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APPENDIX 5A, SECTION F
MODELING TECHNICAL APPENDIX – SEA LEVEL
RISE AND DELTA WATER QUALITY MODELING

5A-F. Appendix 5A, Section F Modeling Technical Appendix – Sea Level Rise and Delta

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Appendix 5A, Section F

Modeling Technical Appendix – Sea Level Rise and Delta Water Quality Modeling

F.1 Introduction

The SCHISM Sea Level Rise Study (Study), described here, investigates how Delta water quality changes under seven sea level rise (SLR) assumptions. The range of sea level rise increments considered span from 1.8 feet (ft) to 10.2 ft.

The objectives of the Study include:

- Assess changes in Delta water quality under a progression of increasingly severe sea level assumptions under the current Sacramento–San Joaquin Bay-Delta (Delta) configuration (geomorphology, facilities, water uses, etc.).
- Identify the vulnerability of the proposed Delta Conveyance Project (project) North Delta Diversion intake locations to salinity intrusion under the most extreme sea level rise scenarios.
- Assess the incremental water cost¹ of meeting current State Water Board regulatory requirements under the increasing sea levels.
- Provide data from detailed three-dimensional (3D) hydrodynamic and water quality modeling to train or calibrate lower-dimension models that can be applied for the 94 years of varying hydrologic conditions that are considered in the project Final Environmental Impact Report (EIR).

Bay-Delta SCHISM (SCHISM), used for this Study, is a three-dimensional model of the Delta and San Francisco Bay that can explicitly simulate estuarine hydrodynamic and salinity transport processes in the Delta. SCHISM is a computationally intense model and was used to generate tidal flows and water quality conditions over a few years in this Study. It is particularly important to simulate transport in 3D for sea level rise studies because many of the mixing mechanisms that cause salinity to increase are due to vertical contrasts in density and velocity, and these processes scale with depth.

F.2 Summary

Three overarching conclusions are supported by the Study and model simulations reported here:

- The vulnerability of the central and western Delta, including the traditional freshwater corridor, to salinity intrusion caused by sea level rise, is potentially severe. However, there remains uncertainty over the degree of salinity intrusion for a specific sea level rise assumption because

¹ Volume of additional Delta outflow needed

many issues that affect model results were not addressed in the Study, e.g., levee failure, changes in water use, continued dredging of the ship channels, changing morphology, island flooding, and potential landscape level defenses.

- Assuming the current State Water Board salinity requirements in the Delta are not modified, the incremental water cost of meeting from the Delta salinity requirements increases non-linearly with sea level rise, with the largest increase in the spring months when historically the Delta is fresher. During April to August, Emmaton agricultural standard is likely to become the controlling objective over a broader range of conditions as sea level increases.
- The project intake locations are not vulnerable to sea level rise from a water quality perspective. SCHISM modeling presented here indicates that the salinity intrusion from the sea level rise will not affect the intake locations. The effects of sea level rise on salinity intrusion do not appear to progress far above the confluence of Sacramento River, Cache Slough, and Steamboat Slough. While it is not a conclusion based on the SCHISM modeling described in here, it is important to note that the intake facilities are designed to accommodate water level elevations corresponding to 10.2 ft sea level rise and 200-year flood flows under climate change conditions projected for the end of the century.

F.3 Modeling Approach

This Study uses two perspectives to describe the consequences of sea level rise that are very different in the view of the Delta salinity conditions they portend: water quality impact and water cost. While neither of the approaches represent what is likely to happen in the future exactly, they provide information on the potential impacts of sea level rise on Delta salinity and provide a glimpse of the potential water supply necessary to continue complying with current Delta salinity regulatory requirements.

F.3.1 Water Quality Impact Approach

In the water quality impact approach (impact approach), Delta inflows, exports, and channel depletions were held at historical levels² and salinity changes modeled as a consequence of sea level rise. In this approach, the goal is to estimate how Delta salinity will change with sea level rise. This approach does not reflect how the SWP and CVP managers may adapt reservoir operations and Delta exports to reduce Delta salinity, assuming current D-1641 salinity requirements would continue. Additionally, the water uses in the Delta and Delta exports remained unchanged from the historical vales even though sea level rise may result in high salinity water in the Delta, e.g., at 4,000 $\mu\text{S}/\text{cm}$, which is unsuitable for agricultural or municipal water purposes.

This approach was also used to assess the vulnerability of the project intakes to the increased salinity intrusion resulting from the sea level rise, and to provide the data needed to train the lower-dimension models to simulate Delta salinity conditions under various sea level rise values.

² Historic conditions represent Delta inflow and exports resulting from the compliance with the D-1641 standards and other upstream and Delta CVP-SWP regulations for the period of the simulation.

F.3.2 Water Cost Approach

In the water cost approach, Delta outflow is augmented from historical levels to maintain compliance with D-1641 salinity standards and guidance salinity levels at Jersey Point to keep the central and the southern Delta fresher. This is achieved by sequentially augmenting outflow in three periods April 1–June 15, June 15–August 15 and August 15–December 31 (preferentially reducing exports, then augmenting Sacramento River flow). The adjustments were made sequentially using univariate optimization based on the output of the last period. The salinity that results from these simulations is far more similar to historical conditions than results obtained from the impact approach. However, the quantity of water required to maintain compliance is simply assumed to be available even if it is several millions of acre-feet, so may not be a plausible representation of extreme cases.

F.4 SCHISM

SCHISM is a 3-dimesnsional hydrodynamic model of the San Francisco Bay and Delta. The model used in this Study is Bay-Delta SCHISM (Ateljevich et al. 2014). SCHISM is an open-source community-supported modeling system, whose origins were to serve as a second-generation model for use in the Columbia River estuary by the Center for Coastal Margin Observation and Prediction (CMOP). The model has subsequently been enhanced by the Virginia Institute of Marine Sciences and used in basins throughout the world in applications as diverse as reservoir temperature, estuarine transport of salinity, morphology, and near-coast tsunami response. The model has been applied in numerous regional benchmarks and is slated for incorporation in the NOAA national water model. A list of peer-reviews papers is maintained on the model website (<http://ccrm.vims.edu/schismweb>). The larger SCHISM suite includes modules for sediment transport, ecology and biology, wind-wave interaction, ice, oil spill, and marsh evolution, listed approximately in order from greatest to least maturity.

Applied to the Delta, SCHISM requires a mesh and other spatial inputs, bathymetry, boundary inflows, outflows and exports, estimates of Delta channel depletions, and atmospheric forcing. Mesh templates and boundary data for the present Study are distributed publicly in the GitHub open-source repository and the California Natural Resources Agency (CNRA) Open Data Platform. The calibration of the Bay-Delta SCHISM model used for this Study is described in Ateljevich et al. (2014).

F.4.1 Model Simulations

The range of sea level rise increments considered in the Study span from 1.8 ft to 10.2 ft, as presented in Table 5A-F.1, and are based on the *State of California Sea-Level Rise Guidance Update 2018*. The sea level rise values simulated in this Study include: 1.8 ft, 2.7 ft, 3.5 ft, 5.2 ft, 6.9 ft, and 10.2 ft. A list of the main simulations performed is given in Table 5A-F.2.

Table 5A-F.1. Sea Level Rise Projections at San Francisco

Year 2040		Year 2050		Year 2070		Year 2100	
0.5% Probability	H++	0.5% Probability	H++	0.5% Probability	H++	0.5% Probability	H++
1.3 ft	1.8 ft	1.9 ft	2.7 ft	3.5 ft	5.2 ft	6.9 ft	10.2 ft

Notes: 0.5% probability corresponds to the Medium-High Risk Aversion. H++ corresponds to an extreme scenario resulting from loss of West Antarctic ice sheet.

Table 5A-F.2. List of Scenarios Simulated

Scenario	SLR (feet)	SLR (cm)	Mesh Extension	Water Cost	Special Assumptions or Application
slr_cc_00_smext	0.0	0	Sac, Mokelumne	Y	
slr_cc_55_smext	1.8	55	Sac, Mokelumne	Y	
slr_cc_82_smext	2.7	82	Sac, Mokelumne	Y	
slr_cc_107_smext	3.5	107	Sac, Mokelumne	Y	
slr_cc_158_smext	5.2	158	Sac, Mokelumne	Y	
slr_cc_210_smext	6.9	210	Sac, Mokelumne	Y	
slr_cc_311_smext	10.2	311	Sac, Mokelumne	N	
sac_yolo	10.2	311	Sac, Mokelumne, Yolo		
sac_moke_311_lowdiffmin	10.2	311	Sac, Mokelumne, Yolo		Low background diffusivity to encourage salinity intrusion into the Delta
slr_cc_00_cm	0.0	0	None		Data for training lower-dimension models
slr_cc_55_cm	1.8	55	None		Data for training lower-dimension models

Notes: SLR = Sea Level Rise; Sac = Sacramento; Water Cost column indicates whether water cost modeling approach was performed.

F.4.2 Study Period

The simulations reported here span 689 days from 2/10/2009 through 12/31/2010. The model was initialized using ocean salinity and temperature on the coast. Salinity results prior to June 1, 2009, were discarded as warmup. For the model simulations under the water cost approach augmented outflows started March 20, 2009—this date overlaps the salinity warm up in order to ensure the target salinity is attainable at the beginning of the salinity evaluation period in the most difficult cases. Hydrodynamics and salinity from the 20-month period (5/1/2009 to 12/31/2010) were used to characterize salinity responses to sea level rise in the Delta and for use in lower-dimension model training.

Historical Net Delta Outflow Index (NDOI), combined State Water Project (SWP) and Central Valley Project (CVP) exports, and Sacramento River inflow at Freeport are plotted on a monthly average basis in **Figure 5A-F.1.** and **Figure 5A-F.2.** for calendar years 2009 and 2010. Based on the Sacramento Valley 40-30-30 Index, Water Year (WY) 2009 was classified as Dry and WY 2010 was classified as Below Normal; the preceding year (2008) was Critical. Vertical bars shown in the two figures are grouped by calendar year. The wetter months of February and March 2009 and December 2010 are omitted from these figures in order to highlight differences between June and November 2009, a period of focus in the analysis.

Historical salinity in early 2009 was low, characterized by a series of outflow events as high as 51,000 cfs. Spring freshets during the Study period appeared to freshen the Delta even under the

largest sea level rise cases. However, this may not be the case for drought years with particularly low winter outflow.

Salinity change maps, time series data, and water costs are reported for the first 14 days of June, August, and November 2009. These periods coincide with relatively constant conditions and match current regulatory periods that are of importance for Delta water quality management.

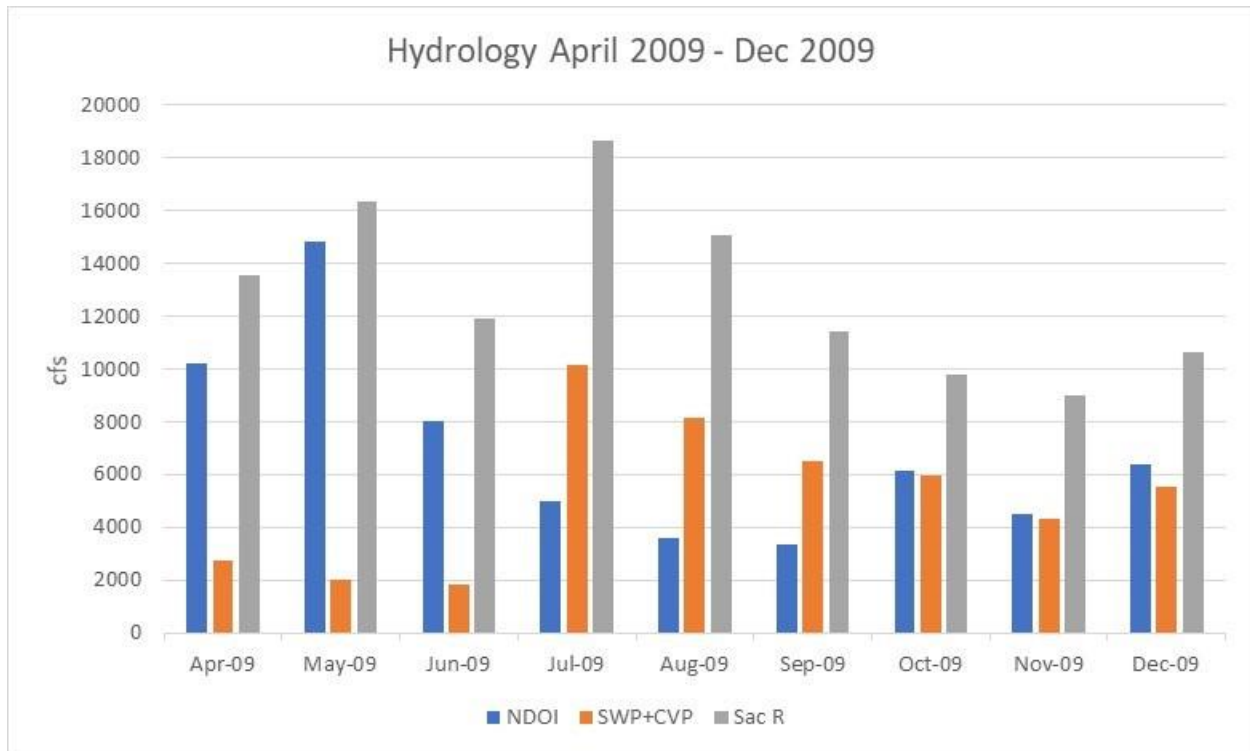


Figure 5A-F.1. Net Delta Outflow Index, State Water Project (SWP) and Central Valley Project (CVP) Combined Exports, and Sacramento River Inflow for the Study Period in 2009

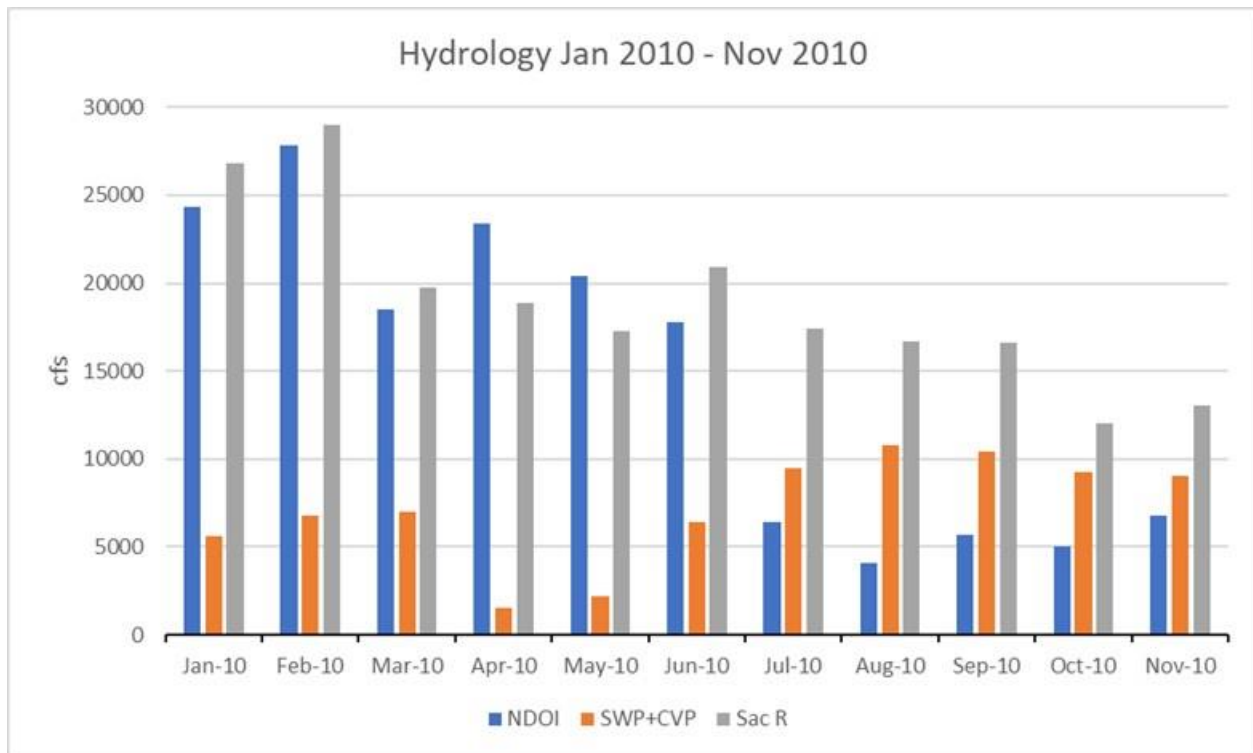


Figure 5A-F.2. Net Delta Outflow Index, State Water Project (SWP) and Central Valley Project (CVP) Combined Exports, and Sacramento River Inflow for the Study Period in 2010

F.4.3 Model Mesh

The Study uses version 98 (v98) of the Bay-Delta SCHISM grid (Ateljevich et al. 2014). The mesh was enhanced for this Study by incorporating recent restoration areas at Tule Red, Yolo Flyway, Decker Island and Lindsey Slough, which are considered part of current geographical conditions in all the hydrodynamic modeling for the project. For comparisons across the seven sea level rise scenarios, the mesh was also modified such that the Sacramento River and Mokelumne River were extended 21 miles (34 kilometers [km]) and 6.5 miles (10.5 km) upstream from their normal location, respectively. The SCHISM models developed for current conditions and 1.8 ft SLR to provide data for the lower-dimension model training did not include these grid extensions; the authors expect this to have negligible effect on the model outputs. Additionally, some sensitivity experiments are performed with an expanded grid intended to open more area of Yolo Bypass to tidal inundation.

The extended v98 mesh is shown in **Figure 5A-F.3.** with the restoration areas and extensions highlighted. The mesh has 323,533 elements and 301,505 nodes. Mesh sizes vary from 1-2 km on the coast to 100-200 meters in the Bay and Suisun, 10s of meters in the Delta, and widths as small as 3 meters in restoration marsh channels.

F.4.4 Model Bathymetry

Bathymetry for Bay-Delta modeling is described by Wang and Ateljevich (2012) and Wang et al.(2018). The collated elevation model, prepared in conjunction with the USGS, is available on the CNRA Open Data Platform at DWR (2021a). GeoTiff formatted raster models of the processed

bathymetry used to populate the grid are available on the CNRA Open Data Platform at DWR (2021b).

F.4.5 Model Boundary Conditions

The model assumes 16 open boundaries, which are shown in **Figure 5A-F.3.** and listed in **Table 5A-F.3.** along with the main sources of data for the Study period. Clifton Court Gate and Export data sources are described in more detail in Ateljevich et al. (2015) and Shu and Ateljevich (2017), which cover modeling specifically in the forebay.

The model includes major hydraulic structures in the Delta, including the Delta Cross Channel, Suisun Marsh Salinity Control Structure, South Delta Temporary Barriers, and smaller structures at Sandmound Slough and Tom Paine Slough, and Clifton Court radial gates. Time series for Delta Cross Channel operations were obtained from USGS and time series for Suisun Marsh Salinity Control Gate were obtained from DWR. South Delta temporary barrier construction timing and culvert manipulations were obtained from the South Delta Branch of DWR.

Channel depletions were modeled using the Delta Channel Depletion model (Liang and Suits 2017) and Suisun Marsh Channel Depletion model (Liang and Suits 2020). The locations where the sources and sinks are applied are unchanged from that model. Several differences are apparent between the DCD model as implemented in DSM2 and the version implemented in SCHISM. SCHISM assumes a smaller net transfer of water away from the channels due to leaching or water table recovery in the months of December and January. Additionally, the Suisun Marsh Channel Depletion model does not reproduce mean flows in the marsh area well and is modulated up by a factor of 30%. These input assumptions are consistent with the assumptions used in the calibration of the Bay-Delta SCHISM. Bay-Delta SCHISM time series inputs are available publicly as a GitHub open-source repository (DWR 2020). Sea level rise templates and time series used in this project are labeled as a branch bay_delta slr.

Table 5A-F.3. Open Water Boundaries, Including Primary Source of Data

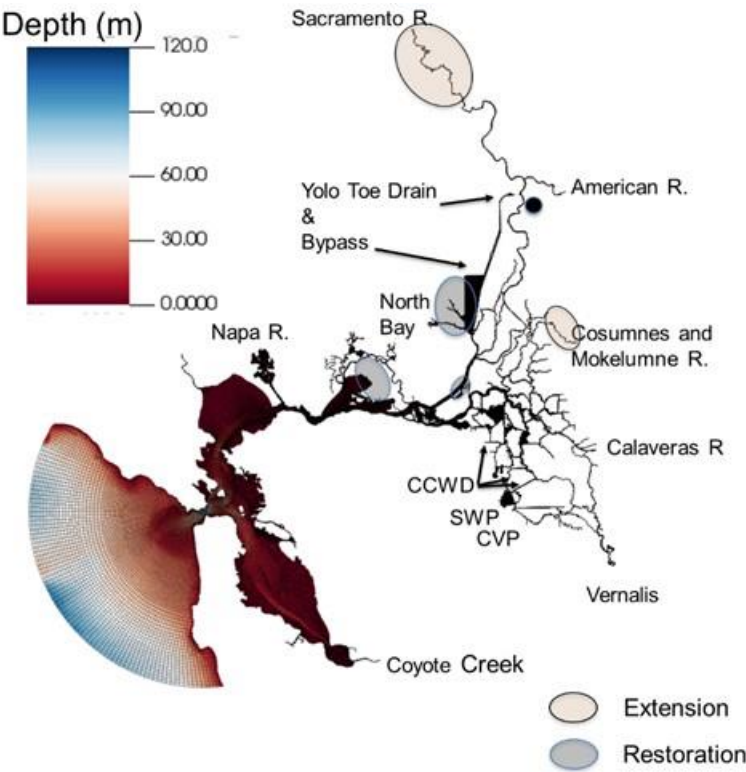
Name	Boundary type	Main sources of data
Coastal Boundary near Farallon Islands	Tidal	NOAA Interpolated (NOAA 2016)
Coyote Cr	Inflow	USGS/NWIS (USGS 2020)
Napa River	Inflow	USGS/NWIS (USGS 2020)
Contra Costa Rock Slough	Export	CDEC
Contra Costa Old River	Export	CDEC
Contra Costa Victoria Canal	Export	CDEC
North Bay Aqueduct	Export	CDEC
State Water Project	Export	DWR O&M
Central Valley Project	Export	CDEC
San Joaquin at Vernalis	Inflow	DWR DES
Calaveras River	Inflow	CDEC, assume zero in summer
Mokelumne/Cosumnes	Inflow	CDEC, USGS, EBMUD
American River	Inflow	USGS/NWIS (USGS 2020)
Sacramento River Knights Landing	Inflow	USGS/NWIS (USGS 2020)
Yolo Bypass Toe Drain near Lisbon Weir	Inflow/outflow	DWR NCRO (DWR 2016)

Name	Boundary type	Main sources of data
Yolo Bypass	Inflow	Inferred (zero for Study)

Key: CDEC = California Data Exchange Center, DWR = California Department of Water Resources, EBMUD = East Bay Municipal Utility District, NCRO = North Central Region Office, NOAA = National Oceanic and Atmospheric Administration, NWIS = National Weather Information System, O&M = Operations and Maintenance, USGS = U.S. Geological Survey.

F.4.6 Atmospheric Data

SCHISM requires atmospheric data to reproduce wind drag, heat exchange, and precipitation. These were interpolated from historical and climate reanalysis sources without manipulation to account for climate change. Wind, air pressure, and specific humidity were obtained from a group of 61 public and private stations primarily operated by DWR, NOAA and WeatherFlow Inc. Radiation (short and long wave) and precipitation were taken from North American Regional Reanalysis data (Mesinger et al. 2006) which is 32 km in resolution. Sensitivity to these variables is lower than sensitivity to wind resolution. These input assumptions are consistent with the assumptions used in the calibration of the Bay-Delta SCHISM.



Key: CVP = Central Valley Project. CCWD = Contra Costa Water District diversion locations, SWP = State Water Project.

Figure 5A-F.3. SCHISM Mesh Including Newly Added Restoration Areas and River Extensions for the Present Study as Well as Boundary Locations

F.5 Regulatory Considerations

This section provides a short review of the stations and regulatory considerations that are most relevant to sea level rise.

The Delta is managed under numerous standards that define the operational range of the system. Particularly in the vicinity of the central and western Delta, water managers refer to the hardest to satisfy standard at any moment as the one that controls SWP and CVP operations. The controlling standard varies seasonally. Several D-1641 objectives, biological opinions (BiOp) and Incidental Take Permit (ITP) requirements have the potential to assume this role, suggesting a balance between standards and water project operations under contemporary conditions.

Assuming the current Delta standards continue in the future, sea level rise will likely disrupt this balance, focusing SWP and CVP management on a smaller number of controlling standards in the Delta, such as the Western Delta salinity standards at Emmaton and Jersey Point. The Western Delta objectives from D-1641 for agricultural beneficial uses are presented in **Table 5A-F.4**. Under most water year types, the standards begin with a more stringent objective of 0.45 mS/cm from April 1 into summer, the duration of which depends on the water year type. This period is followed by a period (two months in 2009) with a less stringent, year-type dependent objective that in the case of a Dry Year is 1.67 mS/cm at Emmaton and 1.35 mS/cm at Jersey Point. After August 15, a 14-day “guidance” Electrical Conductivity or Specific Conductance (EC) level of 1.8 mS/cm at Jersey Point is assumed to inform SWP and CVP operations; this is a proxy used by operators to ensure compliance with Central Delta D-1641 salinity standards that are active year-round and to manage salinity in the freshwater corridor.

Table 5A-F.4. D-1641 Western Delta Agricultural Water Quality Objectives

Year Type	Western Delta			
	Sacramento River at Emmaton		San Joaquin River at Jersey Point	
	0.45 EC from April 1 to date shown	EC value from date shown to Aug 15	0.45 EC from April 1 to date shown	EC value from date shown to Aug 15
W	15-Aug		15-Aug	
AN	1-Jul	0.63	15-Aug	
BN	20-Jun	1.14	20-Jun	0.74
D	15-Jun	1.67	15-Jun	1.35
C		2.78		2.20

Note: Units of specific conductance (EC) are mS/cm.

Changes in X2 induced by sea level rise and operational response to sea level rise are described under model results. However, compliance with D-1641 Spring X2 requirement is unlikely to be affected by sea level rise because of alternative compliance methods based on outflow. X2 standards stipulated under D-1641 constrain the position of the 2.64 mS/cm isohaline (X2) of surface conductance to the Mallard-Collinsville region. D-1641 Spring X2, which is the X2 regulation active in most water year types, also provides for alternative compliance methods based on outflow. As sea level rise pushes salinity higher, flow becomes the more economical compliance option, and at that point water cost becomes fixed even if sea level rise evolves further.

For example, in early June 2009 the historical outflow was approximately 10,000 cfs. The alternate compliance flow was 11,400 cfs. The model results as described below indicate transition to flow-only compliance with X2 would likely happen between 1.8 ft and 2.7 ft of sea level rise.

In contrast, the Fall X2 requirement as stipulated under the BiOps and ITP does not contain a flow compliance alternative. Requirements are specified in Fall (Sep and Oct) following wet and above normal years. The cost of meeting Fall X2 requirements is expected to increase with sea level rise. This cost was not quantified explicitly because the Study described here focused on dry years when there are no Fall X2 requirements, although the Delta outflow corresponding to complying with 045 mS/cm at Emmaton will be most analogous to the complying with Fall X2.

F.6 Sea Level Rise Assumptions and Implementation

As noted above, the sea level rise values studied range from 1.8 ft to 10.2 ft. These sea level rise levels are primarily based on OPC projections for Medium-High Risk at high-emissions (RCP 8.5) and Extreme (H++) Risk Aversion scenarios. The sea level rise values simulated in this Study include: 1.8 ft, 2.7 ft, 3.5 ft, 5.2 ft, 6.9 ft, and 10.2 ft. These numbers were selected to represent a range of possible sea level rise scenarios from 2040 to 2100. New project intakes and conveyance facilities are being designed to be protected under the extreme risk aversion scenario at 2100 of 10.2 ft plus the projected 200-year flood elevations towards the end of the century.

Sea level rise was implemented in the SCHISM by increasing the mean sea level over the ocean boundary. No attempt was made to accommodate changes in short duration storminess on the coast, which can lead to subtidal salinity fluctuations as outlined in Walters (1982) and Monismith (2016). Atmospheric forcing such as wind, air pressure, humidity and radiation; upstream hydrology and operations were held at 2009 historical levels except as noted below for the simulations conducted for the water cost approach and the reduced water use simulation due to high salinity.

The horizontal mesh was not expanded to accommodate sea level rise except for some upstream extensions of the riverine reaches described in Section F.4.3. In particular, overtopping onto subsided Delta islands or low elevation marsh lands along the Bay were not considered. This is sometimes called a “glass wall” approach and assumes that the existing levee elevations would keep up with increasing sea levels. However, some acreage of intertidal habitat even under historical tidal forcing is submerged in the more extreme cases, especially in the Cache Slough Complex.

Overtopping of levees and berms into adjacent land was not considered except in the special case of Yolo Bypass.

In contrast to the horizontal grid, the number of levels in the vertical grid were increased one layer for every meter (3.3 ft) of increase in sea level but maintaining the maximum of 23. The purpose of this modification was to maintain (approximately) the same vertical resolution across the various scenarios modeled in this Study.

The present Study also assumes a fixed bed with no significant morphological response at the time scale of the Study. This is a conservative assumption, as some accretion would occur. Similarly, major ship channels are assumed to remain at current bed elevations, even though occasional dredging is required to maintain these elevations and there would be little need to continue to do so as water levels rise. Other issues, such as accretion in marshes and intertidal shoals, are beyond the scope of the investigation and were not assumed in the modeling for this Study.

1 A final class of significant simplifying assumption for the Delta concerns the continuation of exports
2 and agricultural diversions in the Delta well beyond salinity conditions where such beneficial uses
3 are currently practical.

4 While some of these assumptions are oversimplified, there are at least two important reasons for
5 focusing attention narrowly. First, the assumptions are well defined to answer the specific questions
6 at hand without an explosion of permutations of alternatives and decisions about defense against
7 increasing sea levels. Second, in the case of project intake vulnerability the main consideration is to
8 cover the worst-case scenario. Some assumptions that are arguably unrealistic such as exporting
9 water at 4000 $\mu\text{S}/\text{cm}$ can be safely labeled “as bad or worse” as what will occur as humans adapt to
10 or defend against the new sea levels around the Bay and Delta.

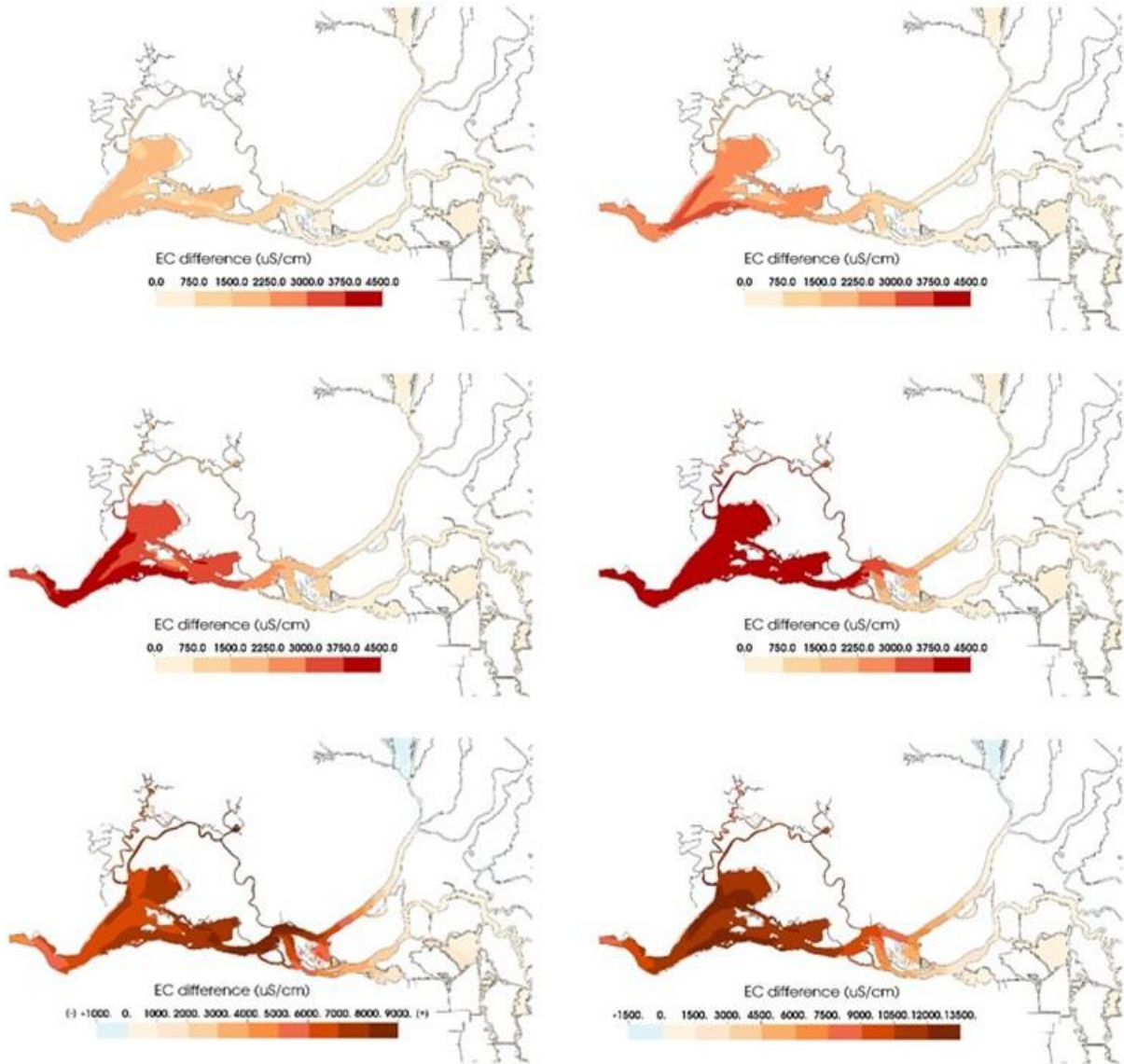
11 F.7 Model Results

12 F.7.1 Salinity Changes using the Impact Approach

13 Figures 5A-F.4, 5A-F.5, and 5A-F.6 show salinity change under a progression of sea level rise
14 increments in the first 14 days of June, August, and November 2009 relative to no sea level rise for
15 the impact approach. The output periods correspond to different regimes of the D-1641 objectives
16 presented in **Table 5A-F.4**, and described as follows:

- 17 • June 1–14 is near the close of the period governed by the 450 $\mu\text{S}/\text{cm}$ standard at Emmaton
- 18 • August 1–14 is near the close of the period governed by the 1,670 $\mu\text{S}/\text{cm}$ for Emmaton
- 19 • November 1–14 is a period when operations are assumed to conform to the 1,800 $\mu\text{S}/\text{cm}$
20 guidance EC level at Jersey Point.

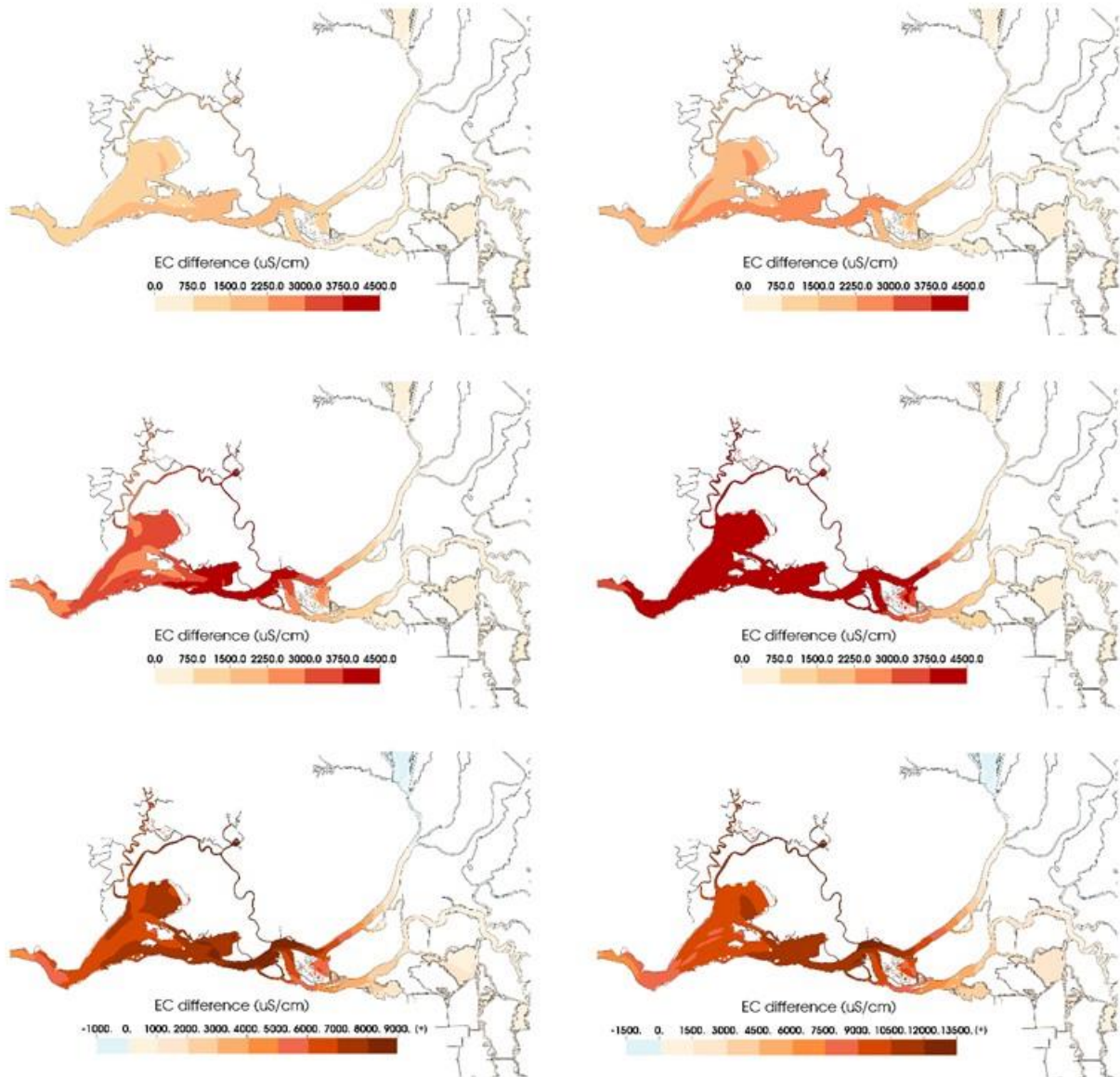
21 The “change maps” indicate that within the Delta region, salinity increases are greatest in absolute
22 terms in the area between Suisun Bay and Collinsville. The area of change migrates upstream along
23 with the typical axes of salinity intrusion over the season, but with significant local geographic
24 differences. For all three periods, there is a considerable increase in severity of impact as sea level
25 rise increases, but relatively few striking patterns spatially. On Sacramento River, as sea level rise
26 progresses, salinity intrusion progresses upstream towards Rio Vista. There are two primary causes
27 for this advance: (1) increased tidal flow due to inundation of tidal prism in the Cache Complex
28 facilitated by larger conveyance capacity and (2) accentuated vertical exchange flow in the
29 Sacramento River downstream of Rio Vista due to greater depth. These causes may be entwined in a
30 positive feedback cycle – as salinity increases, the longitudinal gradient of salinity (from Collinsville
31 to Rio Vista) also increases and excites further baroclinic (density driven) mixing that arise when
32 salinity becomes stratified. While these processes increased salinity levels in the Sacramento River
33 downstream of Rio Vista, in none of the sea level rise scenarios does the salinity intrusion advance
34 more than 15 km upstream from the Sacramento River, Cache and Steamboat Slough junction, well
35 downstream of the proposed intake locations. This topic is revisited in Section F.7.3.



1

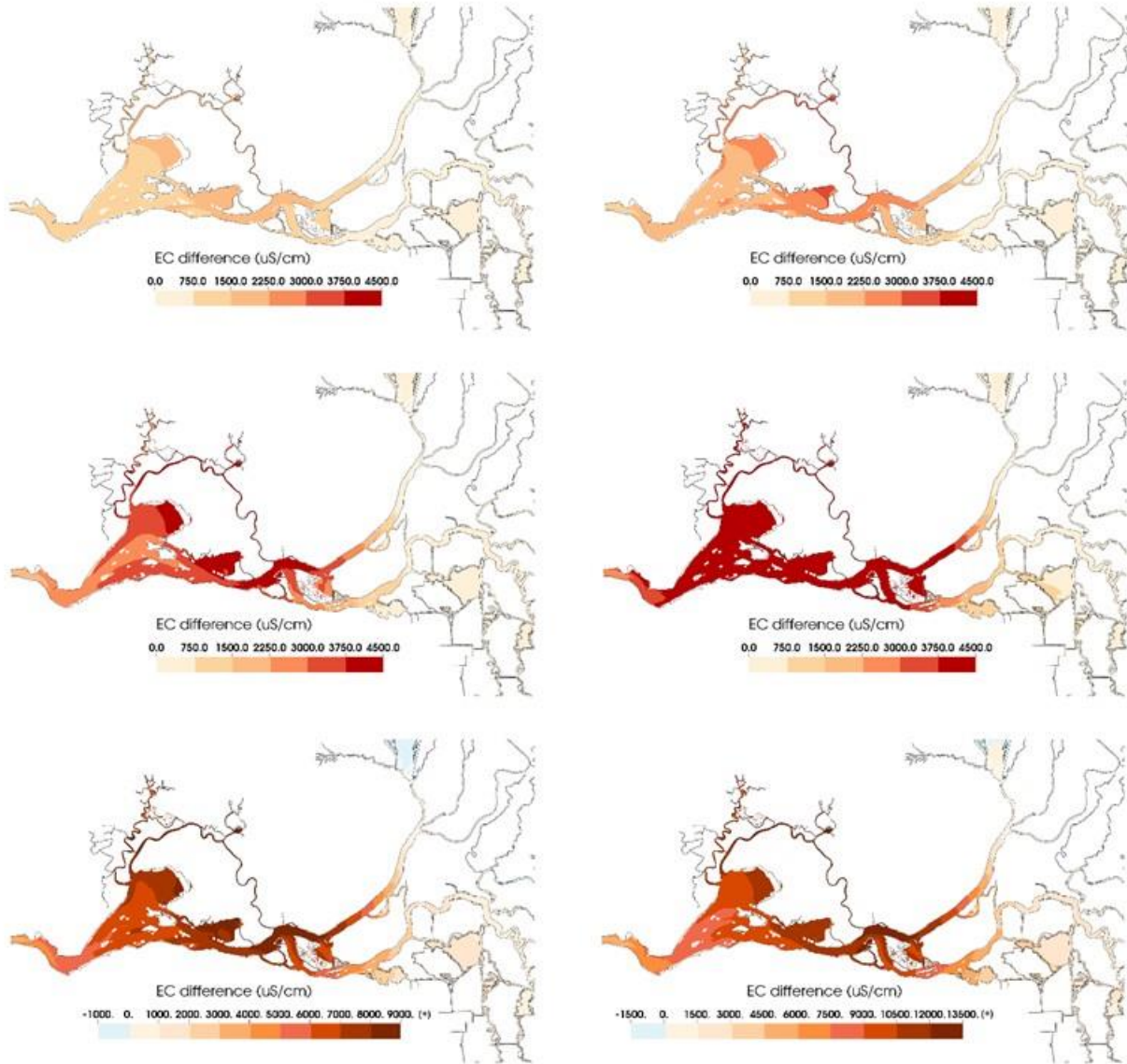
2 Note: The change in color scale for the latter two cases.

3 **Figure 5A-F.4. June 1–14 Average Salinity Change Respectively in the 1.8 feet, 2.7 feet, 3.5 feet 5.2**
 4 **feet, 6.9 feet, and 10.2 feet SLR Cases**



- 1
- 2 Note the change in color scale for the latter two cases.

3 **Figure 5A-F.5. August 1–14 Average Salinity Change Respectively in the 1.8 Feet, 2.7 Feet, 3.5 Feet 5.2**
 4 **Feet, 6.9 Feet, and 10.2 Feet SLR Cases**



1

2 Note the change in color scale for the latter two cases.

3 **Figure 5A-F.6. November 1–14 Average Salinity Change Respectively in the 1.8 feet, 2.7 feet, 3.5 feet**
 4 **5.2 feet, 6.9 feet, and 10.2 feet SLR Cases**

Figure 5A-F.7. plots the August average EC at Emmaton against sea level rise increment and indicates that the response at this site increases with a slight nonlinearity through 10.2 ft. The area of light gray shading shows the range of historical extreme EC value observed from the last two decades. These extreme values largely occurred in droughts and outside the periods with D-1641 agricultural salinity standard (later in the season than August). The area of dark gray area shading represents simulated EC values greater than recent historical experience.

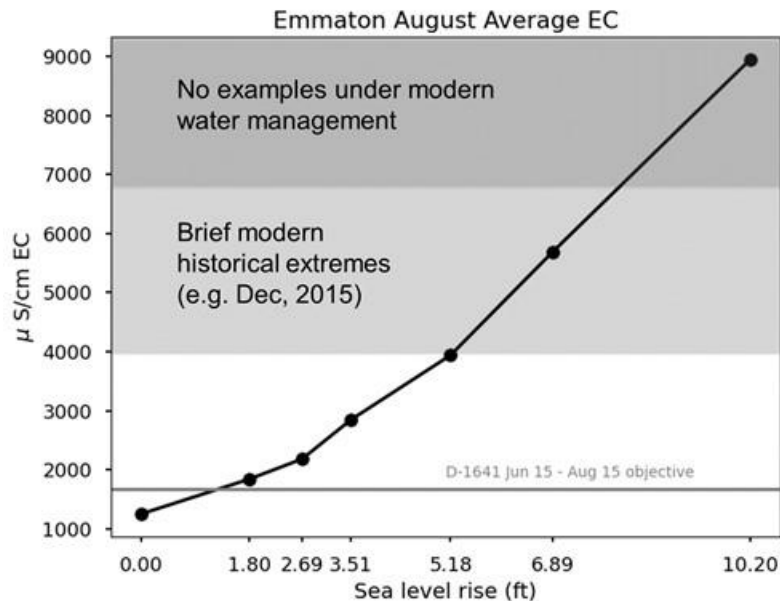
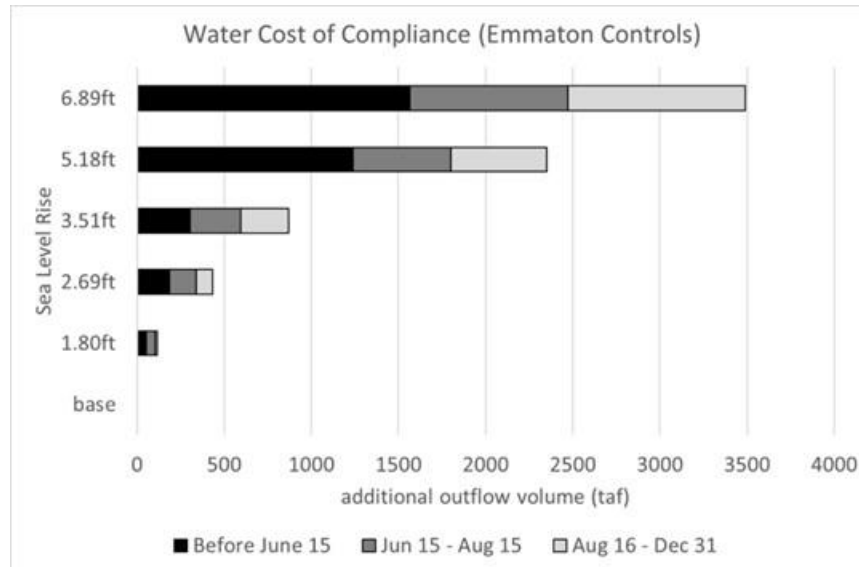


Figure 5A-F.7. Monthly Average Salinity Change at Emmaton Under Seven Values of Sea Level Rise, Holding Inflows and Exports Constant

F.7.2 Results from the Water Cost Approach

To estimate the potential water cost associated with sea level rise, inflows and exports were adjusted to meet D-1641 objectives at Emmaton and the subsequent 1,800 $\mu\text{S}/\text{cm}$ guidance EC level at Jersey Point. The model simulations performed for the water cost approach demonstrated that Emmaton standard will likely become the more frequent controlling standard with increased sea level rise, and by complying with it other D-1641 salinity standards will exist. **Figure 5A-F.8.** presents the water cost of compliance with D-1641 standards. The total length of the horizontal bars indicates the seasonal cost of compliance. This water cost is subdivided into contributions from each of three control periods considered. The darkest shade represents the period before June 15. This is a variable length period timed to begin two weeks before the first exceedance of the D-1641 EC standard that would occur without an operational flow response. The other two periods are fixed in length and represent the applicable periods for the less severe D-1641 objective at Emmaton and the guidance EC level at Jersey Point.



Notes: The controlling standard is Emmaton. The total cost is divided among three control periods.

Figure 5A-F.8. Incremental Water Cost of Compliance with D-1641

Two important results arise from this plot. First, a nonlinear response is much more apparent for water costs shown in **Figure 5A-F.8**, than for salinity impact, as shown in **Figure 5A-F.7**. Second, the cost grows most severely with sea level rise for the early period before June 15 when salinity is low. The Emmaton D-1641 objective of 450 $\mu\text{S}/\text{cm}$ beginning April 1 is shared for all water years, although for different lengths of time. Given that this EC value is most analogous to Fall X2, these greater water costs likely extrapolate to conditions in other, and in particular wetter year types.

Figure 5A-F.9 presents the salinity change for June, August, and November that results when inflows and exports are adjusted to achieve compliance with D-1641 EC standards, specifically by managing EC at Emmaton in June through August and managing Jersey Point guidance EC levels after August under 3.5 ft of SLR. In June and August period, the Delta is broadly freshened or unaltered, which indicates that the water cost required to comply at Emmaton is sufficient to offset salinity increases because of SLR in many other locations in the Delta. Following August 15, Emmaton is no longer the controlling location for managing salinity; the objective that serves as the pivot point for salinity management in the Delta shifts to Jersey Point, which is less stringent and less affected by sea level rise, so the compensation for salinity increases related to the 3.5 ft sea level rise is not complete. Nonetheless, it is notable that the response is fairly balanced over the region, and in the Delta the net effect to the salinity is small in absolute terms.

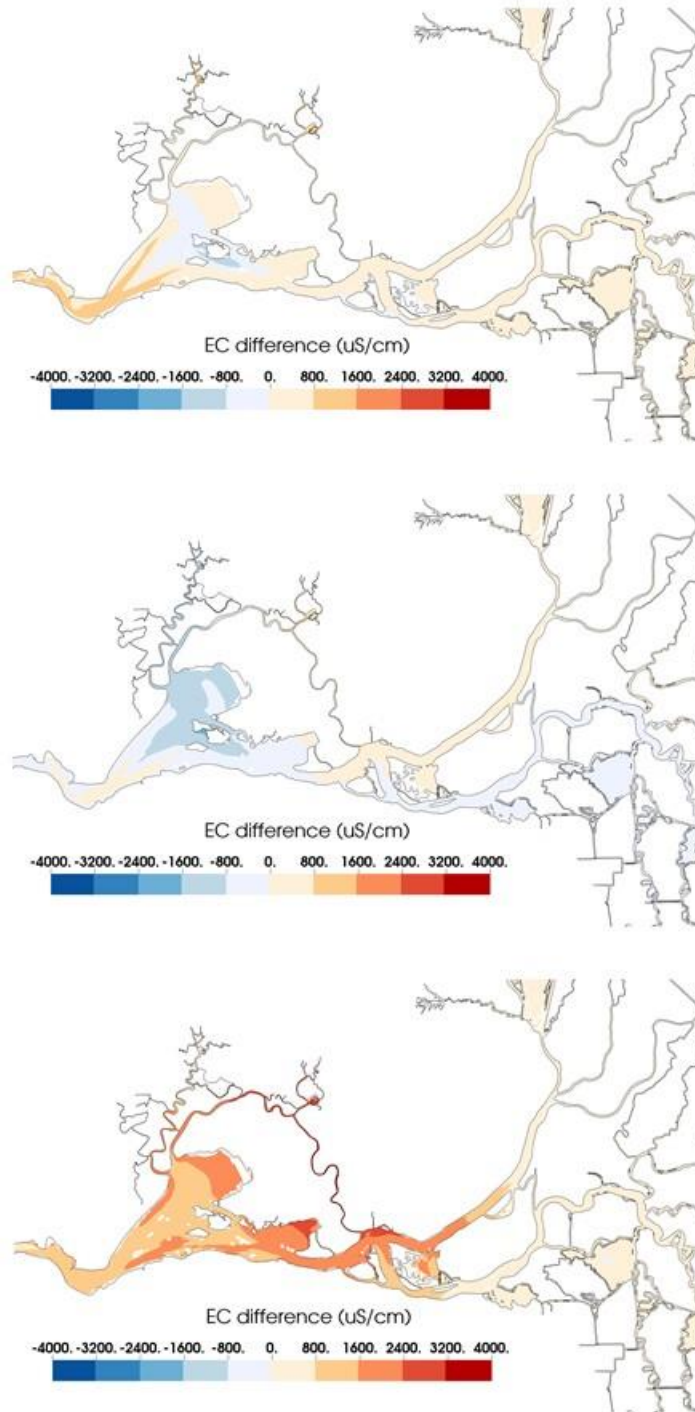
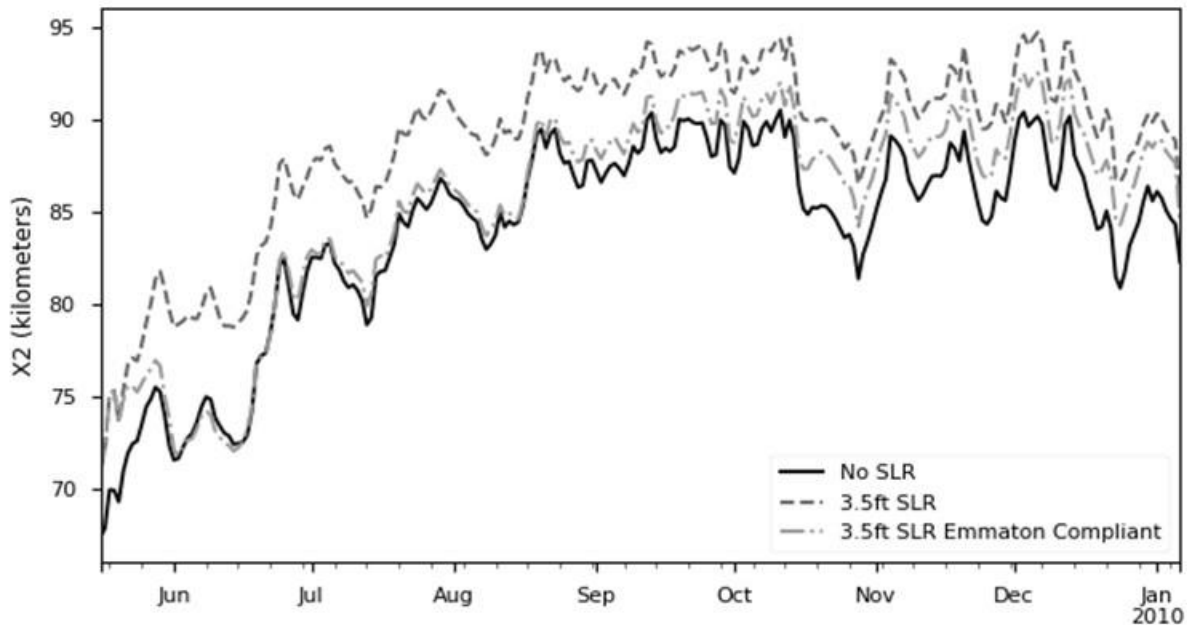


Figure 5A-F.9. Salinity Change Maps for (a) June 1–14, 2009, (b) August 1–14, 2009, and (c) November 1–14, 2009 in Compliant (water cost) Scenarios where Flow has been Applied to Maintain Compliance at Emmatton

Figure 5A-F.10 shows the seasonal position of the 2 ppt (X2) isohaline for 3.5 ft SLR for both the salinity impact and water cost (but compliance is focused on Emmaton D-1641 salinity standard and Jersey Point guidance EC level) approaches and compares them to the corresponding position in the base case with no SLR. In the salinity impact approach, X2 remains about 5 km upstream relative to the baseline condition, the difference being slightly greater at low values of X2 earlier in the season. In the water cost approach, the relatively high extra outflow required to comply to the Emmaton standard roughly offsets the difference in X2 during the pre-June 15 and June 15–August 15 periods, but not after August 15 when the Emmaton standard no longer applies, and the controlling objective is the guidance EC level at Jersey Point.



Note: Three cases are shown: no sea level rise, the impact approach with no operational response and the water cost approach where Emmaton is compliant.

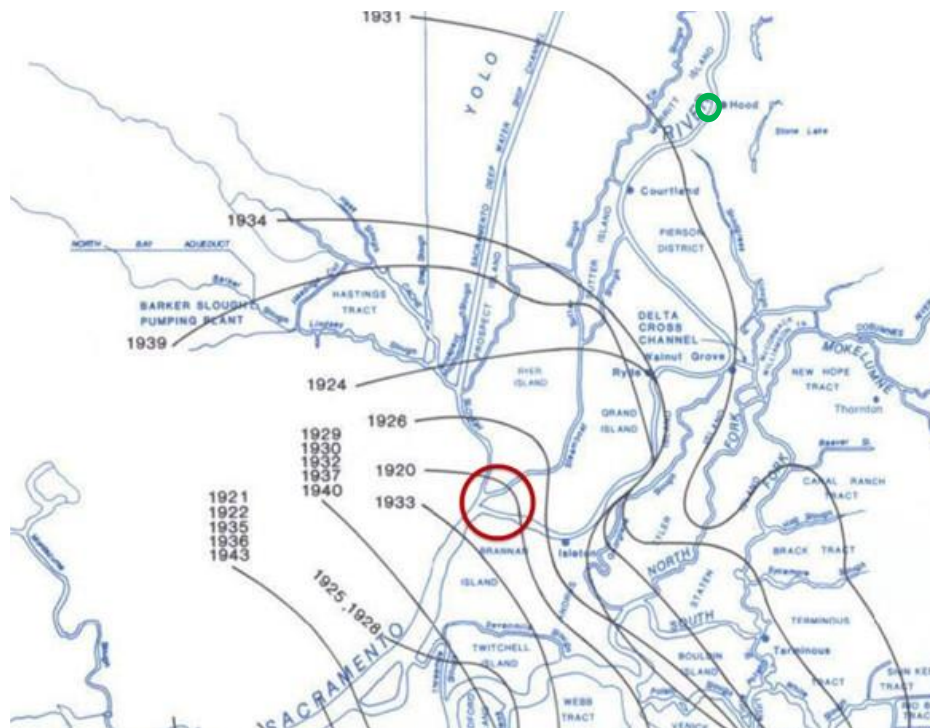
Figure 5A-F.10. Position of the X2 Isohaline Along the Sacramento River Using Simulated Daily Averaged Bottom Salinity

F.7.3 Intake Location Vulnerability

One of the objectives of the Study was to investigate how far salinity intrusion progresses toward the project proposed intake locations under 10.2 ft SLR. The simulations addressing this question were conducted using the same assumptions and 2009-2010 historical flows as described for the scenarios under the impact approach. As described above, some historical assumptions concerning historical water use may ultimately be problematic under high salinity conditions, since historical upstream storage releases are predicated on some exports in the Delta as well as in-Delta water use. Without positive net flow, higher salinity is possible.

Historical measurements of salinity, presented in **Figure 5A-F.12**, suggest that under pre-project hydrology, salinity advanced farther than the simulated values presented and described above. The historical values shown on the figure happened at near-zero or even strongly negative net Delta outflow. In 1931, for instance, the DayFlow (DWR 2022) estimate of NDOI is negative for most days between June 4 and September 10, 1931, and averages -2497 cfs during July and August. It is

assumed here that this possibility would be precluded under future operation of the SWP and CVP, which would continue to serve multiple beneficial uses including Delta outflow and with the proposed project bypass flow rules.



Note: Red circle is the junction of Cache Slough, Steamboat Slough, and Sacramento River mainstem located just upstream of Rio Vista. Green circle indicates approximate downstream end of the Sacramento River reach where the proposed project intakes will be located.

Figure 5A-F.12. Section Plate from of Delta Atlas (DWR 1995) Indicating Historical Maximum Annual Salinity Intrusion as Determined by the 1,000 ppm Contour (Approximately 2,000 uS/cm Specific Conductance).

Figure 5A-F.13 shows locations near Rio Vista used in the present Study to identify the extent of salinity intrusion in the Sacramento River mainstem. Synthetic stations are arranged and labeled according to approximate distance from the location marked RV. This reference location corresponds to a legacy NOAA station at the downstream end of the City of Rio Vista. The Delta Cross Channel is located just upstream of the RV+25km station. Salinity intrusion length along Steamboat Slough were computed as well, since the results are consistent with those on the Sacramento River, not shown in here.



Figure 5A-F.13. Location of Synthetic Stations used to Assess Salinity Encroachment upstream of Rio Vista in the Sacramento River Mainstem Under Extreme Sea Level Rise

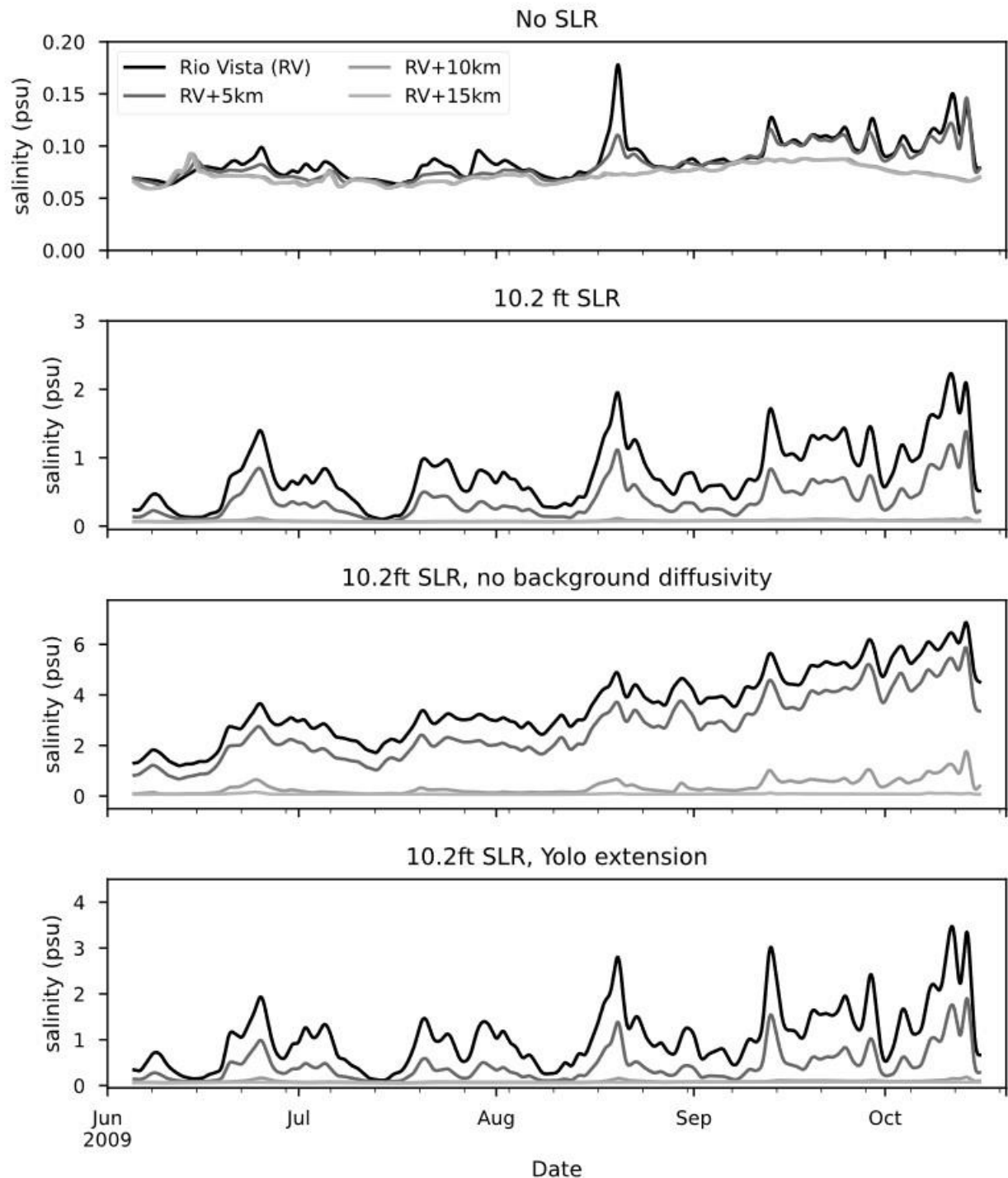
Because worst case scenarios are of interest here, two additional sensitivity cases were also included in the analysis, both involving changes that are significant in the Rio Vista region as follows:

- In the first sensitivity test, background diffusivity in SCHISM was reduced to the coastal value, leading to generally lower diffusivity, greater stratification and increased up-estuary transport. This re-parameterization is approximate but still of value for creating near-worst cases for ocean salinity intrusion.
- In the second sensitivity test, the full region of Yolo Bypass within the new tidal range was opened to inundation. The premise of this simulation was that increased tidal prism leads to larger tidal range of flow, channel mixing and trapping of salinity and make Rio Vista saltier. This increase in salinity is substantial (tens of percent over time) but not large compared to the effect of sea level.

Figure 5A-F.14 presents time series of simulated salinities for 0.0 ft SLR (base case) and 10.2 ft SLR at the synthetic stations shown in Figure 5A-F.13. The y-axis scales vary considerably between the individual plots. In the No SLR base case, Rio Vista salinity is relatively low; in most years it lies at the upstream limit of ocean salinity intrusion. As a result, salinity at Rio Vista and the Cache Slough-Steamboat Slough-Sacramento River confluence (RV and RV+5km) is usually modestly higher than the upstream boundary conditions, primarily on the Sacramento River.

Under the 10.2 ft sea level rise, salinity increases approximately an order of magnitude at Rio Vista. Sensitivity experiments further exaggerate these changes in salinity intrusion, with X2 regularly reaching Rio Vista or the confluence in those two cases. Importantly, however, significant salinity increases do not progress as far as Isleton at RV+10km or apparently at all at RV+15km. Similar results were observed for Steamboat Slough. It appears that the abrupt transition to a narrower, shallower more riverine environment above the Sacramento-Cache-Steamboat junction imposes an important step down in up-estuary salinity transport along the mainstem Sacramento River upstream of Rio Vista. Since salinity increases significantly on the downstream reach and not on the

upstream, a steep gradient is expected to develop at the junction that does not progress significantly beyond one tidal excursion upstream.



Notes: The uppermost, darkest line represents the point RV on Figure 5A-F13. Lighter shades represent upstream locations at increments of 5km.

Figure 5A-F.14. Salinity Under Extreme (10.2 feet SLR) at Locations Upstream of Rio Vista on the Sacramento River Mainstem

The lack of vulnerability at the proposed project North Delta Diversion is associated with the broader result that sea level rise response is modest upstream from Rio Vista on both the Sacramento River and Steamboat Slough. The small response demonstrated by model simulations is expected and can be explained based on the geometry of the Cache Slough-Steamboat Slough-Sacramento River confluence, the bathymetry of which is shown in **Figure 5A-F.15**. The channels enter this junction from upstream in a shelf; upstream depths are generally less than 5 meters (16 ft). Downstream, and along Cache Slough along the Sacramento Deep Water Ship Channel, the water is as deep as 26 meters deep (85 ft).

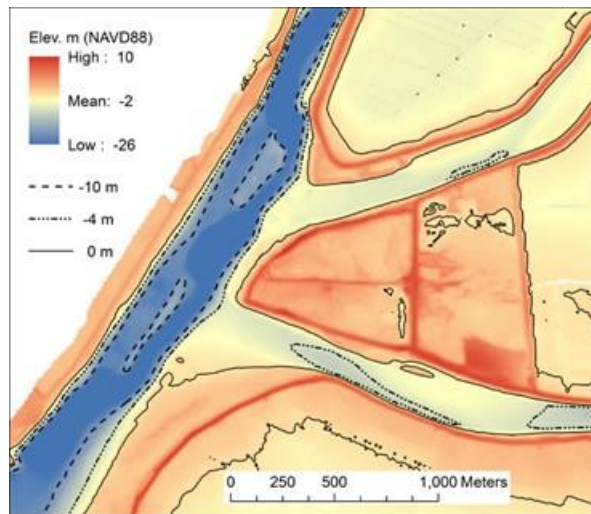


Figure 5A-F.15. Bathymetry of the Junction of the Sacramento River, Steamboat and Cache Sloughs

This sudden transition to shallower water acts as a check on sea level rise response. Sea level rise produces several changes that are pertinent to salinity transport, including inundation of new areas and changes in tidal flows. However, in long channelized areas such as this one, the potential for stratification is indicated by the depth (Stacey et al. 2001; Geyer and MacCready 2014). Upstream from the junction on the mainstem Sacramento River and Steamboat Slough, the water is much shallower and incursions by salinity are quickly pushed back on the ebb tide. To the extent that freshwater flows over salt water, this would occur at the shelf-like entrance to the downstream reach. This transition might generate fronts and more complex mixing mechanisms than are considered here, but this would have its biggest effect downstream from the junction.

Downstream of Rio Vista, conditions are more conducive to density-driven mixing processes. Besides depth, conditions required for baroclinic exchange flow are as follows:

- a strong longitudinal salinity gradient along the main channel.
- sufficiently weak tidal strength to control turbulent mixing that mixes out stratification.
- freshwater inflow.

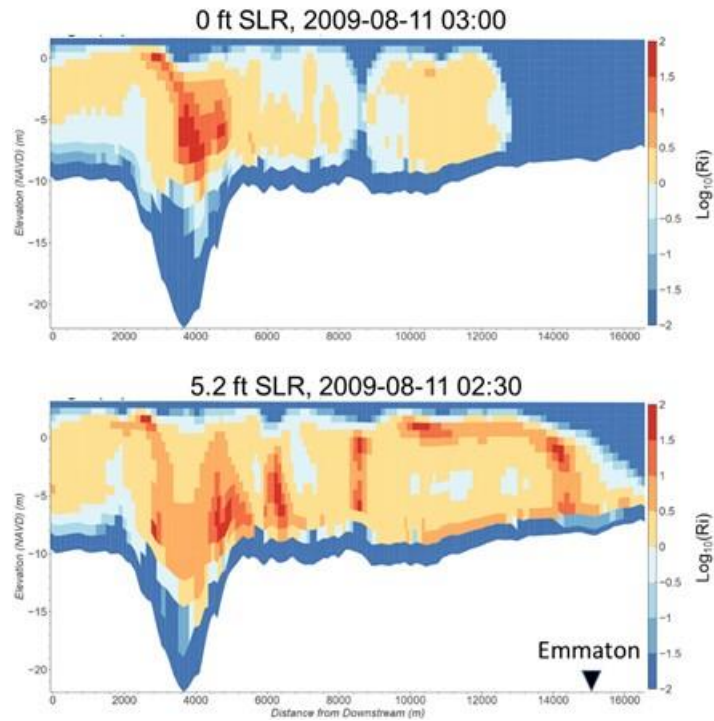
The first of these requirements, the need for a strong longitudinal salinity gradient over an extended area, sets up a feedback: salinity is needed to support salinity-induced transport. Historically, prevailing standards and practices in the areas between Threemile Slough and Rio Vista lead to water fresh enough to suppress this type of transport but results from this Study suggest conditions are otherwise conducive and would be even more so if the reach became significantly deeper with

1 sea level rise. Since depth, not sea level, is the controlling parameter here, any scenario that softens
2 the static bed assumptions made in the Study (e.g., if there were deposition partly keeping pace with
3 SLR) would likely yield a less severe result.

4 An indication of this increased potential for increased baroclinic transport and periodic
5 stratification is offered by examining the gradient Richardson number (Ri) along a longitudinal path
6 along the thalweg of the Sacramento River from the confluence to a point upstream of Decker Island
7 (**Figure 5A-F.16**). Ri is shown approximately 2 hours after maximum ebb tide during a neap on
8 August 11, 2009. Stable levels of stratification ($\log(Ri) > -0.5$) occurs over a larger section of the
9 water column and a longer reach upstream. Though not shown, the duration of stable Ri values is
10 also increased.

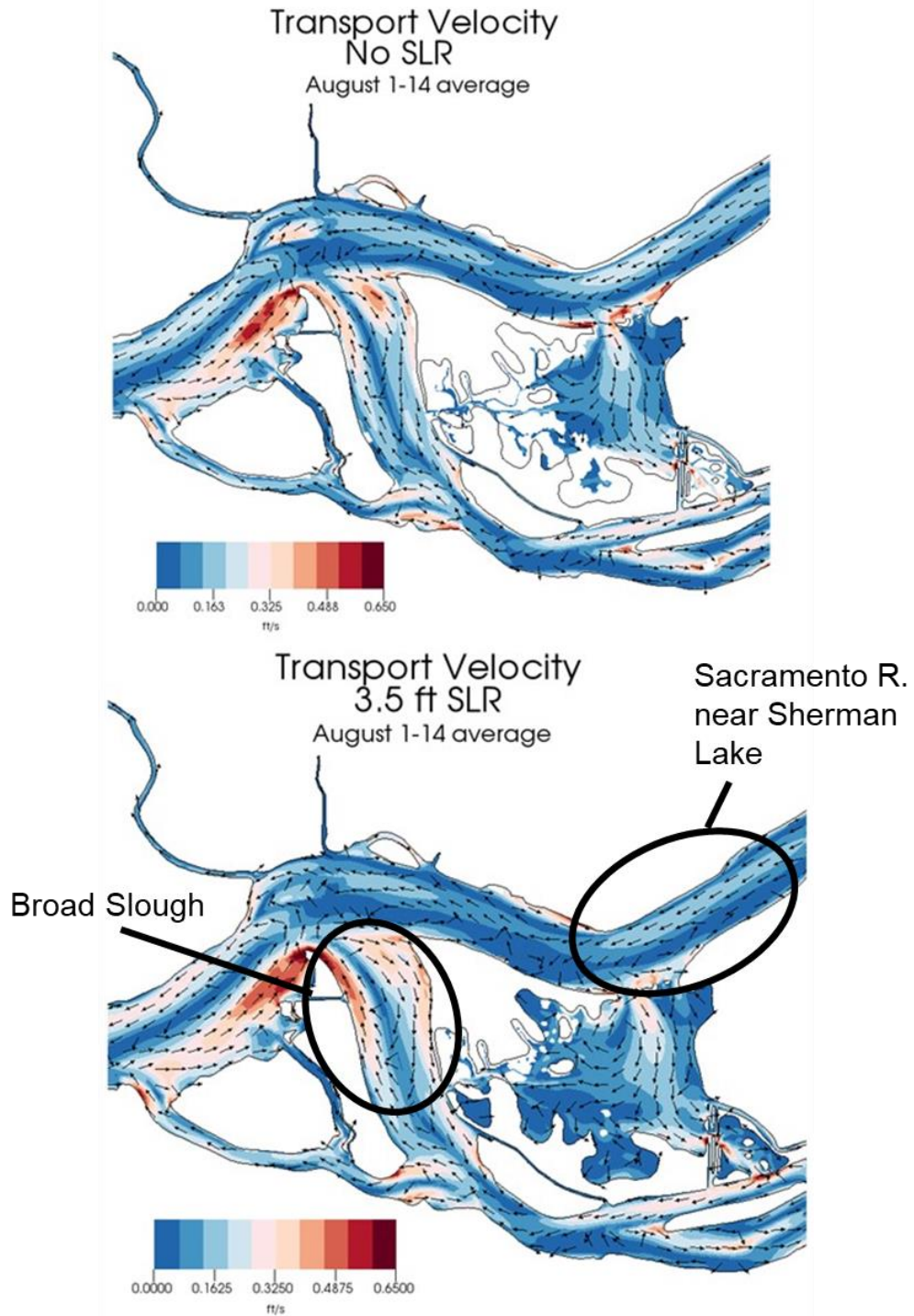
11 Not all depth-induced changes in circulation are baroclinic. Spatial patterns and tidal asymmetries
12 produced by friction, Stokes drift, and bathymetry are also depth-dependent and hence influenced
13 by sea level rise. **Figure 5A-F.17** shows transport velocity in the area of the Sacramento-San Joaquin
14 River confluence. As described in Robinson (1983) and Li and O'Donnell (1997), transport velocity
15 is a residual velocity weighted in such a way as to includes the influence of Stokes Drift on transport,
16 and as such is a good indicator of transport potential for vertically mixed material. Li and O'Donnell
17 describe circulation cells of transport velocity that develop in channels with lateral variation in bed
18 elevation, cells that would be stimulated, shaped, or enhanced by geographical features and side
19 embayments. Under the simple assumptions put forth here, sea level rise alters these residual
20 currents because it imposes nearly the same increment of change on both shoal and channel,
21 reducing the contrast between the two as a ratio. Additionally, sea level rise is a larger fraction of
22 original depth in shallow water than in deep, so Stokes Drift and flood-ebb asymmetries of friction
23 are also changed disproportionately in the shoals and channels (and in some cases weakened rather
24 than strengthened).

25 In **Figure 5A-F.17**, two particularly large changes are evident: barotropic circulation is enhanced in
26 the originally shallow Broad Slough and down-estuary transport velocities in the Sacramento River
27 near Sherman Lake are reduced under 3.5 feet of sea level rise. Though not shown here, the same
28 changes are more pronounced at 5.2 feet of sea level rise, to the point where barotropic transport
29 velocity on the Sacramento River is no longer directed continuously downstream in low outflow
30 conditions, but more through Sherman Lake.



Note: Timing varies by SLR scenario.

Figure 5A-F.16. Longitudinal Profile of Gradient Richardson Number from Honker Bay to Just Above Emmaton for a Time Approximately 2 Hours After Maximum Ebb



Note: Regions of altered circulation described in the text are circled here.

Figure 5A-F.17. Transport Velocity in the Sense of Robinson (1983) in the Confluence Region for No Sea Level Rise and 3.5 feet of Sea Level Rise

F.8 Conclusions

The range of sea level scenarios investigated here span a number of severe cases. The cases are severe not just because of likelihood reported in the OPC guidelines but also because of the Delta response they elicit and because of the difficulty they pose in defining a plausible associated Delta geography (e.g., inundation of Delta islands), water use, and regulatory structure.

Consistent with the spirit of the OPC guidelines, it was the goal of this Study to focus on assumptions that would be challenging for water management. This bracketing approach is a logical method of confirming that the project's North Delta Diversion intakes are not vulnerable to salinity intrusion because of the sea level rise even though most of the Western and Central Delta are vulnerable to sea level rise related salinity impacts.

The cost of compensating for sea level rise and maintaining salinity response reported here is significantly high. The water cost of compliance appears to be the highest when Emmaton is held to its springtime value of 450 $\mu\text{S}/\text{cm}$ level, its lowest value and a value common to all but Critical Year types.

The nonlinearly increasing water costs of maintaining salinity standards under these conditions are also consistent with a transition to more baroclinic transport upstream of the confluence. As this reach transforms to a deeper, higher flow and more stratified estuary, the marginal efficacy of added freshwater outflow to repel salinity decreases. This is because added flow plays two contrasting roles: on one hand it provides the mean fresh flow that carries salinity downstream and freshens the estuary; on the other it is an input of buoyant water that enhances dispersion that brings salinity upstream (Monismith et al. 2002). Freshwater inflow is still an agent of freshening, but its efficiency in doing so decreases with higher sea levels.

Finally, this Study suggests some regulatory and compliance uncertainties, contradictions among assumptions and resource challenges that arise under extreme sea levels. These difficulties are much broader and more intrinsic to the Delta and CVP-SWP water supply systems than they are to the project and the implications will involve integrated statewide modeling to understand. The exact effects will vary considerably under different modeling and landscape assumptions, the full range of which can only be sampled.

F.9 References

Ateljevich, E., Nam K., Zhang Y., Wang R., and Shu Q. 2014. "Bay-Delta SELFE calibration overview." In: Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 35th Annual Progress Report to the State Water Resources Control Board. Chapter 7. Sacramento, CA: Bay-Delta Office. Delta Modeling Section. California Department of Water Resources.

Ateljevich, E, Tu, M-Y., and Le, K. 2015. "Calculation Clifton Court Forebay inflow and re-rating the forebay gates." In: Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 36th Annual Progress Report to the State Water Resources Control Board. Chapter 6. Sacramento (CA): Delta Modeling Section. California Department of Water Resources.

- 1 California Department of Water Resources. 1995. Delta Atlas. RECIRC2646. Accessed online at
2 [https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california](https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/exhibit3/rdeir_sdeis_comments/RECIRC_2646_ATT%203.pdf)
3 [a waterfix/exhibits/exhibit3/rdeir_sdeis_comments/RECIRC_2646 ATT%203.pdf](https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/exhibit3/rdeir_sdeis_comments/RECIRC_2646_ATT%203.pdf).
- 4 California Department of Water Resources. 2016, Water Data Library data available on the World
5 Wide Web (WDL), accessed June 2016, at: <http://www.water.ca.gov/waterdatalibrary/>.
- 6 California Department of Water Resources. 2017. California Data Exchange Center data available on
7 the World Wide Web (CDEC). Available: <http://cdec.water.ca.gov>. Accessed: June 2016.
- 8 California Department of Water Resources. 2020. Bay-Delta SCHISM, GitHub Repository,
9 <https://github.com/CADWRDeltaModeling/BayDeltaSCHISM>.
- 10 California Department of Water Resources. 2021a. San Francisco Bay and Sacramento-San Joaquin
11 Delta DEM for Modeling, Last Revised: Feb 2021. Available: California Open Data Portal
12 [https://data.cnra.ca.gov/dataset/san-francisco-bay-and-sacramento-san-joaquin-delta-](https://data.cnra.ca.gov/dataset/san-francisco-bay-and-sacramento-san-joaquin-delta-dem-for-modeling-version-4-2)
13 [dem-for-modeling-version-4-2](https://data.cnra.ca.gov/dataset/san-francisco-bay-and-sacramento-san-joaquin-delta-dem-for-modeling-version-4-2).
- 14 California Department of Water Resources. 2021b. Bay Delta SCHISM Processed Bathymetry v4.2.
15 Last updated: Feb 26, 2021. Available: [https://data.cnra.ca.gov/dataset/bay-delta-schism-](https://data.cnra.ca.gov/dataset/bay-delta-schism-processed-bathymetry)
16 [processed-bathymetry](https://data.cnra.ca.gov/dataset/bay-delta-schism-processed-bathymetry).
- 17 California Department of Water Resources. 2022. DayFlow, accessed June 2022, at:
18 <https://data.ca.gov/dataset/dayflow>.
- 19 Geyer, W. R., and P. MacCready. 2014. The Estuarine Circulation. *Annual Review of Fluid Mechanics*
20 46:175–197.
- 21 Li, C. and J. O'Donnell. 1997. Tidally driven residual circulation in shallow estuaries with lateral
22 depth variation. *Journal of Geophysical Research: Oceans* 102(C13):27915–27929.
23 doi/10.1029/97JC02330.
- 24 Liang L., and Suits R, 2017. Implementing DETAW in Modeling Hydrodynamics and Water Quality in
25 the Sacramento-San Joaquin Delta. In: *Methodology for Flow and Salinity Estimates in the*
26 *Sacramento-San Joaquin Delta and Suisun Marsh*, 38th Annual Progress Report. Chapter 3.
- 27 Liang L., and Suits, R. 2020. Estimating Suisun Marsh Channel Depletion using DETAW-DCD.
28 *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and*
29 *Suisun Marsh*, 41st Annual Progress Report. Chapter 6.
- 30 Mesinger, F., G. DiMego, E. Kalnay, K. Mitchell, and Coauthors, 2006. North American Regional
31 Reanalysis. *Bulletin of the American Meteorological Society* 87:343–360. doi:10.1175/BAMS-
32 87-3-343.
- 33 Monismith, S. G., Kimmerer, W., Burau, J. R., & Stacey, M. T. (2002). Structure and Flow-Induced
34 Variability of the Subtidal Salinity Field in Northern San Francisco Bay, *Journal of Physical*
35 *Oceanography*, 32(11), 3003-3019. Retrieved June 25, 2021, from
36 [https://journals.ametsoc.org/view/journals/phoc/32/11/1520-](https://journals.ametsoc.org/view/journals/phoc/32/11/1520-0485_2002_032_3003_safivo_2.0.co_2.xml)
37 [0485_2002_032_3003_safivo_2.0.co_2.xml](https://journals.ametsoc.org/view/journals/phoc/32/11/1520-0485_2002_032_3003_safivo_2.0.co_2.xml).
- 38 Monismith, S. G. (2016). A Note on Delta Outflow. *San Francisco Estuary and Watershed Science*,
39 14(3). doi: <https://doi.org/10.15447/sfew.2016v14iss3art3>. Retrieved from
40 <https://escholarship.org/uc/item/89k7b61m>.

- 1 National Oceanic and Atmospheric Administration Tides and Current Data available on the World
2 Wide Web. Available: <https://tidesandcurrents.noaa.gov/>. Accessed: June 2016.
- 3 Robinson, I. S. 1983. Tidally induced residual flows. In Physical Oceanography of Coastal and Shelf
4 Seas. *Elsevier Oceanography Series* 35:321–356 (Johns, B. ed.), Elsevier, New York. doi:
5 10.1016/S0422-9894(08)70505-1.
- 6 Shu, Q., Ateljevich E. 2017. Clifton Court Forebay Transit Time Modeling Analysis. In: Methodology
7 for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 38th
8 Annual Progress Report to the State Water Resources Control Board. Chapter 4. Sacramento,
9 CA: Bay-Delta Office. Delta Modeling Section. California Department of Water Resources.
- 10 Stacey, M. T., Burau, J. R., and Monismith, S. G. (2001), Creation of residual flows in a partially
11 stratified estuary. *Journal of Geophysical Research* 106(C8):17013–17037.
12 doi:10.1029/2000JC000576.
- 13 U.S. Geological Survey. 2020, National Water Information System data available on the World Wide
14 Web (NWIS), accessed June 2016, at URL <http://waterdata.usgs.gov/nwis/>.
- 15 Walters, R. A. 1982. Low-frequency variations in sea level and currents in South San Francisco Bay.
16 *Journal of Physical Oceanography* 12:658–668. doi: [http://dx.doi.org/10.1175/1520-](http://dx.doi.org/10.1175/1520-0485(1982)0122.0.CO;2)
17 [0485\(1982\)0122.0. CO;2](http://dx.doi.org/10.1175/1520-0485(1982)0122.0.CO;2)
- 18 Wang, R., and Ateljevich E. 2012. A Continuous Surface Elevation Map for Modeling (Chapter 6). In
19 Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and
20 Suisun Mars, 33rd Annual Progress Report to the State Water Resources Control Board.
21 California Department of Water Resources, Bay-Delta Office, Delta Modeling Section.
- 22 Wang, R. & Ateljevich, E., Fregoso, T. A. & Jaffe, B. E. (2018). A Revised Continuous Surface Elevation
23 Model for Modeling (Chapter 5). In Methodology for Flow and Salinity Estimates in the
24 Sacramento-San Joaquin Delta and Suisun Marsh, 39th Annual Progress Report to the State
25 Water Resources Control Board. California Department of Water Resources, Bay-Delta
26 Office, Delta Modeling Section.