

Appendix 29A

**Effects of Sea Level Rise on Delta
Tidal Flows and Salinity**

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1 Appendix 29A
2 **Effects of Sea Level Rise on Delta**
3 **Tidal Flows and Salinity**

4 **29A.1 Introduction**

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

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

27 **29A.2 Simulating Effects of Sea Level Rise on Tidal**
28 **Flows and Salinity**

29 The three-dimensional (3-D) UnTRIM Bay-Delta hydrodynamic model is capable of simulating the
30 most important hydrodynamic processes affecting tidal flows and salinity within the SF Estuary
31 (MacWilliams and Gross 2010). This model includes the effects of salinity gradients and density
32 effects on the tidal flows and allows the “gravitational circulation” during moderate flow events to
33 be evaluated. During moderately high outflows, the fresh water (lower density) will flow near the
34 surface of the estuary while seawater (higher density) will tend to move upstream along the bottom
35 of the channel. This increases the net upstream mixing of seawater and increases the seawater
36 intrusion effects in Suisun Bay and the Delta. The salinity effects at Martinez are the cumulative
37 effects of tidal dispersion (gradient mixing) and gravitational circulation (density effects) between
38 the Golden Gate and the Martinez. Tidal dispersion causes mixing along the salinity gradient and

1 gravitational circulation allows salinity to move upstream near the bottom of the channel. High
2 flows increase velocity shear and causes vertical mixing that reduces the gravitational effects. The
3 depth profile and cross-section geometry influence these hydrodynamic mixing processes. An
4 integrated, physically-based model is needed to integrate these multiple processes.

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

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

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

30 Simulating the tidal elevations properly (amplitude and timing lag) generally indicates that the tidal
31 flows are also being accurately simulated. Figure 29A-4 shows the match of the simulated and the
32 measured tidal flows in the Sacramento River below Georgiana Slough. The flows in Georgiana
33 Slough and in the Delta Cross Channel (DCC) were also accurately simulated. Figure 29A-5 shows
34 the comparison of the simulated and measured tidal flows in Threemile Slough for 2002. Figure
35 29A-6 shows the comparison of the simulated and measured tidal flows at Stockton for 2002. Many
36 other USGS and DWR tidal elevation and tidal flow stations were also accurately matched
37 throughout the Delta.

38 The UnTRIM model simulated salinity also matched the measured salinity data throughout the Bay
39 and Delta. The UnTRIM model simulates practical salinity units (psu) which is very similar to
40 salinity as total dissolved solids in grams per liter (g/l) so that ocean water has a salinity of about 32
41 g/l and about 32 psu. The measured salinity data are electrical conductance values (normalized to
42 25°C). The EC data were converted to psu for these validation graphs. Figure 29A-6 shows the
43 comparison of the UnTRIM simulated and the measured salinity (psu) at Martinez for 2002. The
44 maximum Martinez salinity in the fall months when the outflow was about 4,000 cfs was about 20

1 psu (32,000 $\mu\text{S}/\text{cm}$). Figure 29A-7 shows the comparison of the UnTRIM simulated and the
2 measured salinity (psu) at Mallard Slough (Chippis Island) for 2002. The maximum salinity at Chippis
3 Island was about 7.5 psu. Figure 29A-8 shows the comparison of the UnTRIM simulated and the
4 measured salinity (psu) at Collinsville for 2002. The maximum salinity at Collinsville was about 5
5 psu.

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

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

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

29 The UnTRIM model results for 2002 were processed to show the simulated upstream movement of
30 X2 caused by sea level rise. The X2 position is estimated as the location of the daily average near-
31 bottom salinity of 2 psu. This has been assumed in D-1641 to correspond to a surface EC
32 measurement of 2,640 $\mu\text{S}/\text{cm}$, based on the average salinity stratification near X2 and the
33 conversion between 2 psu and 3,800 $\mu\text{S}/\text{cm}$ EC. The X2 position is highly variable within each day
34 because the tidal excursion is several kilometers in this portion of the estuary. Nevertheless, the
35 daily average bottom salinity of 2 psu was calculated for the UnTRIM simulations of the historical
36 2002 conditions (i.e., outflow) with various sea level rise assumptions and the changes (i.e.,
37 upstream movement) of X2 was evaluated. Figure 29A-12 shows the simulated X2 location for the
38 historical simulation and the 15 cm (projected 2025 conditions), 30 cm, 45 cm (projected 2060
39 conditions) and 60 cm sea level rise cases. The UnTRIM model simulated the X2 position to move
40 upstream a constant distance of about 2 km for the projected 2060 conditions of 45 cm sea level rise
41 during the entire year of 2002, with a range of Delta outflow from about 12,000 cfs in April and May
42 to about 4,000 cfs from August to October. The increased daily X2 distance is shown in the bottom
43 panel. Figure 29A-13 shows that the simulated daily changes in X2 increased linearly with projected
44 sea level rise.

1 The simulated salinity effects for 2002 conditions were generally consistent with previous analyses
2 conducted as part of the DRMS studies (Gross et al., 2007a; Gross et al., 2007b). Since the Delta
3 outflow conditions were higher for the sea level rise analysis conducted for DRMS (Gross et al.,
4 2007a), gravitational circulation was estimated to be more substantial for those higher flow
5 conditions. However, the spatial variability of dispersion components and variability with sea level
6 rise simulated in the DRMS studies (Gross et al., 2007a) were generally similar to those simulated
7 for 2002. The salinity effects simulated for the 2002 conditions apply to moderate to low flow
8 conditions typical of summer and fall when salt intrusion is most pronounced.

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

18 29A.3 References

- 19 Anderson, J. and A. Miller. 2005. *Estimation of Electrical Conductivity at Martinez for Sea Level Rise*
20 *Conditions, Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and*
21 *Suisun Marsh*. 26th Annual Progress Report, Chapter 5.
- 22 Gross, E. S., N. Nidzieko, and M. L. MacWilliams. 2007a. *Parameterization of Mixing Using a Three-*
23 *Dimensional Hydrodynamic Model*. Delta Risk Management Strategy. March. Prepared for
24 California Department of Water Resources, Sacramento CA.
- 25 Gross, E. S., MacWilliams M. L., and N. Nidzieko, N. 2007b. *Three-Dimensional Salinity Simulations of*
26 *Sea Level Rise Scenarios, Delta Risk Management Study*. March. Prepared for California
27 Department of Water Resources, Sacramento CA.
- 28 MacWilliams, M. L. and E. S. Gross. 2010. *UNTRIM San Francisco Bay-Delta Model Sea Level Rise*
29 *Scenario Modeling Report*. July 16. Prepared for Science Applications International Corporation
30 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.**

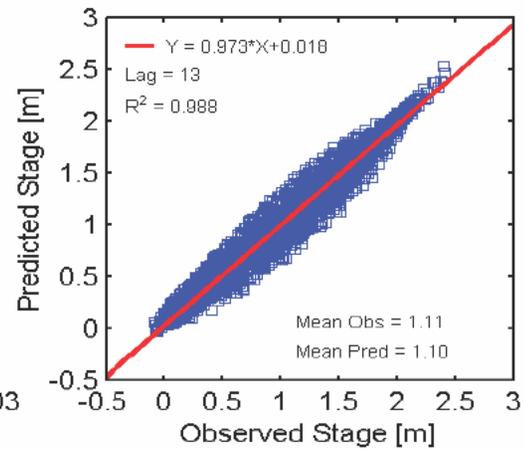
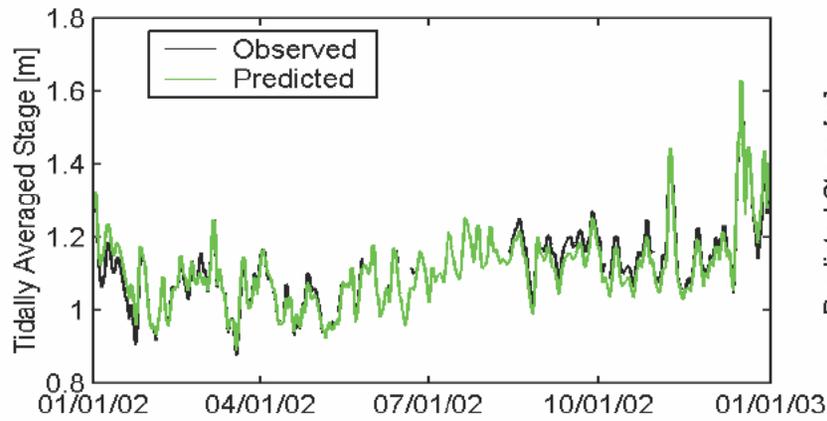
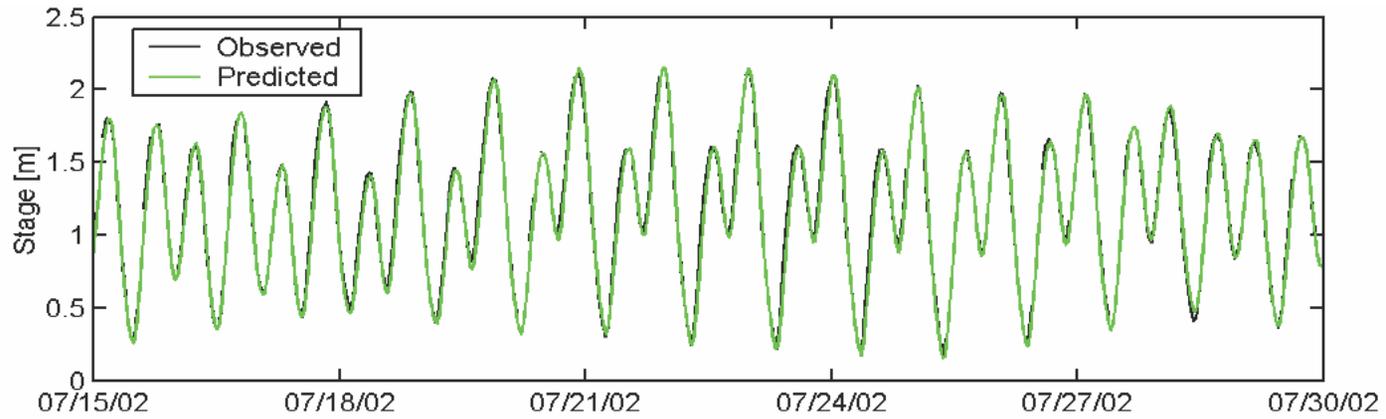
	Length (Miles)	Total Surface Area (acres) @ Elevation (feet msl)				Total Volume (acre-feet) @ Elevation (feet msl)			
		-2	0	2	4	-2	0	2	4
Vernalis to Head of Old River	19.8	275	342	475	592	952	1,573	2,372	3,447
Head of Old River to Stockton DWSC	14.5	326	346	365	384	2,097	2,769	3,480	4,229
DWSC to Turner 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**

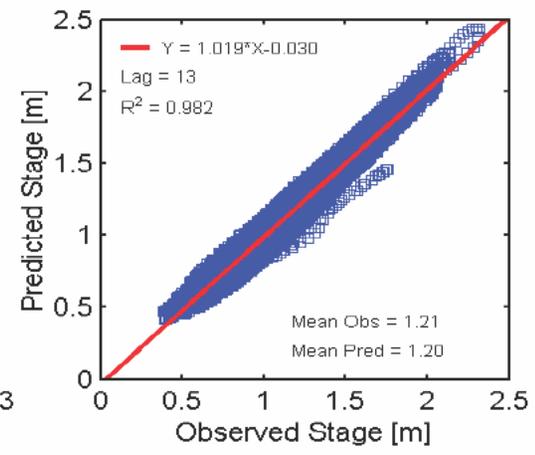
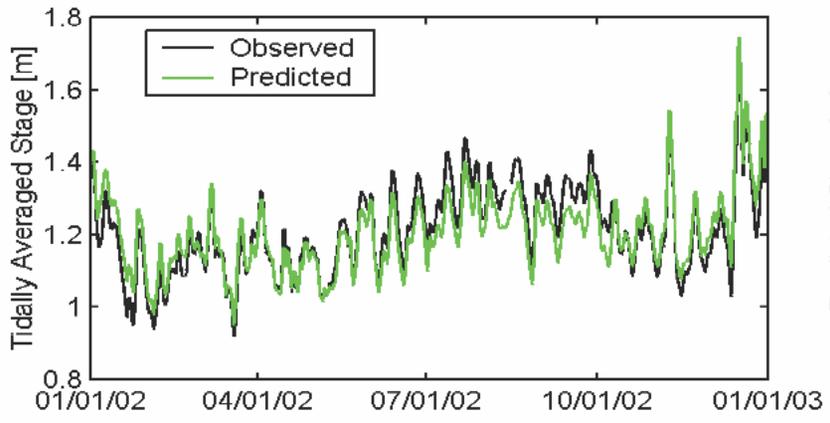
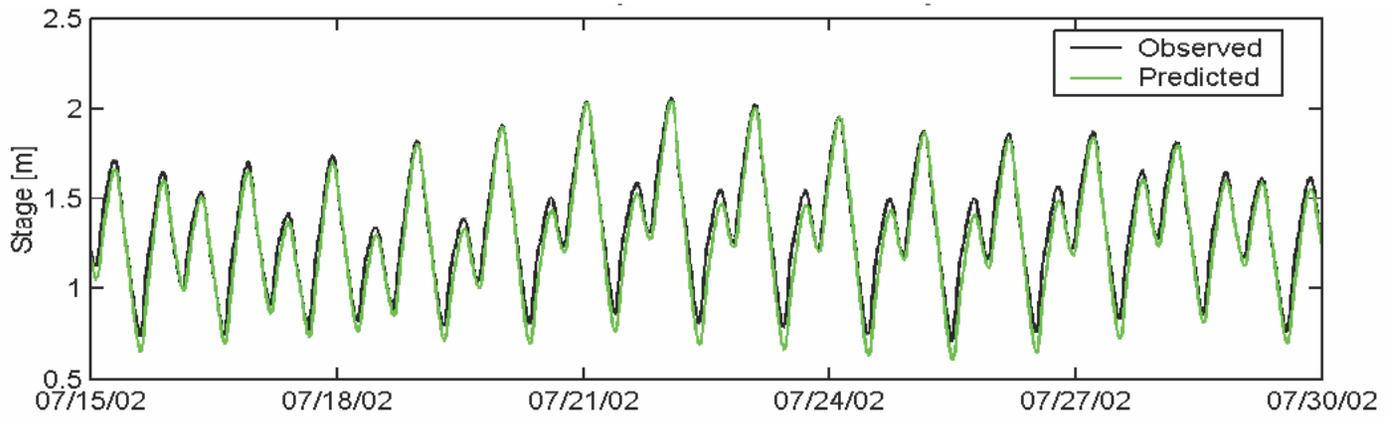
ROA	Area Above EHW (Ac)	Area MHHW to EHW (Ac)	Area MLLW to MHHW (Ac)	Area Below MLLW (Ac)	Total Area (Ac)	% Tidal Habitat (between MLLW and MHHW)
Suisun Marsh	205	435	3,676	10,073	14,389	26%
Cache Slough	4,080	1,955	6,878	7,421	20,334	34%
West Delta	287	39	2,954	956	4,236	70%
Mokelumne-Cosumnes	344	109	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.

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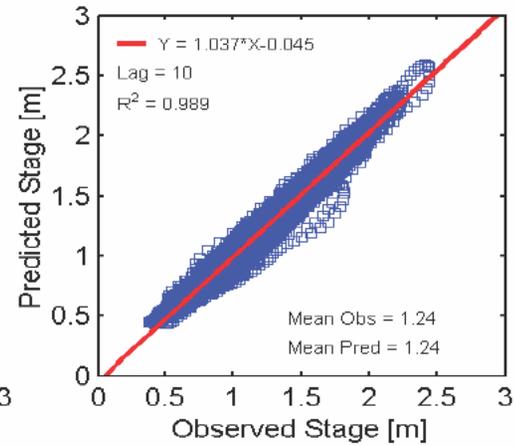
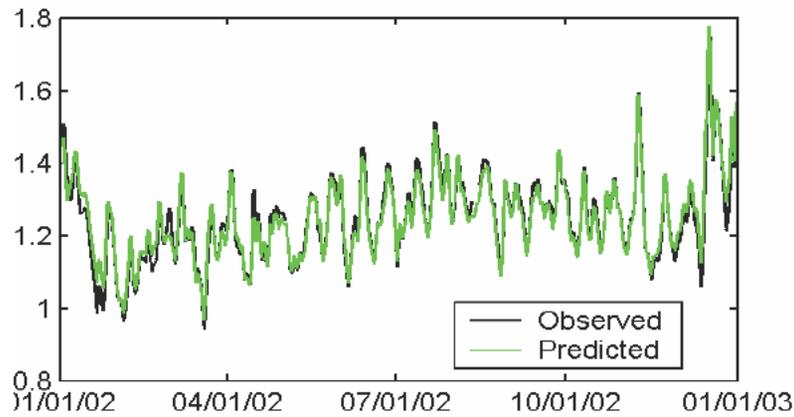
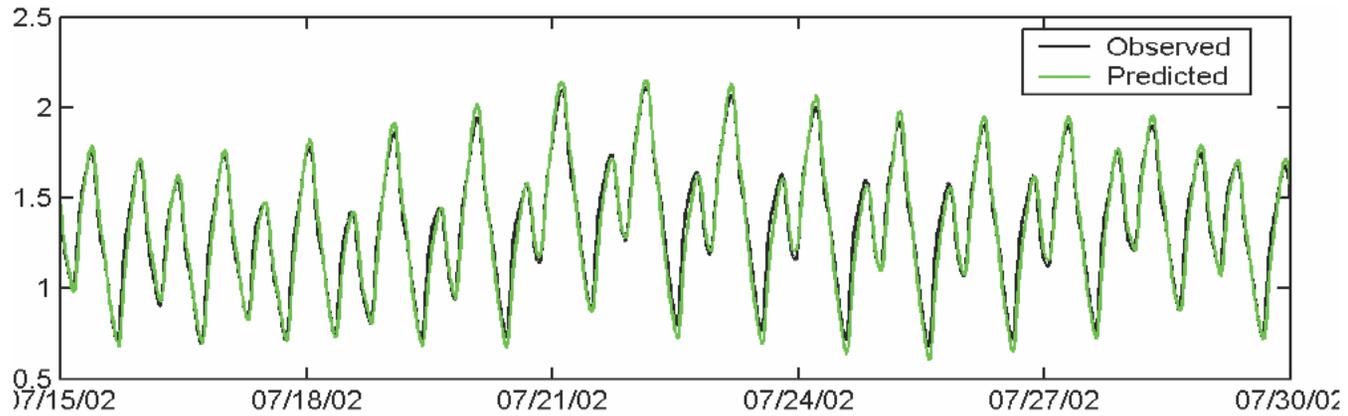


Appendix 29A-1
Comparison of UnTRIM modeled and measured tidal elevations
at Martinez for 2002

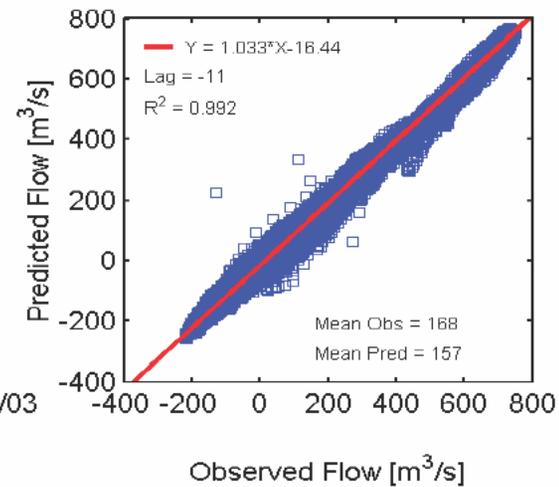
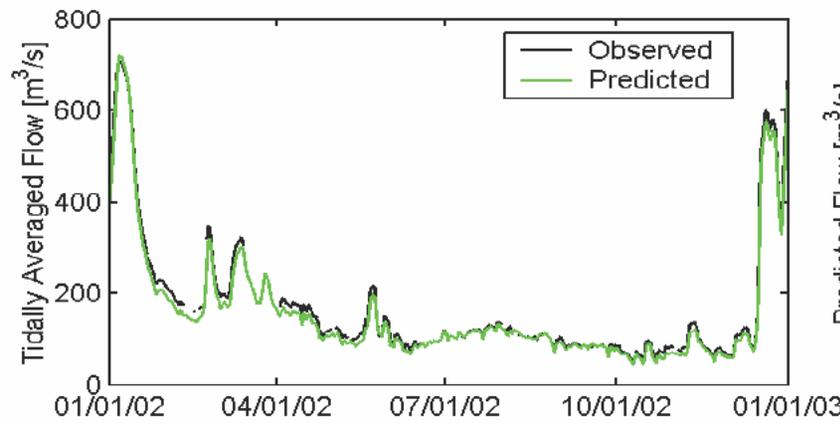
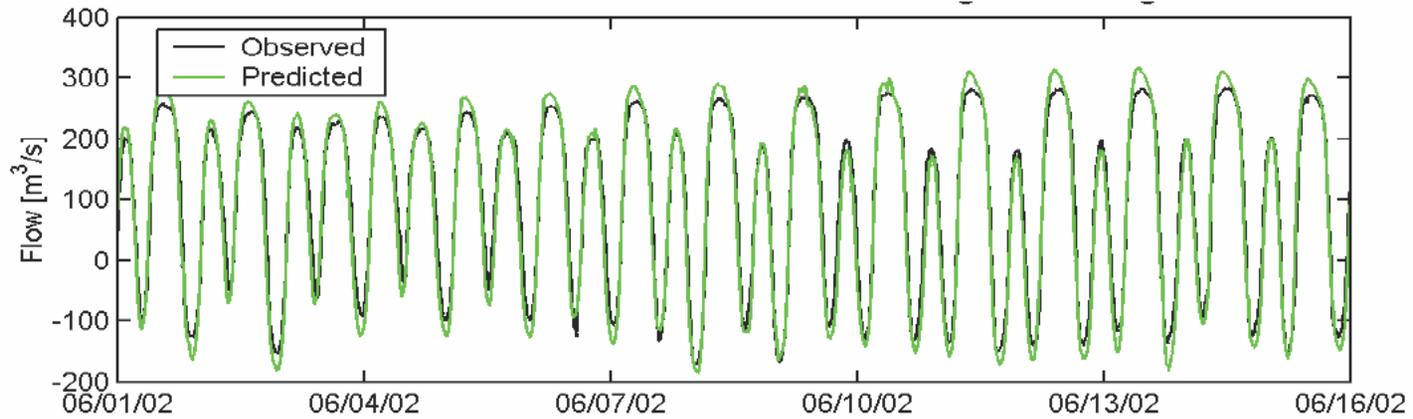


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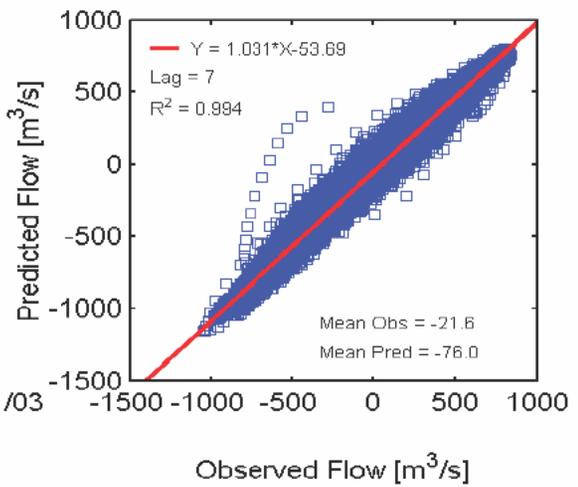
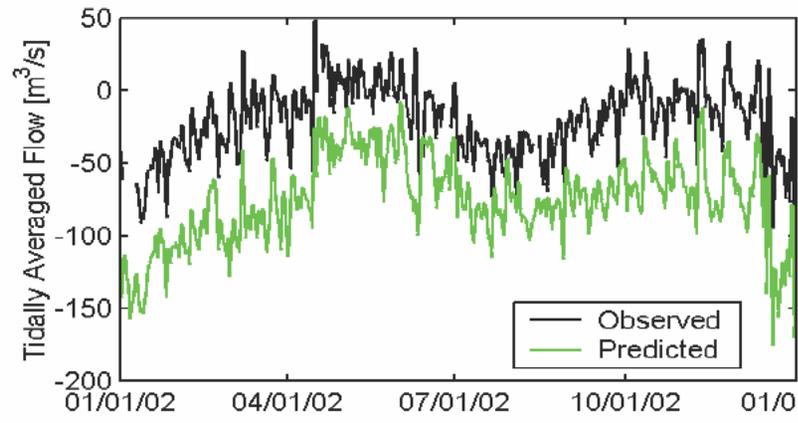
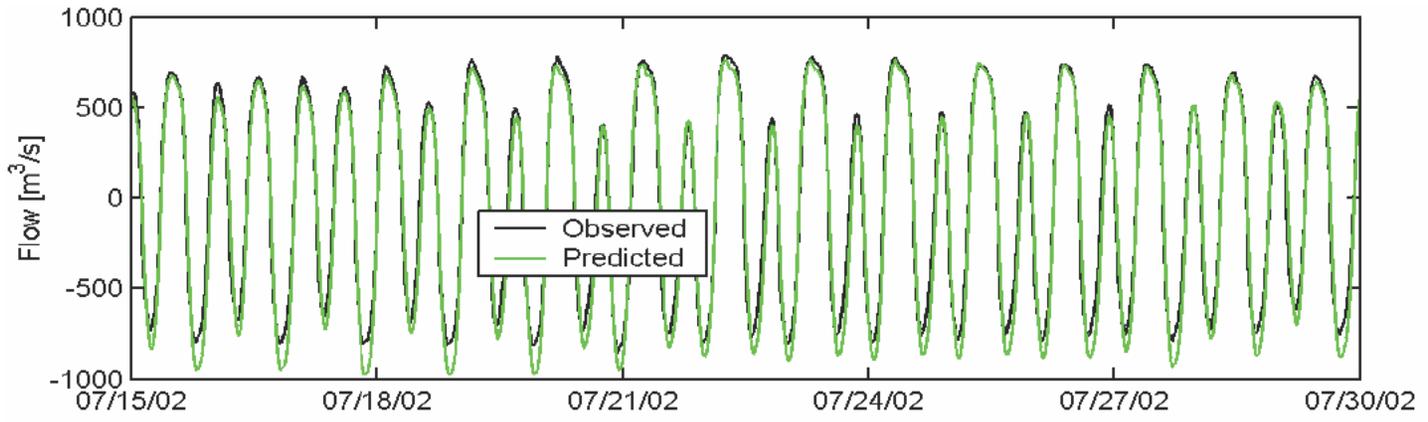
Appendix 29A-2
Comparison of UnTRIM modeled and measured tidal elevations
at Jersey Point for 2002



Appendix 29A-3
Comparison of UnTRIM modeled and measured tidal elevations
at Stockton for 2002



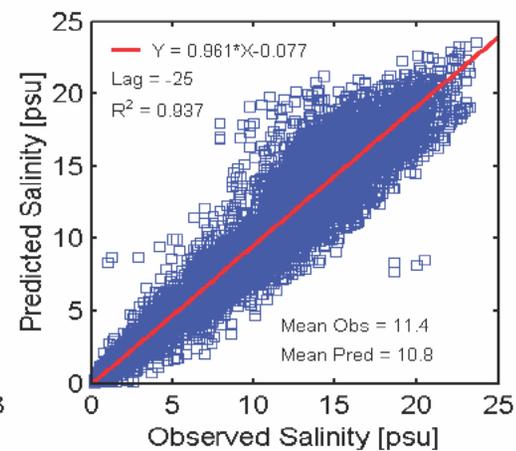
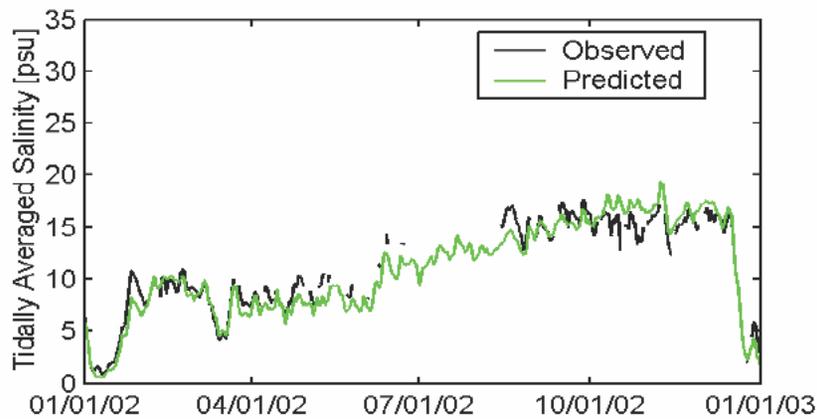
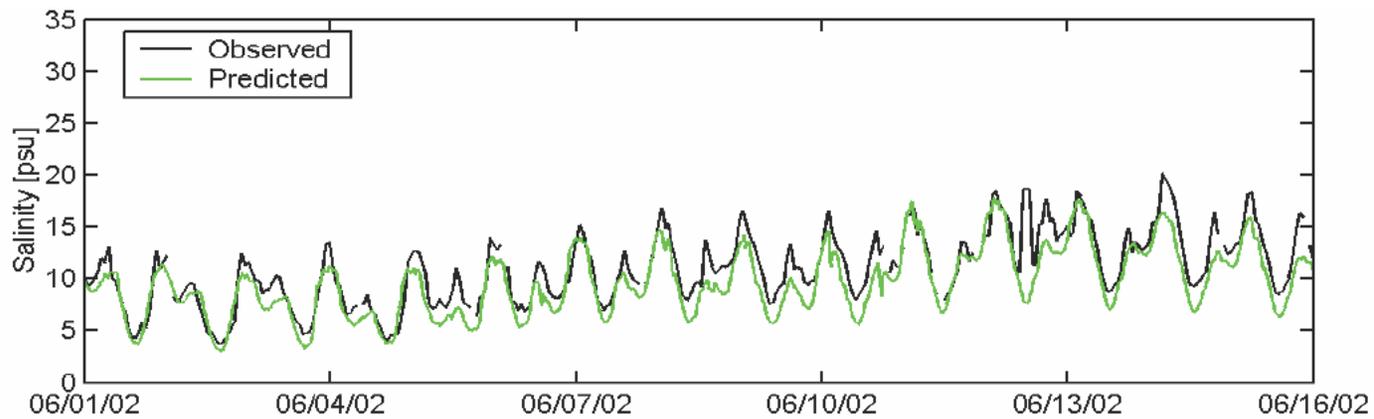
Appendix 29A-4
Comparison of UnTRIM simulated and measured tidal flow in Sacramento River
downstream of Georgiana Slough for 2002



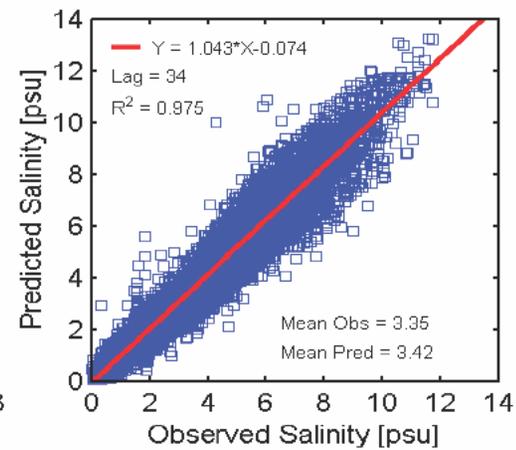
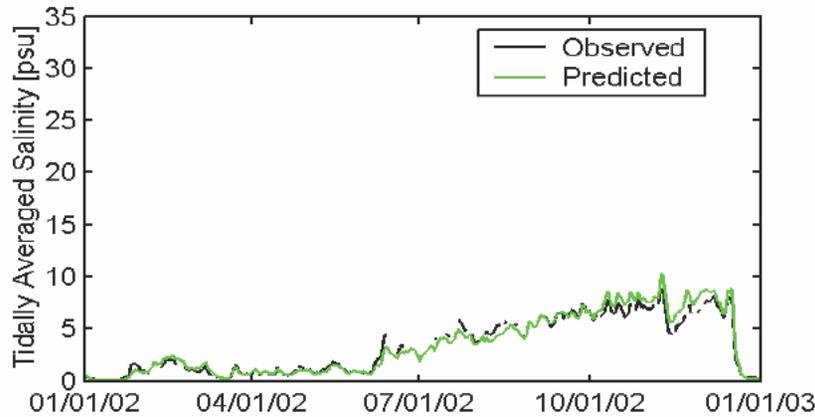
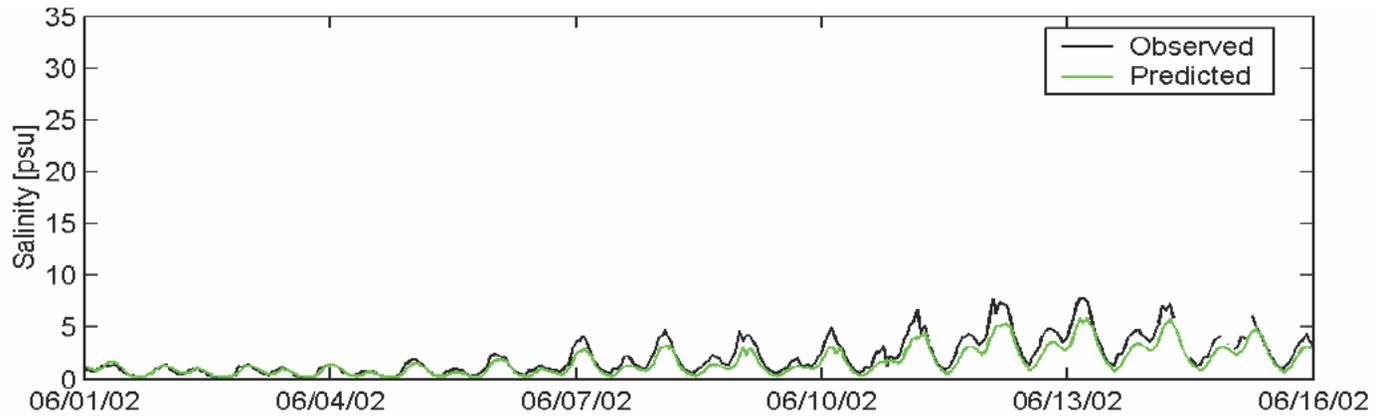
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Appendix 29A-5

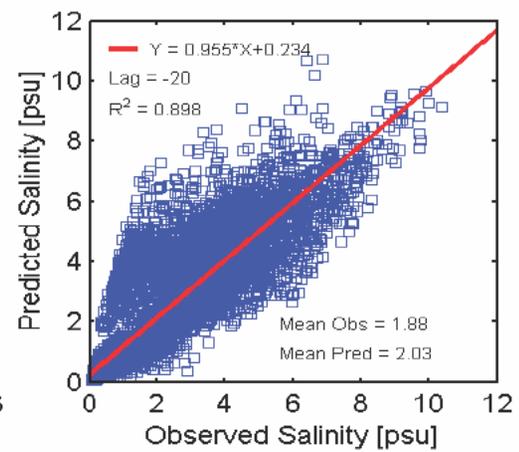
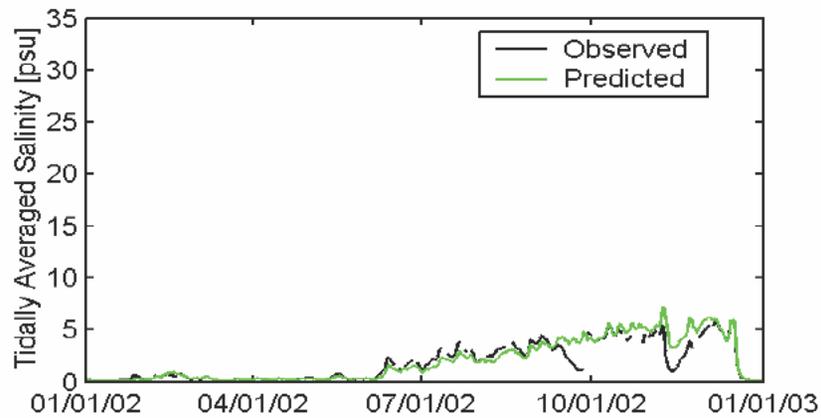
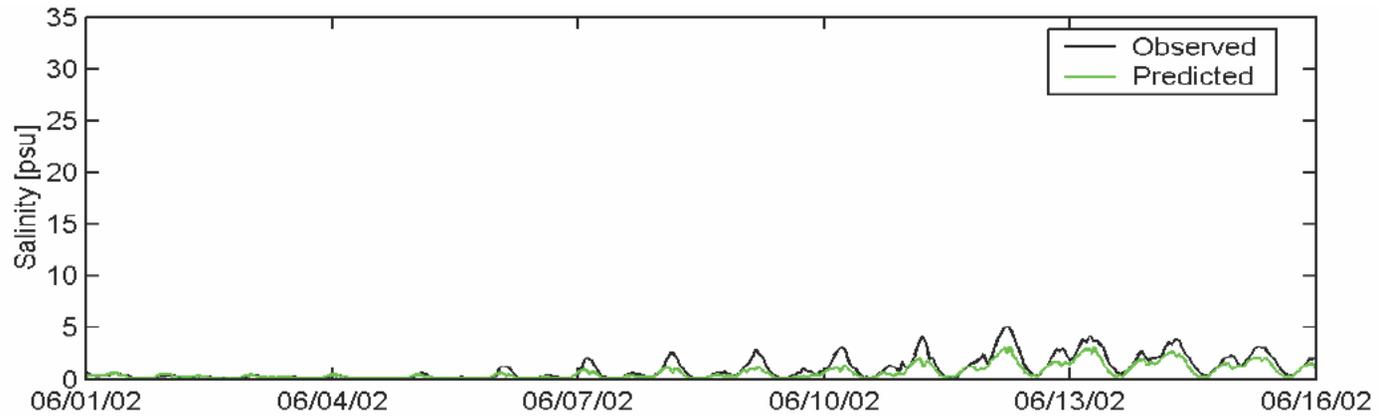
Comparison of UnTRIM simulated and measured tidal flow in Threemile Slough for 2002. [Positive net flow is towards the Sacramento River. The net modeled flows were about 50 cms (1,500 cfs) too high]



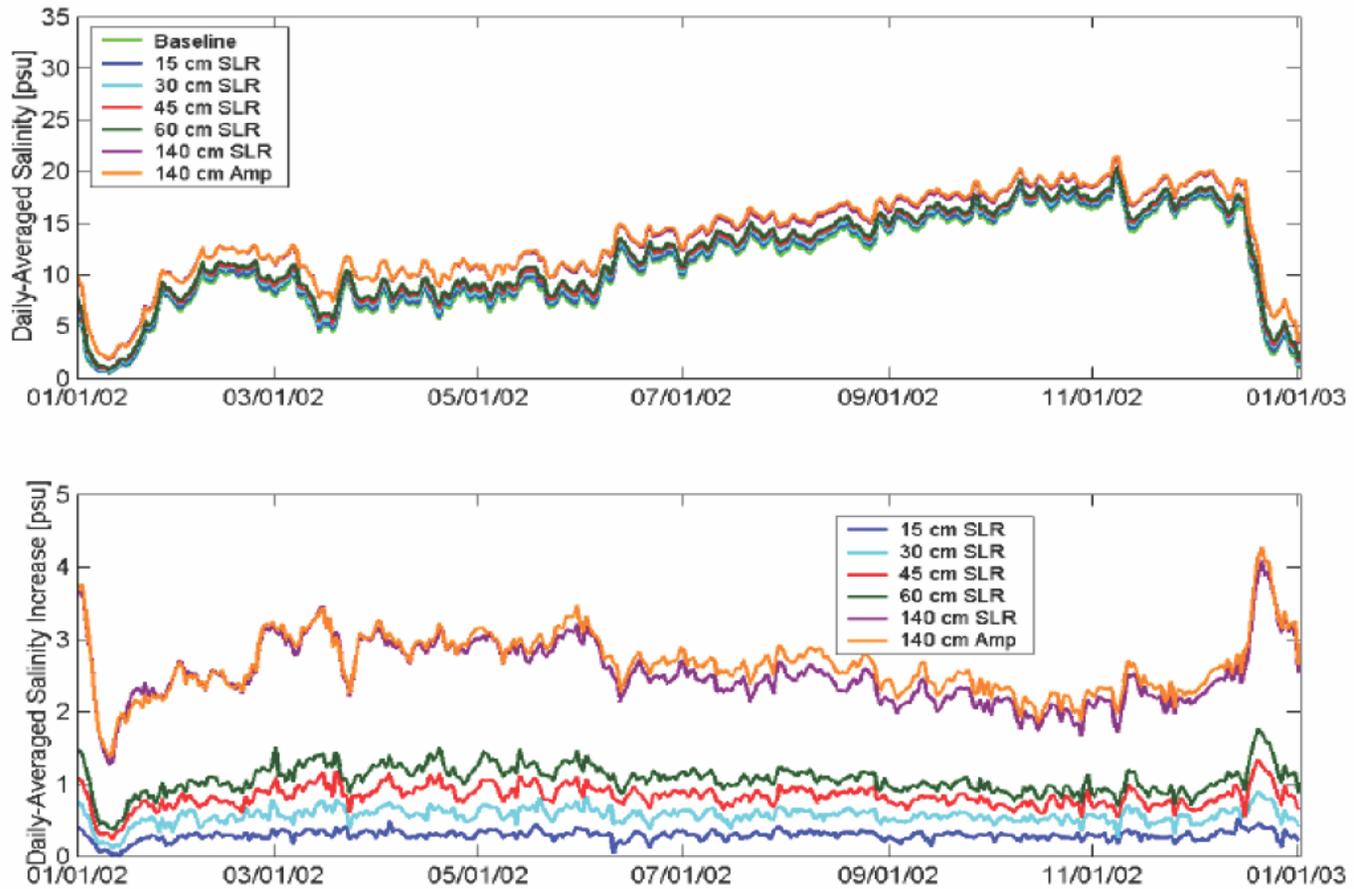
Appendix 29A-6
Comparison of UnTRIM simulated and measured salinity
at Martinez for 2002



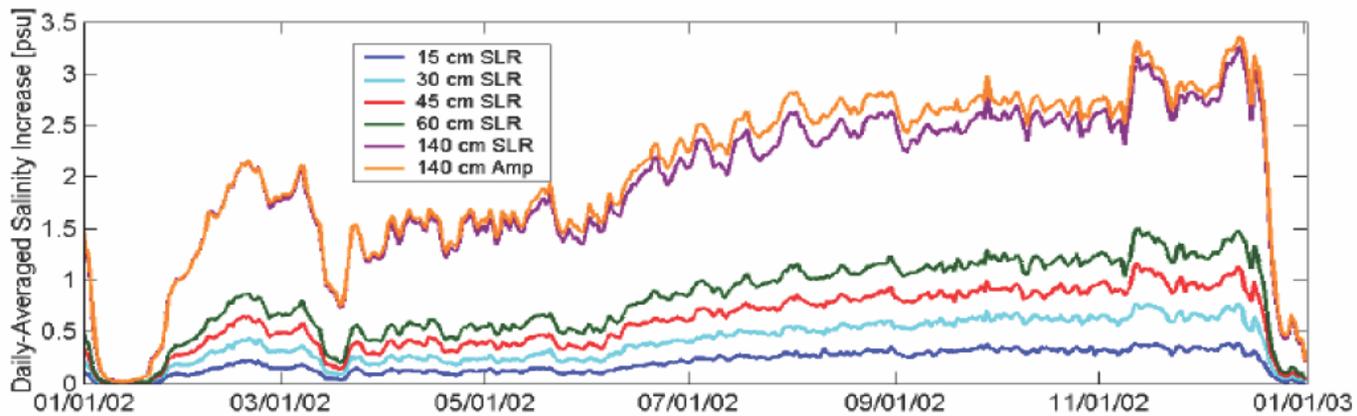
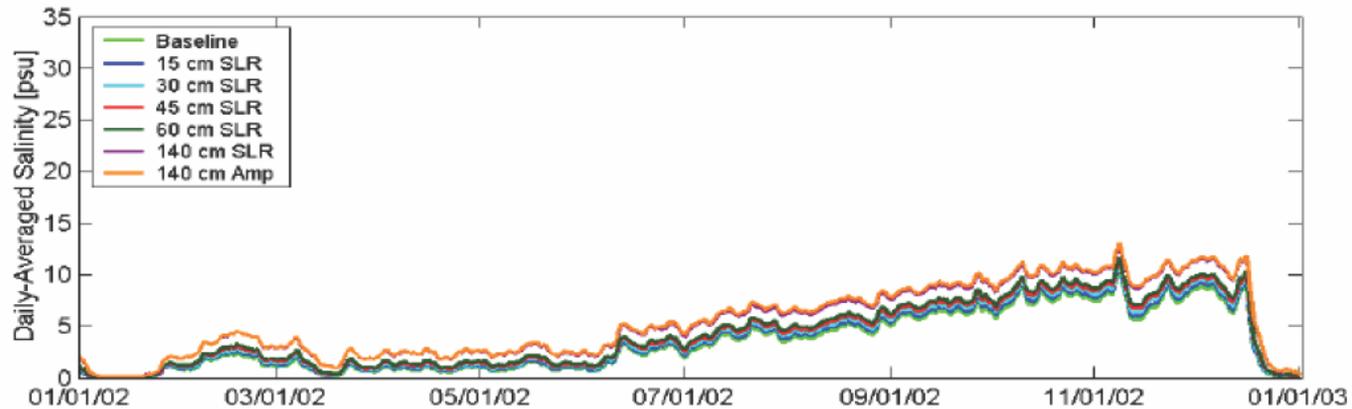
Appendix 29A-7
Comparison of UnTRIM simulated and measured salinity
at Mallard Slough (Chippis Island) for 2002



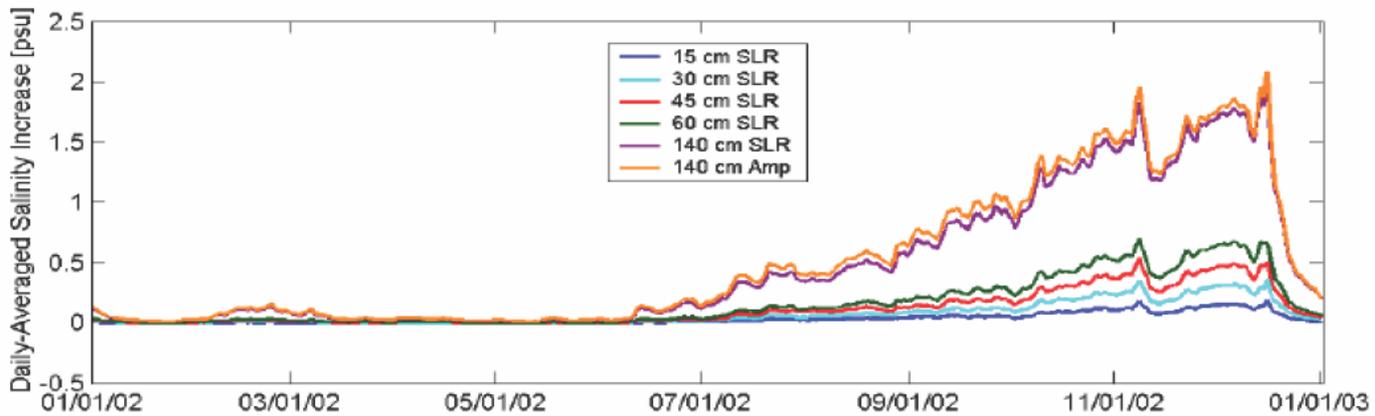
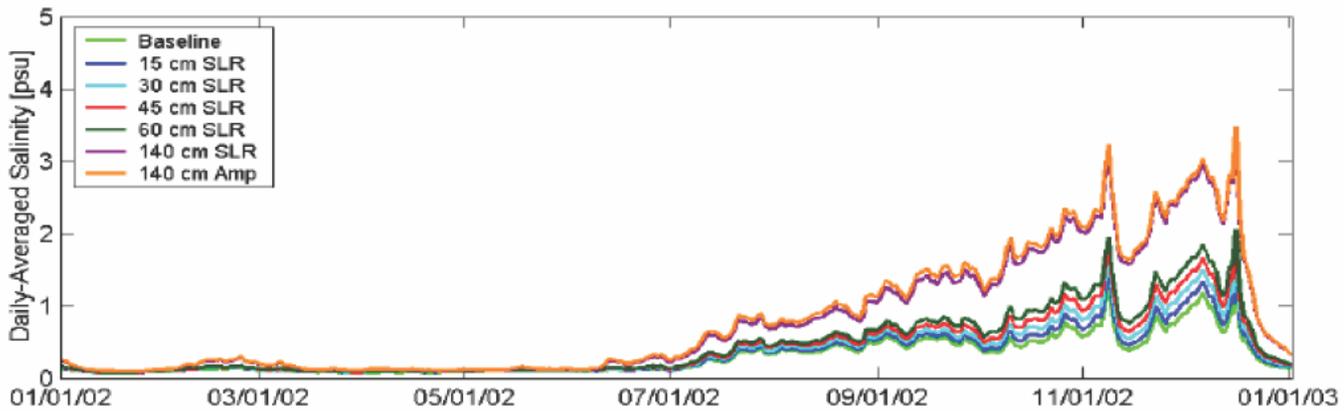
Appendix 29A-8
Comparison of UnTRIM simulated and measured salinity
at Collinsville for 2002



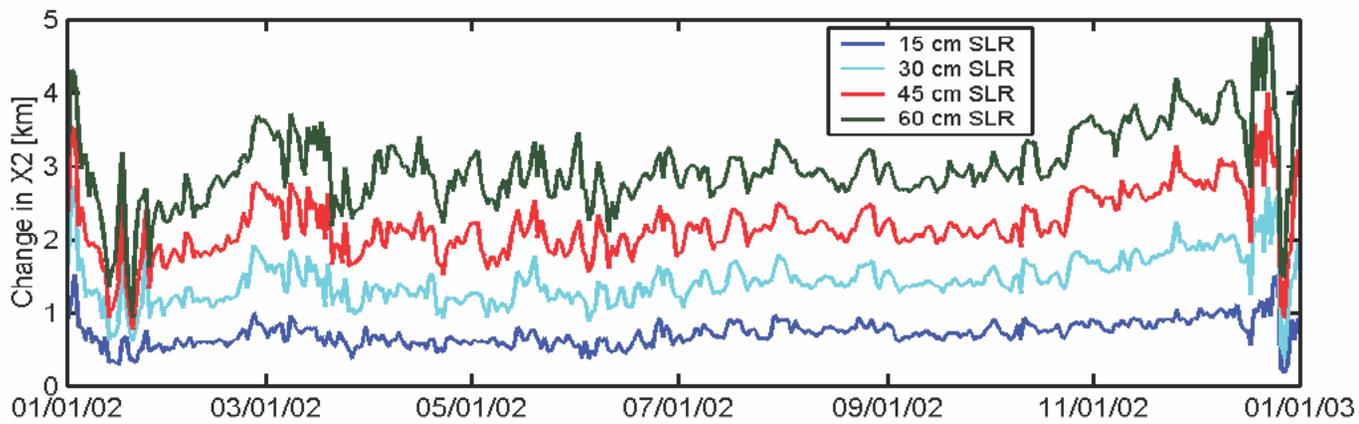
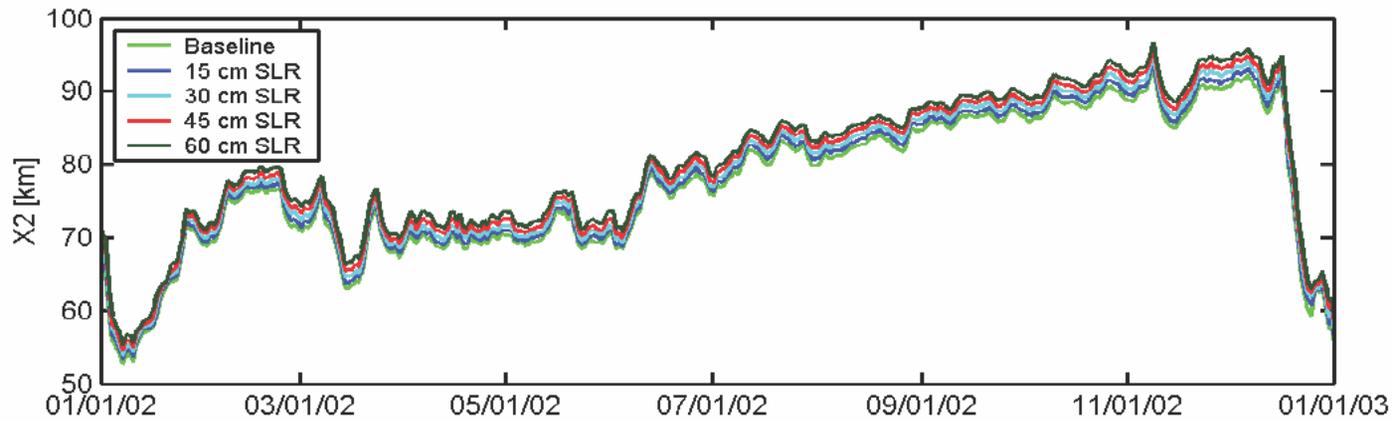
Appendix 29A-9
 UnTRIM Simulated Salinity at Martinez
 for a Range of Assumed Sea Level Rise (15 cm to 140 cm) for 2002



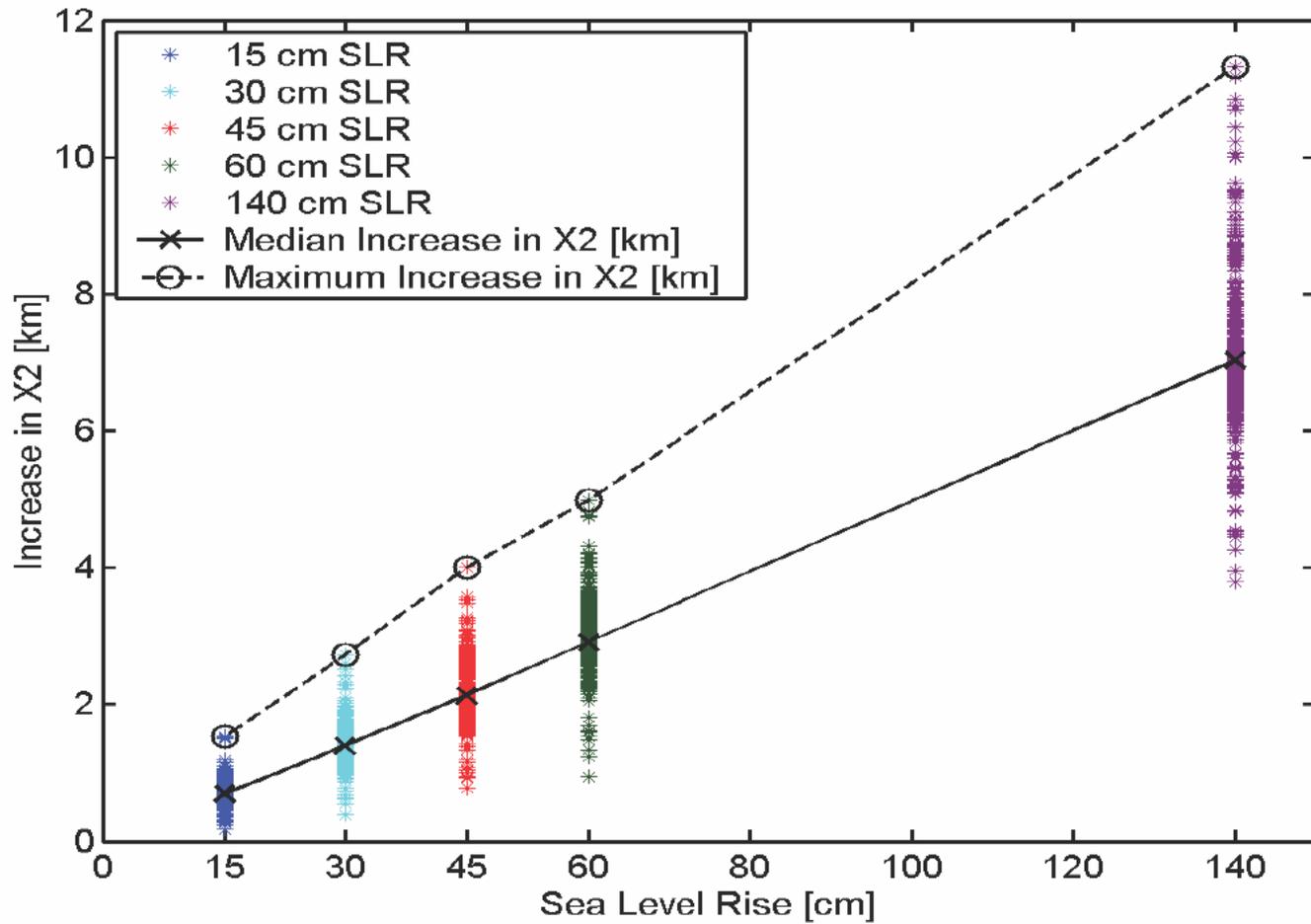
Appendix 29A-10
 UnTRIM Simulated Salinity at Mallard Slough (Chippis Island)
 for a Range of Assumed Sea Level Rise (15 cm to 140 cm) for 2002



Appendix 29A-11
 UnTRIM Simulated Salinity at Jersey Point
 for a Range of Assumed Sea Level Rise (15 cm to 140 cm) for 2002



Appendix 29A-12
UnTRIM Simulated X2 position (km from Golden Gate) for the Historical and Assumed Sea Level Rise Cases (15 cm to 60cm) for 2002 historical flows. The increased X2 distance is shown in the bottom panel



Appendix 29A-13
Scatter Plot of the Simulated Daily Increases in X2
during 2002 for the Sea Level Rise Cases