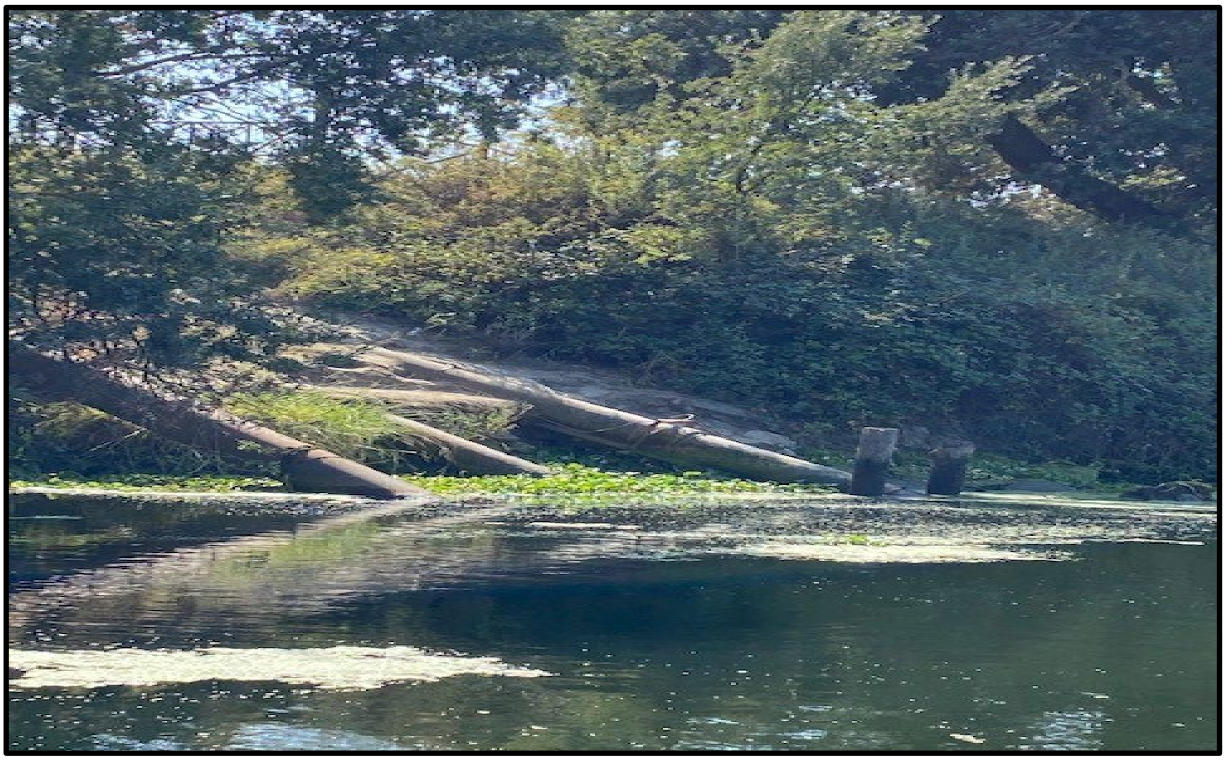
Attachment 2: MSS Salinity Point Source and Ion Sampling

To the Monitoring Special Study Plan

CY 2022–2023 Work Plan
Monitoring Plan



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Authors: Jared Frantzich (DWR); David Colvin (DWR); Patrick Scott (DWR)

Water Quality Evaluation Section
Resource Assessment Branch
North Central Region Office
Division of Regional Assistance
California Department of Water Resources

Technical Lead:
Jared Frantzich, DWR, Jared.Frantzich@water.ca.gov

Project Manager:
Ibraheem Alsufi, DWR, Ibraheem.Alsufi@water.ca.gov

Funders:
California Department of Water Resources
United States Bureau of Reclamation

Collaborators:
Eli Ateljevich, DWR, Eli.Ateljevich@water.ca.gov
Zhenlin Zhang, DWR, Zhenlin.Zhang@water.ca.gov

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Abbreviations/Acronyms

TERM	DESCRIPTION
µg/L	micrograms per liter
µS/cm	microSiemens per centimeter
ANOVA	analysis of variance
Bay–Delta Plan	*2006 Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary*
BDT	San Joaquin River at Brandt Bridge Monitoring Station
CVP	Central Valley Project
CY	calendar year
D-1641	Water Right Decision 1641
DAR	Drainage at Arbor Road Monitoring Station
DGL	Doughty Cut above Grant Line Canal Monitoring Station
DWR	Department of Water Resources
EC	specific conductance
GLC	Grant Line Canal Monitoring Station
GLE	Grant Line Canal East Monitoring Station
GPS	geographic positioning system
GSD	ground surface density
mmhos/cm	millimhos per centimeter
MSD	San Joaquin River at Mossdale Bridge Monitoring Station
MSS	Monitoring Special Study
NCRO	North Central Region Office
OH1	Old River near Head Monitoring Station
OLD	Old River at Tracy Road Bridge Monitoring Station
ORM	Old River near Mountain House Creek Monitoring Station
ORX	Old River above Doughty Cut Monitoring Station
PCA	principal components analysis
PDC	Paradise Cut Monitoring Station
PDUP	Paradise Cut Upstream Monitoring Station
QA/QC	quality assurance/quality control
Reclamation	U.S. Bureau of Reclamation

TERM	DESCRIPTION
SC1	Leprino Wastewater Ponds operated by Westside Irrigation District
SCHISM	Semi-implicit Cross-scale Hydroscience Integrated System Model
SFE	San Francisco Estuary
SGA	Sugar Cut at Golden Anchor Monitoring Station
SOR16	Wicklund Road Outfall
SOR17	Mountain House Creek Drain
SOR6	City of Tracy
SOR8	Drain Upstream of OLD
State Water Board	State Water Resources Control Board
SUR	Sugar Cut Monitoring Station
SWP	State Water Project
TDS	total dissolved solids
TPI	Tom Paine Slough Intake Monitoring Station
TPP	Tom Paine near Pescadero Monitoring Station
TPPA	Tom Paine Slough at Paradise Avenue Bridge Monitoring Station
TWA	Old River at Tracy Wildlife Association Monitoring Station
UAV	unmanned aerial vehicle
UNI	Old River near Middle River Monitoring Station
USGS	U.S. Geological Survey
VER	San Joaquin River at Airport Way Bridge, Vernalis Monitoring Station
VNS	San Joaquin River at Vernalis Monitoring Station
WQES	Water Quality Evaluation Section
WY	water year
YSI	Yellow Springs Instruments

1 Introduction

The interior southern Delta region of the San Francisco Estuary (SFE) has relatively higher seasonal-based salinity compared to other interior freshwater regions. Some of this degradation in water quality in the interior southern Delta likely originates in upstream salt loading from agriculture drainage in the San Joaquin River prior to reaching the channels of Old River and Grant Line Canal. However, there is also measurable increases in salt loading within the channel networks of Old River at Head (OH1) east to lower Old River near Mountain House Creek (ORM) and the interconnected sloughs of Paradise and Sugar Cut in the region of Doughty Cut (Figure 1) (in-Delta agriculture drainage), as well as other naturally occurring (i.e., groundwater) sources and other non-point and point sources. The California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (Reclamation), under the State Water Resources Control Board's (State Water Board) Water Right Decision 1641 (D-1641), are assigned partial responsibility for meeting interior southern Delta water quality objectives each year at multiple compliance stations that measure specific conductance (EC) data continuously at 15-minute intervals (Figure 1). [1]

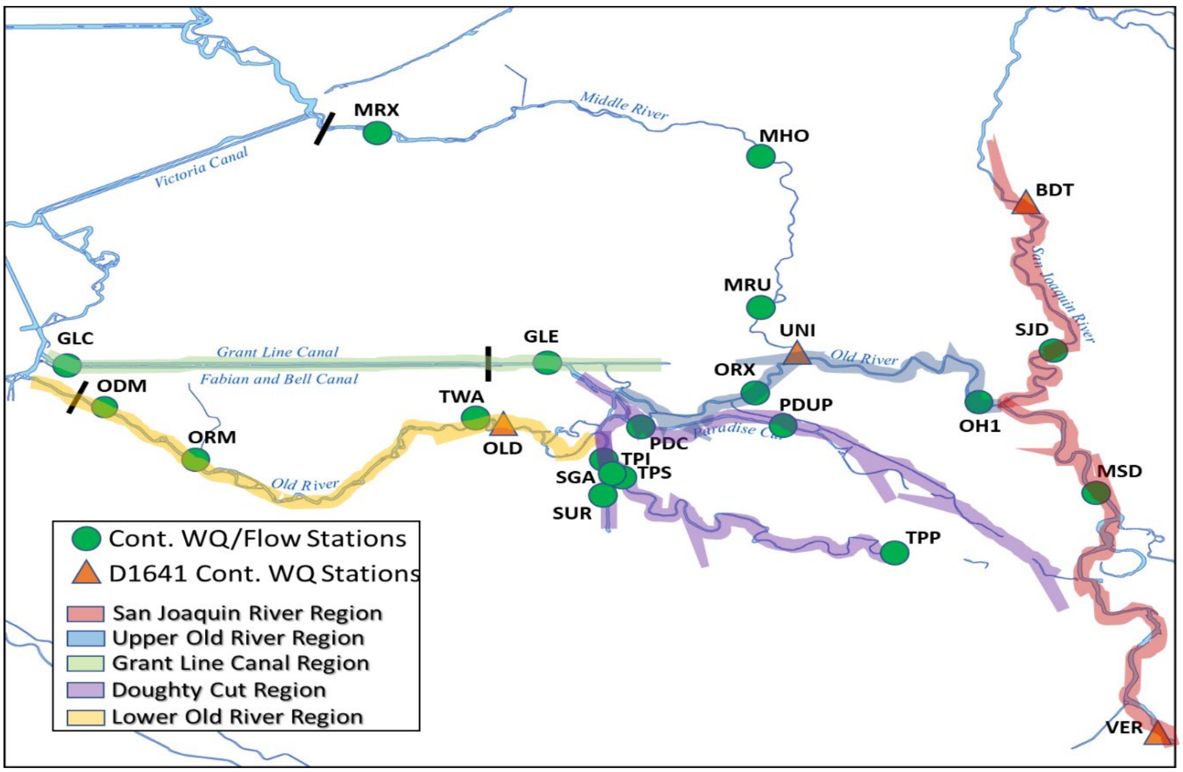

Figure 1. Map of Interior Southern Delta Region, DWR Continuous Water Quality and Flow Network, and DWR/USBR D-1641 Compliance Stations.

[1] D-1641 and related State Water Board communications clarify that enforcement action against DWR and Reclamation to implement the water-quality objectives for agricultural beneficial uses in the southern Delta is not appropriate where any noncompliance is the result of actions beyond the reasonable control of the State Water Project and Central Valley Project (D-1641, p.159, para. 6; Letter from Celeste Cantú, Executive Director, State Water Board, to Lester Snow, Director, DWR, re: Delta Salinity Cease and Desist Order in State Water Board Order WR 2006-0006 (October 13, 2006).

The station at Old River at Tracy Road Bridge (OLD) historically has had the most exceedances of water-quality objectives set forth in the *2006 Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary* (Bay–Delta Plan) (Figure 1), and therefore has become an area of interest for further investigation of salinity sources and associated hydrodynamic conditions that may contribute to elevated seasonal salinity conditions in this region. As part of the Monitoring Special Study (MSS), DWR and Reclamation have developed the Point/Non-Point Source and Ion Sampling Study as a focused monitoring effort to further understand spatial and temporal salinity source contributions, transport, and the dispersal of those salts into adjacent channels upstream and downstream of the OLD compliance station (Figure 1). This study is focused on increased monitoring of EC within the inputs and outputs of water used within Old River, Doughty Cut, and Pescadero Tract regions, including the collection and investigation of standard mineral/ions for determining water source differences (i.e., from drains or channels) and identifying any unique fingerprints of those water sources due to interactions with groundwater and/or local inputs from the Sacramento River, San Joaquin River, Old River, Grant Line Canal, and Doughty Cut (Paradise Cut and Sugar Cut Sloughs). In addition, High-Speed EC Boat Transect Mapping (as described in MSS Plan Attachment 1, *High-Speed Salinity Transect Mapping Work Plan*) will be performed in these regions to target different tidal periods to provide resolution to the temporal net movement and mixing of salinity between primary channels and backwaters. These results will be further incorporated into ongoing development and improvements to other MSS technical studies, including Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM) 3D Modeling and Water Quality Data Assimilation Modeling. The data will be checked for data quality and provided to DWR modelers at a minimum of annually from calendar years (CY) 2022 and 2023. Data will be reviewed and used as a feedback loop between modelers and field scientists for improving future data-collection efforts in the region that will help achieve the goals of the MSS Plan, including characterizing salinity and development of a Long-Term Monitoring and Reporting Plan, as described on page 1 of the MSS Plan.

Table 1. Interior Southern Delta Continuous Monitoring Station Names, CDEC Codes, Agency Affiliation, Coordinates, Monitoring Parameters, and Period of Record

Station	StationCode	StationID	Latitude (WGS84)	Longitude (WGS84)	Telemetry	Flow	Stage	WQ Parameters	Agencies	Install Date
Paradise Cut Upstream	PDUP	B9541050	37.801027	-121.373089	No	No	No	Temp, EC	DWR	3/9/2015
Paradise Cut	PDC	B9541000	37.8020598	-121.4122564	Yes	Yes	Yes	Temp, EC	DWR	4/30/2014
Sugar Cut at Golden Anchor	SGA	B9541500	37.79286	-121.421495	Yes	Yes	Yes	Temp, EC	DWR	4/30/2014
Old River above Doughty Cut	ORX	B9539000	37.8109972	-121.386575	Yes	Yes	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR	3/21/2013
San Joaquin River above Dos Reis Park	SJD	B9576000	37.8223312	-121.3177244	Yes	Yes	Yes	Temp, EC	DWR	6/10/2013
Victoria Canal	VCU	B9528500	37.870944	-121.53	Yes	Yes	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR/USGS	3/30/2007
Grant Line Canal near Clifton Court Forebay	GLC	B9529500	37.820128	-121.544661	Yes	Yes	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR/USGS	2/2/2007
Grant Line Canal East	GLE	B9532000	37.82025	-121.434861	Yes	Yes	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR	2/26/2013
Middle River near Tracy Blvd	MRX	B9550600	37.881425	-121.467399	Yes	No	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR	1/1/2003
Middle River at Howard Road	MHO	B9553100	37.876184	-121.383288	Yes	No	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR	10/1/2019
Middle River at Undine Road	MRU	B9554100	37.8339408	-121.3857561	Yes	Yes	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR	6/4/2002
Old River below DMC barrier	ODM	B9536500	37.810972	-121.544417	Yes	Yes	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR/USGS	1/18/2006
Old River above Mountain House Creek	ORM	B9537000	37.7938408	-121.5173813	Yes	Yes	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR	2/25/2015
Old River at TWA	TWA	B9537800	37.802833	-121.457444	Yes	No	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR	7/14/1999
Old River near Head	OH1	B9540000	37.807595	-121.331218	Yes	Yes	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR	7/10/2001
Tom Paine Slough above Intake Structure	TPI	B9542100	37.790088	-121.41845	Yes	No	Yes	Temp, EC	DWR	7/2/2014
Tom Paine Slough above the Mouth	TPS	B95420	37.790535	-121.418633	Yes	No	Yes	N/A	DWR	10/1/1984
Tom Paine Slough at Pescadero P.P. #6	TPP	B95425	37.767389	-121.351083	Yes	No	Yes	N/A	DWR	10/1/1983
Sugar Cut	SUR	B95422	37.78847	-121.419333	Yes	No	No	Temp, EC	DWR	6/25/2008
San Joaquin River at Mossdale Bridge	MSD	B95820Q	37.786	-121.306	Yes	Yes	Yes	Temp, EC, DO, pH, Turb, Chlor	DWR	4/26/2002
San Joaquin River at Brandt Bridge	BDT		37.864722	-121.323056	Yes	Yes	Yes	Temp, EC	DWR	4/6/2005
Vernalis	VER		37.679376	-121.265002	Yes	No	No	Temp, EC	USBR	3/31/1988
Union Island	UNI		37.8221	-121.37499	Yes	No	No	Temp, EC	USBR	3/27/1999

The primary study area includes five regions in the southern Sacramento–San Joaquin Delta: 1) San Joaquin River; 2) Upper Old River; 3) Lower Old River; 4) Doughty Cut; and 5) Grant Line Canal. These regions are unique from each other in-channel bathymetry, geographic orientation, hydrology, impairments, and salinity point sources. Within each region, DWR, Reclamation, and the U.S. Geological Survey (USGS) operate an extensive network of flow, stage, and water quality monitoring stations (Figure 1 and Table 1). Reclamation and DWR operate compliance stations at San Joaquin River at Brandt Bridge (BDT), Old River near Middle River (UNI), OLD, and San Joaquin River at Airport Way Bridge, Vernalis (VER). These stations are mentioned in the 2006 Bay–Delta Plan with water-quality objectives not to exceed a maximum 30-day running average EC of 1.0 millimhos per centimeter (mmhos/cm) from September 1 through March 31 and 0.7 mmhos/cm from April 1 through August 31 (Figure 1 and Table 1).

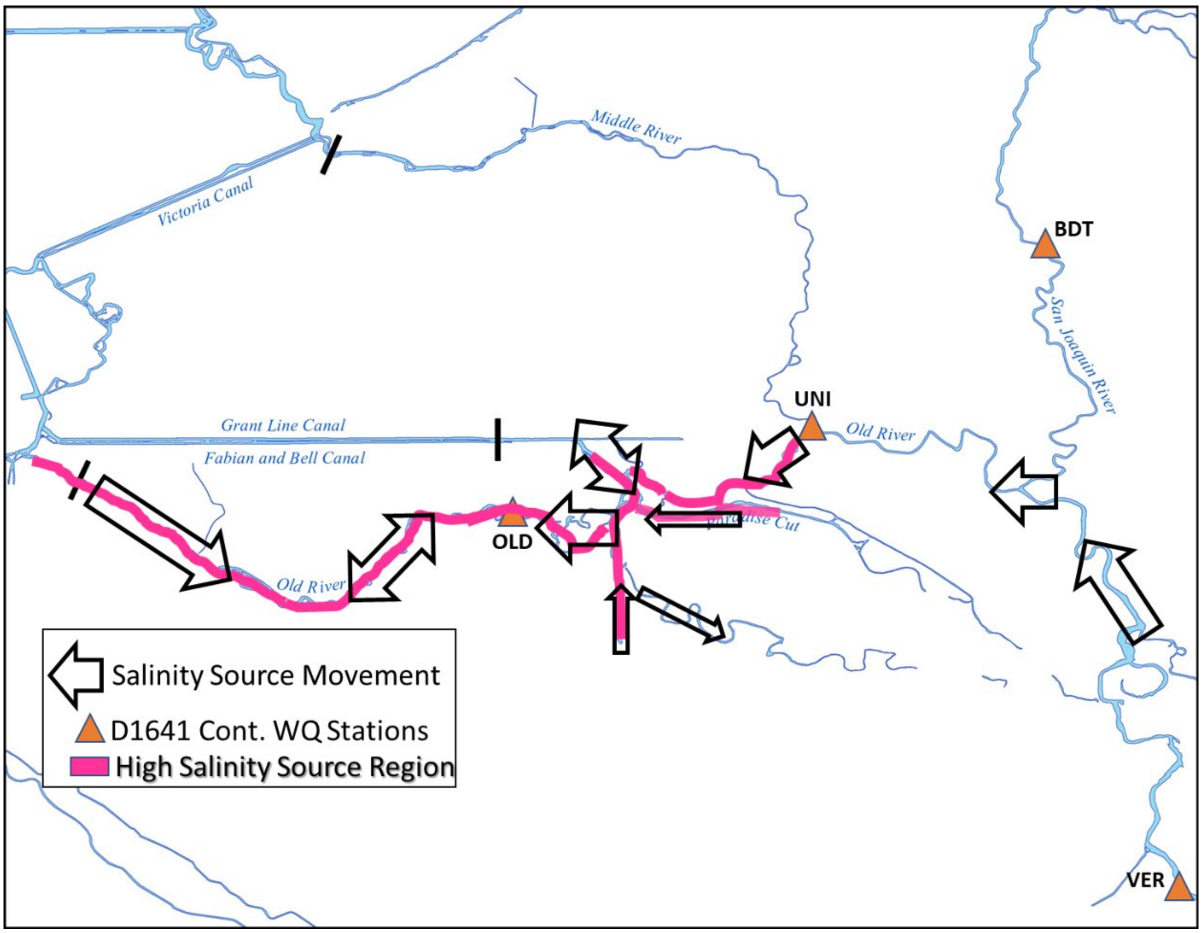

Figure 2. Map Showing Primary Channel Area for Focused Flow and Salinity Monitoring as Part of the Point Source and Ion Sampling Study

As part of this study effort, DWR will be monitoring the baseline conditions in the San Joaquin River, Old River, Grant Line Canal, and Doughty Cut, but the primary focus of the study is to increase monitoring within the section of lower Old River near City of Tracy wastewater outfall, westward to Old River near Mountain House Creek, including Doughty Cut and the side channels of Paradise Cut and Sugar Cut (Figure 2). This area is where the most uncertainty lies in model predictions in flow and salinity, and the area of most issues with elevated salinity and exceedances as observed at site OLD.

Background

Monitoring Special Study

To address the MSS goals, DWR and Reclamation have developed the following technical studies (as described in more detail in Chapter 3, *MSS Study Area and Technical Studies*, of the MSS Plan).

- Salinity Point Source and Ion Sampling
- High-Speed Salinity Transect Mapping
- SCHISM 3D Hydrodynamic and Water Quality Modeling
- Water Quality Data Assimilation Modeling

The Salinity Point Source Sampling and Ion Sampling study, the focus of this workplan, aims to locate areas of increased salinity by collecting additional continuous data and discrete water grab sample data to improve the understanding of local salt sources and how hydrodynamics within the interior southern Delta may influence dispersal and mixing. This sampling effort will be used in the data assimilation process and feedback loop to inform and improve current modeling within the interior southern Delta. All physical data from this study will be assessed with model output results and further used to test model predictions to see if these data provide an improved correlation between field measurements and modeled data. The results will be used to determine the benefits of additional EC monitoring sites in understanding salinity conditions in the interior southern Delta and inform the appropriate locations to assess attainment of the salinity objective in the interior southern Delta, consistent with the 2018 Bay–Delta Plan.

Interior Southern Delta Hydrology

The interior southern Delta has complex hydrology that is influenced by varied San Joaquin Valley precipitation, tidal fluctuation, federal and water project operations, and agricultural and municipal water users. The precipitation and associated runoff in California are dynamic from year to year, as reflected in the water year (WY) index in the San Joaquin Valley, which was highly variable over the past two decades (Figure 3). This complex hydrology from changing water-year type affects the water exchange and ambient water quality conditions (i.e., salinity). Much like other areas of the Delta, the southern channels that encompass the study area are highly altered and do not always maintain a downstream flow direction (Figure 4), primarily due to the consumptive use and tidal fluctuations in this region (see Figure 5). The San Joaquin River is the primary water source for the Upper Old River, Doughty Cut, Lower Old River, and Grant Line Canal regions. Grant Line Canal receives 70–90 percent of the water from Upper Old River and, in most normal and wet water years, has a net downstream movement (Figures 3, 4, and 5). During low net outflow in dry and critically dry water years, the western end of Grant Line Canal is more influenced by Sacramento River water flowing down the Old River corridor to Clifton Court (Figures 3 and 4), which is influenced by a combination of project operations, lower San Joaquin inflows, and local diversions.

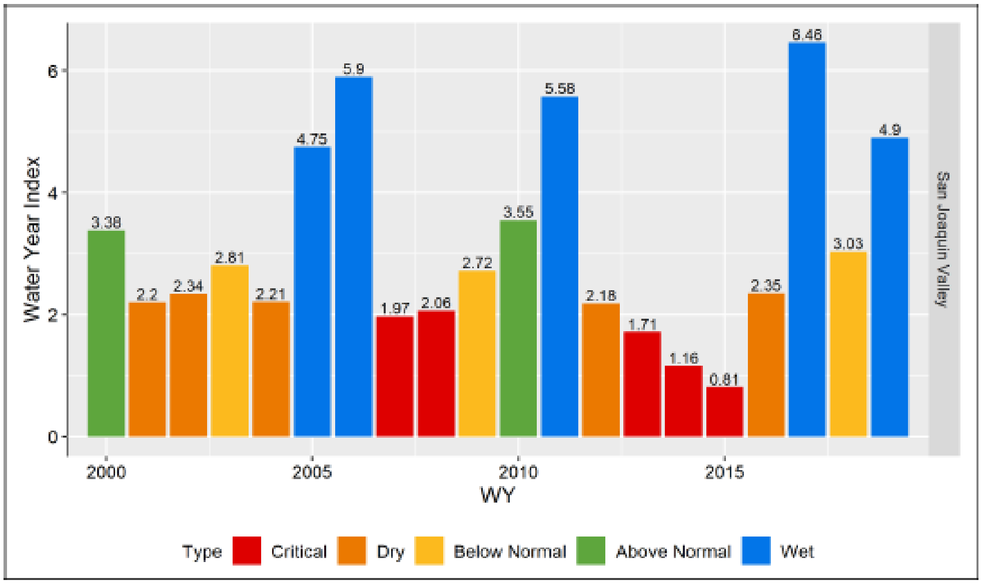

Figure 3. WY Index 2000–2019 for the San Joaquin Valley

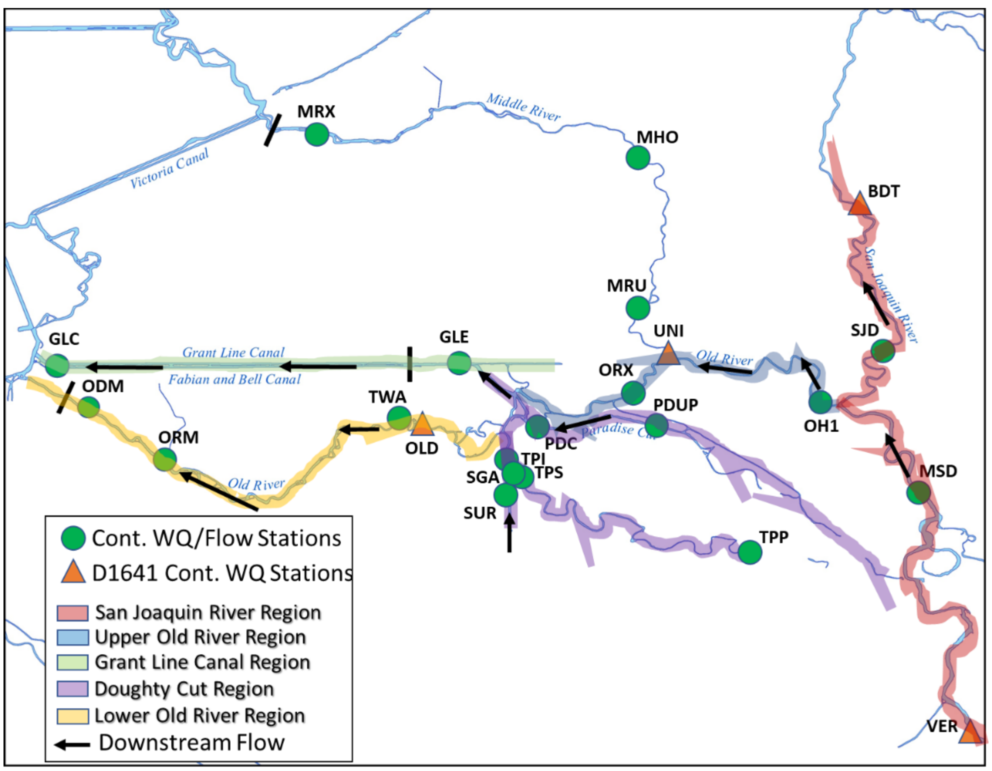

Figure 4. Interior Southern Delta Salinity Monitoring Stations, Regions, and Temporary Barriers

The regional flow conditions vary, based on proximity to the San Joaquin River to the east of the study area and export facilities to the west. Fall and winter conditions are highly reliant on the timing and amount of precipitation within the San Joaquin Valley. In below normal water years, such as WY 2018, San Joaquin River flows in the winter can have minimal fluctuations and in 2018 mean flows were near 2,000 cubic feet per second (Figure 5A). Flows can often peak in the

San Joaquin River during the spring and early summer, as snowmelt and subsequent reservoir water releases increase (Figure 5A). The San Joaquin River at Vernalis (VNS) is unaffected by the Delta tides, but moving north and downstream on the San Joaquin River at Mossdale Bridge (MSD), there is a tidal effect (Figure 5A). The tidal effects become more and more evident moving west to Grant Line Canal, Doughty Cut, and Lower Old River regions (Figures 5C, 5D, and 5E). In WY 2018, flows in Lower Old River and the Doughty Cut region sloughs of Paradise Cut and Sugar Cut have very minimal periods of positive or net downstream flow (Figures 5D and 5E).

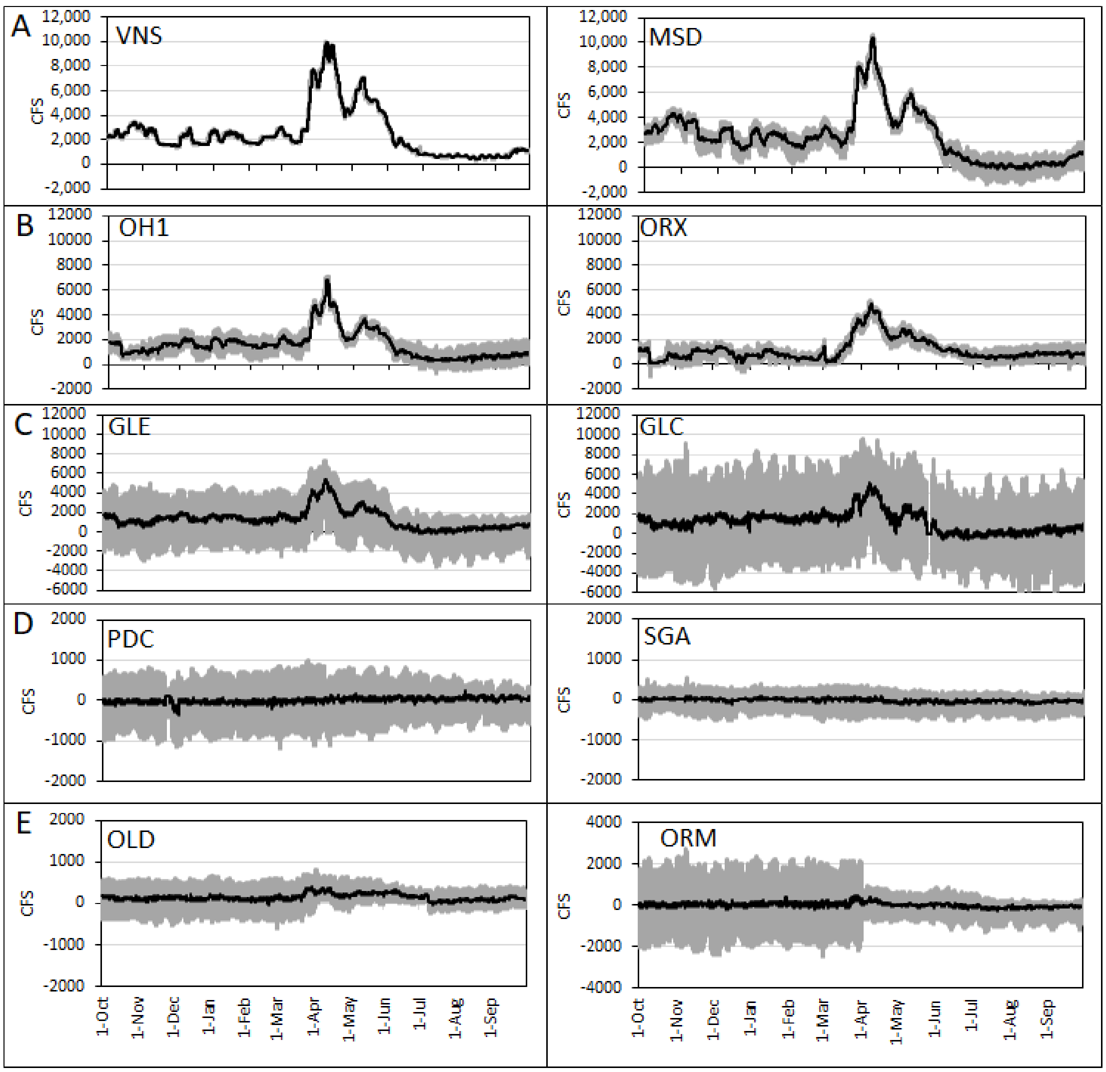

Figure 5 (A-E). WY 2018 Continuous 15-Minute (Gray Line) and Daily Mean Flow (Black Line) in the San Joaquin River Region (A), Upper Old River Region (B), Grant Line Canal (C), Doughty Cut Region (D), and Lower Old River Region (E); Sites for Each Region Are Oriented from Upstream to Downstream, and Regions Are Ordered From East to West; Gaps in Plots Indicate Periods of Missing Data

Interior Southern Delta Salinity

The San Joaquin River is the primary water source to the interior southern Delta channels from the east, and trends in the San Joaquin River EC will often be reflected in Upper Old River and

Grant Line Canal (Figures 6A, 6B, and 6C). However, the trends in EC differ in Lower Old River and the Doughty Cut regions (Figures 6D and 6E).

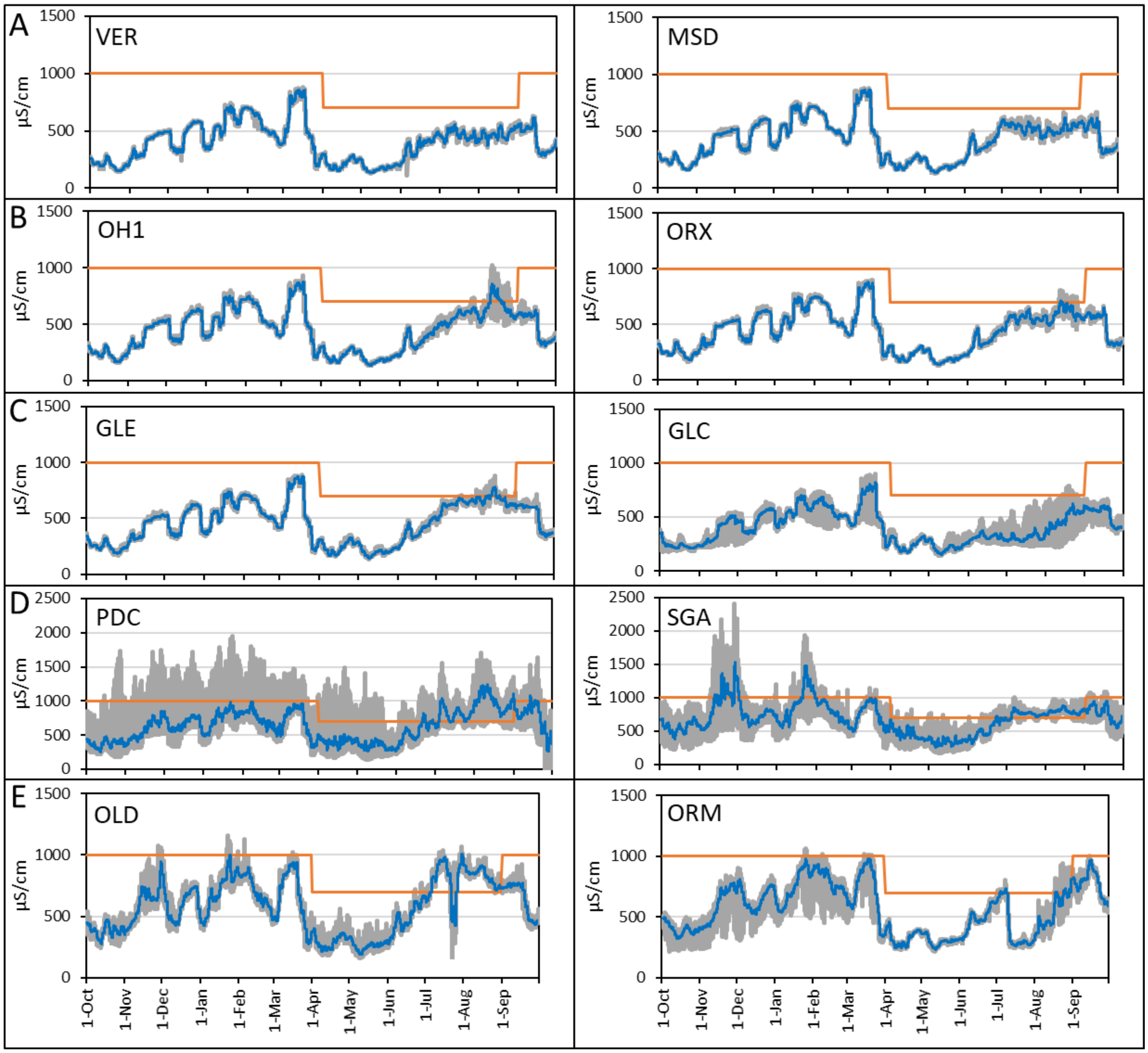

Figure 6 (A-E). WY 2018 Continuous 15-Minute (Gray Line) and Daily Average (Blue Line) EC in the San Joaquin River Region (A), Upper Old River Region (B), Grant Line Canal Region (C), Doughty Cut Region (D), and Lower Old River Region; Orange Line Signifies D1641 EC Compliance Criteria of 1000 µ/cm from September 1 through March 31 and 700 µS/cm from April 1 through August 31 at the Listed Stations; Sites for each Region Are Oriented from Upstream to Downstream and Regions Are Ordered from East to West. Gaps in Plots Indicate Periods of Missing Data

The EC in interior southern Delta regions varies seasonally, annually, and across differing water-year types. These differences are primarily driven by changes in San Joaquin River outflow, water export operations, and agricultural water use in the region. EC in most years and regions is highest during the fall season, when flows are the lowest, but increased runoff and agricultural return water in the winter can also result in high salinity concentrations (Figures 7 and 8). Prior research by Montoya in 2007 determined that Delta Island agricultural practices follow the highest discharge pumping in June and August, but high discharge can also occur in the winter (December and January) to drain flooded fields and as a management strategy to leach salts accumulated in the soil. The trends in EC across years in the San Joaquin River and Upper Old River regions follow each other closely (Figures 7A and 7B). The effects of water exports and subsequent lower EC water contributions from Sacramento River from the west can be observed in Grant Line Canal at (GLC) site (Figure 7C). The EC in Lower Old River as observed at site OLD is higher in all years and seasons (Figure 7D). In general, dry and critically dry water years have the most elevated EC throughout all seasons (i.e., 2015 and 2016), with wet years (i.e., 2017 and 2019) having the lowest concentrations.

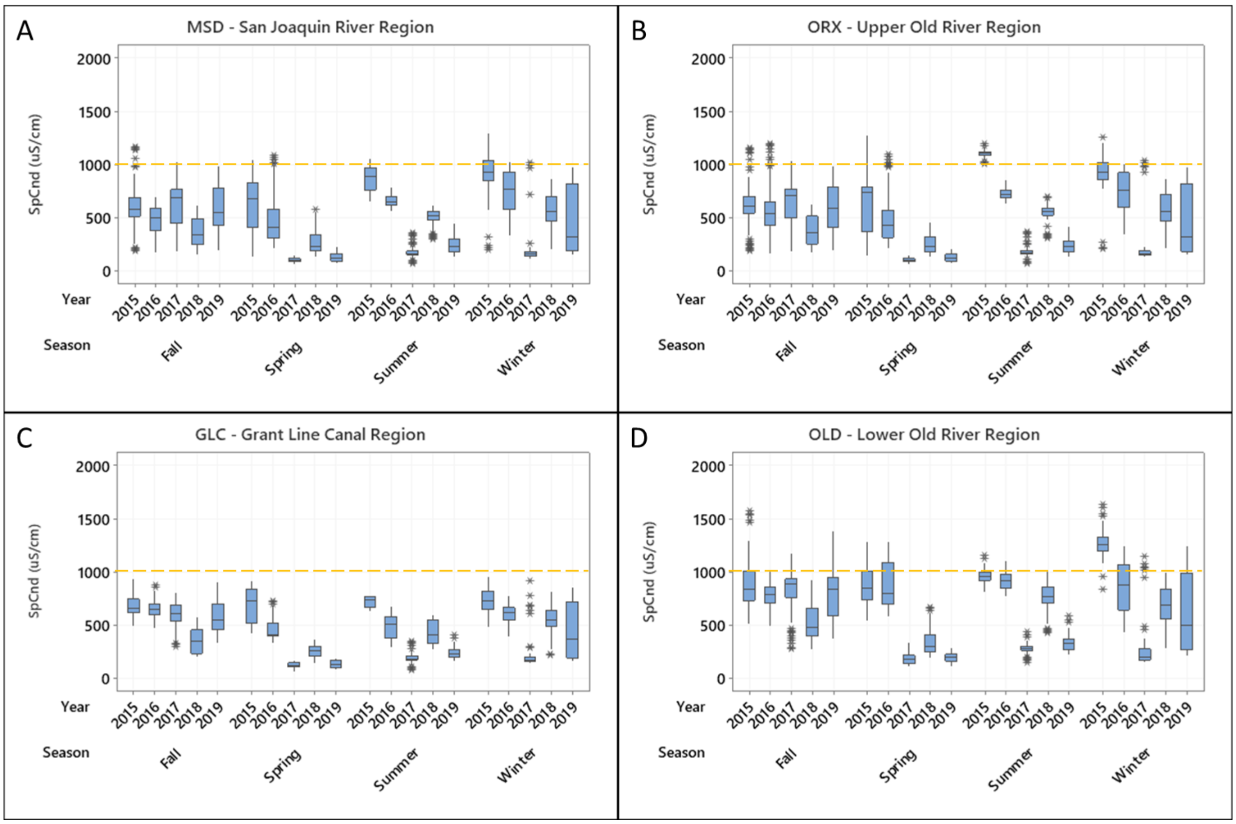

Figure 7 (A–D). WY 2015–19 Boxplots of Daily Mean EC at Site MSD in the San Joaquin River Region (A), Site ORX in Upper Old River Region (B), Site GLC in Grant Line Canal Region (C), and Site OLD in Lower Old River Region (D); Regions are Oriented from East to West; Dotted Yellow Line Signifies 1,000 µS/cm

The OLD compliance station in the Lower Old River region has had a long history of exceeding the established 2006 Bay–Delta Plan water-quality objectives. DWR has conducted various studies over the years to investigate sources of high salinity in this region. Notable reports by Barry Montoya in 2007 and 2012 reflect comprehensive field-study efforts to investigate point sources throughout the San Joaquin, Upper Old River, Doughty Cut, and Lower Old River regions (Montoya 2007, 2012). These studies provided evidence through discrete and transect sampling that there are high-salinity discharge sources upstream and downstream of the OLD compliance station. In addition, Paradise Cut and Sugar Cut sloughs in the Doughty Cut region upstream of the OLD compliance station exhibited high salinity for much of the year and, under certain flow conditions, may be a primary contributor to high salinity at OLD compliance station

(Figure 8). Paradise Cut specifically has a trend of increasing salinity (1,000–3,000 microSiemens per centimeter [µS/cm]) as measurements move upstream in the slough (Figure 9). Further investigations by Russ Brown, using the continuous network of flow stage and water quality monitoring stations, also concluded that Paradise Cut and Sugar Cut are likely sources of high salinity in the Lower Old River region during certain times of the year.

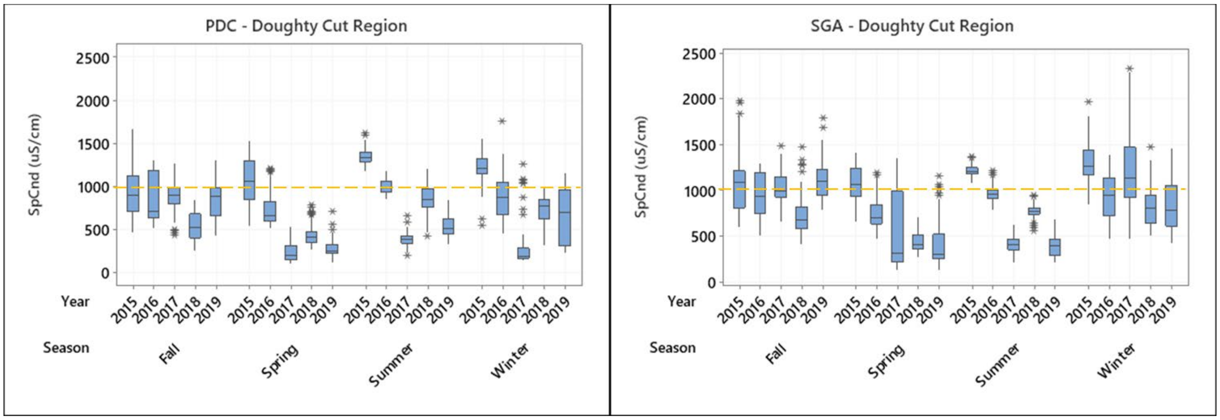

Figure 8. WY 2015–19 Boxplots of Daily Mean EC at Sites in the Doughty Cut Region; Dotted Yellow Line Signifies 1,000 µS/cm

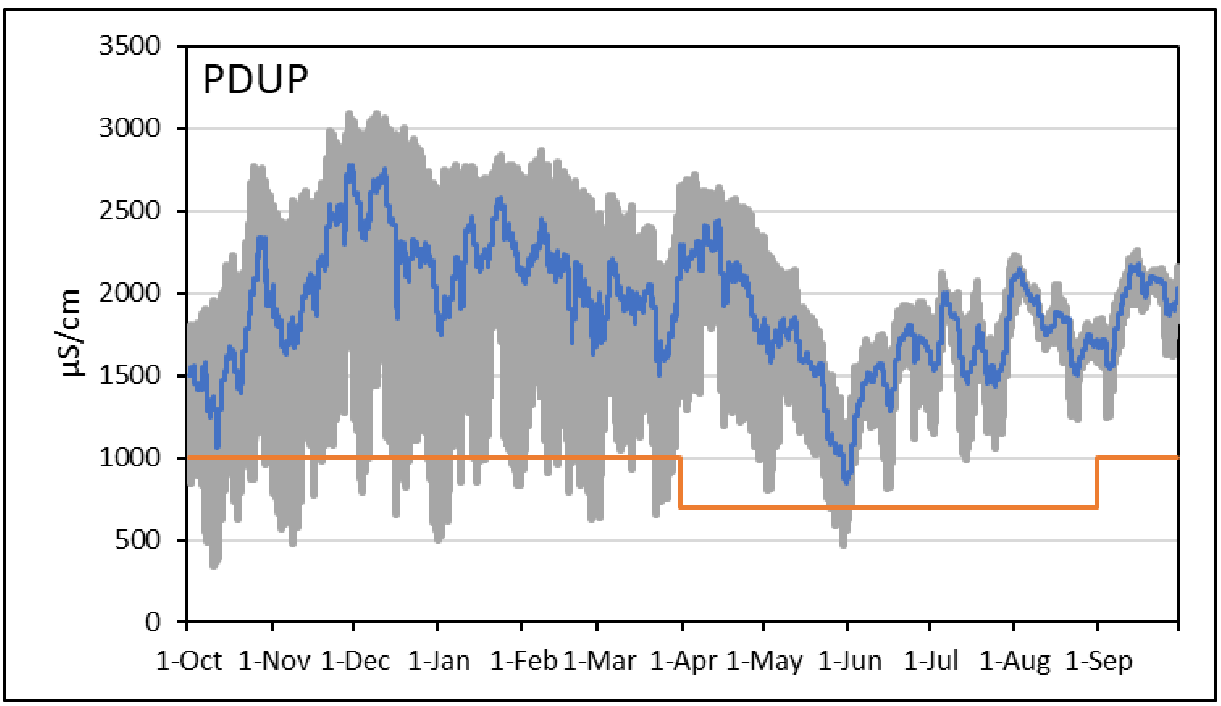

Figure 9. WY 2018 Continuous 15-Minute (Gray Line) and Daily Average (Blue Line) EC at site Paradise Cut Upstream (PDUP); Gaps in Plot Indicate Periods of Missing Data

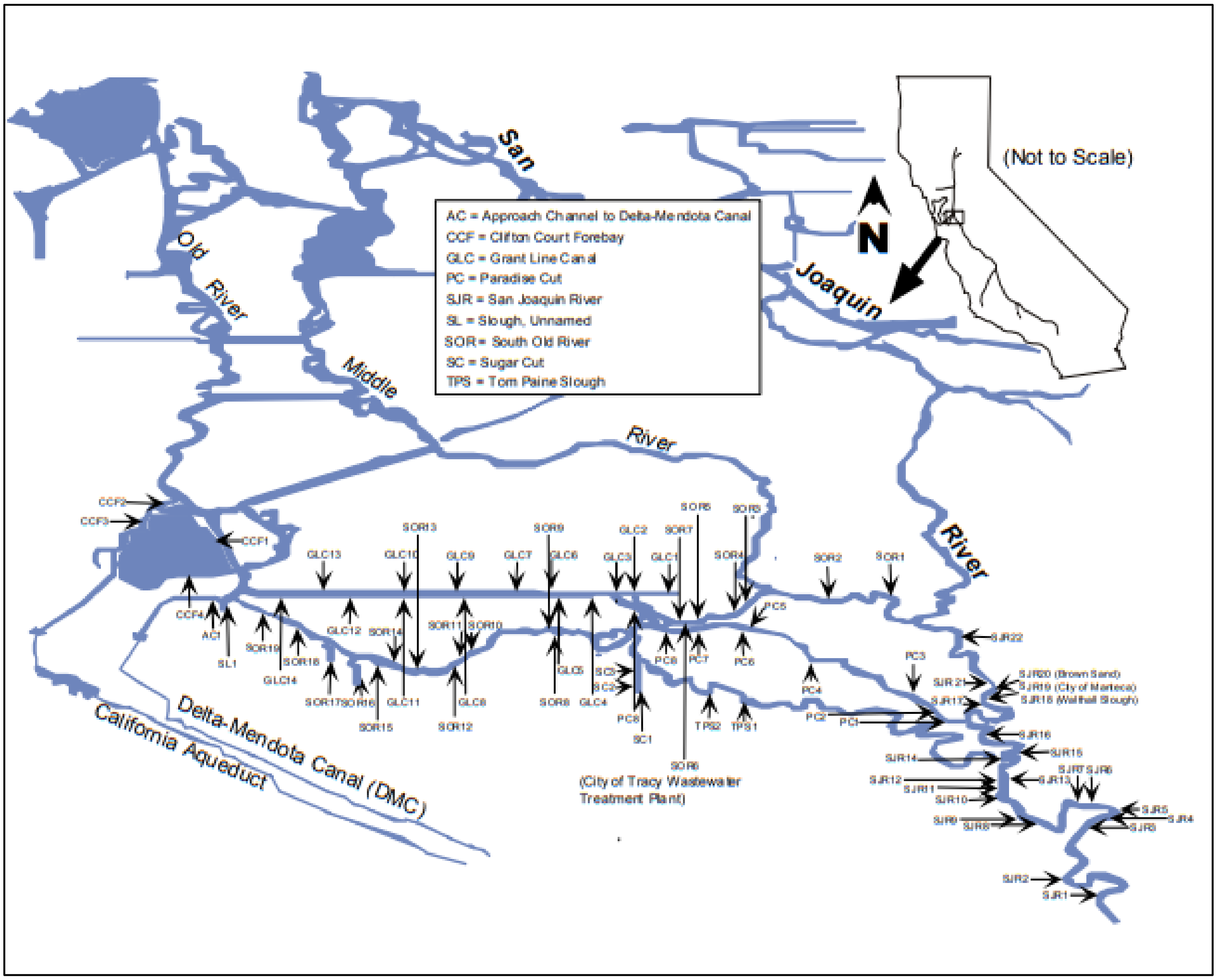

Figure 10. Map of Approximate Locations of Discharges in the Interior Southern Delta from Montoya 2007 Report

Interior Southern Delta Point and Non-Point Sources

Interior southern Delta water quality, like many other regions in the Sacramento–San Joaquin Delta, is influenced by consumptive water use from State Water Project (SWP) and Central Valley Project (CVP) exports, municipalities, and local agriculture. Montoya (2007) determined that there are 74 relatively saline discharges situated along the waterways in the interior southern Delta upstream of the SWP and CVP export sites (Figure 10). These are primarily agricultural, followed by treated sewage, urban runoff, and groundwater. Some of the largest salinity point sources in the San Joaquin River region (from between VER to BDT; Figure 4) of the interior southern Delta were determined to be municipal wastewater from the Cities of Manteca and Lathrop (Montoya 2007), as well as pit drainage from a historical Brown Sand Inc. (SJR20) excavation company (Figure 10). In the Upper Old River region, the largest municipal salinity point sources were from the City of Tracy (SOR6) and the Duel Vocational Institution (PC1) in Paradise Cut Slough (Montoya 2007).

Table 2. Summary Table of Conductivity in Interior Southern Delta Drains Shown on Figure 7

Table 3-1. Summary of conductivity in several south Delta drains

Discharge Location	Minimum	Maximium	Median	Average	Std. Dev.	CV 1/	Sample Size	Date Range	Sources 2/
GLC1	864	2,100	960	1,238	461	37	7	1/86 to 9/87	A
GLC2	810	1,200	950	1,007	160	16	7	1/86 to 9/87	A
GLC3	620	1,500	791	868	296	34	7	1/86 to 9/87	A
GLC5	718	3,230	1,050	1,202	788	66	9	1/86 to 9/87	A
GLC7	820	1,420	1,165	1,096	215	20	8	1/86 to 9/87	A
GLC8	720	1,400	1,100	1,124	235	21	8	1/86 to 9/87	A
GLC11	550	2,600	1,525	1,589	642	40	8	1/86 to 9/87	A
GLC13	550	1,410	1,090	999	367	37	7	1/86 to 9/87	A
PC1	700	2,500	1,150	1,382	733	53	6	1/86 to 9/87	A
PC2	450	2,150	1,405	1,352	566	42	6	1/86 to 9/87	A
PC4	1,400	3,060	1,810	2,037	572	28	11	4/88 to 10/91	B
PC5	710	2,300	1,600	1,641	498	30	9	1/86 to 9/87	A
PC6	1,200	3,160	1,880	1,988	499	25	20	4/87 to 10/91	B
PC6	1,400	2,900	1,550	1,740	494	28	8	1/86 to 9/87	A
PC7	1,230	2,710	1,725	1,798	396	22	18	4/87 to 10/91	B
PC7	1,100	2,600	1,450	1,543	497	32	7	1/86 to 9/87	A
PC8	545	2,680	1,548	1,558	494	32	61	4/87 to 9/97	B
PC8	1,200	2,400	1,700	1,659	419	25	7	1/86 to 9/87	A
SOR3	350	2,550	1,200	1,253	762	61	7	1/86 to 9/87	A
SOR4	750	1,800	960	1,058	377	36	7	1/86 to 9/87	A
SOR5	620	2,500	743	1,009	672	67	7	1/86 to 9/87	A
SOR7	780	2,700	905	1,323	922	70	4	1/86 to 9/87	A
SOR8	1,100	3,880	2,100	2,063	937	45	7	1/86 to 9/87	A
SOR9	920	1,400	1,010	1,076	162	15	8	1/86 to 9/87	A
SOR12	1,200	2,600	1,655	1,785	550	31	8	1/86 to 9/87	A
SOR13	2,400	4,100	2,600	2,779	543	20	8	1/86 to 9/87	A
TPS1	1,300	3,570	1,815	2,238	953	43	8	1/86 to 9/87	A
TPS2	1,100	4,500	2,600	2,597	1,235	48	7	1/86 to 9/87	A
All stations combined (n=28)	350	4,500	1,300	1,496	763	51	285		
Middle River Drains (n=8)	121	3,290	740	947	635	67	56	1/86 to 9/87	A
Victoria Canal Drains (n=5)	350	3,010	620	821	533	65	34	1/86 to 9/87	A
West Delta Drains (n=8)	270	2,800	763	862	440	51	53	1/86 to 9/87	A
South Delta Tile Drainage (n=14)	1,900	4,230	3,100	3,098	704	23	27	6/1/86 and 6/13/86	C
West Delta Tile Drainage (n=14)	780	2,870	1,760	1,822	498	27	20	6/2/86 and 6/16/86	C
CCF1 to CCF4	897	6,970	3,683	3,822	2,821	74	8	6/20/2002	D

1/ Coefficient of Variation

2/ Sources

A: Belden et al. 1989

B: DWR 1990, 1994, and 1999 MWQI data query request

C: Chilcott et al. 1988

D: Unpublished DWR Operations and Maintenance Data

Source: Montoya et al. 2007.

Overall, Montoya concluded that EC at the OLD compliance station was always 100–185 µS/cm higher than other compliance stations in the interior southern Delta (e.g., VER, BDT, UNI) and appears to be influenced by saline inputs from Tom Paine Slough, Paradise Cut, and various groundwater sources. The groundwater influence in surface water drainage point sources was determined to primarily come from four locations: 1) Leprino Wastewater Ponds operated by Westside Irrigation District (SC1); the 2) Wicklund Road Outfall (SOR16) and 3) Mountain House Creek drain (SOR17) downstream of OLD compliance station; and 4) the drain (SOR8) just upstream of OLD (Figure 10). Soils in the interior southern Delta are composed of heavily mineralized, eroded, and marine sedimentary rock found in the Diablo Range (Davis 1961), which makes them very saline. The EC in drains throughout the interior southern Delta are high and average 1,496 µS/cm, with drains in Paradise Cut, Tom Paine Sough, and lower Old River observing the highest minimum and maximum EC (Table 2).

Additional DWR EC transects from 2009–2010 were analyzed and reported by Montoya in 2012 and Brown in 2016. These reports noted elevated salinity in lower Old River near the OLD compliance station. Monthly variability occurred in locations of elevated EC along the extent of the transects that started at the head of Middle River and ended at the terminus of Old River (Figure 11).

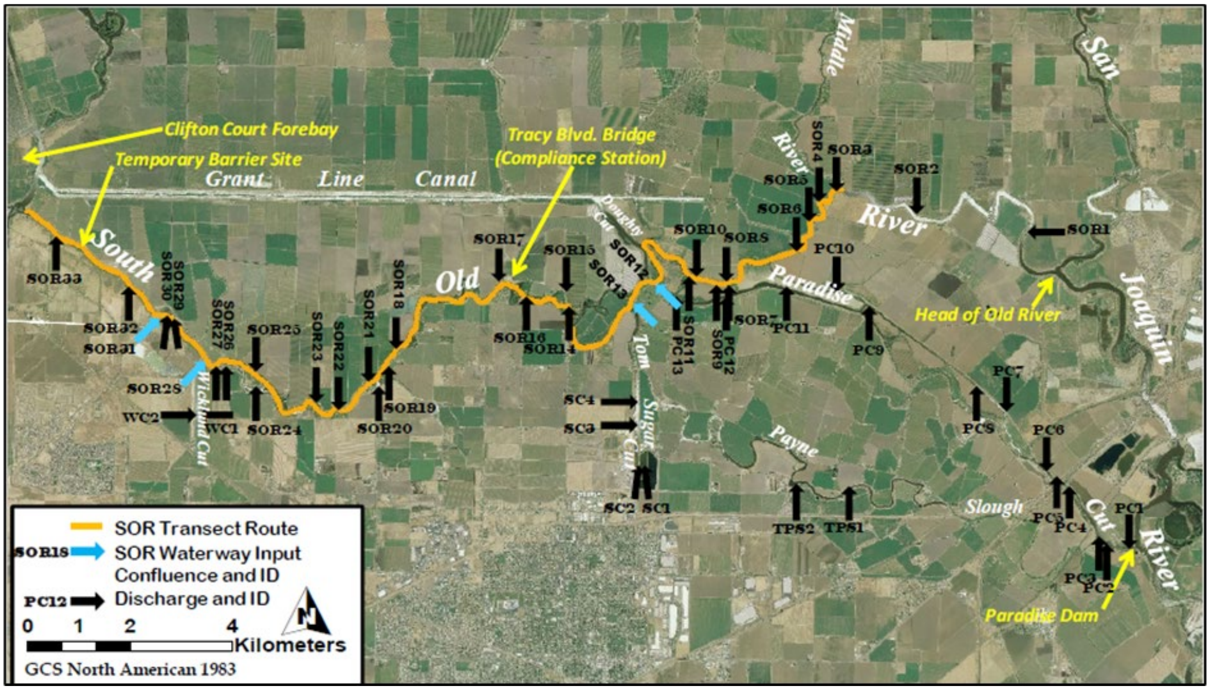

Figure 11. Map of South Old River (SOR) EC Transect Route, Waterway Inputs, and Discharges from Montoya 2012

The trend throughout the transects was an increase in conductivity with distance downstream, with cross-channel gate water from the Sacramento River reducing the conductivity at the western end of Old River and Grant Line Canal, near the export facilities. These transects identified an increase in conductivity between meters 3,000 and 4,500 near SOR7 at the City of Tracy wastewater treatment discharge and a larger increase of nearly 7,000 to 10,000 meters between Paradise Cut and the OLD compliance station (Figures 11 and 12). The transects also provided evidence for repeated influence of passing slugs from upstream sources of high conductivity water at compliance station OLD.

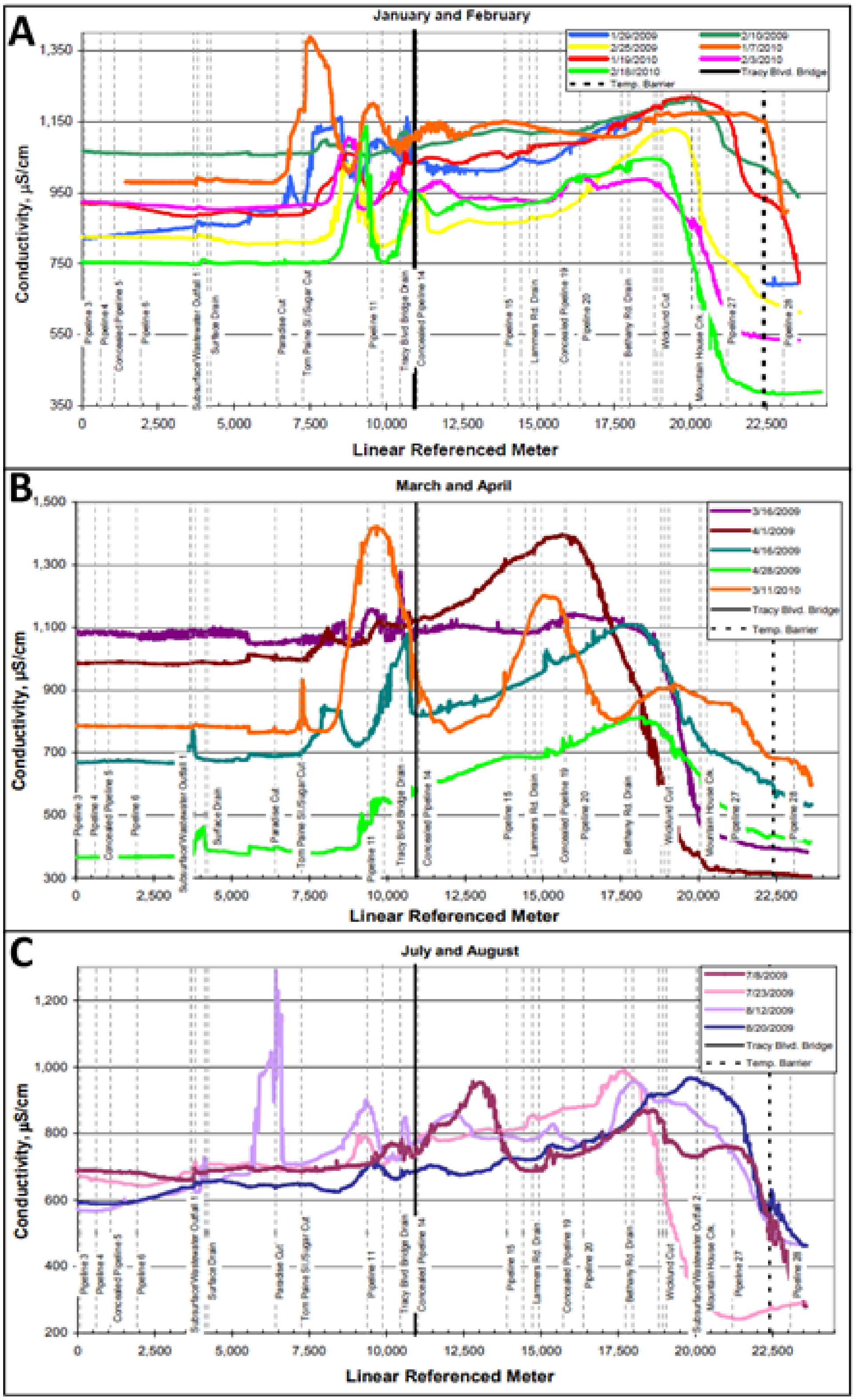

Figure 12 (A–C). Montoya et al. 2012 South Old River Conductivity Transects Conducted during January and February (A), March and April (B), and July and August (C)

These passing slugs would continue to accumulate along with additional inputs in lower Old River and in the downstream extent of the transect. Many of the largest slugs of high conductivity water were determined to originate from Paradise Cut, and oscillations near the mouth of the slough suggested movement of high-conductivity water out of the slough on ebb tides. In addition, January, March, and November were the primary months that Paradise Cut contributed to the elevated conductivity measured in lower Old River, and this timing aligned with the highest periods of groundwater recharge to local aquifers (Montoya 2012; Brown 2016). There was also evidence for tidal movement of high conductivity slugs out of Tom Paine Slough into Sugar Cut during periods when one-way tidal gates are deactivated during the winter and early spring. These transects also corroborated drain-sampling results reported by Montoya 2007, with high conductivity at several lower Old River drains at Lammers Road, Bethany Road, Wicklund Cut, and Mountain House Creek (i.e., SOR17).

Interior Southern Delta Ion Analysis

Montoya 2004 and Denton 2015 identified through Delta standard mineral (i.e., ion) data that there are differing ratios in salinity derived from seawater, Sacramento River, and San Joaquin River sources. These can ultimately be used to identify a “fingerprint” in source waters. Primary ions include chloride, sulfate, sodium, magnesium, potassium, bromide, boron, nitrate, alkalinity, hardness, and total dissolved solids (TDS). Interior southern Delta agricultural drains have been identified as having higher salinity then other regions of the Delta, which can be explained by the origin and makeup of the underlying soils, with the soils being composed of heavily mineralized, marine sedimentary rock from Diablo Range (Davis 1961; DWR 1970).

As part of interior southern Delta salinity investigations by Montoya 2007, ion data was collected at various drains to determine potential groundwater versus channel water ion fingerprints. Montoya determined that Tom Paine Slough, SC1, SOR16, and SOR17, had the same ion fingerprint as nearby wells (Figures 11 and 13). These sampling locations had anionic composition that was either chloride or chloride-sulfate dominant and cationic dominance of either sodium or sodium-calcium. Due to the high similarities and unique fingerprint of these three sampling sites in ionic concentrations, it was concluded by Montoya (2007) that the water quality in these drains was likely driven by the Diablo Range alluvium groundwater effluence. Additional sampling in four agricultural drains in Paradise Cut showed similar, elevated, salt-related minerals of chloride, sulfate, bromide, and nitrate. Montoya 2012 performed additional ion sampling during water-quality transect runs in interior southern Delta channels and found unique differences in Paradise Cut samples, which were dominated by chloride, as compared to south Old River near Tracy Boulevard, which was more inclusive of sulfate and bicarbonate (Figure 14). Montoya (2012) determined that there were not strong differences in ionic fingerprints from south Old River at Tracy Boulevard Bridge, Old River near the head of Middle River, and the San Joaquin River at Vernalis (Figure 15).

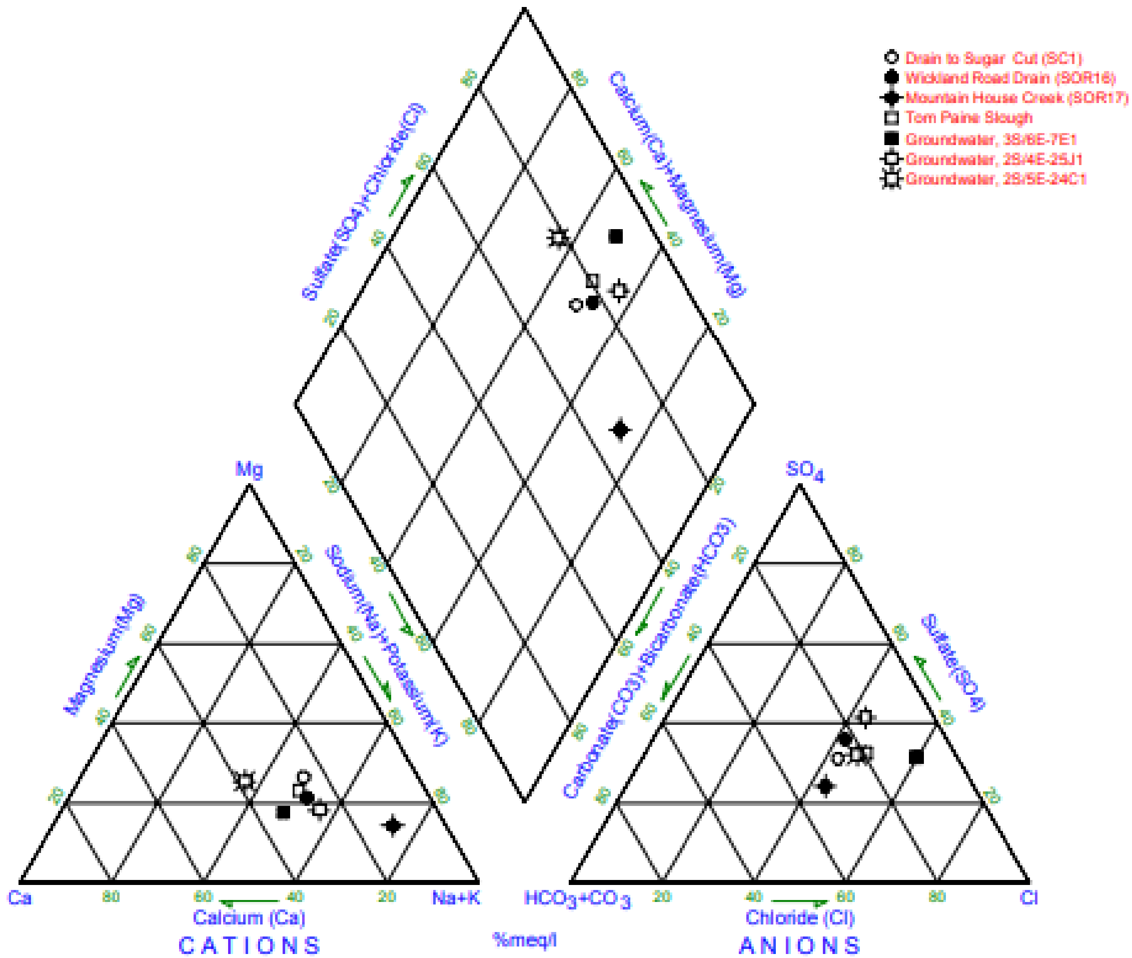

Figure 3-4. Piper graph depiction of several surface and groundwater quality samples collected in the south Delta. The groundwater samples were collected from wells within an approximate 2-mile radius of the center of the City of Tracy. Groundwater was from the semi-confined or upper water-bearing zone (Dubrovsky et al. 1991 and Hotchkiss and Balding 1971).

Figure 13. Piper Graph Depiction of Standard Ion Surface Water Samples from Sites SC1, SOR16, and SOR17 and Groundwater Samples from Wells near City of Tracy from Montoya 2007

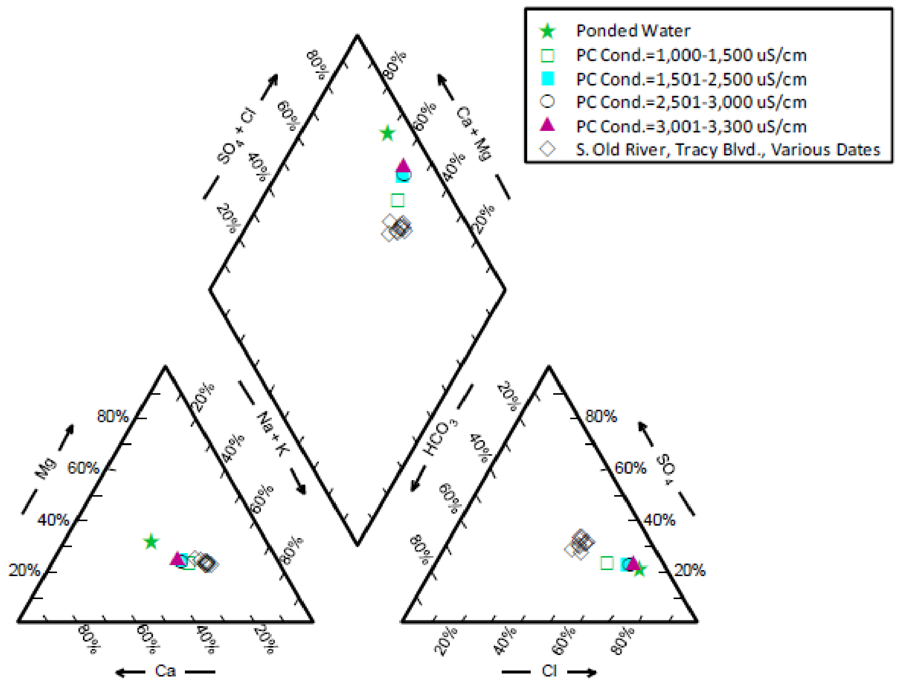

Figure 14. Piper graph of saline ponded water in PC5 versus Paradise Cut (PC) near meter 8,860. Paradise Cut data was segregated by conductivity (Cond.) range.

Figure 14. Piper Graph Depiction of Standard Ion Surface Water Samples from Paradise Cut and South Old River at Tracy Boulevard (OLD)

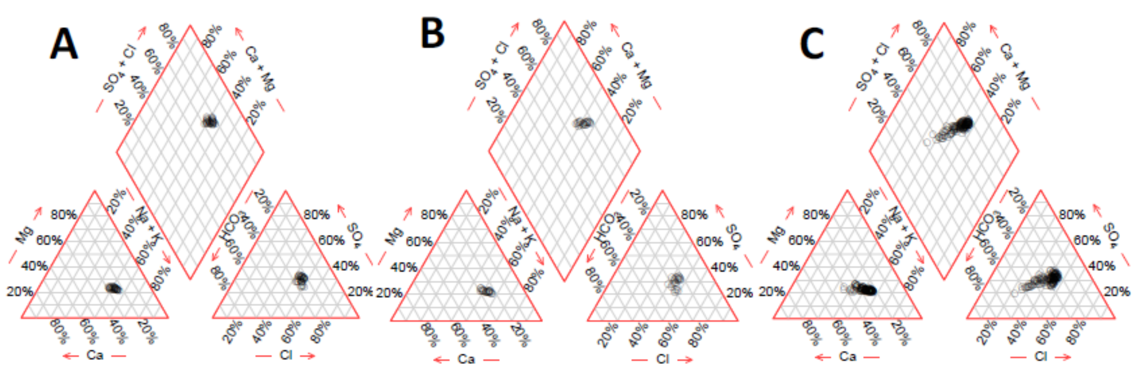

Figure 35. Piper graph depiction of geochemistry in South Old River at Tracy Boulevard Bridge (Tracy, A) and the head of Middle River (meter zero, B). The San Joaquin River at Vernalis is also shown over a wide range of conductivities (range = 99 to 1,120 µS/cm, C) (San Joaquin River data source: DWR's Water Data Library, http://www.water.ca.gov/waterdatalibrary/waterquality/, accessed 11/15/2011).

Figure 15 (A–C). Piper Graph Depiction from Standard Ion Surface Samples from A) South Old River at Tracy Boulevard (OLD), B) Old River at Head of Middle River, C) San Joaquin River at Vernalis from Montoya 2012

In 2018, DWR's North Central Region Office (NCRO) began collecting standard ion surface-water samples at seven sites co-located with continuous water-quality equipment collecting EC data throughout the interior southern Delta (Figure 16). Results from the analysis of monthly samples from 2018–2020 showed that the total dissolved solids across all stations was composed primarily of chloride, sulphate, sodium, and calcium. Much like Montoya 2012, results showed very little difference in the ion ratios between sites in Old River (OH1, ORX], at TWA], and Grant Line Canal East (GLE). However, sites in Paradise Cut (PDC), Paradise Cut Upstream (PDUP), and Sugar Cut at Golden Anchor (SGA) did show some unique ion concentrations (Figure 17). PDUP had the highest EC values and different ionic concentrations of nitrate, potassium, and boron (Figure 17 and 18). Due to the much higher EC range at the PDUP site, there is some uncertainty that these regression equations are the best fit and would properly predict ion concentration at other southern Delta stations under similarly high EC levels (Figure 18). SGA had the highest levels of boron compared to other sites (Figure 17 and 18). Much like observations by Montoya 2012, these data support the conclusion that backwater channels have less exchange and dilution with main channel water sources, whereas sites within Old River are more influenced by mixing from the San Joaquin River inflow.

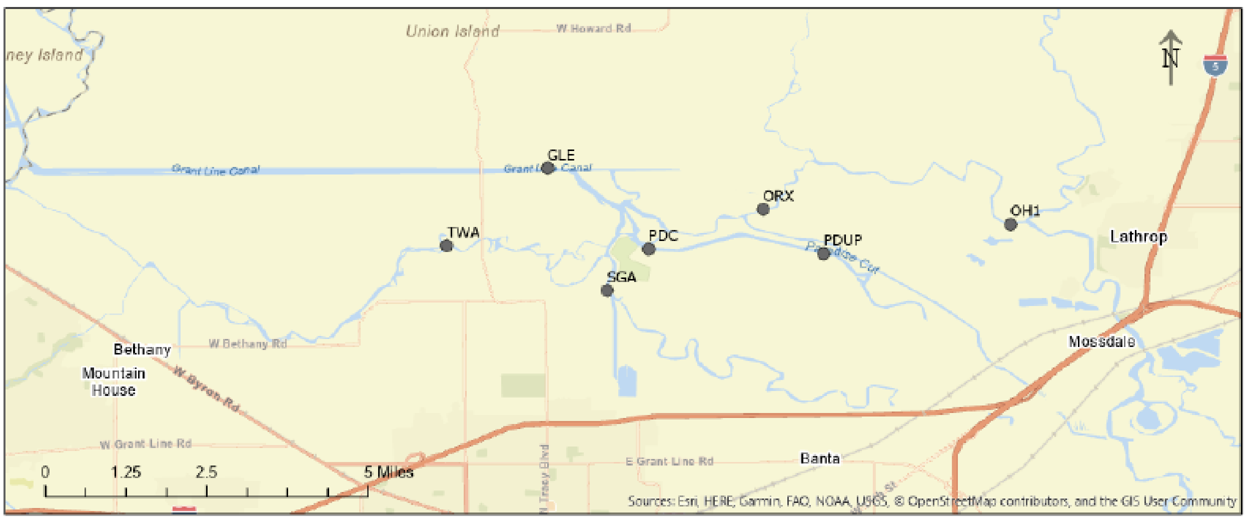

Figure 16. Map of DWR NCRO Stations with Continuous Water Quality and Ion Concentration Measurements in the Interior Southern Delta

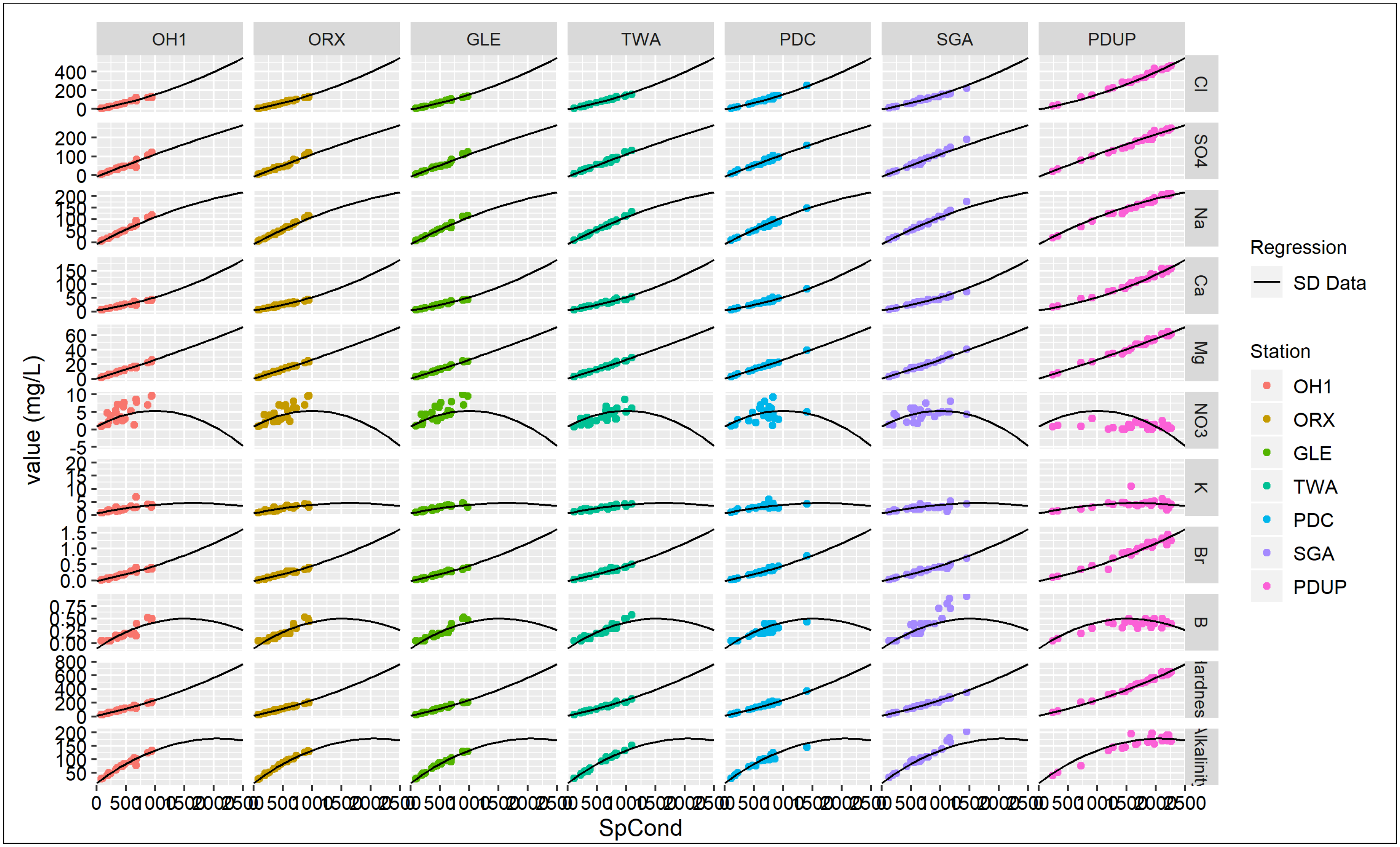

Figure 17. Station Ion Concentrations by EC Separated by Constituent; Regression Line is Formulated Using Fitted Quadratic Model of Ion Concentration from Interior Southern Delta Station Continuous EC Data

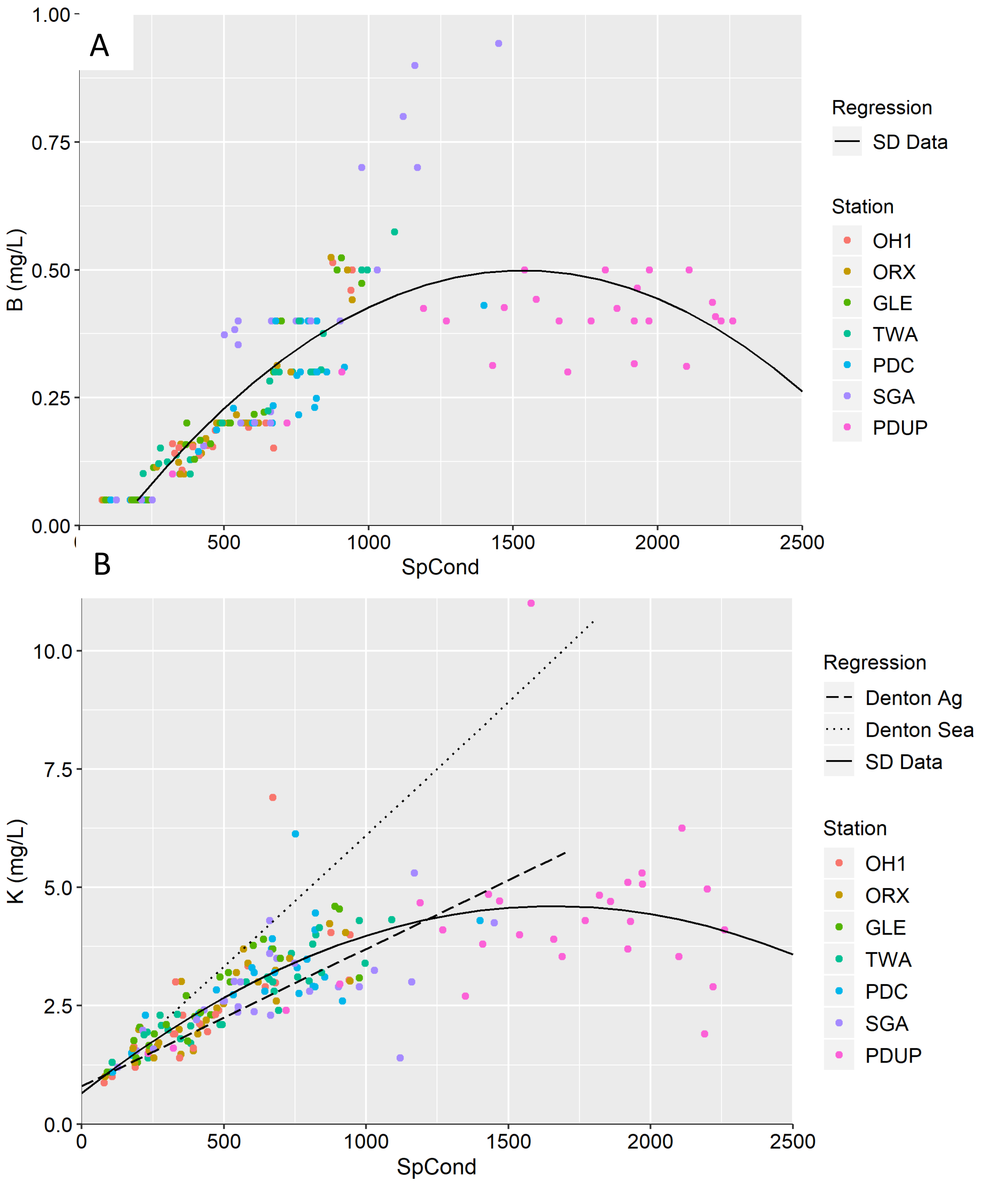

Figure 18 (A–B). Relationship between Boron and EC (A) and Potassium and EC (B) with Fitted Interior Southern Delta Regression Line (Solid Black) and Denton 2015 Agricultural Regression Line (Dashed)

Interior Southern Delta Groundwater

Low numbers of active groundwater wells are within the study area around the interior southern Delta, because much of the water use for agriculture is obtained through surface water pumps along the channels of the San Joaquin, Old River, Grant Line Canal, and Doughty Cut regions. However, past groundwater reports have documented that this region of the San Joaquin Valley has soils composed of heavily mineralized, eroded, and marine sedimentary rock that can be highly saline (Davis 1961; Bertoldi et al. 1991; Montoya 2007). The groundwater on the western side of the San Joaquin Valley has also been described as having higher concentrations of dissolved solids and is typically characterized as the sulfate and bicarbonate type (Bertoldi et al 1991). Groundwater wells tend to be much deeper on the eastern side of the San Joaquin Valley, with the southwestern margin of the San Joaquin Valley (near the study area) having shallow groundwater with high dissolved solids (Bertoldi et al. 1991). The primary anion in the northwest is chloride, and the southwest is sulfate, but both boron and nitrate have been identified at elevated concentrations, with the proximity of Diabolo Range influencing elevated boron concentrations and nitrate concentrations in the Stockton area due to agricultural practices (Bertoldi et al 1991). These findings suggest that groundwater is likely shallow in the study region and could possibly be tracked in surface waters by higher ionic concentrations of sulfate, boron, and nitrate in discrete grab water sample collection.

Another key function of groundwater influence in surface waters is seasonal variability in water table depth. Studies in Delta islands have shown that there are seasonal trends in water table depth, with peaks in winter and lowest levels in summer, suggesting more opportunities for groundwater mixing with surface irrigation and drainage water during this time (Richardson et al 2020).

Montoya (2007) determined through his investigations that groundwater did seem to be interacting with surface drains in interior southern Delta channels in Paradise Cut, Sugar Cut, and south Old River. These were connected via relationships between ion concentrations in both local wells and drains within these channel reaches (Figures 13 and 14). In addition, further EC transect investigations into salinity in Paradise Cut showed the highest concentrations during the highest aquifer recharge periods of winter and spring, as compared to the lowest recharge periods of May–September. This suggests that high saline groundwater is likely mixing with in-channel water sources in Paradise Cut and causing higher-salinity surface waters in the study area (Montoya 2012).

Point Source and Ion Sampling is one study element of the MSS that intends to build off the previous study efforts described above to better characterize the spatial and temporal distribution and associated dynamics of water level, flow, and salinity conditions in the southern Delta waterways, as outlined in the State Water Board's 2018 Bay–Delta Plan. The following section describes details of the Point Source and Ion Sampling Monitoring Plan, which includes monitoring objectives, hypothesis, study questions informing the hypothesis, and methodology for collecting and analyzing data to inform those hypotheses.

2 Monitoring Plan

The Point Source and Ion Sampling Study monitors and evaluates the known high-salinity channel reaches located upstream and downstream of the OLD compliance station. The focus is to improve the understanding of salinity patterns and determine spatial and temporal trends in known high-salinity discharge sources in Old River and the Doughty Cut (Paradise and Sugar Cut) regions and how they may influence salinity at OLD. The study uses additional high-resolution salinity monitoring and mineral/ion monitoring to better determine the origin of salts and how varied seasonal hydrodynamics may contribute to the exchange and increase in salts in lower Old River. DWR hypothesizes that the high salinity concentrations observed at OLD are not tied to one source or one mechanism, but likely to a combination of sources and accentuated by physical channel conditions (i.e., flows, season, water year, tidal phase, and water use). DWR also believes that the Doughty Cut (Paradise and Sugar Cut) region may be a periodic source of salinity at OLD, but it is likely the other culminated local sources in Old River that are dominant during other times of the year and under differing hydrologic conditions. The study will primarily monitor changes in EC as a surrogate for salinity and monitor associated ion concentrations to fingerprint site-specific water sources (Table 1; Figures 1 and 2). In addition, DWR will use High-Speed EC Boat Transect Mapping to better understand seasonal net-transport and dispersal rates of water in Paradise and Sugar Cut to downstream channels of Old River, Doughty Cut, and Grant Line Canal. Presented below is a science monitoring plan for 2021–2023, a budget, and summaries of anticipated deliverables and interagency coordination.

Monitoring Objectives

Hypothesis

The overarching hypothesis for the Point Source and Ion Sampling Study is that local point and non-point source discharges in Old River and the adjacent tributaries of Paradise Cut and Sugar Cut are contributing to periodic elevated salinity and with 2006 Water Quality Control Plan objectives exceedances of the thresholds at the OLD monitoring station.

Study Questions

- Continuous EC Monitoring

    1) What are the temporal and spatial variations in salinity concentrations (as measured by EC) for the San Joaquin River (from Vernalis to Brandt Bridge), Old River, Grant Line Canal, and Doughty Cut (Paradise Cut, Sugar Cut, and Tom Paine Sloughs) regions?
    2) How do discharge point sources in surface waters of Old River, Paradise Cut, and Sugar Cut Sloughs contribute to changes in surface water salinity patterns?
    3) Which salinity point and non-point sources from within Old River, Paradise Cut, and Sugar Cut Slough are contributing salts during periods of exceedances at OLD?
    4) How do Sugar Cut and Paradise Cut spatially and temporally contribute to the EC measurements in Old River over an outgoing tide (high to low)?

- Ion Sampling

    5) What are the relationships between ionic concentrations within the regional surface water in the interior southern Delta regions: San Joaquin River (from Vernalis to Brandt Bridge), Old River, Grant Line Canal, and Doughty Cut (Paradise Cut, Sugar Cut, and Tom Paine Sloughs)?
    6) What are the primary salinity sources in Paradise Cut?
    7) Can unique ion concentrations identified in Paradise and Sugar Cut be identified in tidally dispersed water in Old River?

- Rhodamine Dye Tracer Monitoring

8) What are the net-transport and/or dispersal rates in the upper reaches of Paradise Cut and Sugar Cut under various seasonal conditions (e.g., winter after soil is moist, winter with large Paradise Cut weir flow, summer during peak agricultural discharge)?

9) What is the tidal dissipation in the upstream section of Paradise Cut?

- Pescadero Tract Circulation Investigations

10) What are the temporal and spatial EC and ion concentrations within Pescadero Tract landside agricultural drains before entering Paradise Cut?

11) How do those EC and ion concentrations compare to the primary channels of Tom Paine Slough, Pescadero Tract agricultural drains (drains into Paradise Cut), Paradise Cut, Old River, Doughty Cut, Grant Line Canal, and Sugar Cut?

12) Can ion fingerprinting determine a salinity source coming from upstream in Paradise Cut that differs from Pescadero Tract irrigation drainage water?

Approach to Evaluating Study Questions

The NCRO Water Quality Evaluation Section (WQES) will provide data collection and technical analyses for the MSS studies in the southern Delta. To help support this effort, both continuous and discrete EC measurements will be collected as surrogates for salinity. All sampling data can be used in the data-assimilation process feedback loop to inform and improve modeling. Furthermore, through an increase in the collection of discrete water-quality samples, the local salt sources can be investigated. Discrete water-grab samples will also be analyzed to determine mineral content to support modeling and help build interior southern Delta salinity fingerprints. Understanding these fingerprints and the origin of salts leading to elevated salinity will help to identify the composition of salt loads, including the contribution from local sources, San Joaquin River basin sources, and ocean salts.

The NCRO WQES has established six study tasks to address the above study questions. These include: 1) literature review and drone imagery mapping reconnaissance; 2) continuous EC monitoring; 3) ion data collection; 4) Paradise Cut tidal salinity dispersion monitoring; 5) rhodamine dye tracer monitoring; and 6) Pescadero Tract circulation investigations.

Study Tasks

1) **Interior southern Delta salinity point and non-point source literature and drone imagery mapping reconnaissance:** Perform both literature review and on-water reconnaissance, mapping, and georeferenced imagery of known agricultural and urban based drains, discharges, and pumping platforms that are potential or known sources of return water along Old River, Paradise Cut, and Sugar Cut Sloughs. This will include boat, drone, and land monitoring efforts to best capture all potential high salinity water point sources. Past salinity monitoring efforts in the region will be used to help identify known high salinity sources. This reconnaissance will also be used to identify channel depth and vegetation growth and determine the extent of navigable waterways for performing any future high-speed boat mapping EC transects. On the water, photos and aerial drone imagery will be collected to develop future georeferenced maps, future monitoring strategies, and visuals for reports and presentations to DWR management and

other associated participating organizations[2]. This effort will be used to directly support study design and monitoring efforts for continuous EC monitoring and ion sampling datasets.

2) **Continuous EC monitoring:** EC concentrations will be collected continuously at 15-minute intervals within the spatial extent of the San Joaquin River, Old River, Grant Line Canal, and Doughty Cut (Paradise Cut, Sugar Cut, and Tom Paine Slough) regions. Continuous EC data will be used from existing stations within these regions, and additional EC monitoring equipment will be installed to improve the spatial monitoring coverage. These multiyear time-series data sets will facilitate analysis of temporal and spatial trends over the study period. The monitoring design will attempt to develop a best estimate for the primary agricultural and urban salinity inputs, so that DWR can better determine the rate of increase in these channels seasonally, with support from water grab–sample collection for ion analysis. In addition, supportive MSS high-speed boat EC transect monitoring data in the San Joaquin River, Old River, Grant Line Canal, and Doughty Cut regions will help determine tidal dispersion and downstream movement of salinity sources.
3) **Ion data collections:** The collection of water samples for ion analysis will be performed monthly in the San Joaquin River (from Vernalis to Brandt Bridge), Old River, Grant Line Canal, and Doughty Cut (Sugar Cut, Tom Paine Slough, Paradise Cut) regions. Long-term ion data from stations in Old River, Grant Line Canal, and the San Joaquin River, along with additional ion sample collection in Old River, will be compared using ordination plots, such as principal component analysis or piper plots, to determine spatial and regional relationships between water sources. Additional ion samples collected during high-speed EC transects will be used to provide further determination of tidally dispersed ions moving in and out of Paradise and Sugar Cut into Old River, Doughty Cut, and Grant Line Canal.
4) **Paradise Cut salinity tidal dispersion monitoring:** Perform high-speed boat mapping of EC and coupled ion water- sample collection throughout a high- to- low (i.e., outgoing) tidal excursion in both Doughty Cut regions as they meet at the confluence with Old River and Grant Line Canal. There are currently limitations to fixed station–data collection and the determination of seasonal salinity contributions from Paradise Cut and Sugar Cut to Old River. These limitations include a void of stations at the confluence of these side channels with Old River, as wells as conflicting model results for both flow and salinity in this region. This monitoring would look to further provide further evidence for salinity dispersion under varied tidal and seasonal conditions. Data would be used to develop high- resolution and georeferenced heat maps of varied EC conditions to identify salinity point sources (supporting continuous EC monitoring), track spatial variability, and inform model predictions. The collection of periodic ion samples during the high-speed mapping will be included to help identify potential contributions from discharge/salinity point sources. The use of past research and understanding of local land- use practices will be incorporated into decision making on about the timing of these high-speed mapping transects, as an effort to capture periods of known higher point-

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

source discharge, greater tidal excursion, and periods of exceedances at OLD station in lower Old River.

5) ***Rhodamine dye tracer monitoring:*** To determine the net transport and/or dispersal rates in the upper reaches of Paradise Cut and Sugar Cut, rhodamine dye will be distributed within the middle two-thirds of the channel width near the end of an ebb tidal phase. The dye will be tracked by stationary buoy instruments fitted with Rhodamine WT sensors, and additional, boat-based transects will be performed to track the dispersion and concentrations of the dye throughout multiple tidal cycles. To determine tidal dissipation in the upper channels of Paradise Cut and correlate with dye-dispersion measurements, water level sensors (collocated with EC sensors) will be deployed at a series of locations within the upper extent and split channels to generate a temporal and spatial understanding of how tides may be dampened due to the channel bathymetry and high vegetation. This data can be compared to water level stations at downstream stations and used to further improve model predictions. To help with the MSS objective of better defining low- and null-flow zones in lower Old River and Doughty Cut regions, data would be used to improve the characterization of flow and stage measurements.

6) **Pescadero Tract circulation investigations*:*** EC concentrations will be collected continuously at 15-minute intervals within the spatial extent of Sugar Cut, Tom Paine Slough, major agricultural drains in North Pescadero Tract (that discharge into Paradise Cut), and Paradise Cut. These multiyear time-series data sets will facilitate the analysis of temporal and spatial trends over the study period. In addition, complimentary MSS high-speed EC transect monitoring data in Paradise Cut, Sugar Cut, Doughty Cut, Grant Line Canal, and Old River will help determine tidal dispersion and downstream movement of salinity sources from Paradise Cut into downstream channels. The collection of water samples for ion analysis will be performed monthly in Sugar Cut, Tom Paine Slough, North Pescadero Tract agricultural drains, and Paradise Cut. These, along with long-term ion data from stations in Old River, Grant Line Canal, and the San Joaquin River, will be compared using ordination plots, such as principal component analysis or piper plots, to determine spatial and regional relationships between water sources. Additional ion samples collected during high-speed EC transects will be used to provide further determination of tidally dispersed water sources in and out of Paradise and Sugar Cut into Old River, Doughty Cut, and Grant Line Canal.

Long-Term Monitoring and Reporting Plan

The tasks associated with the Point Source and Ion Sampling Study will inform the development of the Long-Term Monitoring and Reporting Plan by addressing critical and outstanding questions about the drivers of spatiotemporal variability of salinity in interior southern Delta channels. The added continuous EC and ion sample data collection efforts will be used to determine critical locations for necessary additional in-channel salinity monitoring that can be used to improve model predictions and assessments of salinity across designated compliance reaches. The data will also help validate the resolution and accuracy of high-speed EC transect mapping as an additional tool for assisting in reach-based salinity compliance. These data-collection efforts may also lead to greater solutions for local water-use operation and management in the interior southern Delta that could lead to improving seasonal salinity conditions.

Methodology

Time Period and Study Area

The six study tasks outlined above are anticipated to occur primarily over CYs (January–December) 2022–2023, with final analysis and reporting anticipated to be completed in June 2024 (Table 3). Point and non-point source literature review and on-water reconnaissance occurred in September–December 2021, prior to monitoring equipment installation. Drone georeferenced map imagery will occur four times, starting in November 2021, and again every 3 months in 2022, to capture varied seasonal conditions at those channel reaches on Figures 19 and 20. These drone flights will focus on Old River, Paradise Cut, Sugar Cut, and Tom Paine Slough. Continuous EC monitoring equipment will be installed in late December 2021 and/or early January 2022 and will maintain data collection continuously throughout 2022–2023, collecting data at 15-minute intervals at those sites in Table 4 and on Figure 21. Ion water-sample collection will occur at a minimum of monthly (sampling may increase based on seasonal and/or ambient flow conditions) over WYs 2022–23.

The study area will focus on the San Joaquin River (from Vernalis to Brandt Bridge), Grant Line Canal, Old River, and Doughty Cut (Paradise Cut, Sugar Cut, and Tom Paine) regions. Data collected from the long-term continuous EC and discrete monitoring station network in these regions, especially San Joaquin River and Grant Line Canal, will be used to support the data collection efforts for this monitoring study (Figure 21; Table 5). This study will have added focus on the Lower Old River and the Doughty Cut regions because these regions of the interior southern Delta have had the most prolonged issues with salinity exceedances. Therefore, the drone georeferenced mapping will focus on those channel reaches within these regions, including Paradise Cut, Sugar Cut, Tom Paine Slough, and Old River from Middle River junction west to Old River near Mountain House Creek (Figures 19 and 20). The deployment of additional continuous EC monitoring equipment will be in Old River from below the Tracy wastewater release site (SOR7), south–west through Doughty Cut and along Old River to Mountain House Creek (Table 4; Figure 21). Ion sampling will focus on capturing a fingerprint for all study regions and utilizing comparisons with targeted sampling from high-speed EC transect mapping to determine ion and water movement between channel reaches spatially and temporally. The salinity tidal dispersion monitoring around Paradise Cut will focus on performing high-speed EC mapping transects in the Doughty Cut region over different tidal periods and collecting continuous EC and discrete ion data, both upstream and downstream of the confluence of Paradise Cut with Old River, to corroborate transect data (Figure 22).

Pescadero Tract water operations is managed by the Pescadero Reclamation District 2058, under the jurisdiction of the South Delta Water Agency. Pescadero Tract consists of 11 miles of levees and 14 miles of Tom Paine Slough that surround 8,000 acres of agricultural, residential, and industrial land in Tracy, California. Continuous EC monitoring using Yellow Springs Instruments (YSI) EXO or 6-Series Sondes and/or Onset HOBO Conductivity sensors will focus on filling gaps in the current data-collection network around Pescadero Tract channels, which includes collecting data along the full extent of Tom Paine Slough. Currently, existing continuous EC monitoring is taking place at Tom Paine Slough Intake (TPI) at the western end of Tom Paine Slough; continuous EC monitoring will be added in the central portion of Tom Paine Slough at Paradise Avenue Bridge (TPPA) and, at the eastern end, at the existing DWR stage station Tom Paine near Pescadero (TPP; Figure 19; Table 6). In addition, continuous EC monitoring will be placed near landside drainage pumps to measure the EC of irrigation return water prior to discharge into Paradise Cut, the primary drainage channel for northern farmland within Pescadero Tract. This will allow for continuous measurements of EC from these drains prior to mixing with in-channel water sources in Paradise Cut that come from tidal exchange with Old River and Grant Line Canal. Sugar Cut has adequate existing monitoring, with stations located at SGA, Sugar Cut (SUR), and at the upstream end of the slough at Drainage at Arbor Road (DAR).

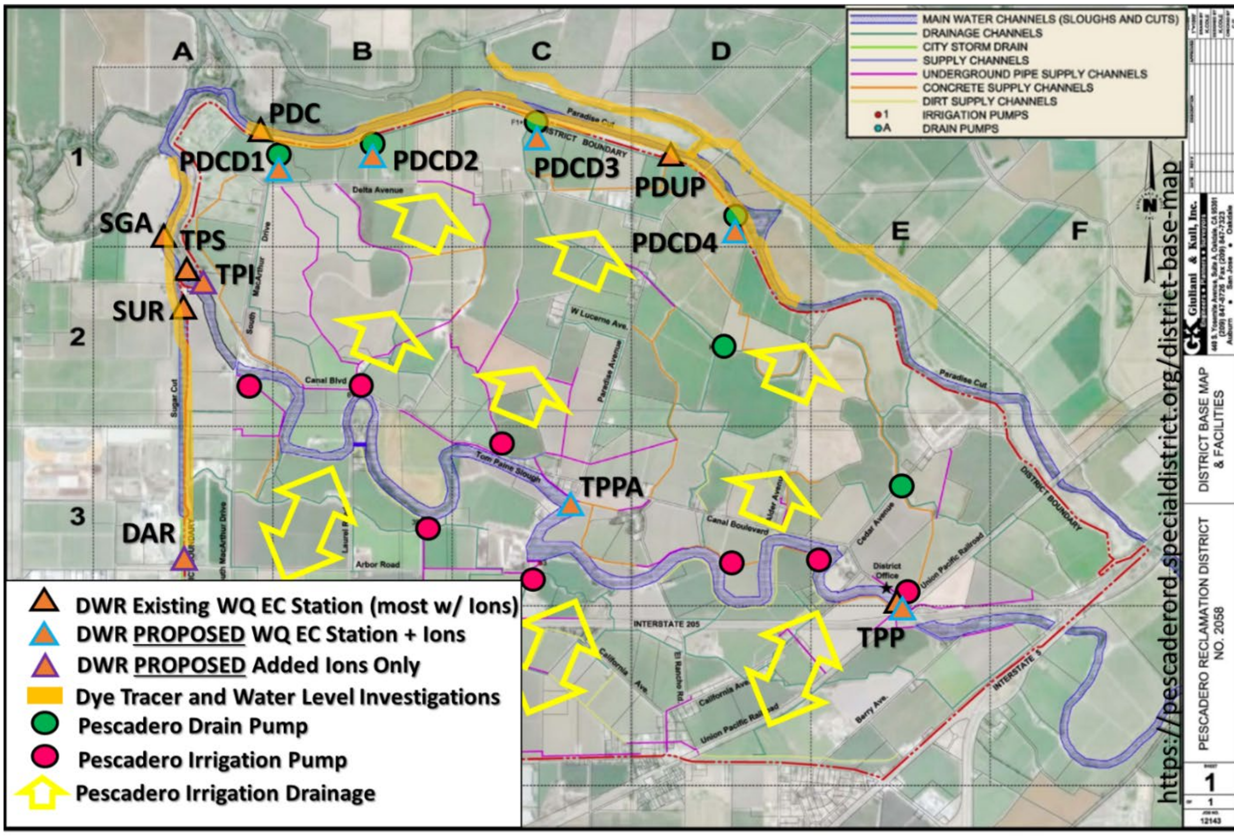

Figure 19. Map of Pescadero Tract with Existing DWR Continous EC Monitoring and Ion Sampling Sites, Proposed EC and Ion Monitoring Sites, Dye Tracer and Water Level Investigation Region within Paradise Cut, and Pescadero Tract Drain and Irrigation Pump Locations

Drone Imagery Mapping

Drone pilots will collect a series of contiguous, high-resolution aerial photos using an Unmanned Aerial Vehicle (UAV), commonly known as a *drone*, for four specified channel reaches within the southern Delta area. The individual channel reaches include: 1) Old River between Middle River and the Federal Intake; 2) Sugar Cut; 3) Paradise Cut; and 4) Tom Paine Slough. DJI Phantom 4 Pro drones will be used to collect photomosaics, which will be approximately centered along the channels, include adjacent levees, and extend outward (i.e., landward) from the channel center approximately 100 feet in each direction. The completed photomosaics will (Figures 20 and 21) would include the following.

1) Paradise Cut will be flown in one segment at a 250-foot altitude, approximate ground surface density (GSD) of 1.79 centimeters/pixel, and approximate channel length of 11.5 miles.

2) Sugar Cut will be flown in one segment at 300 feet, GSD 2.15 centimeters/pixel, and an approximate channel length of 2.0 miles.

3) Old River will be flown in three segments at different altitudes:

   a. Segment 1 at 300 feet, GSD 2.15 centimeters/pixel, and approximate channel length of 3.8 miles;
   b. Segment 2 at 200 feet, GSD 1.43 centimeters/pixel, and approximate channel length of 5.2 miles; and
   c. Segment 3 at 250 feet, GSD 1.79 centimeters/pixel, and approximate channel length of 6.9 miles.

4) Tom Paine Slough will be flown in one segment at 200 feet, GSD 1.43 centimeters/pixel, and approximate channel length of 7.1 miles.

These photomosaics will be used for documenting geometric and physical conditions of the channels throughout the year, which will assist in documenting connectivity of the back-water channels of Sugar Cut, Paradise Cut, Tom Paine Slough, and the seasonal wetted areas. These images will also illustrate existing physical conditions, including seasonal extents of visible floating and submerged aquatic vegetation in the noted channels throughout the year, to study potential impacts to water quality, hydrodynamics, and other related monitoring efforts.

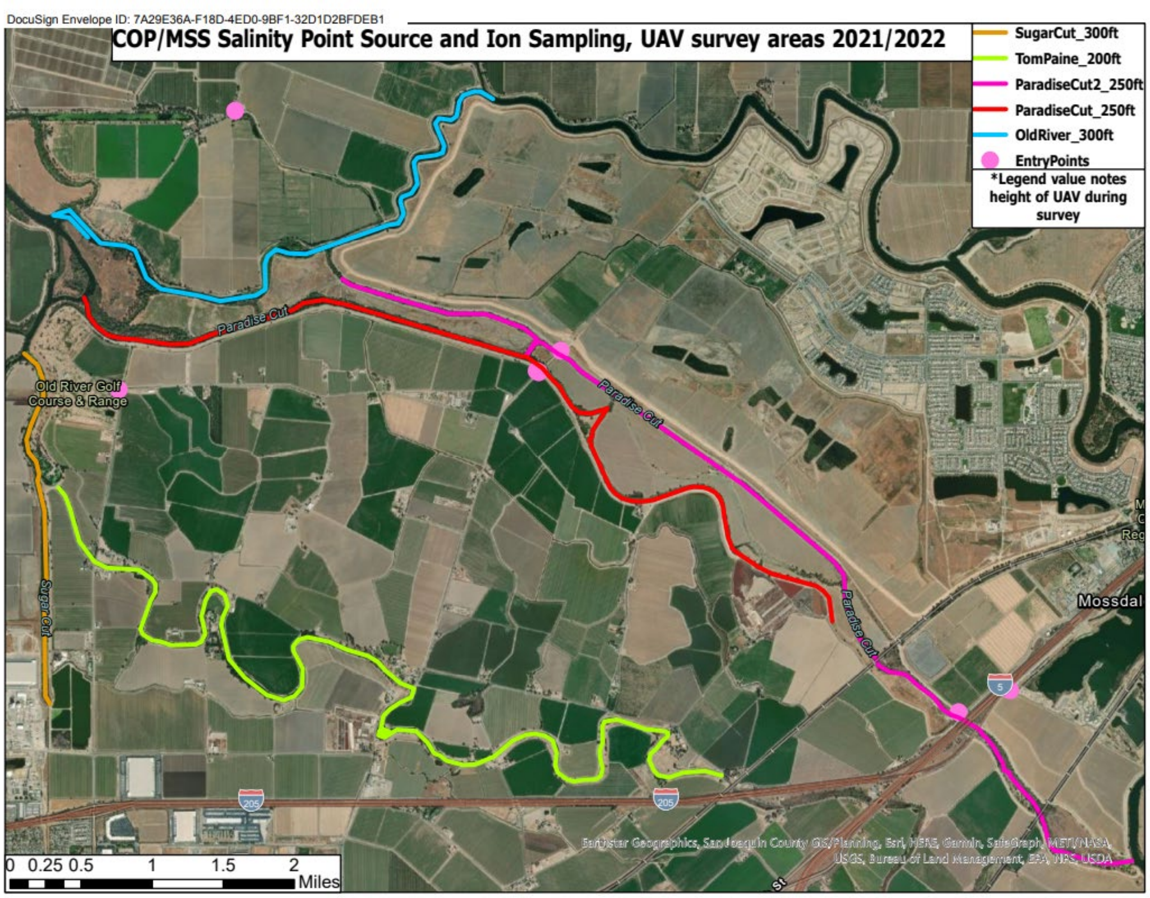

Figure 20. Upper Old River, Paradise Cut, Sugar Cut, and Tom Paine Slough Drone/UAV Survey Area, Entry Points, and Survey Channel Length

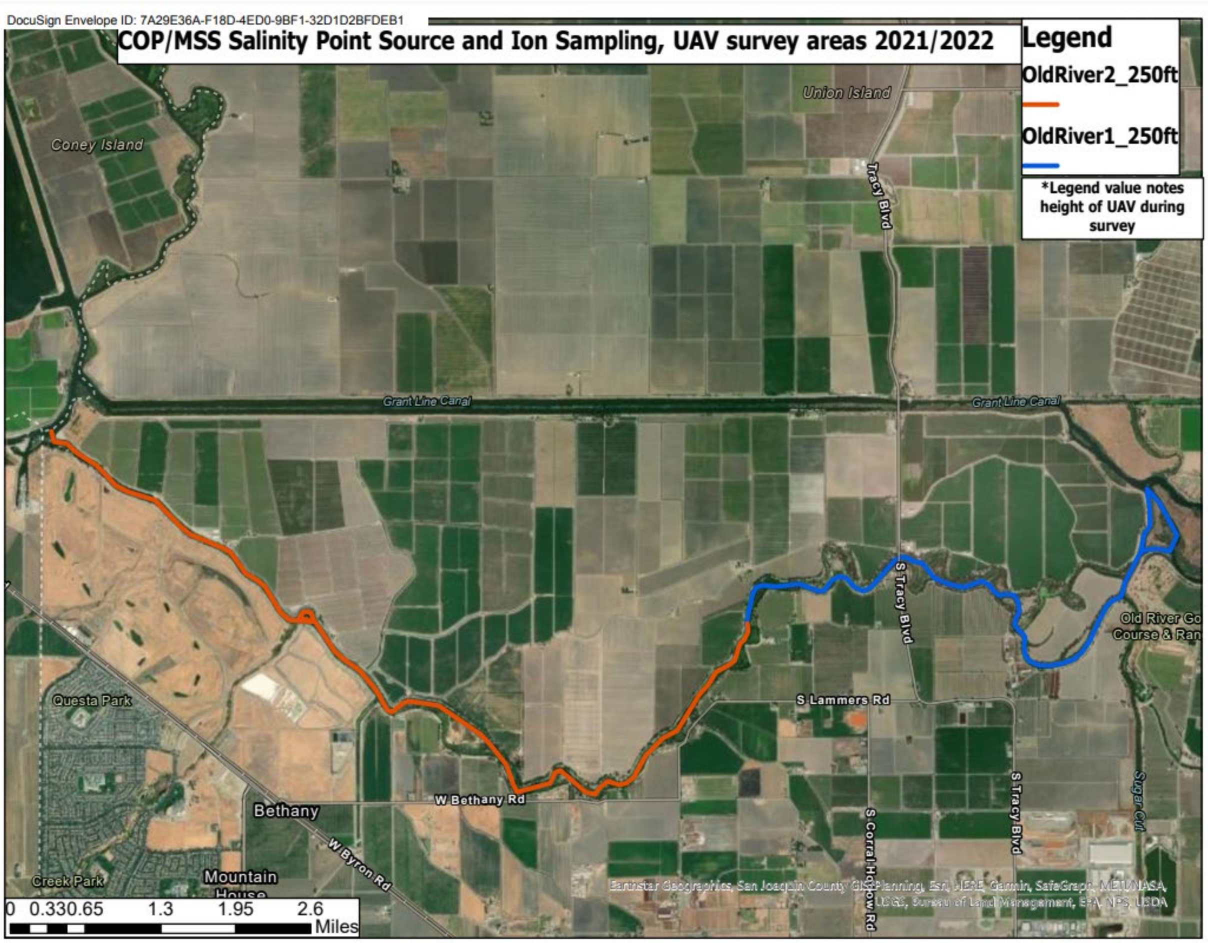

Figure 21. Lower Old River Drone/UAV Survey Area, Entry Points, and Survey Channel Lengths

Continuous EC Monitoring

EC will be monitored and evaluated as a surrogate for salinity for this study at those sites listed in Table 4 and Table 5. EC is electrical conductance that is corrected to a standard 25ºC temperature. Data collected at existing DWR monitoring stations in Table 4 and on Figure 22 use YSI EXO2 or EXO1 multiparameter water quality sondes that utilize an EXO Conductivity and Temperature Smart Sensor with a range of 0–200,000 µS/cm and accuracy of ±0.5 percent of reading. These existing monitoring stations collect monitoring data at a continuous 15-minute interval and are typically checked for sensor error and recalibrated every month. New temporary sites for this study will utilize a combination of YSI 600OMS V2 Multiparameter Sondes and Onset HOBO Conductivity Loggers (Figure 22; Table 3). These instruments provide the advantage of being much smaller than the YSI EXO counterparts, providing more flexibility in installation location and depth. The YSI 600OMS V2 utilizes the same sensor technology and therefore has the same range and precision as the YSI EXO Conductivity and Temperature Sensor. The HOBO Conductivity Loggers have a range of 0–10,000 µS/cm and accuracy of 3 percent of the reading, and the added benefit of an internal battery life of 3 years and length of

6.25 inches. These new temporary sites will collect data at continuous 15-minute intervals and will have the same monthly maintenance schedule to ensure data accuracy.

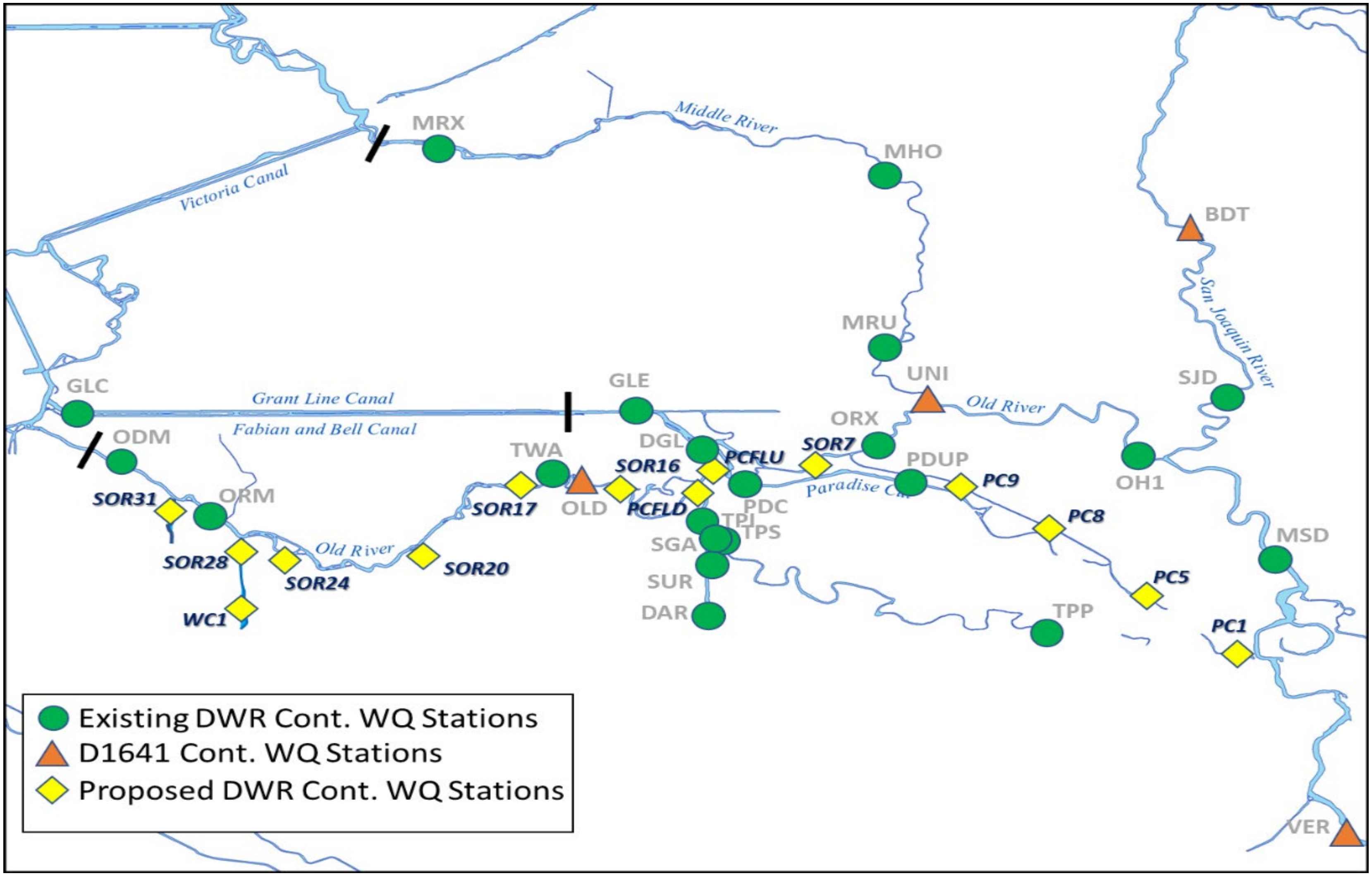

Figure 22. Interior Southern Delta Lower Old River and Paradise Cut Additional Continuous EC Stations (Yellow Diamonds), Existing DWR Continuous Monitoring Stations (Green Circles), and D-1641 Compliance EC Stations (Orange Triangles)

Table 3. Additional Continuous EC Monitoring Stations in Old River and Paradise Cut, Including Station Code, Equipment, Source Description, Source Type, Site Access, Channel Bank Orientation, and GPS Coordinates in WGS84

#	Station Name	Station Code	Equipment	Source Description	Source Type	Site Access	Bank	Latitude	Longitude
1	South Old River 7	SOR7	Onset HOBO Conductivity/ Temperature Logger	Subsurface Treated Sewage Wastewater (City of Tracy) Outfall	Urban	Boat	S	37.8050	-121.4010
2	South Old River 16	SOR16	Onset HOBO Conductivity/ Temperature Logger	Tracy Blvd. Bridge Drain	Agricultural and Groundwater Effluence	Boat	S	37.8020	-121.4428
3	South Old River 17	SOR17	Onset HOBO Conductivity/ Temperature Logger	Pipeline 14 (concealed)	Agricultural	Boat	N	37.8043	-121.4506
4	South Old River 20	SOR20	Onset HOBO Conductivity/ Temperature Logger	Lammers Rd. Drain	Urban Runoff	Boat	S	37.7863	-121.4772
5	South Old River 24	SOR24	Onset HOBO Conductivity/ Temperature Logger	Bethany Rd. Drain	Agricultural/ Groundwater Effluence	Boat	S	37.7853	-121.5046
6	South Old River 28	SOR28	Onset HOBO Conductivity/ Temperature Logger	Wicklund Cut near mouth at Old River	Agricultural, Urban Runoff, Groundwater	Boat	S	37.7897	-121.5162

#	Station Name	Station Code	Equipment	Source Description	Source Type	Site Access	Bank	Latitude	Longitude
7	South Old River 31	SOR31	Onset HOBO Conductivity/ Temperature Logger	Mountain House Creek	Urban Runoff, Groundwater, Grazing Runoff	Boat	S	37.7969	-121.5256
8	Wicklund Cut 1	WC1	Onset HOBO Conductivity/ Temperature Logger	Wicklund Cut Upstream	Agricultural, Urban Runoff, Groundwater	Land	E	37.7801	-121.5172
9	Paradise Cut and Old River Confluence Upstream	POCFLU	YSI 600 Sonde	Paradise Cut and Old River Confluence Upstream	Agricultural, Urban Runoff, Groundwater	Boat	S	37.8080	-121.4155
10	Paradise Cut and Old River Confluence Downstream	POCFLD	YSI 600 Sonde	Paradise Cut and Old River Confluence Downstream	Agricultural, Urban Runoff, Groundwater	Boat	S	37.8032	-121.4206
11	Paradise Cut Water Level 1	PDCWL1	Onset HOBO Conductivity/ Temperature Logger	Upper Paradise Cut North Channel at Paradise Rd. Bridge	Agricultural	Land/ Boat	N	37.801104	-121.367799
12	Paradise Cut Water Level 2	PDCWL2	Onset HOBO Conductivity/ Temperature Logger	Upper Paradise Cut South Channel Below Dairy Farm	Agricultural	Land/ Boat	S	37.790078	-121.354106

#	Station Name	Station Code	Equipment	Source Description	Source Type	Site Access	Bank	Latitude	Longitude
13	Paradise Cut Water Level 3	PDCWL3	Onset HOBO Conductivity/ Temperature Logger	Upper Paradise Cut North Channel Above Agricultural Crossing	Agricultural	Land/ Boat	N	37.790958	-121.34953
14	Paradise Cut Water Level 4	PDCWL4	Onset HOBO Conductivity/ Temperature Logger	Upper Paradise Cut at Railroad Bridge Crossing	Agricultural	Land/ Boat	S	37.776211	-121.335004

Table 4. Existing DWR Monitoring Sites for the Point and Non-Point Source Study, Including Site Codes, Site Description, Data Parameters, Site Access, and GPS Coordinates in WGS84

Site Name	Site Code	Description	Data Parameters	Ion Sample Collection	Site Access	Latitude	Longitude
Paradise Cut Upstream	PDUP	Site affixed to pump platform on southern bank of Paradise Cut	EC, Temperature	Yes	Land	37.801027	-121.373089
Paradise Cut	PDC	Site affixed to steel piling near southern bank of Paradise Cut	EC, Temperature, Stage, Flow, Velocity	Yes	Boat	37.8020598	-121.4122564
Paradise Cut Above Old River	PCO	Site located on southern levee side of Paradise Cut	EC, Temperature	No	Land	37.8020598	-121.4122564
Sugar Cut at Golden Anchor	SGA	Site affixed to steel piling near southern bank of Sugar Cut near Golden Anchor Boat Club	EC, Temperature, Stage, Flow, Velocity	Yes	Boat	37.79286	-121.421495
Sugar Cut	SUR	Site located on northern levee side of Sugar Cut	EC, Temperature	No	Land	37.788333	-121.419167

Site Name	Site Code	Description	Data Parameters	Ion Sample Collection	Site Access	Latitude	Longitude
Tom Paine Slough above Intake Structure	TPI	Site located on southern levee side of Tom Paine Slough near the Sugar Cut Intake structure	EC, Temperature, Stage	Yes	Land	37.790088	-121.41845
Tom Paine Slough Above the Mouth	TPS	Site affixed to pump platform near the Tom Paine Intake in Sugar Cut	Stage	No	Land	37.790535	-121.418633
Tom Paine at Paradise Avenue Bridge	TPPA	Site affixed to Paradise Avenue Bridge	EC, Temperature	Yes	Land	37.773957	-121.382305
Tom Paine Slough near Pescadero	TPP	Site affixed to pump platform on northern bank of Tom Paine Slough	EC, Temperature, Stage	Yes	Land	37.767284	-121.351028
Drainage at Arbor Road	DAR	Site located on southern bank of upper Sugar Cut near the Arbor Road Bridge	EC, Temperature, Stage, Flow	Yes	Land	37.768889	-121.419444
West Canal at Clifton Court Intake	WCI	Site affixed to steel piling near western bank of Old River	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	Yes	Boat	37.8316	-121.554
Doughty Cut Above Grant Line Canal	DGL	Site located and affixed to western bank of Doughty Cut	EC, Temperature, Stage	No	Land	37.815000	-121.425000

Site Name	Site Code	Description	Data Parameters	Ion Sample Collection	Site Access	Latitude	Longitude
Grant Line Canal East	GLE	Site affixed to steel piling near northern bank of Grant Line Canal	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	Yes	Boat	37.82025	-121.434861
Grant Line Canal near Clifton Court Forebay	GLC	Site affixed to steel piling near northern bank of Grant Line Canal	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	No	Boat	37.820128	-121.544661
Old River at Head	OH1	Site affixed to pump platform on southern bank of Old River	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	Yes	Boat	37.807552	-121.331253
Old River at TWA	TWA	Site affixed to floating dock on northern bank of Old River at Tracy Wildlife Area	EC, Temperature, chlorophyll, pH, DO, Turbidity	Yes	Land	37.802833	-121.457444
Old River near Tracy	OLD	Site located on northern levee side of Old River near the Tracy Road Bridge	EC, Temperature, Stage, Flow, Velocity	No	Land	37.80481	-121.44956
Old River above Doughty Cut	ORX	Site affixed to steel piling near northern bank of Old River above Doughty Cut	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	Yes	Boat	37.8109972	-121.386575

Site Name	Site Code	Description	Data Parameters	Ion Sample Collection	Site Access	Latitude	Longitude
Old River below DMC	ODM	Site affixed to steel piling near northern bank of lower Old River	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	No	Boat	37.810972	-121.544417
Old River above Mountain House	ORM	Site affixed to steel piling near northern bank of lower Old River	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	No	Boat	37.7938408	-121.5173813
Middle River near Tracy Blvd	MRX	Site affixed to pump platform on southern bank of Middle River	EC, Temperature, chlorophyll, pH, DO, Turbidity	No	Land	37.881425	-121.467399
Middle River at Howard Road	MHO	Site affixed to pump platform on southern bank of Middle River	EC, Temperature, chlorophyll, pH, DO, Turbidity	No	Land	37.876184	-121.383288
Middle River at Undine Road	MRU	Site affixed to pump platform on southern bank of Middle River	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	No	Land	37.8339408	-121.3857561
Union Island	UNI	N/A	EC, Temperature	No	Land	37.822101	-121.37499
San Joaquin River at Brandt Bridge	BDT	Site affixed to pump platform on northeastern bank of San Joaquin River	EC, Temperature, Stage, Flow, Velocity	No	Land	37.864722	-121.323056

Site Name	Site Code	Description	Data Parameters	Ion Sample Collection	Site Access	Latitude	Longitude
Vernalis	VER	N/A	EC and Temperature Collected at VNS Stage, Flow, Velocity	Yes	Land	37.679376	-121.265002
San Joaquin River at Mossdale Bridge	MSD	Site affixed to bridge piling	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	No	Land	37.786	-121.306
San Joaquin River above Dos Reis Park	SJD	Site affixed to steel piling near northern bank of San Joaquin River	EC, Temperature, Stage, Flow, Velocity	No	Boat	37.8223312	-121.3177244

Ion Sampling

Salinity is the cumulation of dissolved salts, or ions, and can be measured using the EC of water. The fraction that a particular ion contributes to the overall salinity of a sample is the measured ion's concentration divided by the TDS of the sample. *TDS* is the combined total of all organic and inorganic substances dissolved in a water sample (APHA 2012). The relative fractions of all the measured ions to TDS is called the *ion fingerprint*. As of 2018, there were 12 DWR sites with existing ion sampling to help support the monitoring and evaluation of differing ion relationships between the interior southern Delta channels and Pescadero Tract irrigation source water and return (Table 4; Figure 22). The 12 existing DWR sites represent all primary connecting channels in the interior southern Delta study area upstream and downstream of Pescadero Tract. Grab samples are collected monthly for ion analysis at 1-meter depths, using a Van Dorn sampler during routine station maintenance visits at these 12 interior southern Delta stations (Figure 22; Table 4). The grab samples would be filtered using a 0.45-micron cellulose membrane filter, and then analyzed by DWR Bryte Laboratory to determine a suite of 13 parameters according to the established methods referenced in Table 5. New sample collection sites will be established as part of the Pescadero Tract circulation investigations to better determine the ion relationships between water in surrounding channels and water being applied and returned to those channels from Pescadero Tract. In addition, targeted ion samples will be collected during high-speed EC boat transect runs to target specific high salinity discharges, which could help determine the origin of higher salinity sources and where differing regional interactions with ground or surface waters may be contributing to unique ion fingerprints.

Table 5. Ion Sample Analytes, Including Analysis Methods, Reporting Limit, and Units

Parameter	**Abbreviation**	**Method Reference**	**Reporting Limit**	**Units**
Specific Conductance	SpCond	Std Method 2510-B	1	µS/cm@25°C
Total Dissolved Solids	TDS	Std Method 2540 C	1	mg/L
Dissolved Chloride	Cl	EPA 300.0 28d Hold	10	mg/L
Dissolved Sulfate	SO4	EPA 300.0 28d Hold	10	mg/L
Dissolved Sodium	Na	EPA 200.7 (D)	1	mg/L
Dissolved Calcium	Ca	EPA 200.7 (D)	1	mg/L
Dissolved Magnesium	Mg	EPA 200.7 (D)	1	mg/L
Dissolved Nitrate	NO3	EPA 300.0 28d Hold	0.1	mg/L
Dissolved Potassium	K	EPA 200.7 (D)	0.5	mg/L
Dissolved Bromide	Br	EPA 300.0 28d Hold	0.05	mg/L
Dissolved Boron	B	EPA 200.7 (D)	0.1	mg/L
Alkalinity	Alkalinity	Std Method 2320 B	1	mg/L as $CaCO_3$
Dissolved Hardness	Hardness	Std Method 2340 B (D)	1	mg/L as CaCO3

Paradise Cut Salinity Tidal Dispersion

To investigate salinity dispersion out of Paradise Cut into surrounding channels, high-speed EC transect mapping will be performed utilizing a boat outfitted with a water intake system to collect continuous EC measurements while traveling through a predetermined channel reach. Environmental water is pulled directly from the water body and pushed through a flow cell at a steady rate of 2 gallons per minute. The flow cell houses a YSI EXO2 Sonde with a temperature/ conductivity sensor that collects a measurement every second, and the water-intake system will also be used to acquire filtered discrete samples for the collection of ion samples.

The transect will focus on the 5-Points Confluence (Figure 23), which is the confluence region of Paradise Cut, Sugar Cut, Old River, and Grant Line Canal. The transect will begin in Old River, approximately 2,000 feet upstream of the confluence with Doughty Cut. Crews will travel downstream into Doughty Cut until they reach the monitoring station Doughty Cut above Grant Line Canal (DGL), and then head back upstream through the 5-Point Confluence and into Paradise Cut. The crew will aim to travel upstream to PDUP. The distance traveled upstream in Paradise Cut will be dependent on presence of vegetation and water levels. The crew would travel back down Paradise Cut, through the confluence, and into Lower Old River until Bachelli Dairy Cattle Bridge, or as far downstream as possible before floating vegetation blocks the path. Crews would then head back to the 5-Points Confluence and into Sugar Cut, traveling as far down Sugar Cut as possible. This transect will concentrate on varied tidal cycles, with a focus on capturing the low-low tides when the highest volume of water is tidally pumped from Paradise Cut into Old River.

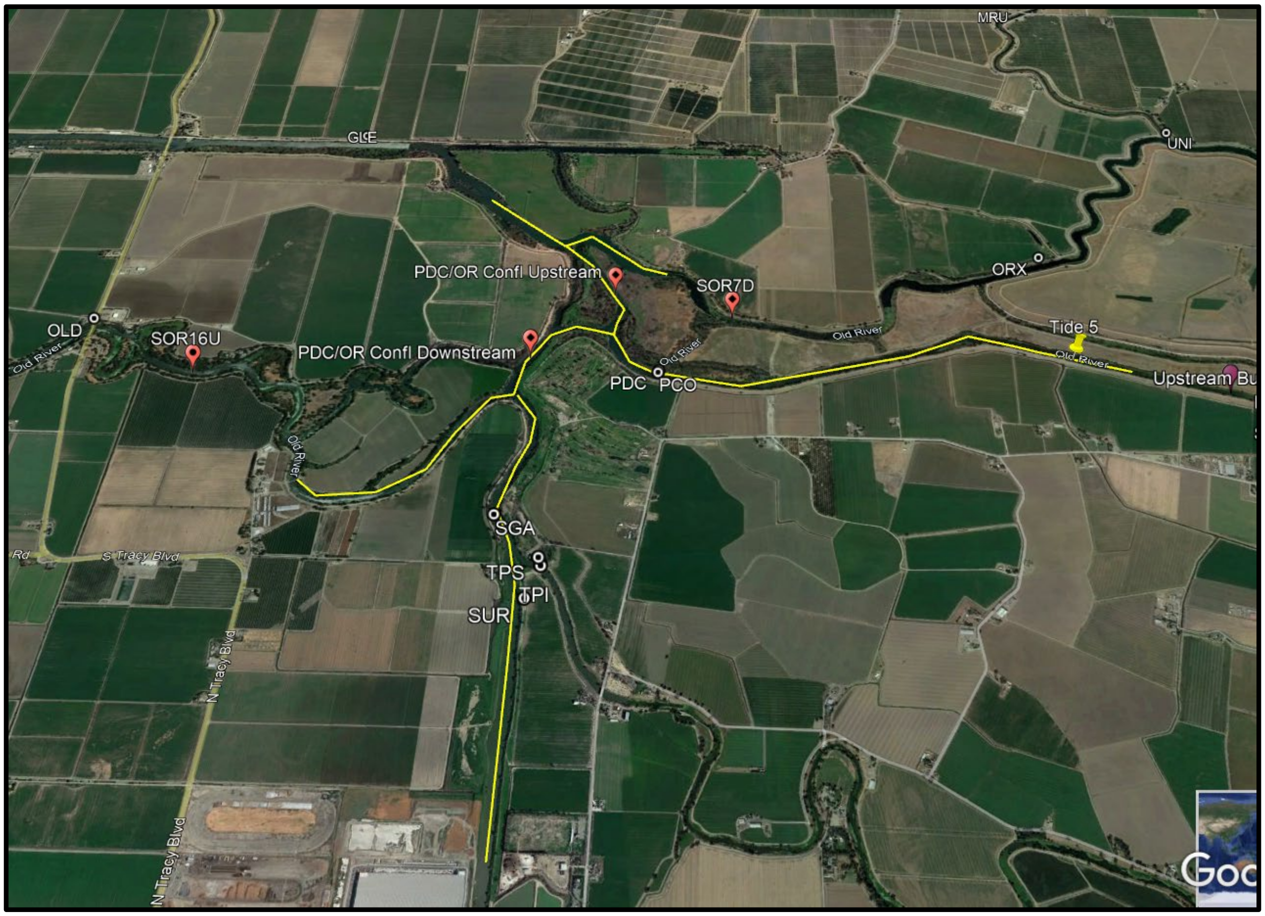

Figure 23. High-Speed EC Transect Mapping Channel Reach Area for Salinity Tidal Dispersion from Paradise Cut

Rhodamine Dye Tracer Monitoring

To facilitate measurement of the mean transport and dispersion rates of water in upper Paradise Cut, rhodamine dye-tracer studies will occur multiple times over the study years of 2022–2023. Currently, existing flow and velocity monitoring occurs only at the PDC site near the lower end of Paradise Cut (Figure 24; Table 6), but model results and data from this station do not agree. This is primarily attributed to the limitations in the PDC site's ability to measure flows below 50 cubic feet per second. However, these flows could be significant in Paradise Cut net-flow direction seasonally.

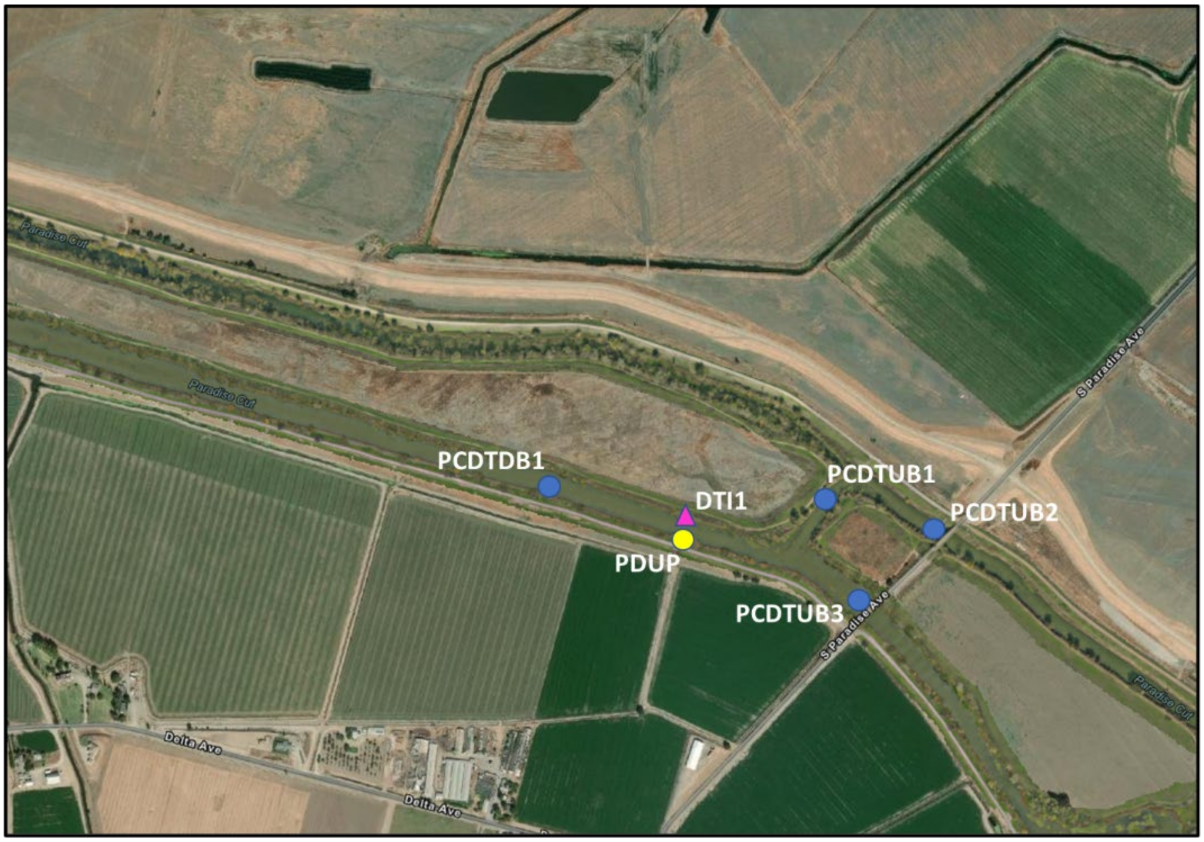

Figure 24. Map of Continuous Rhodamine Dye Monitoring Sites, Dye Tracer Injection Site, and Existing Continuous Water Quality Monitoring Site PDUP Located in Paradise Cut that Provide Supporting Data for the Pescadero Tract Circulation Study; Sites Denoted by Blue Circles will Be Temporary Buoy Monitoring Sites, Yellow Circle Denotes the PDUP Site, and Pink Triangle the Dye Injection Site

The dye-tracer studies will concentrate on capturing various hydrologic conditions, with a primary focus on two periods: in winter after the soil is moist (December–February), with no Paradise Weir flow, and in summer, during the peak agricultural return and diversion period (June–August). Another potential study period will be in the case of a Paradise Weir overtop event, both during a natural flushing event and the recovery period after the flushing.

The study will be executed by the release of rhodamine dye, which can fluoresce. Concentrations will be measured using fluorometer sensors. Rhodamine dye is commonly used in tracer studies for determining rate and direction of flow (KilPatrick and Cobb 1984; Long et al. 2011). To measure the dispersal of rhodamine dye in Paradise Cut, YSI EXO2 Sondes will be deployed with EXO Rhodamine Sensors (https://www.ysi.com/exo/rhodamine), which have a minimum detection limit of 0.01 micrograms per liter (µg/L) and a measurement range of 0–1,000 µg/L (Figure 24). The YSI EXO2 Sondes with rhodamine sensors will be deployed at the existing PDUP site and at temporary mid-channel buoys at sites shown on Figure 24 and in Table 6. In addition to the stationary rhodamine sensors, active monitoring of rhodamine dye dispersal will be tracked by boat using an onboard water intake, EXO Rhodamine Sensor, and paired geographic positioning system (GPS) mapping system to develop complete transect maps of rhodamine concentrations throughout the Paradise Cut channel. The dye will be injected by boat, adjacent to the PDUP site (Figure 24), and distributed across the center two-thirds of the Paradise Cut channel. The dye-injection timing will target a period midway between a spring and neap tide, be released on the mid to end of an outgoing or ebb tide, and monitored over two tidal cycles. This study may be extended to Sugar Cut during the study period to better understand the same physical processes.

Figure 25. Map of Continuous Water Level Monitoring Sites in Paradise Cut that Provide Supporting Data for the Pescadero Tract Circulation Study; Sites Denoted by Blue Circles

To improve the model predictions and overall understanding of tidal dissipation in the upper reaches of Paradise Cut, DWR will deploy a series of five Onset HOBO Water Level Loggers (Model U20-001-01) at those locations shown in Table 6 and on Figure 25. Water-level/stage monitoring currently occurs at PDC, but this site is closer to the confluence of Paradise Cut and Old River (Figure 22; Table 5). Additional water-level monitoring is necessary because channel bathymetry, gradient, and vegetation coverage changes as one moves into the upper reaches of the channel. These inherent changes in the channel affect the tidal variation and, in some cases, dampen the tidal change, which is difficult to model without field measurements for improved calibration. These data are essential in determining the potential tidal exchange of upper Paradise Cut higher-salinity water tidally and seasonally with those downstream water sources.

Pescadero Tract Circulation Investigations

The EC will be monitored and evaluated as a surrogate for salinity for the Pescadero Tract Circulation Study at those sites listed in Table 6 and Table 7. Data collected at existing DWR monitoring stations in Table 7 and on Figure 22 use YSI EXO2 or EXO1 Multiparameter Water Quality Sondes, which collect monitoring data at continuous 15-minute intervals and are typically checked for sensor error and recalibrated every month. New temporary sites for the Pescadero Tract Circulation Study will utilize a combination of YSI 600OMS V2 Multiparameter Sondes and Onset HOBO Conductivity Loggers, which provide the advantages of being much smaller than the YSI EXO counterparts, providing more flexibility in installation location and depth. The YSI 600OMS V2 Optical Monitoring Sonde utilizes the same sensor technology and therefore has the same range and precision as the YSI EXO Conductivity and Temperature Sensor. These new temporary sites will collect data at continuous 15-minute intervals and will have the same monthly maintenance schedule to ensure data accuracy.

Table 6. Sampling Sites for the Pescadero Tract Circulation Study by Field Study, Including Site Codes, Site Access (Land or Boat), and Geocoordinates; Note that Site Geocoordinates for Dye Tracer Studies and Water Level Monitoring may Change over the Study Period

Field Study	Site Name	Site Code	Description	Site Access	Latitude	Longitude
Continuous EC Monitoring and Ion Sampling	Paradise Cut Drainage Pump #1	PDCD1	Pescadero Tract Drain	Land	37.801547	-121.410869
	Paradise Cut Drainage Pump #2	PDCD2	Pescadero Tract Drain	Land	37.802118	-121.401884
	Paradise Cut Drainage Pump #3	PDCD3	Pescadero Tract Drain	Land	37.803659	-121.386341
	Paradise Cut Drainage Pump #4	PDCD4	Pescadero Tract Drain	Land	37.79633	-121.366448
	Tom Paine Slough at Paradise Avenue Bridge	TPPA	Tom Paine Irrigation Channel	Land	37.774148	-121.382273
	Tom Paine Slough near Pescadero	TPP	Tom Paine Irrigation Channel	Land	37.76728	-121.35103
Water Level Monitoring	Paradise Cut Water Level 1	PDCWL1	Upper Paradise Cut North Channel at Paradise Rd. Bridge	Land/Boat	37.801104	-121.367799
	Paradise Cut Water Level 2	PDCWL2	Upper Paradise Cut South Channel Below Dairy Farm	Land/Boat	37.790078	-121.354106
	Paradise Cut Water Level 3	PDCWL3	Upper Paradise Cut North Channel Above Agricultural Crossing	Land/Boat	37.790958	-121.34953
	Paradise Cut Water Level 4	PDCWL4	Upper Paradise Cut at Railroad Bridge Crossing	Land/Boat	37.776211	-121.335004
	Paradise Cut Water Level 5	PDCWL5	Paradise Cut Downstream of PDUP	Land/Boat	37.803975	-121.385706

Field Study	Site Name	Site Code	Description	Site Access	Latitude	Longitude
Dye Tracer Studies	Paradise Cut Dye Tracer Injection Site 1	DTI1	Paradise Cut Mid-Channel adjacent to station PDUP	Boat	37.801482	-121.373071
	Paradise Cut Dye Tracer Downstream Buoy 1	PCDTDB1	Paradise Cut Mid-Channel Downstream of PDUP	Boat	37.801906	-121.376221
	Paradise Cut Dye Tracer Upstream Buoy 1	PCDTUB1	Paradise Cut Mid-Channel in Cross Channel between North and South Channels	Boat	37.801527	-121.370097
	Paradise Cut Dye Tracer Upstream Buoy 2	PCDTUB2	Paradise Cut North Channel Paradise Rd. Bridge	Land/Boat	37.801039	-121.367506
	Paradise Cut Dye Tracer Upstream Buoy 3	PCDTUB3	Paradise Cut South Channel Paradise Rd. Bridge	Land/Boat	37.799851	-121.369144

Table 7. Existing DWR Monitoring Sites that Provide Supporting Data for the Pescadero Tract Circulation Study, Including Site Codes, Site Description, Data Parameters, Site Access (Land or Boat), and Geocoordinates

Site Name	Site Code	Description	Data Parameters	Ion Sample Collection	Site Access	Latitude	Longitude
Paradise Cut Upstream	PDUP	Site affixed to pump platform on south bank of Paradise Cut	EC, Temperature	Yes	Land	37.801027	-121.373089

Site Name	**Site Code**	**Description**	**Data Parameters**	**Ion Sample Collection**	**Site Access**	**Latitude**	**Longitude**
Paradise Cut	PDC	Site affixed to steel piling near south bank of Paradise Cut	EC, Temperature, Stage, Flow, Velocity	Yes	Boat	37.8020598	-121.4122564
Paradise Cut Above Old River	PCO	Site located on south levee side of Paradise Cut	EC, Temperature	No	Land	37.8020598	-121.4122564
Sugar Cut at Golden Anchor	SGA	Site affixed to steel piling near south bank of Sugar Cut near Golden Anchor Boat Club	EC, Temperature, Stage, Flow, Velocity	Yes	Boat	37.79286	-121.421495
Sugar Cut	SUR	Site located on north levee side of Sugar Cut	EC, Temperature	No	Land	37.788333	-121.419167
Tom Paine Slough above Intake Structure	TPI	Site located on south levee side of Tom Paine Slough near the Sugar Cut Intake structure	EC, Temperature, Stage	Yes	Land	37.790088	-121.41845
Tom Paine Slough Above the Mouth	TPS	Site affixed to pump platform near the Tom Paine Intake in Sugar Cut	Stage	No	Land	37.790535	-121.418633

Site Name	Site Code	Description	Data Parameters	Ion Sample Collection	Site Access	Latitude	Longitude
Tom Paine at Paradise Avenue Bridge	TPPA	Site affixed to Paradise Avenue Bridge	EC, Temperature	Yes	Land	37.773957	-121.382305
Tom Paine Slough near Pescadero	TPP	Site affixed to pump platform on north bank of Tom Paine Slough	EC, Temperature, Stage	Yes	Land	37.767284	-121.351028
Drainage at Arbor Road	DAR	Site located on south bank of upper Sugar Cut near the Arbor Road Bridge	EC, Temperature, Stage, Flow	Yes	Land	37.768889	-121.419444
West Canal at Clifton Court Intake	WCI	Site affixed to steel piling near west bank of Old River	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	Yes	Boat	37.8316	-121.554
Grant Line Canal East	GLE	Site affixed to steel piling near north bank of Grant Line Canal	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	Yes	Boat	37.82025	-121.434861
Old River at Head	OH1	Site affixed to pump platform on south bank of Old River	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	Yes	Boat	37.807552	-121.331253

Site Name	Site Code	Description	Data Parameters	Ion Sample Collection	Site Access	Latitude	Longitude
Old River at TWA	TWA	Site affixed to floating dock on north bank of Old River at Tracy Wildlife Area	EC, Temperature, chlorophyll, pH, DO, Turbidity	Yes	Land	37.802833	-121.457444
Old River near Tracy	OLD	Site located on north levee side of Old River near the Tracy Road Bridge	EC, Temperature, Stage, Flow, Velocity	No	Land	37.80481	-121.44956
Old River above Doughty Cut	ORX	Site affixed to steel piling near north bank of Old River above Doughty Cut	EC, Temperature, chlorophyll, pH, DO, Turbidity, Stage, Flow, Velocity	Yes	Boat	37.8109972	-121.386575
Vernalis	VER	N/A	EC and Temperature Collected at VNS Stage, Flow, Velocity	Yes	Land	37.679376	-121.265002

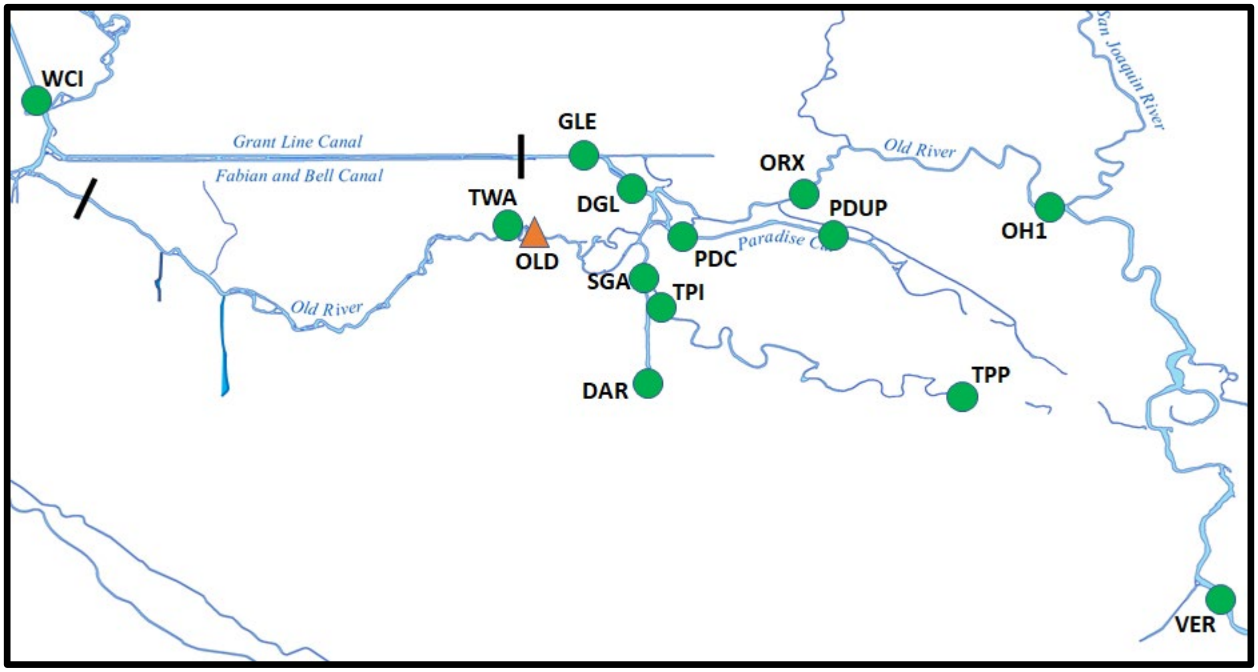

Figure 26. Map of Existing Continuous Monitoring Sites that Provide Supporting Data for the Pescadero Tract Circulation Study; Site Denoted by Orange Triangle Is D-1641 Compliance Station Old River Near Tracy (OLD), and other Sites Denoted by Green Circles Are Supporting Interior Southern Delta Monitoring Stations

Seven DWR sites have existing (as of 2018) ion sampling to help support the monitoring and evaluation of differing ion relationships between the interior southern Delta channels and Pescadero Tract irrigation source water and return (Figure 26; Table 7). The seven existing DWR sites represent all the upstream and downstream channel connections to the Doughty Cut region, where Paradise Cut and Sugar Cut connect, the primary pathways for surface waters both in and out of Pescadero Tract. Grab samples are collected monthly for ion analysis at 1-meter depths using a Van Dorn Water Sampler during routine station maintenance visits at these seven interior southern Delta stations (Figure 26; Table 7). The grab samples are filtered using a 0.45-micron cellulose membrane filter, and then sent to DWR's Bryte Laboratory to test for 13 analytes, according to the established methods referenced in Table 4.

New sample-collection sites will be established as part of the Pescadero Tract circulation investigations to better determine the ion relationships between water in surrounding channels and water being applied and returned to those channels from Pescadero Tract, which can help determine the origin of higher salinity sources and where differing regional interactions with either ground or surface waters may be contributing to unique ion fingerprints. This will include the added monthly collection of grab samples for ion analysis at sites DAR, TPI, TPPA, TPP, Paradise Cut Drainage Pump 1 (PDCD1), and Paradise Cut Drainage Pump 3 (PDCD3) (Figure 19; Table 6). These sampling sites will follow the same collection, filtering, and DWR Bryte Laboratory–analysis methods as existing monitoring sites (Table 4).

Data Analysis

Drone Imagery Mapping

Drone images will be stitched together into photomosaic images of each waterway. These extended photomosaics will be approximately centered along the channel, including adjacent levees, and extend outward (i.e., landward) from the channel to approximately 100 feet in from the channel center. The completed photomosaics will be uploaded to DWR's Atlas server and include the following.

1) Paradise Cut will be flown in one segment at a 250-foot altitude, have an approximate GSD of 1.79 centimeters/pixel, and the channel length traveled will be 11.48 miles.
2) Sugar Cut will be flown in one segment at 300 feet, have an approximate GSD of 2.15 centimeters/pixel, and the channel length traveled will be 2.03 miles.
3) Old River will be flown in one segment at 300 feet, have an approximate GSD of 2.15 centimeters/pixel, and the channel length traveled will be 3.81 miles.
4) Tom Paine Slough will be flown in one segment at 200 feet, have an approximate GSD of 1.43 centimeters/pixel, and the channel length traveled will be 7.11 miles.

The individual high-resolution photos will be archived for later use, on request; however they will be stored separately on a special, private DWR server due to their significant file size. The photomosaic products also will be available via the DWR Atlas server, which is publicly accessible at: https://parcgis.water.ca.gov/arcgisimg/rest/services/Aerial_Photography. Project managers will be provided with these will high-resolution images for visual analysis, reporting, and deliverables for other technical studies within the MSS.

Continuous Time Series EC Data

The continuous time-series EC data collected as part of the Point Source and Ion Sampling Study will be analyzed graphically and compared to the existing monitoring network to determine temporal variations and linkages in EC trends spatially. Analysis (e.g., analysis of variance (ANOVA), pairwise comparisons) may be used to determine relationships between regions, seasons, and years. The visual analysis will include incorporating existing network stage and flow monitoring data to evaluate how changes in hydrology may be contributing to patterns in EC time-series data. This EC data will also be used to corroborate data from the concurrent High-Speed EC Transect MSS Technical Study. This data will also be used for MSS technical studies to improve SCHISM model predictions and incorporated in the Data Assimilation process.

Ion Sampling

The ion sampling data from this effort will be evaluated by using ordination analysis methods, principal components analysis (PCA), and/or Piper diagrams to investigate and compare the ionic composition of interior southern Delta water samples. This will be performed for all site data to determine relationships between regions, months, seasons, and years. The ion data will further be applied to Denton's (2015) equations to compare to known ionic concentrations of seawater, fresh water, and agricultural-dominant water sources of the San Joaquin River. This ion data may also be applied to predictive models, such as the Random Forest prediction system, to improve the accuracy of predicting expected ion constituents (i.e., boron, nitrate) at interior southern Delta stations. This data will also be used for other MSS technical studies to improve SCHISM model predictions and incorporated in the data assimilation process.

Paradise Cut Salinity Tidal Dispersion

This data will be analyzed using ArcGIS Pro software, establishing classifications using the Symbology geoprocessing tool, and setting a range of values to classify differing EC ranges (Figure 23). Data will also be summarized into profile plots by using 3D analysis tools to show time-series EC data changes across river kilometers and network continuous stations (Figures 27, 28, and 29). This data will be assimilated into SCHISM model results to improve predictions of tidal dissipation in the upper and downstream reaches of Paradise Cut. Supplemental ion sample data will be investigated to determine if, along with tidal dispersion of high salinity water from Paradise Cut into Old River, those water sources carry a unique ion fingerprint. This additional data will be layered with baseline ion data and the dispersal salinity patterns to help infer salinity source influences from Paradise Cut into Old River.

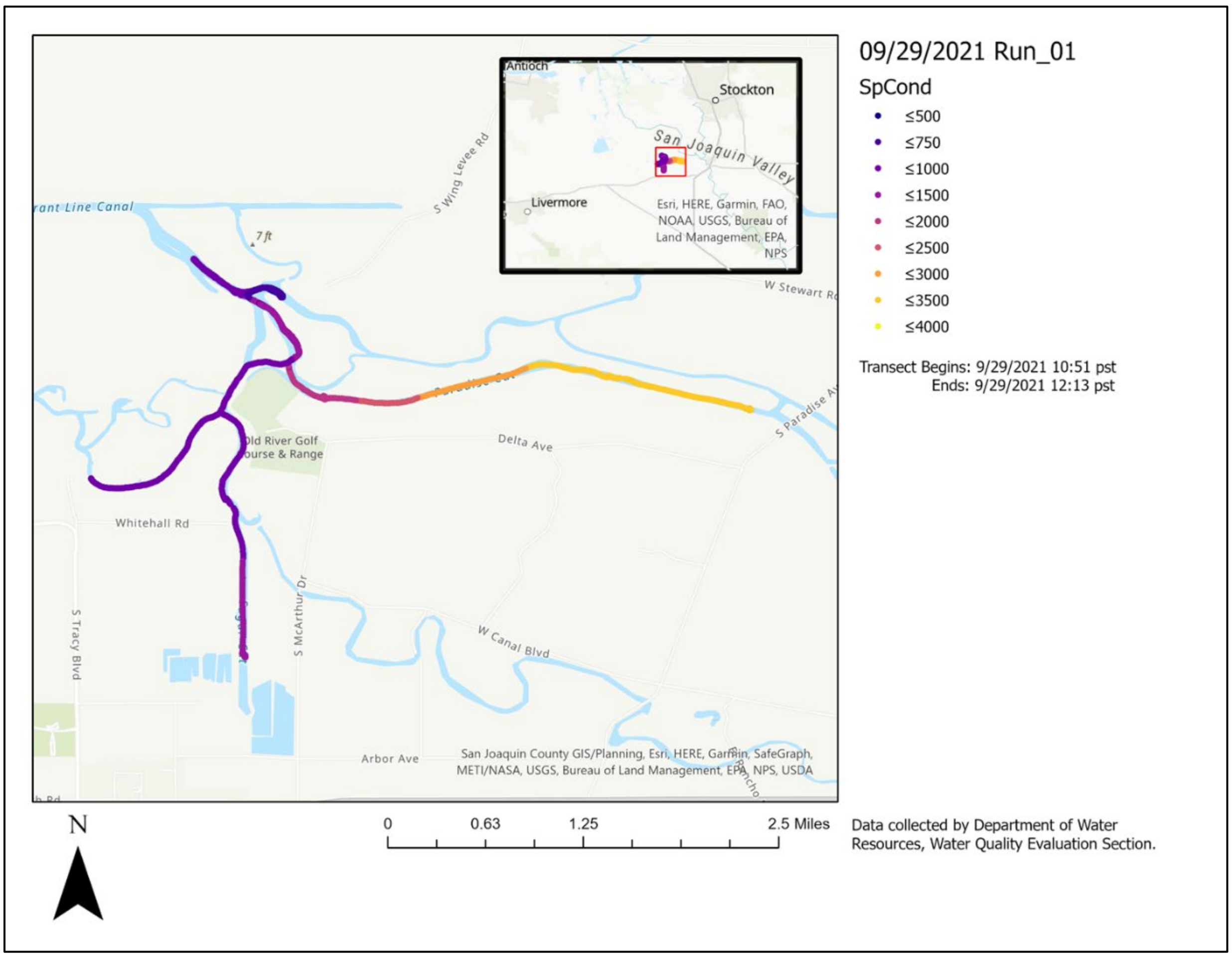

Figure 27. High-Speed EC Transect Mapping Data Analyzed in ArcGIS Pro Using Symbology Graduated-Colors Classification

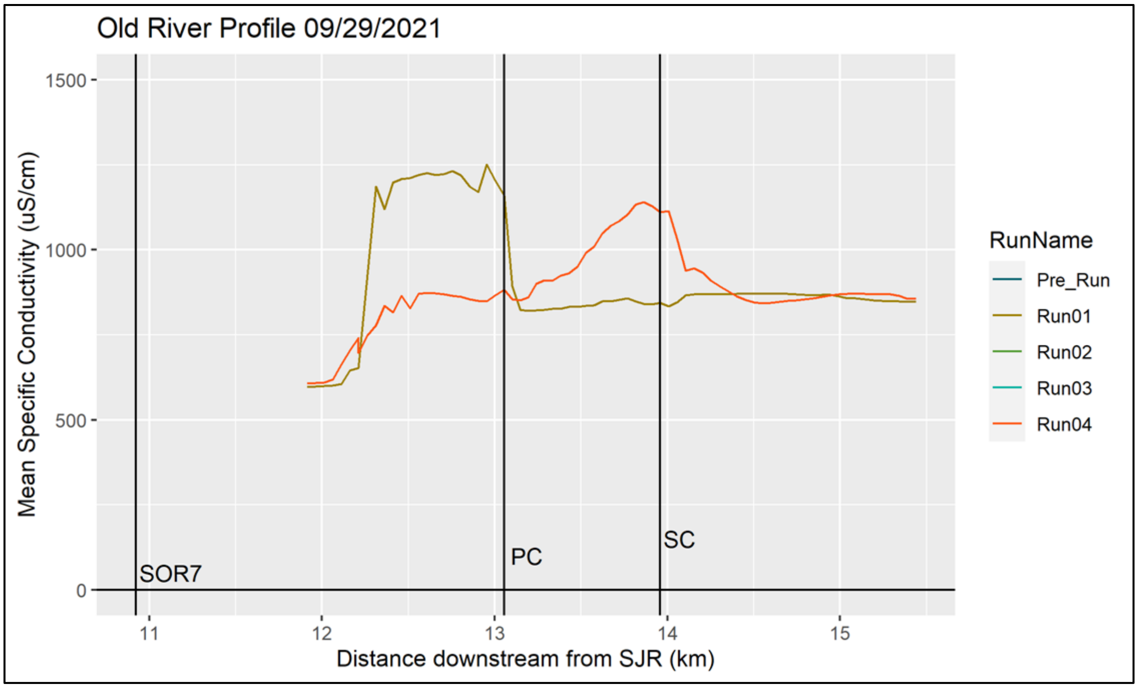

Figure 28. Old River High-Speed EC Transect Profile Time Series Graph by River Kilometer on September 29, 2021

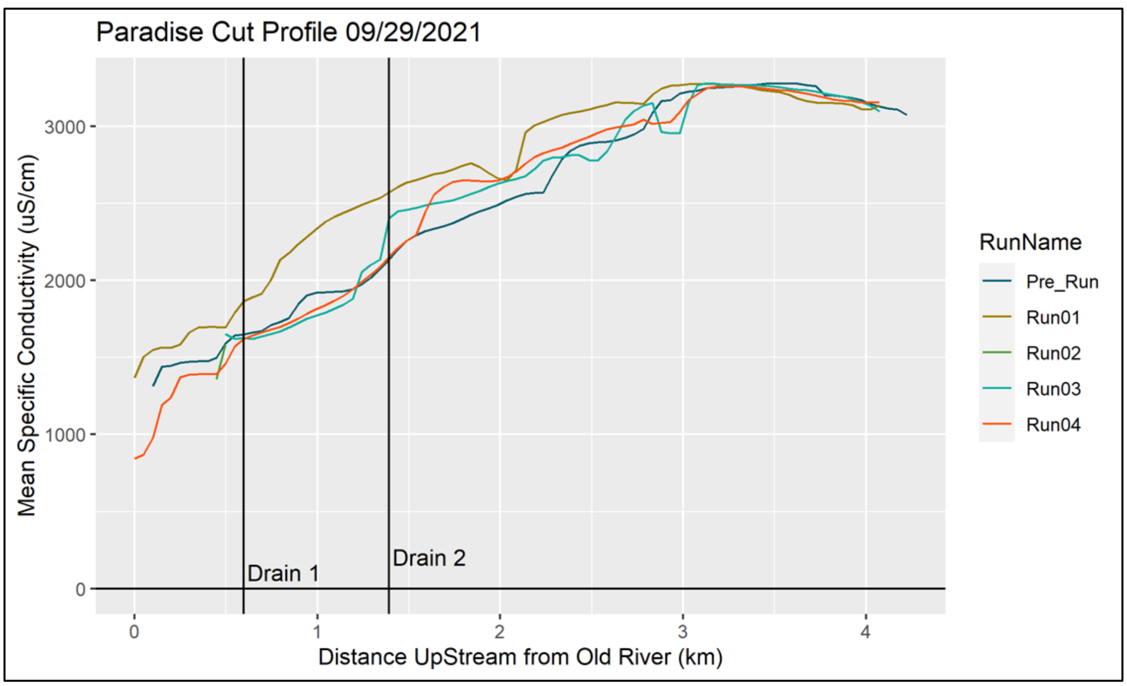

Figure 29. Paradise Cut High-Speed EC Transect Profile Time-Series Graph by River Kilometer on September 29, 2021

Rhodamine Dye Tracer Monitoring

The measured dye concentrations from the various locations will be compiled and analyzed graphically to see how the dye moves and dissipates in Paradise Cut over space and time under varied tidal phases. Results from the dye study can be used to inform and improve SCHISM model results for tidal flow and net flow in the upper portions of Paradise Cut. The continuous time-series water level data within the upper reaches of Paradise Cut will be evaluated graphically and compared to existing monitoring station data at PDC. Both dye concentration measurements and water level data will be assimilated into the SCHISM model to improve tidal dissipation characteristics in the upper reaches of Paradise Cut and improve the model's determination of net flow direction.

Paradise Cut Circulation Investigations

The continuous time-series EC data collected as part of the Pescadero Tract Circulation Study will be analyzed graphically and compared to the existing monitoring network to determine temporal variations and linkages in EC trends spatially. Analysis such as ANOVA and pairwise comparisons may be used to determine relationships between regions, seasons, and years. The visual analysis will include incorporating existing network stage and flow monitoring data to evaluate how changes in hydrology may be contributing to patterns in EC time-series data. This EC data will also be used to corroborate ongoing high-speed EC transect data that will be collected during the same time period under a separate MSS technical study (described in MSS Plan Attachment 1, *High-Speed EC Mapping Transect Work Plan*). The ion sampling data from this effort will be evaluated by using ordination analysis methods, Principal Components Analysis (PCA) and/or Piper diagrams to investigate and compare with the ionic composition of other interior southern Delta water samples. This will be performed for all site data to determine relationships between regions, months, seasons, and years. All data will also be used for other MSS technical studies to improve SCHISM model predictions and incorporated in the data assimilation process.

Deliverables

The Point Source and Ion Sampling Study began the planning stages during WY 2021, and monitoring tasks will take place over WYs 2022 and 2023, with final reporting occurring in WY 2024. The planning efforts include monthly coordination meetings, periodic participating organization meetings, and fact-sheet development.

Timeline of Activities and Deliverables

The anticipated timeline of activities (Table 8) for the Point Source and Ion Sampling Study includes ongoing monthly MSS coordination meetings, as well as quarterly MSS technical workgroup and participating organization meetings, initiated in 2021. Fact-sheet development will occur in October of each year to update planned tasks associated with the study and provide an outline to participating organizations. Deliverables will include data packages of quality assurance/quality control (QA/QC-ed) data for model assimilation, analysis, and reporting. Drone imagery will be collected three times over 2021–2022, with imagery collection in fall, winter, and summer. Monitoring for continuous EC measurements, monthly ion water sample collection, and high-speed EC boat transect mapping will start in November/December 2021 and continue through WY 2023.

Table 8. Timeline of Yearly Activities and Deliverables for the Point Source and Ion Sampling Study and MSS Technical Studies for 2021–2024

Activity	Deliverable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coordination and Planning Meetings	Monthly MSS Coordination Meetings	■	■	■	■	■	■	■	■	■	■	■	■
	MSS Technical Workgroup Meetings	■			■			■			■		
	ParticipatingOrganization Meetings	■			■			■			■		
	Fact Sheets										■		
Deliverables	Data Package for WY22												■
	Data Package for WY23												■
	2024 MSS Report Chapter						■						
Field Monitoring	Drone Imagery		■					■				■	
	Continuous EC Monitoring	■	■	■	■	■	■	■	■	■	■	■	■
	Ion Water Sample Collection	■	■	■	■	■	■	■	■	■	■	■	■
	High-Speed EC Boat Transect Mapping	■	■	■	■	■	■	■	■	■	■	■	■
	Rhodamine Dye Tracer Monitoring				■			■				■	
	Pescadero Tract Circulation Investigations	■	■	■	■	■	■	■	■	■	■	■	■

A variety of deliverables are anticipated to be produced (Table 3). Written and oral reporting will include the following.

1) Data packages for modelers and participating organizations
2) Short summary documents (i.e., fact sheets) that will be generated to communicate results to participating organizations and managers in the spring of every year (e.g., participating-organization meetings)
3) Oral briefings and presentations that will include a short presentation of the study for managers and participating organizations
4) A final summary report in summer of 2024

Funding

Funding for this MSS Technical Study is provided by DWR's Division of Operations and Maintenance, South Delta Branch. Funding supports both labor hours and equipment required for completing monitoring and reporting efforts over the duration of the study, from 2021–2024. Reclamation will also provide labor support through their internal funds to help execute regular monthly sample collection and perform monitoring equipment maintenance over CY 2022–2023.

Sample Collection and Permitting

The monitoring and analysis described in this work plan includes many elements, such as the continuous EC monitoring and discrete ion sampling, that do not require additional permitting. The UAV flights require licensed pilots and submission of a 530 UAV Mission Plan approved by DWR safety officials. In addition, UAV missions will be communicated in advance to local landowners to ensure transparency. The study will utilize Temporary Entry Permits, which are maintained with private landowners, for access to some long-term monitoring sites.

Data Management and Accessibility

All data would be stored on DWR shared drives, cloud-based drives, and external hard drives. All datasheets and databases will be housed in DWR facilities on servers in electronic form; these servers receive daily data back-ups. The time-series EC and water-level data will initially go into the Hydstra database (hyxplore.exe) and, once QA/QC-ed, will be available in the Water Data Library, which has DWR-server backup and cloud-based storage capabilities. Ion water sample data will be archived in the Bryte Laboratory FLIMs database and will be available in the Water Data Library. Water quality, water level, and dye-tracer datasets will be maintained by the DWR's South Delta Branch and made available as excel spreadsheets (i.e., .xls, .xlsx, and .csv); these datasets may also be stored in the DWR cloud-based data repository, DELVE.

Participating Organization Coordination

A key part of this MSS study will be outreach and coordination. As noted above, the primary vehicles for coordination will be the quarterly participating organization coordination meetings and regular technical workgroup meetings (Table 3). These meetings allow key participating organizations to provide input directly to technical leads throughout the duration of the study. Both groups will review this monitoring plan.

The project will also coordinate with existing interior southern Delta monitoring and specific projects that are either already collecting data in the region or have planned studies. Examples include:

- Reclamation EC Compliance Stations
- USGS Flow and Water Quality Monitoring Stations
- USGS Biogeochemistry Water Quality Monitoring
- DWR Division of Integrated Science and Engineering Environmental Monitoring Program Continuous and Discrete Water Quality Monitoring
- DWR Division of Integrated Science and Engineering Municipal Water Quality Water Quality Monitoring
- DWR Division of Operations and Maintenance Water Quality Monitoring

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