Monitoring Special Study Final Report



May 2026

Prepared for: State Water Resources Control Board

California Department of Water Resources
U.S. Bureau of Reclamation

This document was prepared by the California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (USBR). This submission does not constitute a waiver of any rights, objections, claims or remedies available to DWR or USBR in any past, current, or future judicial (Federal or State) or administrative proceedings related to the Bay–Delta Plan, including but not limited to any water rights proceedings to implement the Bay–Delta Plan and/or amend D-1641, and DWR and USBR hereby expressly reserve all such rights, objections, claims or remedies.

Project Leadership Team:

Jacob McQuirk, DWR, Jacob.McQuirk@water.ca.gov

Project Manager:

Bill McLaughlin, DWR, William.McLaughlin@water.ca.gov

Co-Project Manager:

Grace Windler, USBR, gwindler@usbr.gov

Karen Tolentino, DWR, Karen.Tolentino@water.ca.gov

Donna Azar, DWR, Mandana.Azar@water.ca.gov

Technical Study Leads:

Patrick Scott, DWR, High-Speed Salinity Transect Mapping Study

David Colvin, DWR, High-Speed Salinity Transect Mapping Study

Jared Frantzich, DWR, Salinity Point Source and Ion Sampling Study

Eli Ateljevich, DWR, SCHISM 3D Hydrodynamic and Water Quality Modeling Study

Zhenlin Zhang, DWR, Water Quality Data Assimilation Modeling Study

Collaborators:

Ibraheem Alsufi, DWR

Amanda Maguire, DWR

Katherin Cabras, DWR

Dave Huston, DWR

Han Sang Kim, DWR

Sophie Munger, DWR

Kijin Nam, DWR

Seshadri Rajagopal, DWR

Prabhjot Sandhu, DWR

Qiang Shu, DWR

Bradley Tom, DWR

Suggested Citation:

California Department of Water Resources and U.S. Bureau of Reclamation. 2026. *Monitoring Special Study Final Report*. May. California Department of Water Resources, Division of Operations and Maintenance and U.S. Bureau of Reclamation, Interior Region 10.

For assistance accessing any of this information, please contact any of the project team listed on this page.

Table of Contents

Executive Summary **ES-1**
Key Takeaways ES-1
Introduction ES-2
MSS Approach to Evaluating Hydrodynamics of the South Delta ES-3
Key Conclusions ES-4
Key Recommendations ES-9
Chapter 1 Introduction **1-1**
1.1 MSS Goals and Objectives 1-2
1.2 MSS Plan and SWRCB Conditional Approval 1-4
Chapter 2 MSS Study Area Overview **2-1**
2.1 Study Area 2-1
2.2 Overview of South Delta Hydrology 2-4
2.2.1 Flow Patterns 2-4
2.2.2 Salinity Concentrations 2-7
2.2.3 Variables that Influence Flow and Salinity Conditions in the South Delta 2-8
Chapter 3 Technical Study Descriptions and Meeting MSS Goals and Conditions **3-1**
3.1 Description of Technical Studies 3-4
3.2 Meeting the MSS Goals 3-8
3.3 Meeting the MSS Conditional Approval Items 3-8
3.4 Overview of MSS Implementation and Integration between Studies 3-13
3.4.1 Period of Study and Data Collection 3-13
3.4.2 Use of Historical Data 3-14
3.4.3 Modeling Analyses 3-14
Chapter 4 Discussion & Synthesis **4-1**
4.1 Influences on Water Levels, Flow, and Salinity in the South Delta 4-1
4.1.1 State Water Project and Central Valley Project Export Pumping 4-5
4.1.2 Tides 4-7
4.1.3 Unquantified Local Diversions and Discharges 4-8
4.2 Null Zone(s) and Bathymetry Sensitivity 4-9
4.2.1 Lower Old River Null Zone 4-11

4.2.2 Middle River Null Zone....4-13
4.3 Major Sources of Salinity....4-15
4.3.1 Local Salinity Sources are not Quantified....4-17
4.3.2 Source Water and Salinity Vary by Reach....4-18
4.3.3 Discharges on Lower Old River....4-20
4.3.4 Contributions of Salinity from Five Points Region....4-21
4.3.5 Contributions from Groundwater....4-23
4.3.6 Ions....4-24
4.4 Adequacy of Current Monitoring Network in Assessing Reach Salinity....4-24
Chapter 5 Conclusions and Recommendations....5-1
5.1 Conclusions....5-1
5.1.1 Water Levels....5-4
5.1.2 Flow and Circulation....5-5
5.1.3 Salinity....5-6
5.2 Recommendations....5-7
5.2.1 Updated Reach Definitions According to Hydrodynamics....5-8
5.2.2 Suggested Approach to Developing the Long-Term Monitoring and Reporting Plan....5-11
5.2.3 Access to Additional Salinity Data in the South Delta....5-13
Chapter 6 References....6-1
6.1 Chapter 1, Introduction....6-1
6.2 Chapter 2, MSS Study Area Overview....6-1
6.3 Chapter 3, Technical Study Descriptions and Meeting MSS Goals and Conditions....6-1
6.4 Chapter 4, Discussion and Synthesis....6-3
6.5 Chapter 5, Conclusions, Recommendations, and Potential Next Steps....6-3

Appendices

Appendix A Outreach to Participating Organizations since Publishing the Monitoring Special Study Plan

Appendix B Supplemental Stable Water Isotope Analysis

Appendix C Low Water Metrics

List of Attachments

Attachment 1 High –Speed Salinity Transect Mapping

Attachment 2 Salinity Point Source and Ion Sampling

Attachment 3 Circulation, Channel Depletion, and Barrier Assumptions for Modeling the South Delta, 2024 Revision

Attachment 4 Data Integration and Source Inference for Modeling

Attachment 5 Clifton Court Forebay Gate Characterization, Scheduling Study, and Facilities Comparison

Attachment 6 MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study

Attachment 7 Old River Tracy Barrier Flow Study

Attachment 8 Old River Null Zone Study

List of Tables

Table ES-1 Summary of the Sensitivity of Water Level, Salinity, Null Zones, and Tidal Range to Key Variables in the South Delta ES-5

Table 2-1 Water Quality Objectives for Agricultural Beneficial Uses 2-2

Table 5-1 Summary of the Sensitivity of Water Level, Salinity, Null Zones, and Tidal Range to Key Variables in the South Delta 5-2

List of Figures

Figure ES-1 South Delta Map Showing Locations of Interagency Compliance Stations, Key Stations Discussed in the Text, Temporary Barriers, and the Five Points Region ES-3

Figure ES-2 Daily Mean Specific Conductivity by Station and Recommended Compliance Reach. Bold black line is a combined average of stations within that compliance reach. ES-10

Figure 1-1 Depiction of the Connections between MSS Report, MSS Plan, MSS Objectives, and the SWRCB Conditions 1-6

Figure 2-1 South Delta Map Showing Interagency Compliance Station Locations and River Segments Defined by the 2018 Bay-Delta Plan 2-4

Figure 2-2 Map of the Five Points Region in the South Delta. Intake Area and Pescadero Tract are denoted in the inset. 2-6

Figure 2-3 Daily Observations of Vernalis EC and Vernalis Flow from 1990 to 2025 Separated by (a) Season and (b) Time Period 2-7

Figure 2-4 Boxplots of (a) Daily and (b) 30-day Running Average Electrical Conductivity (EC) measured at each of the Four Southern Delta Compliance Locations for Water Years 2010 through 2024. Daily EC data were downloaded from the California Data Exchange Center. 2-8

Table 2-2 Classification Index, Mean Flow, and Mean Salinity Concentrations for the San Joaquin River and Mean Combined Export Rates for Water Years 2010 to 2023 2-9

Figure 3-1 Map Showing the Temporary Flow Monitoring Stations Used in the MSS 3-2

Figure 3-2 Map Showing Existing and Temporary Electrical Conductivity Stations Used in the MSS 3-3

Figure 3-3 Flow Chart of MSS Monitoring and Modeling Efforts. *New and Existing Continuous Data* Includes, but Is Not Limited to, Data Collected from the Salinity Point Source and Ion Sampling Study 3-4

Figure 4-1 Historical Scatter of Vernalis Flow and Specific Conductivity, Colored by Corresponding Specific Conductivity at Old River near Tracy Boulevard. Reproduced from Attachment 6. 4-1

Figure 4-2 Scatter Relationship between Vernalis Flow and Three Null Zone Indicator Stations 4-4

Figure 4-3 Comparison between Regression-Derived Net Flow Sensitivities and SCHISM Model-Derived Sensitivities to Export Pumping for the Case with No Barriers 4-6

Figure 4-4 Comparison between Regression-Derived Net Flow Sensitivities and SCHISM Model-Derived Sensitivities to Export Pumping for the Case with Barriers In 4-7

Figure 4-5 Historical Net Flow Extracted from Observed Data on Old River near Tracy Boulevard (OLD) and Old River at Mountain House Creek (ORM). 4-10

Figure 4-6 Water Year 2022 Old River at Tracy Boulevard and Old River at Mountain House Daily Mean Net Flow and Daily Mean Specific Conductivity at Stations Old River at Tracy Boulevard (OLD), and Old River at Mountain House (ORM), and Old River above Doughty Cut (ORX) 4-11

Figure 4-7 Old River at ADCP Downstream (OAAD), Old River at ADCP Upstream (OAAU), Old River at Tracy Boulevard (OLD), and Old River at Mountain House (ORM) Daily Net Flow and Daily Mean Specific Conductivity for June–October 2022 4-12

Figure 4-8 Composition of Water at Locations along Old River in a Classic Null Zone Flow Regime 4-13

Figure 4-9 Middle River Point Sampling Profiles (June–October 2023) 4-14

Figure 4-10 1%-Quantile Water Levels, Tidally Filtered (Net) Flow, Tidal Range of Flow and Specific Conductivity at an Upstream (Middle River at Undine Road) and a Midstream (Middle River at Howard Road) Site on Middle River with and without Artificial Dredging 4-15

Figure 4-11 Observed Specific Conductivity on the San Joaquin River at Vernalis (solid dark line), Old River at Tracy (OLD), and Pre-MSS DSM2 Model Results at OLD 4-17

Figure 4-12 Comparison Between Model Performance with (MSS Model) versus without (DSM2 v8.2.1) Source Inference 4-18

Figure 4-13 Lower Old River Transect Profile Plots (Summer and Fall 2023) 4-19

Figure 4-14 Map of Interior South Delta Municipal and Agricultural Discharges 4-20

Figure 4-15 Lower Old River Drains from January 2022–September 2023 Daily Mean Specific Conductivity at Stations Mountain House Creek Near Mouth, Wicklund Cut Near Mouth, Old River at Bethany Drain, and Old River at Tracy Boulevard 4-21

Figure 4-16 Paradise Cut, Paradise Cut North Bridge, Paradise Cut South Bridge, Paradise Cut Upstream (PDUP), and San Joaquin River at Mossdale Daily Mean Specific Conductivity from January 1, 2023–September 30, 2023. 4-22

Figure 4-17 Paradise Cut (PDC), Paradise Cut North Bridge (PCNB), Paradise Cut South Bridge (PCSB), Paradise Cut Upstream (PDUP), and San Joaquin River at Mossdale (MSD) Daily Mean Specific Conductivity from January 1, 2023–September 30, 2023. 4-23

Figure 4-18 Map of Interior South Delta Channel Regions, Long-Term Water Quality and Flow Stations, and Monitoring Special Study Temporary Specific Conductivity Monitoring Stations 4-25

Figure 4-19 Boxplots of 2021–2023 Daily Mean Specific Conductivity at Lower Old River Stations Plotted by Month 4-26

Figure 5-1 Map of DWR-Recommended Compliance Reaches and Stations for Assessing Salinity in Those Reaches 5-9

Figure 5-2 Daily Mean Specific Conductivity by Station and DWR-Recommended Compliance Reach. Bold black line is a combined average of all stations within that compliance reach. 5-11

Acronyms and Abbreviations

Acronym	Definition
µS/cm	microsiemens per centimeter
2018 Bay-Delta Plan	San Francisco Bay/Sacramento–San Joaquin Delta Estuary
ADCP	Acoustic doppler current profilers
Bay–Delta Plan	1995 Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary
CCF	Clifton Court Forebay
CDEC	California Data Exchange Center
cfs	cubic feet per second
CNRA	California Natural Resources Agency
COP	Comprehensive Operations Plan
CVP	Central Valley Project
CWEMF	California Water and Environmental Modeling Forum
D-1641	Water Right Decision 1641
Delta	Sacramento–San Joaquin Delta
DMC	Delta-Mendota Canal
DSM2	Delta Simulation Model II
DWR	California Department of Water Resources
EC	electrical conductivity
ft	foot
GTM	General Transport Model
HOR	Head of Old River
LTMRP	Long-Term Monitoring and Reporting Plan
MHO	Middle River at the Howard Road
MRU	Middle River at Undine Road
MSS	Monitoring Special Study
MSS Plan	work plan for the MSS
OH1	Head of Old River
OLD	Old River at Tracy Boulevard
OMR	Old and Middle River
ORM	Old River at Mountain House
PCCU	Paradise Cut Confluence Upstream
Reclamation	U.S. Bureau of Reclamation
SC	specific conductivity
SCHISM	Semi-Implicit Cross-scale Hydroscience Integrated System Model
SWP	State Water Project

Acronym	Definition
SWRCB	State Water Resources Control Board
UNI	Upper Old River
USBR	United States Bureau of Reclamation
WY	water year

Executive Summary

Key Takeaways

- Export levels at the State Water Project (SWP) and Central Valley Project (CVP)—collectively referred to as the Projects—pumping facilities have relatively low impacts on flow and salinity and medium impacts on water levels in the southern Sacramento–San Joaquin Delta (Delta) channels, except for Grant Line Canal. Exports are not a dominant process in any analysis conducted as part of the Monitoring Special Study (MSS). One reason for the low degree of control on Old and Middle Rivers is the relatively high conveyance of Grant Line Canal and downstream channels, which absorb operational adjustments of the Projects, minimizing the influence of those export adjustments in the South Delta.
- The temporary agricultural rock barriers (when all three barriers are fully installed) mitigate upstream water levels beyond the export facilities' influence; however, the barriers indirectly contribute to salt accumulation due to reduced tidal flushing and reinforcement of null zones. A trade-off, therefore, exists between water levels and water quality in the southern Delta channels using the barrier tools at the Projects' disposal.
- Null zones, or areas where flow directions converge and net flow is near zero, are a staple of South Delta hydrology. Null zones generally develop independent of the levels of exports and inflows. It is worth noting that null zones still formed in 2023, despite high-flow conditions. The vigorous tidal flows on Grant Line Canal are the typical method by which the South Delta is flushed under low to moderate flows. Temporary barriers are not required for null zones to form—in most years, null zones form before the first barrier is in place—however, the barriers reinforce null zones and can influence their location along the channel. When null zone convergence points coincide with areas of relative tidal stagnation upstream of the barriers, flushing the South Delta becomes more difficult.
- South Delta salinity is influenced by a combination of water quality of San Joaquin River inflow, local in-Delta discharges, and the westside water sources of seawater and Sacramento River water. The transport of salt throughout the South Delta is shaped by different combinations of exports, barriers, and flow dynamics. Dominant control of salinity within the South Delta channels shifts seasonally. Water quality (or salinity) of river inflow controls salinity from late fall through spring, while in-Delta sources dominate in summer and early fall. There is no simple relationship between San Joaquin River inflow and salinity in the South Delta, especially during low-flow periods. High inflows can influence South Delta salinity through some reaches, but the volume needed for meaningful influence across all water year types and during the dry season is not reliably available, particularly under dry conditions. The South Delta salinity signal is further complicated by the variable relationship between flow and salinity of the San Joaquin River at inflows below 3,000 cubic feet per second (cfs).

Introduction

The California Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) have prepared the MSS to meet requirements detailed in Section B(1)(iv) of the *2018 Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary* (2018 Bay-Delta Plan). First, the MSS characterizes the spatial and temporal distribution and associated dynamics of water level, flow, and salinity conditions in the interior southern Delta, or South Delta. Second, the MSS identifies the extent of low- or null-flow conditions in the South Delta. (Null-flow conditions, or null zones, refer to areas of convergent flow where net flow is near zero that trap water and result in increased residence time in the South Delta channels.) Third, the MSS informs the future development of a Long-Term Monitoring and Reporting Plan (LTMRP), the goal of which is to assess attainment of the salinity objective in the South Delta. Historically, the salinity objective for agricultural beneficial uses in the interior South Delta has been assessed by 30-day average values of specific conductivity (SC)[1] measured at four key compliance monitoring locations (Figure ES-1): (1) San Joaquin River at Airport Way Bridge, Vernalis [D-1641 code C-10, California Data Exchange Center {CDEC} codes VER and VNS], (2) San Joaquin River at Brandt Bridge [C-6, CDEC BDT], (3) Middle River near Old River [C-8, CDEC UNI], and (4) Old River near Tracy Road Bridge [P-12, CDEC OLD].

[1] Specific conductivity (SC) and electrical conductivity (EC) are used interchangeably throughout the report.

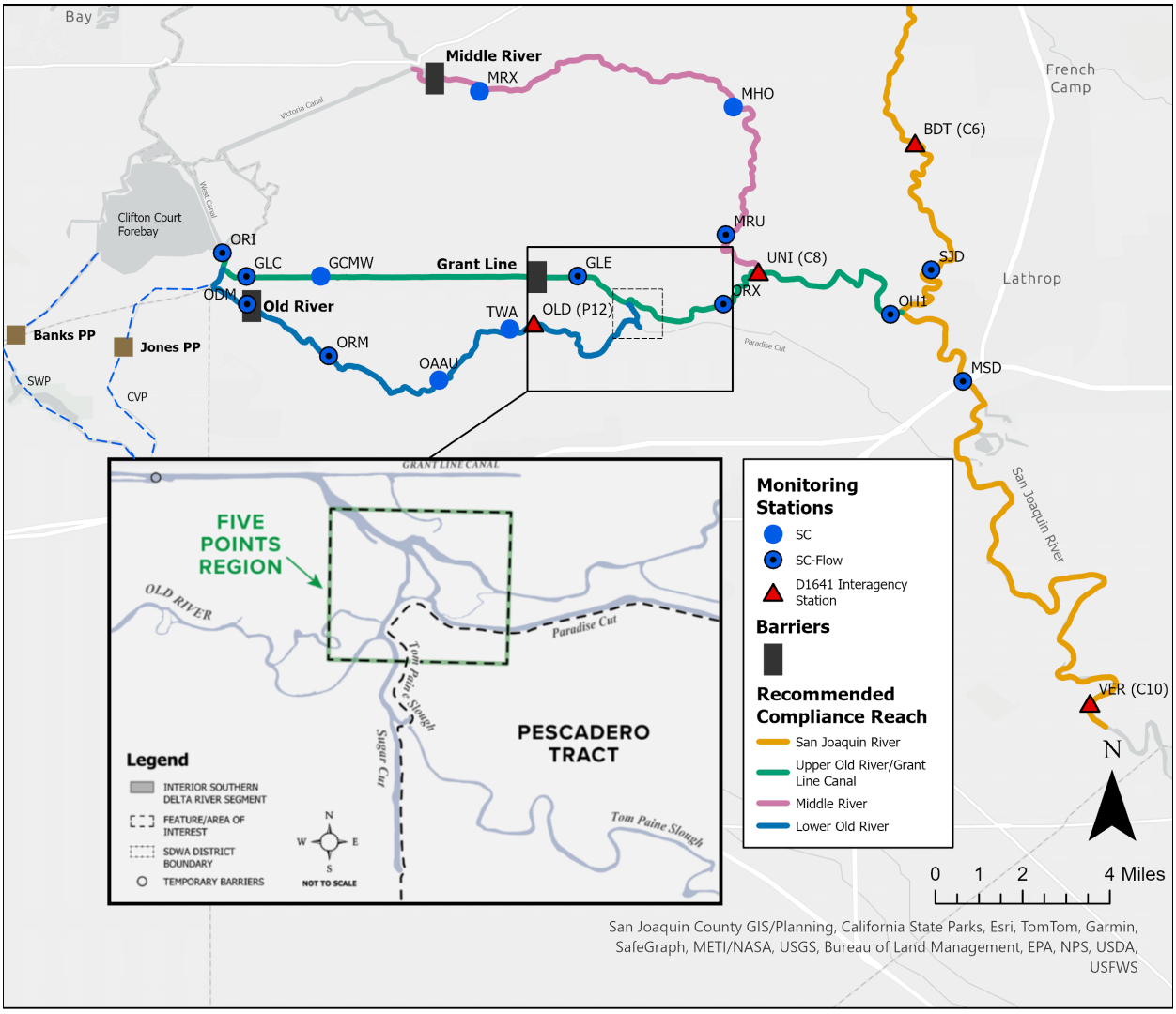


Figure ES-1. South Delta Map Showing Locations of Interagency Compliance Stations, Key Stations Discussed in the Text, Temporary Barriers, and the Five Points Region

MSS Approach to Evaluating Hydrodynamics of the South Delta

The MSS consisted of extensive field efforts to collect observational data during calendar years 2021–2023. Eighteen temporary stations were deployed to continuously monitor SC and/or flow in areas of the South Delta targeted to fill geographic gaps in the pre-existing, permanent monitoring network. Four stations (two permanent and two temporary) continuously monitored flow at strategic locations along Old River, both downstream and upstream of the P-12 compliance station, to better characterize the null zone that commonly forms in this area. Spatially continuous SC data were collected and mapped for six different boat transect routes to evaluate salinity dynamics in South Delta channels between fixed monitoring stations under variable flow, export, and tidal conditions. Additionally, monthly water samples were collected from 16 sites throughout the South Delta and analyzed for ion concentrations to develop ionic fingerprints, which can be used to identify salinity sources and regional differences. Surface-water samples were also collected monthly between February 2023 and January 2024 for

isotopic analysis, to further investigate different South Delta surface water, groundwater, seawater incursion from the bay, and discharge water sources.

Both modeling and statistical analyses were used to calculate sensitivities of South Delta flow, water levels, null zones, tidal range, and salinity to influencing variables such as export rates, San Joaquin River inflow and salinity, the temporary agricultural barriers, tides, channel bathymetry, in-Delta diversions, and in-Delta discharges. Observations of flow and SC in the South Delta collected during the MSS were used to improve and validate the Delta Simulation Model II (DSM2) and the Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM) for application in the South Delta. Key modeling advancements during the MSS include incorporating updated South Delta bathymetry, integration of continuous SC monitoring data to infer salinity sources, a more dynamic representation of Clifton Court Forebay radial gate operations, and improved parameterization of leakage through all three temporary barriers in the South Delta.

The MSS uses the results of statistical analyses of historical observations and modeled scenarios to better understand the factors that drive the physical hydrology of the South Delta channels as well as the sensitivities of South Delta flow, water levels, and salinity under different operational and environmental conditions during both the MSS study period (2021–2023) and the recent past (i.e., 2009–2020). The MSS examines the influences of the following variables: timing and rates of pumping at the SWP and CVP export facilities, San Joaquin River flow and salinity boundary concentrations at Vernalis, presence and/or configuration of the three temporary barriers, strength and extent of tidal flows, volumetric flow and salinity concentrations of local in-Delta diversions and in-Delta discharges, and channel bathymetry.

Key Conclusions

Table ES-1 summarizes the influence of the different variables explored in the MSS (designated by row) on key parameters of interest (designated by column), including water levels, salinity, null zones, and tidal range in the South Delta channels.

Table ES-1. Summary of the Sensitivity of Water Level, Salinity, Null Zones, and Tidal Range to Key Variables in the South Delta

Influencing Variable	General Sensitivity Summary			
	Water Level	**Salinity**	**Null Zones and Net Flow**	**Tidal Range**
SWP/CVP Pumping[1]	• Negative relationship, impact varies by location and pumping increment • Medium[2] impact close to intake area especially on Old and Middle River. At Old R. at Tracy, export drawdown from the full range studied (1,500–10,000 cfs) is 0.5–0.9 ft	• Varied relationship, depending on relative water quality of the SJR inflow and seasonal sources • Low[2] impact particularly when barriers are in	• Low sensitivity • Medium sensitivity on Grant Line Canal • Can influence location of Lower Old River null zone, but not formation of the null zone	• Low sensitivity • Increased sensitivity of water level range with increased pumping levels. Effect is up to 10% of tidal range on Old River. Small compared to barrier impact and small in Middle River. • Moderate impact on Old River tidal range of flow, mostly identifiable with barriers in. Smaller impact on Middle River and Grant Line Canal.
San Joaquin River (SJR) Inflow and Salinity at Vernalis[1]	• Non-linear, positive relationship with SJR flow • High[2] sensitivity when barriers are in place • Low sensitivity in low-flow conditions, especially with no barriers • Sensitivity increases with proximity to the SJR	• Influence proportional to SJR flow • Influence can be fresh or salty depending on SJR inflow EC • Low sensitivity in low-flow conditions (i.e., low inflow volumes cannot flush peak in-Delta sources) • Higher sensitivity at "larger" inflow volumes (develops at flow ranges between 700 and 3,000 cfs), often corresponding to higher salinity (e.g., during winter both SJR flow and EC are higher relative to other seasons)	• Null zones are more common during low-flow conditions • SJR inflow (at flows < 2,000 cfs) may affect location of Lower Old River null zone	• Low sensitivity of water levels in flow conditions < 2,000 cfs inflow compared to the barrier effect. • High sensitivity in peak runoff or storms. High flow dampens tidal range and can eliminate tides entirely in some years.
Temporary Barriers[1] (presence and configuration)	• High, positive impact • Typically more than offsets exports on low water (e.g., at Tracy Blvd, +1.1–1.4 ft of increase due to barriers, 0.5–0.9 ft drawdown from exports at OLD) • Lower sensitivity on Middle River • Lower effectiveness on interior of Tom Paine Slough due to conveyance limitations and nonlinearity of the effect across multiple barriers (temporary barrier plus Tom Paine)	• Indirectly contribute to salt accumulation due to reduced tidal flushing and reinforcement of null zones • When barriers are in place, tidal flows are extinguished on Middle River and Lower Old River, forming what we have called a "tidal null zone"	• Barrier formation is not essential for null zone formation, which often happens before barriers go in • Medium sensitivity of location and strength to barrier presence • Sensitivity to barrier configuration (e.g., partial barrier in 2023 under high flow still led to null zone).	• High impact upstream of barriers. • High impact on Old River • High impact on Grant Line Canal, but tidal range is still extensive when barriers are present • Lower impact on Middle River
Tides[1] (range and extent)	• High impact, especially on Grant Line Canal	• High impact	• Low. However, tidal null zone occurs in conveyance-limited areas such as Old	N/A

Influencing Variable	General Sensitivity Summary			
	Water Level	**Salinity**	**Null Zones and Net Flow**	**Tidal Range**
	• Tidal flows are the dominant variable forcing water level changes in the South Delta channels • Impacts are reduced when barriers are in place • Tidally forced lows impose physical constraints on control over low water levels	• Extent of tidal flushing has high impact on salt accumulation, especially along Lower Old River and Middle River, when the temporary barriers are in place	River at Tracy Blvd. When the net flow null zone coincides with this area of limited tides, salinity is trapped.	
Channel Bathymetry (simple artificial dredging experiments)	• Highest impact on Middle River. Mixed influence. Increased conveyance facilitates higher lows in places that are conveyance limited, lower lows in places that are most hydraulically connected to the South Delta, bringing lower lows when barriers out. • Lower impact on Old River	• Indirectly affects salinity via ability of channels to convey flushing flows • High sensitivity in Middle River • Low sensitivity in Old River	• High impact on Middle River • Lower impact on Old River • High relative depth/conveyance causes most of the overall export sensitivity to be focused on larger channels seaward of the export facilities and concentrates most of the remaining South Delta sensitivity in Grant Line Canal	• High impact in simulated "dredged" channels, especially for Middle River, which is conveyance limited.
Unquantified/ Underquantified In-Delta Diversions or Discharges [1]	• Low impact except in isolated/pooled areas such as parts of Middle River or the end of Tom Paine Slough near Pescadero Irrigation District • Limited study due to data limitations	• High impact, especially near the Five Points Region and Middle River • Dominant control on salinity during summer and fall when SJR inflow volumes are lower and the barriers are in place, truncating tidal dispersion	• High sensitivity to channel depletions (i.e., there is a 1:1 localized effect) • Local depletions required for formation of a null zone	• Possible, but not addressed in the MSS. • There is uncertainty related to vegetation

Notes:
[1] Seasonality complicates the different sensitivities to variables and variable interactions.
[2] The terms high, medium, and low are used qualitatively to describe impacts of different variables relative to one another and relative to different South Delta reaches. Changes in water levels, salinity, null zone convergence points, and tidal range are not geographically or temporally uniform, therefore, quantitative values of these sensitivities are difficult to generalize and at times are difficult to separate. The qualitative assessments were an attempt to characterize the impact of the variables on responses of interest over typical ranges. See Section 4.1 of Attachment 6 where the scaling is discussed.

- **Tidal flows** are the primary influence on relative water levels and dispersion of salinity concentrations through the main channels of the South Delta via the daily reversals of flow direction facilitating the mixing and transport of salt. Water level sensitivity to San Joaquin River inflow and Vernalis salinity is low when flow is below 2,000 cfs. That sensitivity increases to moderate levels on Old River (and on Grant Line Canal primarily when barriers are absent), and becomes high during peak runoff or storm events, when strong flows can substantially dampen or even eliminate tidal ranges.
- **Export pumping** of the SWP and CVP draws water toward the pumping facilities, suppresses tides, and reduces water levels. The drawdown of water levels is greatest near the intakes of the pumping facilities and decreases with distance upstream. High export pumping, paired with high flows on the San Joaquin River, may promote increased movement of water across the South Delta channels. Two caveats to this dynamic are: (1) most export change is absorbed into net flow changes on the downstream reaches of Old and Middle River in the Central Delta, and (2) any remaining export sensitivity in the South Delta is mostly absorbed by Grant Line Canal under low- to moderate-flow conditions, leaving little sensitivity on Old River and Middle River. The local effect on water quality depends on whether the San Joaquin River or intake water is fresher and the direction of flow through the river segments. Water level and flow responses are generally low to moderate, with sensitivity to some variables possibly increasing under high pumping. Old River also exhibits some reduction of tidal range under higher pumping, but the relative reduction (~10% typical upstream of barriers) is smaller than the attenuation caused by barriers (~50% typical).
- **The temporary barriers**, typically present from May to November, have the most profound effect on water levels and circulation in the South Delta. The temporary barriers trap tidal flood flows on the upstream side, protecting upstream water levels from export pumping drawdown, especially at low tide. The temporary barriers also alter circulation and suppress tidal dispersion of salts, allowing salt to accumulate in areas where reduced flushing coincides with high-salinity local sources.
- The relative influence of San Joaquin River flow and SC at Vernalis versus the volume and SC of in-Delta discharges shifts seasonally.
    - **During winter and spring**, both San Joaquin River flow and SC measured at Vernalis are relatively higher compared to other seasons. In other words, a larger volume of water with a higher concentration of salinity enters the Delta on the San Joaquin River during the winter and spring. In the *absence of the temporary barriers*, the seasonally higher San Joaquin River flows exert greater control over salinity concentrations at downstream compliance locations such as OLD during this time of year.
    - **During late summer and fall**, both San Joaquin River flow and SC measured at Vernalis are relatively low when *the temporary barriers are in place*. In other words, the San Joaquin River has low salinity concentrations, but there is less freshwater inflow in the system during the late summer and fall when circulation in the South Delta channels is impeded by the temporary barriers in the interest of raising minimum water levels. Modified circulation due to the barriers and seasonally low San Joaquin River flows mean that in-Delta discharges exert greater control over salinity concentrations at the South Delta compliance locations during this time of year.

  - **Simple salinity sensitivities are elusive.** The complex relationship between flow and SC measured at Vernalis is passed on to all downstream analyses. The need to address in-Delta sources of salinity is greatest from late summer into winter, although there is also an apparent water year type effect with drier years yielding higher concentrations or loadings of salts. Combinations of San Joaquin River flow and SC that have historically produced good water quality outcomes at interior South Delta locations are discussed in the main report.

- **The South Delta is prone to the development of null zones.** Null zones developed on Lower Old River during all three MSS study years (2021–2023), regardless of water year type. Because null zones are places where water converges, it requires a local net sink to form. The size and location of null zones are also influenced by other local flow features, such as the upstream-directed tidal flow tendency introduced by the temporary barriers, ambient San Joaquin inflow, and export conditions. Salinity levels in the null zones are typically amplified when tidal flows are too weak to adequately disperse salt. The null zone and the coinciding "hot spot" of salinity on Lower Old River migrate based on ambient flows and salinity sources. A misconception is that the temporary barriers are required for null zone formation; in fact, null zones form before the installation of the barriers.
- Middle River also develops a null zone, due to the same upstream-directed tidal flow tendency introduced by the temporary barriers, local channel depletions, ambient San Joaquin inflow, and export conditions. However, **Middle River also has an issue of conveyance limitation**, with both lower mean flow and tidal exchange, particularly between Middle River at Undine Road (MRU) and Howard Road. This contributes to null zone formation and elevated salinity seasonally near the Middle River at the Howard Road (MHO) station. Middle River's shallow bathymetry and periods of high aquatic vegetation pose further challenges in both flow and water quality monitoring.
- **Bathymetry sensitivity experiments** suggest that channel dredging has potential to improve tidal flushing and water quality on Middle River. However, dredging alone would not eliminate the transport of salts from Paradise Cut down Old River, which is driven by complex tidal exchanges in the channels of the Five Points Region (see the map on Figure ES-1) where Upper Old River, Lower Old River, Grant Line Canal, Sugar Cut, and Paradise Cut converge.
- **Water levels** are influenced by tides, exports, temporary barriers, and San Joaquin River flows. Generally, reductions in South Delta water levels due to drawdown by exports (0.5 to 0.9 foot [ft] change in water levels at highly influenced sites near the intake area under the full pumping capacity) are more than offset by the temporary barriers (+1.4 ft at the same sites). Exceptions occur in places with conveyance limitations—Middle River between Undine and Howard Roads is one example and Tom Paine Slough is another. In those areas, local influence by in-Delta diversions is greater and the influence of exports and barriers is more complex. Low water metrics were the focus of the MSS and are the only tidal phase that benefits from the temporary barriers.
- From fall through spring, when *the temporary barriers are not installed*, the South Delta water levels historically identified as "water levels of concern" for in-Delta irrigators represent water levels that would be seen routinely at low tides based on the geometry of the Delta and coastally forced tides. Exports influence water levels on top of the coastally forced

levels but controlling for exports (i.e., confining analysis to low export periods), makes it clear that "concern" levels occur naturally during a significant fraction of the daily tidal cycle (typically 30–50%).

Key Recommendations

The South Delta has complex and variable water circulation patterns that challenge precise definitions of river reaches. This complexity makes it challenging to apply uniform water quality compliance standards. Therefore, the MSS authors propose a clarification of the term "compliance reaches" as defined in the 2018 Bay-Delta Plan in view of the actual hydrodynamics of the system (Figure ES-1).

- The current definitions for the **San Joaquin River compliance reach** (Vernalis to Brandt Bridge) and the **Middle River compliance reach** (Old River to Victoria Canal) are considered appropriate. Existing long-term monitoring stations (VER, MSD, and BDT for San Joaquin River; MRU, MRX, and MHO for Middle River) effectively assess salinity conditions within these reaches.
- The **Old River/Grant Line Canal compliance reach** is hydrologically too complex to remain a single reach. Influences such as proximity to water export facilities, temporary barriers, local salinity inputs, null zones, and tidal dynamics necessitate **subdividing it into two distinct reaches**:
    - **Upper Old River/Grant Line Canal** (Head of Old River to Grant Line Canal near Old River)
    - **Lower Old River** (Doughty Cut to Old River below the Old River Barrier)
- The proposed separated compliance reaches are supported by existing long-term monitoring infrastructure, with stations such as OH1, ORX, GLE, and GLC (Upper Old River/Grant Line Canal), and OLD, ORM, and ODM (Lower Old River), capturing upstream, mid-reach, and downstream salinity trends (Figure ES-1, ES-2).
- The **Lower Old River compliance reach** poses significant challenges in meeting current compliance standards, especially during dry to critically dry years. As such, **adaptive compliance objectives** that allow for seasonal or water year-type adjustments should be considered for this reach (Figure ES-2).
- The flow volume needed to flush Lower Old River heavily depends on seasonal local salinity from agricultural and municipal discharges. Conjecture that 2021 is an example of meeting the necessary flushing flow volume is not supported by findings from the MSS. In early summer of that year, flows coincided with low local discharges; therefore, inflows were considerably more than what was needed to flush minimal local discharges. In late summer, flows coincided with very high local discharges and were less than what would have been needed to flush increased local discharges.
- Adjustments to the current monitoring network should be considered when developing the LTMRP. This includes replacing the current GLC station, moving it upstream near the MSS temporary station GCMW, where the data will better represent Grant Line Canal rather than the OMR water sources. In addition, adding a station between the MSS temporary station

OAAU and long-term station TWA would help to better define the extent of the Lower Old River null zone and bracket a major sink in the South Delta.

- DWR and Reclamation look forward to the State Water Resources Control Board gathering more accurate and timely monitoring data for in-Delta sources of both water and salt in the South Delta. Data on volume of diversions and volume of water discharged, as well as the salinity of that water that is discharged into the South Delta waterways, especially in the Lower Old River and Five Points Regions, would improve real-time modeling and water quality management of mainstem channels.

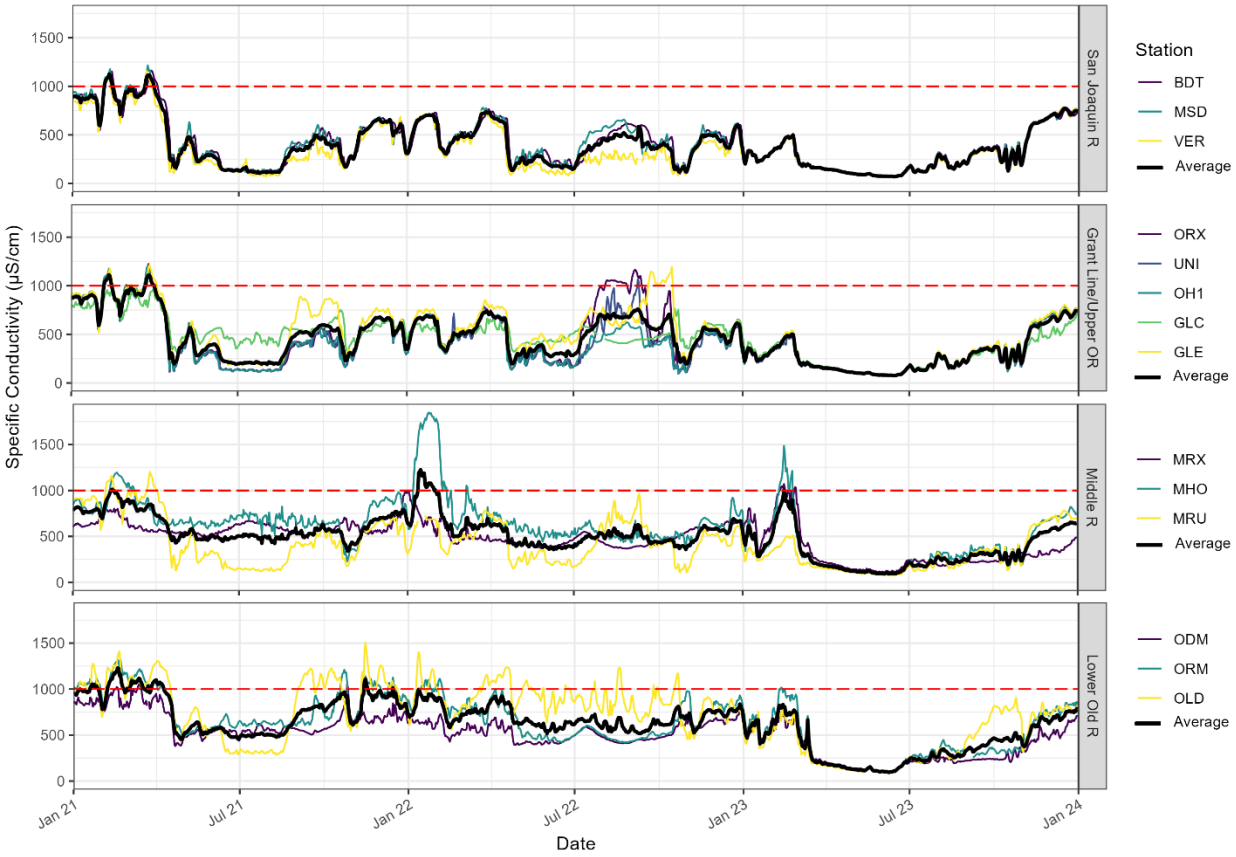


Figure ES-2. Daily Mean Specific Conductivity by Station and Recommended Compliance Reach. Bold black line is a combined average of stations within that compliance reach.

The MSS results are meant to inform the development of an **LTMRP** to assess attainment of the interior southern Delta water quality objectives. Using the four suggested compliance segments listed above, DWR and USBR propose to consider two potential approaches to an LTMRP that recognize the variable hydrology of the South Delta: (1) Recognize the flow regimes and seasonal in-Delta salinity sources, develop indicators to describe the state of circulation, and recognize the challenges involved in establishing reach-based compliance objectives; (2) Use statistical averaging to manage this complexity, prioritizing overall good average performance rather than regulating based on the worst-case condition along the reach. The following points should be considered during development of an LTMRP:

- The OLD compliance station (interagency station P-12) is not representative of salinity along the rest of Old River or Grant Line Canal; therefore, another location or use of the cumulative average of several stations along the reach would provide a better way to assess compliance (Figure ES-1).
- Adjustments to the current permanent monitoring network should be considered before the costly and potentially redundant installation of any new permanent monitoring stations.
- In-Delta discharge rates and SC should be monitored in real-time to quantify in-Delta salinity sources. However, in the absence of actual in-Delta diversions and returns data, observed continuous data was used in the MSS to infer SC sources. The inference process was corroborated with three independent data or model results to demonstrate its robustness. To further validate the inferred sources and improve model accuracy, characterization of the larger interior sources is needed. Support from the State Water Resources Control Board would be essential to collecting this information.

Chapter 1 Introduction

In the *1995 Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary* (Bay-Delta Plan), as amended through 2006, the State Water Resources Control Board (SWRCB) set salinity objectives for the interior southern Sacramento–San Joaquin Delta (Delta), or South Delta. In Water Right Decision 1641 (D-1641), as part of implementation of the 1995 Bay-Delta Plan, the California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR) were held partially responsible for salinity challenges in the South Delta channels and were assigned responsibility, within reasonable control, for meeting water quality objectives, including maintaining 30-day average specific conductivity (SC), herein referred to as either SC or electrical conductivity (EC)[2] at three monitoring stations (Interagency Stations No. C-6, C-8, and P-12) in the South Delta waterways (Figure 2-1). In 2018, SWRCB adopted amendments to the Bay-Delta Plan, in which DWR and USBR were to conduct a Monitoring Special Study (MSS).

Requirements for the MSS are described on pages 35–38 of the 2018 Bay-Delta Plan. Section B(1)(ii) describes existing interior southern Delta compliance locations and the river segments that comprise the 2018 Bay-Delta Plan interior southern Delta salinity compliance locations. Section B(1)(iv) details the requirements of the MSS.

> *ii. Interior Southern Delta Compliance Locations: In D-1641 the State Water Board concluded that DWR and USBR are partially responsible for salinity problems in the southern Delta due to hydrologic changes caused by export pumping. D-1641 imposes conditions on DWR's and USBR's water rights requiring implementation of EC levels of 0.7 mmhos/cm from April through August and 1.0 mmhos/cm from September through March at the three compliance stations in the interior southern Delta (Interagency Stations No. C-6, C-8, and P-12). As part of implementing the salinity water quality objective for the interior southern Delta, the State Water Board will amend DWR's and USBR's water rights to continue to require implementation of the interior southern Delta salinity water quality objectives consistent with this plan. The State Water Board may also consider the responsibility of others for implementing the interior southern Delta salinity objective based on implementation or completion of the Comprehensive Operations Plan, Monitoring Special Study, modeling, or Monitoring and Reporting Plan described below, or development of other information.*
>
> *The interior southern Delta salinity compliance locations are comprised of three river segments rather than three specific point locations so that compliance with the southern Delta salinity objective can be better determined in a Delta environment subject to alternating tidal flows. DWR's and USBR's water rights shall be conditioned to require development of information that will be used to determine the appropriate locations and methods to assess attainment of the salinity objective in the interior southern Delta, including through the Comprehensive Operations Plan, Monitoring Special Study, Modeling, and Monitoring and Reporting Plan described below. Prior to State Water Board approval of the Monitoring and Reporting Plan, compliance with the salinity objective for the interior southern Delta will be assessed at stations C-6, C-8, and P-12, which USBR and DWR shall be required to continue to operate as a condition of their water rights. Chapter III of this plan provides the general rule that unless otherwise provided, water quality objectives cited for a general area are applicable for all locations in that general area. Consistent with this, the use of compliance locations and gage stations to determine compliance*

[2] Specific conductivity (SC) and electrical conductivity (EC) are used interchangeably throughout the report.

by DWR and USBR shall not be interpreted as a limitation on the applicability of the southern Delta salinity objective, which applies throughout the southern Delta.

iv. Special Studies, Modeling and Monitoring and Reporting: To implement and determine compliance with the salinity objective in these river segments, and to inform the COP, the State Water Board will require DWR and USBR to complete the following activities. The State Water Board will require compliance with these activities pursuant to its Porter-Cologne Water Quality Control Act authority to require technical and monitoring requirements, or as a requirement of a water right order:

a. ***Monitoring Special Study**: Prior to development of the long-term Monitoring and Reporting Plan, described below, DWR and USBR shall work with State Water Board staff and solicit* [participating organization[3]] *input to develop and implement a special study to characterize the spatial and temporal distribution and associated dynamics of water level, flow, and salinity conditions in the southern Delta waterways. The study shall identify the extent of low or null flow conditions and any associated concentration of local salt discharges. The State Water Board will request local agricultural water users and municipal dischargers to provide data regarding local diversions and return flows or discharges. DWR and USBR shall submit a plan for this special study to the Executive Director for approval within six months from the date of OAL's approval of this amendment to the Bay–Delta Plan. Once approved, the monitoring contained in this plan shall be conducted until superseded by the long-term Monitoring and Reporting Plan, described below, is approved.*

b. ***Modeling:** DWR and USBR shall provide modeling and other technical assistance necessary to prepare and update the COP, and otherwise assist in implementing the southern Delta agricultural salinity objective. DWR and USBR will be required to continue to provide this assistance as required by State Water Board Order WR 2010-0002, which modifies paragraph A.3 of Order WR 2006-0006.*

c. ***Monitoring and Reporting Plan:** DWR and USBR shall develop long-term monitoring protocols to measure compliance with the performance goals of the COP, and to assess attainment of the salinity objective in the interior southern Delta. These monitoring and reporting protocols shall be based on the information obtained in the **Monitoring Special Study**, and shall include specific compliance monitoring locations in, or monitoring protocols for, the three river segments that comprise the interior southern delta salinity compliance locations. The Executive Director may approve changes to the gage stations at which compliance is determined, except monitoring station C-10, in Table 2, if information shows that other gage stations more accurately represent salinity conditions in the interior southern Delta. The Monitoring and Reporting Plan will be required to be integrated and coordinated with existing monitoring and special studies programs in the Delta. DWR and USBR shall submit the Monitoring and Reporting Plan to the Executive Director for approval within 18 months from the date of OAL's approval of this amendment to the Bay–Delta Plan.*

1.1 MSS Goals and Objectives

Consistent with section B(1)(iv) of the 2018 Bay-Delta Plan, the MSS addresses three goals:

- Characterize the spatial and temporal distribution and associated dynamics of water level, flow, and salinity conditions in the South Delta waterways.

[3] This document uses the term *participating organization* instead of *stakeholder.*

- Identify the extent of low- or null-flow conditions and any associated concentration of local salt discharges.
- Inform the development of a Long-Term Monitoring and Reporting Plan (LTMRP) that will:
    1. Assess attainment of the salinity objective in the South Delta.
    2. Include long-term monitoring and reporting protocols, including specific compliance monitoring locations in, or monitoring protocols for, the three river segments that comprise the South Delta salinity compliance locations (see Figure 2-1 for compliance locations).

Prior to the MSS, DWR and USBR have conducted several studies investigating salinity conditions at the interagency monitoring stations where intermittent exceedances of salinity objectives have occurred. Building on the understanding gained from prior studies and analyses, the MSS is intended to accomplish the following objectives to achieve the goals listed above:

- Better understand salinity, flow, and stage conditions in the South Delta, including data collection and/or analysis of:
    - Flow and salinity levels measured at and downstream of the San Joaquin River at Vernalis.
    - A range of South Delta export pumping scenarios at C.W. Bill Jones Pumping Plant and Harvey O. Banks Pumping Plant.
    - Flows during and after temporary agricultural barrier season.
    - South Delta processes (i.e., seasonal operations of water users and associated EC).
- Assess whether existing compliance stations are representative of river segments in the South Delta.
- During 2021, using best-science practices, DWR and USBR solicited input from participating agencies and worked with SWRCB staff through a series of quarterly meetings to design technical studies to accomplish the MSS goals and objectives. The details of these technical study designs were provided in an MSS workplan, which was submitted to SWRCB for consideration in September 2022 (Section 1.2, *MSS Plan and SWRCB Conditional Approval*, provides more details).

In 2022 and 2023, DWR and USBR continued to conduct quarterly meetings to provide updates to, and discuss questions from, SWRCB and participating organizations on implementation of the technical studies, including data collection and model refinement. DWR and USBR also conducted various technical workgroup meetings to further describe and explain the methodology of the technical studies. An archive of notes from the technical workgroup and public coordination meetings is available on the DWR Monitoring Special Study Website (DWR 2026). A list of quarterly public coordination, technical workgroup meetings, and informal discussions held with interested parties to inform the MSS Plan, respond to questions, and gather feedback that occurred from June 2022 until July 2024 is provided in Appendix A, *Outreach to Participating Organizations since Publishing the Monitoring Special Study Plan*.

This document serves as the final report for the MSS, which summarizes and synthesizes content from each technical study described in the attachments and appendices.

1.2 MSS Plan and SWRCB Conditional Approval

On September 19, 2022, DWR and USBR submitted a work plan for the MSS (MSS Plan) to SWRCB, which included attachments of individual study plans for each of the technical studies.

On May 5, 2023, SWRCB responded with a conditional approval of the MSS Plan, stating,

> *Field monitoring in the MSS Plan was designed for the purpose of validating and improving modeling simulations in the South Delta, and to identify and characterize local salinity sources; these additional field samples can also support additional analyses and new insights. Transparent and accessible modeling will be important for testing management concepts and development of monitoring protocols for compliance in the southern Delta. However, inferences based on traditional data analyses of observed field data remain a centerpiece of our knowledge base and should continue in parallel with any proposed modeling efforts.*
>
> *The MSS Plan is approved subject to satisfaction of the following conditions:*
>
> 1. *Making available to interested stakeholders the custom versions of Bay-Delta models relied upon in the MSS Plan in a usable form. The Bay-Delta SCHISM and the GTM module of DSM-2 are heavily relied upon in the MSS Plan, and should be accessible and transparent. If not published online, these products should be otherwise made readily available, or access should be provided to interested parties. Documentation on calibration, improvements, manuals and other details should be made public consistent with other DSM-2 modules.*
> 2. *Inclusion of analyses of historical flow and salinity data from continuous monitoring stations published on Water Data Library or California Data Exchange Center to characterize the spatial and temporal distribution of flow and salinity and associated dynamics in the southern Delta (to be included as a technical study chapter in the MSS Final Report). The purpose of this analysis of historical data is to identify periods when salinity is not attained, assess conditions that lead to noncompliance (a range of relevant parameters regardless of whether within operational control), evaluate past instances of return to compliance, and identify potential actions that may support returning to and maintaining compliance. At a minimum, hourly data shall be used to understand fate and transport with full tidal variation of ebb and flood tides, and to account for parameters that change on a sub-daily time step (such as Clifton Court Forebay gate operations).*
> 3. *Inclusion of evaluations of whether the existing continuous salinity monitoring stations are sufficient to determine the appropriate locations and methods to assess attainment of the salinity objective in the river segment (section B(1)(ii)). Specifically, approval is conditioned on DWR and Reclamation working with State Water Board staff to determine if collecting ion samples or scheduling seasonal transects in Middle River is needed to support an evaluation of existing compliance stations for the purposes of identifying compliance approaches that are representative of salinity conditions in the interior southern Delta and to validate model results.*
> 4. *Addition of flow monitoring at or near Old River above Paradise Cut Confluence (B9538600) in below normal, dry, and critical water year type conditions prior to completion of the MSS study. DWR and Reclamation have already augmented the flow monitoring with temporary stations in multiple southern Delta locations. However, the amplitude and direction of instantaneous flow remain a critical gap for understanding the fate and transport of salt from Paradise Cut into Doughty Cut and into lower Old River, especially during years with below average runoff.*

5. *Inclusion of at least one additional line of evidence in the technical modeling studies (such as published continuous measurements, transects, point sampling) to validate or support any inferred salinity sources in data assimilation and as used in SCHISM.*

The MSS Plan (DWR and USBR 2022) provided the workplan for conducting the MSS Technical Studies. The workplan was designed to meet the requirements in Section IV.B.1.iv. of the 2018 Bay-Delta Plan and feedback provided by interested parties collected during development of the MSS Plan. Modifications were made to the MSS Plan in 2023 during MSS implementation to satisfy the conditions from SWRCB in their approval of the MSS Plan. The MSS Report (this document) is the culmination of this work. Figure 1-1 shows the evolution of the MSS Plan to the MSS Report with the requirements and conditions it was developed to satisfy.[4] The MSS Plan originally described five topics: (1) High-Speed Salinity Transect, (2) Salinity Point Source and Ion Sampling, (3) SCHISM 3D Hydrodynamic and Water Quality Modeling, (4) Water Quality Data Assimilation, and (5) Quarterly Technical Workgroup and Public Coordination Meetings. These topics are addressed in *High-Speed Salinity Transect Mapping* (MSS Report, Attachment 1), *Salinity Point Source and Ion Sampling* (MSS Report, Attachment 2), *Circulation, Channel Depletion, and Barrier Assumptions for Modeling the South Delta, 2024 Revision* (MSS Report, Attachment 3), *Data Integration and Source Inference for Modeling* (MSS Report, Attachment 4), *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6), and Appendix A of the MSS Report. DWR and USBR have analyzed additional topics, in response to discussions with SWRCB and participating organizations, which are detailed in *Clifton Court Forebay Gate Characterization, Scheduling Study, and Facilities Comparison* (MSS Report, Attachment 5), *2021 Old River Tracy Barrier Flow Study* (MSS Report, Attachment 7), Appendix B, *Supplemental Stable Water Isotope Analysis*, and Appendix C, *Low Water Metrics*.

[4] For Figure 1-1, note that the requirements in the MSS Plan are carried over, but not repeated, in the MSS Report. For example, Appendix A of the MSS Report meets the "coordinate" requirement by transitive property from the MSS Plan.

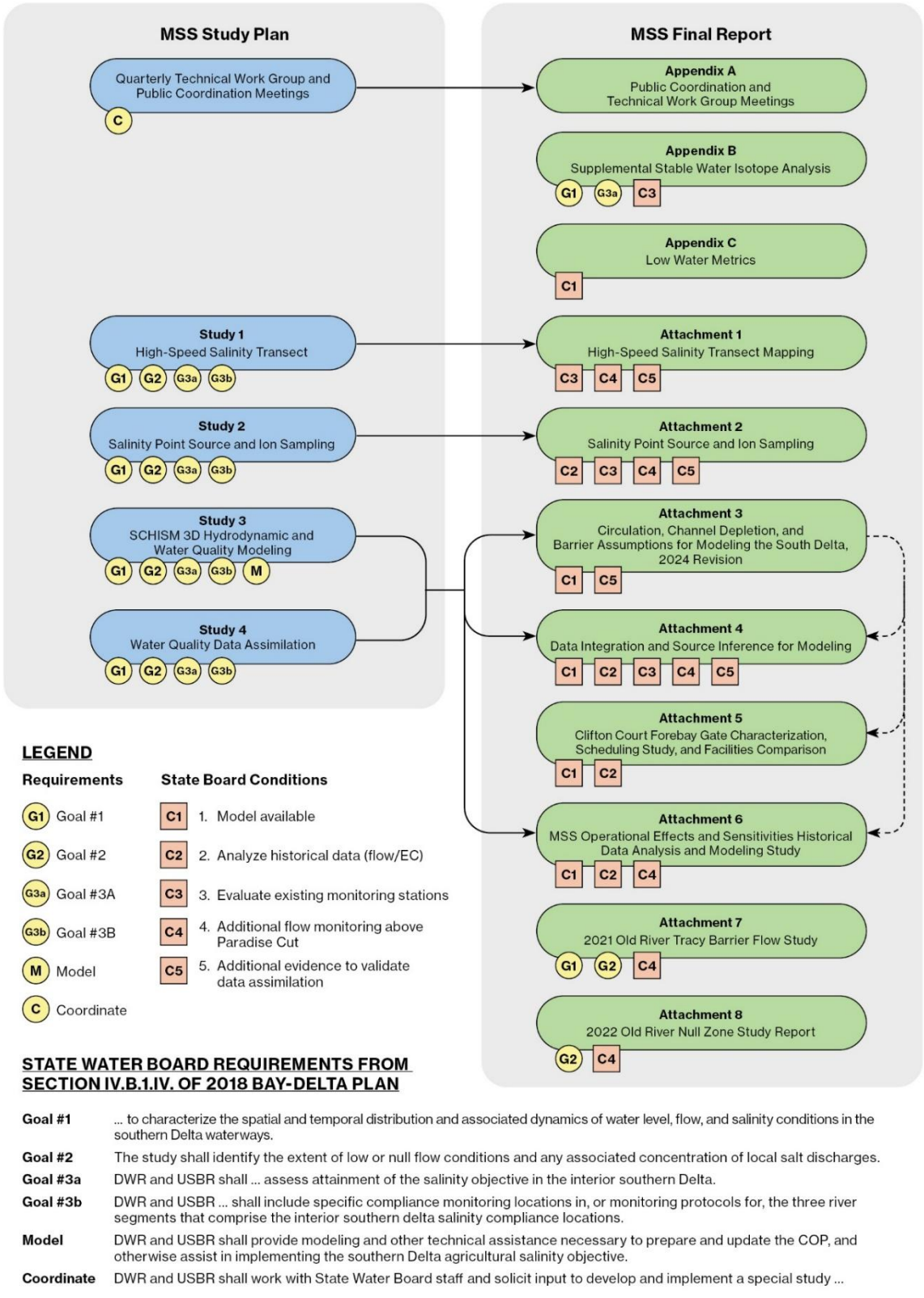


Figure 1-1. Depiction of the Connections between MSS Report, MSS Plan, MSS Objectives, and the SWRCB Conditions

Chapter 2 MSS Study Area Overview

2.1 Study Area

The MSS study area consists of the interior southern Delta, or South Delta, waterways and includes the compliance locations identified under Table 2, on page 12, of the 2018 Bay-Delta Plan. It lists the river segments between the existing South Delta compliance locations, including the San Joaquin River from Vernalis to Brandt Bridge, Middle River from Old River to Victoria Canal, and Old River/Grant Line Canal from Head of Old River to West Canal (see Table 2-1).

As specified in the 2018 Bay-Delta Plan, "The interior southern Delta salinity compliance locations are comprised of three river segments rather than three specific point locations so that compliance with the southern Delta salinity objective can be better determined in a Delta environment subject to alternating tidal flows." The three river segments listed in the 2018 Bay-Delta Plan are, therefore, considered the geographic scope of the MSS. Figure 2-2 shows the MSS study area where the monitoring and modeling efforts were focused, beginning at Airport Way Bridge, Vernalis, and concluding at West Canal.

Table 2-1. Water Quality Objectives for Agricultural Beneficial Uses

Compliance Locations	Interagency Station Number (RKI[1])	Parameter	Description Unit[2]	Water Year Type[3]	Time Period	Value
Western Delta						
Sacramento River at Emmaton	D-22 (RSAC092)	Electrical Conductivity[5] (EC)	Maximum 14-day running average of mean daily EC (mmhos/cm)	--	0.45 EC April 1 to date shown	EC from date shown to Aug 15[4]
				W	Aug 15	--
				AN	Jul 1	0.63
				BN	Jun 20	1.14
				D	Jun 15	1.67
				C	--	2.78
Sacramento River at Jersey Point	D-15 (RSAN018)			--	0.45 EC April 1 to date shown	EC from date shown to Aug 15[4]
				W	Aug 15	--
				AN	Aug 15	--
				BN	Jun 20	0.74
				D	Jun 15	1.35
				C	--	2.20
Interior Delta						
South Fork Mokelumne River at Terminous	C-13 (RSMKL08)	Electrical Conductivity (EC)	Maximum 14-day running average of mean daily EC (mmhos/cm)	--	0.45 EC April 1 to date shown	EC from date shown to Aug 15[4]
				W	Aug 15	--
				AN	Aug 15	--
				BN	Aug 15	--
				D	Aug 15	--
				C	--	0.54
San Joaquin River at San Andreas Landing	C-4 (RSAN032)			--	0.45 EC April 1 to date shown	EC from date shown to Aug 15[4]
				W	Aug 15	--
				AN	Aug 15	--

[5] Specific conductivity (SC) and electrical conductivity (EC) are used interchangeably throughout the report.

Compliance Locations	Interagency Station Number (RKI[1])	Parameter	Description Unit[2]	Water Year Type[3]	Time Period	Value
				BN	Aug 15	--
				D	Jun 25	0.58
				C	--	0.87
South Delta						
San Joaquin River at Airport Way Bridge, Vernalis	C-10[5] (RSAN112)	Electrical Conductivity (EC)	Maximum 30-day running average of mean daily EC (dS/m/m)[6]	All	Year Round	1.0
San Joaquin River from Vernalis to Brandy Bridge	C-6[5] (RSAN073)					
Middle River from Old River to Victoria Canal	C-8[5] (ROLD69)					
Old River/Grant Line Canal from Head of Old River to West Canal	P-12[5] (ROLD59)					
Export Area						
West Canal at mouth of Clifton Court Forebay	C-9 (CHWST0)	Electrical Conductivity (EC)	Maximum monthly average of mean daily EC (mmhos/cm)	All	Oct-Sep	1.0
Delta-Mendota Canal at Tracy Pumping Plant	DMC-1 (CHDMC004)					

Note: Table 2 from the 2018 Bay-Delta Plan lists the South Delta waterways between D-1641 compliance station locations and the associated EC objectives for agricultural beneficial uses.

[1] River Kilometer Index station number.

[2] Determination of compliance with an objective expressed as a running average begins on the last day of the averaging period. The averaging period commences with the first time period for the applicable objective. If the objective is not met on the last day of the averaging period, all days in the averaging period are considered out of compliance.

[3] The Sacramento Valley 40-30-30 water year hydrologic classification index (see Figure 2-2) applies for determination of water year type.

[4] When no date is shown, EC limit continues from April 1.

[5] The salinity objective is subject to the Variance Policy, Salinity Variance Program and Salinity Exception Program adopted in Central Valley Regional Water Board Resolution No. R5-2014-0074, as may be amended.

[6] 1 mmhos/cm = 1 dS/m. The International System of Units for EC is dS/m. As other portions of Table 2 are updated in future amendments to the Bay-Delta Plan, the units of measurement for EC will be updated to the international system.

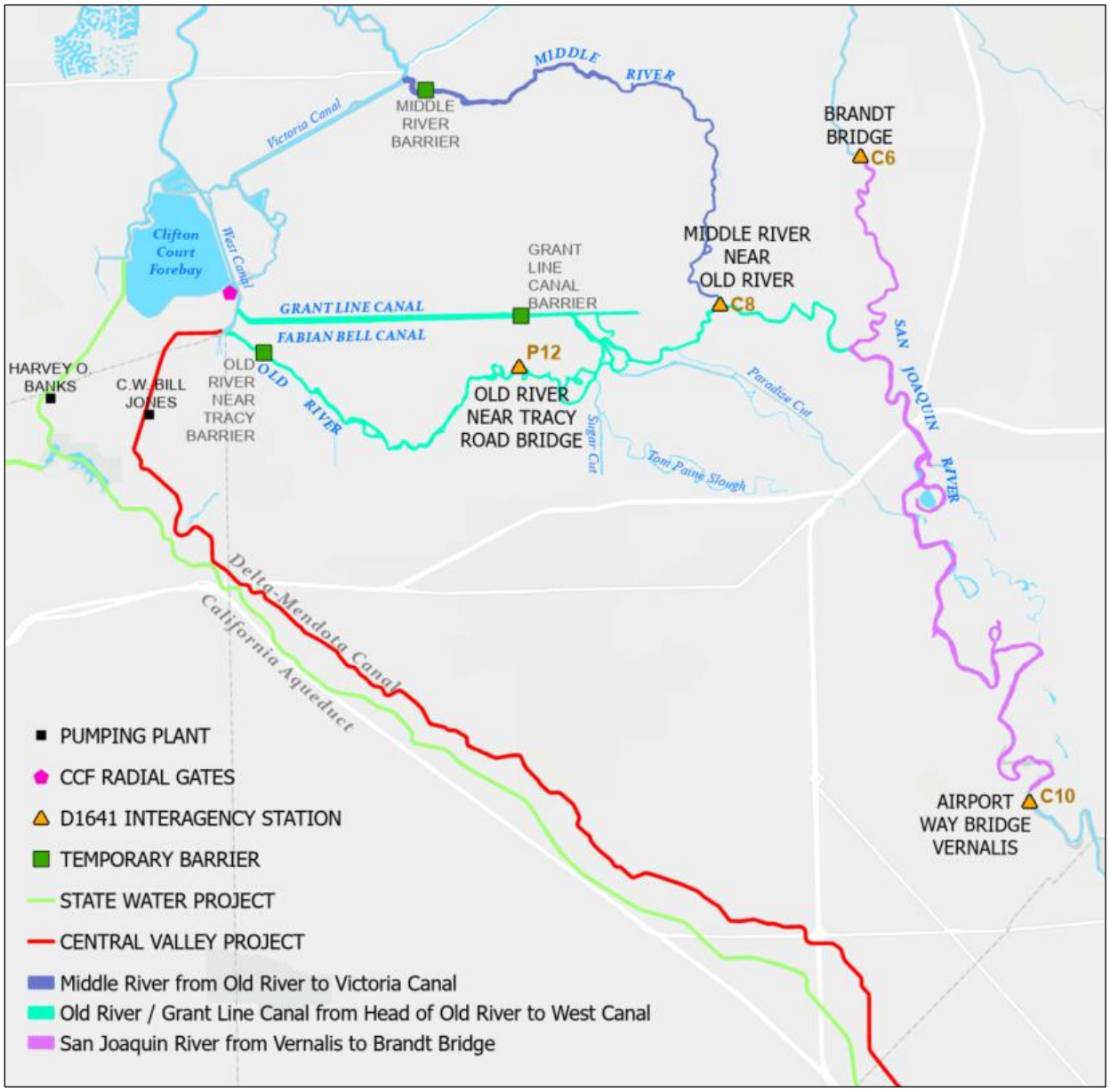


Figure 2-1. South Delta Map Showing Interagency Compliance Station Locations and River Segments Defined by the 2018 Bay-Delta Plan

2.2 Overview of South Delta Hydrology

2.2.1 Flow Patterns

The South Delta is hydrodynamically complex. Generally, the primary freshwater flows are from the San Joaquin River, which flows from south to north along its mainstem. Tidal flows from the northwest—generally a mixture of Sacramento River water and seawater—also contribute to main channel flows via the Old and Middle River region. The intakes for the State Water Project (SWP) and Central Valley Project (CVP) export facilities are situated to the southwest and draw

water from east to west and from north to south at varied rates of pumping. Most of the fresh water that enters the South Delta on the San Joaquin River does so at the Head of Old River (OH1) and flows along Upper Old River, into Grant Line Canal, then west toward the intake area for the SWP and CVP. Along that flow path, a portion of water enters Middle River at its confluence with Upper Old River (UNI) and another portion of that water enters Lower Old River instead of Grant Line Canal.

Given the estuarine setting, tidal cycles influence flows and water levels in the South Delta multiple times a day, the strength of which varies multiple times each month. Twice per day during the flood tide (high tide), water flows in from the San Francisco Bay moving from north to south, raising water levels in South Delta channels. Flows then reverse twice per day during ebb tide (low tide), when water moves out toward the Bay, lowering water levels in the South Delta. The daily tidal cycle, therefore, drives the natural conditions under which water levels are either at their highest or lowest in the South Delta. The magnitude of tidal range, or the difference in height between high and low tide, naturally varies corresponding to spring and neap tides (i.e., twice per month during the spring tide, high and low tides are exaggerated, whereas more moderate tides are observed during neap tide). The strength of high and low tides affects the spatial extent of tidal flows, or how far upstream the flood tide reaches. See Appendix C, *Low Water Metrics*, for a description of metrics used to assess low water levels throughout this report.

The action of drawing water toward the SWP and CVP pumping facilities lowers water levels in nearby channels, the amount of which varies with different combinations of influencing factors. To mitigate for water level drawdown during the summer and fall seasons when local water demand is highest, DWR installs three temporary rock barriers in the South Delta to maintain water levels for local diversions during lower tides. The three agricultural rock barriers are located on Old River near Tracy, Middle River near Victoria Canal, and Grant Line Canal (Figure 2-1). They are typically constructed starting May 1 and removed by November 30 every year, based on conditions of several regulatory permits. The Middle River and Grant Line Canal rock barriers have six 48-inch-diameter culverts while Old River has nine 48-inch-diameter culverts. All culverts have one-way flap gates on the upstream end to allow flood tides to pass through and restrict ebb tides. Trapping the high tide increases the water levels upstream of the barriers. The temporary barriers are effective for their intended purpose of protecting upstream water levels, as will be discussed in more detail below; however, their presence also suppresses the extent of tidal flows and limits circulation in ways that can increase water residence time in the South Delta.

Water use is extensive in the South Delta and the quantity and timing of local diversions and discharges are not well known. Generally, water used for irrigation is pumped from the channels, applied to fields, and then drained back into the channels in varying amounts throughout the year. Paradise Cut, Sugar Cut, and Tom Paine Slough are the three major side tributaries that partially form the area referred to as the “Five Points Region” at their confluence with Old River (Figure 2-2). These three channels primarily serve as conveyance for agricultural water and some municipal discharges, such as from the City of Tracy. Paradise Cut is typically a dead-end slough, except when the Paradise Cut Weir overtops during high-flow conditions (>17,000 cubic feet per second [cfs] at Vernalis) on the San Joaquin River. Sugar Cut and Tom Paine Slough are also dead-end channels that exchange water with one another in addition to Old River.

Downstream of the Five Points Region, the smaller tributaries of Mountain House Creek and Wicklund Cut also exchange water with Lower Old River. In addition to the diversions and discharges along tributaries, many diversion and discharge points exist along the mainstem channels throughout the South Delta, including the San Joaquin, Old, and Middle Rivers as well as Grant Line and Victoria Canals.

A persistent feature of South Delta hydrology is the development of "null zones," or areas of convergent flow (observed flow near zero) that trap water and result in increased water residence times and the accumulation of salts dissolved in the water. Null zones are known to occur on Lower Old River, Middle River, and Grant Line Canal. However, no systematic understanding of the conditions affecting the evolution of specific null zones existed prior to this study.

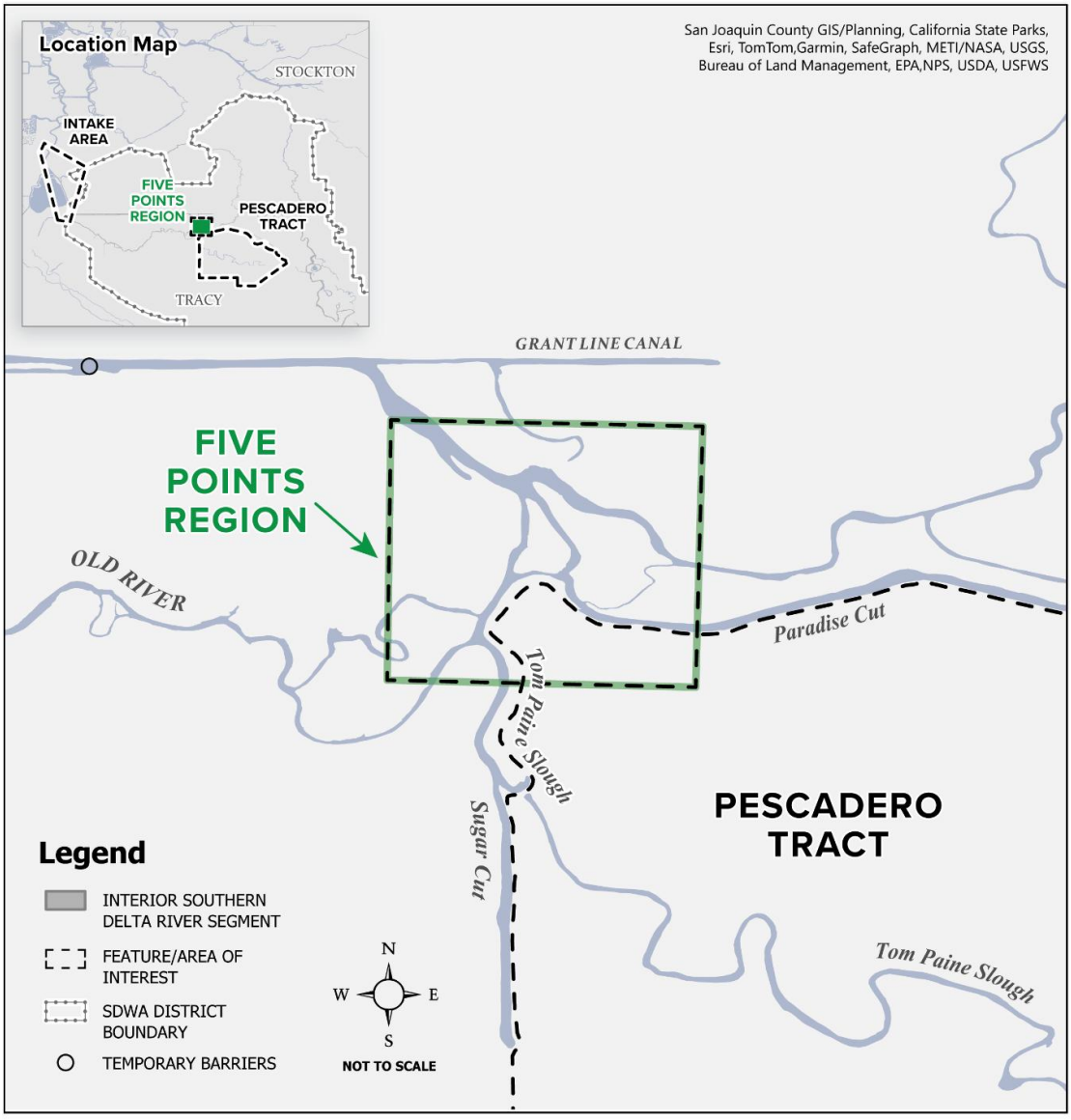


Figure 2-2. Map of the Five Points Region in the South Delta. Intake Area and Pescadero Tract are denoted in the inset.

2.2.2 Salinity Concentrations

The complex flow patterns of the South Delta make it difficult to understand the transport of salts through the region using only observations from the current monitoring network. Historically, compliance with the salinity objectives for agricultural beneficial uses in the South Delta has been monitored at the four established compliance stations from D-1641 (see Figure 2-1 for locations):

1. The San Joaquin River at Airport Way Bridge, Vernalis (C-10, California Data Exchange Center [CDEC] code VER)
2. The San Joaquin River at Brandt Bridge (C-6, CDEC code BDT)
3. Middle River near Old River (C-8, CDEC code UNI)
4. Old River near Tracy Road Bridge (P-12, CDEC code OLD)

Salinity concentrations observed at OLD on Lower Old River are generally higher than those observed on the San Joaquin River at Vernalis or Brandt Bridge, or Middle River near Old River (Figure 2-2). Previous work has examined the empirical relationship between EC measured at OLD and both EC and flow measured upstream at Vernalis, which represents the quality and relative volume of water entering the South Delta from the San Joaquin River—largely finding that a simple relationship cannot be relied on to accurately predict salinity at OLD from observations at Vernalis (USBR 2011, 2025; Fleenor and Ji 2011). Similarly, the historical relationship between EC and flow at Vernalis itself is not straightforward, particularly at the low flow levels typical of drought conditions (Figure 2-3).

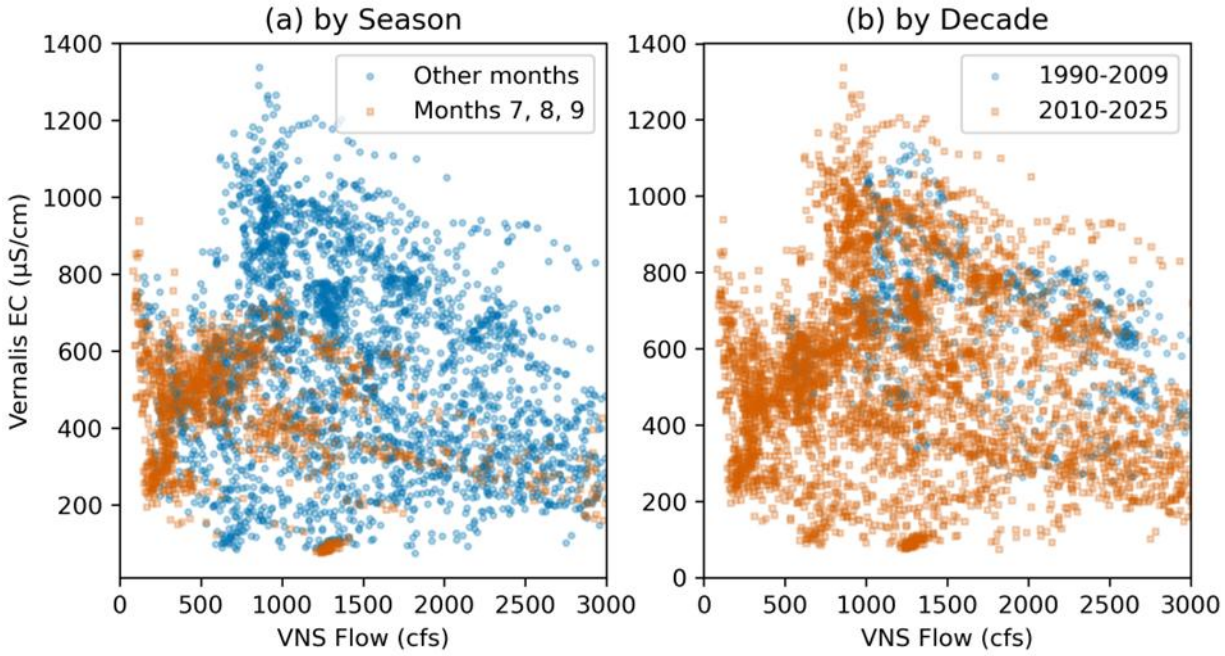


Figure 2-3. Daily Observations of Vernalis EC and Vernalis Flow from 1990 to 2025 Separated by (a) Season and (b) Time Period

The 2018 Bay-Delta Plan specifies three river segments, rather than specific point locations, for compliance with water quality objectives in the South Delta; therefore, a more comprehensive understanding of hydrodynamics within the South Delta and consideration of additional external conditions are necessary to assess what influences salinity concentrations at OLD and whether OLD is regionally representative.

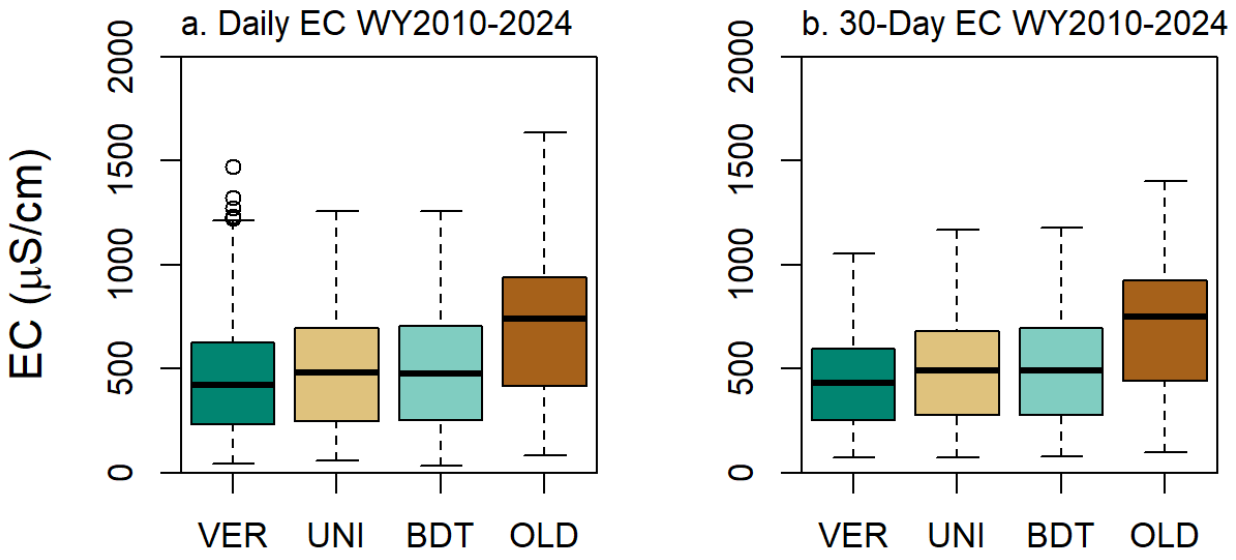


Figure 2-4. Boxplots of (a) Daily and (b) 30-day Running Average Electrical Conductivity (EC) measured at each of the Four Southern Delta Compliance Locations for Water Years 2010 through 2024. Daily EC data were downloaded from the California Data Exchange Center.

In addition to the four point-compliance stations, an extensive monitoring network exists within South Delta channels (Chapter 3, *Technical Study Descriptions and Meeting MSS Goals and Conditions*, provides more details). As water flows through the South Delta, it transports salt mass; therefore, areas that experience restricted circulation (i.e., null zones, or diminished tidal flushing) can accumulate salts from different sources, resulting in high salinity concentrations. External sources of salts into the South Delta follow general flow patterns discussed above and include the San Joaquin River, the Sacramento River, and seawater that can flow in from the northwest via tidal flows. Local internal sources of salinity, including agricultural, municipal, or groundwater discharges, affect the salinity in the main channel depending on the concentrations and volume of the discharged water. High salinity concentrations are often observed in the major tributaries of Sugar Cut, Tom Paine Slough, and Paradise Cut and are thought to result from a mixture of agricultural drainage, salinity accumulation via restricted flow, and some amount of groundwater discharge into the channels when the water table is high.

2.2.3 Variables that Influence Flow and Salinity Conditions in the South Delta

Overall, flow and salinity concentrations in the South Delta vary in response to the combined influence of several factors, including the amount and quality of water entering the South Delta on the San Joaquin River, the rate of exports at the SWP and CVP pumping facilities, tidal flows,

and the configuration of the temporary rock barriers, all of which are well measured and known. Unknown, unquantified factors that also influence flow and salinity in the South Delta include local in-Delta diversions and discharges and groundwater discharges into the channels. While channel bathymetry itself is measured, the impact of bathymetry and vegetation on flow patterns and salinity concentrations in the South Delta channels can be intricate and variable.

Even the influences that are "known" (i.e., San Joaquin River flow and salinity, SWP and CVP pumping rates, and temporary barriers) vary based on hydrologic, operational, and ambient climate conditions, such as temperature, precipitation, or seasonality. Seasonality influences flow over a sub-annual timescale. For instance, the San Joaquin River typically has higher flows during the winter and spring months, when the climate is cooler, precipitation increases, and mountain snowpack begins to melt, feeding the tributaries. In contrast, San Joaquin River flows decrease during the hot, dry months of late summer and early fall when water demand is often the highest (Figure 2-3 (a)).

Longer-term trends in climate, such as multi-year droughts, drive the relative magnitude of seasonal flow. For example, water years that are classified as dry or critically dry in the San Joaquin Valley (e.g., water year [WY] 2012–2016 or WY 2020–2022) correspond to lower mean annual San Joaquin River flow measured at Vernalis relative to wet water years (Table 2-2). Drought conditions not only result in lower flows entering the South Delta, but also operational conditions that reduce the volume of combined exports at the SWP and CVP pumping facilities (Table 2-2). Low-flow conditions during dry years can correspond to increased salinity concentrations due to limited water availability to dilute salts in the system; however, the relationship between flow and salinity measured at Vernalis is not straightforward. Over seasonal timescales, higher winter/spring flows on the San Joaquin River tend to correspond to higher salinity concentrations, whereas lower flows during the summer/fall tend to be fresher. Over interannual timescales, critically dry, low-flow conditions do not always correspond to substantially higher salinity concentrations (Table 2-2). For example, the mean Vernalis flows during the critical WYs 2021 and 2022 were 1,027 cfs and 744 cfs, respectively (Table 2-2), which correspond to the widest distributions of Vernalis EC values ranging from approximately 100 to 1,350 microsiemens per centimeter (µS/cm) (Figure 2-3).

Table 2-2. Classification Index, Mean Flow, and Mean Salinity Concentrations for the San Joaquin River and Mean Combined Export Rates for Water Years 2010 to 2023

Water Year	San Joaquin Valley Water Year Classification Index	Mean San Joaquin flow at Vernalis (cfs)	Mean San Joaquin EC at Vernalis (µS/cm)	Mean Combined SWP and CVP Exports (cfs)
2010	Above Normal	2,489	562	6,336
2011	Wet	9,361	268	9,006
2012	Dry	1,942	556	6,488
2013	Critical	1,485	598	5,578
2014	Critical	880	610	2,569
2015	Critical	605	641	2,508
2016	Dry	1,005	518	4,573
2017	Wet	12,423	258	8,706

Water Year	San Joaquin Valley Water Year Classification Index	Mean San Joaquin flow at Vernalis (cfs)	Mean San Joaquin EC at Vernalis (µS/cm)	Mean Combined SWP and CVP Exports (cfs)
2018	Below Normal	2,551	404	6,118
2019	Wet	6,198	357	7,161
2020	Dry	1,793	469	4,784
2021	Critical	1,027	493	2,090
2022	Critical	744	377	2,825
2023	Wet	11,635	233	7,169

µS/cm = microsiemens per centimeter; cfs = cubic feet per second
Note: Mean values provided are calculated from historical daily discharge data accessed via the California Data Exchange Center.

Chapter 3 Technical Study Descriptions and Meeting MSS Goals and Conditions

Although past studies have provided context to the complexity of water quality and hydrodynamics in the Delta, more monitoring efforts, modeling, and additional data-collection efforts were deemed necessary to properly characterize salinity, flow, and stage levels using state-of-the-art techniques. To meet the goals of the MSS, DWR and USBR analyzed the existing flow, stage, and water quality monitoring stations and deployed additional temporary flow and water quality monitoring stations (Figure 3-1 and Figure 3-2). To examine the utility of these temporary monitoring stations, models (Semi-Implicit Cross-scale Hydroscience Integrated System Model [SCHISM] and Delta Simulation Model II [DSM2] with data assimilation) were used to the extent possible to characterize the flow and water quality conditions in the South Delta and identify where other flow or water quality data was needed to improve water quality modeling results. Figure 3-3 shows the relationship between the different modeling and monitoring efforts of the MSS.

Additionally, coordination and cooperation with participating organizations are vital to obtaining key pieces of information, including local agricultural and municipal water users' diversion and return flow rates and EC[6] levels. Unfortunately, data for local agricultural and municipal water users' diversion and return flow rates were not provided for these analyses, limiting the specificity with which the MSS could quantify the volume and salinity concentrations of local discharges into the South Delta.

[6] *Specific conductivity* (SC) and *electrical conductivity* (EC) are used interchangeably throughout the report.

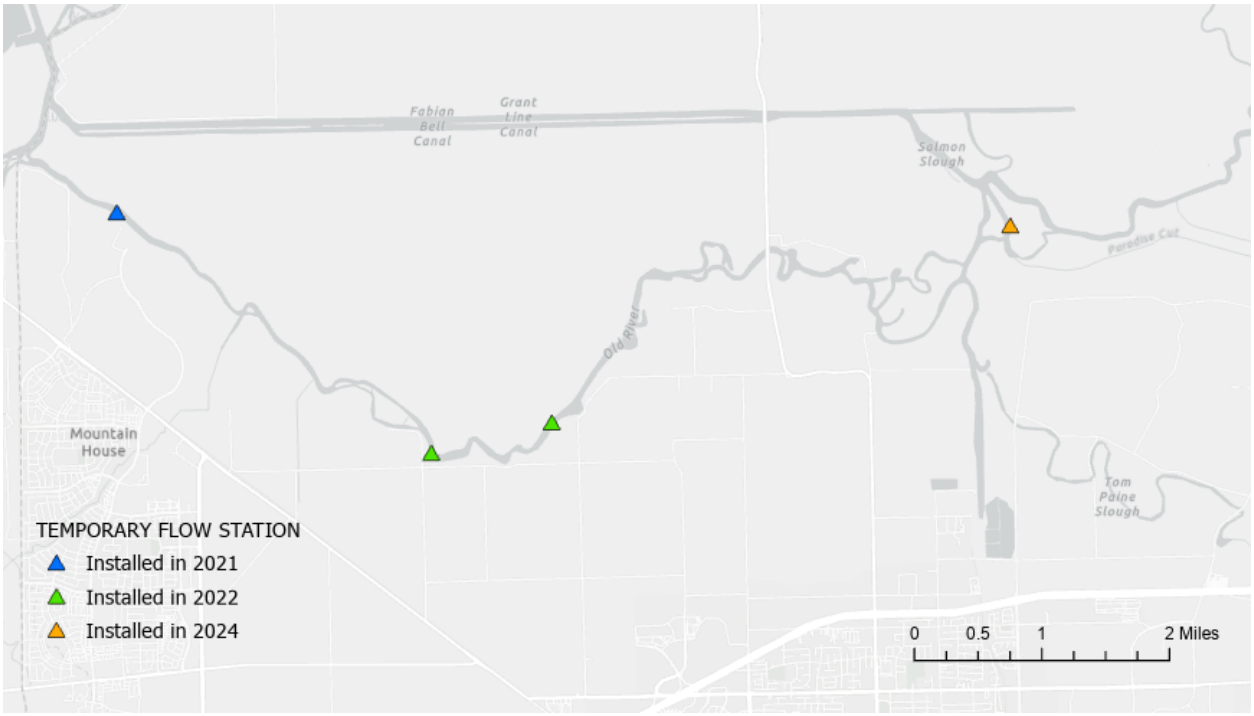


Figure 3-1. Map Showing the Temporary Flow Monitoring Stations Used in the MSS

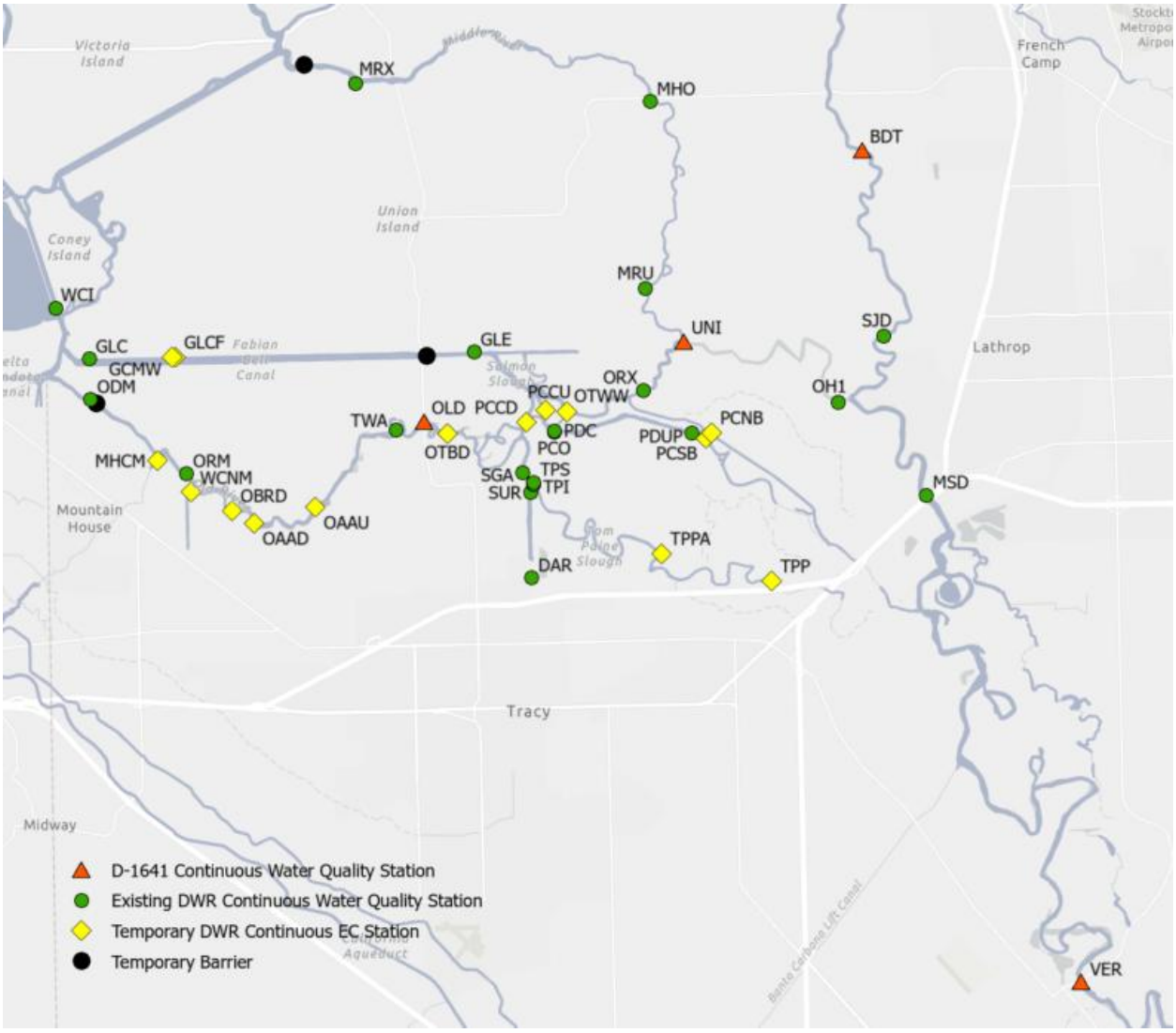
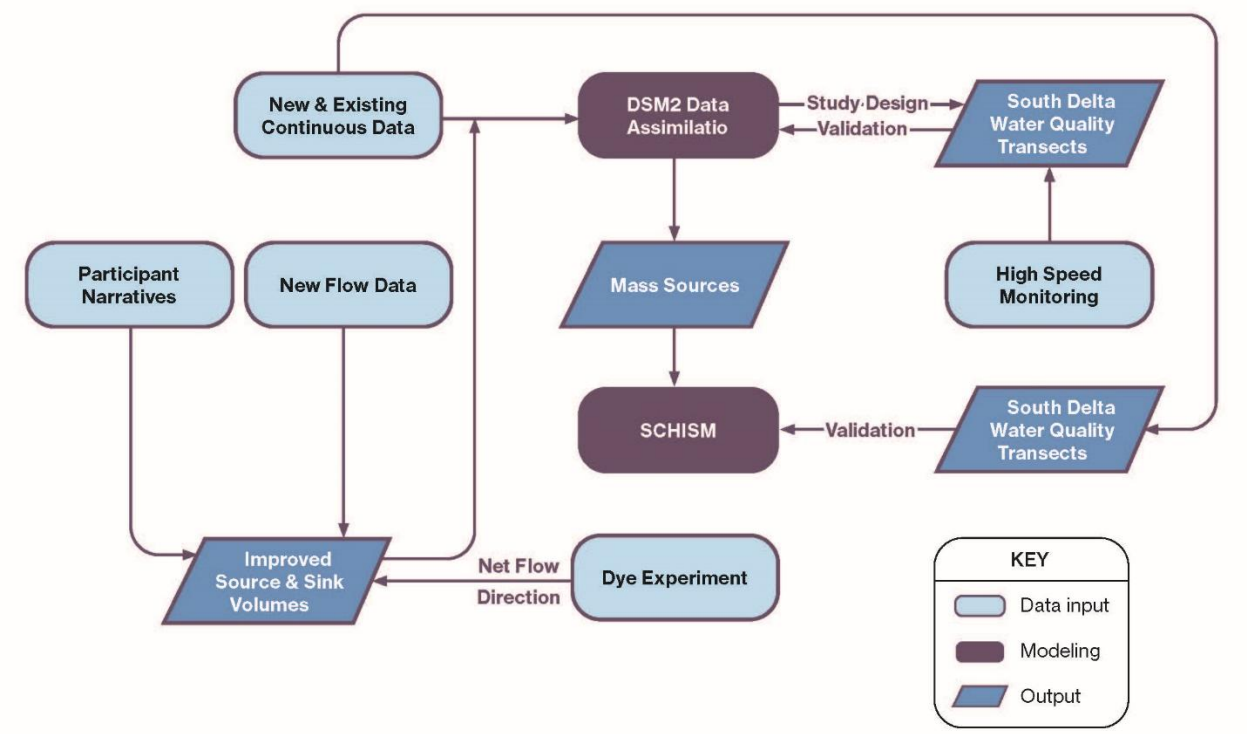


Figure 3-2. Map Showing Existing and Temporary Electrical Conductivity Stations Used in the MSS



Note: New & Continuous Data = Salinity Point Source and Ion Sampling (MSS Report, Attachment 2); DSM2 Data Assimilation = Data Integration and Source Inference for Modeling (MSS Report, Attachment 4); High Speed Monitoring = High-Speed Salinity Transect Mapping (MSS Report, Attachment 1); Dye Experiment = Upper Paradise Cut Rhodamine Dye Tracer Study Report (MSS Report, Attachment 2, Appendix 2C); New Flow Data = Clifton Court Forebay Gate Characterization, Scheduling Study, and Facilities Comparison (MSS Report, Attachment 5); Old River Tracy Barrier Flow Study (MSS Report, Attachment 7); and Old River Null Zone Study (MSS Report, Attachment 8); Participant Narratives = Information gathered through outreach with interested parties (MSS Report, Appendix A).

Figure 3-3. Flow Chart of MSS Monitoring and Modeling Efforts. *New and Existing Continuous Data* Includes, but Is Not Limited to, Data Collected from the Salinity Point Source and Ion Sampling Study

3.1 Description of Technical Studies

The MSS Plan described four main technical studies—two monitoring efforts and two modeling efforts. During data collection, analysis, and discussions with SWRCB, South Delta Water Agency, and Contra Costa Water District regarding topics of interest, some supplemental studies and documentation were developed to address remaining questions or concerns (see Appendix A, *Summary of Outreach to Participating Organizations since Publishing the Monitoring Special Study Plan*). Figure 1-1 shows how the MSS Plan relates to the corresponding studies contained in this report. Brief descriptions of the technical studies—each included with this report—appear below. Detailed methodologies and results are available in the attachment or appendix indicated.

1. High-Speed Salinity Transect Mapping (MSS Report, Attachment 1)

   This study collected and mapped salinity data across six transect routes in the South Delta: the San Joaquin River, Upper Old River, Grant Line Canal, Five Points Region, Lower Old

River, and Middle River. The transects were planned and collected to account for variability in tidal, operational, and seasonal conditions.

The study was conducted using a boat equipped with a water-intake system that collects in-channel water, a Yellow Springs Instruments EXO2 sonde to measure salinity (EC) every 1–3 seconds, and Garmin GPS receiver to record position, allowing the team to detect changes in salinity over space. Due to channel bathymetry constraints, data from Middle River salinity (EC) transects were not collected by boat; instead, staff on land collected point samples by dipping a water quality sonde into the river at set locations, completing four reach profiles in 2023.

Data were then plotted to show salinity conditions across the six transect routes and between the existing monitoring stations. The transect data from this study were used as an independent dataset to validate the MSS modeling work. They also constitute the best and perhaps only means of measuring isolated slugs of salinity trapped in locations with limited tidal connection to monitoring sites. Great care must be taken to reconcile such monitoring with other detection methods and not to assume slugs originate where they are detected—this was an error of interpretation that daunted earlier work.

2. Salinity Point Source and Ion Sampling (MSS Report, Attachment 2)

   This comprehensive data-collection effort involved installing temporary EC monitoring stations in targeted areas of the South Delta to improve modeling resolution and increase confidence in modeling results. Fixed-station continuous EC data were used to further analyze and better describe three topics of interest regarding South Delta salinity conditions: (1) Paradise Cut flushing, (2) Pescadero Tract circulation, and (3) the Lower Old River low flow or null zone. Ion samples were collected monthly and analyzed to develop ionic fingerprints to distinguish between salinity sources and regional differences. Additional monitoring efforts were conducted as needed, including dye-tracing experiments in Paradise Cut, providing improved dispersion rates for models and confirming mean-flow direction in channels with low-flow magnitude.

   Historical salinity data at the four compliance stations—VER, BDT, UNI, and OLD—were considered for WYs 2016–2023. Regional spatial and temporal trends in salinity were analyzed for the full MSS data-collection network of monitoring stations and MSS collection period (WYs 2021–2023). The level of regional salinity representation of each of the four compliance locations was also evaluated. The study area was split into nine regions for the discussion: San Joaquin River, Upper Old River, Grant Line Canal, Paradise Cut, Sugar Cut, Tom Paine Slough, Lower Old River, Old and Middle River (OMR), and Middle River.

3. Circulation, Channel Depletion, and Barrier Assumptions for Modeling the South Delta, 2024 Revision (MSS Report, Attachment 3)

   This report details the improvements made to the hydrodynamic models used in the MSS. Several sources of information—local flow data, recorded diversions, revised channel depletions, and measured barrier characteristics—were used to improve the modeled circulation patterns in the South Delta. Additionally, more realistic Clifton Court Forebay (CCF) gate operations were incorporated into the MSS (*Clifton Court Forebay Gate Characterization, Scheduling Study, and Facilities Comparison* [MSS Report, Attachment 5]), and leakage through the Old River at Tracy Barrier was measured and parameterized and

found to constitute a significant influence on flow. Bathymetry was updated and cross-sections were refined using observations collected from the South Delta. All these refinements improved the ability of both DSM2 and SCHISM to represent hydrodynamic and water quality (EC) conditions in the Delta.

This report was originally shared with interested parties on April 6, 2023, for review and feedback, as described in Appendix A, *Summary of Outreach to Participating Organizations since Publishing the Monitoring Special Study Plan*.

4. Data Integration and Source Inference for Modeling (MSS Report, Attachment 4)

   This document outlines the use of inverse models to infer unmeasured source loadings in the South Delta. The point sources from local POTW (publicly Owned Treatment Work) were obtained from Electronic Self-Monitoring and Reporting (eSMR) and treated as known sources in DSM2. Source inference was performed to better understand where salinity enters the surface-water system and to estimate in-Delta loadings sufficiently to address the main goals of the MSS operational effects and sensitivities study: to assess the effects of inflows, exports, barriers, and in-Delta sources on circulation and salinity.

   Data assimilation is a modeling technique that integrates observational data with a mechanistic model and is used to infer unknown salinity sources. This technique provides additional insight on the locations and time series of dominant EC sources and can help to identify data gaps required to better monitor the system. The inferred salinity loads as a data product were used to improve model performance of EC from both DSM2-GTM (DSM2–General Transport Model) and SCHISM. The model input and validation data were quality assured and controlled from an extensive, continuous monitoring network, hosted on DWR's Water Data Library and the U.S. Geological Survey's National Water Information System, along with additional data collected from the monitoring components of the MSS. This approach provided insight to the geographical origins of the high levels of salinity observed in the South Delta. Additionally, with the assimilated sources, both SCHISM and DSM2 provide more realistic modeling of the spatial and temporal distribution of salinity conditions in the South Delta relative to observed data.

   The inferred sources were additionally validated against the transect data and observed EC at Drainage at Arbor Road. The sensitivity to flow misspecification were also investigated, given the ambiguity between EC and flow error.

5. *Clifton Court Forebay Gate Characterization, Scheduling Study, and Facilities Comparison* (MSS Report, Attachment 5)

   This study was developed in response to inquiries from participating organizations on the potential effects of the CCF radial gate scheduling on water levels and water quality in the South Delta (as opposed to export quantities) and in particular to investigate a hypothesis about closing the gate at high-high tide to encourage west-to-east transport of water over the crests of the temporary barrier weir structures. This study developed more accurate representation of CCF gate operation for modeling in the MSS, source-inferred version of DSM2 to test whether changes in CCF gate operational priorities would result in water level and water quality benefits in the South Delta. This study also isolated the effects of SWP and CVP pumping throughout the tidal cycle. The study concludes that gate scheduling is fairly

constrained and the results indicated that minor adjustments to gate scheduling relative to the tides do not affect local water levels or water quality.

6. MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study (MSS Report, Attachment 6)

   This attachment synthesized observations from the historical monitoring network, the enhanced MSS monitoring network, and modeling results and tested hypotheses related to the effects of the temporary barriers, San Joaquin River flow, and export pumping. Descriptive visualization, applied data analysis, and modeling provided insights to flow and salinity dynamics for the three South Delta river segments identified in the 2018 Bay-Delta Plan. The model was used to assess the likelihood of meeting salinity objectives across the three river segments under different flow, export, and temporary barrier scenarios. Simulations were performed to assess the relative influence of San Joaquin River inflow and EC at Vernalis, state and federal project exports, configuration of the temporary agricultural barriers, and in-Delta sources of water and salinity. The attachment also represents the final report of the SCHISM modeling component of the project. Prior to the simulations, the mesh for the South Delta was refined to achieve better resolution of small bathymetric and flow features. A finer mesh also helped inform data collection and identified knowledge gaps concerning the spatial and temporal distribution of null zones. Bathymetry sensitivity and source tracking experiments were also conducted as part of this study.

7. Old River Tracy Barrier Flow Study (MSS Report, Attachment 7)

   This study was developed to quantify the ratios of Old River flow through the Old River temporary barrier that either passes through the culverts, leaks through the rock barrier, or overtops the barrier during high water levels. Acoustic Doppler current profilers (ADCPs) were installed in three of nine culverts of the Old River temporary rock barrier, and 1-minute data were aggregated to 15-minute intervals and stored. Moving boat ADCP measurements were conducted during different flood and ebb tides to capture the different combinations of flow (i.e., flow through the culverts, overtopping the barrier, or leaking through the barrier). This information was used to improve simulations of temporary barrier flows in DSM2 and SCHISM.

8. Old River Null Zone Study (MSS Report, Attachment 8)

   This study was developed to better understand flow dynamics on Lower Old River between the permanent monitoring stations OLD and ORM, including the potential impacts of diversions and discharges along the reach where a null zone commonly forms. Two temporary flow stations were installed during the 2022 temporary barrier season (mid-May through mid-November) between OLD and ORM. Data from all four monitoring stations were used to refine the location (and migration) of the null zone that formed on Old River in 2022.

9. Supplemental Stable Water Isotope Analysis (MSS Report, Appendix B)

   The scope of the MSS was limited to surface water; however, previous studies and anecdotal evidence suggest that discharges from shallow groundwater can be both frequent and saline, due to the underlying geology. Groundwater discharges are not quantified and are currently, from a modeling perspective, lumped together with other in-Delta discharges from local water use. This supplemental study was developed to attempt to detect groundwater

discharges in the South Delta using stable water isotopes (hydrogen and oxygen) from water collected during the ion sampling effort as part of *Salinity Point Source and Ion Sampling* (MSS Report, Attachment 2).

The isotopic composition of water samples collected in the South Delta during calendar year 2023 were compared to a compilation of existing isotope data for surface water and groundwater from across the Sacramento and San Joaquin Valleys. The compiled dataset was used to characterize the different source categories of water in the South Delta channels and provide a diagnostic framework for identifying where and when groundwater discharges may contribute proportionally more to in-channel flows relative to inflow or drainage water. Some groundwater influence was detectable at the far end of Sugar Cut in the 2023 data, but could not be identified with certainty at any other location.

10. Low Water Metrics (MSS Report, Appendix C)

    This appendix describes metrics used to assess low water and justifies the use of the monthly 1% quantile of water levels as a description of low water. The metric exposes semi-monthly dips that coincide with the water level concerns and complaints that are most prevalent.

3.2 Meeting the MSS Goals

The technical studies described above were conducted to address the specific goals of the MSS (see Section 1.1, *MSS Goals and Objectives*). Figure 1-1 shows how those goals connect to the technical studies planned and completed as part of the MSS.

- MSS Goal 1—characterize the spatial and temporal distribution and associated dynamics of water level, flow, and salinity conditions in the southern Delta waterways—was achieved by the combined efforts of all the technical studies, which were designed to fill knowledge gaps in the existing observational and modeling networks in the South Delta.
- MSS Goal 2—*identify the extent of low- or null-flow conditions and any associated concentration of local salt discharges*—was achieved by the combination of technical studies and informed by the supplemental flow monitoring along Old River: *Old River Tracy Barrier Flow Study* (MSS Report, Attachment 7) and *Old River Null Zone Study* (MSS Report, Attachment 8).
- MSS Goal 3—*inform a Long-Term Monitoring and Reporting Plan*—was achieved by the completion of this MSS Report. Potential recommendations for a future LTMRP are described further in Chapter 5, *Conclusions and Recommendations*.

3.3 Meeting the MSS Conditional Approval Items

SWRCB's conditions for approval of the MSS Plan (see Section 1.2, *MSS Plan and SWRCB Conditional Approval*) were addressed through implementation of the MSS technical studies and publication of this MSS Report and related materials. Those conditions are briefly described below, along with how they were addressed during the MSS process.

Condition 1: Making available to interested stakeholders the custom versions of Bay-Delta models relied upon in the MSS Plan in a usable form. The Bay-Delta SCHISM and the GTM module of DSM-2 are heavily relied upon in the MSS Plan, and should be accessible and transparent. If not

published online, these products should be otherwise made readily available, or access should be provided to interested parties. Documentation on calibration, improvements, manuals and other details should be made public consistent with other DSM-2 modules.

The MSS version of DSM2 (with source inference for 2021–2023) and SCHISM is available with the release of this report. The Windows binaries for the MSS version of DSM2 is Released v8.4.1, and it is available in GitHub repository (GitHub 2026a). The inputs, simulation outputs, and postprocessing scripts for MSS version of DSM2 are available in the California Natural Resources Agency (CNRA) Open Data portal (CNRA 2025a). The SCHISM simulations described in *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6) were built using a public template for SCHISM that is housed in GitHub repository within a branch labeled *bay_delta_v113* (GitHub 2026b). Preprocessed, ready-to-run inputs for the MSS base case are available at the same link on the CNRA Open Data portal (CNRA 2025a). SCHISM is an open source project led by the Virginia Institute of Marine Sciences, and the source is distributed at the GitHub location (GitHub 2026b). Additional outputs and inputs are available on request.

The MSS versions of the models are provided for the purposes of transparency and replicability. They are not actively developed. MSS improvements have been incorporated into the stable line of development for the two models. Interested parties doing new work are urged to research available newer production versions. Inferred sources from the present study (*Data Integration and Source Inference for Modeling* [MSS Report, Attachment 4]) rely on the relatively data-rich 2021–2024 period.

In addition, as indicated in Figure 1-1, SCHISM and DSM2 modeling files were provided to the MSS Technical Workgroup in mid-May 2025. The DWR Modeling Support Office offered office hours May 23–27, 29, and 30, 2025 to provide technical support to parties attempting to re-run the modeling analyses themselves. On an ongoing basis, modeling workshops for SCHISM are offered periodically. Workshops and training sessions are broadcast on the Bay-Delta SCHISM website (DWR 2020), are available on the Delta Modeling User Group site (DWR 2026), and posted on the California Water & Environmental Modeling Forum (CWEMF) website (CWEMF 2021).

Condition 2: Inclusion of analyses of historical flow and salinity data from continuous monitoring stations published on Water Data Library or California Data Exchange Center to characterize the spatial and temporal distribution of flow and salinity and associated dynamics in the southern Delta (to be included as a technical study chapter in the MSS Final Report). The purpose of this analysis of historical data is to identify periods when salinity is not attained, assess conditions that lead to noncompliance (a range of relevant parameters regardless of whether within operational control), evaluate past instances of return to compliance, and identify potential actions that may support returning to and maintaining compliance. At a minimum, hourly data shall be used to understand fate and transport with full tidal variation of ebb and flood tides, and to account for parameters that change on a sub-daily time step (such as Clifton Court Forebay gate operations).

The importance of measured observations was a guiding principle during development of the MSS technical studies. Several studies are based solely on observed continuous data.[7] Analyses of historical flow and salinity data from the pre-existing continuous monitoring network was part of the detailed task list of the MSS Plan and was completed as part of the overall study design. Historical data analyses, using publicly available data, were completed as part of the technical studies in the MSS. *Salinity Point Source and Ion Sampling* (MSS Report, Attachment 2) assesses salinity objective compliance in the South Delta using 15-minute data for WYs 2016–2023. *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6) examines historical data for WYs 2010–2024, using the revised salinity objective of 1,000 µS/cm as listed in the 2018 Bay-Delta Plan as a benchmark for compliance, and discusses different scenarios under which South Delta compliance is likely or unlikely to be achieved. The influence of tidal flows is explored in *Clifton Court Forebay Gate Characterization, Scheduling Study, and Facilities Comparison* (MSS Report, Attachment 5) and Attachment 6, including parameters that change on a sub-daily timescale such as the CCF radial gate schedule. More detailed data analysis over tidal flows is discussed in Attachment 2 for the MSS study period (calendar years 2021–2023) when the temporary EC and flow stations installed as part of the MSS provided more spatial coverage of South Delta channels. Additionally, Attachment 6 includes an historical data analysis that examines the sensitivities of water levels, flow, and salinity in the South Delta to different controlling variables, including San Joaquin River inflow and salinity concentrations at Vernalis, export pumping at the SWP and CVP facilities, and tidal flows.

Many historical data analyses using the existing monitoring network in the South Delta informed the design and implementation of the MSS technical studies. For reference, a list of previous work that analyzed historical data in the South Delta can be found on the CNRA website (CNRA 2025b). Several studies have analyzed historical salinity data at sub-daily timescales (DWR 2012, 2016, 2018, 2024; Montoya 2007, 2012); however, modern studies in the South Delta must carefully consider whether the numerous older studies, especially those completed multiple decades ago, continue to represent the best available science or reflect the most current hydrodynamics and sensitivities of the area.

The sensitivity of South Delta salinity concentrations to relevant parameters (e.g., export pumping, tidal flows, San Joaquin River flow and salinity, in-Delta diversions and discharges) have changed over time and cannot be determined with observational data alone because measurements of flow and salinity at the many in-Delta diversion and discharge locations either do not exist or were not made available for this study. The scope and goals of the MSS, consistent with the 2018 Bay-Delta Plan (see Chapter 1, *Introduction*), were developed "…*to characterize the spatial and temporal distribution and associated dynamics of water level, flow, and salinity conditions in the southern Delta waterways*." While sensitivities of the South Delta system to different forcing parameters are explored in detail graphically, statistically, and through modeling in *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6), describing "potential actions" is out of scope of the MSS.

[7] *High-Speed Salinity Transect Mapping* (MSS Report, Attachment 1), *Salinity Point Source and Ion Sampling* (MSS Report, Attachment 2), *Old River Tracy Barrier Flow Study* (MSS Report, Attachment 7), and *Old River Null Zone Study* (MSS Report, Attachment 8).

> **Condition 3:** Inclusion of evaluations of whether the existing continuous salinity monitoring stations are sufficient to determine the appropriate locations and methods to assess attainment of the salinity objective in the river segment (section B(1)(ii)). Specifically, approval is conditioned on DWR and Reclamation working with State Water Board staff to determine if collecting ion samples or scheduling seasonal transects in Middle River is needed to support an evaluation of existing compliance stations for the purposes of identifying compliance approaches that are representative of salinity conditions in the interior southern Delta and to validate model results.

Evaluating the ability of the current monitoring network to assess compliance with salinity objectives along the three river segments listed in the 2018 Bay-Delta Plan is included as part of MSS Goal #3 (*see* Section 1.1, *MSS Goals and Objectives*, and Section 3.2, *Meeting the MSS Goals*). Goal #3 is stated below:

> *Inform a Long-Term Monitoring and Reporting Plan that will:*
>
> *a. Assess attainment of the salinity objective in the interior southern Delta; and*
>
> *b. Include long-term monitoring and reporting protocols, including specific compliance monitoring locations in, or monitoring protocols for, the three river segments that comprise the interior southern Delta salinity compliance locations.*

The technical studies were designed to help inform the development of a LTMRP, which is intended to detail specific monitoring and reporting protocols. Section 4.4, *Adequacy of Current Monitoring Network in Assessing Reach Salinity*, provides an evaluation of the ability of the monitoring network to assess salinity concentrations along the three river segments listed in the 2018 Bay-Delta Plan, and Chapter 5, *Conclusions and Recommendations*, provides recommendations for potential monitoring protocols to consider during development of a LTMRP.

Navigability along Middle River is a challenge due to limited channel depth and aquatic vegetation coverage. DWR staff attempted a Middle River boat transect during the high tide on March 8, 2023, to determine the feasibility and document the challenges of high-speed salinity transect mapping by boat in Middle River. The experience from this attempted transect helped to validate limitations to completing salinity transects by an outboard-powered boat in this river reach. The limitations were primarily due to the shallow bathymetry, which caused challenges in boat outboard operation, overall increased sampling time due to reduced boat speed, transect flow-through intake equipment operation constraints or fouling impacting salinity data reliability, and overall staff safety concerns. Therefore, to address the request from the SWRCB to perform additional seasonal salinity transects on Middle River, four different point-sampling surveys were performed on Middle River from Undine Road to Middle River near Tracy Blvd Bridge. DWR field staff performed these surveys using a sonde at various points along the route. Details about the Middle River salinity transect route are included in Table 2 and Section 4.7, *Middle River*, of *High-Speed Salinity Transect Mapping* (MSS Report, Attachment 1). Additionally, ion samples were collected and analyzed at three of four monitoring locations along Middle River, as described in Table 1 and Section 3.3, *Ion Sampling*, of *Salinity Point Source and Ion Sampling* (MSS Report, Attachment 2).

> **Condition 4:** Addition of flow monitoring at or near Old River above Paradise Cut Confluence (B9538600) in below normal, dry, and critical water year type conditions prior to completion of the MSS study. DWR and Reclamation have already augmented the flow monitoring with temporary

> stations in multiple southern Delta locations. However, the amplitude and direction of instantaneous flow remains a critical gap for understanding the fate and transport of salt from Paradise Cut into Doughty Cut and into lower Old River, especially during years with below average runoff.

This condition was stipulated in WY 2023, the final year of MSS data collection. This wet year for the Delta watershed resulted in relatively high flows and, in some cases, flood conditions; the associated challenges are detailed in the attached technical studies. In May 2024, before the operation of the South Delta temporary barriers, DWR and USBR installed a temporary autonomous flow station B95386Q at the confluence of Old River and Paradise Cut near B9538600. Data were not available until December 2024, after the barriers were removed, and data were downloaded from the ADCP and processed. DWR and USBR again installed the same temporary autonomous flow station in late April 2025 and removed it in early December 2025. Due to timing, this information is not included in the MSS Report but is available at the Water Data Library website: https://wdl.water.ca.gov/WaterDataLibrary/. Since 2023 was a wet water year, additional flow monitoring at this requested location has been delayed until a below normal, dry, or critical water year type occurs. Although data from this station can be made available to the SWRCB relatively quickly, WY 2024 for the San Joaquin Valley was typed as an *Above Normal* year and WY 2025 was typed a *Below Normal* year. This dataset may not yet yield a good understanding of the fate and transport of salt from Paradise Cut into Doughty Cut during a drier year. As such, a temporary flow station at Paradise Cut Confluence Upstream (PCCU) is planned for installation in late spring of 2026 to potentially capture salt transport in a dry water year. As of May 1, 2026 DWR has forecasted the San Joaquin Valley Index for WY26 as Dry.

> **Condition 5:** Inclusion of at least one additional line of evidence in the technical modeling studies (such as published continuous measurements, transects, point sampling) to validate or support any inferred salinity sources in data assimilation and as used in SCHISM.

As detailed in *High-Speed Salinity Transect Mapping* (MSS Report, Attachment 1), all the high-speed salinity transect data collected for the MSS were withheld from all stages of source inference and used as an independent dataset for cross validation to evaluate the effectiveness of source inference. Cross validation figures are provided in Section 4.5, *Comparisons to Transects*, of the *Data Integration and Source Inference for Modeling* (MSS Report, Attachment 4), and Appendix 4A, *Transect Comparisons*. Additionally, the use of inferred sources from DSM2, testing in SCHISM, and comparison to observed data constitutes a secondary validation because it addresses the concern that data assimilation merely addresses the fitting quirks of a single model. Documentation of validation for the MSS version of DSM2 is provided in Appendix 4B, *DSM2 Model Evaluation for the Monitoring Special Study*, of *Data Integration and Source Inference for Modeling* (MSS Report, Attachment 4). Documentation of validation for the MSS version of SCHISM is provided in Appendix 6A, *Bay-Delta SCHISM Model Evaluation for the Monitoring Special Study*, of *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6).

3.4 Overview of MSS Implementation and Integration between Studies

Each technical study conducted as part of the MSS, detailed in the attachments and appendices of this report, splits the study area into smaller regions to organize discussions of the analyses. The study area segments differ slightly by study; however, six major areas of interest are discussed frequently as exhibiting distinct hydrodynamics (Figures 2-1 and 2-2).

1. San Joaquin River from Vernalis to Brandt Bridge
2. Upper Old River and Grant Line Canal
3. Middle River
4. Five Points Region, including Paradise Cut, Sugar Cut, and Tom Paine Slough
5. Lower Old River
6. Old and Middle River near the Intake Area

3.4.1 Period of Study and Data Collection

The MSS study period spanned calendar years 2021–2023, when data-collection efforts occurred. The first 2 years, 2021 and 2022, were both critically dry water years in the San Joaquin Valley, whereas 2023 was a wet water year (Table 2-2). In 2023, due to high precipitation runoff and record snowpack in the central Sierras, the San Joaquin River maintained high flows (>17,000 cfs) from March to June, resulting in overtopping of the rock weir at the upper-most end of Paradise Cut. The weir overtopping provided an opportunity to observe the progression of salinity flushing and rebound in Paradise Cut (Section 4.5, *Paradise Cut*, of *High-Speed Salinity Transect Mapping* [MSS Report, Attachment 1] and Section 3.2.4, *Paradise Cut Flushing*, of *Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2]). High salinity concentrations returned to the upper portion of Paradise Cut within 2 weeks of the weir no longer being overtopped by San Joaquin River flows (MSS Report, Attachment 2).

Temporary EC and flow monitoring stations collected continuous data during the MSS study period (2021–2023) to supplement the pre-existing monitoring network in the South Delta channels. These continuous data were analyzed for spatial and temporal trends in salinity and flow (MSS Report, Attachment 2). Additionally, the temporary flow stations in Lower Old River were used to evaluate the permeability of the temporary rock barriers (*Old River Tracy Barrier Flow Study* [MSS Report, Attachment 7]) and better understand the Lower Old River null zone (*Old River Null Zone Study* [MSS Report, Attachment 8]). To better understand the spatial variability of salinity between fixed monitoring locations, high-speed salinity transects were collected in the major South Delta waterways under different seasonal, tidal, and flow conditions throughout the MSS study period (MSS Report, Attachment 1).

In addition to the continuous monitoring data collected, monthly water samples were collected from a subset of monitoring locations in the South Delta for ion analyses (MSS Report, Attachment 2). In 2023, further monthly water samples were collected from the South Delta and the Lower San Joaquin River Basin for stable water isotope analysis (^{2}H and ^{18}O; Appendix B, *Supplemental Stable Water Isotope Analysis*). Mean ion concentrations and principal component

analysis were used to distinguish source regions of salts, whereas stable water isotopes were used to determine whether groundwater discharges into the South Delta channels can be detected.

3.4.2 Use of Historical Data

Historical EC observations from the pre-existing monitoring network in the South Delta were analyzed in multiple studies as part of the MSS. *Salinity Point Source and Ion Sampling* (MSS Report, Attachment 2) examined continuous EC data from WYs 2016–2023, and *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6) analyzed observations from WYs 2010–2025 to quantify and compare historical sensitivities of water levels, flow, and salinity in the South Delta channels to several influencing variables. These observations represent all water year types in the San Joaquin Valley (Table 2-2) and, accordingly, provide perspective on the different historical conditions under which the South Delta experiences high salinity concentrations. The MSS has improved the spatial understanding of flow and EC between this network of fixed monitoring locations, through added temporary station and transect data collection that was used to improve model development and validation.

3.4.3 Modeling Analyses

Model simulations were used to better understand the physical aspects of the study area and further examine the sensitivities of water levels and salinity to different controlling variables under environmental conditions experienced during the MSS study period (2021–2023). Integration of the extensive monitoring data network into the MSS version of DSM2 (*Data Integration and Source Inference for Modeling* [MSS Report, Attachment 4]) helped infer in-Delta sources of salinity due to a lack of available local diversion, discharge, and water quality data. This approach greatly improved the model's ability to simulate observed salinity concentrations in the South Delta, particularly in Lower Old River and the Five Points Region, as demonstrated by *Clifton Court Forebay Gate Characterization, Scheduling Study, and Facilities Comparison* (MSS Report, Attachment 5). Emphasis was placed on understanding the system responses in the South Delta during the summer of 2021, which was a critically dry water year in the San Joaquin Valley (Table 2-2) when San Joaquin River flow was higher than typically possible during dry conditions and showed low EC concentrations.

The simulations using DSM2 (MSS Report, Attachment 5) and SCHISM (*MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6]) were designed to understand the influence of known hydrologic variables in the South Delta (i.e., export pumping, San Joaquin River inflow and EC, and the configuration of the temporary agricultural rock barriers). Historically, a fourth temporary rock barrier would be installed in the spring and the fall at the Head of Old River (HOR), near OH1, for environmental purposes. The spring HOR barrier was intended to keep juvenile salmonids from entering the South Delta channels from the mainstem of the San Joaquin River. The fall HOR barrier was intended to keep flows in the San Joaquin River and increase dissolved oxygen levels downstream. The presence of the HOR barrier reduces the amount of water entering the South Delta from the San Joaquin River. The HOR barrier has not been installed since 2018; therefore, it is important to consider whether the barrier was present when performing historical data analysis and interpreting the mechanisms driving those observations.

Detailed methodologies and results are included in each technical study attachment or appendix. In the following chapters, we provide a synthesis discussion of key findings, an evaluation of how well the current monitoring network represents the water quality of the three river segments listed in the 2018 Bay-Delta Plan, provide some alternative river segments for compliance based on the hydrodynamics of the South Delta, and establish potential approaches for developing a future LTMRP.

Chapter 4 Discussion & Synthesis

4.1 Influences on Water Levels, Flow, and Salinity in the South Delta

Dynamics of water levels, flow, and salinity in the interior South Delta are driven by a mixture of influences, including San Joaquin inflows, tidal-riverine mixing, water export operations of the CVP and SWP facilities, seasonal installation of temporary barriers, and exchanges with local agricultural and other in-Delta sources.

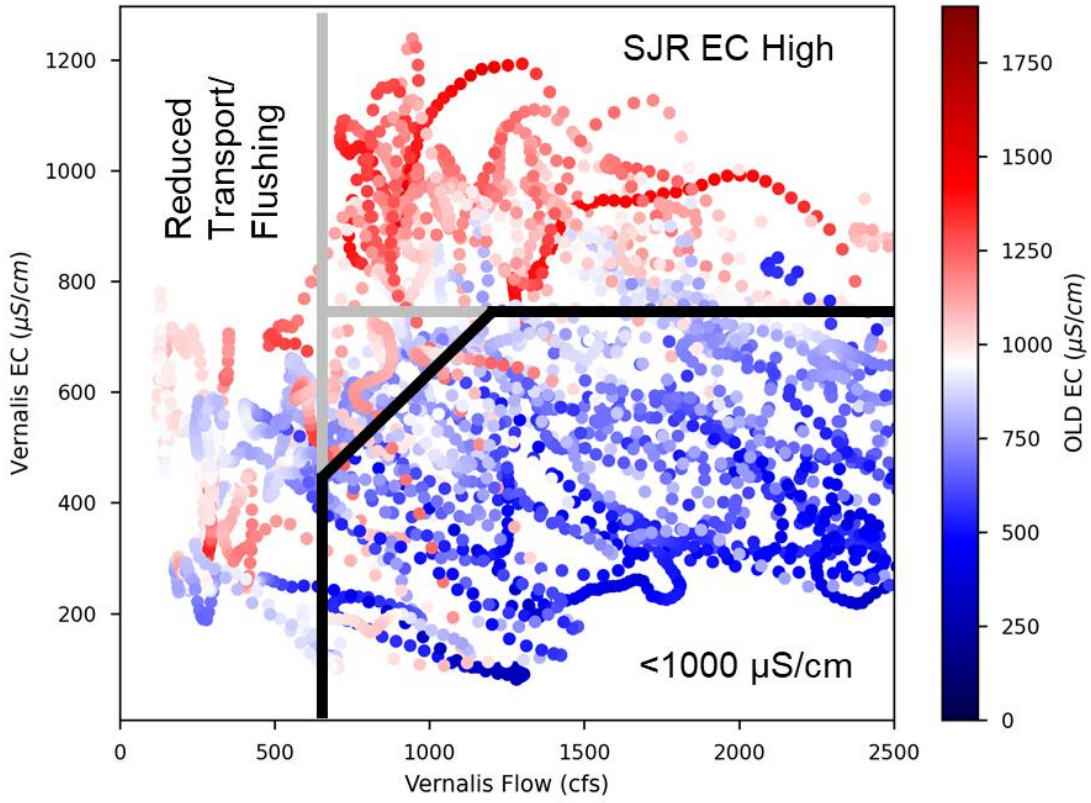


Figure 4-1. Historical Scatter of Vernalis Flow and Specific Conductivity, Colored by Corresponding Specific Conductivity at Old River near Tracy Boulevard. Reproduced from Attachment 6.

San Joaquin River flow and salinity affect South Delta salinity and circulation in proportion to flow volume. Neither flow nor salinity alone on the San Joaquin River is sufficient to predict that salinity objectives are met at interior South Delta compliance stations such as Old River at Tracy Boulevard (OLD), because adequate flow volumes are needed to transport salinity from the San Joaquin River boundary to interior locations and provide dilution of in-Delta sources. Figure 4-1 shows some of the flow and SC[8] combinations that form at Vernalis and the resulting SC (color

[8] *Specific conductivity (SC)* and *electrical conductivity (EC)* are used interchangeably throughout the report.

of the scatter) at OLD. Generally, no simple correlation exists between Vernalis flow and Vernalis SC (Figure 4-1) when Vernalis flows are relatively low (e.g., 2,500 cfs or less) which is typical in all but the wettest of water years (Table 2-2). In other words, incremental increases in Vernalis flow are not always fresher in terms of measured SC. The influence of the San Joaquin River flow and water quality is explored further in *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6), including thresholds at which San Joaquin River flows are too low, regardless of salinity, to flush peak in-Delta sources.

The relative balance of San Joaquin River and in-Delta salinity influences vary seasonally. During the winter and spring, when no temporary barriers are in place, both San Joaquin River flow and SC are high relative to the rest of the year (*Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2, Sections 3.2.1 and 3.2.2]). Under these conditions, San Joaquin River flow and SC are the dominant control on water quality observed in the South Delta. For instance, when San Joaquin River SC at Vernalis is above approximately 850 µS/cm, the corresponding SC downstream in the South Delta at compliance station OLD is typically above the 1,000 µS/cm objective (Figure 4-1). During the late summer and fall seasons, when the temporary barriers are in place, both San Joaquin River flow and SC are lower relative to the rest of the year (*Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2]). The shift in water quality at Vernalis between the summer/fall seasons and the winter/spring seasons is due, in part, to the stricter salinity objective at Vernalis from April through August (SWRCB 2018), as well as the general timing of land and water use practices upstream; however, management programs such as the San Joaquin River Improvement Project have greatly reduced salt loads and concentrations in the San Joaquin River during the past decade or so.

A common term among South Delta practitioners is null zone, referring to an area of convergent flow that occurs mid-reach in South Delta channels. Null zones occur when significant channel depletions coincide with reduced San Joaquin River discharge and are amplified by the directional effects of the temporary barriers on circulation. When null zones form on Lower Old River, in-Delta sources of salinity can become trapped and become the dominant control on interior South Delta SC. Null zone formation occurs in late winter or spring, before barrier construction begins. More detail concerning null zone formation is given in Sections 3.2.3 and 3.2.4 of *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6).

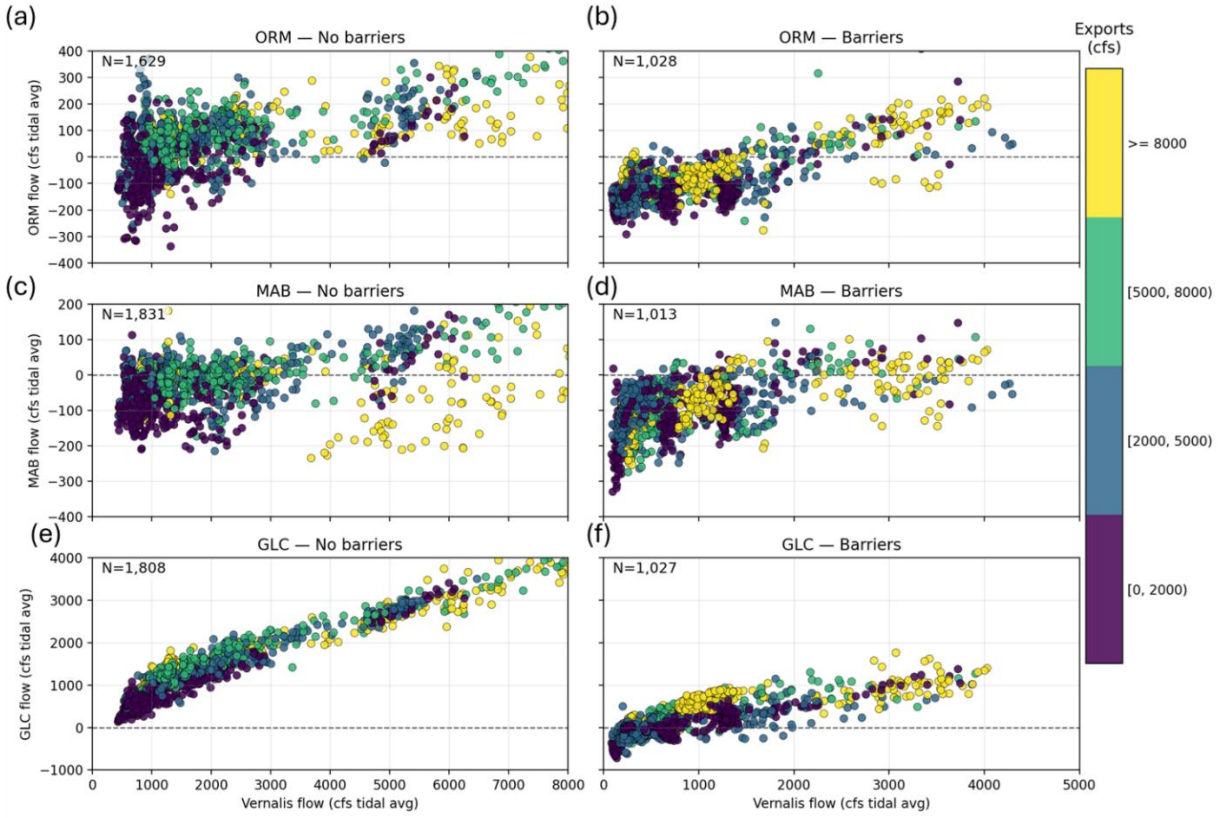
A misconception among South Delta practitioners is the idea that the sole or principal mechanism for flushing the South Delta is overwriting the null zone and re-establishing downstream flow. The water cost of this is high. For instance, Figure 4-2 demonstrates the historical conditions that lead to positive river flow in Old River, Middle River, and Grant Line Canal. The plots were taken from 2014–2025 observations at flow stations close to the downstream end of the reaches within the interior South Delta. Positive flow at these stations is prerequisite to positive flow over the reach and overwriting the null zone. By tracing the dashed line (zero) one can see that it would take at least 2,000 cfs of San Joaquin inflow to create positive flow on Old River and 3,000 cfs to generate positive flow on Middle River, and even these flows are often insufficient because of the indirectness with which San Joaquin flow and exports influence the two channels.

Nevertheless, Figure 4-1 suggests flushing is possible. Grant Line Canal[9] provides a substantial proportional net flow downstream and dilution under all but the most critical conditions. This is the "conveyor belt"—a higher-conveyance channel that competes with the smaller natural channels for conveyance but also provides an alternate pathway for transport. Tidal flows from Grant Line Canal disperse salinity concentrations in the Five Points Region and other reaches into that pathway.

Another potential measure that could be applied on Old River and Middle River that would mitigate the effects of null zones would be to try to separate the net flow null zone from the tidal null zone. Weak tidal excursion generally occurs at or just downstream of the OLD station at Tracy Boulevard. As an example, without considering operational or environmental limitations, when SC is approximately 400 µS/cm at Vernalis, San Joaquin River inflow within the range of 600 to 1,000 cfs is likely needed to flush the in-Delta salinity sources using entirely San Joaquin River water (*MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6]). Much higher San Joaquin River inflow is needed (>3,000 cfs) to establish a stronger relationship between high flow volume and low salinity in Lower Old River (Attachment 6).

In Section 3.3.2.1 of *MSS Operational Effects and Sensitivities Historical Data Analysis and I Modeling Study* (MSS Report, Attachment 6), some of these considerations are applied to narratives of 2021 and 2022. In 2021, a year of focal interest for project participants, the South Delta began the summer with ample flow and few salinity stresses. San Joaquin River and in-Delta sources of salinity were both low initially. In August, in-Delta sources of salinity ramped up to record-high levels just as San Joaquin River flow decreased, reducing its flushing potential. Conditions in 2021 illustrate the importance of seasonality in the region, the role of the San Joaquin River flushing, and the elevated difficulty in meeting salinity objectives in the interior South Delta when in-Delta sources are high. Although 2021–2023 tidal conditions and outflow were the main subject of narratives and provide the planning backdrop, data analysis was applied over a broader range of modern data (typically 2010–2025) which spans the period that is (1) wider than the era of modern instrumentation and system coverage, (2) post-Wanger decision (E.D. Cal. 2009) in the regulation of Old and Middle Rivers, and (3) based on contemporary water quality improvements at Vernalis from management programs in the San Joaquin Basin.

[9] The Grant Line Canal, originally built by local landowners in the late 1800s, reflects the broader development of California's water infrastructure. Evolving from early Delta waterways, it became an important part of 20th-century irrigation and flood-control systems, supporting both agriculture and environmental management in the San Joaquin River Delta. Over time, the canal lead to reduced performance in Delta especially in Old River and Middle River, including reduced water conveyance, formation of a hydraulic "null zone," and lowered water levels.



(a) Old River at Mountain House (ORM), no barriers; (b) ORM with three barriers. (c) Middle River above Barrier (MAB), no barriers; (d) MAB with barriers; (e) Grant Line Canal (GLC), no barriers; (f) GLC with barriers. Points are colored by export magnitude in bins. All flows are tidally averaged and the range of Vernalis flow has been truncated. Flows on the reaches above the dashed line at zero indicate net flow is directed downstream. In the case of Old and Middle Rivers, this is relatively rare when San Joaquin flows are less than 2,000-3,000 cfs regardless of pumping.

Figure 4-2. Scatter Relationship between Vernalis Flow and Three Null Zone Indicator Stations

Temporary barriers have the most profound effect on both water levels and circulation in the South Delta. The barriers introduce no mass of salt on their own, but alter its transport mechanisms. The intention, and clearest benefit, of the temporary barriers is to protect water levels in the South Delta, particularly during low tide, allowing diverters better access to water (*Clifton Court Forebay Gate Characterization, Scheduling Study, and Facilities Comparison* [MSS Report, Attachment 5] and *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6]). For locations that are upstream of the barriers, the modeled increase in water levels is higher, with both data and modeling suggesting that the barriers more than mitigate the drawdown from high (10,000 cfs) pumping at the SWP and CVP facilities. At OLD, for instance, a typical water level increase with barriers is 1.0–1.4 feet (ft) and a typical drawdown from 10,000 cfs is 0.5–0.9 ft.

The temporary barriers function by encouraging asymmetric, upstream-dominated flow. As a result, in addition to maintaining low tide water levels, temporary barriers dampen tides and flow and alter circulation paths. In the most common configuration with temporary barriers on Old

River at Tracy, Middle River, and Grant Line Canal, the temporary barriers increase the range of flows under which null zones are likely to form and change the sensitivity of water levels to San Joaquin River flows and exports, particularly on Old River.

Installation configuration also influences the effectiveness of the barriers. Historically, the Middle River, Old River, and Grant Line Canal temporary barriers have been installed together. In 2023, not including the Grant Line Canal barrier caused more water to be conveyed via Grant Line Canal that year. This had the surprising consequence of inducing negative flows on Old River adjacent to the Five Points Region and Paradise Cut, near sources of high salinity. The resulting null zone trapped local salinity sources in the fall, when salinity concentrations are often at their peak. Local peaks in salinity were observed in 2023 monitoring data and modeled in the region of OLD during this MSS study period because of this effect, despite the generally fresh conditions in the South Delta.

4.1.1 State Water Project and Central Valley Project Export Pumping

Water project exports affect water levels relatively more than they affect salinity, flow, or circulation in the South Delta channels. Modeling (*MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6, Section 3.2.1]) suggests pumping effects on minimum water levels are greatest downstream of the temporary barriers and close to the intake area. The accompanying applied data analysis is largely consistent but shows slightly lower sensitivities and low statistical significance in stations downstream of the barriers like Coney Island, one of three locations monitored for minimum "water levels of concern" (DWR & USBR 2004; see Appendix C for more details).

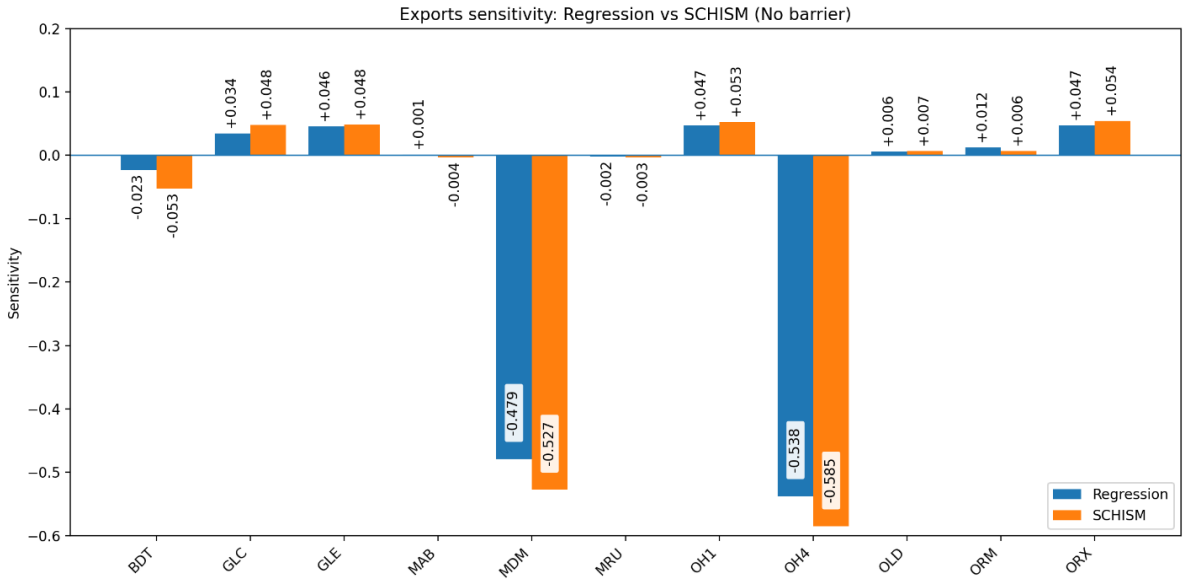
Figures 95 – 98 of Attachment 6 are a summary graphic of model and statistical sensitivities of low tide water levels scaled by the magnitudes of the variables and juxtaposed with the influence of barriers. Higher sensitivities are seen at places like Doughty Cut (0.4–0.76 ft/10,000 cfs of exports without barriers depending on the metric/method/month) and Grant Line Canal above Barrier (0.337–0.763 ft/10,000 cfs), even when pumping is near maximum (~10,000 cfs). Middle River at Howard Road (CDEC station MHO) stands out as a location where the effects of pumping from SWP and CVP export facilities are lower, though the barrier still more than offsets project pumping. Tom Paine Slough is subject to a different dynamic, including local conveyance challenges and nonlinear including local conveyance challenges and nonlinear distortion of the stage-flow relationship caused by water traversing two sets of hydraulic structures (temporary barriers and Tom Paine Slough barrier). Compared with nearby stations, such as those on Sugar Cut, water levels in Tom Paine Slough are relatively sensitive to high exports.

Modeling the effects of exports on circulation showed that sensitivity of net flow is modest for most pumping levels except Grant Line Canal. Modest in this context means compared to other flow drivers such as observed depletions. Net flow in Old and Middle River is in fact a balance between:

- Channel depletions that are modest in magnitude (scale of hundreds of cfs per reach), which influence local channels on a 1:1 basis.

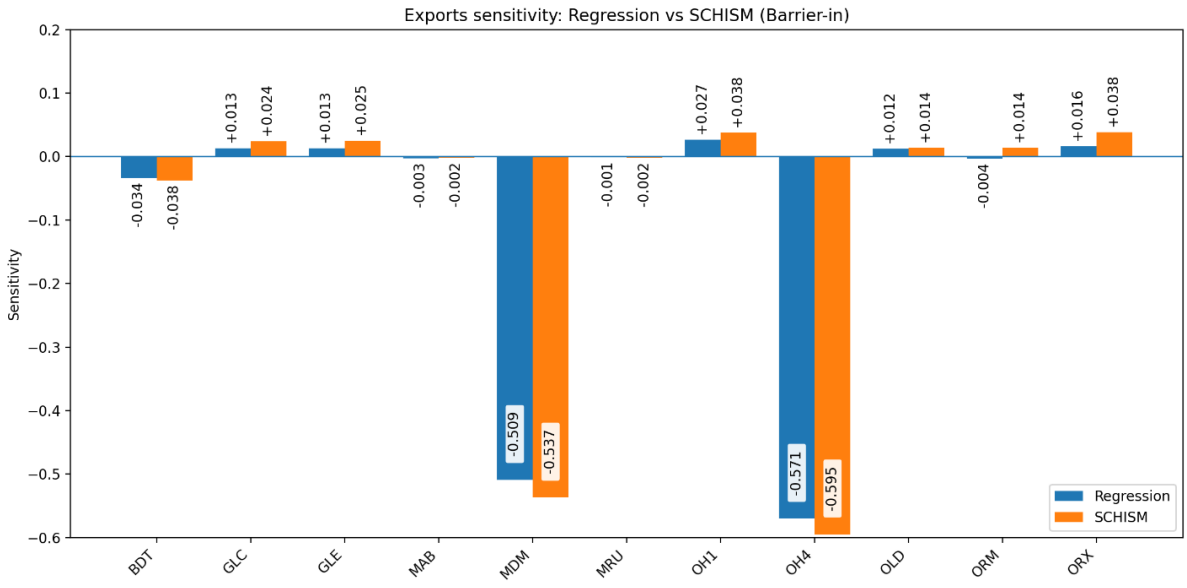
- Exports (10,000 cfs scale) and San Joaquin River flow (2,000 cfs scale considered) that are much larger but induce net flows on South Delta channels with very low sensitivity, often below 1.5% and, on some reaches like upper Middle River, 0.1%.

Sections 3.2.1, *Statistical Net Flow Responses*, and 3.2.2, *Model Net and Tidal Flow Responses*, of *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6) list statistical and model-derived sensitivities of net flow at some of the most commonly discussed stations. Effects on tidal range are also given in the form of contour plots and discussion in Section 3.2.2 of Attachment 6. Summary figures of export sensitivities from Section 4.1.2, *Net Flow*, of Attachment 6 are reproduced in Figure 4-3 and Figure 4-4. Water project operations are mostly supplied from downstream via negative flow on Old and Middle Rivers, resulting in large sensitivities there that sum to roughly 1.0.



Note that data coverage and variable definitions are not identical. The sensitivities are cfs/cfs (formally unitless).

Figure 4-3. Comparison between Regression-Derived Net Flow Sensitivities and SCHISM Model-Derived Sensitivities to Export Pumping for the Case with No Barriers



Note that data coverage and variable definitions are not identical. The sensitivities are cfs/cfs (formally unitless).

Figure 4-4. Comparison between Regression-Derived Net Flow Sensitivities and SCHISM Model-Derived Sensitivities to Export Pumping for the Case with Barriers In

Modeling suggests near-capacity exports may draw more water across the South Delta from the San Joaquin River towards the intake area. Field evidence supports the concept, but statistical sensitivities are smaller than modeling in the with-barrier case. If near-capacity exports are combined with high San Joaquin River flows, then flushing in the South Delta may be increased, but upstream water availability, downstream regulatory constraints, and concerns about high exports will likely render the utility of this possibility moot. Also, the idea of flushing should not be construed to mean downstream-directed flow, as point described in Section 3.2, *Meeting the MSS Goals*, and in Section 3.2.3.2, *Potential to Ameliorate Null Zones*, of *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6).

Modeling suggests that high exports suppress tides, but not as much as the temporary barriers or San Joaquin flow rates. The relative influence varies spatially. See Section 3.2.1, *Statistical Net Flow Responses*, of *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6).

4.1.2 Tides

The entire interior South Delta seaward of Mossdale is tidally influenced. Tidal flows at most locations on main channels in the South Delta are many times larger than net flows and support mixing through *dispersion* mechanisms. Dispersion is the mixing that occurs as gradients in concentrations move in contrasting ways back and forth through the complex network of channels or across the channel width.

Tidal dispersion is particularly important in the Five Points Region and the interconnected downstream reaches of the side tributaries Paradise Cut and Sugar Cut. *Flushing* in this case is provided by the mean flow mostly along Grant Line Canal that entrains salinity from Old and Middle River by means of lateral east-to-west tidal exchanges. Even in conditions of very low mean flow, tidal flow on Grant Line Canal is vigorous enough to facilitate transport of salt between Upper Old River and the intake area. The premise of flushing flow using fully downstream-directed flow on Old River and Middle River is only possible in cases with San Joaquin inflow well over 3,000 cfs as described in the historical analysis in Section 3.2.3.2, *Potential to Ameliorate Null Zones*, of *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6).

When barriers are present, Lower Old River and Middle River experience the relatively rare situation in the Delta where tides become nearly extinguished along a tidal channel. In the case of Lower Old River this happens just downstream of Tracy Boulevard near the OLD compliance station, and in the case of Middle River it happens just upstream of Howard Road Bridge, near the MHO SC monitoring station. If low net flow or a null zone coincides with low tidal volumes at these locations, tidal dispersion (defined as the cross-sectional variation in velocity and salinity due to tidal period and inflow conditions) can no longer make up for lack of mean flow and any adjacent sources of high salinity will become "trapped" and can accumulate in concentration over time. A relatively small source of high-salinity water (e.g., 5–10 cfs) may be quite significant in a reach with zero net flow and limited tidal mixing. The same source may be much less significant during another season when a more significant downstream net flow into the interior South Delta channels from the San Joaquin River dilutes it.

4.1.3 Unquantified Local Diversions and Discharges

Local water use can have an important effect on flow and salinity of Lower Old River and Middle River. Local channel depletions are required for null zones to form. Discharges also provide a significant mass of salt.

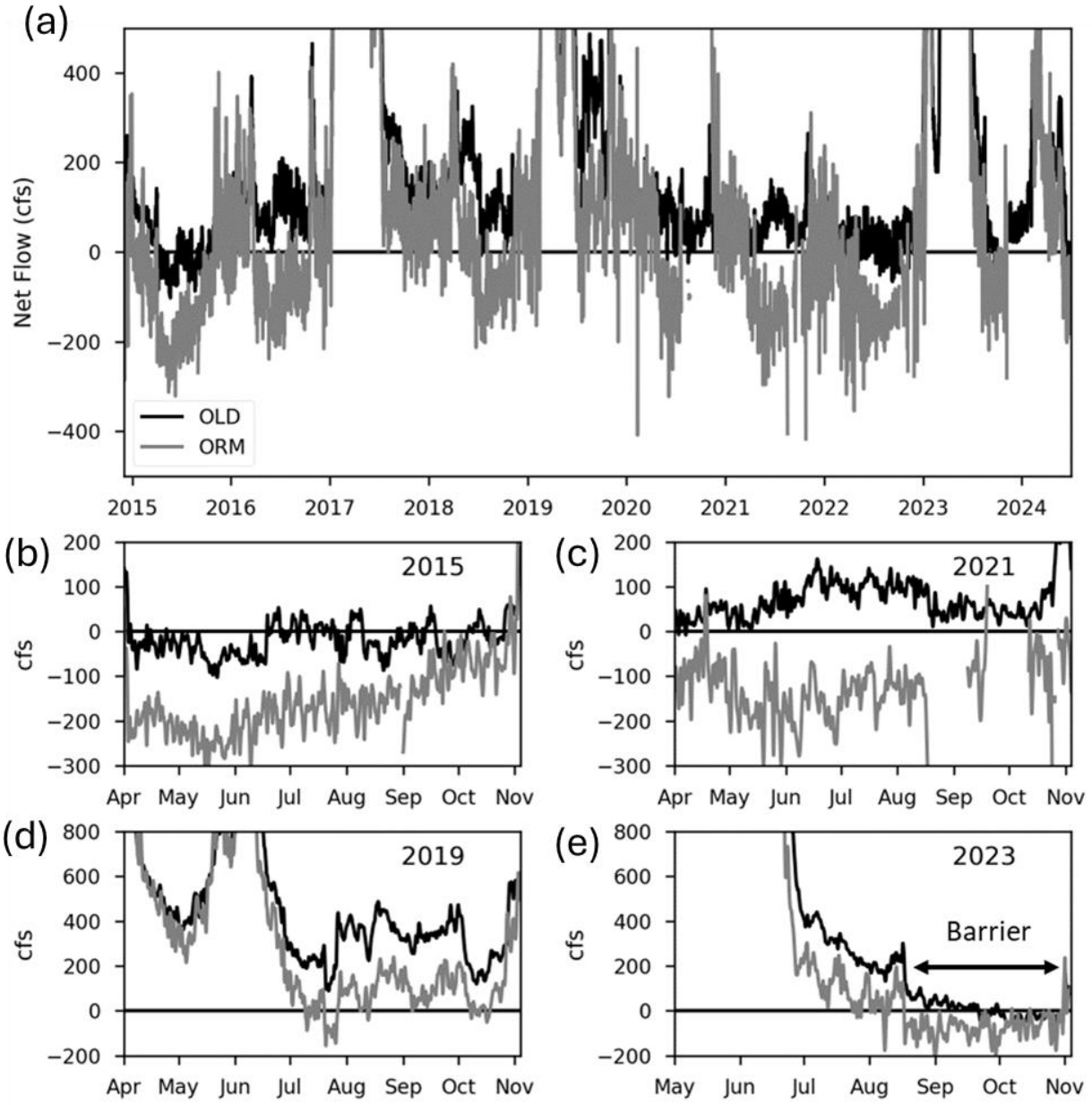
Throughout the MSS, higher salinity concentrations relative to ambient waters were observed in the Pescadero Tract, Five Points Region, and Lower Old River areas during 2021–2023 high-speed salinity transects (*High-Speed Salinity Transect Mapping* [MSS Report, Attachment 1, Sections 4.4, 4.5, and 4.6]) and inferred using inverse modeling techniques (*Data Integration and Source Inference for Modeling* [MSS Report, Attachment 4]). Even after mixing into the local stream, concentrations at times exceeded 3,000 µS/cm, particularly in Tom Paine Slough and Paradise Cut (*Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2, Sections 3.2.2 and 3.2.5]).

Local discharges are not monitored, which complicates analysis and water quality control in the South Delta. Source inference was, therefore, deemed necessary to quantify apparent sources and sinks within these channel reaches. MSS high-speed salinity transects (Attachment 1) and additional SC monitoring (Attachment 2) provided further insight into general locations of some salt discharges, including pulses of salinity discharge trapped in channels with low flow or null zone formation that are hard to infer (Attachment 4, Section 4.5). Although the spatial mapping and inference methods of the MSS are an important advancement in quantifying in-Delta discharges of salt mass and demonstrating the tendency for convergent zones to trap salinity

from in-channel discharges, detailed characterization of salinity dynamics would benefit from measurements of both the volume discharge and EC of all major sources.

4.2 Null Zone(s) and Bathymetry Sensitivity

A *null zone* refers to a location where flow converges around a flow sink: it implies an upstream positive flow meeting a negative flow downstream, and in the process passing through a convergence point where streamwise net discharge is zero. Null zones are a regular occurrence in the main South Delta channels, developing in early spring most years. The formation of null zones both increases residence time and exacerbates the accumulation of channel salts. Modeling shows how null zones create a discontinuity between the upstream region where source water comes mostly from San Joaquin River water and a downstream region where source water comes from downstream sources (*MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6, Section 3.2.2, *Model Net and Tidal Flow Responses*]).



Note: The top plot comprises most of the shared period of record; bottom plots are individual seasons described in the text. Positive flow direction in cfs is westward or downstream, while negative flow direction in cfs is eastward or upstream.

Figure 4-5. Historical Net Flow Extracted from Observed Data on Old River near Tracy Boulevard (OLD) and Old River at Mountain House Creek (ORM).

In the South Delta, the two river segments that develop null zones most readily are Middle River and Lower Old River. Of the two, Lower Old River has presented the greatest management concerns, as this null zone often forms around or near the compliance station OLD (*Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2, Section 3.2.6]; *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment

6, Section 3.2.2]; *Old River Null Zone Study* [MSS Report, Attachment 8]). Figure 4-5 shows the east-to-west convergence in flows within Lower Old River at stations Old River at Mountain House (ORM) and OLD, where downstream flows at ORM are often net negative or eastward in spring and summer, while downstream flows are often net positive at the OLD station.

The null zones in these channel regions arise from the combination of channel depletions, presence of temporary barriers (which are intended to induce negative flow) and ambient flows that are not extreme. San Joaquin River flows around 2,000 cfs and exports around 10,000 cfs produce enough streamwise influence to overcome the null zone with positive flow. The most essential contributing factor is the in-channel depletion—convergent flow can only form around a sink, although in the field the idea of a "sink" may be a simplified description of what is really a spackled accumulation of smaller diversions.

Null zones are usually described in terms of mean flow, but in the South Delta their effects are amplified during periods when net-zero flow coincide spatially with areas with low tidal flow conditions. The combination of net-zero flow and highly attenuated tides creates limited flushing, a situation observed quite often in Lower Old River and Middle River.

4.2.1 Lower Old River Null Zone

The formation of a null zone in Lower Old River was observed in all years (2021, 2022, and2023) of the MSS study period. Although dry water year conditions can prolong the presence of the null zone (i.e., 2021 and 2022), there was null zone formation in late summer and fall even in the record wet and higher flow conditions of 2023.

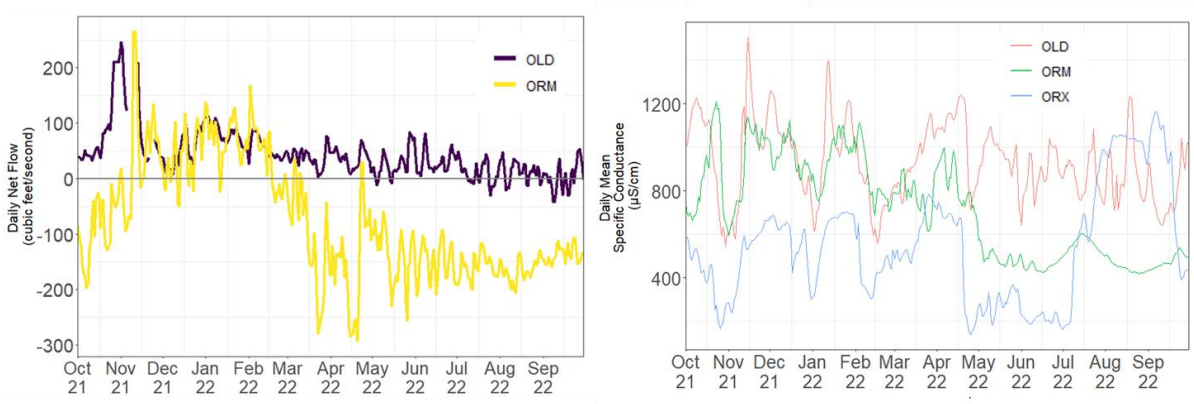


Figure 4-6. Water Year 2022 Old River at Tracy Boulevard and Old River at Mountain House Daily Mean Net Flow and Daily Mean Specific Conductivity at Stations Old River at Tracy Boulevard (OLD), and Old River at Mountain House (ORM), and Old River above Doughty Cut (ORX)

The development of the null zone in Lower Old River varies annually, but tends to start in the spring (i.e., March or April), when peak San Joaquin River inflows reduce, flows at ORM become net negative, and local agricultural diversion begins (Figure **4-6**). The null zone typically occurs between the permanent stations OLD and ORM. Temporary flow monitoring during the 2022 Old River and Grant Line Canal temporary barrier installation periods provides evidence of a null zone bounded between OLD and ORM (Figure 4-7; see also *Old River Null Zone Study* [MSS Report, Attachment 8]). The salinity within the Lower Old River null zone often increases

throughout the summer and fall months. As water residence time increases, local discharge contributions are at their highest, and upstream salinity sources from Paradise Cut and the Five Points Region continue to add to the salt loading in this region. Modeling results further indicate that the null zone in Lower Old River results in the upper part of the reach containing more water sourced from the San Joaquin River and the lower reach having a larger fraction of western/external water sources (Figure 4-8), with in-Delta sources also being trapped within this flow convergence (*MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6, Section 3.3.3]**)**.

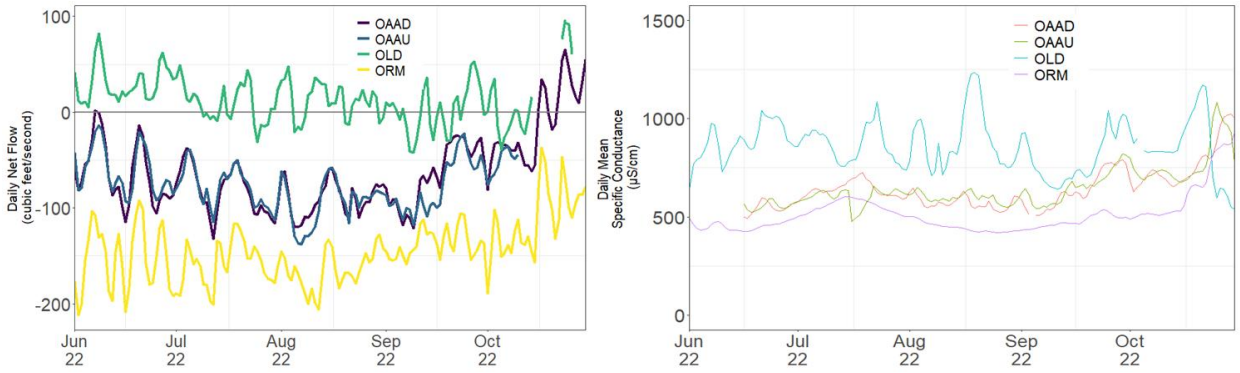


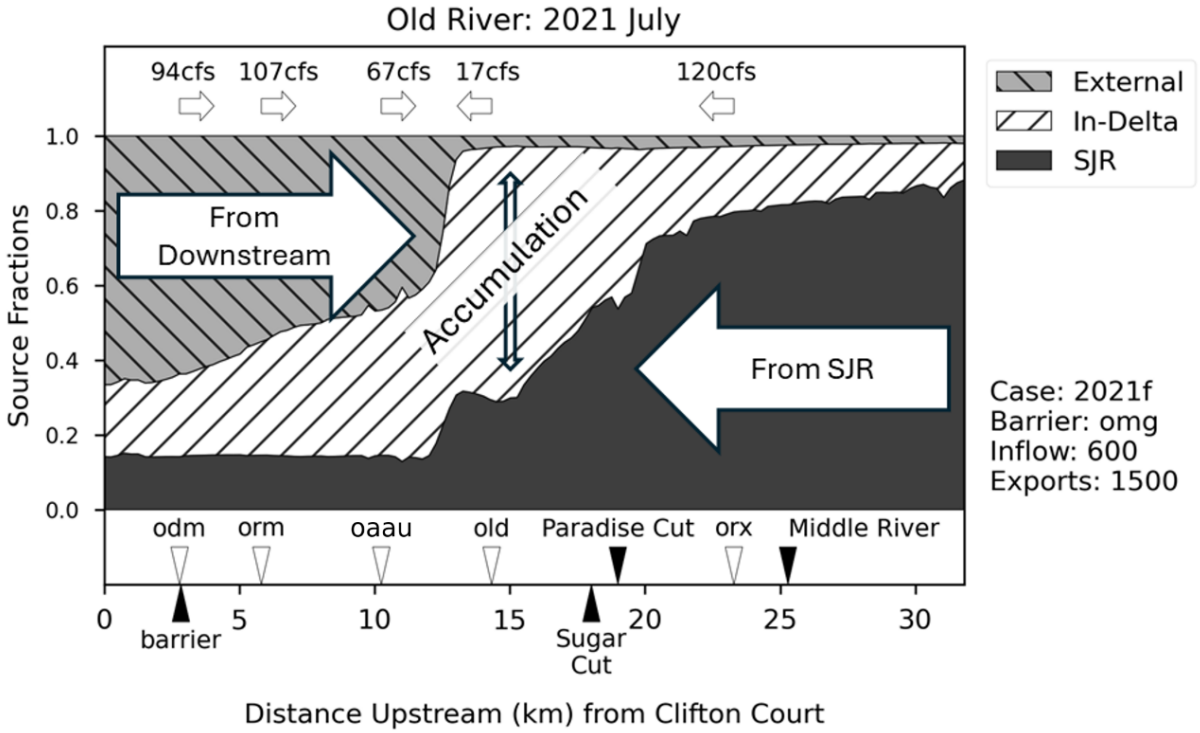
Figure 4-7. Old River at ADCP Downstream (OAAD), Old River at ADCP Upstream (OAAU), Old River at Tracy Boulevard (OLD), and Old River at Mountain House (ORM) Daily Net Flow and Daily Mean Specific Conductivity for June–October 2022

The Lower Old River null zone can migrate seasonally. Water year conditions influence when and how the null zone migrates, and that migration timing and movement differs based on hydrologic conditions, influencing San Joaquin River inflow and the ambient downstream net tidal flow forcings at OLD and upstream forcings at ORM. This migration is further influenced by the large number of privately owned diversions and discharges that exist along the full extent of the Lower Old River channel. Data on the volume of each diversion/discharge point was not made available for this study but was inferred within each segment (*Data Integration and Source Inference for Modeling* [MSS Report, Attachment 4, Section 1.1]). Drought conditions, as observed in 2015 and 2022, can have the potential to cause the null zone to move upstream from the typical null zone location between ORM and OLD, as net flows were slightly negative at OLD and even at the further upstream station ORX (*MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6, Section 3.2.2]).

In 2023, a record wet year, an unusual situation occurred compared to other years: observation of a null zone despite the higher-than-average San Joaquin River inflows. This condition was determined to be caused by the installation of Old and Middle River barriers, but not the Grant Line Canal Barrier, which corralled mean flow into Grant Line Canal rather than the Lower Old River (OLD-ORM) region.

The timing and location of the null zone in Lower Old River has implications for the overall effect of salinity in the South Delta. For example, it can be most disadvantageous for the null zone to hover around the Five Points Region in the summer and fall because Paradise Cut is one of the largest sources of salinity. The null zone causes this salinity to be trapped in this region until temporary barriers are removed and San Joaquin River inflows increase over the winter.

Also, in the case of Lower Old River, the further downstream of OLD the null zone resides, the more tidal dispersion can assist with reducing salinity.



Note: SJR = San Joaquin River at Vernalis; The Case label "2021f" in this figure refers to the Sub-experiment and description of operations or physics explored in the Bay-Delta SCHISM model as "General sensitivity to Vernalis flow, exports, and barriers, as further described in Attachment 6, Table 3. The simulation has barrier configuration OMG (at Old River, Middle River, and Grant Line Canal). Vernalis inflow and combined exports are specified as cubic feet per second. Arrows have been added to highlight direction of propagation of water from the San Joaquin at Vernalis and from downstream.

Figure 4-8. Composition of Water at Locations along Old River in a Classic Null Zone Flow Regime

4.2.2 Middle River Null Zone

A null zone also forms in Middle River seasonally; however, less flow monitoring data is available for this region. Both MSS modeling and monitoring efforts provided evidence for a convergence area near Howard Road or station MHO (*MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6, Section 3.2.2]). MSS transect monitoring and analysis of long-term monitoring salinity data has shown elevated SC at or near the MHO station across multiple water year types (Figure 4-9; see also *High-Speed Salinity Transect Modeling* [MSS Report, Attachment 1], Appendix 1B, and *Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2, Section 3.2.2]). Much like Lower Old River, the null zone formation in Middle River is controlled by changes in ambient flow, from both upstream via the San Joaquin River and downstream via OMR flows that are affected by export operations and tidal fluctuations. The null zone formation is also affected by upstream and

downstream channel depletions, and the seasonal installation of the temporary barrier downstream of station Middle River near Tracy Boulevard (MRX). However, the location of the null zone on Middle River is more stable than on Old River, with a convergence point near Howard Road.

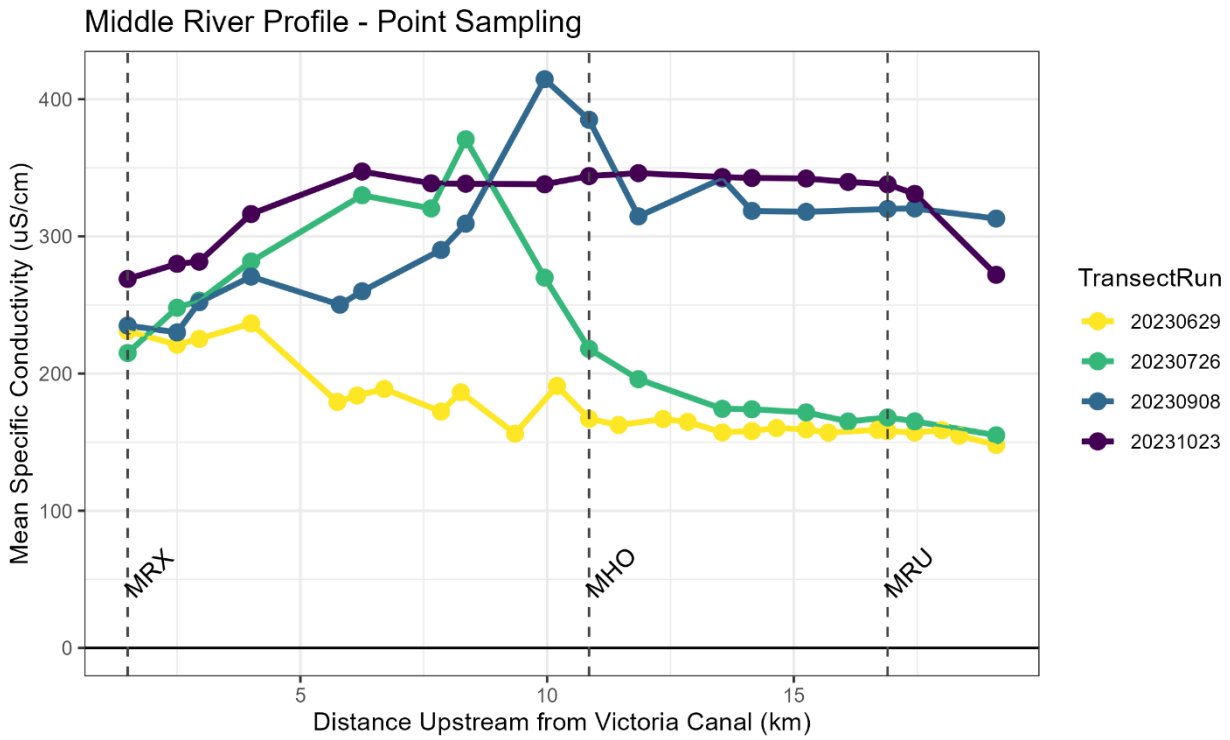


Figure 4-9. Middle River Point Sampling Profiles (June–October 2023)

Middle River has a compounding issue of conveyance limitation, with tidal exchange limitations in the upstream reaches near Middle River close to Undine Road (MRU) and sediment deposition that has caused changes in bed elevation, reducing the cross-sectional channel capacity. Modeling experiments applying artificial dredging to both Lower Old River and Middle River were performed to determine value in improving the conveyance of water flow, salinity, and levels based solely on bathymetry of the channels. Middle River showed the greatest improvement in all three categories, even with a smaller volume of removed materials (Figure 4-10). Lower Old River artificial dredging had less immediate changes in mean flow and freshening; specifically, improvement of up to 150 µS/cm was only observed during periods with limited in-Delta contributions of salinity, mostly during non-temporary barrier seasons (*MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6, Section 3.4.1]). These results suggest that dredging in Lower Old River would only reduce salinity if in-Delta sources are limited and there is enough San Joaquin River inflow to flush local salts, which is not always the case.

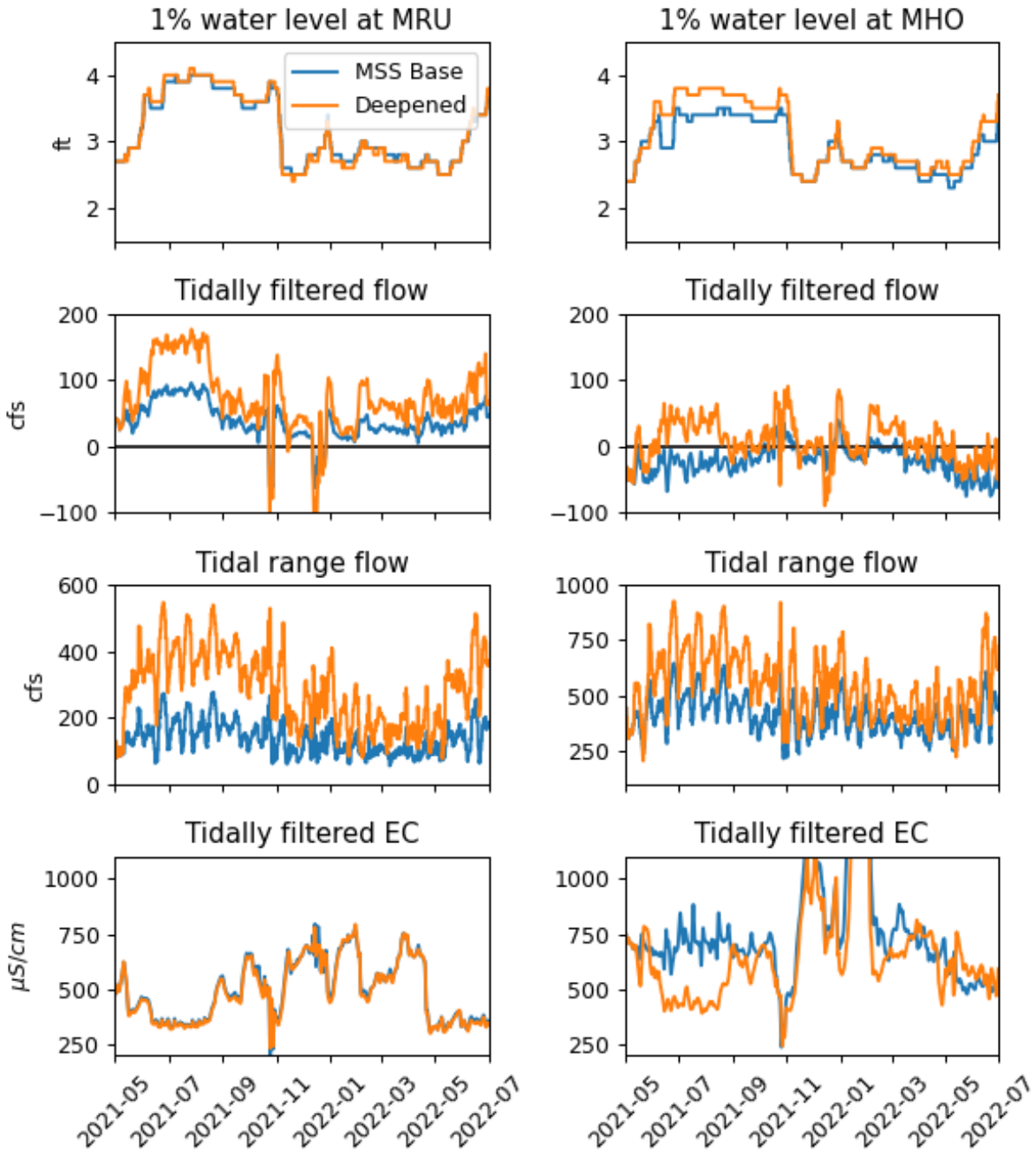


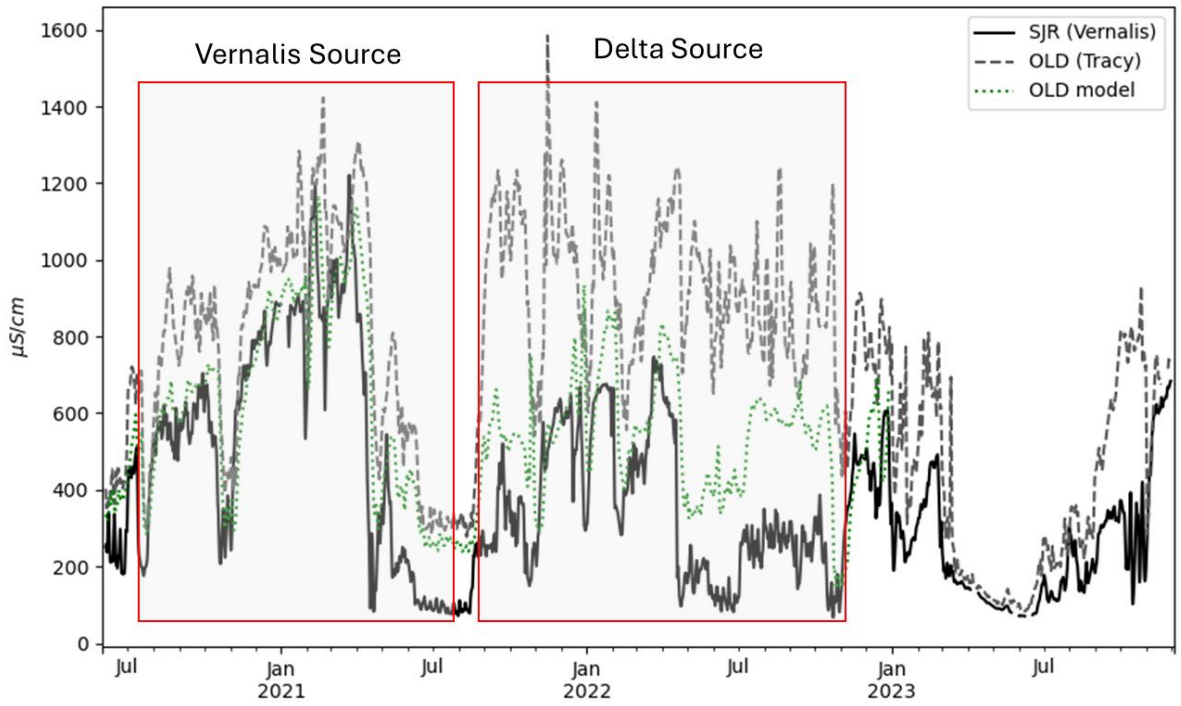
Figure 4-10. 1%-Quantile Water Levels, Tidally Filtered (Net) Flow, Tidal Range of Flow and Specific Conductivity at an Upstream (Middle River at Undine Road) and a Midstream (Middle River at Howard Road) Site on Middle River with and without Artificial Dredging

4.3 Major Sources of Salinity

Sources of salinity in the South Delta are either from the San Joaquin River to the east, from the San Francisco Bay to the west, or from local tributary and/or discharge sources. San Joaquin

River inflow is the primary upstream source of water; however, there are numerous periods when salinity from the San Joaquin River is not sufficient to explain the high levels of salinity in some reaches in the South Delta (Figure 4-11; *Data Integration and Source Inference for Modeling* [MSS Report, Attachment 4, Section 1.1]). Figure 4-11 shows periods when SC trends at OLD coincide with SC trends at Vernalis and periods when they deviate, with OLD SC concentrations far surpassing those observed in the San Joaquin River. This is the case for reaches with less water conveyance (i.e., Lower Old River and Middle River) that are further from the primary San Joaquin River downstream flow pathway through Upper Old River and westward through Grant Line Canal.

The MSS was limited to measuring salinity in surface waters accessible to DWR and USBR. There was specific focus by the MSS to fill data gaps, particularly in reaches where measured salinity and flows were significantly different from modeled values. For this reason, the additional MSS SC monitoring stations as part of the point source and ion sampling technical study (*Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2]) and SC transect data for the high-speed salinity transects mapping technical study (*High-Speed Salinity Transect Mapping* [MSS Report, Attachment 1]) were considered alongside Data Assimilation (Attachment 4) and refined SCHISM modeling (*MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6]). Results from this data collection and modeling support the explanation that higher salinity observed in Lower Old River and Middle River are due to a combined accumulation of local sources of salinity within a year or subsequent years, and the trapping of those salts due to flow convergence and null zone formation. The null zone further exacerbates the salt load as residence time is longer and dilution is low.



Note: Red rectangles delineate periods of Vernalis and In-Delta Control on salinity.

Figure 4-11. Observed Specific Conductivity on the San Joaquin River at Vernalis (solid dark line), Old River at Tracy (OLD), and Pre-MSS DSM2 Model Results at OLD

4.3.1 Local Salinity Sources are not Quantified

Salinity conditions in the South Delta cannot be fully understood until in-Delta sources are quantified. Local salinity sources are evident in both past and recent studies. Without salt load data for in-Delta sources, only measured San Joaquin River–driven fluxes can be explained by the models, and these are not sufficient to account for salinity levels throughout all the South Delta channel reaches. To make the models used in the MSS more accurately align with measured flow and salinity data while retaining the physics of the system, sources had to be inferred (Figure 4-12; see also Attachment 4). Figure 4-12 shows a comparison of model output with and without inferred salinity source loadings to time series data at SC continuous stations in Doughty Cut, Middle River, and Upper and Lower Old River. This shows that source inferences help with aligning modeled data with monitoring stations, but in some cases stations where local salinity source impacts are higher, model outputs may not fully align or capture SC concentrations as observed by local monitoring data. Such inference produces masses of salinity that explain field observations but are not highly resolved locally (i.e., they cannot assign discharges to individual drains). If data were available for local salinity sources that are practical to measure, then these data would be used in the models and source inference would be less necessary for model results to match observed station data.

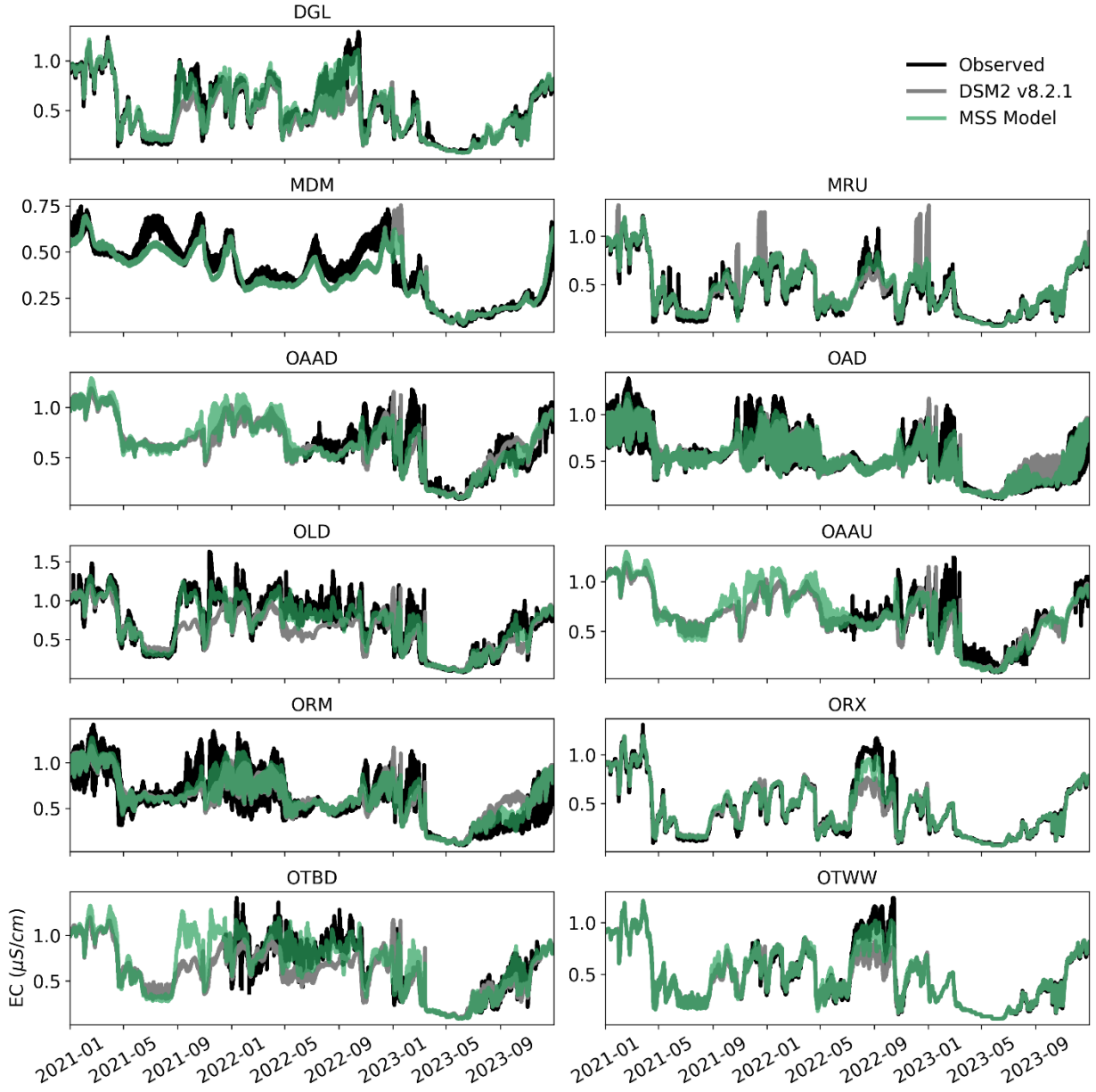


Figure 4-12. Comparison Between Model Performance with (MSS Model) versus without (DSM2 v8.2.1) Source Inference

4.3.2 Source Water and Salinity Vary by Reach

Model source tracking was simulated with sources designated as the San Joaquin River, in-Delta, and external (a combination of Sacramento River and seawater). Results showed that the mixture of different sources varies considerably across the South Delta east to west and is affected by temporary barriers, San Joaquin River inflow, and exports. When null zones are present, abrupt changes in the mixture of salinity sources can form mid-reach (Figure 4-8; *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6, Section 3.3.3.1]).

When barriers are installed, the main flow path from the San Joaquin River in the South Delta is through Old River at Head west through Grant Line Canal. In the South Delta, accumulated salts in Lower Old River or Middle River require sufficient San Joaquin River inflow and/or export rates to promote downstream net flow through these reaches, to flush or dilute local salts (Attachment 6, Section 3.2.1). The required flow is significant (e.g., 3,000 cfs at Vernalis), hence the conceptualization of flushing as arising from positive mean flow on all the South Delta reaches is neither congruent with the usual mechanisms of flushing nor feasible in most water year types. More likely, Grant Line Canal is the main conduit for downstream transport and adjoining parts of Old and Middle Rivers are freshened through lateral tidal exchange. However, the barriers as an improvement to upstream water elevation also dampen the tidal exchange and circulation in these channels, which also reduces the flushing or dilution of local salts.

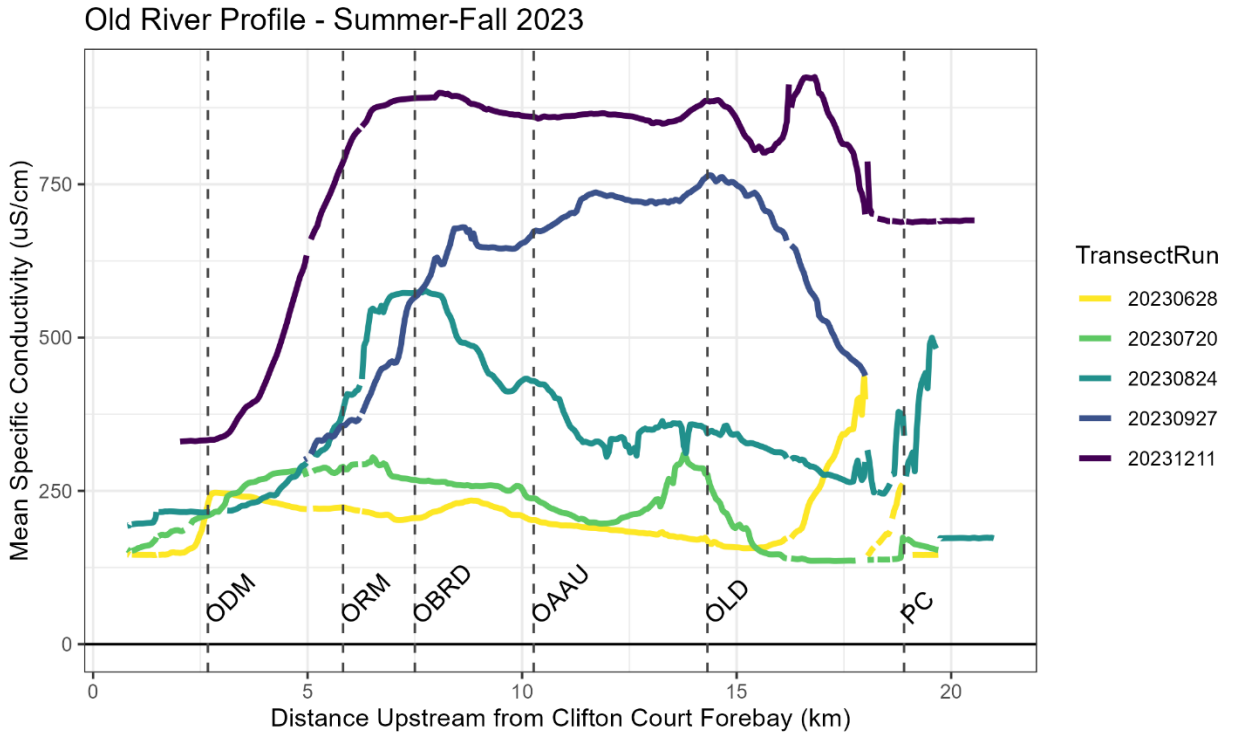


Figure 4-13. Lower Old River Transect Profile Plots (Summer and Fall 2023)

MSS high-speed salinity transect and fixed station monitoring data (Attachments 1 and 2) observed elevated salinity between stations along channel reaches, most notable in Lower Old River, Middle River, Paradise Cut, and Sugar Cut. Figure 4-13 shows Lower Old River high-speed transect results from summer and fall 2023, providing evidence of elevated salinity between fixed stations, likely from local in-Delta sources. These mid-reach increases in salinity concentrations indicate local sources of salinity that are accumulating within reaches, especially during null zone formation. A key difficulty both for monitoring and for source inference occurs when the tidal excursion around a source does not reach a monitoring station. One aspiration for long-term monitoring would be to move the MSS station Old River at Anchored ADCP Downstream (OAAD) upstream between station Old River at Anchored ADCP Upstream (OAAU) and Tracy Wildlife Area (TWA) that resides 0.5 mile downstream of OLD compliance

station. The location would minimize this tidal excursion problem (Figure 4-13). A temporary station was approved by SWRCB and moved to this new location (37°47'53.16"N, 121°28'7.92"W) on May 1, 2025.

4.3.3 Discharges on Lower Old River

High-speed transects show that there are pulses, or slugs, of salinity that form and move through Lower Old River (Figure 4-13; *High-Speed Salinity Transect Mapping* [MSS Report, Attachment 1, Section 4.4]). Transects alone are not sufficient to determine the origin of these observed salinity pulses. Nevertheless, comparisons with time series indicate that some of these salinity pulses do not originate from San Joaquin River inflow or from sources downstream of Clifton Court Forebay, but appear to originate from the Paradise Cut, Sugar Cut area, and Lower Old River (Attachment 2, Section 3.2.3.2 *Sources of Salinity*). These pulses accumulate in Lower Old River, resulting in the highest levels of salinity in the interior portion of Lower Old River during the late summer or fall during the presence of the null zone (Attachment 1, Section 4.4.4).

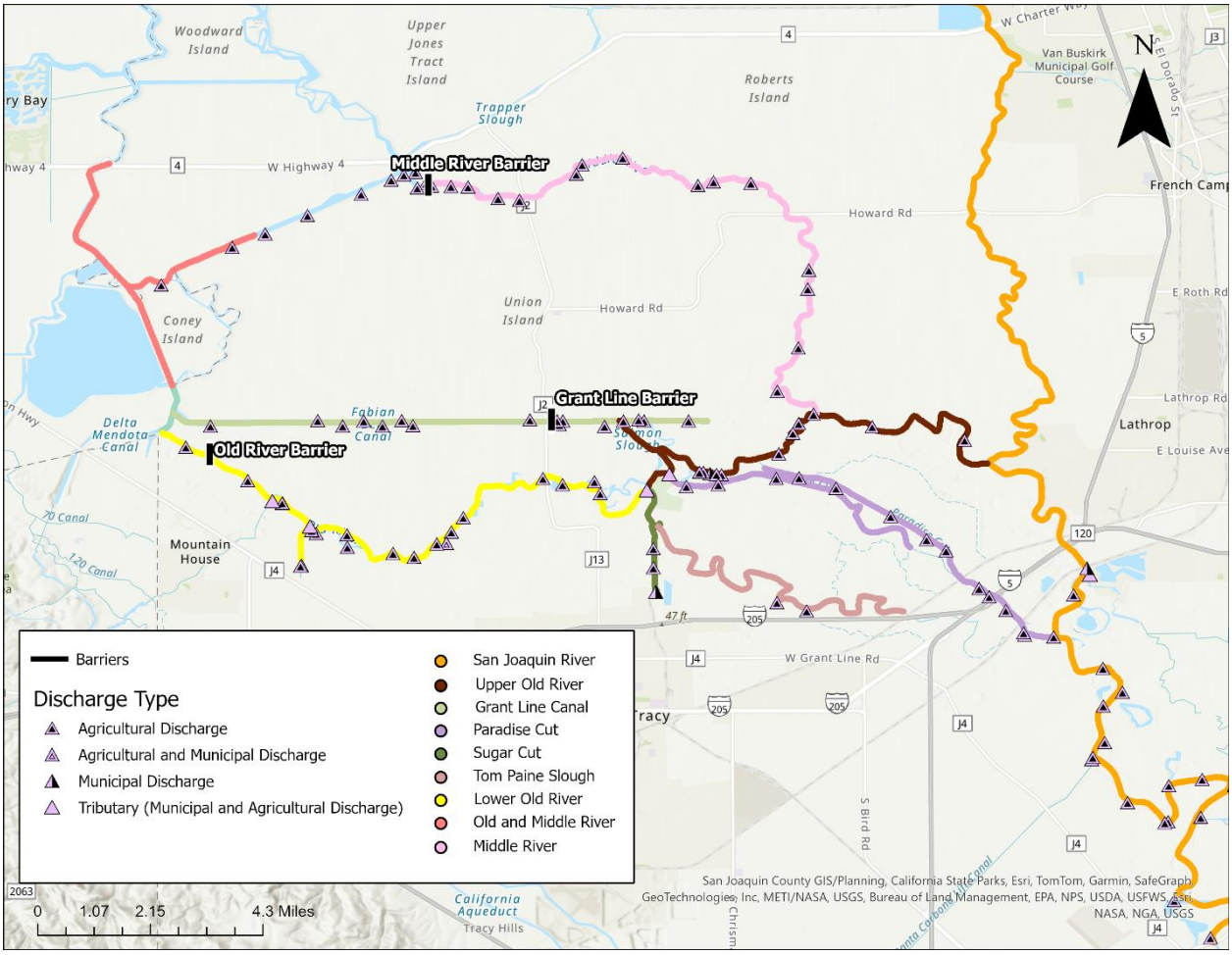


Figure 4-14. Map of Interior South Delta Municipal and Agricultural Discharges

Several agricultural drains and pumps exist in Lower Old River (Figure 4-14; *Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2, Section 1.2]; and *High-Speed Salinity*

Transect Mapping [MSS Report, Attachment 1, Appendix 1C]). Some previously documented high-salinity drains include the Tracy Boulevard drain just upstream of OLD and the drains near Lammers Road and Bethany Road. Although measurements of both the volume discharge and SC at these drains were not monitored as a part of the MSS, nearby temporary in-channel SC monitoring stations and high-speed salinity transects suggested that there was periodic high-salinity discharge into Lower Old River near these drain inputs. Specifically, monitoring at station Old River at Bethany Road Drain (OBRD) adjacent to the Bethany Road Drain showed consistently higher salinity in channel surface waters year-round (Figure 4-15; see also Attachment 2, Section 3.2.2). The data suggest that during periods of null net flow the salt loads from these drains may be accumulating in Lower Old River and diversions in the same area are recirculating that high-salinity water during the agricultural growing season of summer and fall. High-speed transects observe local salinity maxima but not their points of origin.

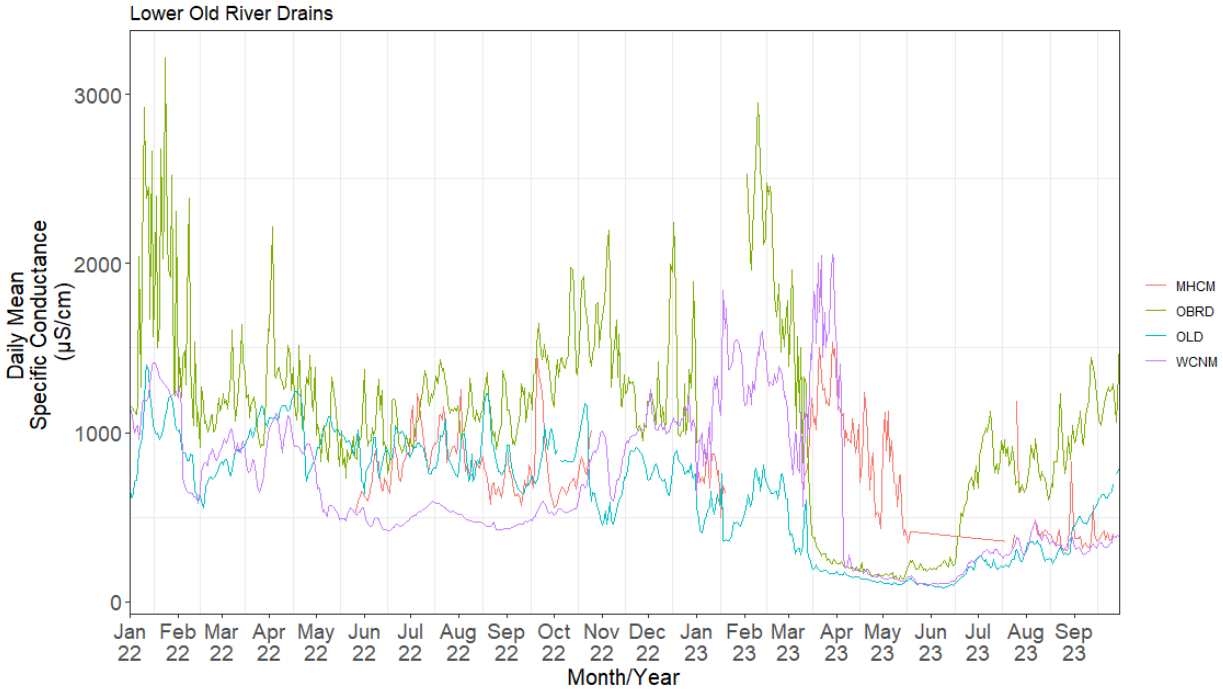


Figure 4-15. Lower Old River Drains from January 2022–September 2023 Daily Mean Specific Conductivity at Stations Mountain House Creek Near Mouth, Wicklund Cut Near Mouth, Old River at Bethany Drain, and Old River at Tracy Boulevard

4.3.4 Contributions of Salinity from Five Points Region

The Five Points Region, including Paradise Cut and Sugar Cut, is a large source of salinity to Lower Old River. Figure 4-16 shows how both Paradise Cut and Sugar Cut have higher salinity in the upstream portion (i.e., near Drainage at Arbor Road [DAR] and Paradise Cut Upstream [PDUP] monitoring stations). After periods when Paradise Weir overtops, as it did March 10–June 23, 2023, salinity rebounds in Paradise Cut to levels well above Old River or the San Joaquin River, indicating the source of high salinity is upstream of MSS SC monitoring stations at the Paradise Avenue bridge or from local drains within Paradise Cut (Figure 4-17; *Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2, Section 3.2.4] and *High-Speed*

Salinity Transect Mapping [MSS Report, Attachment 1, Section 4.5.2]). Figure 4-16 shows the high SC in Paradise Cut leading up to the Paradise Cut Weir overtop event, the alignment in salinity with the San Joaquin River during the overtop period, and the rapid increase in salinity within Paradise Cut, especially in the upper reaches, in just a few days.



Figure 4-16. Paradise Cut, Paradise Cut North Bridge, Paradise Cut South Bridge, Paradise Cut Upstream (PDUP), and San Joaquin River at Mossdale Daily Mean Specific Conductivity from January 1, 2023–September 30, 2023.

The three rhodamine dye studies conducted in Paradise Cut suggest a net downstream movement of water. This downstream flow means that high-salinity water is making its way into Old River (*Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2, Appendix 2C, Section 2C.4]). There are both agricultural drains and diversion pumps along Paradise Cut. Tom Paine Slough showed periods when SC was above 3,000 µS/cm, significantly higher than SC levels in Sugar Cut (Attachment 2, Section 3.2.2). Tom Paine Slough is used for irrigation and drainage and is connected to Sugar Cut through tidal gates and siphons. The operation of these tidal gates and the circulation of Tom Paine Slough is not well documented. Sufficient data concerning the Pescadero Tract circulation and salinity budget were not available for the MSS work.

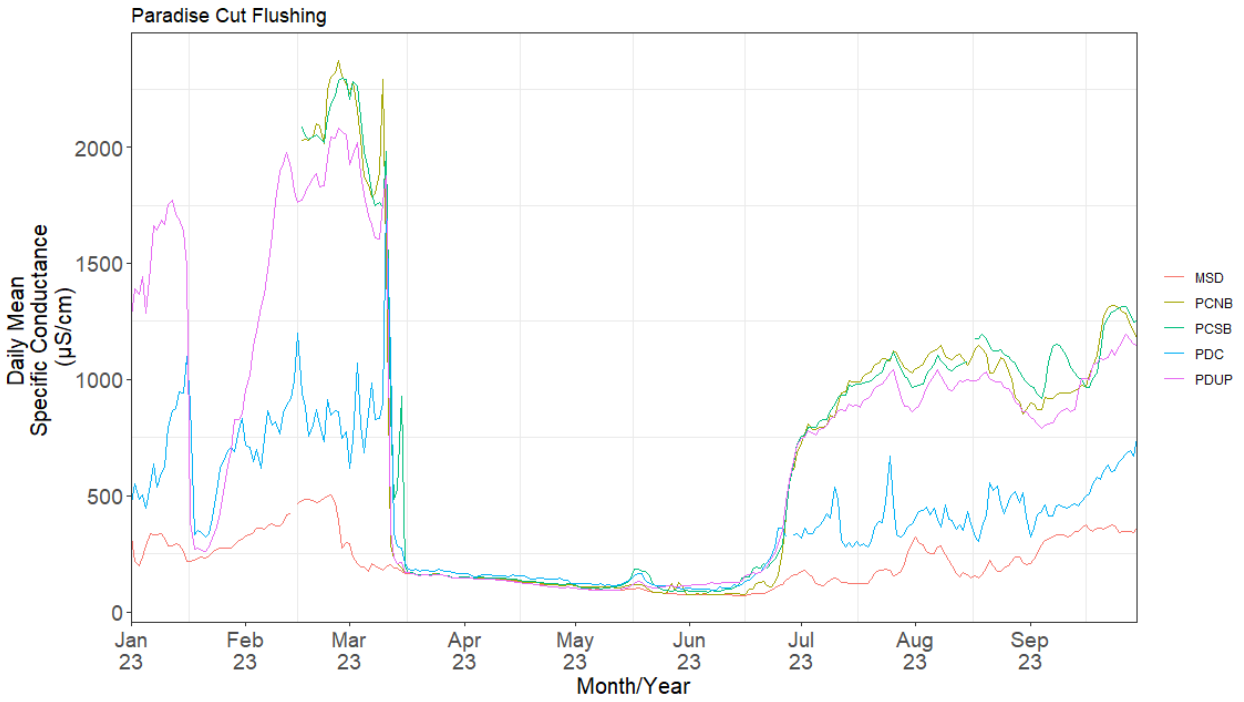


Figure 4-17. Paradise Cut (PDC), Paradise Cut North Bridge (PCNB), Paradise Cut South Bridge (PCSB), Paradise Cut Upstream (PDUP), and San Joaquin River at Mossdale (MSD) Daily Mean Specific Conductivity from January 1, 2023–September 30, 2023.

4.3.5 Contributions from Groundwater

Groundwater discharges in the South Delta are another source of salinity, but groundwater in the South Delta is not monitored sufficiently for use in Delta models or independent data evaluation. Groundwater has been stated anecdotally to be a source of high-salinity water that affects agricultural operations, but groundwater monitoring was not conducted during the MSS due to access, resource, and scope limitations. Previous work (Montoya 2007; Montoya and Cuthbertson 2012) has shown the South Delta drains influenced by groundwater-surface water interactions have a higher salinity content in part from the mineralized soil from the Diablo Range, a section of the southern coast mountain range of California that borders the San Joaquin Valley to the east from the city of Tracy south to the city of Buttonwillow in Kern County (Davis 1961). Underlying soils in the South Delta are composed of alluvium from the Diablo Range; therefore, groundwater in the South Delta that moves through this alluvium is likely to naturally increase in salinity.

Discharges from shallow groundwater into the South Delta channels could not be distinguished from other in-Delta surface water discharges during the MSS studies because no direct, comprehensive measurements of either exist. Appendix B, *Supplemental Stable Water Isotope Analysis*, identified likely groundwater discharge into the upper reach of Sugar Cut at station DAR in fall 2023, suggesting that during dry or critical water years groundwater may contribute a larger proportion of in-channel flow relative to wet years; however, these contributions remain unquantified because water isotope data was not collected prior to the wet conditions of WY 2023. No other location in the South Delta exhibited isotopic evidence of groundwater

contributions to the channels during 2023. The most effective way to quantify groundwater discharges to the South Delta channels is for SWRCB to directly measure and quantify surface water discharges, which can be monitored more easily and accurately.

4.3.6 Ions

Ion concentrations followed patterns similar to SC. Ionic composition was high in sulfate, bicarbonate, boron, sodium, calcium, and magnesium which is consistent with soil composition of the Diablo Range and are prevalent in ground- and surface-water sources in the streams found in this region. The Middle River stations show ionic compositions very similar to one another. PDC, SGA, and TPI also trend toward very similar ionic compositions and tend to take on properties more similar to TWA and GLE than to most stations in the Pescadero Tract region. The Sacramento River influence (WCI) shows more similarities to GLE in Grant Line Canal than to Middle River stations, and the San Joaquin River influence (VER [or C10A] and OH1) show more similarities to the Middle River. Samples from surface waters around the Pescadero Tract showed similar and distinct ionic compositions, especially the back-channel stations PDUP, PDC, TPP, TPPA, and DAR. Station DAR at the upper reach of Sugar Cut and stations Tom Paine Slough near Pescadero (TPP) and Tom Paine Slough at Paradise Avenue (TPPA) in Tom Paine Slough showed high concentrations of boron suggesting groundwater interactions (*Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2, Section 3.3]), which is supported by stable isotope data collected at station DAR in the upper reach of Sugar Cut (Appendix B, *Supplemental Stable Water Isotope Analysis*).

4.4 Adequacy of Current Monitoring Network in Assessing Reach Salinity

DWR, USBR, and the U.S. Geological Survey operate an extensive network of both long-term compliance and supporting monitoring stations that measure continuous SC as a surrogate for salinity conditions in the surface water of the South Delta (*Salinity Point Source and Ion Sampling* [MSS Report, Attachment 2, Section 1, Figure 1]). In addition, several of these stations have co-located continuous flow and stage monitoring to assist with dissemination of interacting water flow, level, and conveyance. In general, the monitoring network is robust and would not require expansion to provide an assessment of the attainment of the salinity objective in the river segments as defined in the 2018 Bay-Delta Plan. Challenges in station networks characterizing river reach salinity conditions arise in locations of the South Delta that have more limited water conveyance and elevated local water diversions and discharges, as well as seasonal installation of temporary barriers (i.e., Lower Old River, Grant Line Canal, and Middle River). Local salinity conditions in these interior South Delta channels can be further affected by water year type, as seasonal San Joaquin River inflow has a critical role in flushing flows for accumulated salts (Figure 4-18). In other words, dry climate conditions lead to reduced San Joaquin River inflow, which limits available flushing flows.

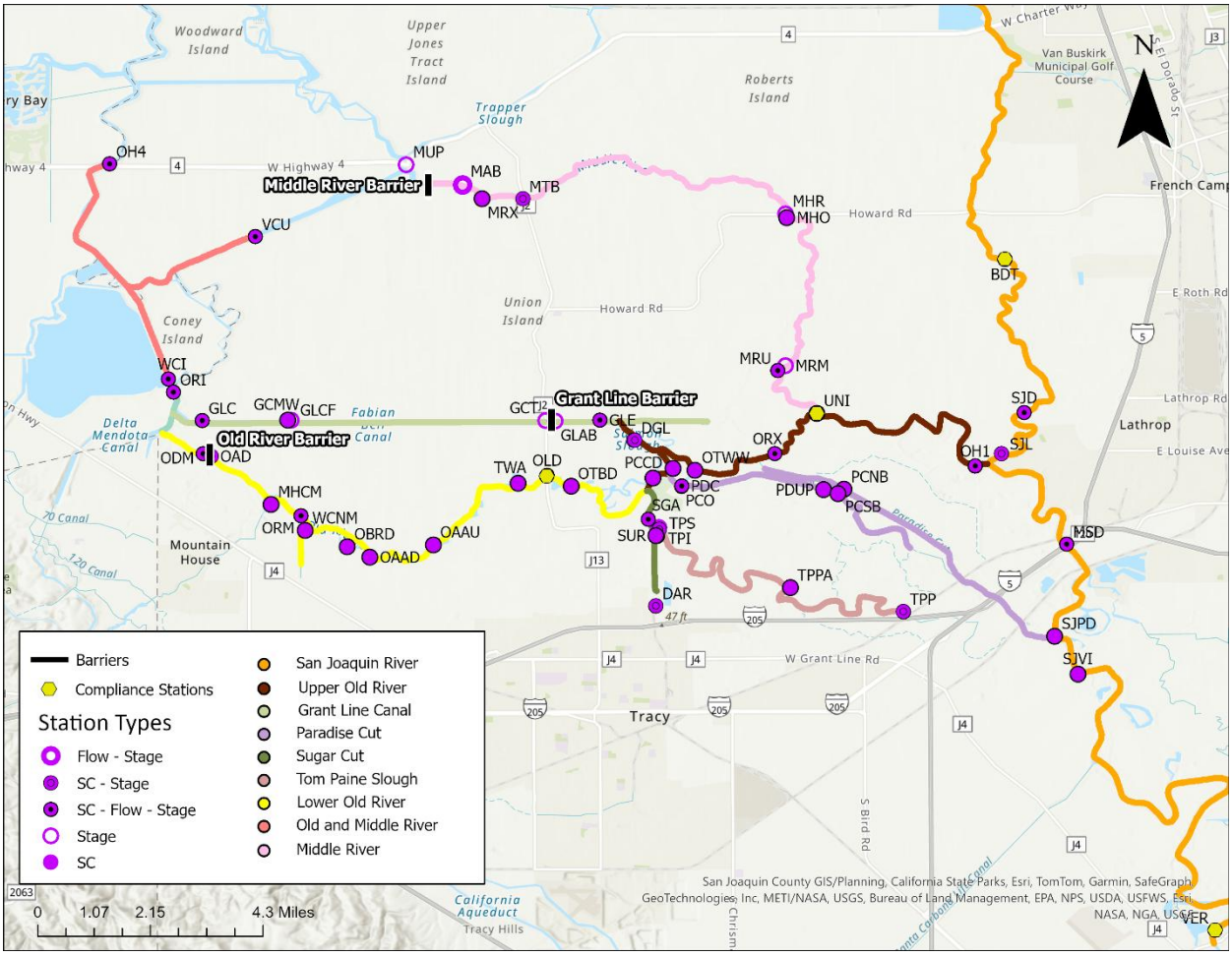
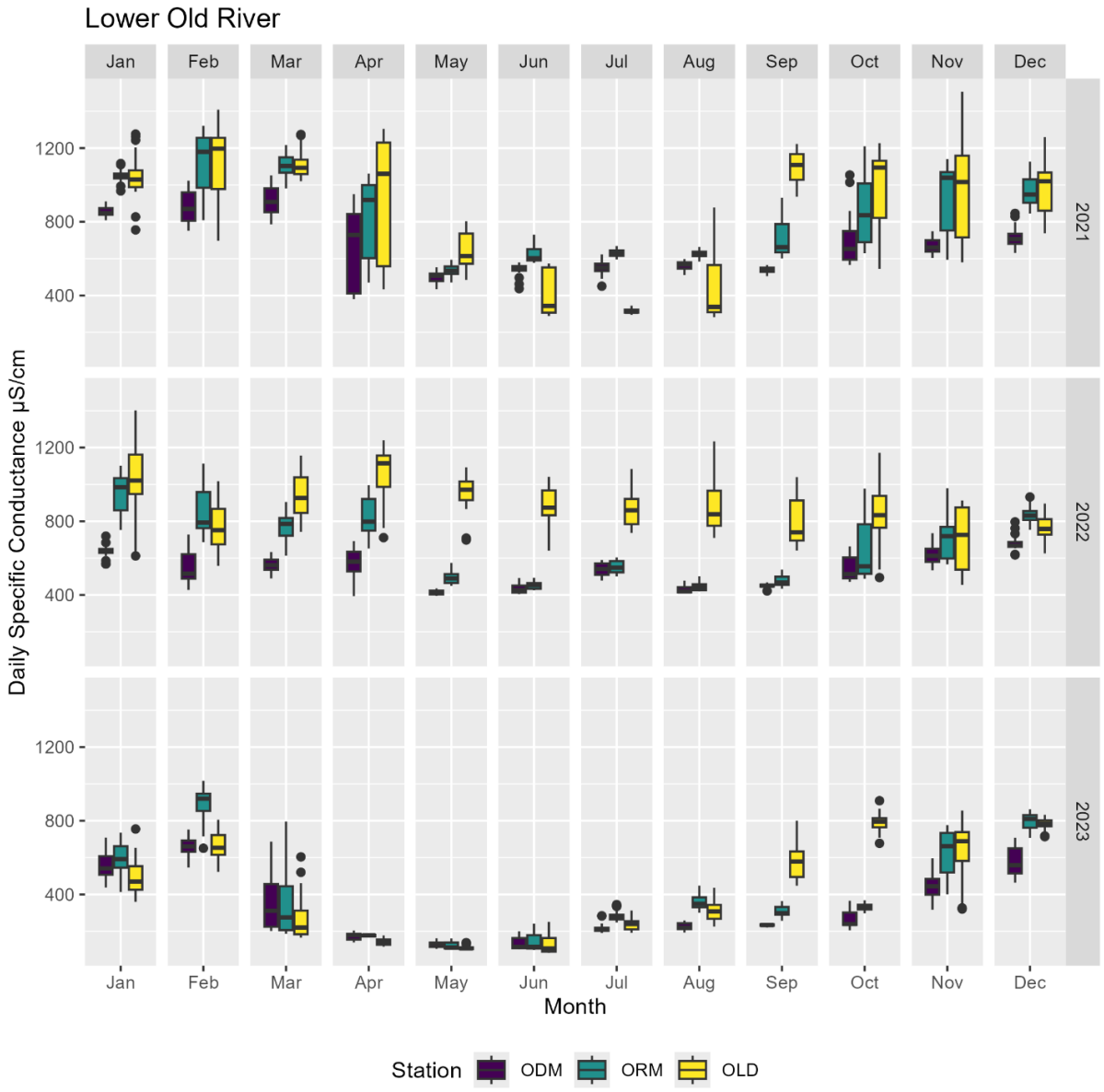


Figure 4-18. Map of Interior South Delta Channel Regions, Long-Term Water Quality and Flow Stations, and Monitoring Special Study Temporary Specific Conductivity Monitoring Stations

Lower Old River is the region with the most challenges in attaining salinity objectives at the OLD compliance station. There are stark differences in SC concentration across the Lower Old River segment, which are driven by several compounding factors tied to the convergence of two different water sources (Figure 4-19). Specifically, due to yearly null zone formation between stations ORM and OLD, the downstream stations of ORM and ODM consist of lower SC western water sources and the stations upstream of the null zone consist of San Joaquin River water sources. The OLD compliance station is not only in a null zone, but also situated upstream of some documented high-salinity drains and downstream of Paradise Cut and Sugar Cut, two known seasonal sources of high salinity; therefore, OLD is influenced by local sources of salinity regardless of the precise location of the null zone or local direction of flow.



Dots represent outlier values that fall outside the upper 75th percentile and lower 25th percentile quartile range of the box plot

Figure 4-19. Boxplots of 2021–2023 Daily Mean Specific Conductivity at Lower Old River Stations Plotted by Month

Some temporary MSS stations may prove beneficial to assessing river segment compliance across varied water years and operational conditions. These include station OAAU in Lower Old River between OLD and ORM, to help with defining the null zone boundaries and seasonal movement from east to west. Additionally, the Grant Line Canal Mid-West (GCMW) station would provide a better representative measurement of westside SC concentrations in Grant Line Canal proper, as the GLC station resides too far west and close to the export facilities and vascillates between measuring Grant Line Canal and other water sources from the west.

Chapter 5 Conclusions and Recommendations

The South Delta experiences a variety of circulation patterns and seasonal influences. In this chapter, the authors summarize the findings of the MSS, describing the sensitivities of the South Delta to operational variables and suggest ways in which the reaches defined in the 2018 Bay-Delta Plan could be better aligned with channel hydrodynamics to reflect the complex hydrology of the interior South Delta.

5.1 Conclusions

Table 5-1 summarizes the influence of the different variables explored in the MSS—namely, export pumping rates, San Joaquin River inflow and EC at Vernalis, the temporary barriers, tides, channel bathymetry, and in-Delta diversions or discharges—on key parameters of interest, specifically water levels, salinity, null zones, and tidal range in the South Delta channels.

Table 5-1. Summary of the Sensitivity of Water Level, Salinity, Null Zones, and Tidal Range to Key Variables in the South Delta

Influencing Variable	General Sensitivity Summary			
	Water Level	**Salinity**	**Null Zones and Net Flow**	**Tidal Range**
SWP/CVP Pumping[1]	• Negative relationship, impact varies by location and pumping increment • Medium[2] impact close to intake area especially on Old and Middle River. At Old R. at Tracy, export drawdown from the full range studied (1,500–10,000 cfs) is 0.5–0.9 ft	• Varied relationship, depending on relative water quality of the SJR inflow and seasonal sources • Low[2] impact particularly when barriers are in	• Low sensitivity • Medium sensitivity on Grant Line Canal • Can influence location of Lower Old River null zone, but not formation of the null zone	• Low sensitivity • Increased sensitivity of water level range with increased pumping levels. Effect is up to 10% of tidal range on Old River. Small compared to barrier impact and small in Middle River. • Moderate impact on Old River tidal range of flow, mostly identifiable with barriers in. Smaller impact on Middle River and Grant Line Canal.
San Joaquin River (SJR) Inflow and Salinity at Vernalis[1]	• Non-linear, positive relationship with SJR flow • High[2] sensitivity when barriers in place • Low sensitivity in low-flow conditions, especially with no barriers • Sensitivity increases with proximity to the SJR	• Influence proportional to SJR flow • Influence can be fresh or salty depending on SJR inflow EC. • Low sensitivity in low-flow conditions (i.e., low inflow volumes cannot flush peak in-Delta sources) • Higher sensitivity at “larger” inflow volumes (develops at flow ranges between 700 and 3,000 cfs), often corresponding to higher salinity (e.g., during winter both SJR flow and EC are higher relative to other seasons)	• Null zones are more common during low-flow conditions • SJR inflow (at flows < 2,000 cfs) may affect location of Lower Old River null zone	• Low sensitivity of water levels in flow conditions < 2,000 cfs inflow compared to the barrier effect. • High sensitivity in peak runoff or storms. High flow dampens tidal range and can eliminate tides entirely in some years.
Temporary Barriers[1] (presence and configuration)	• High, positive impact • Typically more than offsets exports on low water (e.g., at Tracy Blvd, +1.1–1.4 ft of increase due to barriers, 0.5–0.9 ft drawdown from exports at OLD) • Lower sensitivity on Middle River • Lower effectiveness on interior of Tom Paine Slough due to conveyance limitations and nonlinearity of the effect across multiple barriers (temporary barrier plus Tom Paine)	• Indirectly contribute to salt accumulation due to reduced tidal flushing and reinforcement of null zones • When barriers are in place, tidal flows are extinguished on Middle River and Lower Old River, forming what we have called a “tidal null zone”	• Barrier formation not essential for null zone formation, which often happens before barriers go in • Medium sensitivity of location and strength to barrier presence • Sensitivity to barrier configuration (e.g., partial barrier in 2023 under high flow still led to null zone).	• High impact upstream of barriers. • High impact on Old River • High impact on Grant Line Canal, but tidal range is still extensive when barriers are present • Lower impact on Middle River
Tides[1] (range and extent)	• High impact, especially on Grant Line Canal	• High impact	• Low. However, tidal null zone occurs in conveyance-limited areas such as Old	N/A

Influencing Variable	General Sensitivity Summary			
	Water Level	**Salinity**	**Null Zones and Net Flow**	**Tidal Range**
	• Tidal flows are the dominant variable forcing water level changes in the South Delta channels • Impacts are reduced when barriers are in place • Tidally forced lows impose physical constraints on control over low water levels.	• Extent of tidal flushing has high impact on salt accumulation, especially along Lower Old River and Middle River, when the temporary barriers are in place	River at Tracy Blvd. When the net flow null zone coincides with this area of limited tides, salinity is trapped.	
Channel Bathymetry (simple artificial dredging experiments)	• Highest impact on Middle River. Mixed influence. Increased conveyance facilitates higher lows in places that are conveyance limited, lower lows in places that are most hydraulically connected to the South Delta, bringing lower lows when barriers out. • Lower impact on Old River	• Indirectly affects salinity via ability of channels to convey flushing flows • High sensitivity in Middle River • Low sensitivity in Old River	• High impact on Middle River • Lower impact on Old River • High relative depth/conveyance causes most of the overall export sensitivity to be focused on larger channels seaward of the export facilities and concentrates most of the remaining South Delta sensitivity in Grant Line Canal	• High impact in simulated "dredged" channels, especially for Middle River, which is conveyance limited.
Unquantified/ Underquantified In-Delta Diversions or Discharges[1]	• Low impact except in isolated/pooled areas such as parts of Middle River or the end of Tom Paine Slough near Pescadero Irrigation District. • Limited study due to data limitations	• High impact, especially near the Five Points Region and Middle River • Dominant control on salinity during summer and fall when SJR inflow volumes are lower and the barriers are in place, truncating tidal dispersion	• High sensitivity to channel depletions (i.e., there is a 1:1 localized effect) • Local depletions required for formation of a null zone	• Possible, but not addressed in the MSS • There is uncertainty related to vegetation

Notes:
[1] Seasonality complicates the different sensitivities to variables and variable interactions.
[2] The terms high, medium, and low are used qualitatively to describe impacts of different variables relative to one another and relative to different South Delta reaches. Changes in water levels, salinity, null zone convergence points, and tidal range are not geographically or temporally uniform, therefore, quantitative values of these sensitivities are difficult to generalize and at times are difficult to separate. The qualitative assessments were an attempt to characterize the impact of the variables on responses of interest over typical ranges. See Section 4.1 of Attachment 6 where the scaling is discussed.

5.1.1 Water Levels

Low water levels limit access to irrigation water in areas where they cause restricted depth or exacerbate existing conveyance issues. Low water was most frequently cited as the cause of flow and salinity issues; however, as noted in Appendix C, *Low Water Metrics*, MSS participants have also remarked that impacts during other tidal phases—including high tide—could be either (1) a direct cost or (2) part of a chain of physics affecting other variables (for example, the "double barrier" issue on Tom Paine Slough).

The main drivers of low water levels in the South Delta are the natural variation of the tides and the temporary barriers, with secondary impacts from exports and SJR inflows. The influence of tides has been underestimated in past work. Tides propagate in from the coast shaped by wind forces and further modified by friction. In the absence of barriers or exports, what has been historically categorized as "water levels of concern" (DWR & USBR 2004) are within the typical low tide in this region, and in some channels that are hydraulically connected to the estuarine system, propagation of lows would be intensified if channel conveyance were improved. Overall, the authors conclude that the current operating framework in the South Delta appears to support water levels greatly in excess of what would be needed to offset the direct impact of exports on water levels. The MSS analyses focused on low tide statistics (see Appendix C).

Local effects can occur where strong pumping coincides with very limited conveyance such as pooled/isolated areas in the reach between Undine Road and Howard Road on Middle River or the upstream end of Tom Paine Slough, near stations TPP and TPPA. Serious issues appear to exist with depth in these areas, although there has been some conflation between water levels and depth in the discussion of both water access issues and model accuracy. The symptom of local effects is seen at gauges where local water levels are lower than ambient monitoring stations that are better connected to the tidal system.

Exports draw down water levels in the South Delta. However, a typical maximal drawdown seen at locations along Old River is 0.08 ft per 1,000 cfs of pumping or roughly 0.9 ft across the full range of exports (the MSS considered up to 10,000 cfs). Exports also mildly suppress tidal range, particularly when barriers are installed.

The temporary barriers more than compensate for the effect of exports on low water levels at most locations. For instance, at OLD, the example described above for exports, the increase is 1.0 to 1.5 ft depending on the metric, month and method of calculation, which is greater than the maximum estimate of drawdown (0.9 ft). The caveats to these comments are:

- The protection primarily affects metrics of low tide. Low tides are increased, but high tides can be, and often are, reduced. The effect of barriers in altering the relationship between low and high tides offshore and their counterparts in the South Delta is studied in *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6, Section 2.1.5).
- The statements above pertain to the complete (three-barrier) configuration that includes Old River at Tracy, Middle River, and Grant Line Canal. Partial configurations, which arise of necessity during construction, do not offer the full water level mitigation described for the

complete three-barrier installation. For instance, installing just a barrier on Middle River does not protect Middle River thoroughly. See Attachment 6, Section 2.1.4 for more details.

- Barriers do not fully mitigate export influences on water levels on the interior of Tom Paine Slough. There are two reasons for this. First, limited conveyance along the slough severely hampers its performance as a conveyance channel. The downstream or mouth of Tom Paine Slough is able to capture water and equilibrate with the Delta, but demand along the channel causes stage to drop to much lower levels upstream.

Finally, San Joaquin River flows affect water levels, particularly in the upstream side of the South Delta. In the main range of inflow considered during the MSS (generally below 2,000 cfs or 3,000 cfs for some analyses), Vernalis inflow should be considered a modest influence. At very high SJR flows (greater than 10,000 cfs) the region becomes less tidal and SJR water levels become a dominant driver.

5.1.2 Flow and Circulation

Flow in the South Delta reflects a balance between various influences, such as export pumping, San Joaquin River inflow, local in-Delta surface water discharges and channel depletions, and the status of the temporary barriers.

- Exports: Although pumping rates at the SWP and CVP export facilities can range as high as 11,000 cfs (10,000 cfs was used as the scaling for MSS), they exert a low proportional influence on flow in Old River, typically less than 2% on a cfs-per-cfs basis, and an even smaller influence on flow in Middle River. Most export fluctuation is met by downstream flow (via OMR) rather than from upstream flow (San Joaquin River via Upper Old River), and what little influence is exerted on the upstream system is manifest as much as 90% on Grant Line Canal.
- San Joaquin River inflow: For the range of San Joaquin River inflow volumes considered in the MSS, most water enters the South Delta and follows Grant Line Canal. A modest fraction of the flow traverses Lower Old River (4%) and Middle River (1%), giving it some influence on circulation.
- Local sources and sinks: Volumes of local discharges are one to two orders of magnitude smaller than exports or San Joaquin inflow values, even in aggregate. However, channel depletions (sinks) affect adjoining channel flow at a 1-to-1 ratio rather than the very low sensitivities cited above. In-Delta sources and sinks comprise the largest local influence on net flow at low or medium ambient flow conditions. Sensitivities are studied in *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6, Section 4.1).
- Temporary Barriers: The temporary barriers reinforce negative flow in Old River, Middle River, and Grant Line Canal. Barrier installation reinforces the “null zone” pattern. Temporary barriers significantly dampen tides and reduce the local flushing that tidal dispersion fosters near Old River at Tracy Blvd.

With the exception of local sources, these same variables affect tidal range of flow as well as net flow in the South Delta. The temporary barriers dampen tidal range, as do exports, more so when

barriers are in. San Joaquin River flow produces a nonlinear response. At lower flows, Vernalis inflow increases tidal range by elevating water levels and reducing friction. Inflow greater than 2,000 cfs reduces tidal range. The authors are unaware of any effect local sources might have on tidal range, although it is possible that such an effect could happen in conveyance-limited reaches such as Middle River between Undine Road and Howard Road.

The South Delta circulation includes null zones where the net flow converges around regions of significant channel depletion during periods of moderate hydrology. The temporary barriers, which induce upstream flows at downstream locations, reinforce upstream flow at their locations and thus increase the chances of a null zone forming. However, only local channel depletions, not barriers, are required for null zone formation. During average and below average hydrology, null zones routinely form a month or two before barriers are installed.

Old River and Middle River convergence points—the places where null zone flows collect—are close to the location of minimum tidal flows. This proximity results in a zone where neither net flow nor tidal dispersion serves as a transport mechanism, trapping any nearby sources of salinity.

Although the idea of eliminating null zones has been proposed by interested parties, the MSS shows that doing so would require significant inflows to overcome current channel geometry, the presence of barriers, and local channel depletions. Grant Line Canal outcompetes Old and Middle Rivers for conveyance, resulting in nearly negligible sensitivity of these two smaller channels to exports and San Joaquin inflow (i.e., a few percent at most). The depletion of 150–300 cfs along these reaches together with the installation of temporary barriers that impose upstream flow categorize the aspiration to eliminate null zones as somewhere between costly and unachievable. Historical observations offer little encouragement this can be done with less than 2,000–3,000 cfs of incoming flow (*MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* [MSS Report, Attachment 6, Section 3.2.3.2]), although some uncertainty about Old River at Mountain House mean flow in near-stagnant conditions was noted when comparing to EC transport direction (*Circulation, Channel Depletion, and Barrier Assumptions for Modeling the South Delta, 2024 Revision* [MSS Report, Attachment 3, Section 3.1]). This is not a statement of pure pessimism concerning circulation but rather a precise framing. Other flushing mechanisms such as tidal dispersion of salts from Old and Middle Rivers onto the more reliable Grant Line net flow conduit can manifest at inflows as low as 700–1,400 cfs, at which levels of Grant Line Canal flow (if sufficiently fresh) provides dilution and tidal flushing to transport salinity from the Five Points Region out of the area.

5.1.3 Salinity

Salinity in the South Delta comes from a combination of two major inputs: inflow on the San Joaquin River and in-Delta sources. Exports, barriers, null zones and other flow features affect the transport of these sources. The major insights from the MSS analyses include the following:

- There is no simple relationship between San Joaquin River inflow and salinity in the South Delta. There is a relatively straightforward relationship between inflow and the level of San Joaquin River influence over downstream salinity, which tends to develop between approximately 700 and 1,000 cfs of inflow at Vernalis. If that inflow is fresh, it benefits downstream monitoring stations on Old River.

- The dominant influence over South Delta salinity shifts seasonally, with San Joaquin inflow the dominant source of salinity from late fall through spring, and in-Delta sources the dominant source in mid–late summer and early fall. In drier water years, the distinctions blur and both become important for longer periods.
    - This shifting seasonal influence has led to a mischaracterization of June–July 2021 as offering evidence of salinity management via San Joaquin inflow. This is not the case because there was no salinity during that period to manage. Before August 2021, no high-salinity sources were observed anywhere, from Vernalis to typical high-salinity source locations in the backwater areas of Pescadero Tract. There is no way to establish either the necessity or the sufficiency of flow based on a time when there is less salt in the system. In August 2021, in-Delta salinity sources began increasing at the same time that inflow volume decreased, resulting in misrepresentation of the cause of salinity increases in late summer 2021. This period is studied in detail as a vignette, including perturbations, in *MSS Operational Effects and Sensitivities Historical Data Analysis and Modeling Study* (MSS Report, Attachment 6, Section 3.2.2.1).
- There is a longstanding systematic trend in modeling the interior South Delta to capture only the San Joaquin River inflow component of salinity sources (e.g. Suits 2006), which has fed expectations about operational effects. The modeling advancements made during the MSS (which continue to be built upon) have demonstrated the importance of more accurately accounting for local inputs of salinity to the South Delta channels and other influences on the internal hydrodynamics of the area.
- Salinity tends to accumulate in the convergent regions of null zones, causing a localized peak in salt concentrations. This problem is exacerbated if the location of the tidal range minimum coincides with the null zone, so that tidal dispersion is active at the convergence point. While this may lead to ideas for interventions to improve water quality, overall health of the reach is best assessed at multiple points. Source inference is weakest in this context, because trapped salinity does not slosh in front of a gauge, which would allow determination of its location and direction of propagation.

5.2 Recommendations

Section 4.4, *Adequacy of Current Monitoring Network in Assessing Reach Salinity*, discusses the adequacy of the current monitoring network in the South Delta for assessing salinity concentrations in the area. Here, we discuss two potential approaches for assessing attainment of salinity objectives across river segments in the interior southern Delta, as described in the 2018 Bay-Delta Plan. The complexity and variability of South Delta hydrology will continue, and any approach to assessing reach-level salinity concentrations should recognize this variability. One potential approach is to acknowledge the flow regimes and seasonal in-Delta sources, develop indicators to describe the state of circulation, and recognize the level of difficulty in reach-based compliance objectives under certain water year types. The other approach is to try to statistically average over this complexity such that the objective of good average performance prevails over regulating to the worst case along the reach, which is often not representative of conditions along the entire reach.

5.2.1 Updated Reach Definitions According to Hydrodynamics

It is impossible to precisely and unambiguously define a reach for a channel that alternatively experiences null flow dynamics and is dominated by flood tidal flows. Nevertheless, insights from the MSS suggest ways in which regulatory reaches could be better aligned with the physical influences and responses of South Delta hydrodynamics and transport.

Based on monitoring data and physical dynamics of the South Delta system, we conclude that two of the reaches defined in the 2018 Bay-Delta Plan—San Joaquin River from Vernalis to Brandt Bridge and Middle River from Old River to Victoria Canal—are reasonable and the current monitoring network can appropriately assess salinity for the purpose of assessing compliance with water quality objectives within these reaches.

The San Joaquin River reach is best assessed by utilizing long-term salinity monitoring mid-reach at San Joaquin River at Mossdale Monitoring Station (MSD), and existing compliance stations Vernalis (VER) and San Joaquin River at Brandt Bridge (BDT) monitor the upstream and downstream boundary salinity conditions affecting the reach (Figure 5-1). A special case occurs in extreme drought years (i.e., 2021 and 2022) when inflow on the San Joaquin River is very low, net flow at MSD is directed upstream, and net exchanges with local water dicharges essentially "replace" the San Joaquin SC as measured at Vernalis.

The Middle River reach salinity conditions are well defined by the existing station MRX, which is situated upstream of the Middle River temporary barrier and measures salinity from interior Delta westside sources at the downstream boundary near Victoria Canal. The upstream salinity boundary conditions primarily sourced from the San Joaquin River are captured by station MRU, close to the confluence with Upper Old River. The mid-reach water quality conditions in Middle River are often highest in salinity and affected by the formation of a null zone, but this null zone often occurs near the Howard Road Bridge near the current MHO monitoring station. Operational control at the convergence point of this null zone (i.e., through San Joaquin River inflow and/or exports at the pumping facilities) is extremely low when the barriers are in place and the reach will not develop a traditional upstream-to-downstream dynamic during these low-inflow conditions. However, modeling has shown that some interventions such as dredging may influence this dynamic on Middle River.

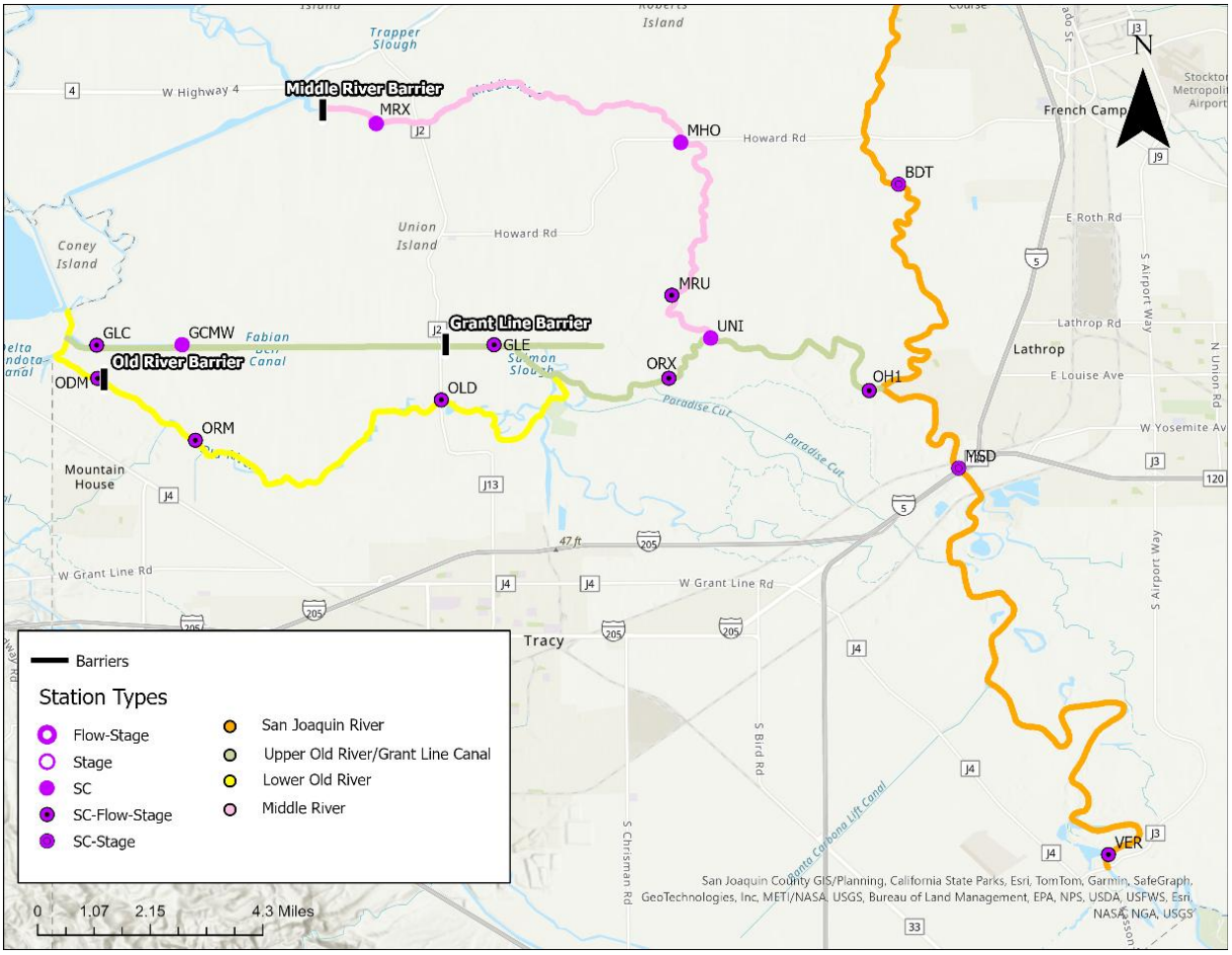


Figure 5-1. Map of DWR-Recommended Compliance Reaches and Stations for Assessing Salinity in Those Reaches

We suggest that the Old River/Grant Line Canal from Head of Old River to West Canal be separated into two river reaches, namely Upper Old River/Grant Line Canal and Lower Old River. This suggested separation is a result of their differing roles in transport, regional differences and complexity in the channel conveyance, different proximity to the export facilities, installation of seasonal temporary barriers, formation of null zones, convergence of western water sources, and different contributions of local in-Delta sources. These boundary reaches can be defined by current long-term SC monitoring stations as follows: (1) Upper Old River/Grant Line Canal reach, defined as Head of Old River to Grant Line Canal near Old River (Old River at Head Monitoring Station [OH1] to GLC) and (2) Lower Old River reach, defined as upper boundary of Lower Old River being the junction at Doughty Cut at Upper Old River south to Old River at Tracy Boulevard to Old River below the Delta-Mendota Canal (DMC) barrier (OLD compliance station to ODM).

The Upper Old River/Grant Line Canal reach compliance objectives can be assessed through the use of upstream and downstream salinity conditions measured by stations OH1 and GLC for flow and GCMW (a temporary MSS station that is more representative of Grant Line Canal and less affected by intake region salinity than GLC). Mid-reach salinity can be further asessed by

stations UNI, Old River above Doughty Cut Monitoring Station (ORX), and Grant Line Canal East Monitoring Station (GLE) (Figure 5-2). The average value for all stations on Upper Old River/Grant Line Canal is generally representative of all stations, except during critically dry years, such as summer 2022. In these circumstances high residence times/poor tidal flushing, and the proximity to high salinity in the Five Points Region can cause elevated salinity mid-reach near ORX and GLE. In addition, due to the proximity of the GLC station to the export facilities, the salinity is influenced more by fresher westside water sources that enter the South Delta through Old and Middle River (OMR) due to export pumping; these are a mix of water sources primarily from Sacramento River, Mokelumne River, and smaller amount of San Joaquin River. The Lower Old River reach salinity would be assessed through the use of OLD as the upstream boundary nearest to the convergence or null zone and the largest local salinity sources; the ODM station as the measure for downstream boundary salinity conditions, representing the influence from western water sources; and the ORM station providing a measure of mid-reach salinity conditions and (through its coherence with the other two) as corroboration of mean flow direction (Figure 5-2). A station analogous to the MSS station Old River at Anchored Acoustic Doppler Current Profiler Upstream Monitoring Station (OAAU) will further bracket the null zone and detect or bracket in-Delta sources with modest tidal excursion between OLD and ORM.

We therefore recommend that there be not three, but four compliance reaches as follows: (1) San Joaquin River from Vernalis to Brandt Bridge, (2) Middle River from Old River to Victoria Canal, (3) Upper Old River/Grant Line Canal from Head of Old River to Grant Line Canal near Old River, and (4) Lower Old River from Doughty Cut south to Old River at Tracy Boulevard to Old River below the DMC barrier (Figure 5-1). Water year types and potentially seasonal changes should be considered in attainability of objectives to better reflect the ambient conditions of a highly variable system.

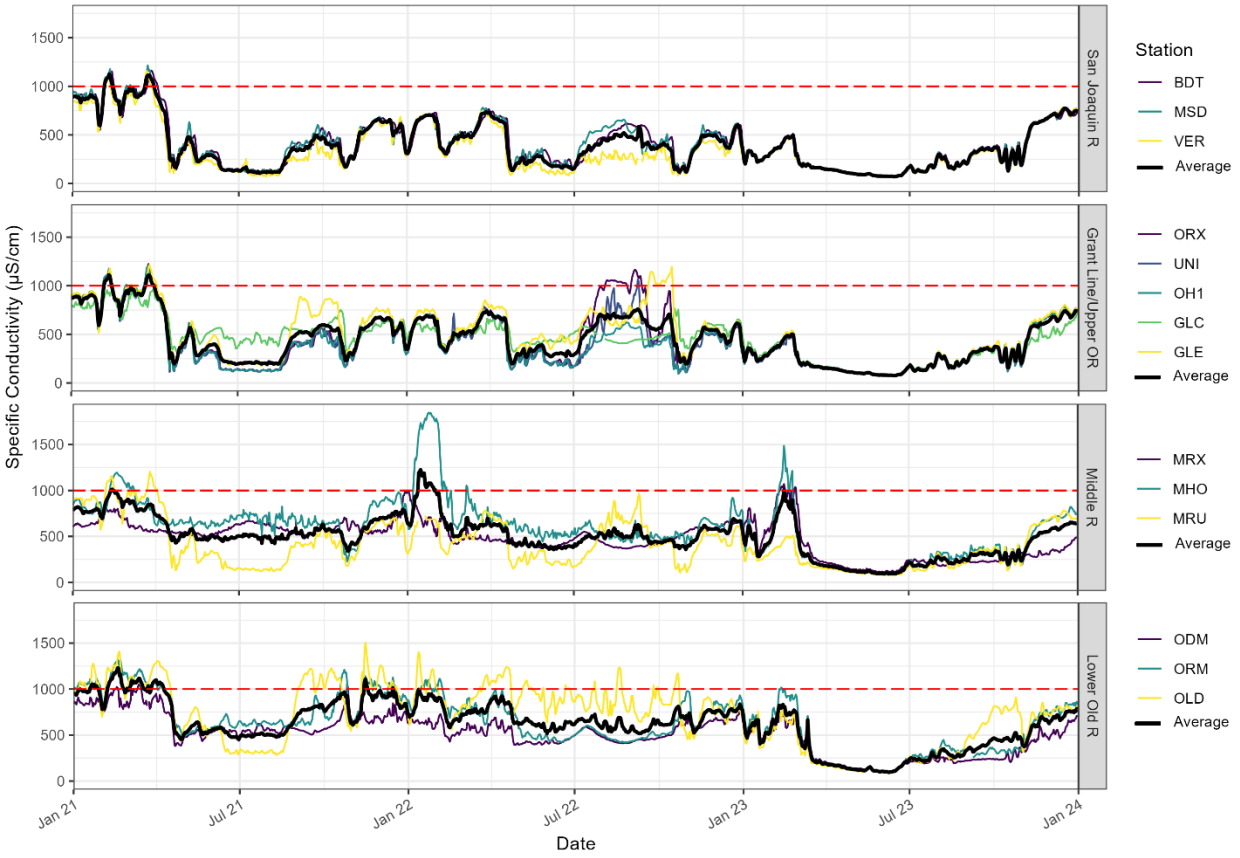


Figure 5-2. Daily Mean Specific Conductivity by Station and DWR-Recommended Compliance Reach. Bold black line is a combined average of all stations within that compliance reach.

5.2.2 Suggested Approach to Developing the Long-Term Monitoring and Reporting Plan

As written in the 2018 Bay-Delta Plan, the work completed as part of the MSS is to be used to inform the development of an LTMRP, which "…shall include specific compliance monitoring locations in, or monitoring protocols for, the three river segments that comprise the interior southern delta salinity compliance locations." Section 4.4, *Adequacy of Current Monitoring Network in Assessing Reach Salinity*, and Section 5.1, *Updated Reach Definitions According to Hydrodynamics*, discuss the adequacy of the monitoring network for evaluating reach compliance with salinity objectives and the adequacy of the three reaches defined in the 2018 Bay-Delta Plan in representing the hydrology of the South Delta. Based on work presented in this MSS Report, Lower Old River should be considered its own reach in terms of monitoring for compliance with salinity objectives. Additionally, the OLD compliance station (interagency station P-12) is not representative of salinity along the rest of Old River or Grant Line Canal; therefore, another location or use of the cumulative average of several stations along the reach should be considered during development of the LTMRP to more accurately monitor compliance of the river segments. The Lower Old River segment, as observed through historical data, may have too many hurdles to meet 2018 Bay-Delta Plan compliance objectives across all water year

type conditions; therefore, we suggest an objective framework be considered in Lower Old River that can be adapted based on environmental conditions or observed spikes in local tributaries.

Adjustments to the current monitoring network may also be considered when developing the LTMRP. The permanent GLC monitoring station and the temporary OAAU and OAAD stations are specific examples where adjustments may improve the monitoring network's representation of the entire region. GLC is located on the west side of Grant Line Canal and its proximity to the confluence with the OMR intake area results in SC measured at GLC reflecting more western water sources than the GLE monitoring station on the upstream east side of Grant Line Canal (Figure 5-2). Monitoring the west side of Grant Line Canal upstream of OMR SC influence would, therefore, be a useful adjustment to consider during development of the LTMRP. OAAD may provide a more precise location of the Lower Old River null zone and better bracket two influential discharges within that zone if it were leap-frogged upstream of the OAAU temporary station and a large diversion point and sink (see *Data Integration and Source Inference for Modeling* [MSS Report, Attachment 4, Section 5.3]), Naglee Burk Irrigation District's Main Irrigation Pumps (Application ID: S017244, POD ID: 52271. Lat/Long: 37.7888, -121.4761), between its current location and the Old River Tracy Wildlife Association Monitoring Station. This change, in addition to continuing to monitor the OAAU location, would allow for the bracketing of another major sink in the area, Byron-Bethany Irrigation District at the end of Wicklund Cut, which is upstream of the permanent ORM monitoring station. This potential movement and the feasibility of maintaining OAAU and OAAD long term may be considered in the LTMRP. See *Salinity Point Source and Ion Sampling* (MSS Report, Attachment 2) for map exhibits of these two temporary monitoring stations.

Section 4.2, *Null Zone(s) and Bathymetry Sensitivity*, describes the timing and movement of null zone formation on Lower Old River between OLD and OMR and another, more stationary null zone on Middle River near Howard Road. The variation in timing and location of the Lower Old River null zone depends on variable conditions, such as ambient flow, tidal extent, pumping rates, and volume and timing of local in-Delta diversions from and discharges to Old River. The formation of the Lower Old River null zone is relatively insensitive to changes in SWP and CVP export facility pumping rates, which may affect the precise location of the null zone along the reach, but do not determine its existence in the first place. The transient properties of the Lower Old River null zone make it difficult to predict; therefore, developing an indicator to track the null zone and its associated risk of salinity accumulation is a logical step to consider for the LTMRP.

A key piece of missing information remains the volume of diversions and volume and quality of water discharged into the South Delta waterways, especially those in the Five Points Region or along Lower Old River. Observations of in-Delta discharges may provide the opportunity for real-time modeling to support real-time management of salinity concentrations in the mainstem. This approach has been successful by water users in the San Joaquin Basin in accordance with the Central Valley Regional Water Quality Control Board's Salt and Boron Total Maximum Daily Load Program in the Water Quality Control Plan for the Lower San Joaquin River Basin (Central Valley Regional Water Quality Control Board 2019). SWRCB's assistance in collecting the missing information is necessary.

5.2.3 Access to Additional Salinity Data in the South Delta

Salinity dynamics in the South Delta can only be fully understood to the extent that in-Delta sources of both water and salt are quantified. This is particularly true in summer low-flow conditions when in-Delta sources are the dominant contributor of salt mass. In order for the models used in the MSS to more accurately represent regional sources and trapping of high salinity, salinity sources were inferred. Often this inference was successful, producing regionally balanced salinities that had correct direction of propagation in both a tidal and tidally averaged sense. However, to further improve accuracy of analysis and of models generally used to forecast salinity in the South Delta, and certainly to describe the provenance of this salinity, best available data directly from the sources of salinity in the South Delta would be helpful.

The "low-hanging fruit" in this pursuit is agricultural discharges. Groundwater seepage and agricultural drainage are thought to be the two types of local in-Delta salinity sources. The two remain unquantified individually and, therefore, cannot be analytically distinguished from one another. If one of these missing variables were directly measured, then both can be quantified by taking the difference between the measured variable and the amount of salinity still not explained by simulations or data analysis. Between the two types of local discharges (groundwater and agricultural drainage), directly monitoring agricultural drainage volumes and salinity concentrations is the most promising way to quantify in-Delta sources. Direct monitoring of surface water discharges is the simplest and more accurate approach. Monitoring and/or modeling groundwater seepage is notoriously approximate. SWRCB assistance would be necessary to collect this data.

Chapter 6 References

6.1 Chapter 1, Introduction

California Department of Water Resources (DWR). 2026. Monitoring Special Study. Available: https://water.ca.gov/Programs/State-Water-Project/Operations-and-Maintenance/Monitoring-Special-Study. Accessed: January 8, 2026.

California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR). 2022. *Draft Monitoring Special Study Plan*. August. Available: https://resources.ca.gov/Home/Programs/State-Water-Project/Operations-and-Maintenance/Monitoring-Special-Study. Accessed: April 27, 2026.

6.2 Chapter 2, MSS Study Area Overview

Fleenor, W. E., and P. Ji. 2011. *Predicting Electrical Conductivity in the South Delta using Multivariate Regression*. Prepared for the State Water Resources Control Board.

U.S. Bureau of Reclamation (USBR). 2011. *Special Study: Evaluation of Dilution Flow to Meet Interior South Delta Water Quality Objectives*. Available: https://data.cnra.ca.gov/dataset/e7142b22-43f3-4257-93f5-fbe8cf68d4e0/resource/1bd4e579-ffab-4949-b032-997ced178945/download/05_dilutionflowwaterquality_usbr_2011_spcl_stdy1.pdf

U.S. Bureau of Reclamation (USBR). 2025. *Exploring Flow and Water Quality Relationships Between the Interior Southern Delta and the San Joaquin River at Vernalis.* Technical Report. Available: https://data.usbr.gov/rise/content-rise-public/rise/catalog-item/binary/USBR%202025_WQ%20Relationships%20Report.pdf

6.3 Chapter 3, Technical Study Descriptions and Meeting MSS Goals and Conditions

California Department of Water Resources (DWR). 2012. *South Old River Salinity Transect Study*. Technical Memorandum Report. 64 pp. [Government Report.] Available: https://data.cnra.ca.gov/dataset/south-delta-studies-reference/resource/b6345824-70a8-4e9c-bd68-25c96aef3566. Accessed: January 8, 2026.

California Department of Water Resources (DWR). 2016. *Evaluation of Salinity Patterns and Effects of Tidal Flows and Temporary Barriers in South Delta Channels*. Prepared by ICF. Available: https://data.cnra.ca.gov/dataset/south-delta-studies-reference/resource/0971adfb-52d9-4c12-afc0-4034cb2b8dd4. Accessed: January 8, 2026.

California Department of Water Resources (DWR). 2018. *South Delta Salinity Study—Water Year 2015*. 49 pp. [Government Report.] North Central Region Office. Available: https://data.cnra.ca.gov/dataset/south-delta-studies-reference/resource/20cacd48-7ec1-486c-861a-eb8e1670b694. Accessed: January 8, 2026.

California Department of Water Resources (DWR). 2020. Bay-Delta SCHISM Project. Available: https://cadwrdeltamodeling.github.io/BayDeltaSCHISM/help.html. Accessed: January 8, 2026.

California Department of Water Resources (DWR). 2024. *South Delta Salinity Flux Study Water Years 2016–2022*. Prepared by: Division of Regional Assistance, Northern Central Region Office, Water Quality Evaluation Section. Available: https://data.cnra.ca.gov/dataset/south-delta-studies-reference/resource/7e548025-6044-4627-b6cd-f0b7d695ac0f. Accessed: January 8, 2026.

California Department of Water Resources (DWR). 2026. Delta Modeling User Group. Available: https://water.ca.gov/Library/Modeling-and-Analysis/Bay-Delta-Region-models-and-tools/Delta-Modeling-User-Group. Accessed: January 8, 2026.

California Natural Resources Agency (CNRA). 2025a. South Delta Monitoring Special Studies (MSS) Modeling Inputs and Selected Outputs. Available: https://data.cnra.ca.gov/dataset/south-delta-monitoring-special-studies-mss-modeling-inputs-and-selected-outputs. Accessed: January 8, 2026.

California Natural Resources Agency (CNRA). 2025b. South Delta Studies Reference. Available: https://data.cnra.ca.gov/dataset/south-delta-studies-reference. Accessed: January 8, 2026.

California Water & Environmental Modeling Forum (CWEMF). 2021. Workshops. Available: https://cwemf.org/wp/services/workshops/. Accessed: January 8, 2026.

GitHub. 2026a. DSM2 Release v8.4.1. Available: https://github.com/CADWRDeltaModeling/dsm2/releases/tag/v8.4.1. Accessed: January 8, 2026.

GitHub. 2026b. schism-dev/schism. Available: https://github.com/schism-dev/schism. Accessed: January 8, 2026.

Montoya, B. L. 2004. *Factors Affecting the Composition and Salinity of Exports from the South Sacramento–San Joaquin Delta*. Memorandum Report by Barry Montoya, Staff Environmental Scientist, to Dan Peterson, Environmental Program Manager. February. Division of Operations and Maintenance, Environmental Assessment Branch. Available: https://cawaterlibrary.net/wp-content/uploads/2017/11/factors_affecting_the_composition_and_salinity_of_exports_from_delta_2004.pdf. Accessed: January 8, 2026.

Montoya, B. L. 2007. *Memo Report: Sources of Salinity in the South Sacramento-San Joaquin Delta*. Prepared for the California Department of Water Resources. Available: https://data.cnra.ca.gov/dataset/south-delta-studies-reference/resource/4dc60146-12e8-4cfa-a209-552fb8bde27a. Accessed: January 8, 2026.

Montoya, B. L., and A. Cuthbertson. 2012. *South Old River Salinity Transect Study. Technical Memorandum Report.* 64 pp. Available: https://data.ca.gov/mk/dataset/south-delta-studies-reference/resource/6b8bfd44-18a5-4f77-942c-d7b295d64ef9?inner_span=True. Accessed: June 20, 2024.

6.4 Chapter 4, Discussion and Synthesis

California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR). 2004. Response Plan for Water Level Concerns in the South Delta Under Water Rights Decision 1641. Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/jpod/docs/water_level_response_plan.pdf. Accessed: November 25, 2025.

California State Water Resources Control Board (SWRCB). 2018. "Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary." https://www.waterboards.ca.gov/plans_policies/docs/2018wqcp.pdf.

Davis, G. H. 1961. Geologic control of mineral composition of stream waters of the eastern slope of the Southern Coast Ranges, California. *U.S. Geological Survey Water-Supply Paper 1535-B*. Washington D.C.: U.S. Government Printing Office. 38 pp. Prepared by the U.S. Department of the Interior. Available: https://pubs.usgs.gov/wsp/1535b/report.pdf. Accessed: April 15, 2024.

District Court, E.D. California (E.D. Cal.). 2009. San Luis & Delta-Mendota Water Authority v. Salazar, 686 F. Supp. 2d 1026. November 13. Available: San Luis & Delta-Mendota Water Authority v. Salazar – CourtListener.com. Accessed: April 27, 2026.

Montoya, B. L. 2007. *Sources of Salinity in the South Sacramento–San Joaquin Delta*. Memorandum Report. Prepared by the California Department of Water Resources. Division of Operations and Maintenance, Environmental Assessment Branch. 54 pp. Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/comments040609/dwr_appendixc.pdf. Accessed: April 15, 2024.

Montoya, B. L., and A. Cuthbertson. 2012. *South Old River Salinity Transect Study.* Technical Memorandum Report. 64 pp. Available: https://data.ca.gov/mk/dataset/south-delta-studies-reference/resource/6b8bfd44-18a5-4f77-942c-d7b295d64ef9?inner_span=True. Accessed: June 20, 2024.

6.5 Chapter 5, Conclusions, Recommendations, and Potential Next Steps

California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR). 2004. Response Plan for Water Level Concerns in the South Delta Under Water Rights Decision 1641. Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/jpod/docs/water_level_response_plan.pdf. Accessed: November 25, 2025

Central Valley Regional Water Quality Control Board. 2019. *The Water Quality Control Plan (Basin Plan) for the Sacramento River Basin and the San Joaquin River Basin*. Available: https://www.waterboards.ca.gov/centralvalley/water_issues/basin_plans/sacsjr_201902.pdf

Suits, B. 2006. Chapter 4: Using volumetric fingerprinting to study sources of salinity in the South Delta. In *Methodology for flow and salinity estimates in the Sacramento–San Joaquin Delta and Suisun Marsh: Twenty-seventh annual progress report to the State Water Resources Control Board*. California Department of Water Resources, Bay-Delta Office, Sacramento, CA.