Diefenderfer et al. 2021). Cumulative effects can be challenging to quantify because of the complex interactions between stressors, lack of data, and the multiple ways cumulative effects can manifest (Foley et al. 2017). As a result, cumulative effects are often described qualitatively by focusing on the relationships among stressors (Crain et al. 2008)

Many of the aquatic ecosystem stressors described in the section above interact with each other, creating cumulative impacts on native fish species. One example is the interaction between increasing water temperature and contaminants (Gandar et al. 2017; Fuller et al. 2022) in which both contaminant bioaccumulation and toxicity can increase with higher water temperatures (Patra et al. 2015). Increased water temperature can similarly affect predation risk for native species in the Bay-Delta (Marine and Cech 2004; Michel et al. 2020a; Nobriga et al. 2021). A synergistic effect of contaminants, predation, and water temperature was documented by McInturf et al. (2022) where metabolism of predators and contaminant accumulation in prey species increased with water temperature while predator avoidance in prey species declined due to contaminant accumulation, leading to an overall increase in predation rates.

2.5 Impacts of Aquatic Ecosystem Stressors on Tribal Uses of Water in the Bay-Delta

This documentation of TEK from California Native American tribes and analysis of the impacts of aquatic ecosystem stressors on tribal uses of water in the Bay-Delta watershed and its tributaries is intended to supplement the analyses of the Draft Supplement Report and the 2017 Scientific Basis Report.

The Sacramento-San Joaquin Delta was settled by California Native Americans over 5,000 years ago (Zedler and Stevens 2018). The San Joaquin River supported multiple villages of up to 200 people and a combined population of approximately 1,300 (Stuart 2016). Overall, the Delta may have supported a population of around 10,000 of the estimated 300,000 people inhabiting California before European settlement (Whipple et al. 2012). Many California landscapes were traditionally managed to improve yields of fish, wildlife, and plants. Stewardship practices often included performing fire management for riparian vegetation and food productivity, harvesting fish and other native species sustainably, and tending to the land to prevent the overgrowth of vegetation (Hankins 2018; Norgaard 2014). Colonization, genocide, and disease prevented Native Californians from continuing their land management practices and cultural ceremonies (Zedler and Stevens 2018; Norgaard 2014).

The relationship of many California Native American tribes to water is profound, with water considered the “backbone” of many tribal societies. Water is at the heart of traditional stories about human origins and spiritual passage as well as sacred in places used for story, ceremony, healing, and other purposes. Culturally, individuals or tribes may view themselves as belonging to the water and as stewards, which is distinct from the western notion of asserting individual ownership and dominion over natural resources (DWR 2009). This is true even in California, where water belongs to the people and therefore water rights are considered “usufructuary,” meaning that one has a right to the use and enjoyment of the resource without owning it, destroying it, or wasting its substance (Wat. Code § 102).

2.5.1 Culturally Significant Species in the Bay-Delta Watershed

Native fish species are culturally significant to many tribes in the Bay-Delta watershed. Delta smelt, Chinook salmon, and green sturgeon are important food species for the Plains Valley Miwok (Hankins 2018), and green sturgeon are also significant to the Yurok people (Ramos 2021). Salmon (called "NUR" by the Winnemem Wintu [Middle Water People]) are integral to the Winnemem Wintu's way of life in the McCloud River watershed. Their creation story tells of the connection between the Winnemem Wintu and the salmon, where the first humans had no voice until the salmon gave their voice to the people; from then on, the fish were silent and the Winnemem Wintu promised to always speak for them (Mulcahy pers. comm.). Salmon nourish their people and, in return, the people speak for, protect, and care for the salmon. The Winnemem Wintu have had a physical and spiritual connection with salmon for thousands of years (Middleton-Manning et al. 2018). Chinook salmon also play a significant role in the Karuk's creator story and have traditionally provided half of the diet for Karuk tribal members in California (Norgaard 2014; Long and Lake 2018). Prior to colonization by European settlers, fish species including pacific lamprey (*Entosphenus tridentatus*) and steelhead, coho (*Oncorhynchus kisutch*), sockeye (*Oncorhynchus nerka*), pink (*Oncorhynchus gorbuscha*), and Chinook salmon were abundant on Karuk tribal lands (Kondrashova 2020). The Karuk collectively imposed sustainable limits on harvests so that all tribes could depend on salmon as a primary food source (Norgaard 2014).

In addition to fish species, Native Californians likely harvested over 500 plant species from the Delta region (reviewed by Zedler and Stevens 2018). Along the San Joaquin River and its tributaries, people clustered near oak groves to harvest abundant acorns. The Northern Valley Yokuts gathered acorns and established territories for fishing, hunting, and gathering. They subsisted primarily on fish, fowl, acorns, and tule roots but also relied on freshwater bivalves, small mammals, corms, bulbs, grass, and forb seeds. California Native Americans also harvested plants for medicinal, spiritual, and ceremonial uses (reviewed by Zedler and Stevens 2018). In the Delta, mugwort (*Artemisia douglasiana*) was an important medicine 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*), were used as basketweaving materials. Other plants such as milkweed (*Asclepias californica*) and Indian hemp (*Apocynum cannabinum*) were used to make fish and deer nets and for ceremonial regalia. Tule (*Schoenoplectus acutus*) was a culturally significant plant species; indigenous people used every part of the plant, and it served a variety of purposes, such as for food, boat-making material, and duck decoys for fishing and hunting.

2.5.2 Flow and Water Quality Effects on Tribal Uses of Water

Tribal uses of water are connected to the hydrology and ecology of 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 pers. comm.). Flows support geomorphic, chemical, and biological processes that contribute to water quality and maintain tribal subsistence fishing and other TBUs. For example, peak river flows are needed to move sediment and clean gravels and to expose bare mineral soil. These exposed soils help cottonwood (*Populus* spp.) seeds germinate, and cottonwood flowering has historically coincided with peak flows. Cottonwoods provide building materials and medicine for tribes, and therefore scouring flows sustain these cultural uses. Functional flows also cue salmon migrations and build floodplains to sustain salmon rearing (Moloney pers. comm.).

Tribes in the Bay-Delta watershed need access to clean water as a spiritual and cultural resource and to protect human health (Moreno pers. comm). For example, the Winnemem Wintu utilize cultural sites for ceremonies along the McCloud River. Girls Puberty Rock is the site of a coming-of-age ceremony, and Children's Rock is where Winnemem Wintu children begin their journey along their spiritual and cultural path (Mulcahy pers. comm.). Other important sites include burial sites and medicinal gathering sites. The Winnemem Wintu hold the girls coming-of-age ceremony along the shore of the McCloud River, where during the ceremony they gather herbs and meditate and complete the ceremony by swimming across the river. Access to clean water for these ceremonies is a TBU (Mulcahy pers. comm.). The Buena Vista Rancheria of Me-Wuk Indians ("people of the fish net") in Amador County of the Mokelumne River watershed (Mokelumne is Miwok for "fish net"), the lower San Joaquin River, and the southern Delta call water "Ki-ku" (Moloney pers. comm.). To the Me-Wuk, "Ki-ku is life, Ki-ku is a relation," and 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 and, therefore, water itself is a significant resource (Moloney pers. comm.). 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 used in basket weaving and building sweat lodges. Tribal uses of water are the historical human use and management of water in California, and these uses have been disrupted by colonization, genocide, and aquatic ecosystem stressors (Moloney pers. comm.).

2.5.3 Impacts of Aquatic Ecosystem Stressors

Many of the aquatic ecosystem stressors described elsewhere in this chapter (Table 2-1) have had significant, ongoing impacts on California Native American tribes in the Bay-Delta watershed. Land development, water management infrastructure, flow alteration, climate change, nonnative species, and HABs are some of the aquatic ecosystem stressors that have negatively affected aquatic resources that are significant to tribes. Those stressors have in turn affected the physical, cultural, and spiritual health of tribal communities. Drained wetlands, diverted streams, and decimated fisheries have disrupted not only the ecology of the region but also the Indigenous way of life (Claire and Surprise 2021).

Water management infrastructure such as dams and hydrologic alteration of streams have had substantial negative effects on tribes throughout the Bay-Delta watershed. These stressors have degraded the abundance, accessibility, and quality of freshwater mussels, salmonids, lamprey, and sturgeon in Northern California (Long and Lake 2018). Anadromous fish species, which are a staple of traditional tribal diets, have declined substantially. Salmon and tanoak (*Notholithocarpus densiflorus*) traditionally provided half of the diet among members of the Karuk tribe. However, consumption of salmon has dropped to an average of 2.25 kilograms per person per year, down from 200 kilograms per person per year (Long and Lake 2018). 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 of the CVP flooded the land of the Winnemem Wintu and North Fork Mono Indians, respectively (Claire and Surprise 2021; Mulcahy pers. comm.). Middleton-Manning et al.

(2018) review how three Native American nations at the headwaters of the Pit River, Winnemem Wintu, and Mountain Maidu have advocated for the restoration and preservation of their homelands, as hydrologic alteration of rivers has significantly affected the tribal resources of these Northern California Native Americans. In 1947, Shasta Reservoir flooded over 90 percent of the Winnemem Wintu's homelands and prevented salmon from returning to their natal spawning sites in the McCloud River (Mulcahy pers. comm.). Shasta Reservoir also affected traditional lives of the Pit River, Shasta, Modoc, and other nations, who rely on salmon that historically migrated upstream past the dam and whose homelands were flooded by the reservoir (Middleton-Manning et al. 2018).

Mountain Maidu homeland is in the headwaters of the north fork Feather River in Plumas County and parts of Lassen and Butte Counties. Today, Mountain Maidu people include two federally recognized nations of Greenville and Susanville Rancherias and two tribes petitioning for federal recognition, United Maidu Nation and Tsi' Akim Maidu. The Maidu people have lost part of their way of life due to the powerhouses and dams constructed in the Feather River Canyon (Middleton-Manning et al. 2018). A part of the circle of life for the Maidu was the annual trek to the canyon to harvest salmon and eels (Pacific lamprey). Aside from losing access to salmon, eels, turtles, river otters, beavers, and other aquatic animals, they lost religious ceremonies and sites associated with the harvest as well as their spiritual relationship with the salmon. Other food sources that were important to the Maidu, from animals that consumed the salmon, have also diminished (Middleton-Manning et al. 2018).

Climate change has a significant effect on tribes' concepts of time and seasons and access to their culturally significant resources. The alteration of long-standing associations between phenological events essentially challenges "the fundamental belief about how elements of the natural world are connected, as well as the timing of when traditional patterns occur and behaviors are performed" (Hatfield et al. 2018). For example, traditional burning practices rely on predictable environmental cues that are being disrupted by climate change, with the potential to affect historical means of subsistence (Flores and Russell 2020). Climate change has also affected 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, and warm temperatures have increased toxins due to HABs in lakes, rivers, and streams, threatening tribal communities' access to clean water and food. Elevated temperatures along with reduced streamflows have harmed native fish, including salmon, which 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 outcompeted native plant species of cultural and spiritual importance to tribes (OEHHA 2022). HABs have also contributed to the decline of culturally important species for tribes in the Bay-Delta watershed (Kondrashova 2020).

Chapter 3
Description of Flow and Non-Flow Assets

3.1 Tributary Assets

Tributary assets described below include flow and non-flow assets negotiated as of March 29, 2022, and outlined in Appendices 1 and 2 of the VA Term Sheet. Flow assets are new contributions to tributary flow that are additive to the Delta outflows required by D-1641 and resulting from the 2019 BiOps (i.e., the 2019 BiOps condition) and vary according to the water year type based on the Sacramento Valley index unless otherwise noted. These flows would generally be provided in January through June, but the timing varies by tributary system. Flows may also be shaped in timing and seasonality, to test biological hypotheses and to respond to hydrologic conditions while reasonably protecting beneficial uses. Such shaping would occur through the Governance Program (Section 9 of the VA Term Sheet) and be subject to the Implementing Agreements and applicable regulatory requirements. A portion of the volumes of water described below would be managed with a priority of providing increased flows in the months of April and May in Dry, Below Normal, and Above Normal water years to replicate average outflow resulting from the Inflow/Export ratio in the 2009 NMFS BiOp as modeled (NMFS 2009).

Flow would be deployed in accordance with a flexibility bracket defined for each tributary system, CVP/SWP Export Reductions, and the PWA Water Purchase Program. The flexibility bracket describes, by water year type, the range of the percent of total water-year VA flows to be provided in each month (with a default of the flows focused in the months of March, April, and May). The total flow asset for each system would be attained in each water year as described in the VA Term Sheet and the flow flexibility bracket allows the flow to be deployed with variable percentages across the months contained in the flexibility bracket. The purpose of the flexibility bracket is to allow VA governance entities to optimize provision of VA Flow Measures for the benefit of native fish and to test hypotheses, thus informing adaptive management of Flow Measures. The flexibility bracket is set such that operators can work within operational and hydrological constraints of each system. The description of Flow Measures in the VA Strategic Plan provides details on the flexibility bracket for each water source and water year type.

Flows made available through reservoir reoperations would be subject to accounting procedures described in the VA Term Sheet, and all flows would be verified as a contribution above 2019 BiOps condition using these accounting procedures. An assessment based on the accounting procedures would be developed (pursuant to Section 8.4 of the VA Term Sheet) and conducted prior to year 8 of the VAs to determine if the flows described below have materialized on average above 2019 BiOps condition by water year type. If this analysis does not demonstrate that flows have materialized as described below, then the VAs would be subject to VA Term Sheet provisions of Section 7.4(B)(ii) or (iii). Off-ramps for flows during Critical years would be subject to negotiations involving real-time conditions including storage forecasts for cold water pool preservation, but flows described below reflect average Critical year contributions over the term of the VAs. The habitat restoration measures described below would be additive to physical conditions and regulatory requirements existing as of December 2018, when the State Water Board adopted Resolution 2018-0059. Implementation of such measures by Parties after that date, but prior to execution of the VAs, would be considered as contributing toward implementation of the Narrative Salmon Protection Objective (referred to as the Narrative Salmon Objective in the VA Term Sheet) and Narrative Viability Objective. The habitat restoration described below represents the habitat restoration commitments from Appendix 2 of the VA Term Sheet.

Table 3-1 represents the minimum additive contribution to habitat restoration, in acres and by general location, committed in the VA Term Sheet, within the 8-year VA term. These efforts include activities to increase spawning habitat, instream rearing habitat, and floodplain habitat including levee setbacks, breaches, side-channel improvements, and other improvements based on site-specific objectives. Proposed projects have been developed to provide habitat at a frequency, magnitude, and duration necessary to produce biological benefits for species such as fall-run Chinook salmon. Collectively, they seek to improve rearing and spawning capacity for salmonids, as well as other native fish, by enhancing the quantity and quality of available habitat. Additional habitat improvement actions (e.g., removal of barriers or invasive aquatic weeds) might be pursued if it is determined that such actions would contribute toward meeting the objectives of the VAs by addressing one or more of the ecosystem stressors described in Chapter 2, *Aquatic Ecosystem Stressors*.

Table 3-1. Summary of VA Tributary Habitat Restoration Commitments by Habitat Type and Watershed

Watershed	Spawning (acres)	Instream Rearing (acres)	Floodplain Rearing (acres)
Sacramento River	113.5	137.5	-
Sutter Bypass, Butte Sink, and Colusa Basin	-	-	20,000
Feather River	15	5.25	1,655
Yuba River	-	50	100
American River	25	75	-
Mokelumne River	-	1	25
Putah Creek	1.4	-	-

Source: Voluntary Agreements Parties 2022.
Flow assets are described in Table 4-1 in Chapter 4, *Hydrology and Operations Modeling Methods and Results*.

3.1.1 Sacramento River

The Sacramento River has both flow and non-flow assets identified. Flow assets for the Sacramento River have been identified as 100 thousand acre-feet (TAF) in Dry, Below Normal, and Above Normal years. No additional water would be available from the Sacramento River in Wet or Critical years. An additional 2 TAF were included in the VA Term Sheet in Critical and Dry years, but these flows were excluded from these analyses because they were not backed up by a concrete proposal or MOU signatories.

Non-flow assets for the Sacramento River include restoration of 137.5 acres of instream habitat and 113.5 acres of spawning habitat.

No direct flow assets are proposed for flood basins. While Sutter Bypass inundation is expected to increase with the VAs, changes in flow in the Sutter Bypass would primarily be due to changes in operation of the Tisdale Weir notch, rather than direct effects of VA flow assets. Non-flow assets for three flood basins (Sutter Bypass, Butte Sink, and Colusa basin) include more frequent inundation of

20,000 acres of flood basin habitat and 20,000 acres of land for fish food production. This habitat will be generated via modifications to Tisdale Weir and other infrastructure modifications and will be subject to analysis showing that the acreage meets suitability criteria. The fish food production program will be subject to analysis of effectiveness. Water will be pumped out onto rice fields, held for a period of time to allow fish food production (e.g., zooplankton), and then discharged to the river for the benefit of native fishes downstream. These actions will mainly focus on fish passage improvements, food production, and enhancement of rearing habitat quantity and quality.

There are currently at least six distinct project efforts identified within this region for implementation within the VA term, four of which are intended to begin implementation by 2024.

3.1.2 American River

The American River has both flow and non-flow assets identified. Flow assets for the American River have been identified in Critical, Dry, Below Normal, and Above Normal years of 30, 40, 10, and 10 TAF, respectively. These flows would be deployed in 3 out of 8 years of the VA in the above year types. No additional water will be available from the American River in Wet years. These flow assets are contingent on funding for groundwater substitution infrastructure, which would be completed by a subsequent year. In addition to flows, restoration of 25 acres of spawning habitat and 75 acres of rearing habitat would be completed on the American River.

3.1.3 Yuba River

The Yuba River has both flow and non-flow assets identified. Flow assets for the Yuba River have been identified as 60 TAF in Dry, Below Normal, and Above Normal years. No additional water will be available from the Yuba River in Critical or Wet years. Non-flow assets for the Yuba River include restoration of 50 acres of instream habitat and 100 acres of floodplain habitat. This constructed floodplain would be activated at 2,000 cfs.

There are approximately five distinct projects identified in this region that seek to improve fish access to enhanced quality and quantity off-channel rearing habitat, four of which are intended to initiate implementation by 2024.

3.1.4 Feather River

The Feather River has both flow and non-flow assets identified. Flow assets for the Feather River have been identified as 60 TAF in Dry, Below Normal, and Above Normal years. No additional water will be available from the Feather River in Critical or Wet years. Non-flow assets for the Feather River include restoration of 5.25 acres of instream habitat, 15 acres of spawning habitat, and 1,655 acres of floodplain habitat. This consists of added instream habitat complexity and side-channel improvements.

Currently, there are approximately seven projects identified within this region that include improved fish access to off-channel rearing habitat through enhancement or restoration, at least four of which are intended to begin implementation by 2024.

3.1.5 Putah Creek

Putah Creek has both flow and non-flow assets identified. Flow assets for Putah Creek have been identified in Critical, Dry, Below Normal, and Above Normal years. In Critical years 7 TAF would be available, while 6 TAF would be available in Dry, Below Normal, and Above Normal years. No additional water will be available in Wet years. In addition to flows, restoration of 1.4 acres of spawning habitat would be done on Putah Creek.

3.1.6 Friant System

Flow assets have been identified for the Friant system of 50 TAF of additional water in Dry, Below Normal, and Above Normal years. No additional water will be available from Friant in Critical or Wet years. Flow contributions would result from forgone recapture of up to 50 TAF of San Joaquin River Restoration Program flows and would be provided based on San Joaquin water year type. However, VA participation by Friant Parties is uncertain at the time of this writing. No new restoration is proposed for this area.

3.1.7 Mokelumne River

The Mokelumne River has both flow and non-flow assets identified. Flow assets have been identified for the Mokelumne River in Dry, Below Normal, and Above Normal years of 5, 5, and 7 TAF, respectively. No additional water would be available in Critical or Wet Years. Flow contributions would result from modified operations and not be protected as Delta outflow (i.e., they could be diverted downstream of the tributary mouth), as discussions for these VAs are still underway. The Mokelumne VA flow assets are based on Joint Settlement Agreement (JSA) water year types. Funding to partially support PWA water purchases would also be provided. The Mokelumne VA reflects updated volumes from the Mokelumne VA Term Sheet addendum (August 2022).

In addition to flows, restoration of 1 acre of instream habitat and 25 acres of floodplain habitat would be done on the Mokelumne River. This restoration would target creation of habitat to improve rearing capacity. The creation of floodplain habitat to enhance rearing capacity is identified in one project that is intended to begin implementation by 2024.

3.2 Bay-Delta Assets

3.2.1 Habitat Actions in the Delta

The VA Term Sheet includes restoring a total of 5,227.5 acres of tidal wetland and associated floodplain habitats within the North Delta Arc and Suisun Marsh regions. These restoration projects would target the creation and enhancement of a mosaic of habitats, including floodplain, tidal, and riparian, to restore ecological functions and improve fish passage, access to higher quality and quantity spawning and rearing habitat, and food production. Restoration objectives for the Delta are sited and designed to improve conditions for native species including Delta smelt, longfin smelt, splittail, and salmonids.

Among the various efforts proposed for the Delta, there are approximately 10 projects identified through the VA planning process.

3.2.2 Forgone Exports

Contributions to Bay-Delta flow assets from forgone exports would total 125 TAF in both Dry and Below Normal water year types, and 175 TAF in Above Normal water year types.

3.2.3 Water Purchases

Permanent state water purchases would total 65 TAF in Critical, 108 TAF in Dry, 9 TAF in Below Normal, 52 TAF in Above Normal, and 123 TAF in Wet water year types.

The PWA Water Purchase Fixed Price Program would total 3 TAF in Critical, 63.5 TAF in Dry, 84.5 TAF in Below Normal, 99.5 TAF in Above Normal, and 27 TAF in Wet water year types. This program is intended to purchase water at a fixed price from known sellers to be delivered as Delta outflow.

PWA Water Purchase Market Price Program would total 50 TAF in Dry, 60 TAF in Below Normal, and 83 TAF in Above Normal water year types. This program would purchase water at market rates from sellers on the water transfer market and would include updated volumes resulting from the Mokelumne VA Term Sheet addendum (August 2022).

Chapter 4
Hydrology and Operations Modeling Methods and Results

4.1 Background

This chapter describes the changes in hydrology and system operations that could occur as a result of the proposed VAs. SacWAM is used as a tool for understanding these potential changes. SacWAM is a hydrologic and system operations model developed on the WEAP ("Water Evaluation and Planning" system) platform for planning studies in the Sacramento/Delta watershed (Appendix A, *Sacramento Water Allocation Model Methods and Results for the Proposed Voluntary Agreements*). SacWAM includes the major tributaries and water management infrastructure of the Sacramento River watershed, the Cosumnes, Mokelumne, and Calaveras Rivers, and the Sacramento-San Joaquin Delta, with a San Joaquin River boundary condition at Vernalis. The model shares a common unimpaired inflow hydrology with CalSim 3 and currently simulates a 94-year historical record of water years 1922 to 2015 on a monthly timestep. SacWAM uses perfect foresight based on historical water year types. The SacWAM results presented in this chapter are focused on changes in hydrology and operations that could occur as a result of the VA flow assets identified in the VA Term Sheet. SacWAM results are not available for VA non-flow assets because SacWAM is not a habitat model. Habitat analyses use SacWAM results as inputs, and the methods and results of those analyses are described in Chapters 5, *Analytical Approach to Evaluating Assets*, and 6, *Anticipated Biological and Environmental Outcomes*, respectively.

Understanding the appropriate use of model results is important. The changes associated with the proposed VAs are relatively small compared with the volume of water in the system and some details of the VAs, such as which reservoirs may be reoperated, which fields would be fallowed, when reservoirs can refill, and when groundwater substitution would occur, have not been fully specified. For these reasons, SacWAM results should not be taken as indicating the exact changes in water supply and changes in hydrology from implementation of the proposed VAs but rather should be used to indicate the general timing and trends that may occur with the proposed VAs.

Actual operations of the proposed VAs would vary from modeled outcomes presented in this section for many reasons including unknown future hydrology, approximations necessary to implement a long-term monthly hydrology and operations model, and real-time operational decision-making. For example, the proposed VAs include flexibility in the timing of flow assets, so changes to streamflows and reservoir levels could deviate from modeled results. In addition, the VA Term Sheet describes flow assets that would be provided through a water purchase program, but the sources of water purchases described in the VA Term Sheet are not fully known at this time. Therefore, the VA assets as modeled in SacWAM do not fully match the volumes (volumes can be higher or lower) identified in the VA Term Sheet for a number of reasons: (1) the theoretical accounting base (2019 BiOps condition) upon which the VA flows are added is different than the reference condition (see Section 4.2, *Reference Condition and SacWAM Modeling Approach*), (2) reservoir operations associated with the VAs (including changes in release patterns and issues associated with refill and spills), (3) the dynamic nature of the modeling, and (4) other necessary modeling assumptions. Nonetheless, the model results are a good tool for estimating the relative effects of the proposed VAs on water supply and hydrology. Because it simulates hypothetical conditions, SacWAM is not intended to be used in a real-time predictive manner at this time. SacWAM results are intended to be used in a comparative manner, which allows for assessing the changes in system operations and resulting incremental effects between scenarios.

In 2022, the VA Parties released an updated MOU (VA Term Sheet) with updated information on the VA flow and non-flow assets. The updated 2022 VA flow assets can be found in Table 4-1 below. Table 4-1 has been modified from the tables presented in the VA Term Sheet to represent the flow assets attributable to signatories to the MOU.

Please note that not all VA flow assets listed in the VA Term Sheet are represented explicitly in SacWAM for the VA due to the extent of the model domain (flows originating in the San Joaquin River basin) or uncertainty as to the origins of those flows (market price purchases and permanent state water purchase). Those commitments that were not modeled in SacWAM are indicated by the shading in Table 4-1 and are discussed further in Section 4.12.2, *VA Postprocessing*.

Table 4-1. 2022 Voluntary Agreements Flow Assets as Modeled

Number	Tributary	Season	Source	C	D	BN	AN	W
1	Sacramento River	Spring/Summer	Land fallowing	0	100	100	100	0
2	Feather River	Spring/Summer	Land fallowing	0	60	60	60	0
3	Yuba River	Spring	Reservoir storage	0	50	50	50	0
4	American River[1]	Spring	Groundwater substitution, reservoir storage	30	40	10	10	0
5	Friant System[2]	Mar–May	Reduction in San Joaquin River Restoration Project recapture	0	0–50	0–50	0–50	0
6	Mokelumne River[3]	Mar–May, Oct	Reservoir release	0	5	5	7	0
7	Putah Creek[3]	Nov–May	Reservoir release	7	6	6	6	0
8	CVP/SWP Export Reduction (Delta)	Spring	Export reduction	0	125	125	175	0
9	PWA Water Purchase: Fixed Price (total)	-	-	3	63.5	84.5	99.5	27
9a	PWA Fixed Price: Sac Valley NOD[4]	-	-	0	10	10	10	0
9b	PWA Fixed Price: CVP SOD[4]	-	-	0	12.5	24.5	35	0
9c	PWA Fixed Price: WWD SOD[4]	-	-	3	6	15	19.5	27
9d	PWA Fixed Price: Add CVP SOD[4]	-	-	0	5	5	5	0
9e	PWA Fixed Price: SWP SOD[4]	-	-	0	30	30	30	0
10	PWA Water Purchase: Market Price	-	-	0	50	60	83	0
11	Permanent State Water Purchases	-	-	65	108	9	52	123
12	Tuolumne (by San Joaquin Water Year Type)	-	-	37	62	78	27	0
	Total			155	825.5	750.5	824.5	150

Note: Values are in TAF. Shading is used to indicate elements that were included through the Delta Outflow postprocessing.
Additional information can be found in the VA Term Sheet. Flow assets are proposed to be additive to the Delta outflows resulting from Revised D-1641 and implementation of the 2019 BiOps for operations of the SWP and CVP.
C = Critical, D = Dry, BN = Below Normal, AN = Above Normal, W = Wet. Water year types are based on Sacramento Valley Index unless otherwise noted.

[1] These flows would be deployed in 3 out of 8 years of the VA in AN, BN, D, or C years.

[2] Only reduction in recaptured San Joaquin River Restoration Project flows with current facilities in the Delta were considered (no flood flows or future potential recapture). Based on the San Joaquin River Restoration Project water year types. VA participation by Friant Parties is uncertain at the time of this writing.

[3] Flow contributions will be generated by the Mokelumne VA release quantities listed in Section 4.8, *Mokelumne River VA*, and, if necessary, by Mokelumne-funded purchases. VA flows are from modified operations and not protected as Delta outflow, as discussions for these VAs are still underway. Mokelumne VA reflects updated volumes from the Mokelumne VA Term Sheet addendum (August 2022); based on JSA water year types.

[4] Subcategories for the PWA Fixed Price Water Purchases (No. 9). These water purchase elements were included in SacWAM.

NOD = north of Delta; SOD = south of Delta; WWD = Westlands Water District

4.2 Reference Condition and SacWAM Modeling Approach

The process for updating the Bay-Delta Plan has been ongoing since 2009, with a revised Notice of Preparation issued for the Sacramento/Delta Update to the Bay-Delta Plan in 2012. When the 2017 Scientific Basis Report was developed, it used—for comparison when evaluating expected Delta outflow from changes to the Bay-Delta Plan—a regulatory baseline that included the flows resulting from implementing the State Water Board's Revised D-1641 and the CVP and SWP federal Endangered Species Act BiOps issued by USFWS in 2008 and NMFS in 2009 for long-term CVP/SWP operations, as modeled (i.e., the reference condition). In contrast, the VA proposal, as submitted, accounts for environmental flows relative to flows resulting from D-1641 and BiOps for CVP/SWP long-term operations issued in 2019, as modeled (i.e., the 2019 BiOps condition). Because this report is a supplement to the 2017 Scientific Basis Report, the expected benefits of the VAs are analyzed relative to the same reference condition as the 2017 Scientific Basis Report to provide a consistent basis of comparison. This approach analyzes VA flows and habitat above flows resulting from D-1641 and the 2008/2009 BiOps as modeled, and above habitat required by D-1641 and the 2008/2009 BiOps (i.e., the reference condition, including assuming completion of the 8,000 acres of tidal wetland restoration required by the BiOps).

The general approach to using SacWAM to model the effects of the proposed VAs on hydrology and water supply is first to simulate the 2019 BiOps condition scenario and then build the VA scenario from the 2019 BiOps condition scenario. The 2019 BiOps condition scenario in SacWAM also includes operation of a notch in the Tisdale Weir as proposed in the VAs. The Tisdale Weir notch is one component of the Tisdale Weir Rehabilitation and Fish Passage Project, which is intended to rehabilitate the weir to extend the design life and also provide passage for fish to the Sacramento River (DWR 2023). The VA proposes to operate the Tisdale Weir notch to increase flows into the Sutter Bypass during December through mid-March. The reason that the Tisdale Weir notch is included in the 2019 BiOps condition is because changing the flows into the Sutter Bypass from the Sacramento River results in substantial changes to flow in the Sacramento River downstream of Tisdale Weir that are separate from the flow assets proposed in Table 4-1.

As described above, some of the differences between the SacWAM VA scenario flows and the flow assets as described in the VA Term Sheet are due to differences in the base upon which those flows are added. The major differences between the reference condition and 2019 BiOps condition scenario relative to Delta outflows is the applicability of San Joaquin River inflow to export (I:E) constraints that apply during April and May in the reference condition, and the higher fall outflow requirements in the reference condition. The I:E export limits have the effect of restricting exports and increasing Delta outflow during April and May. Therefore, in the 2019 BiOps condition scenario, Delta outflow is lower on average in April and May compared to the reference condition. The higher fall outflow requirements included in the reference condition result in higher outflows in October and November, which reduces reservoir storage and thus results in changes to spill dynamics during the following winter and spring months.

As discussed above, the SacWAM VA scenario is built upon the 2019 BiOps condition scenario and includes new flow requirements to represent flow assets from the Sacramento River, American River, Feather River, Mokelumne River, Yuba River, and Putah Creek. The flow assets for these Sacramento/Delta tributaries are identified Table 4-1. The VA scenario also includes modified operational curves for New Bullards Bar on the Yuba River, fallowing of land in the Sacramento and Feather River watersheds, flow assets that would be provided through the PWA Fixed Price Water Purchase Program, and CVP/SWP export reductions identified in the VA Term Sheet. Delta exports are limited in the VA scenario based on the 2019 BiOps condition scenario and CVP/SWP export reductions specified in the VA Term Sheet.

Further descriptions of the modeling assumptions for each component of the VAs can be found in Sections 4.3, *Sacramento River VA*, through 4.12, *Delta Outflow*, below.

Delta outflow for the VA scenario is postprocessed to add a representation of several additional components that are not modeled explicitly in SacWAM. These components include unspecified water purchases (flow assets that would be provided through the PWA Water Purchase Market Price Program and permanent state water purchases), contributions from the Friant system, and the Tuolumne VA proposal. The unspecified water purchases were not included in SacWAM because the sources of the unspecified water purchases described in the VA Term Sheet are not fully known at this time. It is assumed that flow assets provided through the PWA Water Purchase Market Price Program and permanent state water purchases would be distributed throughout the watershed and would have minor effects on streamflows and reservoir levels.

4.3 Sacramento River VA

The Sacramento VA contains two measures to augment flows and implement non-flow habitat measures:

- Provide flows for Delta outflow from Land Fallowing in Above Normal, Below Normal, and Dry years (modeled based on historical Sacramento water year type). Although the Sacramento River VA itself provides 100 TAF of water in each of Above Normal, Below Normal, and Dry water years, as modeled in SacWAM, the 10 TAF Sacramento Valley north of Delta PWA fixed price purchase is included within the model logic to implement the Sacramento River VA. As such, 110 TAF are assumed to be provided in each of these three water year types.
    - In Above Normal/Below Normal years, 110 TAF of water is assumed to be released evenly in April/May or June/July/August based on End-of-March Shasta Storage.

Shasta End-of-March Reservoir Storage	Sacramento VA Pulse Flow
Equal to or Greater than 3,800 TAF	55 TAF each in April/May
Less than 3,800 TAF	36.67 TAF each in June/July/August

    - In Dry years, the water is assumed to be provided as instream flow based on the delivery pattern of the fallowed land. The delivery pattern of fallowed land is assumed to follow a fixed pattern of 10 percent April, 15 percent May, 20 percent each June to August, 10 percent September, and 5 percent October.
    - A flow requirement on the Sacramento River at Knights Landing is set equal to the flow at that location in the 2019 BiOps condition scenario (including the proposed VA operation of the Tisdale Weir notch) plus the VA flow volume for that month. The flow requirement is only in effect during months when VA flows are provided.
    - In Above Normal, Below Normal, and Dry years, 6 percent of land is assumed to be fallowed across all CVP Sacramento River settlement contractor demands to provide the water to

meet the flow requirement. The fallowing is assumed to be distributed equally across all crops within each demand site.

- Tisdale Weir notch for Sutter Bypass Habitat
  - A notch in Tisdale Weir is anticipated to be operated from December 1 through March 15. With the notch closed, the weir is assumed to pass approximately 75 percent of Sacramento River flows over 18,000 cfs. When the notch is open, it is assumed to pass 54 percent of Sacramento River flows between 10,000 cfs and 18,000 cfs. Between 18,000 cfs and 23,760 cfs, the notch is assumed to pass 4,320 cfs of Sacramento River flows. The entire weir is assumed to be activated at flows over 23,760 cfs and can pass approximately 75 percent of flows. During March, the weir is assumed to behave according to a weighted average of 15 days with the notch open and 16 days closed.

Modeled changes to Sacramento River inflow resulting from the VA are depicted on Figure 4-1 and in Table 4-2. Sacramento River inflow is summarized as the total of Sacramento River flow at Knights Landing, inflow from the Sutter Bypass, and inflow to the Knights Landing Ridge Cut from the Colusa basin drain. Monthly flows on Figure 4-1 and subsequent figures are shown as box plots; the bold horizontal line shows the median, the box shows the interquartile range (25th to 75th percentiles), and the whiskers show the full range of values over the modeled hydrologic record.

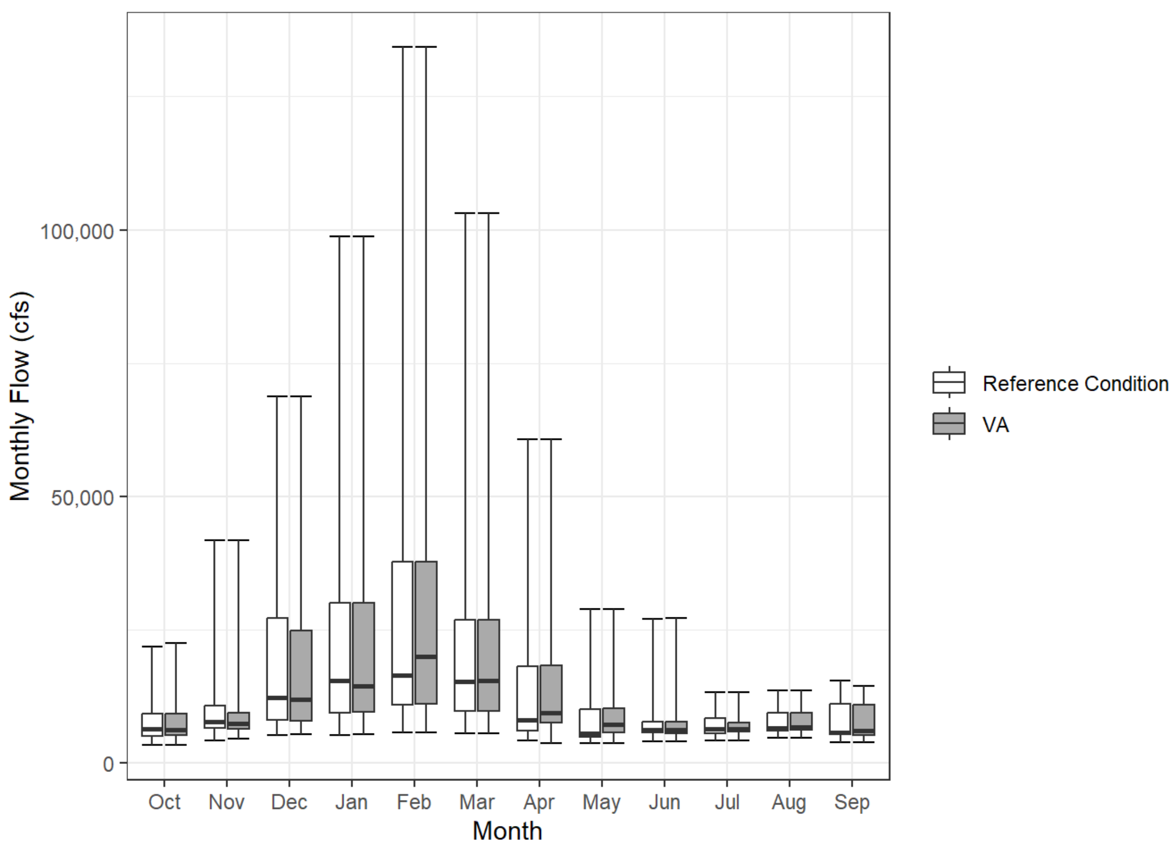

Figure 4-1. Reference Condition and VA Modeled Sacramento River Inflow (cfs)

Table 4-2. Water Year Type Averaged January–June Total Reference Condition Flow and VA Change From Reference Condition (TAF), Sacramento River Inflow

Water Year Type	Reference Condition	VA
W	10,199	12
AN	7,511	211
BN	4,667	141
D	3,522	147
C	2,766	-45
All	6,135	82

These results also include flows from the north of Delta Fixed Price Water Purchase (10 TAF AN/BN/D) because the north of Delta Fixed Price Water Purchase was included in the Sacramento Valley Land Fallowing; see Table 4-8.
AN = Above Normal; BN = Below Normal; C = Critical; D = Dry; W = Wet

4.4 Feather River VA

The Feather VA provides 60 TAF per year of Delta outflow in Above Normal, Below Normal, and Dry years (modeled based on historical water year type) predominantly through land idling, crop shifting, and/or reservoir reoperation within the Feather River service areas (the model assumes all water is made available through land fallowing). The VA flows provide 30 TAF each in April and May for Delta outflow. The flow requirement on the Feather River is placed at the same location as the existing flow requirement on the high-flow channel of the Feather River, immediately downstream of the Sunset Pumps. As described for the Sacramento River, the VA flow requirement is defined as the sum of the flow from the 2019 BiOps condition and the VA flow contribution, and the requirement is only altered during months in which VA flows are being provided. In Above Normal, Below Normal, and Dry years, 6 percent of land is assumed to be fallowed across all Feather River Service Area demands to provide the water to meet the flow requirement. The fallowing is assumed to be distributed equally across all crops within each demand site.

Modeled changes to Feather River flow resulting from the VA are depicted on Figure 4-2 and in Table 4-3.

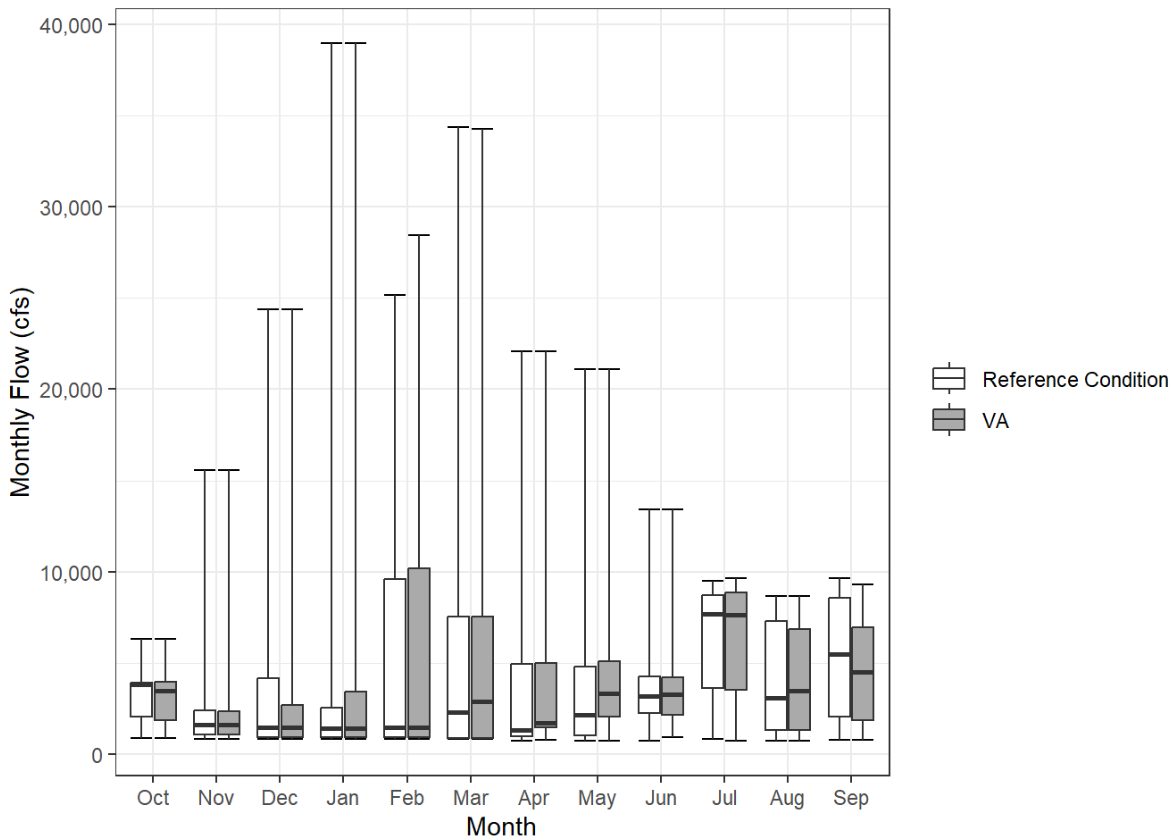

Figure 4-2. Reference Condition and VA Modeled Flow (cfs), Feather River below Thermalito

Table 4-3. Water Year Type Averaged January–June Total Reference Condition Flow and VA Change from Reference Condition (TAF), Feather River below Thermalito

Water Year Type	Reference Condition	VA
W	3,505	41
AN	1,506	138
BN	802	153
D	621	133
C	590	12
All	1,632	90

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

4.5 Yuba River VA

YWA proposes to provide a Delta flow component of about 50 TAF per year during Above Normal, Below Normal, and Dry years, as measured at the Marysville gage. The flow proposal in the YWA VA Project is founded on the lower Yuba River Accord-based flows, including the requirements for instream flows specified in the Yuba Accord Fisheries Agreement and the State Water Board's Corrected Order WR 2008-0014, and transfer operations and accounting provisions of the Yuba

Accord Water Purchase Agreement. YWA VA Project operations would be supplemental to the Yuba Accord flows and associated Yuba River Development Project operations.

The YWA VA Project includes two quantifiable water components that would provide about 50 TAF of additional Bay-Delta inflows in Above Normal, Below Normal, and Dry year types through the following changes in Yuba River Development Project operations:

a. All Yuba Accord transfer releases in April, May, and June that cannot be backed into Lake Oroville or exported by DWR would be repurposed from potential in-basin use and Delta exports to Bay-Delta outflows (YWA VA Project Component 1).

b. Additional storage releases from New Bullards Bar Dam would occur by operating to a new target September 30 storage level of 600 TAF, which is 50 TAF below the Yuba Accord target September 30 storage level of 650 TAF (YWA VA Project Component 2). The YWA VA Project also includes accounting for refill of storage releases from YWA VA Project Component A and B that exceed 9 TAF annually in Above Normal, Below Normal, and Dry year types.

The Yuba River VA is modeled in SacWAM by reducing the New Bullards Bar Reservoir buffer pool starting in April to target a lower end of September storage (Table 4-4). The buffer pool represents the volume below which releases will not be made for lower priority demands such as hydropower operations. During VA years, lowering the buffer pool routes more water through the Colgate Powerhouse to the degree that generating capacity is available.

Because the Yuba River VA relies on reservoir reoperation rather than a fixed volume of flow, the quantity of water to be routed to Delta outflow is determined by calculating the increase in flow below Englebright Dam associated with the VA scenario relative to the 2019 BiOps condition. This flow is added to the total Delta outflow requirement for the VA scenario (see Section 4.12, *Delta Outflow*).

Table 4-4. New Bullards Bar Reservoir Buffer Pool (TAF)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2019 BiOps Condition and Non-VA Years	660	660	650	600	650	750	850	940	920	825	715	650
VA Years	650	660	650	600	650	750	780	850	845	770	660	595

Modeled changes to Yuba River flow resulting from the VA are depicted on Figure 4-3 and in Table 4-5.

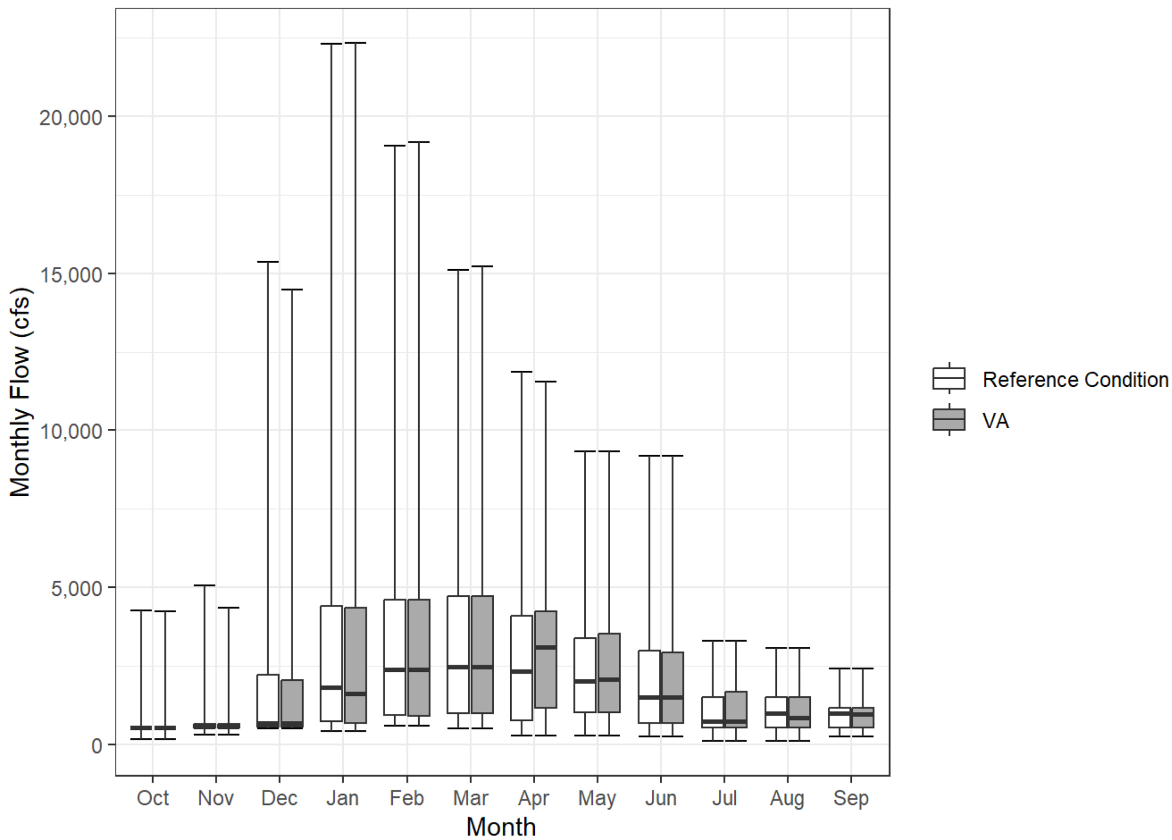

Figure 4-3. Reference Condition and VA Modeled Flow (cfs), Yuba River at Mouth

Table 4-5. Water Year Type Averaged January–June Total Reference Condition Flow and VA Change from Reference Condition (TAF), Yuba River at Mouth

Water Year Type	Reference Condition	VA
W	1,947	-9
AN	1,268	48
BN	779	33
D	483	21
C	262	-10
All	1,044	13

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

4.6 American River VA

The American River VA is to augment flows and implement habitat measures. The SacWAM representation of the VA proposal on the American River includes increased streamflows and groundwater substitution of surface water.

The increased streamflows are represented as a new instream flow requirement below Nimbus Dam distributed by year type and month as shown in Table 4-6. Increased flows on the American River are assumed to be increases from the 2019 BiOps condition (including the proposed VA operation of the Tisdale Weir notch). The VA flow requirement shown in Table 4-6 occurs only in the first 3 non-Wet years of every 8-year cycle.

To reduce the effects of rebalancing storage in Folsom and Shasta in the VA scenario, releases from Lake Natoma were required to be no less than releases from the VA baseline with the Tisdale Weir notch scenario between the months of January through June of all years.

Table 4-6. American River VA Flows by Month and Water Year Type (TAF)

Water Year Type	March	April	May
AN	5	5	0
BN	5	5	0
D	13.33	13.33	13.33
C	15	15	0

AN = Above Normal; BN = Below Normal; C = Critical; D = Dry

Groundwater substitution of surface water is represented in Dry and Critical years when the VA flow requirements apply by limiting the surface water available. All surface diversions from the American River are reduced by 35 TAF in Dry and 30 TAF in Critical year in March, April, and May to the Roseville water treatment plant, Peterson water treatment plant, Folsom water treatment plant, Bajamont water treatment plant, Fairbairn water treatment plant, Sacramento River water treatment plant, Folsom South Canal, and Freeport Pumping Plant demands.

Modeled changes to American River flow resulting from the VA are depicted on Figure 4-4 and in Table 4-7.

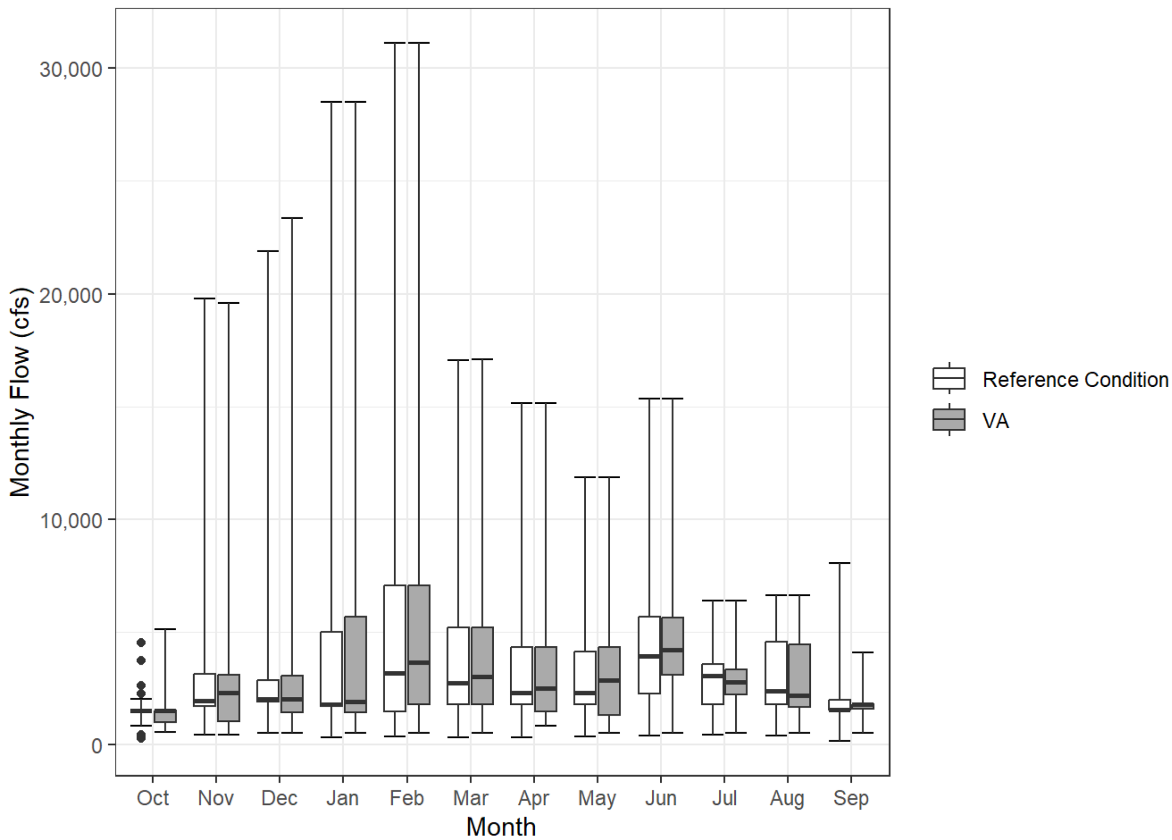

Figure 4-4. Reference Condition and VA Modeled Flow (cfs), American River below Natomas

Table 4-7. Water Year Type Averaged January–June Total Reference Condition Flow and VA Change from Reference Condition (TAF), American River below Natomas

Water Year Type	Reference Condition	VA
W	2,563	18
AN	1,699	75
BN	1,113	46
D	771	64
C	477	50
All	1,445	46

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

4.7 Friant VA

The Friant VA includes reduction of recaptured San Joaquin River Restoration Project flows in the Delta. In all years, except for those determined to be Wet, Critical-High, or Critical-Low under the San Joaquin River Restoration Settlement, the Friant VA reduces the recapture of restoration flows to the extent necessary to achieve a goal of total Delta outflows during the period of February through May.

- Reduction of Restoration Recapture:
    - Recapture in the Delta can be reduced by up to 50 percent during the period of February through May. (This was not modeled.)
    - Restoration recapture in the Delta is reduced to achieve the 50 TAF Delta outflow goal.

Modeled changes to restoration recapture resulting from the Friant VA are modeled in CalSim 3 and included in the SacWAM representation of the VAs in a postprocessing procedure to include non-modeled components in Delta outflow (see Section 4.12, *Delta Outflow*).

4.8 Mokelumne River VA

The Mokelumne River VA includes modified operations to increase minimum instream flows.

The Mokelumne River VA scenario includes increased releases from Camanche Reservoir based on the April–September Mokelumne JSA water year type and includes a low storage off-ramp. In March, the model assumes perfect foresight of the April JSA water year type. In October, the VA flows are based on the preceding year's April–September JSA year type.

The total VA required release is calculated as the minimum JSA release plus the additional flows shown in Table 4-8. If the March projected combined end-of-September storage in Pardee and Camanche is less than 350 TAF, it is assumed that no additional VA flows will be provided.

Table 4-8. Mokelumne River VA Additional Flow by Month and JSA Water Year Type (TAF)

JSA Water Year Type	March	April	May	September	October
D	2.7	2.7	2.7	0.95	0.95
BN	5.4	5.4	5.4	1.9	1.9
N and AN	12.15	12.15	12.15	4.275	4.275

AN = Above Normal; BN = Below Normal; D = Dry; N = Normal

Modeled changes to Mokelumne River flow resulting from the VA are depicted on Figure 4-5 and in Table 4-9. The values identified in Table 4-1 represent the additional flow from the VA based on preliminary modeling and may be revised consistent with refined modeling and flow accounting procedures to be developed for the VAs.

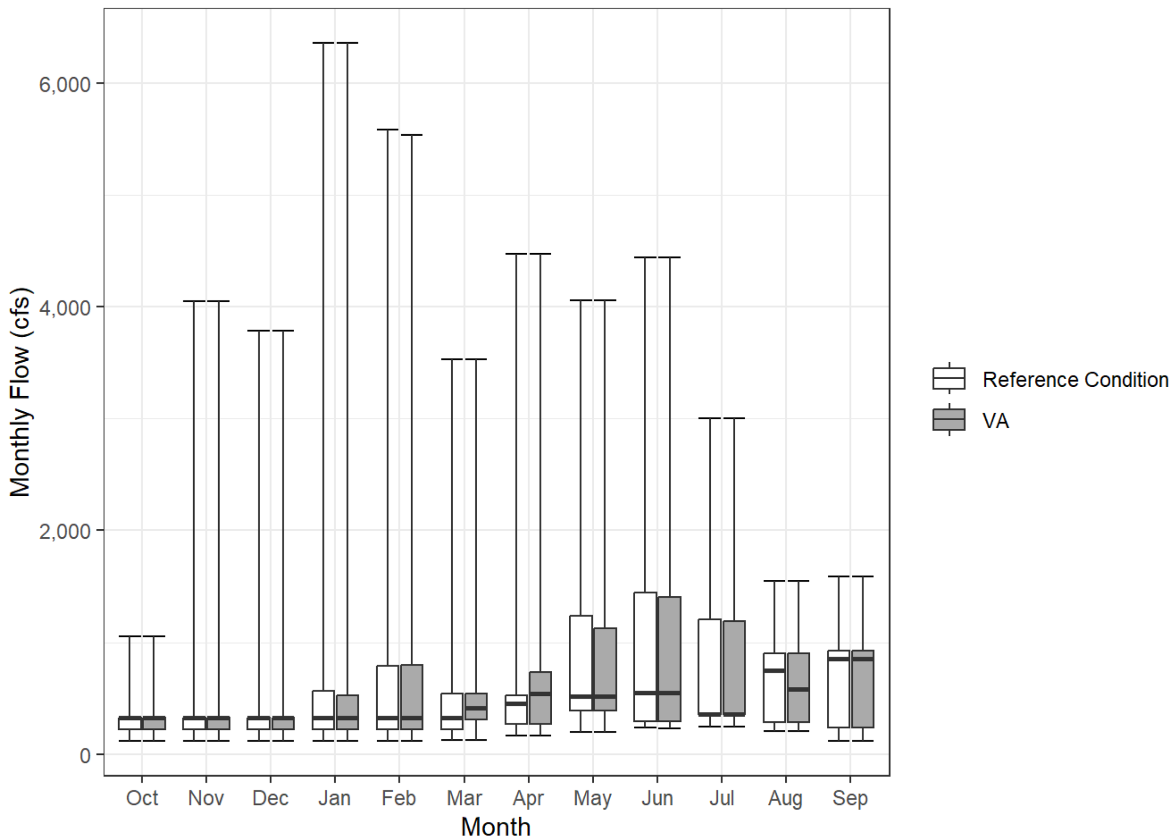

Figure 4-5. Reference Condition and VA Modeled Flow (cfs), Mokelumne River below Camanche

Table 4-9. Water Year Type Averaged January–June Total Reference Condition Flow and VA Change from Reference Condition (TAF), Mokelumne River below Camanche, by Sacramento Water Year Type

Water Year Type	Reference Condition	VA
W	545	2
AN	279	2
BN	178	3
D	115	3
C	88	1
All	273	2

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

4.9 Putah Creek VA

The Putah Creek VA scenario includes additional flow at the downstream end of Putah Creek above the Toe Drain. Additional VA flows occur in addition to Putah Creek Accord required flows in all water year types unless it is a drought year as defined by certain conditions when Lake Berryessa storage is below 750 TAF. The additional flows include a winter pulse, spring flushing flows, and ramping flows between the pulse and flushing flows. The additional flows on Putah Creek are shown in Table 4-10. Putah Creek VA flows are not protected from in-basin use or Delta exports.

Table 4-10. Putah Creek Additional Flows by Month (TAF)

	November	December	January	February	March	April	May
Pulse Flow	1.67	0.83					
Ramping Flow		0.37	0.71	0.71	0.71		
Flushing Flow						0.5	0.5

Modeled changes to Putah Creek flow resulting from the VA are depicted on Figure 4-6 and in Table 4-11.

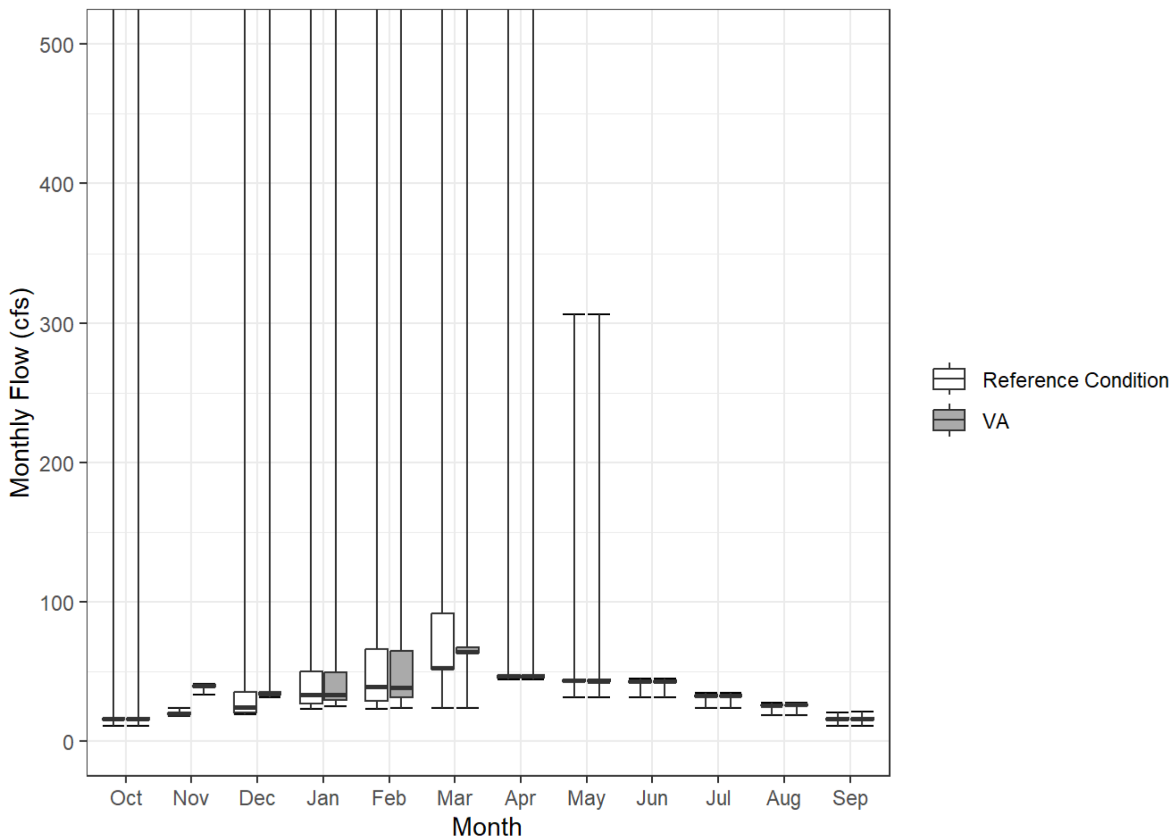

Figure 4-6. Reference Condition and VA Modeled Flow (cfs), Putah Creek near Davis
Note that the y-axis is truncated; maximum modeled flows range from approximately 1,000 cfs in October to nearly 7,000 cfs in February and March, and they are not substantially changed by the VA.

Table 4-11. Water Year Type Averaged January–June Total Reference Condition Flow and VA Change from Reference Condition (TAF), Putah Creek near Davis

Water Year Type	Reference Condition	VA
W	193.9	-4.6
AN	29.6	-1.5
BN	24.1	0.3
D	15	0.9
C	14.6	0.7
All	72.4	-1.2

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

4.10 CVP/SWP Export Reduction VA

The CVP and SWP Export Reduction VA provides VA flows for Delta outflow by reducing CVP/SWP exports of unstored water. The VA provides the following:

- Above Normal years: 175 TAF during April and May
- Below Normal and Dry years: 125 TAF during March through May
- April and May exports are maintained at the Health and Safety level of 1,500 cfs (in other words, no VA action if CVP plus SWP exports are at or below 1,500 cfs).
- March exports are maintained at 3,000 cfs (i.e., no VA action if CVP plus SWP exports are at or below 3,000 cfs).

Further export cuts due to Fixed Price Water Purchases (see Section 4.11, *Water Purchases*) are included in the model expressions that implement the export cuts described above. For the purposes of those further cuts, Wet years are treated like Above Normal years (cuts are initiated in April) and Critical years are treated like Below Normal and Dry years (cuts are initiated in March).

Modeled changes to flow resulting from the CVP/SWP export reductions are captured in the summary of changes to Delta outflow (see Section 4.12, *Delta Outflow*).

4.11 Water Purchases

The sources of water purchases described in the VA Term Sheet were not fully identified. Therefore, considering the time schedule for this effort and using existing VAs already in the SacWAM VA model, only the Fixed Price Water Purchases were modeled and included in the Sacramento and CVP/SWP Export Reduction VAs as briefly described in Sections 4.3, *Sacramento River VA*, and 4.10, *CVP/SWP Export Reduction VA*. The Market Price and Permanent State Water Purchases were not included in the SacWAM VA scenario. The specific Fixed Price Water Purchase volumes that fell into the Sacramento and CVP/SWP Export Reduction VAs are shown in Table 4-12 below.

Table 4-12. Sacramento and CVP/SWP Export Reduction VAs with Fixed Price Water Purchases

Number	Tributary	Season	Source	Application	W	AN	BN	D	C
Sacramento VA with Water Purchases									
1	PWA Fixed Price: Sac Valley NOD	-	-	-	0	10	10	10	0
2	Sacramento VA	Spring/Summer	Land Fallowing	Block	0	100	100	100	0
3 = 1 + 2	Total Sacramento VA with Water Purchases	Spring/Summer	Land Fallowing	Block	0	110	110	110	0
CVP/SWP Export Reduction VA with Water Purchases									
4	PWA Fixed Price: CVP SOD	-	-	-	0	35	24.5	12.5	0
5	PWA Fixed Price: WWD SOD	-	-	-	27	19.5	15	6	3
6	PWA Fixed Price: Add CVP SOD	-	-	-	0	5	5	5	0
7	PWA Fixed Price: SWP SOD	-	-	-	0	30	30	30	0
8	CVP/SWP Export Reduction VA	Spring	Export Reduction	Block	0	175	125	125	0
9 = 4 + 5 + 6 + 7 + 8	Total CVP/SWP Export Reduction VA with Water Purchases	Spring	Export Reduction	Block	27	265	200	179	3

Please note this is a modeling assumption only and was only made to represent the Fixed Price Water Purchases in the SacWAM VA model in a simplified manner. Actual water purchase commitments and the development of such water will be based on the VA Term Sheet and discussions between the VA Parties.
Changes to flow resulting from water purchases not included in this table are captured in the postprocessing of changes to Delta outflow (see Section 4.12.2, *VA Postprocessing*).
AN = Above Normal; BN = Below Normal; C = Critical; D = Dry; NOD = north of Delta; SOD = south of Delta; W = Wet; WWD = Westlands Water District

4.12 Delta Outflow

The VA Term Sheet states that VA flows "will be additive to the Delta outflows required by D-1641 and resulting from the 2019 BiOps, although the 2019 BiOps may be modified, including to resolve litigation concerning those opinions" (Section 4.1 of the VA Term Sheet). However, the 2017 Scientific Basis Report considered expected Delta outflow resulting from the possible changes to the Bay-Delta Plan being considered at the time additive to the 2008 and 2009 BiOps. To be consistent with the analysis in the 2017 Scientific Basis Report, expected Delta outflow resulting from the VA flows was compared to the reference condition, as defined in Sections 1.4, *Description of the Proposed Voluntary Agreements*, and 4.2, *Reference Condition and SacWAM Modeling Approach*, above.

The SacWAM VA model scenario does not include a subset of the VA flow actions (Table 4-1, rows 5 and 9–12) because the source tributaries for water purchases are not known at the time of preparation of this report, the Friant VA is uncertain, and the Tuolumne VA would be subject to State Water Board decision-making under a separate process. For the purposes of assessing changes in Delta outflow, these flows are included through a postprocessing exercise.

4.12.1 Reference Condition Representation

As described in Section 1.3.1.8, *Hydrology and Operations Modeling*, above, an earlier draft of this report relied upon a postprocessing procedure to account for changes between the 2019 BiOps condition and 2008/2009 BiOps condition (reference condition). This approach created confusion and has been replaced by explicit modeling of the reference condition using SacWAM, as described in Section 4.2, *Reference Condition and SacWAM Modeling Approach*, above.

4.12.2 VA Postprocessing

A postprocessing exercise is used to account for the Delta outflow effects of water purchases and potential Friant and Tuolumne VA flow actions that are not modeled in the SacWAM VA scenario. Water purchases are assumed to be provided in the quantities reflected in Table 4-1 by Sacramento water year type. Friant VA flows are included as the time series of forgone exports previously modeled by CalSim 3. Tuolumne River VA flows are represented as the change in flow at the mouth of the Tuolumne River as modeled by the State Water Board's Water Supply Effects model for the lower San Joaquin tributaries and added to Delta outflows.

In general, VA flow actions are intended to be concentrated during April and May, which are generally the most impaired months with respect to inflow to and outflow from the Delta. For the purposes of this report, water purchases are assumed to be provided in April and May, although they may also be deployed differently under the VAs. Modeled Delta outflow results including postprocessed purchases and with and without San Joaquin basin VA contributions are shown on Figure 4-7 and in Table 4-13.

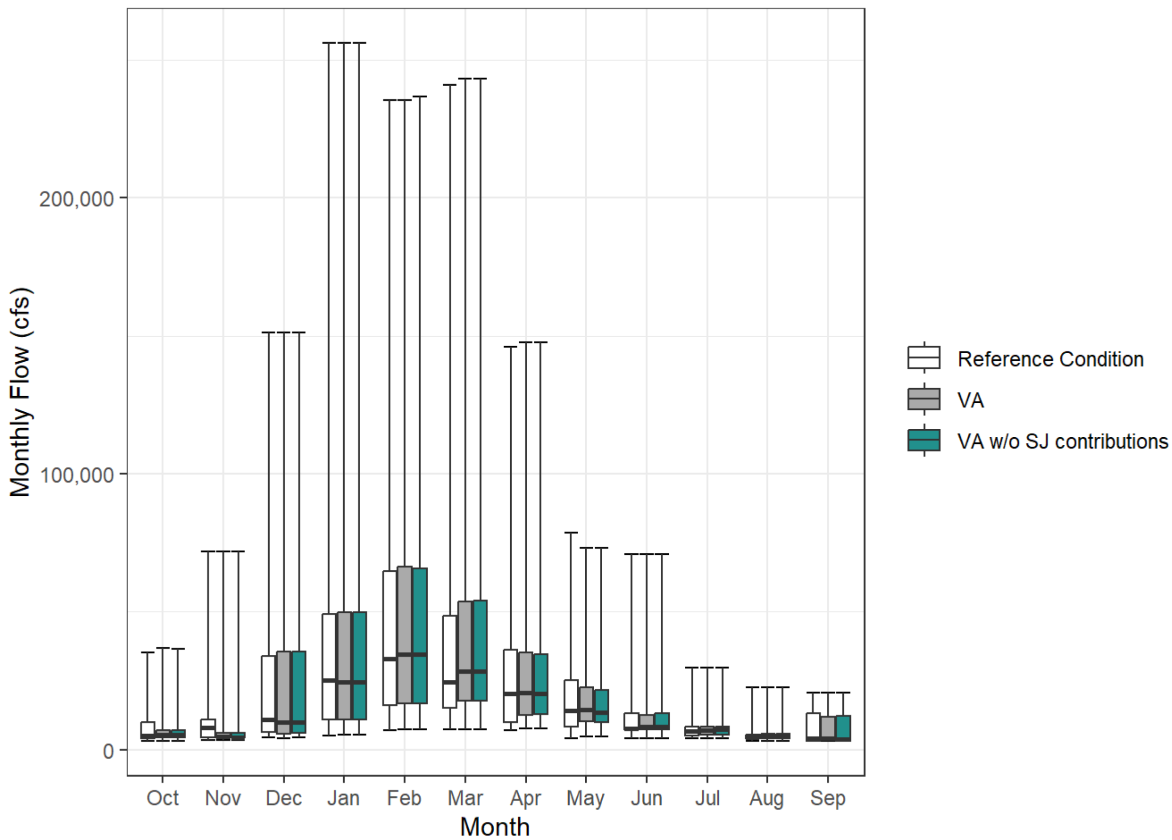

Figure 4-7. Reference Condition and VA Modeled Flow Including Postprocessed Components (cfs), Delta Outflow

Table 4-13. Water Year Type Averaged January–June Total Reference Condition Flow and VA Change from Reference Condition (TAF), Delta Outflow (Including Postprocessed Components)

Water Year Type	Reference Condition	VA	VA without San Joaquin Contributions
W	22,337	-330	-323
AN	13,907	439	402
BN	7,881	340	256
D	5,058	556	469
C	3,636	165	116
All	11,689	172	126

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

In addition to the VA and VA without San Joaquin contributions scenarios described above, two additional VA scenarios are included for evaluating January through June Delta outflows that provide a higher bookend of possible Delta outflows under the VAs. These additional scenarios are provided in recognition of the following: (1) additional VAs on the Merced River and Stanislaus River may be agreed upon in the future; (2) the VAs are intended to protect as Delta Outflows both VA flows and flows that may be provided by implementing the 2018 updated Lower San Joaquin River flow objectives; (3) different credible hydrology and operations modeling tools produce different estimates of the incremental effect on Delta outflow associated with changes in operations between the reference condition and the 2019 BiOps condition. The differences between the reference condition and 2019 BiOps condition between DWR's CalSim 2 systems operations modeling (relied on in the January 2023 Draft Scientific Basis Report Supplement to evaluate the effect of this change on Delta outflow) and SacWAM are accounted for by applying a bias correction factor to Delta outflows modeled by SacWAM. CalSim 2 results indicate a smaller difference between these two scenarios than SacWAM. While the results are largely comparable, particularly in relation to the magnitude of total Delta outflows, the differences could affect the expected Delta outflow benefits of the VAs. Therefore, these higher end bookends include a correction factor between CalSim 2 and SacWAM in recognition that Delta outflows under the VAs may be somewhat higher than assumed in SacWAM when compared to the reference condition. The accounting produced for the VAs is intended to ensure that the expected Delta outflows are realized.

The first higher bookend scenario assumes the remaining San Joaquin River placeholder volumes identified in the VA Term sheet above the Tuolumne River contributions are provided by the Merced and Stanislaus Rivers to Delta outflows (referred to as "VA w/Bias Correction and LSJR Placeholder"). The second scenario assumes additional Delta outflows from implementation of the 2018 Lower San Joaquin River Flow updates to the Bay-Delta Plan on the Merced and Stanislaus Rivers (40 percent of unimpaired flow from February through June) (referred to as "VA w/Bias Correction and 40% UF Merced & Stanislaus"). Both scenarios include the Tuolumne River VA and Friant contributions, as well as other VA contributions, including unspecified water purchases. For additional details, see Appendix A, *Sacramento Water Allocation Model Methods and Results for the Proposed Voluntary Agreements*. The January through June flows from these two additional bookend scenarios are provided in Table 4-14. They are only available as January through June flows and not for the full SacWAM hydrology timeseries because the bias correction and San Joaquin flow adjustments were only applied to total January through June flows for each water year type.

Table 4-14. Water Year Type Averaged January–June Total Reference Condition Flow and VA Change from Reference Condition (TAF) for Delta Outflow (Including Postprocessed Components) for Higher End Bookends of Possible VA Flows

Water Year Type	Reference Condition	VA w/Bias Correction and LSJR Placeholder	VA w/Bias Correction and 40% UF Merced & Stanislaus
W	22,337	-96	70
AN	13,907	631	829
BN	7,881	599	735
D	5,058	535	680
C	3,636	76	195

The bias correction refers to the correction process to adjust for differences between CalSim 2 and SacWAM modeling.
AN = Above Normal; BN = Below Normal; C = Critical; D = Dry; LSJR = lower San Joaquin River; UF = unimpaired flow; W = Wet; w/ = with

4.13 Flow Flexibility Scenarios

To assess the potential variability in tributary habitat area that could be provided within the flow flexibility brackets (described in Section 3.1, *Tributary Assets*), it was necessary to develop flow scenarios that represent the potential flexibility in the deployment of the VA assets as described in the draft VA Flow Measures description document submitted to the State Water Board by the VA Parties on February 28, 2023, and included in the VA Strategic Plan. Scenarios were selected that enveloped the greatest possible range in provision of habitat area and are considered variations on the VA scenario (described generally in Section 4.2, *Reference Condition and SacWAM Modeling Approach*). Three flow scenarios were developed that could occur under the proposed VA program's flow flexibility bracket (Table 4-15). The first scenario, "VA default," is the default provision of flow by month as described in the Flow Measures description within the VA Strategic Plan, which generally assumes deployment of VA flows in the months of April and May. The second scenario, "VA Concentrated," concentrates the flows as much as possible outside the January to June period or, if that was not possible within the flexibility brackets, outside April and May. The third VA flow scenario, "VA distributed," assumed an even distribution of VA flows throughout the months included in the flexibility bracket. The default scenario from the Flow Measures description document was included separately from the direct model results from SacWAM because the default scenario did not always agree with the VA Term Sheet specifications or the manner in which the flows were modeled in SacWAM (or CalSim 3), resulting in flow differences that are thus evaluated through the flow flexibility scenarios. These scenarios were constructed as the proportion of the water-year total VA flow contribution that would be provided in each month. Because the VA flow contributions and the proposed flexibility depended on water year type, the proportions of flow commitments provided by month differed by water year type for each flow flexibility scenario. All three flow flexibility scenarios were compared with the reference condition (as described in Section 4.2, the same reference condition as in the 2017 Scientific Basis Report) and with the modeled VA Scenario, which is described above in Sections 4.2 through 4.12, *Delta Outflow*.

Table 4-15. Description of Flow Scenarios Developed to Evaluate the Range of Habitat Area Available across Different Variations of Flow Deployments Consistent with Flow Flexibility Brackets Provided in the Flow Measures Description Document

Flow Flexibility Scenario	Description
VA Default	The default deployment described for each system and WYT in the VA Flow Measures Description document
VA Concentrated	VA flows deployed in a concentrated fashion as much as possible outside the January to June period or, if that was not possible within the flexibility brackets for each system and WYT, outside April and May
VA Distributed	VA flows distributed throughout months contained in the flexibility bracket for each system and WYT

WYT = water year type

To estimate the tributary flows under each flow flexibility scenario, the water year additional VA flows for each tributary reach and water year were first calculated. Reference condition and VA flows were first summed across months within a water year. Then, for each water year, reference condition flows were subtracted from VA flows to find the water year additional VA flows. To calculate the monthly flows under each flow flexibility scenario, the water year additional VA flows were multiplied by the respective flow flexibility proportion (for the given tributary, flow flexibility scenario, water year type, and month) and added to the monthly reference condition flow. The process is described in equation 1:

$$VA_{wy,m,ff} = \left(VA_{wy} - RC_{wy}\right)Prop_{wyt,m,ff} + RC_{wy,m}, \quad (1)$$

where $VA_{wy,m,ff}$ is VA flow for a given water year, month, and flow flexibility scenario; VA_{wy} is total VA flows for a given water year; RC_{wy} is total reference condition flows for a given water year; $RC_{wy,m}$ is total reference condition flows for a given water year and month; and $Prop_{wyt,m,ff}$ is the proportion of water year additional VA flows distributed under each flow flexibility scenario for a given water year type and month. In water years where a flow flexibility scenario did not exist, VA flows were used. In some cases, the reference condition was greater than the VA due to reoperation effects or other factors (see Section 4.1. *Background*), and additional flows were therefore assumed to be 0.

The approach used to estimate Delta Outflow under each flow flexibility scenario was similar to that described above for the tributary flows. For all VA contributions (tributary flows and forgone exports) to Delta Outflow except the Mokelumne, SacWAM produces a variable accounting for the VA additional flows, or such a variable was used to add the contributions with postprocessing. For Mokelumne, the approach described above of subtracting reference condition flows from VA flows was used to estimate the VA additional flows from the Mokelumne just above its entry into the Delta. The VA additional flows from all VA contributions to outflow were then summed into the total VA additional flows for each water year. This water year total VA additional flows was then subtracted from the Delta Outflow in the VA scenario. Next, the VA additional flows from each VA component were multiplied by the flow flexibility proportions under each flow flexibility scenario and added back to the Delta Outflow value produced in the prior step (Figure 4-8). This is represented in equation 2:

$$VA_{wy,m,ff} = \left(VA_{wy} - VAadditional_{wy,m}\right) + VAadditional_{wy,m}Prop_{wyt,m,ff}, \qquad (2)$$

where $VAadditional_{wy,m}$ is a variable returned by SacWAM (except for the Mokelumne) representing the VA flow contributions for each water year and month.

The resulting dataset included monthly flows for each tributary (or Delta Outflow) and year for the three flow flexibility scenarios: default, concentrated, and distributed. The default scenario differs slightly from the VA scenario modeled using SacWAM, as the SacWAM VA scenario was designed to closely represent the MOU.

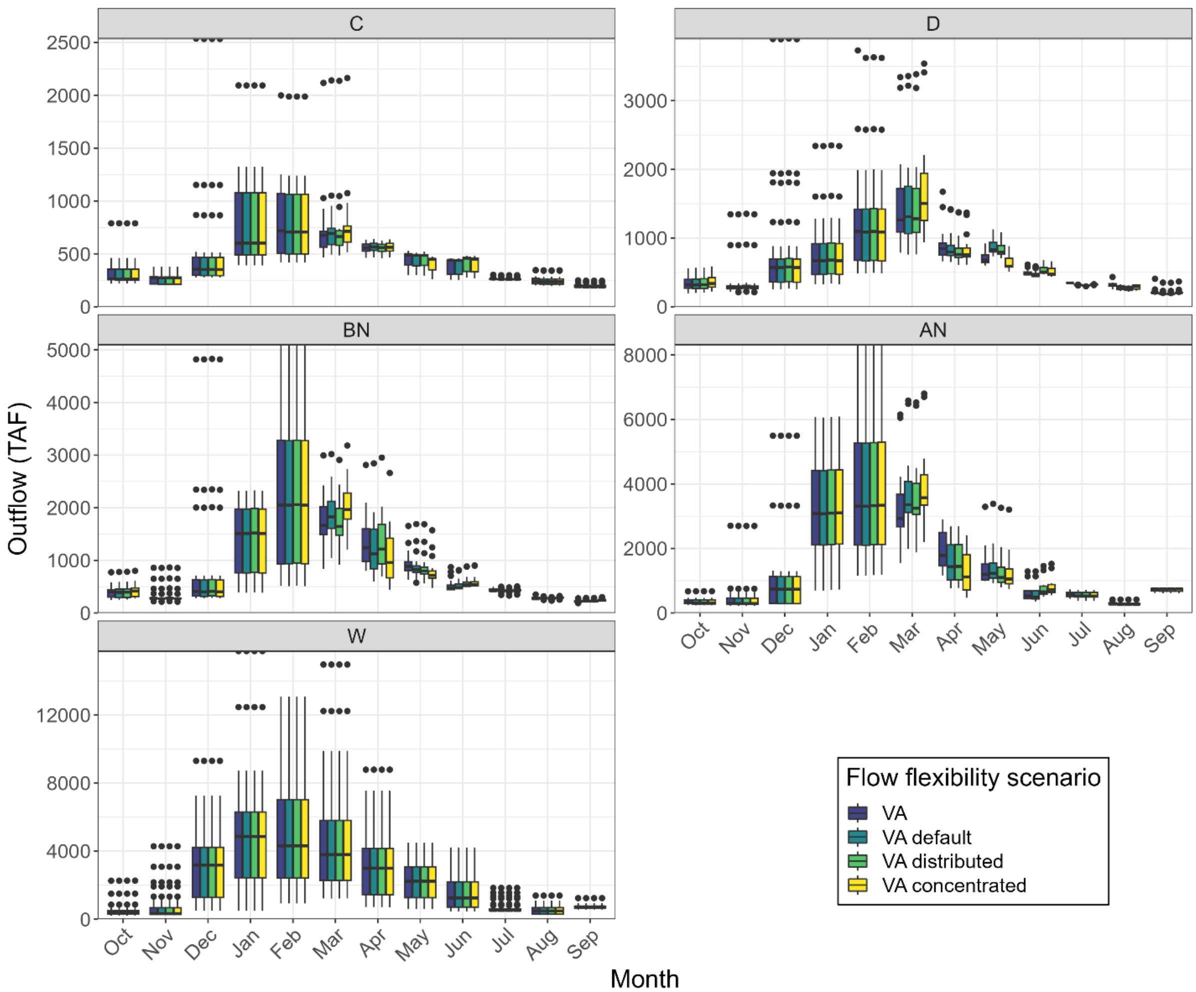

Figure 4-8. Boxplots of Delta Outflow from SacWAM VA flows (VA) and the Three Flow Flexibility Scenarios, for Each Water Year Type and Month
Note that the y-axis limits differ among panels.

Chapter 5
Analytical Approach to Evaluating Assets

To evaluate the benefits of the VA package, quantitative modeling was combined with qualitative literature review and analysis. These analyses provide estimates of potential population changes for four native estuarine indicator species (California Bay shrimp, Sacramento splittail, longfin smelt, and starry flounder). They also provide a qualitative description of population benefits and ecosystem improvements that are expected by habitat restoration and additional flows contributing to higher springtime flows, but for which no quantitative models exist. Because the VAs have some flexibility for when flow and non-flow assets would be provided, the evaluation of benefits for target species has some inherent uncertainty and is subject to assumptions, which are described below in Chapter 7, *Conclusions and Uncertainties*. However, the flexibility of flow asset deployment is evaluated through the flow flexibility scenarios (Section 4.13, *Flow Flexibility Scenarios*). Furthermore, the results of these analyses reflect expected benefits at a date when all restoration projects are completed.

The overall analysis is described on Figure 5-1. To describe changes in spawning and instream rearing habitat, SacWAM operations results were combined with models of suitable habitat at each flow level. Area of spawning and rearing habitat were then compared to the amount of habitat required to achieve the salmonid doubling goal (i.e., the Narrative Salmon Protection Objective, referred to as the Narrative Salmon Objective in the VA Term Sheet). While the target for the 8-year term of the VAs is to provide habitat necessary to support 25 percent of the offspring of the doubling goal populations for each tributary (Section 1.4, *Description of the Proposed Voluntary Agreements*), VA habitat benefits are presented relative to a range of percentages of the full doubling goal: 25 percent (the target), 50 percent, 75 percent, and 100 percent. To describe the changes in off-stream habitat on the tributaries, SacWAM operations results were combined with habitat restoration to model the number of Meaningful Floodplain Events (MFEs) expected at each level of flow.

In the Bay-Delta, the SacWAM operations modeling was used with established flow-abundance relationships for populations of several native fish species to calculate potential increases in population with increased flow (State Water Board 2017). SacWAM operations modeling was also used to predict the benefits of the VAs in achieving ecological flow thresholds. To describe the changes in habitat in the Bay-Delta, operations results from CalSim 2 were combined with more detailed Delta Simulation Model 2 (DSM2) models of gate operations, historical temperature, historical turbidity, and potential habitat restoration sites. These analyses were completed in 2019, and subsequent to the analysis several changes have been made to flow and non-flow habitat commitments. Therefore, the model results are postprocessed to estimate the expected benefits under the updated flow contributions in the VA Term Sheet as modeled in SacWAM. However, the results were not adjusted for the change in Bay-Delta habitat assets and current habitat restoration commitments in the VA Term Sheet are higher than what was modeled.

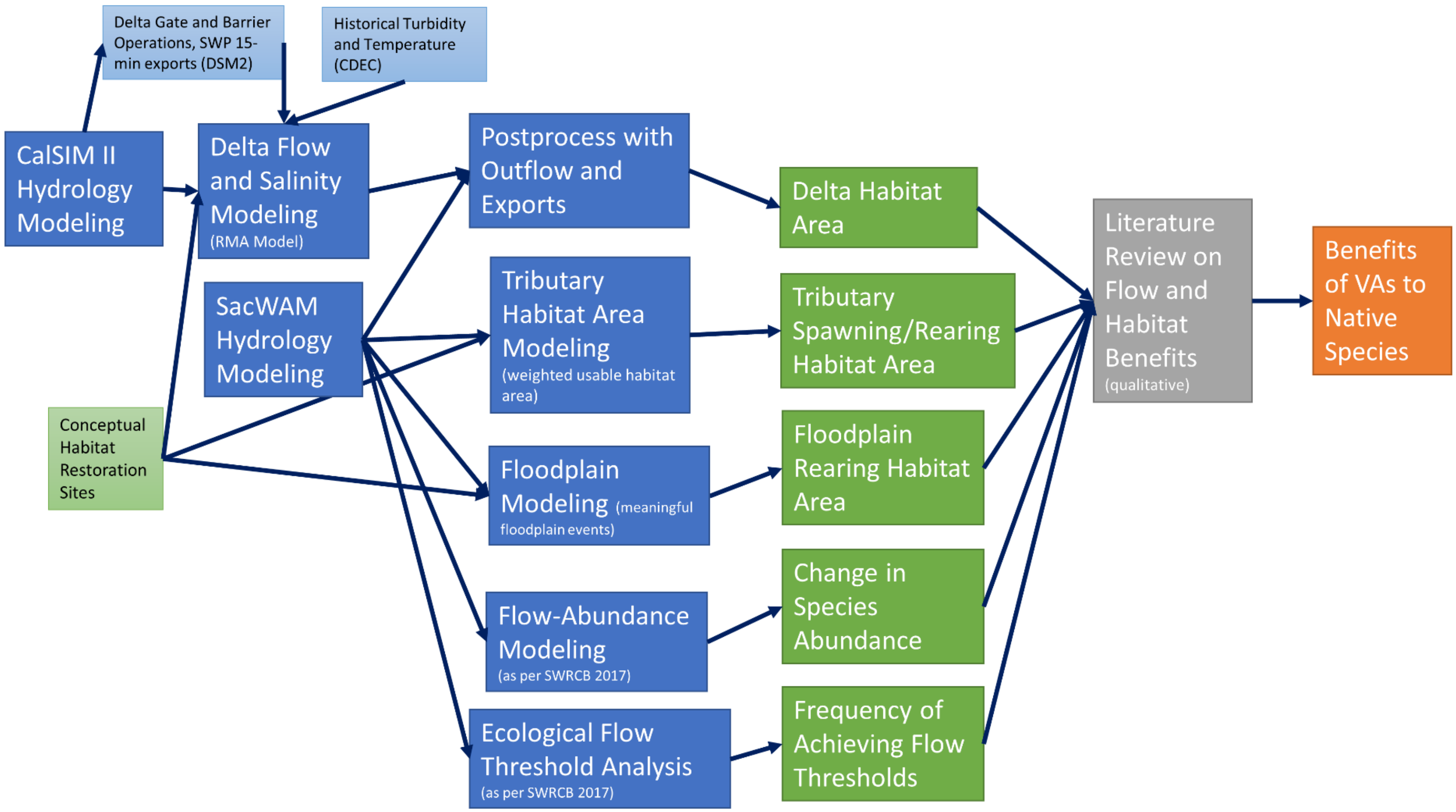

Figure 5-1. Diagram Showing Workflow Used to Evaluate VA Assets
The diagram demonstrates a qualitative and quantitative assessment. The connection between inputs and results is described using arrows.

Flow-abundance relationships can provide predictions of population changes, and there are models to assess the quantitative benefit of spawning and rearing habitat in the tributaries. However, researchers have not yet developed quantitative relationships between fish populations and many types of habitat restoration, including floodplain habitat and tidal wetland habitat. Many uncertainties remain in how effective increases in both flow and non-flow habitat will be in restoring native fish populations. Therefore, an extensive review of literature is included to describe the conceptual model for how the VA package may provide benefits to native species.

5.1 Tributary Habitat Analysis

5.1.1 Suitable Habitat Quantification

This section explains the overall approach for the analysis of tributary non-flow assets. Tributary non-flow assets include constructed spawning, instream rearing, and floodplain rearing habitat for fall-run Chinook salmon and spring run in the Sacramento River (Table 3-1 in Chapter 3, *Description of Flow and Non-Flow Assets*) and were evaluated under different flow scenarios. The analysis compared the VA flow and non-flow assets to the reference condition.

The fall-run rearing period is defined as February through June, which represents the time period that could potentially benefit rearing juvenile salmonids by increasing rearing habitat. The fall-run spawning period is defined as October through December. An analysis of spring-run Sacramento River Chinook salmon is also included where the rearing period is adjusted to November through May and the spawning period is adjusted to March through October (Peterson and Duarte 2020). Modeled average monthly flow results from SacWAM and the flow flexibility scenarios (Section 4.13, *Flow Flexibility Scenarios*) for the appropriate months were used to predict the area of available spawning and instream rearing habitat as well as the frequency and magnitude of floodplain inundation events for rearing in the Sacramento, Feather, Yuba, Mokelumne, and American Rivers under reference condition, VA, and flow flexibility scenarios. Flow flexibility scenarios are a variation on the VA scenario and were identical to the VA scenario in every aspect except for the differences in distribution of flows over the months.

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 and spring run in the Sacramento River consistent with the suitable habitat quantification for the CVPIA. Analyses are primarily 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 VA assets to existing and potential future conditions, estimates were generated of the habitat needed to support the doubling goal population established in the CVPIA AFRP (i.e., the Narrative Salmon Protection Objective, referred to as the Narrative Salmon Objective in the VA Term Sheet). The analyses and modeling are not site specific, and instead use the scientific literature and expert opinion to estimate the anticipated benefits of habitat and flow actions; with this approach, results and expected outcomes are intended to be robust with respect to specific locations of constructed habitat.

5.1.2 Calculating Habitat Needed to Support Doubling Goal Population

The AFRP doubling goal (i.e., the Narrative Salmon Protection Objective, referred to as the Narrative Salmon Objective in the VA Term Sheet) is the doubled (average) natural production from the population size calculated for 1967 to 1991. *Natural production* is defined as the portion of production that is not produced in hatcheries. To calculate the habitat needed to support the doubling goal, the escapement values associated with the doubling goal (Table 3-Xa-1 in the Working Paper on Restoration Needs Volume 3; USFWS 1995) were used as the targeted spawner abundance and doubled to align with the doubled natural production. Using spawner abundance allows the translation of the doubling goal to habitat area needed to support natural production. Escapement values for the appropriate Chinook salmon run from Table 3-Xa-1 in the Working Paper on Restoration Needs Volume 3 (USFWS 1995) were used to calculate the target doubled salmon abundance (Table 5-1).

Table 5-1. Summary of the Doubled Escapement of Fall Run (all tributaries) and Spring Run (Sacramento River), Number of Juveniles, and Rearing and Spawning Habitat Needed to Support the Doubled Escapement

Watershed	Doubled Escapement	Juveniles Produced	Rearing Area (acres)	Spawning Area (acres)
Sacramento River: Fall Run	154,000	146,300,000	1,808	177
Sacramento River: Spring Run	22,000	20,900,000	258	25
Feather River	98,000	93,100,000	1,150	112
Yuba River	26,000	24,700,000	305	30
American River	82,000	77,900,000	962	94
Mokelumne River	6,600	6,270,000	77	8

Table 5-2. Input Parameters Used to Calculate the Rearing and Spawning Habitat Area Needed to Support the Doubling Goal Population

Region	Spawner Sex Ratio	Fecundity	Egg-to-Fry Survival	Fry Territory Requirement (m^2)	Redd Size (m^2)
Sacramento Valley	0.5	5,000	0.38	0.05	9.29

Source: Central Valley Flood Protection Board 2016.
m^2 = square meters

The total amount 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 spawner sex ratio and redd size (Table 5-2 and equation 3). The rearing habitat required to meet the territory size needs of the doubling goal population is based on the number of fry expected to be produced by the doubled adult population and the individual fry territory requirement (equations 4 and 5) and also relies on assumptions about spawner sex ratio, individual fecundity, and egg-to-fry survival ratio (Table 5-2).

The egg-to-fry survival parameter (Table 5-2) is from Quinn (2005). This parameter is assumed to be an upper bound, as egg-to-fry survival varies across the Central Valley and has decreased in recent years. Using an upper bound survival estimate results in more rearing habitat required to satisfy the juvenile habitat rearing need. Therefore, this is a more conservative approach with respect to salmon recovery than using a lower survival rate, which would result in fewer fry and less rearing habitat needed to support the doubling goal population.

The individual fry-rearing territory size requirement (Table 5-2) applies to all fry produced by the doubled number of adults before any growth, movement, or juvenile mortality. Growth, movement, and juvenile mortality factors are not included because they vary significantly in data quality and availability across the VA watersheds. The territory size requirement used to determine habitat needed to support the doubling goal is based on Grant and Kramer (1990) territory size and fork length relationship. Fork lengths for fry (between 37.5 and 42 millimeters) were used to determine the individual territory requirement (Table 5-2). It is assumed that increases in territory size requirements with fork length are offset by fish mortality. Territory size requirements may be greater than the value used in these calculations. For example, Keeley and McPhail (1998) found that territory size ranged from approximately 0.03 to 0.4 square meter (m^2) for individual juvenile steelhead trout between 30 and 40 millimeters. The use of a larger territory size requirement would result in greater habitat needed to support the doubling goal population. The spawning habitat need (acres, H_s) is calculated as the product of the spawner sex ratio (0.5), redd size (9.29 m^2), and the doubled escapement (E), divided by 4,047 (to convert m^2 to acres).

$$H_s = \frac{0.5 * 9.29 * E}{4047} \quad (3)$$

The number of juveniles (J) is calculated as the product of the spawner sex ratio (0.5), fecundity (5,000), egg-to-fry survival (0.38), and doubled escapement (E).

$$J = 0.5 * 5{,}000 * 0.38 * E \quad (4)$$

The suitable rearing habit need (acres) is calculated as the product of the number of juveniles (J) and the territory requirement (0.05 m^2) divided by 4,047 (to convert m^2 to acres).

$$H_r = \frac{0.05J}{4047} \quad (5)$$

5.1.3 Spawning and Rearing Habitat Evaluation

5.1.3.1 Existing Habitat Quantification

Existing spawning and rearing habitat inputs (i.e., habitat used in the reference condition scenario) are sourced from a repository of flow to suitable area relationships (Gill and Tompkins n.d.[a]). In 2017, FlowWest met with Mark Gard (USFWS, currently CDFW) to catalog and document the available habitat models as well as acquire the data from the various studies. FlowWest processed the data into a consistent format and published the habitat repository as an R package on GitHub (Gill and Tompkins n.d.[b]). On behalf of the CVPIA Science Integration Team, FlowWest hosted several expert elicitation workshops (CVPIA Science Integration Team n.d.). In attendance were representatives from USFWS, CDFW, Reclamation, DWR, non-governmental organizations, and other interested parties with expertise on watersheds within the Central Valley. During these meetings, the flow-to-habitat relationships were presented and experts evaluated the modeling veracity compared to their on-the-ground observations. FlowWest used this feedback to refine some of the estimates and included additional datasets made available through the workshops. Additionally, workshop participants provided the habitat extents for spawning and rearing within the Central Valley. The technical lead(s) for each watershed then confirmed the source of existing non-flow habitat information was the best available. See Table 5-5 through Table 5-7 for specific experts who provided information. The Yuba River rearing habitat was updated with more recent data provided in a YWA comment letter on the last draft of this report (see Section 1.3.1, *Response to Comments on the Draft Supplement*, for a description of how this report was revised in response to comments).

The studies cataloged with Mark Gard (Gill and Tompkins n.d.[b]) report suitable habitat as weighted usable area in square feet per 1,000 feet of channel length as a function of flow in cfs. The methodology for determining the weighted usable area (which is also called a Relative Suitability Index or RSI) is a key component of the Instream Flow Incremental Methodology (Bovee et al. 1998) for evaluating biological effects of streamflow. Weighted usable area is calculated using a hydrodynamic model of the tributary and a habitat suitability model. This is typically done using Hydrologic Engineering Center's River Analysis System (HEC-RAS) for hydrodynamics and Physical Habitat Simulation (PHABSIM) for physical habitat within a stream. PHABSIM uses the hydraulic model results of depth and velocity and weights these values based on the suitability determined through the habitat suitability criteria (HSC), resulting in relationships between flow and suitable physical habitat. The HSC are developed through empirical on-the-ground surveys, typically snorkel surveys where fish presence (i.e., use) is associated with the depth and velocity where fish are observed. The HSC for each tributary are displayed on Figure 5-2 and Figure 5-3 where for comparison the shaded area shows the suitability criteria used for the quantification of VA habitat. For the analysis, the weighted usable area (in units of suitable area per channel length) was calculated for each of the modeled hydrology scenarios' time series and then converted to total suitable areas by multiplying by the total spawning or rearing extent length. Watershed lengths are based on expert outreach conducted in 2017 and are available through the DSMHabitat R package (CVPIA - Open Science Collaborative 2021). This calculation results in a time series of suitable habitat areas as a function of modeled hydrology for each tributary or, in some cases, tributary reach. For instance, on the Feather River existing habitat was modeled separately for the Low Flow Channel and High Flow Channel, as hydrologic conditions vary substantially between these reaches due to flow operations through the Oroville-Thermalito Complex.

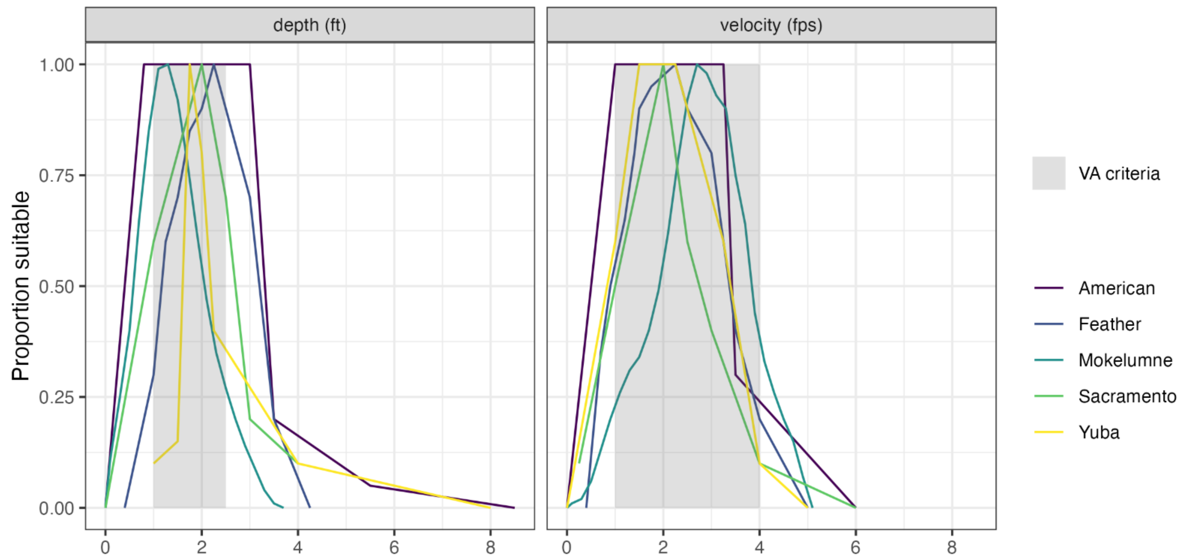

Figure 5-2. Comparison of Existing Spawning Habitat Suitability Criteria with VA Spawning Habitat Suitability Criteria

Spawning HSC developed based on empirical field surveys. Shaded area represents the suitability criteria used to quantify VA habitat, while colored lines represent the criteria curves applied to the existing habitat.

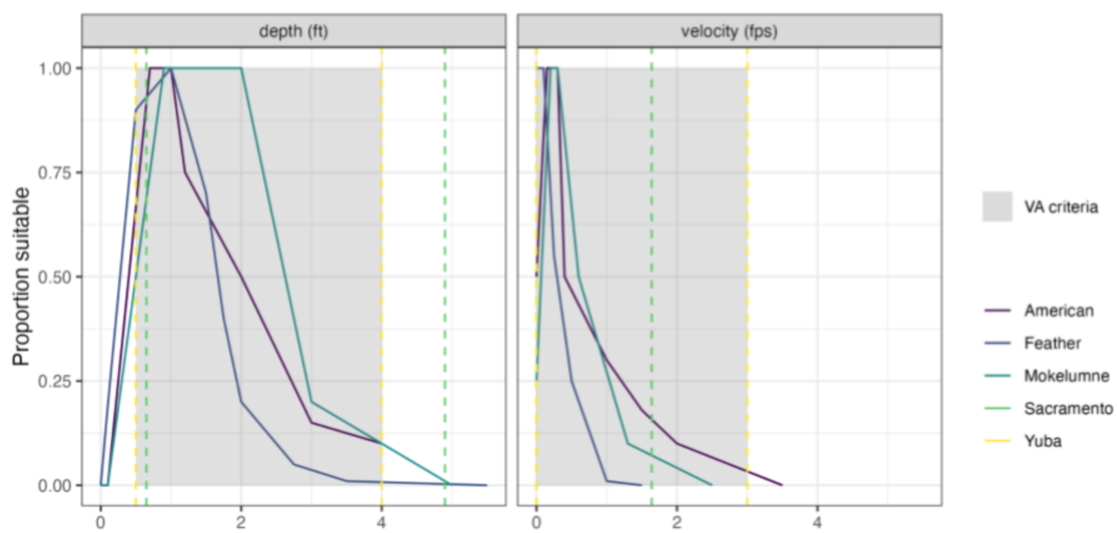

Figure 5-3. Comparison of Existing Rearing Habitat Suitability Criteria with VA Rearing Habitat Suitability Criteria

Rearing HSC developed based on empirical field surveys. Full HSC are not available for the Sacramento and Yuba Rivers, so for these tributaries, habitat suitability is displayed as a range bordered by vertical lines. Shaded area represents the suitability criteria used to quantify VA habitat, while colored lines represent the criteria curves applied to the existing habitat.

5.1.3.2 VA Habitat Quantification

VA habitat was not quantified using the same methodology as for existing habitat. The VA Assets to Outcomes workgroup participants identified a representative for each VA watershed. These watershed representatives were given the criteria to define non-flow assets (i.e., constructed habitat) for VA analysis. The watershed representative then identified the appropriate technical lead(s) to provide the best available scientific information on VA commitments for non-flow assets satisfying these criteria to describe VA non-flow habitat. Suitable habitat for the evaluation of VA proposed habitat was defined as physical habitat within specified depth and velocity ranges (Table 5-4) identified by the Conservation Planning Foundation for Restoring Chinook Salmon and *O. mykiss* in the Stanislaus River (Anchor QEA, LLC 2019).

The VA Parties have developed draft non-flow habitat accounting methods that would ultimately determine how restored acreage would count toward the commitments in the VA Term Sheet. These accounting measures would thus determine how the implementation of VA non-flow habitat assets aligns with the assumptions used to model the VA assets and quantify their expected benefits.

In the analyses presented in this report, the proposed habitat areas for the VAs are assumed to satisfy both depth and velocity suitability criteria (Table 5-4) under expected flow conditions (i.e., the “design flow” for the habitat) during the period relevant to the salmonid life stage using the habitat. However, because flow conditions can change during the period relevant to the salmonid life stage occupying the habitat, some of the proposed VA habitat is expected to become less suitable at flows higher or lower than the design flow. VA proponents provided estimates of how depth and velocity habitat suitability is expected to change with flow, and the analyses in this report reproduced those flow-suitable habitat relationships (described in Table 5-5 through Table 5-7). It is assumed here that, at a minimum, VA habitat assets would be constructed to reproduce these flow-suitable habitat relationships provided by the VA proponents.

In addition to depth and velocity criteria, prior research indicates that cover is important for rearing habitat suitability and is often the most limiting factor when applied alongside velocity and depth (San Joaquin River Restoration Program 2012). Therefore, this analysis assumes that rearing habitat has suitable cover, defined as features summarized within the San Joaquin River Restoration Program November 2012 Technical report with at least a Habitat Suitability Index value of 0.5. Cover suitability is a narrative assumption and is not explicitly modeled in this report. Available literature indicates that habitat for rearing Chinook salmon contains suitable cover if cover features constitute at least 20 percent (Raleigh et al. 1986) or at least 75 percent (Whipple et al. 2019) of the habitat area, or if suitable cover features are present within 1 meter of any point in the stream area (San Joaquin River Restoration Program 2012). The current draft non-flow habitat accounting methods require that cover features constitute a minimum of 20 percent of the habitat area for some VA projects, but allowable cover features include cobble (3 to 12 inches), which has uncertain suitability for rearing salmonids (it is not included as suitable cover in the San Joaquin River Restoration Program (2012) report).

These draft non-flow habitat accounting methods include the same depth and velocity criteria as Table 5-4. They also require 20 percent cover and suitable floodplain inundation regimes (see Section 5.1.3.4, *Floodplain Habitat Evaluation* for a description of suitable floodplain inundation regimes) for non-flow habitat not completed as part of early implementation. Early implementation non-flow habitat, defined as projects that have reached the permitting stage by January 1, 2024 (potentially the majority of non-flow assets; Table 5-3), would be required to provide an explanation that is acceptable to State Water Board and CDFW that the projects provide suitable cover and inundation regimes for the intended benefits. Therefore, the extent to which these projects would result in equivalent cover and inundation suitability as assumed here is unknown. In addition, for all projects, alternative depth, velocity, cover, and inundation criteria may be proposed and would be subject to review by the State Water Board and CDFW, in consultation with USFWS and NMFS. Bypass and tidal wetland projects (see Section 5.3, *Bay-Delta Two-Dimensional Hydrodynamic Analysis* for a description of tidal wetland modeling assumptions) are treated differently; they would propose project-specific design criteria that would be reviewed by the State Water Board and CDFW, in consultation with USFWS and NMFS. This would allow some of these non-flow habitat projects to be designed to benefit species other than salmonids, Therefore, all of the 20,000 acres of bypass non-flow habitat assets may not be constructed for salmonid suitability, although less than 10 percent of that acreage would fulfill the full doubling goal need on the Sacramento River (Table 5-1).

These analyses assume that the suitable habitat acreage described in Table 5-5 through Table 5-7 corresponds with how the habitat would be constructed, with suitability defined by the criteria in Table 5-4. If the suitable acreage of the implemented projects differs from the assumed suitability curves in Table 5-5 through Table 5-7 and suitability criteria in Table 5-4, then the suitable habitat acreage resulting from VA non-flow commitments would be different than the acreage presented in these results.

Table 5-3. Potential Acreage of Early Implementation Projects by Habitat Type and Tributary

Tributary	Habitat Type	Early Implementation Acres	Total Commitment	Percent Early Implementation
Sacramento	Spawning	113.5	113.5	100%
Sacramento	In-channel rearing	113.72	137.5	83%
Bypasses	Floodplain rearing	12,200	20,000	61%
Feather	Spawning	9	15	60%
Feather	Instream rearing	0	5.25	0%
Feather	Floodplain rearing	100	1,655	6%
Yuba	Instream rearing	50	50	100%
Yuba	Floodplain rearing	100	100	100%
American	Spawning	25	25	100%
American	Rearing	39	75	52%
Mokelumne	In-channel rearing	1	1	100%
Mokelumne	Floodplain rearing	14.67	26	56%
Putah	Spawning	1.4	1.4	100%
North Delta and Suisun Marsh	Tidal wetland	3000	5227.5	57%

In the draft VA non-flow habitat accounting methods, early implementation projects would be required to provide an explanation that is acceptable to State Water Board and CDFW that the projects would provide suitable cover and inundation regimes for the intended benefits, rather than meet the numeric criteria that would apply to the non-flow habitat assets that have not begun permitting or been constructed. Early implementation is defined by the draft VA non-flow habitat accounting methods as any projects at the permitting, construction, or project completion stage by January 1, 2024. However, the VA strategic plan specifies the implementation schedule based on when projects would be completed, within 3- to 6-year bins. Therefore, to estimate the maximum acreage that may fall into the early implementation category, we count as early implementation any projects expected to be completed during the December 2018–2024 and 2025–2027 time periods.

While water quality parameters such as dissolved oxygen are key attributes of suitable habitat, they were not included in the suitability criteria for VA habitat due to the lack of available data. Furthermore, this analysis assumes that habitat is productive and occupied. However, the same habitat suitability assumptions were applied to the assessment of reference condition habitat as were applied to the VA habitat (Figure 5-2 and Figure 5-3), allowing for a direct comparison of reference conditions versus VA habitat. Table 5-5 through Table 5-7 list the specific experts who provided habitat information.

Table 5-4. Description of Suitability Criteria Used to Define VA Suitable Spawning and Rearing Habitat

Habitat Type	Depth Suitability Range (ft)	Velocity Suitability Range (fps)	Cover	Temperature (°C)
Spawning	1.0–2.5	1.0–4.0		13
Instream and Floodplain Rearing	0.5–4.0	0.0–3.0	≥20–75% cover or cover features within 1 meter of any point in the stream	18

Instream rearing and floodplain habitat are defined by the same depth and velocity criteria, though VA floodplain habitat analysis also considers inundation duration and frequency. VA depth and velocity suitability criteria are based on the Conservation Planning Foundation for Restoring Chinook Salmon (*Oncorhynchus tshawytscha*) and *Oncorhynchus mykiss* in the Stanislaus River (Anchor QEA, LLC 2019), while cover criteria are based on the San Joaquin River Restoration Program 2012 report, Raleigh et al. 1986, and Whipple et al. 2019. Cover criteria are considered suitable if they have a habitat suitability index of 0.5 or higher from San Joaquin River Restoration Program 2012 and the sources cited therein. The justification for the temperature criteria is provided in Section 5.1.4.1, *Temperature Criteria*.
°C = degrees Celsius; fps = feet per second; ft = feet

Whenever possible, VA habitat was described as a function of flow for each tributary (Table 5-5 through Table 5-7). The VA habitat data source provided areas of suitable VA habitat at different flow levels, including at least a minimum, maximum, and target or other intermediate flows over which habitat area was assumed to change. A linear interpolation was then applied across those flows to create a function over the range of flows within the SacWAM data for that watershed/scenario. This function was then used to estimate the additional VA habitat area for the flows provided by SacWAM for each year in the SacWAM results. Once the assets were in units of suitable habitat area, the proposed VA non-flow habitat area in acres was added to the existing suitable habitat area for each watershed evaluated in the VA scenario. Data sources for VA habitat were developed in 2019 and are assumed to be the best available information. In 2022, VA habitat data sources were modified to reflect the revised 8-year VA term.

Spawning and rearing habitat timeseries under the reference condition (i.e., existing habitat) and VA were modeled using SacWAM for each year of the modeling period between water years 1923 and 2015. Water year is defined as the 12-month period beginning October 1, for any given year, through September 30 of the following year. Model results of suitable habitat area under each scenario were compared by filtering the data set to the spawning or rearing months defined above in Section 5.1.1, *Suitable Habitat Quantification*, then calculating the mean suitable habitat area for each year and then the median across the entire time series. Median suitable habitat area was used to account for skewed distributions of habitat across the modeling period (i.e., extremely large values occurred during large flood events, which inflated the mean, so the median was more representative of conditions across all years). Rearing habitat was evaluated for instream habitat alone, and for the combination of instream and floodplain habitat.

5.1.3.3 Spawning and Instream Rearing Habitat Modeling

Spawning habitat was evaluated for the Sacramento, Feather, and American Rivers. The Putah Creek VA includes 1 acre of spawning habitat, but it was not included in the analysis because currently no existing suitable habitat data are available for comparison. Instream rearing habitat was evaluated for the Sacramento, Feather, Yuba, American, and Mokelumne Rivers.

Spawning Data Sources

Table 5-5. Sources for Spawning Habitat Versus Flow Relationships and Modified Spawning Habitat Availability as Proposed in the VAs

River	Existing Habitat Source	VA Habitat Source
Sacramento	USFWS 2003 (pg. 29–31)[1,2]	John Hannon, U.S. Bureau of Reclamation Assumptions: • VA habitat is all suitable habitat. • A flow-to-area relationship was not provided, and all 113.5 acres of VA habitat were added to existing habitat consistently across all flows. Added to existing habitat at the Red Bluff to Deer Creek reach.
Feather	Phase 2 Report Evaluation Of Project Effects on Instream Flows and Fish Habitat SP-F16, DWR 2004 (pg. 35–36)[3,4] Habitat to flow relationships for the High Flow Channel and Low Flow Channel.	Jason Kindopp, DWR Assumptions: • DWR provided the number of suitable acres at minimum (70% of proposed acres suitable at 650 cfs), maximum (80% of proposed acres suitable at 1,100 cfs), and target (90% of proposed acres suitable at 850 cfs) flow. Added to existing habitat on the Low Flow Channel.
Yuba	Paul Bratovich, HRC; Steve Grinnel, SEG Water	*No spawning habitat committed.*
American	Lower American River Biological Rationale, Development and Performance of the Modified Flow Management Standard 2017 (pg. 91–107)[5,6]	Tom Gohring, CBEC Eco Engineering Assumptions: • VA habitat is all suitable habitat. • A flow-to-area relationship was not provided, and all 25 acres of VA habitat were added to existing habitat consistently across all flows. Added to existing spawning habitat.
Mokelumne	East Bay Municipal Utility District	*No spawning habitat committed.*

For each VA habitat source, the identified contact provided the number of acres of new VA habitat at select flow levels. VA habitat acreage was then linearly interpolated across these flow values to create a relationship between flow and habitat across the entire flow range.
[1,2] USFWS 2003; Gill and Thompkins 2020a.
[3,4] DWR 2004; Gill and Thompkins 2020b.
[5,6] Bratovich et al. 2017; Gill and Thompkins 2020c.

Instream Rearing Data Sources

Table 5-6. Sources for Instream Rearing Habitat Versus Flow Relationships and Modified Instream Rearing Habitat Availability as Proposed in the VAs

River	Existing Habitat Source	VA Habitat Source
Sacramento	CVFED HEC-RAS hydraulic model refined for use in the NOAA-NMFS Winter Run Chinook Salmon life cycle model[1,2]	John Hannon, U.S. Bureau of Reclamation Assumptions: • Reclamation provided the number of suitable acres of new side-channel habitat (25 acres) at three flow levels (60% of acres suitable below 8,000 cfs; 100% suitable at 8,000 cfs; 80% suitable above 8,000 cfs). • Reclamation provided the number of suitable acres of new instream habitat (112.5 acres) at three flow levels (0% of acres suitable below 8,000 cfs; 25% suitable at 30,000 cfs; 100% suitable at 15,000 cfs). Added to existing instream habitat.
Feather	Addendum to Phase 2 Report Evaluation of Project Effects on Instream Flows and Fish Habitat SP-F16, DWR 2005 (pg. 2-7 and 2-9)[3,4] Habitat to flow relationships for the High Flow Channel and Low Flow Channel.	Jason Kindopp, DWR Assumptions: • DWR provided the number of suitable acres at minimum (80% of proposed acres suitable at 650 cfs), maximum (50% of proposed acres suitable at 3,000 cfs), and target (90% of proposed acres suitable at 725 cfs) flow. Added to existing habitat on the Low Flow Channel.
Yuba	Paul Bratovich, HDR – Lower Yuba River Management Team; Steve Grinnel, HDR – Lower Yuba River Management Team	Paul Bratovich, HDR; Steve Grinnel, SEG Water Assumptions: • HDR provided the number of suitable acres for total VA habitat (existing + additional VA acres) and existing habitat for a number of flows. • Existing habitat was subtracted from total VA habitat (existing + additional VA acres) to calculate additional VA habitat. The updated existing habitat acreage (see Section 1.3.1.12) was not used for this calculation because updates to total VA habitat (existing + additional VA acres) were not provided at the same time. The additional number of suitable VA acres at three flow levels are as follows: minimum (10% of proposed acres suitable at 880 cfs), maximum (55% of proposed acres

River	Existing Habitat Source	VA Habitat Source
		suitable at 5,000 cfs), and target (90% of proposed acres suitable at 2,500 cfs) flow. • When representing total acres under the VA scenario (existing + additional VA acres), the updated existing habitat acreage was added to the calculated VA additional acres described above.
American	Chris Hammersmark, CBEC Eco Engineering	Chris Hammersmark, CBEC Eco Engineering Assumptions: • CBEC provided the number of suitable acres for a number of flows, including minimum (27% of proposed acres suitable at 500 cfs), maximum (53% of proposed acres suitable at 20,000 cfs), and target (87% of proposed acres suitable at 5,500 cfs) flow. Added to existing instream habitat.
Mokelumne	EBMUD	Robyn Bilski, EBMUD Assumptions: • EBMUD provided the number of suitable acres for a number of flows including minimum (35% of proposed acres suitable at 100 cfs) and maximum/target flows (85% of proposed acres suitable at 1,000 cfs). Added to existing instream habitat.

For each VA habitat source, the identified contact provided the number of acres of new VA habitat at select flow levels, except where exceptions are identified. VA habitat acreage was then linearly interpolated across these flow values to create a relationship between flow and habitat across the entire flow range.
[1,2] Queda Consulting, LLC et al. 2017; Gill and Thompkins 2020a.
[3,4] DWR 2005; Gill and Thompkins 2020b.
CVFED = Central Valley Floodplain Evaluation and Delineation; EBMUD = East Bay Municipal Utility District; NOAA = National Oceanic and Atmospheric Administration

5.1.3.4 Floodplain Habitat Evaluation

To represent existing floodplain habitat relationships with flow, the best available flow to suitable area relationships generated from the results of floodplain hydraulic modeling studies were acquired. To analyze proposed VA actions of constructed habitat assets, water districts, CDFW, DWR, and Reclamation provided clarified modeling assumptions. If the habitat is seasonally inundated, the districts were asked to provide the flow at which the area is inundated and the percent of suitable inundated area that they will design to. Table 5-7 describes data sources and assumptions about VA acres of suitable floodplain habitat (according to the depth, velocity, and cover suitability criteria provided in Table 5-4) that are expected across a range of flow conditions for each tributary. However, as described in Section 5.1.3.2, *VA Habitat Quantification*, the draft non-flow habitat accounting methods developed by the VA Parties do not include pre-determined criteria for bypass habitats, so the acreage of bypass habitats that is suitable for Chinook salmon rearing may differ from what is assumed here. Data sources for VA habitat were developed in 2019 and are assumed to be the best available information. In 2022 VA habitat data sources were modified to reflect the revised 8-year VA term.

Floodplain Rearing Data Sources

Table 5-7. Sources for Floodplain Habitat Versus Flow Relationships and Modified Floodplain Habitat Availability as Proposed in the VA

River	Existing Habitat Source	VA Habitat Source
Sacramento	CVFED HEC-RAS hydraulic model refined for use in the NOAA-NMFS Winter Run Chinook Salmon life cycle model[1,2]	*No floodplain habitat committed.*
Sutter Bypass	CVFED HEC-RAS hydraulic model refined for use in the NOAA-NMFS Winter Run[3,4]	Lee Bergfeld, MBK Engineers Assumptions: • Flow and suitable area were not provided for VA habitat. • Number of suitable acres for VA habitat was assumed to have the same relative flow to suitable area relationship as existing habitat: minimum (3% of proposed acres suitable at 10 cfs), maximum (75% of proposed acres suitable at 10,000 cfs), and target (100% of proposed acres suitable at 5,000 cfs) flows. Assumed habitat is accessible to fish.

Feather	CVFED
	HEC-RAS hydraulic model[5,6]
		Jason Kindopp, California DWR
		Assumptions:
		• DWR provided the number of suitable acres for minimum, target, and maximum flows for three types of project designed for different inundation flows: 3,000 cfs, 4,000 cfs, and 30,000 cfs.
		  ○ A total of 550 acres was expected to be inundated at 3,000 cfs with the following suitability: minimum (75% of total inundated acres [550 acres] suitable at 3,000 cfs), maximum (50% of total inundated acres [550 acres] suitable at 10,000 cfs), and target (80% of total inundated acres [550 acres] suitable at 4,000 cfs) flows.
		  ○ A total of 300 acres was expected to be inundated at 4,000 cfs with the following suitability: minimum (80% of total inundated acres [300 acres] suitable at 4,000 cfs), and maximum/target (80% of total inundated acres [300 acres] suitable at 25,000 cfs) flows.
		  ○ A total of 805 acres was expected to be inundated at 30,000 cfs with the following suitability: minimum (80% of total inundated acres [805 acres] suitable at 30,000 cfs), maximum (50% of total inundated acres [805 acres] at 50,000 cfs), and target (90% of total inundated acres [805 acres] at 35,000 cfs) flows.

River	Existing Habitat Source	VA Habitat Source
Yuba	Paul Bratovich, HDR – Lower Yuba River Management Team; Steve Grinnel, HDR – Lower Yuba River Management Team	Paul Bratovich, HDR; Steve Grinnel, SEG Water Assumptions: • Constructed to be inundated at 2,000 cfs (i.e., above flows of 2,000 cfs in the lower Yuba River). • Flow and suitable area were not provided for VA habitat, so 100% of the proposed acreage was assumed suitable for flows over 2,000 cfs. • The 100 acres of VA proposed floodplain habitat were added to existing habitat beginning at 2,000 cfs, with a 50-50 split (i.e., 50% [50 acres] upstream of Daguerre Point Dam and 50% [50 acres] downstream of Daguerre Point Dam) for the lower Yuba River.
American	Chris Hammersmark, CBEC Eco Engineering	*No floodplain habitat committed.*
Mokelumne	EBMUD	Robyn Bilski, EBMUD • EBMUD provided the number of suitable acres for a number of flows including minimum (50% of proposed acres suitable at 800 cfs), maximum (100% of proposed acres suitable at 1,700 cfs), and target (100% of proposed acres suitable at 1,300 cfs) flows. • Inundation beginning at 800 cfs.

[1,2] Queda Consulting, LLC et al. 2017; Gill and Thompkins 2020a.
[3,4] Queda Consulting, LLC et al. 2017; Gill and Thompkins 2020d.
[5,6] Wood Rogers 2014; Gill and Thompkins 2020b.
For each VA habitat source, the identified contact provided the number of acres of new VA habitat at select flow levels. VA habitat acreage was then linearly interpolated across these flow values to create a relationship between flow and habitat across the entire flow range.
CVFED = Central Valley Floodplain Evaluation and Delineation; EBMUD = East Bay Municipal Utility District; NOAA = National Oceanic and Atmospheric Administration

Floodplain Evaluation Criteria

Typically, monthly floodplain habitat under the reference condition across watersheds is 0 acres, which makes quantification of monthly floodplain habitat area (as was done for the other habitat types) difficult. One option is to provide an acre-day analysis comparing the frequency during the modeling period that floodplain flows are achieved across scenarios where significant benefits are defined as a 10-percent change in frequency and are validated through professional judgment (2017 Scientific Basis Report). While this analysis provides a high-level assessment of floodplain habitat availability, it does not acknowledge differences in the quality of floodplain habitat in terms of critical dimensions of duration, magnitude, and frequency.

Alternatively, a multidimensional metric is provided to communicate floodplain habitat under the reference condition and VA scenarios. Floodplain habitat is analyzed using the MFE approach. The MFE was developed to evaluate the VA based on literature recommending longer inundation periods and repeated pulses throughout the year and interannually (Grosholz and Gallo 2006; Opperman 2012; Takata et al. 2017). The MFE accounts for four dimensions of floodplain habitat.

In addition to the suitability criteria described above (e.g., Table 5-4), also important to providing suitable habitat are hydrologic criteria, including the frequency of floodplain flows and their duration and magnitude. 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. 2001c, 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 developed for this report evaluates floodplain flows in terms of magnitude, interannual frequency, intra-annual frequency, and duration.

- **Magnitude** is the suitable area inundated by a floodplain event based on hydrology.
- **Interannual frequency** is the long-term average in which cohorts are exposed to floodplains. The targeted interannual frequency is a desired inundated area occurring 2 out of every 3 years. Interannual 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 2 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, at least 7 days are needed and after 21 days there is minimal additional gain in productivity. For the purposes of modeling MFEs, it is assumed that an event will last at least 30 days because SacWAM provides a monthly timestep and this is a more conservative metric for floodplain benefit.

The MFE is calculated for four given areas (i.e., magnitudes): the area needed to support 25 percent (the target for the VAs), 50 percent, 75 percent, and 100 percent of the doubling goal population (see Section 5.1.1, *Suitable Habitat Quantification*). The proportion of MFE occurrence throughout the model period is compared for reference condition and VA scenarios. A 10-percent difference or greater between the reference condition and VA is determined to be substantial. The parameters chosen for MFE are somewhat conservative, so actual benefits may be greater than model results suggest. However, see the discussion below about how the habitat accounting procedures for VA floodplain restoration projects may produce benefits that differ from what is assumed here.

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., 25 percent 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 months during the rearing period?
3. Determine if the interannual floodplain frequency is met.
   - Are the floodplain magnitude and intra-annual frequency met 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 (1923) and last (2015) year.

The MFE analysis was used to assess flooding on the Feather, Mokelumne, and Yuba Rivers and Sutter Bypass using suitable habitat data (according to suitability criteria provided in Table 5-4) across a range of flow conditions as described in Table 5-7.

Variability in the MFE analysis was evaluated by comparing the proportion of MFE occurrence using the metrics described above, with upper and lower bounds using more relaxed and restrictive metrics, respectively. The lower bounds were defined as the proportion of event occurrence when MFE criteria are restricted to require floodplain events 4 out of every 5 years, and the upper bounds were defined as the proportion of event occurrence when MFE criteria are loosened to require floodplain events 1 out of every 2 years.

Among the three flood basins (Sutter Bypass, Butte Sink, and Colusa basin), the Sutter Bypass will have more frequent inundation due to the changes to Tisdale Weir. Infrastructure changes to increase fish access, inundation frequency, and duration are being explored in these flood basins. The change in flows through the Tisdale Weir (achieved by a Tisdale Weir notch) was analyzed in addition to using the MFE analysis.

Because specific projects have not yet been identified in these flood basins, a simplifying assumption was made that topographic changes to the Sutter Bypass would create suitable depth and velocity conditions in 20,000 total acres (approximately 11,000 acres of existing habitat and approximately 9,000 acres of additional habitat from VA commitments among the three flood basins) for juvenile salmon rearing at flows similar to existing habitat. The Sutter Bypass MFE analysis assumes up to 20,000 acres of suitable habitat will be inundated within the Sutter Bypass between 0 and 10,000 cfs, where the maximum habitat area of 20,000 acres occurs at 5,000 cfs. This includes approximately 9,000 acres of VA habitat added to existing habitat toward the total 20,000 acres of additional floodplain habitat committed in the Sutter Bypass, Colusa basin, and Butte Sink. The addition of 9,000 acres was modeled only for the Sutter Bypass because additional floodplain projects have not been identified with enough specificity to include the full 20,000 acres of additional VA habitat in the model at this time. Figure 5-4 shows the existing suitable rearing habitat by reach and flow within the Sutter Bypass and cumulatively across reaches, with a peak of 11,348 acres at a flow of 5,000 cfs in the bypass. This scenario of topographic changes (VA—proposed topography) under VA flows was compared to: (1) existing habitat (i.e., existing topographic conditions) under reference condition flows and (2) existing habitat (i.e., existing topographic conditions) under VA flows, which captures flow modifications to the weir (VA—Tisdale Weir). Expected benefits from projects occurring outside the specific footprint of the Sutter Bypass would be similar.

The VA Parties have developed draft non-flow habitat accounting methods that would ultimately determine how restored floodplain habitat acreage would count toward the commitments in the VA Term Sheet. These draft non-flow habitat accounting methods require that tributary floodplain habitats have either two periods of 7- to 18-day inundation, or one period of more than 18 days of inundation, in 2 out of every 3 years on average and within a range of 50–80 percent of years. However, these requirements do not apply to early implementation projects (Table 5-3), which would instead be required to provide an explanation that is acceptable to State Water Board and CDFW that the projects provide suitable inundation regimes for the intended benefits. They also do not necessarily apply to bypass floodplain projects, which would propose project-specific design criteria subject to review by the State Water Board and CDFW, in consultation with USFWS and NMFS. Therefore, the quantity of VA restored floodplain habitat conforming to these MFE criteria may differ from the acreage presented in this report.

The additional floodplain habitat provided under the VAs in these flood basins could provide rearing habitat to juvenile fish from the Sacramento River and its tributaries upstream and, based on the assumptions described above, it would exceed the rearing habitat doubling goal for the Sacramento River (1,961 acres). This analysis assumes this habitat is physically accessible by juvenile fish; however, current access to these flood basins is limited. If accessibility to flood basins is not improved, then the benefits of the proposed VAs for increasing floodplain habitat would be less than what is suggested by the analyses presented here. Enhancing connectivity between these flood basins and the Sacramento and Feather Rivers to improve juvenile salmon access to rearing habitat and/or improve adult fish passage is currently being explored. Such modifications will require project-specific analyses not included in this report.

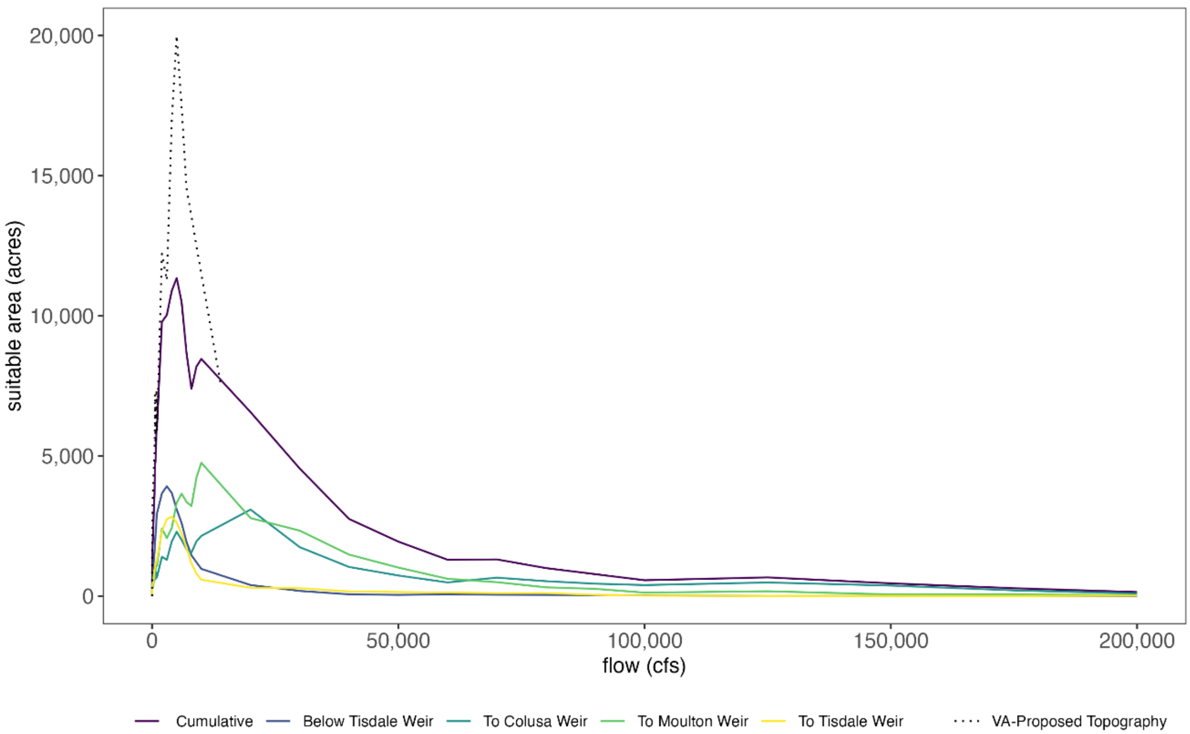

Figure 5-4. Flow (cfs) to Suitable Area (Acres) Curves for Four Sections of the Sutter Bypass
Lines indicate flow to Moulton Weir (green), to Colusa Weir (light blue), to Tisdale Weir (yellow), below Tisdale Weir (blue), cumulatively across all sections (purple), and additional VA habitat resulting from expected changes to topography (black, dotted).

5.1.4 Application of Temperature Criteria for Spawning and Rearing Habitat

5.1.4.1 Temperature Criteria

Spawning

Evaluation of salmonid spawning habitat used an upper thermal limit of 13°C (55°F) based on the U.S. Environmental Protection Agency (USEPA) Region 10 temperature criteria for salmonid spawning (USEPA 2003).

Rearing

Evaluation of salmonid rearing habitat used an upper thermal limit of 18°C (64°F) based on a review of the literature and recommendations from USEPA (2003). Past studies have found suboptimal temperatures (temperatures at which physiological performance measures such as growth or metabolism begin to decline) ranging from 16 to 20°C (61 to 68°F; Zillig et al. 2018, 2020; Poletto et al. 2017). Furthermore, the 75th percentile temperature of field detections for juvenile Chinook salmon in the Delta and Suisun Marsh was 18.3°C (65°F; Davis et al. 2022). Additionally, USEPA (2003) identifies the preferred rearing temperature as less than 18°C (64°F) based on the 7-day average daily maximum temperatures, the same metric used in this analysis (see below). Generally, higher growth rates occur in Central Valley floodplain habitats compared with riverine habitats because of the shallower water (Sommer et al. 2001c), but with warmer temperatures predation risk can be higher (Sommer et al. 2020b; Nobriga et al. 2021). Therefore, the 18°C (64°F) value used for estimation of habitat area here was chosen to represent a temperature below a value that is prohibitive for growth or causes direct temperature-induced mortality based on laboratory studies.

5.1.4.2 Temperature Data Sources

Modeled temperatures using SacWAM hydrology were available for the American, Sacramento, and Feather Rivers for the reference condition and VA scenarios across the entirety of the modeling timeframe. These temperatures were produced with a modified version of the Reclamation planning model. The temperature model and details regarding its application are documented in Appendix B, *Water Temperature Modeling for the Sacramento, Feather, and American Rivers*. Modeled temperatures were not available for the flow flexibility scenarios, so it was assumed that temperatures under the flow flexibility scenarios would be the same as under the VA scenario. Table 5-8 describes the relative location of the temperature values on these tributaries and their application to the habitat analysis.

Table 5-8. Description of Modeled Temperature Locations Applied to Habitat Analysis

River Name	Location	Application
American River	Watt Ave	American River rearing habitat
	Hazel Ave	American River spawning habitat
Sacramento River	Above Clear Creek	Sacramento River spawning habitat
	At Wilkins Slough	Rearing habitat on the Sacramento River and in the Sutter Bypass
Feather River	Low Flow Channel at Robinson Riffle	Feather River low-flow channel habitat
	High Flow Channel at Gridley	Feather River high-flow channel habitat

Modeled temperatures using SacWAM hydrology were not available for the Mokelumne and Yuba Rivers, so historical gage or modeled data were used as the next best alternative. Table 5-9 summarizes the selected data source for each river and describes the period of record that temperature data were available. All data sources were identified for each river, and data sources were selected based on the following criteria:

- Data did not have significant data quality issues.
- More than 10 years of temperature data were available.
- If multiple data sources with 10+ years of temperature data exist, data sources closest to the center of river reaches were selected. Data source locations were evaluated to be representative of spawning and rearing habitat.

Data source locations were selected to be representative of spawning and rearing habitat; however, it is expected that floodplain temperature may be more variable and higher than the selected data. Although floodplain temperatures may exceed the temperatures identified for the selected data sources, fish are expected to tolerate higher temperatures in floodplain habitats due to greater food availability (Sommer et al. 2001a). Therefore, we used the same temperature data and criteria for instream and floodplain rearing habitat under the assumption that the higher floodplain temperatures would be negated by the higher temperature tolerances of fish on floodplains.

Table 5-9. Sources of Temperature Data to Evaluate Habitat Based on Temperature Criteria, for the Tributaries without Available Temperatures Modeled with SacWAM Hydrology

River Name	Source	Gage Location	Time Period
Mokelumne River	EBMUD	Elliot Road	2003–2023
Yuba River	Yuba River Development Project water temperature model (Yuba County Water Agency 2023)	Long Bar (spawning); below Daguerre Point Dam (rearing)	1970–2017

EBMUD = East Bay Municipal Utility District

5.1.4.3 Methodology for Expanding Temperature Dataset and Applying to Habitat Modeling

The modeled temperatures using SacWAM hydrology were provided as 7-day average daily maximum temperatures for each location and scenario (reference condition or VA). Mokelumne

River maximum historical daily temperatures were extracted for the time periods described above (Table 5-9), then 7-day average daily maximum temperatures were calculated for consistency. Yuba River modeled data were provided as 7-day average daily maximums (Yuba County Water Agency 2023). Next, the proportion temperature suitable in each month of each year was calculated from each dataset as the proportion of days below the temperature criteria (13°C [55°F] for spawning and 18°C [64°F] for rearing), which will be referred to as the proportion temperature suitable.

Because the Mokelumne and Yuba River data did not extend through the entire modeling timeframe, a subsampling approach dependent on water year type was used to expand the data through the modeling timeframe. A pool of potential proportion temperature suitable values was created to represent each month and water year type for each location. For each month and year in the modeled period, a proportion suitable value was then sampled from the corresponding pool of proportion temperature suitable values. This approach was not required for the modeled temperatures because they were available for the same timeframe as the SacWAM flows.

The proportion temperature suitable timeseries described above was then applied to discount suitable habitat from the habitat analysis by multiplying the proportion temperature suitable for the given month, watershed, and scenario by the acres of suitable habitat (by depth, velocity, and/or cover criteria) calculated in the prior steps.

5.2 Bay-Delta Flow-Abundance Relationships

Flow-abundance models were fit with the same data and structure as in the 2017 Scientific Basis Report (State Water Board 2017). Briefly, abundance indices of estuarine species (California Bay shrimp, longfin smelt, Sacramento splittail, and starry flounder) were obtained from the CDFW Fall Midwater Trawl (CDFW 2016b) and San Francisco Bay Study otter trawl (Hieb 2017) surveys. Delta outflow data were obtained from Dayflow (DWR 2017). Analyses were conducted with the R statistical programming language (R Core Team 2022). Each abundance index was then modeled as a function of outflow, using a linear regression with log-transformations applied to both the abundance index and outflow. Abundance indices for Sacramento splittail and starry flounder were incremented by 1 and 10, respectively, to account for zeros prior to the log transformation. For species that experienced a substantial decline immediately following the introduction of *Potamocorbula amurensis* (1987) or the Pelagic Organism Decline (2002), step changes were introduced for each applicable event. The *P. amurensis* step change was included for starry flounder, and both step changes were included for longfin smelt. More complete documentation of these relationships and their uncertainty is contained in the 2017 Scientific Basis Report (State Water Board 2017).

To estimate the effect of outflow changes from the VAs on species abundance while quantifying uncertainty in those predictions, bootstrapping was applied with the R package *car* (Fox and Weisberg 2019). For each model, 1,000 bootstrapped samples were created of the model parameters. From each sample, the predicted species abundances were calculated with the reference condition, VA, VA without San Joaquin contributions, or flow flexibility outflow values (see Sections 4.12.2, *VA Postprocessing*, and 4.13, *Flow Flexibility Scenarios*), and then the percent changes from reference condition were calculated from those values. The 1,000 bootstrapped samples of percent change were then aggregated to the 2.5-percent, 50-percent (median), and 97.5-percent quantiles to quantify the uncertainty and central tendency of the predictions.

Model results (and their uncertainty) only represent the expected impact of VA and flow flexibility scenario annual outflow changes on species abundance. They do not account for any other factors that may also change with the VAs. They further assume a linear, causal relationship between log outflow and log abundance at the annual timestep for each species (with corrections for step changes for a few species). Consistent with this, uncertainty estimates represent uncertainty in the expected outcomes from changes in annual outflow resulting from the VAs, where annual outflow is the only difference between the VA and reference condition scenarios.

5.3 Bay-Delta Two-Dimensional Hydrodynamic Analysis

5.3.1 Resource Management Associates Bay-Delta Model

To quantify the area of total habitat (both pelagic and wetland habitat for species of interest), the Resource Management Associates (RMA) Bay-Delta model was used to simulate flow and salinity. This information was combined with representative historical temperature and turbidity fields to estimate habitat changes associated with VA alternatives. Because the RMA model was fit to outdated CalSim 2 inputs, the RMA model results were regressed against Delta outflow and exports to develop relationships that were then used to predict estuarine habitat areas based on the latest flow modeling. While relationships between pelagic habitat area and abundance of some fishes has been debated (Kimmerer et al. 2009, but see Nobriga et al. 2008, Feyrer et al. 2011), this analysis provides an assessment of habitat quantity combined with a qualitative description of habitat quality in describing the expected benefits of the VAs. This section presents an overview of the RMA Bay-Delta model, description of the geometric and boundary conditions used for the analysis, and the habitat analysis approach.

The model evaluation was conducted using the RMA Bay-Delta model for flow and salinity. The model extends from Golden Gate up the Sacramento River above the confluence with the American River, and up the San Joaquin River near Vernalis. A two-dimensional depth-averaged approximation is used to represent the San Francisco Bay, Suisun Bay region, portions of Suisun Marsh, the Sacramento-San Joaquin confluence area, Sherman Lake, the Sacramento River up to Rio Vista, Cache Slough, Liberty Island, Shag Slough, portions of Lindsey Slough, the Sacramento River Deep Water Ship Channel and Miner Slough, Big Break, the San Joaquin River up to its confluence with Middle River, False River, Frank's Tract and surrounding channels, Mildred Island, Old River south of Frank's Tract, the Delta Cross Channel area, and all tidal marsh restoration sites. The other Delta and Suisun Marsh channels and tributary streams are represented using a one-dimensional cross-sectionally averaged approximation. The model has undergone continual development through dozens of projects since 1997 (e.g., RMA 2012, 2015a, 2015b).

All major Delta and Suisun Marsh control structures are represented in the model (e.g., cross-channel, Suisun Marsh Salinity Control Gates), and the Delta Island Consumptive Use is based upon DWR's DSM2.

The model uses the finite element method to simulate two-dimensional depth-averaged/one-dimensional cross-sectionally averaged flow and salinity for a 7.5-minute computational time step. The RMA Bay-Delta model produces a wide variety of model results including flow, velocity, depth, EC (a measure of salinity), residence time, and particle tracking. For the current study, the model application has focused upon velocity, depth, and EC.

5.3.2 Bathymetry

The RMA Bay-Delta model grid and bathymetry have been continually updated over the years as new and better bathymetry data become available. For all areas of the model grid, the most current, best-quality bathymetric data were used to set grid elevations (Figure 5-5), as follows.

- Most recently, elevations were set using data collected in the Cache Slough Complex during 2015, 2017, and 2018 by the U.S. Geological Survey (Fregoso et al. 2020).
- In Cache Slough and Sutter Slough, elevations were set using data collected by Environmental Data Solutions (2012).
- Coarsely spaced single-beam transects were available from the Central Valley Floodplain Evaluation and Delineation (CVFED) program for upper Cache Slough, Hass Slough, and Lindsey Slough. Additionally, the CVFED multibeam data were used to update the bathymetry of the Sacramento River above the Georgiana Slough confluence, above the American River confluence to the crossing of Interstate 5. Data are available on the DWR Delta Bathymetry website (DWR 2022a).
- For the San Francisco Bay and Suisun Bay, DWR's 2012 10-meter San Francisco Bay and Sacramento-San Joaquin Delta digital elevation model version 3 was used (DWR 2012).
- The model grid includes elevations based on the multibeam bathymetry surveys performed by DWR for selected Delta channels and posted on the DWR Delta Bathymetry website (DWR 2018).
- For all areas not covered by more recent data sets listed above, bottom elevations and the extent of mudflats were based on bathymetry data collected by the National Oceanic and Atmospheric Administration, DWR, U.S. Army Corps of Engineers, and U.S. Geological Survey. These datasets have been compiled by DWR and can be downloaded from DWR's Cross Section Development Program websites (DWR 2022b).
- Topography data from DWR's Delta light detection and ranging (LiDAR) survey were used (DWR 2022c).

Two versions of the model grid were developed to represent different tidal marsh restoration scenarios under the reference condition and VA scenarios, which are discussed in the following sections of this report. Geometry of future VA tidal marsh restoration sites was based on the most recent available designs at the time of grid generation.

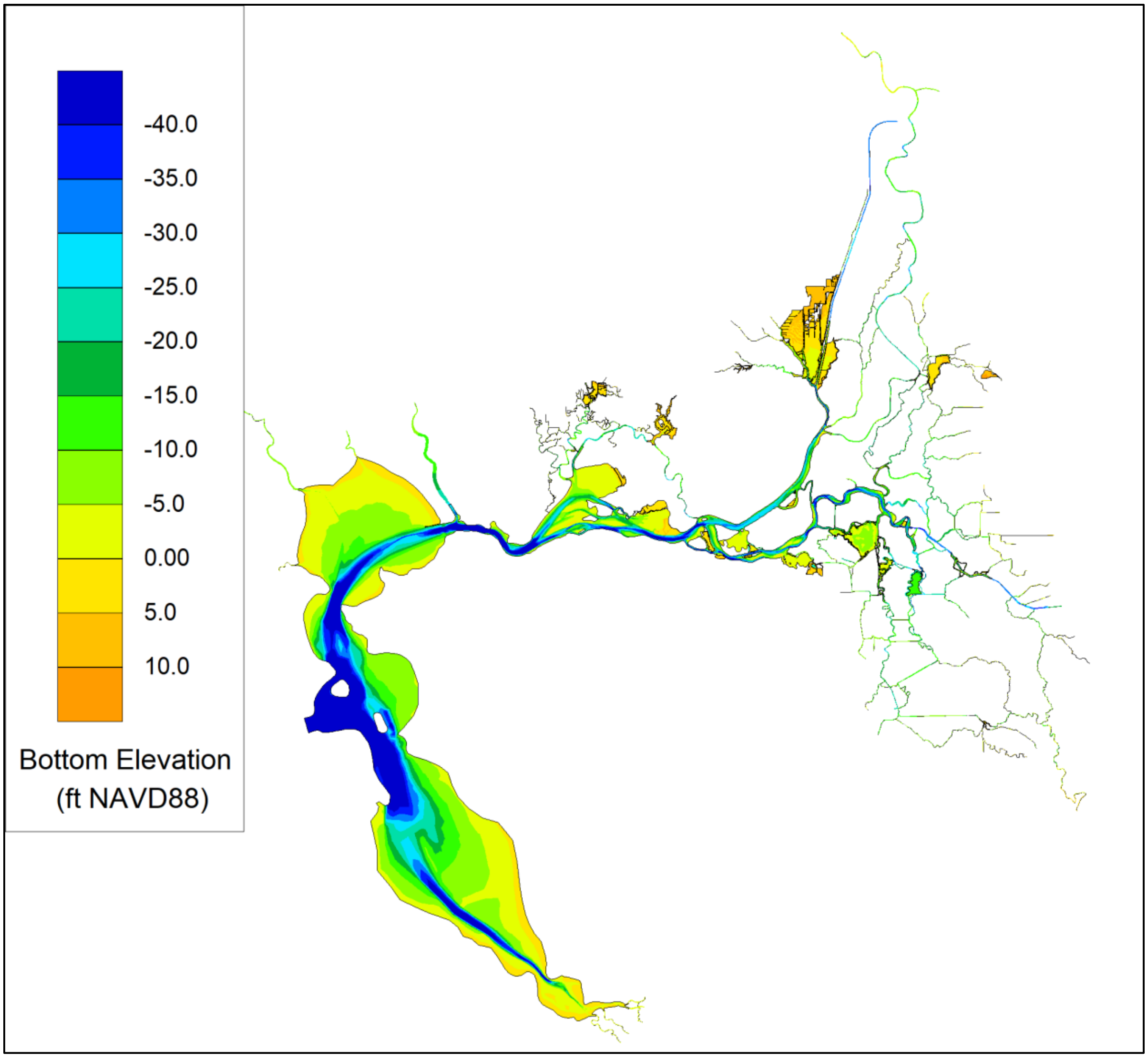

Figure 5-5. RMA Bay-Delta Model Bathymetry
A bathymetric map of the Bay-Delta symbolized using bottom elevation (North American Vertical Datum of 1988, in feet) with a scale ranging from about 10 to about -40.

5.3.3 Model Application to Voluntary Agreement Habitat Analysis

The modeling approach, illustrated in a flow chart on Figure 5-6, included operations modeling (CalSim 2) to generate flow boundary conditions and DSM2 modeling to generate Clifton Court intake flows and Delta gate and barrier operations, both of which were provided as boundary condition inputs to the RMA Bay-Delta model. The RMA Bay-Delta model then produced Delta flow and salinity results.

These analyses were run in 2019, prior to finalization of the VA Term Sheet and prior to the update from CalSim 2 to CalSim 3. SacWAM was used in the rest of the modeling presented above, but CalSim 2 remains a viable alternative. Typically, it is best to use these models in a comparison mode, where compatible scenarios using the same model version are compared to evaluate changes due to an alternative condition like VA flow effect on outflow. Even though these are different models, the incremental change in those differences between compatible scenarios created with the same model version would be small.

All models were run for the period of 1975 to 1991, with 1975 serving as a spin-up period only and not included in the analyses. This period was chosen because it is the DSM2 planning period and includes a variety of conditions, including an extreme drought (1976–1977) and an extreme wet year (1983). This period will provide an estimate of potential habitat conditions. However, this estimate may not characterize the increased frequency of extreme events seen in more recent years as climate change has altered hydrology in California.

The CalSim 2 model simulations were run by DWR and results were provided to RMA. DSM2 and the RMA Bay-Delta model simulations were run by RMA. While the 17-year period ran relatively quickly in the one-dimensional DSM2, the multidimensional RMA Bay-Delta model simulations required several central processing unit (CPU) days per year of simulated time. To complete the large modeling task in a reasonable amount of time, year-long hydrodynamic simulations were run in parallel on the Amazon Cloud, while the less computationally demanding water quality simulations were run locally on RMA computer servers.

The RMA Bay-Delta model results, combined with observed data, were processed to calculate acres of suitable habitat in the Bay, Suisun, and Delta for Delta smelt, longfin smelt, and salmonid rearing. Suitable habitat differs by species and is defined by combinations of one or more of the following parameters: salinity, temperature, turbidity, depth, and velocity. This approach is similar to the habitat modeling approach undertaken in the tributaries (Section 5.1, Tributary Habitat Analysis), with the addition of water quality parameters other than temperature. This modeling approach does not evaluate survival, abundance, or production (similar to the tributary approach in Section 5.1). Specific details on the habitat area calculations and metrics are provided below.

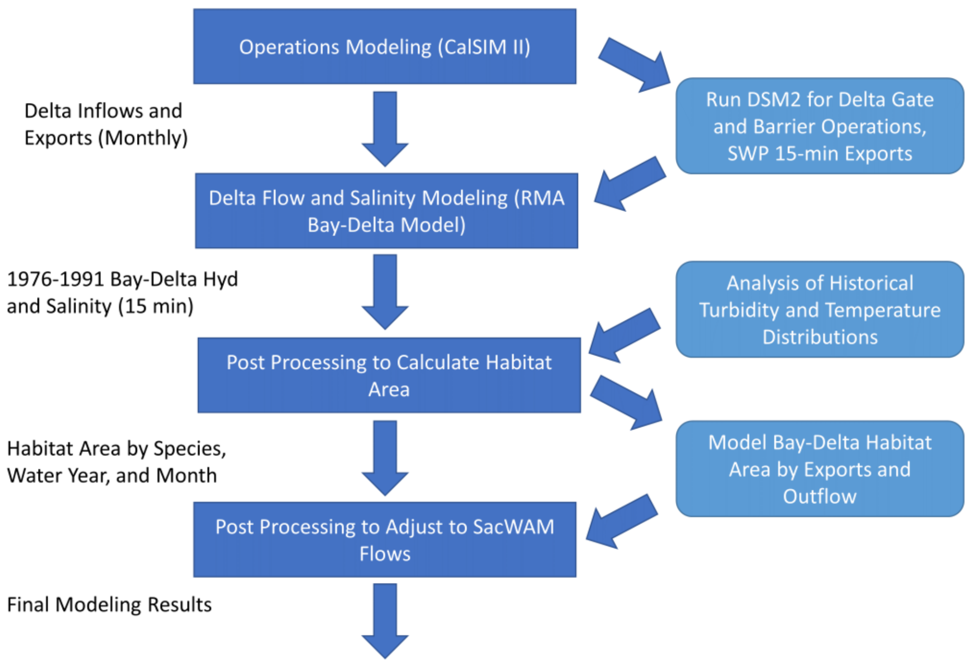

Figure 5-6. Modeling Approach Flow Chart
A flow chart of boxes and arrows shows the modeling approach.

5.3.3.1 Model Configurations

Two different model geometry configurations, shown on Figure 5-7, were used to represent the reference condition and VA habitat scenarios.

The "reference condition" geometry included 2,433 acres of newly constructed marsh habitat restoration at Tule Red, Flyway Farms, Decker Island, Dutch Slough, and Lindsey Slough, along with 11,097 acres of habitat restoration sites under active construction or planning: Prospect Island, McCormack-Williamson Tract, Lookout Slough, Lower Yolo Ranch, Bradmoor Island, Arnold Slough, Wings Landing, Chipps Island, Grizzly Slough, Winter Island, and Hill Slough.

The "VA" geometry included, in addition to reference condition restoration, 4,074 acres of proposed tidal habitat restoration with Little Egbert Tract, Grizzly King, and Potrero Marsh. These particular sites have not been committed to restoration under the VAs, but they are proposed sites and are used here for illustrative purposes only. Other sites may result in slightly different changes to appropriate habitat area (e.g., salinity, turbidity), but not enough to affect overall benefits of the VA package. Due to the significant influence of the tides in the Delta, restoration site geometry (e.g., location, topography/bathymetry) is a key factor in informing the RMA model configuration. Therefore, model geometries were used that had been previously generated under other efforts for several existing tidal restoration sites within the North Delta Arc.

Habitat areas do not include the Yolo Bypass (except for areas of the bypass that are tidally influenced). Changes in flow may result in changes to frequency and amount of inundation in the Yolo Bypass, but they were not modeled as part of this analysis.

An additional 1,153.5 acres of tidal wetlands and associated floodplain habitat have been added to the VA package since the completion of this modeling work. This, and any additional tidal wetland habitat, will result in larger increases to available habitat than presented here.

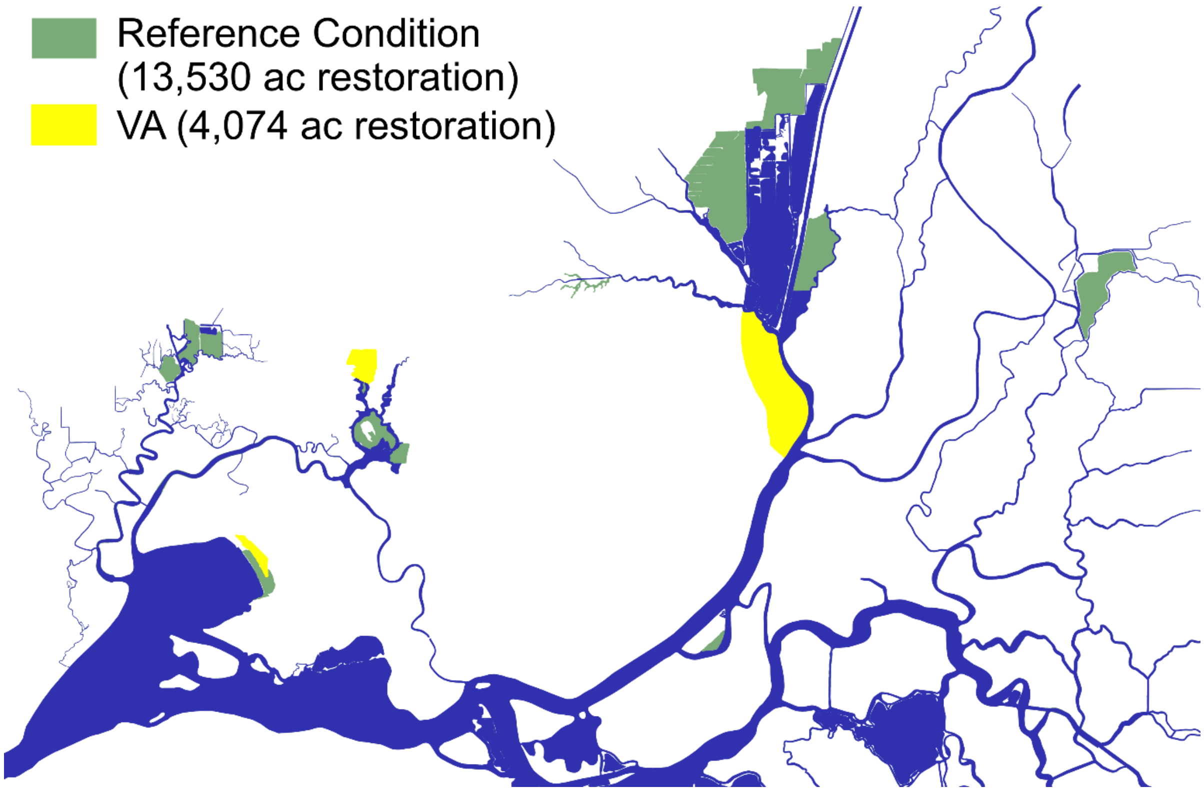

Figure 5-7. Model Habitat Restoration Configurations
The figure shows the RMA model area symbolized by yellow (VAs—with 4,074 acres of planned restoration) and green (reference condition—with 13,530 acres of planned restoration).

5.3.3.2 Analysis Scenarios

Analysis scenarios were a combination of model habitat restoration configuration and model boundary conditions to represent possible future conditions. CalSim 2 was used to develop the flow boundary conditions. The matrix of possible habitat restoration configurations and future flow scenarios was large, and it was impractical to simulate all combinations with the RMA Bay-Delta model. The following scenarios were selected for final analysis.

- Reference condition habitat and CalSim 2 2019 BiOps condition flows (reference condition CalSim 2 flows were not available when the model was run)
- VA habitat and CalSim 2 VA flows

5.3.4 Model Boundary Conditions

Figure 5-8 shows the location of the model boundary conditions. Each model inflow boundary condition requires a corresponding EC value be specified. The model boundary conditions are:

- Tidal Boundary at Golden Gate (National Oceanic and Atmospheric Administration Predicted Tide)
- Inflows (CalSim 2)
  - Sacramento River
  - San Joaquin River near Vernalis
  - Yolo Bypass
  - Mokelumne River
  - Cosumnes River
  - Calaveras River
- Exports/Diversions
  - SWP, Clifton Court Forebay gates (DSM2). While daily SWP exports are available from the operations models, the 15-minute result from DSM2 is required to run the RMA Bay-Delta model.
  - CVP Tracy Pumping Plant (CalSim 2)
  - Contra Costa Water District intakes at Rock Slough, Old River, and Victoria Canal (CalSim 2)
  - North Bay Aqueduct, Barker Slough Pumping Plant (CalSim 2)
  - Delta Island Consumptive Use, throughout Delta (DSM2)
- Major Control Structures (DSM2)
  - Delta Cross Channel gates
  - Suisun Marsh Salinity Control Gate
  - South Delta Temporary Barriers
  - Old River near Tracy temporary barrier
  - Head of Old River barrier
  - Middle River temporary barrier
  - Grant Line Canal temporary barrier

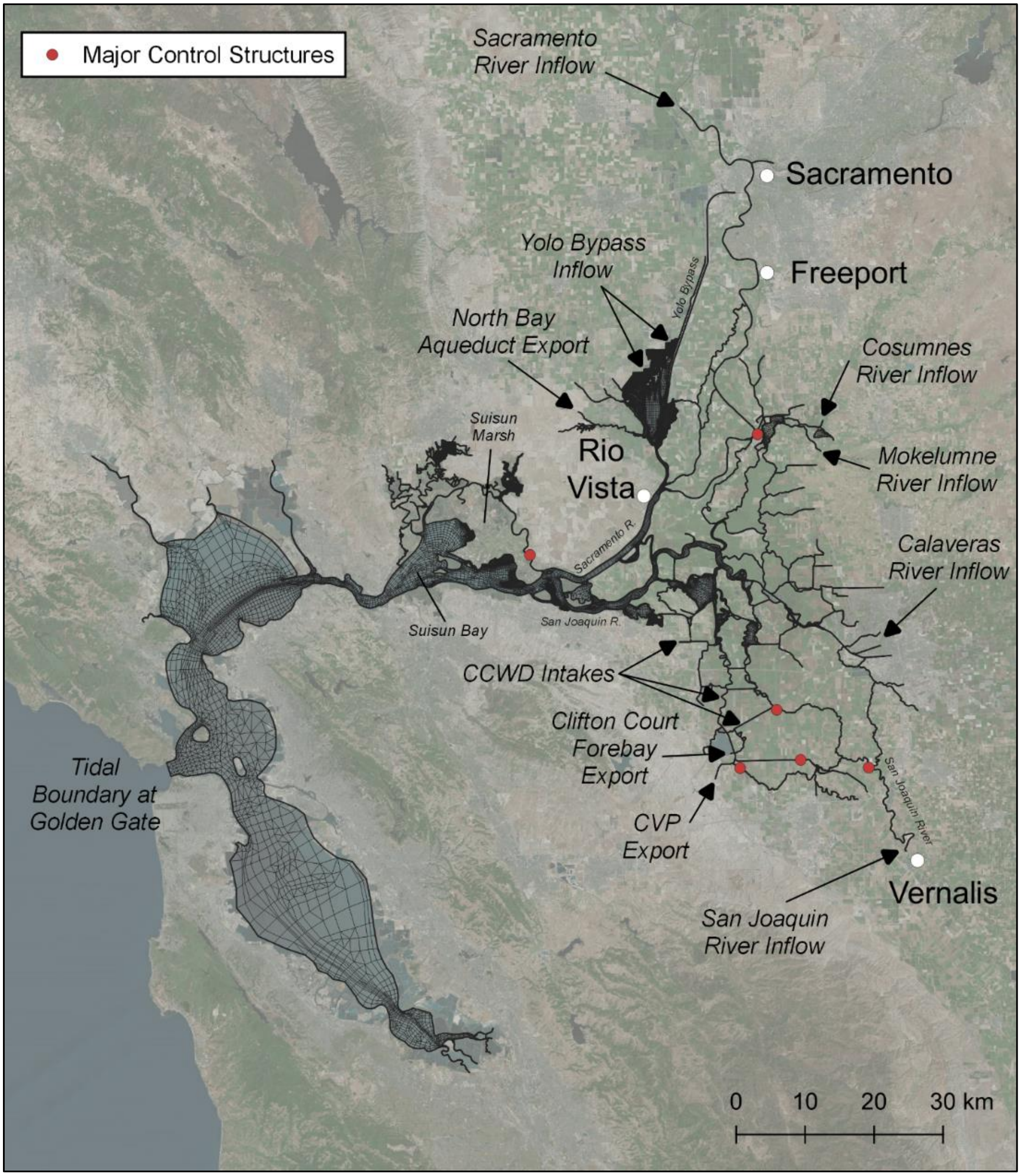

Figure 5-8. RMA Bay-Delta Model Boundary Conditions
A map with labels shows the model boundary conditions. Major control structures are symbolized with red dots.

5.3.5 Preliminary Habitat Area Calculations

Habitat area calculations were performed for discrete regions within the Bay-Delta and based on a combination of model results (hydrodynamics and EC/salinity) and observed historical data (temperature and turbidity). Observed data were the same for the VA and reference condition scenarios, so only model results differed between scenarios. Habitat criteria varied by fish species and life stage (see Section 5.3.5.3, *Species*).

Criteria were set for each fish species and life stage (see Section 5.3.5.3, *Species*), and data layers were developed to represent all areas in the model domain where each criterion was met. The intersection of all data layers, where all criteria were met, was considered habitat. It is important to note that these criteria are based entirely on water quality parameters and water depth. Other important habitat characteristics, such as food supply, refuge habitat, and vegetation, were not included. In addition, these criteria are not used by the VA Parties for accounting of VA non-flow commitments for tidal habitat restoration. Design criteria for tidal non-flow habitat would be project-specific and would include inundation levels of constructed channels and marsh plains in response to the daily tidal regime, among other metrics specific to the individual project goals and objectives. Design criteria would be subject to review by the State Water Board and CDFW, in consultation with USFWS and NMFS. If the design criteria for tidal habitat restoration projects differ from criteria presented below for native estuarine fish species, then the area of suitable habitat created by the VA non-Flow Measures may differ from the results presented in this report.

5.3.5.1 Data

Temperature and turbidity data were compiled throughout the Bay and Delta from continuous water quality sensors maintained by DWR and the U.S. Geological Survey and were shared publicly on the California Data Exchange Center. Monthly averages were computed for all available data for 2010 to 2019. While it is assumed that the VA assets generally do not alter these metrics, they do serve an informative bounding function to appropriately limit habitat suitability, especially seasonally.

The 2010 to 2019 observed data period was selected to represent modern conditions in the Delta because temperature and turbidity have changed since the 1976 to 1991 simulation period. Changes in sediment loads and increases in aquatic vegetation over time have lowered turbidity in the Delta (Schoellhamer 2011; Hestir et al. 2016). Climate change, among other factors, has increased water temperature (Bashevkin et al. 2022). Additionally, data availability is poor for the 1976 to 1991 simulation period. Because the 2010 to 2019 data do not specifically represent the modeled periods, statistics were computed to develop a range of values for application to the habitat criteria calculations.

Observed data processing steps were as follows:

1. Downloaded and cleaned available temperate and turbidity data for the 2010 to 2019 period (data from the California Data Exchange Center; see Appendix C, *Bay-Delta Habitat Modeling Supplemental Methods and Results*, Figure C-1 and Figure C-142, for station location maps).
2. Computed monthly averages of all data.
3. From the monthly averages, computed means for each month of the year (e.g., for all Junes for the 2010 to 2019 period).
4. Set these known values in the model and computed diffusion solutions for each month of the year and each statistical value to generate data layers with continuous fields of temperature and turbidity over the model domain for each condition. These data layers were then applied in habitat area calculations.

Further detail is available in Section C.1, *Observed Data Processing*, of Appendix C, *Bay-Delta Habitat Modeling Supplemental Methods and Results*.

5.3.5.2 Model Results

Modeled EC, velocity, and depth for 1976 to 1991 at a 7.5-minute timestep were monthly averaged for application to the habitat criteria calculations. These averages were used in the habitat calculations as a continuous field over the model domain.

5.3.5.3 Species

Habitat areas were computed by species for each month and season of the 1976 to 1991 simulation period. Species-relevant seasonal period averages were reported. Habitat criteria and relevant periods are consolidated in Table 5-10 and described below.

Table 5-10. Suitability Criteria and Seasons used in the RMA Estuarine Habitat Analysis

Species and Life Stage	Season	Salinity	Depth	Velocity	Temperature	Turbidity
Delta Smelt Larvae	Mar–Jun	< 6 ppt			≤ 19°C	> 12 NTU
Delta Smelt Juveniles	Jul–Nov	< 6 ppt			≤ 21°C	> 12 NTU
Longfin Smelt Larvae	Jan–Apr	< 12 ppt			≤ 13°C	
Longfin Smelt Juveniles	Mar–Aug	< 12 ppt			≤ 19°C	
Salmonid Rearing	Oct–Jun		0.28–1.32 m	< 0.24 m/s	≤ 18°C	

Note: All values represent monthly averages.
m = meter; m/s = meter per second; NTU = nephelometric turbidity units; ppt = parts per thousand

Delta Smelt Larvae: March–June

Delta smelt larvae have suboptimal temperature thresholds in the literature ranging from 20 to 23°C (68 to 73°F; Komoroske et al. 2015; Jeffries et al. 2016) and the 75th percentile temperature value for Delta smelt larval catch in the field is 19.9°C (68°F; Davis et al. 2022). Therefore, the temperature threshold for Delta smelt larvae was chosen as 19°C (66°F). Salinity and turbidity tolerances were from Bever et al. (2016).

Mean habitat conditions—the areas where the following criteria are met:

- Monthly average salinity less than 6 parts per thousand (ppt) (EC less than 10,600 microSiemens per centimeter [μS/cm])
- Overall monthly average turbidity greater than 12 nephelometric turbidity units
- Overall monthly average temperature 19°C (66°F) or lower

Delta Smelt Juvenile: July–November

Juvenile Delta smelt have suboptimal temperature thresholds in the literature ranging from 20 to 22°C (68 to 72°F; Komoroske et al. 2021; Davis et al. 2019a) and the 75th percentile temperature value for Delta smelt juvenile catch in the field is 21.2°C (70°F). Therefore, the temperature threshold for Delta smelt juveniles was chosen as 21°C (70°F). Salinity and turbidity tolerances were from Bever et al. (2016).

Mean habitat conditions—the areas where the following criteria are met:

- Monthly average salinity less than 6 ppt (EC less than 10,600 µS/cm)
- Overall monthly average turbidity greater than 12 nephelometric turbidity units
- Overall monthly average temperature 21°C (70°F) or lower

Longfin Smelt Larvae: January–April

Longfin smelt larvae have estimated suboptimal temperature thresholds in the literature from 12 to 14°C (54 to 57°F; Yanagitsuru 2021; Jeffries et al. 2016). Therefore, we chose 13°C (55°F) as the threshold for larval longfin smelt. Longfin smelt larvae habitat analyses used a salinity range of 0 to 12 ppt as documented by Grimaldo et al. (2017). This salinity tolerance is most relevant in the winter and spring when longfin are spawning, because juvenile longfin have a much wider salinity tolerance (Baxter 1999; Merz et al. 2013).

Mean habitat conditions—the areas where the following criteria are met:

- Monthly average salinity less than 12 ppt (EC less than 20,137 µS/cm)
- Overall monthly average temperature 13°C (55°F) or lower

Longfin Smelt Juveniles: March–August

There are no published physiology studies on juvenile longfin smelt, but the 75th percentile temperature value for longfin smelt juvenile catch in the field is 19°C (66°F; Davis et al. 2022). Therefore, 19°C (66°F) was used as the temperature threshold for juvenile longfin smelt. Longfin smelt juvenile habitat analyses used the larval salinity tolerance range of 0 to 12 ppt as documented by Grimaldo et al. (2017). This salinity tolerance is most relevant in the winter and spring when longfin are spawning, because juvenile longfin have a much wider salinity tolerance (Baxter 1999; Merz et al. 2013).

Mean habitat conditions—the areas where the following criteria are met:

- Monthly average salinity less than 12 ppt (EC less than 20,137 µS/cm)
- Overall monthly average temperature 19°C (66°F) or lower

Salmonid Rearing: October–June

Justification of the salmonid rearing temperature threshold is provided in the *Rearing* subsection of Section 5.1.4.1, *Temperature Criteria*.

Mean habitat conditions—the areas where the following criteria are met:

- Monthly average depth between 0.28 and 1.32 meters
- Overall monthly average velocity less than 0.24 meter per second
- Overall monthly average temperature 18°C (64°F) or lower

5.3.6 Postprocessing to Calculate Final Habitat Area

Because the RMA model was run on CalSim 2 inputs and it was computationally infeasible to re-run DSM2 and the RMA model using SacWAM inputs, the final habitat areas from the RMA model were postprocessed with SacWAM flows. This also allowed estimation of estuarine habitat area over the full timeseries of the SacWAM hydrology (1923–2015) rather than just the years available from DSM2 (1976–1991). For each species and life stage, the total habit area over the full model domain of the RMA model (Figure 5-8) was modeled with Delta outflow and exports (from CalSim 2) as predictors. Modeling was conducted with generalized additive models (GAMs), which model nonlinear relationships and interactions among predictors. GAMs were fit with the "mgcv" package in R (Wood 2011; Wood et al. 2016).

Because outflow and exports are correlated, exports were represented as the residuals of the linear log-log regression of exports by outflow, fit separately for the reference condition and VA flows. Outflow was log-transformed, then centered (by subtracting the mean) and standardized (by dividing by the standard deviation) prior to inclusion in the GAMs. Month (coded as a factor) and scenario (reference condition or VA) were included as random effects and allowed to interact with the outflow and exports. Three GAM structures with different combinations of outflow and exports were fit for each species and life stage: a model with outflow alone, a model with additive non-interacting effects of outflow and exports, and a model with interacting effects of outflow and exports. Interactions were encoded with tensor product smooths, and outflow and exports were each represented via thin-plate regression splines. Model fits were evaluated by inspecting model diagnostic plots with special attention to how well the model predictions aligned with the observed data and any biases in such predictions. The best model for each species and life stage was then selected with a combination of Akaike's Information Criteria and parsimony such that the more complex model was selected if it was at least 5 Akaike's Information Criteria points lower than the simpler model (Table 5-11). The best fit model for each species and life stage was then used to predict habitat areas using SacWAM hydrology inputs for each year in the SacWAM hydrology dataset (1923–2015) and the following scenarios: reference condition, VAs with San Joaquin contributions (referred to simply as VA), VAs without San Joaquin contributions, and the flow flexibility scenarios. Plots of the postprocessing model performance can be found in Section C.2, *Postprocessing*, of Appendix C, *Bay-Delta Habitat Modeling Supplemental Methods and Results*.

Table 5-11. The Best Model Structures for Each Species and Life Stage

Species and Life Stage	Model
Longfin Smelt Larvae	Outflow
Longfin Smelt Juvenile	Outflow X Exports
Delta Smelt Larvae	Outflow X Exports
Delta Smelt Juvenile	Outflow + Exports
Salmonids	Outflow X Exports

"Outflow X Exports" represents the interaction between outflow and exports while "Outflow + Exports" represents their additive noninteractive effects.

5.4 Bay-Delta Flow Thresholds and X2

The frequency of achieving ecologically relevant flow thresholds specified in the 2017 Scientific Basis Report was analyzed across all scenarios. This includes flows at interior Delta locations (Freeport and Rio Vista) as well as net Delta outflow-based flows. As further described in the 2017 Scientific Basis Report, each flow threshold was chosen to represent flows at which specific benefits are achieved, generally to support the needs of specific species, but some thresholds were chosen to correspond to key X2 thresholds known to be beneficial for native species. The definition of each threshold is provided in Table 5-12 below, but additional information and the rationale for each threshold can be found in Chapters 3 and 5 of the 2017 Scientific Basis Report.

Table 5-12. Flow Threshold Definitions

Threshold	Months	Location	Flow (cfs)
Georgiana Slough Flow Reversal Low	Nov–May	Freeport	17,000
Georgiana Slough Flow Reversal High	Nov–May	Freeport	20,000
Fall Run Outmigration	Apr–Jun	Rio Vista	20,000
Winter Run Outmigration	Feb–Apr	Rio Vista	20,000
Bay Shrimp Low	Mar–May	Net Delta Outflow	20,000
Bay Shrimp High	Mar–May	Net Delta Outflow	25,000
Longfin Smelt	Jan–Jun	Net Delta Outflow	43,000
Sacramento Splittail Low	Feb–May	Net Delta Outflow	30,000
Sacramento Splittail High	Feb–May	Net Delta Outflow	47,000
Starry Flounder	Mar–Jun	Net Delta Outflow	21,000
Green and White Sturgeon	Mar–Jul	Net Delta Outflow	37,000
Collinsville X2	Jan–Jun	Net Delta Outflow	7,100
Chipps Island X2	Jan–Jun	Net Delta Outflow	11,400
Port Chicago X2	Jan–Jun	Net Delta Outflow	29,200

The Georgiana Slough flow reversal threshold represents monthly flows while the other thresholds represent seasonally averaged flows. Thresholds for Collinsville, Chipps Island, and Port Chicago represent the flows that correspond to an average X2 location downstream of the specified location.

Chapter 6

Anticipated Biological and Environmental Outcomes

6.1 Tributaries—Species and Habitat

The results of the habitat analysis indicate that VA non-flow assets produce more suitable habitat for fall-run Chinook salmon and spring-run Sacramento River Chinook salmon during spawning and rearing as compared to the reference condition scenario. For spawning habitat in all watersheds except the American River, both existing and VA habitat exceed the habitat necessary to support approximately 25 percent of the offspring of the doubling goal populations (the target of the 8-year term of the VAs) and the VA habitat exceeds 50 percent of the required habitat. Rearing habitat improvements varied by tributary, with the 25-percent target being met in the Mokelumne, Sacramento (spring run), and Yuba Rivers for both the reference condition and VA, and in the Feather River in the VA scenario. However, it is not projected to be met in any scenario in the American and Sacramento (for fall run) Rivers. Additional floodplain acreage is planned on the Sacramento River to achieve the 25-percent rearing habitat target (see Section 6.1.2, *Salmonid Habitat Results: Rearing*).

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 and Setka 2004; Roni et al. 2008; McManamay et al. 2010) and consequently 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 (State Water Board and California Environmental Protection Agency 2018). Suitable rearing habitat for juvenile fall-run Chinook salmon supports growth and survival during outmigration (Maslin et al. 1998; Limm and Marchetti 2009). Phillis et al. (2018) found that Sacramento River winter-run Chinook salmon rely on a more diverse suite of rearing habitats than previously thought, thereby motivating the need to restore instream rearing habitat in the Sacramento River and its contributing tributaries.

Both spawning and rearing habitat must have suitable temperatures to benefit salmonids. Elevated water temperatures are a major factor contributing to the decline of salmon and steelhead (Myrick and Cech 2001). Low flows elevate temperatures in the tributaries, which is in part mitigated by temperature management actions (State Water Board 2017). However, increased water demand and climate change will limit the effectiveness of temperature management. More information on water temperatures can be found in the 2017 Scientific Basis Report, Sections 3.4 and 4.3.4 (State Water Board 2017).

6.1.1 Salmonid Habitat Results: Spawning

The proposed habitat restoration commitments identified in the VA Term Sheet include spawning habitat for the Sacramento River (113.5 acres), Feather River (15 acres), American River (25 acres), and Putah Creek (1.4 acres). Numerous studies have found an increase in the number of salmon or steelhead redds or spawners following habitat improvement efforts, such as gravel addition (Merz and Setka 2004; Roni et al. 2008; McManamay et al. 2010). Across 14 studies reviewed by Roni et al. (2008), 70 percent showed an increase in adult salmon to the placement of instream structures for habitat improvement (Roni et al. 2014). However, it is important to note that flows and water quality parameters such as temperature must be sufficient for the benefits of this restoration to be realized.

Figure 6-1 provides the median spawning habitat area across all modeled years (1922–2015) under the reference condition and VA scenarios. The labels below the bars represent the median amount of habitat as a percentage of the habitat needed to support the doubling goal. Reference condition and VA habitat for all watersheds, except the American River, exceed the VA target of 25 percent of the doubling goal for spawning habitat in all water year types. In the Sacramento (for spring run) and Yuba Rivers, this was over 100 percent, indicating that the VA scenario (as well as the reference condition) likely provides enough spawning habitat to support the doubling goal. Flow flexibility scenarios had little impact on the spawning habitat area.

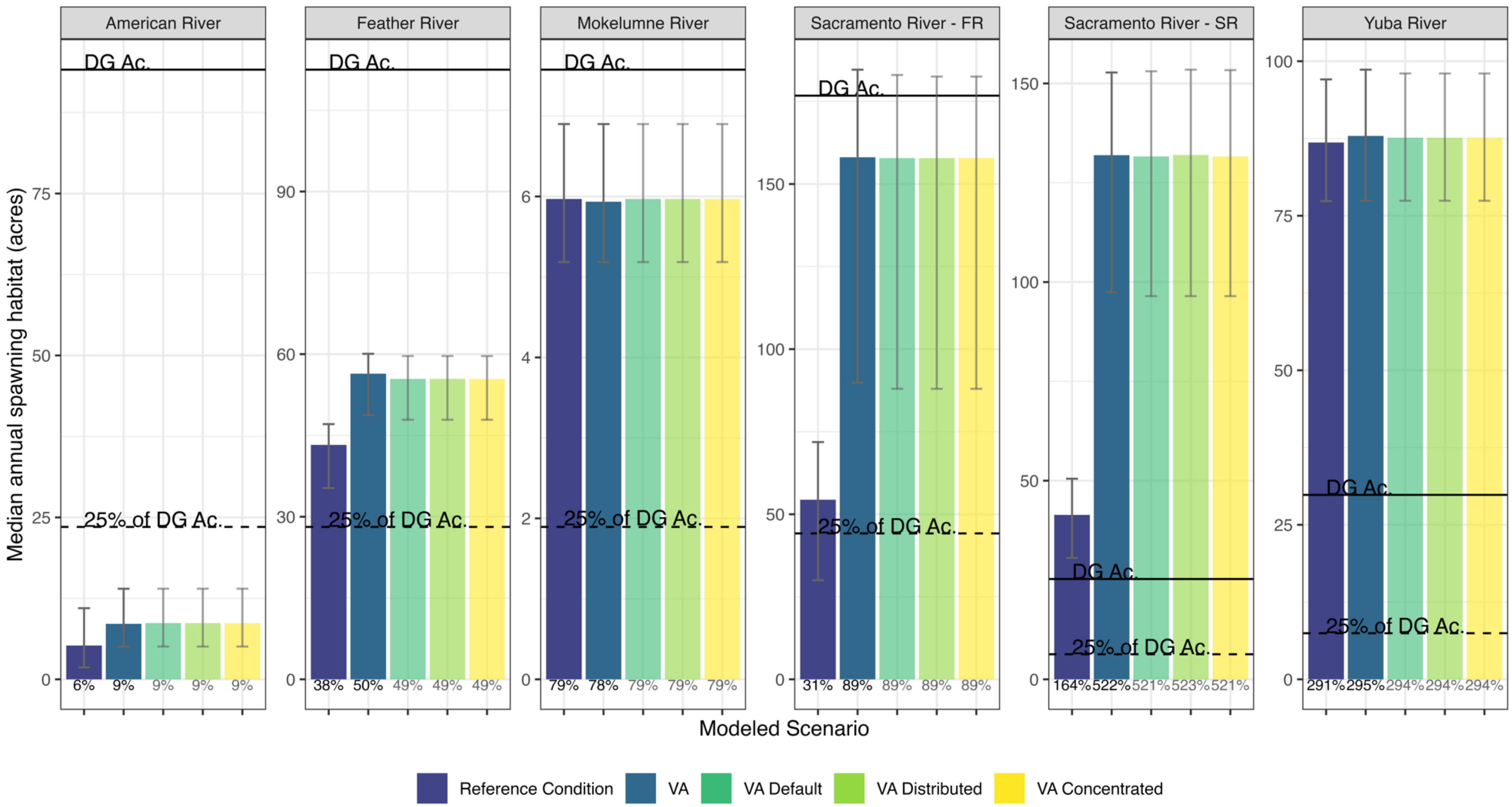

Figure 6-1. Median (across All Years) Spawning Habitat (Acres) under Reference Condition, VA, and Flow Flexibility Scenarios for Each Watershed

Results are presented for fall run in all tributaries and for spring run in the Sacramento River. Solid lines represent area of habitat required to support the doubling goal population, and dashed lines represent 25 percent of the doubling goal area. The amount of habitat as a percentage of the habitat needed to support the doubling goal is printed below each bar. Error bars represent the upper and lower quartiles. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes.

Figure 6-2 shows the median annual spawning habitat (acres) for the reference condition and VA scenario by watershed and water year type. Across all water year types, the VAs offer more spawning habitat (October through December) than the reference condition in the American, Feather, and Sacramento Rivers. Across Critical to Wet water year types, the VAs offer 49 to 122 percent more spawning habitat (0–5 total acres) in the American River; 27 to 31 percent more spawning habitat in the Feather River (10–14 acres); 144 to 205 percent more spawning habitat in the Sacramento River for fall run (71–113 acres); and 158 to 233 percent more spawning habitat in the Sacramento River for spring run (41–108 acres). For the Yuba and Mokelumne Rivers, spawning habitat area is the same for the reference condition and VA scenarios because there were no spawning habitat commitments in the VAs (Table 6-1, Figure 6-2).

Table 6-1. Median Percent Change between the Reference Condition and VA Scenarios for Suitable Spawning Habitat by Water Year Type and Watershed

Watershed	Critical	Dry	Below Normal	Above Normal	Wet
American River	59% (2)	60% (3)	49% (0)	59% (2)	122% (5)
Feather River	27% (10)	29% (13)	30% (13)	31% (14)	30% (13)
Mokelumne River	0% (0)	0% (0)	0% (0)	0% (0)	NA
Sacramento River: FR	151% (71)	160% (110)	144% (113)	167% (103)	205% (104)
Sacramento River: SR	158% (41)	184% (76)	176% (90)	206% (96)	233% (108)
Yuba River	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)

Note: The numbers in parentheses are median increases in suitable spawning habitat acreage. Results are presented for fall run in all tributaries and for spring run in the Sacramento River. Mokelumne River results are based on the Mokelumne River water year type definitions, which do not contain a "wet" category.
FR = fall run; NA = not applicable; SR = spring run

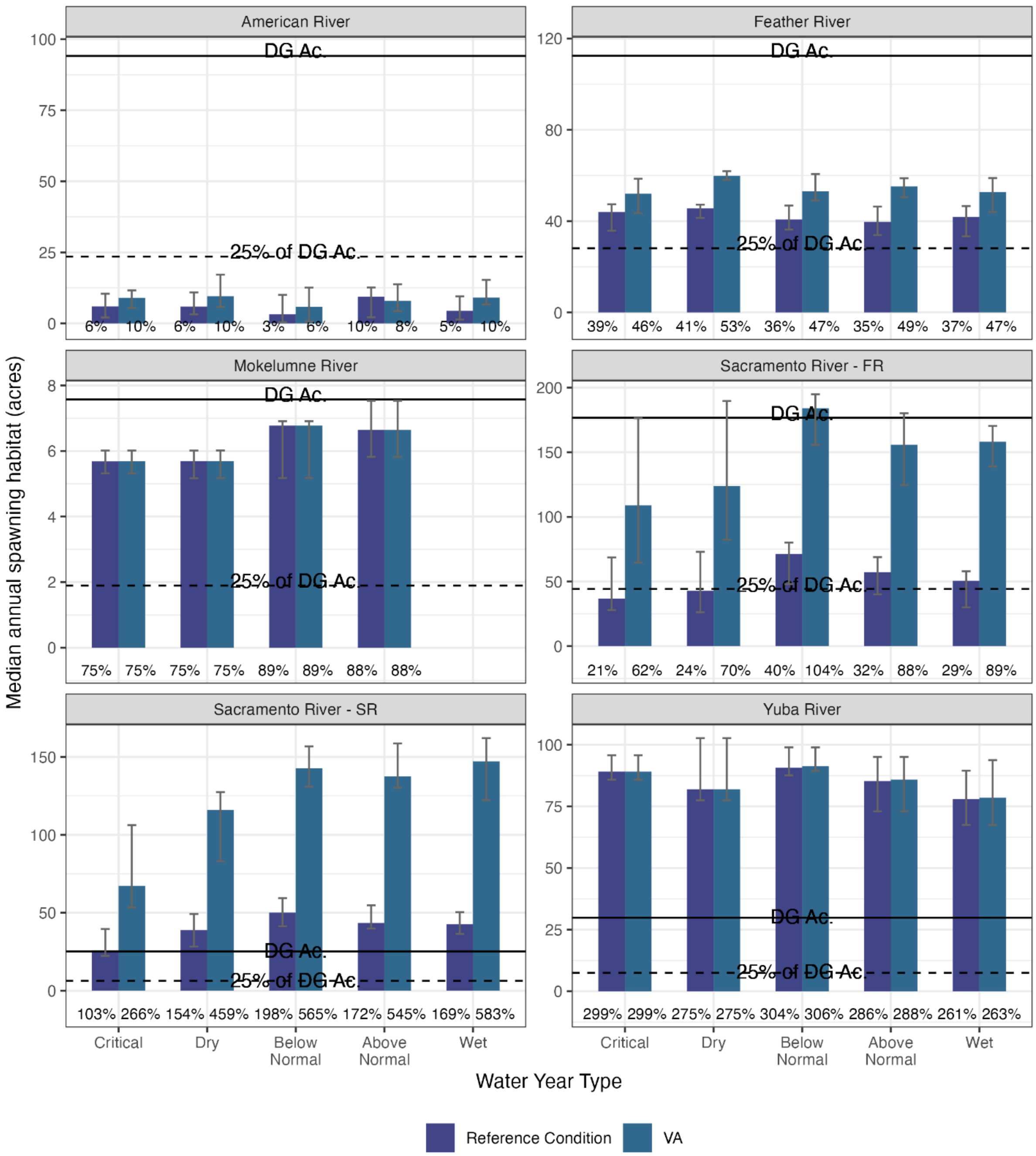

Figure 6-2. Median Annual Spawning Habitat (Acres) by Water Year Type under Reference Condition, VA, and Flow Flexibility Scenarios for Each Watershed

Results are presented for fall run in all tributaries and for spring run in the Sacramento River. Error bars represent the upper and lower quartiles. Medians and quantiles were calculated across years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes. The amount of habitat as a percentage of the habitat needed to support the doubling goal (DG) is printed below each bar. The solid line represents the spawning area required to support the doubling goal, and the dashed line represents 25 percent of the doubling goal area. Note that Mokelumne River results are based on the Mokelumne River water year type definitions, which do not contain a "wet" category.

Increasing the amount of suitable spawning habitat will support a greater number of redds and therefore potentially greater production of juveniles. In areas with insufficient suitable spawning area, more spawning pairs may arrive than the existing habitat can support, and lack of spawning habitat has been identified by the CVPIA as a limiting factor by the Science Integration Team model (Reclamation and USFWS 2020). Increases in suitable spawning habitat through habitat improvement efforts such as gravel addition supports a greater number of redds or spawners (Roni et al. 2014), leading to an increased capacity to produce more juveniles.

6.1.2 Salmonid Habitat Results: Rearing

Rearing habitat was evaluated for instream habitat alone, floodplain habitat alone, and for the combination of instream and floodplain habitat.

6.1.2.1 In-Channel Rearing

The proposed habitat restoration commitments identified in the VA Term Sheet include in-channel habitat for the Sacramento River (137.5 acres), Feather River (5.25 acres), Yuba River (50 acres), American River (75 acres), and Mokelumne River (1 acre). Across 99 studies reviewed by Roni et al. (2008), more than 60 percent showed an increase in juvenile salmon to the placement of instream structures for habitat improvement, though results were mixed. Increases in suitable instream rearing habitat through habitat improvement efforts led to an increased capacity to produce more juveniles. Instream rearing habitat met the 25-percent-of-doubling-goal threshold for the reference condition and the VA in the Mokelumne, Yuba, and Sacramento (spring run) Rivers, but not the American, Feather, or Sacramento (fall run) Rivers (Figure 6-3). Flow flexibility scenarios had little impact on instream rearing habitat area. The effect of flow on habitat availability means that not all the restored habitat is available in all water year types, but additional rearing habitat is available in floodplains during higher flow years (see Section 6.1.2.3, *Combined Rearing Habitat*).

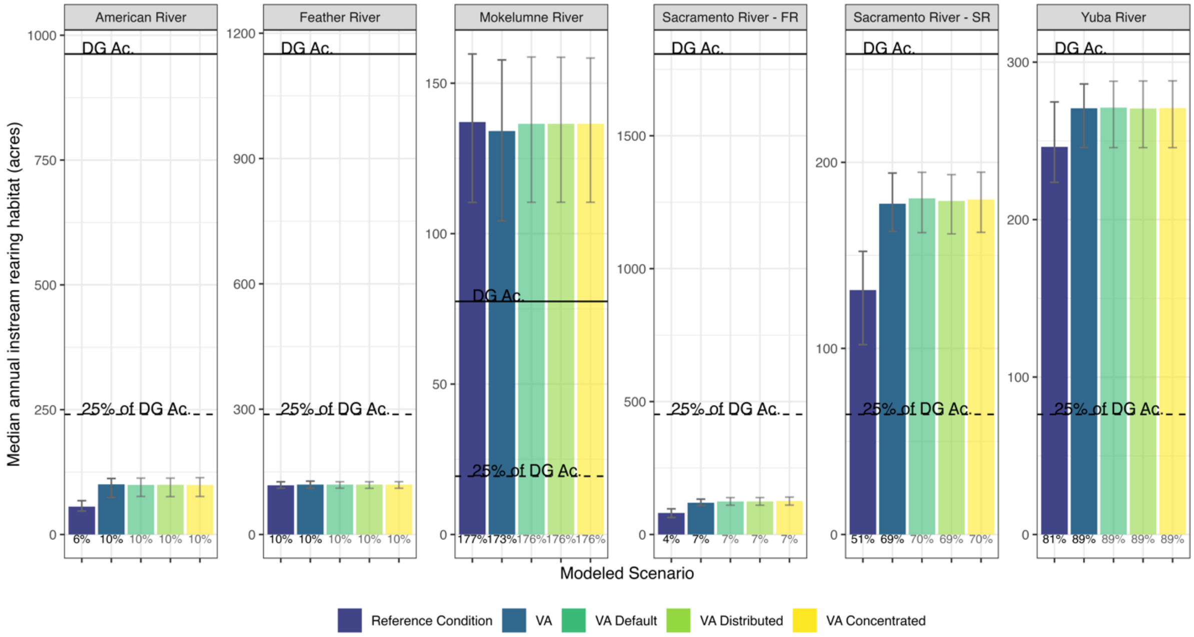

Figure 6-3. Median (across All Years) In-Channel Rearing Habitat (Acres) under Reference Condition, VA, and Flow Flexibility Scenarios for Each Watershed
Results are presented for fall run in all tributaries and for spring run in the Sacramento River. Solid lines represent area of habitat required to support the doubling goal (DG) population, and dashed lines represent 25 percent of the doubling goal area. The amount of habitat as a percentage of the habitat needed to support the doubling goal is noted below each bar. Error bars represent the upper and lower quartiles. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes.

Figure 6-4 shows the median annual in-channel habitat area (acres) for the reference condition and VA scenario by watershed and water year type. Across most water year types, the VAs offer more in-channel rearing habitat than the reference condition in the American, Sacramento, and Yuba Rivers, equivalent in-channel rearing habitat in the Feather River, and reduced in-channel rearing habitat in the Mokelumne River. The VAs offer 45 to 128 percent more in-channel rearing habitat (21–51 acres) in the American River; 1 percent less to 4 percent more in the Feather River (-2–4 acres); 3 to 0 percent less in the Mokelumne River (-3–0 acres); 15–83 percent more in the Sacramento River for fall run (14–50 acres); 13 to 69 percent more in the Sacramento River for spring run (23–64 acres); and 3 to 11 percent more in the Yuba River (7–25 acres) (Table 6-2, Figure 6-4).

These analyses show reductions in in-channel rearing habitat in some wetter year types in the Sacramento, American, Mokelumne, and Yuba Rivers, which may seem counterintuitive. However, in wetter years, velocities and depths become less suitable in the channels, particularly when the flows are confined by levees. These results highlight the importance of restoring floodplain and off-channel habitat to provide lower-velocity refugia during high flow years.

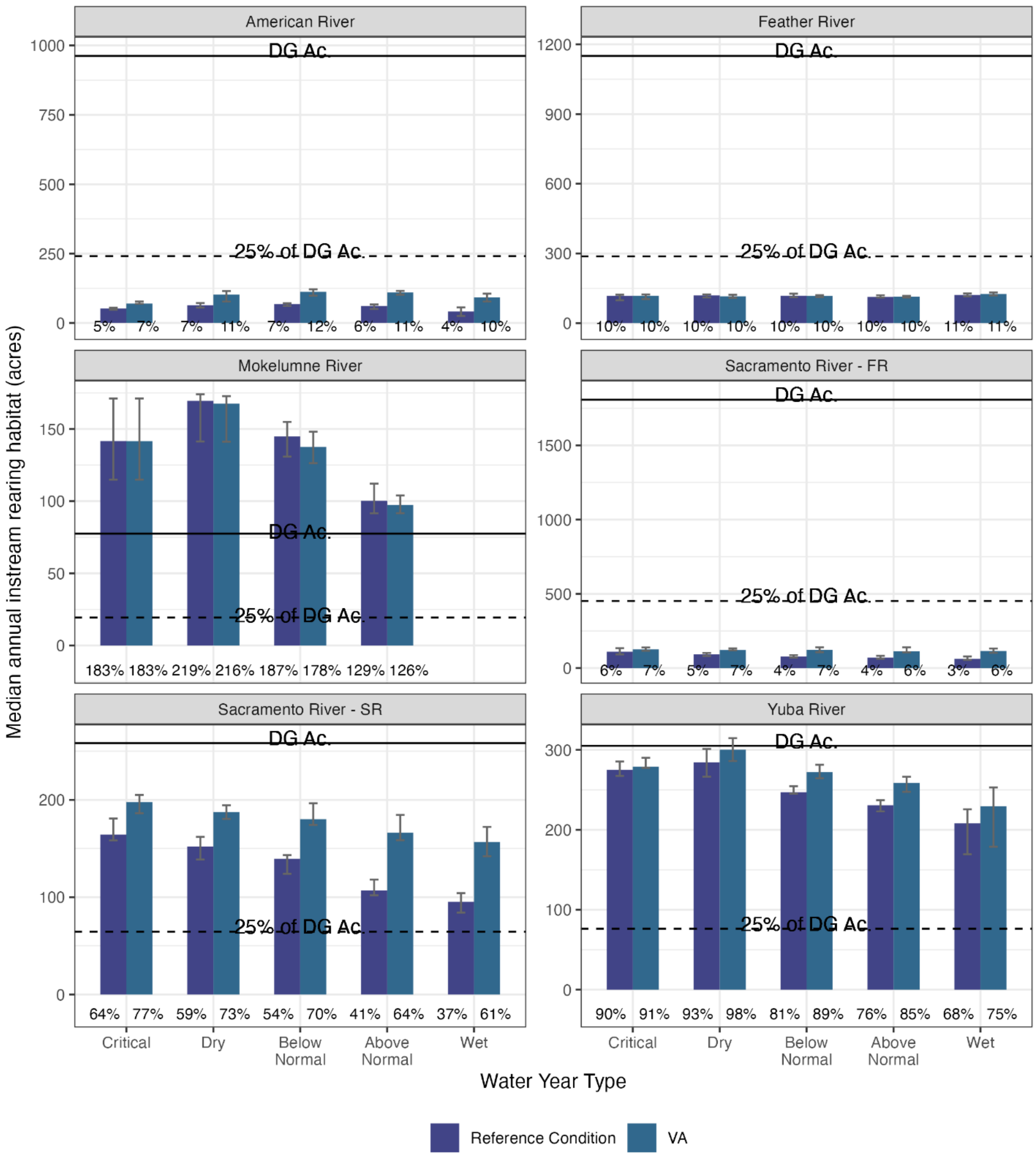

Figure 6-4. Median Annual In-Channel Rearing Habitat (Acres) by Water Year Type under Reference Condition, VA, and Flow Flexibility Scenarios for Each Watershed
Results are presented for fall run in all tributaries and for spring run in the Sacramento River. Solid lines represent area of habitat required to support the doubling goal (DG) population, and dashed lines represent 25 percent of the doubling goal area. The amount of habitat as a percentage of the habitat needed to support the doubling goal is noted below each bar. Error bars represent the upper and lower quartiles. Medians and quantiles were calculated across years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes. Note that Mokelumne River results are based on the Mokelumne River water year type definitions, which do not contain a "wet" category.

Table 6-2. Median Percent Change between the Reference Condition and VA Scenarios for Suitable Instream Rearing Habitat by Water Year Type and Watershed

Watershed	Critical	Dry	Below Normal	Above Normal	Wet
American River	45% (21)	52% (37)	63% (44)	78% (49)	128% (51)
Feather River	4% (4)	0% (0)	-1% (-2)	2% (2)	3% (4)
Mokelumne River	0% (0)	-1% (-2)	-3% (-3)	0% (0)	NA
Sacramento River: FR	15% (14)	23% (23)	63% (49)	75% (48)	83% (50)
Sacramento River: SR	13% (23)	24% (35)	35% (49)	57% (64)	69% (61)
Yuba River	3% (7)	5% (13)	10% (24)	11% (25)	10% (20)

Note: The numbers in parentheses are median changes in suitable instream rearing habitat acreage. Results are presented for fall run in all tributaries and for spring run in the Sacramento River. Mokelumne River results are based on the Mokelumne River water year type definitions, which do not contain a "wet" category.
FR = fall run; NA = not applicable; SR = spring run

The additional habitat on the Mokelumne River is offset due to the inverse relationship between flow and existing rearing habitat area on the Mokelumne River (Gill and Thompkins 2020e). However, under the reference condition and VA in all water year types, the Mokelumne River exceeds the habitat area needed to support 100 percent of the doubling goal for the juvenile population target (Figure 6-3).

6.1.2.2 Floodplain and Fish Food Production

The survival of juvenile Chinook salmon 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 (Bayley 1991 as cited in Jeffres et al. 2008; USFWS 2014). Life history diversity in salmonids is also enhanced with access to floodplain habitat (Goertler et al. 2018a) and is recognized as a critical component of population viability (Carlson and Satterthwaite 2011).

The proposed floodplain and flood basin actions identified in the VA Term Sheet include floodplain habitat and/or fish food production for the Sutter Bypass, Butte Sink, and Colusa basin (20,000 acres of fish food and 20,000 acres of flood habitat); Feather River (1,655 acres); Yuba River (100 acres); and Mokelumne River (25 acres), though habitat improvements must be accompanied by inundation and connectivity for fish access for the habitat to be useful. Juveniles in shallow, low-velocity habitats supported by floodplain inundation have been found to grow more rapidly than juveniles in deeper, faster habitat, due to high prey abundance, lower water velocities, and higher temperatures compared to the adjacent river channel (Sommer et al. 2001b; Benigno and Sommer 2008; Jeffres et al. 2008). Access to floodplain habitat also provides increased space required for growth, development, and survival. Furthermore, faster growth has been linked to higher marine survival in other West Coast Chinook salmon populations (Beckman et al. 1999). Landform modifications and improvements to Tisdale Weir and other infrastructure in the three flood basins (Sutter Bypass, Butte Sink, and Colusa basin) are expected to reduce stranding and migratory delays of all life stages of anadromous fishes. In addition, flooding of rice fields in the Sutter Bypass, Butte Sink, and Colusa basin (20,000 acres) may be used for fish food production, dependent on evaluation of its effectiveness.

The VAs will likely offer a greater proportion of MFE occurrence for the Feather (Figure 6-5), Mokelumne (Figure 6-6), and Yuba (Figure 6-7) Rivers. On the Feather River, the VA scenario provides MFEs 66 percent of years at 25 percent of the doubling goal (the target for the VAs); at 50 percent and 75 percent of the doubling goal, VA MFEs occur 49 percent and 20 percent of years, respectively (Figure 6-5). For the Mokelumne River, the VA and reference condition scenarios allow for similar MFE occurrence (51 percent for both) at 25 percent of the doubling goal (the target for the VAs), whereas the VAs provide higher MFE occurrence than the reference condition at 50 to 100 percent of the doubling goal (Figure 6-6). On the Yuba River, the reference condition MFEs meet 25 percent of the doubling goal in 11 percent of the years, while the VAs meet 25 percent of the doubling goal in 72 percent of the years (Figure 6-7).

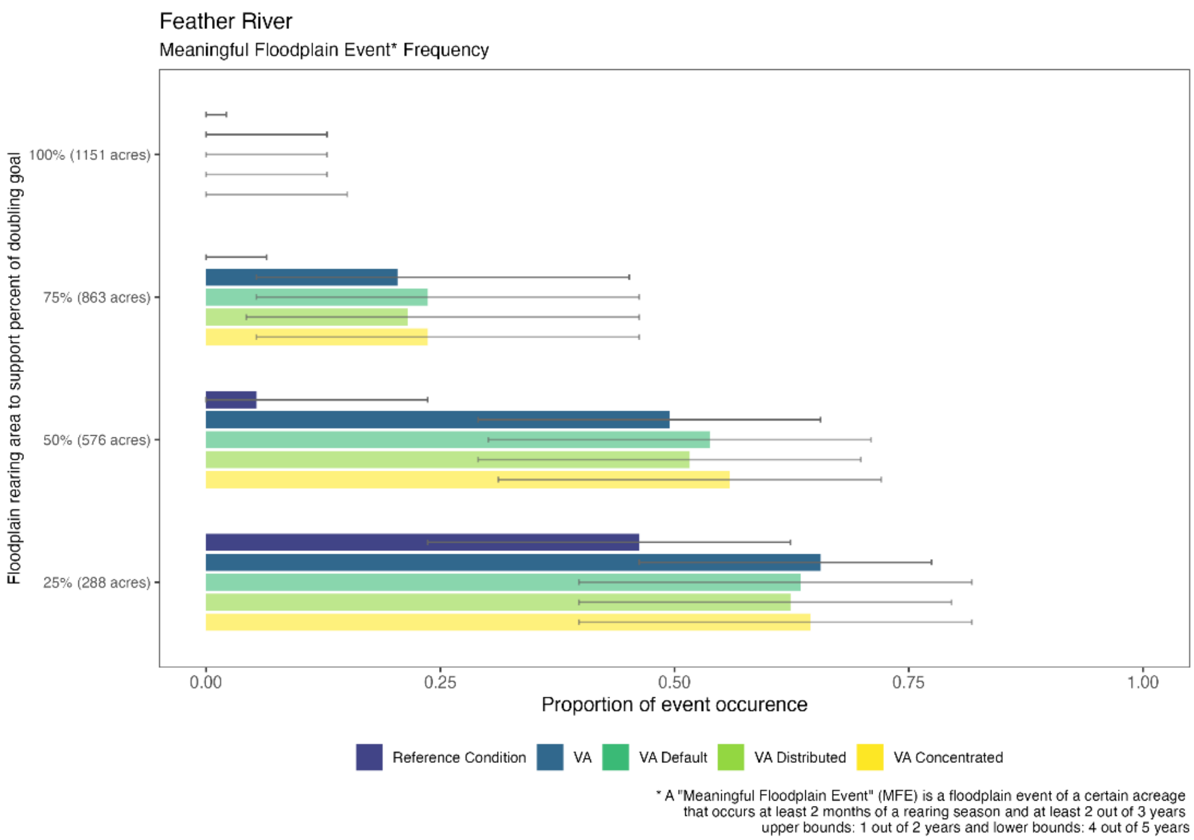

Figure 6-5. Proportion of Meaningful Floodplain Event Occurrence for the Reference Condition, VA, and Flow Flexibility Scenarios on the Feather River
An MFE is defined as a floodplain event of a certain acreage that occurs at least 2 months of a rearing season and at least 2 out of 3 years. This bar chart is oriented horizontally. 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 loosened to require floodplain events 1 out of 2 years.

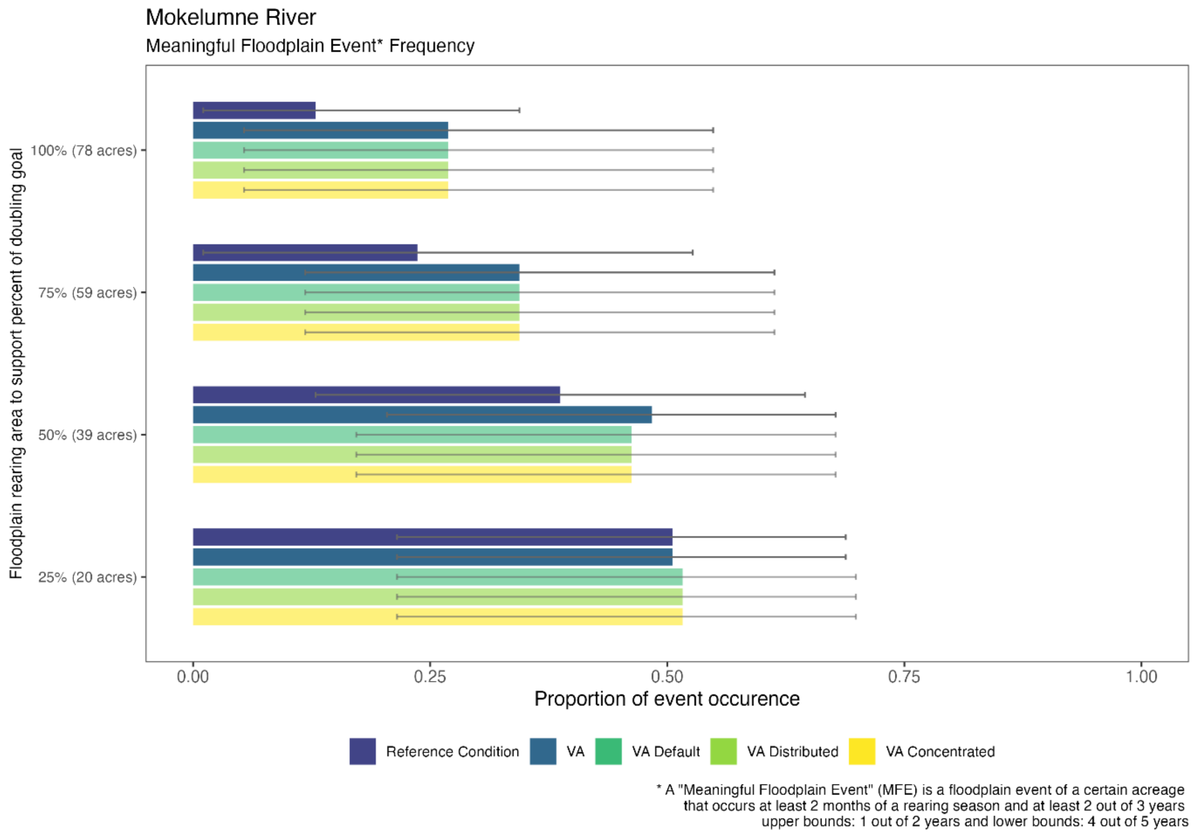

Figure 6-6. Proportion of Meaningful Floodplain Event Occurrence for the Reference Condition, VA, and Flow Flexibility Scenarios on the Mokelumne River
An MFE is defined as a floodplain event of a certain acreage that occurs at least 2 months of a rearing season and at least 2 out of 3 years. This bar chart is oriented horizontally. 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 loosened to require floodplain events 1 out of 2 years.

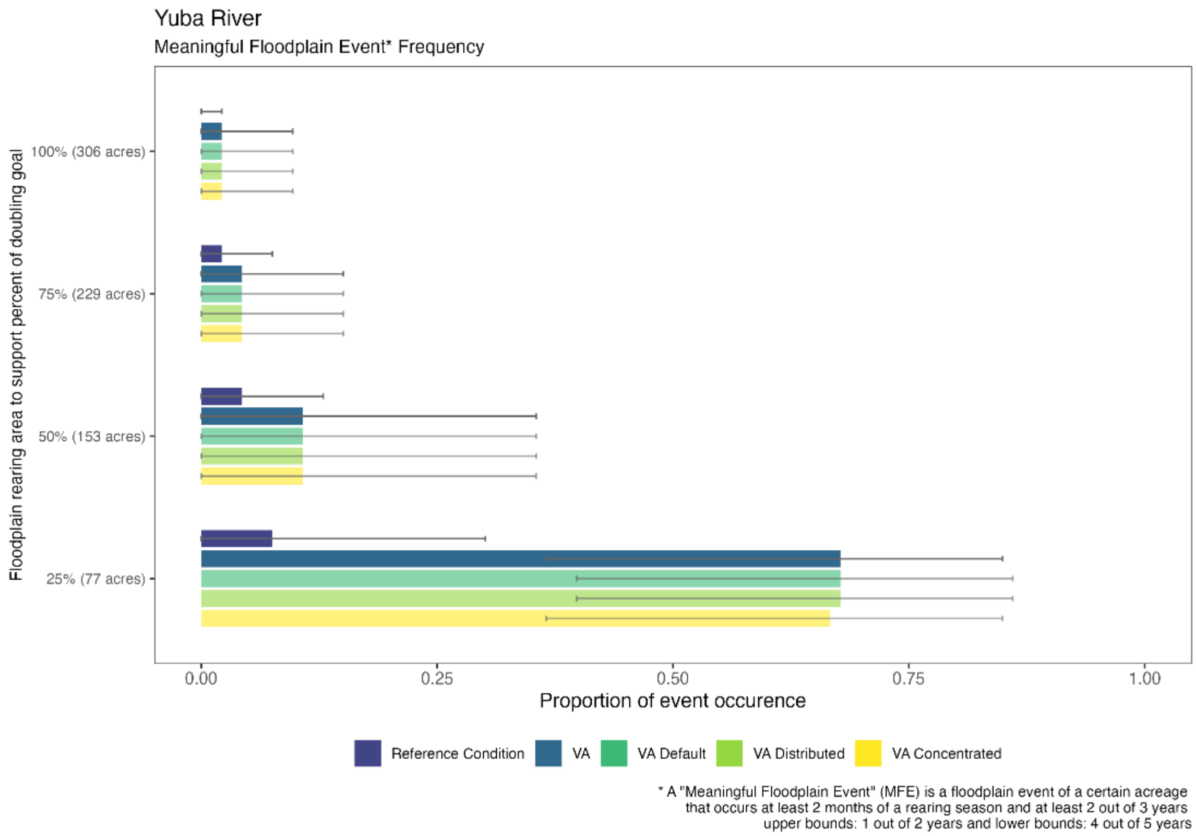

Figure 6-7. Proportion of Meaningful Floodplain Event Occurrence for the Reference Condition, VA, and Flow Flexibility Scenarios on the Yuba River
An MFE is defined as a floodplain event of a certain acreage that occurs at least 2 months of a rearing season and at least 2 out of 3 years. This bar chart is oriented horizontally. 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 loosened to require floodplain events 1 out of 2 years.

Twenty thousand acres of floodplain habitat within the three flood basins (Sutter Bypass, Butte Sink, and Colusa basin) are described as being generated via the Tisdale Weir and other modifications. However, modeling indicates most of that habitat will need to be generated via other topographic modifications, rather than solely through changes to Tisdale Weir. In the Sutter Bypass, changes to Tisdale Weir result in increased frequency of spill over the Tisdale Weir such that monthly spills between 0 and 4,000 cfs increased by as much as 5 percent for the VAs compared to the reference condition (Figure 6-8). This change in hydrologic operations of the Tisdale Weir does not create new physical habitat; rather, it improves the inundation frequency and duration of reference condition and VA proposed floodplain habitat in the Sutter Bypass. This will need to be accompanied by additional topographic modifications, land management changes, and habitat enhancements in these flood basins to generate the full 20,000 acres of floodplain habitat identified in the VAs. Based on the Sutter Bypass MFE assumptions, Figure 6-9 describes the number of acres that meet MFE criteria. These are not put in terms of a percentage of the doubling goal because doubling goal acreage has not been specifically defined for the Sutter Bypass. However, the additional floodplain habitat provided under the VAs in these flood basins could provide rearing habitat to juvenile fish from the

Sacramento River and its tributaries upstream. Based on the assumptions described above, the additional floodplain habitat would exceed the rearing doubling goal habitat need for the Sacramento River (1,961 acres) during times when the floodplain is inundated, and fish have access.

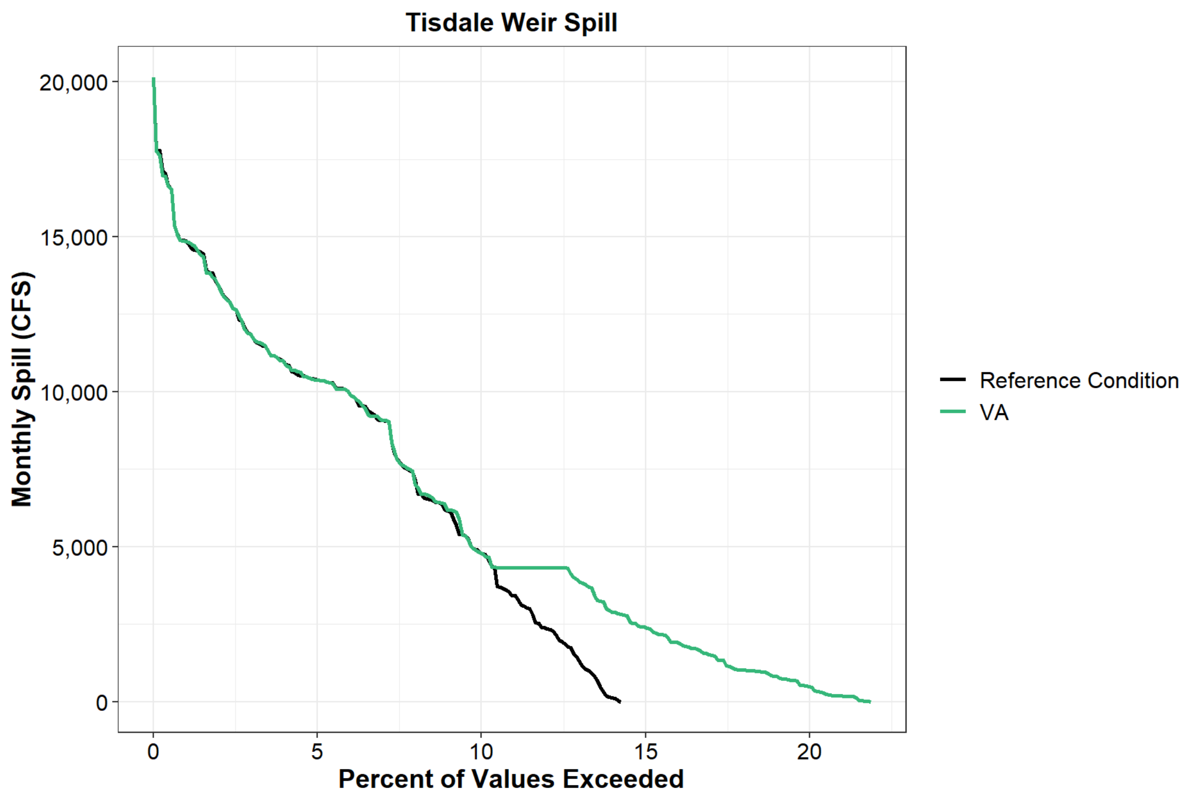

Figure 6-8. Change in Spill over the Tisdale Weir with the Notching Project Included in the VAs
The figure shows monthly spill (in cfs) on the y-axis and percent of values exceeded on the x-axis for reference condition (in black) and the VAs (in green).

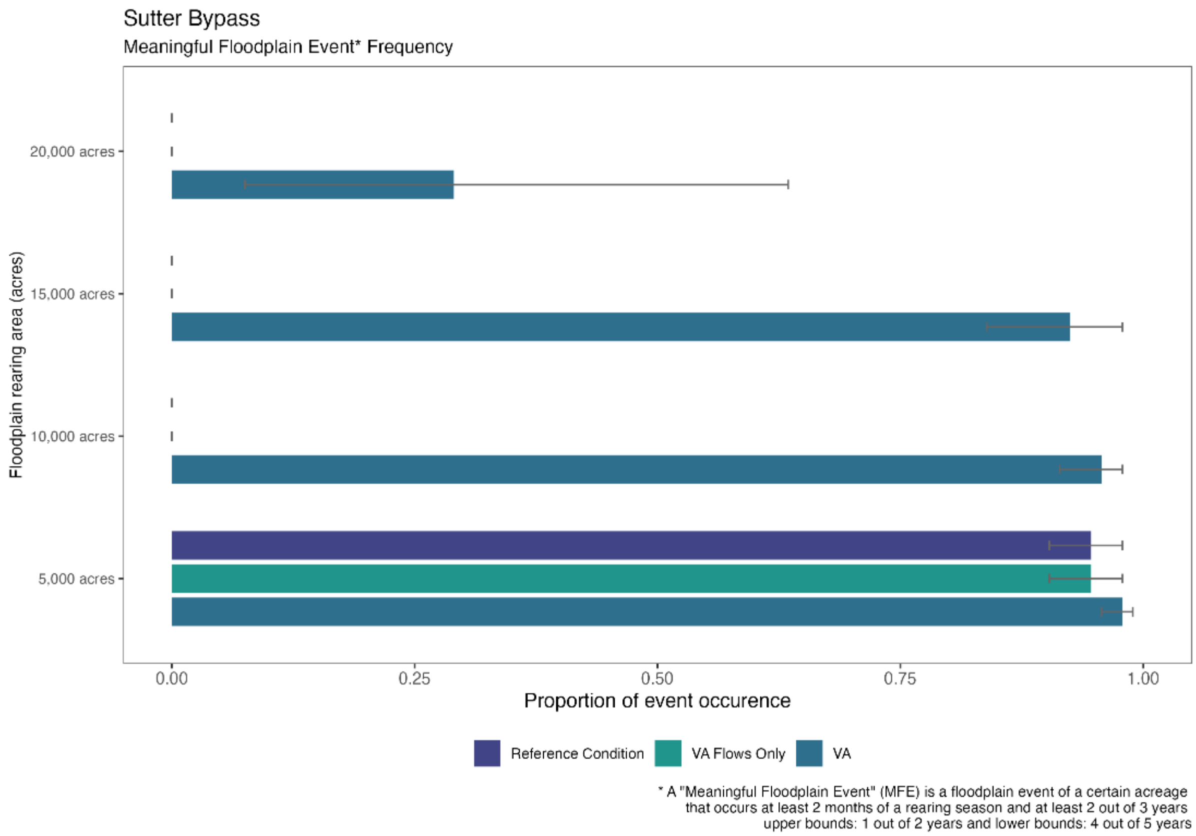

Figure 6-9. Proportion of Meaningful Floodplain Event Occurrence for the Reference Condition and VA Scenarios at the Sutter Bypass
This bar chart is oriented horizontally. Colored bars for each acreage (5,000, 10,000, 15,000, and 20,000) show reference condition and VA scenarios. The "VA flows only" scenario demonstrates effects of flows resulting from changes to Tisdale Weir notch added to existing habitat (i.e., existing topographic conditions), and the "VA" scenario shows the effects of adding these flows to new VA habitat assumed to be generated via topographic modifications. Changes in flow in the Sutter Bypass are primarily due to changes in the operation of the Tisdale Weir notch, rather than direct effects of VA flow assets. Because there is no proposed flexibility in the notch operations, flow flexibility scenarios are not evaluated for the Sutter Bypass. An MFE is defined as a floodplain event of a certain acreage that occurs at least 2 months of a rearing season and at least 2 out of 3 years. 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 loosened to require floodplain events 1 out of 2 years.

6.1.2.3 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 habitat increases habitat diversity and resilience for the population as a whole. The combined rearing habitat in the reference condition and the VAs met the target of 25 percent of the area necessary to support the doubling goal on the Mokelumne, Sacramento (spring run), and Yuba Rivers in all water year types (Figure 6-10, Figure 6-11). The Feather River met the target under the VAs with overall median habitat area and in Below Normal, Above Normal, and Wet years (Figure 6-10, Figure 6-11). The addition of 9,000 acres toward the 20,000 acres of floodplain restoration in the three Sacramento flood basins would surpass the 25-percent goal in the Sacramento River (fall run) during times when this floodplain is inundated and fish have access. However, this is not shown on Figure 6-10 because assumptions about juvenile fish access to this habitat mean it is not directly comparable to other floodplain habitat where accessibility is not a concern. Rearing habitat for all watersheds would change -1 to 72 percent from reference condition to VAs (Table 6-3).

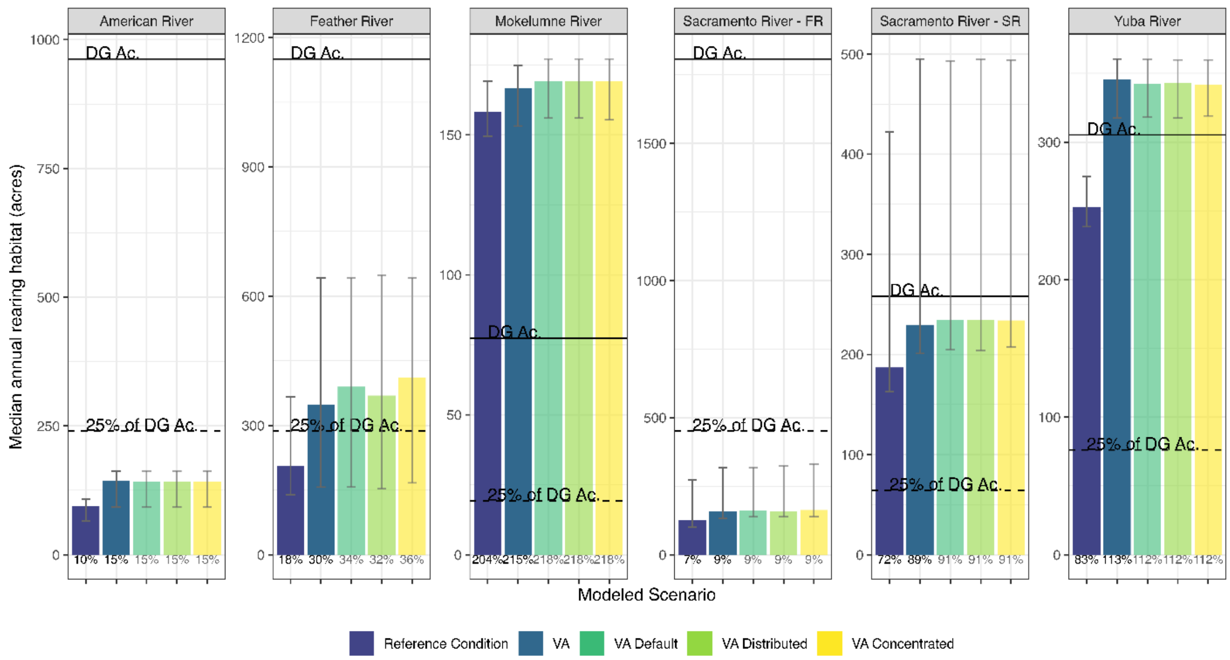

Figure 6-10. Median (across All Years) Rearing Habitat (Acres) under Reference Condition, VA, and Flow Flexibility Scenarios for Each Watershed, Including Both Floodplain and In-Channel Rearing Habitat

Results are presented for fall run in all tributaries and for spring run in the Sacramento River. The amount of habitat as a percentage of the habitat needed to support the doubling goal (DG) is printed below each bar. Solid lines represent area of habitat required to support the doubling goal population, and dashed lines represent 25 percent of the doubling goal area. Error bars represent the upper and lower quartiles. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes. Note that this does not include the 20,000 acres of floodplain restoration on the Sutter Bypass that may be available as rearing habitat for fish from the Feather and Sacramento Rivers during times when this floodplain is inundated and fish have access.

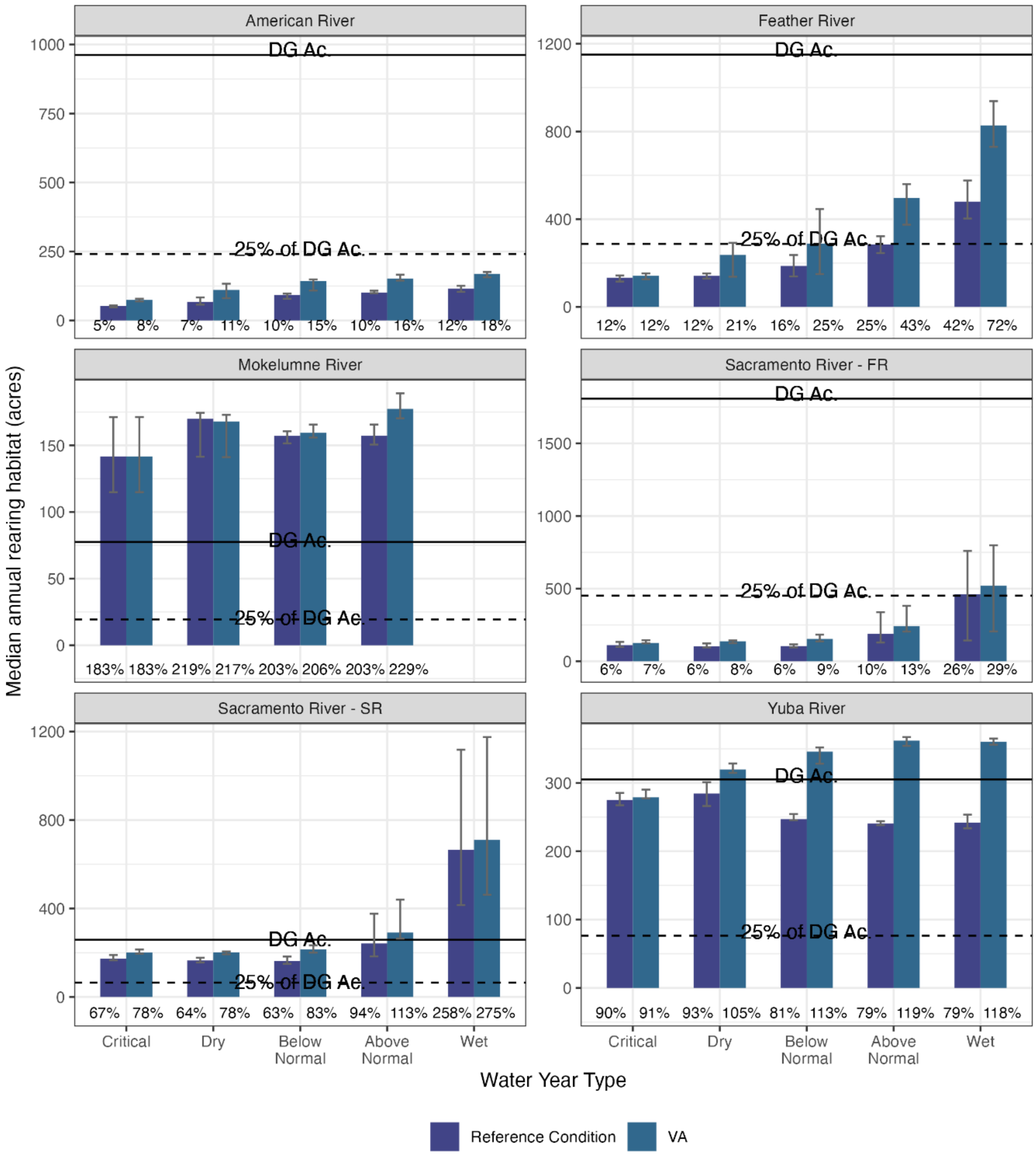

Figure 6-11. Median Annual Rearing Habitat (Acres) by Water Year Type under Reference Condition, VA, and Flow Flexibility Scenarios for Each Watershed, Including Both Floodplain and In-Channel Rearing Habitat

Results are presented for fall run in all tributaries and for spring run in the Sacramento River. The amount of habitat as a percentage of the habitat needed to support the doubling goal (DG) is printed below each bar. Solid lines represent area of habitat required to support the doubling goal population, and dashed lines represent 25 percent of the doubling goal area. Error bars represent the upper and lower quartiles. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes.

Note that this does not include the 20,000 acres of floodplain restoration on the Sutter Bypass that may be available as rearing habitat for fish from the Feather and Sacramento Rivers during times when this floodplain is inundated and fish have access. Note that Mokelumne River results are based on the Mokelumne River water year type definitions, which do not contain a "wet" category.

The VAs offer 46 to 52 percent more rearing habitat (23–51 total acres) in the American River; 5 to 72 percent more in the Feather River (6–344 acres); 1 percent less to 14 percent more in the Mokelumne River (-1 to 8523 acres); 11–42 percent more in the Sacramento River for fall run (14–51 acres); 10 to 28 percent more in the Sacramento River for spring run (24–65 acres); and 3 to 51 percent more in the Yuba River (7–122 acres) (Table 6-2; Figure 6-4).

Table 6-3. Median Percent Change between the Reference Condition and VA Scenarios for Suitable Rearing Habitat (Including Both Instream and Floodplain) by Water Year Type and Watershed

Watershed	Critical	Dry	Below Normal	Above Normal	Wet
American River	48% (23)	52% (38)	52% (50)	51% (50)	46% (51)
Feather River	5% (6)	47% (75)	67% (114)	72% (204)	67% (344)
Mokelumne River	0% (0)	-1% (-1)	0% (0)	14% (23)	NA
Sacramento River: FR	15% (14)	20% (24)	42% (50)	24% (51)	11% (50)
Sacramento River: SR	13% (24)	24% (38)	28% (51)	23% (65)	10% (62)
Yuba River	3% (7)	10% (30)	41% (101)	51% (122)	46% (113)

Notes: Results are presented for fall run in all tributaries and for spring run in the Sacramento River. Numbers in parentheses are median changes in suitable rearing (including instream and floodplain) habitat acreage. Mokelumne River results are based on the Mokelumne River water year type definitions, which do not contain a "wet" category.
FR = fall run; NA = not applicable; SR = spring run

6.1.3 Benefits of Increased Flow

Altered flow regimes in the Sacramento River and other large Central Valley rivers have contributed to reduction of spring outmigration survival of juvenile salmon (Notch et al. 2020). Studies using acoustic tagged salmonids on the Sacramento River show that flow was the most important covariate in predicting outmigration success (Michel et al. 2015; Notch et al. 2020). Flow-survival thresholds have recently been developed using spring and summer season salmonid releases in the Sacramento River, based on river stage at Wilkins Slough (Michel et al. 2021). Chinook smolt survival is estimated as greater than 50 percent when Wilkins Slough flows are 10,700 cfs or greater, and survival is estimated as near zero when Wilkins Slough flows are less than 4,000 cfs (Michel et al. 2021). Flow pulses can trigger outmigration cues and aid juvenile outmigration from upper reaches of tributaries toward the Delta to increase systemwide longitudinal connectivity to the benefit of both juvenile and adult life stages of native fishes.

While increased flow may provide survival benefits for actively outmigrating juvenile Chinook and steelhead, it may also simultaneously benefit rearing and foraging salmon by increasing connectivity and activating floodplain habitat. Floodplain habitat has ecological importance to Chinook salmon and steelhead during multiple life stages as it provides a suite of benefits for fish. Within floodplains, rearing and foraging salmonids may find increased food resources (Sommer et al. 2001c; Bellmore et al. 2013) and habitat (Sommer et al. 2005; Cordell et al. 2011), and they may subsequently grow faster (Takata et al. 2017), theoretically conferring survival benefits (Sommer et al. 2001c, 2005).

Takata et al. (2017) found the duration of floodplain flooding in the Yolo Bypass positively affected total growth in coded wire tagged hatchery-origin fall-run Chinook salmon in the bypass. Floodplain habitat can provide high densities of zooplankton, aquatic insects, and benthic invertebrates, particularly when there are periods of disconnection and reconnection with the river to allow productivity to increase (Grosholz and Gallo 2006).

6.1.4 Synergy between Flow and Non-Flow Habitat

Modeling results show the benefits of increased flow in tributaries by a resulting increase in salmonid habitat. The modeled median percent changes between reference condition and VA scenarios for suitable spawning habitat and instream rearing habitat are positive for most watersheds (American River, Feather River, and Sacramento River) in most water year types (Table 6-1, Table 6-2). The Mokelumne River is the only exception; modeled median percent change of suitable instream rearing habitat is 0 percent, but that is expected because only 1 acre of rearing habitat is included in the VAs. Suitable spawning and rearing habitat provide a suite of benefits to Chinook salmon and steelhead across all Central Valley tributaries during multiple life stages.

The earliest life history stage of salmonids (egg incubation to emergence from the gravel) is particularly sensitive to environmental stressors. This life stage requires suitable water temperature regimes and stable and continuous river flows to prevent redds from being dewatered or exposed to warm, deoxygenated water. Redds constructed in shallow areas are susceptible to dewatering by flow reduction actions when operations transition from summer to winter flow regimes (Revnak et al. 2017). Augmented flows timed to decrease redd dewatering can mitigate this risk.

Before juveniles begin outmigration through the tributaries to the Delta, availability of rearing habitat that provides diverse, abundant food resources in non-natal tributaries and off-stream habitats is important. Along the upper Sacramento River, these areas that provide high-value resources are hypothesized to support growth (Limm and Marchetti 2009; Phillis et al. 2018), increasing chances of survival. Larger otolith increments, translating to faster growth rates, were found in salmonids sampled in off-channel habitats compared to those sampled in main-channel habitats along the Sacramento River (Limm and Marchetti 2009). While modification of a river's hydrology can have detrimental impacts on salmonids by reducing access to rearing habitat for early life stages, modeled results show the VA flows may increase suitable rearing habitat in the tributaries.

Flows directly increase connectivity of floodplain habitat with the surrounding rivers, which has been identified as a key ecosystem stressor limiting salmonid resilience (Chapter 2, *Aquatic Ecosystem Stressors*; Beechie et al. 2013; Herbold et al. 2018). Freshwater flows from the Sacramento River into floodplains activate habitat for Chinook salmon and steelhead, increasing primary and secondary productivity, which benefits rearing, foraging, and outmigrating juveniles (Sommer et al. 2001c; Sturrock et al. 2022). However, for flood bypasses, which differ from natural floodplains in that connectivity is limited by weirs and water control structures, inundating the floodplain may not be enough. Flows must be sufficient to restore functional connectivity of these habitats to provide volitional ingress/egress for fishes. Several studies of the Yolo Bypass, Sutter Bypass, and Cosumnes River floodplains indicate higher concentrations of phytoplankton and invertebrates than in the surrounding channel (Grosholz and Gallo 2006; Frantzich and Sommer 2015; Goertler et al. 2018a; Corline et al. 2021; Sturrock et al. 2022), providing improved growth conditions for juvenile fish (Sommer et al. 2001c; Jeffres et al. 2008; Takata et al. 2017; Goertler et al. 2018b).

Flows may also facilitate transport of production and food resources to areas with appropriate fish habitat, depending on season. Several years of experimental studies have been investigating whether summer-fall pulse flows can deliver food resources to downstream regions. Frantzich et al. (2018) demonstrated from 4 years of weekly lower trophic data that densities of both calanoid copepod adults and cladocerans differ significantly between the Yolo Bypass and the Sacramento River, with higher densities in the perennial drainage channel in Yolo Bypass. Studies of flooded rice fields have also found high concentrations of zooplankton that potentially can provide a benefit if exported to the surrounding rivers with agricultural drainage in spring (Katz et al. 2017; Sommer et al. 2020b). However, more recent research suggests that higher chlorophyll-*a* concentrations and zooplankton densities in the Yolo Bypass in the summer-fall are unlikely to be transported out of the Yolo Bypass by pulse flows to suitable downstream fish habitat (Davis et al. 2022).

Foodweb hotspots benefit many native fish species, and productive habitats have the capacity to supplement the diet of species through subsidies (Farly et al. 2019). In a system similar to the Delta, Lake Saint-Pierre (a shallow fluvial lake of the St. Lawrence River), the isotopic signatures of fish tissues indicated that floodplain production contributed up to 50 percent of the diet (Farly et al. 2019). In the Yolo Bypass, Sturrock et al. (2022b) reported juvenile fall-run Chinook guts were fullest in wet years (2016 and 2017), emptiest at the end of a multiyear drought (2015), and significantly differed among years. Additionally, supporting the subsidies theory, cladoceran abundance both in situ and in salmon gut contents was highest closest to a floodplain source (Sturrock et al. 2022).

6.2 Bay-Delta—Species and Habitat

The analysis of biological and environmental outcomes in the Bay-Delta are based on three sources of information:

1. Quantitative modeling of stationary habitat (acreage of tidal wetlands) and the quantity of dynamic habitat (water quality and velocity)
2. Quantitative modeling of flow-abundance relationships and flow thresholds for several native fishes
3. A qualitative description of expected benefits to habitat restoration where no appropriate habitat-abundance models exist. Because habitat restoration in the Bay-Delta is in its infancy and restoration sites may take many years to achieve their full benefits, the quantitative benefits of habitat restoration on population growth for fishes of concern cannot be directly modeled. Therefore, a literature review of studies evaluating benefits of habitat restoration to salmonids and smelt is provided.

6.2.1 Benefits of Increased Flow

As cited in the 2017 Scientific Basis Report, increased flow is expected to increase the abundance of several native species in the Delta. The mechanisms behind the flow-abundance relationships vary by species and are not fully understood, but the abundances of several native species residing or rearing in or migrating through the Bay-Delta show persistent positive relationships with the volume of Delta outflow during the winter and spring (2017 Scientific Basis Report, Sections 3.2.2, 3.5.4, 3.7.4, 3.9.4, and 3.10.4). The 2017 Scientific Basis Report presented expected increases in the abundance indices of longfin smelt, starry flounder, Sacramento splittail, and California Bay shrimp based on the flow-abundance relationships for each species (2017 Scientific Basis Report, Section 5.3.3). Based on the modeled changes in Delta outflow, the expected percent changes for each of these four species are shown on Figure 6-12. Consistent with the approach taken in the 2017 Scientific Basis Report, these results are meant to give a general sense of the relative benefit each species may realize for a given flow scenario and they should not be interpreted as a prediction of future population abundances. Because the median water year type in the Sacramento River watershed is Below Normal, the values estimated for Below Normal years reflect a reasonable estimate of the likely long-term effect of VA flows on the abundances of these species. Lastly, it is important to note that the flows used to predict the flow-abundance benefits in this Draft Supplement Report represent modeled expected flows, whereas those used in the 2017 Scientific Basis Report represented required flows, which are lower than modeled flows. At the time the 2017 Scientific Basis Report was produced, modeling that included uncontrolled flows was not available, so the best scientific information was used at the time. The Staff Report will include an update to the 2017 Scientific Basis Report flow-abundance results to address this.

Abundance indices are expected to increase in all water year types except Wet, with the greatest increases in Dry years. Removal of the San Joaquin contributions diminishes expected increases by 1 to 3 percentage points while the flow flexibility scenarios generally result in slightly higher or similar benefits as the modeled VA scenario. Longfin smelt have the greatest expected response while starry flounder have the smallest.

Compared to the VA scenario, greater benefits to abundance indices would generally be realized under the “VA w/Bias Correction and LSJR Placeholder” and “VA w/Bias Correction and 40% UF Merced & Stanislaus” scenarios (as described in Section 4.12.2, *VA Postprocessing*, and Table 4-14). These scenarios would have smaller decreases (VA w/Bias Correction and LSJR Placeholder) or increases (VA w/Bias Correction and 40% UF Merced & Stanislaus) in abundance indices in Wet years, and greater increases in abundance indices in Above Normal and Below Normal years than the VA scenario when compared to the reference condition. In Dry and Critical years, the VA w/Bias Correction and LSJR Placeholder scenario would have smaller increases in abundance indices than the VA scenario, while the VA w/Bias Correction and 40% UF Merced & Stanislaus scenario would have greater increases than the VA scenario.

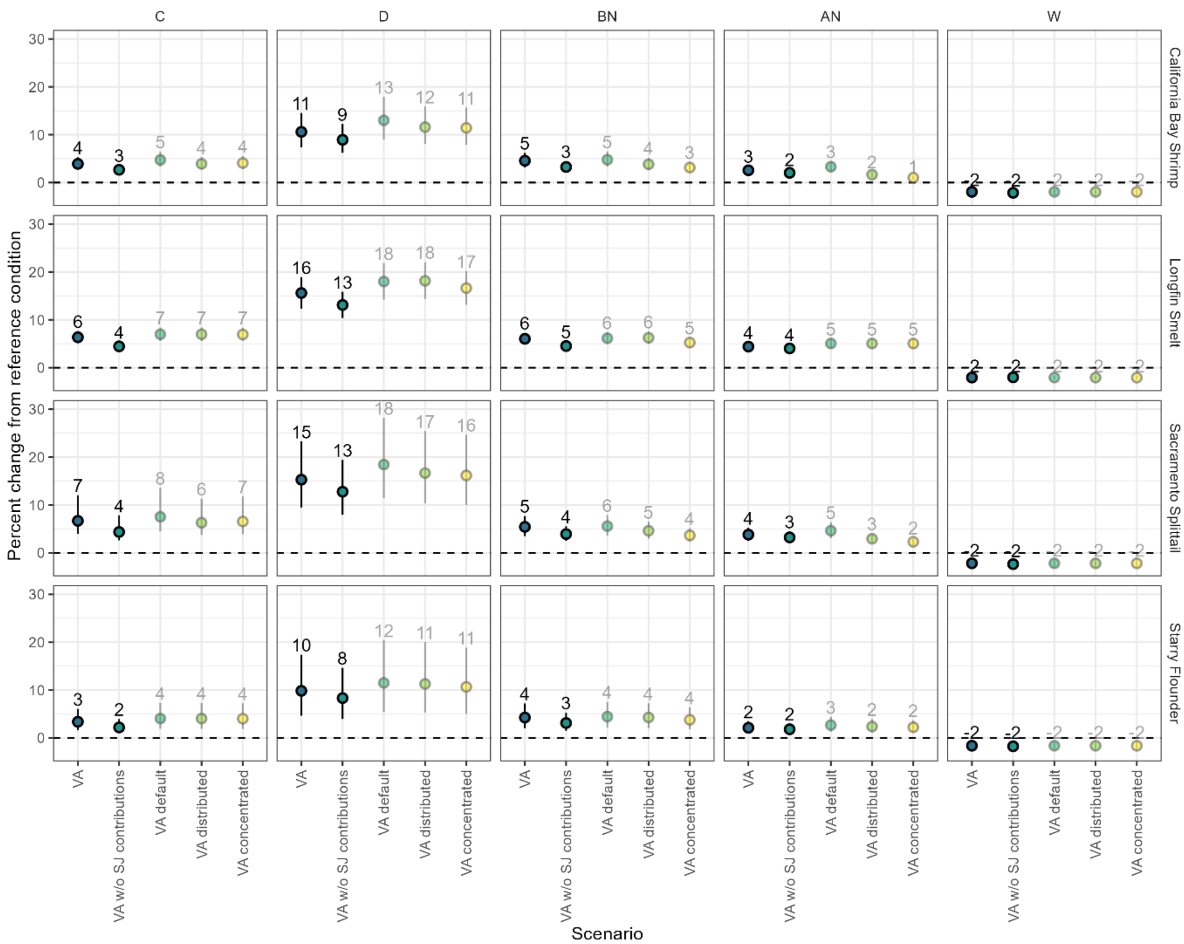

Figure 6-12. Potential Percent Change (Median Prediction ± 95 percent Confidence Intervals) in Abundance Indices Relative to the Reference Condition
The median predictions (rounded to a whole number) are also printed above each point. The VA without San Joaquin contributions scenario excludes Friant and Tuolumne VA flows because the Friant VA is uncertain and the Tuolumne VA would be subject to State Water Board decision-making under a separate process.

The frequency of achieving ecological flow thresholds would generally increase under the VAs, although in some cases there are slight decreases (Table 6-4). Some thresholds such as the Collinsville X2 flows are nearly always achieved under all scenarios whereas others such as the green and white sturgeon threshold are not often achieved under any scenario. Some of the greatest benefits (3–6 percentage point increases) of the VAs are achieved for winter-run outmigration, bay shrimp, starry flounder, and Chipps Island X2.

Table 6-4. Frequency of Exceeding Ecological Flow Thresholds within the Seasons Specified in Section 5.4

Threshold (cfs)	Reference Condition	VA	VA w/o SJ Contributions	VA Default	VA Distributed	VA Concentrated
Georgiana Slough Flow Reversal Low (17,000)	53%	52%	52%			
Georgiana Slough Flow Reversal High (20,000)	43%	44%	44%			
Fall-Run Outmigration (20,000)	26%	26%	26%			
Winter-Run Outmigration (20,000)	57%	60%	60%			
Bay Shrimp Low (20,000)	51%	55%	52%	54%	53%	53%
Bay Shrimp High (25,000)	41%	45%	44%	45%	44%	44%
Longfin Smelt (43,000)	29%	29%	29%	29%	29%	29%
Sacramento Splittail Low (30,000)	39%	43%	41%	44%	42%	41%
Sacramento Splittail High (47,000)	26%	25%	25%	26%	25%	25%
Starry Flounder (21,000)	42%	46%	46%	46%	46%	46%
Green and White Sturgeon (37,000)	15%	15%	15%	15%	15%	15%
Collinsville X2 (7,100)	99%	99%	99%	99%	99%	99%
Chipps Island X2 (11,400)	81%	87%	87%	87%	87%	87%
Port Chicago X2 (29,200)	41%	43%	43%	43%	43%	43%

Note: The Georgiana Slough flow reversal threshold represents monthly flows while the other thresholds represent seasonally averaged flows. Flow flexibility scenarios were not evaluated for interior Delta flow thresholds (Georgiana Slough flow reversal and salmonid outmigration). The VA interior Delta flows used for the Georgiana Slough flow reversal and the fall- and winter-run outmigration thresholds do not include any unspecified water purchases (market price and permanent state water purchases) because the origin of that water is unknown. Thresholds for Collinsville, Chipps Island, and Port Chicago represent the flows that correspond to an average X2 location downstream of the specified location.
SJ = San Joaquin; w/o = without

Flow actions also have the potential to increase food supply in certain regions of the Bay-Delta. For example, high abundances of the calanoid copepod *Pseudodiaptomus forbesi* occupy freshwater reaches of the Delta during the spring and summer regardless of inflow (Kimmerer et al. 2018b). During high flow years, these high densities are flushed into Suisun Marsh, which is hypothesized to be good habitat for Delta smelt, juvenile salmon, and other native fishes (Colombano et al. 2020; Sommer et al. 2020a; Aha et al. 2021). When spatial subsidies of zooplankton combine with a low salinity zone in Suisun Bay and Suisun Marsh, stationary habitat (extensive shallow water and wetlands), dynamic habitat (high turbidity, appropriate salinity, and lower temperatures), and food supply combine to create ideal conditions for pelagic fish species.

While not directly addressed by any actions within the VAs, providing higher springtime flows and restoring habitat for native species may limit the competitive advantage that invasive predatory fishes (centrarchids, catfish, etc.) currently possess. Unfortunately, presence of invasive species may also limit the effectiveness of the actions proposed in the VAs, because invaders cannot be blocked from restoration sites and will not be excluded by flow actions.

Increased flows may decrease predation on juvenile salmonids by moving them more quickly through the system between habitat patches or to the ocean, providing a benefit for migrating juveniles. Higher flows increase survival rates of juvenile salmonids moving through the Delta, most likely due to decreased travel time and decreased exposure to predation (Perry et al. 2018). Greater Sacramento River inflow also results in a higher proportion of juvenile Chinook salmon from the Sacramento River basin remaining in the mainstem Sacramento River, as opposed to the entering the low-survival interior Delta via Georgiana Slough, for example (Perry et al. 2018; Hance et al. 2022). Perry et al. (2018) estimated that the survival probability of acoustic tagged late-fall-run Chinook salmon from Freeport to Chipps Island increased from just over 0.30 at approximately 7,000 cfs of Sacramento River inflow to 0.70 at over 75,000 cfs, with a particularly steep rate of increase up to approximately 35,000 cfs. Both Perry et al. (2018) and Hance et al. (2022) illustrated that flow-survival relationships are particularly strong in Delta reaches that transition between mostly riverine and mostly tidal, e.g., in the Sacramento River between Sutter/Steamboat Slough and Rio Vista. This is because the magnitude of Sacramento River inflow affects the amount of time flow is unidirectional (i.e., more riverine) versus bidirectional (i.e., more tidal), which affects factors such as travel time and the proportion of flow entering the interior Delta (Cavallo et al. 2015; Perry et al. 2016). Increased inflows would decrease the amount of bidirectional flow in such reaches, thereby increasing the probability of juvenile Chinook salmon survival.

Increased flows may also improve water quality parameters, though the amount of additional VA flows is relatively modest in comparison with total flows, so changes to water quality are also likely to be relatively modest. Higher flows are usually accompanied by higher turbidity due to increased sediment loading (Livsey et al. 2021). Higher flows are also correlated with lower water temperatures (though the extent to which this is a causal relationship is unknown; Bashevkin and Mahardja 2022). The estuarine habitat analysis presented in Section 6.2.2, *Bay-Delta Habitat Analysis Results*, does not include an explicit model of the impact of flow on temperature and turbidity in the Delta, but if increased flow increases turbidity or lowers temperatures, results may be better than indicated in Section 6.2.2.

CyanoHABs decrease in frequency and severity with increasing flow (Lehman et al. 2013, 2022; Hartman et al. 2022b). However, research to date has focused primarily on the impact of summer flows on cyanoHABs in the Delta, whereas the VAs are proposing increased flows primarily in the spring, before *Microcystis* blooms and other cyanoHABs typically form. It is therefore unknown but unlikely that the VAs will have any benefits in reducing the frequency or severity of cyanoHABs in the Delta. Furthermore, cyanoHABs increase in frequency during years with higher temperatures (Hartman et al. 2022b; Lehman et al. 2022), so increases in temperatures caused by climate change may counteract any benefits of increased flow.

6.2.2 Bay-Delta Habitat Analysis Results

Estuarine habitat analyses demonstrated small benefits to suitable habitat area for longfin smelt, Delta smelt, and salmonids. Habitat area for all species except salmonids was greatest in Wet years and smallest in Critical years. Interannual variability in habitat area also increased in wetter years for longfin smelt larvae and juveniles and Delta smelt juveniles (Figure 6-13). Results for each month and water year type can be found in Section C.2, *Postprocessing*, of Appendix C, *Bay-Delta Habitat Modeling Supplemental Methods and Results*.

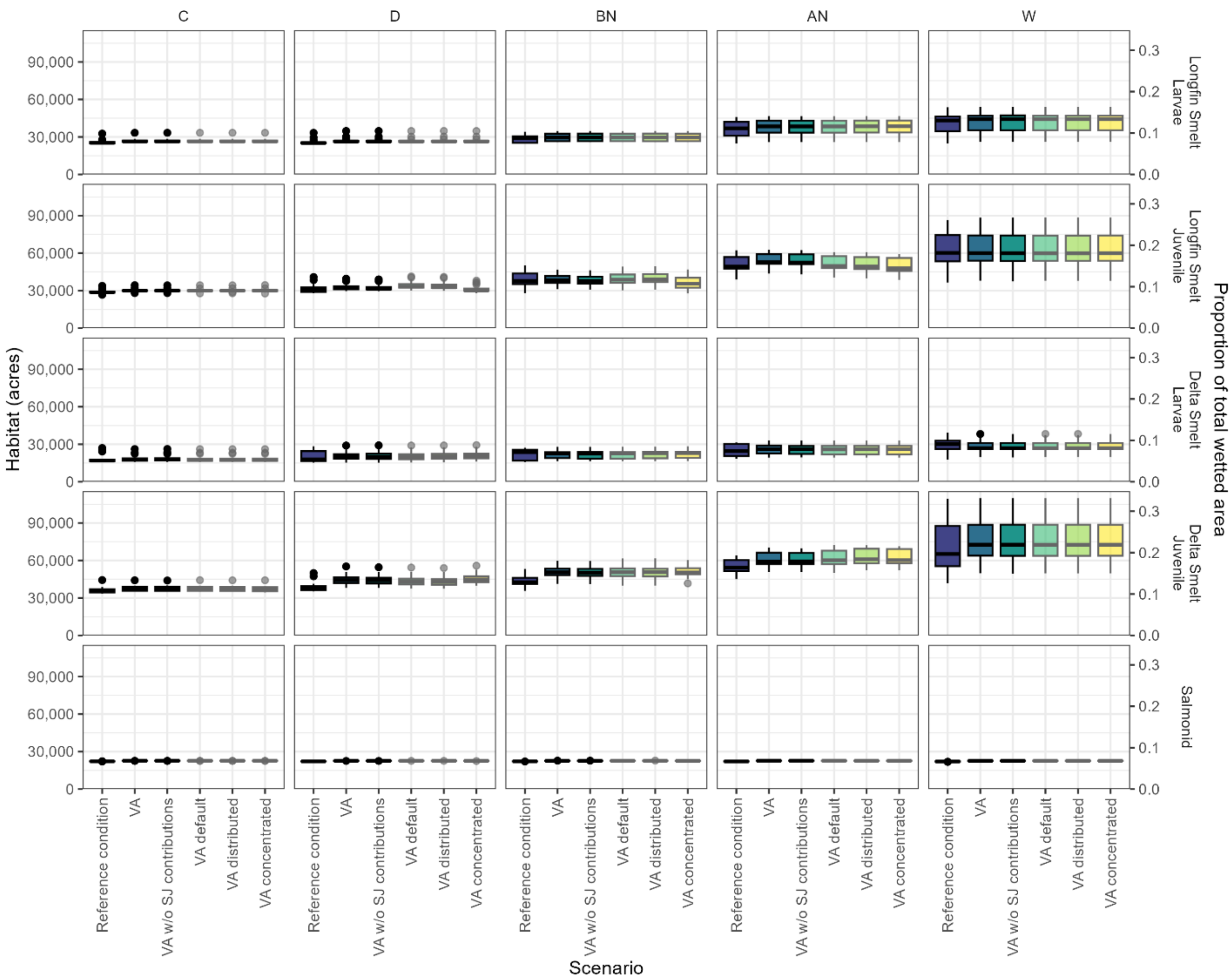

Figure 6-13. Total Suitable Estuarine Habitat Area Expected for Each Species, Scenario, and Water Year Type
Habitat area was first averaged within each water year across the designated months for each species and life stage (Section 5.3.5.3, Species) and is represented as the total acreage (left axis) and as the proportion of the total wetted area (right axis).

Table 6-5. Projected Increases in Habitat Area for Delta Smelt, Longfin Smelt, and Salmonids within Relevant Seasons for Each Species

Species and Life Stage	Season	Scenario	VA Change from Reference Condition (acres)	VA Change from Reference Condition (percent)
Longfin Smelt Larvae	Jan–Apr	VA	635–1,600	2–5
		VA w/o SJ	635–1,580	2–5
Longfin Smelt Juveniles	Mar–Aug	VA	-166–3,547	0–7
		VA w/o SJ	-241–3,238	0–7
Delta Smelt Larvae	Mar–Jun	VA	-3,184–2,260	-11–13
		VA w/o SJ	-3,204–1,993	-11–11
Delta Smelt Juveniles	Jul–Nov	VA	1,694–7,917	5–19
		VA w/o SJ	1,555–7,634	4–18
Salmonid Rearing	Oct–Jun	VA	475–578	2–3
		VA w/o SJ	476–581	2–3

Note: The VA w/o SJ contributions scenario excludes Friant and Tuolumne VA flows because the Friant VA is uncertain and the Tuolumne VA would be subject to State Water Board decision-making under a separate process. Results are provided as ranges across water year types. The VA Term Sheet proposes 5,227.5 acres of tidal wetland and floodplain habitat restoration, but only 4,074 acres were included in the modeling.
SJ = San Joaquin; w/o = without

Delta smelt juveniles had the greatest increases in habitat area from the reference condition to the VA scenario, from 5 to 19 percent (1,694–7,917 acres), followed by Delta smelt larvae with changes of -11 to 13 percent (-3,184–2,260 acres), longfin smelt juveniles with changes of 0 to 7 percent (-166–3,547 acres), longfin smelt larvae with changes of 2 to 5 percent (635–1,600 acres), and lastly salmonids with changes of 2 to 3 percent (475–578 acres). Benefits from the VA without San Joaquin scenario were similar to those of the VA scenario but often slightly lower (Table 6-5). All increases were small relative to the total wetted area of the Bay-Delta. The flow flexibility scenarios also produced similar results, although the concentrated scenario had the greatest divergences from the VA scenario, resulting in either more (e.g., Delta smelt juvenile) or less (e.g., longfin smelt juvenile) habitat area (Figure 6-13).

6.2.3 Benefits of Habitat Restoration

While there is a clear relationship between flow and abundance for many native fish species, other factors in addition to flow contribute to population viability. For example, the R-squared value for the relationship between juvenile salmon catch at Chipps Island and flow at Rio Vista provided in the 2017 Scientific Basis Report (pg. 3–44) is 0.44, meaning that 56 percent of the variability in salmon catch is explained by factors other than Rio Vista flow. Such non-flow factors could include other environmental variables such as temperature, biological variables such as food supply or the population level from the prior year, or the area of available suitable habitat. Habitat restoration may provide benefits related to some of the ecosystem stressors discussed in Chapter 2, *Aquatic Ecosystem Stressors*, as discussed further below.

Restoration of tidal wetlands within the Delta is hypothesized to increase ecosystem productivity and provide increased food supply. This hypothesis is based both on analyses of primary production from tidal wetlands in the Bay-Delta and on similar estuaries where large-scale restoration has resulted in significant improvement to fish populations. The Delta is currently composed mostly of deep, open-water habitats with low productivity due to lack of light penetration (Jassby et al. 2002; Dahm et al. 2016). The tidal wetlands that surround open-water areas may export resources and food into the open-water channels on the outgoing tide where they are available for pelagic species (Sherman et al. 2017), though evidence has not yet been found conclusively demonstrating net export (Yelton et al. 2022). Wetlands have high production of organic carbon produced by the large stands of emergent vegetation (in the Delta this is chiefly cattails [*Typha* spp.] and tules [*Schoenoplectus* spp.]). Carbon from vegetation forms the base of the foodweb in wetlands in the Delta (Howe and Simenstad 2011; Cohen et al. 2014; Schroeter et al. 2015; Young et al. 2021). While phytoplankton are also a critical part of the open-water foodweb (Sobczak et al. 2005), carbon from wetland plants was probably a much larger part of the open-water foodweb historically (Cloern et al. 2016).

The shallow water in wetlands also allows for greater phytoplankton production because light can penetrate to the bottom of the water column. This has been demonstrated both theoretically (Cloern 2007; Lucas et al. 2009) and empirically (Muller-Solger et al. 2002; Lopez et al. 2006; Lehman et al. 2015). Furthermore, water will remain within dead-end channels and wetland ponds longer than in river habitat, allowing for accumulation of greater phytoplankton biomass (Downing et al. 2016; Montgomery 2017). Longer water residence times can result in higher chlorophyll-*a* levels (Stumpner et al. 2020). For example, tidal slough in the North Delta adjacent to wetlands have relatively high levels of phytoplankton (Sommer et al. 2001b; Lehman et al. 2010; Frantzich et al. 2018).

The VAs propose restoration of 5,227 acres of tidal wetlands within the Delta and Suisun Marsh. This is about 1 percent of the historical extent of tidal wetlands in the Delta. Cloern et al. (2021) conducted a literature review to determine median values for productivity on tidal wetlands in the Delta from major groups of primary producers (Table 6-6). Given 5,227 acres of additional tidal wetland restoration in the Delta, and assuming restoration of agricultural land or other areas not hydrologically connected, this could result in additional algal production of 0.9 to 1.95 kilotons per year and additional vascular plant production of over 12 kilotons per year, or an increase in aquatic primary production of up to 15 percent over current levels of productivity (estimated at 74–84 kilotons per year according to Cloern et al. 2021).

Table 6-6. Potential Primary Production Rates in Freshwater Tidal Wetlands in the Delta as Derived by Cloern et al. (2021) and Scaled Up to the Potential Production from 5,227 Acres of Tidal Wetland Restoration Included in the VAs

Primary Producer group	Median and Interquartile Range (from Cloern et al. 2021)	Potential Production from VA Restoration Sites
Phytoplankton	44.9 (25.2–68.62) $g/m^2/yr$	0.950 (0.533–1.45) kt/yr
Epiphytic algae	44 (14–71) $g/m^2/yr$	0.931 (0.296–1.501) kt/yr
Marsh plants	576 (388–917) $g/m^2/yr$	12.184 (8.207–19.397) kt/yr

$g/m^2/yr$ = grams per square meter per year; kt/yr = kilotons per year

The high concentrations of organic carbon and phytoplankton in wetlands provide food for the zooplankton and other invertebrates that fish eat. Recent research has found higher zooplankton and invertebrate abundance in freshwater tidal wetland complexes than in other parts of the Delta (Montgomery 2017; Frantzich et al. 2018), particularly in the Cache Slough Complex (Kimmerer et al. 2018a). As with phytoplankton, small, dead-end channels and wetlands can also support higher biomass of zooplankton than larger channels or rivers (Frantzich et al. 2018; Corline et al. 2021). Wetlands also provide high biomass of epiphytic and epibenthic invertebrates, such as amphipods, isopods, and insect larvae, that are often more nutritious than zooplankton (Howe et al. 2014; Whitley and Bollens 2014; Hartman et al. 2019). Terrestrial arthropods are also more abundant in wetland habitats than in open water, which is particularly important for juvenile salmon rearing (David et al. 2016). Accessing these resources may be particularly important for native fishes, given recent declines in zooplankton biomass (Winder and Jassby 2011; Brown et al. 2016a).

Benefits of increased food supply directly translate to increased fish foraging efficiency, growth, and survival. Many native and nonnative fishes forage in tidal wetlands in the Bay-Delta, where they feed on epiphytic and epibenthic invertebrates as well as zooplankton (Colombano et al. 2021). Hammock et al. (2019) found an increase in stomach fullness in fish captured near areas of extended tidal wetlands, even when nearby zooplankton sampling indicated zooplankton biomass was low. The conclusion was that fish may be foraging in tidal wetlands and accessing resources not available to the channel-based zooplankton tows. Juvenile salmon growth rates in complex off-channel remnant floodplain habitats were higher when compared to main-channel habitats (Limm and Marchetti 2009; Sturrock et al. 2022). In sites restored in the Salmon River Estuary, Oregon, juvenile salmon foraged primarily on amphipods in older marshes and on chironomids in newer marshes, but all sites supported large numbers of juvenile salmon (Gray et al. 2002). Riparian and marsh vegetation was associated with higher feeding rates in juvenile salmon in the Fraser River Estuary (Levings et al. 1991; Levings and Nishimura 1997) and the Nisqually River Delta (Woo et al. 2019).

The 20,000 acres in the Sutter Bypass, Butte Sink, and Colusa basin that are to be managed for fish food production are also expected to help increase food availability. Salmon reared near outfalls from managed wetlands or rice fields also have higher growth and condition factors than those reared farther from sources of wetland production (Jeffres et al. 2020; Aha et al. 2021). These habitats with higher water residence times produce higher chlorophyll-*a*, zooplankton biomass, and ultimately higher salmon growth rates (Cordoleani et al. 2022). Zooplankton prey biomass is elevated in these habitats, which may be contributing to the increased growth rates (Corline et al. 2017; Aha et al. 2021). Zooplankton subsidies from floodplains can also benefit fish farther downstream (Sturrock et al. 2022).

Besides providing productivity, wetlands provide physical habitat for fish to feed and grow. Salmonids frequently use estuaries as habitat to feed and reside in along their migratory journey (Moore et al. 2016). Magnussen and Hilborn (2003) found that salmonids that rear in West Coast estuaries have higher survival than those that rear in other habitats, but overall survival of Pacific salmon is correlated to the percentage of the Bay-Delta that is in pristine condition. Therefore, increasing the area of habitat in the Delta that is appropriate for salmon rearing should increase the survival of juvenile salmonids in their emigration to the ocean (Herbold et al. 2018). It was estimated that approximately 23,475 acres of additional marsh habitat in the Bay-Delta would create well-distributed, suitable habitat for outmigrating salmon (SFEI 2020), so the VAs would contribute up to 2.5 percent of this amount (Table 6-5). In other systems, tidal marshes have been shown to increase juvenile salmon survival and provide important refuges to allow salmonid growth, maximizing their size at ocean entry (Chalifour et al. 2019; Davis et al. 2019b). In the Nisqually River Delta, restoration of previously diked wetlands had juvenile salmon using restored areas within a year of the project, showing that restoration sites can respond rapidly (Ellings et al. 2016). Estuaries can benefit and support different salmonid life histories, thereby increasing population resilience (Craig et al. 2014).

While the VA restoration commitment includes 5,227 acres of stationary habitat, this restoration must overlap with appropriate water quality conditions in order to provide fish habitat. Not all of this habitat will be appropriate for salmonid rearing. In the Delta and Suisun region, the modeled VA scenario increased salmonid winter–spring rearing habitat areas by 475 to 578 acres depending on water year type. While not all the tidal wetland restoration can be directly used for winter–spring rearing every year, wetland restoration may provide increased resiliency through a broadened portfolio of potential habitat that may be appropriate in different water year types. Furthermore, the habitat will provide increased primary productivity that may be transported to regions of the Bay-Delta with better habitat.

There are relatively few areas within the Delta that are close enough to large tidal marshes (i.e., greater than 500 hectares, a size associated with the presence of dendritic channel networks) to allow juvenile salmonids to reach them within 1 day of swimming (fry: 2 kilometers; smolts: 15 kilometers; SFEI 2020). Tidal habitat restoration under the VAs could therefore increase habitat connectivity for juvenile salmonids.

Water quality factors will also improve with habitat restoration. For example, temperatures in wetlands may be reduced at some times when compared to nearby channels due to cooling of water at night on the marsh plain during summertime spring tides (Enright et al. 2013). Restoration projects in regions that already have lower temperatures may increase their effectiveness at providing refugia in a changing climate (Mahardja et al. 2022). While none of the VA actions are designed specifically to address contaminant stressors, restoration of wetlands may help remove pesticides from the water (Budd et al. 2009) and conversion of managed wetlands to tidal wetlands may reduce mercury methylation (Lee and Manning 2020). Converting managed wetlands or agricultural fields to tidal wetlands may also reduce issues with low dissolved oxygen exported from the site (Stringfellow et al. 2008; Siegel et al. 2011). However, in other situations restoration may release contaminants from the sediment (Helfield and Diamond 1997; Miles and Ricca 2010). Therefore, the potential contaminant impacts and benefits are likely to be site specific.

6.2.4 Synergy between Flow and Non-flow Habitat

While both flow and non-flow habitat are important in and of themselves, optimal conditions for native species only occur when both flow and non-flow habitat function in conjunction with each other. In the Bay-Delta, the dynamic components of habitat (turbidity, salinity, etc.) are influenced heavily by freshwater flow, whereas the static components of habitat targeted by restoration projects are not (Feyrer et al. 2021). If restoration projects increase the amount of stationary habitat but flow conditions do not provide optimal dynamic habitat, the expected benefit of habitat restoration will not be realized. Similarly, if high flows provide optimal water quality but the area with optimal water quality occurs in a channelized, rip-rapped physical region of the Bay-Delta, the expected benefit of the dynamic habitat will not be realized.

This situation is demonstrated best by the concept of low-salinity-zone habitat for Delta smelt (Figure 6-14). As explained in the 2017 Scientific Basis Report, increased Delta outflow will move X2 farther downstream so that the low-salinity zone (the "dynamic habitat," specifically the area where salinity is 0.5 to 6 ppt) is centered in Suisun Bay. This area has more tidal wetlands, extended shallows, and hydrodynamic complexity (good stationary habitat) than upstream regions (Feyrer et al. 2011, 2021; IEP-MAST et al. 2015; FLOAT-MAST 2021). Delta smelt caught in this region have higher stomach fullness, better liver and gill indices, and better condition, which may be due to increased foraging opportunities provided by extensive tidal wetlands (Hammock et al. 2017, 2019, 2022).

The VA scenario changed longfin smelt habitat area by -166 to 3,547 acres, depending on life stage and water year type. The VA scenario similarly changed Delta smelt habitat by -3,184 to 7,917 acres, depending on life stage and water year type. This analysis shows that while stationary habitat restoration only provides an increase of 5,227.5 acres, flow and non-flow habitat restoration together can increase available Delta smelt habitat by over 7,000 acres (for juveniles in Below Normal and Wet water year types).

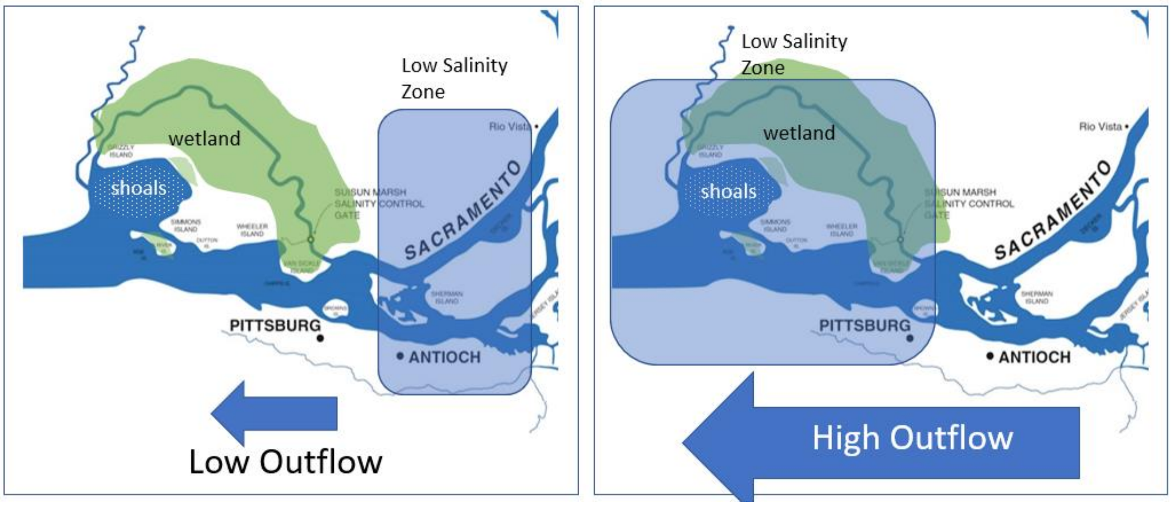

Figure 6-14. Conceptual Diagram of How Delta Smelt Preferred Dynamic Habitat Shifts Eastward with Decreased Outflows and Westward with Increased Outflows
At low outflow (left panel), the low-salinity zone is upstream in the narrow, rip-rapped channels of the Sacramento and San Joaquin Rivers where the total habitat size (quantity) is low and the stationary habitat quality is also low. At high outflows, the low-salinity zone overlaps with Suisun Marsh where there is better quality of stationary habitat (wetlands and shallow shoals with high turbidity and food supply shown conceptually) and larger quantities of appropriate dynamic habitat.

Similarly, the synergy of flow and non-flow habitat may explain the mechanisms behind some of the observed flow-abundance relationships. Longfin smelt have one of the strongest flow-abundance relationships of any fish in the Bay-Delta (Kimmerer 2002). One hypothesized mechanism is that higher flows allow spawning longfin smelt access to the productive, lower-temperature wetlands on the edge of Suisun Bay and San Pablo Bay by lowering salinity of these areas (as evidenced by longfin larvae found in wetlands in these areas; Grimaldo et al. 2017; Lewis et al. 2020). Large numbers of longfin smelt are found rearing in these regions during Wet years, but not during Dry years, suggesting that spawning in the region is flow dependent (Parker et al. 2017; Lewis et al. 2019). However, another analysis found that longfin smelt larval abundance east of Carquinez Strait was poorly related to outflow, indicating that rearing habitat, rather than spawning habitat, was behind the strong relationship between flow and abundance (Kimmerer and Gross 2022). Regardless, increases in Delta outflow will be more effective if more habitat is available, and restoration in the mesohaline regions of Suisun Bay and San Pablo Bay will increase the benefits of increases to flow.

Flow can increase connectivity between off-channel habitats for salmonids (Ellings et al. 2016; Perry et al. 2018) and between natal streams and rearing habitat lower in the system. Flows and habitat structure also influence optimal water quality conditions in the tributaries, including temperature, dissolved oxygen, and channel velocities that benefit spawning salmonids (Merz and Setka 2004; Merz et al. 2019) and survival of early life stages of Chinook salmon (Del Rio et al. 2019). River flows can interact with tides in the Delta to affect travel time and survival (Perry et al. 2018). This is discussed in more depth in Section 6.2.2, *Bay-Delta Habitat Analysis Results*, and Section 6.2.3, *Benefits of Habitat Restoration*.

6.3 Systemwide

High flows are critical for many of California's native species. However, flow may not be able to recover at-risk fish species when the frequency of floods and droughts increases with climate change. Reliance on one management tool, such as flow, is less likely to result in a desired outcome, given the level of uncertainty with future conditions. While flow actions rely on a certain amount of precipitation falling each year, many habitat restoration sites may be available to fishes in all water years. Providing higher springtime flows for the benefit of native fish species is more effective when paired with physical habitat restoration in order to achieve optimal system resiliency, as reviewed by Chilton et al. (2021) and suggested for the Bay-Delta by Robinson et al. (2016). With estuarine fish populations at all-time lows and resilience of many fishes to drought-managed flows decreasing over time (Mahardja et al. 2021), the system may no longer have the flexibility to recover from major ecological disturbances. Both habitat restoration and changes to flows have been proposed in the Delta Smelt Resiliency Strategy (California Natural Resources Agency 2016) and the Sacramento Valley Salmon Resiliency Strategy (California Natural Resources Agency 2017).

Improvements in multiple types of rearing habitat including natal rearing habitat, off-channel habitat in the tributaries, and estuarine habitat can increase population resiliency through a "portfolio effect," which may assist with population persistence even in low flow years (Robinson et al. 2016; Herbold et al. 2018; Woo et al. 2019). The portfolio effect is an ecological principle addressing how multiple life history strategies, habitat types, or species will increase a community's resiliency (Schindler et al. 2015). The construction of dams, water management, and the subsequent reliance on hatcheries for salmon in the Central Valley have weakened the portfolio effect in the population as a whole (Satterthwaite et al. 2015, 2017). Future strategies should bolster a greater diversity of life history strategies with diverse rearing habitats and unique spawning habitats in order to restore lost resilience (Yamane et al. 2018).

6.3.1 Limitations to Benefits During Multi-Year Droughts

An extended drought during the 8-year term of the VAs could significantly decrease the realized benefits. Restoration of stationary spawning, rearing, and wetland habitat throughout the system will be more effective when flows provide appropriate water quality and connectivity to allow fish to access the habitat. Flows included in the VAs will help provide this access, but the additional flows in the VAs will not be enough to make up for the difference between a Wet and a Dry year. The analyses of flow and habitat benefits analyzed in this report assume frequencies of Wet and Dry conditions will be similar to past conditions. If the 8-year term of the VAs is Dry, then the synergistic benefits of flow and non-flow habitat will not be realized.

Multiple successive Dry years will have larger impacts than a single Dry year. Mahardja et al. (2021) found that pelagic fishes tended to decline during multi-year droughts, and while they often recovered quickly, they did not always fully recover in Wet years following a drought. Longfin smelt have a particularly strong flow-abundance relationship, with large increases in population during high-outflow years and decreases during droughts (Kimmerer 2002; Nobriga and Rosenfield 2016), though single Dry years tend to be as detrimental as multi-year droughts (Nelson et al. in prep). American shad and young-of-the-year striped bass also have declines during Dry years (Nelson et al. in prep; Mahardja et al. 2021). Chinook salmon show marked declines during multi-year droughts; while a single Dry year does not noticeably affect their cohort replacement rate, 3 or more Dry years cause significant declines (Nelson et al. in prep). During droughts, juvenile outmigration survival is often low because low streamflows and higher temperatures result in higher rates of redd dewatering (Sellheim et al. 2020), reduced access to off-channel habitat (Sommer et al. 2001b), higher thermal stress (Marine and Cech 2004), and higher rates of predation (Nobriga et al. 2021). Littoral fishes are more resistant to drought. In particular, the invasive Mississippi silverside (*Menidia audens*) experienced a marked increase in abundance during previous droughts (Mahardja et al. 2016).

6.3.2 Limitations to Benefits with Climate Change

Climate change is increasing the intensity and duration of droughts, a trend predicted to continue in the future (Swain et al. 2018; Williams et al. 2020; DSC 2021). In addition to its drought effects, climate change affects native species directly as hotter, drier weather changes flow and temperature and indirectly through other mechanisms, such as increasing periods of warm, slow water that benefit invasive and nonnative predatory species and increase predation rates. See Chapter 2, *Aquatic Ecosystem Stressors*, and Chapter 4 of the 2017 Scientific Basis Report (State Water Board 2017) for discussion of these effects on species. Climate change may have impacts on the benefits of the proposed VAs, though discerning the magnitude of effects directly attributable to climate change over the initial VA 8-year term may be challenging. Below we briefly review how climate change has altered the Bay-Delta ecosystem and how future changes in temperature, precipitation, and sea level rise could affect the benefits of proposed VA assets for Chinook salmon and native estuarine species.

Since the 2017 Scientific Basis Report, we have learned that water temperature in the Delta has increased by an average of 0.017°C (0.03°F) per year over the past 50 years, with the greatest temperature increases occurring in the North Delta where much of the VA tidal wetland and floodplain habitat restoration would occur (Bashevkin et al. 2022). Outflow in the Delta has become more variable and has been accompanied by greater upstream salinity intrusion in the spring because of reduced inflow due to changes in precipitation and water management (Hutton et al. 2021). Salinity intrusion resulting from changes in outflow will likely be further exacerbated by sea level rise (Cloern et al. 2011; DSC 2021; Herbold et al. 2022). As a result of warmer air temperature, more precipitation is predicted to fall as rain during winter, shifting peak runoff to earlier in the year (reviewed in Chapter 4 of the 2017 Scientific Basis Report). These climate change impacts will degrade the flow assets and thus expected benefits of the VAs, especially considering that additional spring flows for the Delta and most tributaries are not proposed in the driest year types (Table ES-1, Table 4-1) when water temperature may increase the most substantially (Bashevkin et al. 2022; Bashevkin and Mahardja 2022).

These climatic changes may be especially detrimental for fishes relying on floodplain habitat for rearing or spawning. Floodplain inundation is expected to occur earlier in the wet season as the dominant form of precipitation shifts from snowmelt to rainfall (Cloern et al. 2011; Dettinger et al. 2016). Concurrently, the frequency and duration of flood events may decrease (Cloern et al. 2011; Herbold et al. 2022). A shift in the timing and duration of floodplain inundation could reduce floodplain restoration benefits by reducing food supplies. Important prey organisms like aquatic insects require several weeks of floodplain inundation to increase in abundance, and their densities may be reduced by shorter inundation periods (Sommer et al. 2004; Benigno and Sommer 2008). If high-flow events occur less often, this may further reduce prey export from floodplains, which is dependent on flow (Sturrock et al. 2022). Changes in inundation may reduce foraging opportunities for juvenile Chinook salmon if flooding occurs too early for them to access the floodplain or reduces floodplain subsidies to riverine habitats (Sturrock et al. 2022). Climate change may also result in a mismatch between the timing of floodplain inundation and life-history events for Sacramento splittail. Early inundation or short duration of inundation is harmful for splittail, which enter floodplain habitats during high flows and spawn in flooded vegetation (Moyle et al. 2004; Sommer et al. 1997, 2001c, 2014). Floodplains must be inundated for a minimum of 30 consecutive days for splittail to spawn, and it is likely that this requirement will be satisfied less often in the future (Sommer et al. 1997; Cloern et al. 2011).

Sea level rise may reduce the suitability and persistence of restored wetland habitat, and more flow will be necessary to offset salinity intrusion (Cloern et al. 2011; DSC 2021; Herbold et al. 2022). Movement of the salinity field upstream may stress native wetland plant species and fishes, altering community composition (DSC 2021). Tidal wetlands may be most affected by sea level rise, especially in the low-salinity zone and the interior Delta, where many tidal wetlands could be susceptible to drowning and habitat conversion by the year 2100 (Swanson et al. 2015; Dettinger et al. 2016; DSC 2021; Herbold et al. 2022). The degree to which tidal wetlands can resist drowning will depend on whether sediment accumulation is sufficient to outpace sea level rise and whether sites are connected to upland transition zones (DSC 2021; Herbold et al. 2022). Sediment transport has decreased by approximately one half since the mid-1900s (Jassby et al. 2002; Wright and Schoelhamer 2004), and a continued decrease in sediment supply could limit the ability of tidal wetlands to withstand sea level rise, although recent research predicts increased sediment supply with climate change (Stern et al. 2020). However, wetlands near upland transition zones may be able to migrate inland to outpace sea level rise given sufficient connectivity and space, and restoration planning should account for the effects of sea level rise when selecting and designing restoration locations (DSC 2021; Herbold et al. 2022).

Elevated water temperatures may also affect the benefits of VA habitat restoration for sustaining Chinook salmon and native estuarine species. Water temperature is projected to continue increasing by up to 3 to 5°C (5 to 9°F) on average in the Sacramento River by the end of the century (Wagner et al. 2011). Extreme temperature events will also occur with greater frequency (DSC 2021). For example, the number of days that the Delta exceeds stressful and lethal temperatures for Delta smelt will increase, maturation windows may decrease, and the spawning season will likely shift to earlier in the spring (Wagner et al. 2011; Brown et al. 2016). The North Delta may be especially susceptible to increasing water temperature (Bashevkin et al. 2022), although many monitoring sites throughout the Delta are already near the thermal critical temperature for Delta smelt during the summer and fall period (Appendix C, *Bay-Delta Habitat Modeling Supplemental Methods and Results*). The degree to which water temperature will exceed critical temperatures for survival of native estuarine species will depend on the trajectory of climate change and future management decisions (Cloern et al. 2011). Although temperature increases will be small in the next 8 years, potential future impacts should be accounted for during VA implementation to realize objectives. Notably, reservoir temperature and reservoir releases can affect temperature in the tributaries, although the extent of their causal effect on water temperatures in the upper estuary is unknown (Bashevkin et al. 2022). Therefore, at least in the tributaries, flows could be managed to help mitigate temperature increases from climate change.

Chapter 7
Conclusions and Uncertainties

Native aquatic species have been declining in the Sacramento River, its tributaries, off-stream habitats, and the Bay-Delta due to anthropogenic stressors. These stressors include inadequate flows, barriers to habitat connectivity, impaired water quality, direct entrainment, limited high-quality habitat, reduced food supply, invasive species, and climate change. The VAs propose a combination of flow and restoration assets to improve conditions for native species under the hypothesis that habitat restoration in combination with higher flows would provide enhanced benefits (Voluntary Agreements Parties 2022). As previously described, for the purposes of this Draft Supplement Report, the VA flow and non-flow habitat assets are analyzed consistent with the 2017 Scientific Basis Report regulatory reference condition (i.e., D-1641 and the 2008/2009 BiOps).

The expectation from the VAs is that the proposed combination of flow and non-flow restoration assets improve conditions for native species to: (1) achieve a new Narrative Viability Objective to "maintain water quality conditions, including flow conditions in and from tributaries and into the Delta, together with other measures in the watershed, sufficient to support and maintain the natural production of viable native fish populations"; and (2) provide the participating parties' share, during implementation of the VAs, to contribute to achieving the existing Narrative Salmon Protection Objective (doubled salmon population relative to the reference population of 1967 to 1991), which they propose doing by 2050 (Voluntary Agreements Parties 2022).

To evaluate the scientific support for the expectation of achieving the dual objectives, this report analyzed the contributions of the proposed flow and restoration assets toward habitat and population increases for salmonids and estuarine fishes. This was achieved through quantitative modeling coupling hydrodynamic and operations models to flow-dependent habitat and abundance models. A qualitative literature review was used where no quantitative models exist (e.g., linking habitat improvements to expected population-level outcomes).

The quantitative analyses indicate expected increases in suitable spawning and rearing habitat for salmonids and increases in suitable habitat and population abundance indices for estuarine species. Salmonid spawning (Figure 6-1, Figure 6-2, and Table 6-1 in Chapter 6, *Anticipated Biological and Environmental Outcomes*), rearing (Figure 6-3, Figure 6-4, Figure 6-10, Figure 6-11, Table 6-2, and Table 6-3 in Chapter 6), and floodplain (Figure 6-5 through Figure 6-9 in Chapter 6) habitats are expected to contribute toward the narrative objectives described above. However, the magnitude of increase varies with water year type and tributary such that not all habitat categories will have increases in all water year types. The VAs and reference condition are projected to surpass the spawning habitat needed to support 25 percent of the doubling goal (the target for the VAs) in all tributaries except the American River (Figure 6-1 in Chapter 6). The combination of instream rearing and floodplain habitat needed to support 25 percent of the doubling goal population is projected to be met in the Mokelumne, Sacramento (spring run), and Yuba Rivers for both the reference condition and VA, and in the Feather River in the VA scenario, but it is not projected to be met in any scenario in the American and Sacramento (for fall run) Rivers (Figure 6-10 in Chapter 6). Sacramento River rearing habitat would surpass the habitat needed to support 25 percent of the doubling goal population with the addition of 20,000 acres of floodplain enhancement on the Sutter Bypass, provided that juvenile fish passage issues are addressed. Under the VAs, floodplain habitat is expected to be provided to support 25 percent of the doubling goal population in 66 percent of years in the Feather River (Figure 6-5 in Chapter 6), 51 percent of years in the Mokelumne River (Figure 6-6 in Chapter 6), and 72 percent of years in the Yuba River (Figure 6-7 in Chapter 6).

Habitat areas for estuarine species are also expected to increase in the Bay-Delta (Figure 6-13 and Table 6-5 in Chapter 6, *Anticipated Biological and Environmental Outcomes*) contributing toward the Narrative Viability Objective proposed in the VAs. However, increases are small relative to total region size. Abundance indices based on increases in flows under the VAs of four species (California Bay shrimp, Sacramento splittail, longfin smelt, and starry flounder) are expected to increase in all water year types except Wet years (in which they are expected to decrease) (Figure 6-12 in Chapter 6). The frequency of achieving ecological flow thresholds would generally increase under the VAs, although in some cases there are slight decreases (Table 6-4 in Chapter 6). Qualitatively, the synergy of flow and non-flow habitat restoration assets proposed in the VAs is expected to improve conditions for salmonids and estuarine species toward achieving the proposed new Narrative Viability Objective and existing Narrative Salmon Protection Objective.

The potential benefits of the VAs described in this report for protecting fish and wildlife beneficial uses, including increased springtime flows and improvements to salmon and estuarine species habitat, may help improve TBUs as well. However, ensuring protection of tribal uses of water will require ongoing engagement with the tribes and incorporation of TEK into the VA adaptive management process.

While the modeling and qualitative analyses described above indicate expected benefits from the VAs, the actual outcomes of the VAs are not certain at this time. As with all modeling analyses, the results have uncertainty arising from assumptions and simplifications.

1. The VAs have some flexibility for when assets could be provided and the outcome could deviate from modeled results in this report if not provided on the proposed schedule or within the analyzed flow flexibility brackets.
2. Accounting methods have yet to be finalized for the VA flow and non-flow habitat assets. This Draft Supplement Report therefore makes assumptions for how those assets would be accounted for, based in part on their suitability, to quantify the resulting flow, acres of suitable habitat, and other benefits of the proposed VAs. The draft non-flow habitat accounting methods do not fully align with the assumptions in this report, since there is flexibility in those requirements that was not possible to model. Therefore, the amount of suitable habitat may differ from the values presented here. When the VA accounting procedures are finalized, and if they are changed to include additional specificity in the implementation of VA assets, they would provide additional certainty in how the assets would be provided and therefore in the benefits these assets would be expected to provide.
3. Analysis of habitat restoration benefits is based on the assumption that restored sites will replicate natural ecosystem functions and that restoration sites will be maintained over time such that species benefits do not diminish over time.
4. Specific locations for VA habitat restoration projects are not yet available, so the modeling relied upon possible locations selected with regional expert opinion. Different locations for these restoration projects could affect the actual outcomes.
5. While reference condition suitable spawning and rearing habitat area was determined with a quantitative method (weighted usable area; Section 5.1.3.1, *Existing Habitat Quantification*), based on needs of fall-run Chinook salmon, VA-proposed spawning and rearing habitat was all

assumed to be suitable from expert opinion and commitments from the VA Parties. If the habitat is not all suitable, that would reduce the VA habitat contributions.

6. The MFE method was designed conservatively so suitable habitat would be guaranteed. This likely underestimated the amount of floodplain habitat that would be available, assuming the restored habitat is accessible and suitable.
7. Floodplain habitat results presented in this report assume that habitat is accessible to juvenile fish; however, access to these flood basins is currently limited. If accessibility to flood basins is not improved, then the benefits of the proposed VAs for increasing floodplain habitat may be less than what is suggested by the analyses presented in this report.
8. Current and future hydrologic conditions will likely be more extreme than those of the modeling periods used, which were limited by computational demands. While the modeling periods did include past extreme events (e.g., the DSM2 modeling period of 1975–1991 included an extreme drought and Wet year), they may not be fully reflective of the current conditions (e.g., extended dry periods) and those expected in the future (e.g., climate whiplash [Swain et al. 2018]).
9. The quantitative connection between restored non-flow habitat and species abundance was not modeled, only evaluated qualitatively, so benefits are expected but unquantified with respect to species abundance. However, the flow-abundance relationship was quantified.
10. Analyses were focused on a few 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 all beneficial uses of water resources. For salmonids in particular, modeling was primarily conducted based on needs of fall-run Chinook salmon and spring run in the Sacramento River, but needs of other species and runs will vary.

The VAs, 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. As described in more detail in Chapter 1, *Introduction*, the VA governance, strategic planning, and science programs are under development and are proposed to work to address uncertainties described above with oversight by the State Water Board.

Chapter 8
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Appendix A
Sacramento Water Allocation Model Methods and Results for the Proposed Voluntary Agreements

Appendix A
Sacramento Water Allocation Model Methods and Results for the Proposed Voluntary Agreements

A.1 Introduction

This document describes the SacWAM model assumptions and methods used to simulate the proposed Voluntary Agreements (VA) proposed by parties in the Sacramento/Delta Watershed and results of the model simulations. The model assumptions were based on descriptions 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* (Voluntary Agreements Parties 2022; MOU; hereafter referred to as the VA Term Sheet) as submitted on March 29, 2022 and amended on August 11, 2022, and November 10, 2022, and the CalSim 3 draft model produced by the Department of Water Resources (DWR).

SacWAM is hydrologic and operations model developed by the State Water Board and consultants to facilitate the assessment of alternatives for the update of the Sacramento/Delta Update of the Water Quality Control Plan (Bay-Delta Plan). SacWAM includes a representation of all the major tributaries, reservoirs, and diversions in the Sacramento Watershed, Delta Eastside Tributaries and Legal Delta regions. For a full description, assumptions, and limitations of the SacWAM model, refer to the SacWAM Documentation (SWRCB 2023).

A.1.1 Appropriate Use of Model Results

Understanding the appropriate use of model results is important. The changes in hydrology and supply associated with the proposed VAs are relatively small compared with the volume of water in the system, and some details of the VAs such as which reservoirs may be reoperated, which fields will be fallowed, when reservoirs can refill, and when groundwater substitution will occur, have not been fully specified. Further, because it simulates hypothetical conditions, SacWAM is not intended to be used in a real-time predictive manner. SacWAM results are intended to be used in a comparative manner, which allows for assessing the changes in system operations and resulting incremental effects between scenarios. For these reasons, SacWAM results should not be taken as indicating the exact changes in water supply and changes in hydrology from implementation of the proposed VAs but rather should be used to indicate the general timing and trends that may occur with the proposed VAs.

Actual operations of the proposed VAs may vary from modeled outcomes presented in this section. For example, the proposed VAs include flexibility in the timing of flow assets, so streamflows and reservoir levels could deviate from modeled results. In addition, the VA Term Sheet describes flow assets that would be provided through a water purchase program, but the sources of water purchases described in the VA Term Sheet are not fully known at this time. Nonetheless, the model results are an appropriate tool for estimating the relative effects of the proposed VAs on water supply and hydrology.

A.2 SacWAM Proposed Voluntary Agreements Modeling Methods

The VA Term Sheet describes VA flow assets as being additive to flows required by D-1641 and resulting from the 2019 Biological Opinions (BiOps), referred to as 2019 BiOps conditions. The general approach to using SacWAM to model the effects of the proposed VAs on hydrology and water supply is first to simulate the 2019 BiOps conditions scenario, and then build the VA scenario from the 2019 BiOps conditions scenario. For the purpose of modeling the VA, the 2019 BiOps conditions scenario also includes a notch in the Tisdale Weir as proposed in the VAs. The Tisdale Weir notch is one component of the Tisdale Weir Rehabilitation and Fish Passage Project, which is intended to rehabilitate the weir to extend the design life and also provide passage for fish to the Sacramento River. (DWR 2023). The VA proposes to operate the Tisdale Weir notch to increase flows into the Sutter Bypass during December through mid-March. The reason that the Tisdale Weir notch is included in the 2019 BiOps conditions is because changing the flows into the Sutter Bypass from the Sacramento River results in substantial changes to flow in the Sacramento River downstream of Tisdale Weir that are separate from the flow assets proposed in Chapter 4, *Hydrology and Operations Modeling Methods and Results*, Table 4-1. SacWAM version 2023.06.12 was used for the model scenarios described in this Appendix.

A.2.1 General Assumptions

Table A-1 summarizes the major regulatory assumptions that vary among the scenarios used in the VA analysis presented in the main body of the final Draft Supplement Report. Further discussion of the modeling assumptions for each scenario is presented in Sections A.2.2 through A.2.4, below. All scenarios share a common assumption for the San Joaquin River inflow at Vernalis, which assumes D-1641 flow objectives with shoulder flows during the pulse period. The boundary condition was developed using a CalSim 3 simulation based on the *2021 Delivery Capability Report* (DCR) (DWR 2022) specified to include Decision 1641 (D-1641) Vernalis minimum monthly flows and salinity requirements. In the absence of Vernalis Adaptive Management Plan (VAMP) implementation of "pulse flows" in the period April 15–May 15, minimum monthly flows from the February 1–April 14 and May 16–June 30 periods were applied to the April 15–May 15 period, at the tier based on water year type and applicable footnotes. Additionally, reservoir flood-release spills, other instream flow requirements such as BiOp-required flows from the Stanislaus River, Federal Energy Regulatory Commission (FERC) Settlement Agreement flows from the Tuolumne River, FERC instream flows from the Merced River, and other local accretions combine to produce the total resulting flow at Vernalis. The DCR study includes San Joaquin River Restoration flows and recapture above Vernalis.

Table A-1. SacWAM Model Assumptions for Each Scenario

Regulation	Reference Condition	2019 BiOps Condition	VA
D-1641	WQ Objectives	WQ Objectives	WQ Objectives
	Min NDOI	Min NDOI	Min NDOI
	Export Limits (E:I)	Export Limits (E:I)	Export Limits (E:I)
	Export Limits (SJ I:E)	Export Limits (SJ I:E)	Export Limits (SJ I:E)
	DCC Closures	DCC Closures	DCC Closures
	SJ Vernalis Min Flow[1]	SJ Vernalis Min Flow[1]	SJ Vernalis Min Flow[1]
	Table 4 (Spring X2)	Table 4 (Spring X2)	Table 4 (Spring X2)
2008 / 2009 Biological Opinions	2006 American River FMS		
	OMR		
	Fall X2		
	HORB		
	San Joaquin I:E		
	Suisun Marsh Salinity Control Gate Ops (D-1641)		
2019 Biological Opinions		American River FMS	American River FMS
		OMR	OMR
		DCC Closures[2]	DCC Closures[2]
		Fall Action (Fall X2)	Fall Action (Fall X2)

[1] Vernalis shoulder flows are assumed to apply for entire pulse period.
[2] DCC may be closed as early as October pursuant to the 2019 BiOps.

A.2.2 Reference Condition Scenario

The Reference Condition scenario represents the operational conditions associated with the implementation of the federal Endangered Species Act BiOps issued by USFWS in 2008 and NMFS in 2009 for long-term CVP/SWP operations. This scenario includes all D-1641 requirements but does not include more recent changes in regulations included in the 2019 Biological Opinions or the 2020 Incidental Take Permit.

The Reference Condition scenario includes the 2006 American River Flow Management Standard (Water Forum 2006). Old and Middle River reverse flow limits are included as described in the 2008 and 2009 BiOps, which are slightly more restrictive than required in the 2019 BiOps and the 2020 ITP. The Reference Condition scenario also includes the Fall X2 and San Joaquin I:E ratio as described in the BiOps. The Head of Old River Barrier (HORB) installation was included in the Reference Condition scenario as well as Suisun Marsh Salinity Control Gate (SMSCG) operations to meet D-1641 water quality objectives.

A.2.3 2019 BiOps Scenario

The 2019 BiOps Scenario includes all D-1641 requirements, implements 2019 BiOps requirements for long-term CVP/SWP operations, does not include the 2020 ITP, and includes a change to Tisdale Weir operations.

A notch in Tisdale Weir is assumed to be operated from December 1 through March 15. With the notch closed, the weir is assumed to pass approximately 75% of Sacramento River flows over

18,000 cfs. When the notch is open, it is assumed to pass 54% of Sacramento River flows between 10,000 cfs and 18,000 cfs. Between 18,000 cfs and 23,760 cfs, the notch is assumed to pass 4,320 cfs of Sacramento River flows. The entire weir is assumed to be activated at flows over 23,760 cfs and can pass approximately 75% of flows. During March, the weir is assumed to behave according to a weighted average of 15 days with the notch open and 16 days closed.

A.2.4 VA Scenario

A.2.4.1 Sacramento River

SacWAM modeling of the Sacramento VA includes a change to the overtopping flow into the Sutter Bypass through the Tisdale Weir, additional streamflows at Knights Landing, and land fallowing in the Sacramento Valley.

In the VA scenario, Tisdale Weir operations are consistent with those described in Section A.2.3, *2019 BiOps Scenario*.

Flow contributions from the Sacramento River include additional flows in the spring and summer based on year type and end-of-March Shasta storage. The total additional streamflow is represented as an instream flow requirement at Knights Landing. The required flow is calculated as the flow that occurs at Knights Landing under 2019 BiOps Condition with the Tisdale Weir notch, plus the additional flow shown in Table A-2. Although the Sacramento River VA itself provides 100 TAF of water in each of Above Normal, Below Normal, and Dry water years, as modeled in SacWAM, the 10 TAF Sacramento Valley north of Delta PWA fixed price purchase is included within the model logic to implement the Sacramento River VA. As such, 110 TAF are assumed to be provided in each of these three water year types.

Table A-2. Sacramento River Additional VA Flows by Water Year Type

Water Year Type	Quantity (TAF)
Above Normal	110
Below Normal	110
Dry	110

In Dry years the additional flows occur when there is a reduction in diversions because of the land fallowing. The delivery pattern of fallowed land is assumed to follow a fixed pattern of 10 percent April, 15 percent May, 20 percent each June to August, 10 percent September, and 5 percent October. In Above Normal and Below Normal years, the 110 TAF is provided either in the Spring or the Summer based on the end-of-March Shasta storage shown in Table A-3.

Table A-3. Shasta Storage Trigger for Spring Deployment

Shasta End-of-March Reservoir Storage	Sacramento VA Pulse Flow
Equal to or Greater than 3.8 MAF	55 TAF in April and May
Less than 3.8 MAF	36.67 TAF in each month June-August

The source of additional flows is assumed to be from land fallowing by CVP Settlement Contractors and from releases from Keswick Reservoir. Land fallowing is implemented by reducing irrigated acreage of all settlement contractor demands by 6% in all Above Normal, Below Normal and Dry years.

A.2.4.2 Feather River

The SacWAM simulation of the VA scenario includes additional flows in the Feather River above the confluence with the Yuba River and fallowing of land in the Feather River Basin.

The increased flows proposed in the VA are represented by a new instream flow requirement above the confluence with the Yuba. The instream flow requirement is calculated as the 2019 BiOps Condition with Tisdale Weir notch plus the additional VA flow and is only active in April and May. The additional Feather VA flows are shown in Table A-4.

Table A-4. Feather River VA Additional Flows by Water Year Type

	April	May
Above Normal	30 TAF	30 TAF
Below Normal	30 TAF	30 TAF
Dry	30 TAF	30 TAF

Land fallowing in the Feather River Service Area is assumed to occur in all demands associated with SWP Settlement Contractors, by decreasing irrigated acreage by 6% in Above Normal, Below Normal, and Dry years.

A.2.4.3 American River

The SacWAM representation of the VA proposal on the American River includes increased streamflows and groundwater substitution of surface water.

The increased streamflows are represented as a new instream flow requirement below Nimbus Dam distributed by year type and month shown below. Increased flows on the American are assumed to be increases from the 2019 BiOps Condition scenario with the Tisdale Weir notch in place. The VA flow requirement shown in Table A-5 occurs only in the first three non-Wet years of every eight-year cycle.

To reduce the effects of rebalancing storage in Folsom and Shasta in the VA scenario, releases from Lake Natoma were required to be no less than releases from the 2019 BiOps Condition with the Tisdale Weir Notch scenario between the months of January through June of all years.

Table A-5. American River Additional VA flows by Month and Water Year Type

Water Year Type	March (TAF)	April (TAF)	May (TAF)
Above Normal	5	5	0
Below Normal	5	5	0
Dry	13.33	13.33	13.33
Critical	15	15	0

Groundwater substitution of surface water is represented in Dry and Critical years when the VA flow requirements apply by limiting the surface water available. Surface water diversions from the American River to the Roseville WTP, Peterson WTP, Folsom WTP, Bajamont WTP, Fairbairn WTP, Sacramento River WTP, Folsom South Canal and Freeport PP demands are reduced by 35 TAF in Dry and 30 TAF in Critical years in the aggregate during March, April and May.

A.2.4.4 Yuba River

The Yuba River VA proposal is represented in SacWAM by reducing the New Bullards Bar Reservoir buffer pool volume. The buffer pool represents the volume below which releases will not be made for lower priority demands such as hydropower operations. In the 2019 BiOps Condition scenario, the end of September buffer pool volume is 650 TAF. In the VA scenario, the end of September buffer pool in Dry, Below Normal, and Above Normal water year types is 595 TAF (Figure A-1).

In the VA scenario the buffer pool is the same as the Reference Condition and 2019 BiOps scenarios from November through March. Beginning in April the buffer pool is lower in VA, which results in greater releases from New Bullards Bar through Colgate Powerhouse.

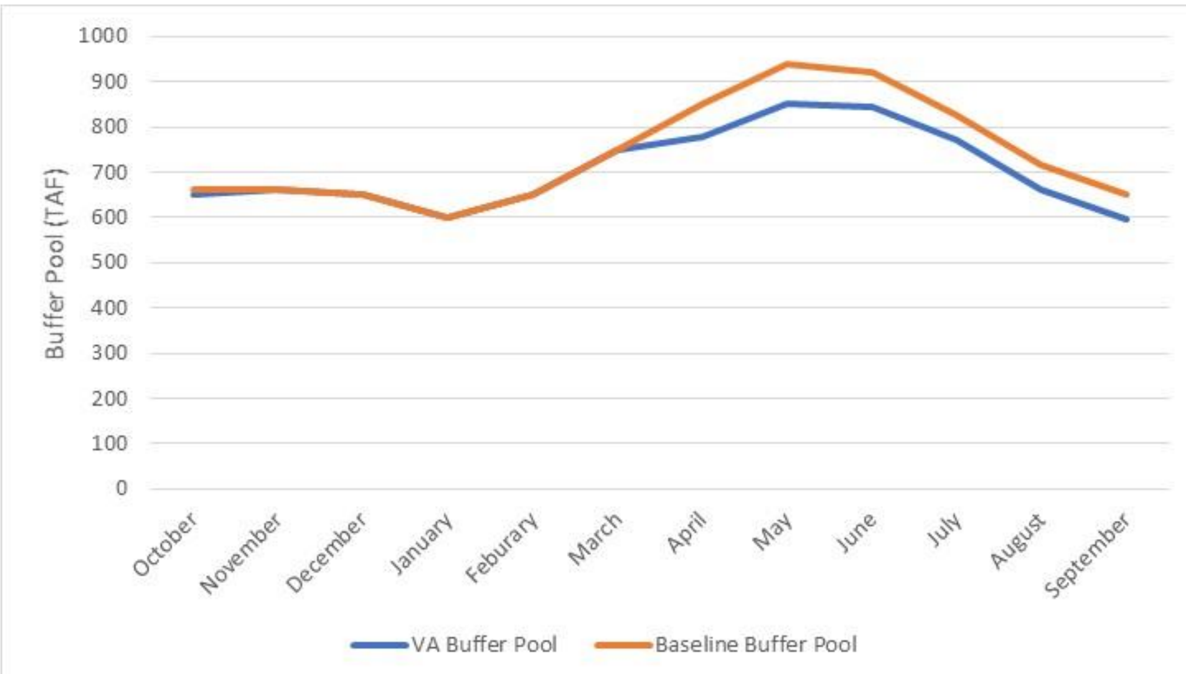

Figure A-1. New Bullards Bar Reservoir Buffer Storage Volume by Month

A.2.4.5 Putah Creek

The Putah Creek VA scenario includes additional flow at the bottom of Putah Creek above the Toe Drain. Additional VA flows occur in addition to Putah Creek Accord required flows in all water year types unless it is a drought year as defined by certain conditions when Lake Berryessa storage is below 750 TAF. The additional flows include a winter pulse, spring flushing flows, and ramping flows between the pulse and flushing flows. The additional flows on Putah Creek are shown in Table A-6.

Table A-6. Putah Creek Additional Flows by Month (TAF)

	November	December	January	February	March	April	May
Pulse Flow	1.67	0.83					
Ramping Flow		0.37	0.71	0.71	0.71		
Flushing Flow						0.5	0.5

A.2.4.6 Mokelumne River

The Mokelumne River VA scenario includes increased releases from Camanche Reservoir based on the April-September Mokelumne JSA water year type and includes a low storage off-ramp. In March, the model assumes perfect foresight of the April JSA water year type. In October, the VA flows are based on the preceding year's April-September JSA year type.

The total VA required release is calculated as the minimum JSA release plus the additional flows shown in . If the March projected combined end of September storage in Pardee and Camanche is less than 350 TAF, it is assumed that no additional VA flows will be provided.

Table A-7. Mokelumne River VA Additional Flow by Month and JSA Water Year Type (TAF)

	March	April	May	September	October
Dry	2.7	2.7	2.7	0.95	0.95
Below Normal	5.4	5.4	5.4	1.9	1.9
Normal and Above	12.15	12.15	12.15	4.275	4.275

A.2.4.7 Export Reduction

Constraints are added to reduce exports at Banks and Jones Pumping Plants from 2019 BiOps Condition pumping rates in March, April, and May. The reductions shown in Table A-8 are first applied in March during Below Normal, Dry, and Critical years, but total exports are not reduced below 3,000 cfs. If the volumes listed in the table are not achieved in March, the remaining volume is reduced in April with a minimum total export of 1,500 cfs. In Wet and Above Normal years, export cuts are made during April and May, with a minimum total export of 1,500 cfs in each month. To reduce the effects of system reoperation, total Banks and Jones exports are limited to no more than 2019 BiOps Condition exports during months in the January through June period when export cuts are not applied.

Table A-8. Assumed Reduction in SWP and CVP Exports from South of Delta in the VA Scenario (TAF)

	Export Reduction
Critical	3
Dry	179
Below Normal	200
Above Normal	265
Wet	27

A.2.4.8 Delta Outflow Requirement

Increases in Delta outflow required in the VA scenario are a combination of tributary contributions. The VA Delta outflow requirement is calculated as the 2019 BiOps Condition Delta outflow + additional VA flows from the Sacramento River + Feather River + Yuba River + American River. Note that VA additional flows from the Mokelumne River and Putah Creek are not included in the VA Delta outflow requirement. Delta outflow VA contributions are enforced through an instream flow requirement during months when VA export reductions are not in place.

A.2.4.9 Delta Outflow Postprocessing

A postprocessing exercise is used to account for the Delta outflow effects of water purchases and potential Friant and Tuolumne VA flow actions that are not modeled in the SacWAM VA scenario. Water purchases are assumed to be provided in the specified quantities by Sacramento water year type. Friant VA flows are included as the time series of forgone exports previously modeled by CalSim 3. Tuolumne River VA flows are represented as the change in flow at the mouth of the Tuolumne River as modeled by the State Water Board's Water Supply Effects model (WSE) for the lower San Joaquin tributaries and added to Delta outflows (see Attachment A1, *Water Supply Effects Model Updates for the Tuolumne Voluntary Agreement*). The water year type averaged values of each postprocessed component are shown in Table A-9 by Sacramento water year type (note that for the Friant and Tuolumne VAs these values differ from the San Joaquin water year type averaged values indicated shown in Chapter 4, *Hydrology and Operations Modeling Methods and Results*, Table 4-1).

Table A-9. Postprocessed VA Flow Actions (TAF) by Sacramento Water Year Type

Flow Action	Critical	Dry	Below Normal	Above Normal	Wet
PWA Market Price Purchases	0	50	60	83	0
Permanent State Water Purchases	65	108	9	52	123
Friant	8	23	19	13	5
Tuolumne	41	65	65	25	-13

In general, VA flow actions are intended to be concentrated during April and May, which are generally the most impaired months with respect to inflow to and outflow from the Delta. For the purposes of this report, water purchases are assumed to be provided in April and May, although they may also be deployed differently under the VAs. Modeled Delta outflow results including postprocessed purchases and with and without San Joaquin basin VA contributions from the Friant Division and Tuolumne River are shown on Figure A-2 and in Table A-10.

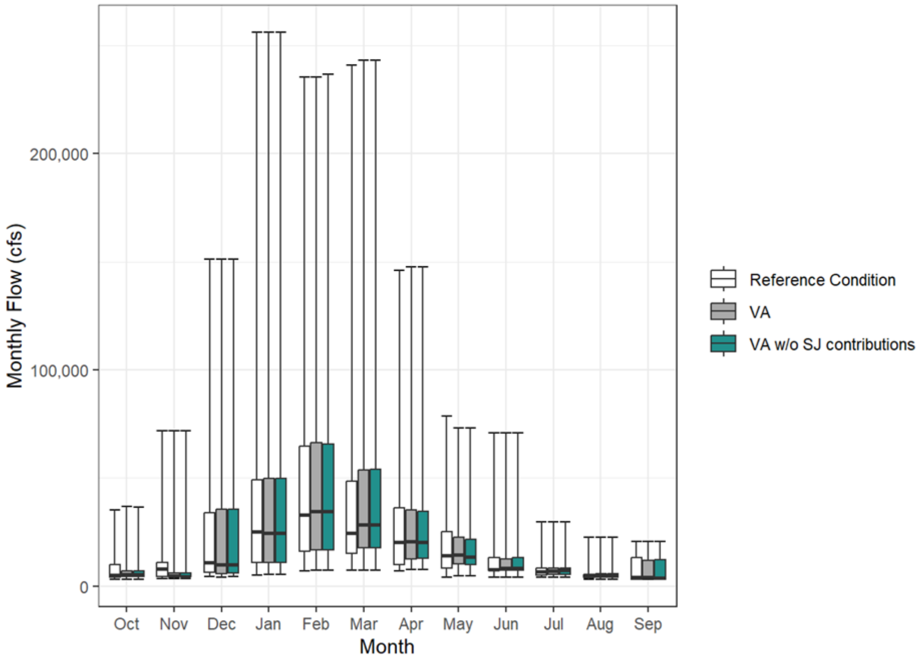

Figure A-2. Reference Condition and VA Modeled Flow Including Postprocessed Components (cfs), Delta Outflow

Table A-10. Water Year Type Averaged January–June Total Reference Condition Flow and VA Change from Reference Condition (TAF), Delta Outflow (Including Postprocessed Components)

Water Year Type	Reference Condition	VA	VA without San Joaquin Contributions
Critical	3,636	165	116
Dry	5,058	556	469
Below Normal	7,881	340	256
Above Normal	13,907	439	402
Wet	22,337	-330	-323
All	11,689	172	126

As described in Section 4.12.2, *VA Postprocessing*, two additional VA scenarios are included for evaluating January through June Delta outflows that provide a higher bookend of possible Delta outflows under the VAs. These additional scenarios are provided in recognition of the following: (1) additional VAs on the Merced River and Stanislaus River may be agreed upon in the future; (2) the VAs are intended to protect as Delta Outflows both VA flows and flows that may be provided by implementing the 2018 updated Lower San Joaquin River flow objectives; (3) different credible hydrology and operations modeling tools produce different estimates of the incremental effect on Delta outflow associated with changes in operations between the Reference condition and the 2019 BiOps condition.

Because the VA is modeled relative to the 2019 BiOps condition but compared to the Reference Condition, estimates of the change in Delta outflow resulting from the VA are sensitive to the modeled incremental effect of 2019 BiOps on Delta outflow. At the time of this writing, the only models available to assess Reference Condition and 2019 BiOps conditions are SacWAM version 2023.06.12, as documented in the Staff Report and the CalSim II model jointly developed by DWR and Reclamation. The CalSim II model scenarios relied upon for this analysis were produced for the 2019 incidental take permit application submitted to CDFW by DWR in December, 2019 and its supporting environmental documentation (DWR 2019a, 2019b). In Below Normal, Above Normal, Wet years, and over the long-term average SacWAM generally estimates a larger incremental reduction in Delta outflow during January through June associated with the 2019 BiOps (Table A-11) than CalSim II (Table A-12; Reference Condition and 2019 BiOps correspond to Existing Conditions and Proposed Project simulations, respectively, as described in DWR 2019a). In Critical and Dry years, SacWAM estimates a smaller magnitude increase or decrease in January through outflow associated with the 2019 BiOps than CalSim II. SacWAM also estimates a larger increase in South of Delta exports associated with the 2019 BiOps relative to CalSim II in all non-Critical water year types (Table A-13).

Table A-11. Water Year Type Averaged Incremental Change in January through June Delta Outflow (TAF), 2019 BiOps Relative to Reference Condition, as Modeled by SacWAM

Water Year Type	Reference Condition	2019 BiOps	2019 Change
Critical	3,636	3,671	35
Dry	5,058	5,026	-32
Below Normal	7,881	7,663	-218
Above Normal	13,907	13,658	-249
Wet	22,337	21,868	-469
All	11,689	11,474	-215

Table A-12. Water Year Type Averaged Incremental Change in January through June Delta Outflow (TAF), 2019 BiOps Relative to Reference Condition, as Modeled by CalSim II

Water Year Type	Reference Condition	2019 BiOps	2019 Change
Critical	3,344	3,272	-72
Dry	5,154	5,029	-126
Below Normal	7,526	7,476	-50
Above Normal	13,574	13,451	-123
Wet	22,666	22,405	-262
All	12,079	11,931	-148

Table A-13. Water Year Type Averaged Incremental Change in January through June South of Delta Exports (TAF), 2019 BiOps Relative to Reference Condition, as Modeled by SacWAM and CalSim II

Water Year Type	SacWAM	CalSim II
Critical	26	53
Dry	239	176
Below Normal	393	353
Above Normal	476	417
Wet	538	378
All	354	288

The differing responses to changed BiOp assumptions observed in SacWAM and CalSim II result from multiple differences between the models that are not fully understood at the time of this writing. In recognition of this uncertainty, a bias correction was calculated by subtracting the SacWAM incremental change in Delta outflow from the corresponding CalSim II change (Table A-14).

Table A-14. Delta Outflow Bias Correction (TAF), 2019 BiOps Relative to Reference Condition, as Modeled by SacWAM and CalSim II

Water Year Type	SacWAM Bias Correction
Critical	-107
Dry	-94
Below Normal	168
Above Normal	126
Wet	207

In addition to the uncertainty in the incremental effect of changes to Project operations associated with the 2019 BiOps, future flow conditions from the Stanislaus, Tuolumne, and Merced Rivers (lower San Joaquin River or LSJR tributaries) will be affected by water quality control planning and implementation activities outside the scope of the Sacramento/Delta effort. Potential activities include implementation of Bay-Delta Plan amendments adopted in 2018 requiring 40 percent of unimpaired flow, within a range of 30 to 50 percent of unimpaired flow, February through June from the Stanislaus, Tuolumne, and Merced Rivers and potential VA proposals, if approved. The potential flow contributions of the Merced and Stanislaus Rivers are considered in two bookends. For the lower bookend, The Merced and Stanislaus Rivers are assumed to provide the balance of San Joaquin River placeholder volumes identified in the VA Term Sheet less the Tuolumne VA flow contributions. For the higher bookend, the Merced and Stanislaus are assumed to provide 40 percent of unimpaired flow during February through June, as modeled by WSE (Attachment A1, *Water Supply Effects Model Updates for the Tuolumne Voluntary Agreement*). In each instance, the additional flow contributions from San Joaquin basin sources are summarized as the net change from existing conditions during January through June, averaged by to Sacramento water year type. For modeled time series, such as those from WSE, this is accomplished by simple averaging by water year type. For San Joaquin River placeholder flows, the averaging is accomplished by assuming that the placeholder flow is provided in each year by San Joaquin water year type, then averaged by Sacramento water year type. In both instances the CalSim II period of record of 1922-2003 (which is common to WSE) is used. The resulting values for each bookend are summarized in Table A-15.

Table A-15. Merced and Stanislaus Higher Bookend Flow Contributions (TAF) by Sacramento Water Year Type

Water Year Type	Merced & Stanislaus Placeholder	Merced & Stanislaus 40% UF
Critical	18	137
Dry	73	218
Below Normal	90	226
Above Normal	66	264
Wet	26	192

The bias correction in Table A-14 is combined with the potential contributions from the Merced and Stanislaus Rivers in Table A-15 to formulate two higher bookend scenarios for future January through June Delta outflow conditions under the VA, presented in Table A-16. Both scenarios include the Tuolumne River VA and Friant contributions, as well as other VA contributions, including unspecified water purchases. They are only available as January through June flows and not for the full SacWAM hydrology timeseries because the bias correction and San Joaquin flow adjustments were only applied to total January through June flows for each water year type.

Table A-16. Water Year Type Averaged January–June Total Reference Condition Flow and VA Change from Reference Condition (TAF) for Delta Outflow (Including Postprocessed Components) for Higher Bookends of Possible VA Flows

Water Year Type	Reference Condition	VA with Bias Correction and LSJR Placeholder	VA with Bias Correction and 40% UF Merced & Stanislaus
Critical	3,636	76	195
Dry	5,058	535	680
Below Normal	7,881	599	735
Above Normal	13,907	631	829
Wet	22,337	-96	70

A.2.4.10 Artificial Neural Network (ANN) Blinding

The ANN was “blinded” for the VA scenario to prevent VA flows to change the flow required to meet salinity objectives. The ANN inputs such as Sacramento River flows, South of Delta (SOD) exports and Delta outflows are affected by VA actions. VA flows are removed from these inputs to keep ANN salinity outflow requirement similar to 2019 BiOps scenario.

A.2.4.11 San Joaquin River Inflow at Vernalis

The San Joaquin River inflow at Vernalis for the VA scenario is identical to that assumed for the Reference Condition and 2019 BiOps scenarios. VA flow contributions from the San Joaquin River watershed are accounted for through postprocessing of SacWAM modeled results, as described in Section A.2.4.9, *Delta Outflow Postprocessing.*

A.3 References

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Attachment A1

Water Supply Effects Model Updates for the Tuolumne Voluntary Agreement

Attachment A1

Water Supply Effects Model Updates for the Tuolumne Voluntary Agreement

This document describes the State Water Resources Control Board's (State Water Board's) modeling efforts to represent proposed Voluntary Agreement (VA) provisions on the Tuolumne River. Staff performed the analysis using a revised version of the Water Supply Effects (WSE) spreadsheet model that was originally developed to evaluate potential changes in flow and water supplies in the San Joaquin basin associated with the 2018 update to the Bay-Delta Plan.[1] WSE was used to model the Tuolumne VA because it is already set up to analyze the impacts of new flow requirements on the Tuolumne River and it allows for the most direct method to compare the effects of the VA flow requirements with current flow requirements or with unimpaired flow (UF) requirements. The revised version of WSE, titled "WSE-VA_082123" (referred to in this document as WSE-VA), also includes some general updates and corrections that improve the model's representation of the LSJR and the current conditions. The sections below describe all the mathematical and operational changes applied since the release of the 2018 version of WSE to produce the latest WSE-VA version.

A1.1 General Updates

The changes described here represent those updates that directly affect the calculation of results, primarily for instream flow, but are not tied to any specific model alternative. Some of these changes may affect results of UF alternatives when compared with results in the SED. In addition, there were various organizational, text, and cosmetic updates in WSE-VA that do not affect results and are not described here. These changes were made primarily to improve the usability of the model or to remove redundant or unused information. This includes reorganizing the model control tabs and the addition of new tabs to organize input data. These updates are described in more detail on the "README" tab within the model spreadsheet.

A1.1.1 CALSIM II Model Data

As described in Appendix F.1 of the 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. The version of CALSIM II used to support WSE in the SED was based on a model run provided to the State Water Board by the United States Bureau of Reclamation (Reclamation) in response to comments on the draft 2012 SED release. For WSE-VA, it was desired to have a baseline more analogous to the existing conditions, in part, to reflect new modeling information and changes in operational parameters since the State Water Board adopted the SED. Therefore, the Department of Water Resources (DWR) provided a

[1] The 2018 Bay-Delta Plan established new flow objectives based on unimpaired flow for the Lower San Joaquin River (LSJR) and its three eastside tributaries, the Stanislaus, Tuolumne, and Merced Rivers. Documentation of the WSE model was released with the substitute environmental document (SED) for the 2018 Bay-Delta Plan in Appendix F.1.

more recent CALSIM II model run, titled "*CALSIM_011319_rev06_NoCC*", which was based on the version of CALSIM II used for the 2017 Delivery Capability Report (DWR 2017). Furthermore, this CALSIM II model run served as the starting point for DWR's own CALSIM II VA analysis and using the same base data would improve consistency in representing the San Joaquin basin between the two analyses.

With regards to the San Joaquin basin, the major differences between this newer version of CALSIM II and the CALSIM II version from the SED include the following.

- Land Use is modeled at 2030 level of development rather than 2020.
- New Melones Starting Storage (Sep 1922) is set to 1,700 TAF rather than 1,000 TAF.
- The Vernalis Adaptive Management Plan (VAMP) is turned off.
- The San Joaquin River Restoration Program (SJRRP) flows are turned on.
- It includes updated Tuolumne River Operations.

Table A1-1 lists the CALSIM II timeseries imported into WSE-VA from *CALSIM_011319_rev06_NoCC* and stored in the new "*CALSIM Data*" tab, along with a description of what they were in CALSIM II and how they are applied in WSE-VA. The CALSIM II data primarily represents boundary conditions for WSE-VA, such as inflows, or parameters that WSE-VA cannot directly calculate, including reservoir evaporation rates and agricultural consumptive use demands. Some of the CALSIM II timeseries in Table A1-1 are not used for specific calculations in WSE-VA, but are instead imported to characterize the CALSIM II water balance and for comparison with final WSE-VA results. Finally, a few of the timeseries are used only to represent parameters under *CALSIM* mode (see SED Appendix F.1 for more information about the modes in WSE).

Table A1-1. CALSIM II Timeseries Imported into WSE-VA

CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE-VA?
R564A	Return flow from local/riparian Merced diverters back to the Merced River	Local Inflow to the Merced River
R564B	Return flow from MeID to the Merced River	Component of MeID demand Local inflow to the Merced River
R620	Return flow from Stevinson ID to the San Joaquin River	Local Inflow to the San Joaquin River
R545A	Return flow from TID to the Tuolumne River	Component of TID demand Local inflow to the Tuolumne River
R545C	Return flow from MoID to the Tuolumne River	Component of MoID demand Local inflow to the Tuolumne River
R630J	Return flow from local/riparian Tuolumne diverters to the San Joaquin River	Local Inflow to the San Joaquin River
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
R630L	Return flow from TID to the San Joaquin River	Component of TID demand Local inflow to the San Joaquin River
R566	Return flow from TID to the Merced River	Component of TID demand Local inflow to the Merced River

CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE-VA?
R636A	Return flow from MoID to the San Joaquin River	Component of MoID demand Local inflow to the San Joaquin River
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
R636C	Return flow from MoID to the San Joaquin River	Component of MoID demand Local inflow to the San Joaquin River
R637A	Return flow from MoID to the San Joaquin River	Component of MoID demand Local inflow to the San Joaquin River
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
R528C	Return flow from MoID to the Stanislaus River	Component of MoID demand Local inflow to the Stanislaus River
R528A	Return flow from OID south to the Stanislaus River	Component of OID south demand Local inflow to the Stanislaus River
R528B	Return flow from SSJID/OID north to the Stanislaus River	Component of SSJID/OID north demand Local inflow to the Stanislaus River
R637C	Return flow from local/riparian Stanislaus diverters to the San Joaquin River	Local Inflow to the San Joaquin River
R534B	Return flow from OID south to non-district lands on the north side of the Tuolumne River	Component of OID south demand
R545B	Return flow from OID south to the Tuolumne River	Component of OID south demand Local inflow to the Tuolumne River
R532	Return flow from OID south to MoID	Component of OID south demand Component of MoID demand
R526	Return flow from SSJID to non-district lands east of SSJID	Component of SSJID/OID north demand
R630M	Return flow from local San Joaquin diverters back to the San Joaquin River	Local Inflow to the San Joaquin River
R630WEST	Return flow from the west side of the San Joaquin River	Local Inflow to the San Joaquin River
R637D	Return flow from local San Joaquin diverters back to the San Joaquin River	Local Inflow to the San Joaquin River
R639A	Return flow from local San Joaquin diverters back to the San Joaquin River	Local Inflow to the San Joaquin River
R639WEST	Return flow from the west side of the San Joaquin River	Local Inflow to the San Joaquin River
D561	MeID surface water diversion from the Merced River	Calibration of MeID diversions (*CALSIM* mode only)
D562	Local/Riparian surface water diversions from the Merced River	Cowell Agreement diversion (CAD) demand (*CALSIM* mode only)

CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE-VA?
D566	Stevinson ID, El Nido, riparian surface water diversions from the Merced River	Riparian diversion demand on the Merced River
D562A	Delivery to Local/Riparian Lands on the Merced River	Characterizing CALSIM II water delivery in the Merced River watershed
D574	Delivery to Stevinson ID, El Nido, and riparian lands	Characterizing CALSIM II water delivery in the Merced River watershed
D571	Delivery to MeID	Characterizing CALSIM II water delivery in the Merced River watershed
D572	Delivery to Merced National Wildlife Refuge from MeID	Characterizing CALSIM II water delivery in the Merced River watershed
D540A	MoID surface water diversions from the Tuolumne River	Calibration of TID and MoID diversions (*CALSIM* mode only)
D540B	TID surface water diversions from the Tuolumne River	Calibration of TID and MoID diversions (*CALSIM* mode only)
D545	Local/Riparian surface water diversions from the Tuolumne River	Riparian diversion demand on the Tuolumne River
D551	Delivery to Non-district lands south of the Tuolumne River	Characterizing CALSIM II water delivery in the Tuolumne River watershed
D549	Delivery to TID	Characterizing CALSIM II water delivery in the Tuolumne River watershed
D545A	Delivery to Local/Riparian Lands on the Tuolumne River	Characterizing CALSIM II water delivery in the Tuolumne River watershed
D79_SEEP	Turlock regulating reservoir groundwater seepage	Turlock reservoir seepage (*CALSIM* mode only)
D535	Delivery to Non-district lands north of the Tuolumne River	Characterizing CALSIM II water delivery in the Tuolumne River watershed
D533	Delivery to MoID	Characterizing CALSIM II water delivery in the Tuolumne River watershed
D78_SEEP	Modesto regulating reservoir groundwater seepage	Modesto reservoir seepage (*CALSIM* mode only)
D78A	Surface water delivery to Modesto M&I	Modesto M&I diversion demand (*CALSIM* mode only)
D520A	SEWD and CSJWCD surface water diversion from the Stanislaus River	Characterizing CALSIM II water delivery in the Stanislaus River watershed
D520A1	OID and SSJID water sales to SEWD	Characterizing CALSIM II water delivery in the Stanislaus River watershed

CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE-VA?
D520B	SSJID/OID north surface water diversion from the Stanislaus River	Calibration of OID and SSJID diversions (*CALSIM* mode only)
D520C	OID south surface water diversion from the Stanislaus River	Calibration of OID and SSJID diversions (*CALSIM* mode only)
D528	Local/Riparian surface water diversions from the Stanislaus River	Riparian diversion demand on the Stanislaus River
D528A	Delivery to Local/Riparian Lands on the Stanislaus River	Characterizing CALSIM II water delivery in the Stanislaus River watershed
D531	Delivery to OID south	Characterizing CALSIM II water delivery in the Stanislaus River watershed
D530_VAMP	Transfer of water from OID to MoID in exchange for MoID meeting OID's Vernalis Adaptive Management Plan (VAMP) requirement	Characterizing CALSIM II water delivery in the Stanislaus River watershed
D75_SEEP	Woodward regulating reservoir groundwater seepage	Woodward reservoir seepage (*CALSIM* mode only)
D523	Delivery to SSJID/OID north	Characterizing CALSIM II water delivery in the Stanislaus River watershed
D620C	Stevinson ID, El Nido, riparian surface water diversions from the San Joaquin River	San Joaquin River Baseline diversion
D620A	Non-district diversion from the San Joaquin River on the south side of the Tuolumne River	San Joaquin River Baseline diversion
D620B	Local surface water diversion from the San Joaquin River between the Merced and Tuolumne Rivers	San Joaquin River Baseline diversion
D630A	Non-district diversion from the San Joaquin River on the north side of the Tuolumne River	San Joaquin River Baseline diversion
D630B	Local surface water diversion from the San Joaquin River between the Tuolumne and Stanislaus Rivers	San Joaquin River Baseline diversion
D637	Local surface water diversion from the San Joaquin River downstream of the Stanislaus River	San Joaquin River Baseline diversion
D639	Non-Project surface water diversions near Vernalis	San Joaquin River Baseline diversion
S20	Lake McClure storage	Characterizing CALSIM II water storage on the Merced River
S81	New Don Pedro reservoir storage	Characterizing CALSIM II water storage on the Tuolumne River
S79	Turlock regulating reservoir storage	Characterizing CALSIM II water storage on the Tuolumne River
S78	Modesto regulating reservoir storage	Characterizing CALSIM II water storage on the Tuolumne River

CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE-VA?
S10	New Melones reservoir storage	Calculation of New Melones Index (*CALSIM* mode only)
S76	Tulloch reservoir storage	Tulloch reservoir storage
S75	Woodward regulating reservoir storage	Characterizing CALSIM II water storage on the Stanislaus River
E20	Lake McClure evaporation	Estimate of evaporative losses from Lake McClure to determine water available for diversion
E81	New Don Pedro reservoir evaporation	Estimate of evaporative losses from New Don Pedro to determine water available for diversion
E10	New Melones reservoir evaporation	Estimate of evaporative losses from New Melones to determine water available for diversion
E76	Tulloch reservoir evaporation	Evaporative loss from Tulloch
GP573	Stevinson ID, El Nido, riparian groundwater pumping	Characterizing CALSIM II groundwater use in the Merced River watershed
GP570	MeID groundwater pumping	Characterizing CALSIM II groundwater use in the Merced River watershed
GP550	Non-district groundwater pumping on the south side of the Tuolumne River	Characterizing CALSIM II groundwater use in the Tuolumne River watershed
GP548	TID groundwater pumping	Characterizing CALSIM II groundwater use in the Tuolumne River watershed
GP534	Non-district groundwater pumping on the north side of the Tuolumne River	Characterizing CALSIM II groundwater use in the Tuolumne River watershed
GP532	MoID groundwater pumping	Characterizing CALSIM II groundwater use in the Tuolumne River watershed
GP78A	Groundwater pumping for Modesto M&I	Characterizing CALSIM II groundwater use in the Tuolumne River watershed
GP530	OID south groundwater pumping	Characterizing CALSIM II groundwater use in the Stanislaus River watershed
GP522	SSJID/OID north groundwater pumping	Characterizing CALSIM II groundwater use in the Stanislaus River watershed
GP528A	Riparian groundwater pumping	Characterizing CALSIM II groundwater use in the Stanislaus River watershed
C20	Lake McClure release	Characterizing CALSIM II Flow on the Merced River
C561	Crocker Huffman release	Characterizing CALSIM II Flow on the Merced River
C562	Merced River Crocker Huffman to Snelling, after riparian diversions	Characterizing CALSIM II Flow on the Merced River
C564	Merced River from Snelling to Cressy	Characterizing CALSIM II Flow on the Merced River
C566	Merced River above the confluence with the San Joaquin River	Characterizing CALSIM II Flow on the Merced River

CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE-VA?
C81	New Don Pedro reservoir release	Characterizing CALSIM II Flow on the Tuolumne River
C540	Tuolumne River from La Grange to Modesto	Characterizing CALSIM II Flow on the Tuolumne River
C545	Tuolumne River above the confluence with the San Joaquin River	Characterizing CALSIM II Flow on the Tuolumne River
C10	New Melones reservoir release	Characterizing CALSIM II Flow on the Stanislaus River
C76	Tulloch reservoir release	Characterizing CALSIM II Flow on the Stanislaus River
C520	Stanislaus River from Goodwin to Ripon	Characterizing CALSIM II Flow on the Stanislaus River
C528	Stanislaus River above the confluence with the San Joaquin River	Characterizing CALSIM II Flow on the Stanislaus River
C614	San Joaquin River above Salt Slough	Boundary flow on the mainstem San Joaquin River
C619	Westside return flows to the San Joaquin River near the Merced River confluence	Local Inflow to the San Joaquin River
C620	San Joaquin River between the Merced and Tuolumne Rivers	Characterizing CALSIM II Flow on the San Joaquin River
C630	San Joaquin River between the Tuolumne River and Maze	Characterizing CALSIM II Flow on the San Joaquin River
C636	San Joaquin River between Maze and the Stanislaus River	Characterizing CALSIM II Flow on the San Joaquin River
C637	San Joaquin River between the Stanislaus River and Vernalis	Characterizing CALSIM II Flow on the San Joaquin River
C639	San Joaquin River below Vernalis	Characterizing CALSIM II Flow on the San Joaquin River
VERNWQFINAL	Vernalis Electrical Conductivity	Determining flow needed to meet D1641 salinity requirements
I20	Inflow to Lake McClure	Inflow to Lake McClure
I561	Merced River accretions between New Exchequer dam and Crocker Huffman	Local inflow to the Merced River
I562	Merced River accretions between Crocker Huffman and Cressy	Local inflow to the Merced River
I566	Merced River accretions between Cressy and Stevinson	Local inflow to the Merced River
I81	Inflow to New Don Pedro reservoir	Inflow to New Don Pedro reservoir
I545	Tuolumne River accretions between La Grange and Modesto	Local inflow to the Tuolumne River
I10	Inflow to New Melones reservoir	Inflow to New Melones reservoir
I76	Stanislaus River accretions between New Melones reservoir and Tulloch	Local inflow to the Stanislaus River

CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE-VA?
I520	Stanislaus River accretions between Tulloch and Goodwin	Local inflow to the Stanislaus River
I528	Stanislaus River accretions between Goodwin and Ripon	Local inflow to the Stanislaus River
I636	San Joaquin River accretions between the Tuolumne River and Maze	Local inflow to the San Joaquin River
I637	Stanislaus River accretions below Ripon	Local inflow to the San Joaquin River
CUAW_562A_PAG	CUAW demand for local/riparian diverters on the Merced River	Characterizing CALSIM II demands in the Merced River watershed
CUAW_571_ND	CUAW demand for non-district lands in MeID	Characterizing CALSIM II demands in the Merced River watershed
CUAW_571_PAG	CUAW demand for MeID	Component of MeID 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
DEMAND_D572	Bear Creek Refuge demand	Bear Creek Refuge demand
CUAW_545A_PAG	CUAW demand for local/riparian diverters on the Tuolumne River	Characterizing CALSIM II demands in the Tuolumne River watershed
CUAW_549_ND	CUAW demand for non-district lands in TID	Characterizing CALSIM II demands in the Tuolumne River watershed
CUAW_533_PAG	CUAW demand for MoID	Component of MoID 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
CUAW_549_PAG	CUAW demand for TID	Component of TID 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
CUAW_511_ND	CUAW demand for non-district lands in SEWD	Characterizing CALSIM II demands in the Stanislaus River watershed
CUAW_511_PAG	CUAW demand for SEWD	Characterizing CALSIM II demands in the Stanislaus River watershed
CUAW_512_PAG	CUAW demand for CSJWCD	Characterizing CALSIM II demands in the Stanislaus River watershed
DEMAND_D523_MI_A	Non-district M&I demand in SSJID	Characterizing CALSIM II demands in the Stanislaus River watershed
CUAW_528A_PAG	CUAW demand for local/riparian diverters on the Stanislaus River	Characterizing CALSIM II demands in the Stanislaus River watershed
CUAW_523OID_PAG	CUAW demand for OID north	Component of OID north demand
CUAW_523SSJ_PAG	CUAW demand for SSJID	Component of SSJID demand
CUAW_531_ND	CUAW demand for non-district lands in OID south	Component of OID south demand
CUAW_531_PAG	CUAW demand for OID south	Component of OID south demand
EVAP_S20	Lake McClure evaporation rate	Lake McClure evaporation rate
EVAP_S81	New Don Pedro evaporation rate	New Don Pedro evaporation rate

CALSIM II Timeseries	CALSIM II Description	What is it used for in WSE-VA?
S81LEVEL4	New Don Pedro CALSIM storage zone 4	New Don Pedro flood storage curve
EVAP_S10	New Melones evaporation rate	New Melones evaporation rate

Abbreviations:
MeID = Merced Irrigation District,
MoID = Modesto Irrigation District,
TID = Turlock 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
Notes: Shaded rows are extracted from CALSIM_011319_rev06_NoCC\common\DSS\2020D09ESV.dss. Non-shaded rows are extracted from CALSIM_011319_rev06_NoCC\CONV\DSS\2020D09EDV.dss.

A1.1.2 Merced River Representation

Two changes were made to the calculation of Merced River instream flow requirements to be more representative of current conditions. First, the Davis-Grunsky flow requirement, based on a 1967 agreement between DWR and Merced Irrigation District for recreation and fish enhancement flows (DWR 1967), was turned off to reflect that the agreement ended in 2017. Second, implementation of the Merced FERC requirement was updated to use its dry year flow schedule in Dry and Critically Dry years, as determined based on the San Joaquin River water year type (SJR WYT) index. See Table A1-2 for the Merced FERC flow requirements implemented in WSE-VA. Like in the SED, Merced flow requirements also include an additional fall fishery release of 12,500 acre-feet, about 203 cubic feet per second (cfs), in October.

Table A1-2. Minimum Monthly Flow Requirements on the Merced River

Calendar Month	Normal Year FERC Requirement (cfs)[1]	Dry Year FERC Requirement (cfs)[2]
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

Notes: Requirements based on FERC license 2179, Article 40 and 41
[1] Normal year schedule applied in years with a Wet, Above Normal, or Below Normal WYT based on the SJR WYT index.
[2] Dry year schedule applied in years with a Dry or Critically Dry WYT based on the SJR WYT index.

A1.1.3 Tuolumne River Representation

A reference error related to the New Don Pedro evaporation rates was found and corrected in WSE-VA. In the 2018 version of WSE, the monthly evaporation rate from CALSIM II was being applied one month later than it should have been (i.e., October 1921 evaporation rates was applied to determine November 2021 evaporation). Over the long term the effect of this error would have been minimized.

A1.1.4 Stanislaus River Representation

On the Stanislaus River, the baseline minimum instream flow requirements have been updated to reflect the 2019 biological opinion and the New Melones Stepped Release Plan (SRP) (Reclamation 2019). The SRP provides default daily hydrographs on the Stanislaus for each water year type, which are shown in Table A1-3 through Table A1-7. As WSE is a monthly model, the SRP flows are implemented based on the total monthly flows resulting from each default daily hydrograph. These requirements are similar to those set forth in Reclamation's 2009 biological opinion Table 2E, which defined the Baseline flow requirements on the Stanislaus in SED version of WSE. 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 Above Normal Years would release the same as Below Normal Years in Table 2E and Wet Years would release the same as Above Normal Years in Table 2E. The requirements in wetter years would be reduced from current operations to promote storage for potential future droughts and preserve cold water pool. Another difference is that WYTs in the New Melones SRP would be determined based on the SJR WYT index rather than the New Melones Index which was used for the Table 2E requirements.

Table A1-3. New Melones Stepped Release Plan Daily Hydrographs for Critically Dry Year Types

Day of Month	Target Daily Flow Hydrographs in Critically Dry Years (cfs)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	200	200	200	200	200	200	200	725	150	150	150	150
2	200	200	200	200	200	200	200	725	150	150	150	150
3	200	200	200	400	200	200	200	725	150	150	150	150
4	200	200	200	400	200	200	200	725	150	150	150	150
5	200	200	200	200	400	200	200	725	150	150	150	150
6	200	200	200	200	400	200	200	725	150	150	150	150
7	200	200	200	200	200	200	200	725	150	150	150	150
8	200	200	200	200	200	200	200	725	150	150	150	150
9	200	200	200	200	200	200	200	725	150	150	150	150
10	200	200	200	200	200	200	200	725	150	150	150	150
11	200	200	200	200	200	200	200	725	150	150	150	150
12	200	200	200	200	200	200	200	725	150	150	150	150
13	200	200	200	200	200	200	200	550	150	150	150	150
14	200	200	200	200	200	200	200	450	150	150	150	150
15	500	200	200	200	200	200	350	300	150	150	150	150
16	750	200	200	200	200	200	500	150	150	150	150	150
17	1,000	200	200	200	200	200	725	150	150	150	150	150
18	1,250	200	200	200	200	200	725	150	150	150	150	150
19	1,250	200	200	200	200	200	725	150	150	150	150	150
20	1,250	200	200	200	200	200	725	150	150	150	150	150
21	1,250	200	200	200	200	200	725	150	150	150	150	150
22	1250	200	200	200	200	200	725	150	150	150	150	150
23	1,250	200	200	200	200	200	725	150	150	150	150	150
24	1,250	200	200	200	200	200	725	150	150	150	150	150
25	1,250	200	200	200	200	200	725	150	150	150	150	150
26	1,000	200	200	200	200	200	725	150	150	150	150	150
27	750	200	200	200	200	200	725	150	150	150	150	150

Day of Month	Target Daily Flow Hydrographs in Critically Dry Years (cfs)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
28	500	200	200	200	200	200	725	150	150	150	150	150
29	200	200	200	200		200	725	150	150	150	150	150
30	200	200	200	200		200	725	150	150	150	150	150
31	200		200	200		200		150		150	150	
Monthly Flow (AF)	35,505	11,901	12,298	13,091	11,901	12,298	27,372	24,595	8,926	9,223	9,223	8,926

Table A1-4. New Melones Stepped Release Plan Daily Hydrographs for Dry Year Types

Day of Month	Target Daily Flow Hydrographs in Dry Years (cfs)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	200	200	200	200	200	200	200	1000	200	200	200	200
2	200	200	200	200	200	200	200	1000	200	200	200	200
3	200	200	200	400	200	200	200	1000	200	200	200	200
4	200	200	200	400	200	200	200	1000	200	200	200	200
5	200	200	200	400	400	200	200	1000	200	200	200	200
6	200	200	200	200	400	200	200	1000	200	200	200	200
7	200	200	200	200	400	200	200	1000	200	200	200	200
8	200	200	200	200	200	200	350	1000	200	200	200	200
9	200	200	200	200	200	200	500	1000	200	200	200	200
10	200	200	200	200	200	200	750	1000	200	200	200	200
11	200	200	200	200	200	200	1000	1000	200	200	200	200
12	200	200	200	200	200	200	1000	1000	200	200	200	200
13	200	200	200	200	200	200	1000	1000	200	200	200	200
14	200	200	200	200	200	200	1000	1000	200	200	200	200
15	500	200	200	200	200	200	1000	1000	200	200	200	200
16	750	200	200	200	200	200	1000	800	200	200	200	200
17	1,000	200	200	200	200	200	1000	600	200	200	200	200
18	1,250	200	200	200	200	200	1000	450	200	200	200	200
19	1,250	200	200	200	200	200	1000	300	200	200	200	200

Day of Month	Target Daily Flow Hydrographs in Dry Years (cfs)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
20	1,250	200	200	200	200	200	1000	200	200	200	200	200
21	1,500	200	200	200	200	200	1000	200	200	200	200	200
22	1500	200	200	200	200	200	1000	200	200	200	200	200
23	1,500	200	200	200	200	200	1000	200	200	200	200	200
24	1,250	200	200	200	200	200	1000	200	200	200	200	200
25	1,250	200	200	200	200	200	1000	200	200	200	200	200
26	1,250	200	200	200	200	200	1000	200	200	200	200	200
27	1000	200	200	200	200	200	1000	200	200	200	200	200
28	750	200	200	200	200	200	1000	200	200	200	200	200
29	500	200	200	200		200	1000	200	200	200	200	200
30	200	200	200	200		200	1000	200	200	200	200	200
31	200		200	200		200		200		200	200	
Monthly Flow (AF)	39,075	11,901	12,298	13,488	12,298	12,298	45,621	38,777	11,901	12,298	12,298	11,901

Table A1-5. New Melones Stepped Release Plan Daily Hydrographs for Below Normal Year Types

Day of Month	Target Daily Flow Hydrographs in Below Normal Years (cfs)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	250	200	200	200	200	200	400	1500	900	250	250	250
2	250	200	200	200	200	200	750	1500	600	250	250	250
3	250	200	200	400	200	200	1000	1500	600	250	250	250
4	250	200	200	400	200	200	1250	1500	600	250	250	250
5	250	200	200	400	400	200	1500	1500	600	250	250	250
6	250	200	200	400	400	200	1700	1500	600	250	250	250
7	250	200	200	200	400	200	2000	1500	450	250	250	250
8	250	200	200	200	400	200	2000	1500	450	250	250	250
9	250	200	200	200	200	200	2000	1500	450	250	250	250
10	250	200	200	200	200	200	1500	1500	450	250	250	250
11	250	200	200	200	200	200	1500	1500	300	250	250	250

Day of Month	Target Daily Flow Hydrographs in Below Normal Years (cfs)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
12	250	200	200	200	200	200	1500	1500	300	250	250	250
13	250	200	200	200	200	200	1500	1500	300	250	250	250
14	250	200	200	200	200	200	1500	1250	300	250	250	250
15	500	200	200	200	200	200	1500	1250	250	250	250	250
16	750	200	200	200	200	200	1500	1250	250	250	250	250
17	1,000	200	200	200	200	200	1500	1250	250	250	250	250
18	1,250	200	200	200	200	200	1500	1250	250	250	250	250
19	1,500	200	200	200	200	200	2000	1250	250	250	250	250
20	1,500	200	200	200	200	200	2000	1000	250	250	250	250
21	1,500	200	200	200	200	200	2000	1000	250	250	250	250
22	1500	200	200	200	200	200	2000	1000	250	250	250	250
23	1,500	200	200	200	200	200	1500	1000	250	250	250	250
24	1,500	200	200	200	200	200	1500	1000	250	250	250	250
25	1,500	200	200	200	200	200	1500	1000	250	250	250	250
26	1,500	200	200	200	200	200	1500	1000	250	250	250	250
27	1500	200	200	200	200	200	1500	900	250	250	250	250
28	1250	200	200	200	200	200	1500	900	250	250	250	250
29	1000	200	200	200		200	1500	900	250	250	250	250
30	750	200	200	200		200	1500	900	250	250	250	250
31	500		200	200		200		900		250	250	
Monthly Flow (AF)	47,604	11,901	12,298	13,885	12,694	12,298	91,439	76,365	21,620	15,372	15,372	14,876

Table A1-6. New Melones Stepped Release Plan Daily Hydrographs for Above Normal Year Types

Day of Month	Target Daily Flow Hydrographs in Above Normal Years (cfs)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	250	200	200	200	200	200	400	1500	900	250	250	250
2	250	200	200	200	200	200	750	1500	600	250	250	250
3	250	200	200	400	200	200	1000	1500	600	250	250	250
4	250	200	200	400	200	200	1250	1500	600	250	250	250
5	250	200	200	400	400	200	1500	1500	600	250	250	250
6	250	200	200	400	400	200	1700	1500	600	250	250	250
7	250	200	200	200	400	200	2000	1500	450	250	250	250
8	250	200	200	200	400	200	2000	1500	450	250	250	250
9	250	200	200	200	200	200	2000	1500	450	250	250	250
10	250	200	200	200	200	200	1500	1500	450	250	250	250
11	250	200	200	200	200	200	1500	1500	300	250	250	250
12	250	200	200	200	200	200	1500	1500	300	250	250	250
13	250	200	200	200	200	200	1500	1500	300	250	250	250
14	250	200	200	200	200	200	1500	1250	300	250	250	250
15	500	200	200	200	200	200	1500	1250	250	250	250	250
16	750	200	200	200	200	200	1500	1250	250	250	250	250
17	1,000	200	200	200	200	200	1500	1250	250	250	250	250
18	1,250	200	200	200	200	200	1500	1250	250	250	250	250
19	1,500	200	200	200	200	200	2000	1250	250	250	250	250
20	1,500	200	200	200	200	200	2000	1000	250	250	250	250
21	1,500	200	200	200	200	200	2000	1000	250	250	250	250
22	1500	200	200	200	200	200	2000	1000	250	250	250	250
23	1,500	200	200	200	200	200	1500	1000	250	250	250	250
24	1,500	200	200	200	200	200	1500	1000	250	250	250	250
25	1,500	200	200	200	200	200	1500	1000	250	250	250	250
26	1,500	200	200	200	200	200	1500	1000	250	250	250	250
27	1500	200	200	200	200	200	1500	900	250	250	250	250
28	1250	200	200	200	200	200	1500	900	250	250	250	250

Day of Month	Target Daily Flow Hydrographs in Above Normal Years (cfs)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
29	1000	200	200	200		200	1500	900	250	250	250	250
30	750	200	200	200		200	1500	900	250	250	250	250
31	500		200	200		200		900		250	250	
Monthly Flow (AF)	47,604	11,901	12,298	13,885	12,694	12,298	91,439	76,365	21,620	15,372	15,372	14,876

Table A1-7. New Melones Stepped Release Plan Daily Hydrographs for Wet Year Types

Day of Month	Target Daily Flow Hydrographs in Wet Years (cfs)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	300	200	200	200	200	200	3000	3000	1200	300	300	300
2	300	200	200	200	200	350	3000	3000	1200	300	300	300
3	300	200	200	400	200	700	3000	3000	1200	300	300	300
4	300	200	200	400	200	1200	3000	3000	1200	300	300	300
5	300	200	200	400	400	1800	2300	2300	1200	300	300	300
6	300	200	200	400	400	2300	1500	1500	1200	300	300	300
7	300	200	200	400	400	3000	1200	1500	1200	300	300	300
8	300	200	200	200	400	3000	800	1500	1200	300	300	300
9	300	200	200	200	400	3000	800	1500	1000	300	300	300
10	300	200	200	200	200	3000	800	1500	1000	300	300	300
11	300	200	200	200	200	3000	800	1500	1000	300	300	300
12	300	200	200	200	200	3000	800	1500	1000	300	300	300
13	300	200	200	200	200	1200	800	1500	1000	300	300	300
14	300	200	200	200	200	800	800	1500	1000	300	300	300
15	500	200	200	200	200	800	800	1200	1000	300	300	300
16	750	200	200	200	200	800	800	1200	1000	300	300	300
17	1,000	200	200	200	200	800	800	1200	1000	300	300	300
18	1,250	200	200	200	200	800	800	1200	1000	300	300	300
19	1,500	200	200	200	200	800	800	1200	1000	300	300	300
20	1,500	200	200	200	200	800	800	1200	1000	300	300	300

Day of Month	Target Daily Flow Hydrographs in Wet Years (cfs)											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
21	1,500	200	200	200	200	800	800	1200	1000	300	300	300
22	1500	200	200	200	200	800	800	1200	1000	300	300	300
23	1,500	200	200	200	200	800	800	1200	1000	300	300	300
24	1,500	200	200	200	200	800	800	1200	750	300	300	300
25	1,500	200	200	200	200	800	800	1200	750	300	300	300
26	1,500	200	200	200	200	800	800	1200	500	300	300	300
27	1500	200	200	200	200	1200	1500	1200	500	300	300	300
28	1250	200	200	200	200	1500	2300	1200	500	300	300	300
29	1000	200	200	200		2300	3000	1200	300	300	300	300
30	750	200	200	200		3000	3000	1200	300	300	300	300
31	500		200	200		3000		1200		300	300	
Monthly Flow (AF)	48,992	11,901	12,298	14,281	13,091	93,522	83,307	95,605	55,935	18,447	18,447	17,852

A1.1.5 San Joaquin River Representation

Implementation of February through June Decision 1641 (D-1641) flow requirements was modified to be consistent with CALSIM II implementation of D-1641. The CALSIM II representation only includes D-1641 base flows from February 1 to April 14 and May 16 to June 30 and does not include the D-1641 pulse flow from April 15 to May 15 because responsibility was never agreed on. Table A1-8 shows the D-1641 base flow requirement modeled in WSE-VA; the higher flow target would occur for days where X2[2] is west of Chipps Island. The number of days at the higher and lower base flow is determined in WSE-VA using 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 (see the "chs_days" column of CALSIM_011319_rev06_NoCC\CONV\Run\Lookup\x2days.table). As WSE is a monthly model the daily flow targets are averaged to produce a constant monthly base flow target. However, in April and May no requirement is applied during the pulse flow period (4/15 to 5/15), which results in only 14 days of base flow during April and 16 days of base flow during May. Therefore, the averaged D-1641 monthly base flow volume is multiplied by 14/30 in April and 16/31 in May to produce the final D-1641 base flow targets.

Table A1-8. D-1641 Base Flow Requirement by San Joaquin River Basin (60-20-20) Water Year Type

	Flow Requirements at Vernalis from Feb 1 - Apr 14 and May 16 - June 30	
SJR 60-20-20 Water Year Type	Target if X2 is East of Chipps Island (cfs)	Target if X2 is West of Chipps Island (cfs)
W	2,130	3,420
AN	2,130	3,420
BN	1,420	2,280
D	1,420	2,280
C	710	1,140

A1.2 Tuolumne River Voluntary Agreement Alternatives

The primary source for information on the Tuolumne VA flow requirements is Appendix A6 to the "Project Description for Proposed Voluntary Agreements" submitted by DWR and the California Department of Fish and Wildlife (CDFW) to the State Water Board on March 1st, 2019.[3] The Tuolumne VA flow requirements include updated base flows year-round, a fall flushing pulse, a floodplain inundation pulse in the early spring, and an outmigration pulse from mid-April through May. Both the floodplain and outmigration pulses also include dry year off ramps that are triggered in sequences of multiple Dry and Critically Dry years, as described below. Finally, an infiltration gallery (IG) diversion at about half river on the Tuolumne (RM 25.9) is included to protect water

[2] The X2 standard, introduced in the 1995 Bay-Delta Plan, refers to the position at which 2 parts per thousand (ppt) salinity occurs in the Delta estuary and is designed to improve shallow-water fish habitat in the spring of each year and can limit export pumping.

[3] The VA project description can be found here: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/bay_delta/complete_va_package03012019.pdf

supply by recapturing some of the base flows during the summer. Another source of information useful in providing background to the Tuolumne VA work is the Amended Final License Application (AFLA) for the Don Pedro Hydroelectric Project, submitted to the Federal Energy Regulatory Commission (FERC) (TID/MID 2017). The Tuolumne VA incorporates many of the measures proposed in the AFLA.

WSE modeling of the Tuolumne VA provisions was updated from what is described in the March 2019 project description based on discussions with the Tuolumne VA parties in 2020 and again in 2022 to reflect ongoing negotiations. These updates include modifications to the duration and volume for the floodplain inundation pulse and reductions in summer baseflows. A switch is included in the model (cell I2 of the "Tuol VA with pulses" tab) to control whether these updates are included on top of the March 2019 version of the VA. For the results in this report the Tuolumne VA model runs were set up to be consistent with discussions from 2022.

The latest version of the Tuolumne VA was 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).[4] The MOU presents a summary of the flow to be provided under the Tuolumne VA 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 Tuolumne VA as only applying from January through June, while the March 2019 VA project description presented flow requirements year-round. The WSE modeling in this report is based on the year-round flow schedules shown in the VA project description (with updates based on Tuolumne VA party discussions), but actual effects may be different if the Tuolumne VA is only adopted for January through June.

A1.2.1 VA Base Flow Requirements

Table A1-9 below presents the year-round Tuolumne VA base flows to be released at La Grange diversion dam, as determined by SJR WYT. This table is based on the preferred AFLA minimum flow schedule, modified by the VA to decrease the flow requirement from 350 cfs to 300 cfs in Below Normal, Above Normal, and Wet years during July 1 to October 15. Since the base flow requirements for April, May, and October are defined on a half month basis and WSE-VA uses a monthly timestep, average monthly flow targets are produced weighted by the number of days at each flow requirement. Over the month the average cfs target will result in the same total volume released as the original half month flow requirements.

[4] The MOU can be found here: https://resources.ca.gov/-/media/CNRA-Website/Files/NewsRoom/Voluntary-Agreement-Package-March-29-2022.pdf

Table A1-9. Base Flow Requirements at La Grange

Period	Days in Period	Base Flow Release Targets (cfs) 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[1]	30	200 (125)	200 (125)	200 (150)	200 (150)	200 (150)
July[1]	31	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
August[1]	31	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
September[1]	30	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
October 1 - 15[1]	15	300 (150)	300 (175)	300 (225)	300 (225)	300 (225)
October 1 – 31	16	200	225	275	275	275
November[2]	30	200	225	275	275	275
December[2]	31	200	225	275	275	275

[1] Values in Parentheses are from the AFLA, Exhibit E, Table 5.6-2 and represent the interim release requirement at La Grange to be provided until both infiltration galleries are operational.

A1.2.2 VA Pulse Flow Requirements and Dry Year Off Ramps

Table A1-10 and Table A1-11 describe the outmigration and floodplain pulse flows associated with the Tuolumne VA, including the duration, volume, and assumed modeling period in WSE. As with the base flows, the pulse flow requirements are dependent on WYT. The spring outmigration pulse is intended to encourage outmigration and increase survival of parr and smolt salmon during the spring and 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 2,750 cfs (when added on top of the base flow described above) for a continuous period of 9 to 20 days. The floodplain pulse generally has a decreasing pulse length as WYT gets drier. The VA project description also includes an additional 1000 cfs fall flushing pulse for 3 days (about 5950 AF), intended for maintenance to clean gravels of built-up algae, debris, and surface fines prior to the start of substantial spawning. The fall flushing pulse is only released in Wet (W), Above Normal (AN), and Below Normal (BN) water years. In WSE, the flushing pulse is applied in October on top of the base flows.

Both the outmigration and floodplain pulses also include dry year relief off ramps to conserve water supply during droughts. For the outmigration pulse, in any sequence of C years all but the 1st C year will have an offramp and in any sequence of D years all but the 1st D year will have an offramp. Furthermore, the sequence of off ramps is not reset unless a BN or wetter water year type occurs. For example, if there was a sequence of five WYTs of D-D-C-D-C, the second and third D and second 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, only the third C water year would have a reduced outmigration pulse flow volume. For the floodplain pulse, any sequence of years that begins with either a C or D year will trigger offramps in all successive C, D, and BN years, until the next AN or W year. For example, if there were a sequence of five WYTs of D-D-C-D-C, the second and third D and both C water years would have reduced floodplain pulse flow durations. If there were a sequence of six WYTs of C-D-BN-C-D-C, off ramps would be applied in all years except for the first C year. Table A1-10 shows the years that trigger off ramps in WSE-VA for both pulses based on actual historical water year type, assuming perfect foresight.

Based on discussions with the Tuolumne VA parties in 2022, 10,000 AF was added to the Floodplain Inundation pulse in Dry and Critical Years with off-ramps that was not included in the VA project description from March 2019. In those discussions it was assumed that this increase in pulse volume would be followed by a 10,000 AF reduction in summer baseflow releases. In WSE-VA this reduction is distributed evenly each month (2,500 AF/month) from July through October.

As the pulse periods do not match the monthly timestep of WSE-VA, the pulses are modeled as total volumes of water released in each month or months with no shaping. The intent of WSE-VA 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-VA, they represent the monthly average flow rate.

Table A1-10. Outmigration Pulse Flow Assumptions used in WSE

Water Year Type	Pulse Period Start Date[1]	Pulse Period End Date[1]	Pulse Length (Days)	Pulse Volume (AF)[2]
Wet	16-Apr	31-May	46	150,000
Above Normal	16-Apr	31-May	46	150,000
Below Normal	16-Apr	31-May	46	100,000
Dry	16-Apr	31-May	46	75,000
Critical	16-Apr	31-May	46	35,000
Dry Year Off-Ramp	16-Apr	31-May	46	45,000
Critical Year Off-Ramp	16-Apr	31-May	46	11,000

[1] Assumed pulse period based on when fall-run Chinook salmon are large parr or smolt-sized. In reality, adaptive management principles will be applied to optimize timing, duration, and flow rate.

[2] Pulse volumes in this table are in addition to the base flows.

Table A1-11. Floodplain Inundation Pulse Flow Assumptions used in WSE

Water Year Type	Pulse Period Start Date	Pulse Period End Date	Pulse Length (Days)	Pulse Volume (AF)[1]	Target Flow Rate (cfs)[2]
Wet	1-Mar	20-Mar	20	99,174	2,750
Above Normal	1-Mar	20-Mar	20	99,174	2,750
Below Normal	1-Mar	20-Mar	20	99,174	2,750
Dry	1-Mar	16-Mar	14	70,116	2,750
Critical	1-Mar	9-Mar	9	55,521	2,750
Below Normal Year Off-Ramp	1-Mar	14-Mar	14	69,421	2,750
Dry Year Off-Ramp[3]	1-Mar	2-Mar	2	10,000	NA
Critical Year Off-Ramp[3]	1-Mar	2-Mar	2	10,000	NA

[1] Pulse volumes are additive on top of the base flows.

[2] 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.

[3] The 10,000 AF pulse volume available in dry and critical years with off-ramps applied is not associated with reaching a flow rate of 2750 cfs. The 2-day pulse length is assumed so that it will average 5000 AF per day, which is similar to the other year types. However, since WSE has a monthly timestep all pulse durations of less than a month will produce the same results for total monthly flow.

Table A1-12. Dry Year Off Ramps for VA Pulse Flows based on Actual SJR WYT

		Is the Off Ramp Applied?				Is the Off Ramp Applied?	
Year	Actual SJR WYT	Floodplain Inundation Pulse	Outmigration Pulse	Year	Actual SJR WYT	Floodplain Inundation Pulse	Outmigration Pulse
1922	W	No	No	1963	AN	No	No
1923	AN	No	No	1964	D	No	No
1924	C	No	No	1965	W	No	No
1925	BN	Yes	No	1966	BN	No	No
1926	D	Yes	No	1967	W	No	No
1927	AN	No	No	1968	D	No	No
1928	BN	No	No	1969	W	No	No
1929	C	No	No	1970	AN	No	No
1930	C	Yes	Yes	1971	BN	No	No
1931	C	Yes	Yes	1972	D	No	No
1932	AN	No	No	1973	AN	No	No
1933	D	No	No	1974	W	No	No
1934	C	Yes	No	1975	W	No	No
1935	AN	No	No	1976	C	No	No
1936	AN	No	No	1977	C	Yes	Yes
1937	W	No	No	1978	W	No	No
1938	W	No	No	1979	AN	No	No
1939	D	No	No	1980	W	No	No

Year	Actual SJR WYT	Is the Off Ramp Applied? Floodplain Inundation Pulse	Is the Off Ramp Applied? Outmigration Pulse	Year	Actual SJR WYT	Is the Off Ramp Applied? Floodplain Inundation Pulse	Is the Off Ramp Applied? Outmigration Pulse
1940	AN	No	No	1981	D	No	No
1941	W	No	No	1982	W	No	No
1942	W	No	No	1983	W	No	No
1943	W	No	No	1984	AN	No	No
1944	BN	No	No	1985	D	No	No
1945	AN	No	No	1986	W	No	No
1946	AN	No	No	1987	C	No	No
1947	D	No	No	1988	C	Yes	Yes
1948	BN	Yes	No	1989	C	Yes	Yes
1949	BN	Yes	No	1990	C	Yes	Yes
1950	BN	Yes	No	1991	C	Yes	Yes
1951	AN	No	No	1992	C	Yes	Yes
1952	W	No	No	1993	W	No	No
1953	BN	No	No	1994	C	No	No
1954	BN	No	No	1995	W	No	No
1955	D	No	No	1996	W	No	No
1956	W	No	No	1997	W	No	No
1957	BN	No	No	1998	W	No	No
1958	W	No	No	1999	AN	No	No
1959	D	No	No	2000	AN	No	No
1960	C	Yes	No	2001	D	No	No
1961	C	Yes	Yes	2002	D	Yes	Yes
1962	BN	Yes	No	2003	BN	Yes	No

A1.2.3 VA Infiltration Gallery Diversions

During the period from June 1st through October 15th, Turlock Irrigation District and Modesto Irrigation District plan to operate two in-river infiltration galleries (IGs) at approximately RM 25.9.[5] The IGs would divert a portion of the base flows released upstream allowing the districts to reduce their diversion requirements at La Grange diversion dam. Until the IGs are fully operational the VA base flow release requirement at La Grange for June 1st through October 15th would be set to the interim flow values, which are shown above in Table A1-9 in parentheses. The VA project description from March 2019 includes the expected instream flow just downstream of the infiltration galleries, which is shown in Table A1-13 for the period when the IGs would be operational. These flows do not indicate a flow requirement and assume that there are no other losses between the La Grange release and the IG diversions. As part of the VA, the expected downstream flow was modified from its proposal in the AFLA to increase the flow from 75 cfs to 125 cfs in Critically Dry and Dry years during June 1st to October 15th, effectively reducing the expected infiltration gallery diversion during those periods. The difference between Table A1-13 and Table

[5] For reference, La Grange diversion dam is located at about RM 52.2.

A1-9 represents the expected infiltration gallery diversion modeled in WSE-VA, which is shown in Table A1-14. For the results presented in this report, the IGs are turned off and the interim base flow releases are applied since the IGs are not currently operational and it is not clear when they will be.

Table A1-13. Potential Flow downstream of the Infiltration Galleries at RM 25.9 during the Period of IG Operation

		Potential Flow Downstream of Infiltration Galleries (cfs)				
Period	Days in Period	Critically Dry	Dry	Below Normal	Above Normal	Wet
June[1]	30	125 (125)	125 (125)	100 (150)	100 (150)	100 (150)
July[1]	31	125 (150)	125 (175)	150 (225)	150 (225)	150 (225)
August[1]	31	125 (150)	125 (175)	150 (225)	150 (225)	150 (225)
September[1]	30	125 (150)	125 (175)	150 (225)	150 (225)	150 (225)
October 1 – 15[1]	15	125 (150)	125 (175)	150 (225)	150 (225)	150 (225)
October 1 – 31	16	200	225	275	275	275

[1] Values in Parentheses are from the AFLA, Exhibit E, Table 5.6-2 and represent the interim release requirement at La Grange to be provided until both infiltration galleries are operational.

Table A1-14. Assumed Infiltration Gallery Diversion used in WSE

		Infiltration Galleries Diversions (cfs)				
Period	Days in Period	Critically Dry	Dry	Below Normal	Above Normal	Wet
June	30	75	75	100	100	100
July	31	175	175	150	150	150
August	31	175	175	150	150	150
September	30	175	175	150	150	150
October 1 - 15[1]	15	175	175	150	150	150
October 1 - 31[1]	16	0	0	0	0	0

Notes:

[1] For use in the WSE model with its monthly timestep, the October values are averaged based on the number of days in each period. For Critically Dry and Dry years the average October IG diversion is about 85 cfs and for Below Normal, Above Normal, and Wet years it is about 73 cfs.

A1.2.4 Representation of New Don Pedro Operations under the Tuolumne VA

The Tuolumne VA project definition does not contain reservoir operating rules or information on how New Don Pedro operations may change. In discussions with the Tuolumne River VA parties, they indicated that the reservoir carryover guideline should be set to reflect minimum dead pool storage levels. However, historical evidence shows that reservoir operators and water districts generally operate to meet multiple objectives of maximizing water delivery to meet demands, saving some water in reservoirs, and providing minimum allocations when water supply is low. A dead pool carryover guideline would not simulate the process of meeting these multiple objectives and as a result low storage conditions could occur much more often than they are observed in the historical record. Because a dead pool carryover guideline does not reflect actual past practices, it may not be a reasonable representation of how the VA would be implemented. Therefore, two Tuolumne VA alternatives with different reservoir operating parameters are included in WSE-VA. The first alternative is called "CC_VA_NCS" and is characterized by reservoir operations parameters that maximize the use of the reservoir without letting it fall below a minimum operating pool of 309 TAF. The second alternative, referred to as "CC_VA", includes reservoir operations the same as in the 2018 SED. Table A1-15 presents the reservoir parameters for New Don Pedro under both Tuolumne VA alternatives. The results presented in this report were produced using the CC_VA alternative.

Table A1-15. Reservoir Operating Parameters for Tuolumne VA alternatives

	Tuolumne VA Alternatives	
Reservoir Parameters	CC_VA_NCS	CC_VA
Minimum Annual District Diversion (%)	0%	50%
Carryover Storage Target (TAF)	375	800
Maximum Storage Drawdown (%)	100%	65%

A1.3 Other Pre-Defined Model Alternatives

For WSE-VA, the "Current Conditions" Baseline alternative serves as the basis for the comparative assessment of the Tuolumne VA effects. This baseline is intended to reflect the existing or current condition on top of which the VA will be implemented. In the SED, the WSE Baseline alternative represented the existing water regulatory and infrastructure conditions for around when the project (the Bay-Delta Plan Update) began, which was 2009. Apart from the differences described in the General Updates section above, the only other difference from the SED between the Baseline alternatives is that the Vernalis Adaptive Management Plan (VAMP) pulse flow requirement in April and May, established by the San Joaquin River Agreement (Reclamation and SJRGA 1999), was turned off in WSE-VA to reflect that the Agreement expired in 2011.

In addition, WSE-VA still includes all the UF scenarios available in the SED version of the model with flow requirements ranging from 20% to 60% UF, in increments of 5%, on each of the Eastside tributaries. The only difference in implementation of the UF alternatives compared to the SED are those changes listed in the General Updates section above.

A1.4 References Cited

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Appendix B
Water Temperature Modeling for the Sacramento, Feather, and American Rivers

Appendix B
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B.1 HEC-5Q History of Model Development and Application

B.1.1 HEC-5Q Model Development

HEC-5Q was developed to add water quality calculations to the HEC-5 hydraulic model. The original HEC-5 model was created by Bill S. Eichert at the Hydrologic Engineering Center in 1973 and was originally used to model reservoir system operation for a single flood event. The capabilities of the HEC-5 program were expanded to model historical or synthetic hydrology to determine conservation storage requirements, emergency releases, and flood control storage throughout a reservoir system. It is also used for modeling reservoir releases for hydropower generation and meeting downstream flow or water supply objectives (USACE 1998).

In 1979 water temperature calculations were added to HEC-5 to create HEC-5Q, allowing for temperature simulation in a single reservoir and the downstream river channel. Between 1979 and 1997, multiple improvements were made to HEC-5Q including adding multiple conservative and non-conservative water quality constituents; capacity to simulate many reservoirs, river branches, and control points; ability to increase reservoir releases to meet downstream water quality objectives; and selective withdrawal from reservoirs with multiple outlet ports to meet reservoir release water quality targets. While streams are modeled longitudinal in one dimension in HEC-5Q, reservoirs can be modeled in layers and/or longitudinally.

B.1.2 Early Application of HEC-5Q to the Sacramento River System

HEC-5Q has been used to simulate water temperature in the Sacramento River system for decades. Several documents provide descriptions of milestones in the model development process.

U.S. Army Corps of Engineers (USACE) 1986: The Sacramento River system was one of the first systems modeled by HEC-5Q as one of several demonstration applications. This first version of the Sacramento model included the Sacramento River starting at Shasta Reservoir, Feather River starting at Oroville Reservoir, and American River starting at Folsom Reservoir. The HEC-5 model had been developed initially by USACE to simulate Shasta, Oroville, and Folsom operation from a basin-wide perspective. The inflow from the Trinity River and export to the Thermalito complex were represented as a source and a sink, respectively. Water temperature was only one of several water quality parameters modeled. The model was compared to data measured prior to 1980 and produced reasonable results for Sacramento River temperatures between Shasta Reservoir and Hamilton City. Data limitations precluded evaluation of performance for the American and Feather River portions of the model. (USACE 1986).

At the time this model was created, data limitations (STORET data seldom included more than 10 measurements per year) generally precluded rigorous calibration. In contrast, all subsequent model applications for this system utilized detailed vertical lake profiles and sub-daily temperature time series data. Much of the HEC-5Q input data for this model were hypothetical, and essentially all of the inputs were replaced during subsequent projects. Additionally, this was one of the last applications to use a 24-hour time step that severely limited model performance.

Resource Management Associates, Inc. (RMA) 2003: Further refinements for modeling the Trinity River and upper Sacramento River are described in RMA 2003. This effort focused on Shasta Reservoir down to Knights Landing, and Trinity River and Stony Creek inputs to the Sacramento River. There was considerable effort made to accurately simulate water temperatures released through the Shasta Temperature Control Device (TCD) that was completed in 1997; modeling included addition of an algorithm to release target temperature for combined discharges based on TCD gate operations, flood control, and leakage flows. The model was calibrated with measured data from 1998–2002 and validated with data from 1990–1997 (RMA 2003). California Irrigation Management Information (CIMIS) hourly weather data, primarily from the Gerber station, were processed to provide meteorological inputs compatible with 6-hour computational time steps (RMA 2003). Stream cross-section inputs were developed from hydrodynamic model (RMA2) simulation results (RMA 2003). The meteorological input processing procedures and stream cross sections have remained the same since this project.

A primary goal of the upper Sacramento River modeling work was to use CalSim results for 1921–2002 hydrologic conditions to simulate potential future changes in operation or infrastructure such as raising Shasta Dam or adding North of Delta Offstream Storage (e.g., Sites Reservoir) (RMA 2003). The 2003 document describes some techniques employed to extend the modeling beyond the calibration/validation period to simulate water temperature for the full set of CalSim output (e.g., RMA 2003).

RMA and Watercourse Engineering 2013: During this model development project, the Feather and American Rivers were added to the Sacramento Basin model (referred to as the Sacramento River Water Quality Model) along with the Sutter Bypass. The Feather River model included Lake Oroville and the three Thermalito complex reservoirs. The American River model included Folsom Lake and Lake Natoma. The selective withdrawal capability of the Oroville Dam power intake and the Folsom Dam TCD were simulated by reservoir specific coding. To combine all river components, the Sacramento River was extended from Knights Landing to Freeport and the Sutter Bypass was added. River cross sections were based on available HEC-RAS models. Meteorological data for the Feather and American Rivers were based primarily on the Nicolaus CIMIS data. The Feather and American River components were calibrated to measured water temperature data through 2011. (RMA and Watercourse Engineering 2013).

U.S. Bureau of Reclamation (Reclamation) 2015: HEC-5Q went through an update for the 2015 Coordinated Long-Term Operation of the Central Valley Project and State Water Project (Reclamation 2015). This version utilized components of the 2013 model without the Feather River or the Sacramento River downstream of Knights Landing. There were four main tasks, which included organizing all prior work to create a base version of the model, adjusting the Trinity-Sacramento and American River models to better match measured data, improving mapping between CALSIM II and HEC-5Q input flows, and refining reservoir-release withdrawal logic and/or temperature targets at Trinity, Shasta, and Folsom Dams (Reclamation 2015).

2015–2020: Between 2015 and 2020, additional model adjustments occurred as a result of calibration runs performed for work with Jacobs and preparation for a training session sponsored by the Water Boards in 2017 (Smith 2017). This work included extension of the meteorology and hydrology for the Sacramento and American River systems through 2017 and evaluation of model performance.

B.2 Model Performance

This section presents the performance of the versions of the models used for evaluation of the Sacramento/Delta Update to the Bay-Delta Plan. It first describes the model adjustments and inputs leading up to the current performance evaluation and then presents the results of the evaluation.

B.2.1 Model Adjustments Prior to Performance Evaluation

The performance of the HEC-5Q models of the Sacramento, Feather, and American Rivers has been evaluated periodically during the course of model development by comparing simulated temperatures to measured temperatures. To improve model performance, various adjustments have been made to the model. Some typical adjustments include scaling of meteorological data to individual reservoirs and stream reaches, adjustments to vertical dispersion coefficients in reservoirs, and adjustments to seasonal variations in inflow temperatures and their relationships to meteorology.

In preparation for water temperature modeling for the Sacramento/Delta Update to the Bay-Delta Plan, further adjustments were made to the HEC-5Q model of the Feather and American Rivers. These most recent adjustments include refinements to the Oroville power bypass algorithm and reservoir release temperature targets, which are discussed below in Section A.2.2, *Model Inputs for Performance Evaluation*. Current model input procedures and the function of the Trinity, Folsom, and Oroville Dam withdrawal algorithms are summarized in Smith 2022. The withdrawal algorithm for Shasta Dam is described in RMA 2003.

B.2.2 Model Inputs for Performance Evaluation

B.2.2.1 Hydrology for Performance Evaluation

The channel geometry/flow relationships have not changed since the original model development. The channel data were based on hydrodynamic model output (RMA2 and HEC-RAS) and field observations. The RMA2 hydrodynamic model was the basis for the Sacramento River geometry. The Clear Creek and Trinity River geometry was based on field investigation and aerial photograph reconnaissance, and the Feather and American River geometry was developed from detailed HEC-RAS cross sections.

The reservoir geometry has remained the same other than minor changes to the reservoir outlet specifications. In general, inflows, accretions, and depletions are based on direct measurement, main stem river gage differences, and reservoir inflows by mass balance.

B.2.2.2 Meteorology for Performance Evaluation

Hourly air temperature, relative humidity, solar radiation, and wind speed affect water temperature (Edinger et al. 1974). Data for these meteorological parameters are processed to develop the HEC-5Q model inputs. Meteorological inputs starting in 1985 were based on hourly data from the Gerber CIMIS station to represent the northern Sacramento Valley and the Nicolaus CIMIS station to represent the Feather and American River systems. However, CIMIS stations have changed over time and, as a result, stations used to provide model inputs vary with the year being simulated. The modeling uses data from two CIMIS station locations at Gerber (due to station relocation), Nicolaus, Shasta College (to provide a better representation of temperatures near Lake Shasta), and Verona and Fair Oaks (to replace the Nicolaus station when it was discontinued). Furthermore, if CIMIS data are missing for one station, data from nearby stations are used, including values from the Durham and Colusa stations (RMA and Watercourse Engineering 2013). To avoid effects on model performance for years simulated with older CIMIS station data, the values used for the meteorological record for each of the models are established using a weighted average approach for all the stations that heavily weights data from the original stations, resulting in little change in the older values. The CIMIS data are used to calculate 6-hour water temperature equilibrium temperatures and exchange rates for input to the HEC-5Q models.

B.2.2.3 Boundary Temperatures for Performance Evaluation

Inflow temperatures for Oroville and Folsom Reservoirs were estimated with a combination of a yearly repeating seasonal pattern and equilibrium temperatures based on meteorological data. When inflow is high, inflow temperatures tend to follow a seasonal pattern that often reflects snowmelt conditions. When inflow is low, temperature is more affected by heat exchange based on the difference between the seasonal temperature and equilibrium temperature, where the equilibrium temperature is calculated with a site-specific adjustment to the equilibrium value calculated with the CIMIS meteorological data for the watershed. To mimic this mixture of seasonal and meteorological effects, estimated inflow temperatures were influenced more by the seasonal pattern at high flows and more influenced by meteorological driven equilibrium temperatures at lower flows, with intermediate values at intermediate flows. Because more data are available for inflow temperatures for Lake Shasta, its inflow temperatures were calculated as a flow-weighted average of observed temperatures and flows. Temperature of accretions (including small streams) are set to match stream temperatures, so have no effect on simulated temperatures.

The Feather and American River model domain includes the Sacramento River between the Feather River and Freeport (downstream of the American River). To simulate temperatures for this section of the Sacramento River, the Feather and American River model requires input for Sacramento River temperatures upstream of the Feather River near Knights Landing. At this location far downstream of Lake Shasta, water temperatures approach equilibrium values and are therefore largely controlled by meteorological conditions. For the model performance evaluation, these inflow temperatures were set equal to the Knights Landing temperature results from the Sacramento River HEC-5Q model of baseline conditions, which has results extending through September 2015. Use of the modeled baseline temperatures for Knights Landing provides a more complete record than measured values. After September 2015, the Sacramento River inflow temperatures for the Feather and American River model were based on measured temperatures.

B.2.2.4 Reservoir Release Target Temperatures for Performance Evaluation

The water temperature models mimic selective withdrawal from the various elevations within the reservoirs that are available based on infrastructure. The models are able to blend water from available elevations to release water with temperatures close to specified target temperatures. As long as sufficiently cold (or warm) water is accessible in the reservoir, the target temperatures can be met approximately.

For the purpose of evaluating model performance and for modeling the Sacramento Water Allocation Model (SacWAM) scenarios, temperature targets were based on algorithms. These algorithms represent an approximation of current operations. Model performance below the reservoirs is better if the target temperatures are based on measured temperatures, but model performance presented here uses the same temperature target approach used for the modeling of the SacWAM scenarios. As such, the model accuracy represents the uncertainty in the SacWAM scenario results that could result from discrepancies between actual target temperatures and those derived from the algorithms. Actual target temperatures may differ from the target temperatures estimated by the algorithms described here for multiple reasons. For example, protocols have changed through time, real-time targets for Folsom and Shasta are developed through more detailed modeling informed by current conditions, and Oroville releases are managed through real-time adjustments in releases if downstream temperature objectives are not met. The algorithms described here are used for planning purposes in order to simulate temperatures through a full set of planning model results (SacWAM results in this case).

Algorithm for Shasta Dam Target Temperatures

Shasta Dam target temperatures were set by using a four-tier algorithm based on end-of-May storage in Lake Shasta. The lower tiers are associated with lower end-of-May storage and higher temperature targets starting as early as May 10 (Figure B-1). This methodology has been used by Reclamation for past planning studies using CalSim results.

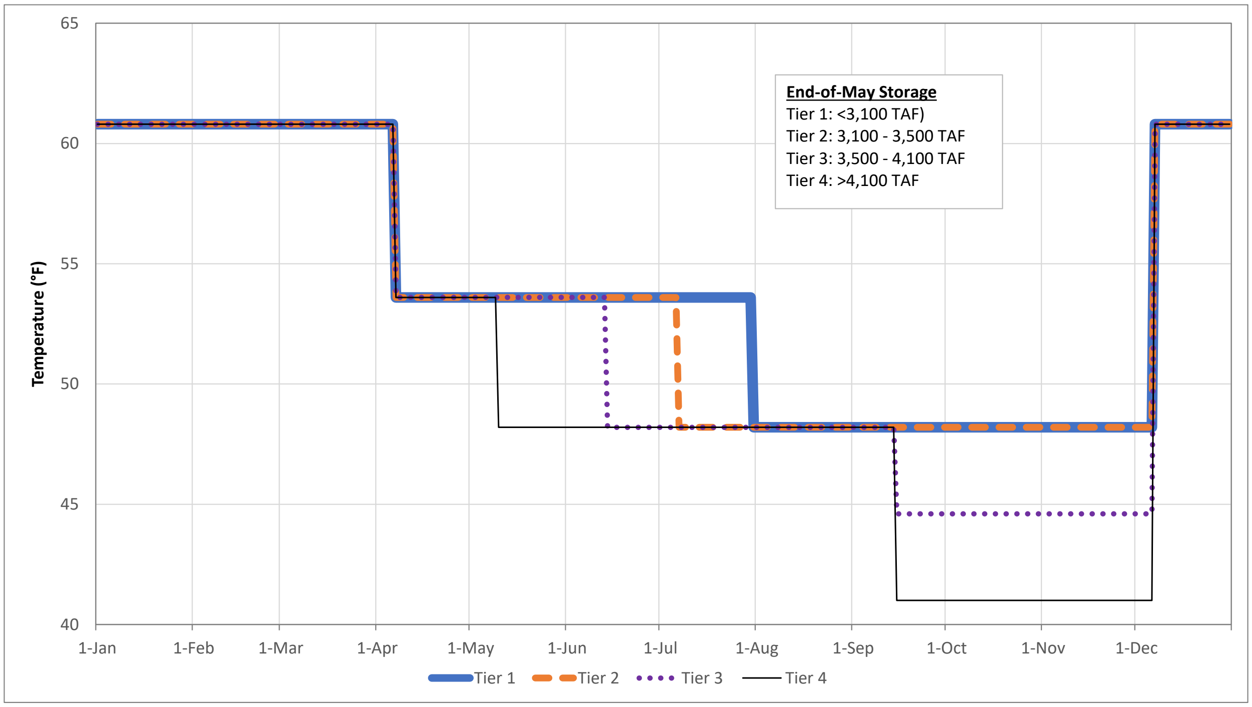
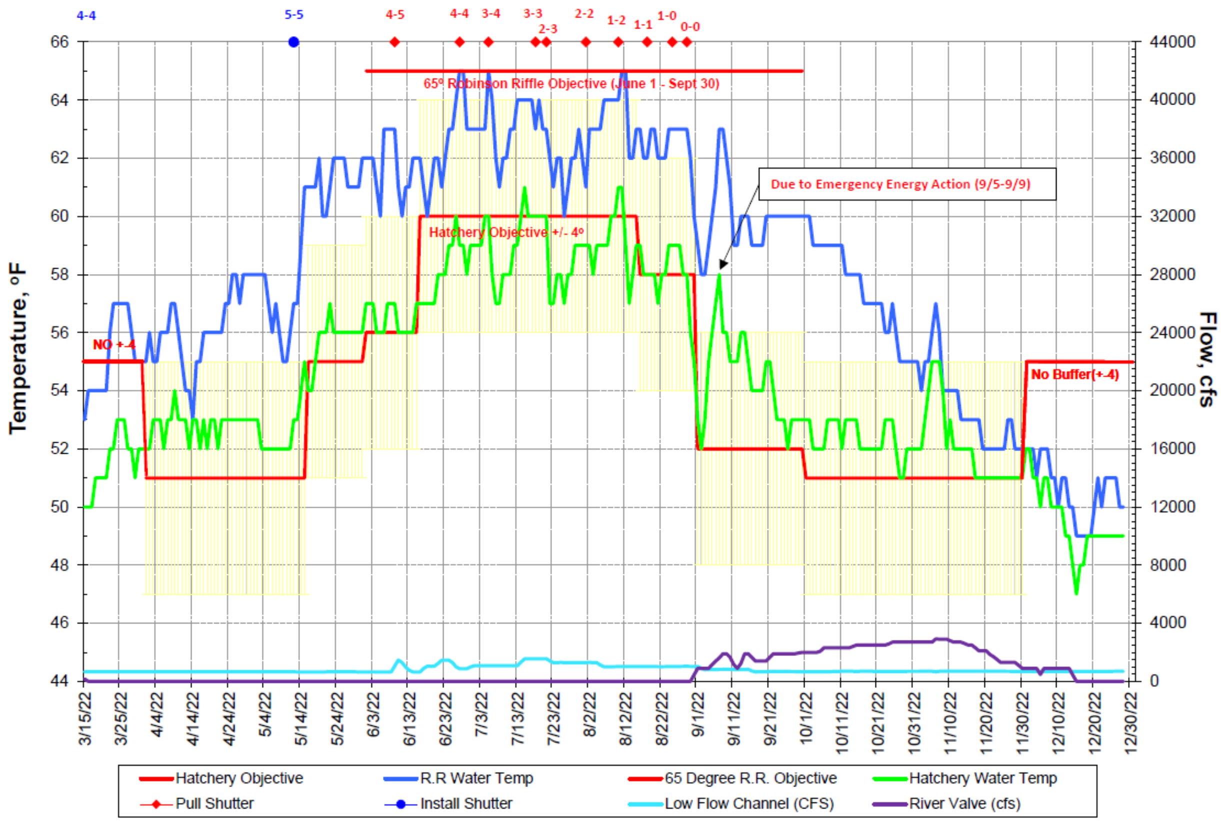


Figure B-1. Lake Shasta Target Temperatures Based on End-of-May Storage

Algorithm for Oroville Dam Target Temperatures

Oroville releases are managed to meet the 1983 agreement between the California Department of Water Resources and the California Department of Fish and Wildlife (then California Department of Fish and Game) for hatchery temperatures and the *Biological Opinion on the Long-Term Central Valley Project and State Water Project Operations Criteria and Plan* for Robinson's Riffle in the low-flow channel (Reclamation 2019; NMFS 2004). Temperatures are attained through a mixture of reducing hydropower peaking operations, pulling shutters, increasing flow, and using the river-outlet (which bypasses the hydropower facility). Adjustments are made based on the temperature response at the hatchery or Robinson's Riffle. Figure B-2 (reproduced from DWR 2022) shows the temperature objectives used to guide releases from Oroville Reservoir, along with actions and temperature results for 2022. The hatchery objective has a buffer of +/- 4 degrees Fahrenheit (°F) for much of the year, with temperatures generally maintained well below the upper limit of the buffer. During June 1–September 30, maintenance of hatchery temperatures at or below the objective line allows for warming between the hatchery and Robinson's Riffle without exceeding the Robinson's Riffle objective.



Source: DWR 2022

Figure B-2. Feather River Hatchery and Robinson's Riffle Temperature Operations in 2022

For the temperature simulations, the Oroville Dam temperature targets were established by adjusting the hatchery objectives to account for the warming (or cooling) that may occur between the dam and the hatchery. This approach lowers the target during the summer to account for more rapid heating and increases the target during the winter. The target temperature is computed as the temperature objective at the hatchery intake adjusted based on the daily averaged equilibrium temperature (calculated from meteorological input) as follows:

$$Targ = Th + (Tk - Te) * Tf$$

Where:

Targ = Oroville outflow target (F)

Th = Hatchery Intake objective (F)

Tk = constant (55 F)

Te = Equilibrium Temperature (F)

Tf = Scaling factor (0.13)

Algorithm for Folsom Dam Target Temperatures

Releases from Folsom Reservoir are actively managed based on current conditions and iterative model runs to determine how to most closely meet objectives of the modified flow management standard (PCWA 2017). This is a complex process and difficult to implement in simulations that span many years for planning purposes. As a result, planning analyses have used reservoir-release temperature targets that are based on end-of-May storage plus June through September inflow (Table B-1). These targets were developed for planning based on CalSim results and are described in the *Biological Assessment for the California WaterFix* (DWR 2016). These same target temperatures were used for the SacWAM scenarios but based on SacWAM results.

Table B-1. Temperature Target (°F) for Folsom Dam

Folsom End-of-May Storage plus Jun-Sep Inflow (TAF)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<=600	52	52	52	59	66.8	66.0	66.0	63.0	67.5	68.0	60.5	56
700	52	52	52	59	65.9	65.2	66.2	63.3	66.7	68.1	60.6	56
750	52	52	52	59	66.3	65.6	65.6	62.9	67.0	67.3	59.7	56
850	52	52	52	59	65.6	65.0	66.0	63.5	66.3	67.5	59.8	56
900	52	52	52	59	65.8	65.2	65.2	62.8	66.4	66.6	58.8	56
950	52	52	52	59	65.0	64.4	65.4	63.1	65.6	66.7	58.9	56
1,050	52	52	52	59	65.2	64.6	64.6	62.4	65.7	65.8	57.9	56
1,100	52	52	52	59	64.3	63.8	64.8	62.7	64.9	65.9	58.0	56
1,200	52	52	52	59	64.5	64.0	64.0	62.0	65.0	63.0	58.0	56
1,250	52	52	52	59	63.7	63.2	64.2	62.3	64.2	63.1	58.1	56
1,350	52	52	52	59	63.7	63.2	63.2	61.3	64.2	63.1	58.1	56
1,400	52	52	52	59	62.9	62.4	63.4	61.6	63.3	63.2	58.1	56
1,500	52	52	52	59	62.9	62.4	62.4	60.6	63.3	63.2	58.1	56
1,550	52	52	52	59	61.9	61.4	62.4	60.6	62.3	63.2	58.1	56
1,650	52	52	52	59	62.0	61.6	61.6	59.9	62.5	58.3	57.2	56
1,700	52	52	52	59	61.0	60.6	61.6	59.9	61.5	58.3	57.2	56
1,800	52	52	52	59	61.0	60.6	60.6	58.9	61.5	58.3	57.2	56
1,850	52	52	52	59	60.0	59.6	60.6	58.9	60.5	58.3	57.2	56
1,950	52	52	52	59	60.0	59.6	59.6	57.9	60.5	58.3	56.2	56
2,000	52	52	52	59	59.0	58.6	59.6	57.9	59.5	57.3	56.2	56
2,100	52	52	52	59	59.0	58.6	58.6	56.9	59.5	56.3	55.2	56
2,150	52	52	52	59	58.0	57.6	58.6	56.9	58.5	55.3	55.2	56

Source: DWR 2016, Appendix 5c, Table 5.C-4.
TAF = thousand acre-feet

Temperatures in Folsom Reservoir are also affected by the operations of the TCD for the Folsom water supply intake. Note that for Folsom Lake, the term TCD often refers to this structure, which has been a source of confusion in the past. Generally, relatively warm water of about 63–65°F is withdrawn for water supply, which helps maintain cold-water supply in the reservoir. The Folsom water supply intake is modeled with a temperature target of 64.4°F (18 degrees Celsius), a minimum submergence constraint of 15 feet, and an operating elevation range of 320–460 feet.

B.2.2.5 Power Bypass at Oroville Dam for Performance Evaluation

Power bypass operations at Oroville Dam were included in the simulations. Releasing this water may sometimes provide colder water to the river but would reduce flow through the Oroville Dam hydropower facility. Power bypass flows usually represent only a portion of the total water released from the reservoir. Oroville power bypass is modeled to start contributing to outflow when Oroville storage is less than 1.19 million acre-feet. This threshold was chosen based on the changes in measured release temperatures that occur when storage drops to about this level. Power bypass at Oroville Dam was not included in prior versions of the Feather River model. Inclusion of Oroville Bypass generally improves model performance when Oroville storage is low.

B.2.3 Results

Table B-2 through Table B-22 summarize model ability to match measured temperatures for the Sacramento, Feather, and American Rivers. These tables represent comparisons between measured and modeled temperatures for each 6-hour time increment with corresponding measured data. All stations except the Sacramento River at Anderson have 9–19 years of temperature measurements starting after 2001. For these temperatures to match precisely, the model must not only be accurately capturing the daily energy balance, but also matching the timing of the temperature fluctuations.

Generally, average monthly model bias is less than 2°F, with a few exceptions. Temperatures immediately below Oroville and Folsom Dam may not perform as well as temperatures farther downstream due to fluctuations in flow for hydropower peaking, making it difficult to accurately calculate flow-weighted average temperatures (Table B-10 and Table B-16). The most persistent bias occurs in temperatures for the Thermalito Afterbay river outlet, where modeled monthly average temperatures are more than 3°F warmer than the measured temperatures during December through April. However, there is good agreement between the modeled and observed temperatures at this location during the warmer months (Table B-14). Furthermore, Feather River temperatures downstream of the Thermalito outlet at Gridley match the measured data well with all monthly bias values less than 1.5°F (Table B-15).

Table B-2. Model Performance for Temperatures in the Sacramento River below Shasta Dam (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,828	1,681	1,832	1,764	1,819	1,770	1,828	1,788	1,774	1,825	1,675	1,662
Mean Absolute Error	1.1	0.8	1.2	1.9	2.1	1.2	1.9	1.9	2.0	1.7	1.0	1.9
Root Mean Square Error	1.5	1.2	1.8	2.5	2.8	1.8	2.4	2.5	2.7	2.2	1.4	2.4
Average Observed	49.4	48.0	48.1	49.1	49.8	50.1	50.5	50.7	51.8	54.1	54.9	52.5
Average Modeled	50.0	48.2	48.8	50.8	50.5	49.9	49.6	49.0	50.2	53.1	55.0	54.3
Bias (Modeled - Observed)	0.6	0.2	0.7	1.6	0.7	-0.2	-1.0	-1.7	-1.6	-1.0	0.0	1.8

Table B-3. Model Performance for Temperatures in the Sacramento River below Keswick Dam (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,849	1,647	1,810	1,778	1,839	1,728	1,760	1,821	1,776	1,832	1,680	1,732
Mean Absolute Error	1.4	1.3	1.4	2.0	2.0	1.2	1.3	1.1	1.2	1.2	1.1	2.1
Root Mean Square Error	1.8	1.7	1.9	2.6	2.7	1.6	1.6	1.4	1.5	1.6	1.4	2.5
Average Observed	49.1	48.0	48.8	50.3	51.1	51.5	52.2	52.6	53.2	54.3	54.5	51.8
Average Modeled	50.1	48.9	49.9	52.2	52.2	52.0	52.2	52.0	53.0	54.5	55.1	53.8
Bias (Modeled - Observed)	1.1	0.9	1.1	1.9	1.1	0.4	-0.1	-0.5	-0.2	0.2	0.6	2.0

Table B-4. Model Performance for Temperatures in the Sacramento River above Clear Creek (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,852	1,680	1,857	1,795	1,853	1,767	1,852	1,858	1,790	1,857	1,710	1,725
Mean Absolute Error	1.4	1.2	1.5	2.0	2.1	1.3	1.3	1.3	1.4	1.3	1.2	2.1
Root Mean Square Error	1.8	1.6	1.9	2.6	2.6	1.7	1.7	1.7	1.8	1.7	1.5	2.5
Average Observed	49.2	48.7	49.7	51.5	52.3	52.7	53.4	53.8	54.3	55.0	54.4	51.5
Average Modeled	50.1	49.3	50.6	53.0	53.0	52.9	53.1	53.0	53.8	54.9	55.1	53.5
Bias (Modeled - Observed)	1.0	0.6	0.9	1.4	0.8	0.2	-0.2	-0.8	-0.5	0.0	0.7	2.0

Table B-5. Model Performance for Temperatures in the Sacramento River near Anderson (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	179	212	236	223	232	240	248	248	240	231	155	124
Mean Absolute Error	1.3	1.8	1.9	2.0	2.0	2.0	1.6	2.2	2.2	1.7	1.4	1.4
Root Mean Square Error	1.6	2.2	2.3	2.4	2.6	2.5	2.0	2.7	2.6	2.1	1.7	2.0
Average Observed	50.6	51.4	52.7	55.1	56.3	56.8	56.1	56.1	55.6	55.7	55.5	52.5
Average Modeled	49.8	50.4	51.4	54.7	55.1	55.5	55.9	54.0	53.5	54.7	56.4	53.7
Bias (Modeled - Observed)	-0.8	-1.0	-1.3	-0.4	-1.2	-1.3	-0.2	-2.1	-2.1	-1.1	0.9	1.2

Table B-6. Model Performance for Temperatures in the Sacramento River at Balls Ferry Bridge (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,575	1,495	1,759	1,788	1,855	1,791	1,851	1,853	1,789	1,803	1,578	1,514
Mean Absolute Error	1.6	1.2	1.4	1.8	2.2	1.9	1.8	1.7	1.8	1.4	1.2	1.8
Root Mean Square Error	1.9	1.5	1.8	2.2	2.7	2.3	2.2	2.1	2.1	1.7	1.5	2.3
Average Observed	48.4	48.8	50.8	53.2	54.2	54.6	55.0	55.3	55.6	55.5	53.8	50.1
Average Modeled	48.7	48.8	50.7	53.9	54.7	55.0	55.1	55.0	55.5	55.5	54.2	51.3
Bias (Modeled - Observed)	0.4	0.0	-0.1	0.6	0.5	0.4	0.1	-0.3	-0.1	0.0	0.4	1.2

Table B-7. Model Performance for Temperatures in the Sacramento River at Jellys Ferry (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,827	1,678	1,858	1,771	1,856	1,788	1,829	1,826	1,751	1,856	1,709	1,723
Mean Absolute Error	1.4	1.2	1.3	1.6	2.1	2.1	2.1	2.0	1.8	1.3	1.0	1.8
Root Mean Square Error	1.7	1.5	1.6	2.0	2.5	2.4	2.5	2.2	2.1	1.6	1.3	2.3
Average Observed	48.2	49.0	51.5	54.3	55.7	56.1	56.3	56.5	56.6	56.1	53.9	49.9
Average Modeled	48.2	48.8	51.1	54.6	55.9	56.5	56.6	56.5	56.7	56.1	54.0	50.0
Bias (Modeled - Observed)	0.0	-0.2	-0.3	0.2	0.2	0.4	0.3	0.0	0.1	0.0	0.1	0.1

Table B-8. Model Performance for Temperatures in the Sacramento River at Bend Bridge (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,826	1,680	1,795	1,778	1,801	1,769	1,848	1,847	1,783	1,839	1,677	1,701
Mean Absolute Error	1.4	1.1	1.1	1.4	1.9	2.1	2.1	1.9	1.6	1.2	0.9	1.8
Root Mean Square Error	1.7	1.4	1.4	1.8	2.3	2.4	2.5	2.2	2.0	1.4	1.2	2.3
Average Observed	48.1	49.1	51.7	54.7	56.2	56.6	56.9	57.0	57.1	56.2	53.8	49.8
Average Modeled	48.2	48.9	51.5	55.0	56.4	57.1	57.3	57.1	57.3	56.3	54.0	49.9
Bias (Modeled - Observed)	0.1	-0.2	-0.3	0.3	0.2	0.5	0.3	0.1	0.2	0.1	0.2	0.2

Table B-9. Model Performance for Temperatures in the Sacramento River at Site of Red Bluff Diversion Dam (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,850	1,695	1,853	1,777	1,835	1,796	1,850	1,855	1,794	1,851	1,681	1,734
Mean Absolute Error	1.4	1.1	1.1	1.2	1.4	1.3	1.4	1.1	1.1	1.0	0.9	1.8
Root Mean Square Error	1.7	1.4	1.4	1.5	1.8	1.6	1.7	1.4	1.4	1.3	1.1	2.3
Average Observed	48.1	49.4	52.3	55.7	57.5	58.4	58.7	58.8	58.5	56.9	53.9	49.5
Average Modeled	48.2	49.1	51.9	55.6	57.2	58.1	58.3	58.2	58.1	56.7	54.1	49.8
Bias (Modeled - Observed)	0.2	-0.3	-0.5	-0.1	-0.3	-0.3	-0.4	-0.6	-0.4	-0.2	0.2	0.3

Table B-10. Model Performance for Temperatures in the Feather River below Oroville Dam (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,116	1,016	1,116	1,080	1,116	1,080	1,116	1,116	1,080	1,116	1,080	1,116
Mean Absolute Error	1.2	1.7	3.5	1.9	2.2	2.0	2.3	2.6	2.9	2.0	1.6	3.4
Root Mean Square Error	1.7	2.4	4.5	2.2	2.8	2.5	3.0	3.3	3.6	2.6	2.0	4.3
Average Observed	46.7	45.9	46.5	48.9	51.7	55.3	56.1	56.4	52.3	51.9	52.3	49.8
Average Modeled	47.1	47.0	49.8	50.1	51.4	55.7	57.3	57.1	50.8	51.4	52.3	53.1
Bias (Modeled - Observed)	0.3	1.1	3.3	1.1	-0.3	0.4	1.3	0.7	-1.5	-0.4	0.0	3.3

Table B-11. Model Performance for Temperatures in the Feather River near the Diversion Pool Outlet to the Thermalito Power Canal (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,115	1,016	1,116	1,080	1,116	1,080	1,116	1,116	1,080	1,116	1,080	1,050
Mean Absolute Error	1.4	1.9	4.2	2.9	2.3	1.6	1.5	1.6	2.6	2.8	2.0	2.6
Root Mean Square Error	1.7	2.3	4.9	4.4	3.2	1.9	1.9	2.1	3.2	4.9	3.2	3.3
Average Observed	47.4	47.4	49.6	52.3	53.7	57.2	58.1	58.5	54.5	54.8	54.1	50.7
Average Modeled	47.7	48.2	51.6	52.4	53.0	56.9	58.4	58.2	52.3	52.5	52.7	53.1
Bias (Modeled - Observed)	0.3	0.8	2.0	0.2	-0.7	-0.3	0.3	-0.3	-2.2	-2.3	-1.4	2.4

Table B-12. Model Performance for Temperatures in the Feather River below the Fish Barrier Dam (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	991	904	992	960	992	960	992	992	960	992	960	910
Mean Absolute Error	2.2	2.6	4.2	2.3	2.1	1.7	2.1	1.8	1.9	1.3	1.2	3.7
Root Mean Square Error	2.4	3.0	4.7	2.8	2.6	2.1	2.5	2.2	2.4	1.6	1.4	4.2
Average Observed	45.5	45.3	46.9	49.9	52.6	56.6	57.7	57.8	53.1	52.1	51.7	48.6
Average Modeled	47.2	47.6	50.9	51.8	53.0	57.2	58.7	58.6	52.7	52.5	52.4	52.3
Bias (Modeled - Observed)	1.7	2.3	4.1	1.9	0.5	0.6	1.1	0.8	-0.5	0.4	0.7	3.7

Table B-13. Model Performance for Temperatures in the Feather River at Robinson's Riffle (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	2,232	2,139	2,356	2,280	2,356	2,280	2,356	2,356	2,280	2,356	2,280	2,352
Mean Absolute Error	1.9	2.0	2.5	2.9	3.7	4.1	4.4	4.2	3.9	3.1	2.1	1.9
Root Mean Square Error	2.3	2.4	3.1	3.5	4.5	5.0	5.3	5.2	4.7	3.8	2.7	2.4
Average Observed	48.0	48.4	50.4	53.5	56.3	60.0	61.8	61.1	56.7	54.5	52.6	49.9
Average Modeled	46.9	47.8	51.3	53.4	55.6	59.7	61.8	61.1	55.7	53.3	51.6	50.6
Bias (Modeled - Observed)	-1.0	-0.6	0.9	-0.1	-0.7	-0.3	0.0	0.0	-1.0	-1.3	-1.0	0.6

Table B-14. Model Performance for Temperatures in the Thermalito Afterbay River Outlet (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,062	904	992	960	992	960	992	992	960	992	960	992
Mean Absolute Error	3.3	3.9	5.7	5.7	3.1	2.1	1.6	1.5	1.8	1.5	2.1	4.8
Root Mean Square Error	3.7	4.3	6.2	6.9	4.2	2.9	2.1	1.8	2.4	1.9	2.6	5.0
Average Observed	45.7	48.7	52.9	56.1	61.3	65.4	65.4	64.9	61.8	57.7	52.3	47.2
Average Modeled	49.0	52.5	58.6	61.7	63.4	65.7	65.9	65.8	62.6	58.8	54.3	52.0
Bias (Modeled - Observed)	3.2	3.9	5.7	5.6	2.1	0.3	0.5	1.0	0.8	1.1	2.0	4.8

Table B-15. Model Performance for Temperatures in the Feather River at Gridley (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	992	900	1,099	1,185	1,305	1,220	1,240	1,240	1,098	1,116	1,080	1,112
Mean Absolute Error	1.8	1.8	2.3	2.2	2.5	2.6	2.3	2.1	2.1	1.7	1.4	1.9
Root Mean Square Error	2.1	2.2	2.9	2.8	3.0	3.2	2.7	2.7	2.6	2.0	1.7	2.5
Average Observed	49.1	50.4	53.1	56.5	61.1	65.4	66.8	65.3	61.4	58.3	53.7	50.2
Average Modeled	47.9	50.1	54.2	57.3	60.8	65.1	66.4	65.3	61.2	57.6	53.4	51.5
Bias (Modeled - Observed)	-1.1	-0.2	1.2	0.9	-0.3	-0.3	-0.4	0.0	-0.2	-0.7	-0.2	1.3

Table B-16. Model Performance for Temperatures in the American River below Folsom Dam (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,852	1,673	1,834	1,782	1,977	1,957	1,969	2,045	1,872	1,970	1,978	2,066
Mean Absolute Error	1.6	1.1	1.1	1.7	2.1	2.8	3.1	2.9	2.7	3.8	2.2	3.1
Root Mean Square Error	2.0	1.4	1.5	2.0	2.4	3.1	3.3	3.6	3.4	4.4	2.9	3.9
Average Observed	47.8	47.7	49.3	51.9	54.2	57.1	60.1	61.5	62.4	62.4	57.3	52.2
Average Modeled	48.4	48.1	49.2	50.7	52.7	54.9	58.5	62.6	63.7	60.0	57.4	54.5
Bias (Modeled - Observed)	0.6	0.4	-0.2	-1.2	-1.4	-2.2	-1.6	1.1	1.2	-2.4	0.0	2.3

Table B-17. Model Performance for Temperatures in the American River at Hazel Avenue (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	2,232	2,032	2,232	2,160	2,232	2,163	2,356	2,356	2,280	2,356	2,280	2,352
Mean Absolute Error	1.6	1.0	1.1	1.7	2.1	2.7	2.9	3.0	3.0	3.5	2.0	2.7
Root Mean Square Error	1.9	1.4	1.4	1.9	2.4	3.1	3.7	4.4	4.4	4.4	3.0	3.5
Average Observed	48.5	48.5	50.6	53.3	55.8	58.4	61.2	62.6	62.9	62.2	57.4	52.2
Average Modeled	48.3	48.4	50.2	52.4	54.7	56.8	60.4	64.2	65.0	60.9	57.2	53.9
Bias (Modeled - Observed)	-0.2	-0.1	-0.4	-0.9	-1.1	-1.6	-0.8	1.6	2.2	-1.3	-0.2	1.7

Table B-18. Model Performance for Temperatures in the American River at Fair Oaks (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	2,232	2,139	2,356	2,280	2,356	2,280	2,356	2,356	2,280	2,356	2,280	2,352
Mean Absolute Error	1.6	1.2	1.3	1.7	1.9	2.2	2.4	2.4	2.4	3.0	1.6	2.5
Root Mean Square Error	2.0	1.6	1.7	2.1	2.4	2.5	2.7	3.0	2.8	3.5	2.0	3.2
Average Observed	48.5	48.6	51.0	53.9	56.5	59.1	62.3	63.7	64.1	63.1	58.1	52.4
Average Modeled	48.4	48.7	50.8	53.1	55.5	57.7	61.1	64.8	65.5	61.2	57.3	53.9
Bias (Modeled - Observed)	-0.1	0.1	-0.2	-0.8	-1.0	-1.5	-1.2	1.1	1.4	-1.9	-0.8	1.5

Table B-19. Model Performance for Temperatures in the American River at William Pond Park (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	2,232	2,139	2,356	2,280	2,356	2,280	2,356	2,356	2,280	2,356	2,280	2,352
Mean Absolute Error	1.7	1.5	1.9	2.4	2.7	2.9	3.0	2.9	2.8	3.1	1.7	2.4
Root Mean Square Error	2.0	1.8	2.2	2.9	3.3	3.6	3.7	3.6	3.4	3.7	2.1	3.1
Average Observed	48.6	49.1	51.9	55.2	58.3	61.0	64.1	65.6	65.6	63.8	58.0	52.2
Average Modeled	48.7	49.3	51.7	54.3	57.0	59.1	62.5	66.0	66.5	61.8	57.4	53.8
Bias (Modeled - Observed)	0.0	0.1	-0.2	-0.9	-1.3	-1.8	-1.6	0.4	0.9	-2.0	-0.6	1.6

Table B-20. Model Performance for Temperatures in the American River at Watt Avenue (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	2,232	2,139	2,356	2,280	2,356	2,280	2,356	2,356	2,280	2,356	2,280	2,352
Mean Absolute Error	1.6	1.4	1.6	2.0	2.3	2.5	2.7	3.0	2.9	2.3	1.4	2.4
Root Mean Square Error	1.9	1.8	2.0	2.5	2.7	3.0	3.3	3.6	3.5	2.9	1.8	3.1
Average Observed	48.7	49.5	52.5	56.0	59.3	61.9	65.0	66.4	66.1	63.8	57.6	51.8
Average Modeled	49.1	50.2	53.2	56.2	59.2	61.4	64.7	67.9	68.1	62.8	57.7	53.7
Bias (Modeled - Observed)	0.4	0.7	0.7	0.1	-0.1	-0.5	-0.3	1.5	2.0	-0.9	0.1	1.9

Table B-21. Model Performance for Temperatures in the Sacramento River at Verona (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,364	1,304	1,481	1,440	1,472	1,436	1,488	1,488	1,427	1,470	1,387	1,484
Mean Absolute Error	1.1	1.3	1.2	1.4	1.7	1.9	1.8	1.8	1.7	1.3	1.2	1.6
Root Mean Square Error	1.4	1.7	1.5	1.8	2.2	2.4	2.3	2.3	2.2	1.6	1.9	2.0
Average Observed	48.6	51.4	55.1	59.7	64.8	69.9	71.5	70.4	67.6	61.7	54.8	49.2
Average Modeled	48.3	50.8	54.6	60.2	65.5	70.0	72.3	71.3	68.5	62.1	55.6	49.2
Bias (Modeled - Observed)	-0.2	-0.6	-0.5	0.5	0.7	0.1	0.8	0.9	0.8	0.4	0.8	0.0

Table B-22. Model Performance for Temperatures in the Sacramento River at Freeport (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Number of Points	1,116	1,122	1,116	1,093	1,240	1,200	1,240	1,240	1,196	1,116	1,080	1,116
Mean Absolute Error	1.5	1.1	0.8	1.3	1.4	1.7	1.7	1.8	1.6	1.3	1.6	1.2
Root Mean Square Error	1.9	1.3	1.0	1.7	1.7	2.1	2.1	2.2	1.9	1.7	3.0	1.5
Average Observed	48.6	50.8	55.6	59.6	65.6	69.3	71.4	71.3	68.8	63.3	57.2	49.6
Average Modeled	47.8	50.5	55.4	60.2	66.2	69.8	72.5	72.7	69.9	63.2	56.4	50.4
Bias (Modeled - Observed)	-0.8	-0.3	-0.2	0.6	0.6	0.4	1.1	1.4	1.2	-0.1	-0.8	0.8

B.3 Temperature Modeling with SacWAM flows

B.3.1 Model Inputs for SacWAM Scenarios

B.3.1.1 Hydrology for SacWAM Scenarios

Channel geometry/flow relationships and reservoir geometry were the same in the SacWAM scenarios as is described above for the performance evaluation.

SacWAM results were used to provide hydrologic inputs for HEC-5Q model domain. These inputs include inflows to the major reservoirs, reservoir releases, creek flows, net effect of smaller accretions/depletions, and diversions. In order to verify that SacWAM results were properly incorporated into the HEC-5Q simulations, flows at downstream river locations calculated within the HEC-5Q model were compared to the flows simulated for those same locations by SacWAM.

Monthly SacWAM river hydrology results were converted to equal daily flows by setting daily values equal to the monthly values. Use of constant monthly flows has little effect on the simulated temperature effects because:

- Flow is most variable during winter and early spring, when water temperatures tend to be cool regardless of flow,
- Variable local rainfall-runoff flows are unregulated and would not be affected by the SacWAM scenario,
- Flows downstream of Shasta, Oroville, and Folsom re-regulating reservoirs during warmer times of the year tend to be fairly uniform, and
- Use of 6-hour equilibrium temperatures provides daily variability in the simulated temperatures.

B.3.1.2 Meteorology for SacWAM Scenarios

For simulation period years with measured CIMIS data (starting in 1985), the meteorology data used in the models are the same as described above for the performance evaluation.

For earlier years as required for longer-term SacWAM planning simulations, measured meteorological conditions were extended back in time. This was done by selecting days of CIMIS data to represent past days by matching CIMIS minimum and maximum daily air temperatures and time of year to daily minimum and maximum air temperatures at long-term U.S. Weather Service stations at Orland and Davis. In this manner, CIMIS data were used to calculate 6-hour water temperature equilibrium temperatures and exchange rates for the full SacWAM simulation period.

B.3.1.3 Boundary Temperatures for SacWAM Scenarios

Boundary-condition temperatures for the SacWAM scenarios were the same as the boundary temperatures for the performance evaluation with two exceptions:

- For Lake Shasta inflow temperatures, instead of basing the inflow values directly on measured inflow water temperatures as was done for the performance evaluation, the 16 years of flow-weighted inflow temperatures were averaged to define the seasonal variation for the entire 1922–2015 simulation period. The Lake Shasta inflow temperatures for the SacWAM scenarios were then estimated as falling between the seasonal pattern and the meteorological driven equilibrium temperatures, with equilibrium temperatures having more effect at lower flows. This approach is similar to the approach for the Feather and American River inflow temperatures as described above in Section A.2.2.3, *Boundary Temperatures for Performance Evaluation*. This approach produces inflow temperatures that closely follow the inflow temperatures calculated from the 16 years of measured inflow temperatures and flows.

- The Feather and American River model domain includes the Sacramento River between the Feather River and Freeport (downstream of the American River). For SacWAM scenarios, these inflow temperatures were set equal to the Knights Landing temperatures from the Sacramento River HEC-5Q model of baseline conditions. Temperatures at this location approach equilibrium values so differences between scenarios at this location are smaller than upstream differences. Simulated Sacramento River temperatures downstream of Knights Landing are not used in the assessment of fish habitat.

B.3.1.4 Reservoir Release Target Temperatures for SacWAM Scenarios

The target-temperature algorithms are the same as described above for the performance evaluation.

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Appendix C

Bay-Delta Habitat Modeling Supplemental Methods and Results

Appendix C
Bay-Delta Habitat Modeling Supplemental Methods and Results

C.1 Observed Data Processing

Observed data were used to produce habitat data layers for temperature and turbidity. Data were downloaded for the 2010–2019 period, outliers were removed, and small data gaps were filled by interpolation.

All data were monthly averaged and then processed to produce overall monthly statistics (e.g., statistics for all Junes in the dataset). Statistics include mean, 25 percent quantiles, and 75 percent quantiles. Monthly averages and overall monthly statistics are plotted for each temperate and turbidity station in the sections below.

C.1.1 Temperature

Observed temperature data were downloaded from the California Department of Water Resources' (DWR) California Data Exchange Center at the locations shown in Figure C-1 (DWR 2022a).

For each station, bar and whisker plots and monthly average temperature time series plots are provided in Figure C-2 through Figure C-141. The bar and whisker plots show, for each month of the year, the overall data range (maximum and minimum values) as the "whiskers" and the mean, 25 percent, and 75 percent quantile values as the "bars." In the time series plots, annual temperature time series are plotted for each year that data are available during the 2010–2019 period. The Maximum temperature limits for habitat criteria are included on all plots for reference as follows:

- 19° Celsius for Delta smelt larvae
- 21° Celsius for Delta smelt juveniles
- 13° Celsius for longfin smelt larvae
- 19° Celsius for longfin smelt juveniles
- 18° Celsius for salmonid rearing

Each of the two types of plots provides information about the data ranges, and the time series plots give more information about the data availability. At some locations, data are only available for a few years out of the 10-year period.

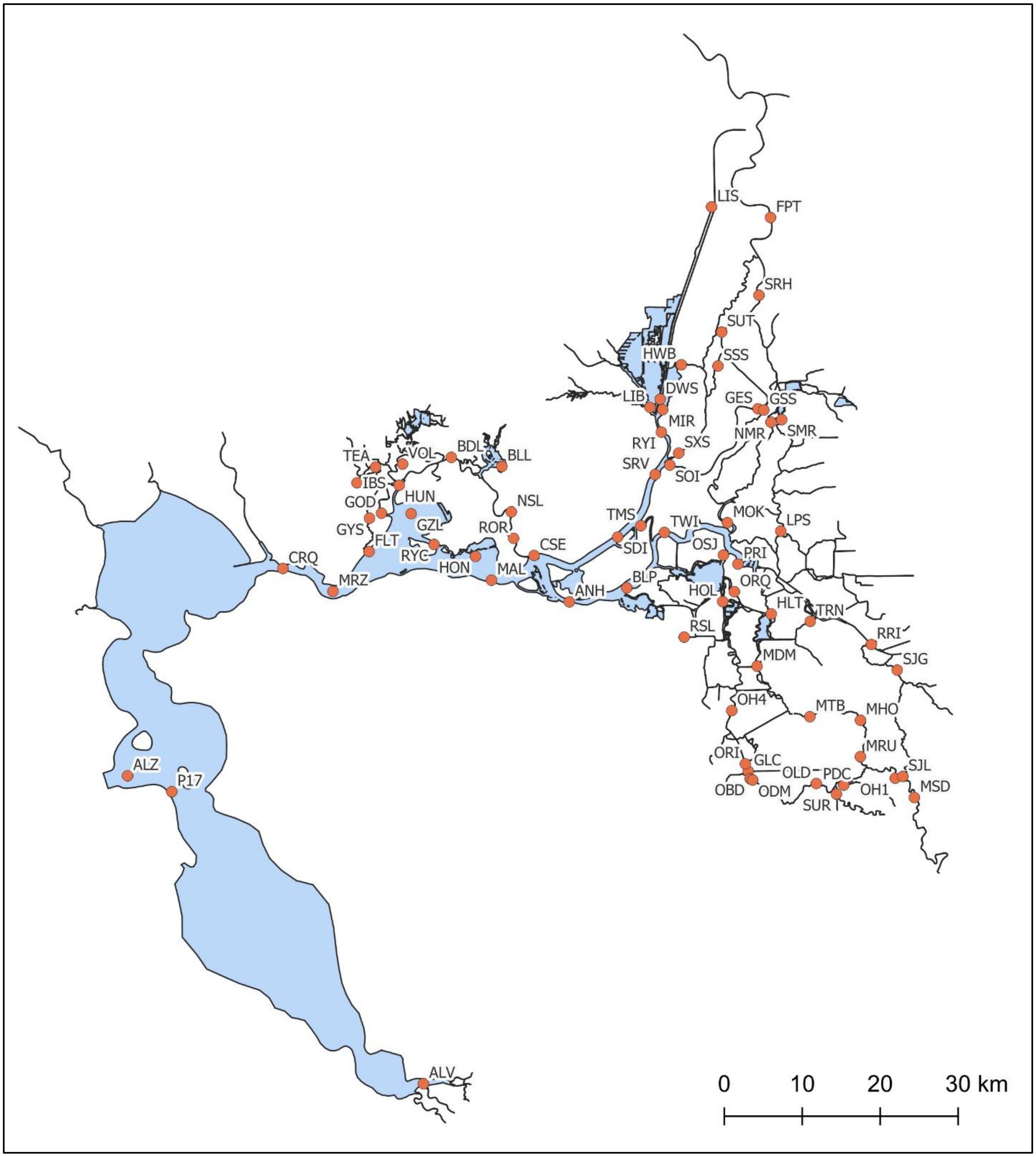

Figure C-1. Locations of Observed Temperature Stations Used to Calculate the Temperature Data Layers for the Habitat Calculations

Figure is a map of the San Francisco Bay Estuary showing red points denoted by three-letter station codes representing sampling stations.

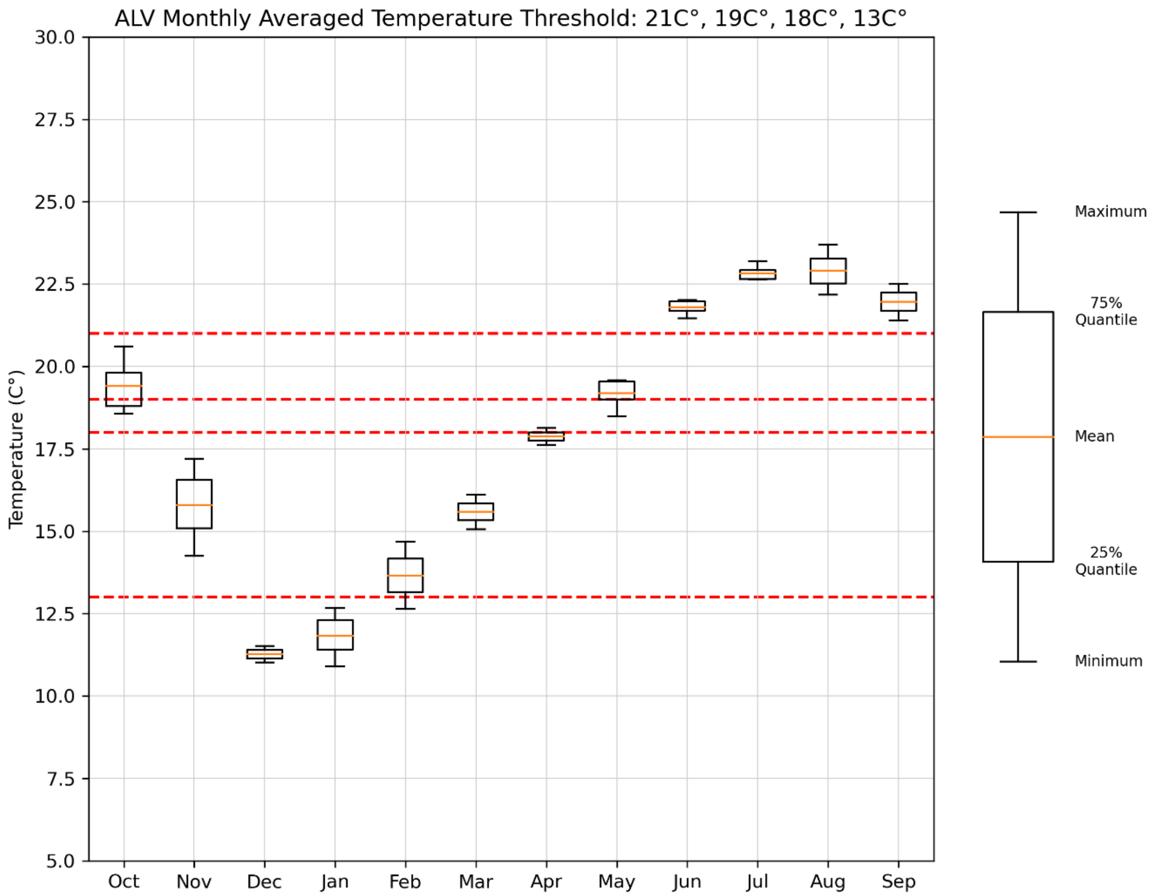

Figure C-2. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ALV – Alviso Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention.

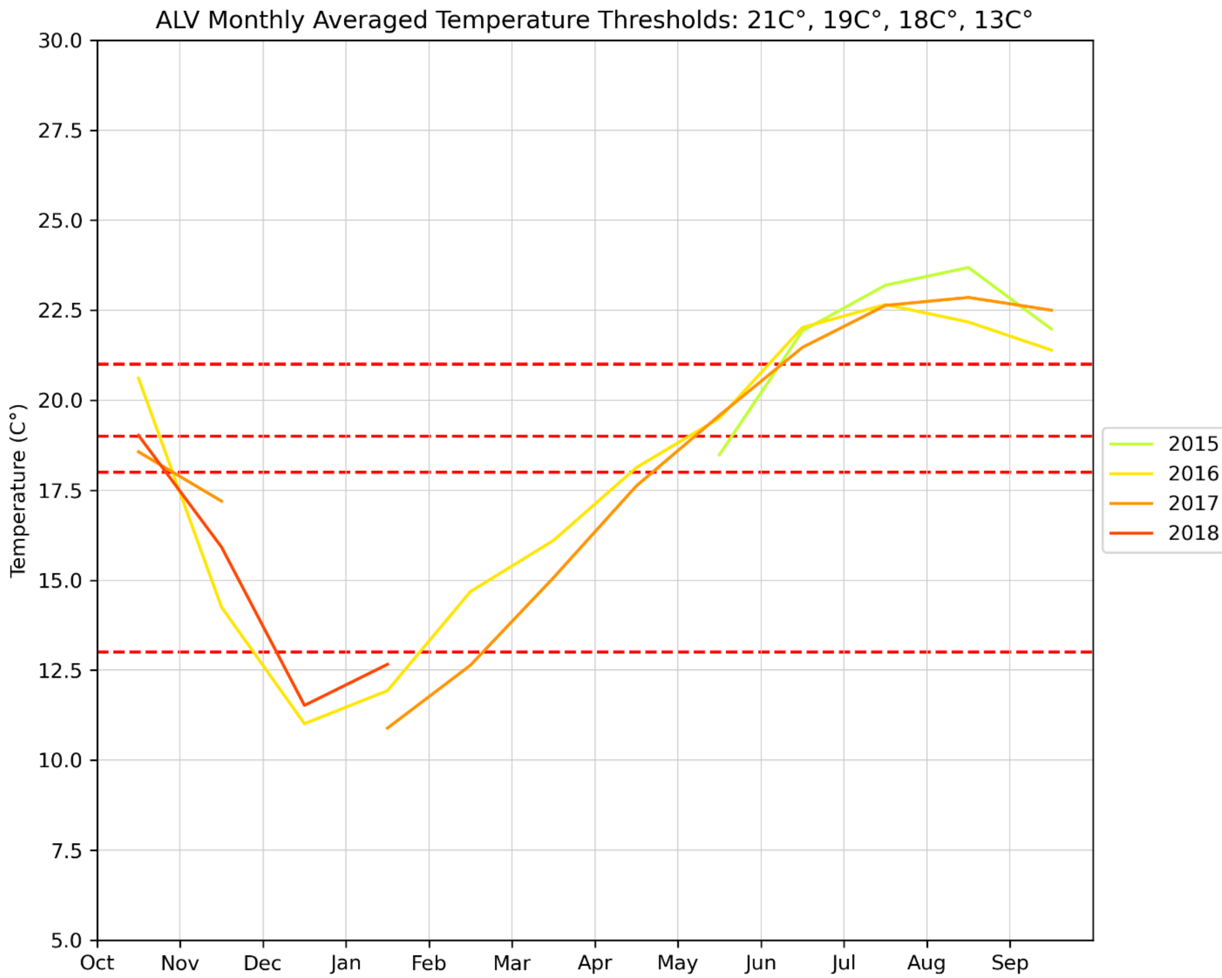

Figure C-3. Monthly Average Temperature for the Period of Record at Station ALV – Alviso Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

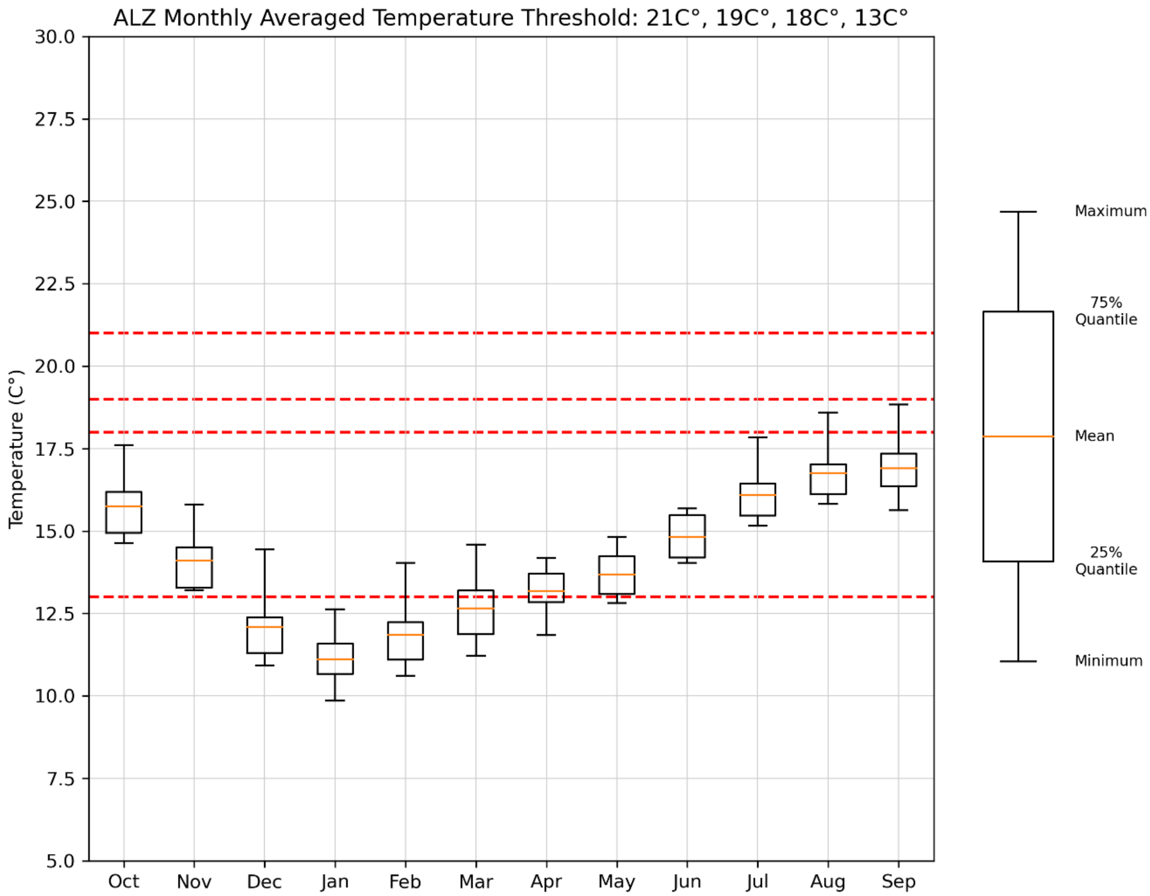

Figure C-4. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ALZ – Alcatraz Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; top and bottom portions of the whisker are maximum and minimum, respectively.

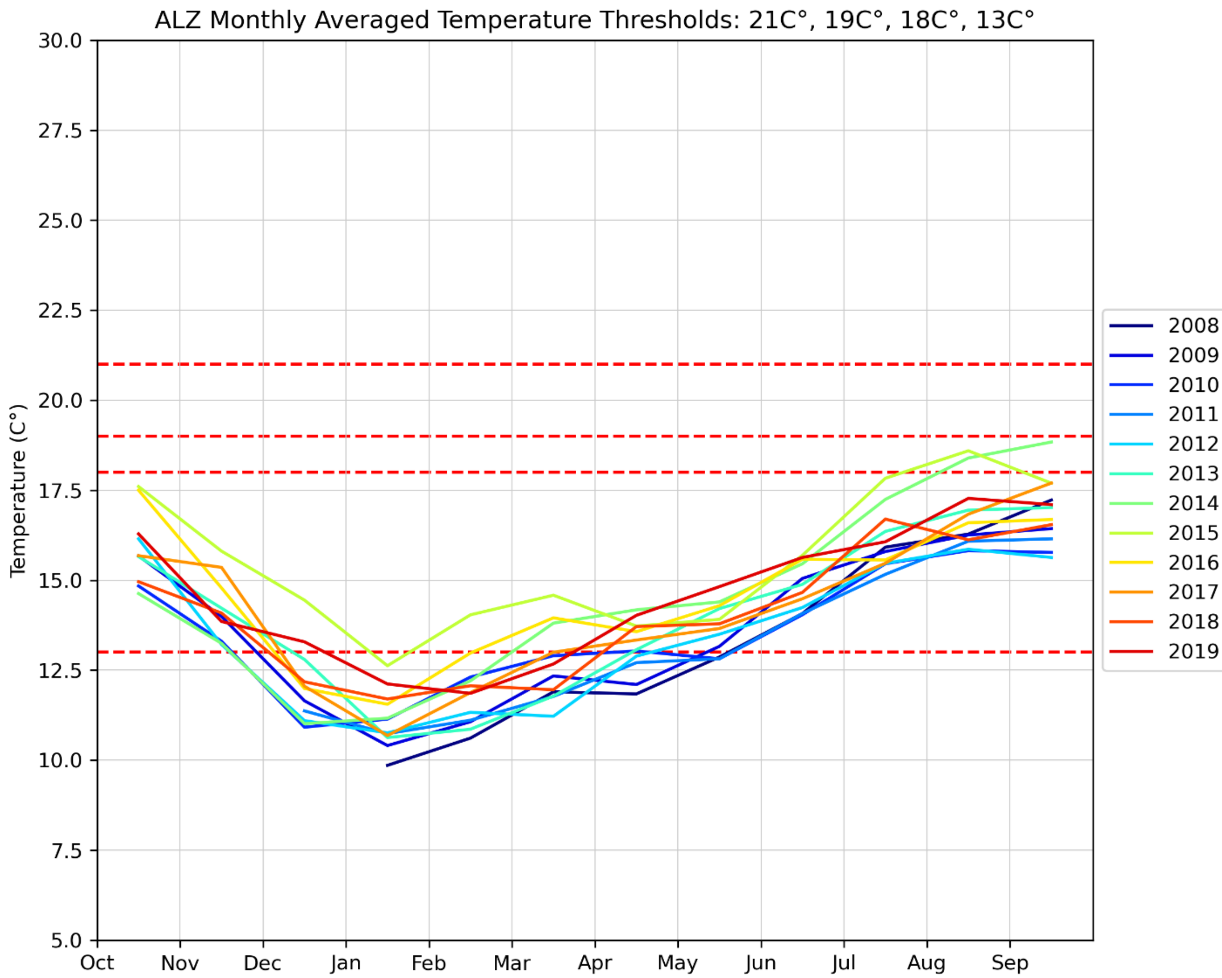

Figure C-5. Monthly Average Temperature for the Period of Record at Station ALZ – Alcatraz Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

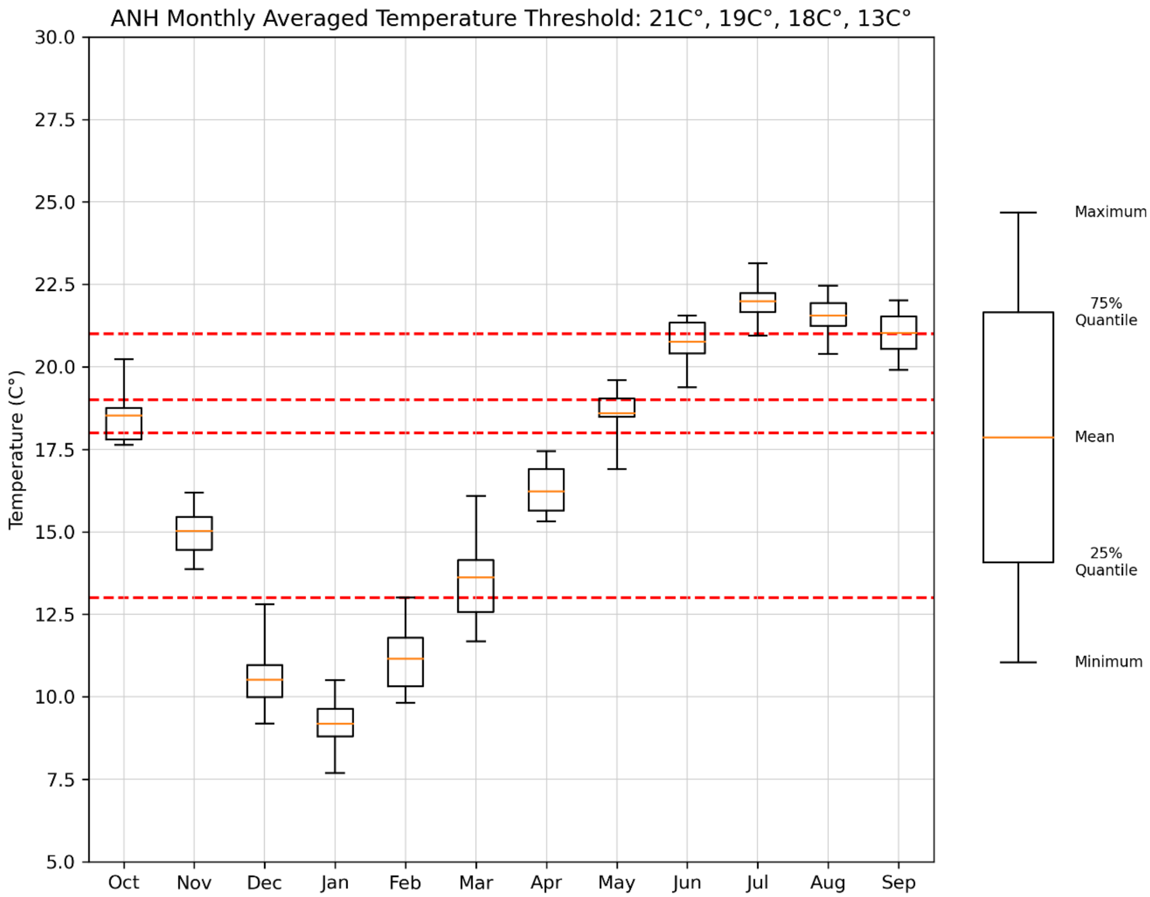

Figure C-6. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ANH – San Joaquin River at Antioch

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

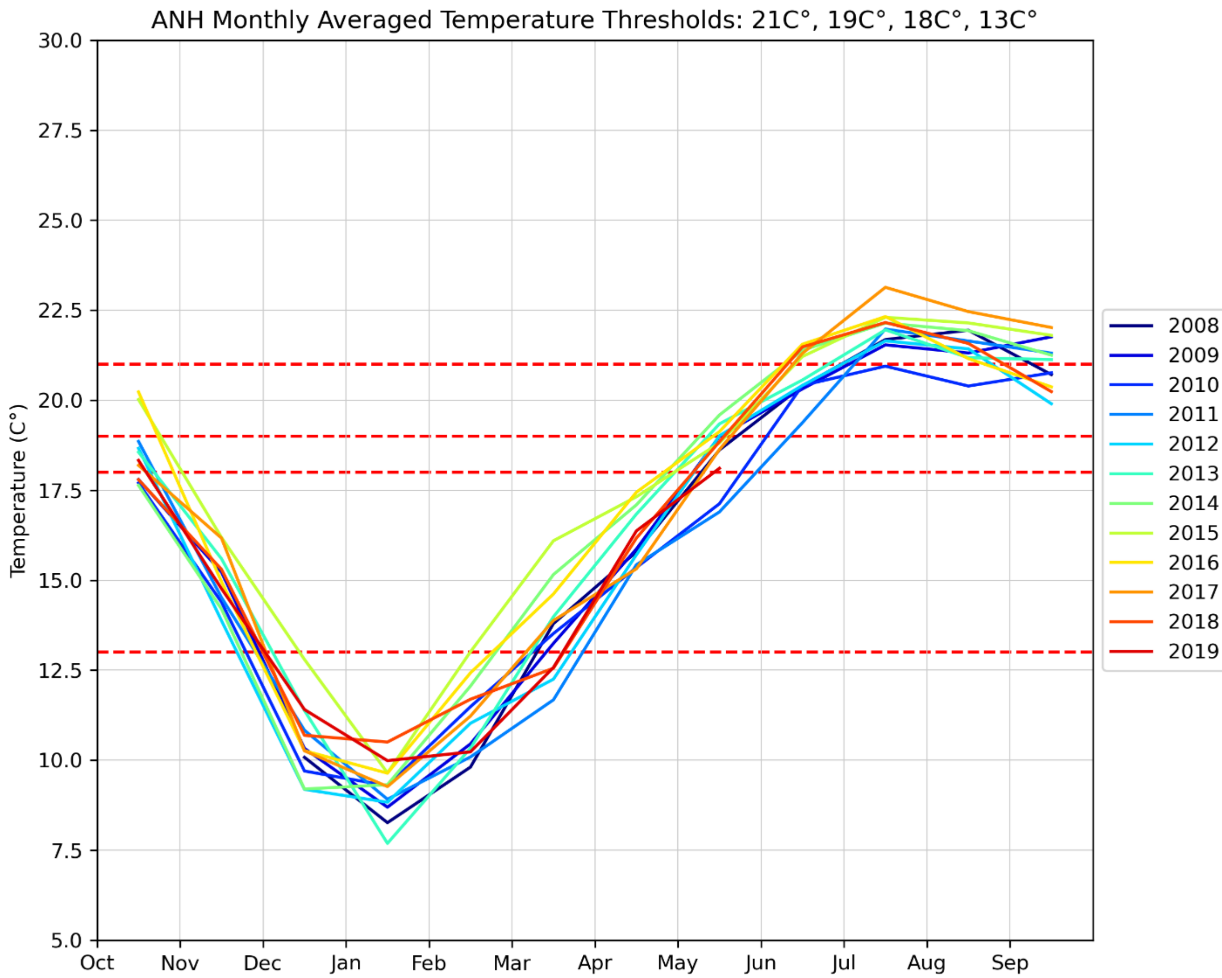

Figure C-7. Monthly Average Temperature for the Period of Record at Station ANH – San Joaquin River at Antioch

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

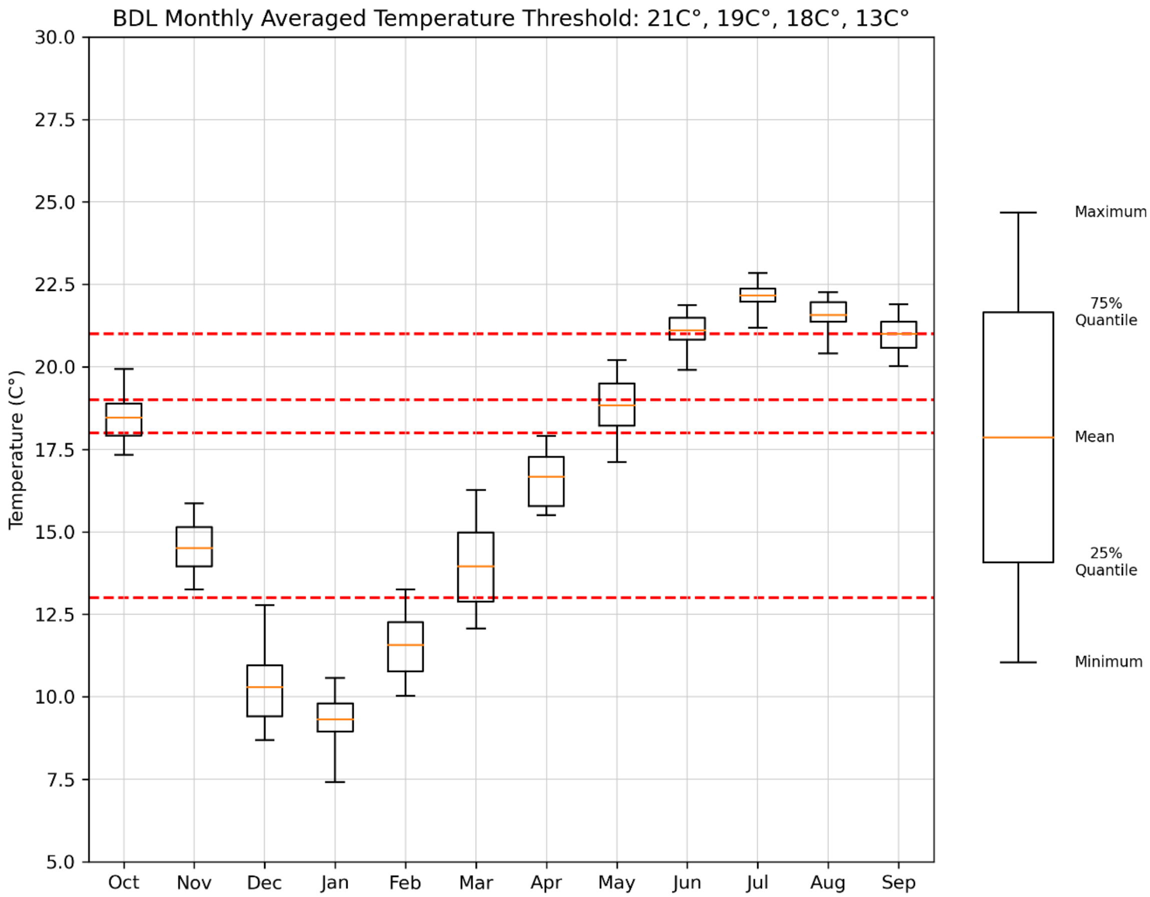

Figure C-8. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station BDL – Montezuma Slough at Beldon Landing

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

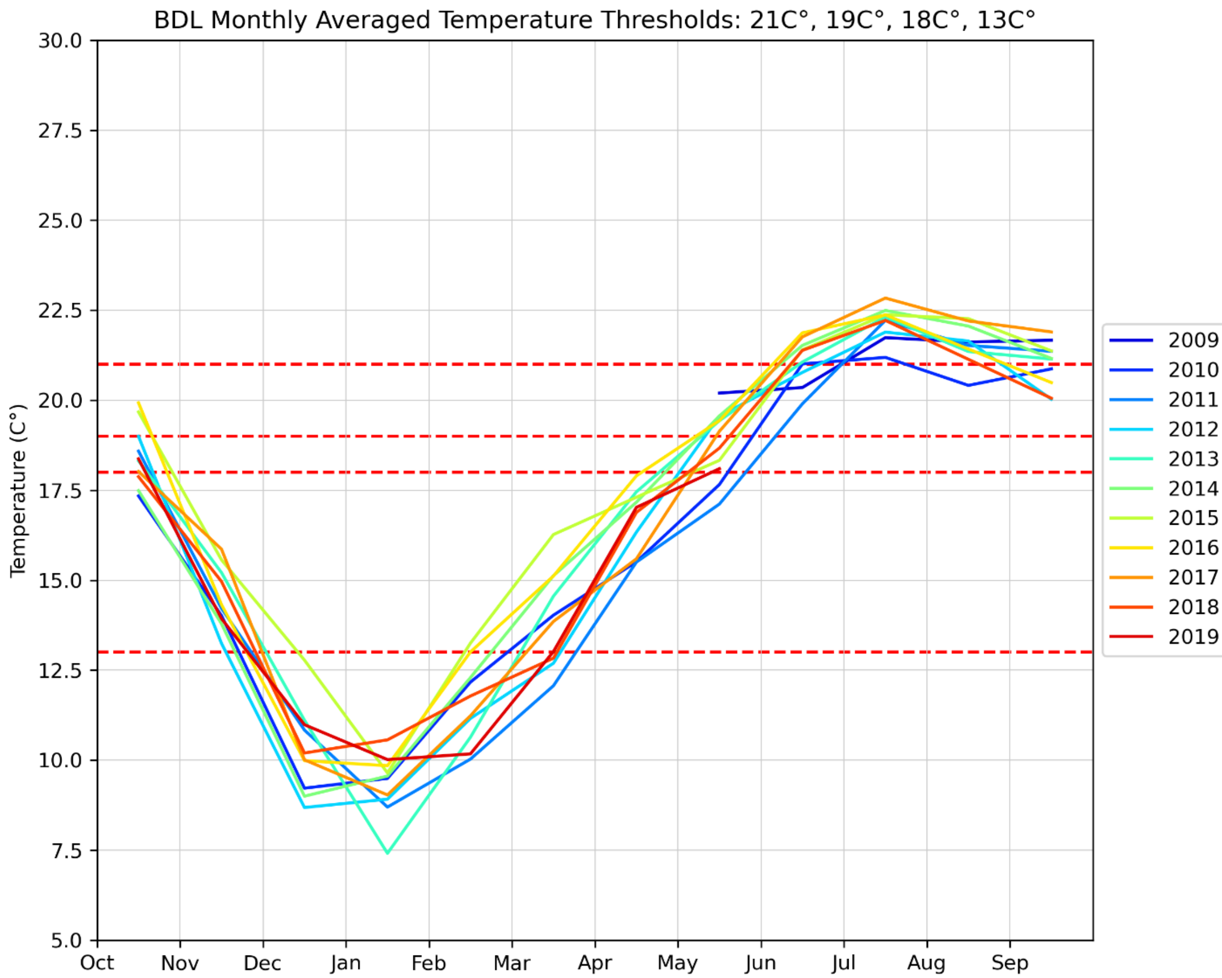

Figure C-9. Monthly Average Temperature for the Period of Record at Station BDL – Montezuma Slough at Beldon Landing

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

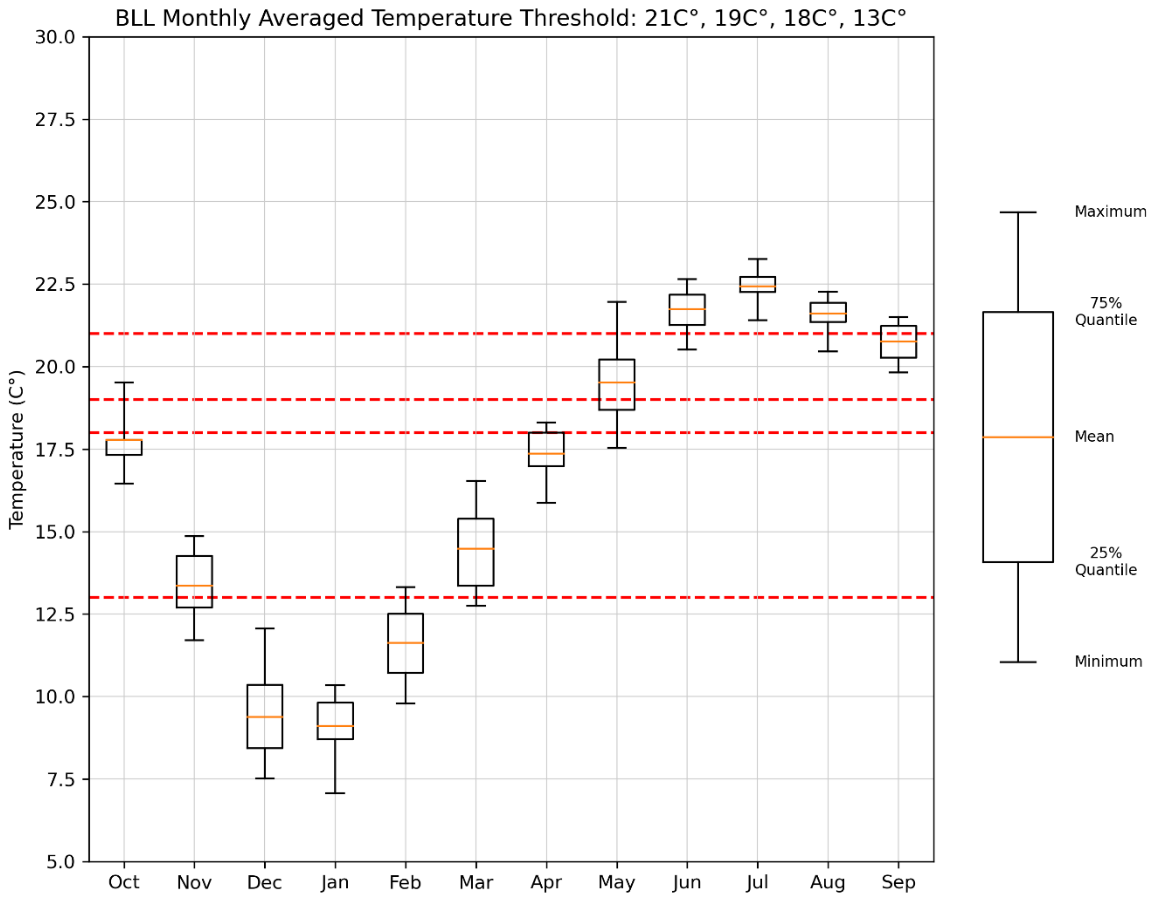

Figure C-10. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station BLL – Blacklock

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

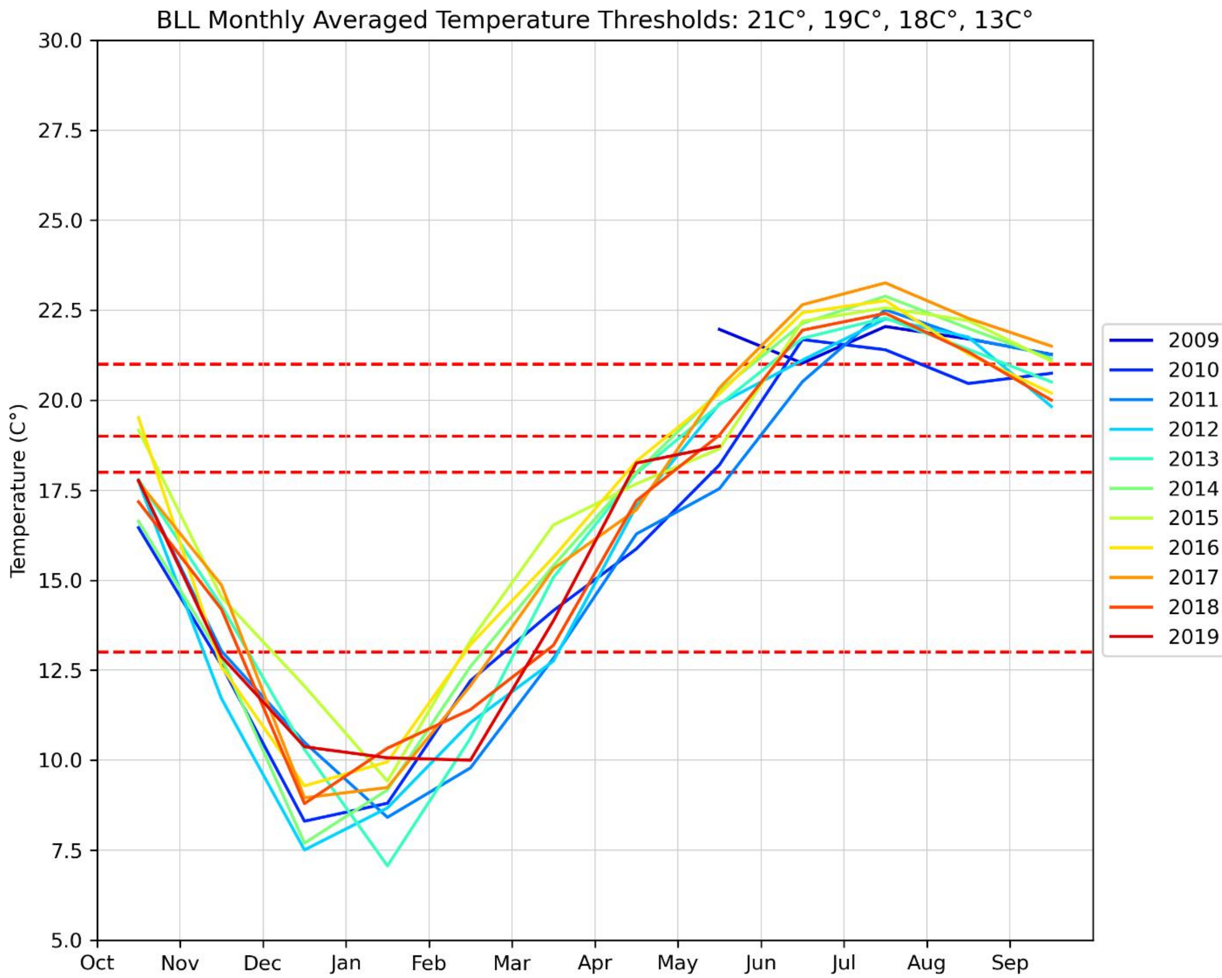

Figure C-11. Monthly Average Temperature for the Period of Record at Station BLL – Blacklock

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

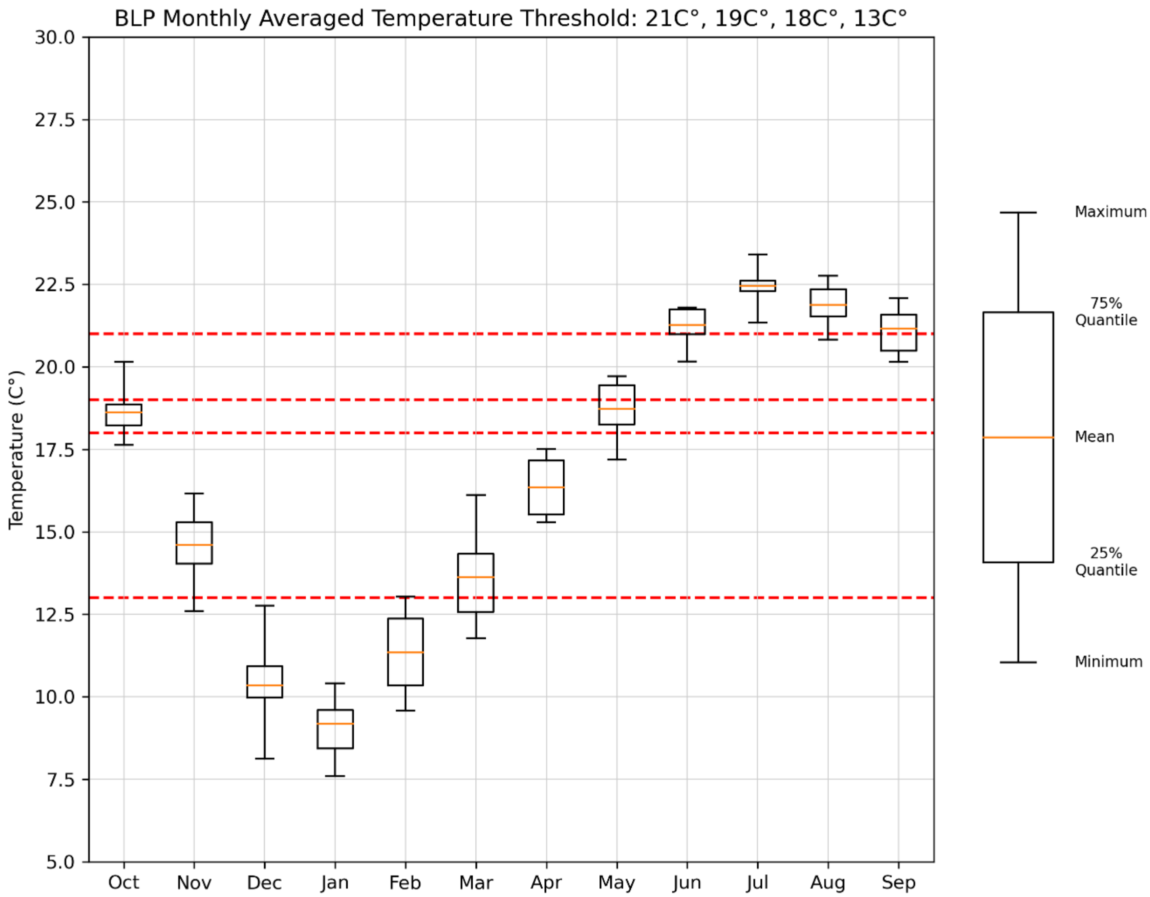

Figure C-12. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station BLP – Blind Point

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

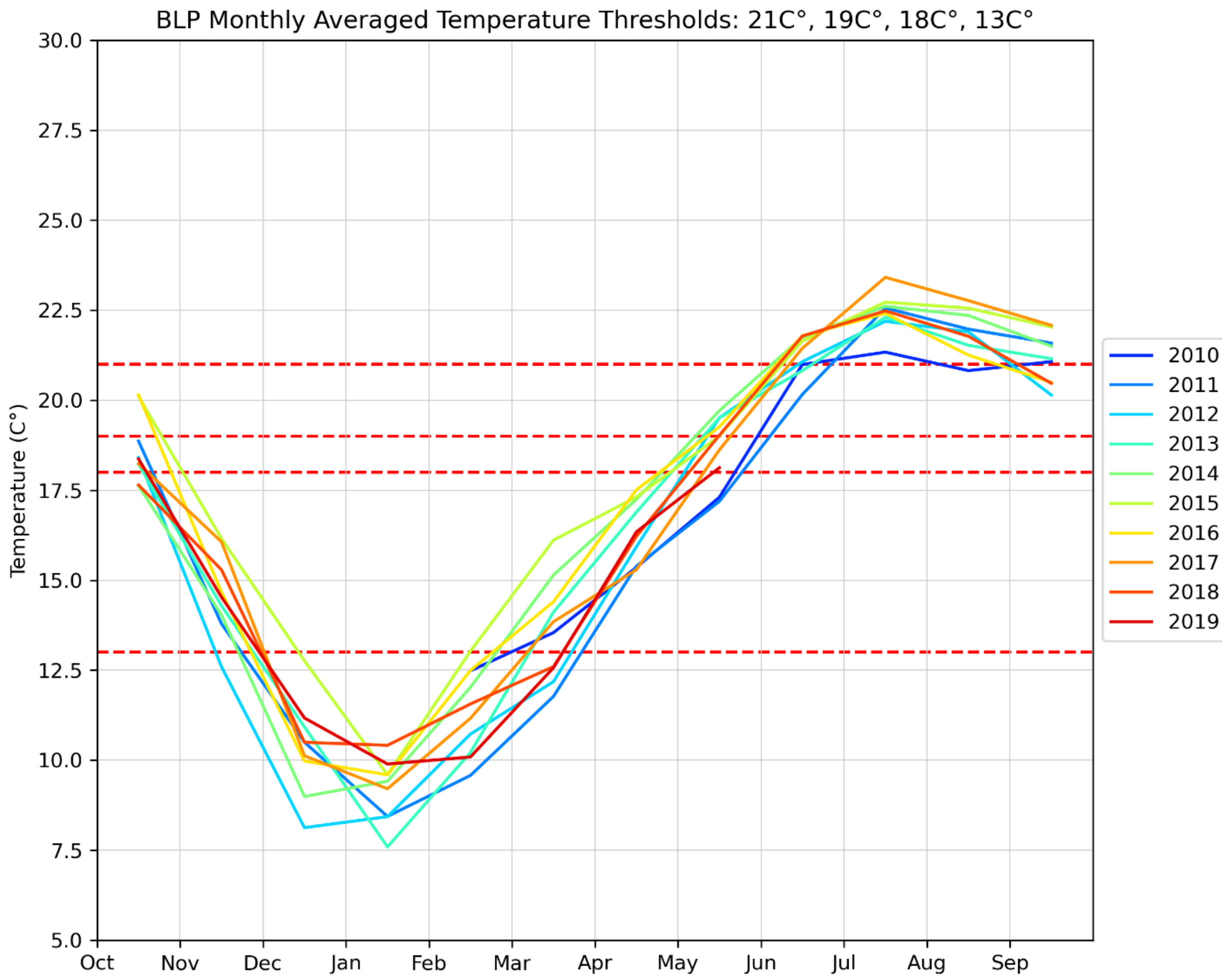

Figure C-13. Monthly Average Temperature for the Period of Record at Station BLP – Blind Point

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

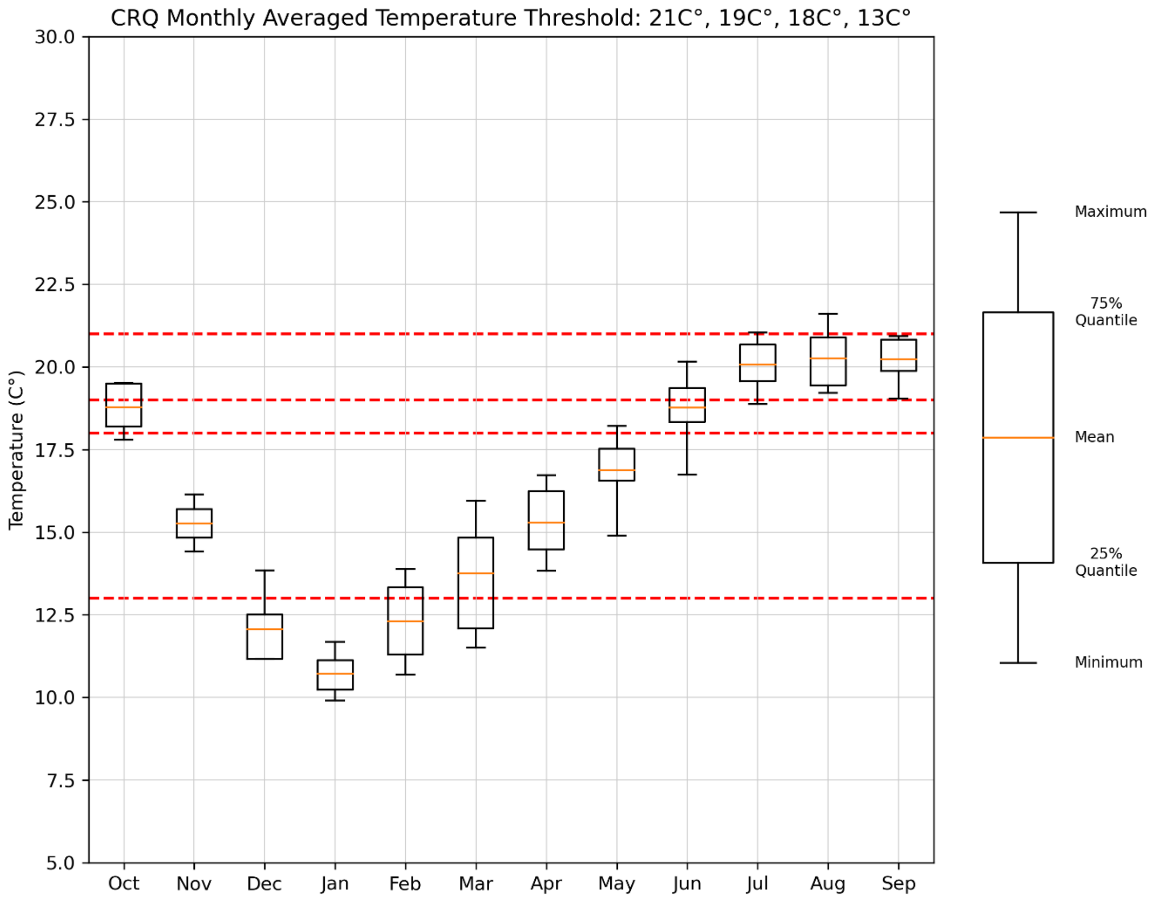

Figure C-14. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station CRQ – Carquinez Straight at Carquinez Bridge near Crockett

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

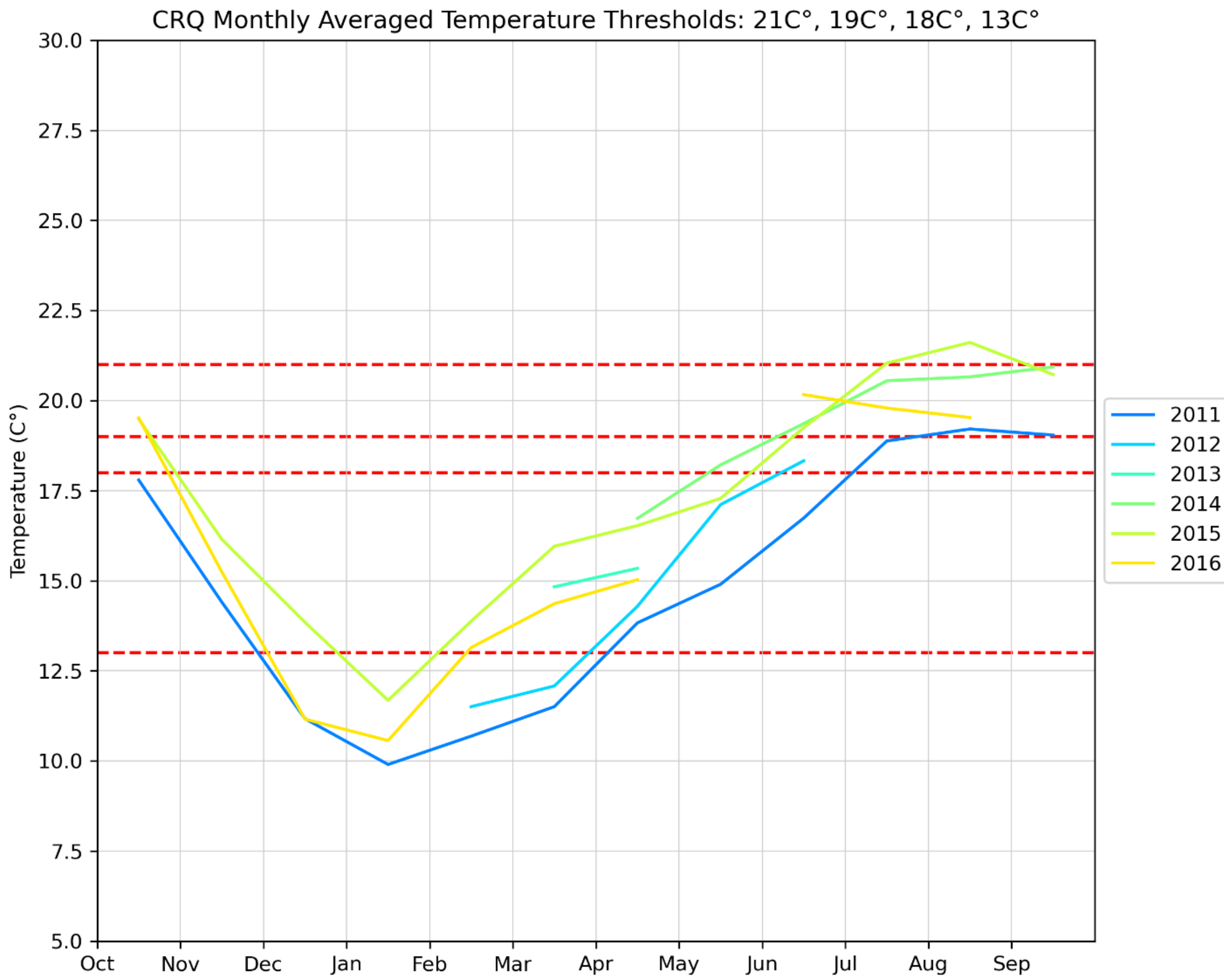

Figure C-15. Monthly Average Temperature for the Period of Record at Station CRQ – Carquinez Straight at Carquinez Bridge near Crockett

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

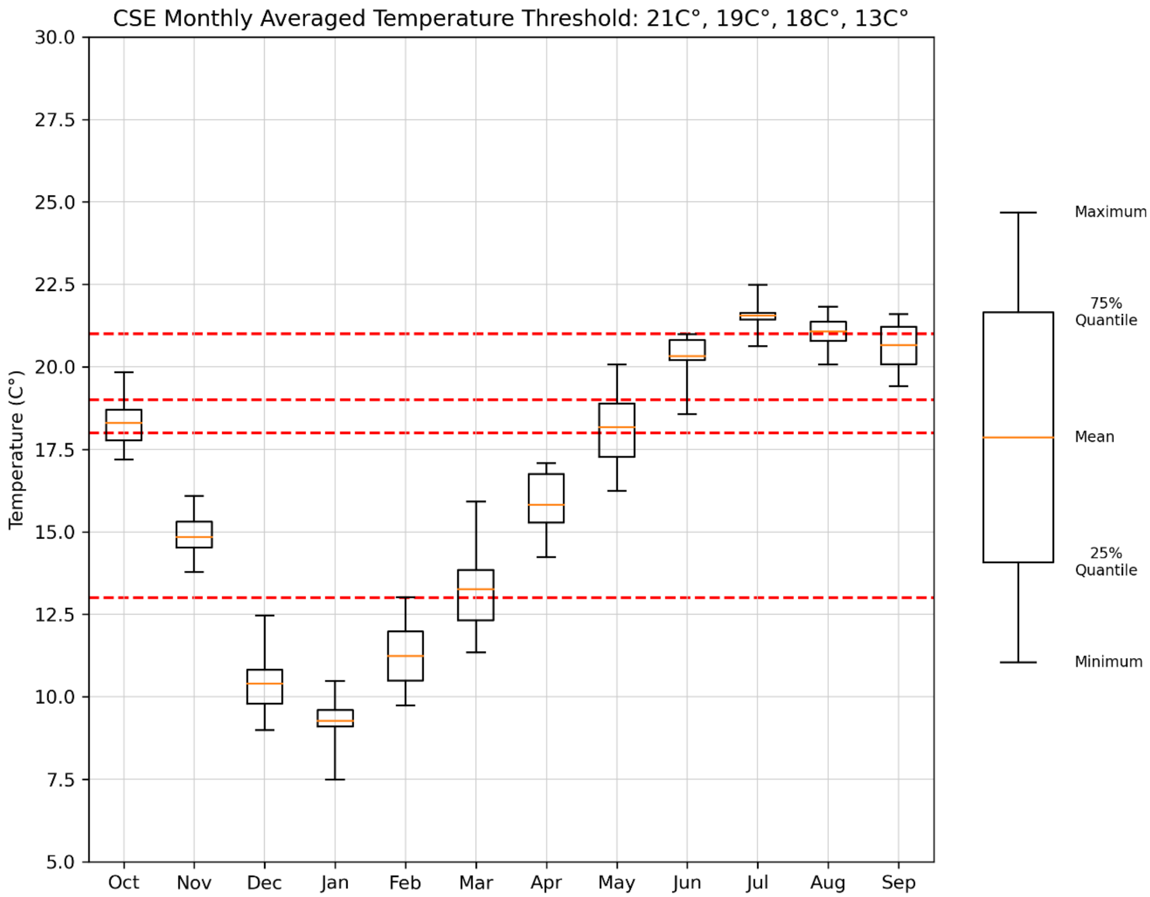

Figure C-16. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station CSE – Sacramento River at Collinsville

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

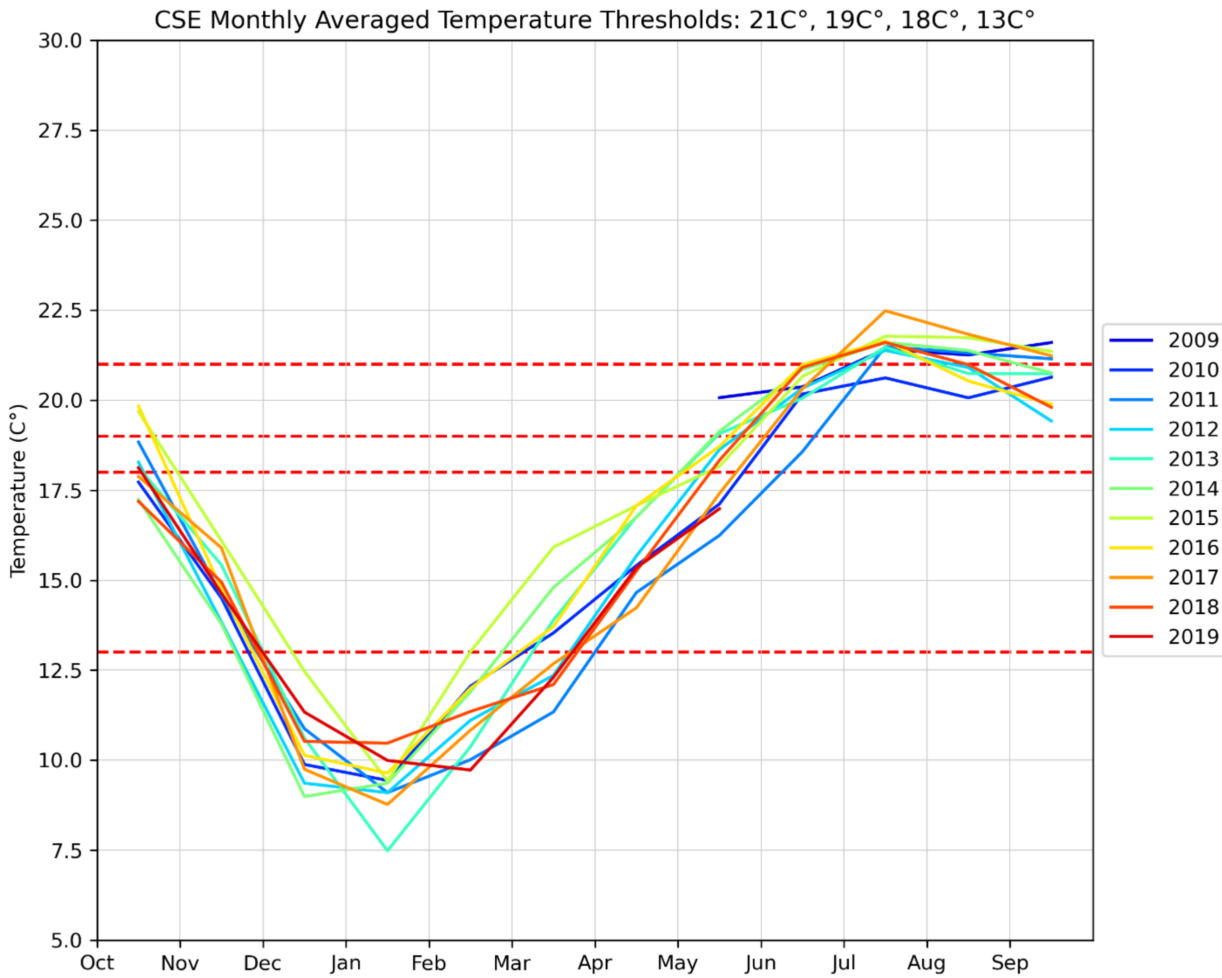

Figure C-17. Monthly Average Temperature for the Period of Record at Station CSE – Sacramento River at Collinsville

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

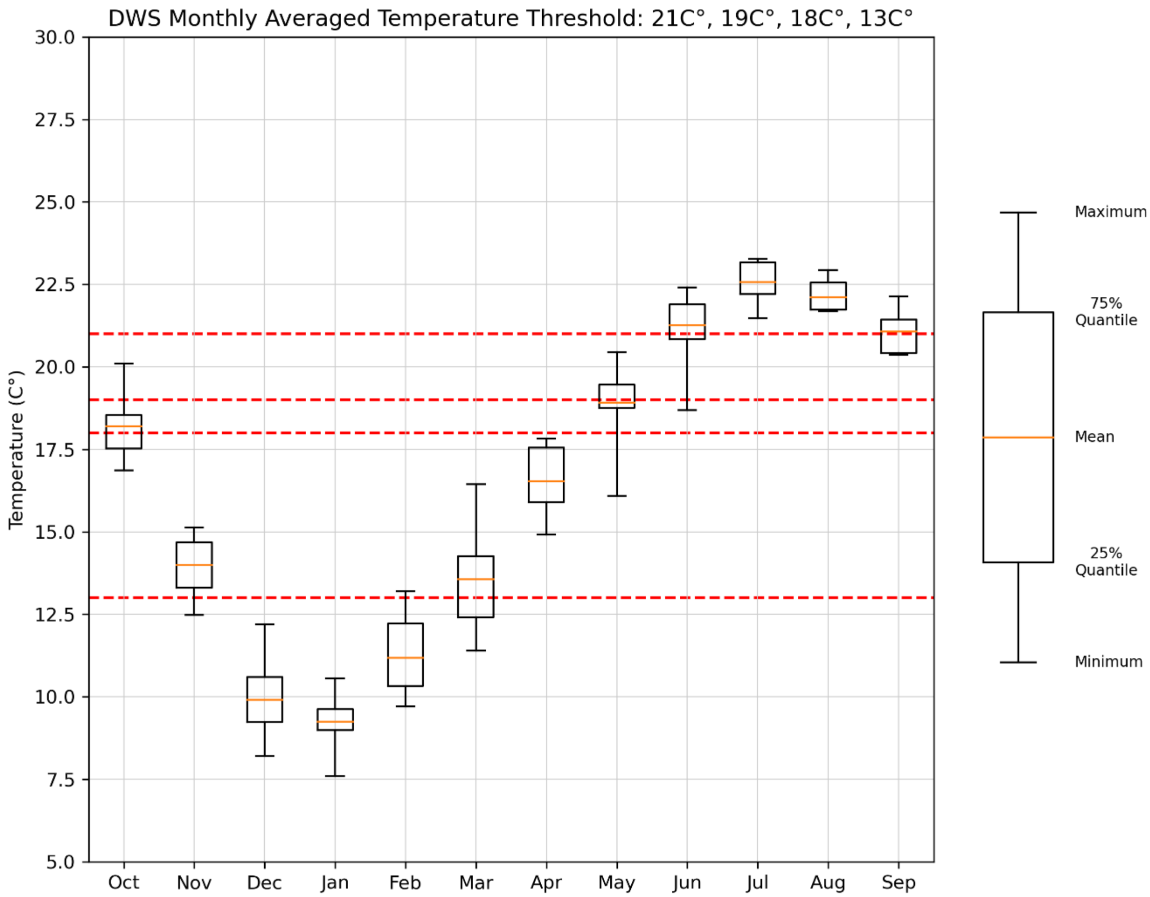

Figure C-18. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station DWS – Sacramento Deep Water Shipping Channel

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

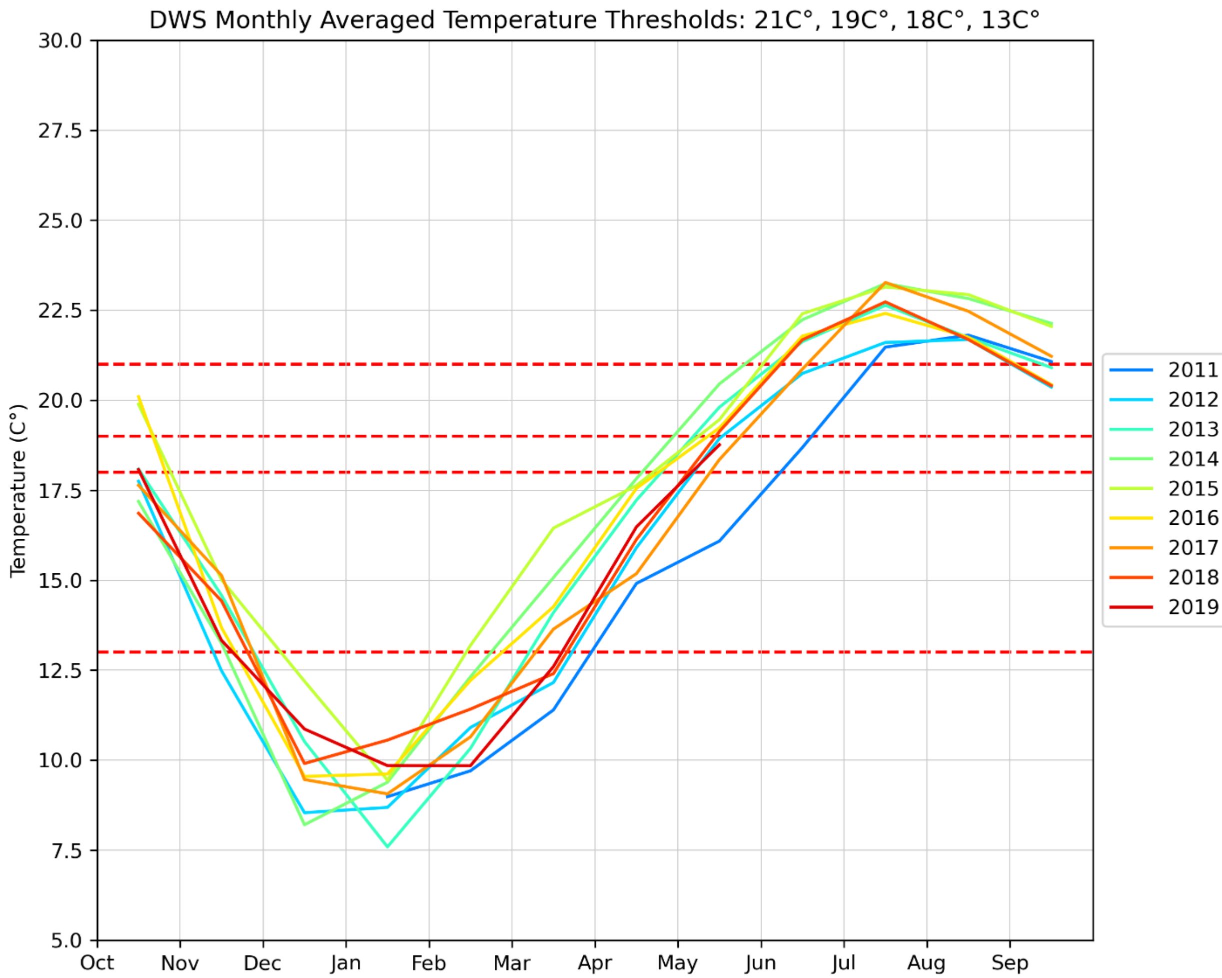

Figure C-19. Monthly Average Temperature for the Period of Record at Station DWS – Sacramento Deep Water Shipping Channel

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

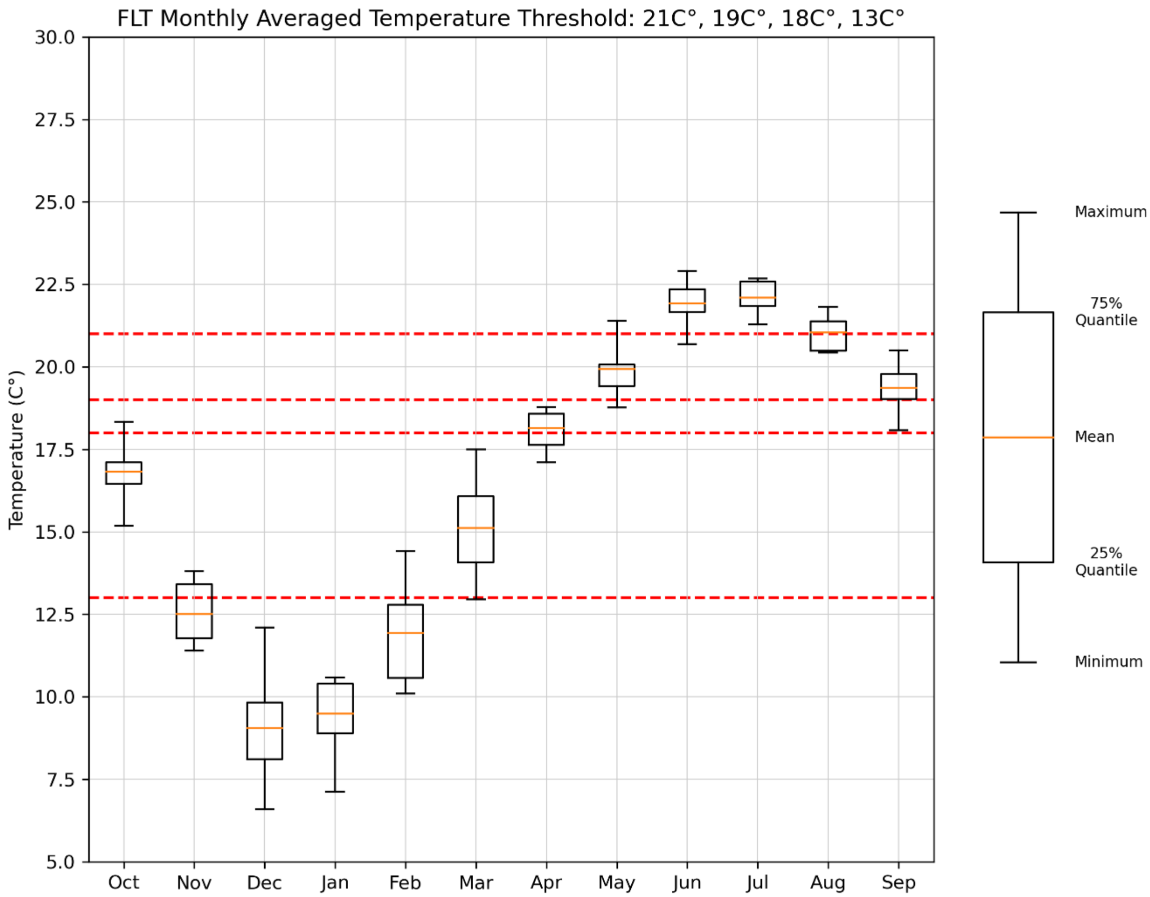

Figure C-20. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station FLT – Goodyear Slough Outfall at Naval Fleet

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

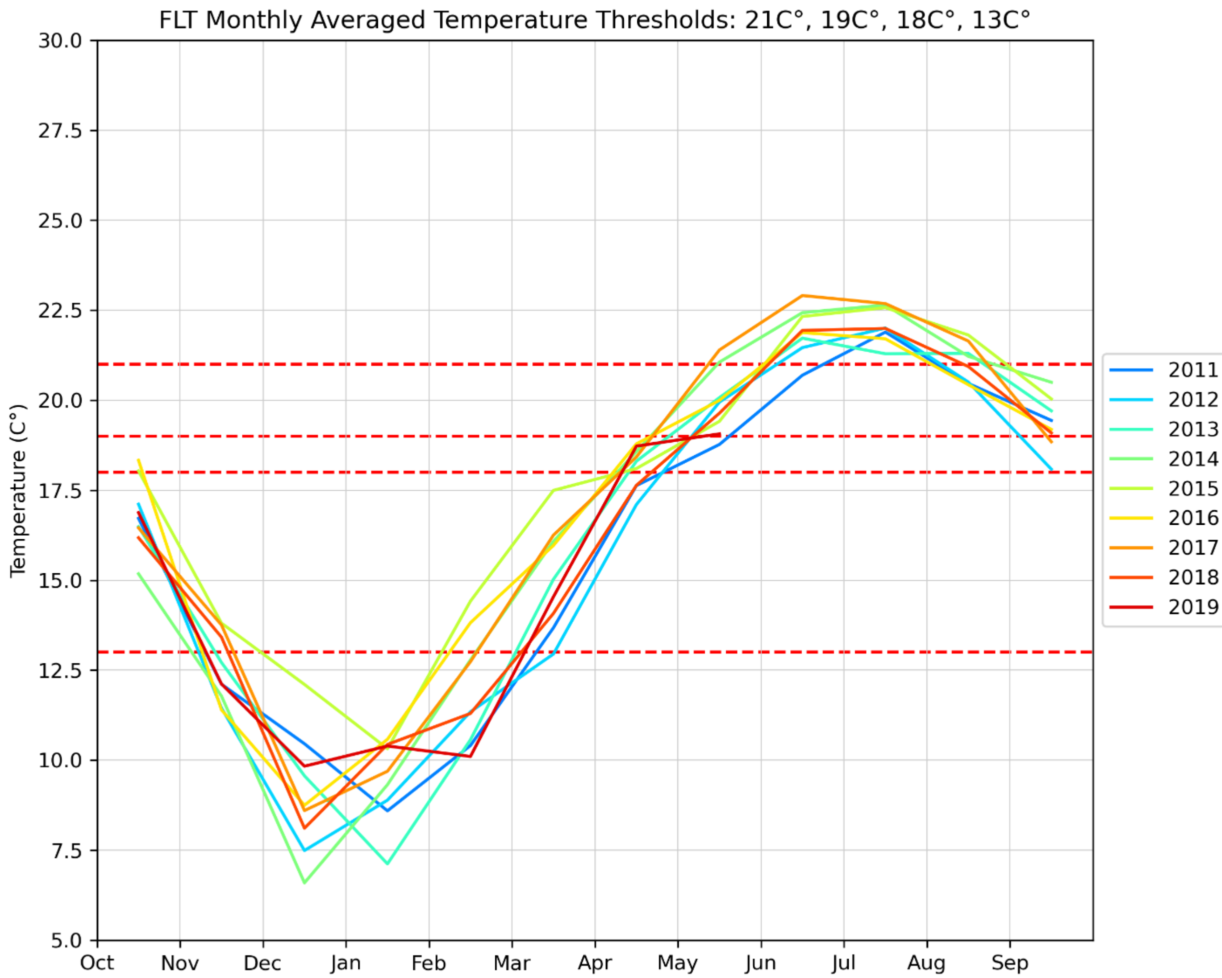

Figure C-21. Monthly Average Temperature for the Period of Record at Station FLT – Goodyear Slough Outfall at Naval Fleet

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

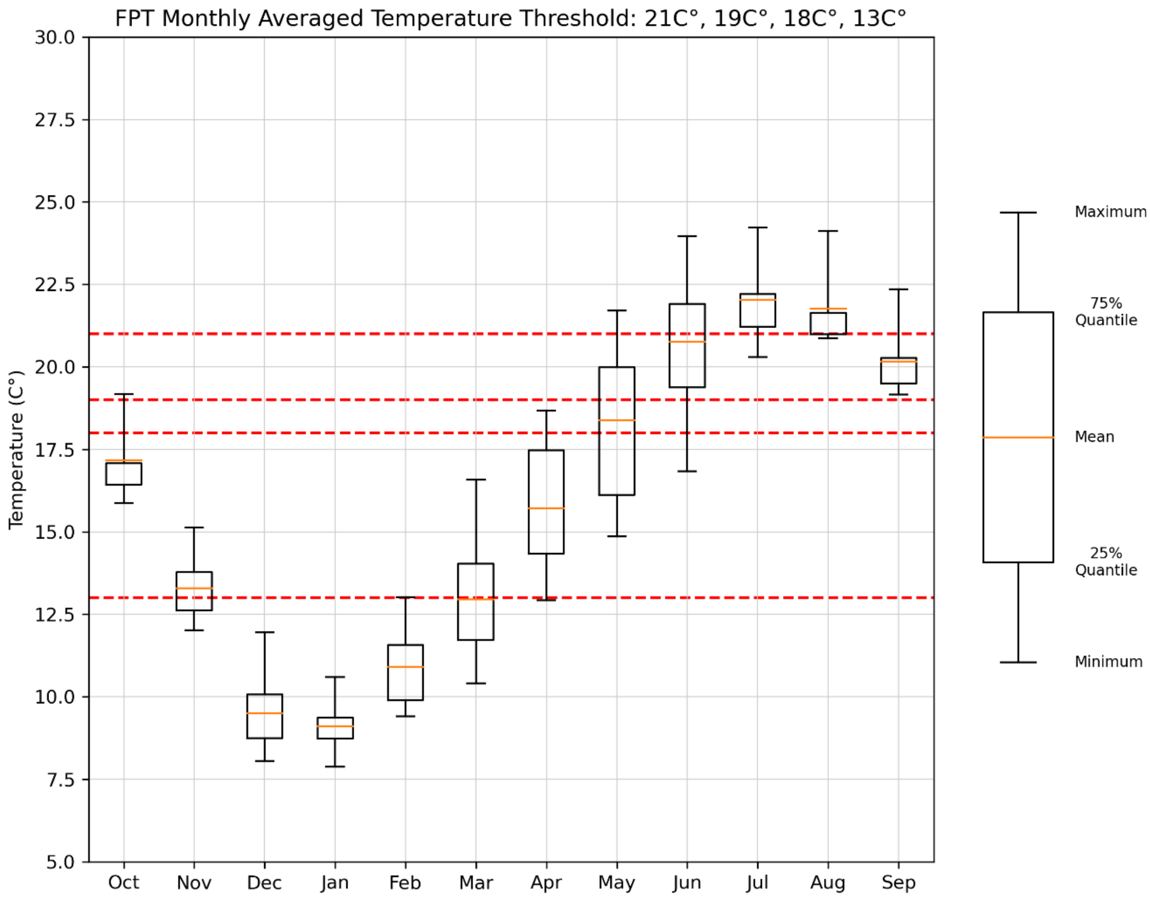

Figure C-22. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station FPT – Sacramento River at Freeport

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

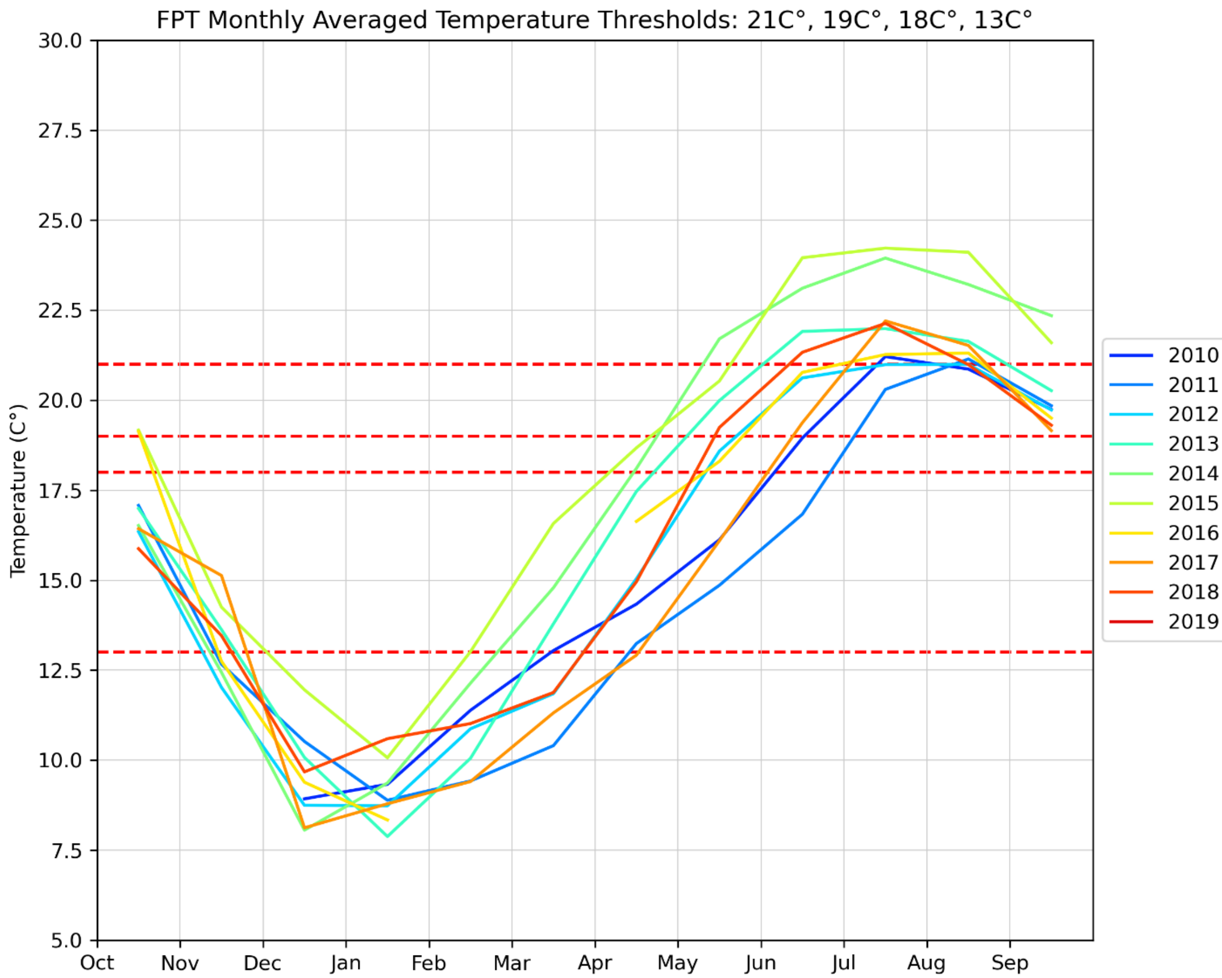

Figure C-23. Monthly Average Temperature for the Period of Record at Station FPT – Sacramento River at Freeport

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

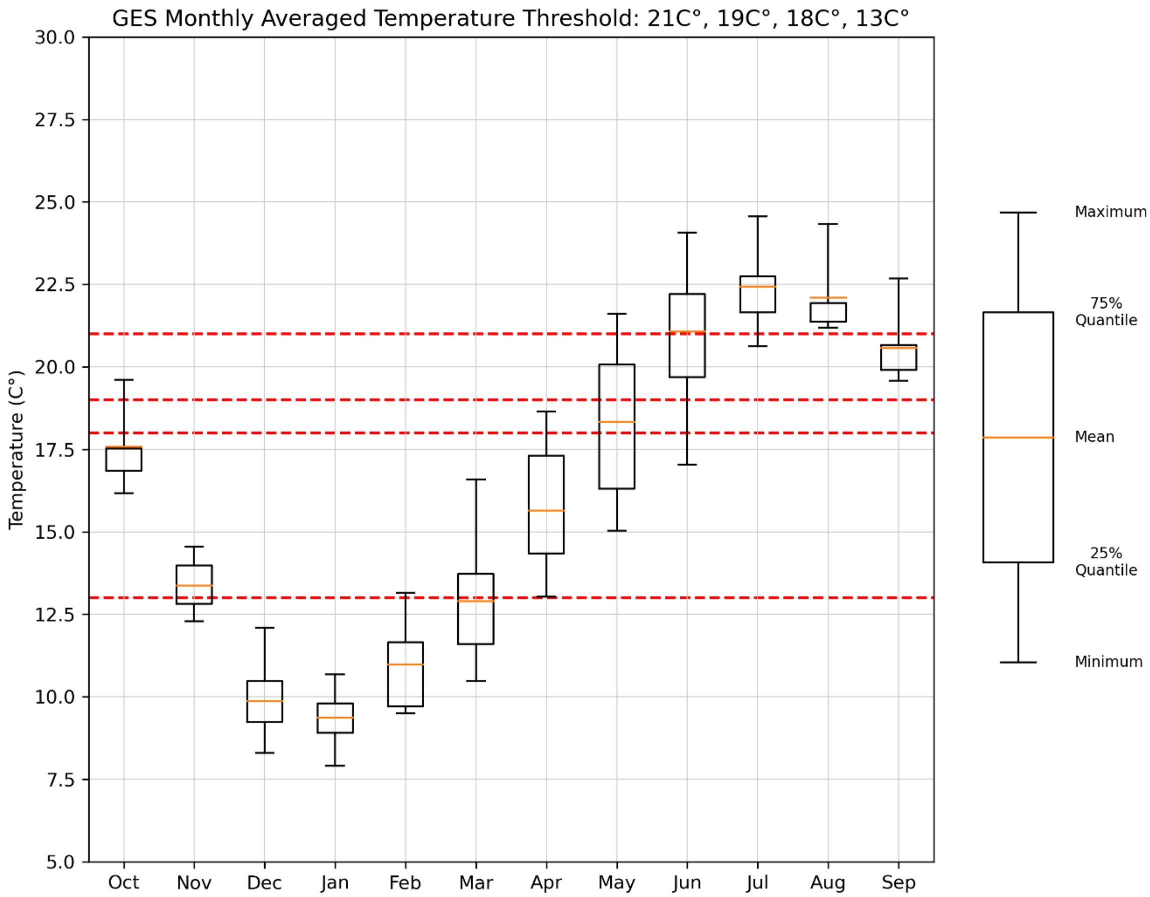

Figure C-24. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GES – Sacramento River below Georgiana Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

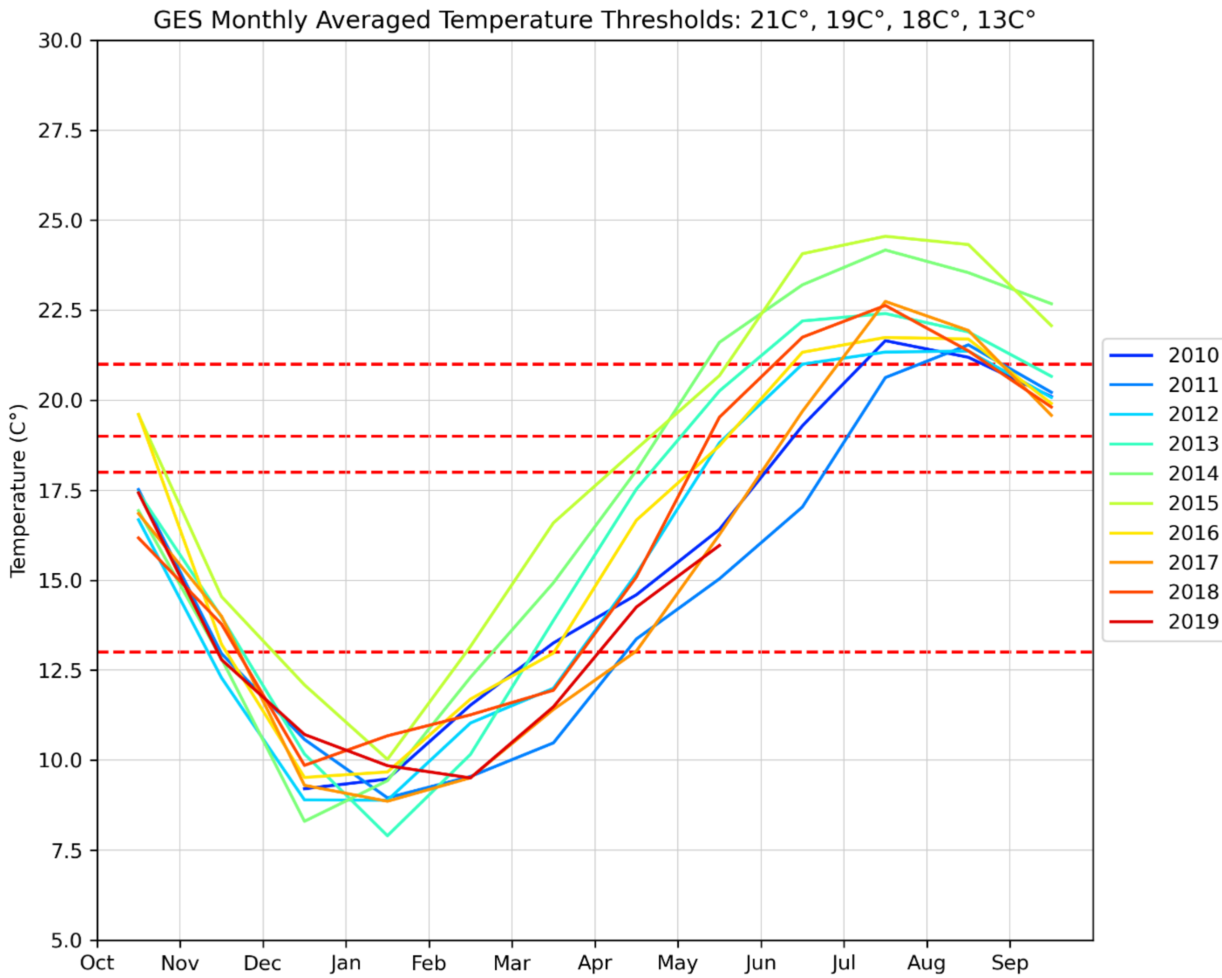

Figure C-25. Monthly Average Temperature for the Period of Record at Station GES – Sacramento River below Georgiana Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

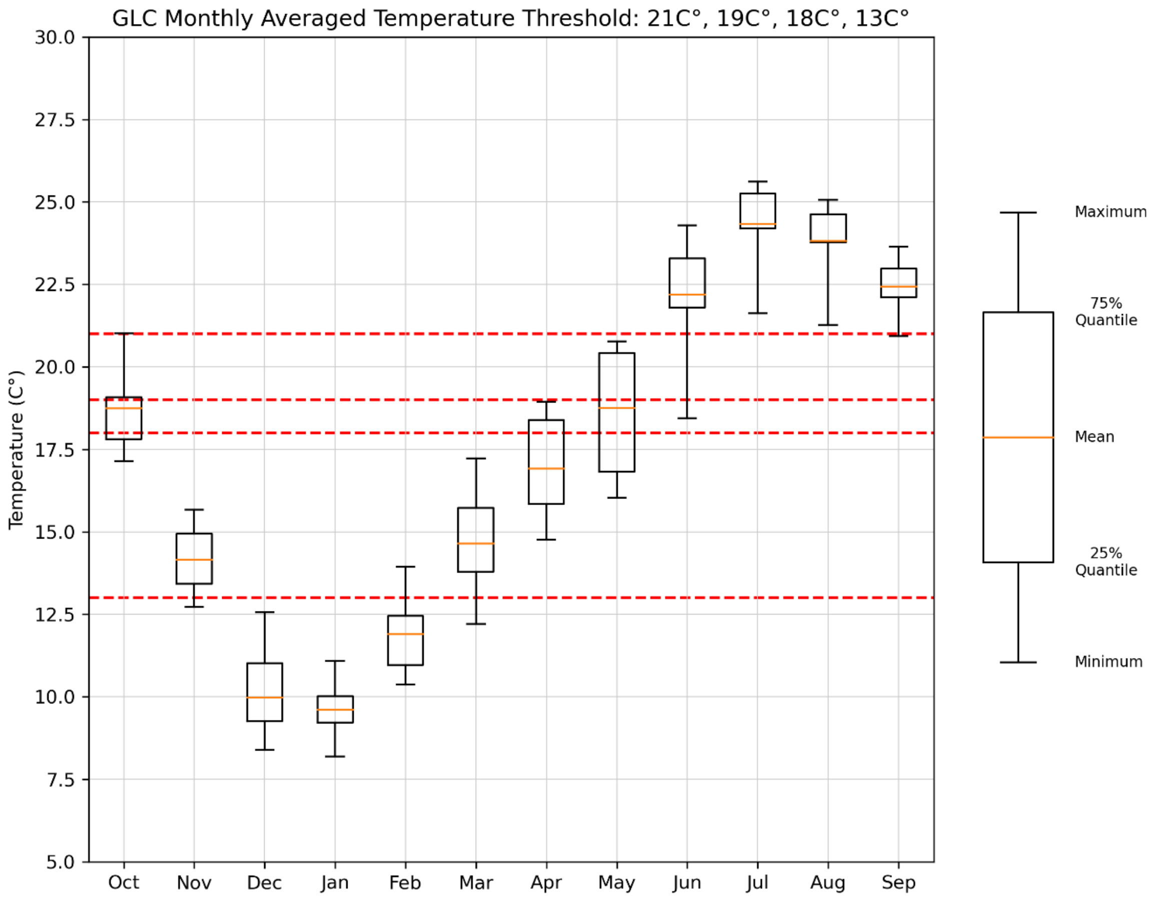

Figure C-26. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GLC – Grantline Canal

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

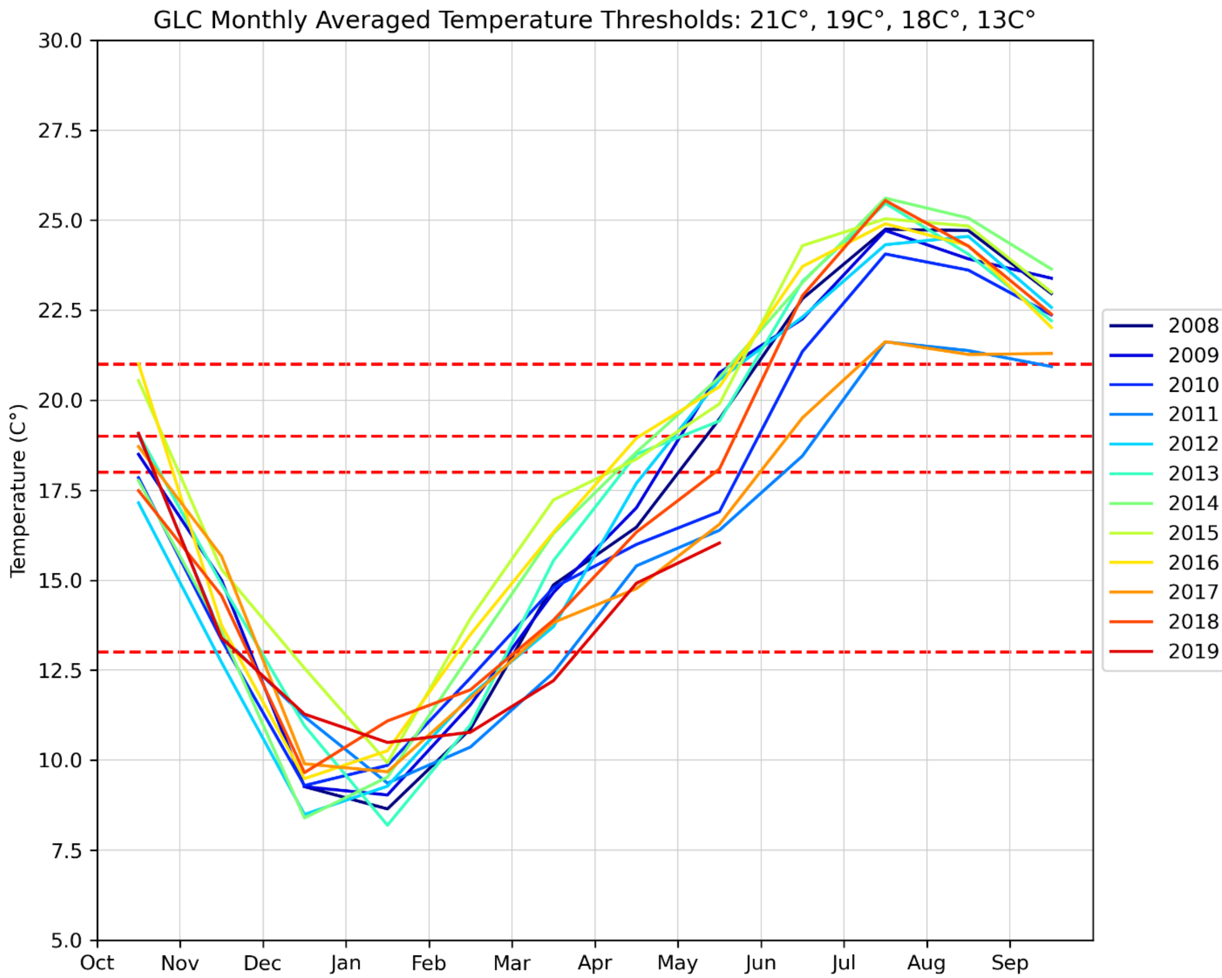

Figure C-27. Monthly Average Temperature for the Period of Record at Station GLC – Grantline Canal

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

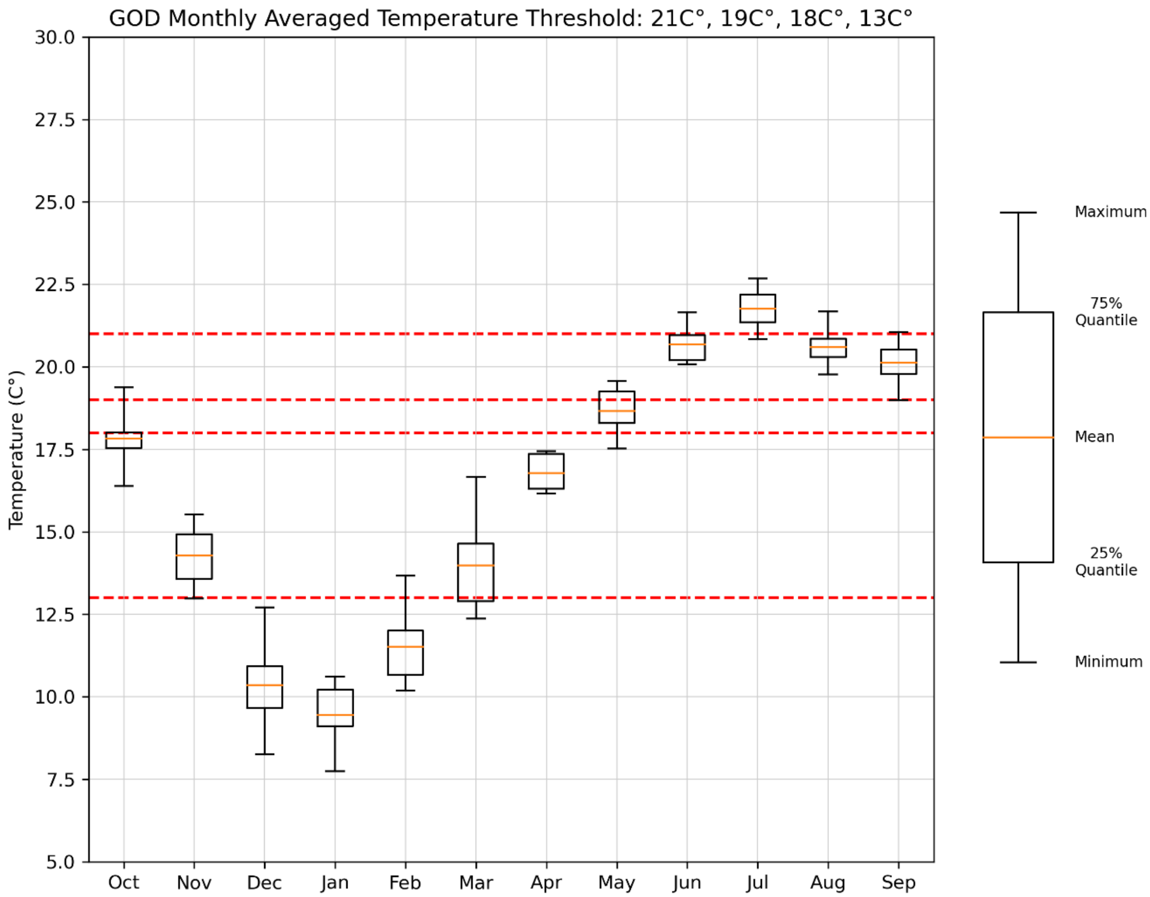

Figure C-28. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GOD – Godfather II on Suisun Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

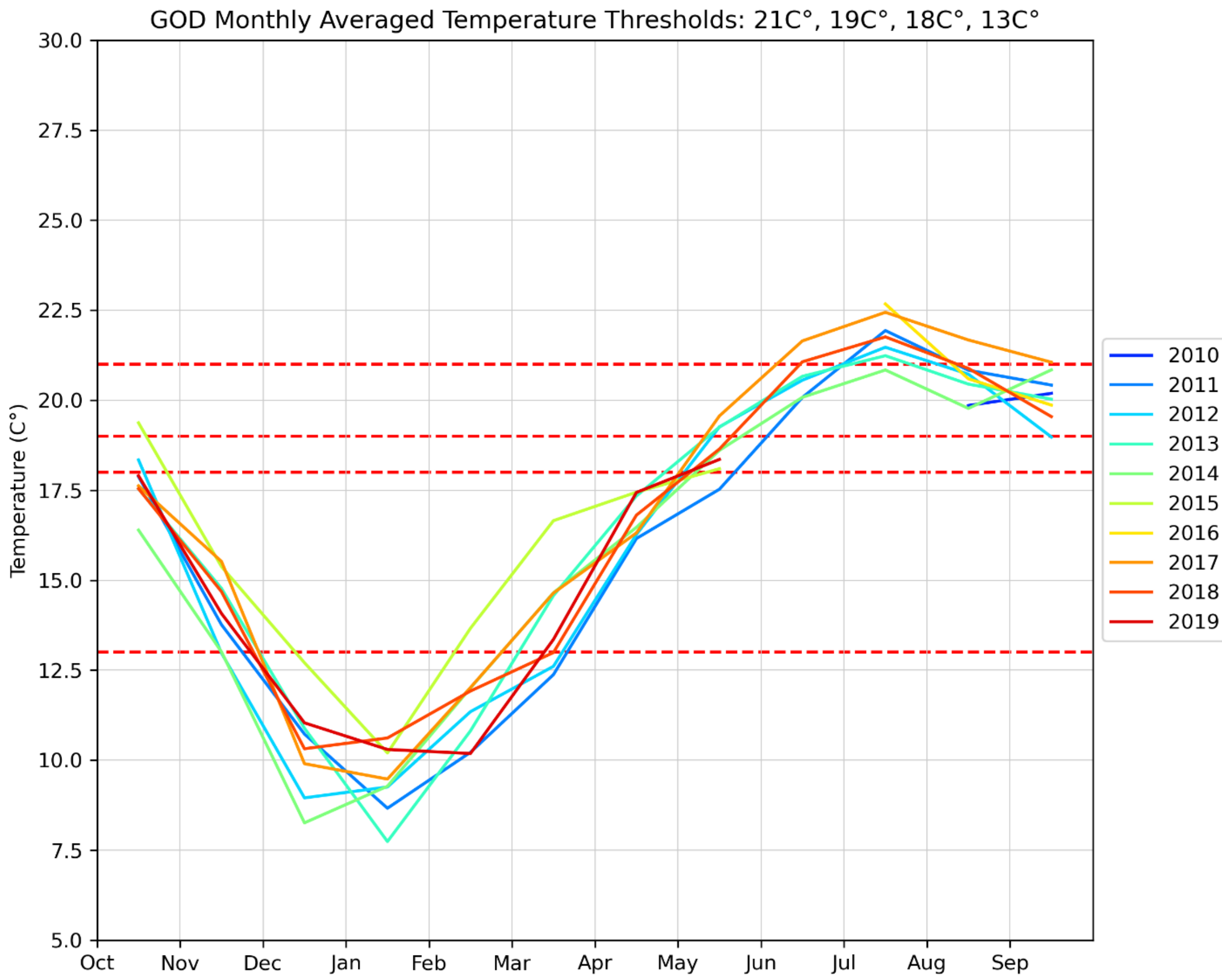

Figure C-29. Monthly Average Temperature for the Period of Record at Station GOD – Godfather II on Suisun Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

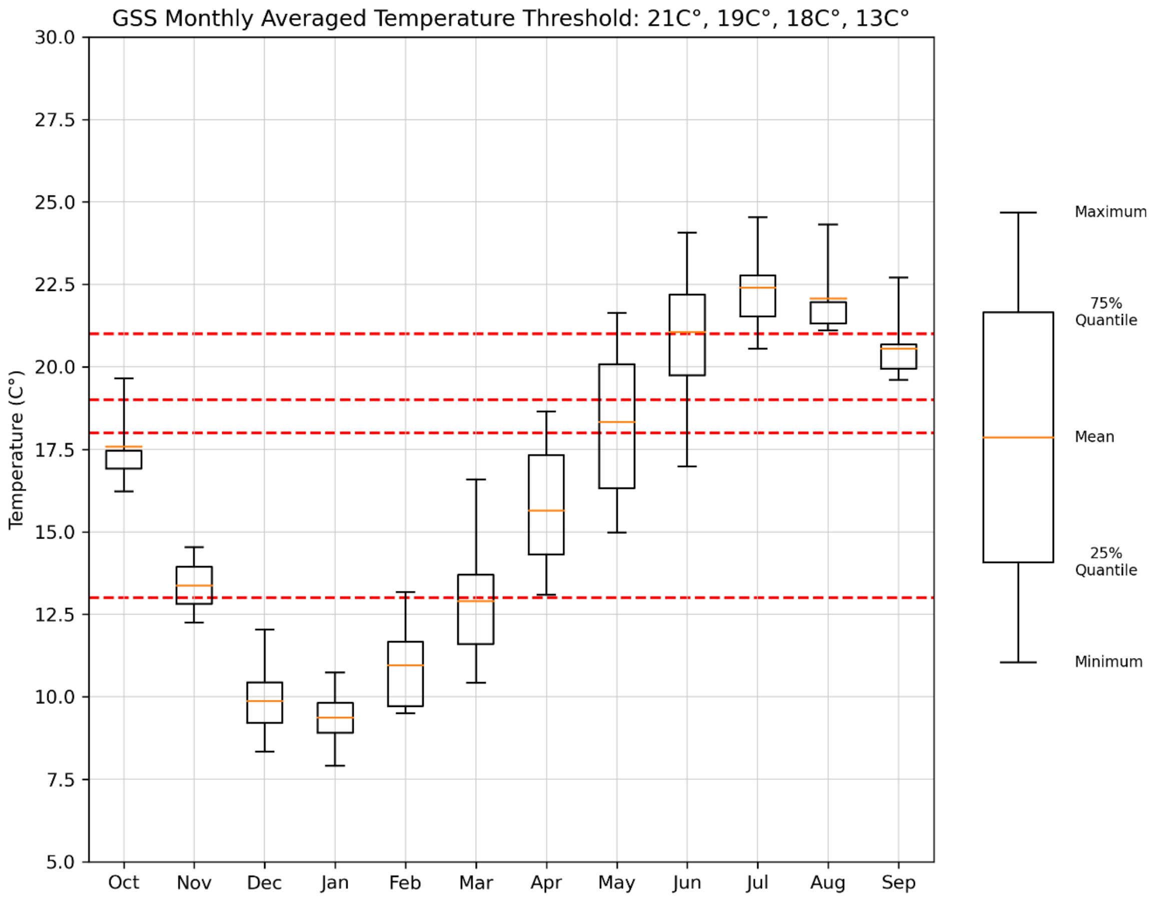

Figure C-30. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GSS – Georgiana Slough at Sacramento River

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

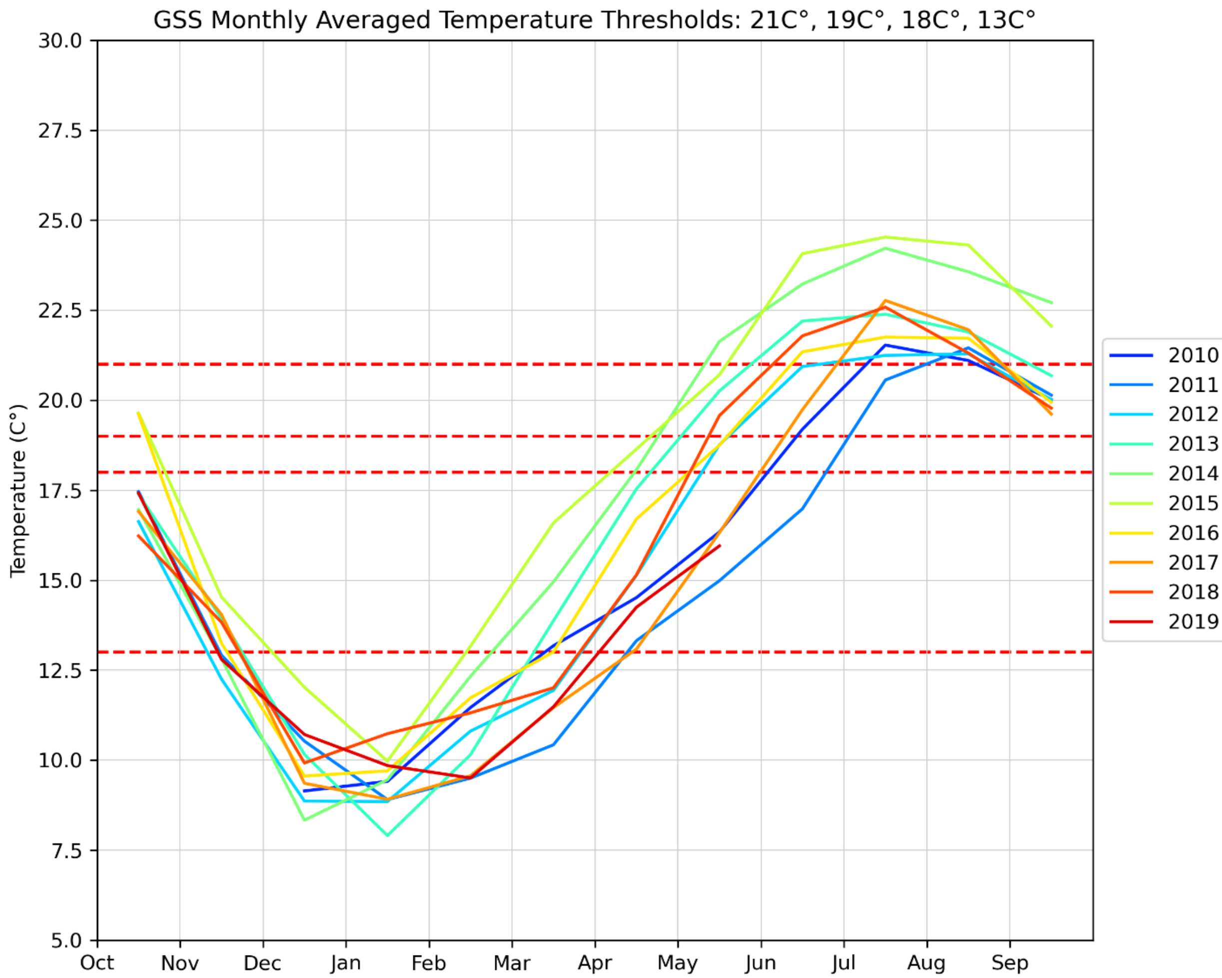

Figure C-31. Monthly Average Temperature for the Period of Record at Station GSS – Georgiana Slough at Sacramento River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

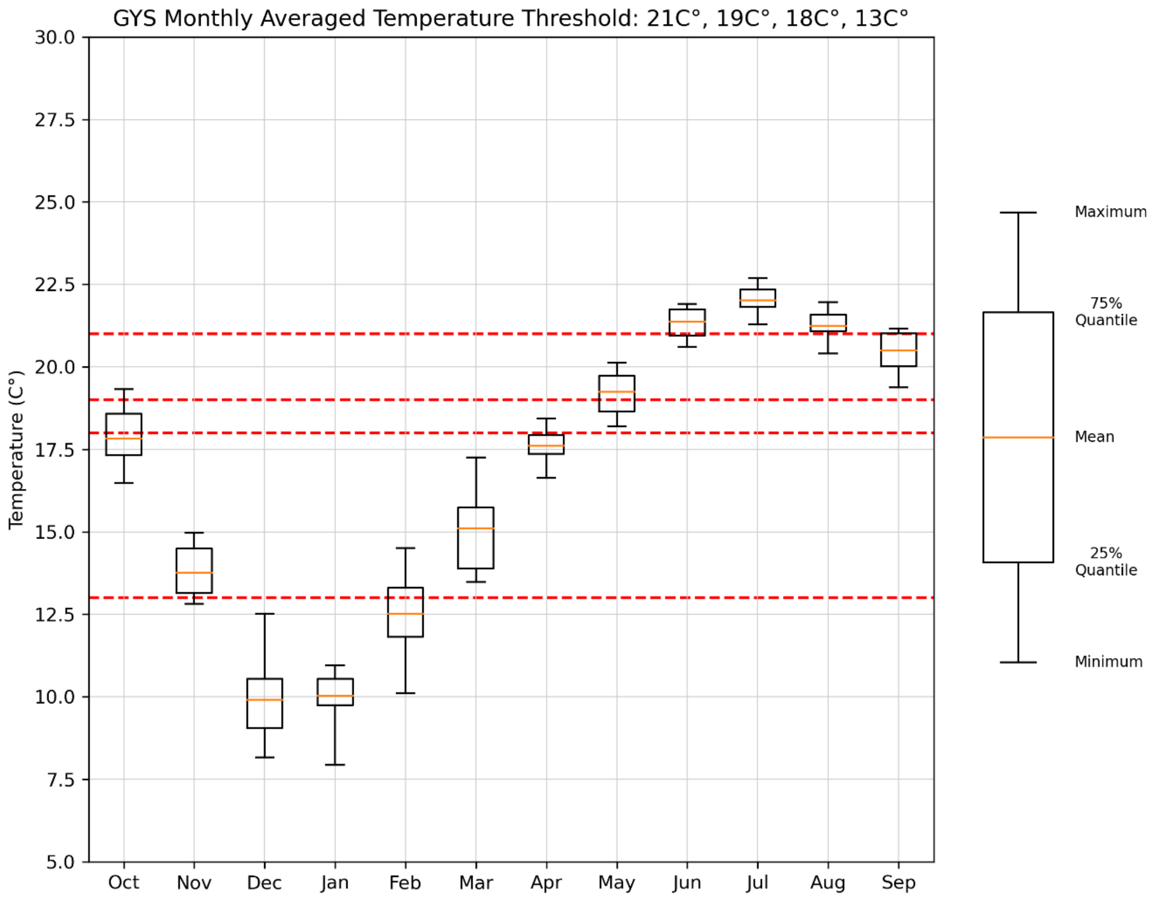

Figure C-32. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GYS – Goodyear Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

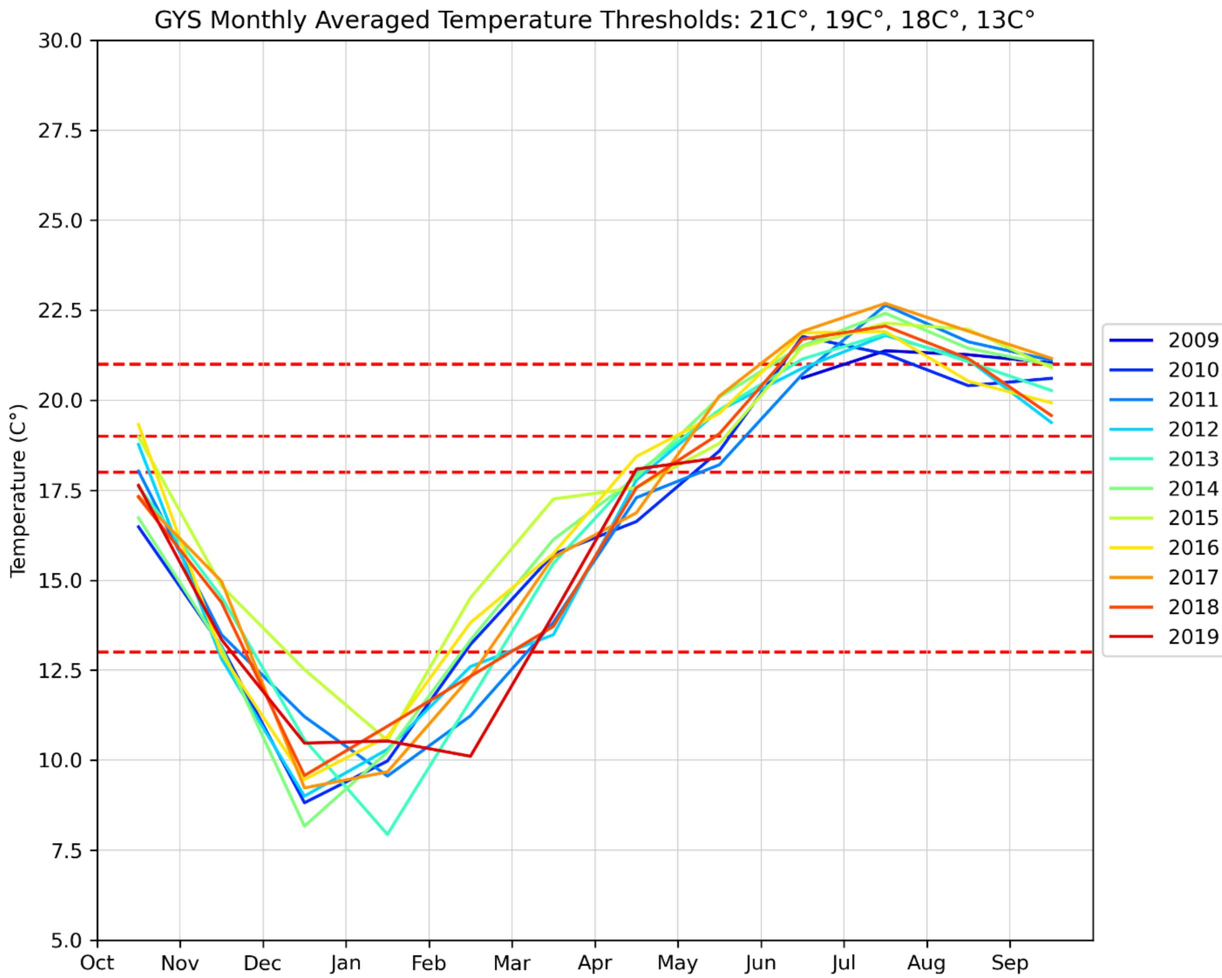

Figure C-33. Monthly Average Temperature for the Period of Record at Station GYS – Goodyear Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

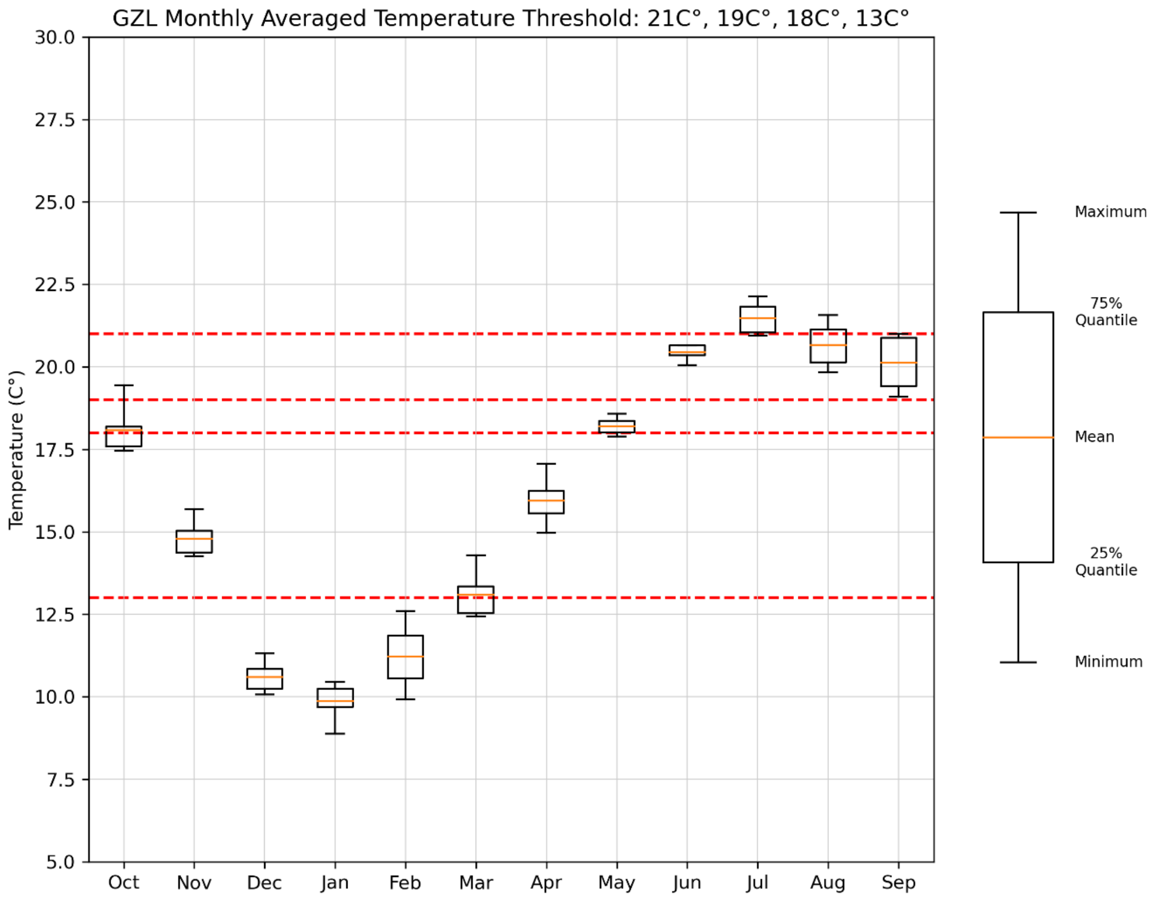

Figure C-34. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GZL – Grizzly Bay

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

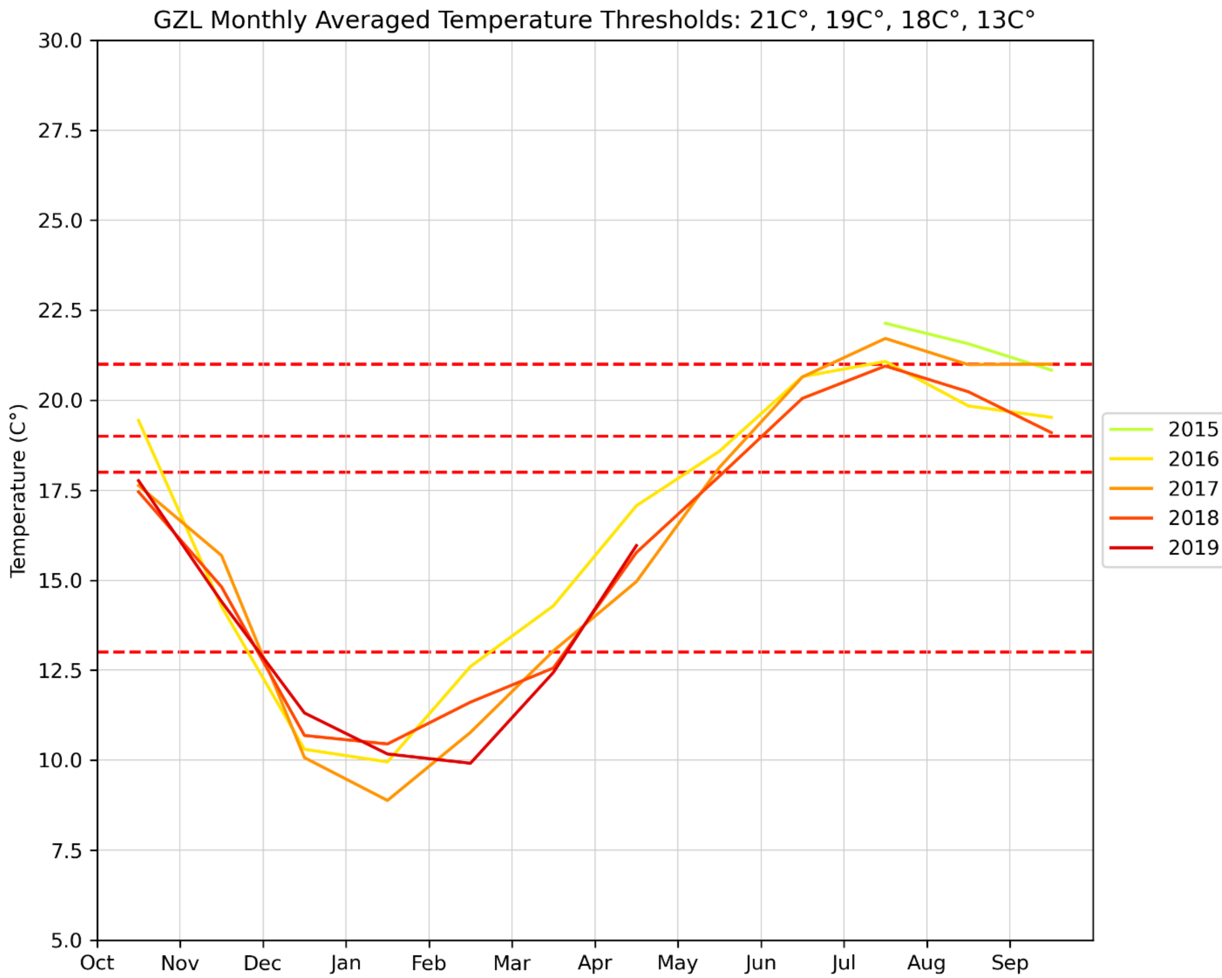

Figure C-35. Monthly Average Temperature for the Period of Record at Station GZL – Grizzly Bay

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

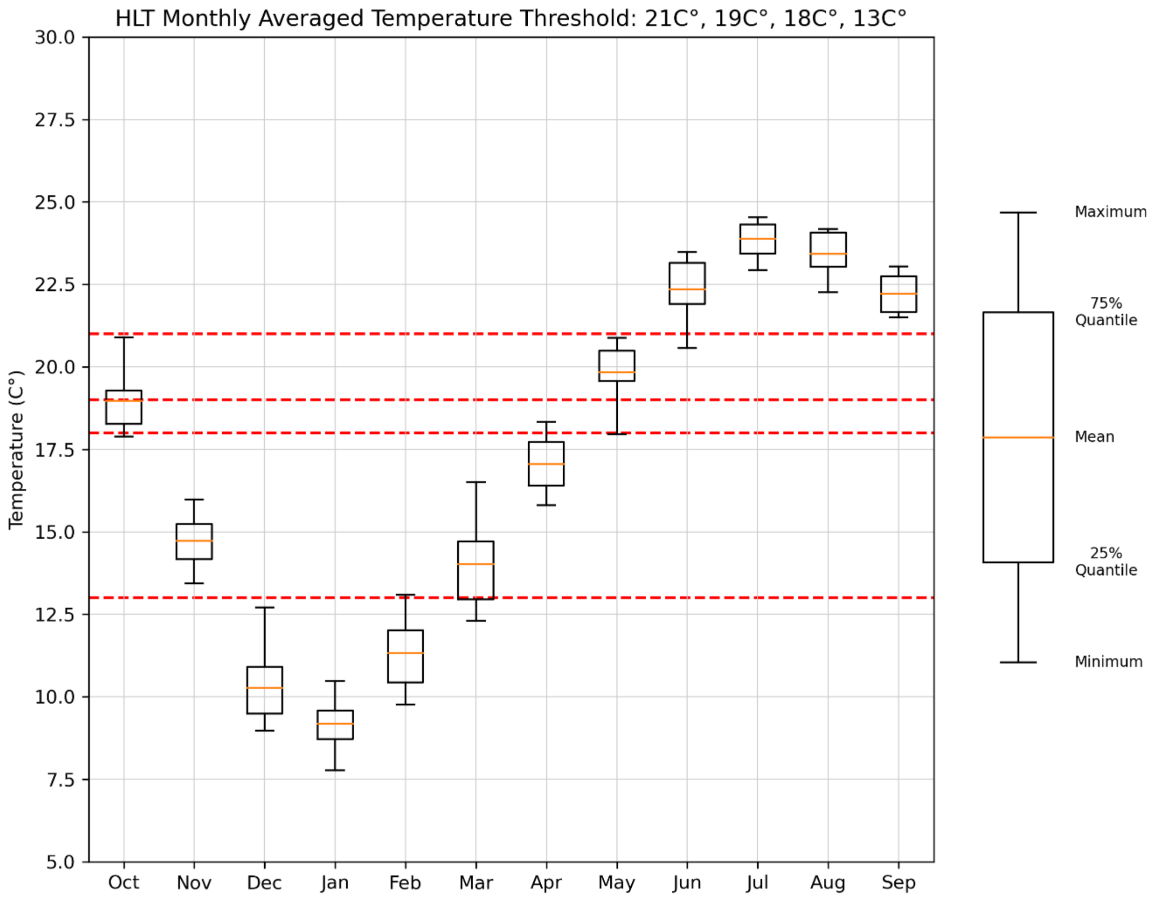

Figure C-36. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station HLT – Middle River near Holt

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

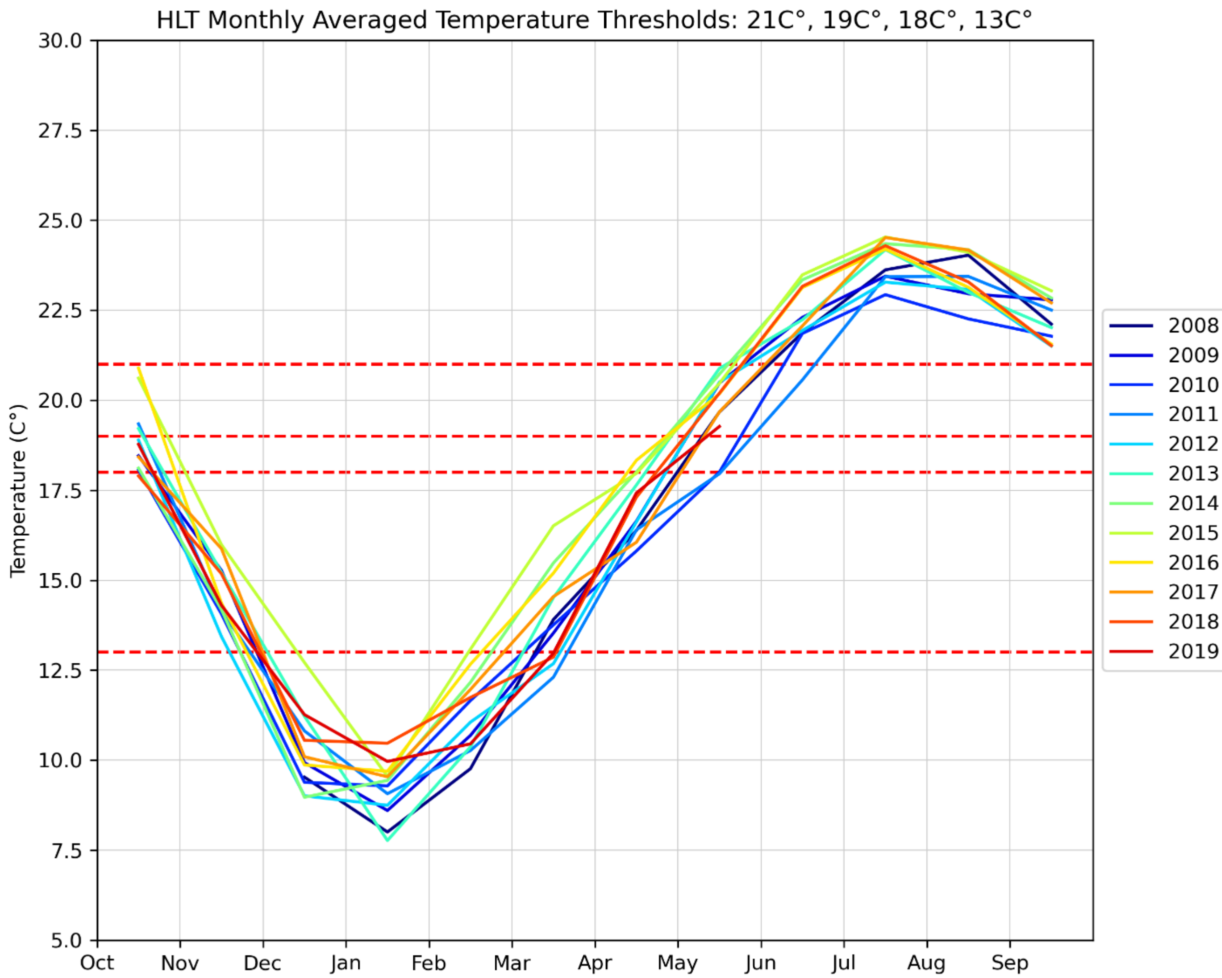

Figure C-37. Monthly Average Temperature for the Period of Record at Station HLT – Middle River near Holt

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

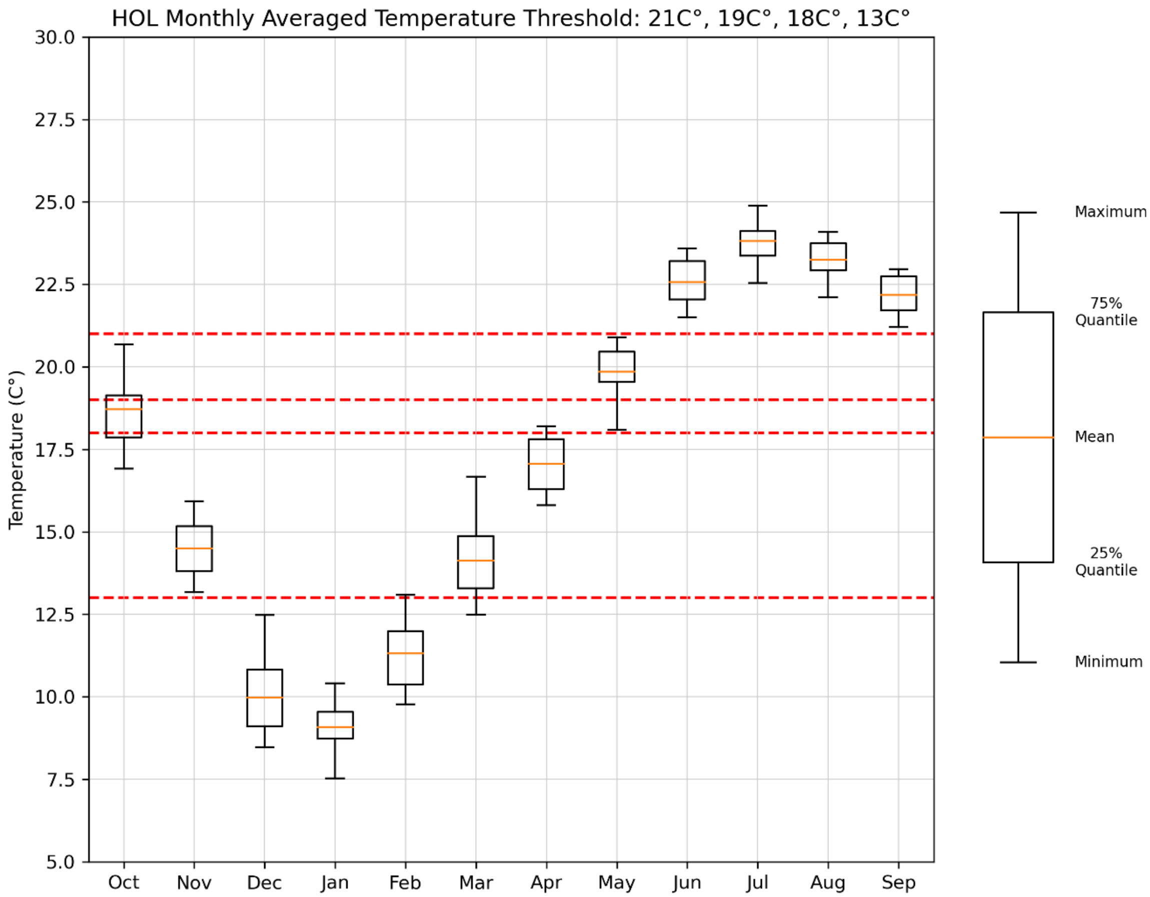

Figure C-38. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station HOL – Holland Cut near Bethel Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

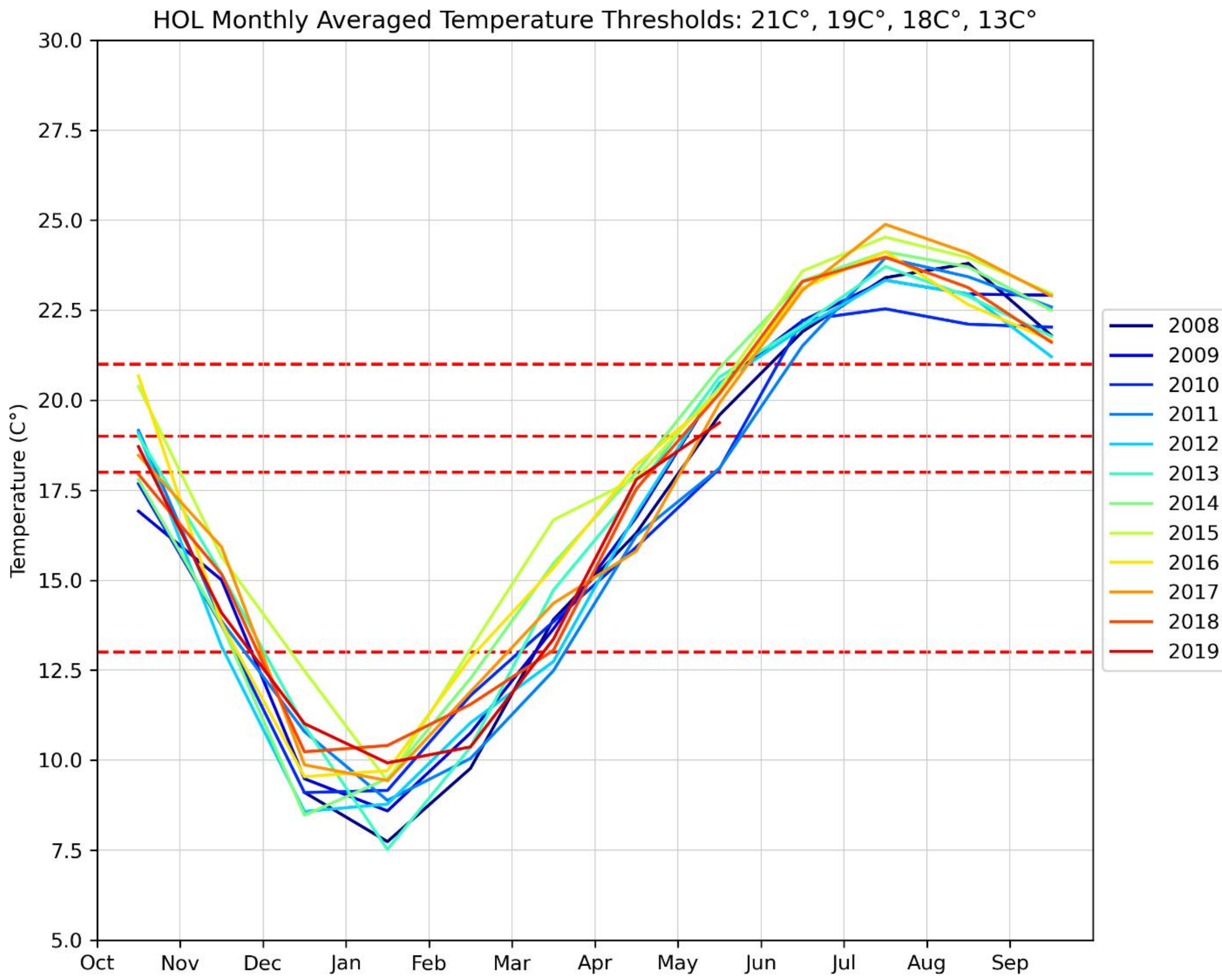

Figure C-39. Monthly Average Temperature for the Period of Record at Station HOL – Holland Cut near Bethel Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

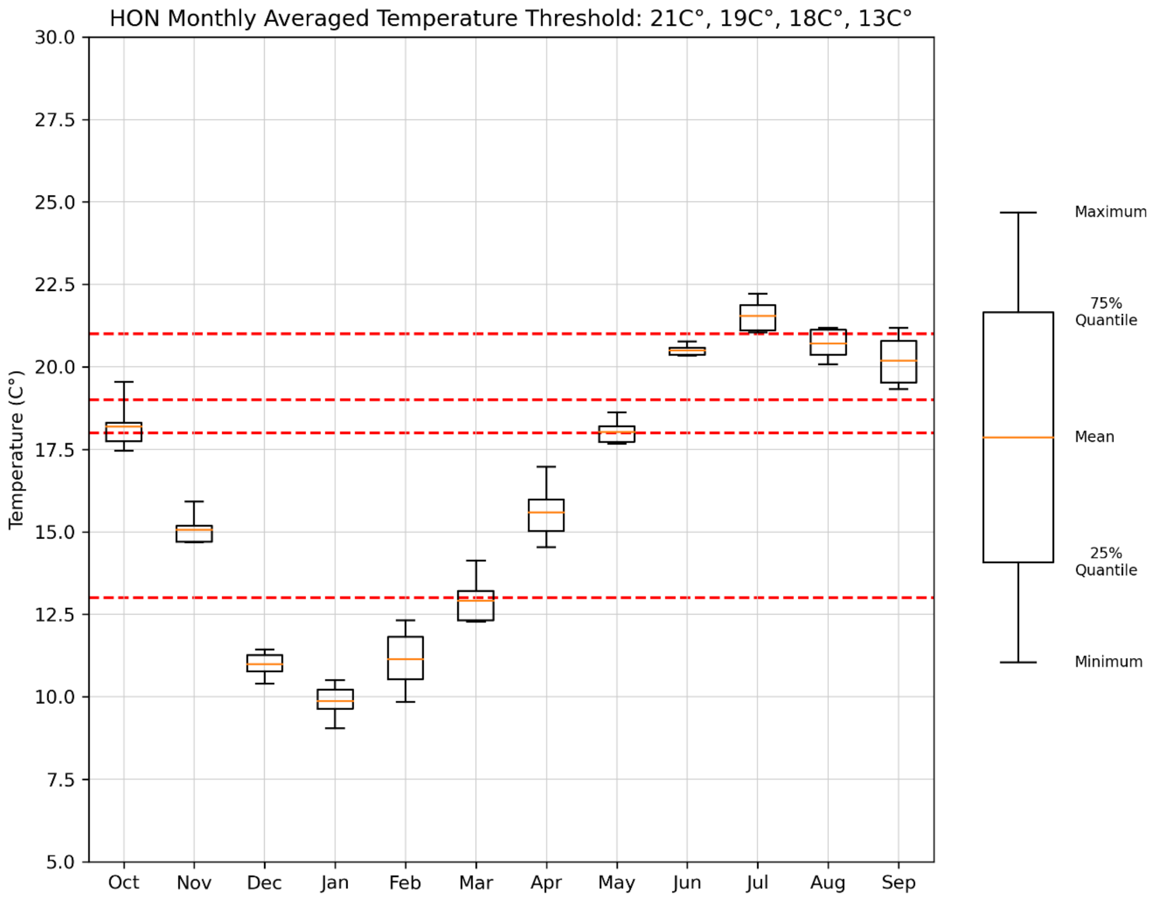

Figure C-40. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station HON – Honker Bay

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

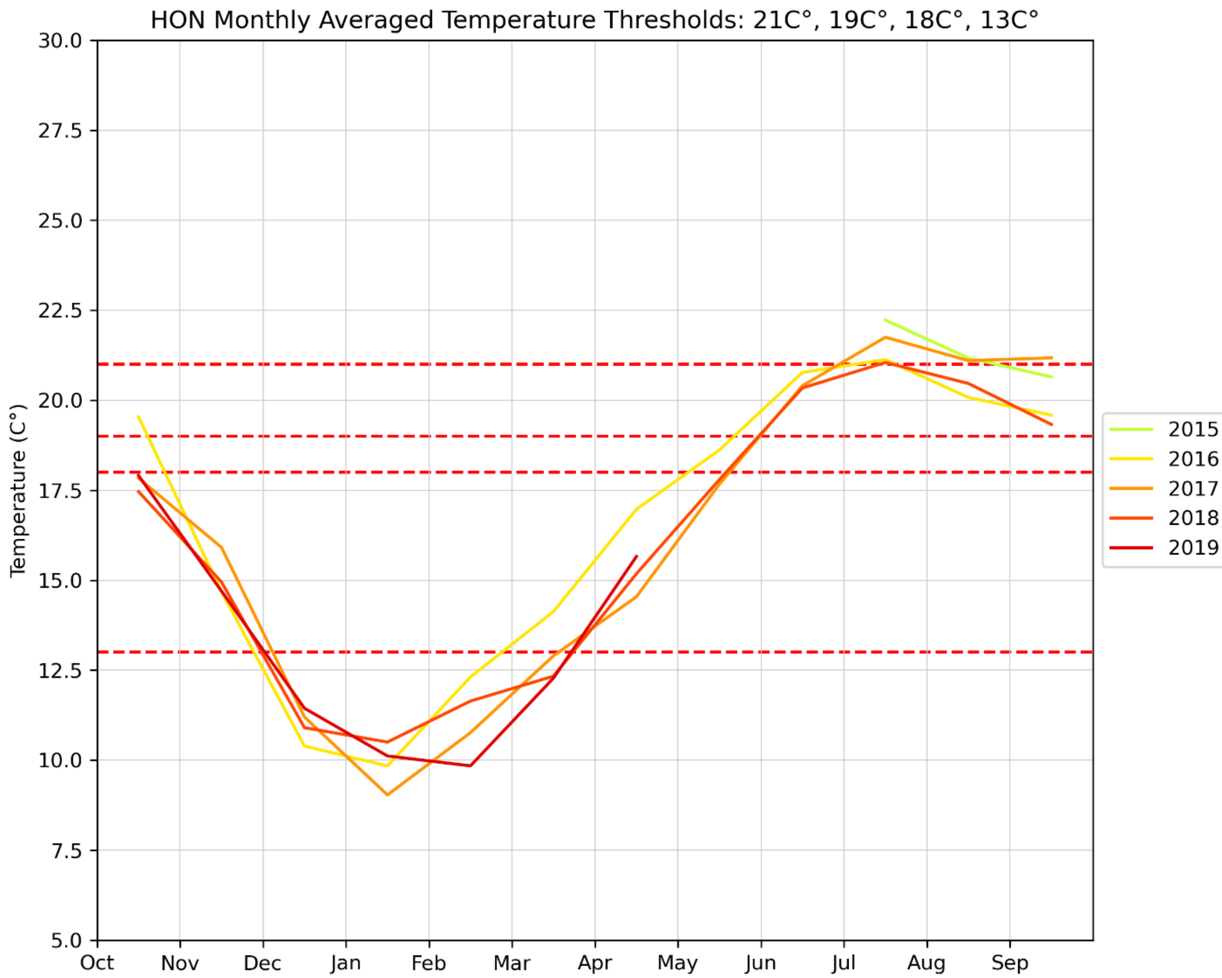

Figure C-41. Monthly Average Temperature for the Period of Record at Station HON – Honker Bay

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

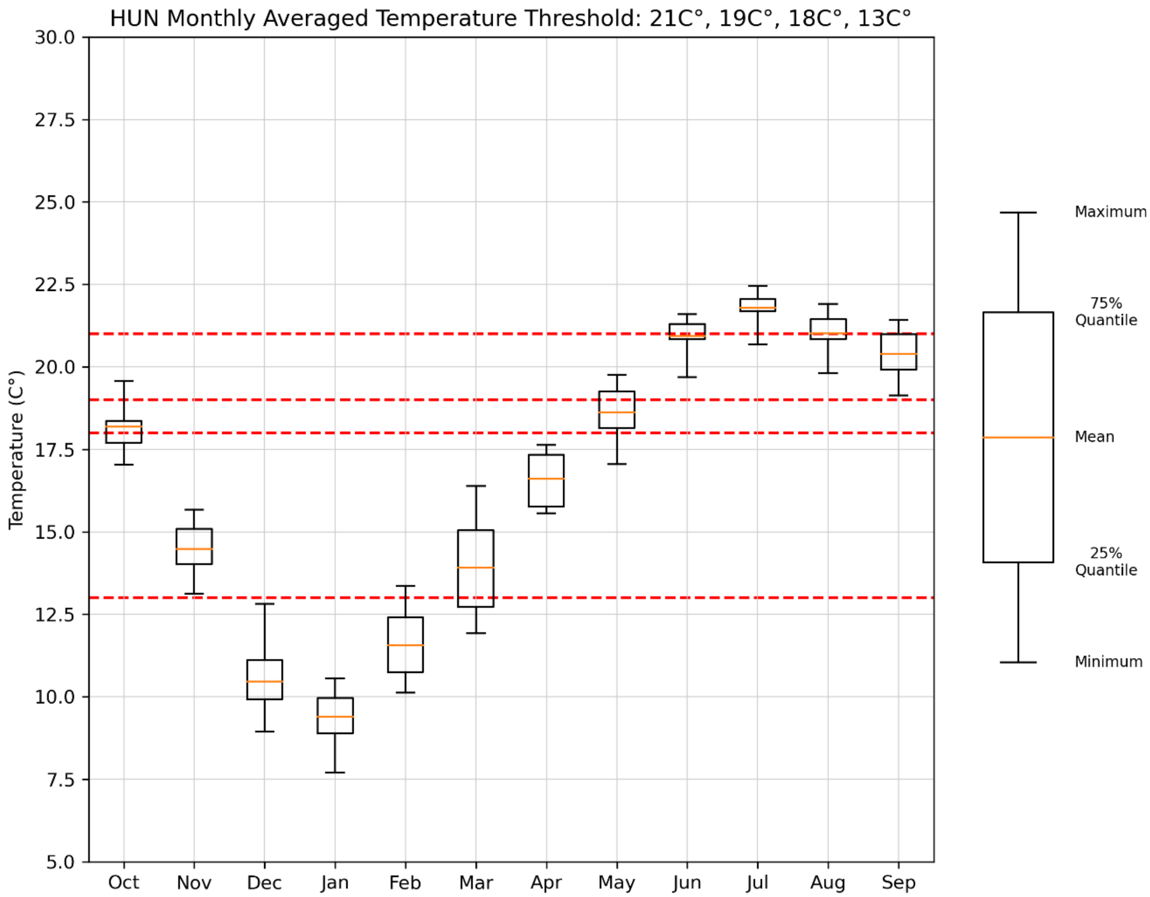

Figure C-42. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station HUN – Hunter Cut at Montezuma Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

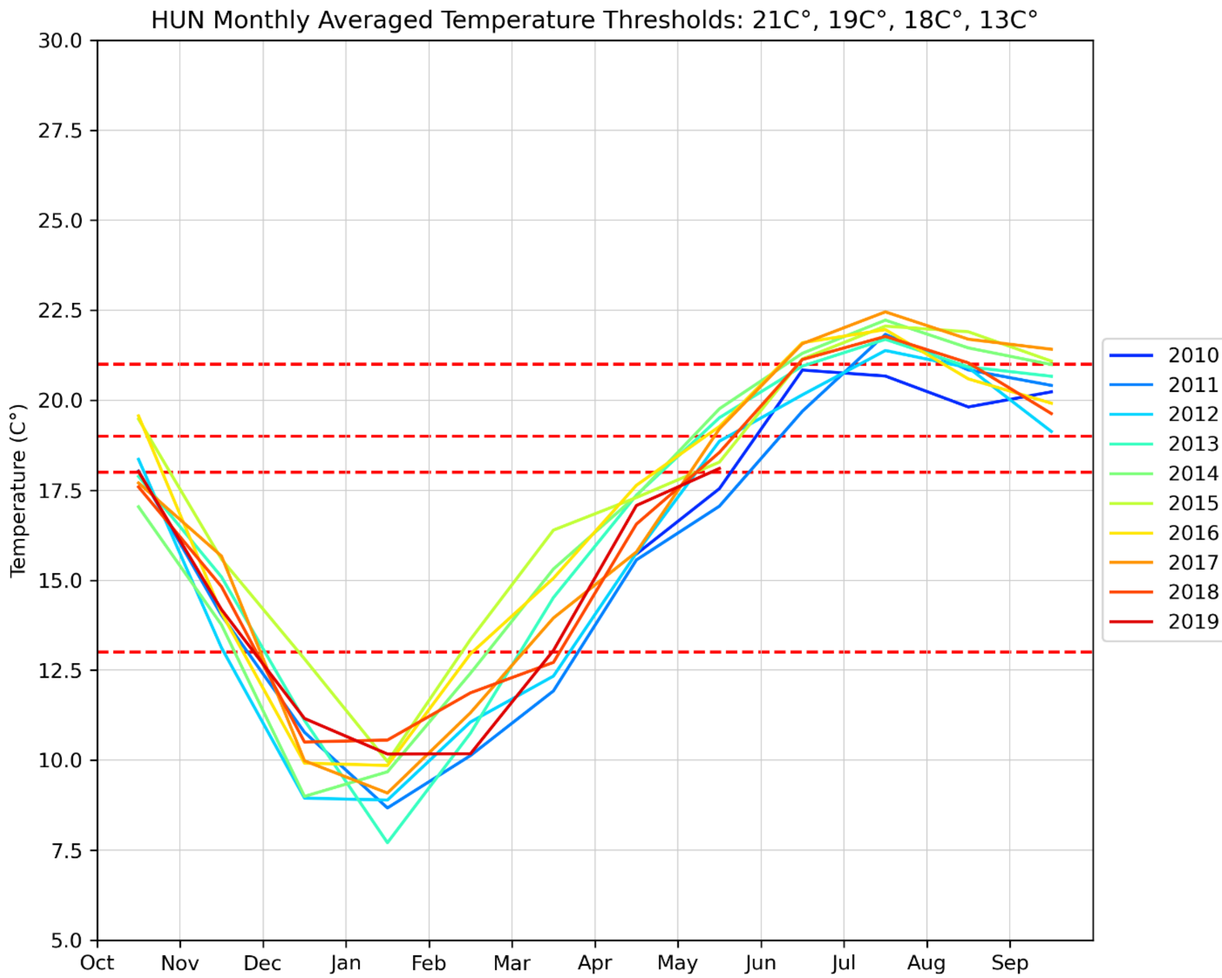

Figure C-43. Monthly Average Temperature for the Period of Record at Station HUN – Hunter Cut at Montezuma Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

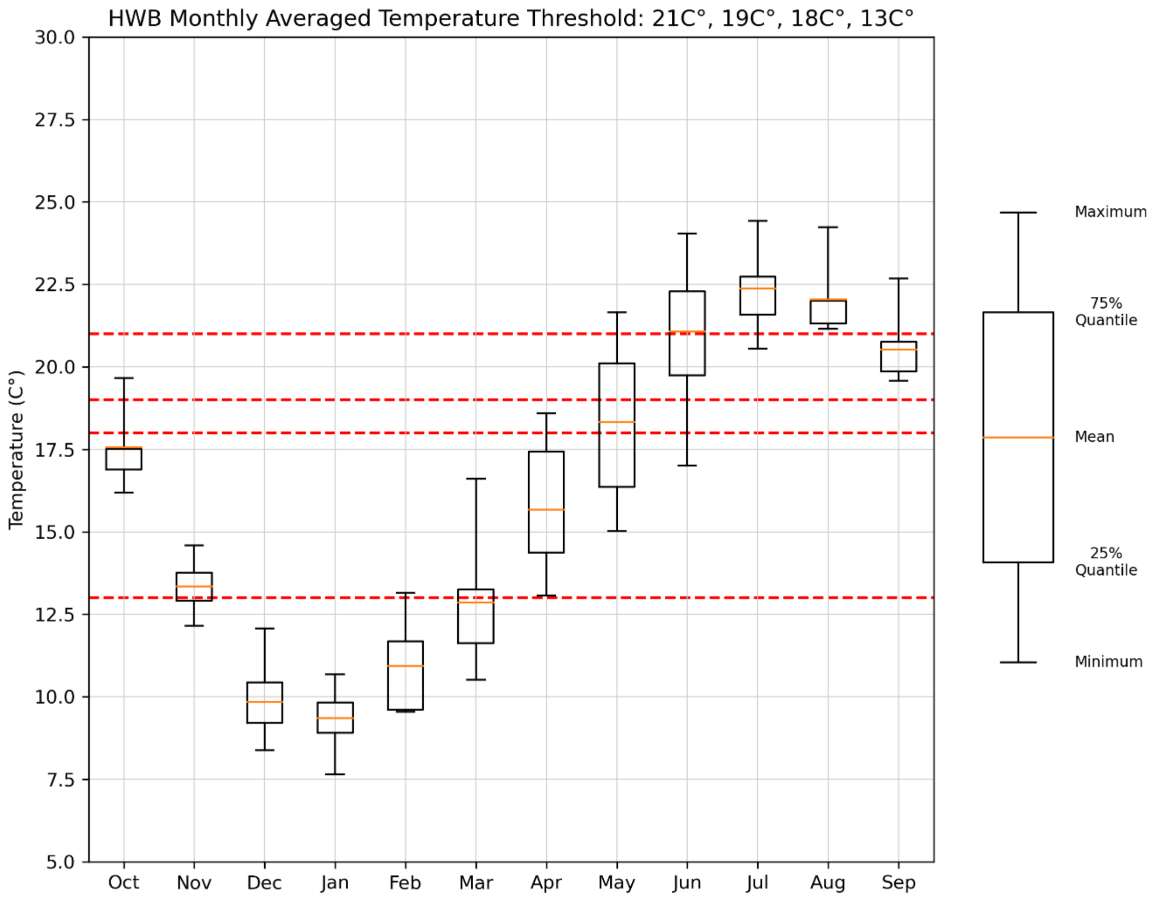

Figure C-44. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station HWB – Miner Slough at Highway 84 Bridge

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

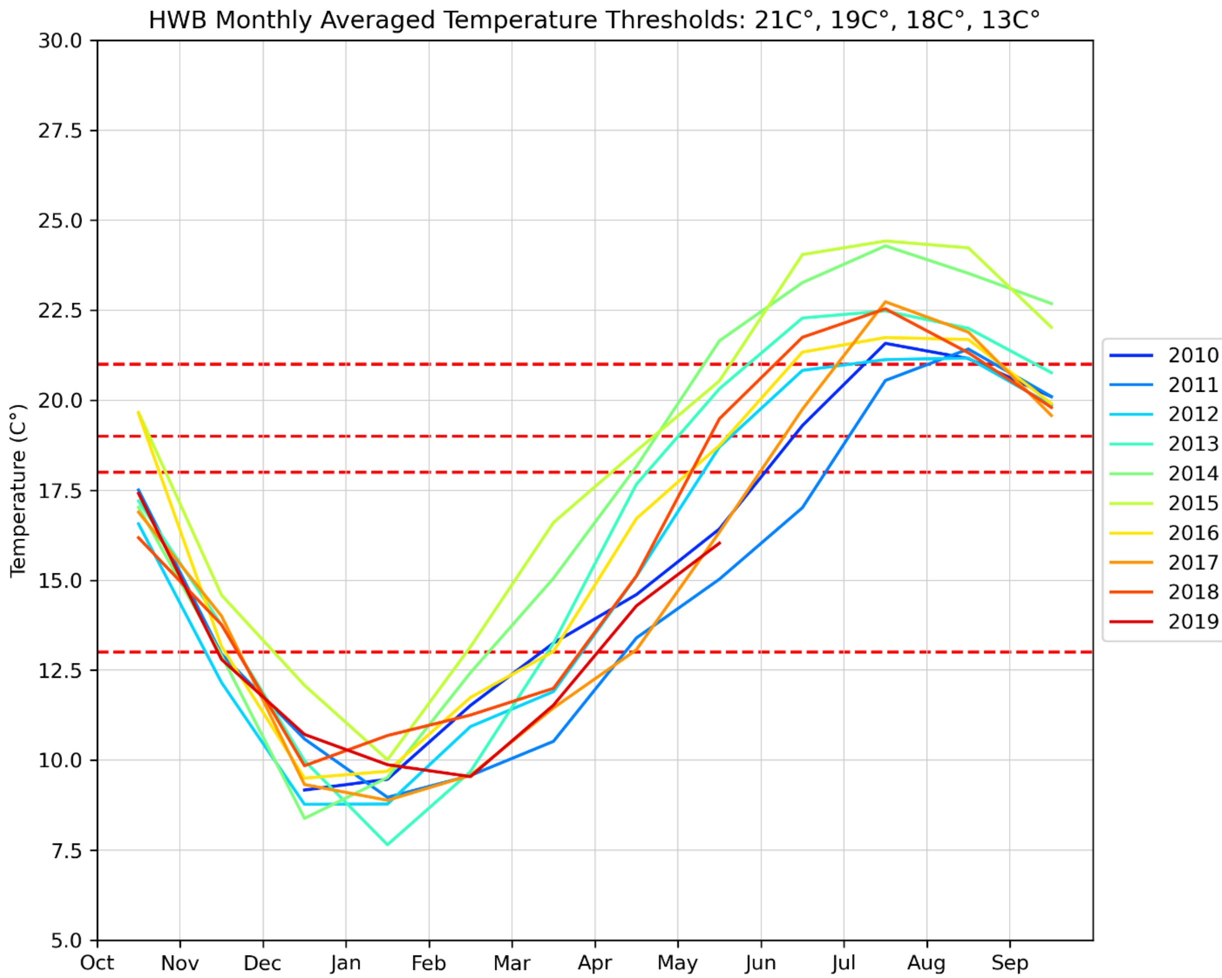

Figure C-45. Monthly Average Temperature for the Period of Record at Station HWB – Miner Slough at Highway 84 Bridge

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

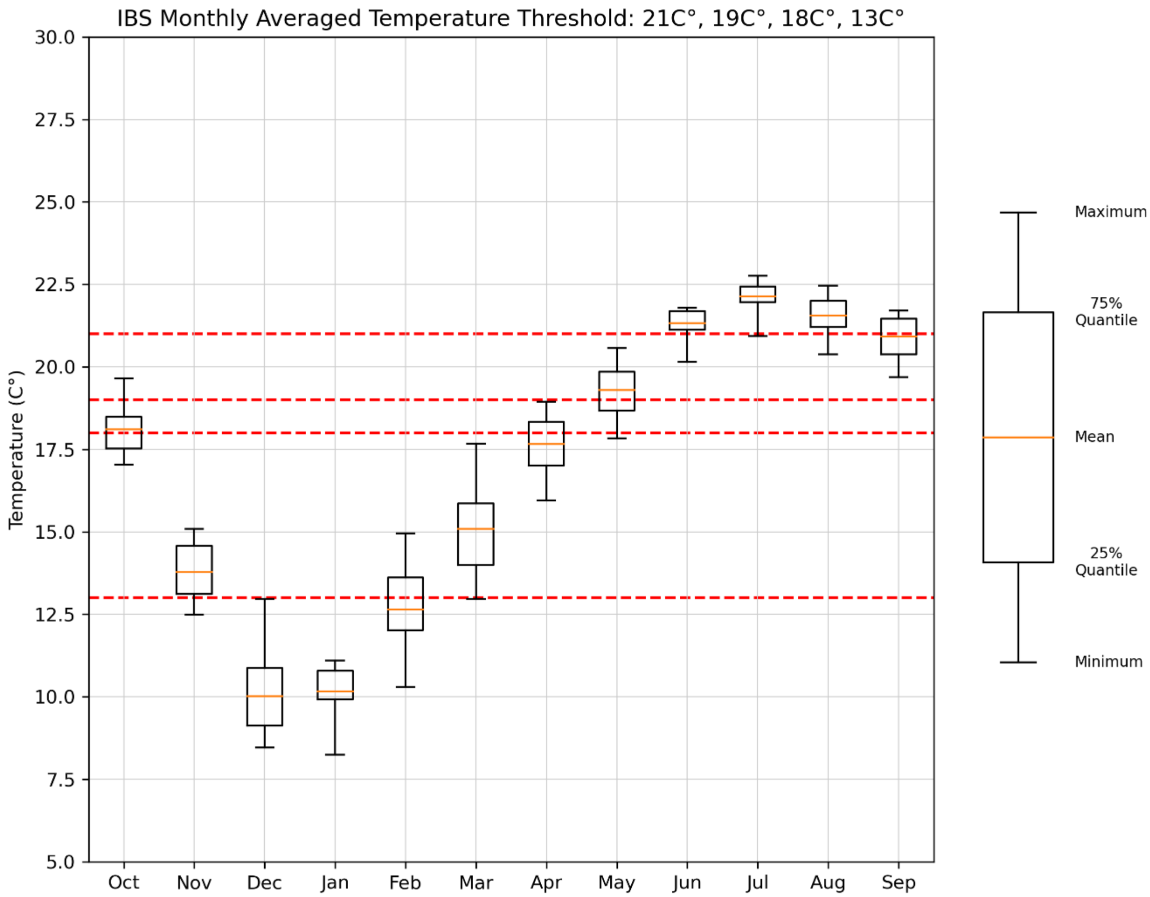

Figure C-46. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station IBS – Cordelia Slough at Ibis

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

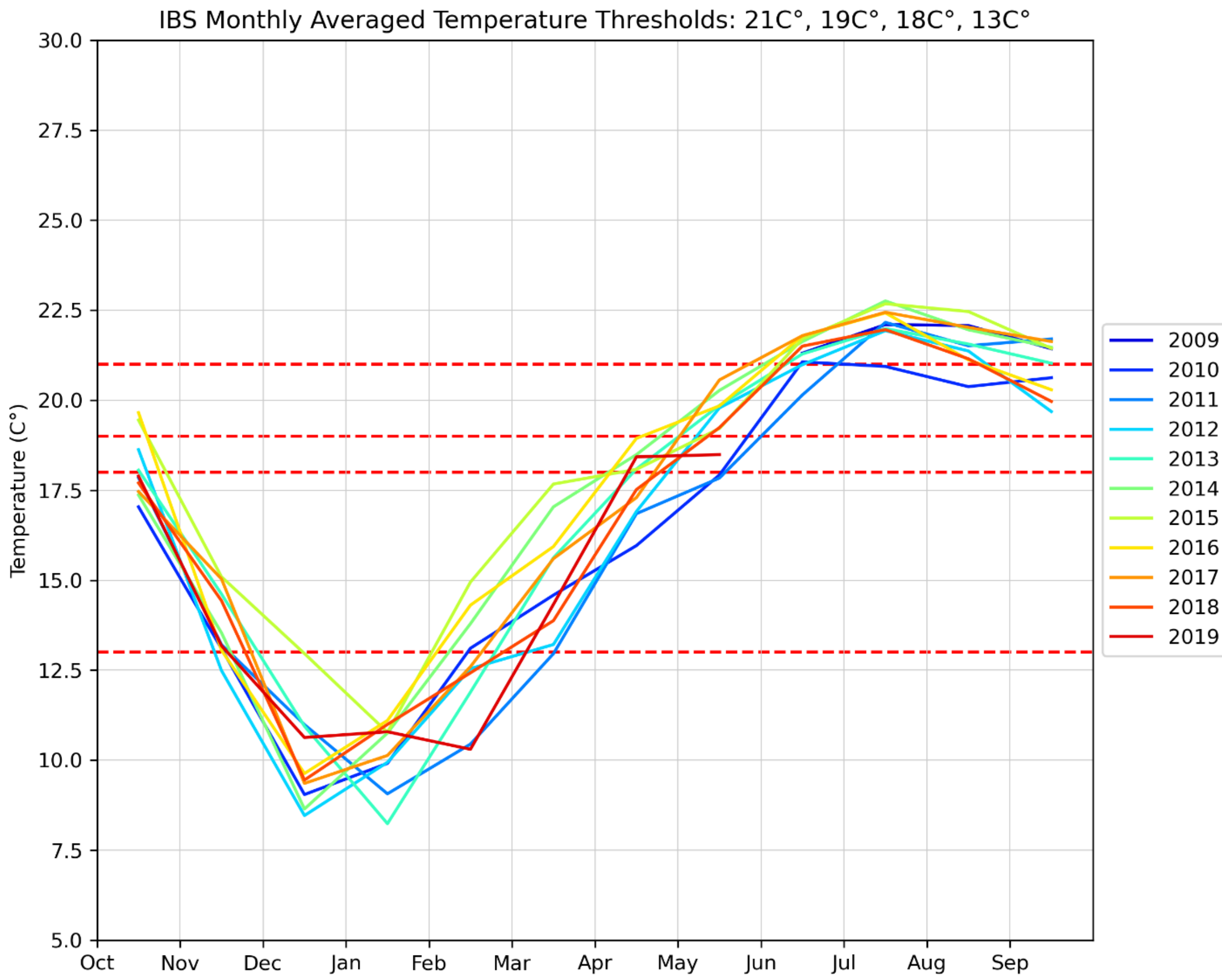

Figure C-47. Monthly Average Temperature for the Period of Record at Station IBS – Cordelia Slough at Ibis

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

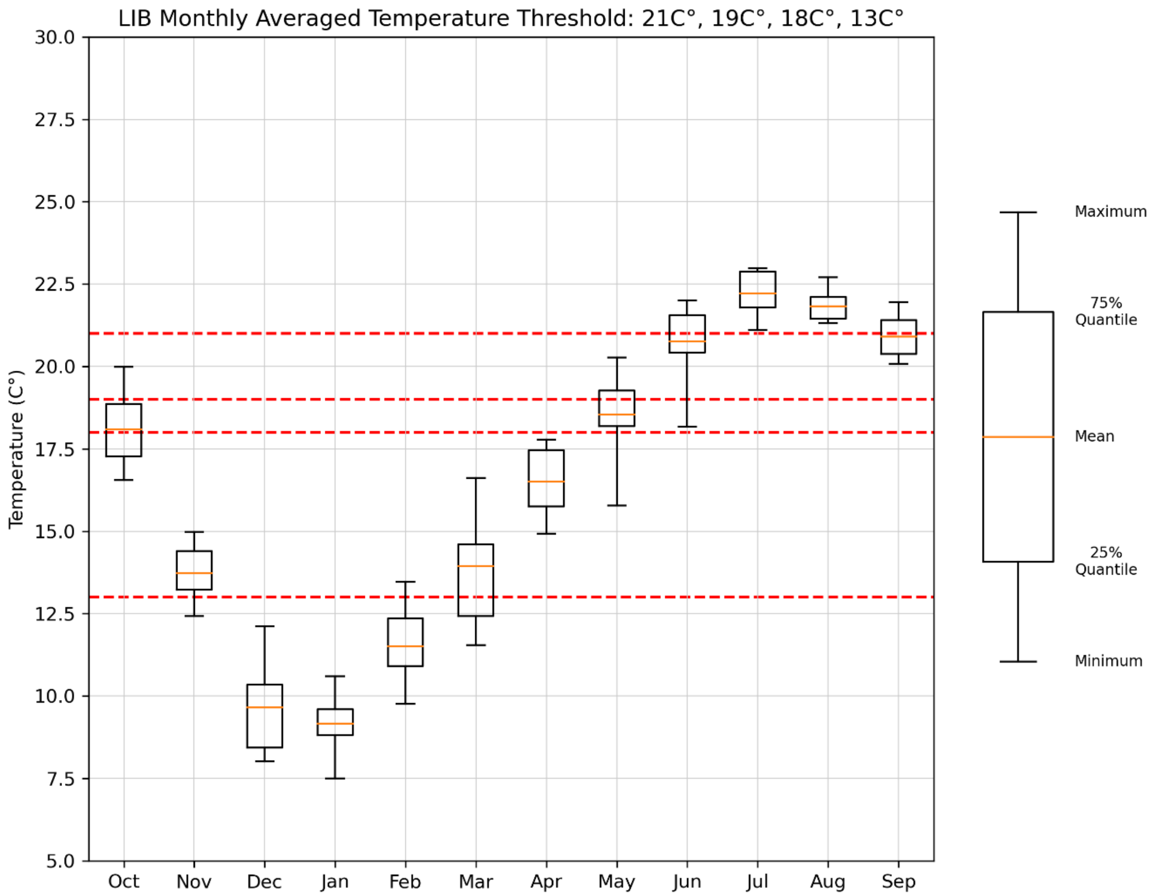

Figure C-48. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station LIB – Liberty Island at Approximately Center South End

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

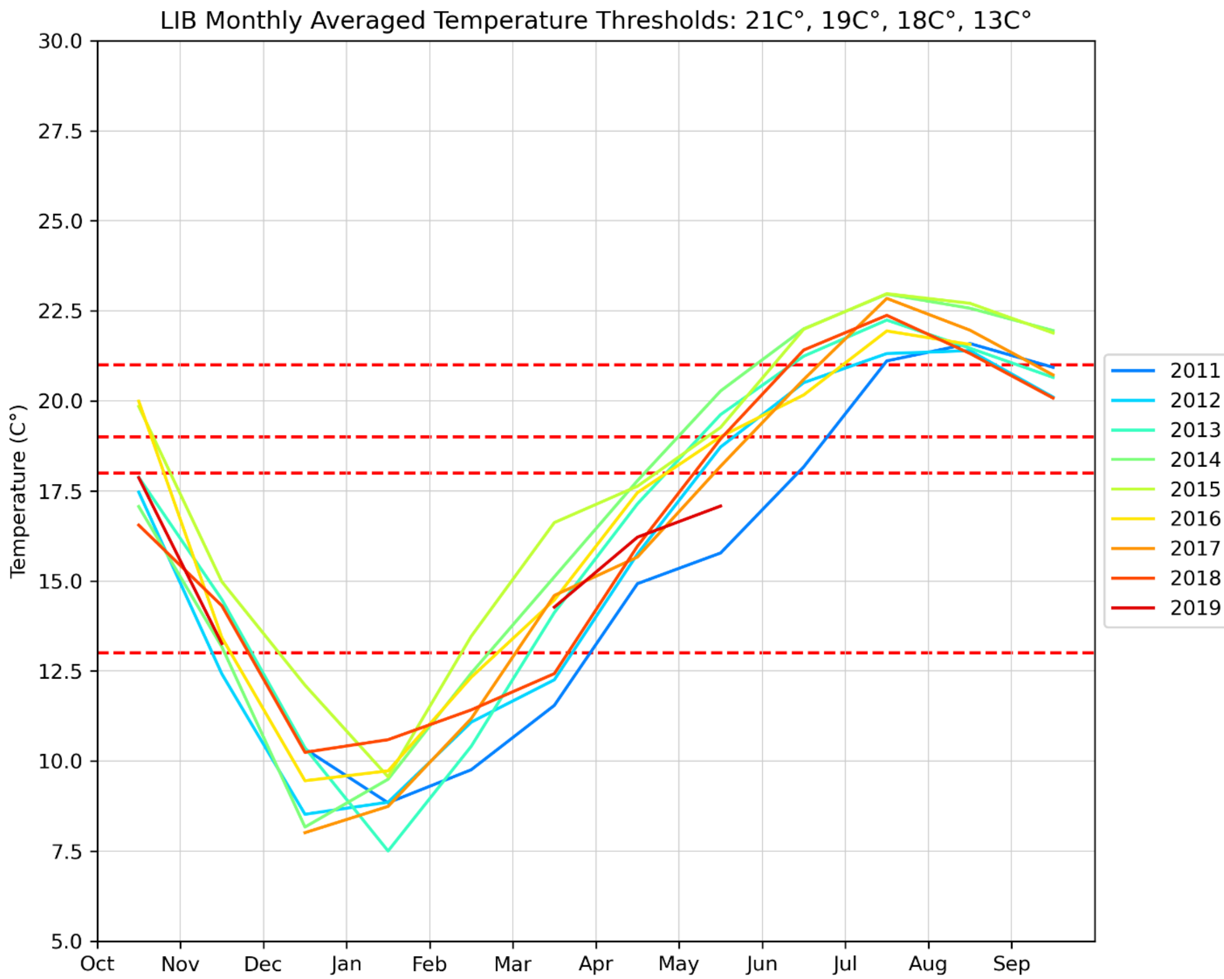

Figure C-49. Monthly Average Temperature for the Period of Record at Station LIB – Liberty Island at Approximately Center South End

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

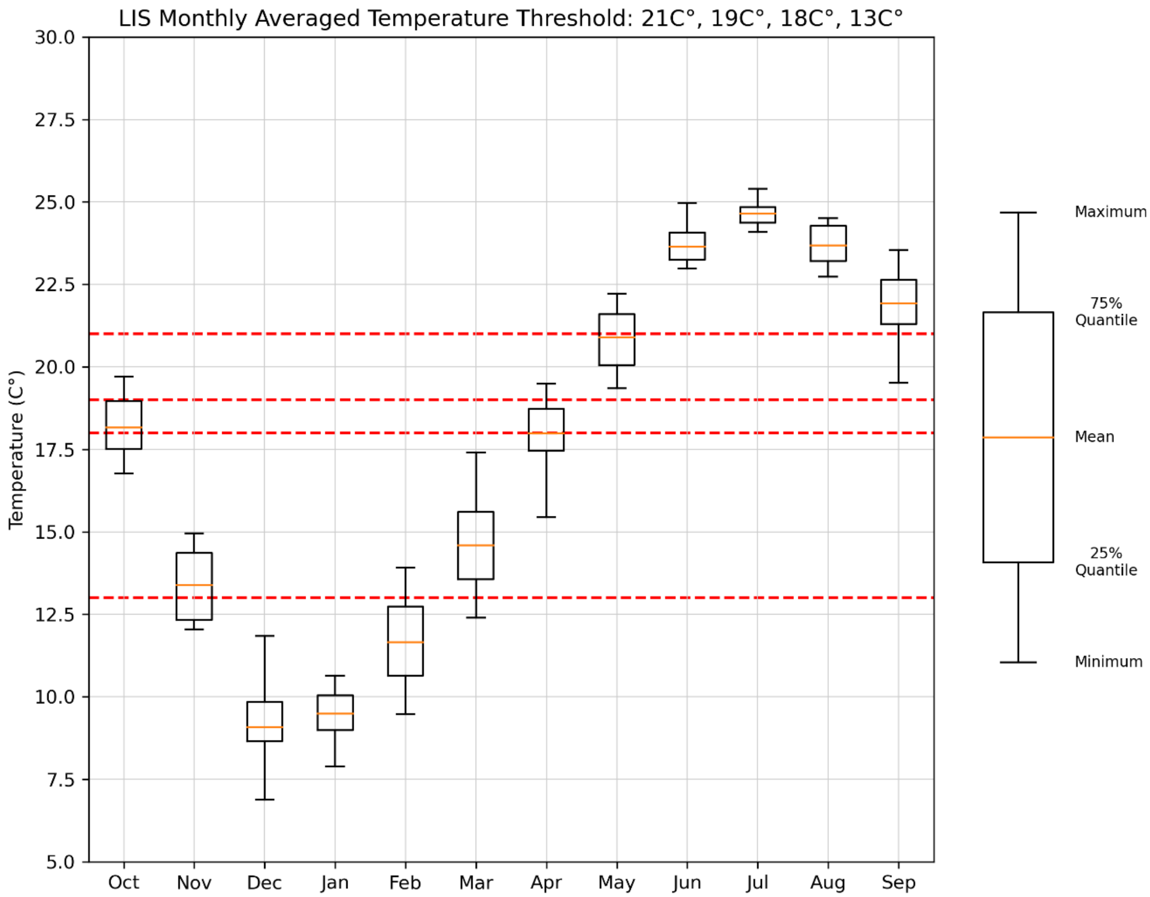

Figure C-50. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station LIS – Yolo Bypass at Lisbon

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

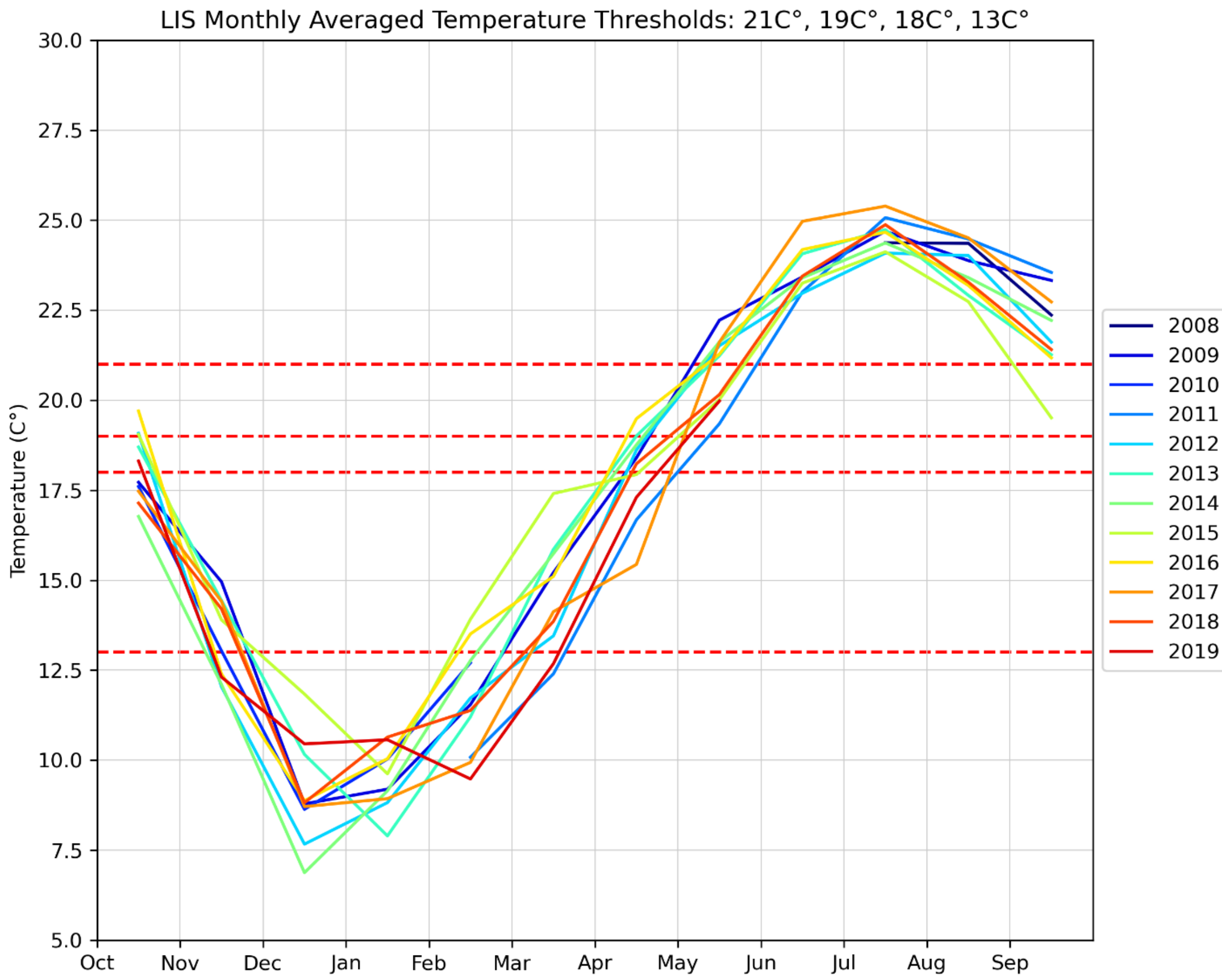

Figure C-51. Monthly Average Temperature for the Period of Record at Station LIS – Yolo Bypass at Lisbon

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

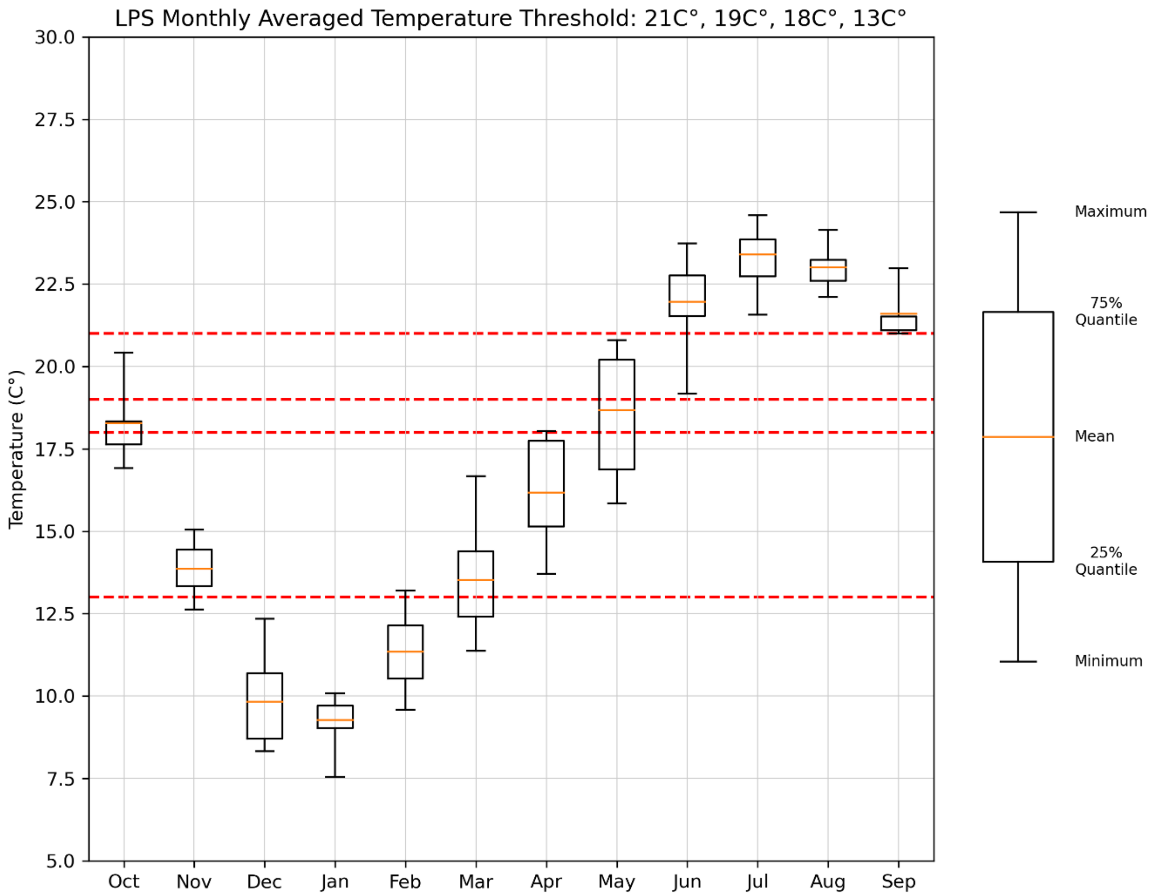

Figure C-52. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station LPS – Little Potato Slough at Terminus

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

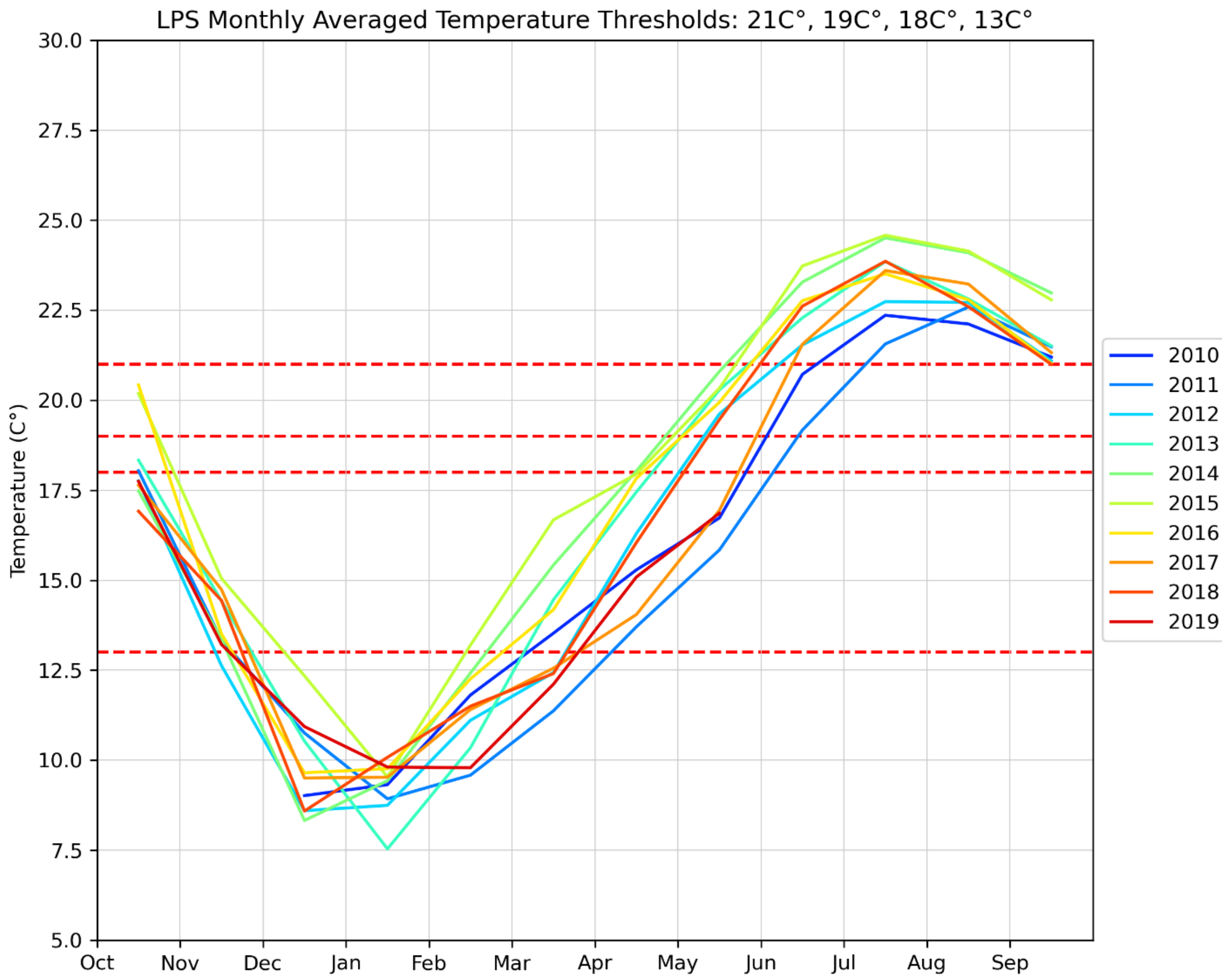

Figure C-53. Monthly Average Temperature for the Period of Record at Station LPS – Little Potato Slough at Terminus

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

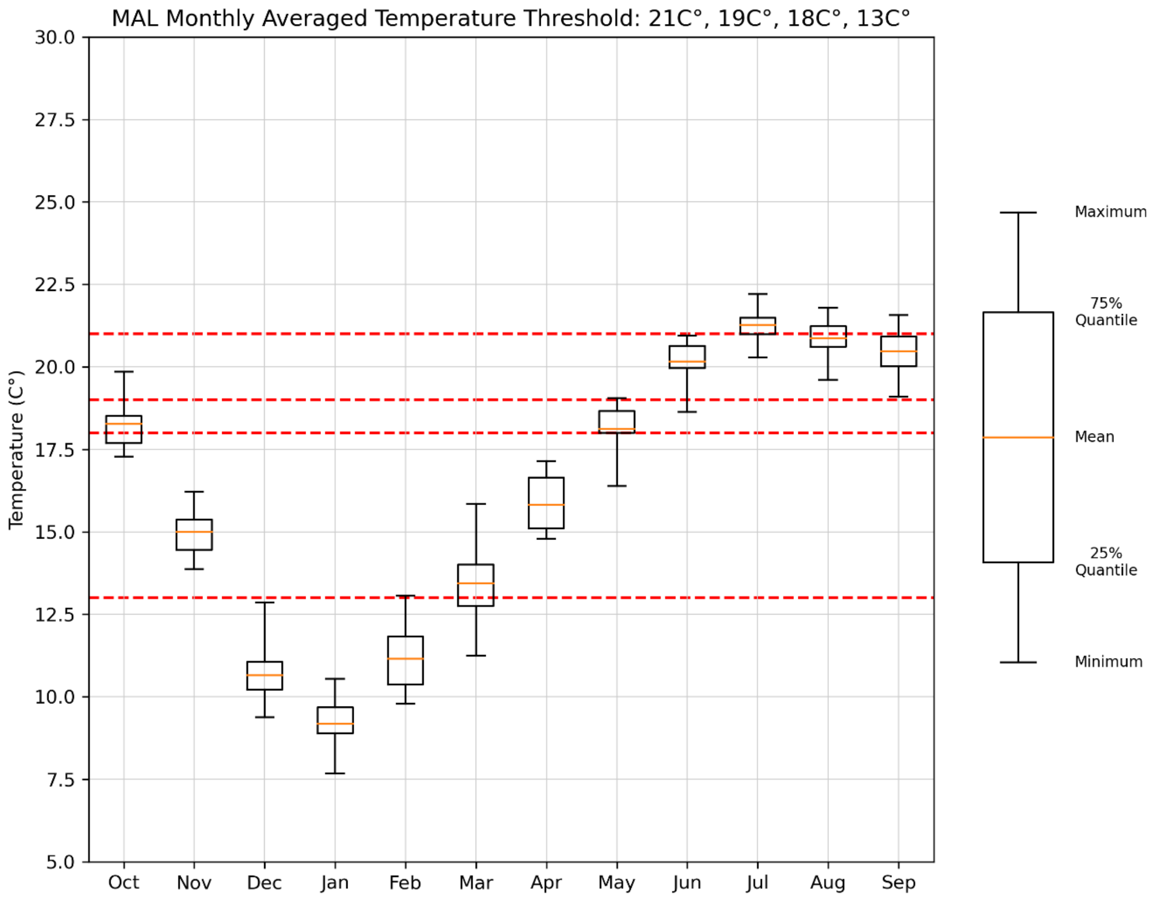

Figure C-54. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MAL – Sacramento River at Mallard Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

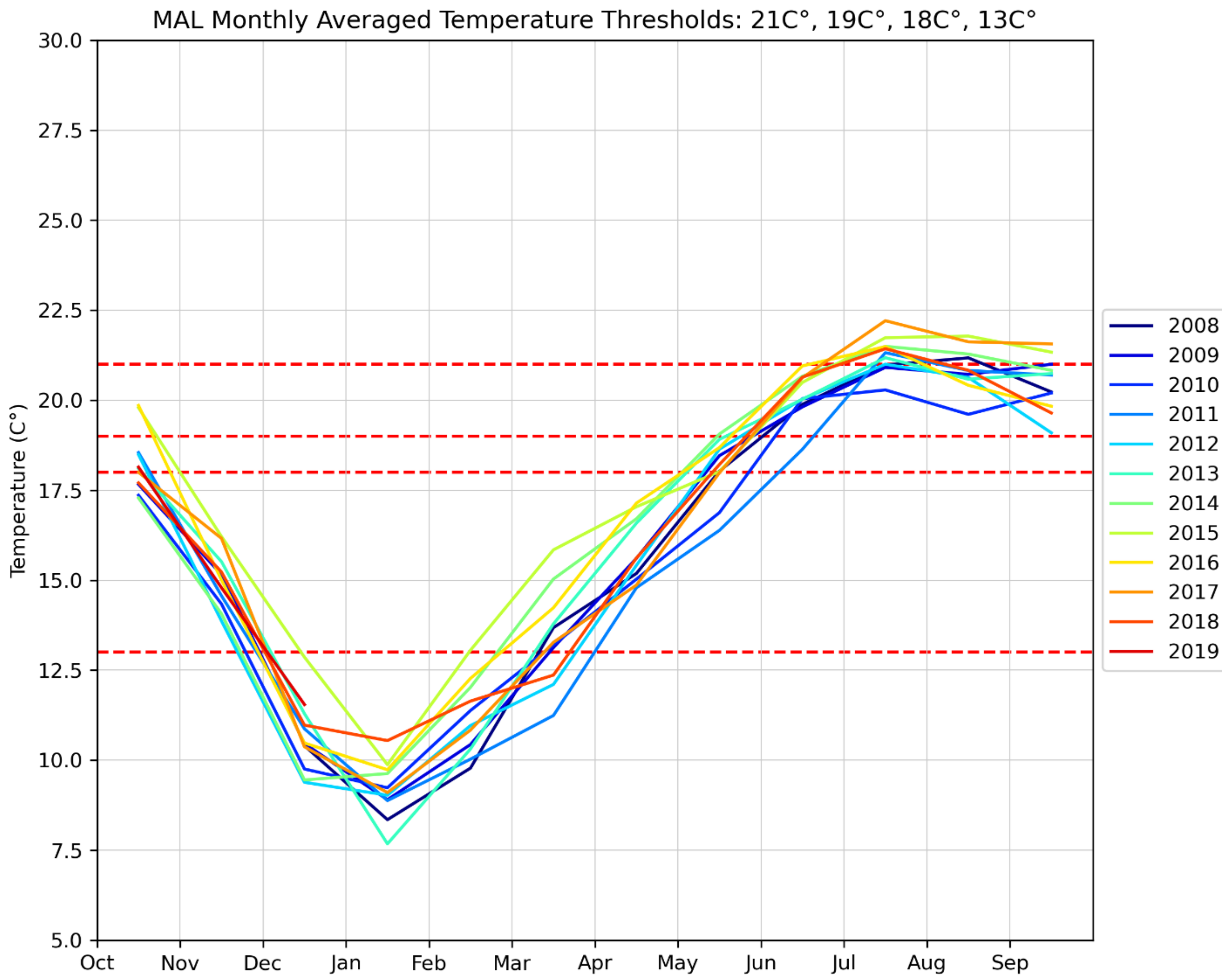

Figure C-55. Monthly Average Temperature for the Period of Record at Station MAL – Sacramento River at Mallard Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

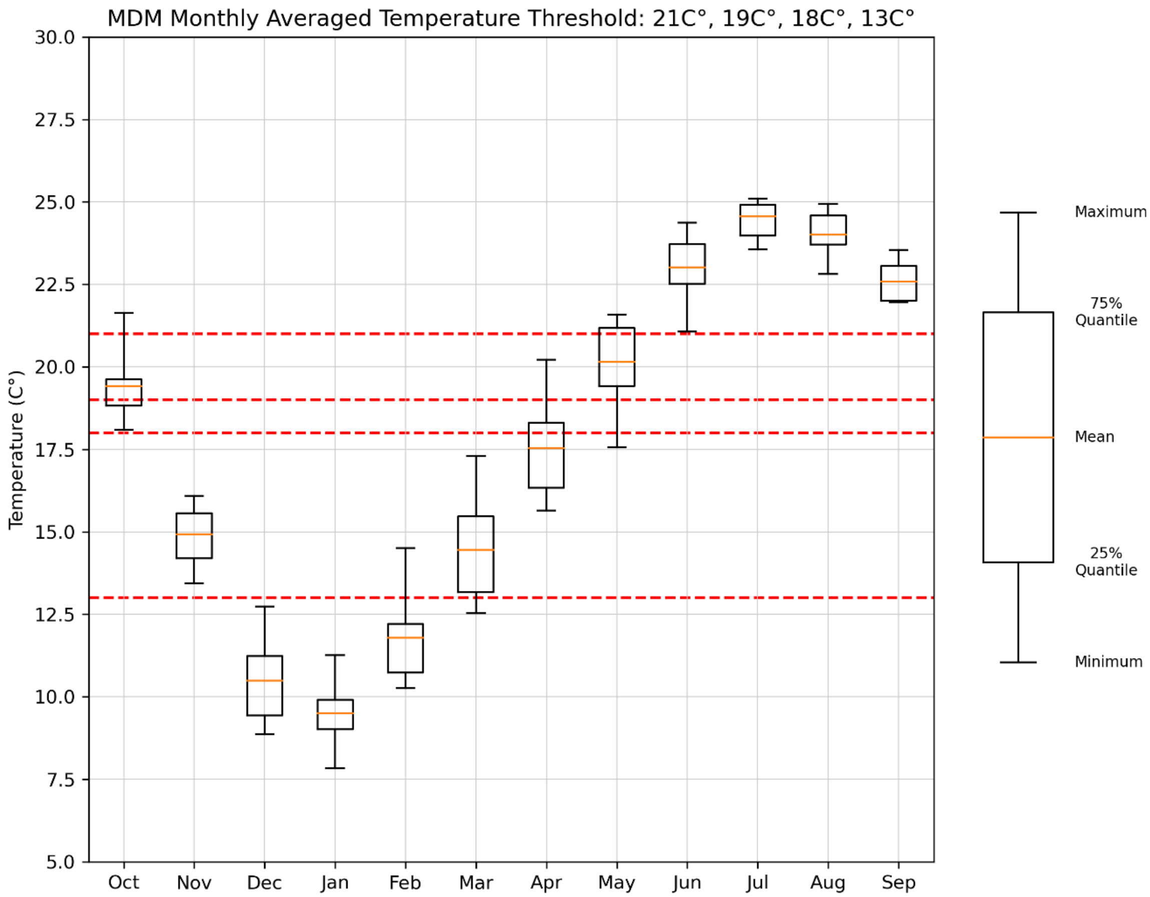

Figure C-56. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MDM – Middle River at Middle River

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

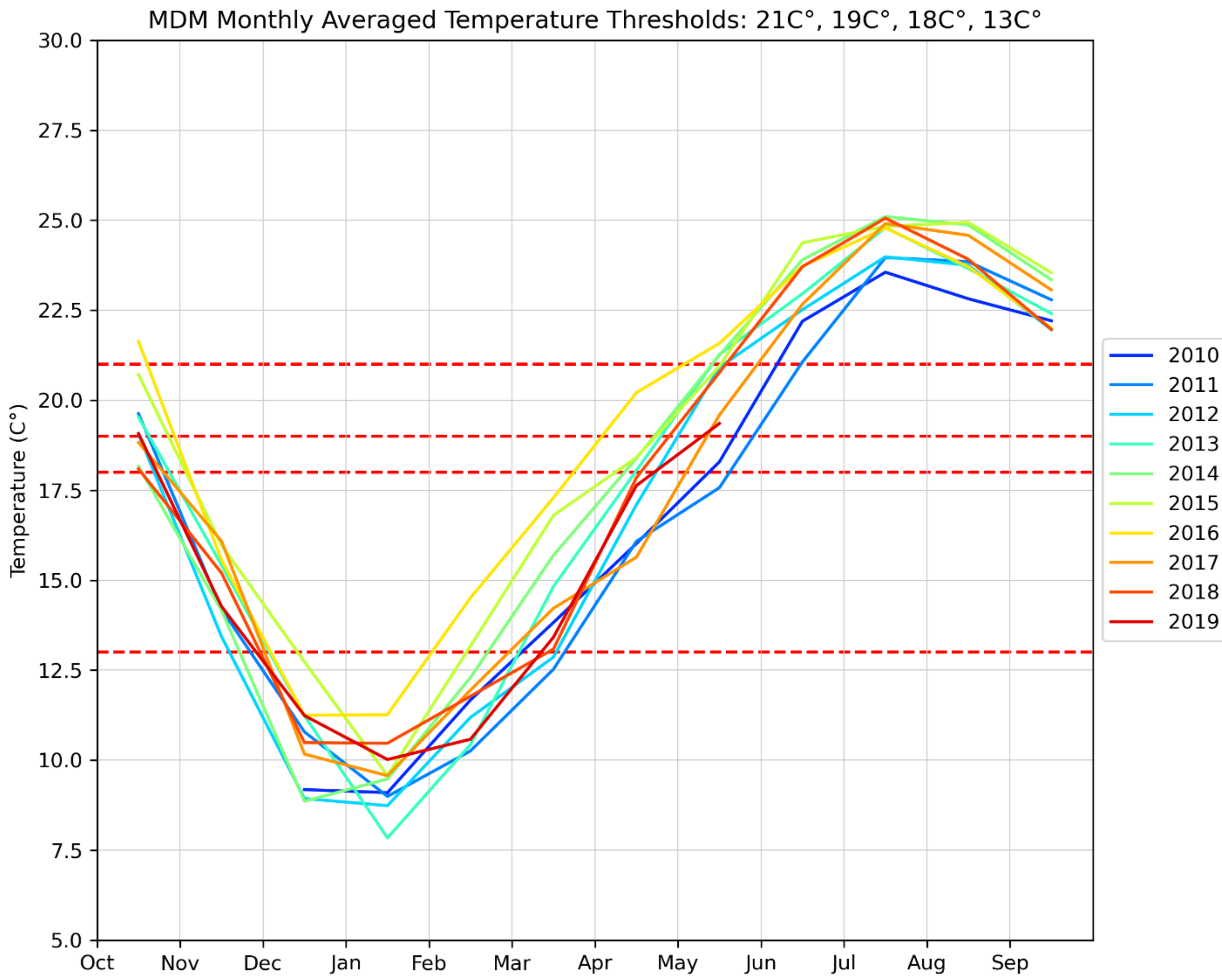

Figure C-57. Monthly Average Temperature for the Period of Record at Station MDM – Middle River at Middle River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

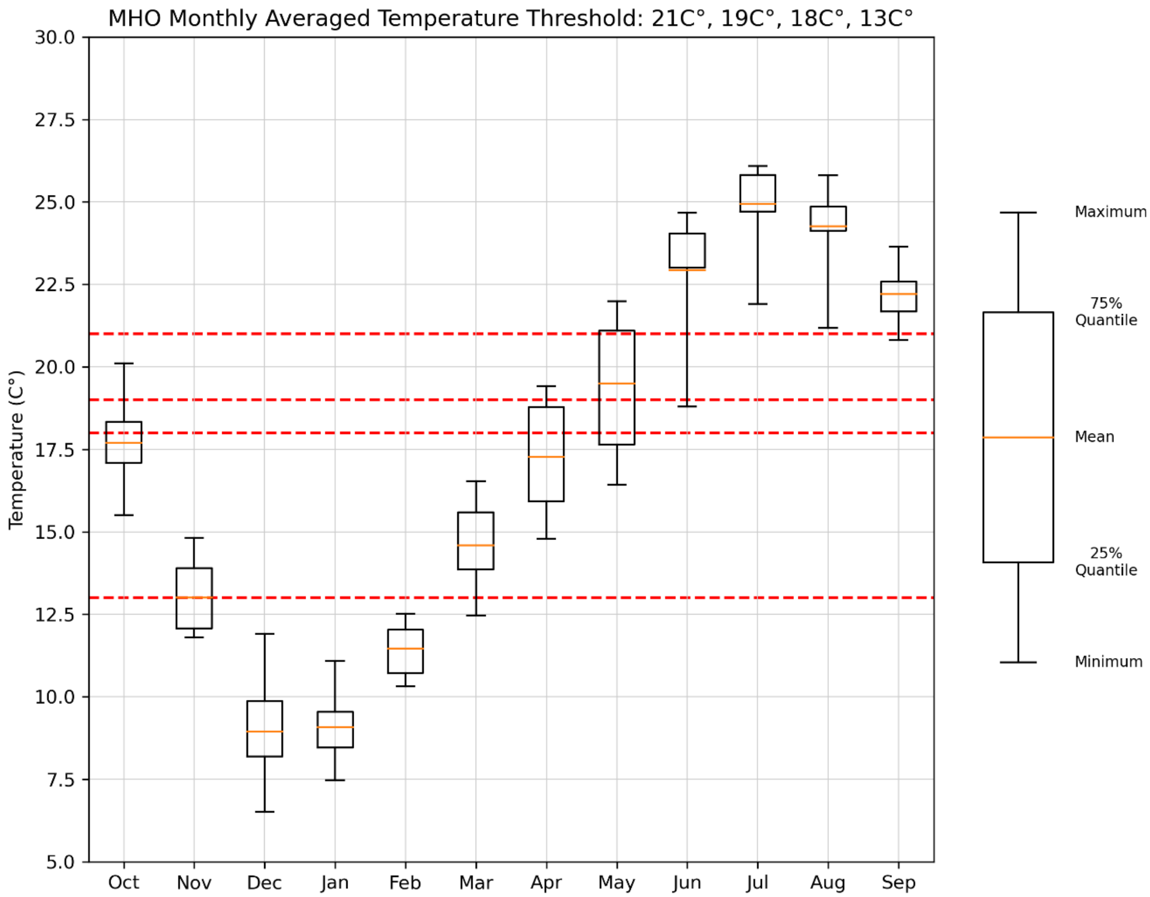

Figure C-58. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MHO – Middle River near Howard Road Bridge

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

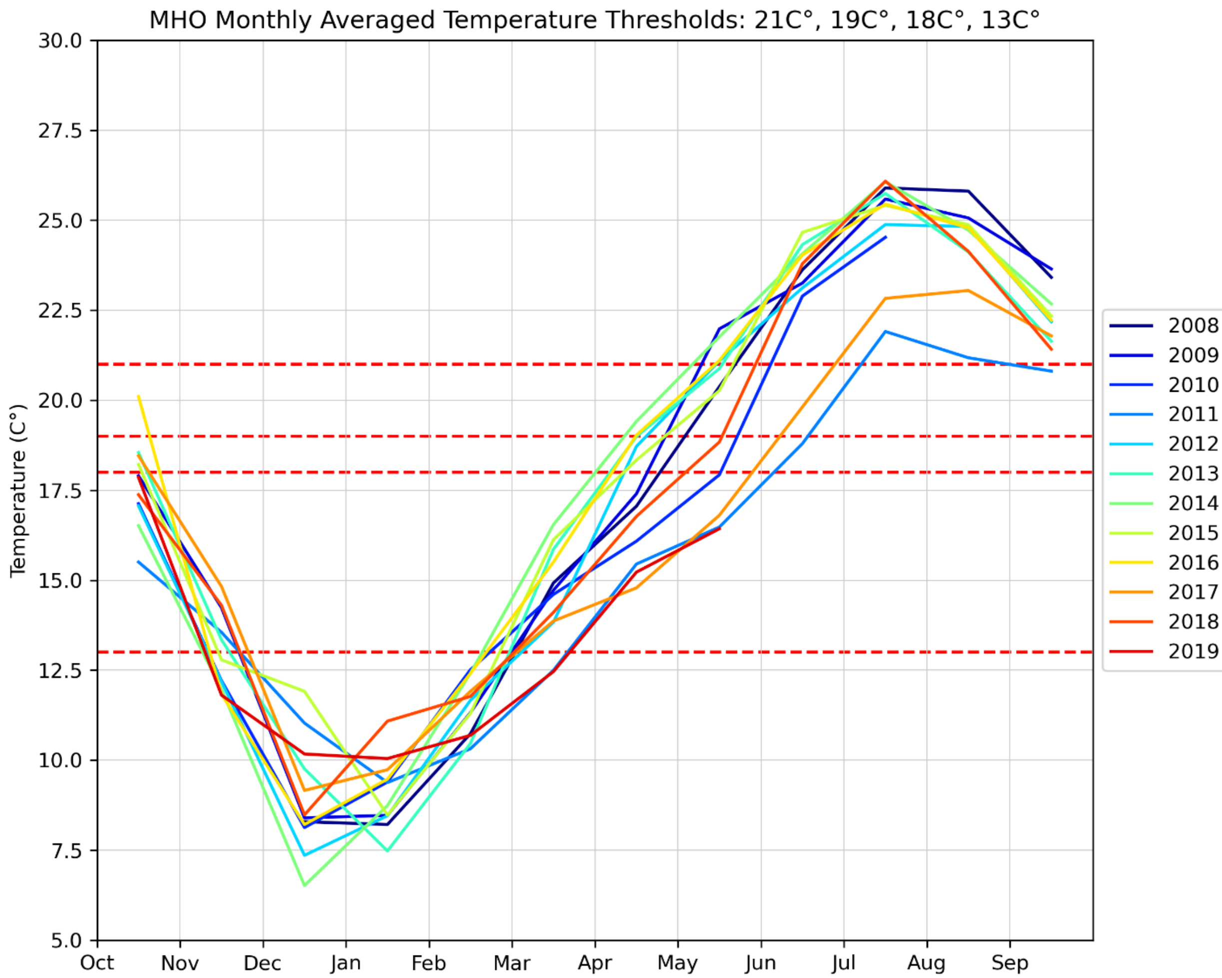

Figure C-59. Monthly Average Temperature for the Period of Record at Station MHO – Middle River near Howard Road Bridge

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

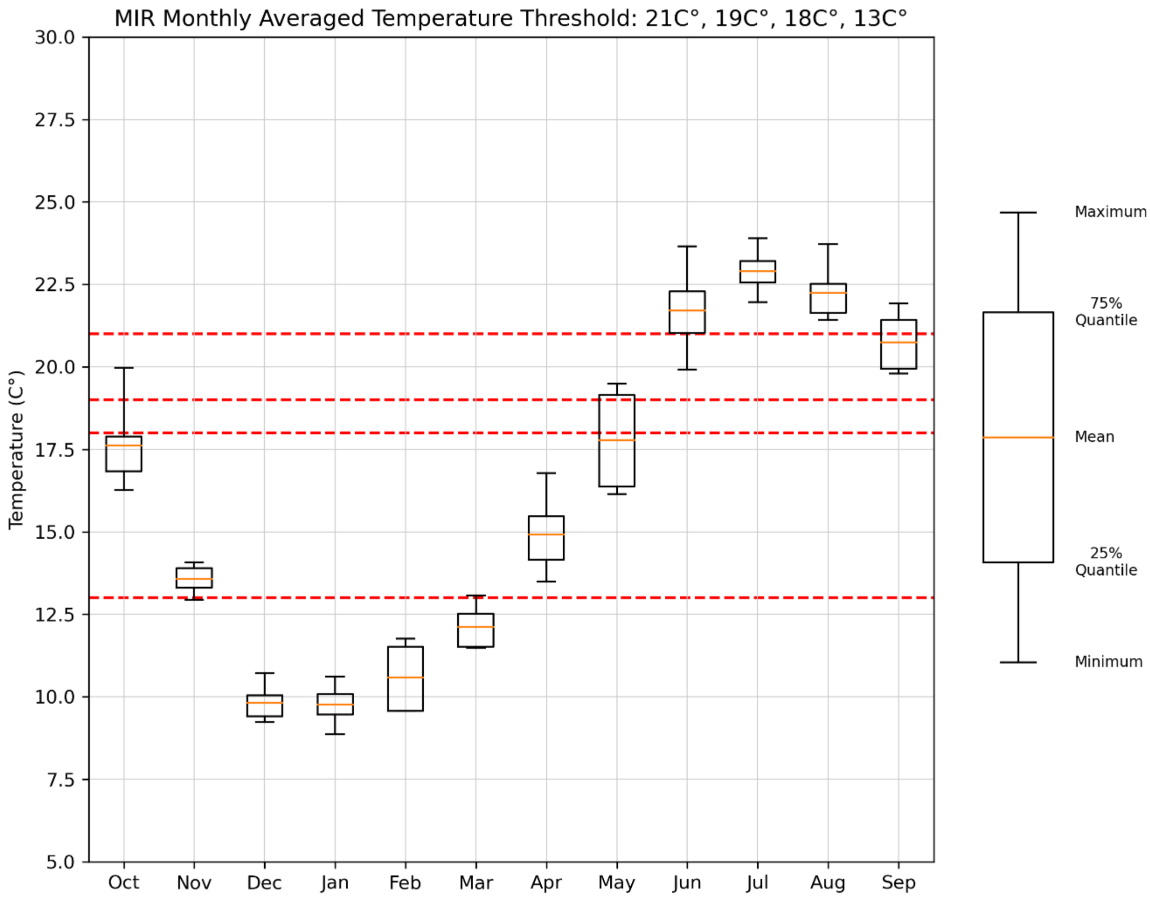

Figure C-60. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MIR – Miner Slough near Sacramento River

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

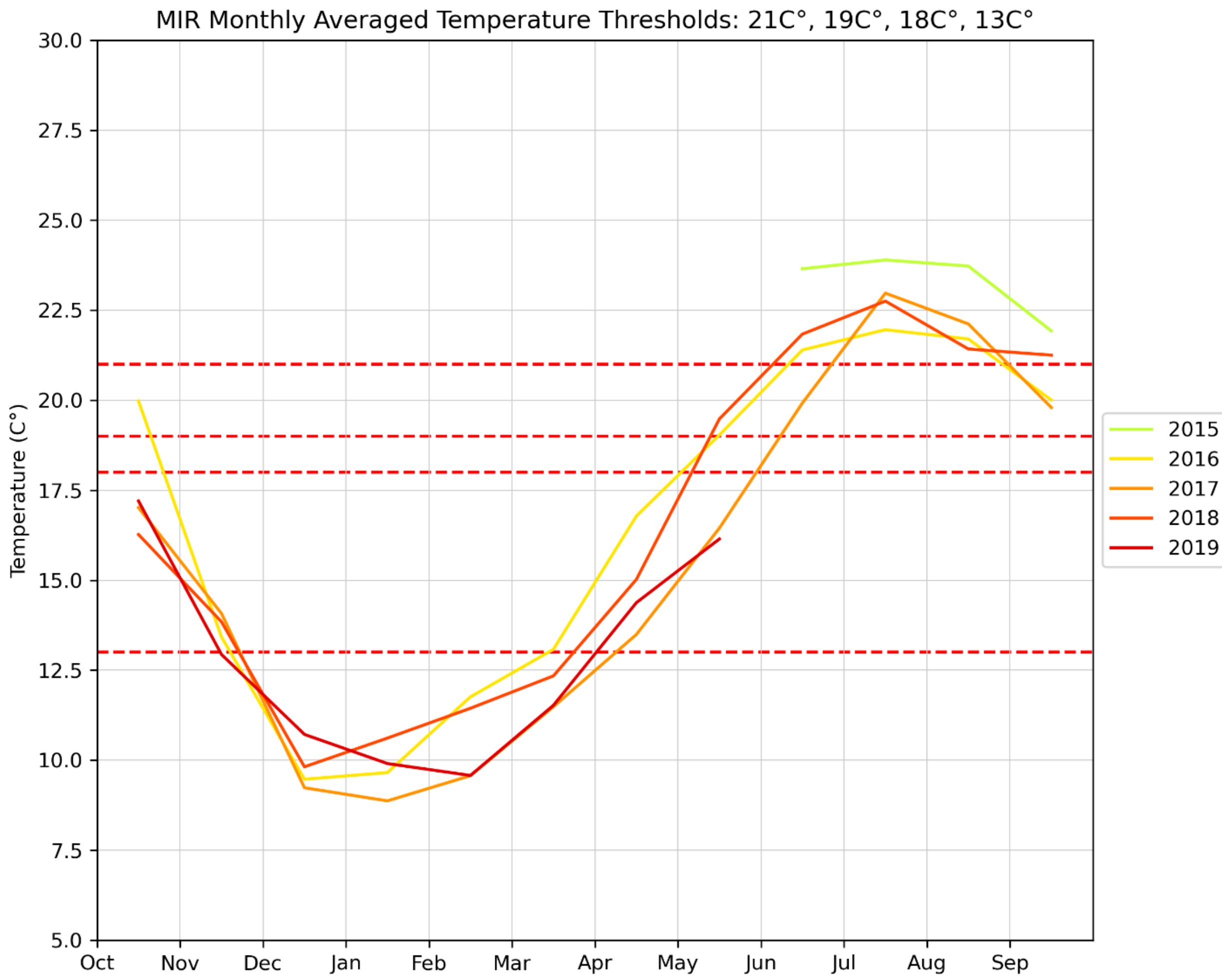

Figure C-61. Monthly Average Temperature for the Period of Record at Station MIR – Miner Slough near Sacramento River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

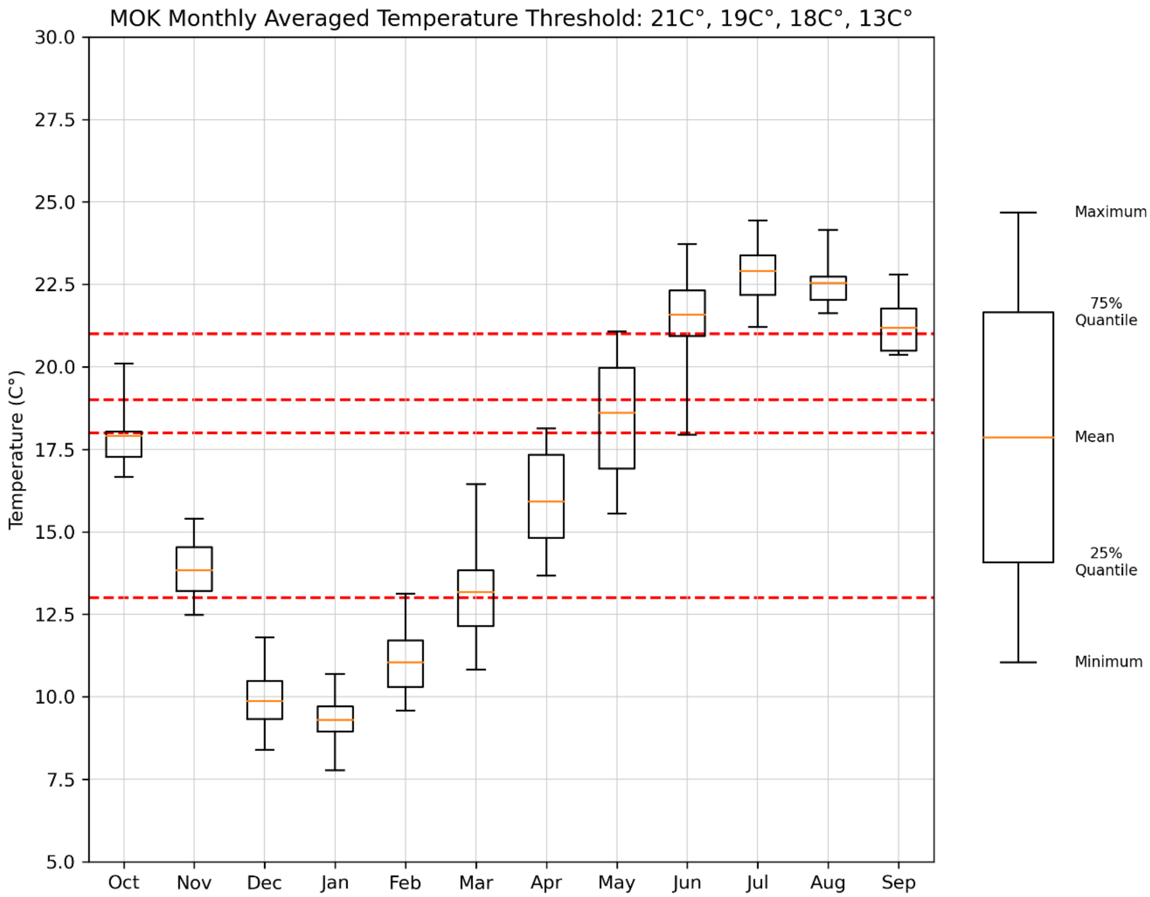

Figure C-62. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MOK – Mokelumne River at San Joaquin River

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

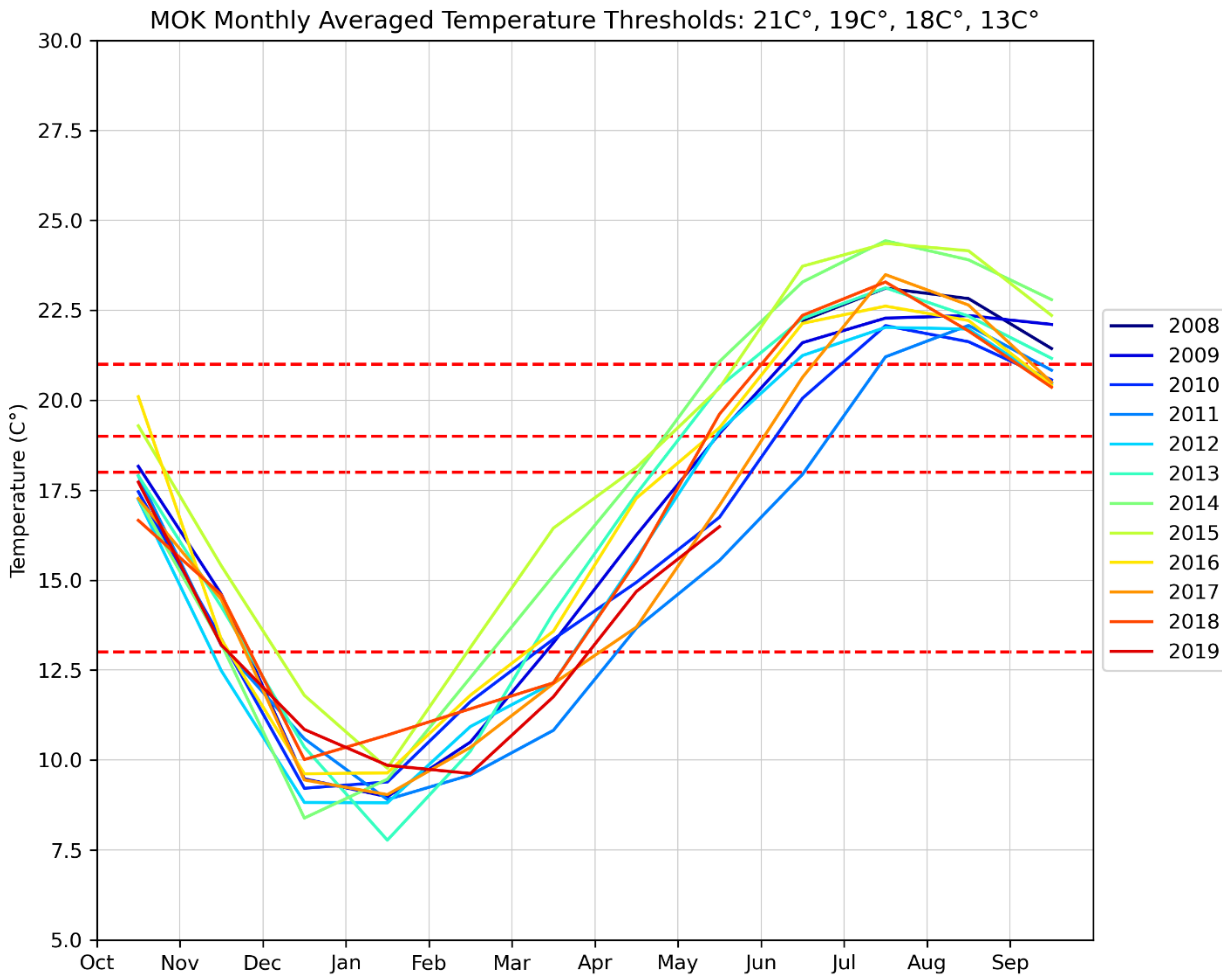

Figure C-63. Monthly Average Temperature for the Period of Record at Station MOK – Mokelumne River at San Joaquin River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

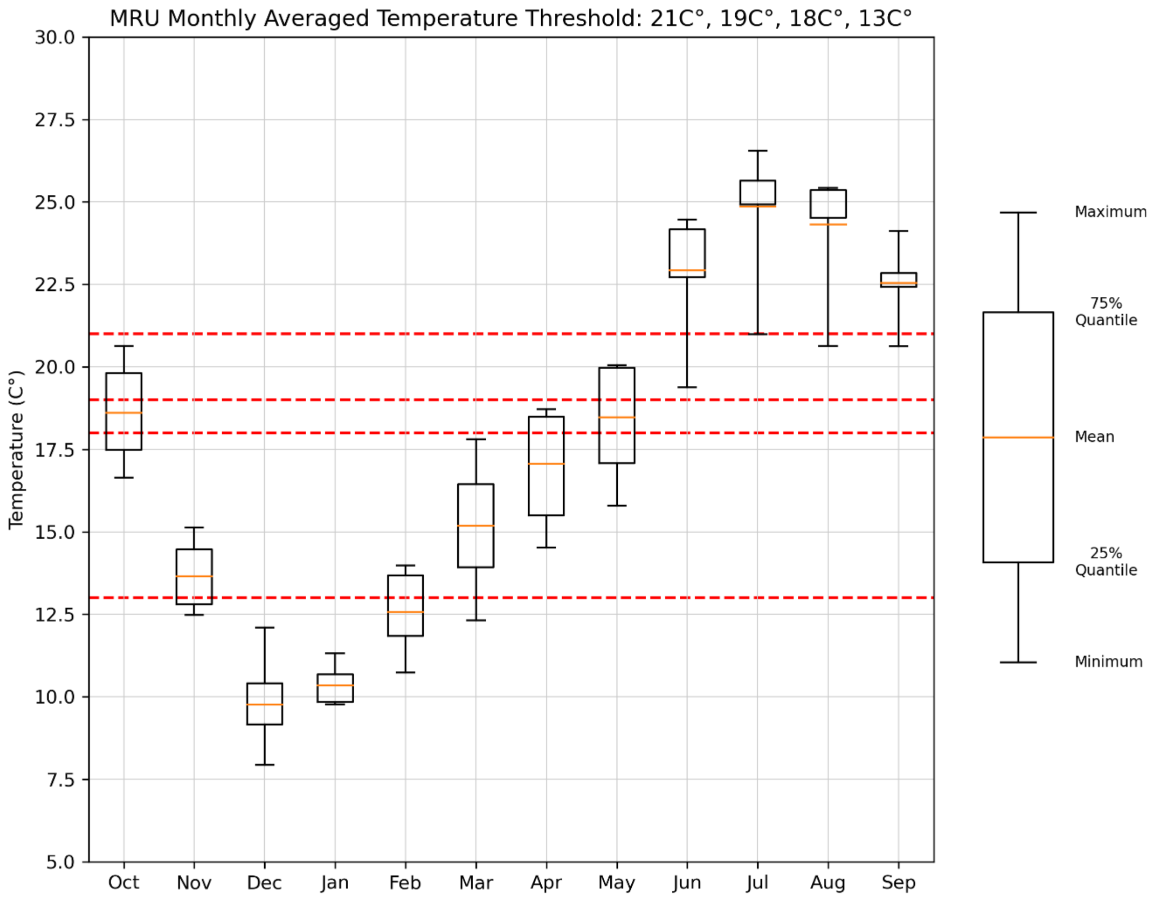

Figure C-64. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MRU – Middle River at Undine Road

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

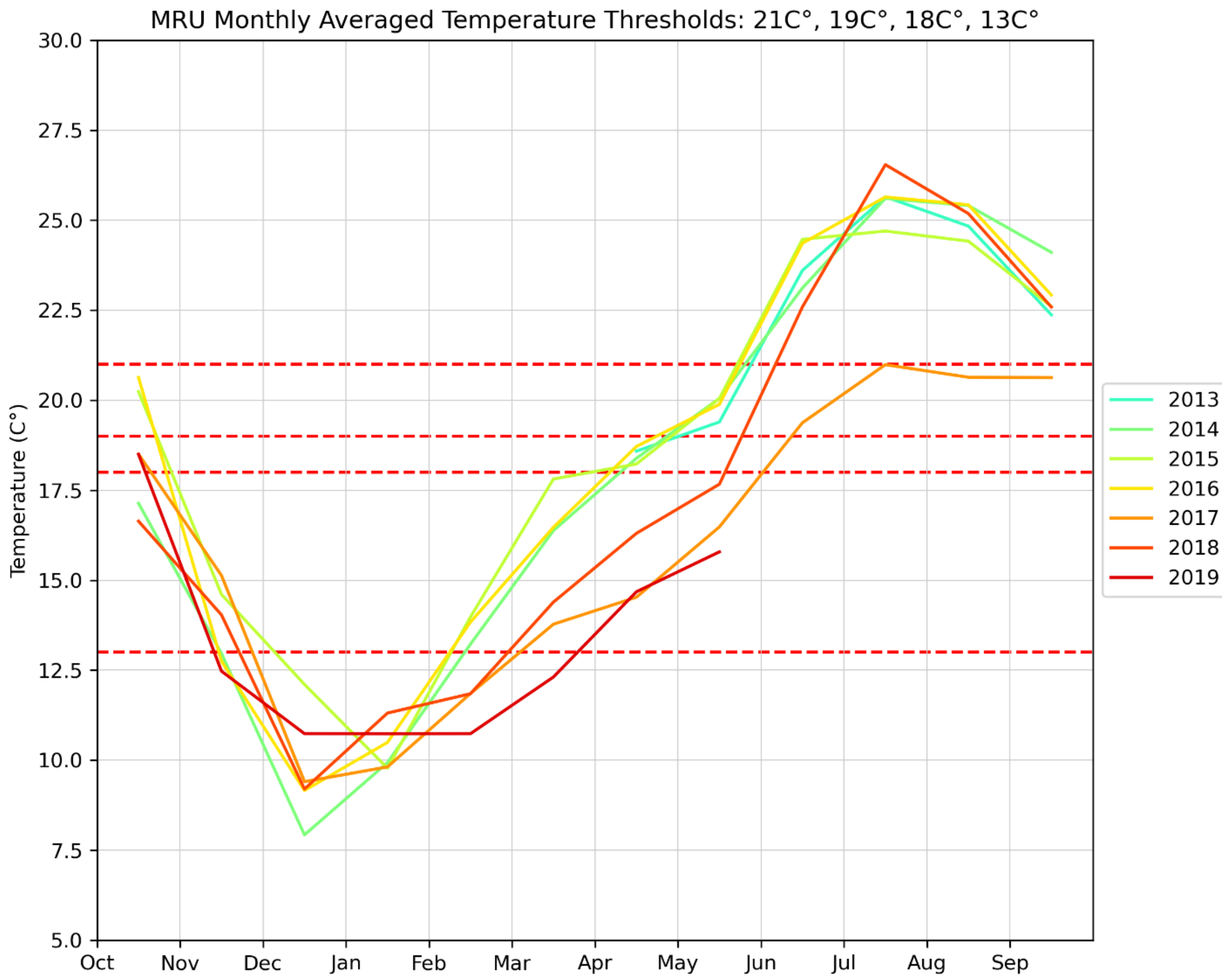

Figure C-65. Monthly Average Temperature for the Period of Record at Station MRU – Middle River at Undine Road

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

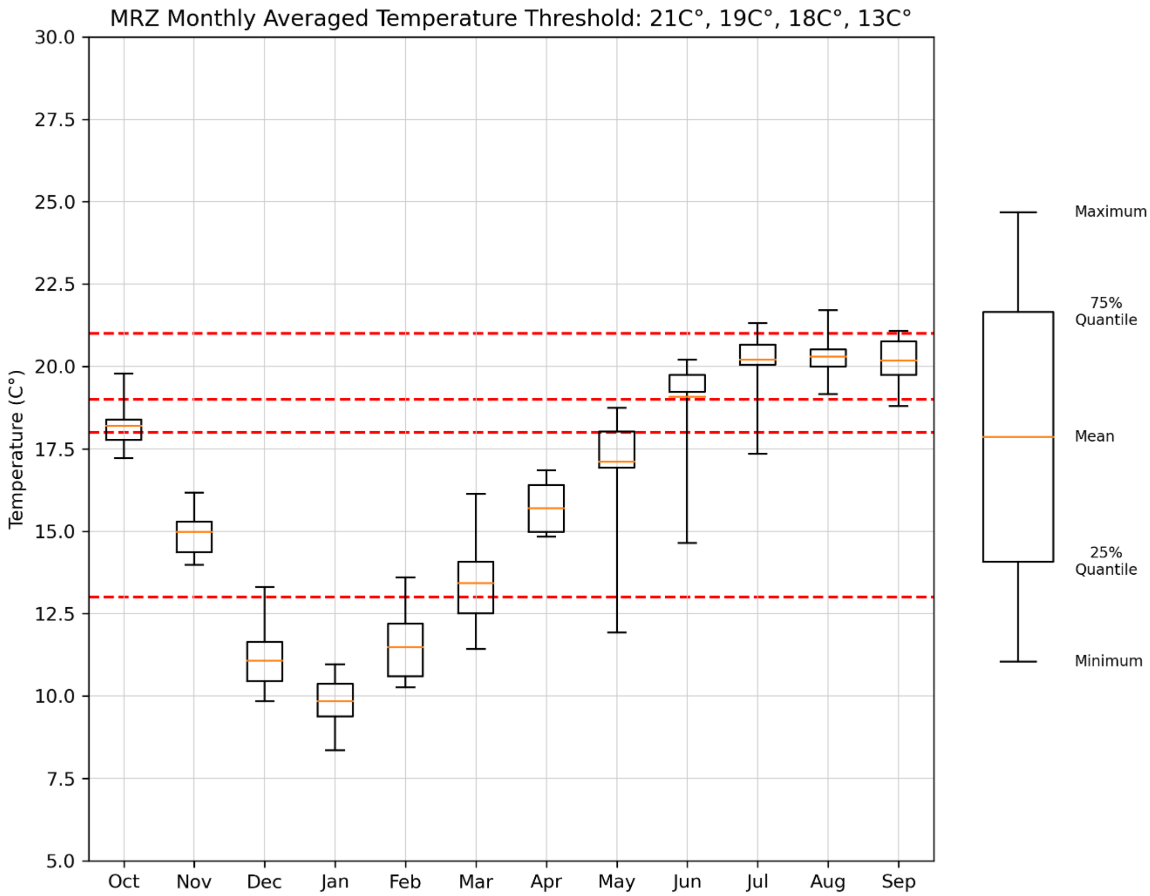

Figure C-66. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MRZ – Martinez

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

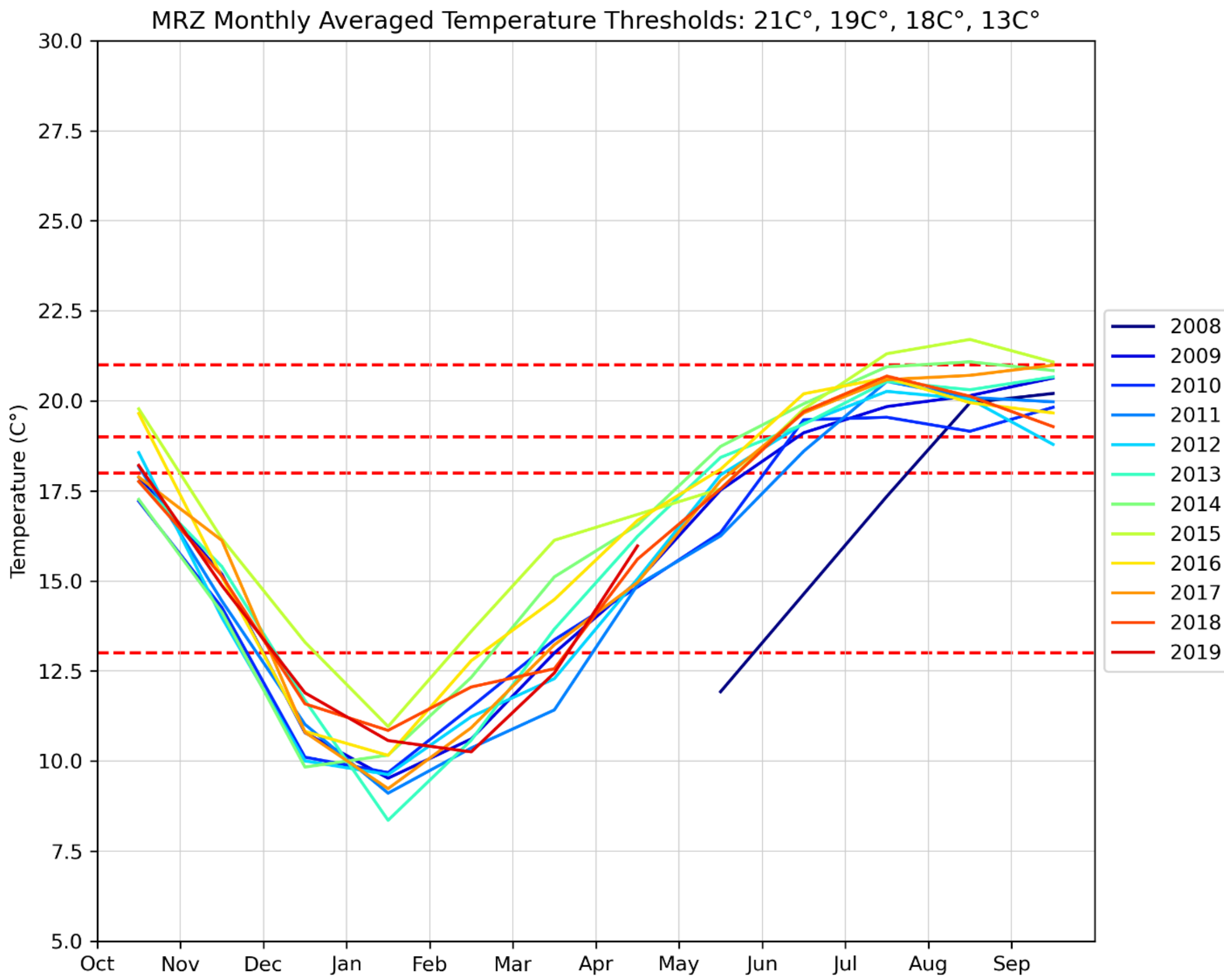

Figure C-67. Monthly Average Temperature for the Period of Record at Station MRZ – Martinez

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

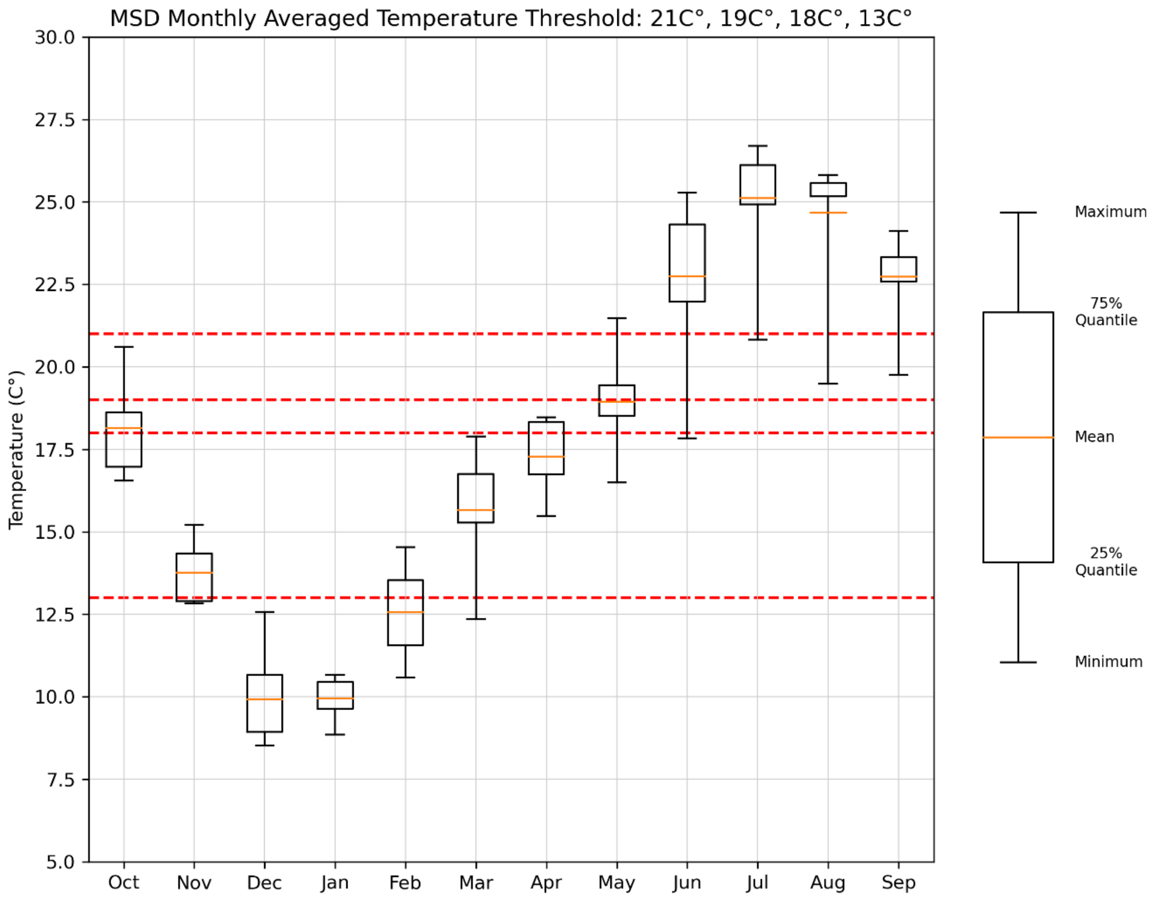

Figure C-68. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MSD – San Joaquin River at Mossdale Bridge

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

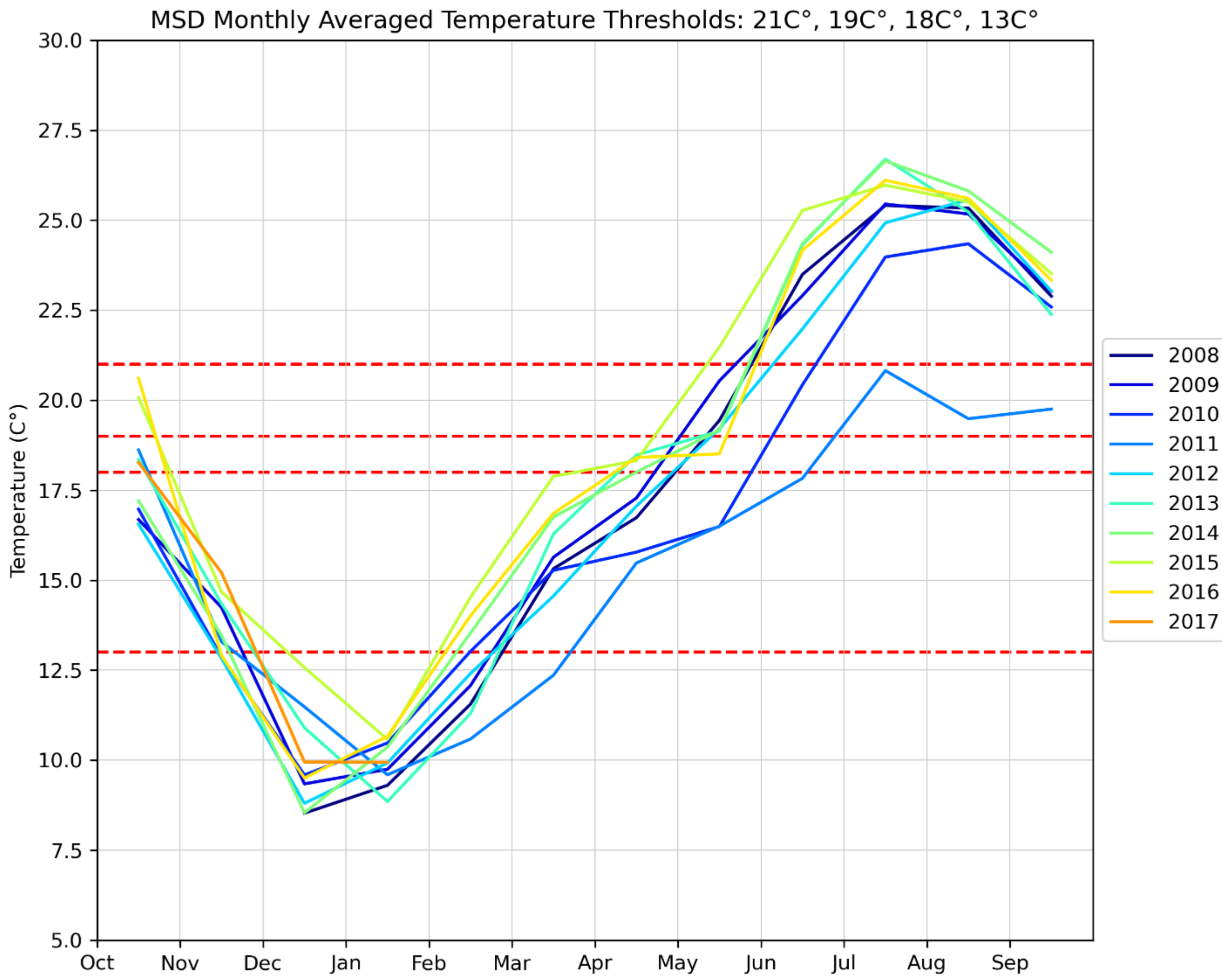

Figure C-69. Monthly Average Temperature for the Period of Record at Station MSD – San Joaquin River at Mossdale Bridge

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

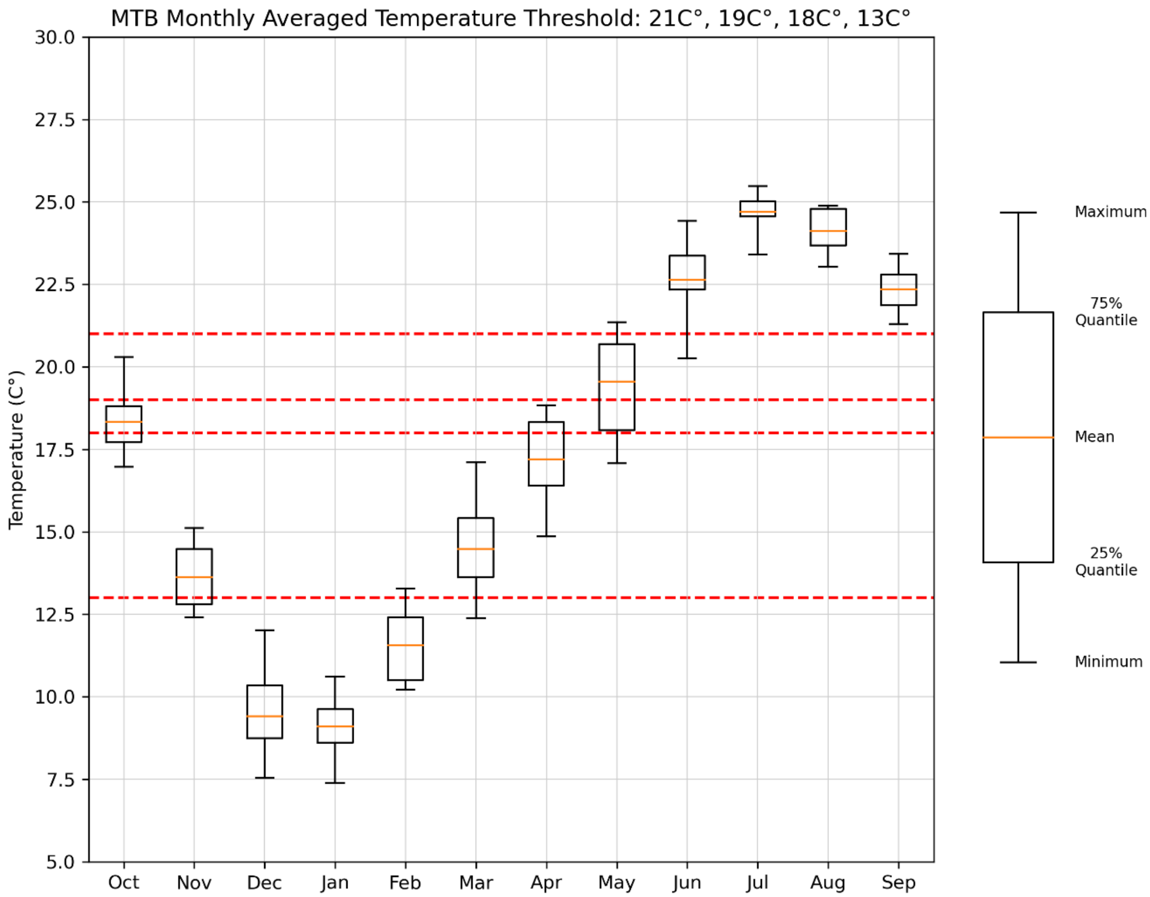

Figure C-70. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MTB – Middle River at Tracy Boulevard

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

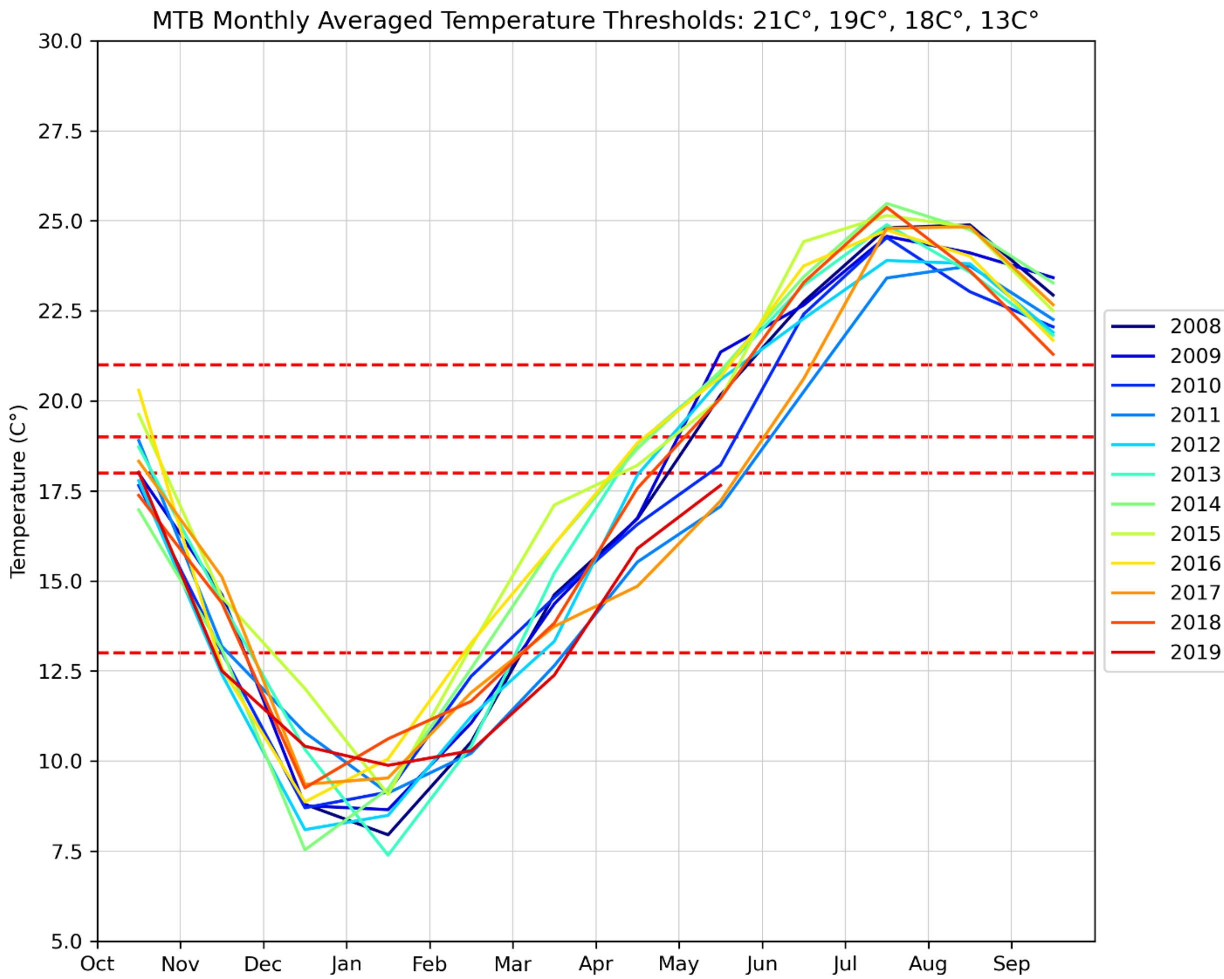

Figure C-71. Monthly Average Temperature for the Period of Record at Station MTB – Middle River at Tracy Boulevard

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

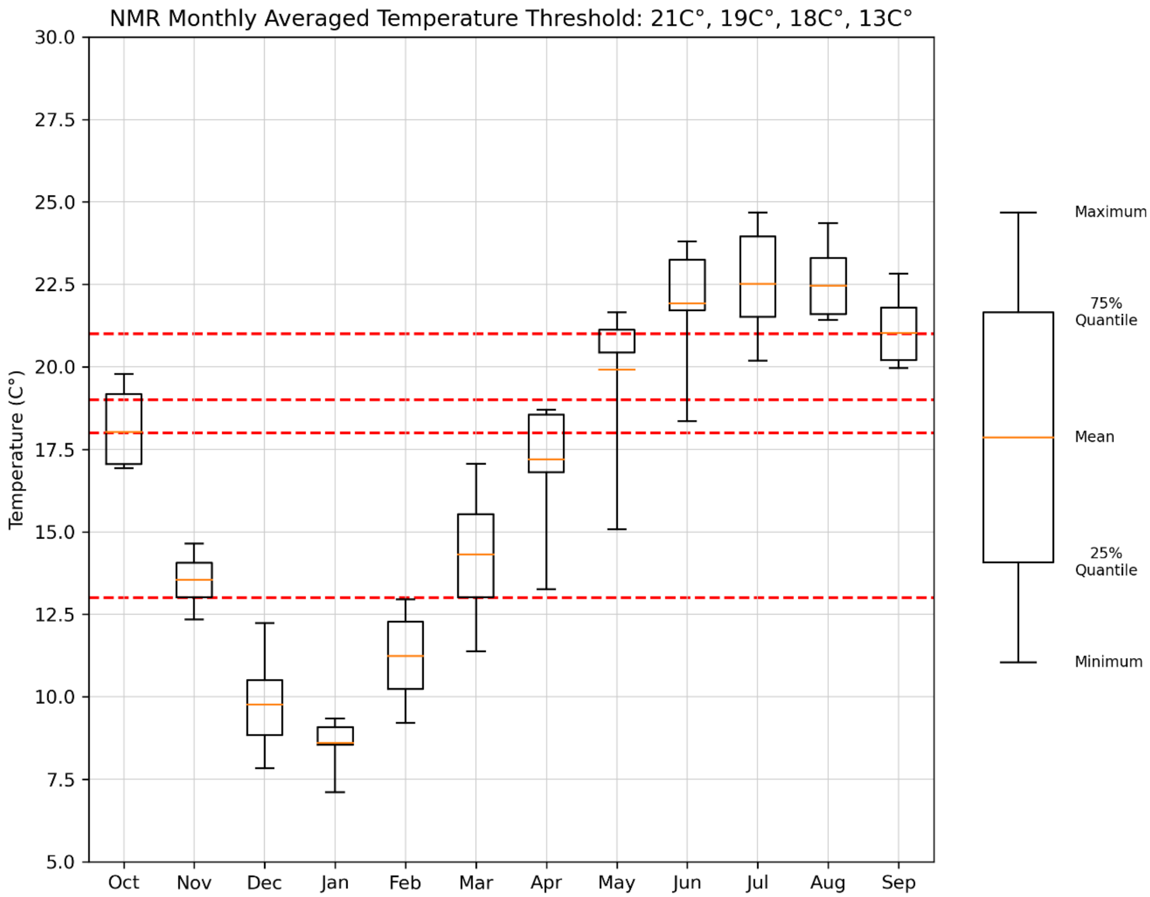

Figure C-72. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station NMR – North Mokelumne River at West Walnut Grove Road

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

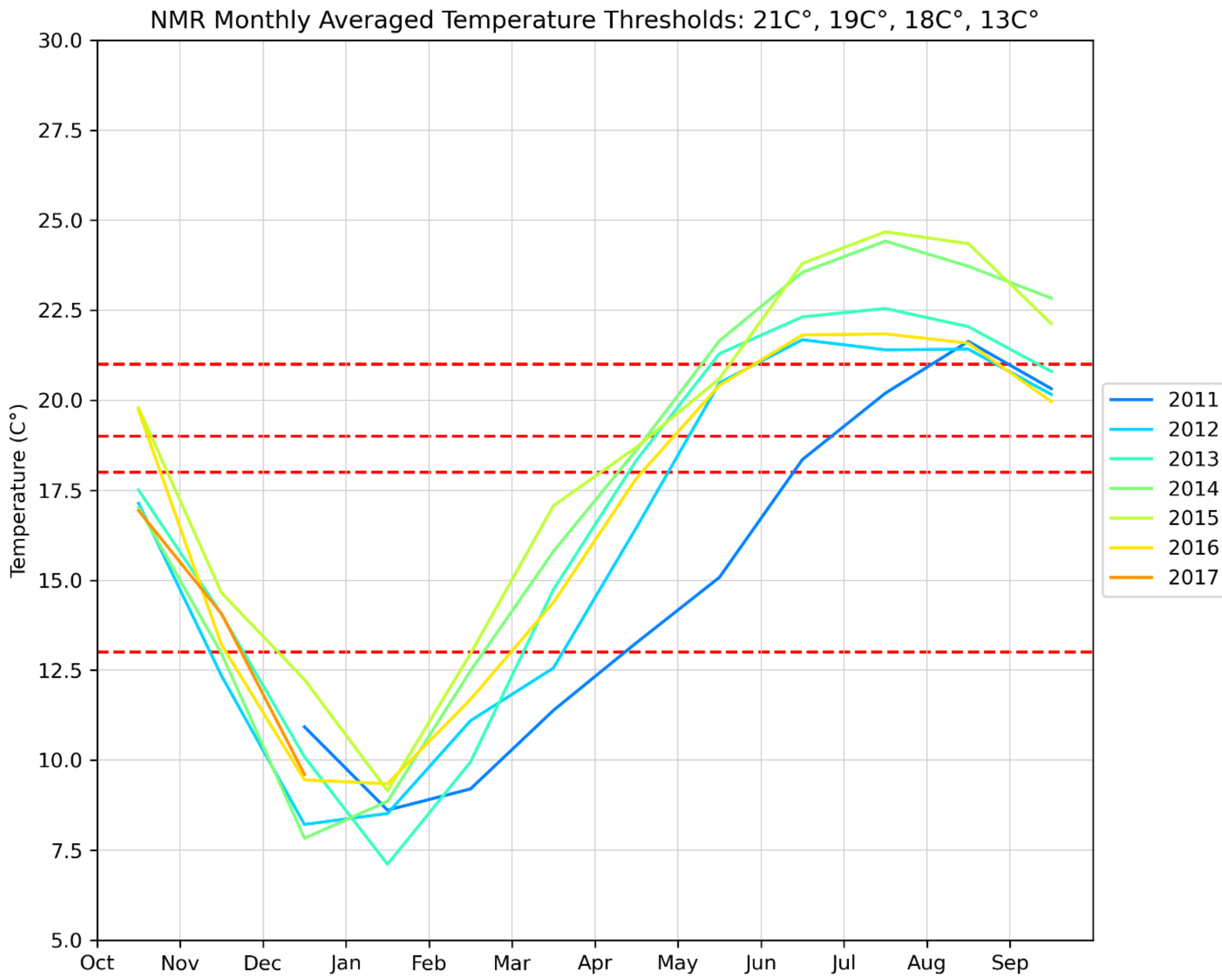

Figure C-73. Monthly Average Temperature for the Period of Record at Station NMR – North Mokelumne River at West Walnut Grove Road

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

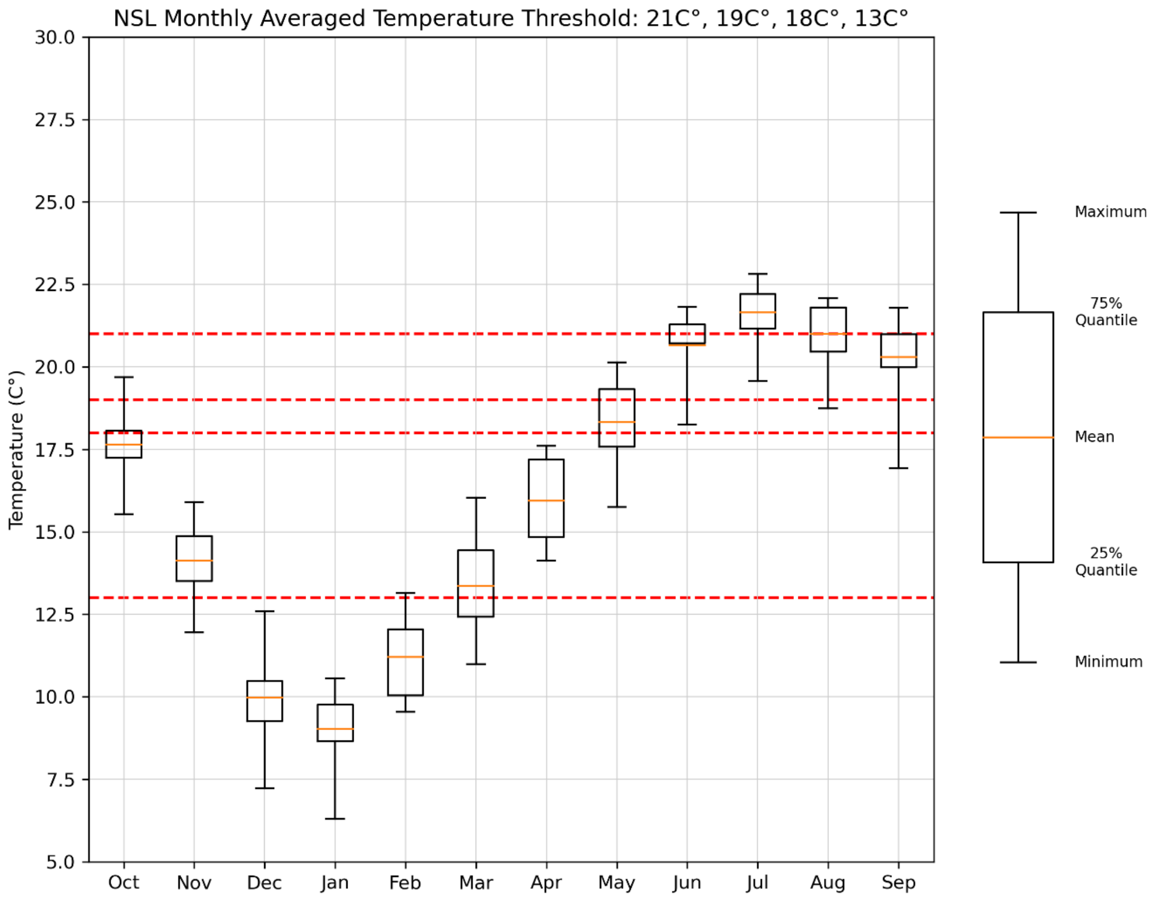

Figure C-74. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station NSL – Montezuma Slough at National Steel

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

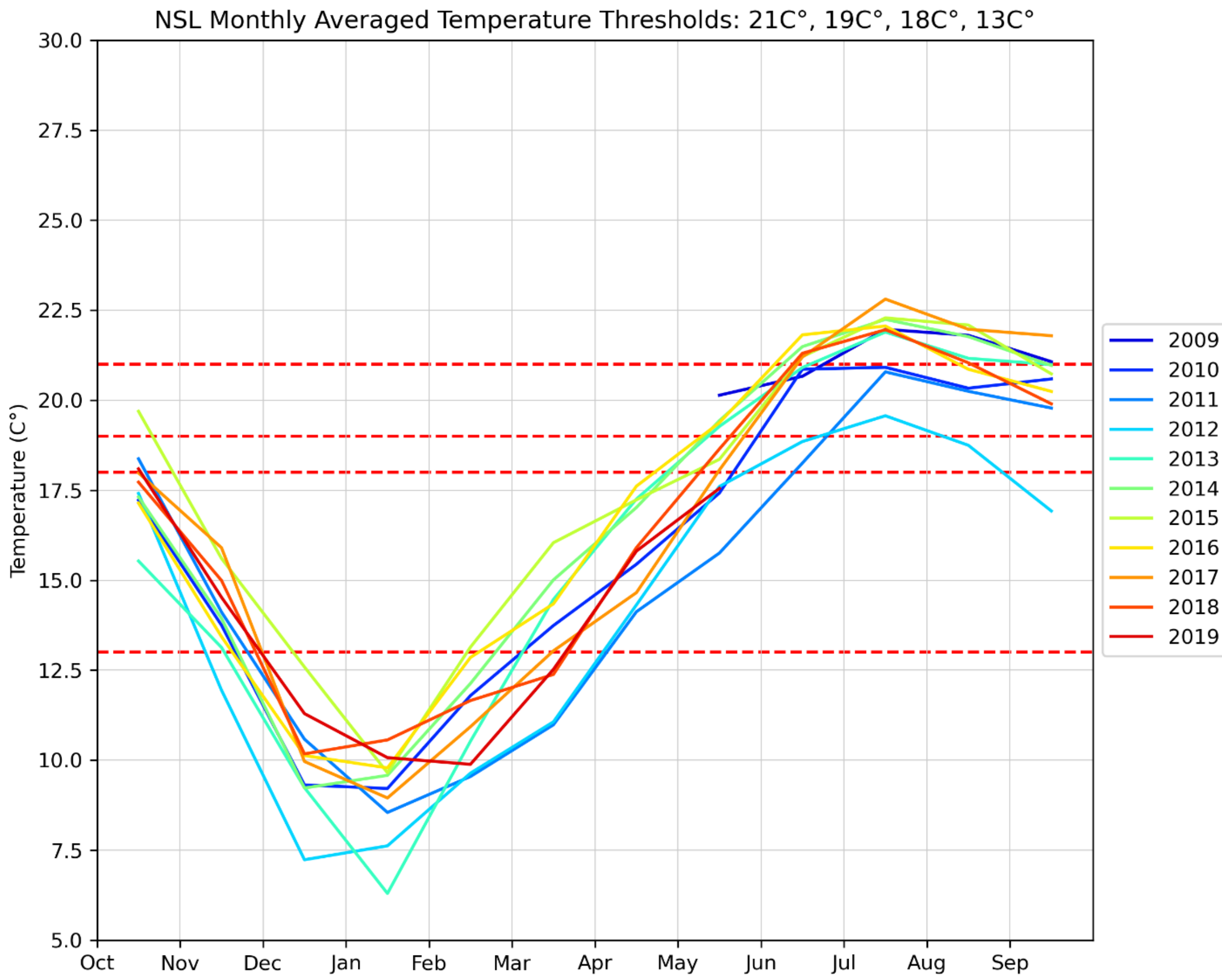

Figure C-75. Monthly Average Temperature for the Period of Record at Station NSL – Montezuma Slough at National Steel

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

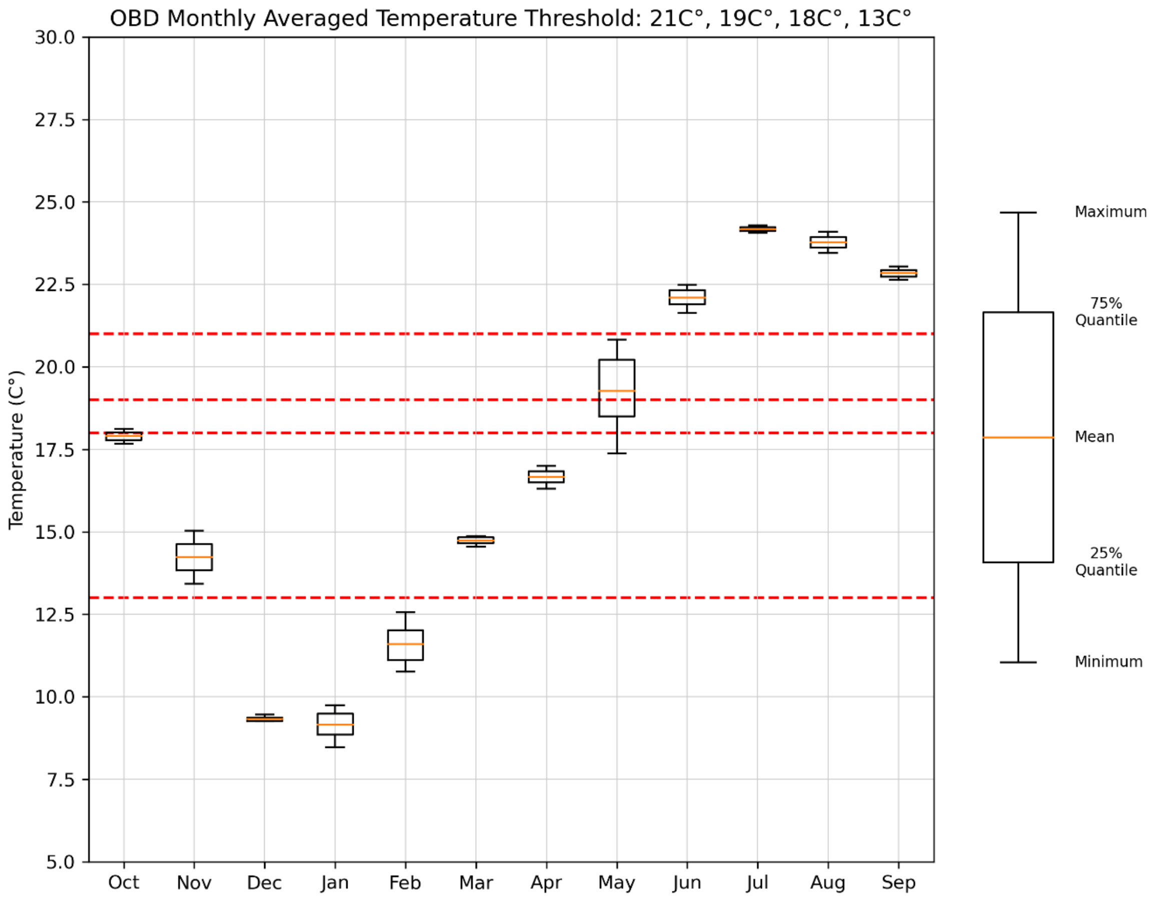

Figure C-76. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station OBD – Old River near DMC Below Dam

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

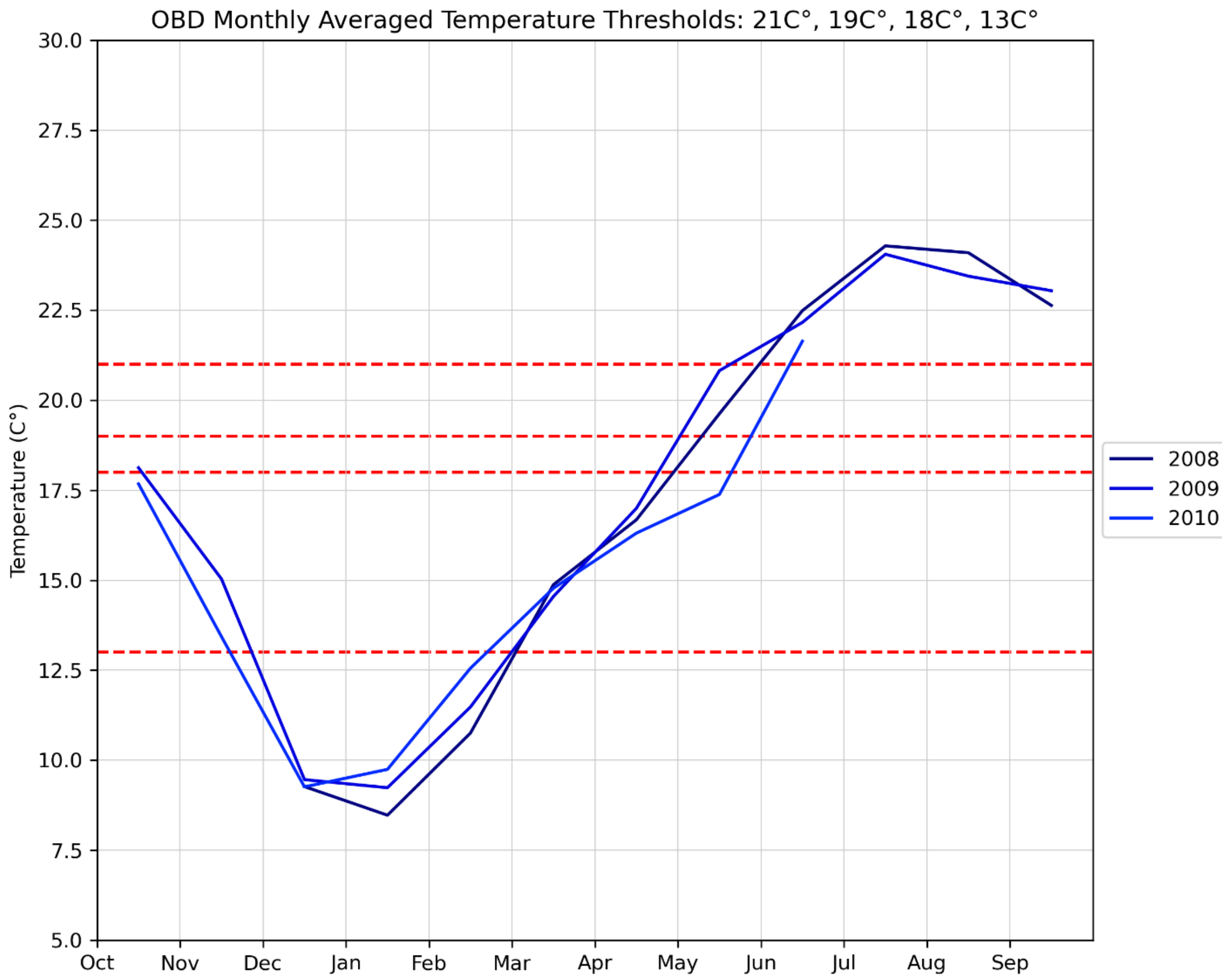

Figure C-77. Monthly Average Temperature for the Period of Record at Station OBD – Old River near DMC Below Dam

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

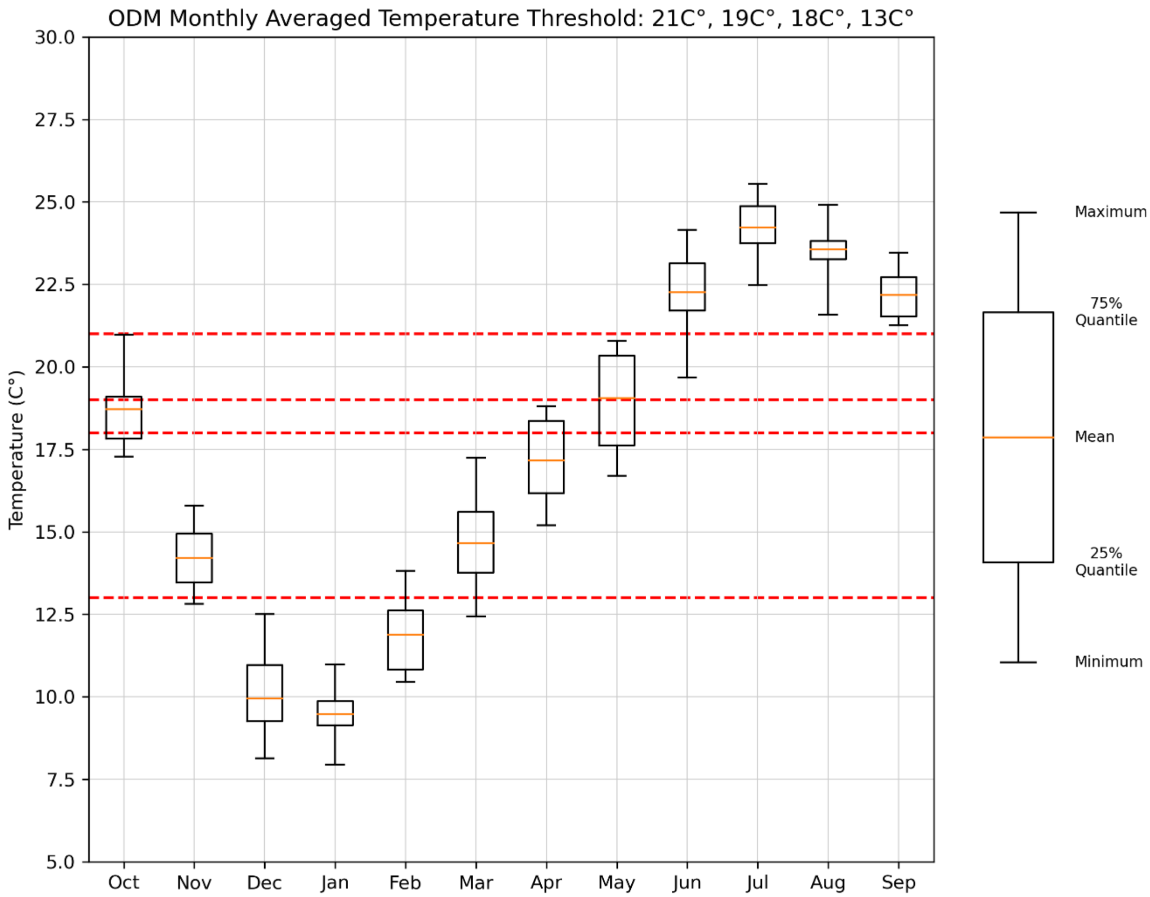

Figure C-78. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ODM – Old River at Delta Mendota Canal

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

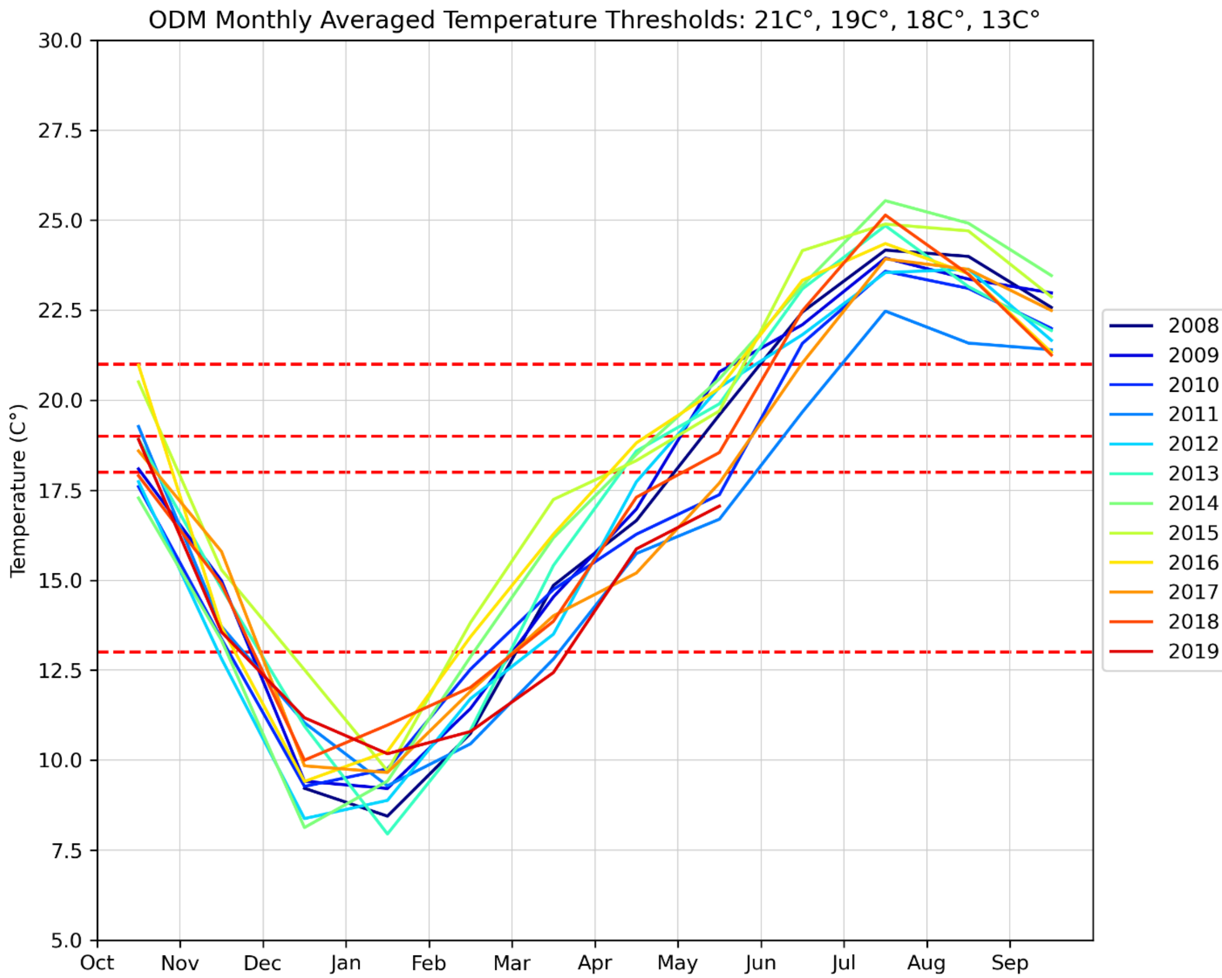

Figure C-79. Monthly Average Temperature for the Period of Record at Station ODM – Old River at Delta Mendota Canal

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

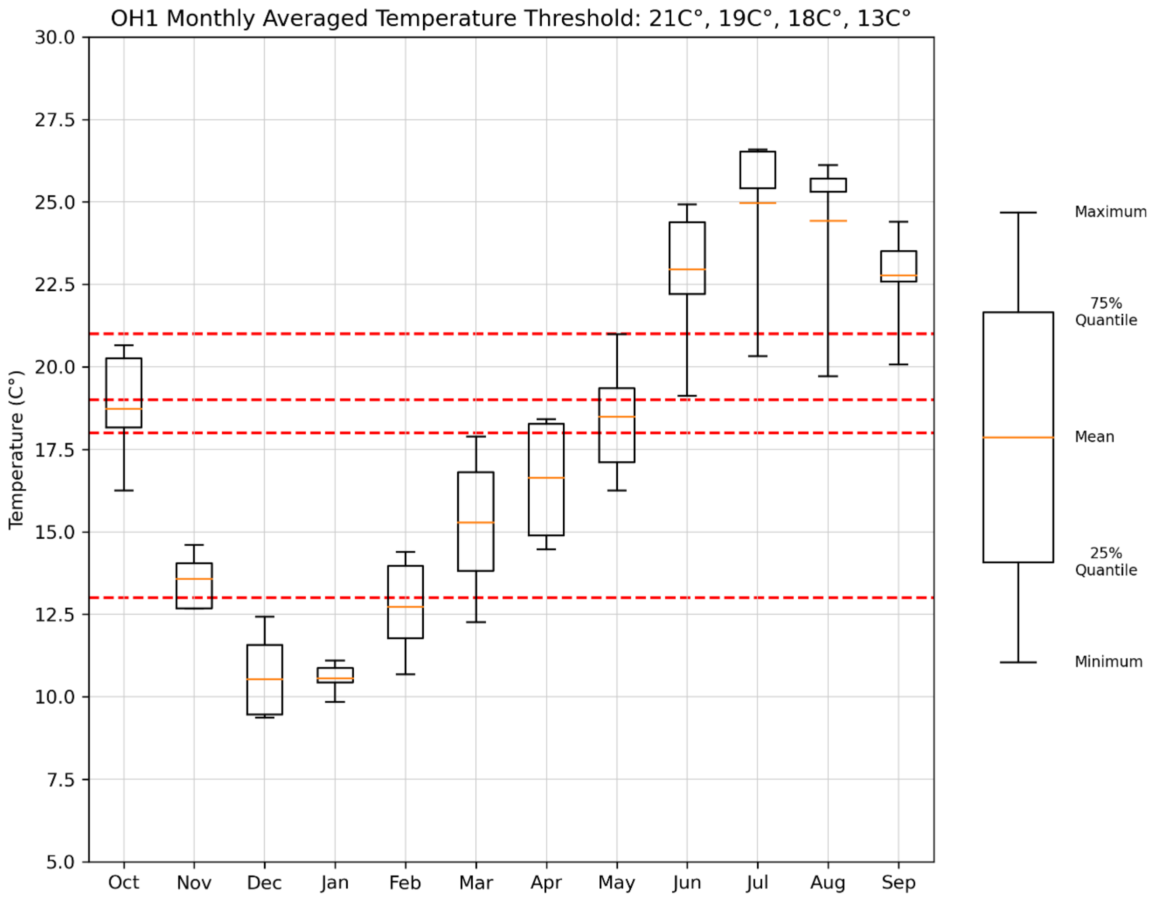

Figure C-80. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station OH1 – Old River at Head

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

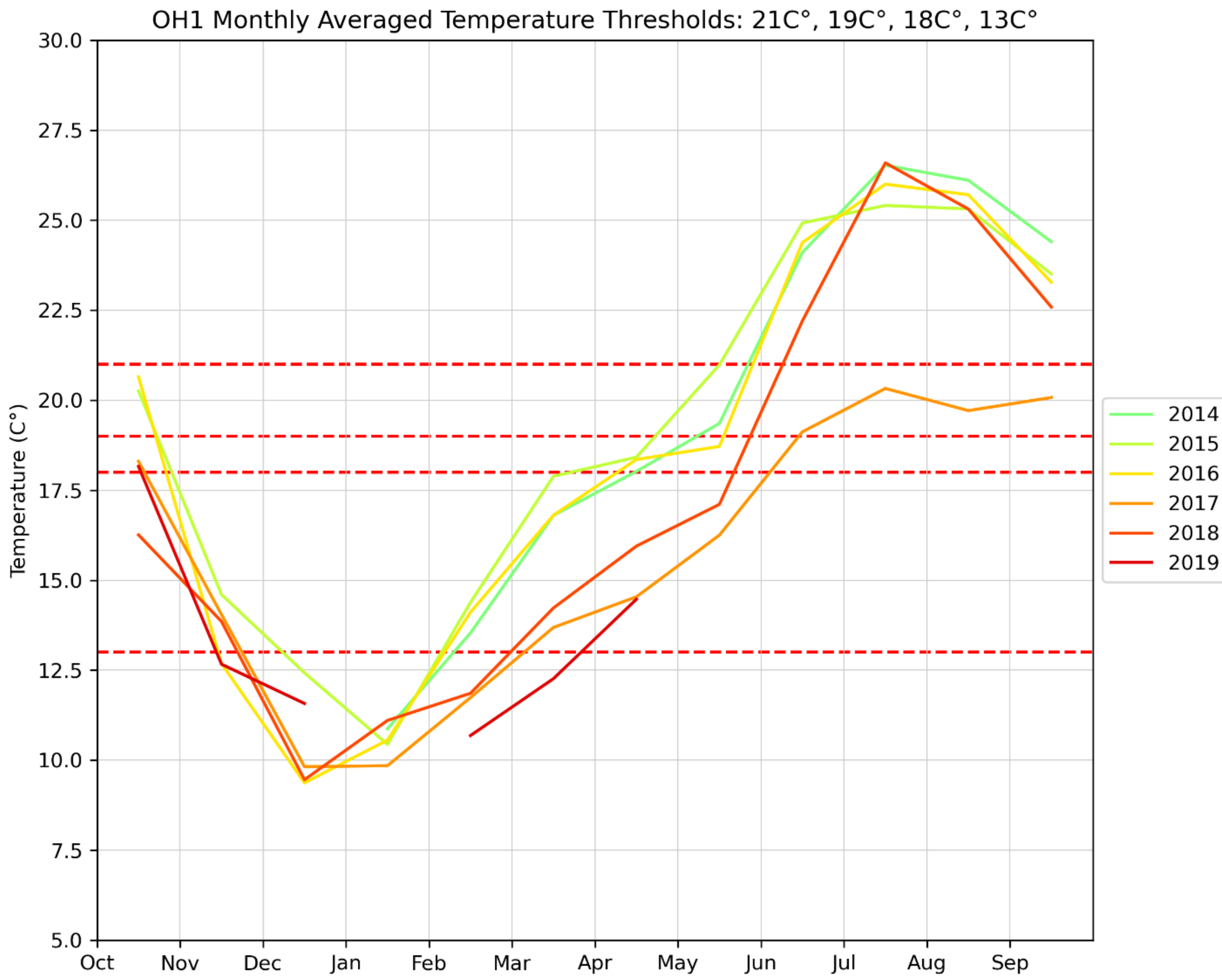

Figure C-81. Monthly Average Temperature for the Period of Record at Station OH1 – Old River at Head

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

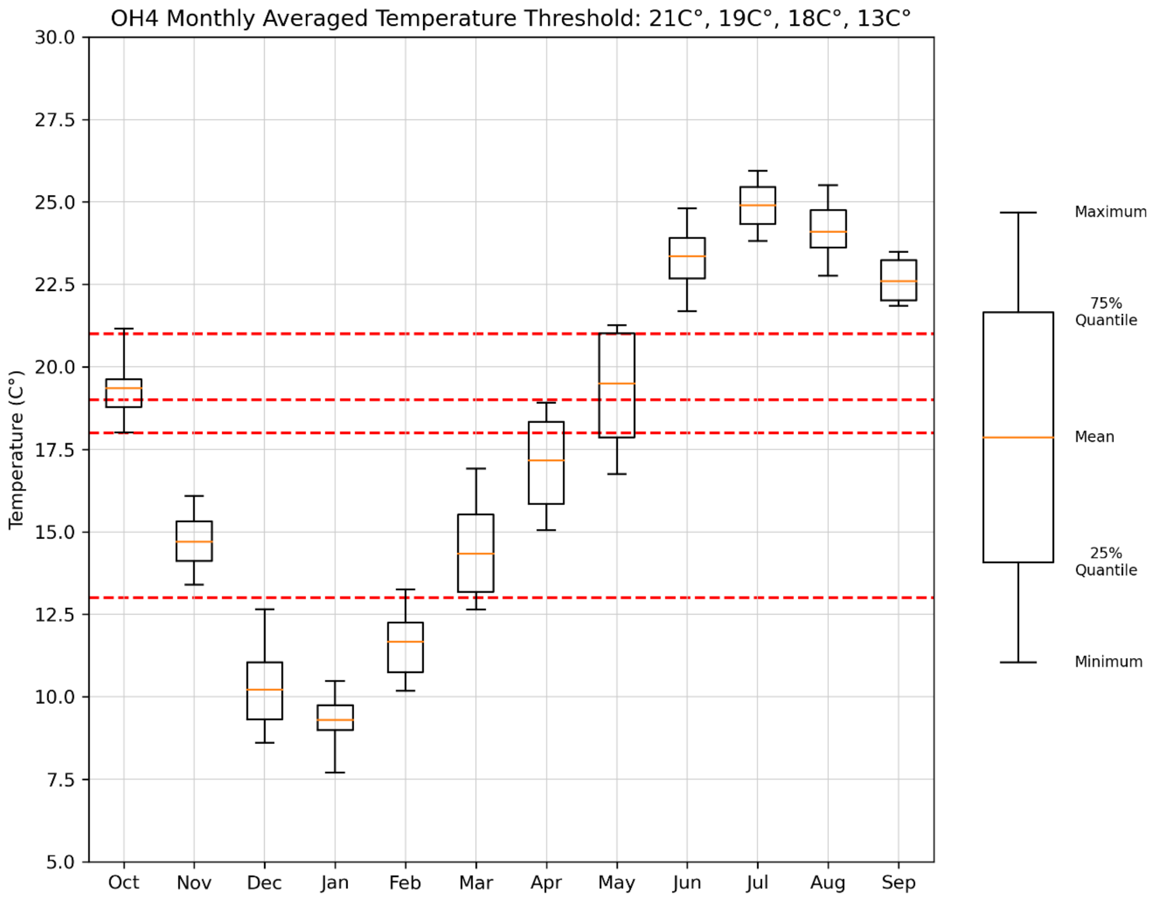

Figure C-82. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station OH4 – Old River at Highway 4

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

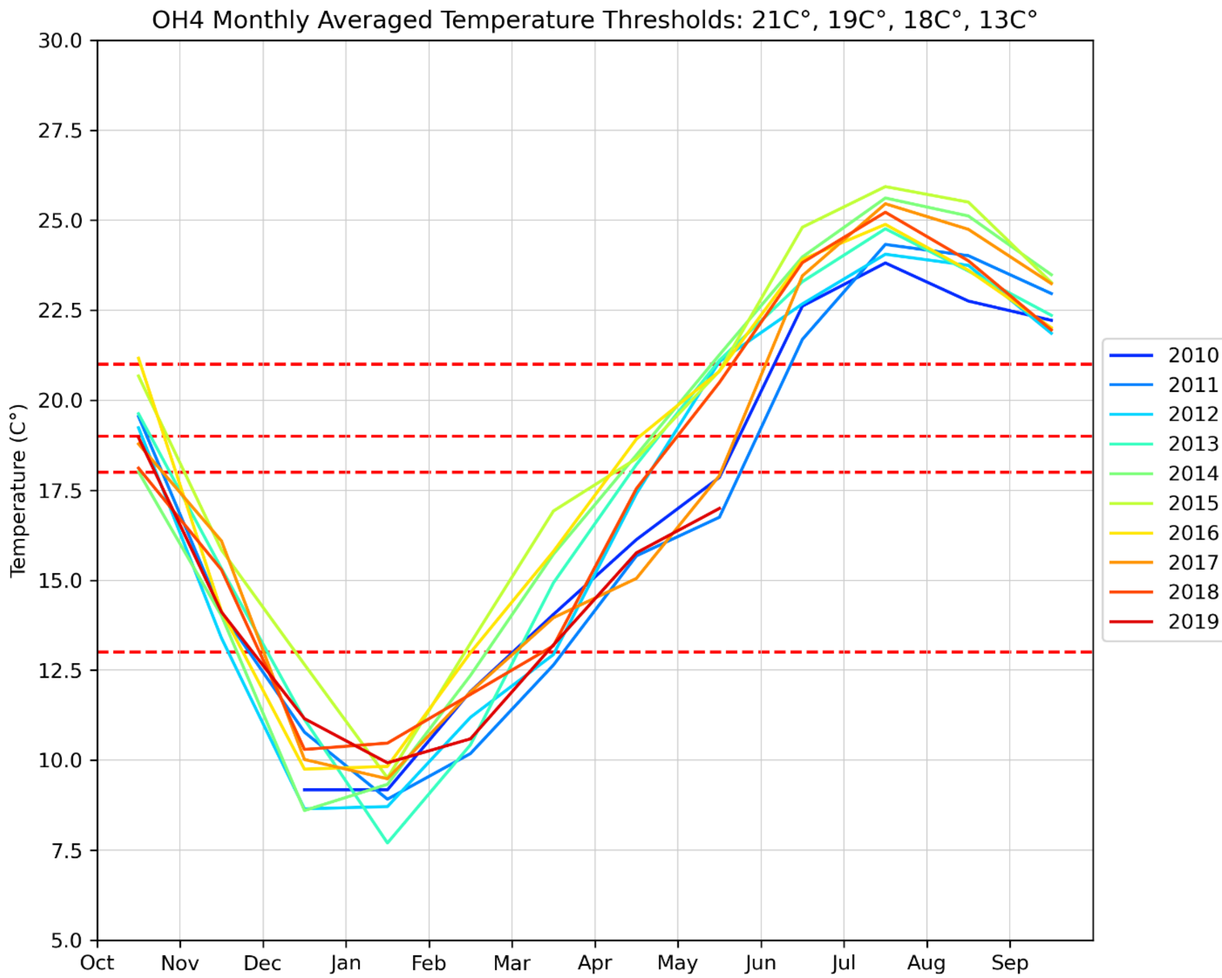

Figure C-83. Monthly Average Temperature for the Period of Record at Station OH4 – Old River at Highway 4

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

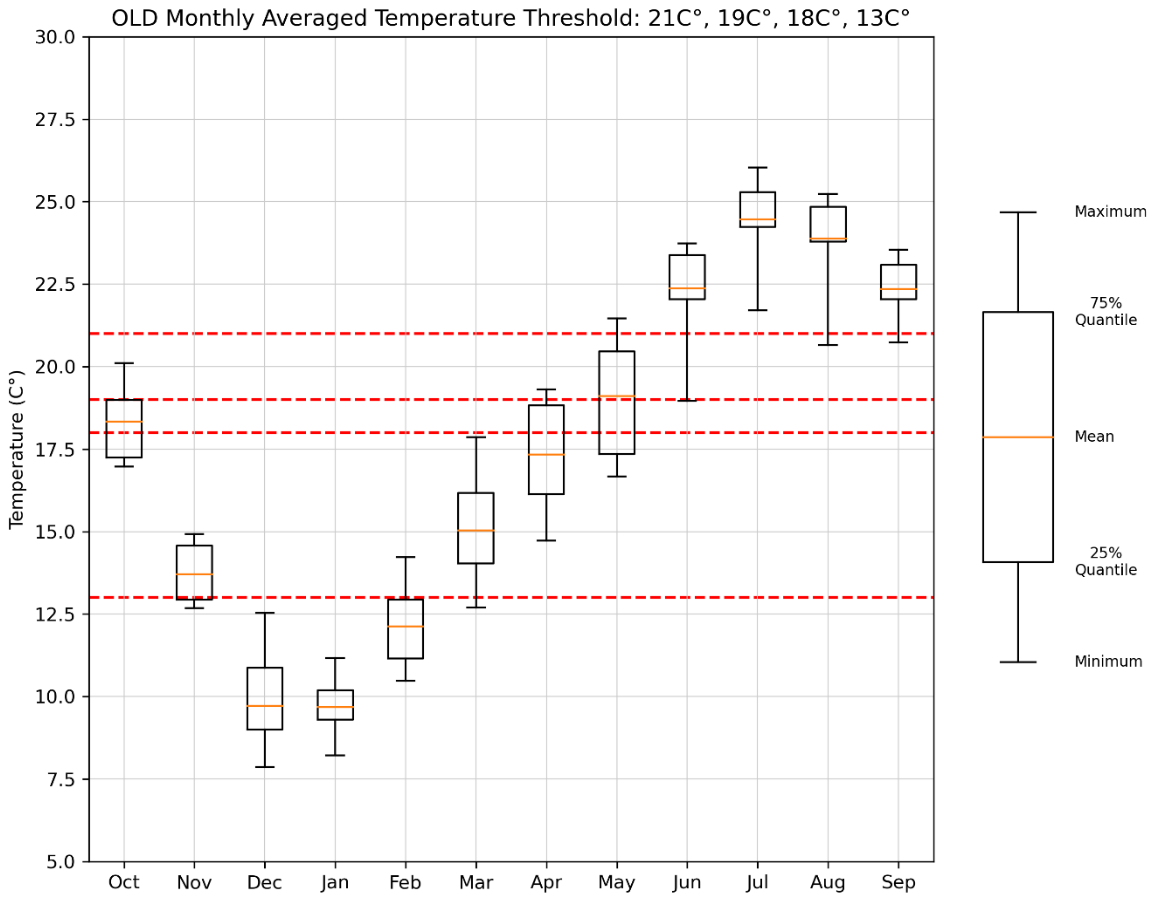

Figure C-84. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station OLD – Old River near Tracy

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

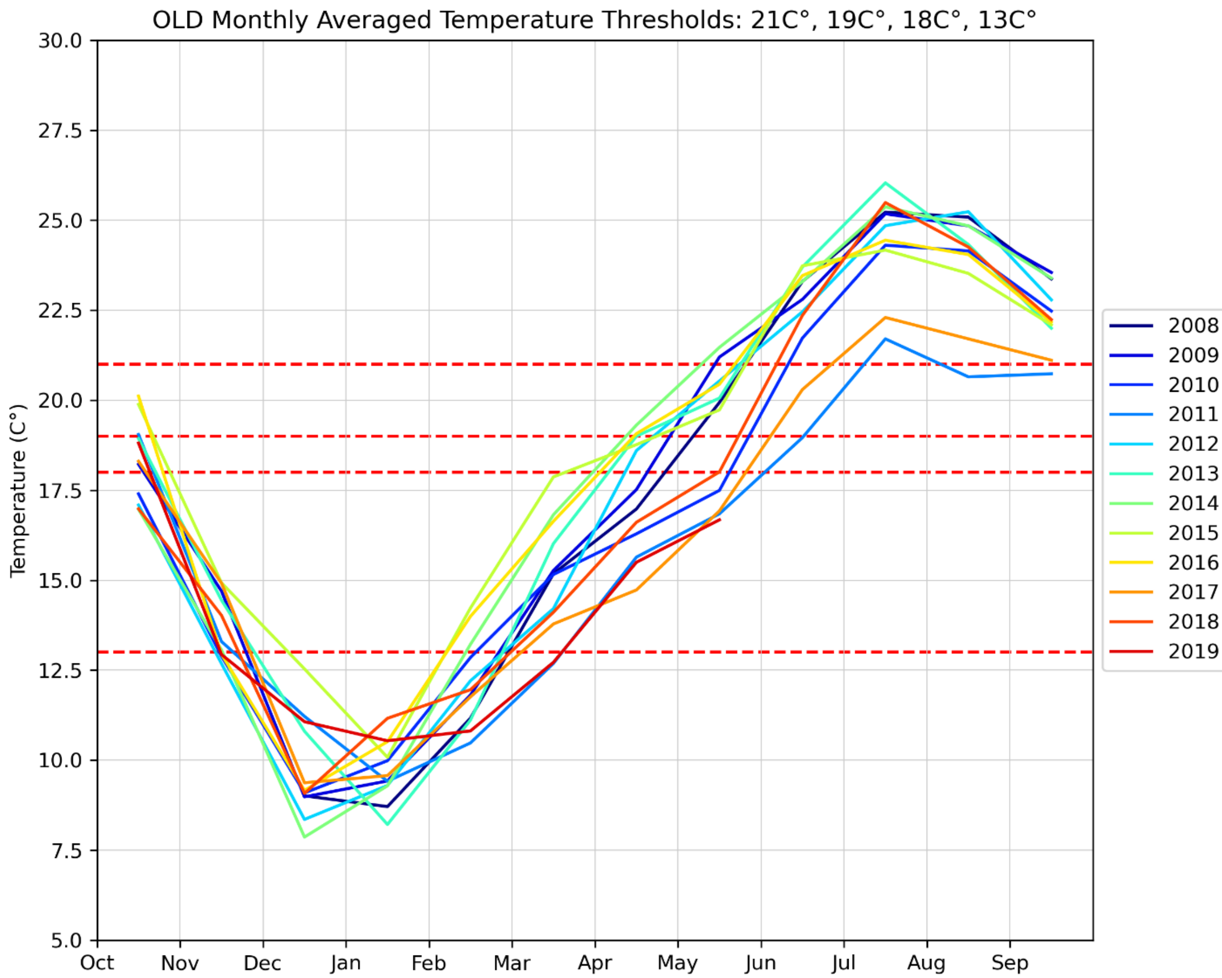

Figure C-85. Monthly Average Temperature for the Period of Record at Station OLD – Old River near Tracy

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

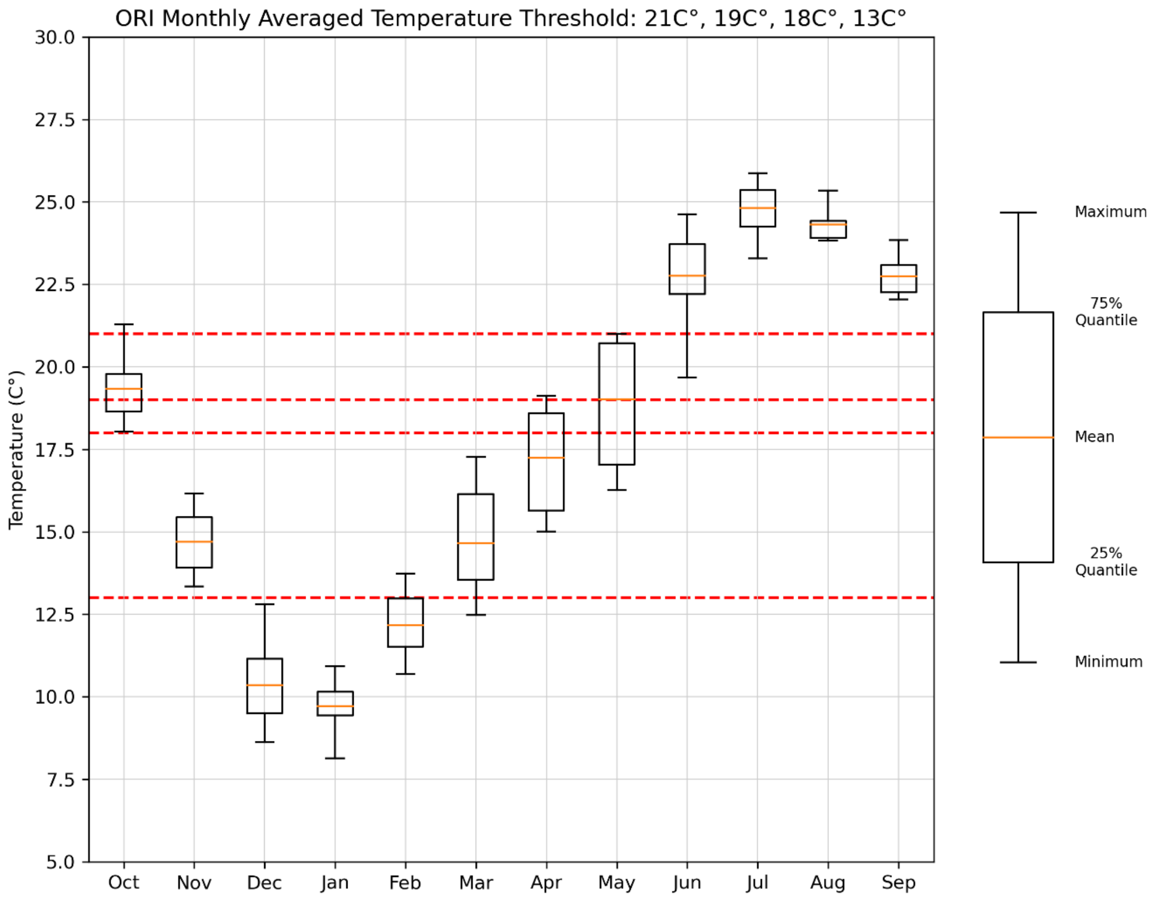

Figure C-86. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ORI – Old River at Clifton Court Intake

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

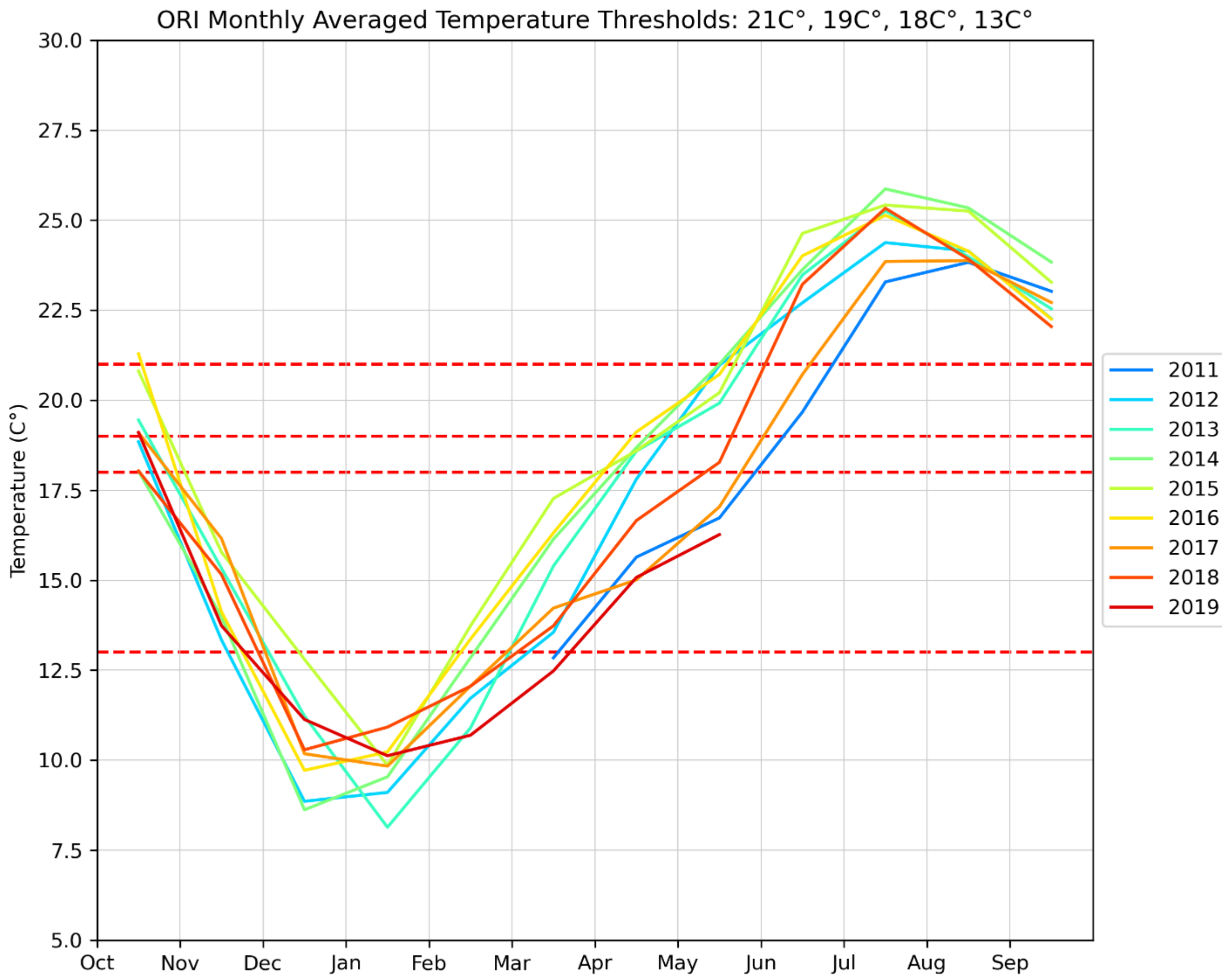

Figure C-87. Monthly Average Temperature for the Period of Record at Station ORI – Old River at Clifton Court Intake

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

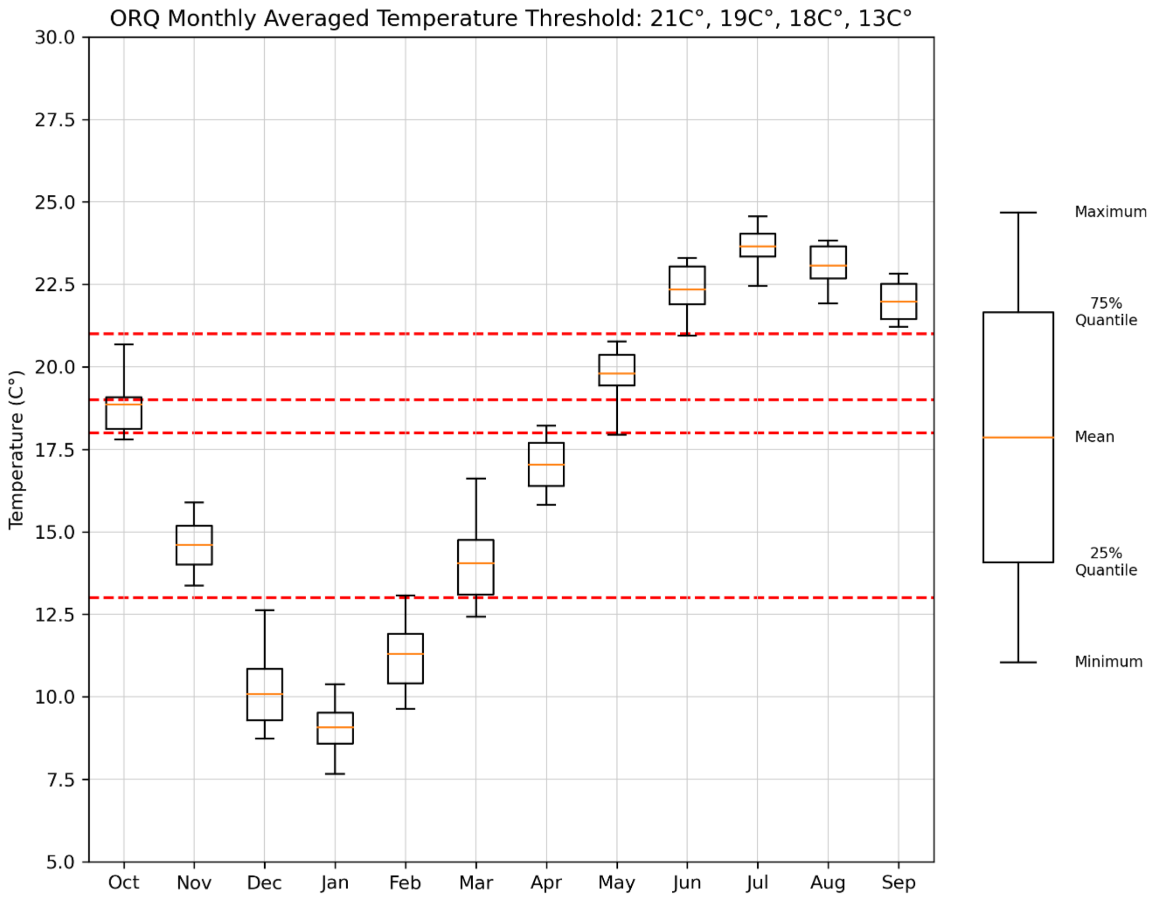

Figure C-88. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ORQ – Old River at Quimby Island near Bethel Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

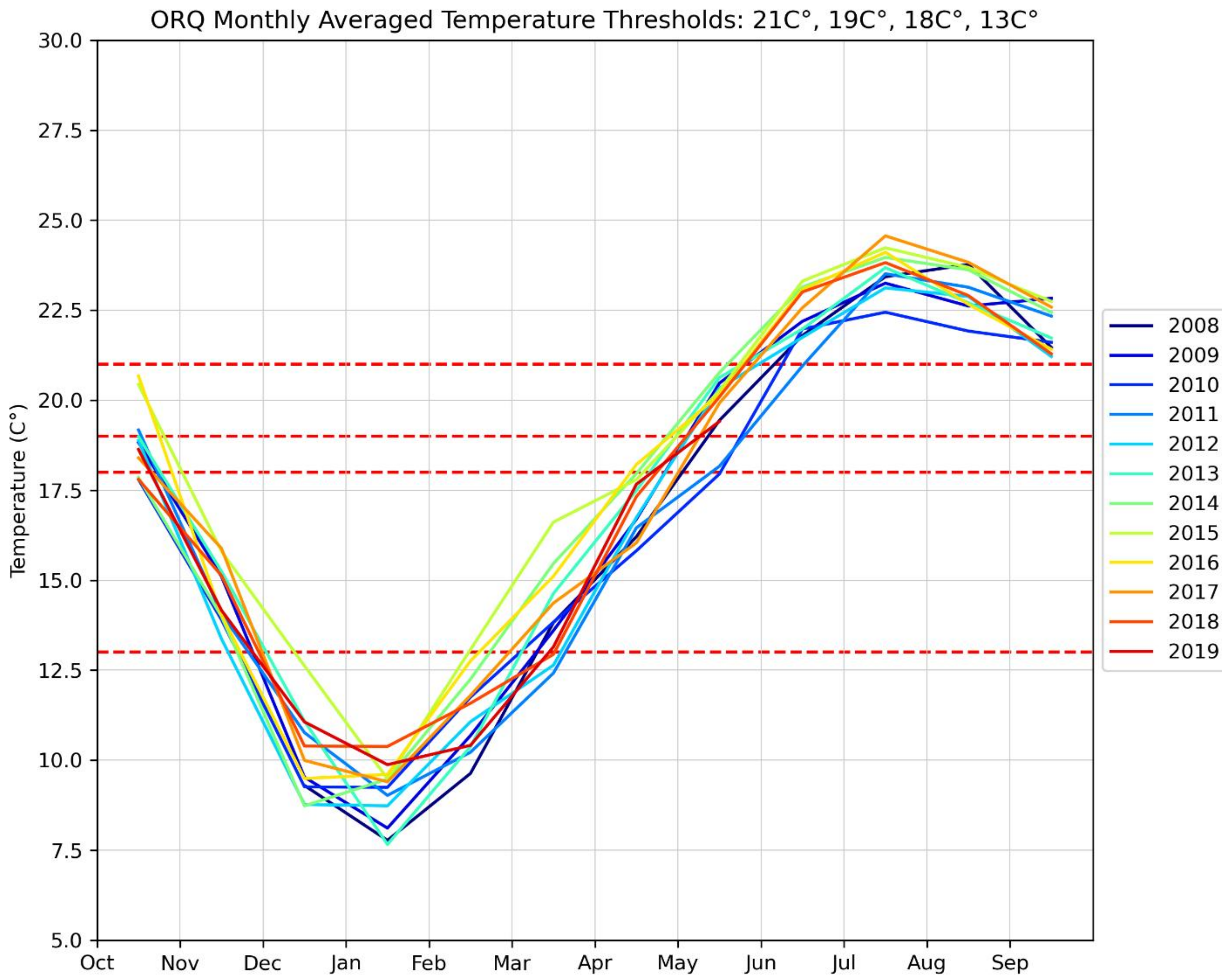

Figure C-89. Monthly Average Temperature for the Period of Record at Station ORQ – Old River at Quimby Island near Bethel Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

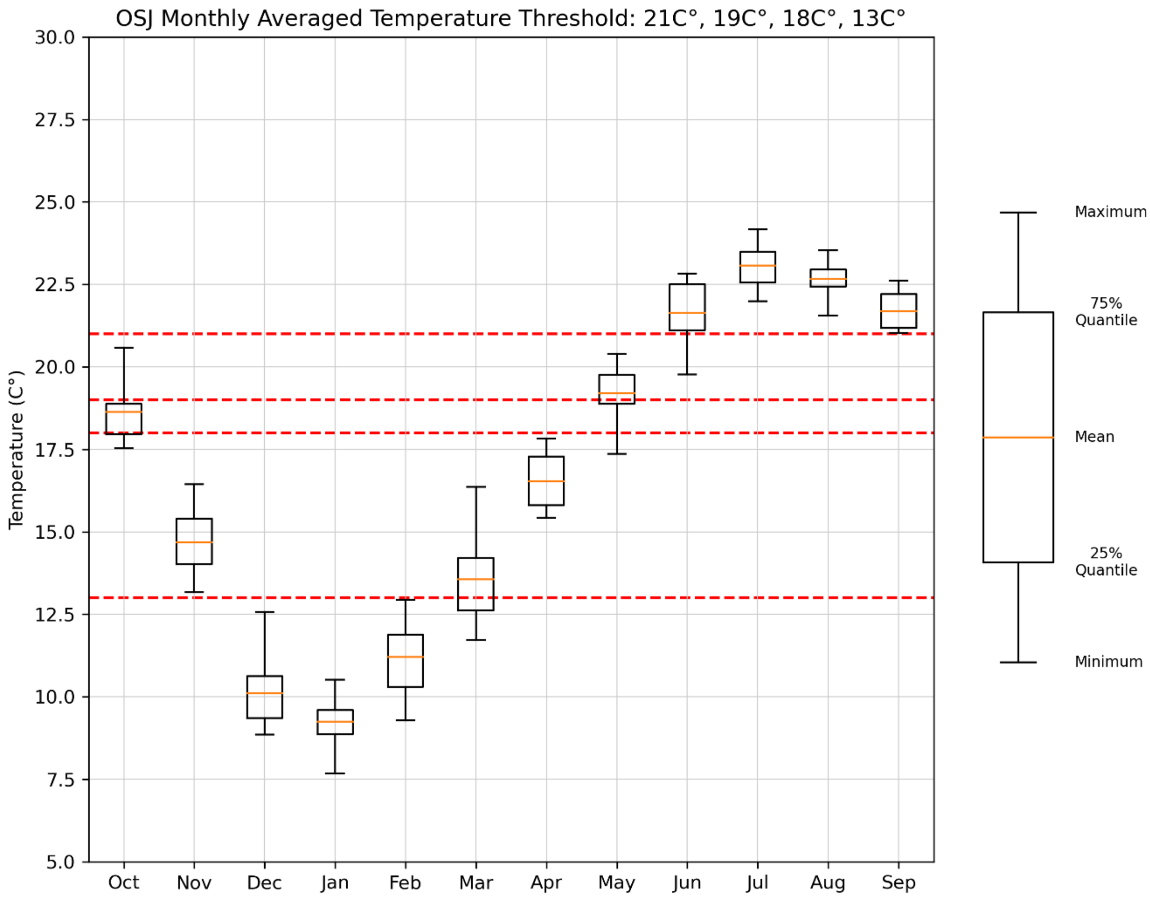

Figure C-90. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station OSJ – Old River at Frank's Tract near Terminus

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

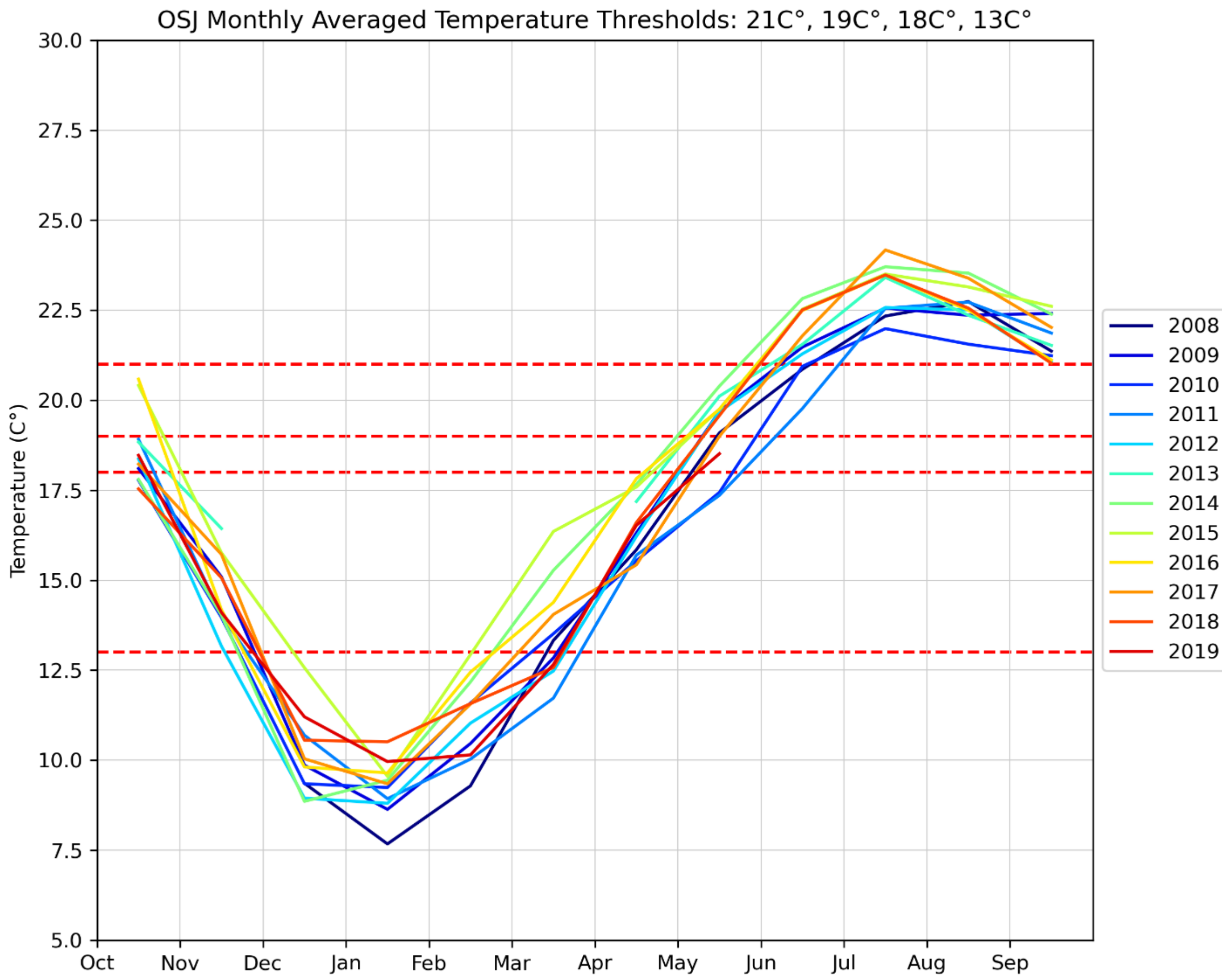

Figure C-91. Monthly Average Temperature for the Period of Record at Station OSJ – Old River at Frank's Tract near Terminus

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

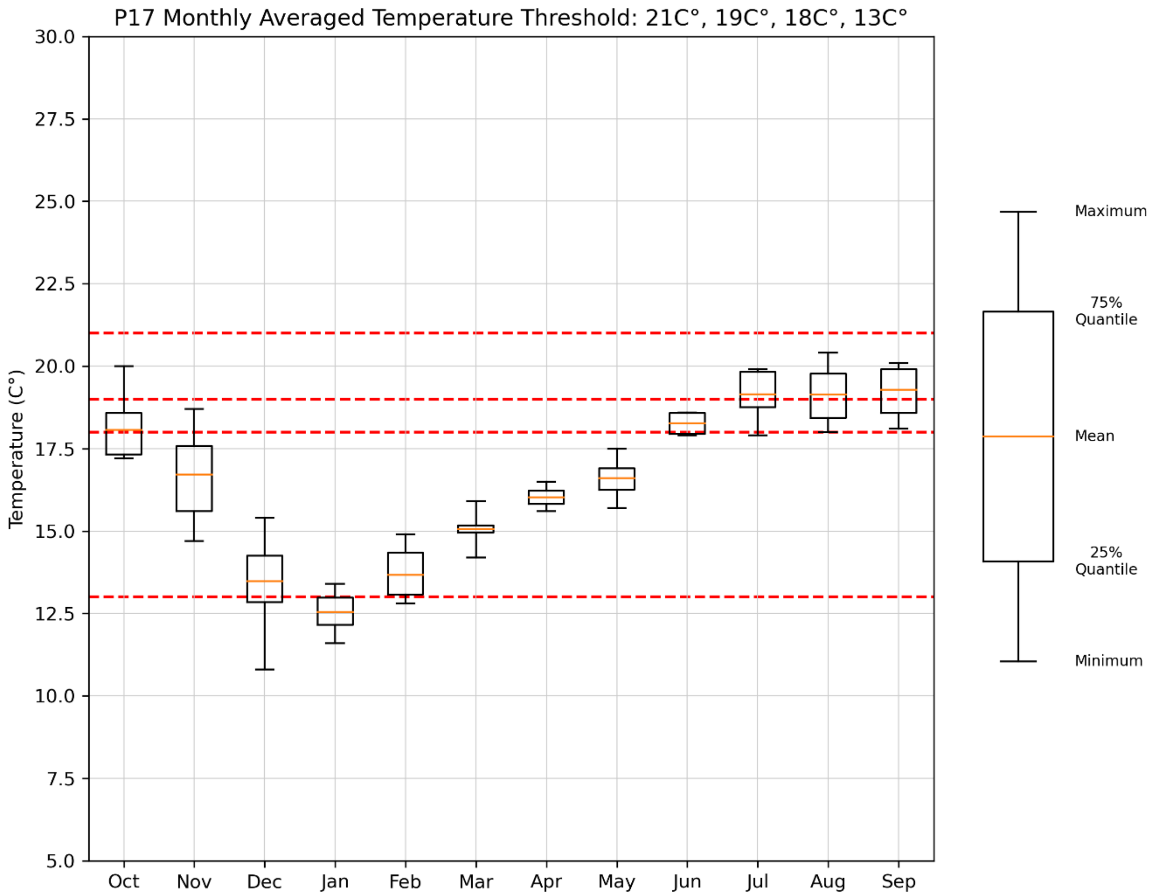

Figure C-92. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station P17 – Pier 17

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

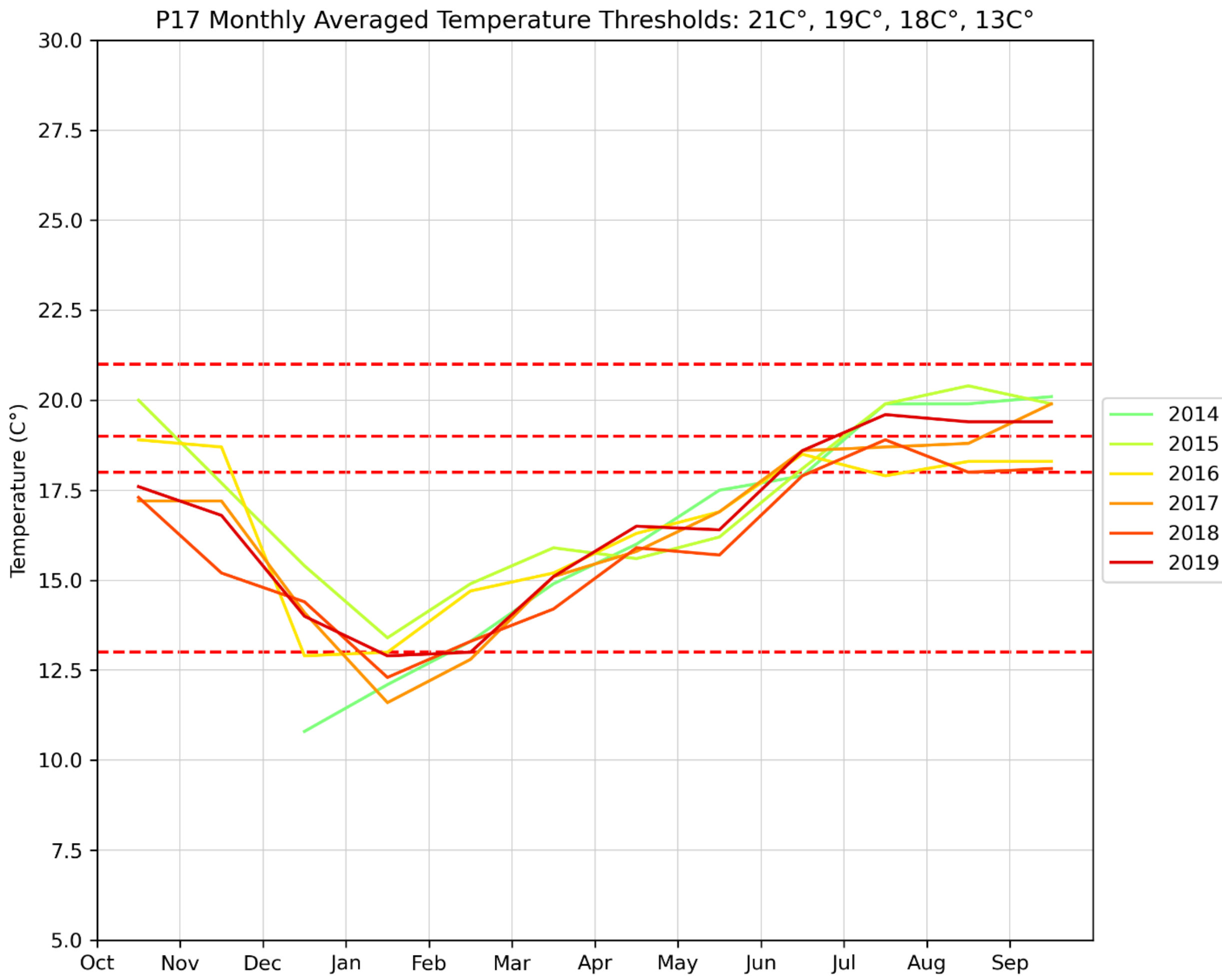

Figure C-93. Monthly Average Temperature for the Period of Record at Station P17 – Pier 17

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

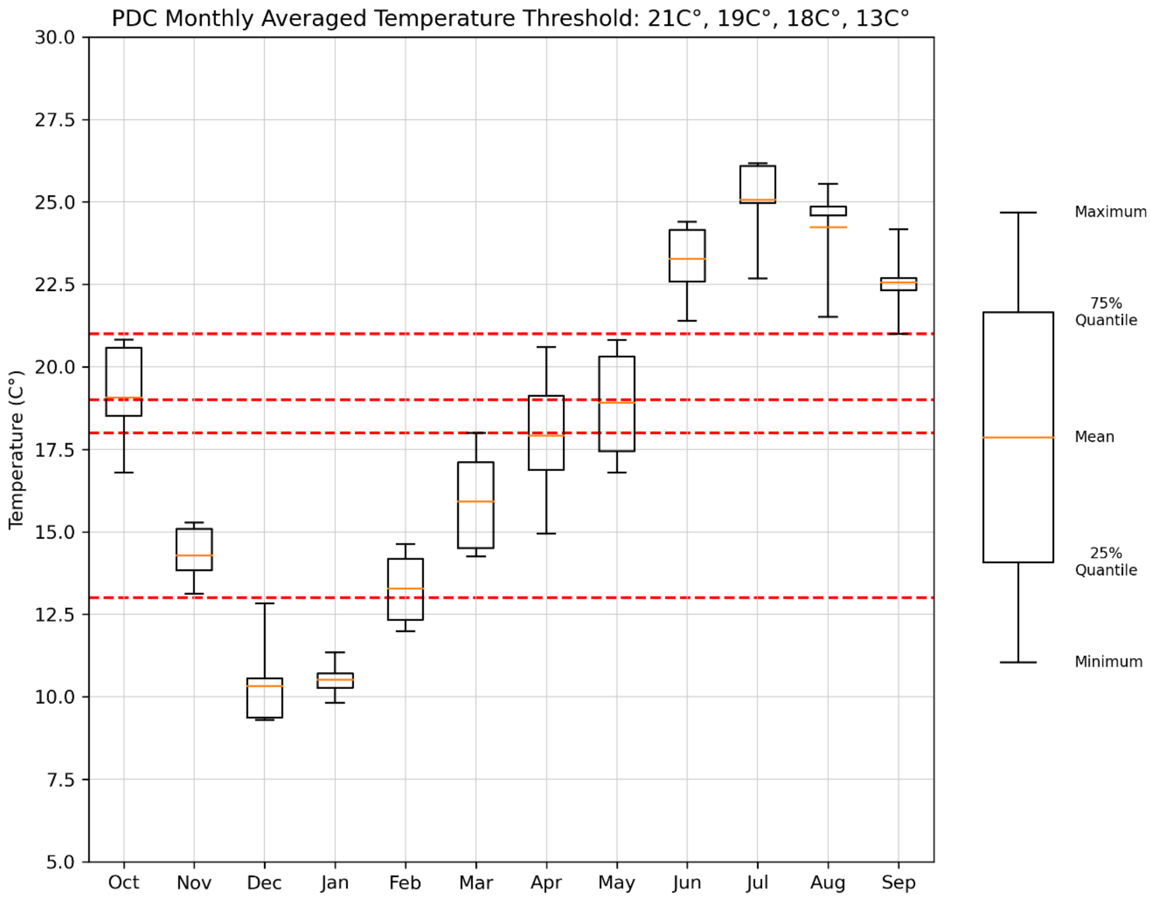

Figure C-94. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station PDC – Paradise Cut

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

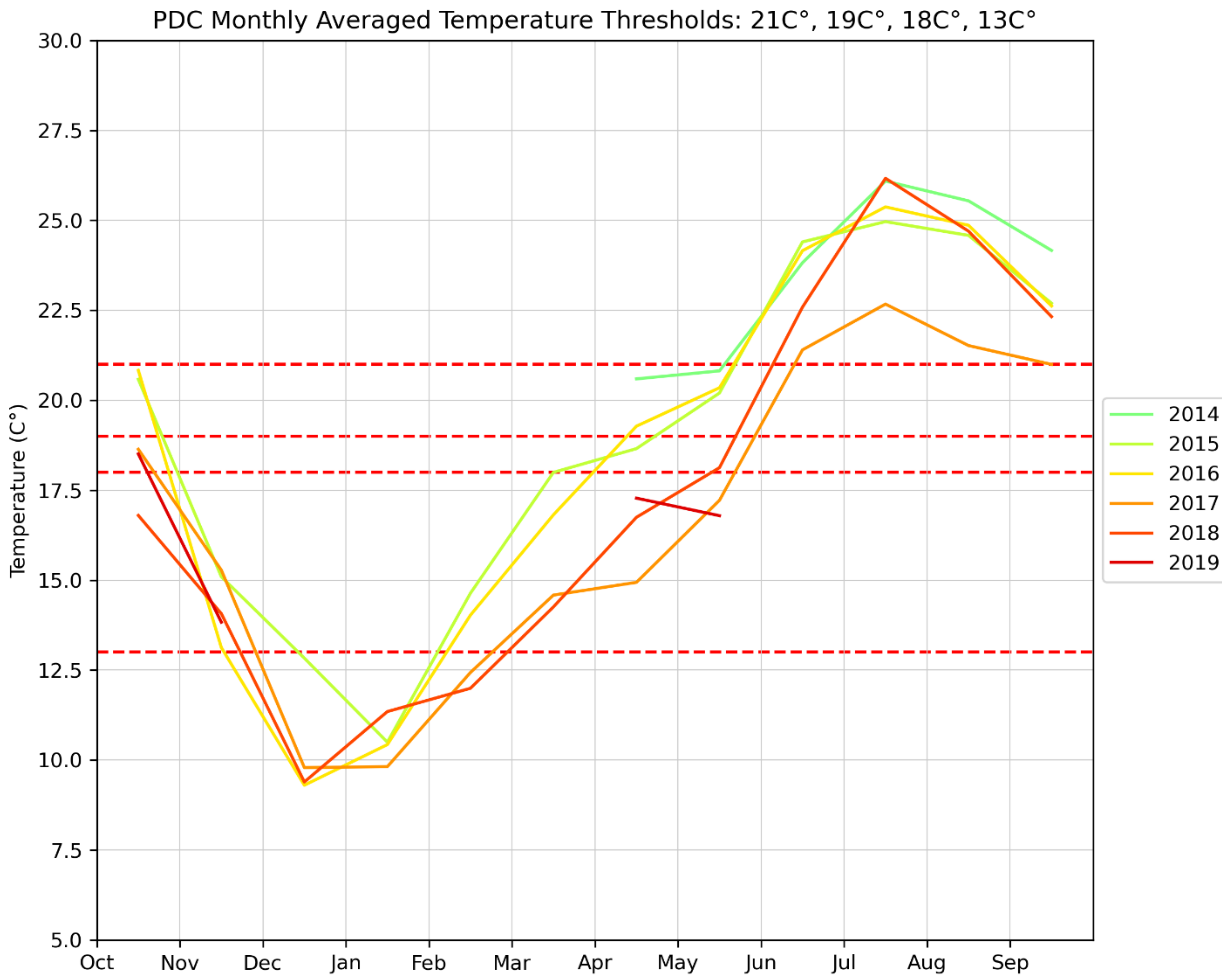

Figure C-95. Monthly Average Temperature for the Period Of Record at Station PDC – Paradise Cut

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

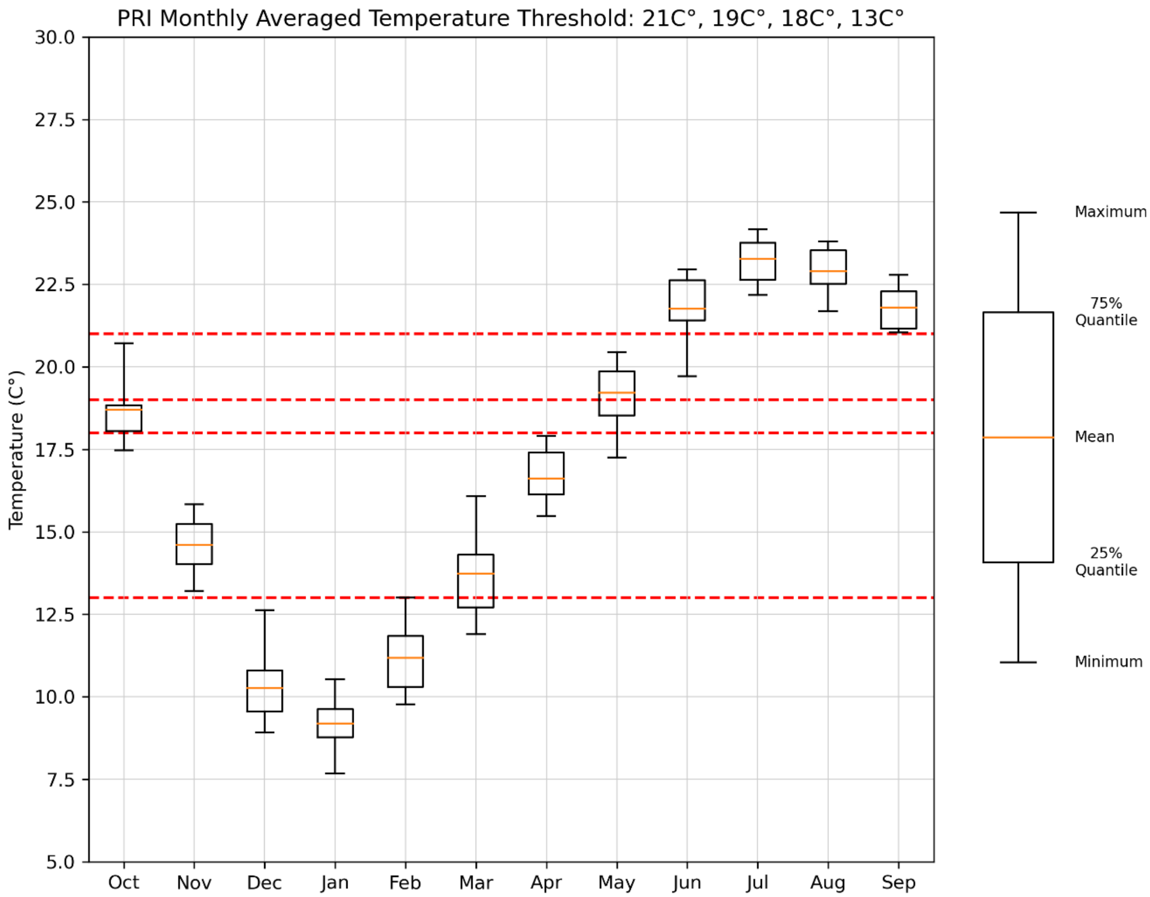

Figure C-96. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station PRI – San Joaquin River at Prisoners Point near Terminus

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

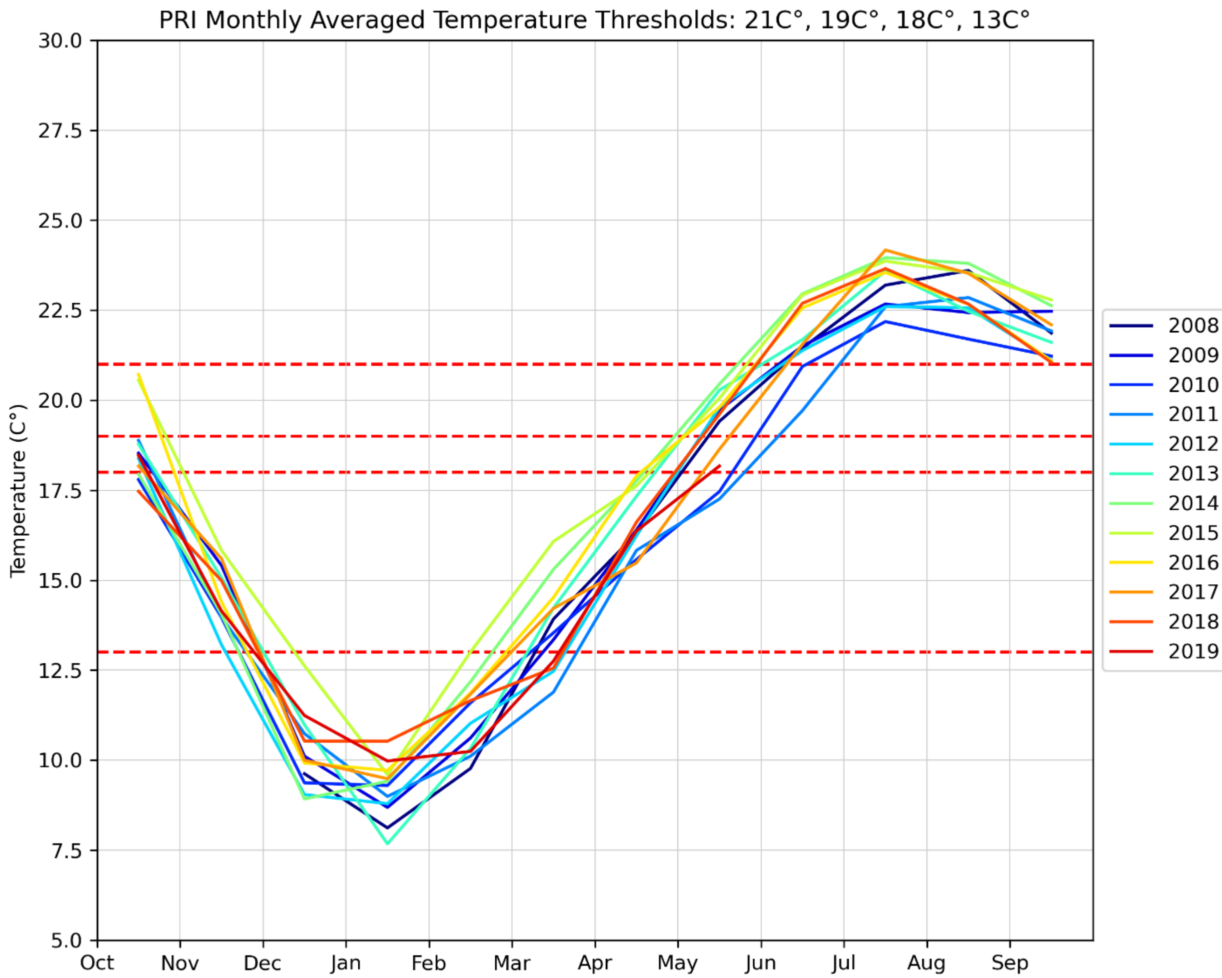

Figure C-97. Monthly Average Temperature for the Period of Record at Station PRI – San Joaquin River at Prisoners Point near Terminus

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

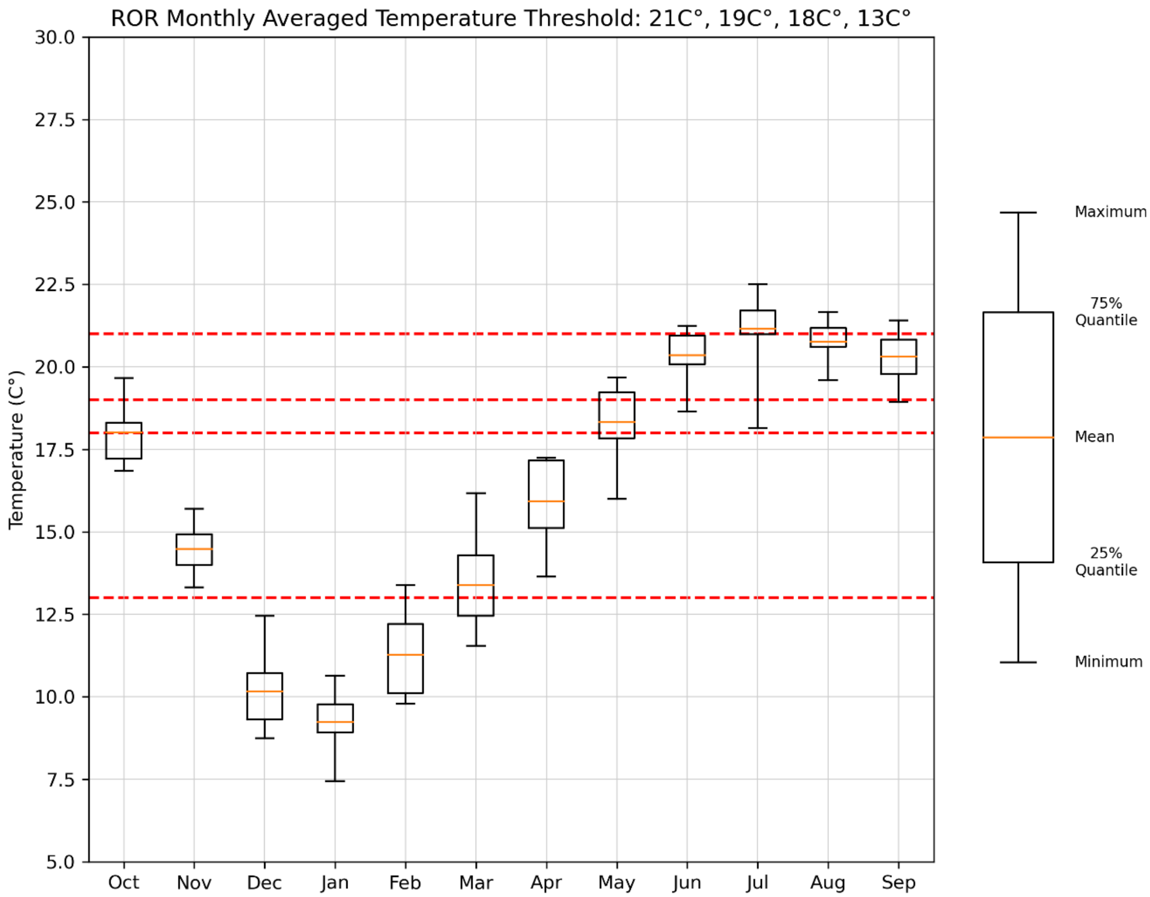

Figure C-98. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ROR – Roaring River

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

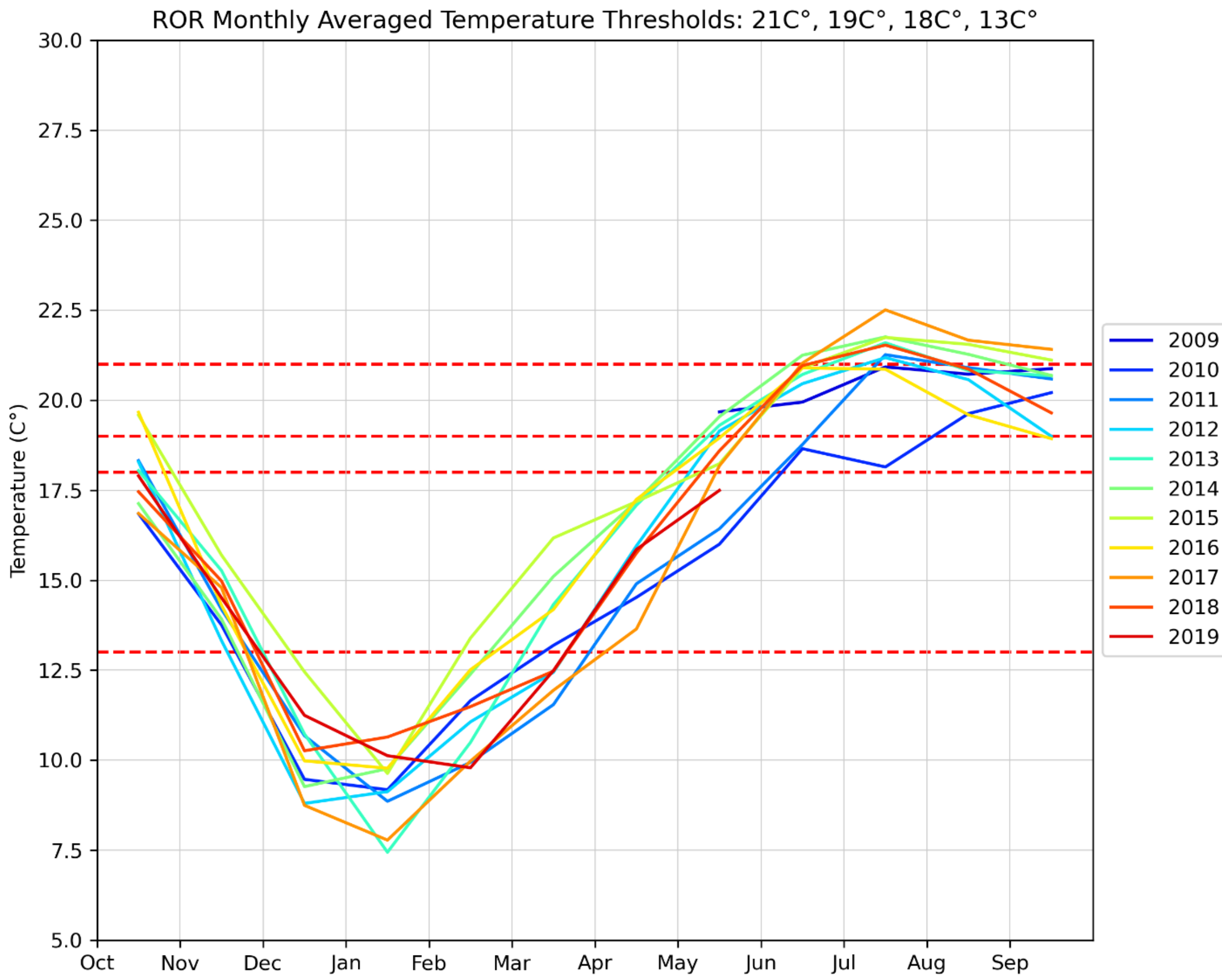

Figure C-99. Monthly Average Temperature for the Period of Record at Station ROR – Roaring River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

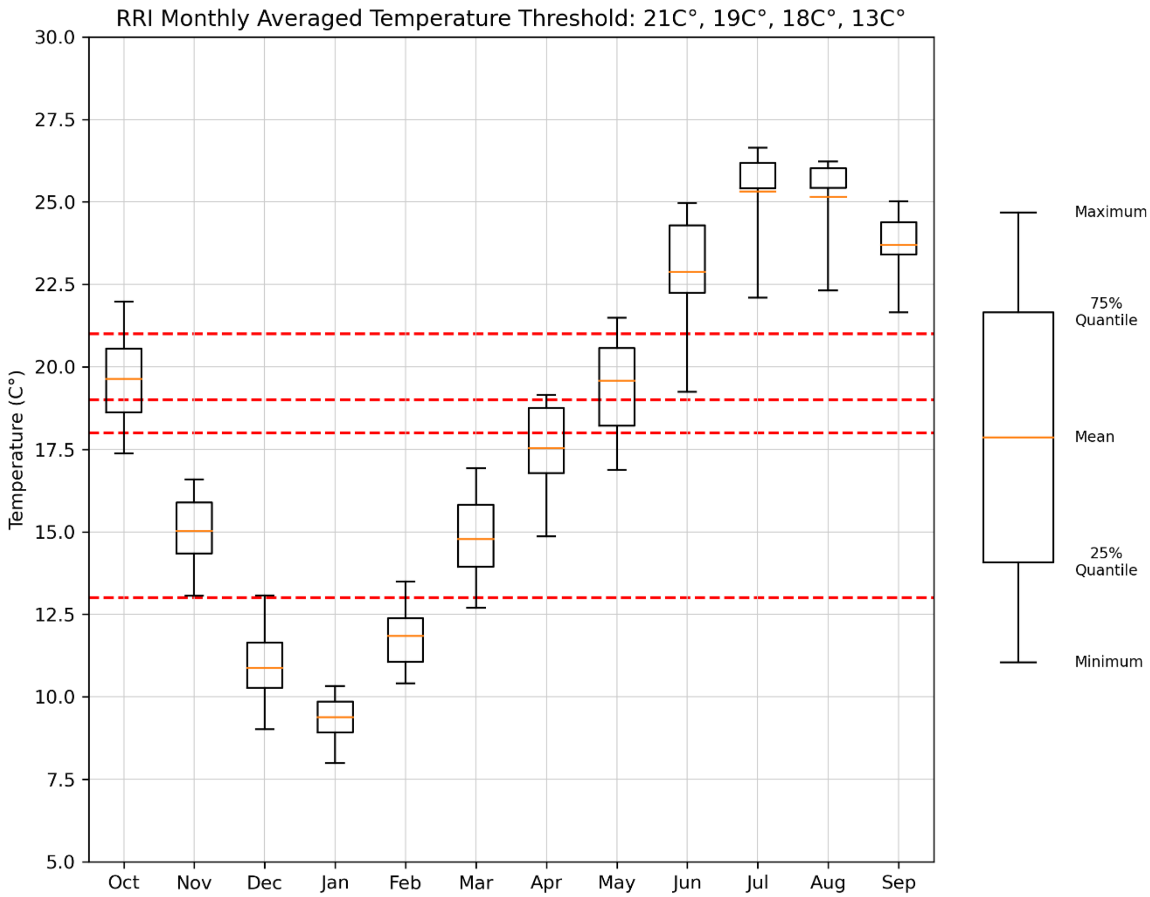

Figure C-100. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station RRI – Rough and Ready Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

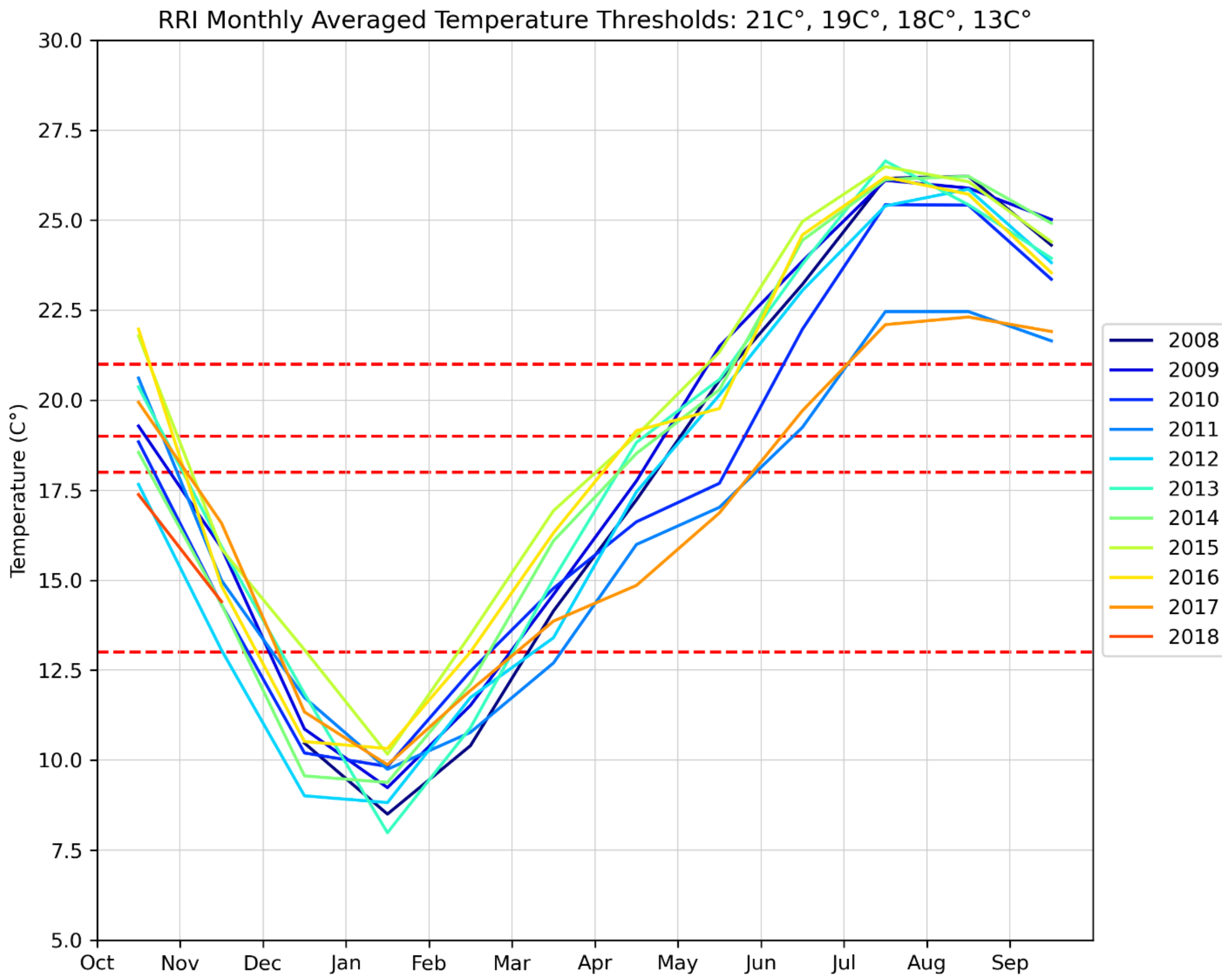

Figure C-101. Monthly Average Temperature for the Period of Record at Station RRI – Rough and Ready Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

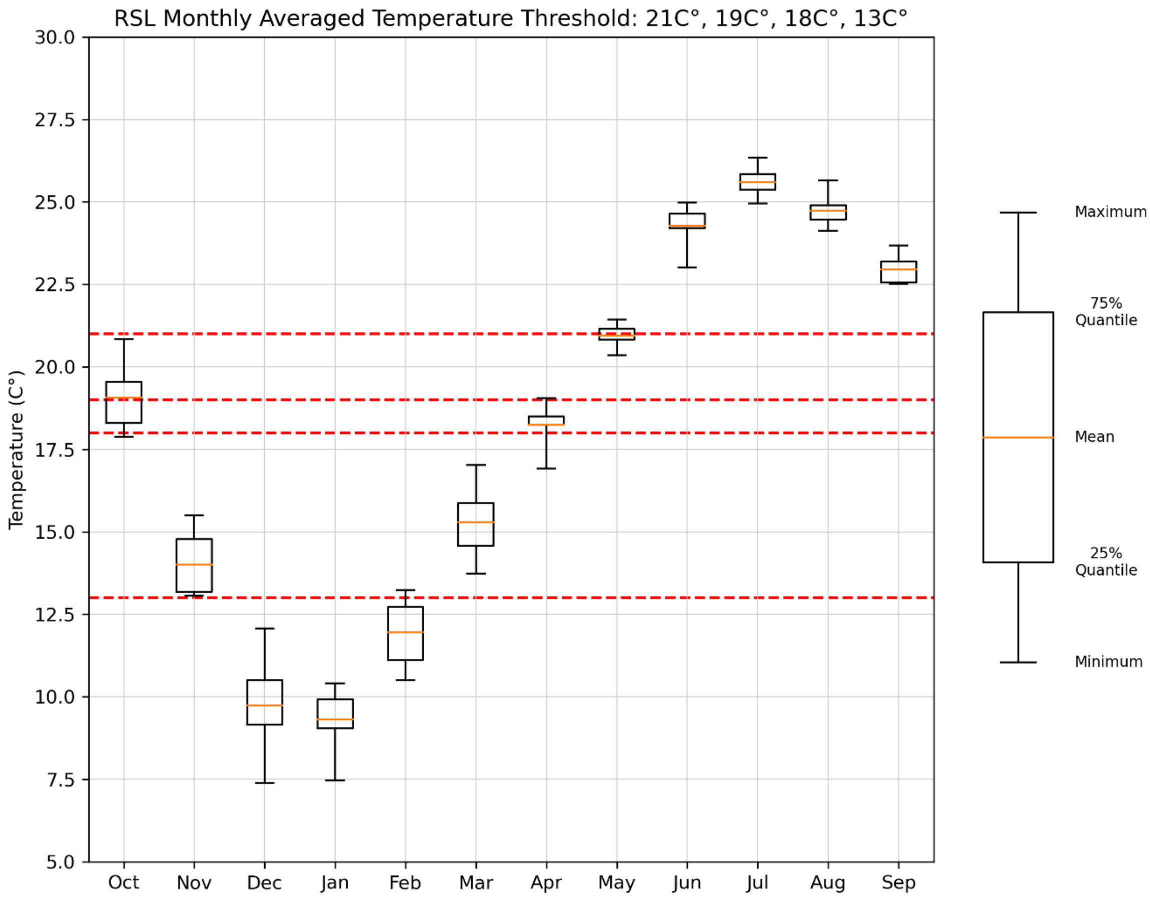

Figure C-102. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station RSL – Rock Slough Above Contra Costa Canal

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

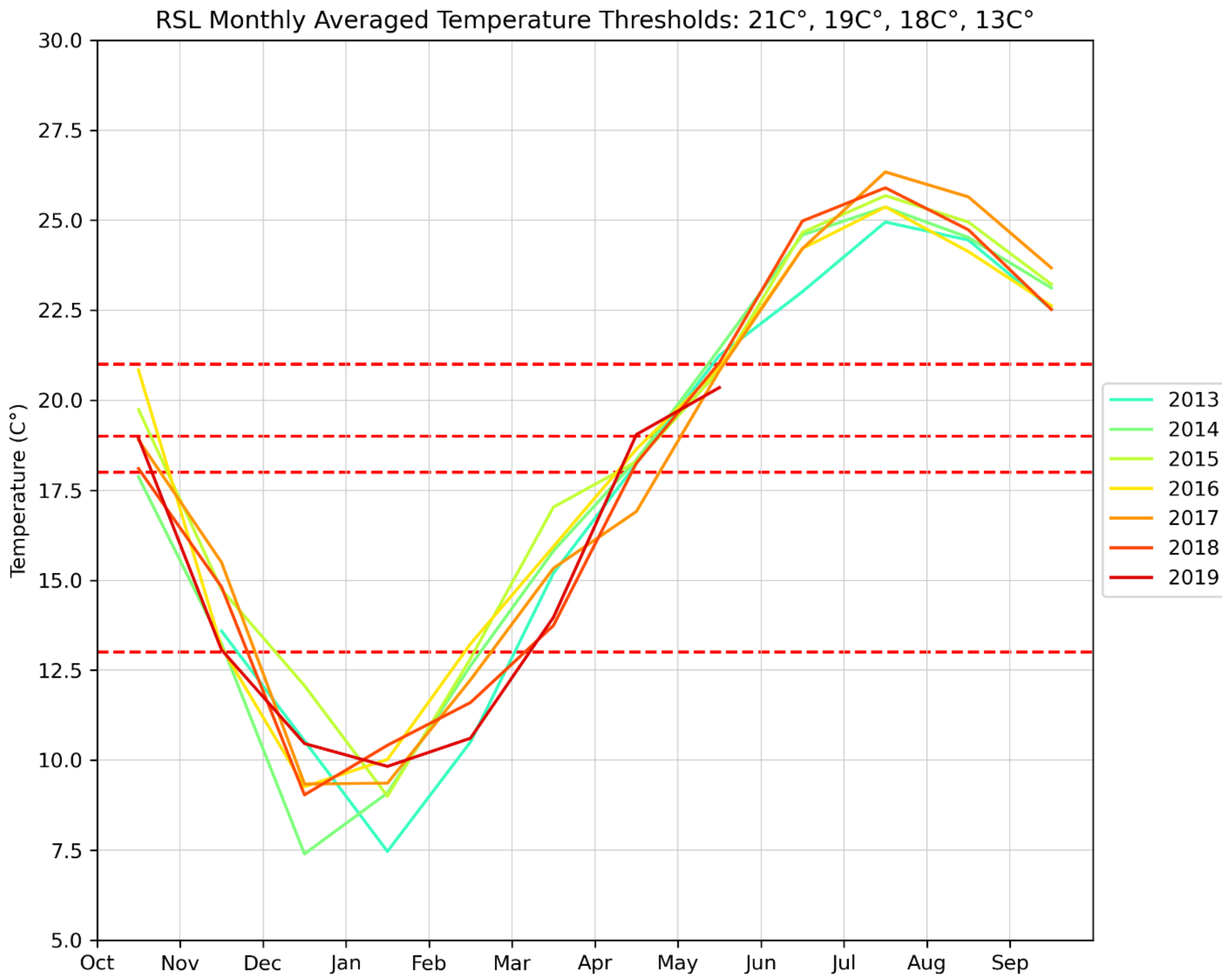

Figure C-103. Monthly Average Temperature for the Period of Record at Station RSL – Rock Slough above Contra Costa Canal

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

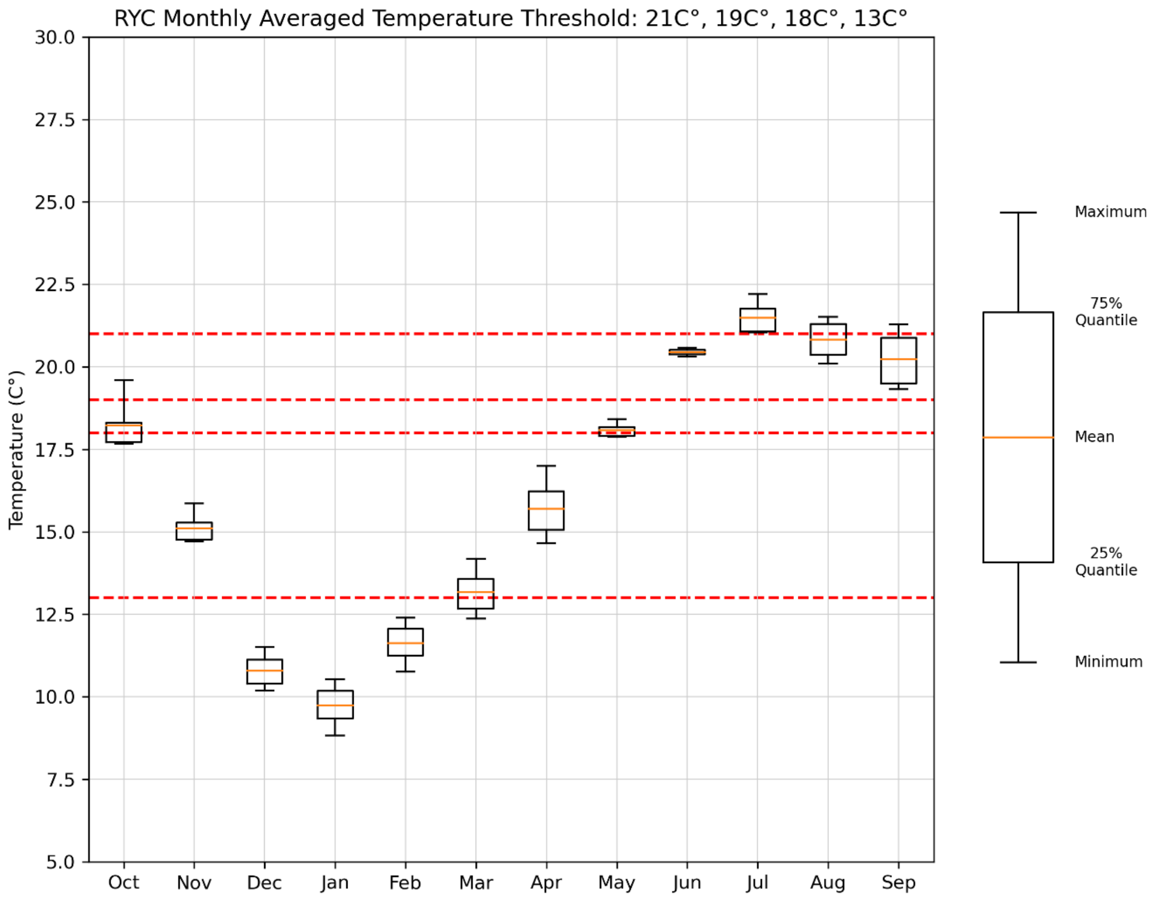

Figure C-104. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station RYC – Suisun Bay Cutoff near Ryer

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

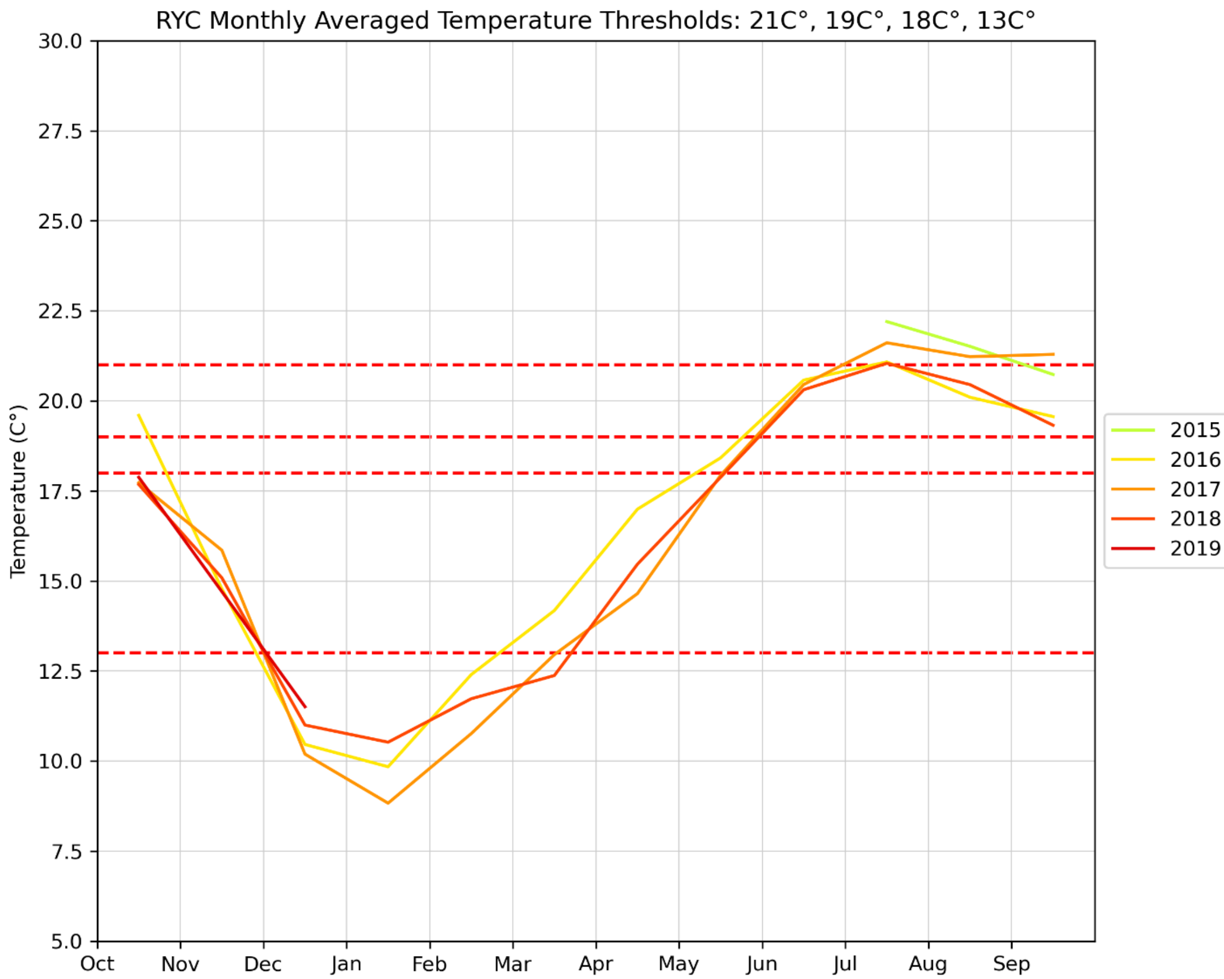

Figure C-105. Monthly Average Temperature for the Period of Record at Station RYC – Suisun Bay Cutoff near Ryer

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

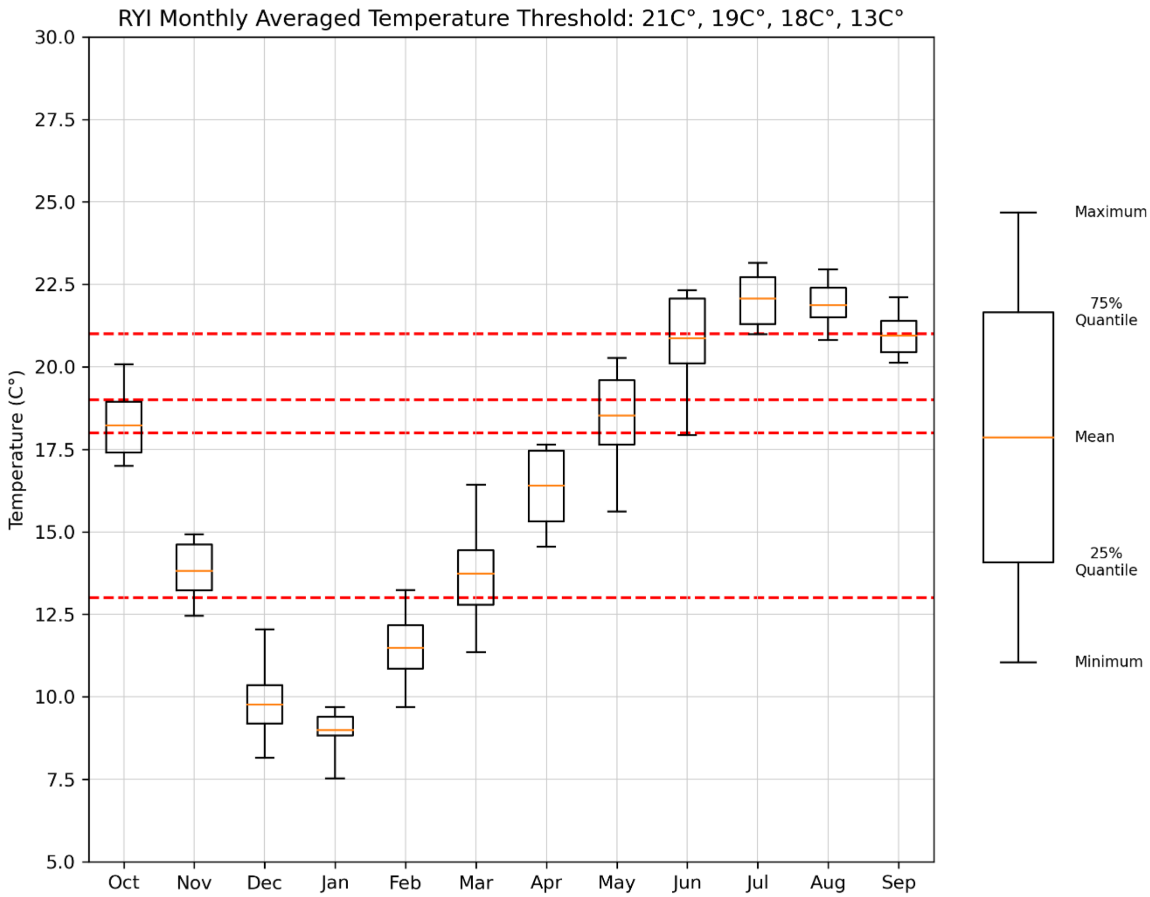

Figure C-106. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station RYI – Cache Slough at Ryer Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

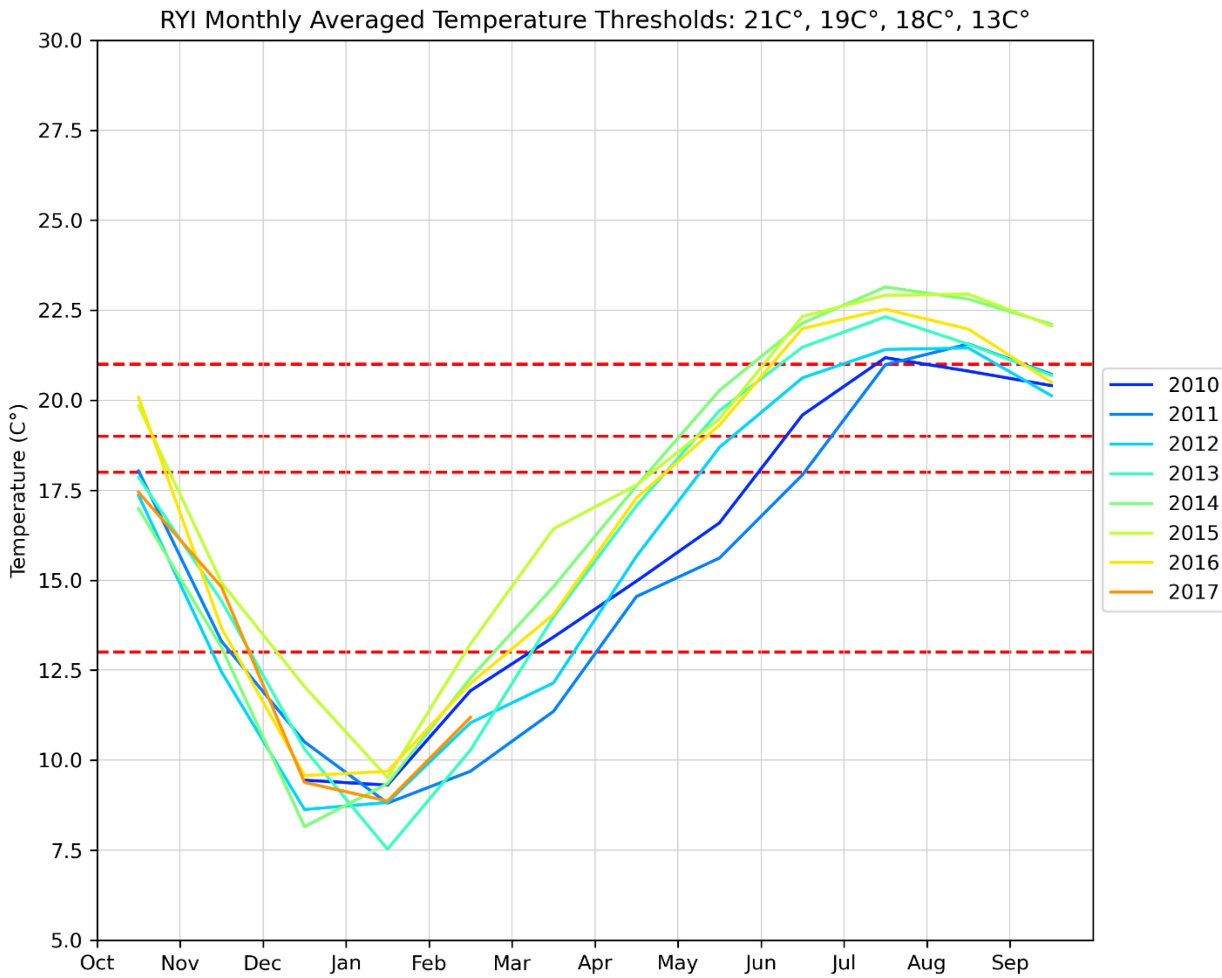

Figure C-107. Monthly Average Temperature for the Period of Record at Station RYI – Cache Slough at Ryer Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

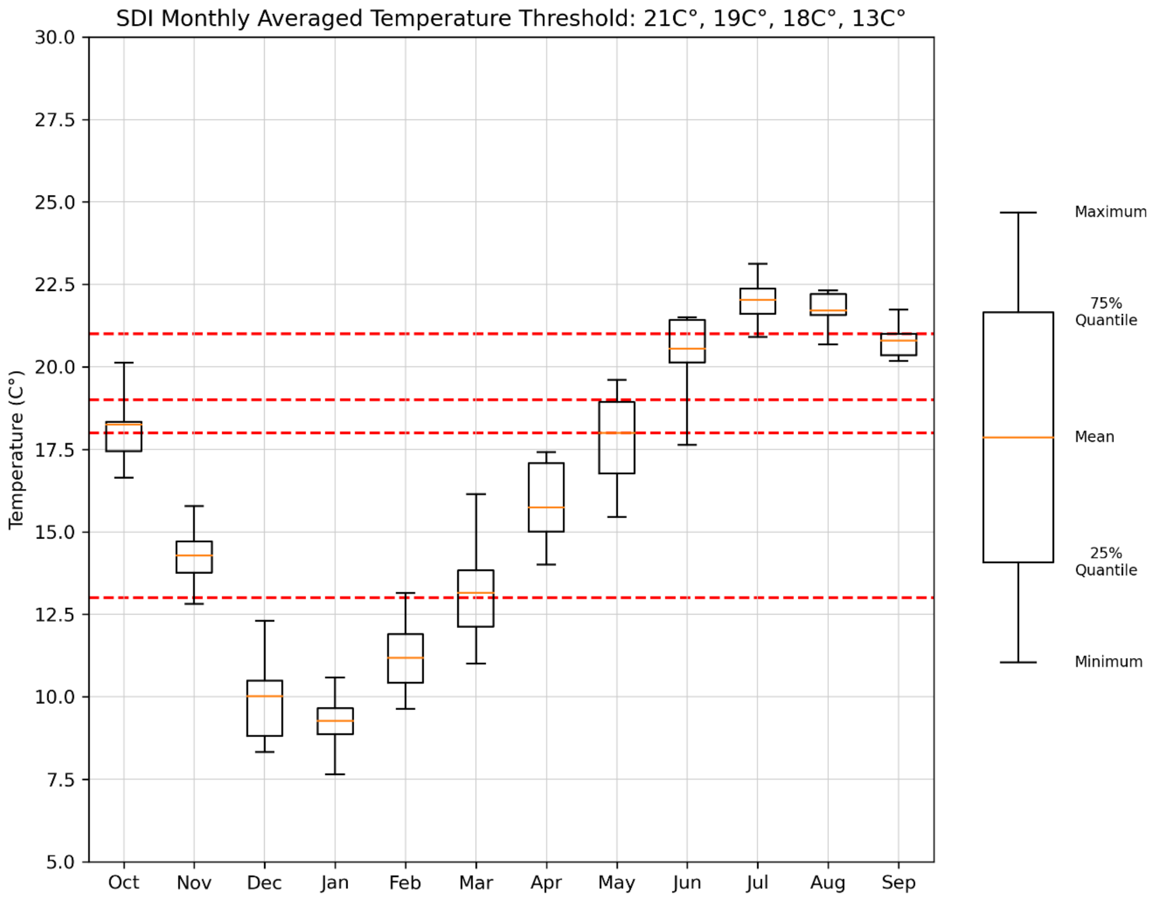

Figure C-108. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SDI – Sacramento River at Decker Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

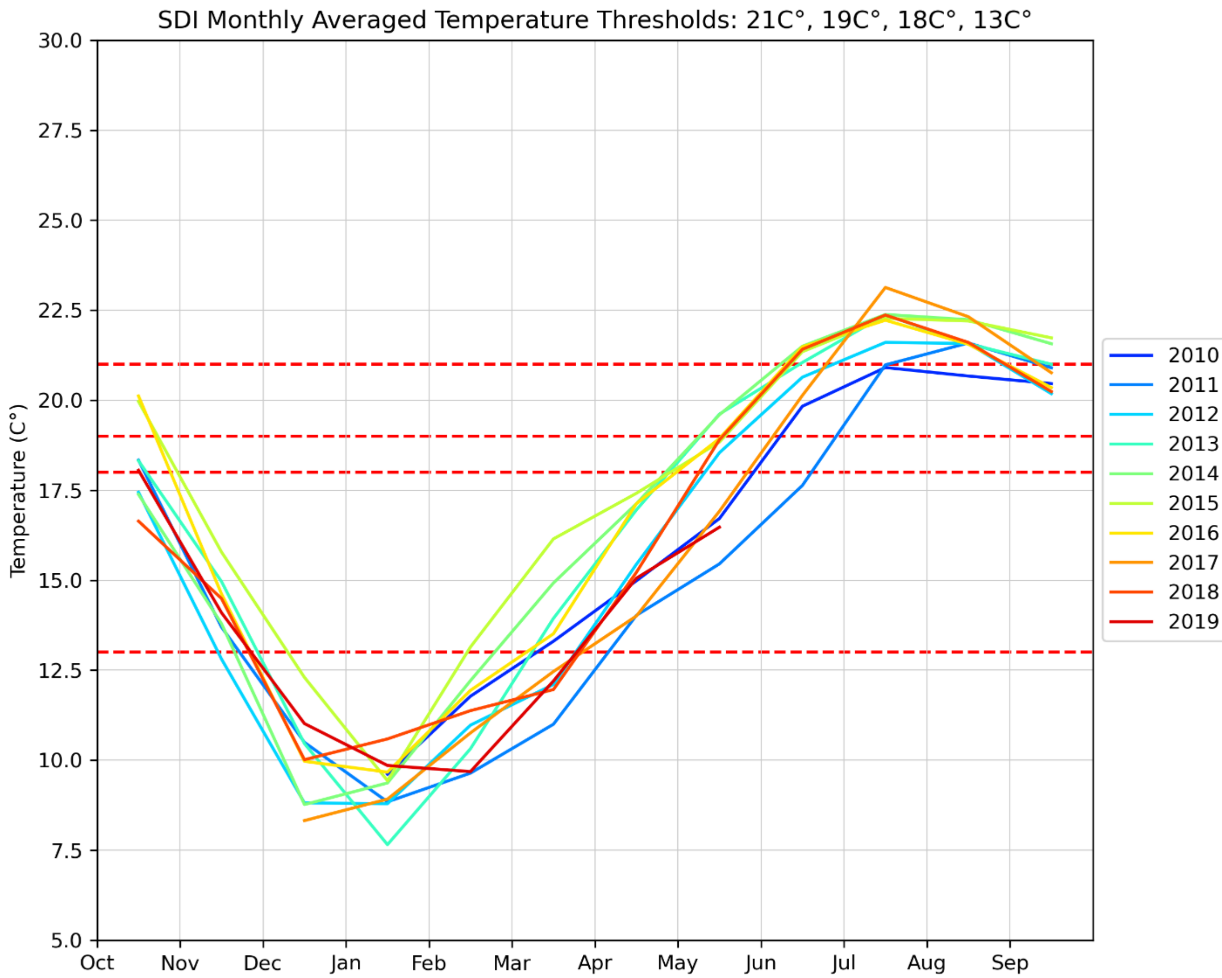

Figure C-109. Monthly Average Temperature for the Period of Record at Station SDI – Sacramento River at Decker Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

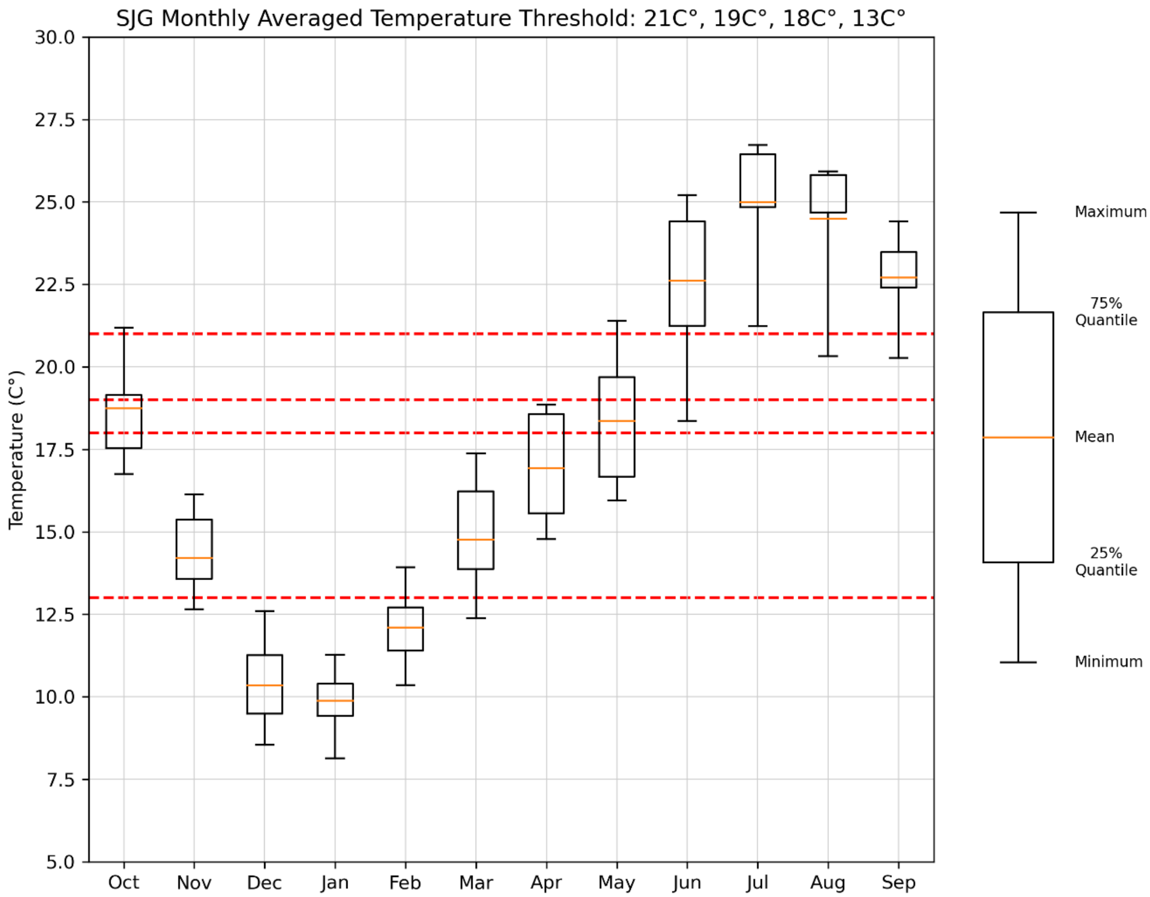

Figure C-110. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SJG – San Joaquin River at Garwood Bridge

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

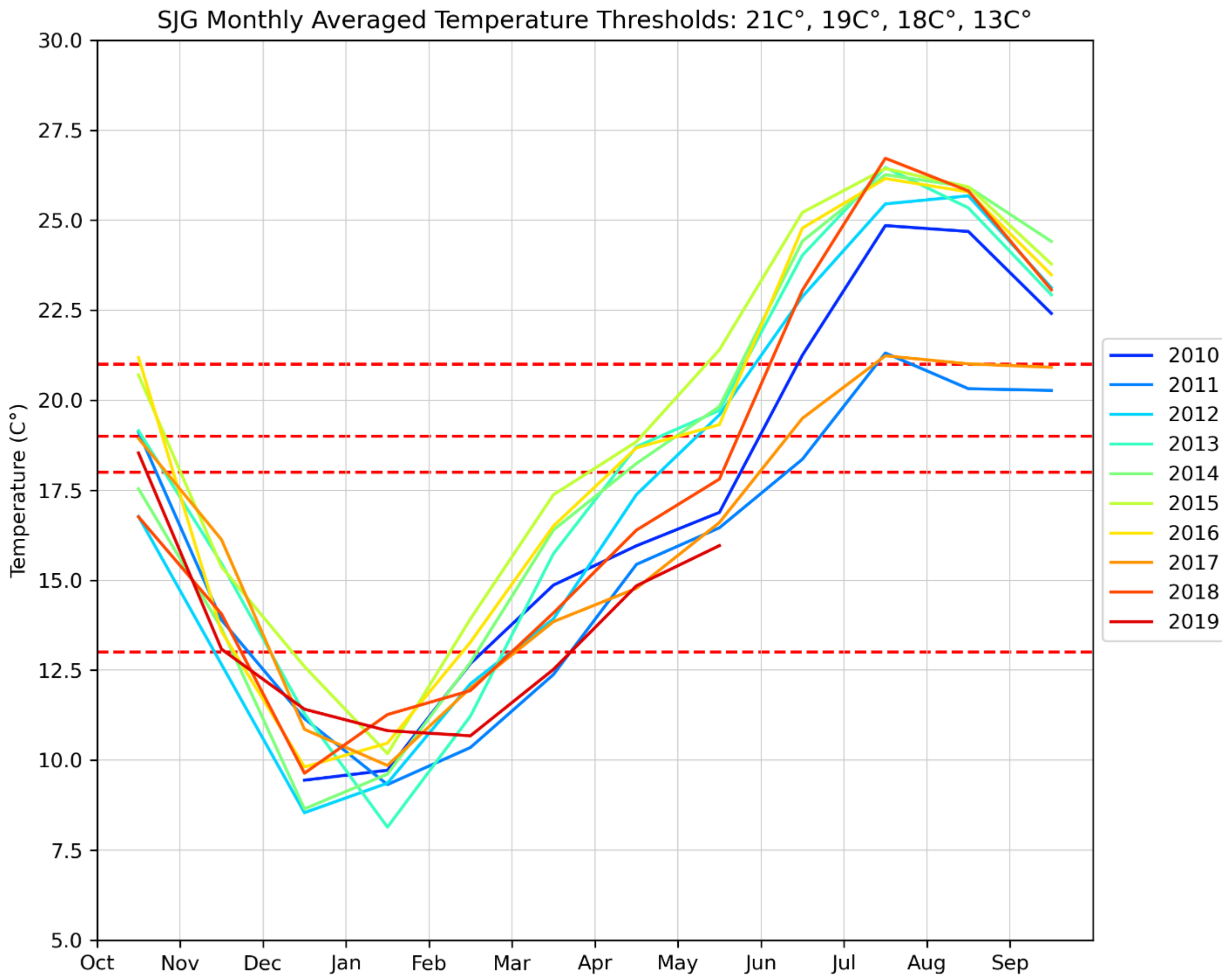

Figure C-111. Monthly Average Temperature for the Period of Record at Station SJG – San Joaquin River at Garwood Bridge

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

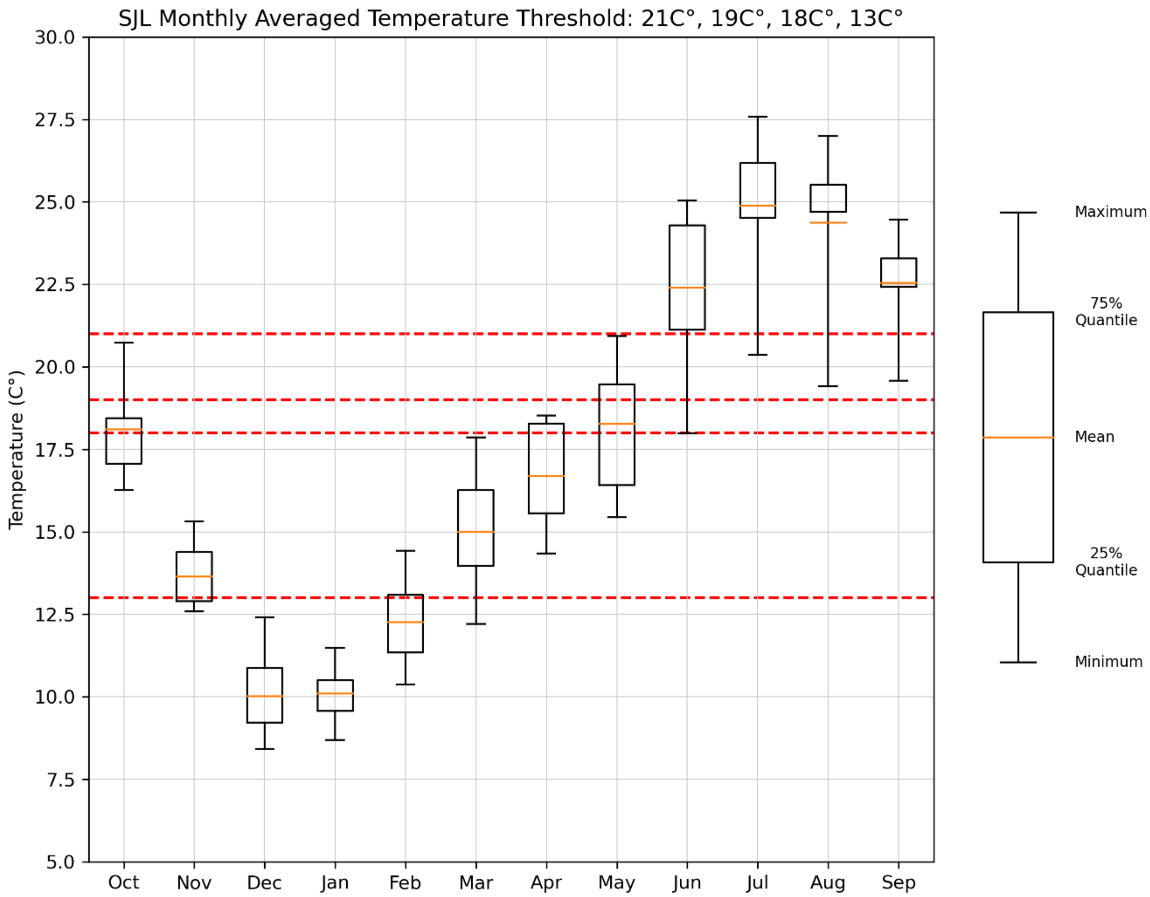

Figure C-112. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SJL – San Joaquin River below Old River near Lathrop

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

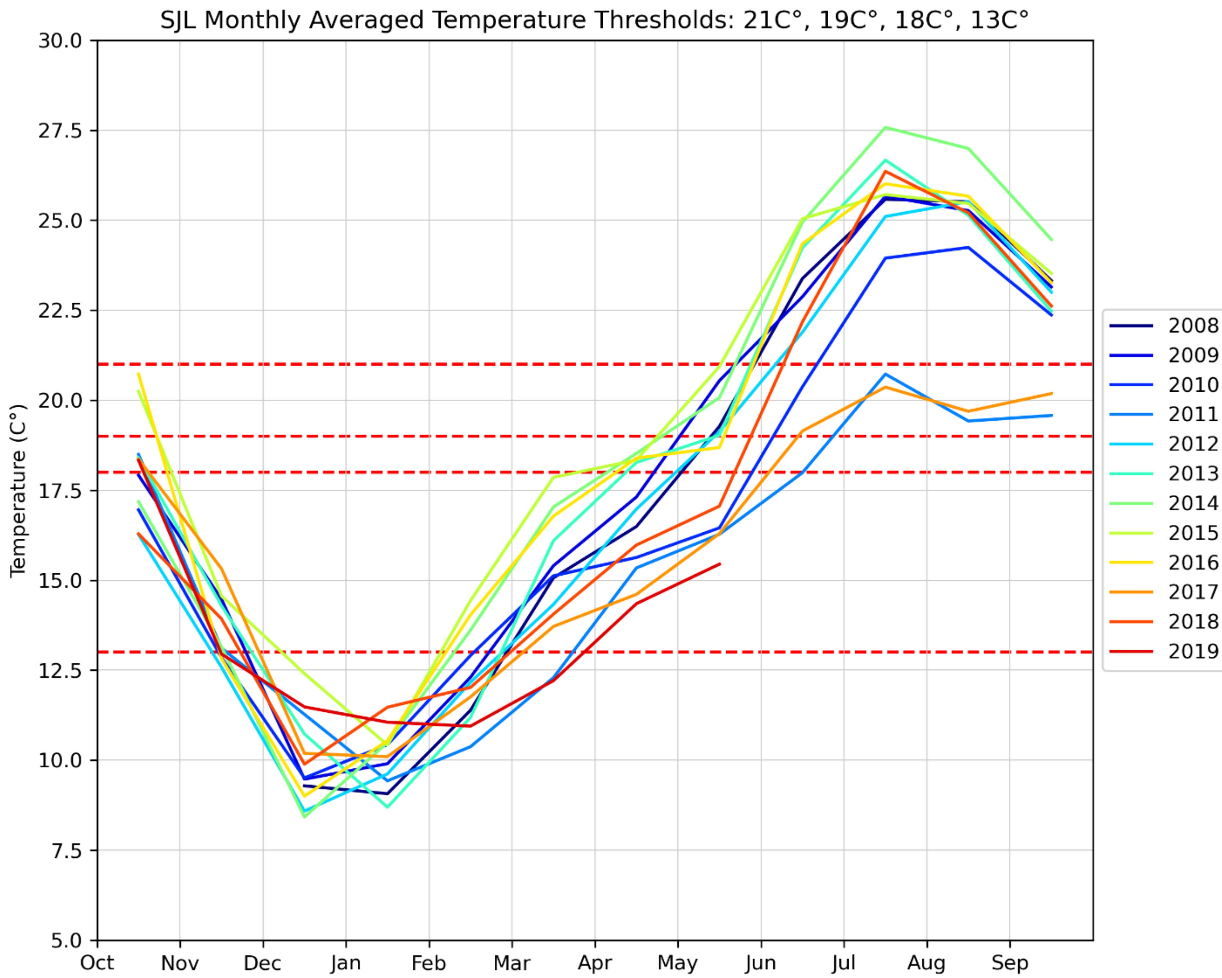

Figure C-113. Monthly Average Temperature for the Period of Record at Station SJL – San Joaquin River below Old River near Lathrop

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

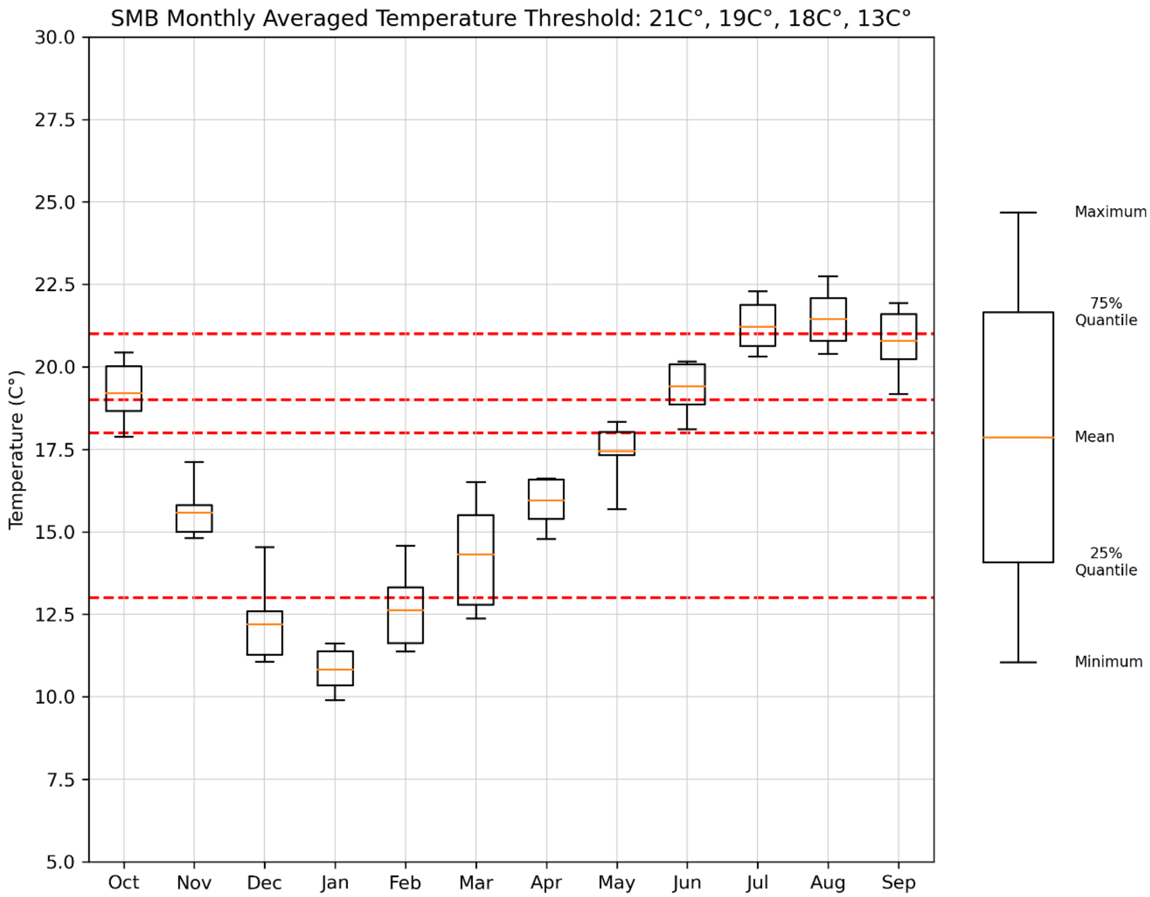

Figure C-114. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SMB – Santa Margarita Booster

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

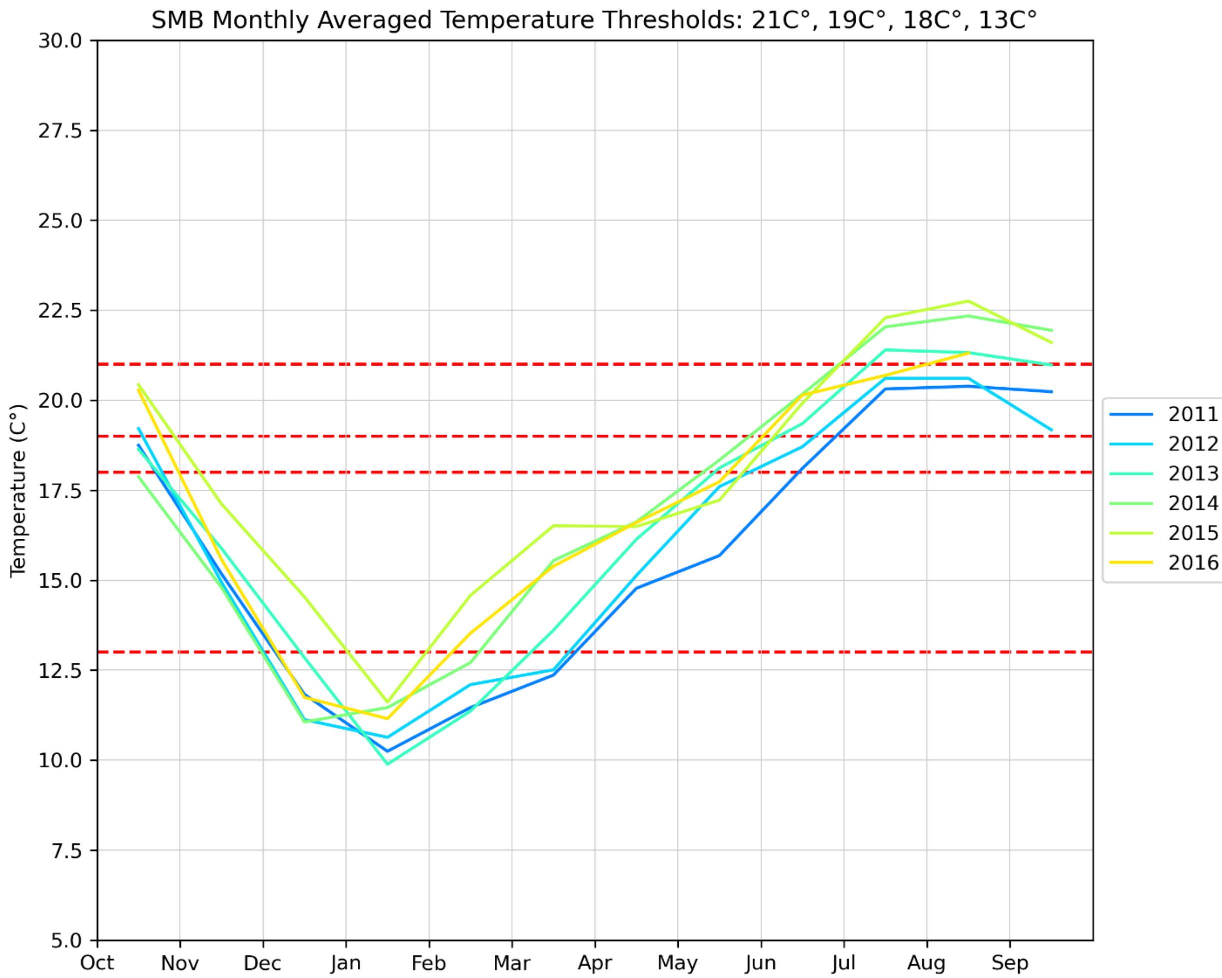

Figure C-115. Monthly Average Temperature for the Period of Record at Station SMB – Santa Margarita Booster

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

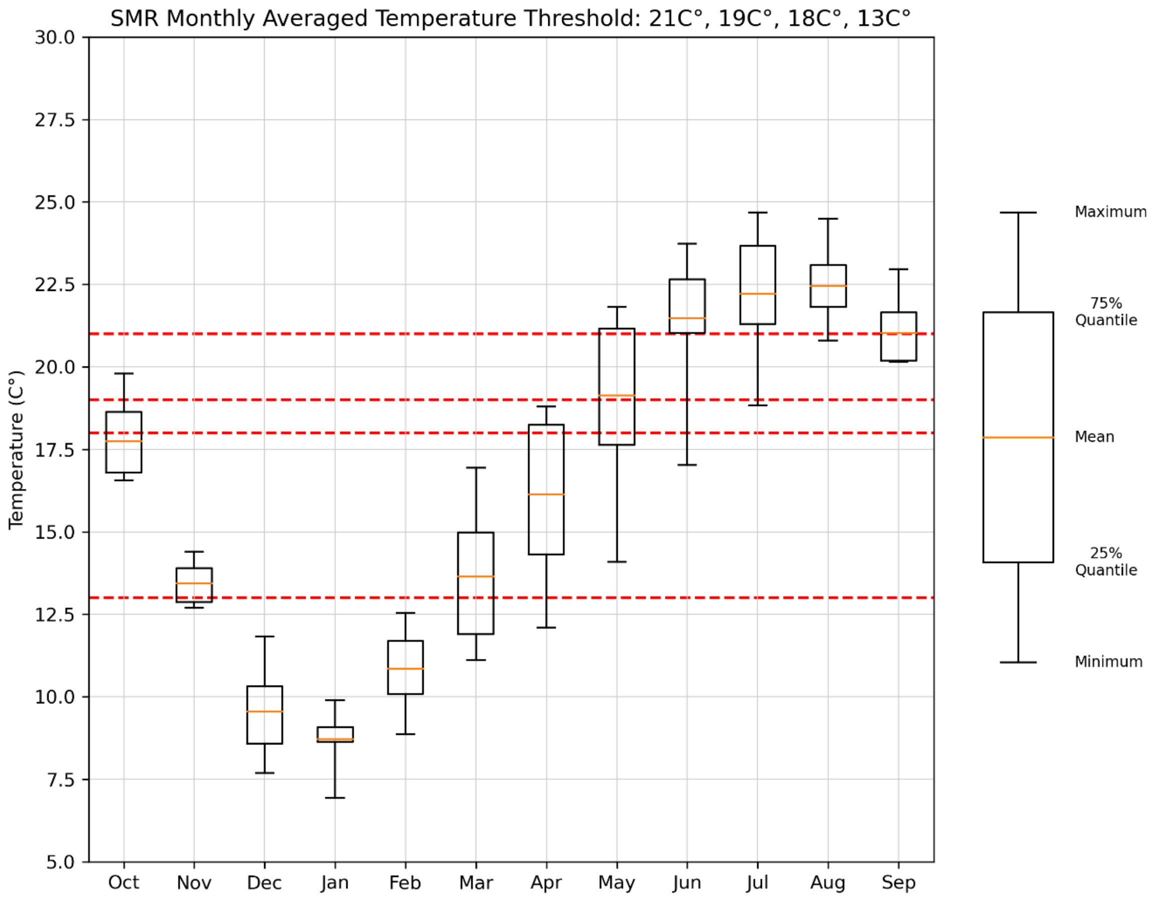

Figure C-116. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SMR – South Mokelumne River at West Walnut Grove Road

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

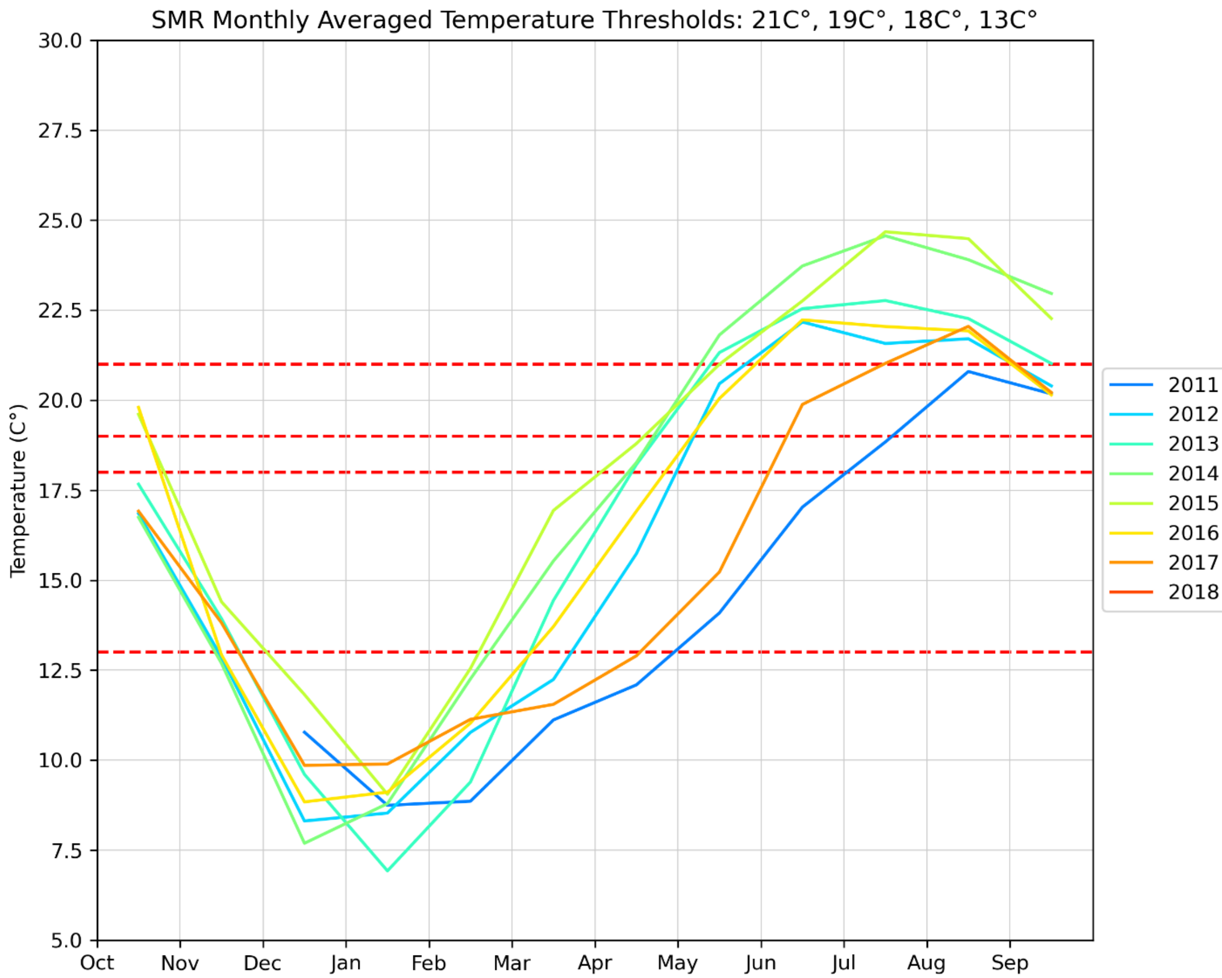

Figure C-117. Monthly Average Temperature for the Period of Record at Station SMR – South Mokelumne River at West Walnut Grove Road

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

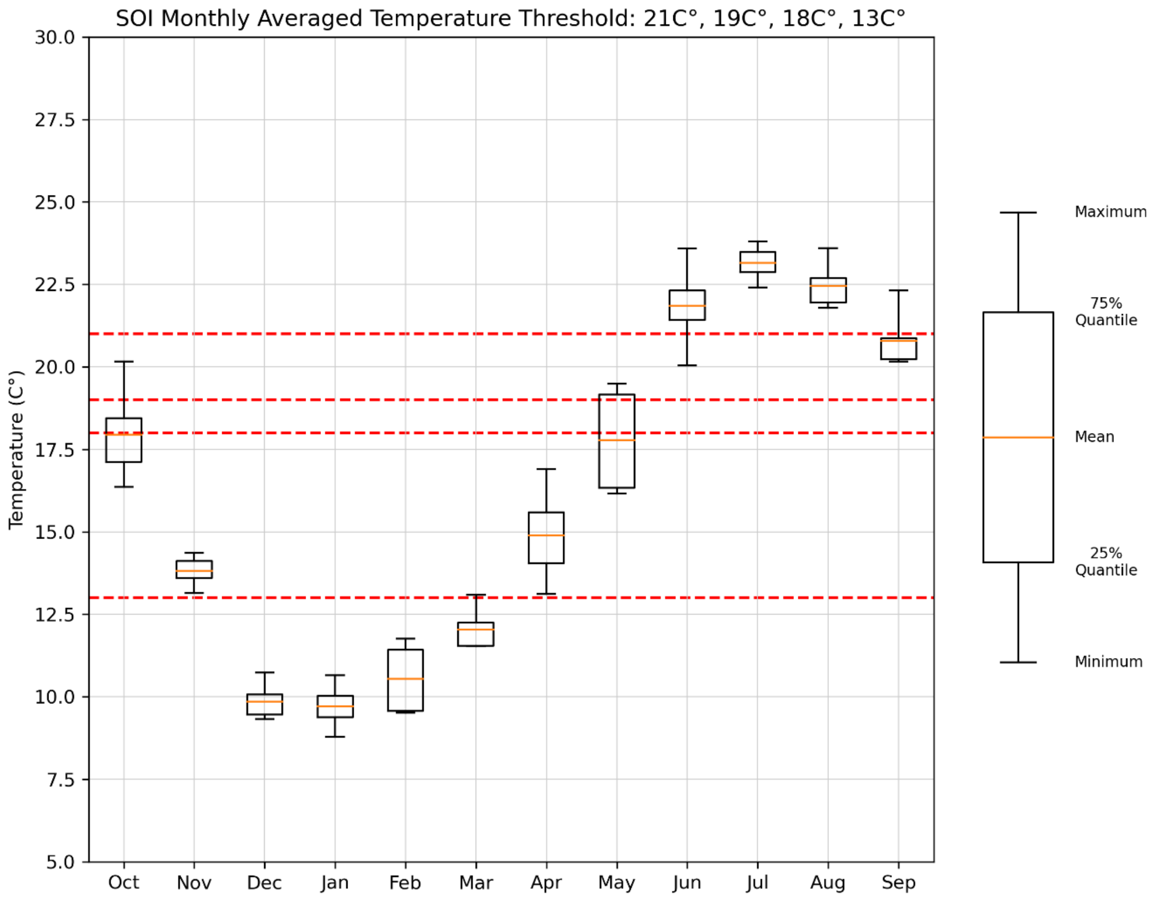

Figure C-118 Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SOI – Sacramento River Downstream of Isleton

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

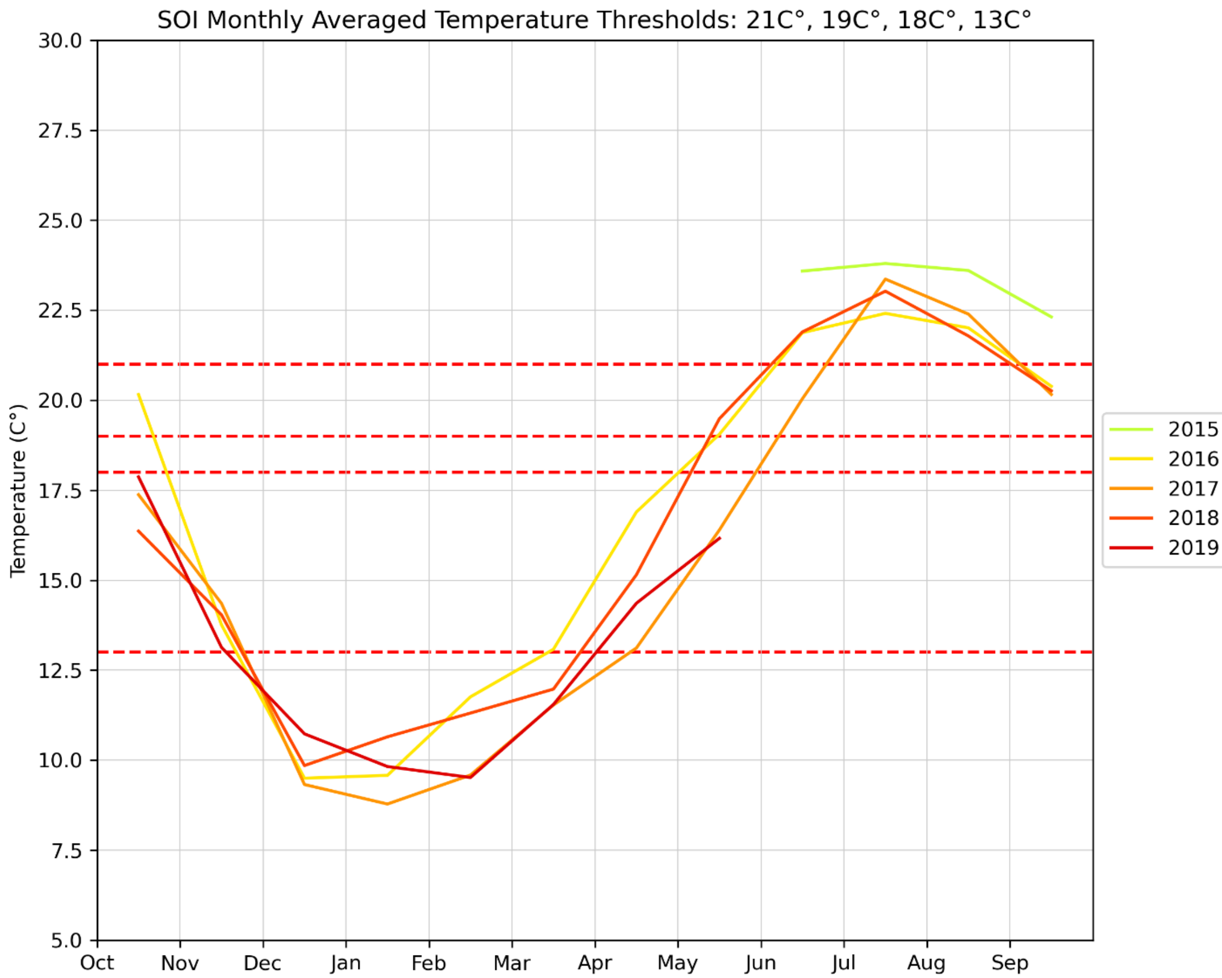

Figure C-119. Monthly Average Temperature for the Period of Record at Station SOI – Sacramento River Downstream of Isleton

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

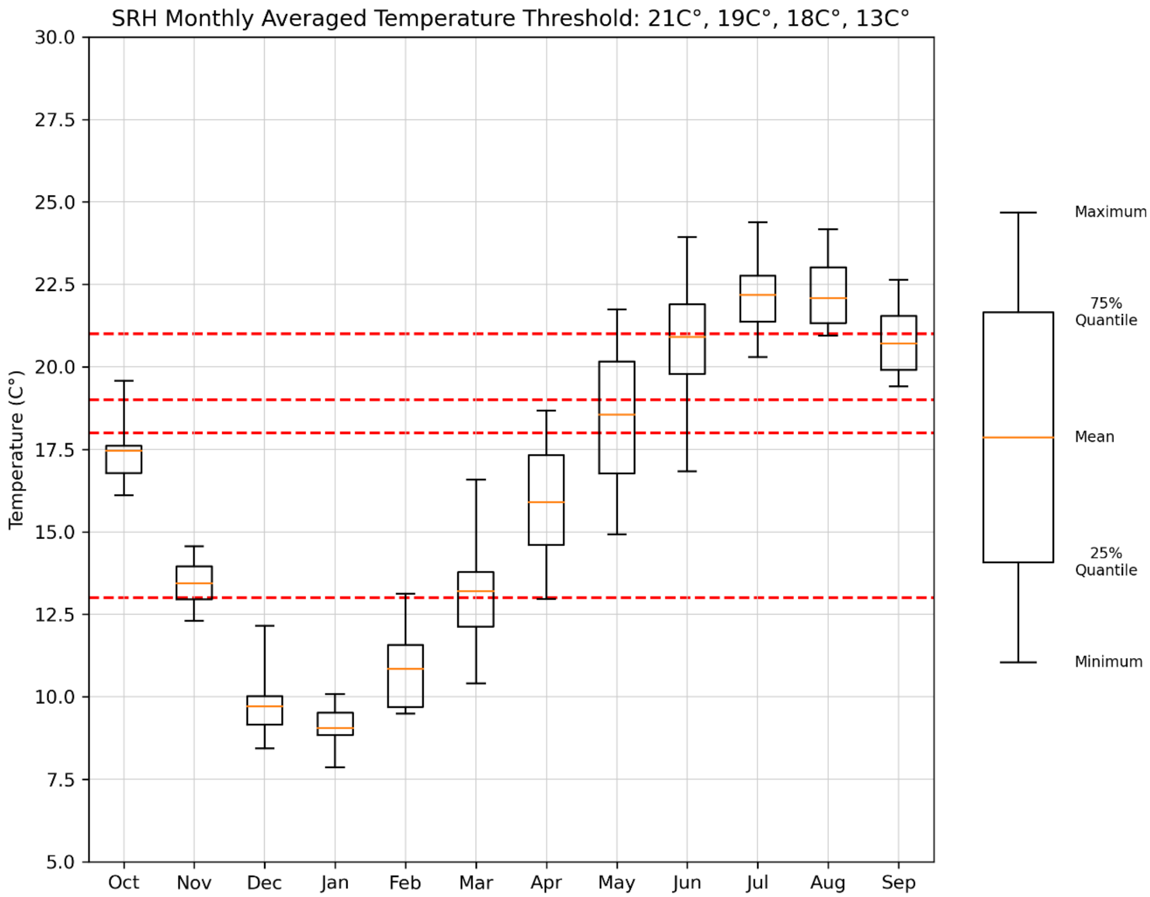

Figure C-120. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SRH – Sacramento River at Hood

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

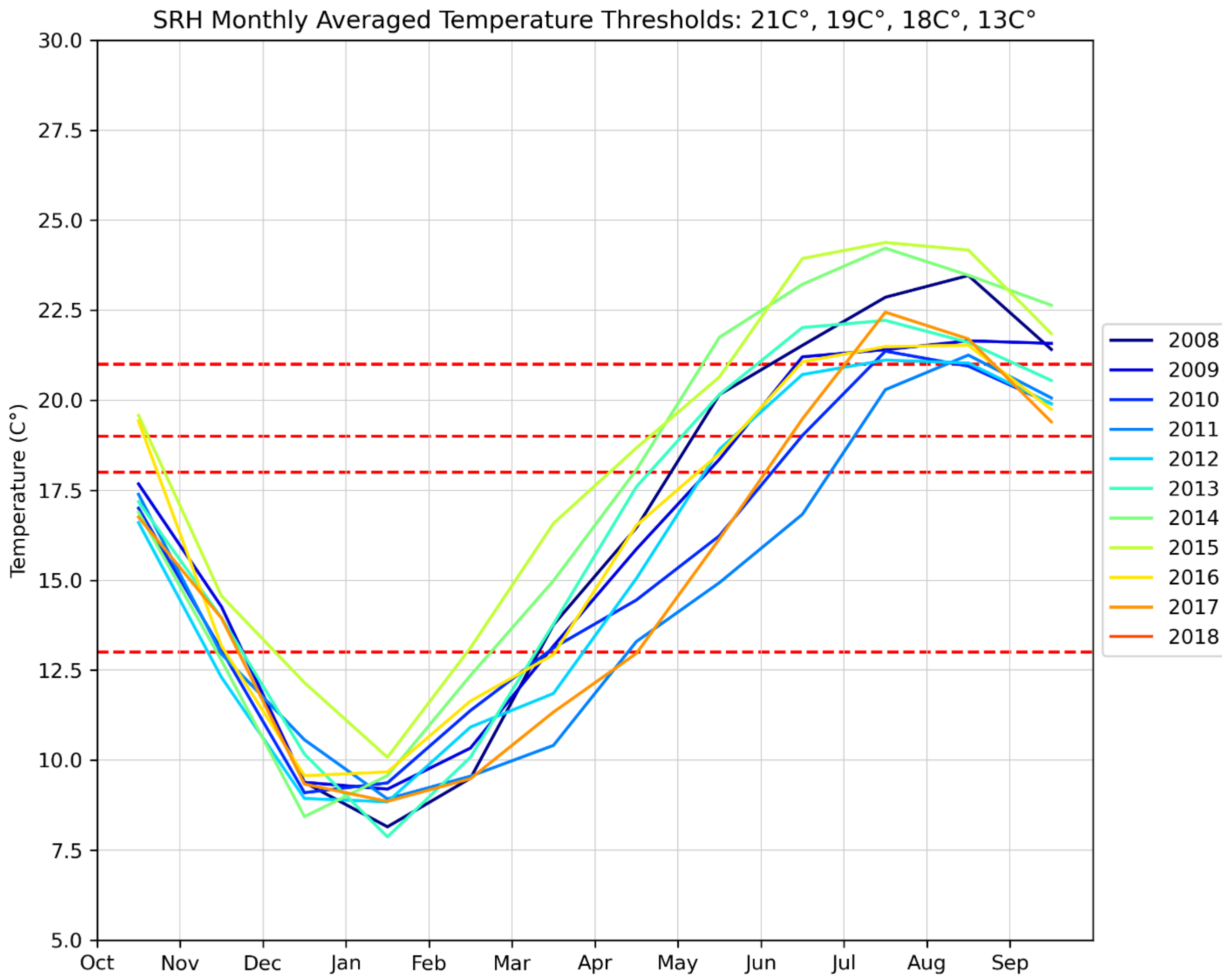

Figure C-121. Monthly Average Temperature for the Period of Record at Station SRH – Sacramento River at Hood

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

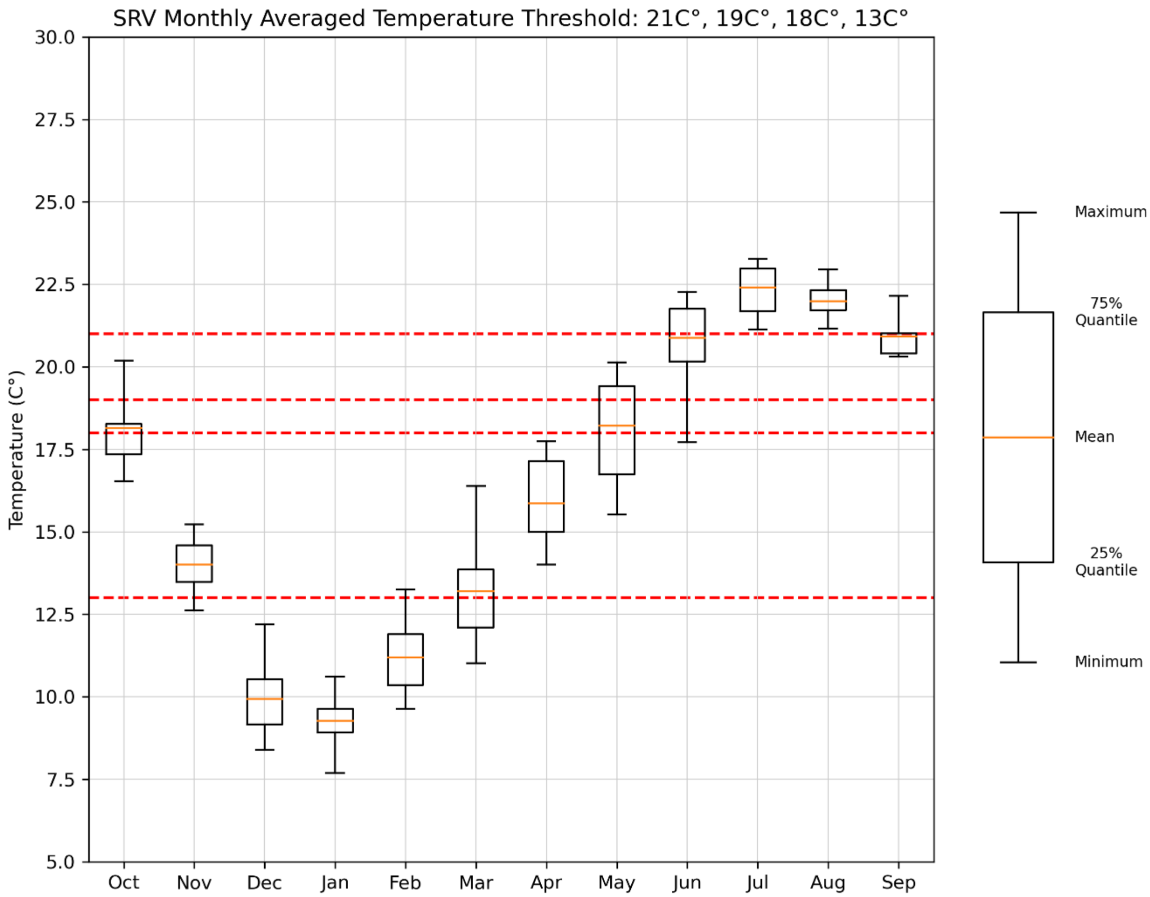

Figure C-122. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SRV – Sacramento River at Rio Vista

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

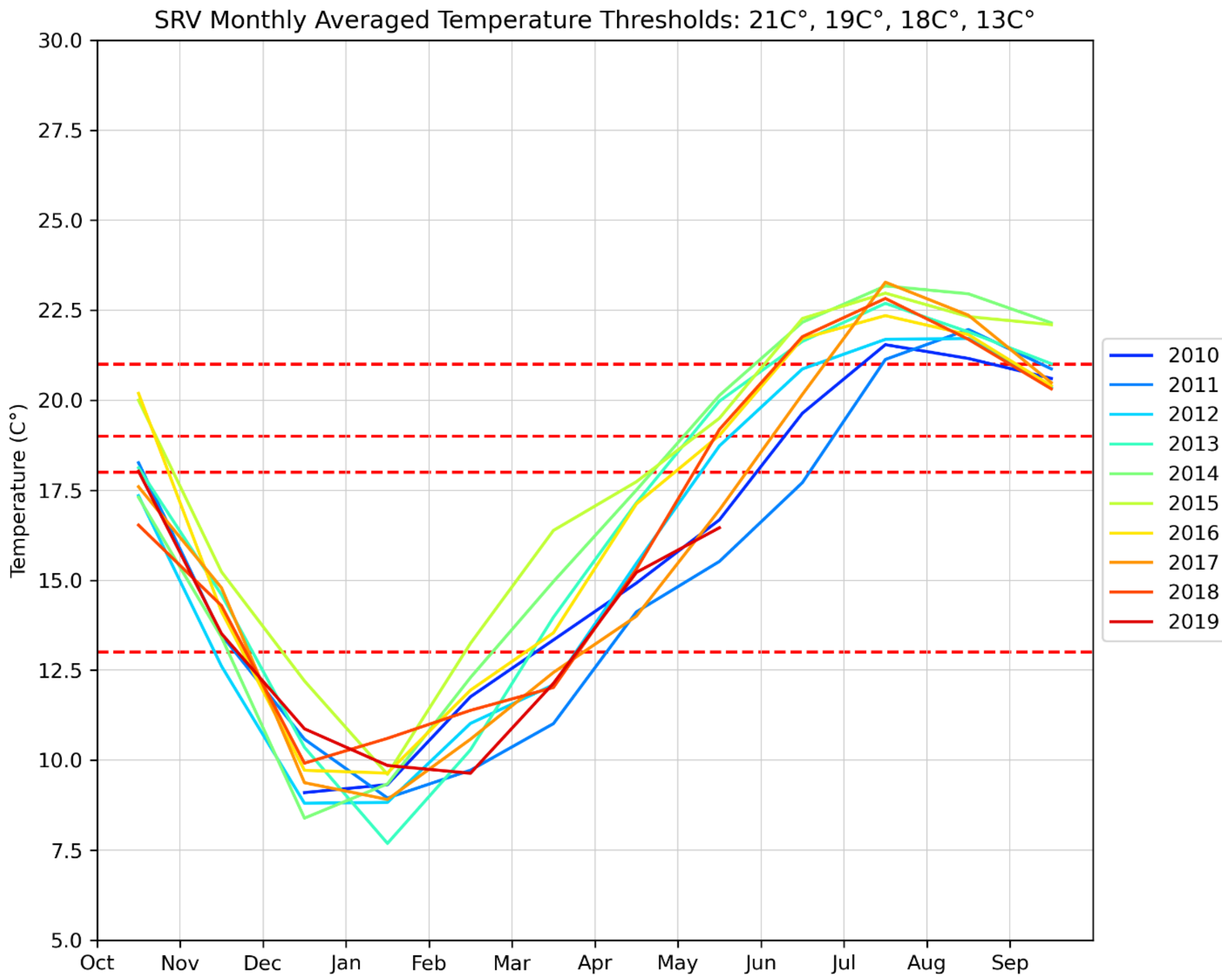

Figure C-123. Monthly Average Temperature for the Period of Record at Station SRV – Sacramento River at Rio Vista

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

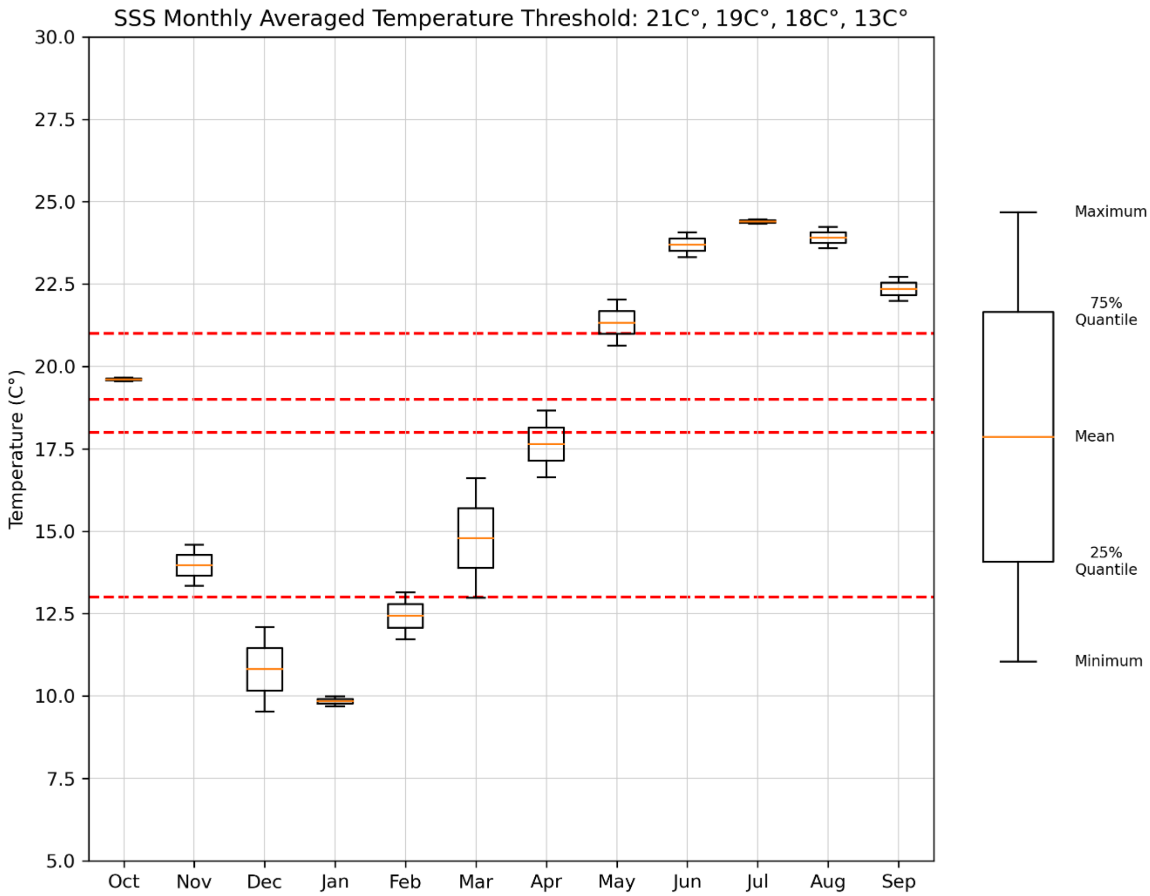

Figure C-124. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SSS – Steamboat Slough between Sacramento River and Sutter Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

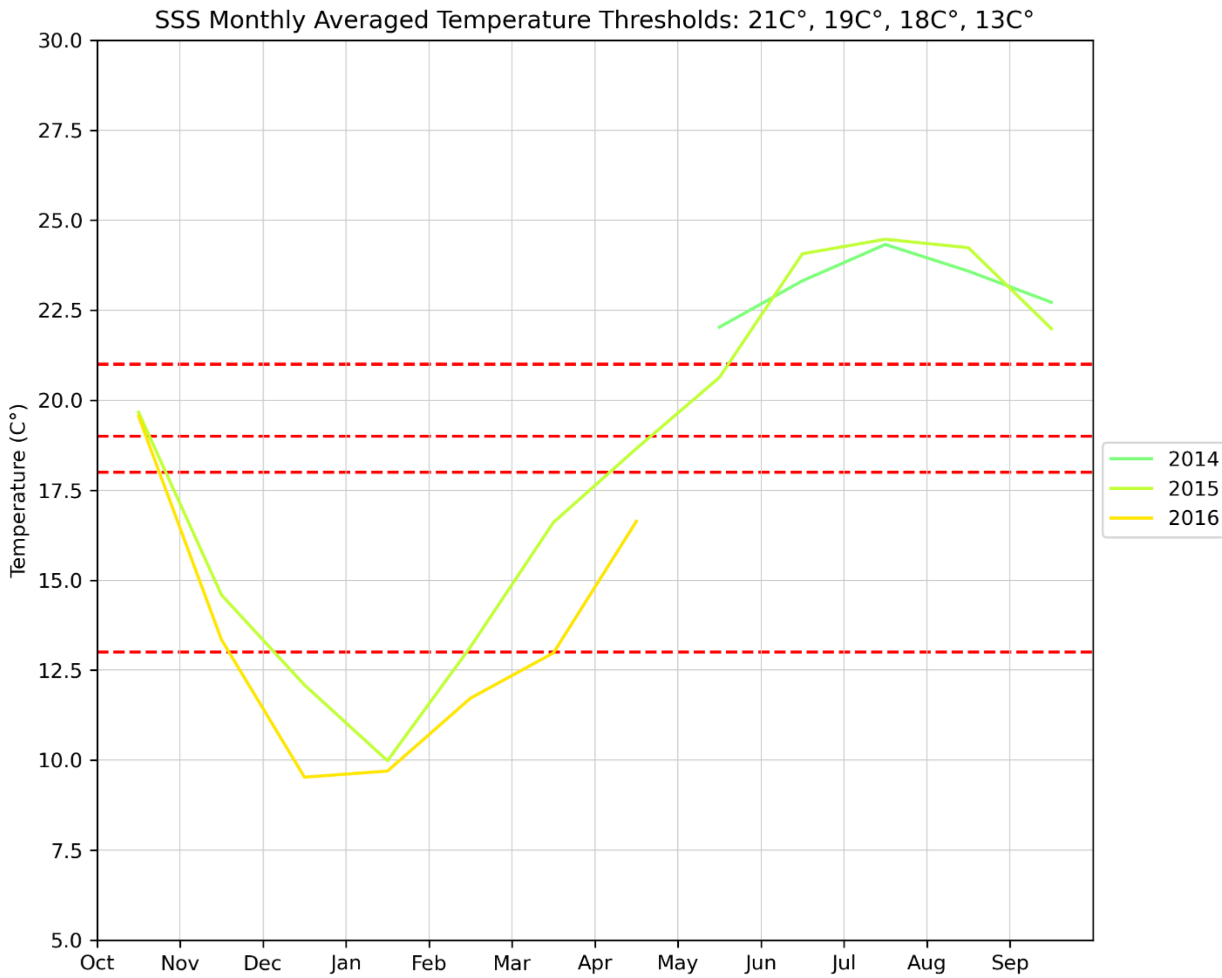

Figure C-125. Monthly Average Temperature for the Period of Record at Station SSS – Steamboat Slough between Sacramento River and Sutter Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

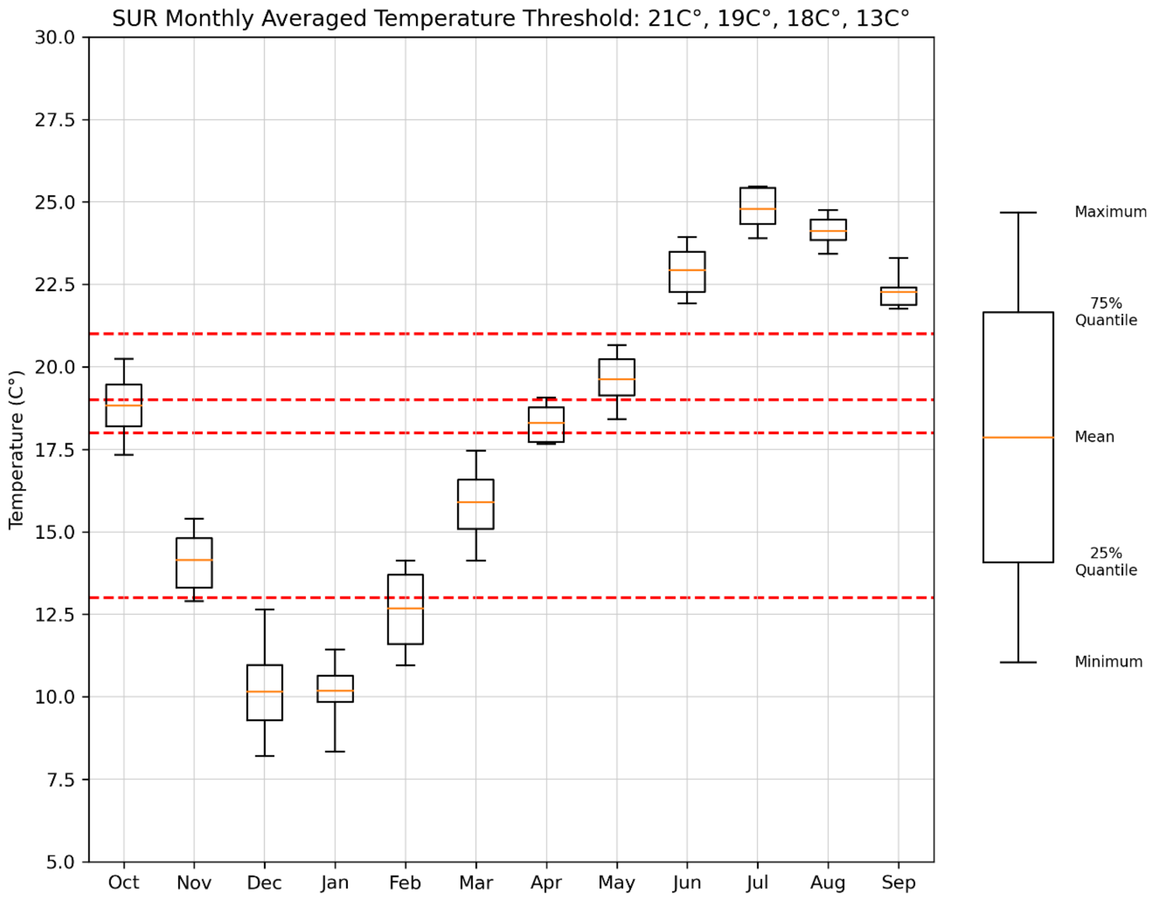

Figure C-126. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SUR – Sugar Cut

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

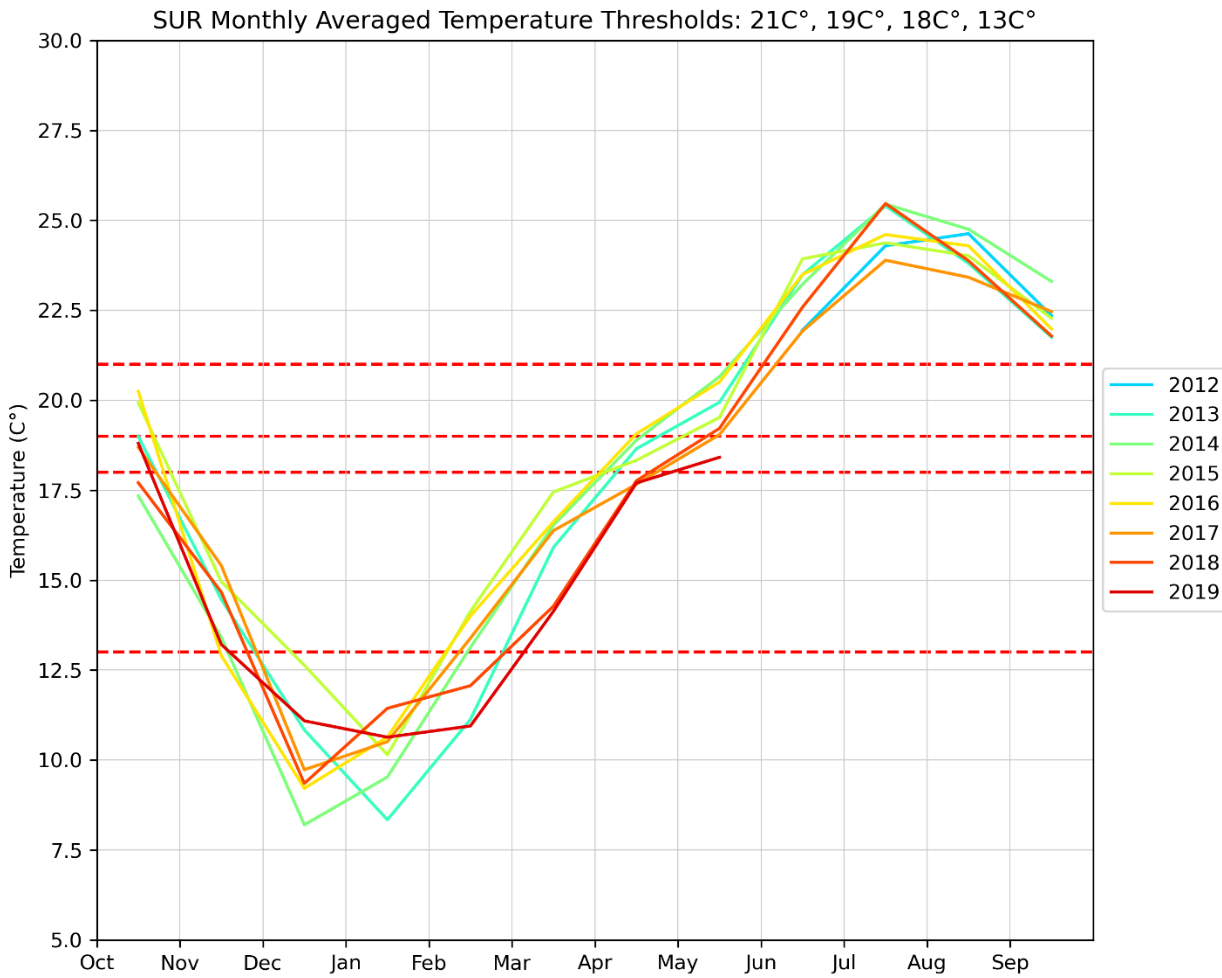

Figure C-127. Monthly Average Temperature for the Period of Record at Station SUR – Sugar Cut

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

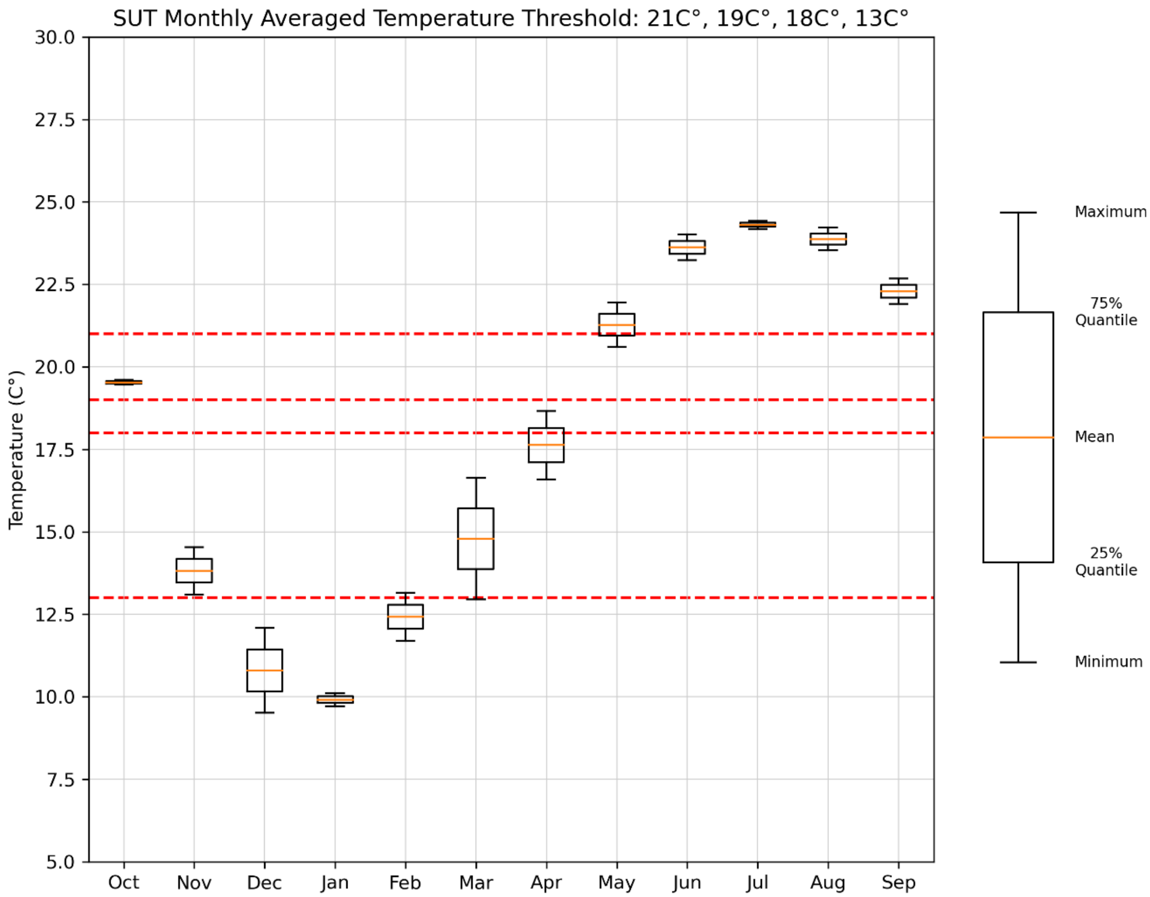

Figure C-128. Bar and whisker plot summarizing range of monthly averaged temperature at station SUT – Sutter Slough at Courtland

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

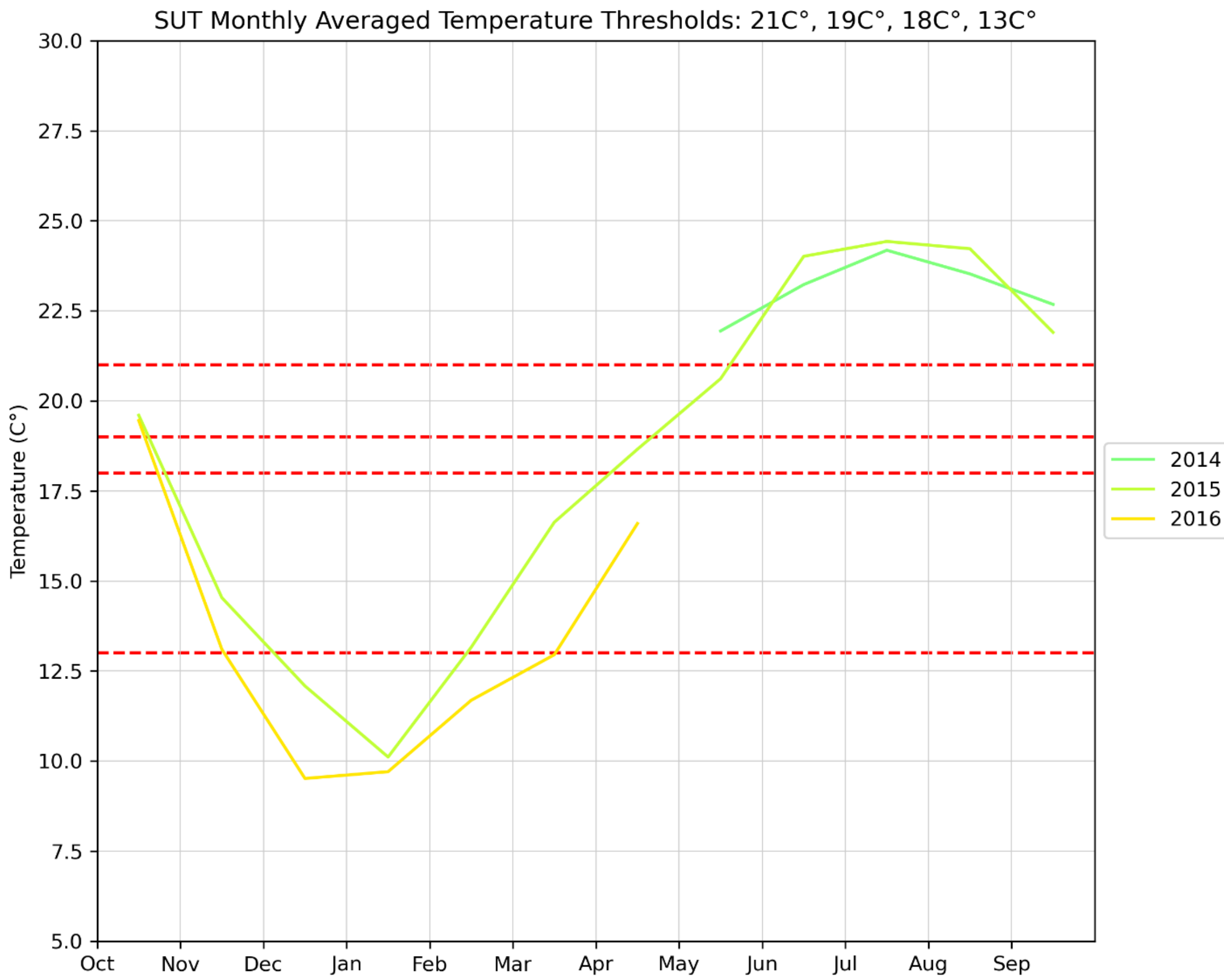

Figure C-129. Monthly Average Temperature for the Period of Record at Station SUT – Sutter Slough at Courtland

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

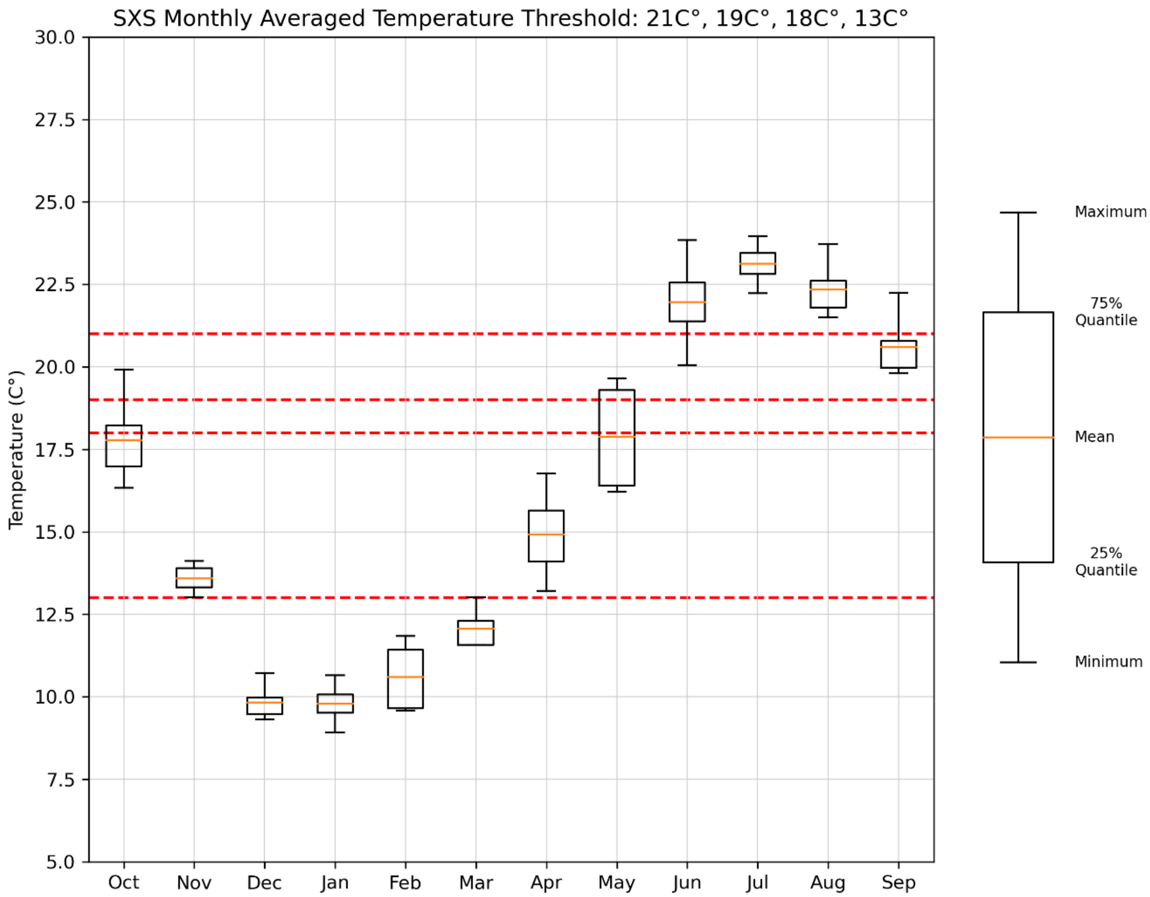

Figure C-130. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SXS – Steamboat Slough near Sacramento River

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

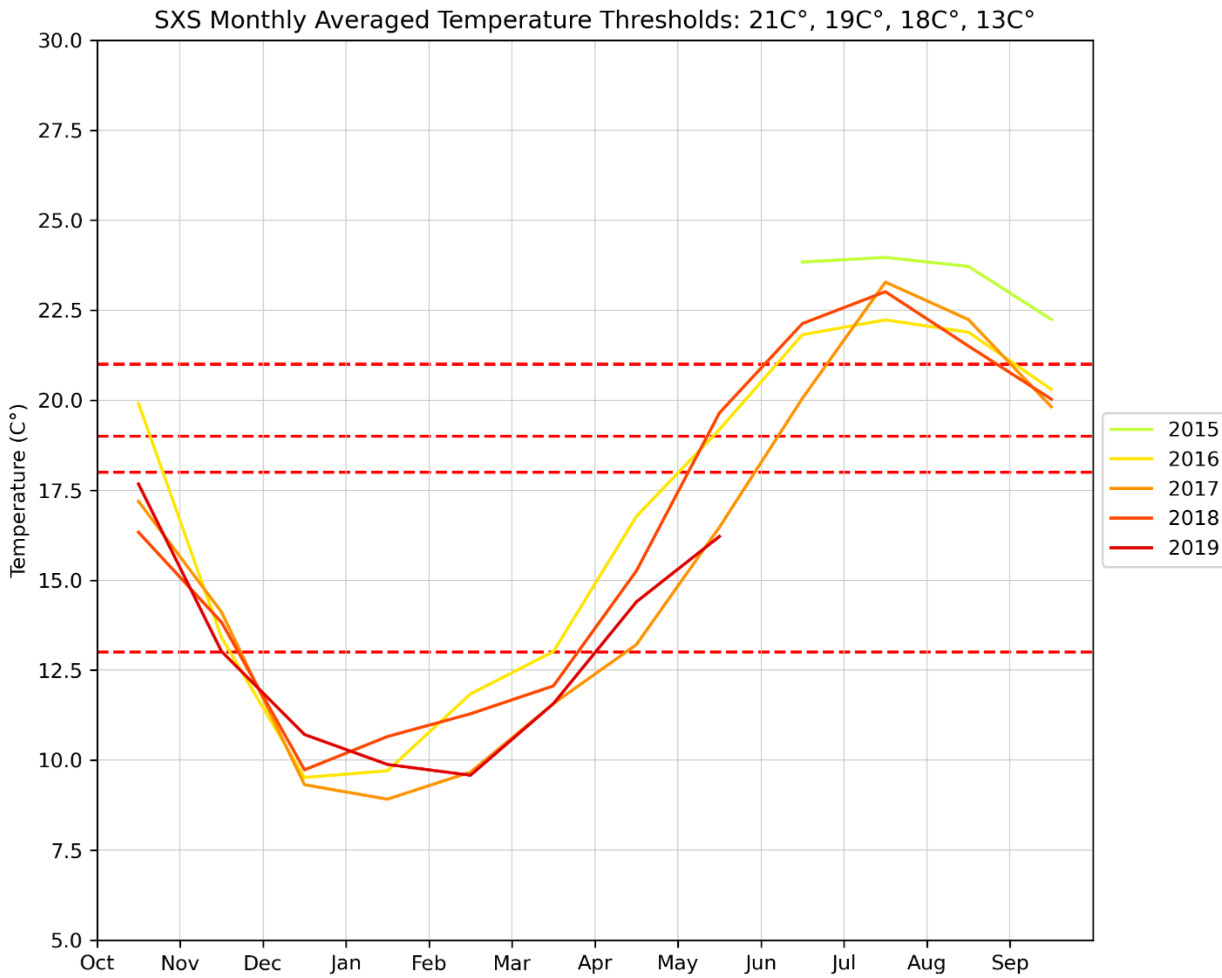

Figure C-131. Monthly Average Temperature for the Period of Record at Station SXS – Steamboat Slough near Sacramento River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

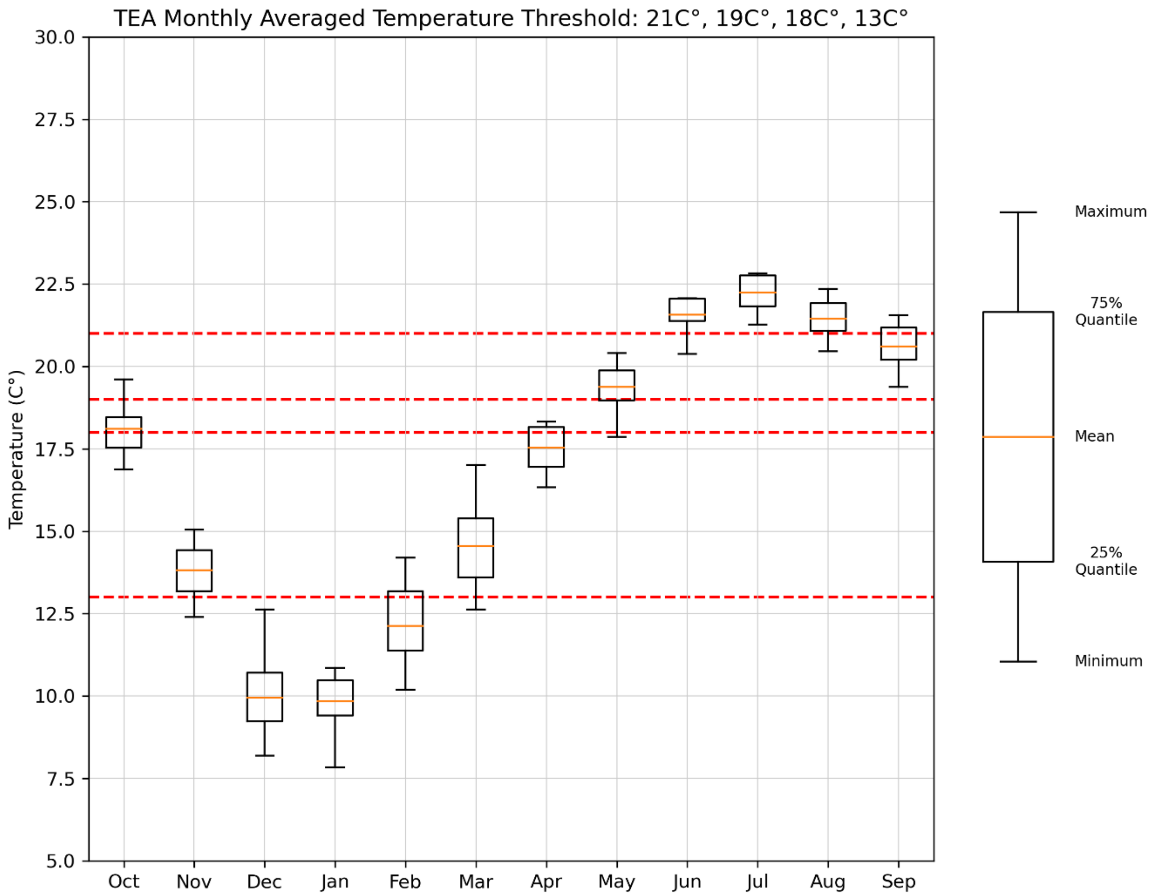

Figure C-132. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station TEA – Teal Club at Frank Horan Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

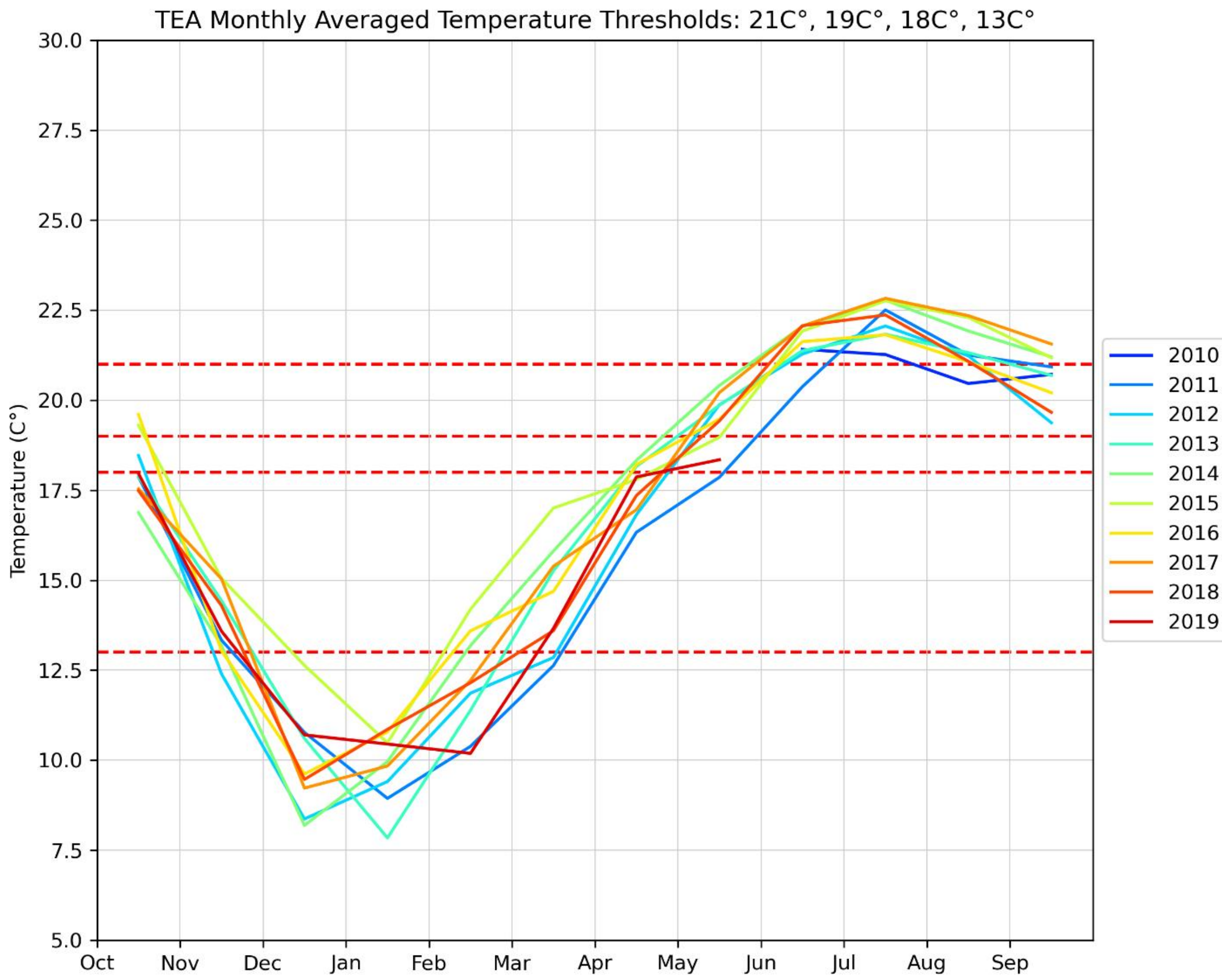

Figure C-133. Monthly Average Temperature for the Period of Record at Station TEA – Teal Club at Frank Horan Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

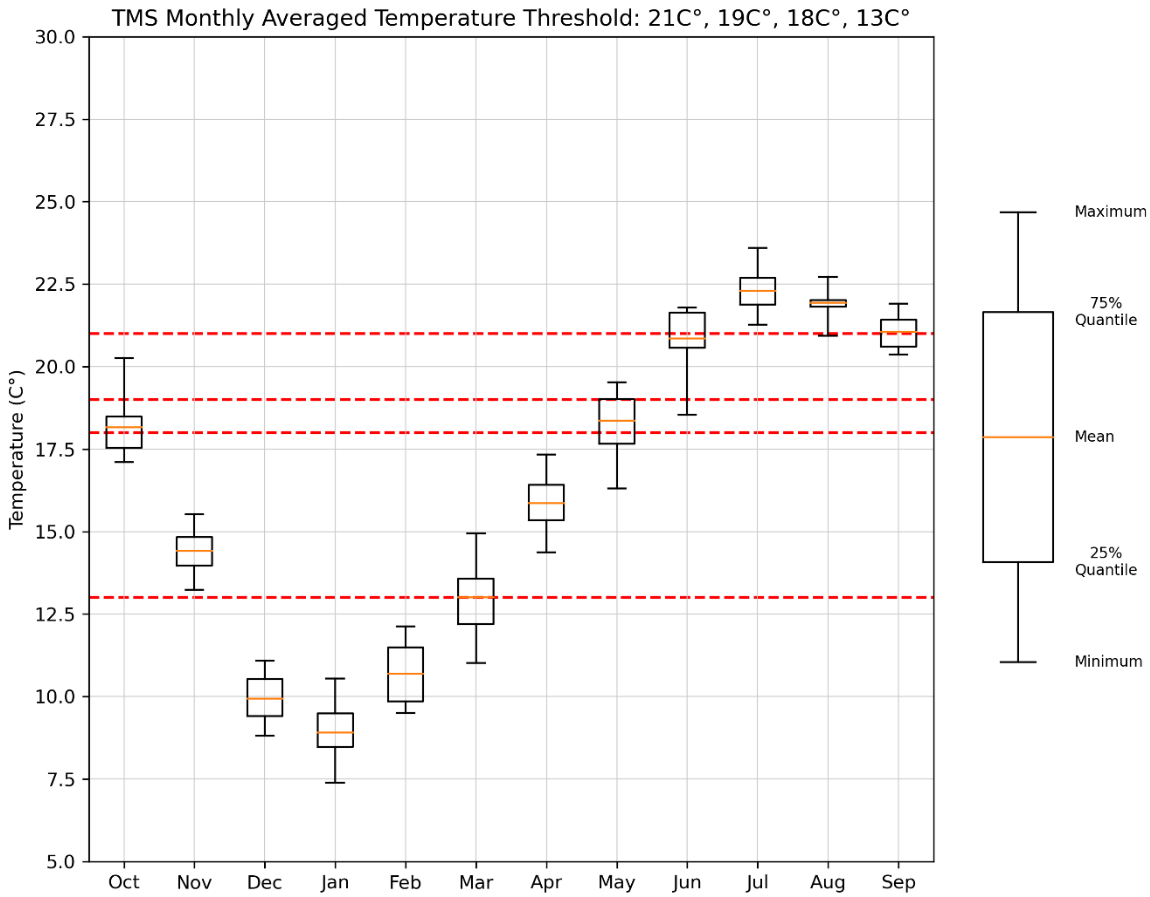

Figure C-134. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station TMS – Threemile Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

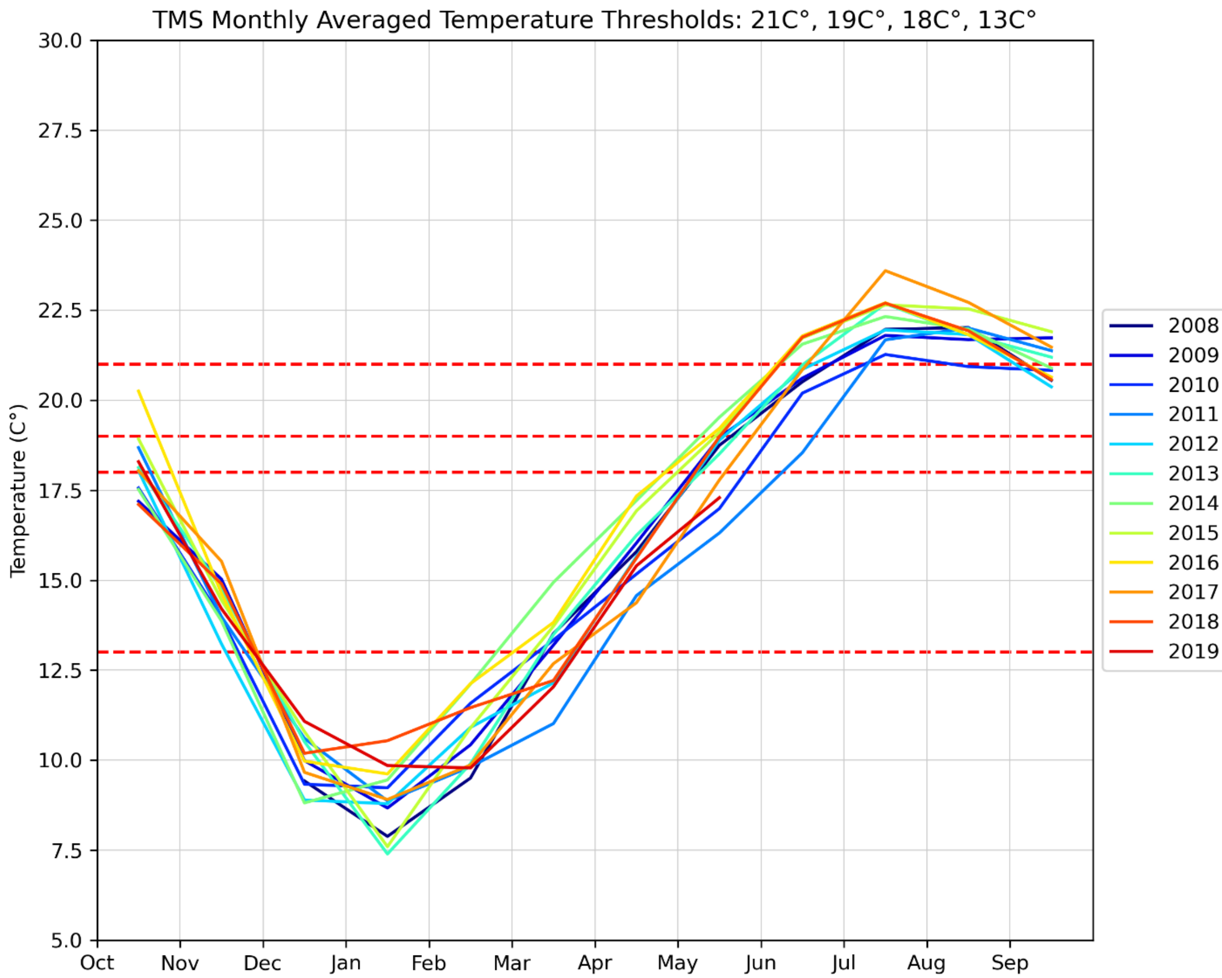

Figure C-135. Monthly Average Temperature for the Period of Record at Station TMS – Threemile Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

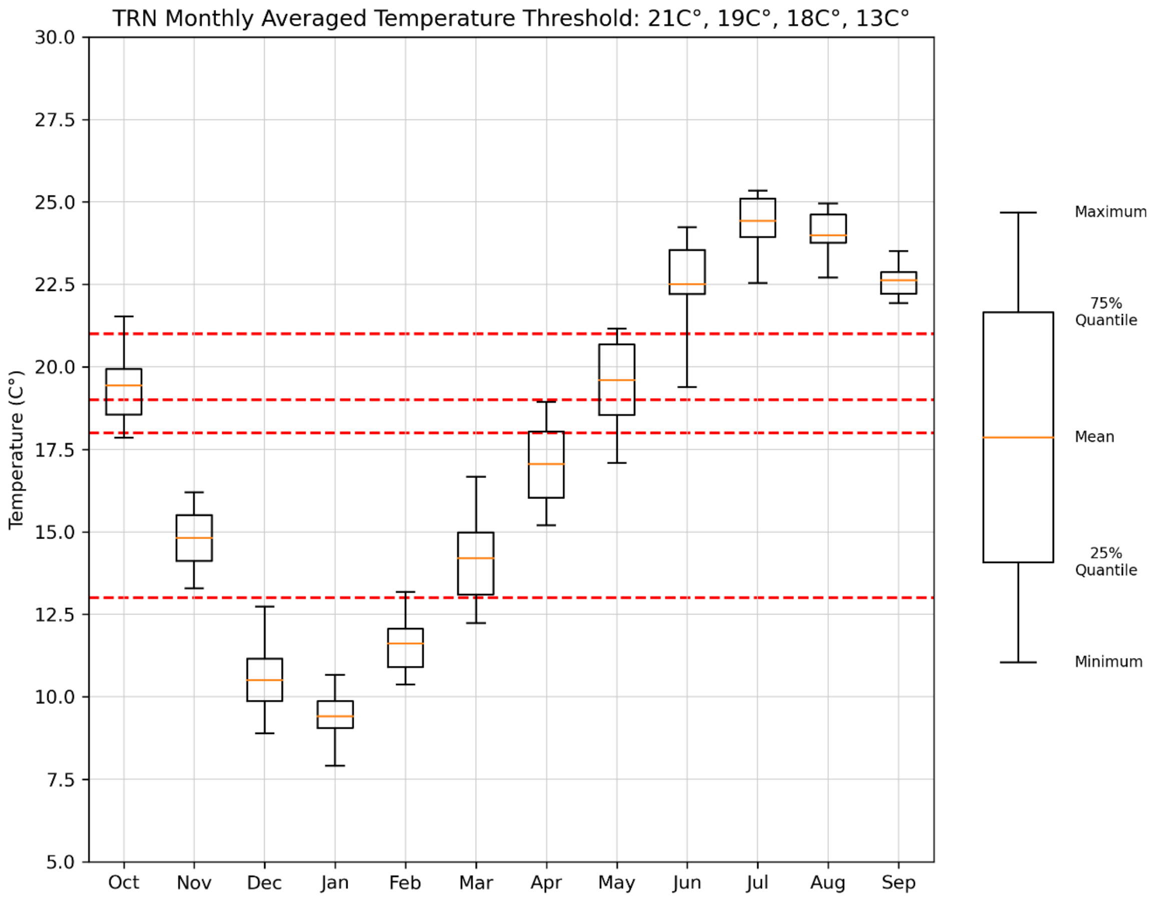

Figure C-136 Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station TRN – Turner Cut near Holt

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

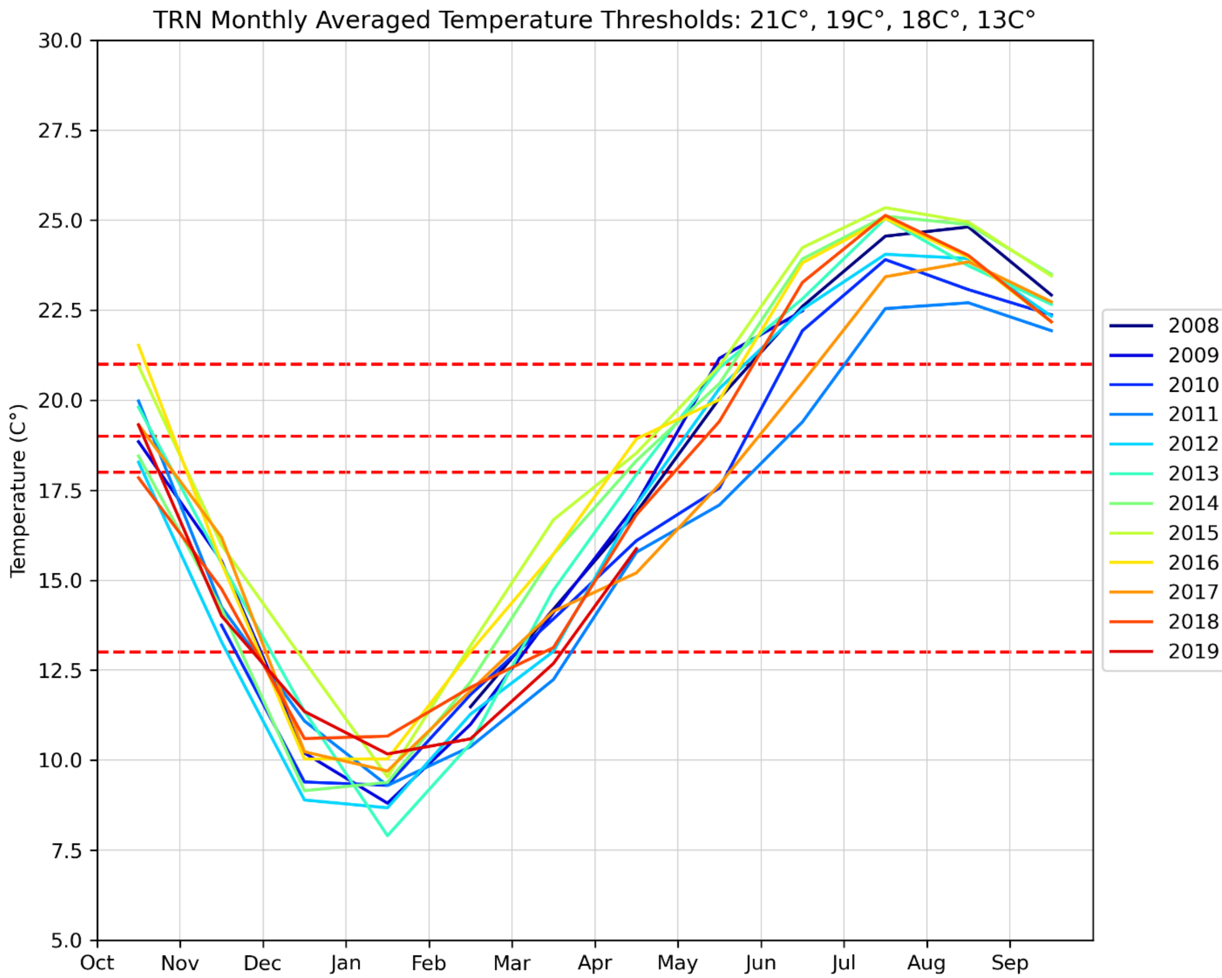

Figure C-137 Monthly Average Temperature for the Period of Record at Station TMS – Turner Cut near Holt

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

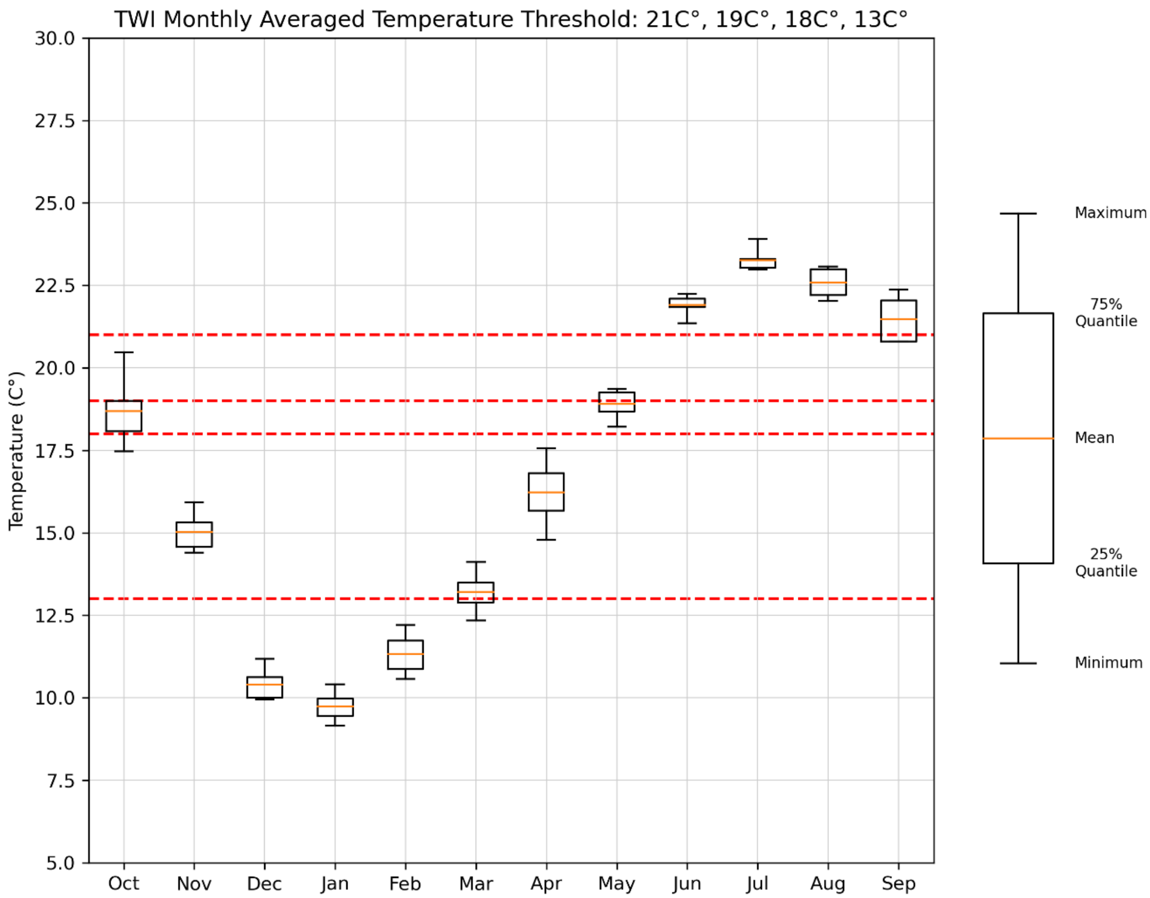

Figure C-138 Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station TWI – San Joaquin River at Twitchell Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

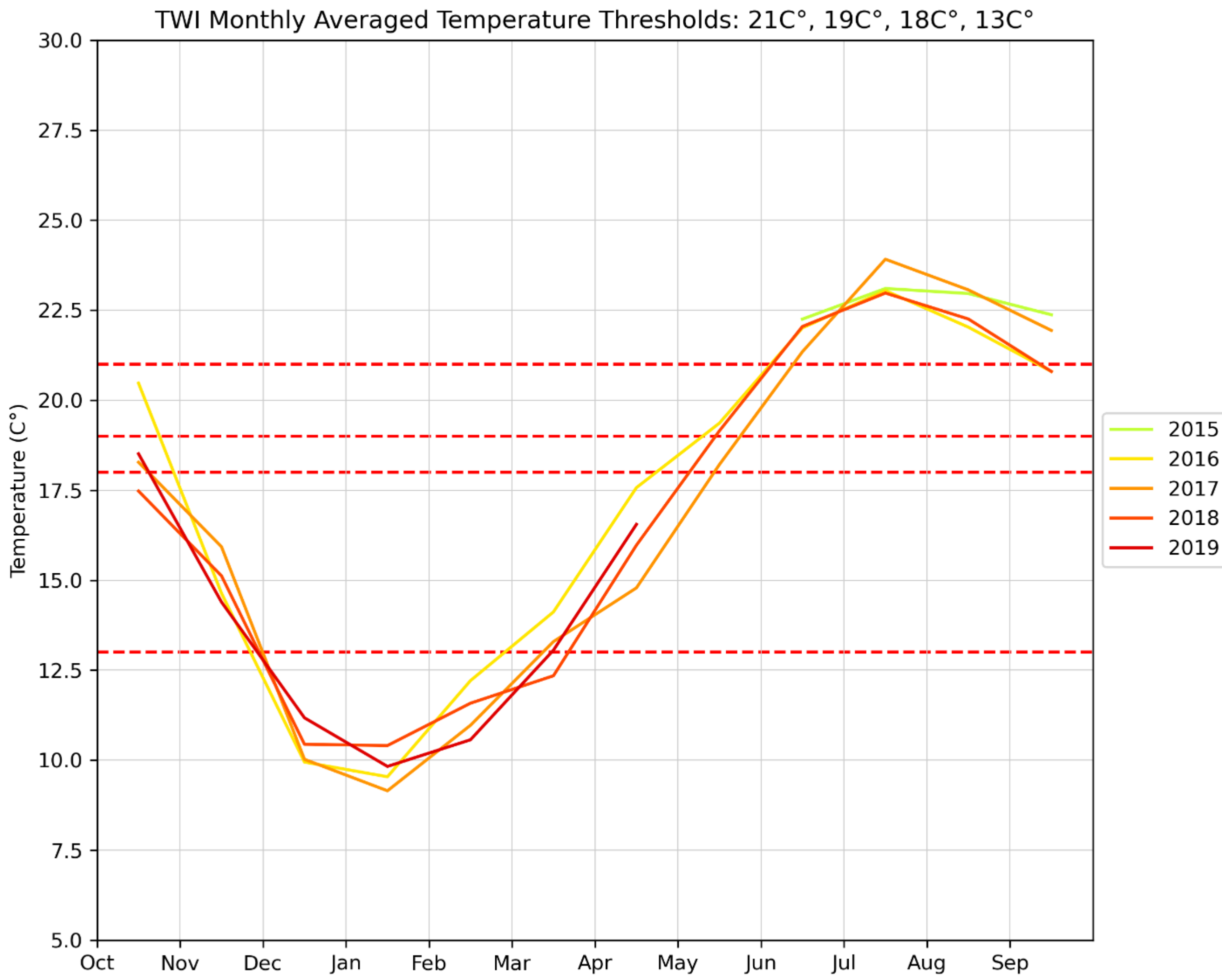

Figure C-139 Monthly Average Temperature for the Period of Record at Station TWI – San Joaquin River at Twitchell Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

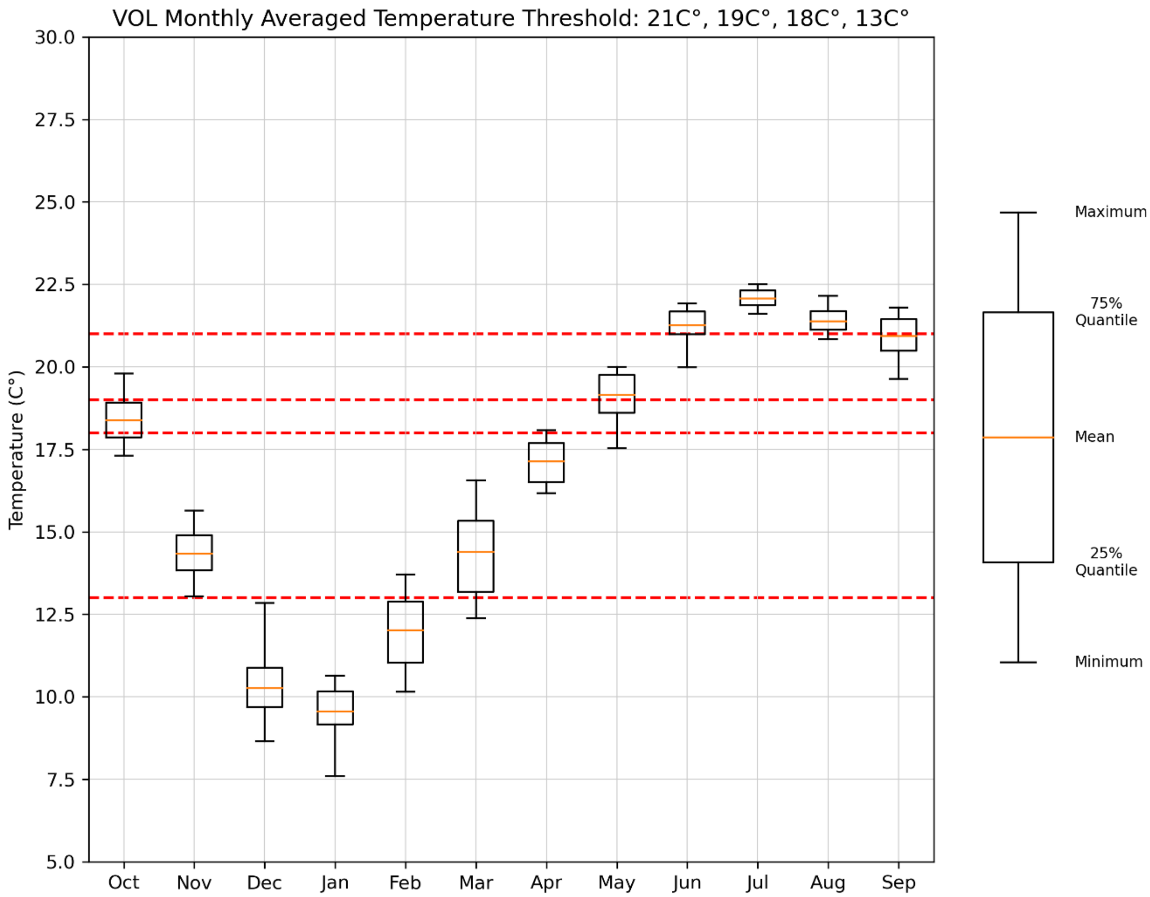

Figure C-140. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station VOL – Volanti

Figure shows data plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

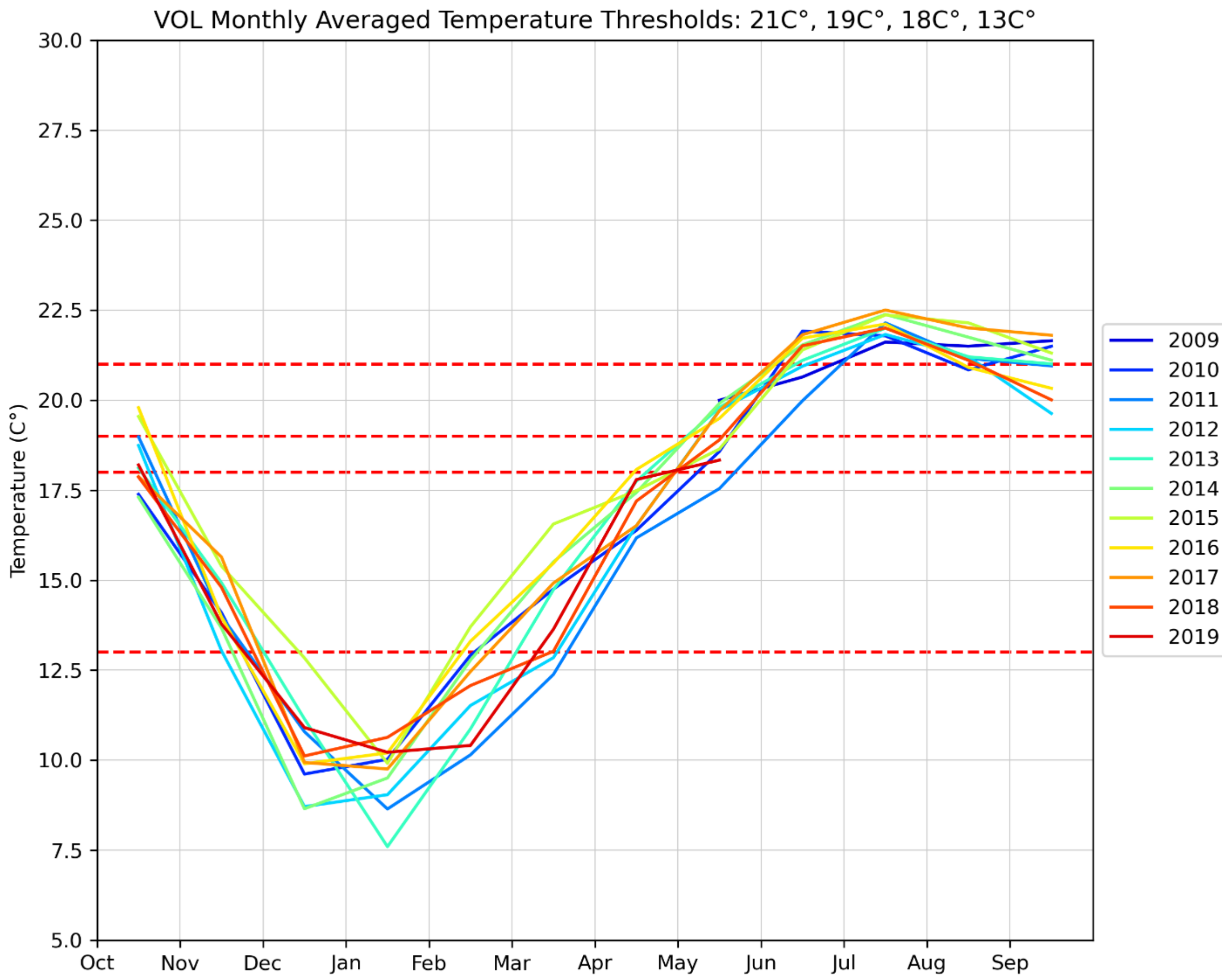

Figure C-141. Monthly Average Temperature for the Period of Record at Station VOL – Volanti

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in degrees Celsius) on the y-axis.

C.1.2 Turbidity

Observed turbidity data were downloaded from the California Department of Water Resources' California Data Exchange Center and Water Data Library (DWR 2022a, 2022b) and the U.S. Geological Survey (2022).

The map in Figure C-142 shows the locations of all observed turbidity stations that were used to calculate the turbidity data layers for the habitat calculations.

For each station, bar and whisker plots and monthly average turbidity time series plots, similar to those for temperature data, are provided in Figure 143 through Figure 190. The 12 Nephelometric Turbidity Unit (NTU) minimum limit for Delta smelt habitat is included on all plots for reference.

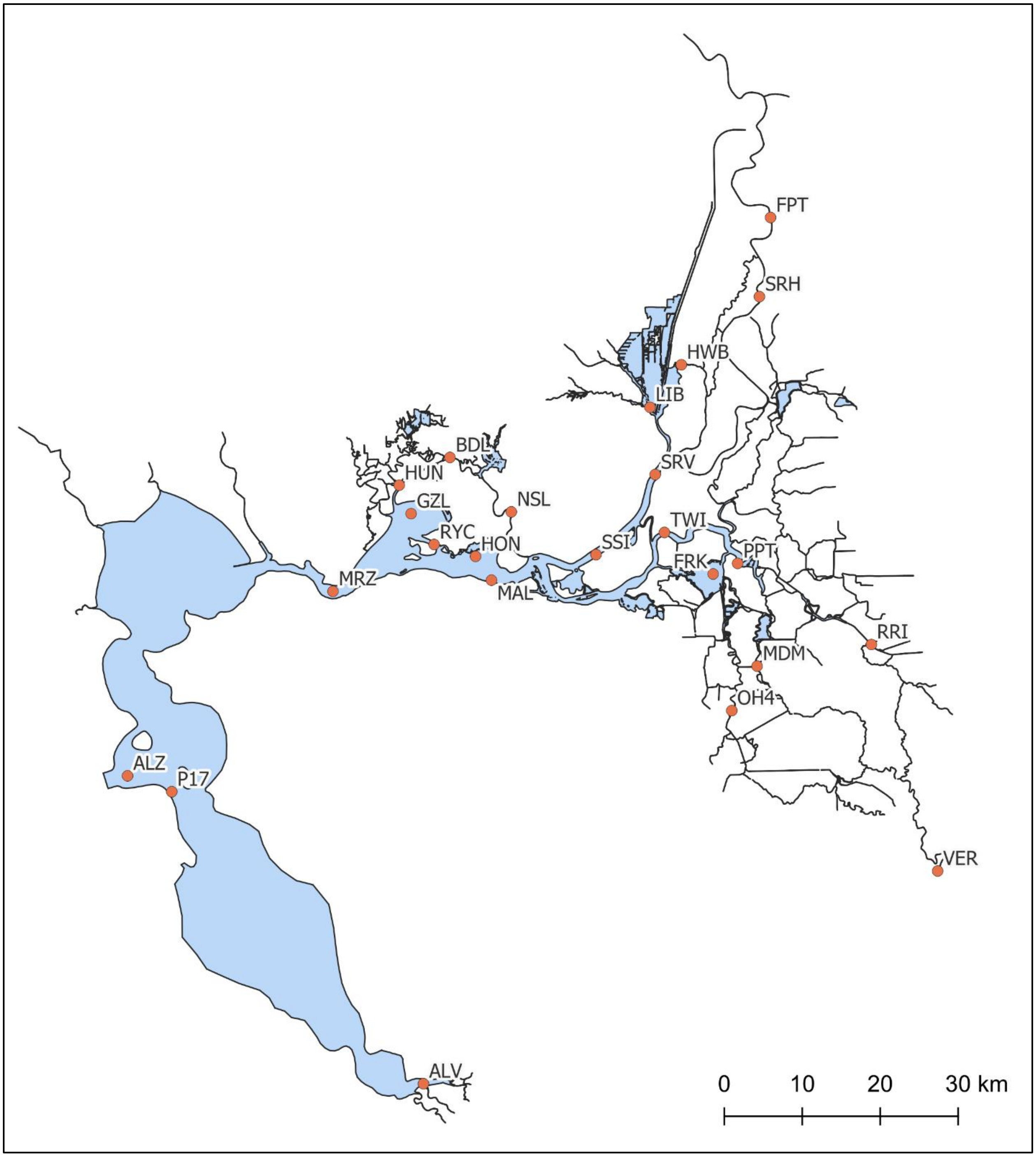

Figure C-142. Locations of Observed Turbidity Stations Used to Calculate the Turbidity Data Layers for the Habitat Calculations

Figure is a map of the San Francisco Bay Estuary showing red points denoted by three-letter station codes representing sampling stations.

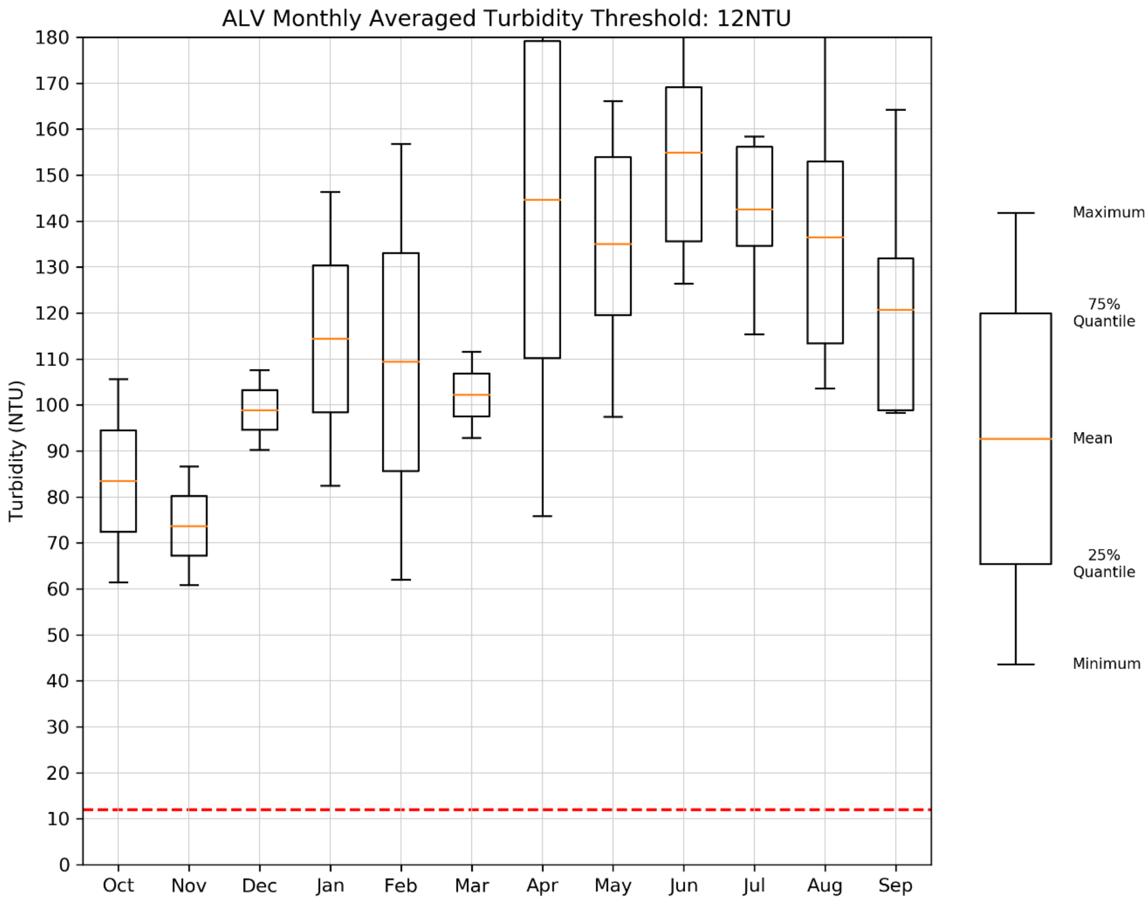

Figure C-143. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station ALV – Alviso Slough

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

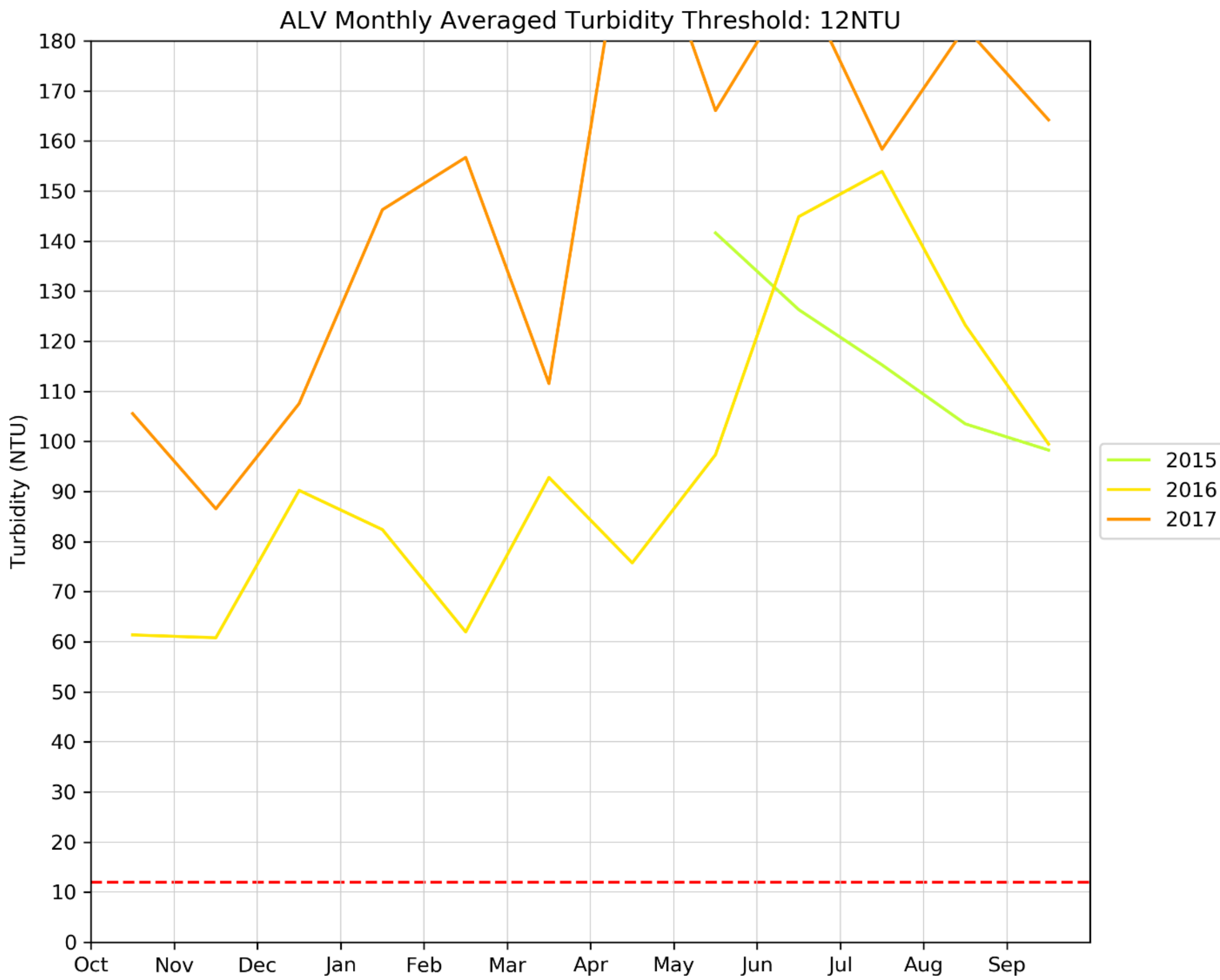

Figure C-144. Monthly Average Turbidity for the Period of Record at Station ALV – Alviso Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

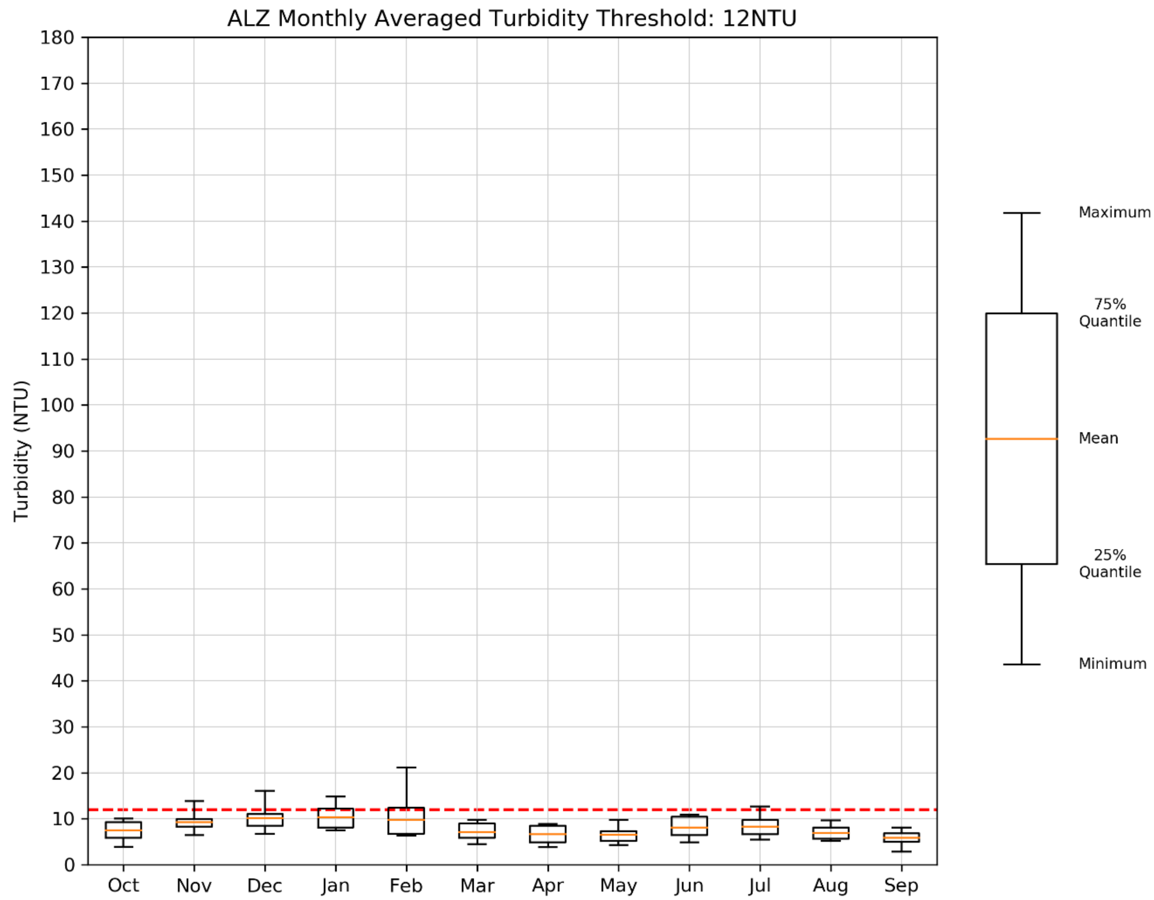

Figure C-145. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station ALZ – Alcatraz Island

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean: top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

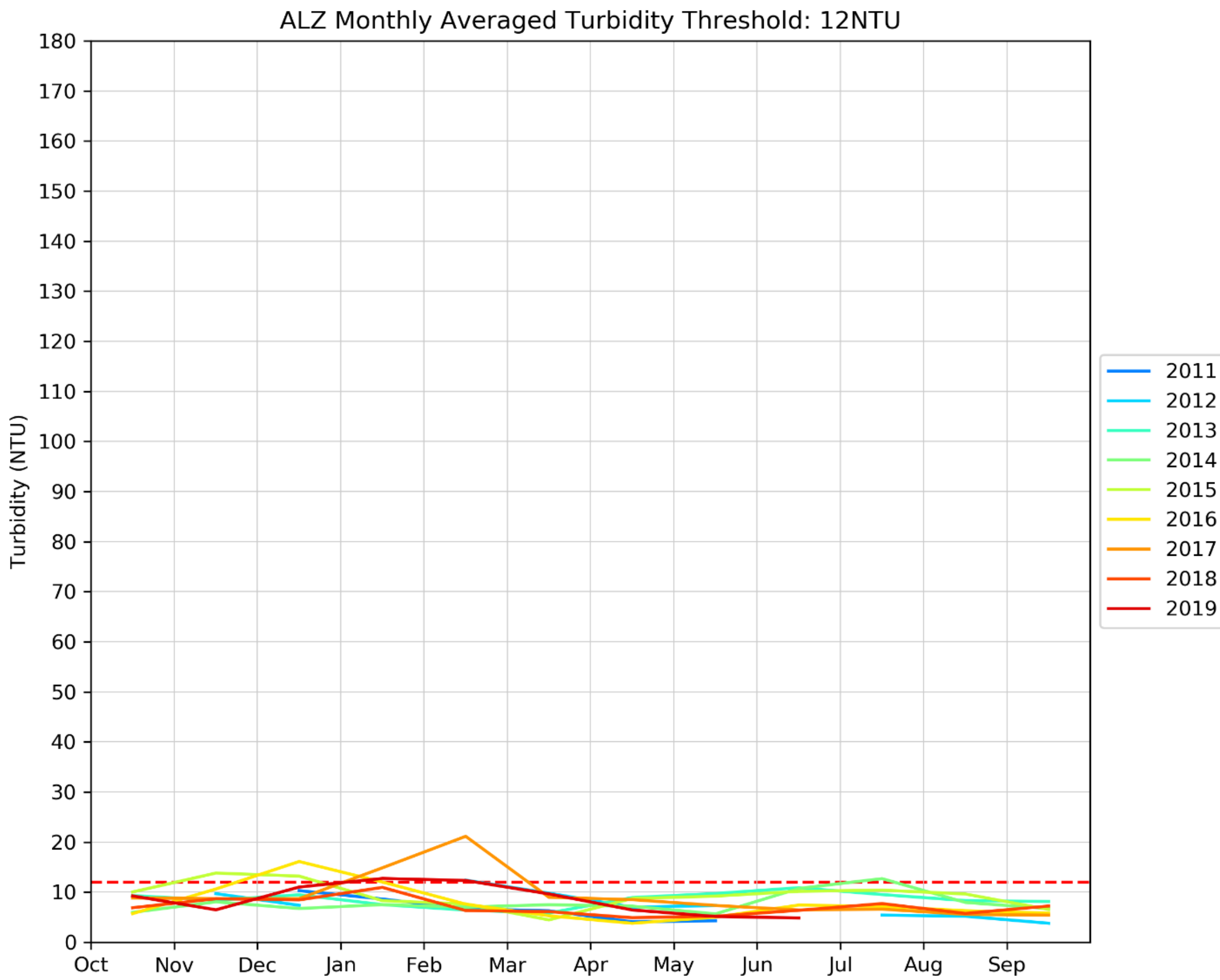

Figure C-146. Monthly Average Turbidity for the Period of Record at Station ALZ – Alcatraz Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

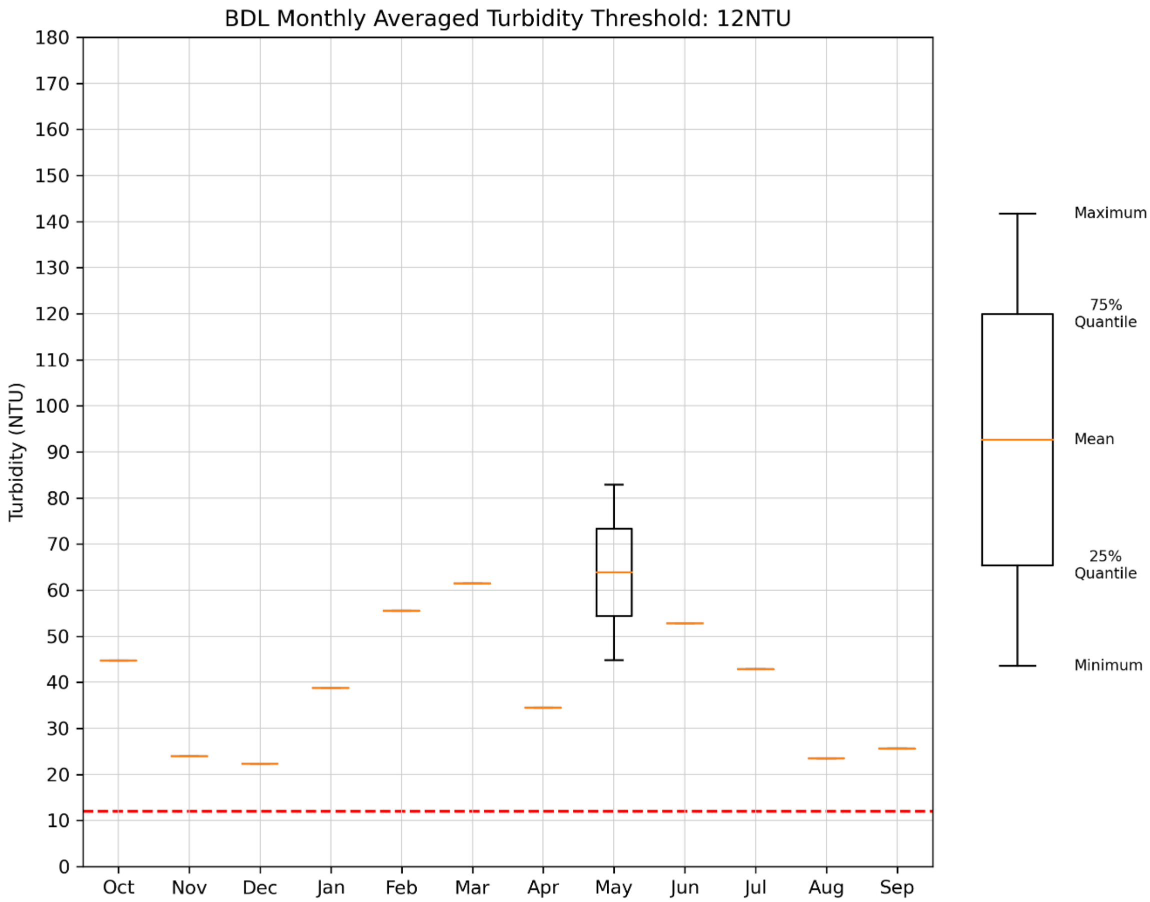

Figure C-147. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station BDL – Montezuma Slough at Beldon Landing

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

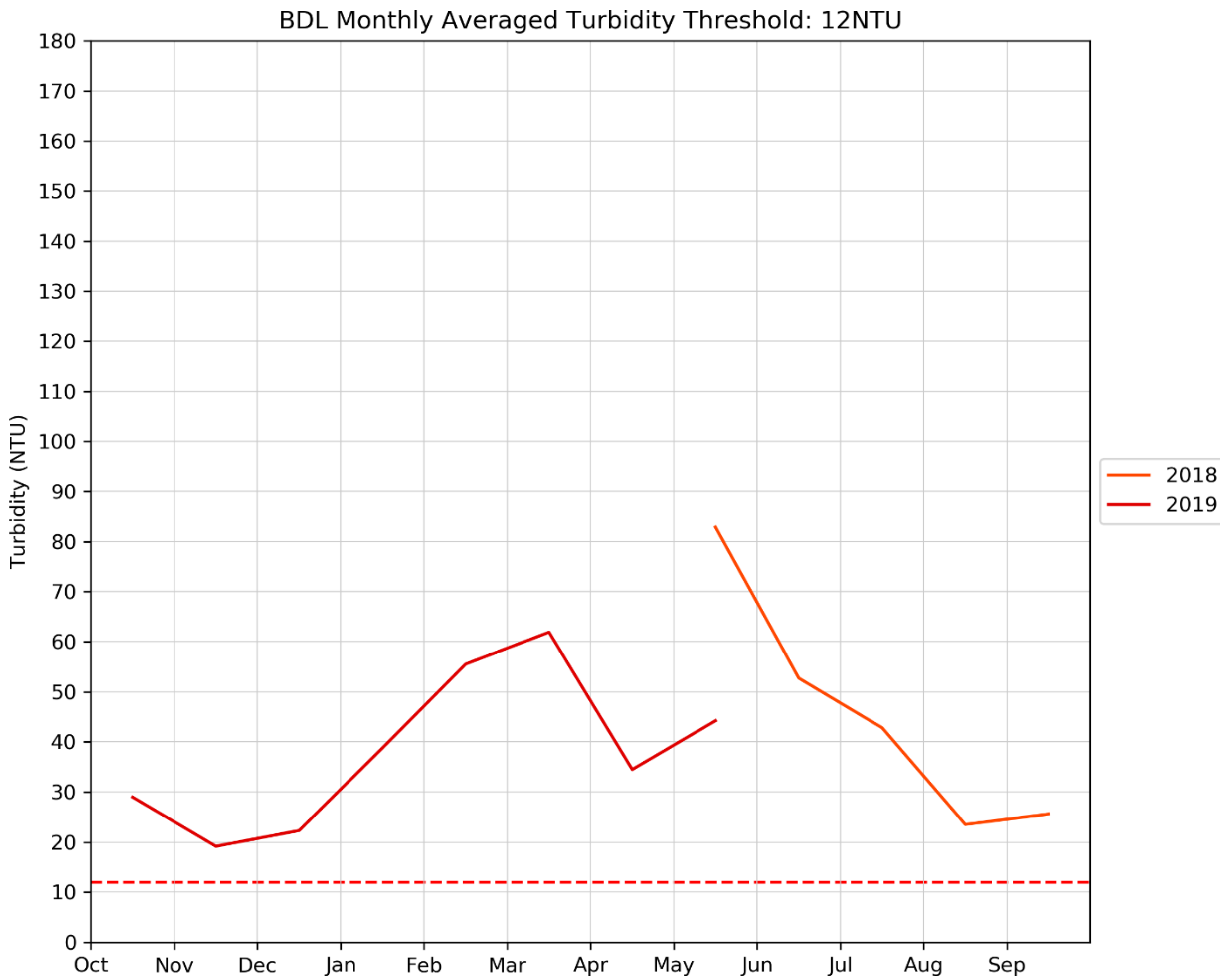

Figure C-148. Monthly Average Turbidity for the Period of Record at Station BDL – Montezuma Slough at Beldon Landing

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

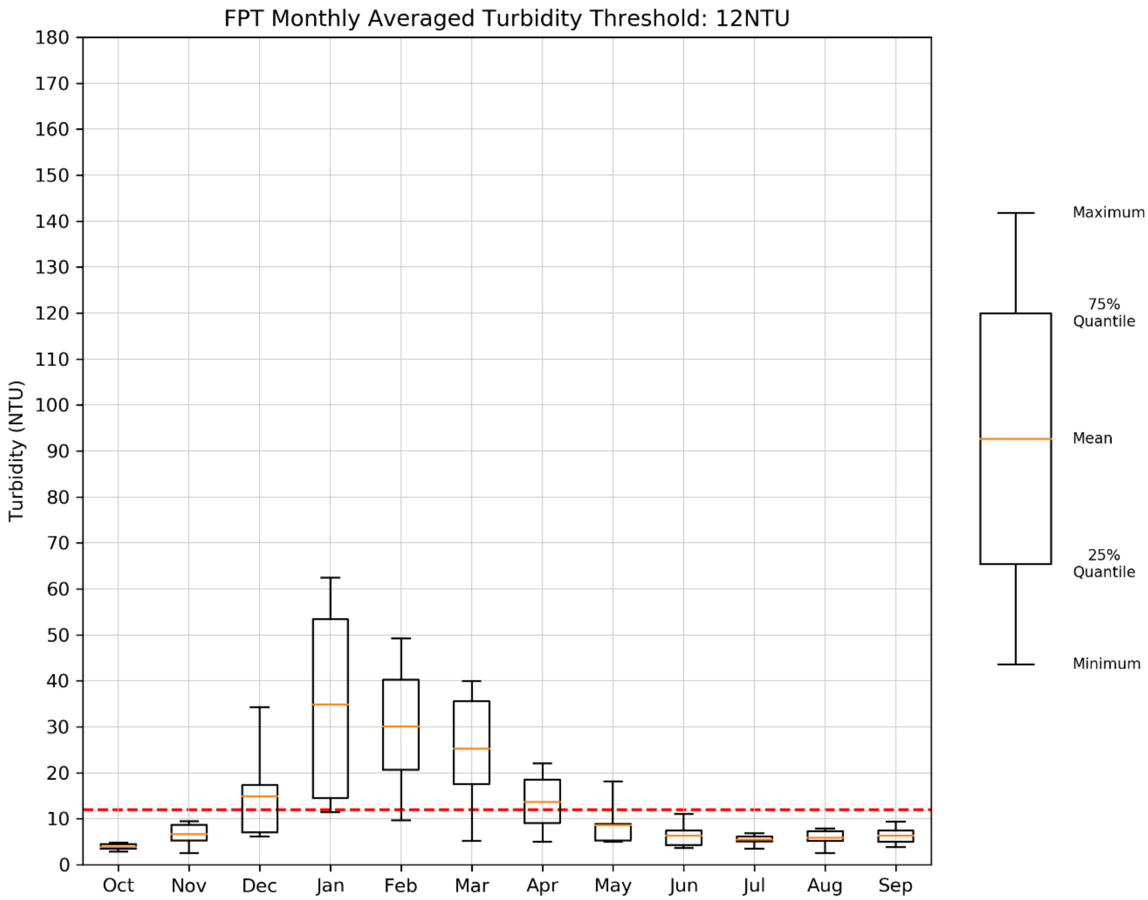

Figure C-149. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station FPT – Sacramento River at Freeport

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

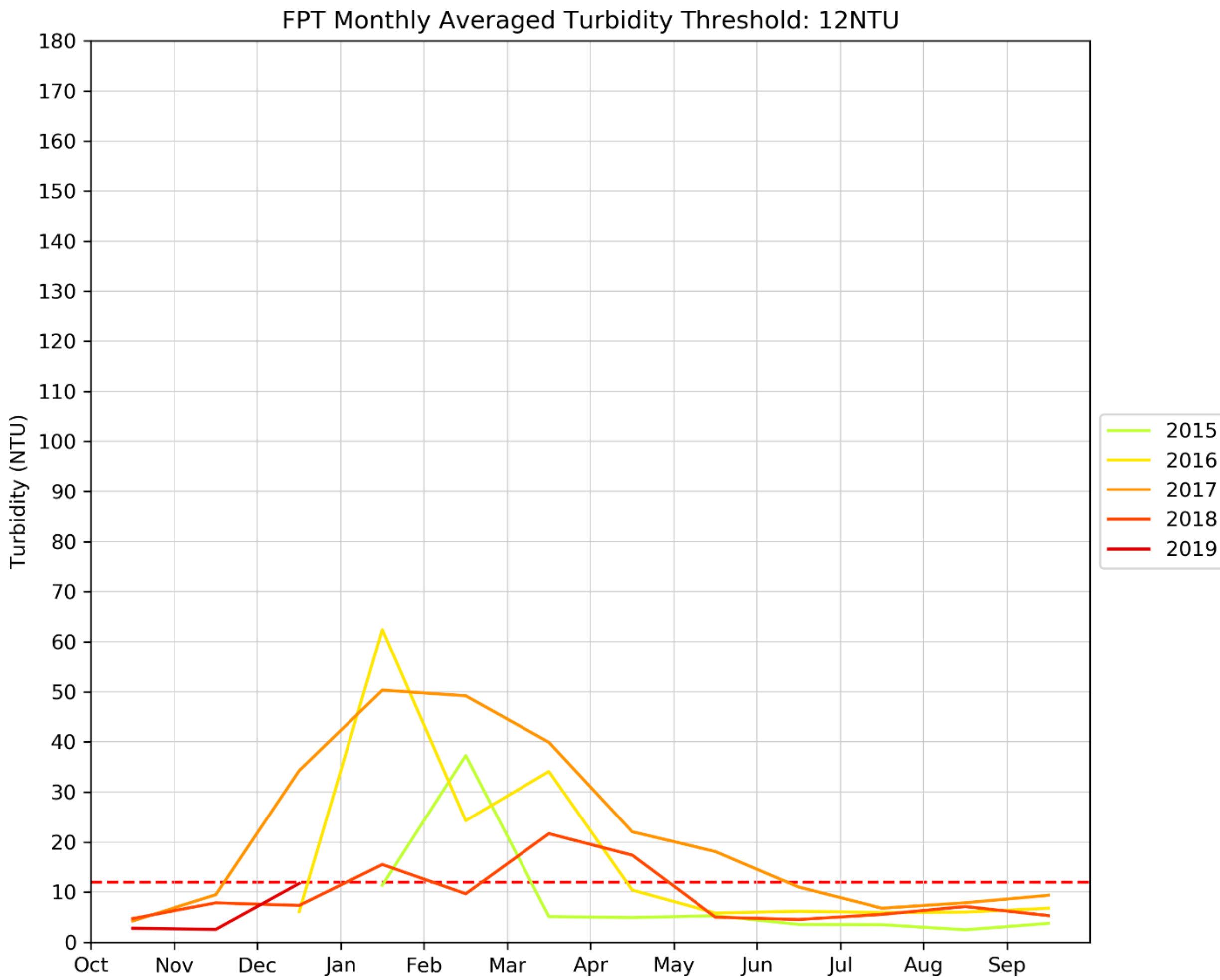

Figure C-150. Monthly Average Turbidity for the Period of Record at Station FPT – Sacramento River at Freeport

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

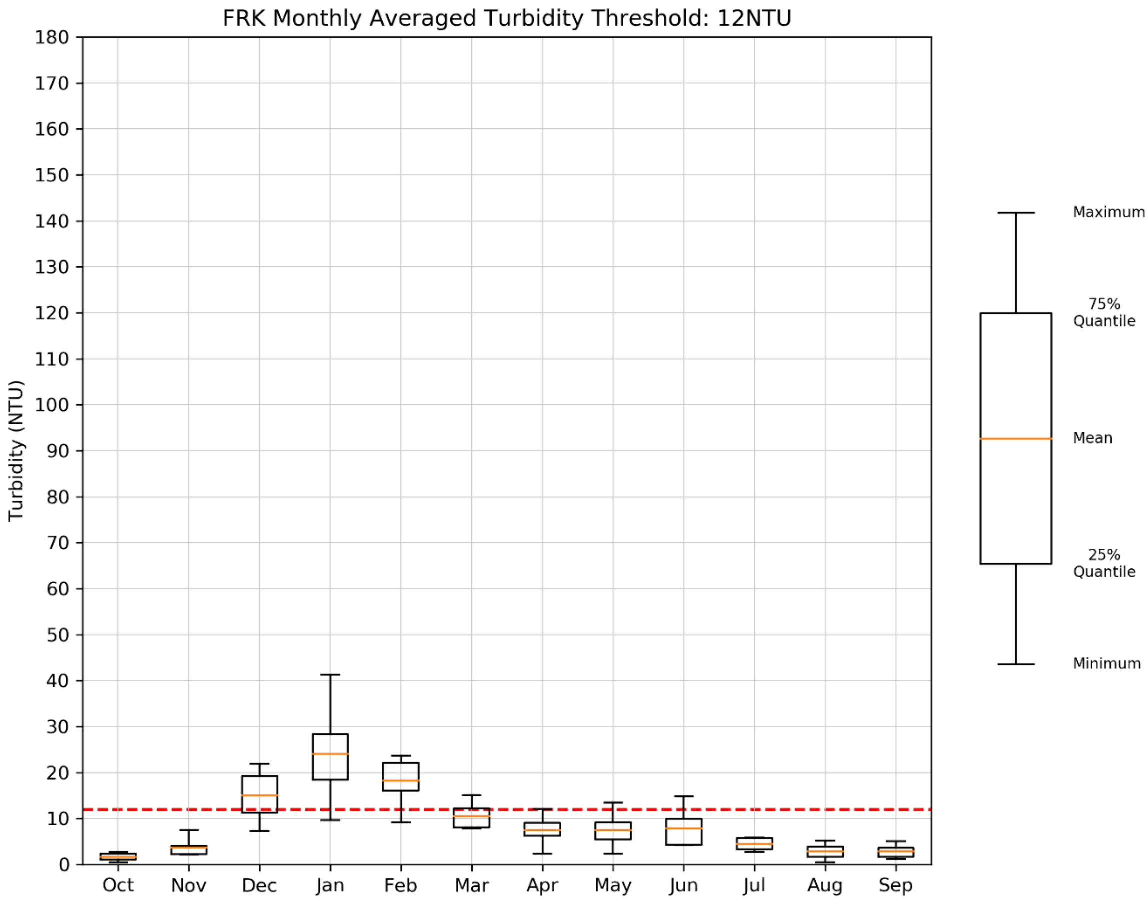

Figure C-151. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station FRK –San Joaquin River Frank's Tract Mid Tract

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

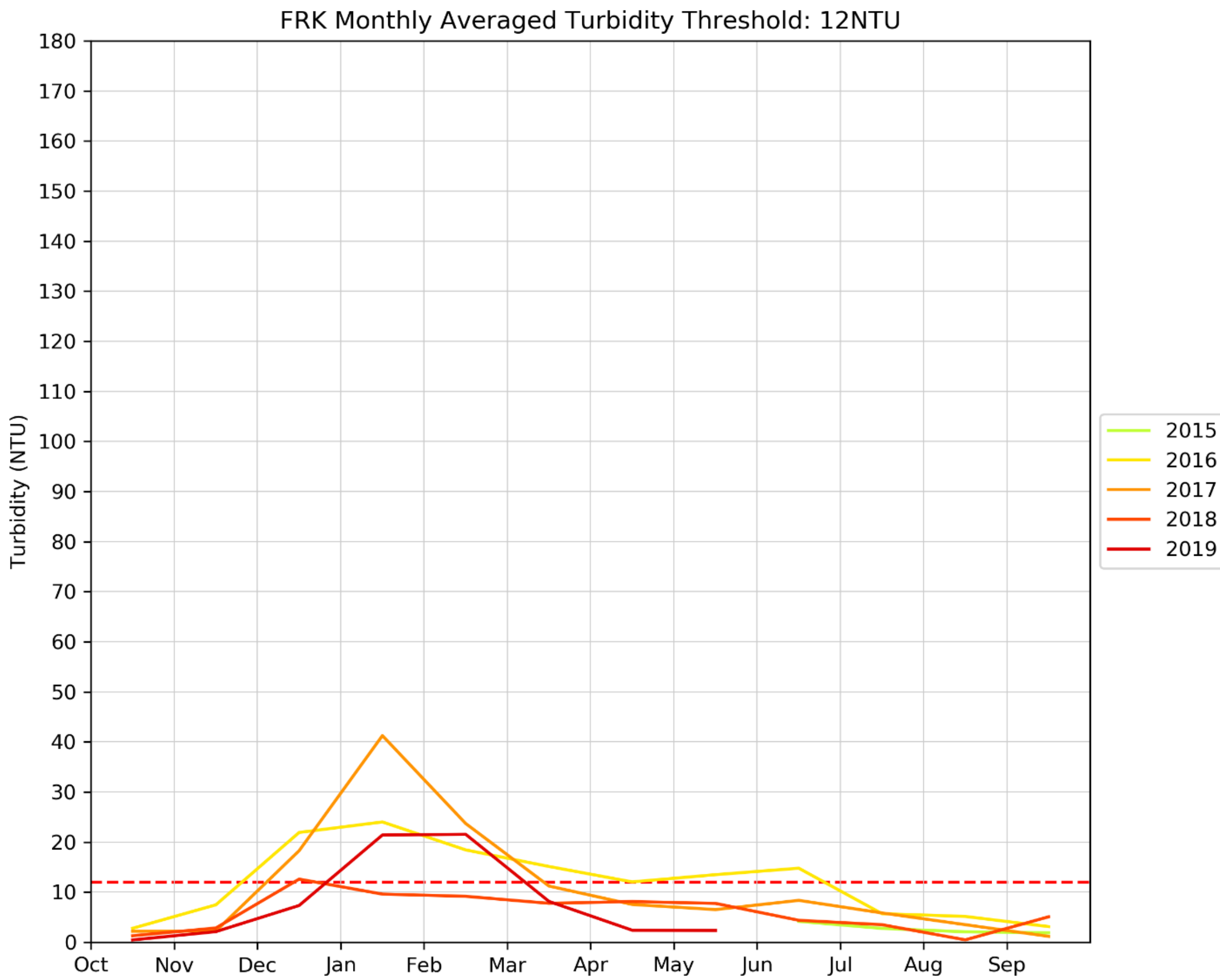

Figure C-152. Monthly Average Turbidity for the Period of Record at Station FRK – San Joaquin River Frank's Tract Mid Tract

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

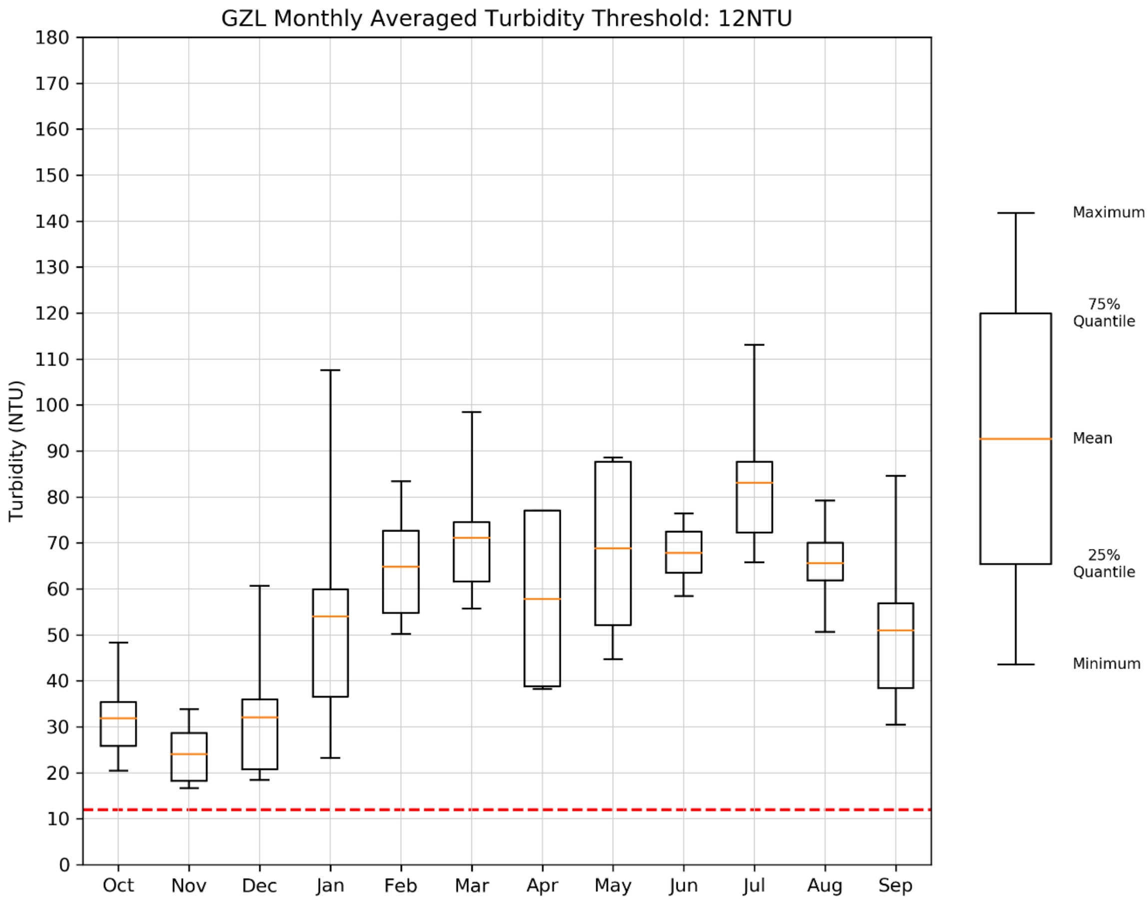

Figure C-153. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station GZL – Grizzly Bay

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

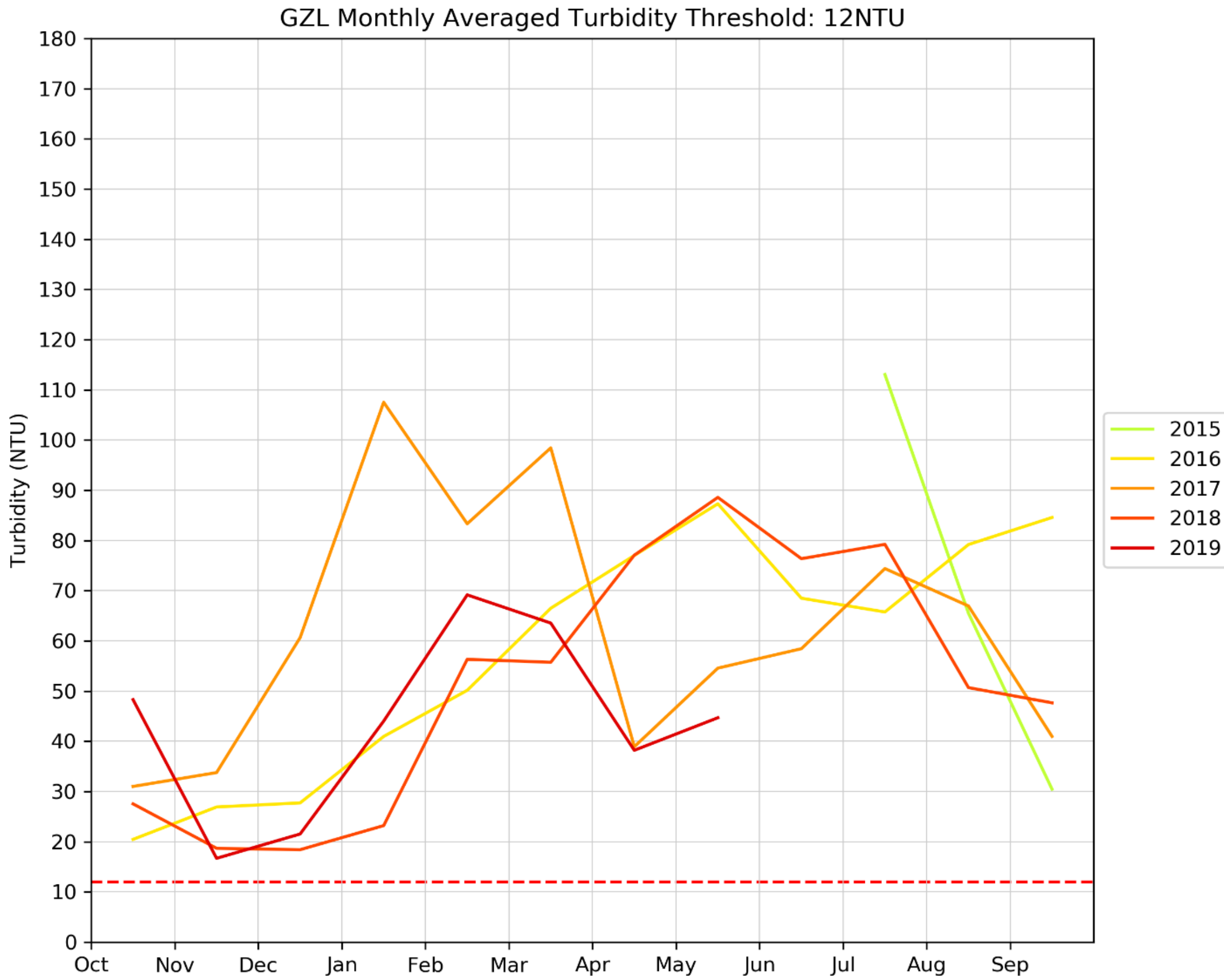

Figure C-154. Monthly Average Turbidity for the Period of Record at Station GZL – Grizzly Bay

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

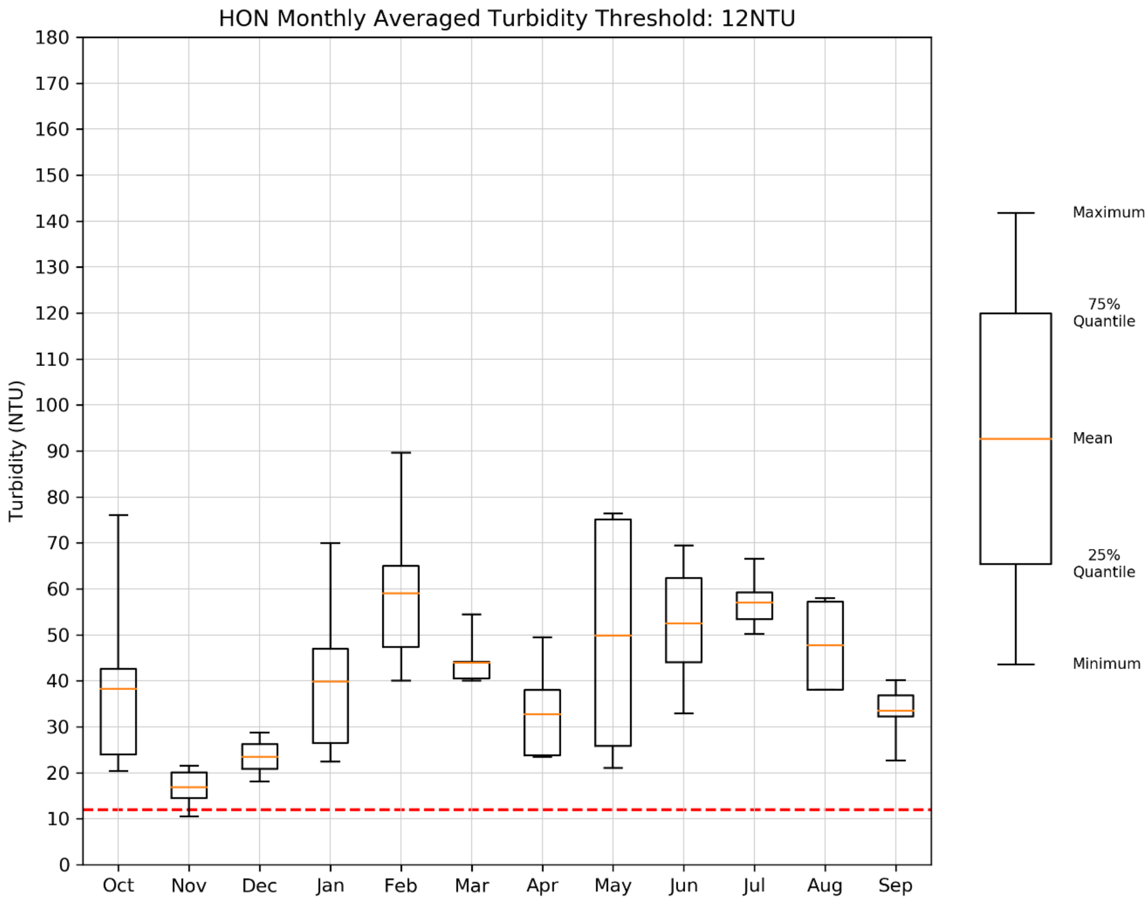

Figure C-155. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station HON – Honker Bay

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

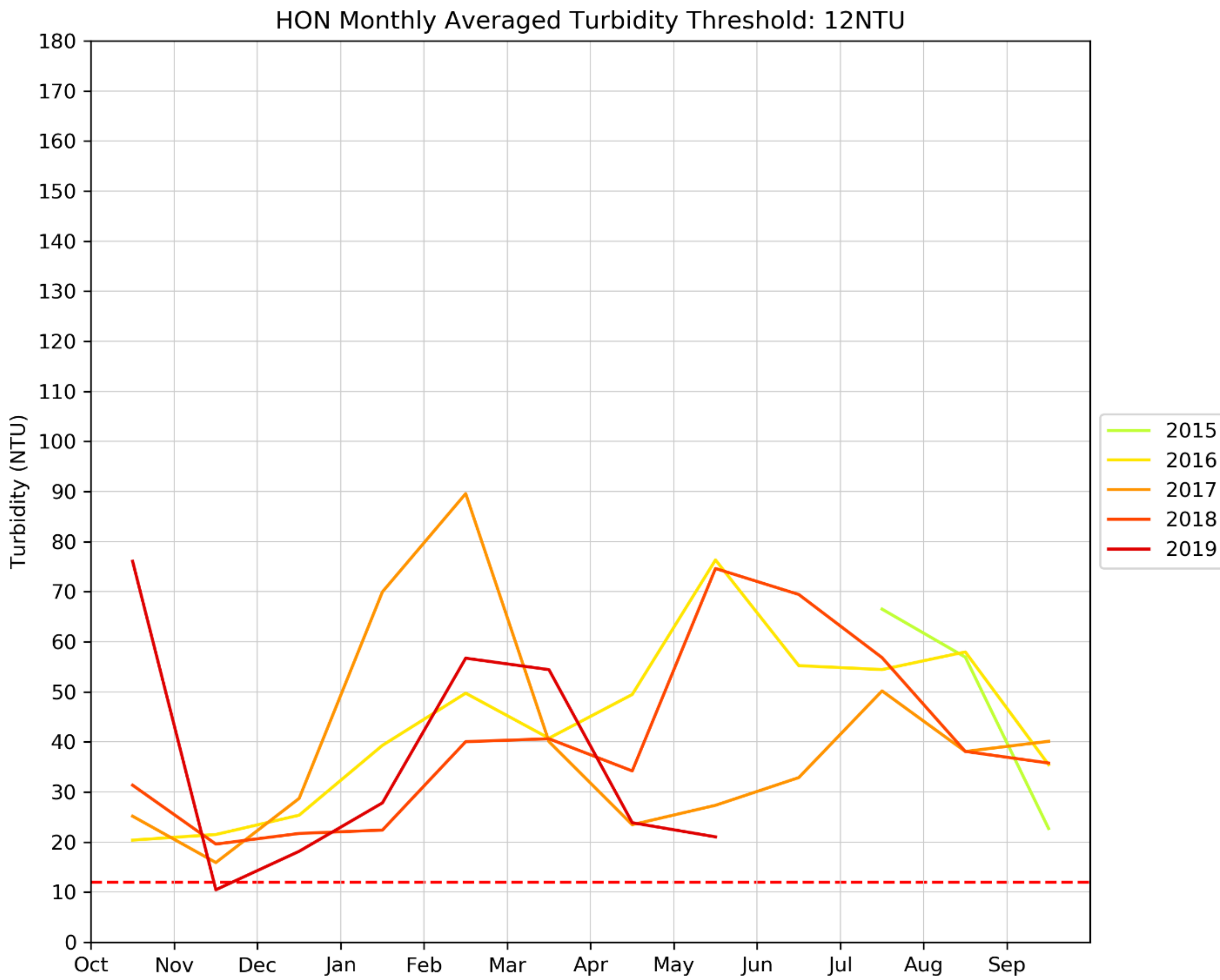

Figure C-156. Monthly Average Turbidity for the Period of Record at Station HON – Honker Bay

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

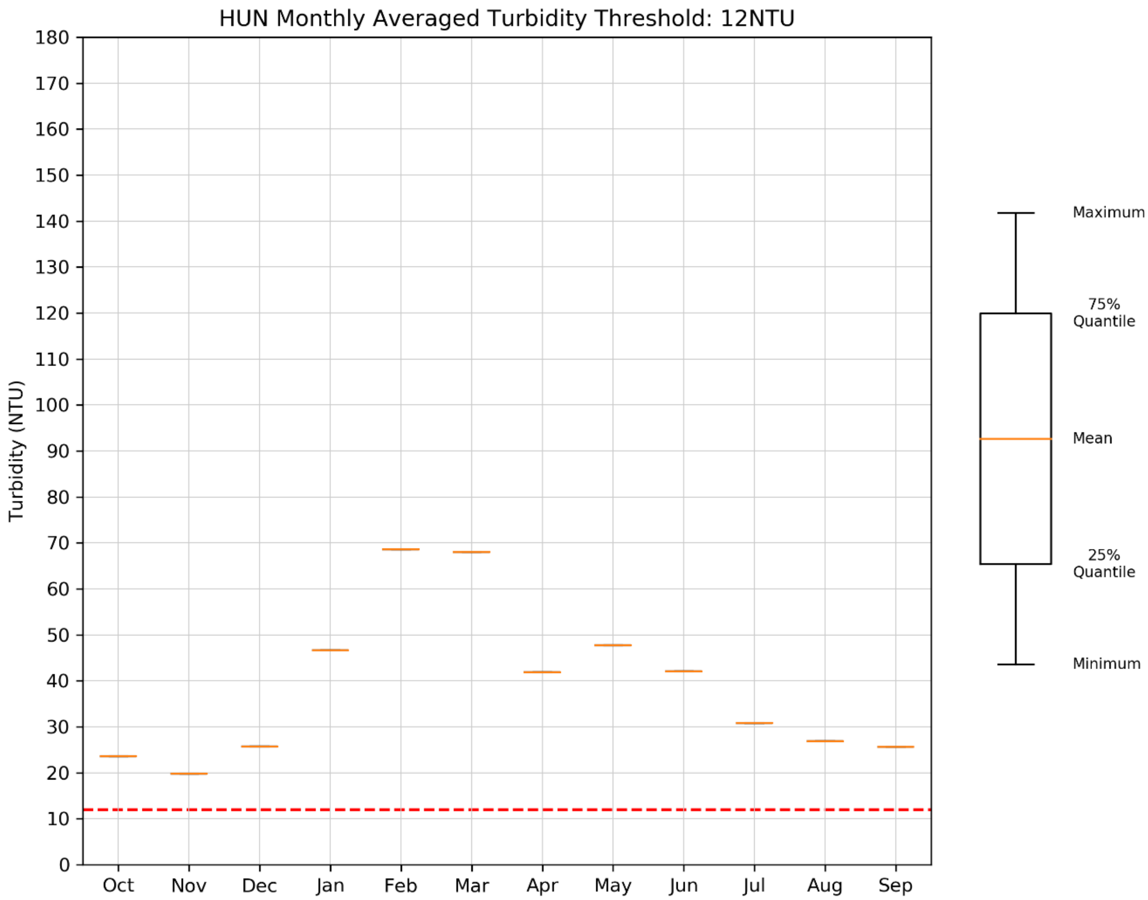

Figure C-157. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station HUN – Hunter Cut at Montezuma Slough

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

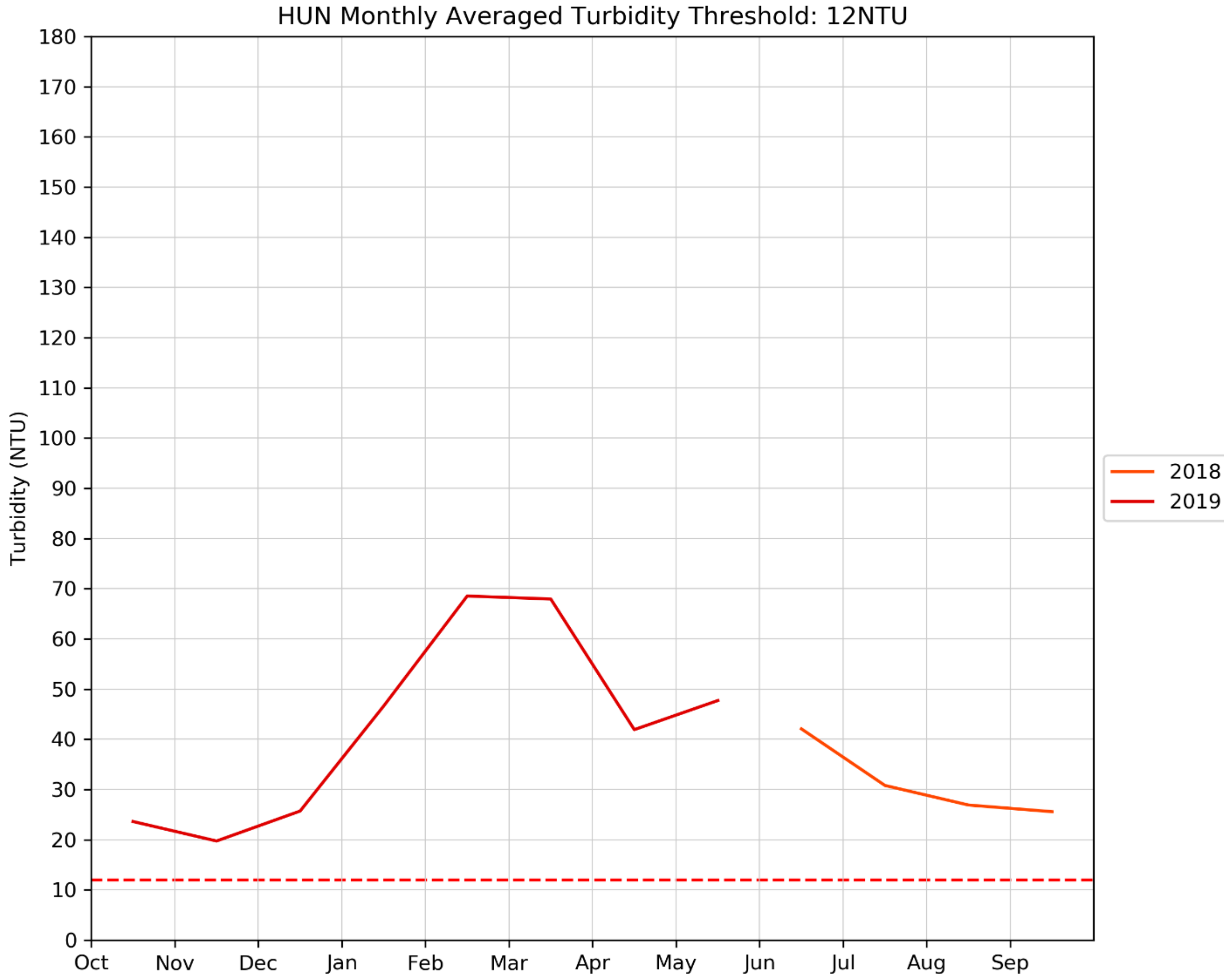

Figure C-158. Monthly Average Turbidity for the Period of Record at Station HUN – Hunter Cut at Montezuma Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

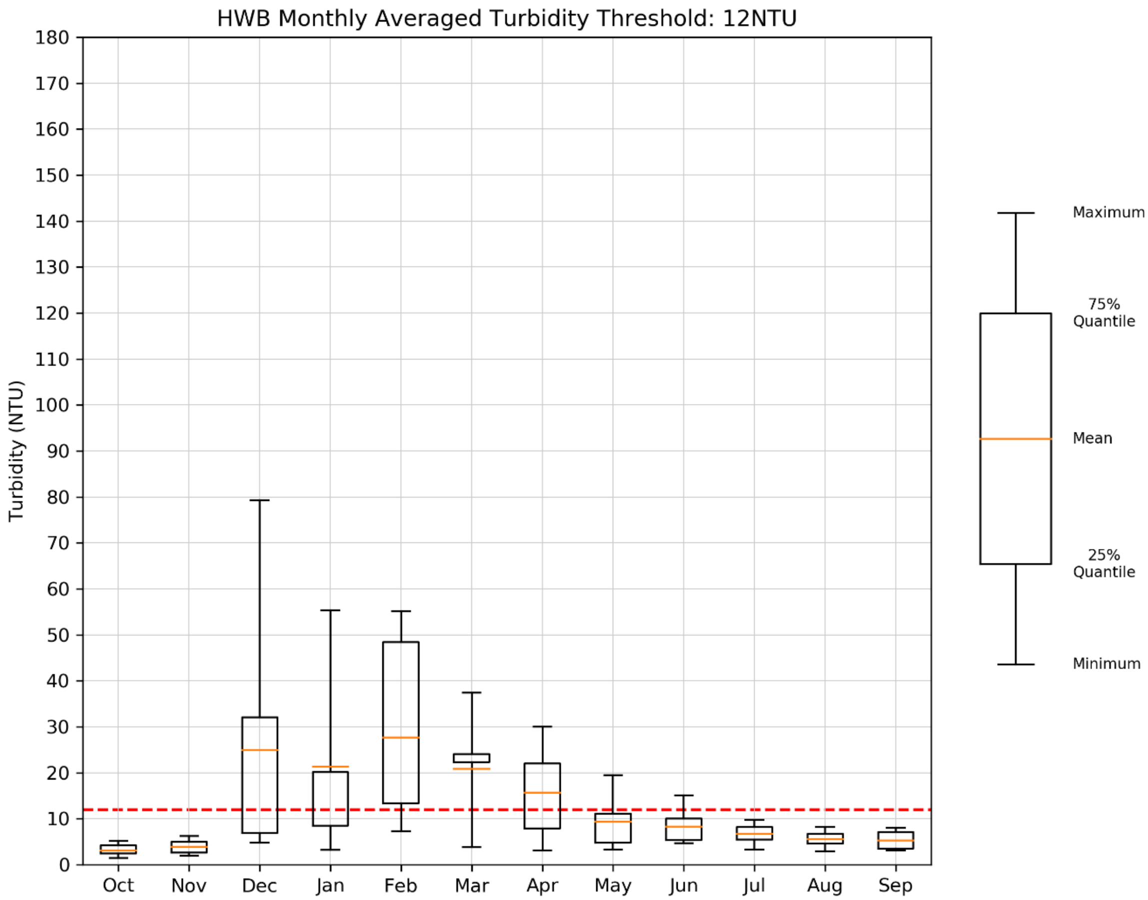

Figure C-159. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station HWB – Miner Slough at Highway 84 Bridge

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

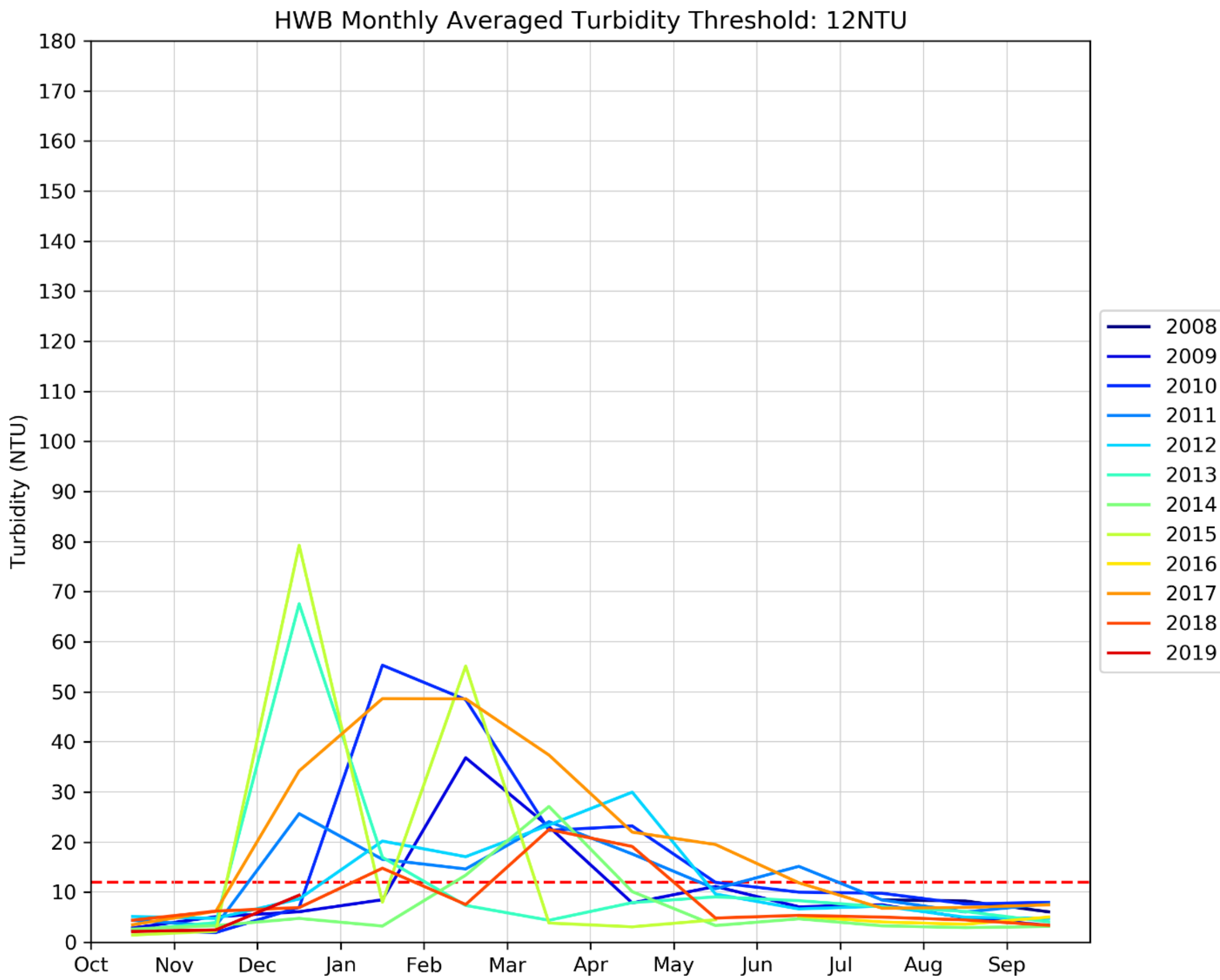

Figure C-160. Monthly Average Turbidity for the Period of Record at Station HWB – Miner Slough at Highway 84 Bridge

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

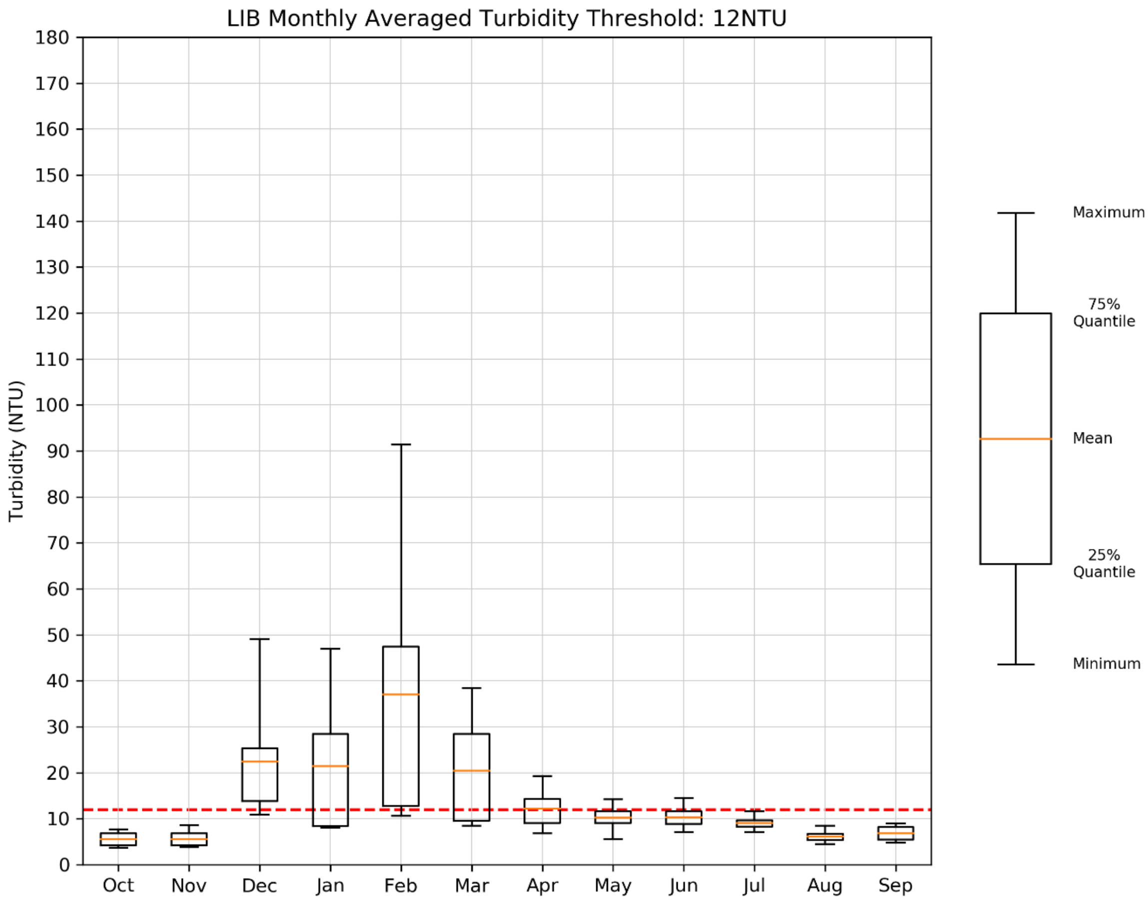

Figure C-161. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station LIB – Liberty Island at Approximately Center South End

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

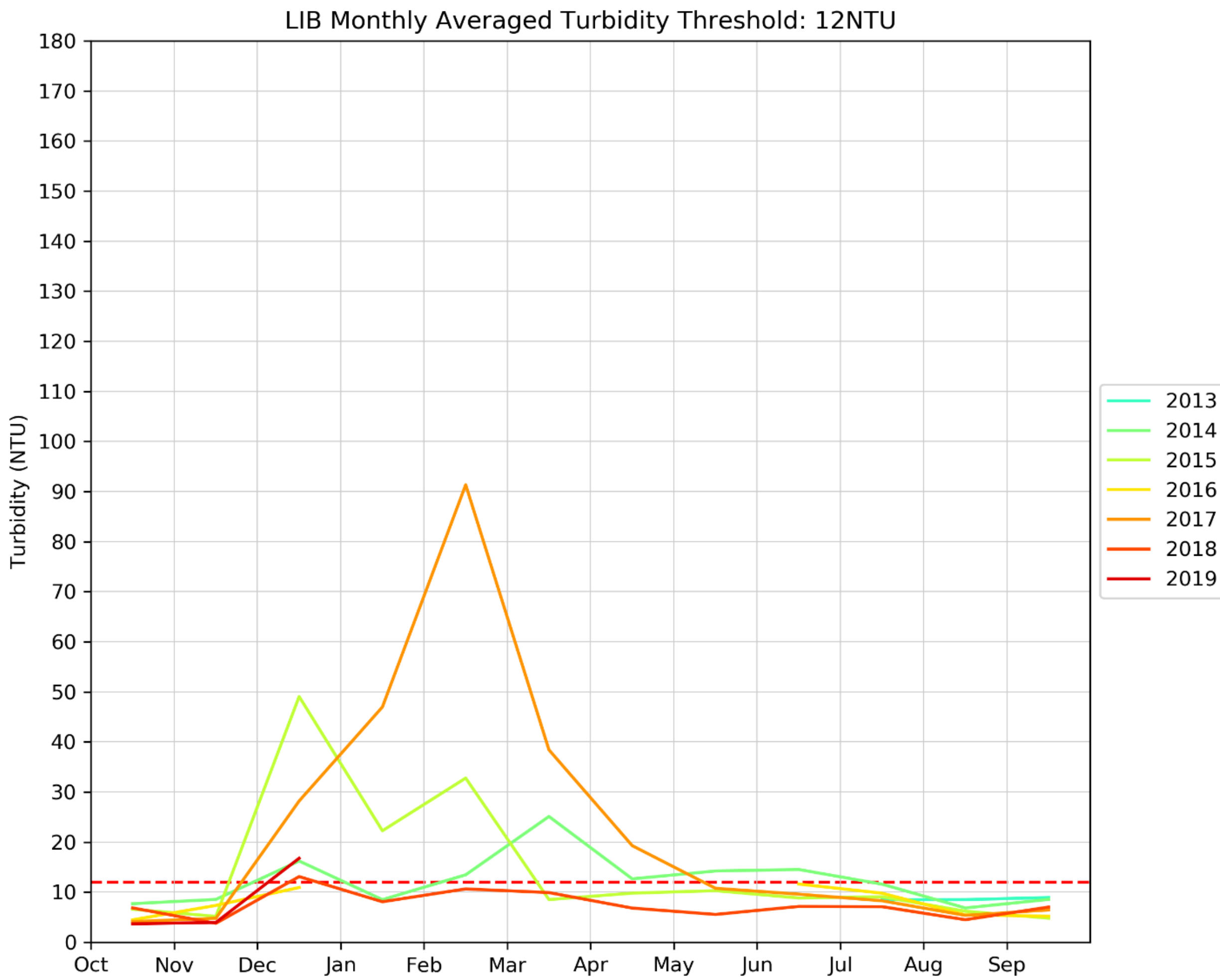

Figure C-162. Monthly Average Turbidity for the Period of Record at Station LIB –Liberty Island at Approximately Center South End

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

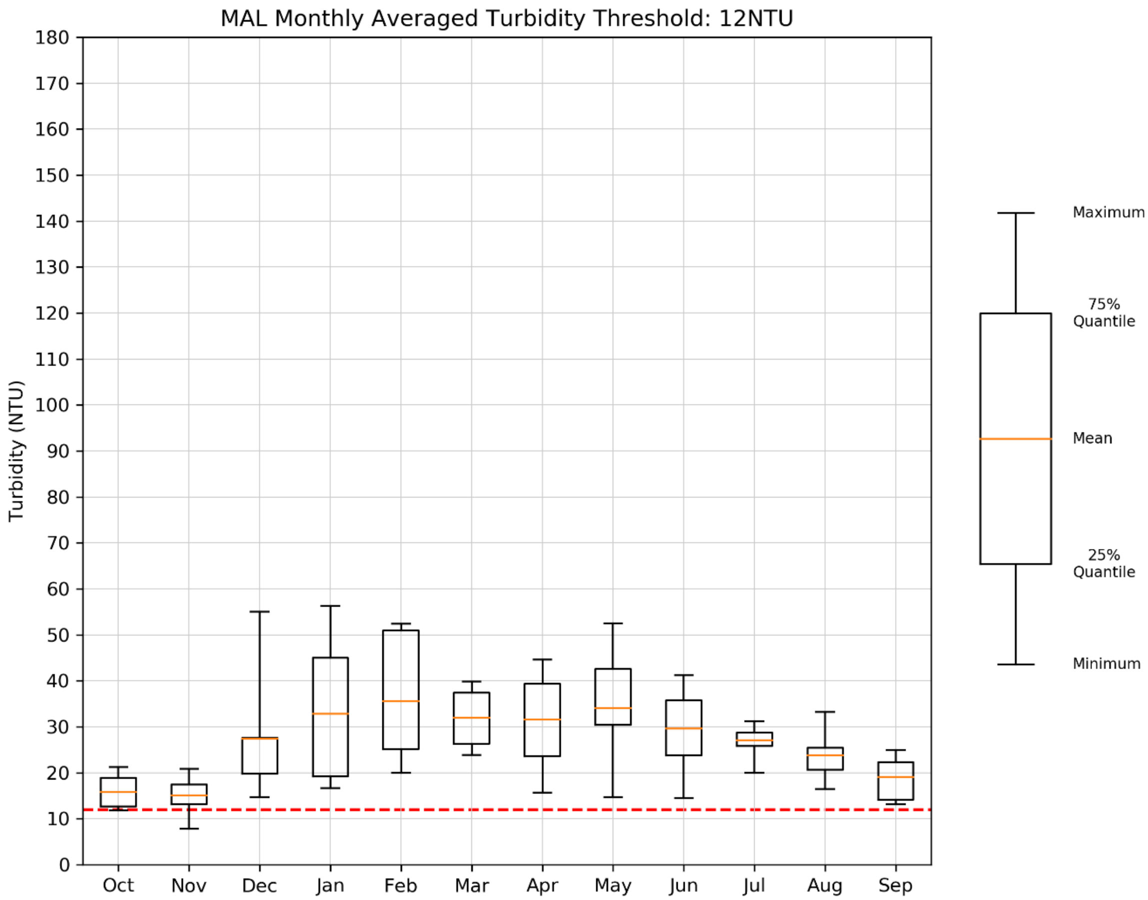

Figure C-163. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station MAL – Sacramento River at Mallard Island

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

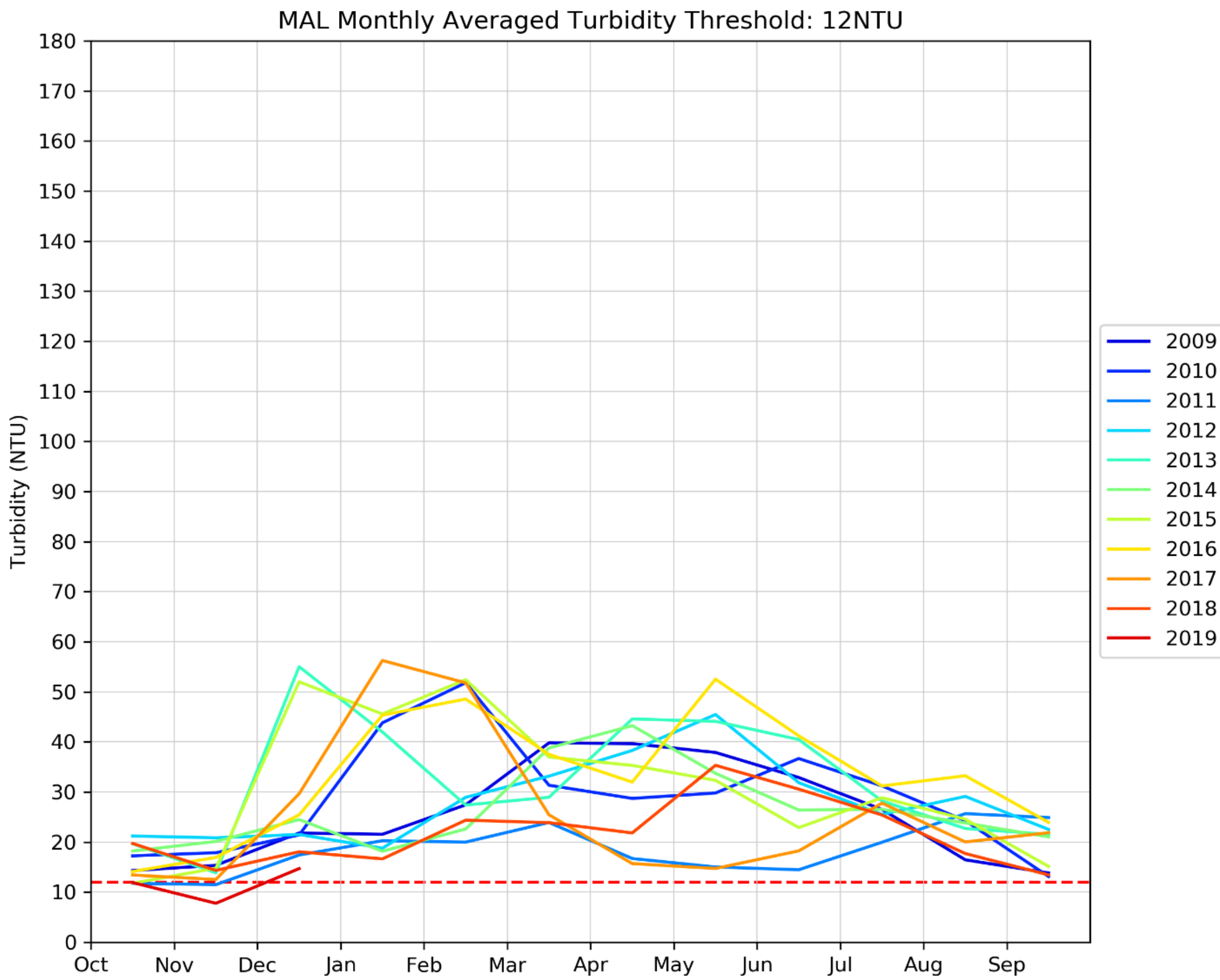

Figure C-164. Monthly Average Turbidity for the Period of Record at Station MAL – Sacramento River at Mallard Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

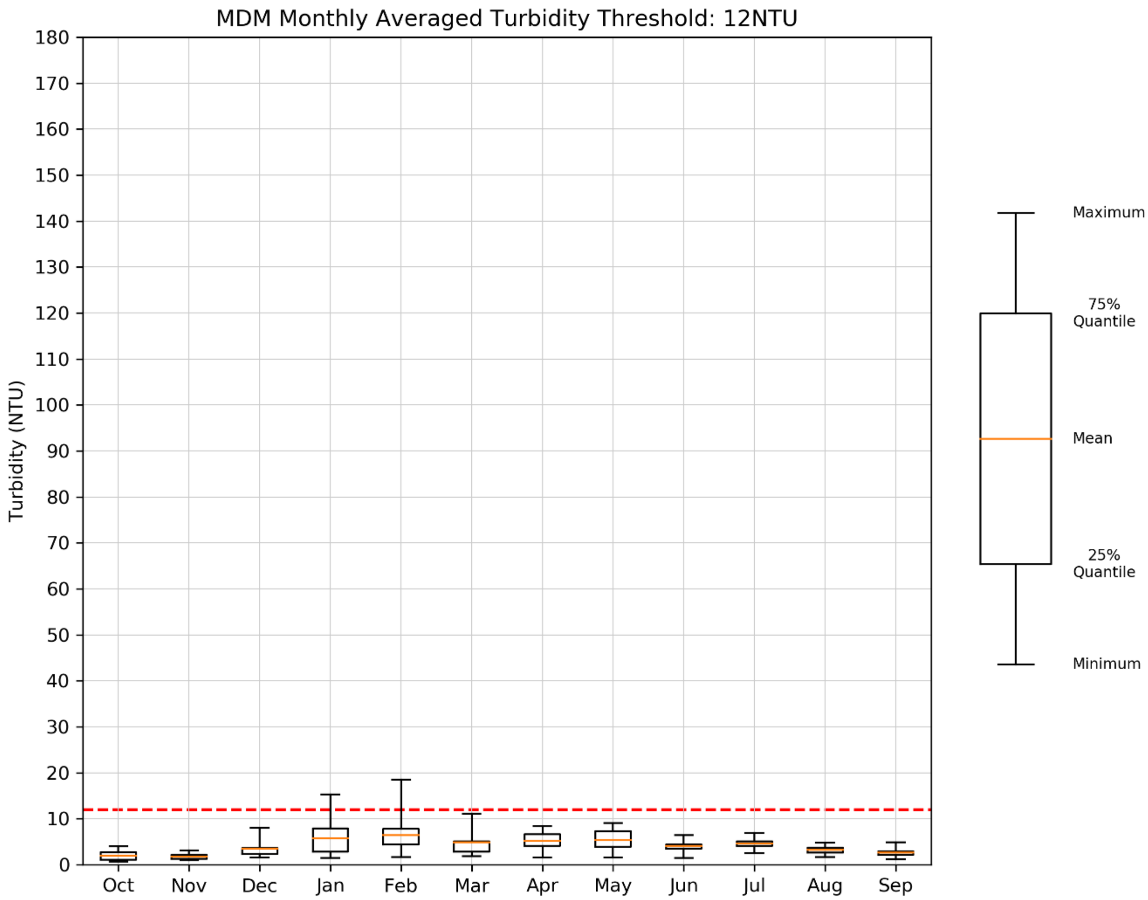

Figure C-165. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station MDM –- Middle River at Middle River

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

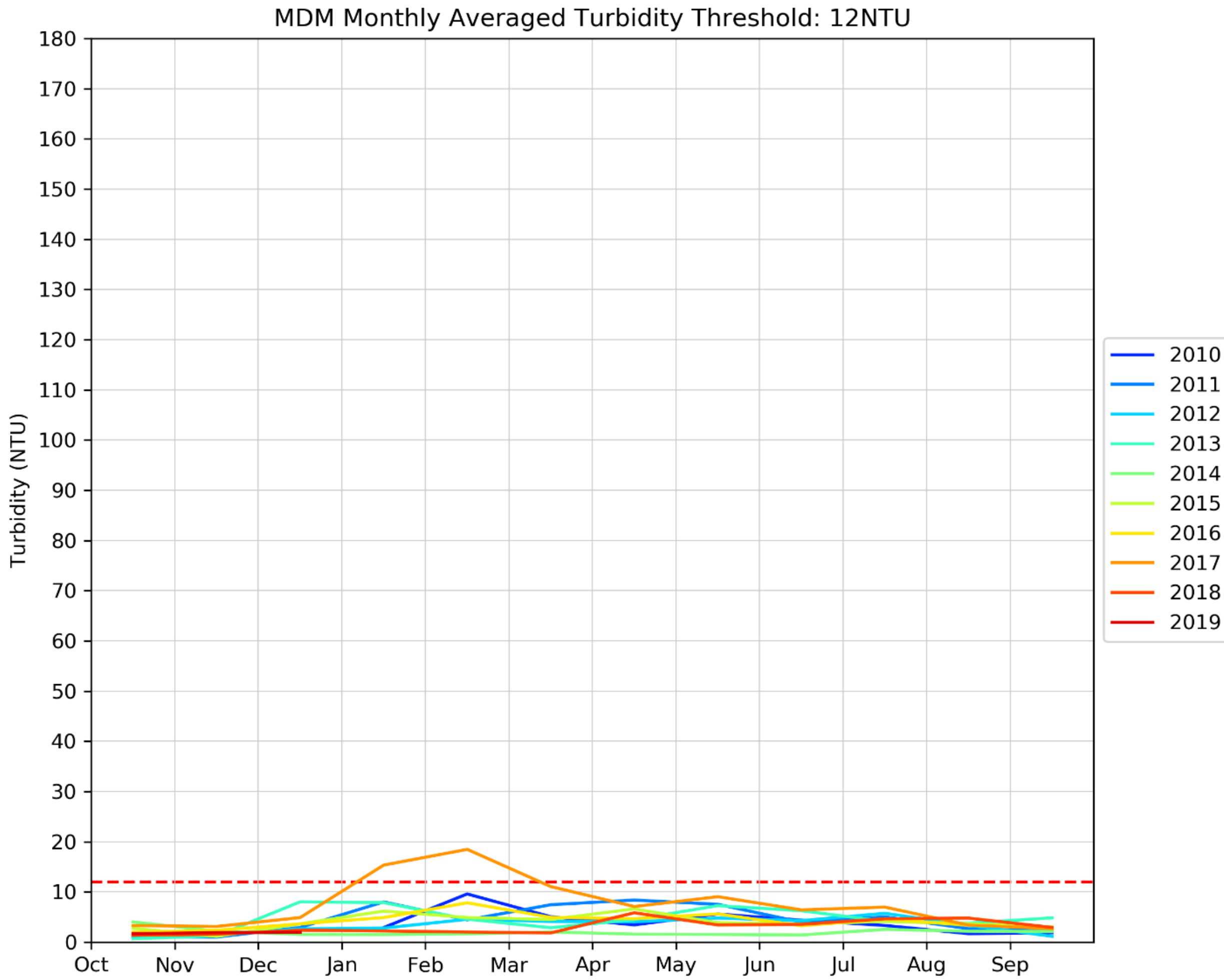

Figure C-166. Monthly Average Turbidity for the Period of Record at Station MDM – Middle River at Middle River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

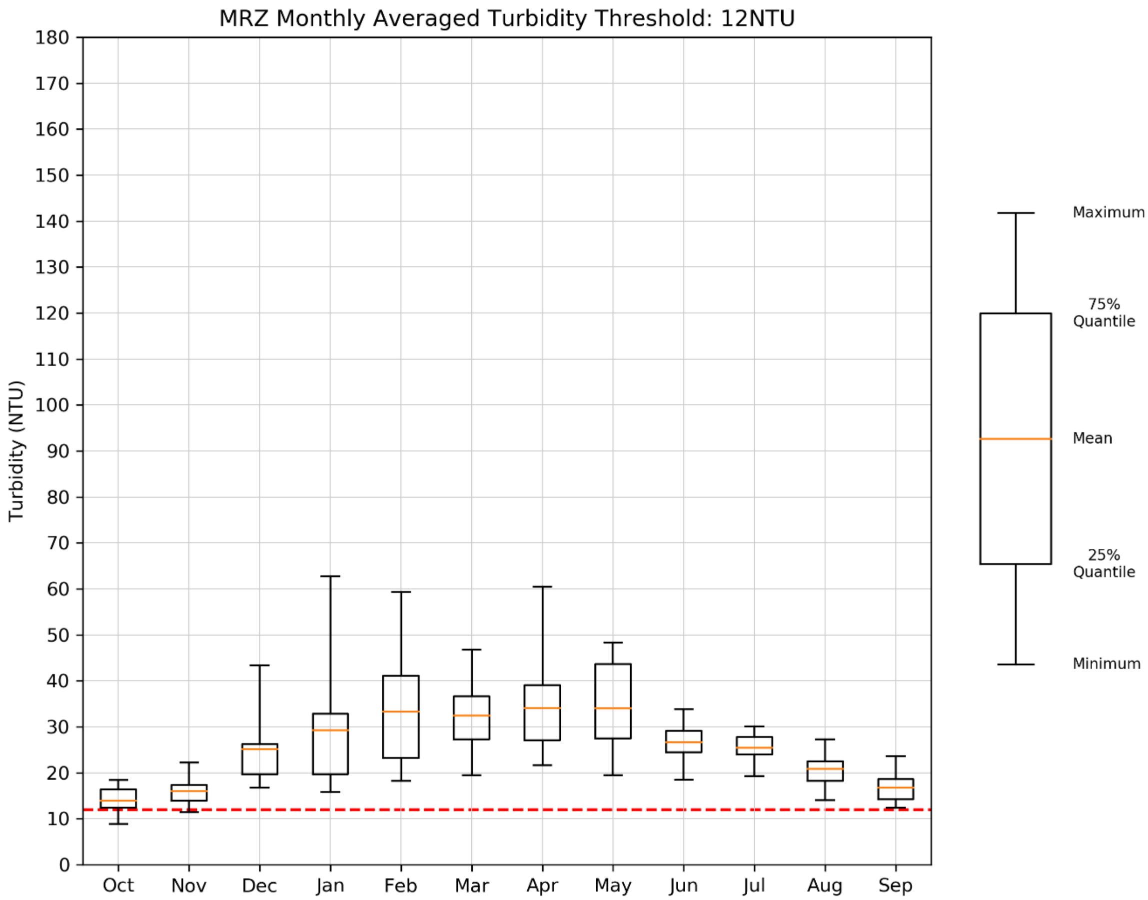

Figure C-167. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station MRZ – Martinez

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

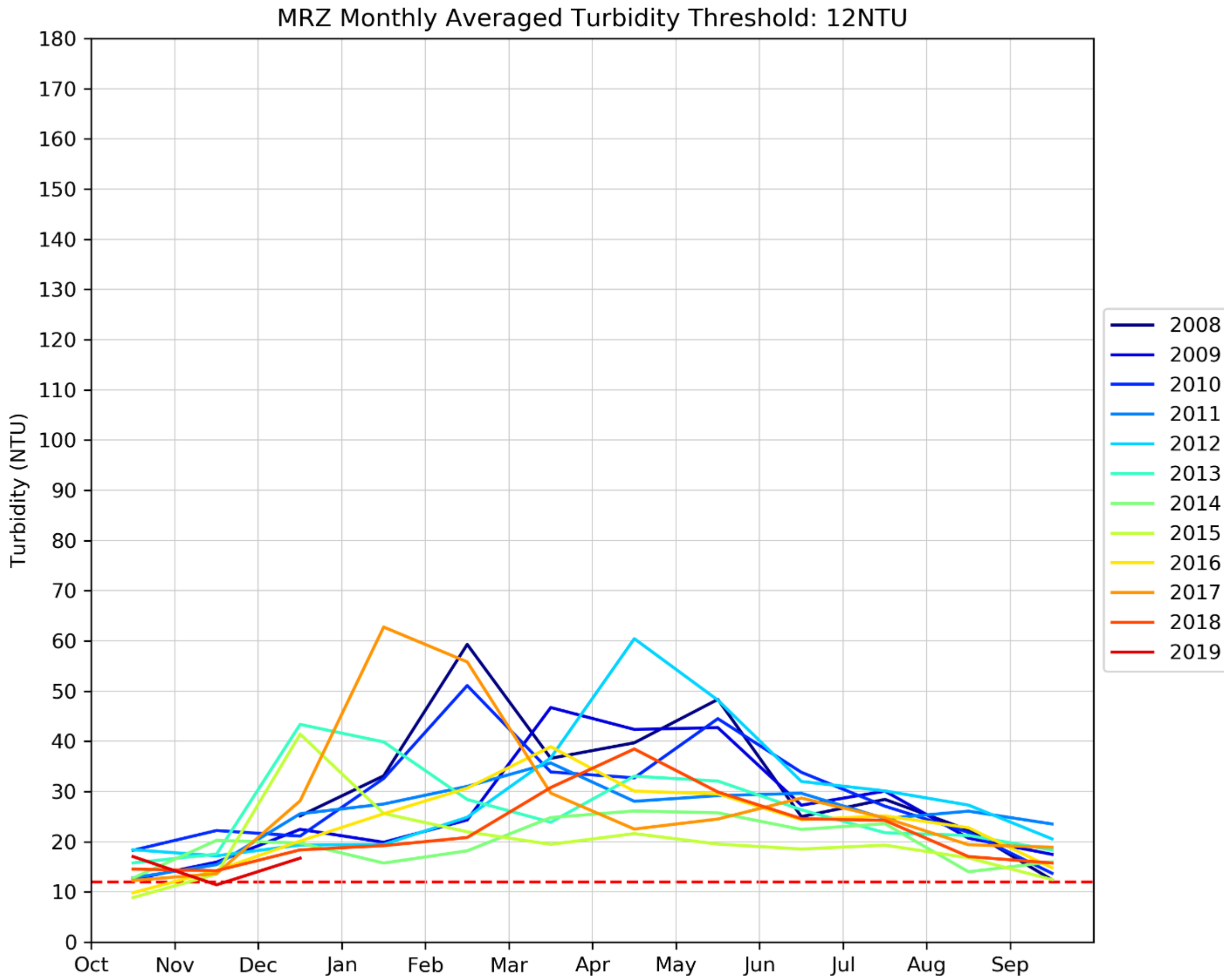

Figure C-168. Monthly Average Turbidity for the Period of Record at Station MRZ – Martinez

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

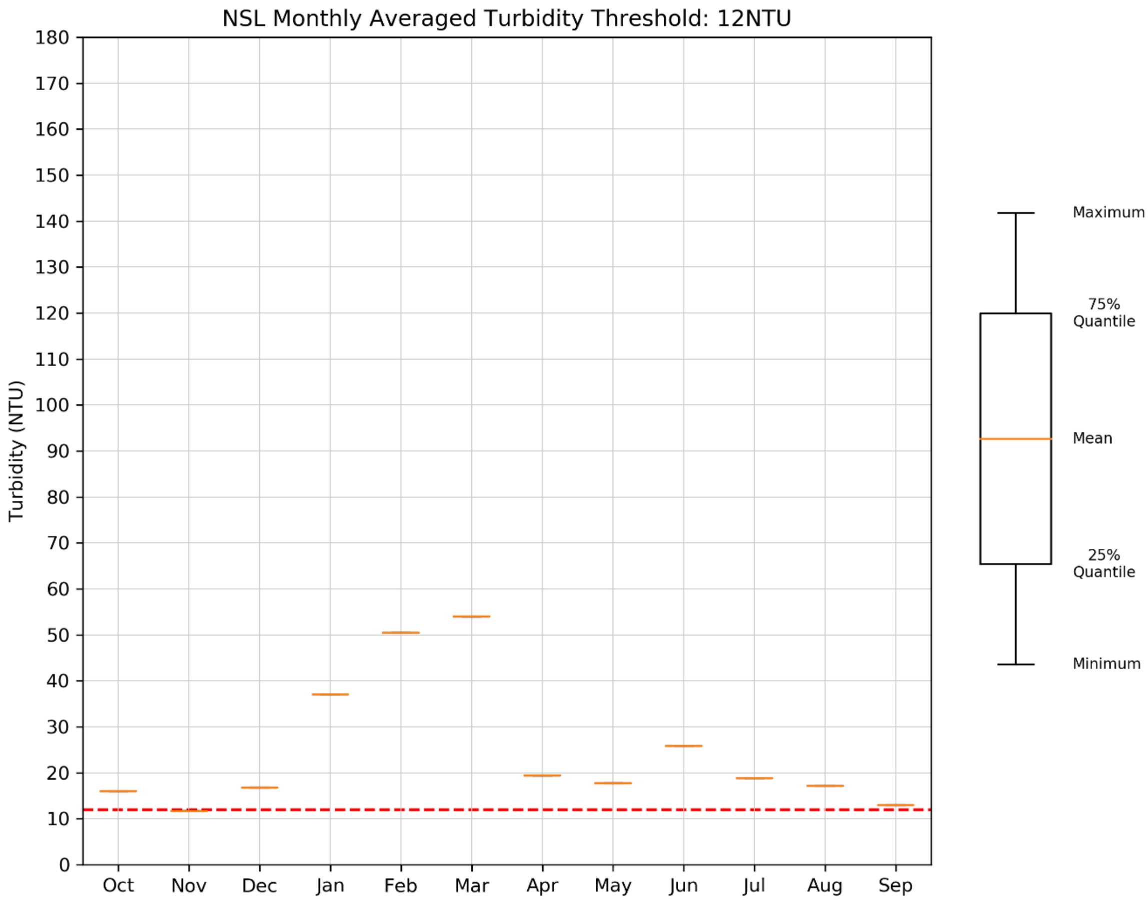

Figure C-169. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station NSL – Montezuma Slough at National Steel

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

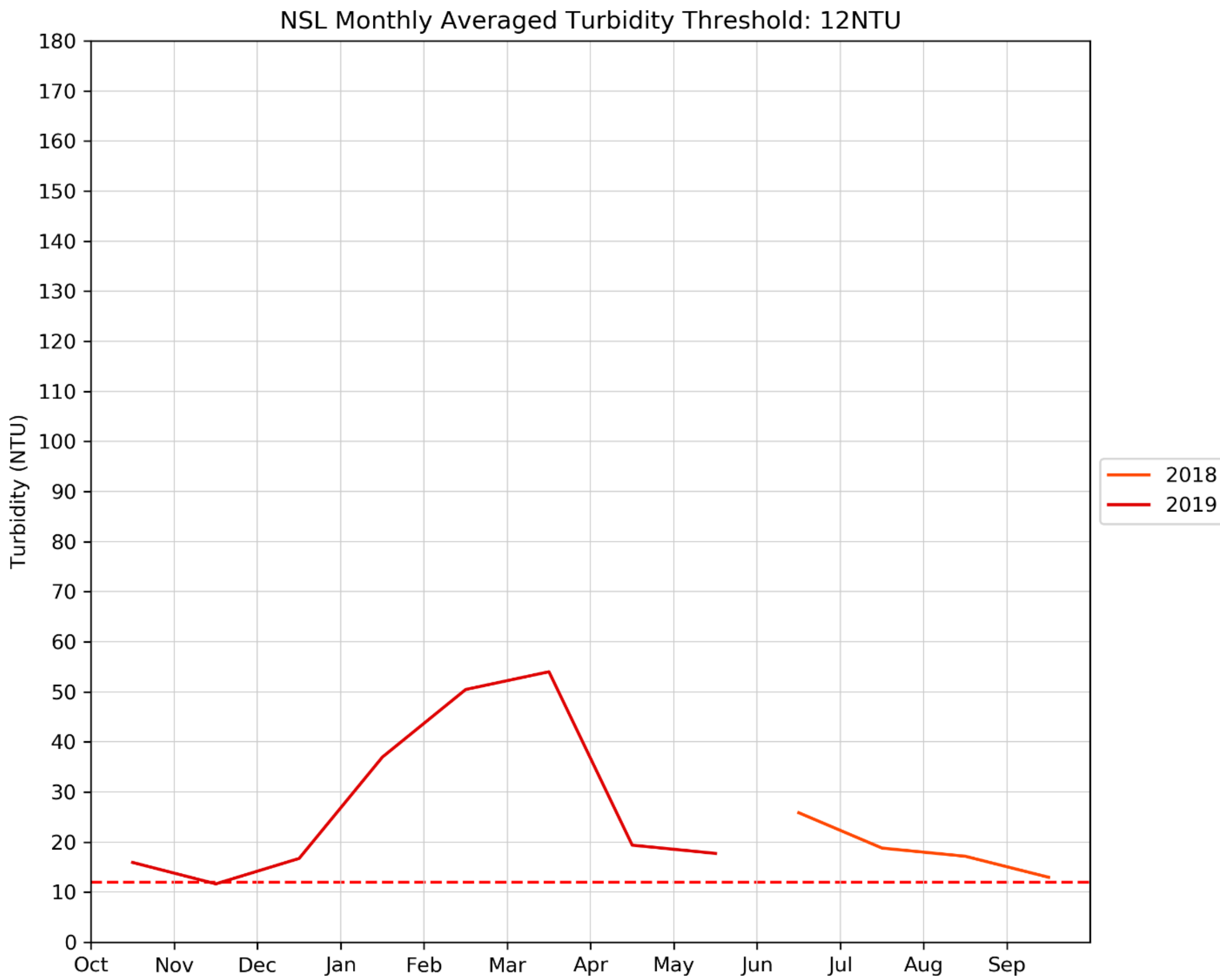

Figure C-170. Monthly Average Turbidity for the Period of Record at Station NSL – Montezuma Slough at National Steel

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

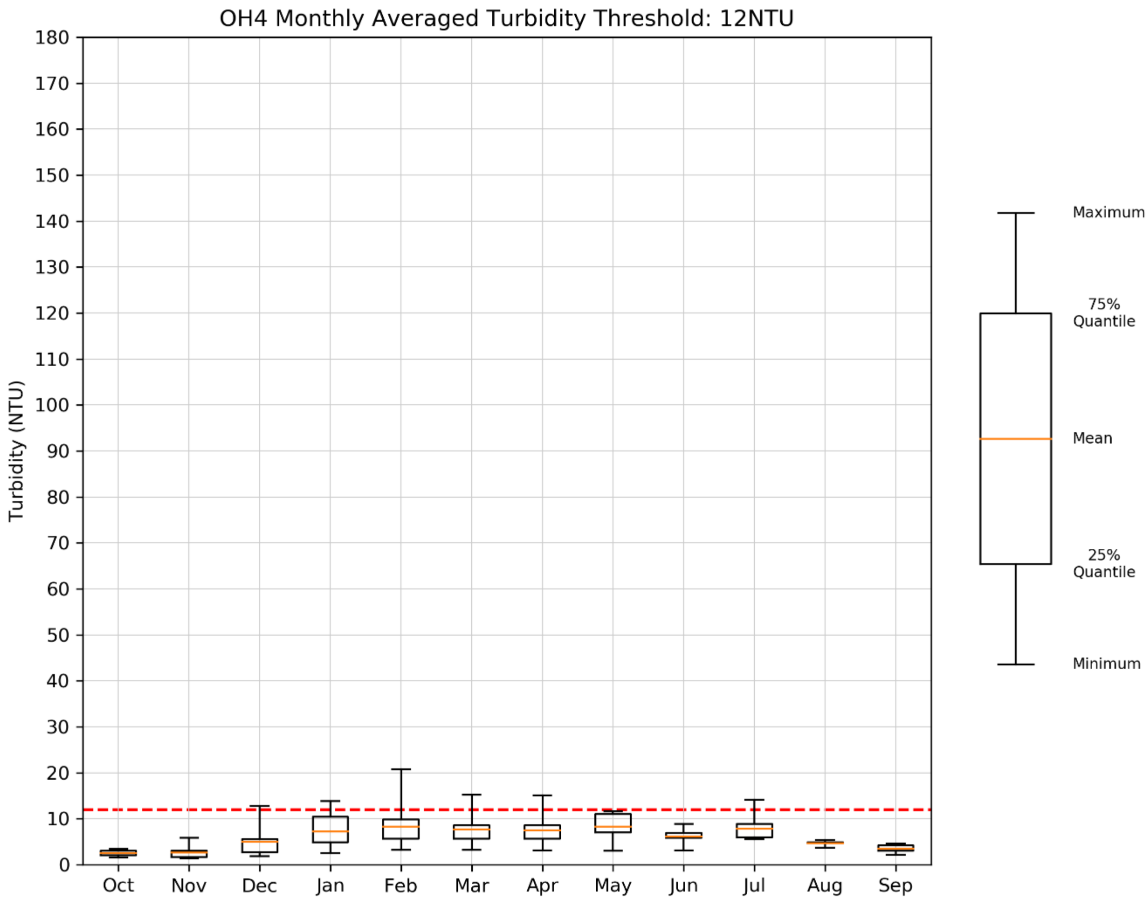

Figure C-171. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station OH4 – Old River at Highway 4

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

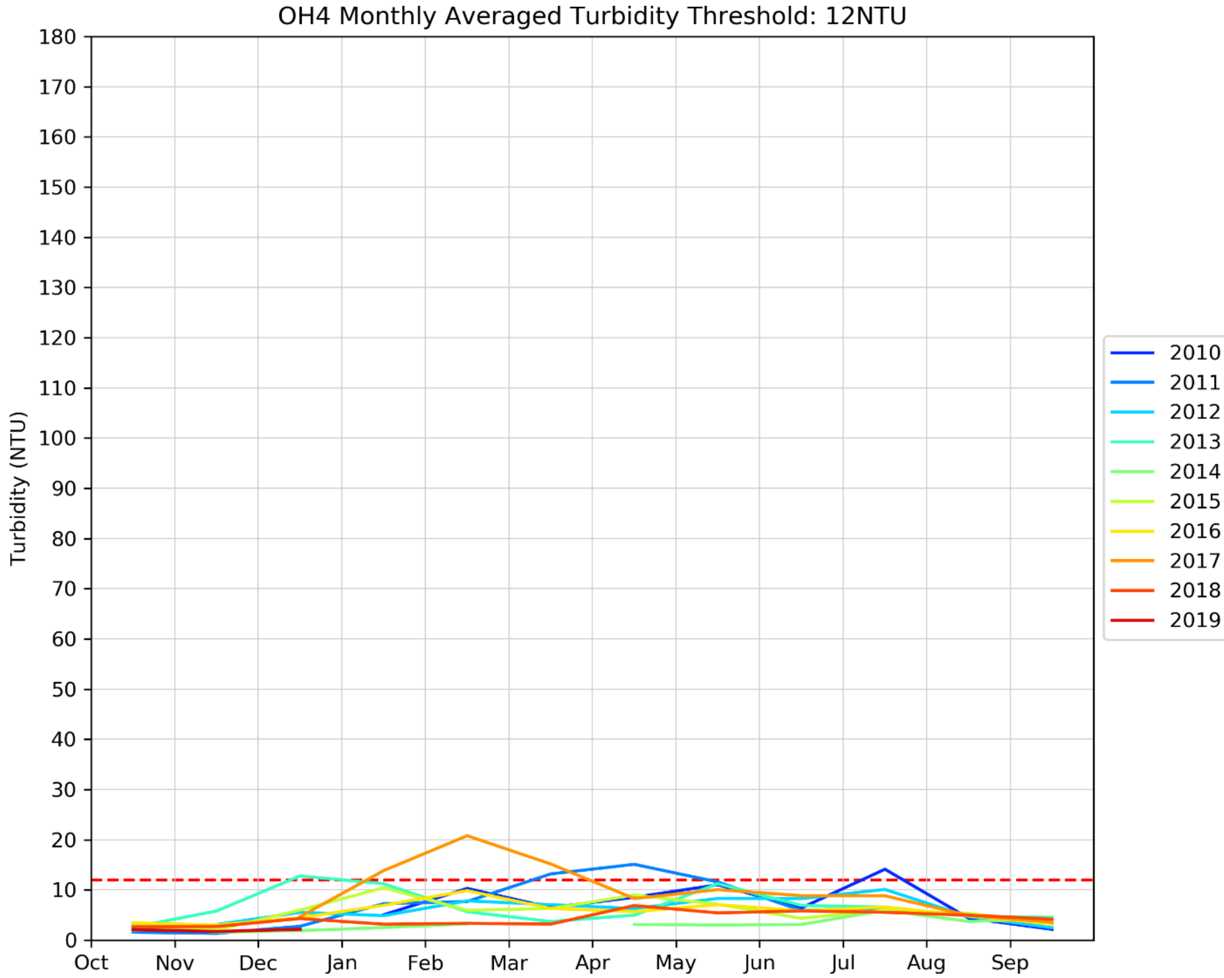

Figure C-172. Monthly Average Turbidity for the Period of Record at Station OH4 – Old River at Highway 4

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

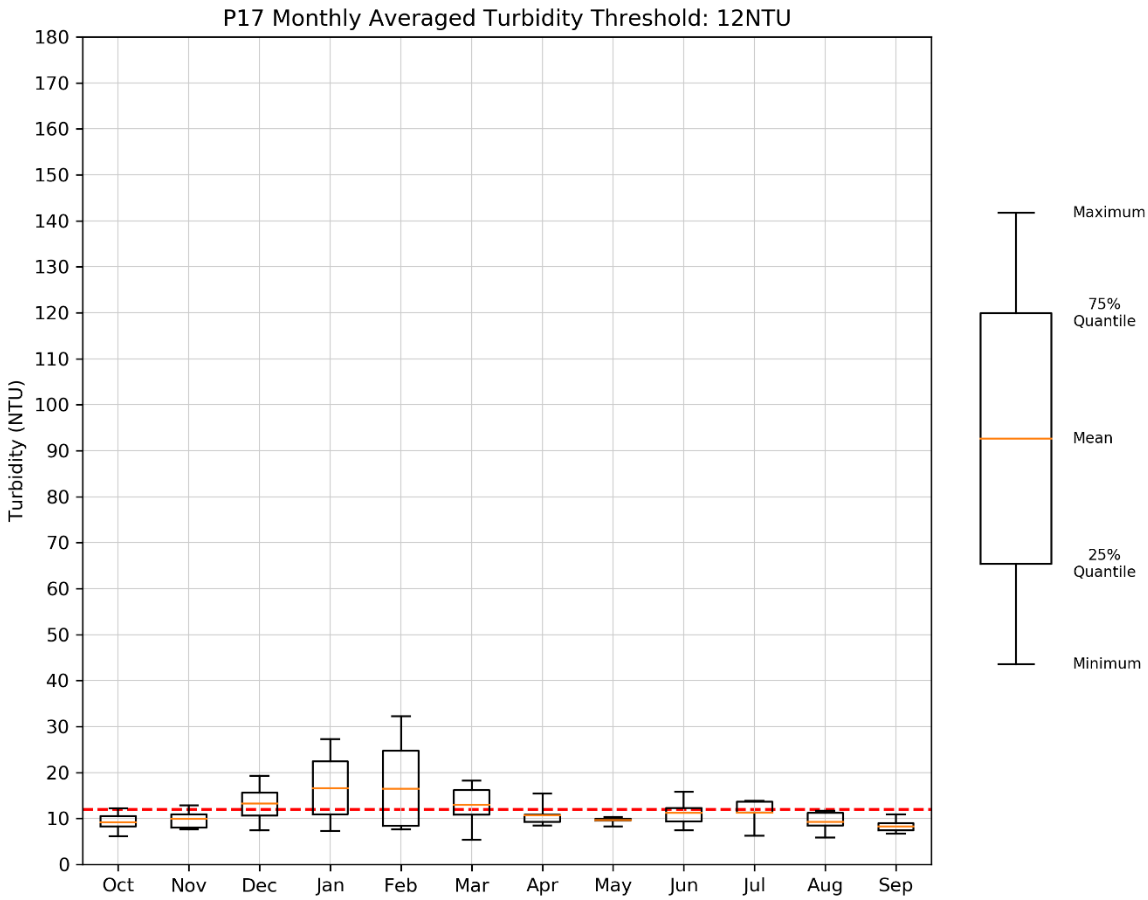

Figure C-173. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station P17 – Pier 17

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

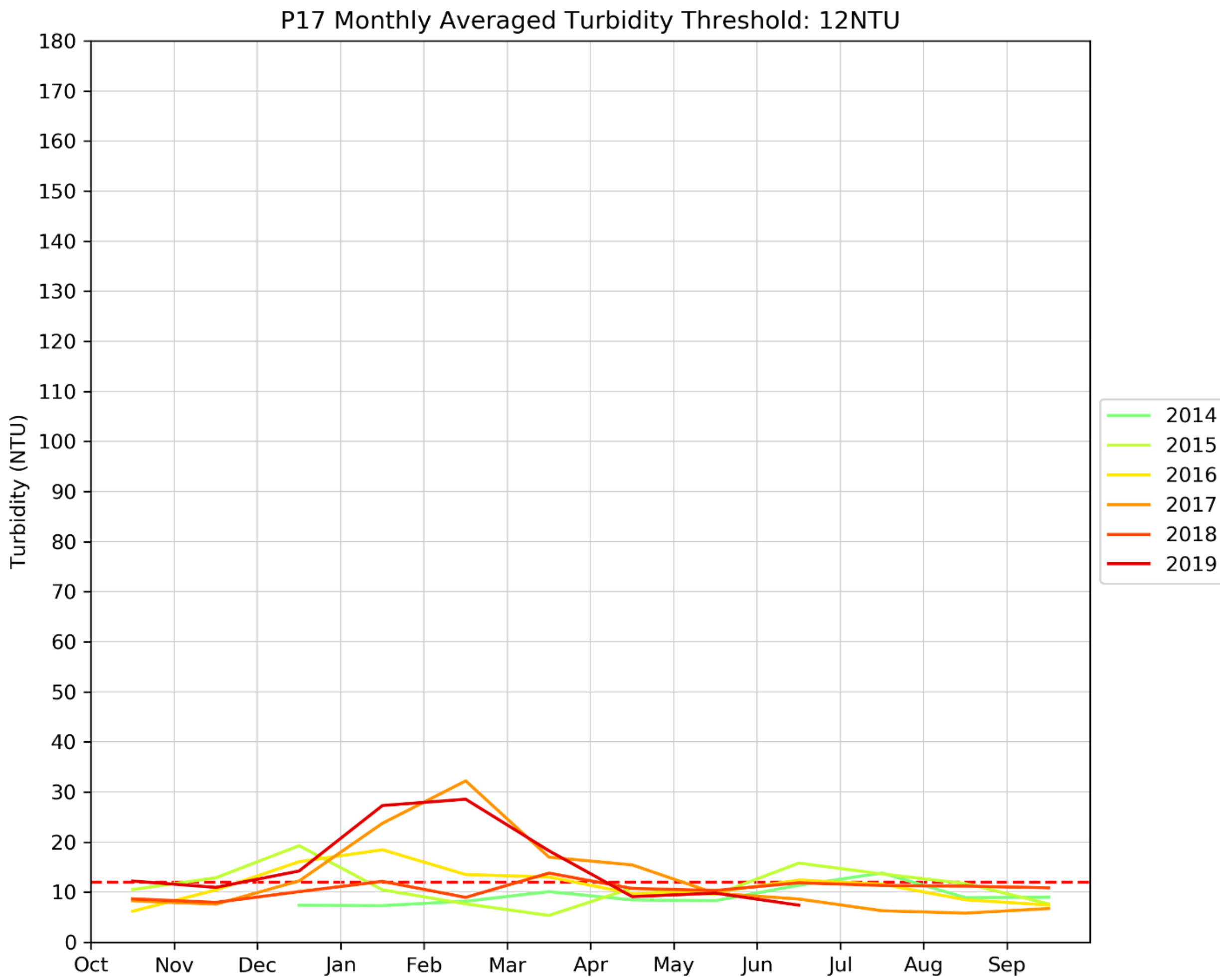

Figure C-174. Monthly Average Turbidity for the Period of Record at Station P17 – Pier 17

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

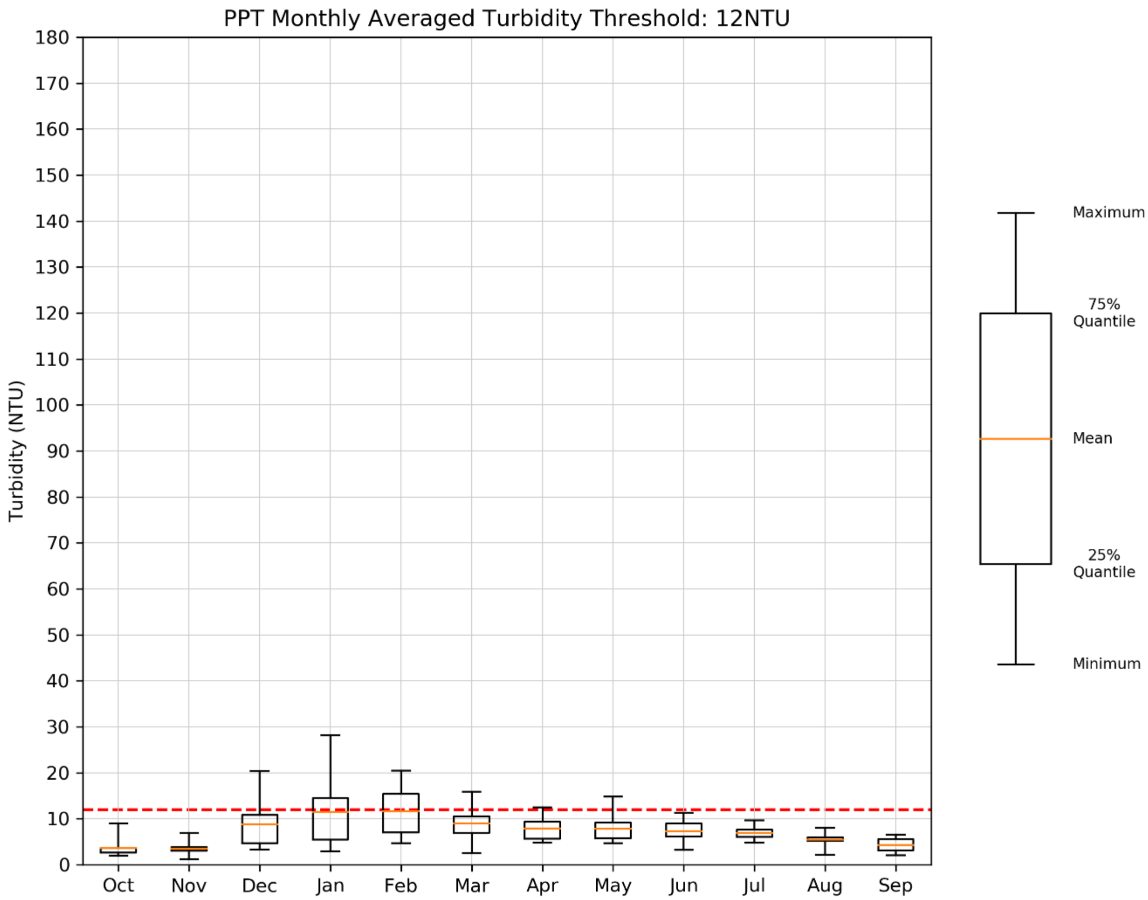

Figure C-175. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station PPT – San Joaquin River at Prisoners Point near Terminus

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

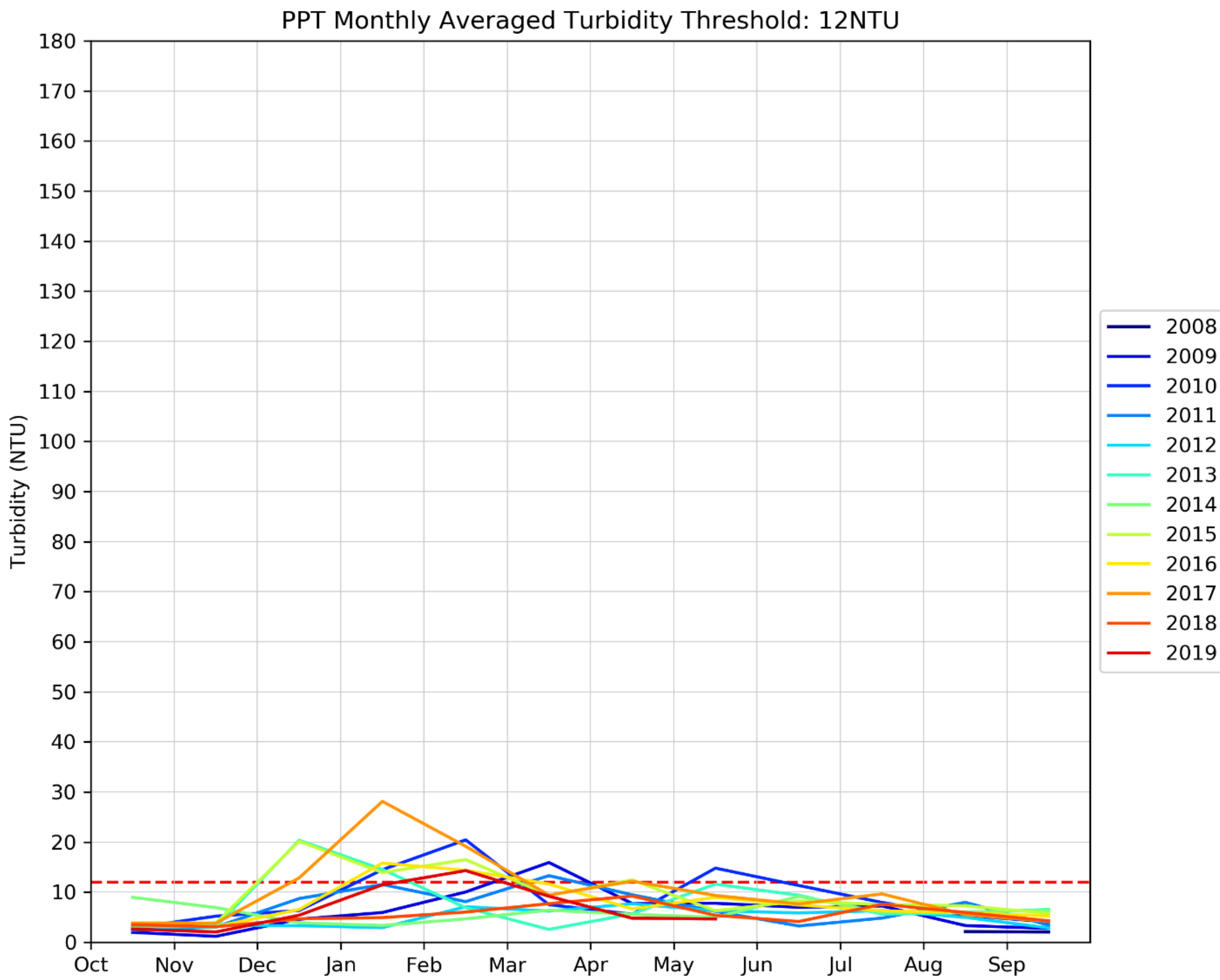

Figure C-176. Monthly Average Turbidity for the Period of Record at Station PPT – San Joaquin River at Prisoners Point near Terminus

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

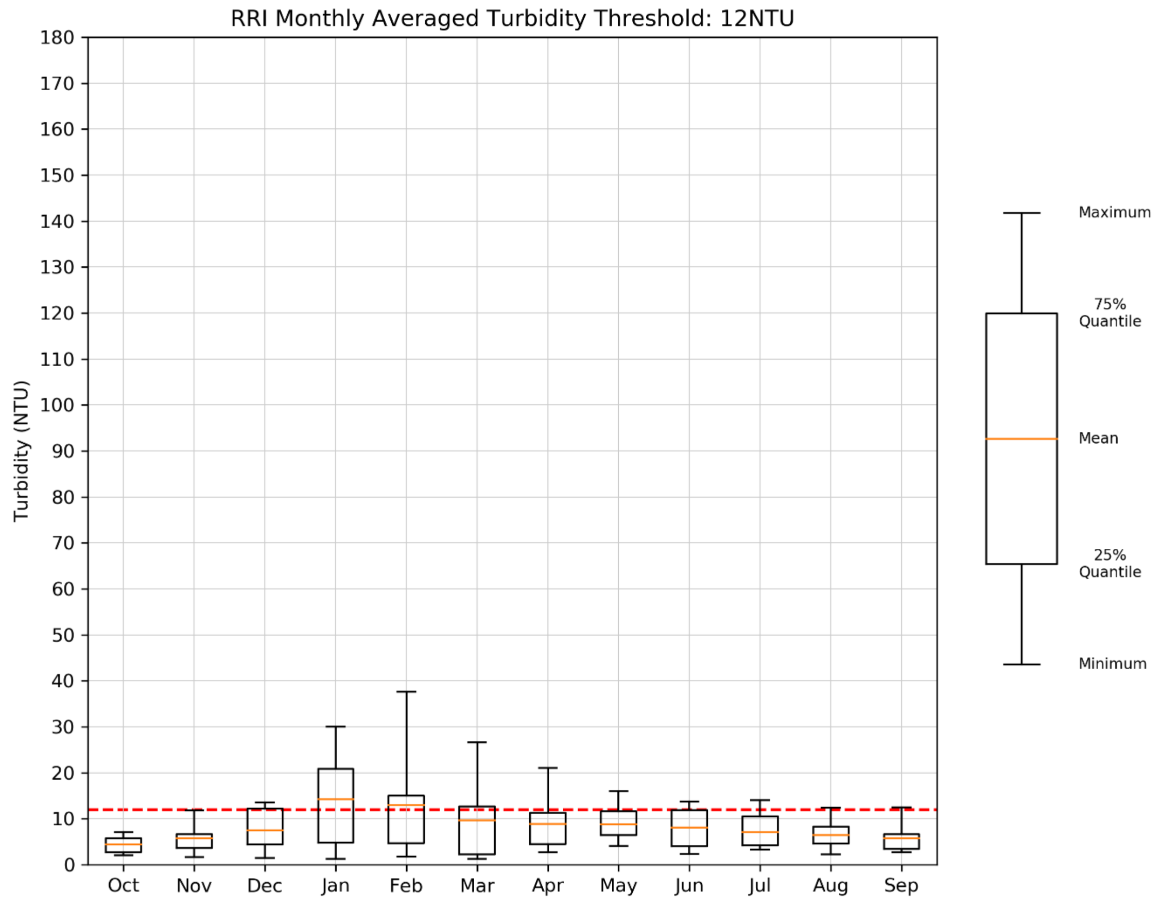

Figure C-177. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station RRI – Rough and Ready Island

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

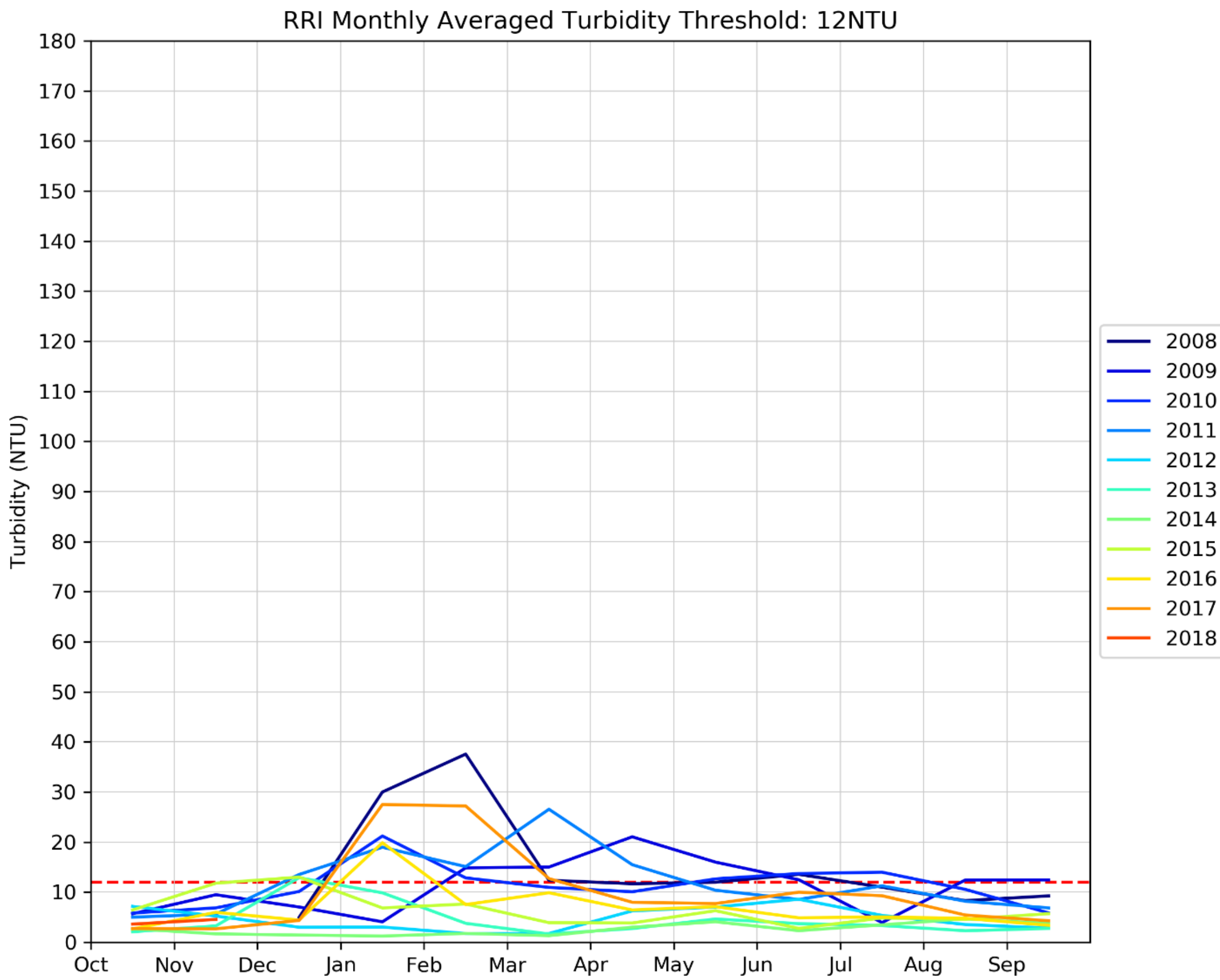

Figure C-178. Monthly Average Turbidity for the Period of Record at Station RRI – Rough and Ready Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

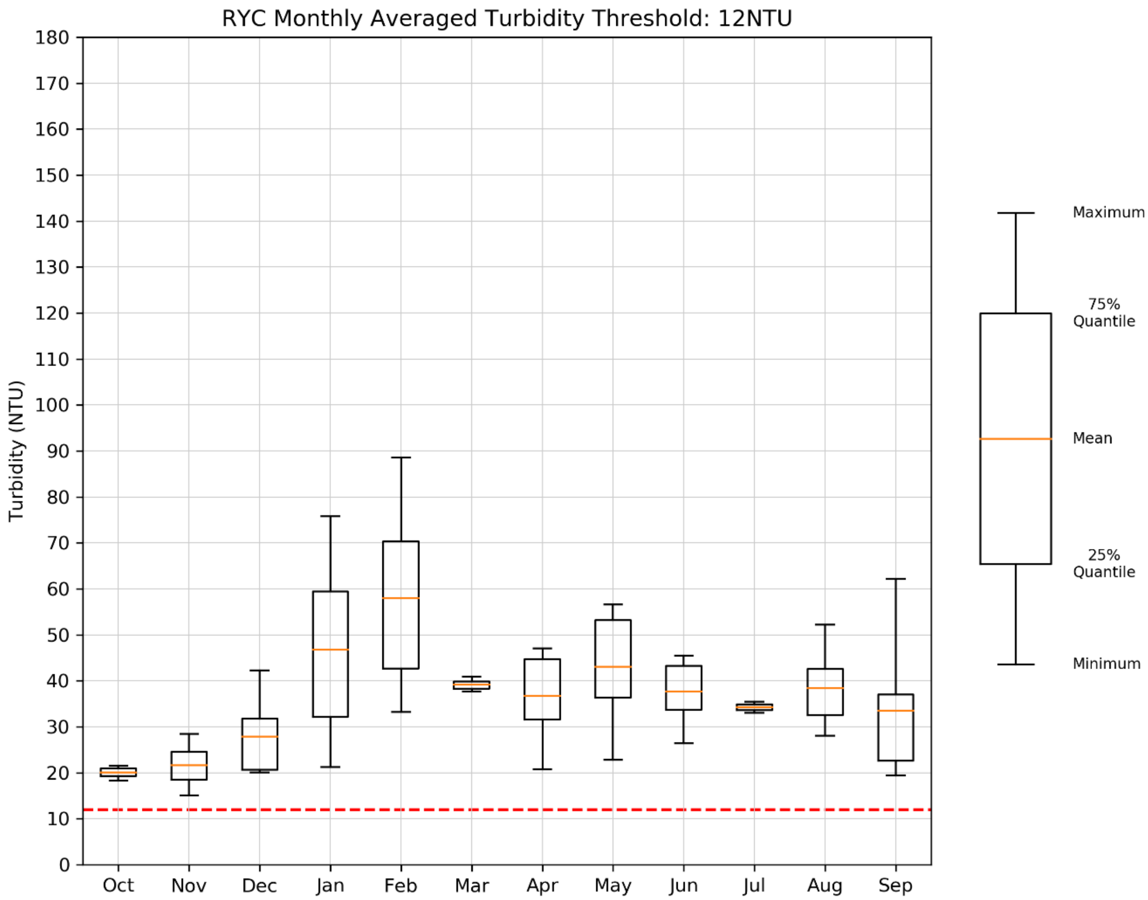

Figure C-179. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station RYC –Suisun Bay Cutoff near Ryer

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

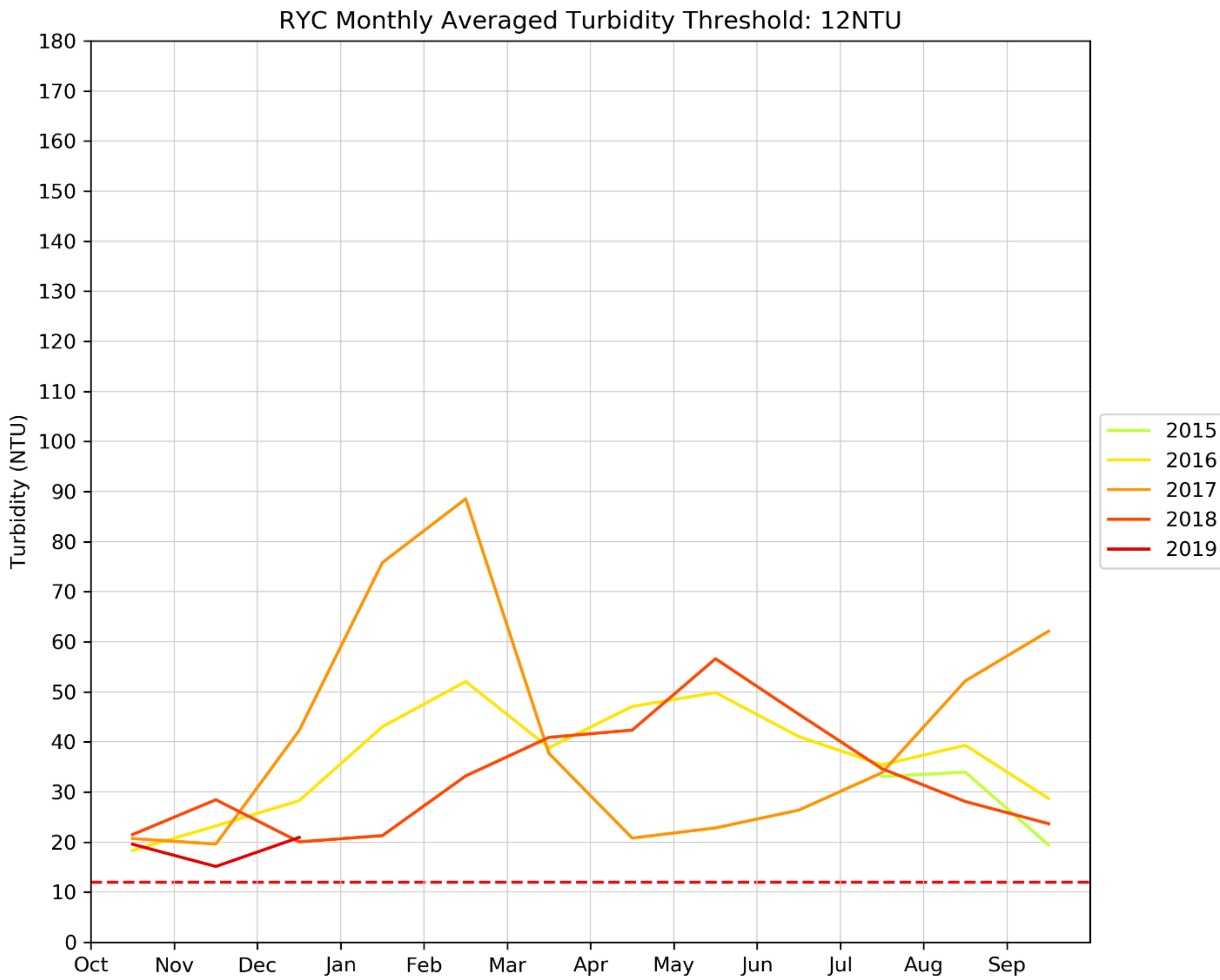

Figure C-180. Monthly Average Turbidity for the Period of Record at Station RYC – Suisun Bay Cutoff near Ryer

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

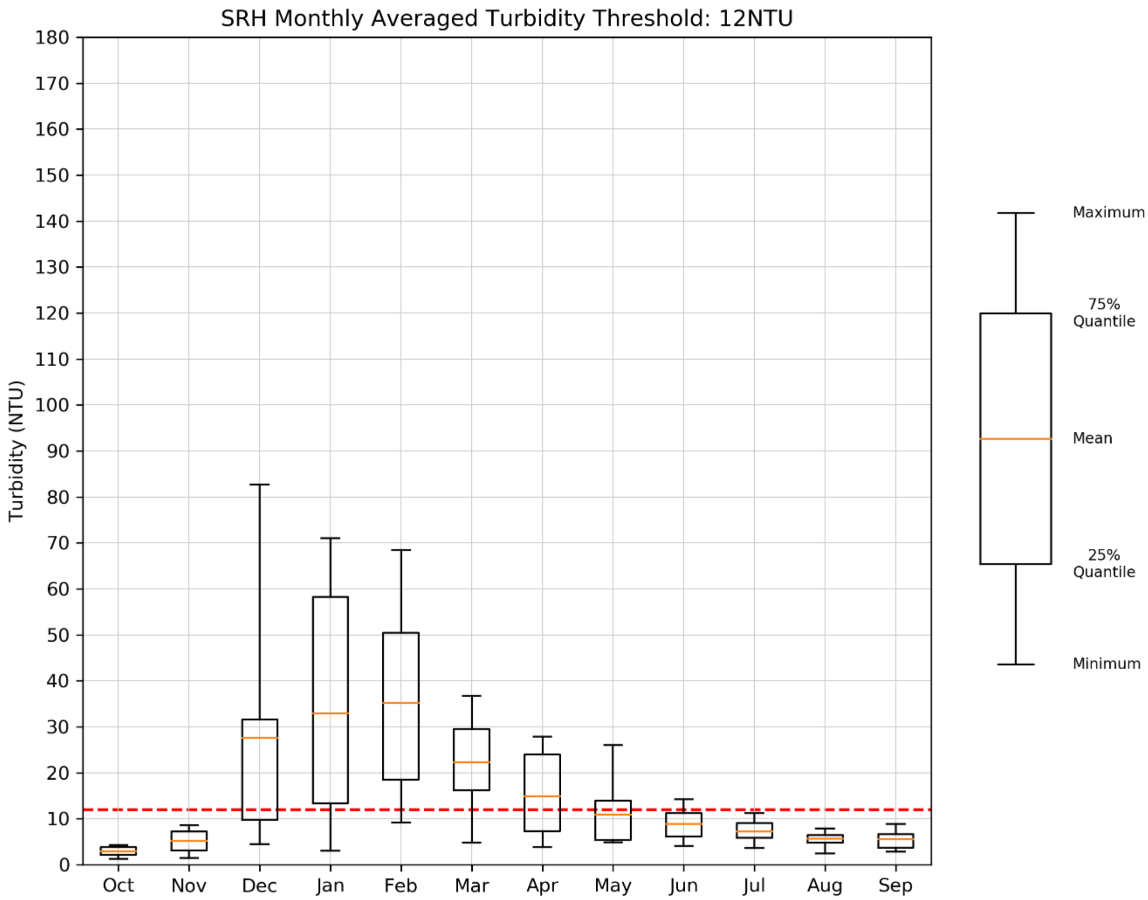

Figure C-181. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station SRH – Sacramento River at Hood

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

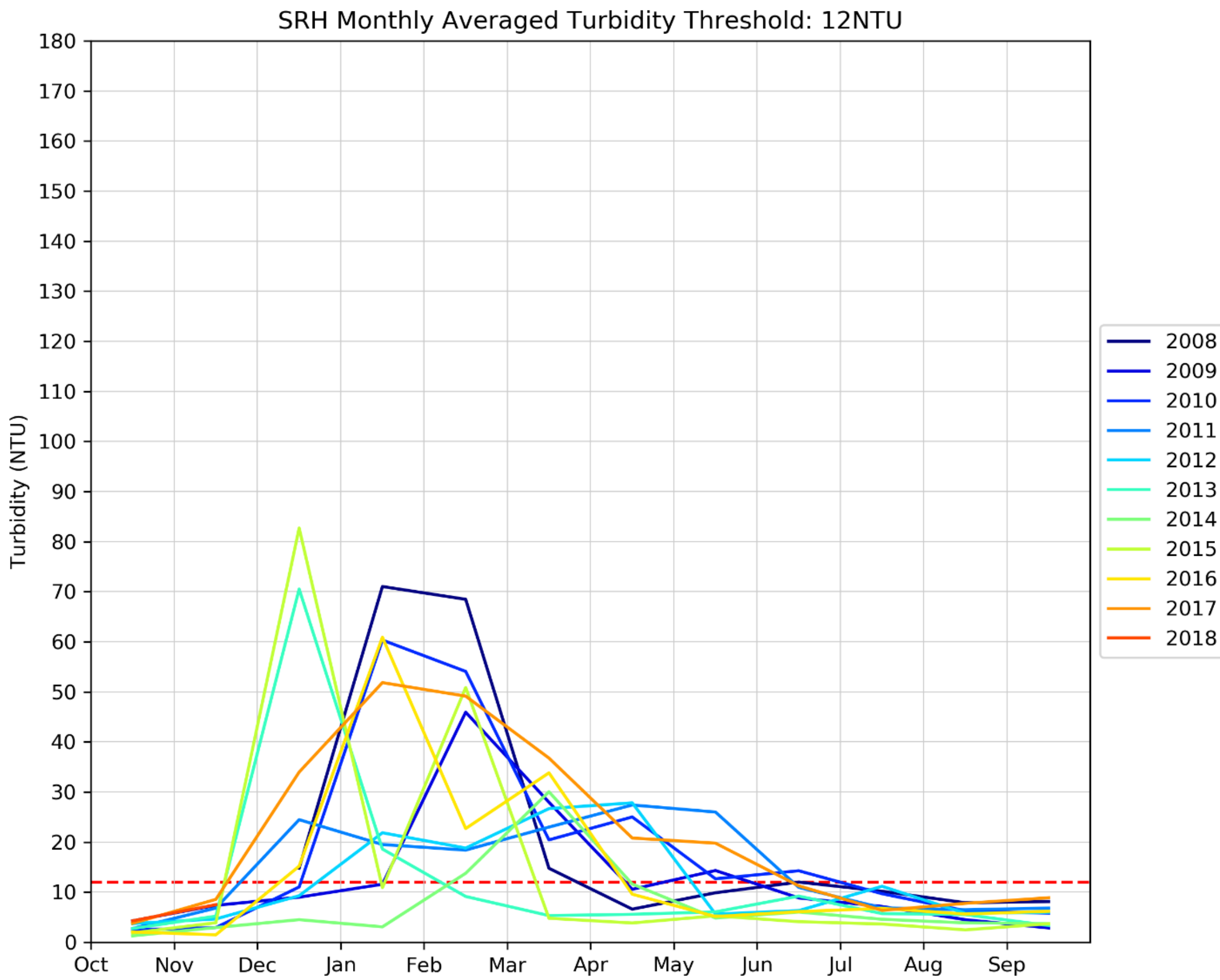

Figure C-182. Monthly Average Turbidity for the Period of Record at Station SRH – Sacramento River at Hood

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

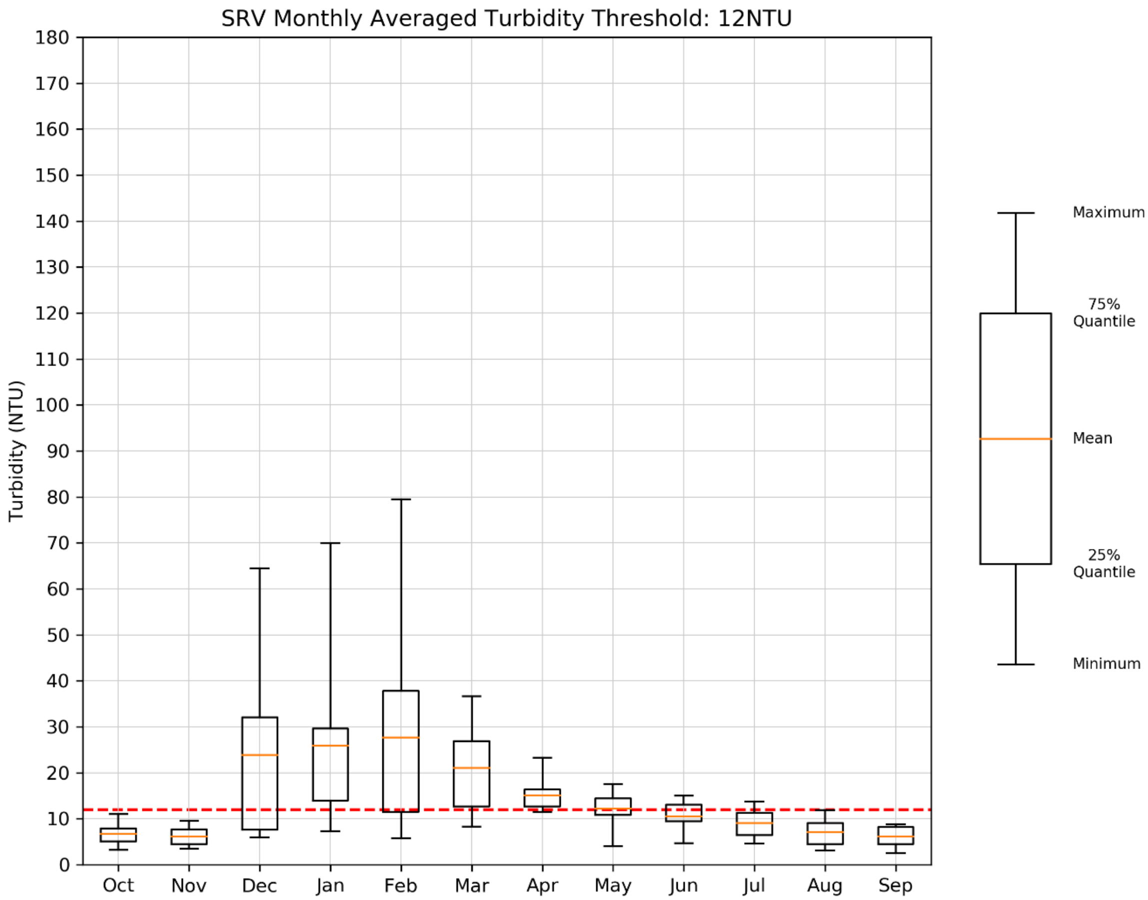

Figure C-183. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station SRV – Sacramento River at Rio Vista

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

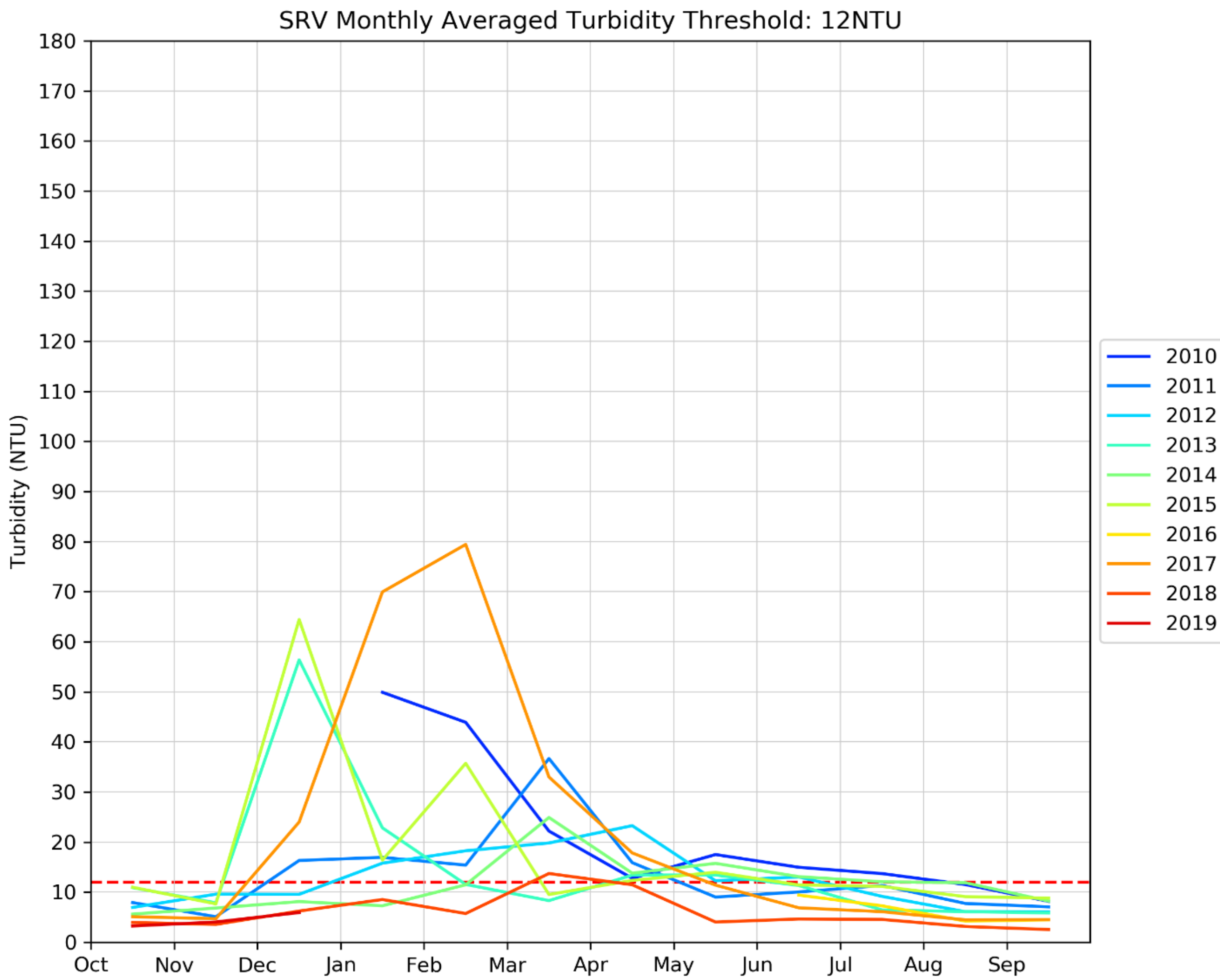

Figure C-184. Monthly Average Turbidity for the Period of Record at Station SRV – Sacramento River at Rio Vista

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

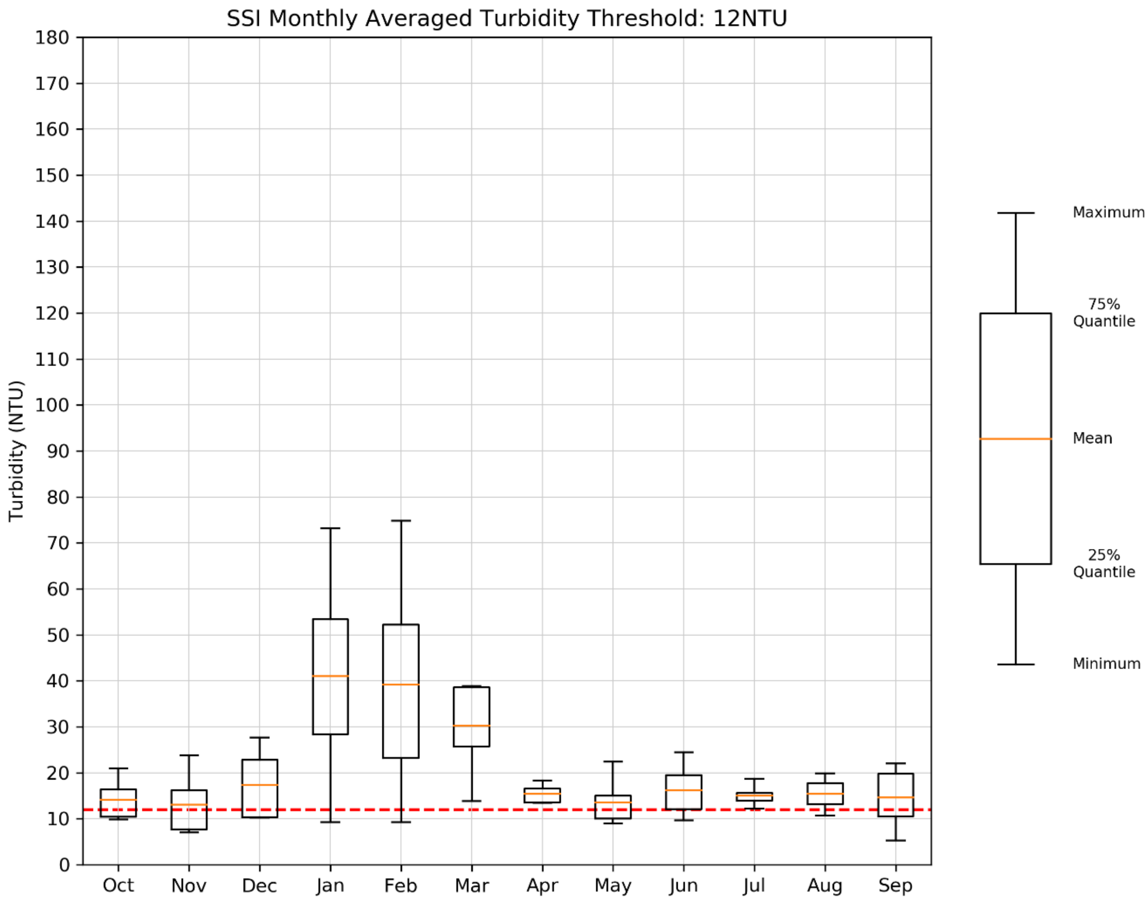

Figure C-185. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station SSI – Sacramento River near Sherman Island

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

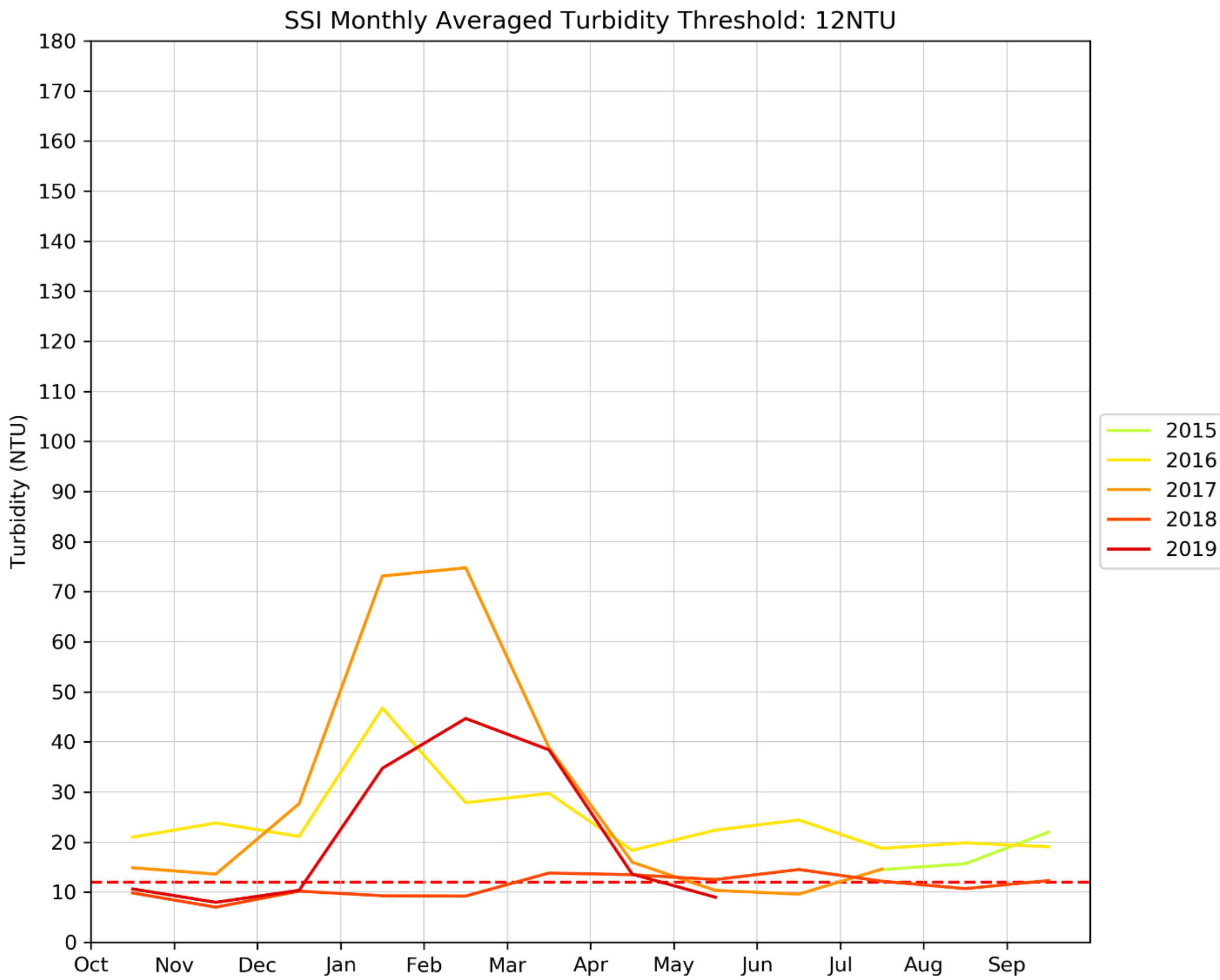

Figure C-186. Monthly Average Turbidity for the Period of Record at Station SSI – Sacramento River near Sherman Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

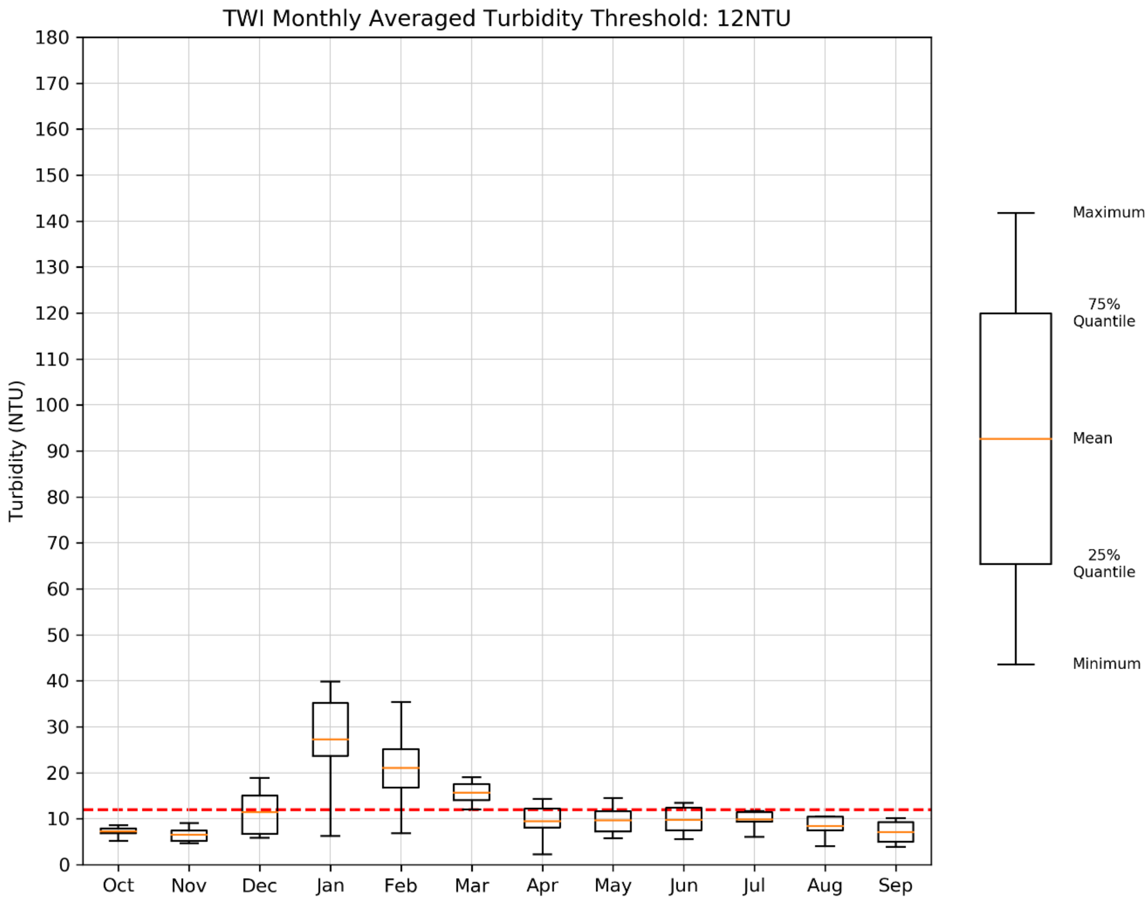

Figure C-187. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station TWI – San Joaquin River at Twitchell Island

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

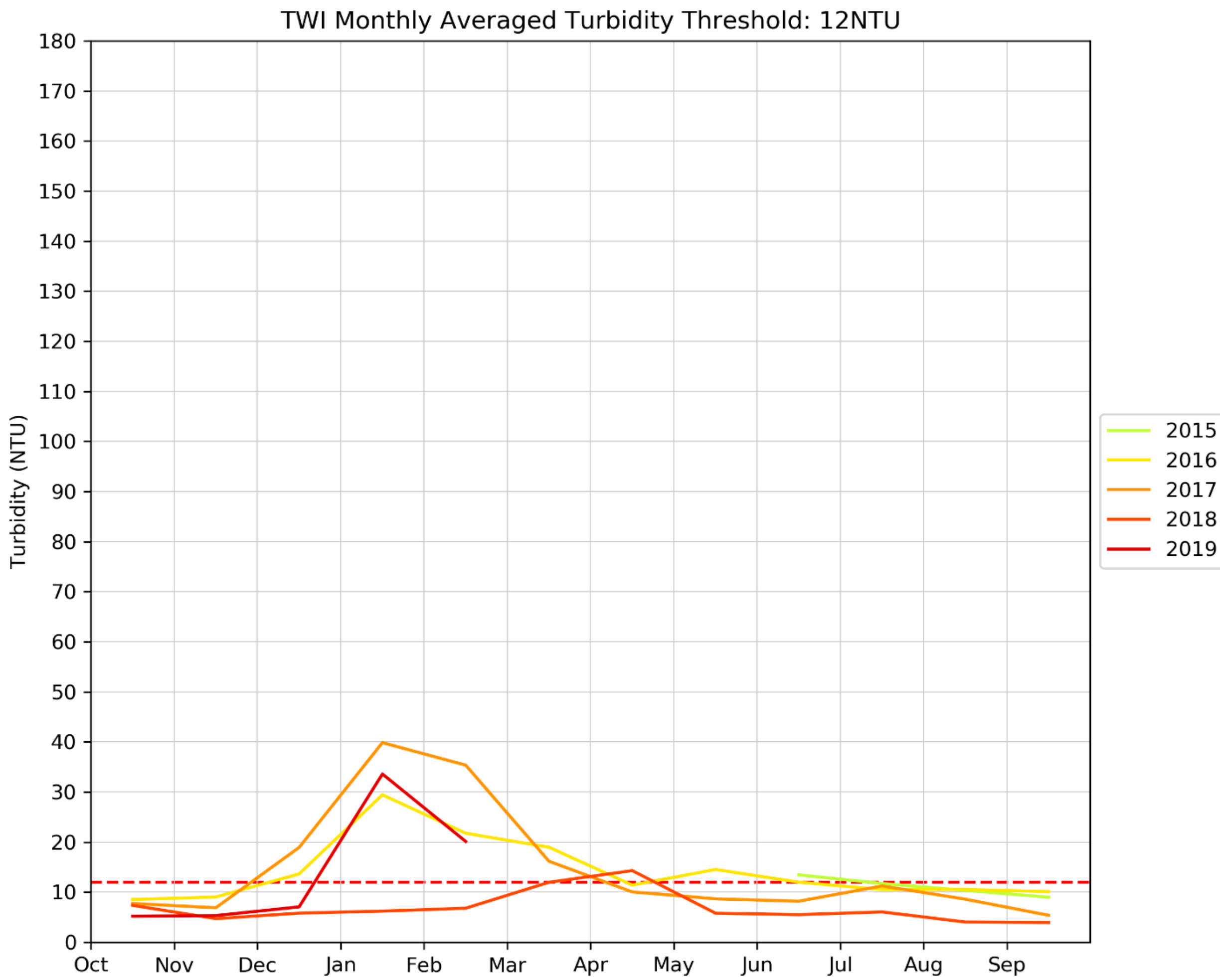

Figure C-188. Monthly Average Turbidity for the Period of Record at Station TWI – San Joaquin River at Twitchell Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

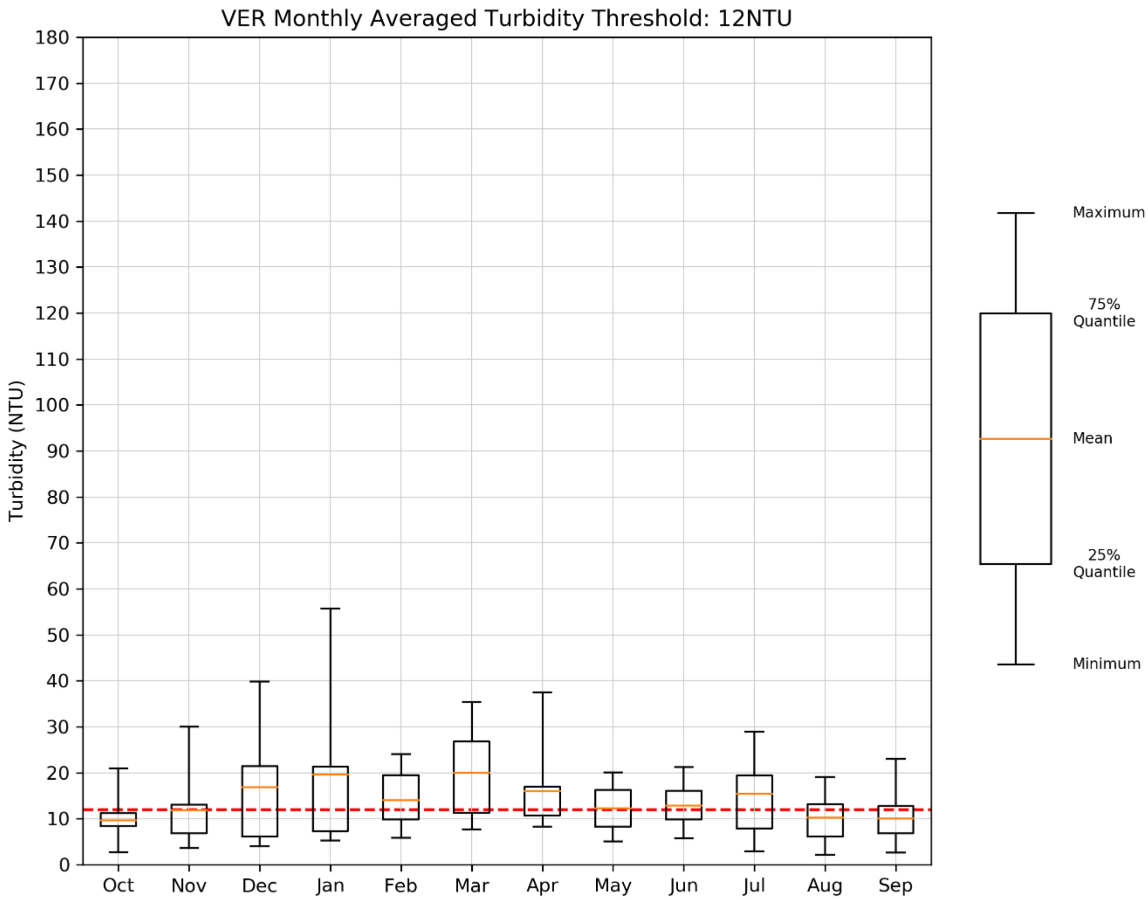

Figure C-189. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station VER – San Joaquin River near Vernalis

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75 percent and 25 percent quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

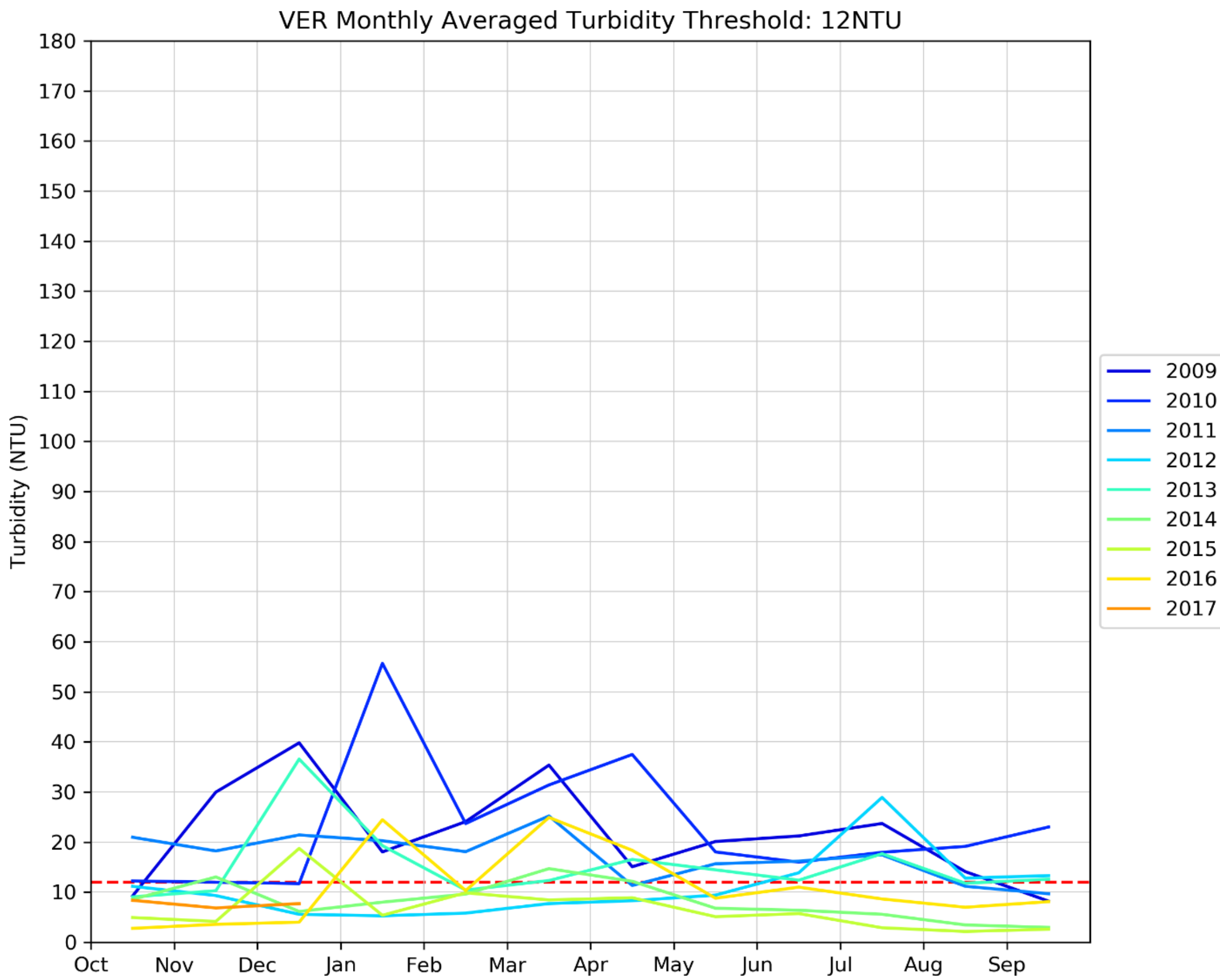

Figure C-190. Monthly Average Turbidity for the Period of Record at Station VER – San Joaquin River near Vernalis

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

C.2 Postprocessing

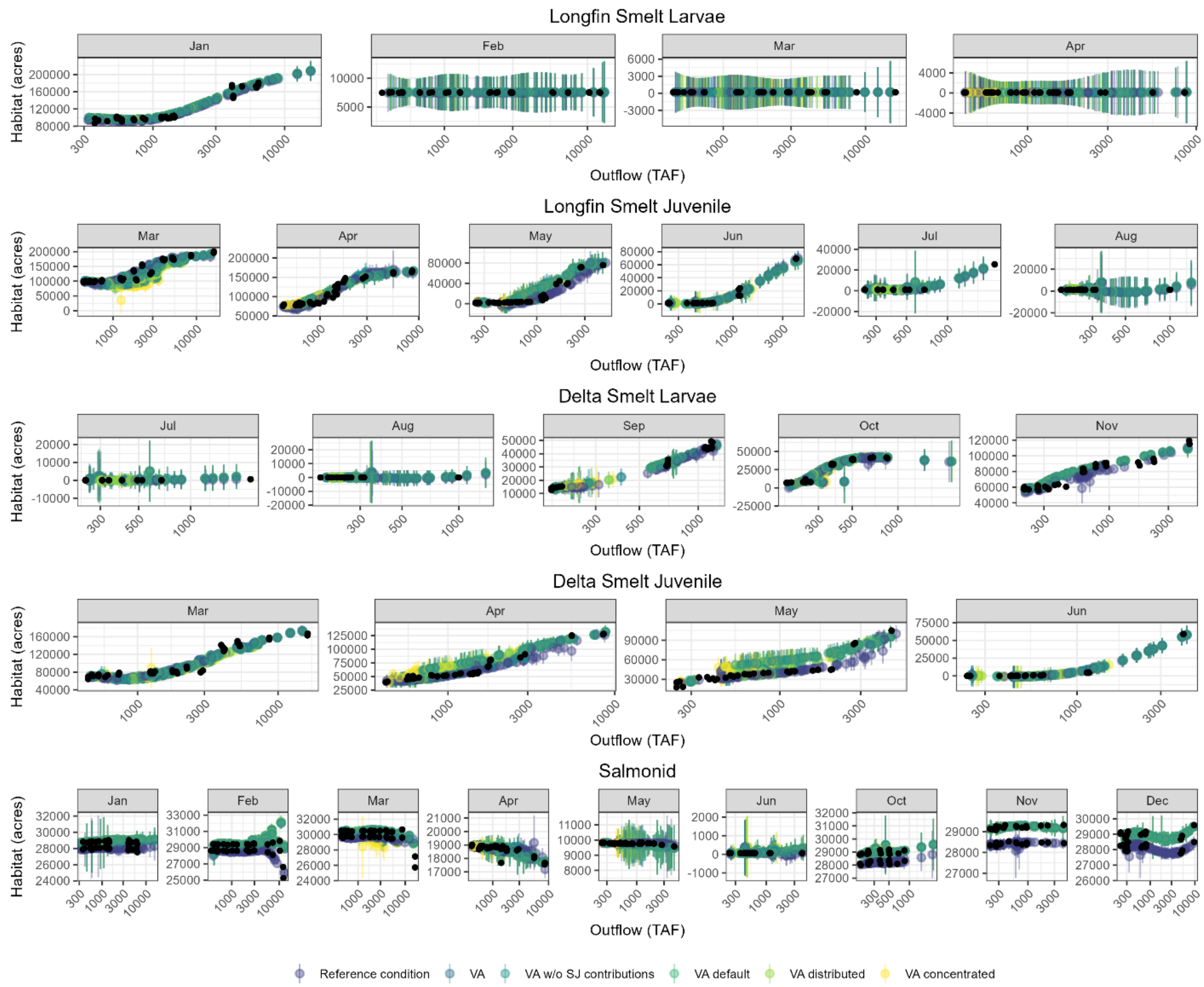

Figure C-191. Postprocessing Model Fit Represented via the Overlap between Postprocessed Model Predictions and the Original RMA Habitat Data

The postprocessed model predictions (colored points with 95 percent confidence intervals) and original RMA habitat data (black points) are plotted against delta outflow.

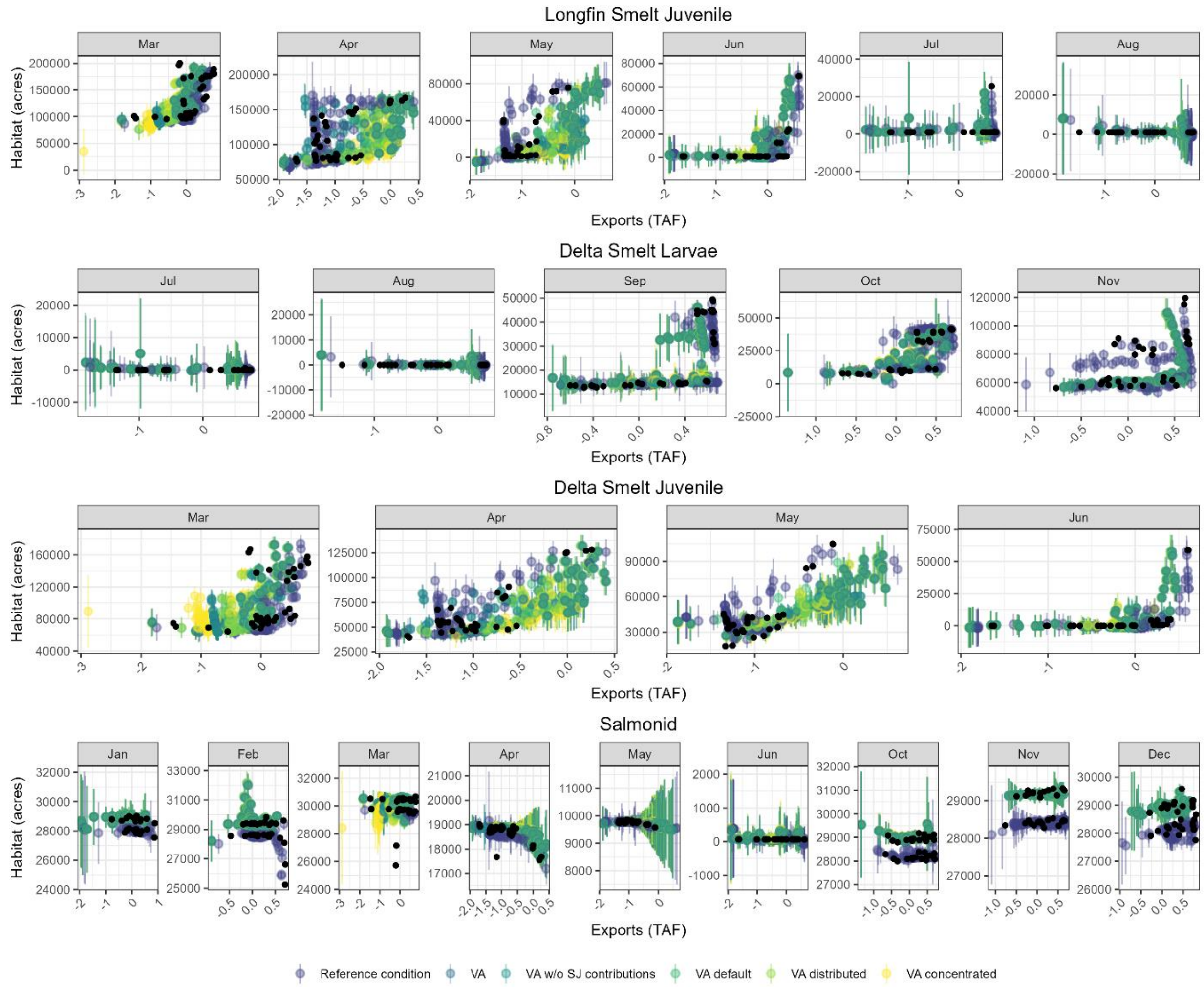

Figure C-192. Postprocessing Model Fit Represented via the Overlap between Postprocessed Model Predictions and the Original RMA Habitat Data

The postprocessed model predictions (colored points with 95 percent confidence intervals) and original RMA habitat data (black points) are plotted against total south of Delta exports, represented as the residuals of the regression of log (exports) by log (outflow). Longfin smelt larvae are not represented in this plot because the best model for longfin smelt larvae only included outflow as a predictor.

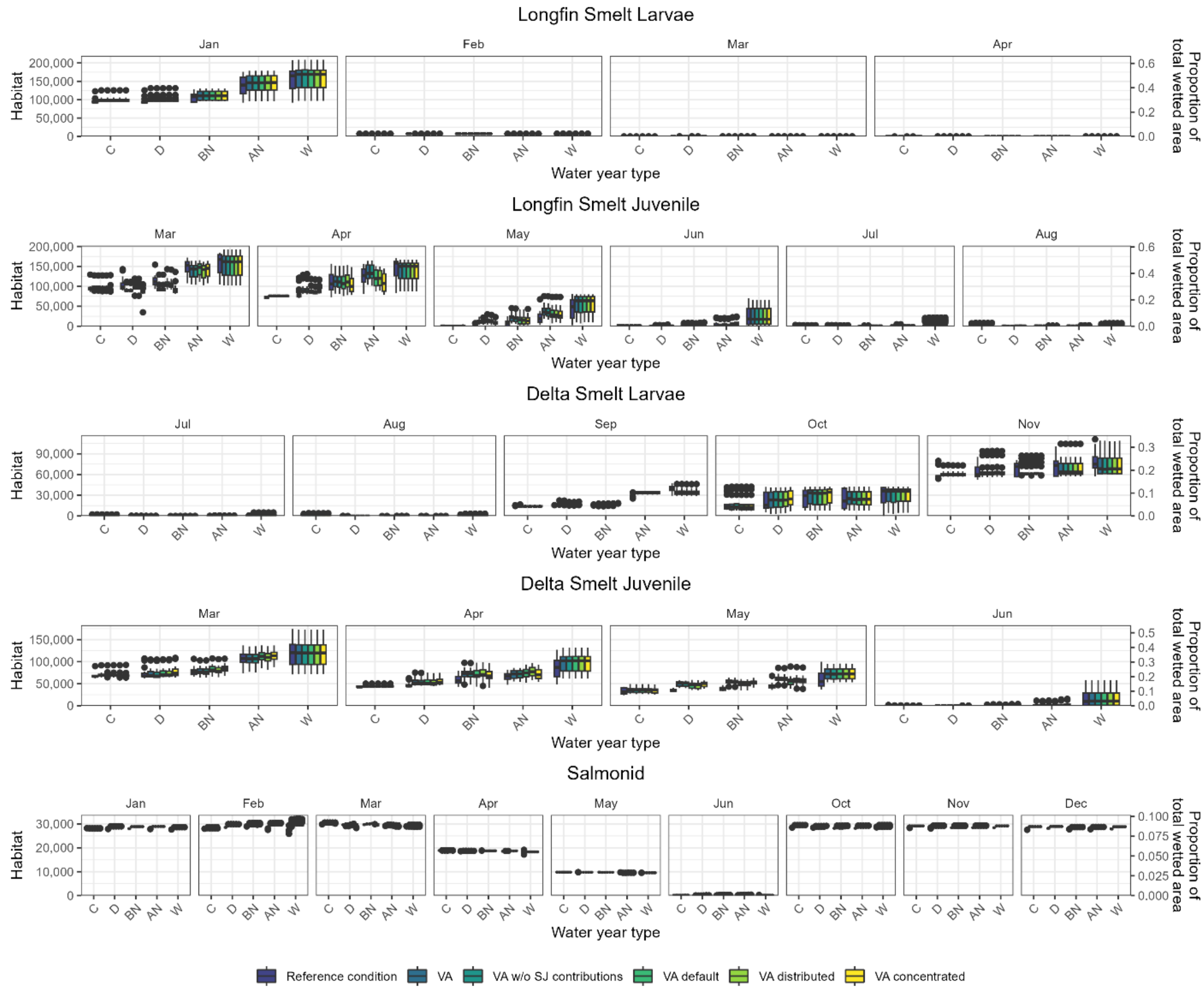

Figure C-193. Total Suitable Estuarine Habitat Area Expected for Each Species, Scenario, Month, and Water Year Type

Habitat area is represented as both the total acreage (left axis) and as the proportion of the total wetted area (right axis). Note that y-axis limits differ among species and life stages.

C.3 References

California Department of Water Resources (DWR). 2022a. California Data Exchange Center Historical Data Selector. Available: https://cdec.water.ca.gov/dynamicapp/selectQuery.

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