Appendix 29A
Effects of Sea Level Rise on Delta Tidal Flows and Salinity

29A.1 Introduction

This appendix contains a summary of projected climate change modeling analyses of Delta tidal flows and salinity conditions conducted for Chapter 6, *Surface Water* and Chapter 8, *Water Quality*. This information was used to support the quantitative analysis of climate change effects on Delta tidal flows and salinity patterns described in Appendix 3E, *Potential Seismic and Climate Change Risks to SWP/CVP Water Supplies*, and Chapter 29, *Climate Change*, Section 29.6. Note that the results and findings presented in this appendix are based on projections of future climate changes. The general methods for projecting the effects of sea-level rise on the Delta tidal hydrodynamics are described in section A.5, *Delta Hydrodynamics and Water Quality* of Appendix 5A, *BDCP EIR/EIS Modeling Technical Appendix*.

The 2-D RMA Bay-Delta and the 3-D UnTRIM Bay-Delta tidal hydrodynamic models were used to simulate and evaluate the effects of projected climate change of sea level rise on Bay-Delta tidal flows and salinity intrusion. The effects of sea level rise were then combined with the anticipated effects from the BDCP (north Delta intake diversions and tidal habitat expansion) to simulate the future Delta tidal conditions (water elevations, flows, velocities) and salinity patterns. This appendix summarizes the simulated effects of projected future sea level rise on Delta tidal flows and salinity. The UnTRIM model was used primarily to simulate the potential effects of sea level rise on tidal flows and salinity intrusion (i.e., a deeper estuary will allow greater seawater intrusion). These effects of sea level rise were incorporated in the DSM2 modeling for salinity and in the CALSIM modeling of required Delta outflows for salinity control. The RMA Bay-Delta model was used primarily to simulate the effects of tidal habitat expansion on tidal flows and salinity within the Delta channels; these RMA results will not be described in this appendix, but can be found in Appendix 5A, *BDCP EIR/EIS Modeling Technical Appendix,* Section A.5.

29A.2 Simulating Effects of Sea Level Rise on Tidal Flows and Salinity

The three-dimensional (3-D) UnTRIM Bay-Delta hydrodynamic model is capable of simulating the most important hydrodynamic processes affecting tidal flows and salinity within the SF Estuary (MacWilliams and Gross 2010). This model includes the effects of salinity gradients and density effects on the tidal flows and allows the “gravitational circulation” during moderate flow events to be evaluated. During moderately high outflows, the fresh water (lower density) will flow near the surface of the estuary while seawater (higher density) will tend to move upstream along the bottom of the channel. This increases the net upstream mixing of seawater and increases the seawater intrusion effects in Suisun Bay and the Delta. The salinity effects at Martinez are the cumulative effects of tidal dispersion (gradient mixing) and gravitational circulation (density effects) between the Golden Gate and the Martinez. Tidal dispersion causes mixing along the salinity gradient and gravitational circulation allows salinity to move upstream near the bottom of the channel. High flows increase velocity shear and causes vertical mixing that reduces the gravitational effects. The depth profile and cross-section geometry influence these hydrodynamic mixing processes. An integrated, physically-based model is needed to integrate these multiple processes.

The UnTRIM Bay-Delta model simulated effects of sea level rise on tidal elevations amplitude showed that there was almost no change in the tidal amplitude between the Golden Gate and Martinez (DSM2 Model boundary). Therefore, a linear offset can be applied to the measured tidal elevation at Martinez. The increase in the average tidal elevation at Martinez was about 44 cm for the 45 cm sea level rise assumed at the ocean boundary. The UnTRIM model simulated a 5% increase in the average tidal prism (water volume between low tide and high tide) for the 45 cm sea level rise case at Martinez. The average tidal prism is proportional to the flood-tide flows (upstream) and ebb-tide flows (downstream) each day. The SF Estuary has a mixed-tide with two uneven high tides and two uneven low tides each lunar day. The average flood-tide flow is about 75% of the tidal prism (mean higher high water [MHHW] to mean lower low water [MLLW] volume). These increased tidal flows throughout the estuary may cause increased tidal dispersion (mixing) along the salinity gradient, and cause the salinity at Martinez and upstream in the Delta to increase with sea level rise.

The salinity effects of sea level rise within the Bay and Delta channels were simulated with the 3-D UnTRIM model for six projected sea level rise increments from 15 cm (0.5 feet) to 150 cm (5 feet). The UnTRIM model results generally indicated that the effects of sea level rise on salinity at Martinez and upstream at Chipps Island and Collinsville were linear with sea level rise. The results for 2025 conditions with 15 cm (0.5 feet) projected sea level rise were about 33% of the effects simulated for 2060 conditions with 45 cm (1.5 feet) projected sea level rise.

The calendar year 2002 was used for the UnTRIM model study period. The model was previously calibrated and matched this new period without additional calibration adjustments. The match of the tidal amplitude to the measured tidal elevations was excellent as shown in Figure 29A-1 for tidal elevations at Martinez and Figure 29A-2 for tidal elevations in the San Joaquin River at Jersey Point. Figure 29A-3 shows the match of tidal elevations at Stockton, located 40 miles upstream from the SJR confluence with the Sacramento River.

Simulating the tidal elevations properly (amplitude and timing lag) generally indicates that the tidal flows are also being accurately simulated. Figure 29A-4 shows the match of the simulated and the measured tidal flows in the Sacramento River below Georgiana Slough. The flows in Georgiana Slough and in the Delta Cross Channel (DCC) were also accurately simulated. Figure 29A-5 shows the comparison of the simulated and measured tidal flows in Threemile Slough for 2002. Figure 29A-6 shows the comparison of the simulated and measured tidal flows at Stockton for 2002. Many other USGS and DWR tidal elevation and tidal flow stations were also accurately matched throughout the Delta.

The UnTRIM model simulated salinity also matched the measured salinity data throughout the Bay and Delta. The UnTRIM model simulates practical salinity units (psu) which is very similar to salinity as total dissolved solids in grams per liter (g/l) so that ocean water has a salinity of about 32 g/l and about 32 psu. The measured salinity data are electrical conductance values (normalized to 25°C). The EC data were converted to psu for these validation graphs. Figure 29A-6 shows the comparison of the UnTRIM simulated and the measured salinity (psu) at Martinez for 2002. The maximum Martinez salinity in the fall months when the outflow was about 4,000 cfs was about 20 psu (32,000 μS/cm). Figure 29A-7 shows the comparison of the UnTRIM simulated and the measured salinity (psu) at Mallard Slough (Chipps Island) for 2002. The maximum salinity at Chipps Island was about 7.5 psu. Figure 29A-8 shows the comparison of the UnTRIM simulated and the measured salinity (psu) at Collinsville for 2002. The maximum salinity at Collinsville was about 5 psu.

Figure 29A-9 shows the simulated salinity at Martinez (RSAC054) for the historical conditions and six sea level rise cases (0.5 to 5 feet) for 2002. The simulated increase in daily-average salinity at Martinez was relatively constant throughout the year, with the exception of the high flow periods. Figure 29A-10 shows the simulated salinity at Mallard Slough (Chipps Island) for the historical conditions and six sea level rise cases (0.5 to 5 feet) for 2002. The simulated increase in daily-average salinity was close to zero during January following the high outflows and gradually increases throughout the summer. The predicted salinity increase for all sea level rise cases approaches zero during December as salt was pushed out of Suisun Bay by high Delta outflows. Figure 29A-11 shows the simulated salinity at Jersey Point for the historical conditions and six sea level rise cases (0.5 to 5 feet). The simulated increase in daily-average salinity at Jersey Point was 0 psu from January through May for all cases. The simulated increase in daily-average salinity gradually increased throughout the summer. The largest increases in daily-average salinity for all cases were in November and December, prior to the high flows in late December.

The results from the UnTRIM model at Martinez indicated that the effects of 45 cm of sea level rise (projected 2060 conditions) would be a nearly constant increase in salinity of about 0.8 psu (equivalent to about 1,500 μS/cm). Anderson and Miller (2005) used a similar approach to estimate the effects of sea level rise at Martinez by analyzing EC simulated using the RMA2 Bay-Delta model for 30 cm sea level rise. They found a constant increase of about 840 μS/cm. This compares to a constant increase of about 0.6 psu (1,200 μS/cm) found with the UnTRIM model.

The simulated salinity increased at all Bay-Delta locations with sea level rise. Much of the simulated increase in salinity was attributed to increases in tidal dispersion associated with the increased tidal prism for sea level rise cases. Gravitational circulation was simulated to increase slightly with sea level rise in Suisun Bay and the Western Delta but show little increase in the Bay itself.

The UnTRIM model results for 2002 were processed to show the simulated upstream movement of X2 caused by sea level rise. The X2 position is estimated as the location of the daily average near-bottom salinity of 2 psu. This has been assumed in D-1641 to correspond to a surface EC measurement of 2,640 μS/cm, based on the average salinity stratification near X2 and the conversion between 2 psu and 3,800 μS/cm EC. The X2 position is highly variable within each day because the tidal excursion is several kilometers in this portion of the estuary. Nevertheless, the daily average bottom salinity of 2 psu was calculated for the UnTRIM simulations of the historical 2002 conditions (i.e., outflow) with various sea level rise assumptions and the changes (i.e., upstream movement) of X2 was evaluated. Figure 29A-12 shows the simulated X2 location for the historical simulation and the 15 cm (projected 2025 conditions), 30 cm, 45 cm (projected 2060 conditions) and 60 cm sea level rise cases. The UnTRIM model simulated the X2 position to move upstream a constant distance of about 2 km for the projected 2060 conditions of 45 cm sea level rise during the entire year of 2002, with a range of Delta outflow from about 12,000 cfs in April and May to about 4,000 cfs from August to October. The increased daily X2 distance is shown in the bottom panel. Figure 29A-13 shows that the simulated daily changes in X2 increased linearly with projected sea level rise.

The simulated salinity effects for 2002 conditions were generally consistent with previous analyses conducted as part of the DRMS studies (Gross et al., 2007a; Gross et al., 2007b). Since the Delta outflow conditions were higher for the sea level rise analysis conducted for DRMS (Gross et al., 2007a), gravitational circulation was estimated to be more substantial for those higher flow conditions. However, the spatial variability of dispersion components and variability with sea level rise simulated in the DRMS studies (Gross et al., 2007a) were generally similar to those simulated for 2002. The salinity effects simulated for the 2002 conditions apply to moderate to low flow conditions typical of summer and fall when salt intrusion is most pronounced.

The simulations of the effects of sea level rise on salinity with the UnTRIM model assumed no operational response (i.e., no increased outflow) to the increased salinity intrusion. The simulated effects of sea level rise on salinity from the UnTRIM Bay-Delta model were subsequently used to modify the increased salinity at Martinez (downstream boundary) and the increased tidal dispersion in Suisun Bay so that the DSM2 model results generally matched the UnTRIM model results. The CALSIM II model required Delta outflow calculations (using ANN methods) was also modified to match the DSM2 model results. The CALSIM model then was used to estimate the increased Delta outflow that would be required to maintain the X2 position with the projected sea level rise conditions (0.5 feet for ELT, 1.5 feet for LLT).

29A.3 References

Anderson, J. and A. Miller. 2005. *Estimation of Electrical Conductivity at Martinez for Sea Level Rise Conditions, Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh*. 26th Annual Progress Report, Chapter 5.

Gross, E. S., N. Nidzieko, and M. L. MacWilliams. 2007a. *Parameterization of Mixing Using a Three-Dimensional Hydrodynamic Model*. Delta Risk Management Strategy. March. Prepared for California Department of Water Resources, Sacramento CA.

Gross, E. S., MacWilliams M. L., and N. Nidzieko, N. 2007b. *Three-Dimensional Salinity Simulations of Sea Level Rise Scenarios, Delta Risk Management Study*. March. Prepared for California Department of Water Resources, Sacramento CA.

MacWilliams, M. L. and E. S. Gross. 2010. *UNTRIM San Francisco Bay–Delta Model Sea Level Rise Scenario Modeling Report*. July 16. Prepared for Science Applications International Corporation and California Department of Water Resources.

1 **Table 29A-1. Summary of Existing Surface Area and Volume of Delta Channels at -2 feet, 0 feet, +2 feet and +4 feet msl.**

	Length (Miles)	Total Surface Area (acres) @ Elevation (feet msl)				Total Volume (acre-feet) @ Elevation (feet msl)			
		-2	0	2	4	-2	0	2	4
Vernalis to Head of Old River	19.8	275	342	475	592	952	1,573	2,372	3,447
Head of Old River to Stockton DWSC	14.5	326	346	365	384	2,097	2,769	3,480	4,229
DWSC to Turner Cut	13.5	743	757	770	783	12,276	13,776	15,303	16,855
SJR Turner to Old River Mouth	17.8	1,644	1,684	1,720	1,753	30,788	34,117	37,521	40,995
Mouth of Old River to Jersey Point	21.5	4,644	4,754	4,834	4,884	98,870	108,272	117,865	127,587
Jersey Point to Confluence	33.3	8,542	8,680	8,771	8,839	156,280	173,166	190,276	207,543
Head of Old River to Grant Line Canal	8.2	173	187	199	212	935	1,296	1,683	2,094
Old River at Grant Line to DMC	16.2	313	359	393	419	1,569	2,242	2,995	3,808
Old River from DMC to Victoria & West Canal	3.1	192	202	211	222	1,676	2,069	2,482	2,914
Old River Victoria to Rock Slough	25.9	1,539	1,578	1,614	1,645	17,688	20,805	23,997	27,257
Old River Rock Slough to Mouth	17.2	1,228	1,280	1,312	1,340	16,941	19,449	22,043	24,696
Middle River Head to Victoria	12.3	126	167	204	230	363	656	1,028	1,462
Middle River Victoria to Mouth	46.0	3,575	3,697	3,801	3,892	46,929	54,201	61,701	69,395
Sugar Cut and Tom Paine	4.6	111	115	119	122	312	538	772	1,013
Paradise Cut & Drainage Canal	6.2	148	165	171	177	522	840	1,177	1,525
Grant Line Canal	8.9	335	366	388	412	2,131	2,835	3,588	4,388
Victoria Canal (North Canal)	4.8	229	246	261	276	1,863	2,340	2,847	3,384
Franks Tract & Big Break	35.7	6,275	6,385	6,437	6,483	46,742	59,407	72,230	85,150
Mokelumne River Channels	105.8	4,398	4,639	4,868	5,075	46,615	55,656	65,165	75,109
Liberty Island	5.0	4,500	4,750	5,000	5,250	18,000	27,500	37,500	47,500
Sutter & Steamboat Sloughs	36.2	951	1,023	1,070	1,111	7,477	9,452	11,547	13,728
Sacramento Ship Channel	29.7	1,900	1,960	2,016	2,074	34,901	38,761	42,738	46,828
Cache Slough	21.7	1,235	1,273	1,309	1,339	14,547	17,056	19,639	22,288
Sacramento River to Emmaton	56.5	5,423	5,562	5,682	5,783	82,952	93,938	105,187	116,653
Suisun Bay	48.3	22,282	22,958	23,357	23,603	320,309	365,577	411,919	458,891
Suisun Marsh	110.7	12,390	12,624	12,775	12,881	42,281	66,932	91,976	117,264
Total Delta	708.6	78,996	81,349	83,123	84,530	988,018	1,147,722	1,311,528	1,478,503
Upstream of Chipps Island	549.6	44,324	45,766	46,991	48,046	625,428	715,213	807,634	902,348
South Delta Channels	178.4	16,124	16,616	16,980	17,301	150,743	183,499	217,108	251,397
Upstream of South Delta Barriers	45.7	947	1,078	1,184	1,273	4,999	7,029	9,293	11,751
Clifton Court Forebay	2.0	2,140	2,150	2,160	2,170	13,905	18,200	22,515	26,850

1 **Table 29A-2. Summary of Tidal Habitat Restoration Areas Simulated for the Late-Long-Term Period with the RMA Bay-Delta Model**

ROA	Area Above EHW (Ac)	Area MHHW to EHW (Ac)	Area MLLW to MHHW (Ac)	Area Below MLLW (Ac)	Total Area (Ac)	% Tidal Habitat (between MLLW and MHHW)
Suisun Marsh	205	435	3,676	10,073	14,389	26%
Cache Slough	4,080	1,955	6,878	7,421	20,334	34%
West Delta	287	39	2,954	956	4,236	70%
Mokelumne-Cosumnes	344	109	822	2,018	3,293	25%
East Delta	792	221	240	910	2,163	70%
South Delta	8,292	1,395	1,848	10,948	22,483	8%
Total	14,000	4,154	16,418	32,326	66,898	25%

Tidal volume below MLLW estimated assuming average depth below MLLW of 4 feet to be about 125,000 af.
Tidal volume between MLLW and MHHW estimated assuming 6 feet tidal range to be about 240,000 af.

2