Appendix X

Watson, K.W., Yang, L., and Mades, D. 2011. Memorandum to Mr. Douglas A. Leeper, Southwest Florida Water Management District, dated February 8, 2011. Regarding: technical memo, use of a hydrodynamic model for evaluating salinities in the Homosassa River in support of MFLs development, P.O. 11POSOW0482. HSW Engineering, Inc. Tampa, Florida.

MEMORANDUM

TO: Mr. Douglas A. Leeper, Chief Environmental Scientist
Southwest Florida Water Management District

From: Ken W. Watson, Ph.D., Principal Hydrologist
Lei Yang, Ph.D., P.E., Project Engineer
Dean Mades, P.E., Senior Hydrologist
HSW Engineering, Inc.

Date: February 08, 2011

Re: Technical Memo
Use of a Hydrodynamic Model for Evaluating Salinities in the Homosassa River in Support of MFLs Development
P.O. 11POSOW0482

A hydrodynamic model (Model) was developed for the Homosassa River (HSW 2011) and was used to evaluate the impacts of freshwater flow reduction on thermal and salinity characteristics of the river for a one year simulation period, calendar year 2007. In the referenced report, freshwater flow was reduced from 5 to 30% in 5% increments, and the reduction in habitat associated with 2, 3, 5 and 12 psu isohalines was evaluated. Habitat was defined using three surrogates; the river volume associated with a depth-averaged salinity and river bottom area associated with a bottom or depth-averaged salinity less than or equal to the prescribed isohaline. When freshwater flow is reduced, a particular isohaline will move further upstream in the river and thus habitat area and volume associated with that isohaline will be reduced. As part of the peer review process it was determined that flow reductions of 1 to 4% at a 1% increment should be evaluated with respect to the position of the 2 psu isohaline.

The Model was run with freshwater flow reductions of 1, 2, 3, and 4%. The flow adjustments were applied to all three upstream inflow boundaries of the Model, i.e., Homosassa Springs, Southeast Fork Homosassa Spring, and Halls River. The 3-hour interval cell-by-cell salinity outputs for each model run were processed by extracting the surface and bottom salinities and calculating the depth-averaged salinity for the centerline cells. An isohaline location is represented by the centerline channel distance upstream from the mouth, termed river kilometers (RKMs), that were assigned using ArcGIS when the Model was developed. The 2-psu surface, bottom, and depth-averaged isohaline locations were then interpolated for each time step (i.e., 3-hour interval). The medians of all interpolated 2 psu bottom and depth-averaged isohaline locations within the simulation period were calculated for each flow reduction scenario (Table 1).

Using the median bottom isohaline locations associated with baseline and each flow reduction condition, the corresponding river bottom areas (Table 1) were obtained by linear interpolation using the functional relationships of RKM versus river bottom area (Appendix C in HSW 2011). River volumes associated with baseline and each flow reduction condition were determined in a similar manner using median depth-averaged isohaline locations.

Table 1. Change in 2 psu isohaline habitat from baseline flow condition for different flow reduction scenarios.
[Results for flow reductions greater than 4% are from HSW 2011]

Flow Reduction Condition	Based on the Depth-averaged Salinity					Based on the Bottom Salinity		
	RKM	Volume (m^3)	Relative Reduction from Baseline Volume (%)	Area (m^2)	Relative Reduction from Baseline Area (%)	RKM	Area (m^2)	Relative Reduction from Baseline Area (%)
Baseline (0%)	12.18	49,013	–	30,504	–	12.33	14,470	–
1%	12.26	32,834	33	21,590	29	12.35	12,282	15
2%	12.27	31,433	36	20,772	32	12.38	8,515	41
3%	12.28	29,830	39	19,835	35	>12.40	<6,498	>55
4%	12.28	28,496	42	19,056	38	>12.40	<6,498	>55
5%	12.29	27,034	45	18,201	40	>12.40	<6,498	>55
10%	12.37	13,298	73	10,175	67	>12.40	<6,498	>55
15%	>12.40	<7,006	>86	<6,498	>79	>12.40	<6,498	>55
20%	>12.40	<7,006	>86	<6,498	>79	>12.40	<6,498	>55
25%	>12.40	<7,006	>86	<6,498	>79	>12.40	<6,498	>55
30%	>12.40	<7,006	>86	<6,498	>79	>12.40	<6,498	>55

The 2 psu isohaline is very near to the spring area and even a small change (e.g., 1%) in flow results in a relative large change (≥ 29%) in volume and areas based on the depth-averaged salinity, and 15% in bottom area based on the bottom salinity only. Bar charts illustrate the volume and area associated with each flow reduction scenario normalized to the baseline volume and area (Figures 1 and 2, respectively). The bar charts level off at the higher flow reductions indicating that the change in volume and area are greater than those represented by the bars.

As noted in HSW (2011), use of the median location for the 2 psu isohaline for evaluating flow-related changes in salinity zones within the Homosassa River system is problematic because the average measured salinity (converted through measured conductivity) associated with Homosassa and Southeast Fork Springs is very near 2 psu and often exceeds 2 psu. The modeled bottom salinity in the most upstream cell exceeded 2 psu about 47% of the time for baseline conditions. In addition, the modeled input locations for the spring discharges are near or at the most upstream Model cell at about RKM 12.48. A meaningful evaluation of the sensitivity of the 2 psu isohaline location to flow reduction scenarios is precluded by the proximity of the isohaline to the Model boundary.

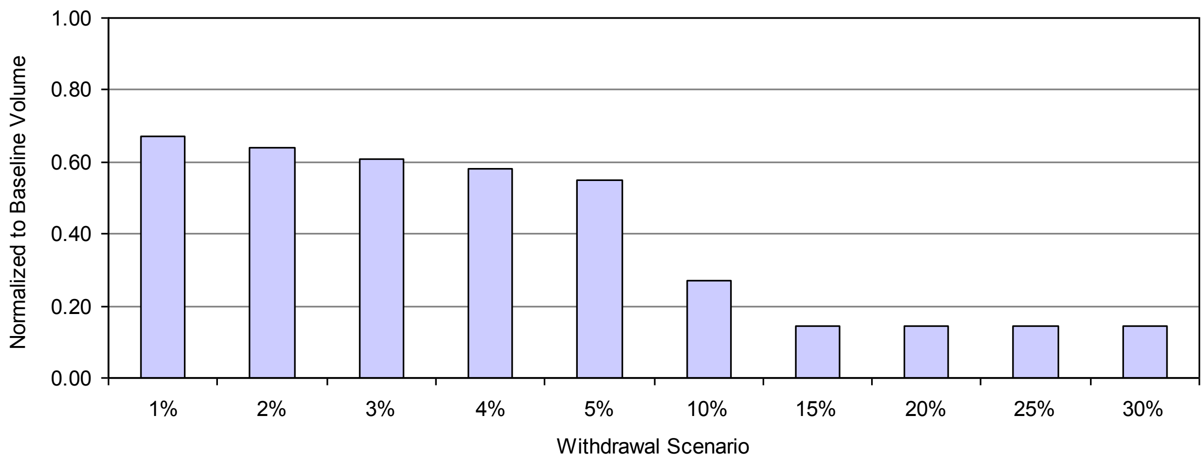


Figure 1. Effect of withdrawals on baseline river volume for 2 psu isohaline

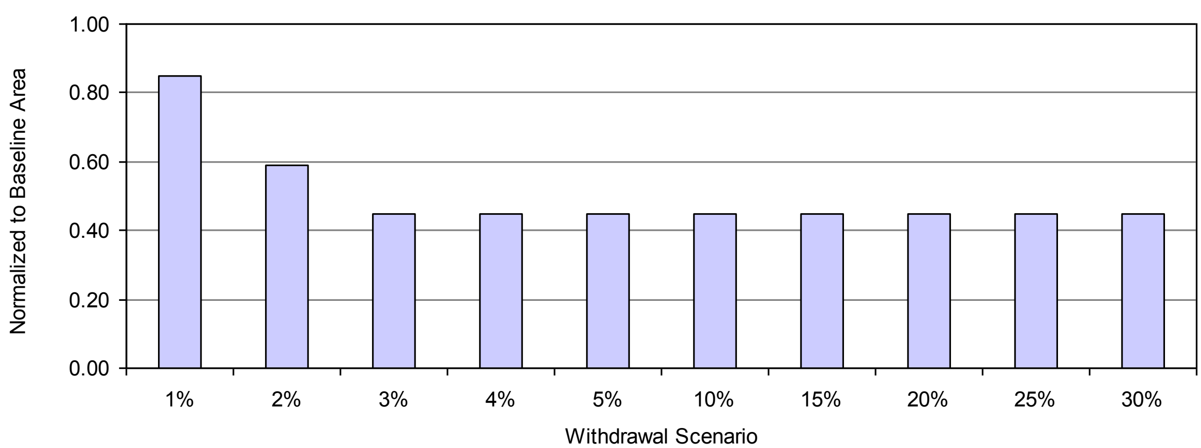


Figure 2. Effect of withdrawals on baseline river area for 2 psu isohaline

Two data files are provided on a CD in Microsoft Excel format: file “2psu isohaline location_vol_area (1-4% reduction).xls” and file “12psu surface isohaline location (5-30% reduction).xls”. The workbooks contain the data, tabulations, and graphics presented in this technical memorandum.

Reference

HSW Engineering, Inc. (HSW). A modeling study of the relationships of freshwater flow with the salinity and thermal characteristics of the Homosassa River, February 2011. Prepared for the Southwest Florida Water Management District (SWFWMD).

Appendix Y

Watson, K.W. and Yang, L. 2011. Memorandum to Mr. Douglas A. Leeper, Southwest Florida Water Management District, dated May 13, 2011. Regarding: technical memo, use of a hydrodynamic model for evaluating effects of sea level change on salinities in the Homosassa River in support of MFLs development, P.O. 11POSOW0482. HSW Engineering, Inc. Tampa, Florida.

MEMORANDUM

To: Mr. Douglas A. Leeper, Chief Environmental Scientist
Southwest Florida Water Management District

From: Ken W. Watson, Ph.D., Principle Hydrologist
Lei Yang, Ph.D., P.E., Project Engineer
HSW Engineering, Inc.

Date: May 13, 2011

Re: Technical Memo – Use of a Hydrodynamic Model for Evaluating Effects of Sea Level Change on Salinities in the Homosassa River in Support of MFLs Development
P.O. 11POSOW0482

A hydrodynamic model (Model) was developed for the Homosassa River (HSW 2011) and was used to evaluate the impacts of freshwater flow reduction on thermal and salinity characteristics of the river for a one-year simulation period, calendar year 2007. Additional model runs recently were performed to characterize potential effects for sea level changes of five prescribed magnitudes (-6, -2, +2, +6, and +12 inches) on 3, 5, and 12 psu isohaline locations and associated habitats in the Homosassa River. A freshwater flow reduction of 4% also was evaluated in combination with the sea level changes. Habitat is defined using the river volume associated with a depth-averaged salinity and river bottom area associated with bottom and depth-averaged salinities less than or equal to the prescribed isohaline.

The river volume and bottom area versus river kilometer (RKM) relationships were updated to account for the five sea level changes (Figures 1 and 2). The method used to calculate river volumes and areas under these sea level conditions is the same as that described in Appendix C (HSW 2011). Compared with the baseline condition (i.e., no sea level change), a sea level rise (+2″, +6″, and +12″) would increase the river volume and area, and a sea level decline (-2″ and -6″) would decrease the river volume and area at a given river location (i.e., river kilometer). The bottom-area and volume relationships (Figures 1 and 2, respectively) were used to determine river volumes and areas associated with 3, 5, and 12 psu isohaline locations simulated for the various sea level changes in combination with a 4 % flow reduction.

Spring flows at Homosassa Springs at Homosassa and Southeast (SE) Fork Homosassa Spring at Homosassa are calculated by the USGS using the rating curves (equations 1-a and 2-a) developed by the USGS (Appendix B, HSW 2011). Changes in spring flow were calculated by adjusting the 15-minute flow data under the baseline condition using equations (1-b) and (2-b). The adjusted amount is defined in equations (1-c) and (2-c). The flow at Halls River was estimated at 88% of the sum of adjusted Homosassa Springs flow and SE Fork Homosassa Spring flow.

$$Q_{\text{Homosassa Springs}} = 90.8162 + 3.823\,(GW) - 20.3771(GH) \quad (1\text{-a})$$

$$Q_{\text{Homosassa Springs due to SLC}} = Q_{\text{Homosassa Springs}} + \Delta Q_{\text{Homosassa Springs due to SLC}} \quad (1\text{-b})$$

$$\Delta Q_{\text{Homosassa Springs due to SLC}} = -\,20.3771(SLC) \quad (1\text{-c})$$

$$Q_{\text{SE Fork}} = 18.63 + 3.31\,(GW) - 10.31(GH) - 418.14(dS/dt) \quad (2\text{-a})$$

$$Q_{\text{SE Fork due to SLC}} = Q_{\text{SE Fork}} + \Delta Q_{\text{SE Fork due to SLC}} \quad (2\text{-b})$$

$$\Delta Q_{\text{SE Fork due to SLC}} = -\,10.31(SLC) \quad (2\text{-c})$$

where $Q_{\text{Homosassa Springs}}$ and $Q_{\text{SE Fork}}$ are the 15-minute flow at Homosassa Springs and SE Fork Homosassa Spring, respectively, in cubic feet per second (cfs); GW is the maximum daily groundwater level measured at the Weeki Wachee well at Weeki Wachee on the day of the discharge measurement used for rating, in ft-NGVD29; dS/dt is the change in river stage during a 15-minte period, in ft; GH is the 15-minute gauge height of the river stage recorded at the time of the discharge measurement used for the rating, in ft-NAVD88; $\Delta Q_{\text{Homosassa Springs due to SLC}}$ and $\Delta Q_{\text{SE Fork due to SLC}}$ are the changes in spring flow associated with a sea level change at Homosassa Springs and SE Fork Homosassa Spring, respectively, in cfs; and SLC is the sea level change, equivalent to -6, -2, +2, +6, +12 inches, expressed in units of feet. The spring flow changes due to sea level changes were calculated with an assumption that the groundwater level at the Weeki Wachee well (i.e., GW) is not affected by the sea level change.

Based on the average flow during the calendar year 2007, the sea level declines would increase the spring flows by about 3 to 12% for the two spring locations at the Homosassa Springs and SE Fork (Table 1) while sea level increase would decrease the spring flows by about 3 to 25% for the two spring locations.

Table 1. Average flows of year 2007 at Homosassa Springs, SE Fork Homosassa Spring, and Halls River under baseline and sea level change conditions

Baseline and Sea Level Change Scenario	Homosassa Springs		SE Fork Homosassa Spring		Halls River	
	Average Flow (cfs)	Relative Change from Baseline (%)	Average Flow (cfs)	Relative Change from Baseline (%)	Average Flow (cfs)	Relative Change from Baseline (%)
Baseline	81.61	–	53.92	–	119.26	–
SLC-6″	91.79	12	59.07	10	132.76	11
SLC-2″	85.00	4	55.63	3	123.76	4
SLC+2″	78.21	-4	52.20	-3	114.76	-4
SLC+6″	71.42	-12	48.76	-10	105.76	-11
SLC+12″	61.23	-25	43.61	-19	92.25	-23

cfs = cubic feet per second

A total of 20 model runs were performed that include combinations of the five sea level changes and flow reduction. The results for 10 model runs are based on the assumption that spring flow would not change in response to sea level change (Table 2), and the results for another 10 model runs are based on the assumption that spring flow would change in response to sea level change (Table 3). Modeling results associated with a 4% flow reduction (i.e., MFL scenario) are listed in each table beneath the no-flow reduction results.

Procedures for processing the isohaline locations and associated river volumes and areas were the same as presented by HSW (2011). The 3-hour interval cell-by-cell salinity outputs for each model run were processed by extracting the surface, middle, and bottom salinities and calculating the depth-averaged salinity for the centerline cells. An isohaline location is represented by the centerline channel distance upstream from the mouth that was assigned using ArcGIS. The 3, 5, and 12-psu surface, bottom, and depth-averaged isohaline locations were then interpolated for each output time step (i.e., 3-hour interval). The medians of all interpolated 3, 5, and 12-psu depth-averaged and bottom isohaline locations within the simulation period were then calculated (Tables 2 and 3).

In general, sea level rise would result in habitat loss while sea level decline would increase the habitat associated with a particular isohaline (Tables 2 and 3, and Figures 3 to 5). Greater relative changes from baseline are predicted for the 3-psu isohaline compared to the other two isohalines because the baseline quantities associated with the 3-psu isohaline are smaller than those for the other two isohalines. The 3-psu isohaline is very close to the spring area and a 12-inch sea level rise would result in no habitat associated with salinity less than or equal to 3 psu (Table 3). For the 3- and 5-psu isohalines, volume and bottom-area habitat reductions of at least 15% are associated with a sea level increase of approximately 6 inches or more. For the 12-psu isohaline, a sea level increase of 6 or more inches could result in a bottom area habitat decline of 15% or more.

Change in habitat is essentially a net balance associated with sea level change, flow reduction and isohaline movement. A sea level rise would shift the isohaline location upstream and therefore decrease the river volume. However, it would also increase the river volume universally over the river course compared with baseline. The net effect of sea level change on habitat volume relative to baseline depends on the magnitude and whether there is an effect of sea level in spring flow. For example, the volume gain due to the 12-inch sea level rise would outweigh the volume loss due to the upstream movement of the isohaline, and the net result is an increased habitat volume compared to that under baseline, as occurred for the scenario where sea level rise is 12 inches and no flow reduction is considered (Table 2).

Use of the median location for the 3 psu isohaline for evaluating sea level-related changes in salinity zones within the Homosassa River system is problematic in a few model scenarios because the modeled depth-averaged and bottom salinity exceeded 3 psu more than 50% of the time and the corresponding river locations are outside of the most upstream location by more than 50% of time. A meaningful river location and associated river volume and area were not assigned (Table 3).

Twelve data files are provided in Microsoft Excel 2007 format along with this memorandum and twenty sets of EFDC model run files:

a. One file “HomR_Vol_Area_Calculation_Supplement.xlsx” contains the supplemental river volume and area versus RKM relationships under five sea level change conditions

b. One file “SLR_Spring_Q_Change.xlsx” includes the calculation of spring flow for three USGS gauges at Homosassa Springs at Homosassa, SE Fork Homosassa Spring, and Halls River.

c. Five files containing model predicted locations of surface, bottom areas and water column volume associated with these salinities for five modified sea level scenarios and five modified sea level scenarios with a 4% flow reduction for the Homosassa River system, as follow.

   “1_SL-6 isohaline RKM_vol_area.xlsm” (sea level change at -6 inches)
   “2_SL-2 isohaline RKM_vol_area.xlsm” (sea level change at -2 inches)
   “3_SL+2 isohaline RKM_vol_area.xlsm” (sea level change at +6 inches)
   “4_SL+6 isohaline RKM_vol_area.xlsm” (sea level change at +2 inches)
   “5_SL+12 isohaline RKM_vol_area.xlsm” (sea level change at +12 inches)

d. Five files containing model predicted locations of surface, bottom areas and water column volume associated with these salinities for five modified sea level scenarios that incorporate potential spring flow changes associated with the sea level modifications, and five modified sea level scenarios that incorporate potential flow changes associated with the sea level changes as well as a 4% flow reduction for the Homosassa River system, as follow.

   “6_SL_Q-6 isohaline RKM_vol_area.xlsm” (sea level change at -6 inches)
   “7_SL_Q -2 isohaline RKM_vol_area.xlsm” (sea level change at -2 inches)
   “8_SL_Q +2 isohaline RKM_vol_area.xlsm” (sea level change at +6 inches)
   “9_SL_Q +6 isohaline RKM_vol_area.xlsm” (sea level change at +2 inches)
   “10_SL_Q +12 isohaline RKM_vol_area.xlsm” (sea level change at +12 inches)

Reference

HSW Engineering, Inc. (HSW). A modeling study of the relationships of freshwater flow with the salinity and thermal characteristics of the Homosassa River, February 2011. Prepared for the Southwest Florida Water Management District (SWFWMD).

HSW Engineering, Inc. (HSW). Use of a hydrodynamic model for evaluating salinities in the Homosassa River in support of MFL development, February 2011. Technical Memo. Prepared for the Southwest Florida Water Management District (SWFWMD).

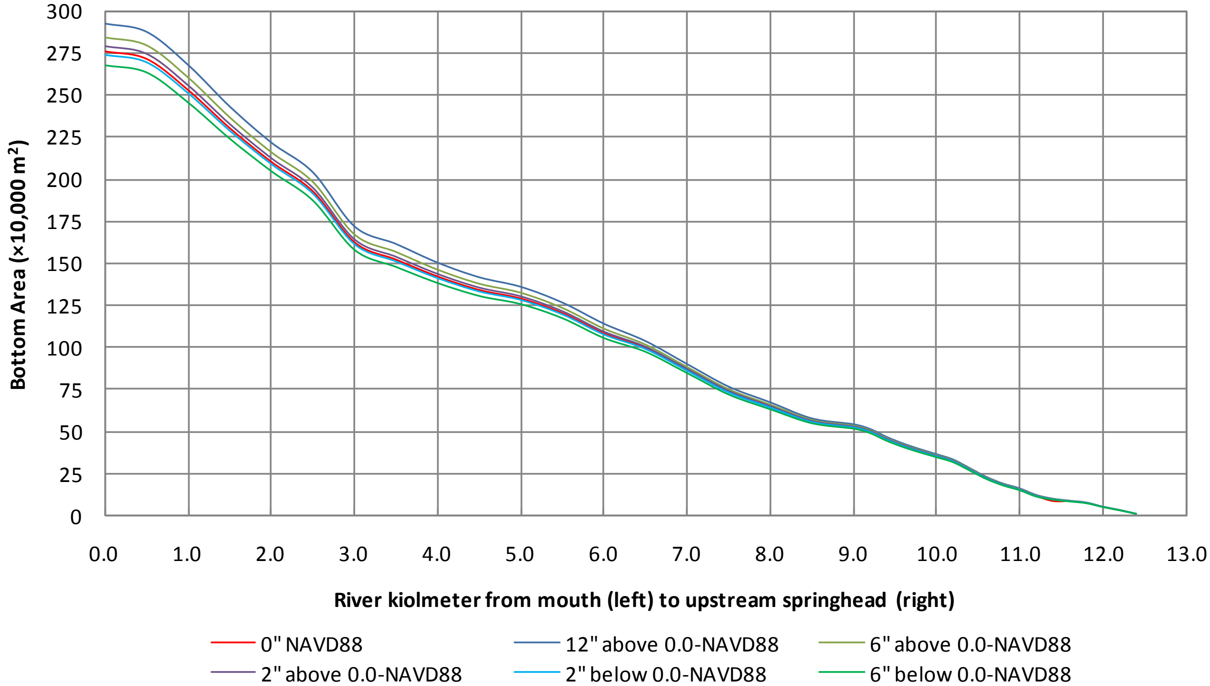


Figure 1. Homosassa River main channel bottom area versus river kilometer for baseline and five sea level change conditions

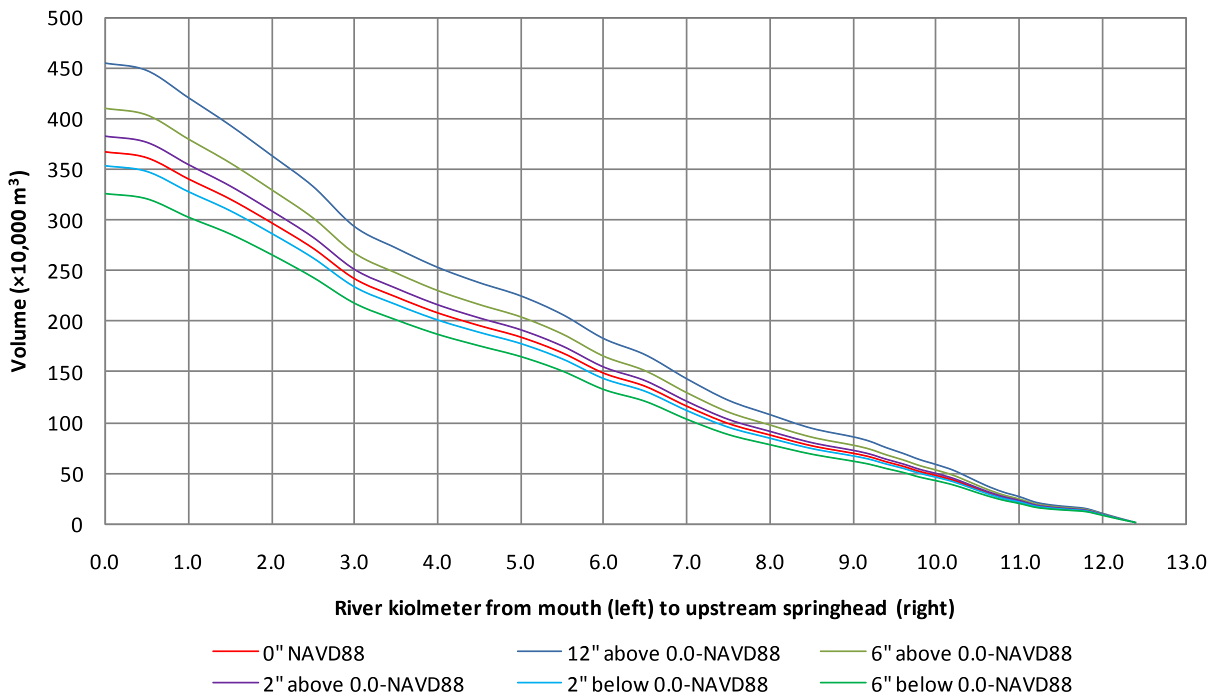


Figure 2. Homosassa River main channel volume versus river kilometer for baseline and five sea level change conditions

Table 2. Decrease in 3, 5 and 12 psu isohaline habitat from baseline condition for different sea level change (SLC) scenarios without considering spring flow changes

Sea Level Change Condition (flow reduction percentage)	Based on the Depth-averaged Salinity					Based on the Bottom Salinity		
	RKM	Volume (m^3)	Relative Decrease from Baseline Volume (%)	Bottom Area (m^2)	Relative Decrease from Baseline Area (%)	RKM	Bottom Area (m^2)	Relative Decrease from Baseline Area (%)
3 psu								
Baseline (0%)*	10.90	236,409	–	164,680	–	10.92	162,199	–
SLC-6″ (0%)	10.39	330,466	-40	266,251	-62	10.44	254,083	-57
SLC-2″ (0%)	10.76	256,697	-9	185,644	-13	10.79	179,014	-10
SLC+2″ (0%)	10.99	227,019	4	153,173	7	11.01	149,497	8
SLC+6″ (0%)	11.21	188,897	20	114,363	31	11.23	112,148	31
SLC+12″ (0%)	11.42	178,661	24	96,061	42	11.51	90,965	44
SLC-6″ (4%)	10.49	304,204	-29	241,478	-47	10.54	227,719	-40
SLC-2″ (4%)	10.89	230,558	2	165,257	0	10.90	163,754	-1
SLC+2″ (4%)	11.05	213,964	9	142,537	13	11.07	138,335	15
SLC+6″ (4%)	11.40	165,946	30	94,985	42	11.47	91,002	44
SLC+12″ (4%)	11.51	171,473	27	90,789	45	11.60	85,410	47
5 psu								
Baseline (0%)*	9.03	687,505	–	518,409	–	9.10	508,851	–
SLC-6″ (0%)	8.44	694,182	-1	555,352	-7	8.49	547,141	-8
SLC-2″ (0%)	8.84	689,248	0	529,931	-2	8.92	525,128	-3
SLC+2″ (0%)	9.19	684,276	0	499,345	4	9.26	483,614	5
SLC+6″ (0%)	9.49	654,157	5	438,755	15	9.67	407,378	20
SLC+12″ (0%)	9.94	595,192	13	370,818	28	10.15	337,854	34
SLC-6″ (4%)	8.58	672,758	2	541,039	-4	8.63	537,760	-6
SLC-2″ (4%)	8.96	672,188	2	522,258	-1	9.02	516,828	-2
SLC+2″ (4%)	9.31	655,585	5	473,650	9	9.39	453,021	11
SLC+6″ (4%)	9.92	545,339	21	368,215	29	10.08	343,152	33
SLC+12″ (4%)	10.07	562,666	18	351,479	32	10.26	313,817	38
12 psu								
Baseline (0%)*	5.81	1,565,149	–	1,127,570	–	6.19	1,047,360	–
SLC-6″ (0%)	5.22	1,587,416	-1	1,219,098	-8	5.54	1,163,254	-11
SLC-2″ (0%)	5.66	1,565,755	0	1,153,460	-2	5.97	1,079,489	-3
SLC+2″ (0%)	5.97	1,552,550	1	1,096,220	3	6.40	1,018,508	3
SLC+6″ (0%)	6.37	1,545,738	1	1,038,178	8	6.63	979,023	7
SLC+12″ (0%)	6.65	1,590,725	-2	993,293	12	7.00	897,823	14
SLC-6″ (4%)	5.03	1,547,559	1	1,195,675	-6	5.64	1,139,962	-9
SLC-2″ (4%)	5.74	1,533,326	2	1,133,633	-1	6.09	1,056,575	-1
SLC+2″ (4%)	6.16	1,498,350	4	1,060,924	6	6.45	1,009,308	4
SLC+6″ (4%)	6.57	1,478,219	6	995,034	12	6.95	892,474	15
SLC+12″ (4%)	6.78	1,530,899	2	958,781	15	7.05	884,306	16

* Results are from HSW 2011

Table 3. Decrease in 3, 5 and 12 psu isohaline habitat from baseline condition for different sea level change (SLC) scenarios considering spring flow changes

Sea Level Change Condition (flow reduction percentage)	Based on the Depth-averaged Salinity					Based on the Bottom Salinity		
	RKM	Volume (m^3)	Relative Decrease from Baseline Volume (%)	Bottom Area (m^2)	Relative Decrease from Baseline Area (%)	RKM	Bottom Area (m^2)	Relative Decrease from Baseline Area (%)
3 psu								
Baseline (0%)*	10.90	236,409	–	164,680	–	10.92	162,199	–
SLC-6″ (0%)	10.14	391,447	-66	321,929	-95	10.23	306,310	-89
SLC-2″ (0%)	10.63	289,232	-22	210,918	-28	10.69	198,448	-22
SLC+2″ (0%)	11.05	213,964	9	142,537	13	11.07	138,335	15
SLC+6″ (0%)	11.40	165,946	30	94,985	42	11.47	91,002	44
SLC+12″ (0%)	12.30	31,307	87	19,000	88	> 12.40	–	–
SLC-6″ (4%)	10.26	363,266	-54	297,468	-81	10.31	287,102	-77
SLC-2″ (4%)	10.76	255,421	-8	184,653	-12	10.80	177,391	-9
SLC+2″ (4%)	11.19	181,000	23	115,117	30	11.21	112,479	31
SLC+6″ (4%)	11.49	159,046	33	89,541	46	11.56	85,874	47
SLC+12″ (4%)	> 12.40	–	–	–	–	> 12.40	–	–
5 psu								
Baseline (0%)*	9.03	687,505	–	518,409	–	9.10	508,851	–
SLC-6″ (0%)	8.15	750,116	-9	605,109	-17	8.18	600,165	-18
SLC-2″ (0%)	8.73	706,492	-3	537,687	-4	8.81	532,346	-5
SLC+2″ (0%)	9.31	655,585	5	473,650	9	9.39	453,021	11
SLC+6″ (0%)	9.92	545,339	21	368,215	29	10.08	343,152	33
SLC+12″ (0%)	10.80	311,839	55	187,742	64	10.98	162,287	68
SLC-6″ (4%)	8.25	729,711	-6	586,958	-13	8.28	582,748	-15
SLC-2″ (4%)	8.86	687,677	0	529,224	-2	8.93	524,518	-3
SLC+2″ (4%)	9.43	624,562	9	446,036	14	9.53	427,267	16
SLC+6″ (4%)	10.04	515,786	25	349,039	33	10.22	318,829	37
SLC+12″ (4%)	10.92	283,612	59	170,555	67	11.02	154,891	70
12 psu								
Baseline (0%)*	5.81	1,565,149	–	1,127,570	–	6.19	1,047,360	–
SLC-6″ (0%)	5.03	1,642,358	-5	1,251,386	-11	5.22	1,219,354	-16
SLC-2″ (0%)	5.57	1,602,112	-2	1,175,688	-4	5.86	1,104,557	-5
SLC+2″ (0%)	6.16	1,498,350	4	1,060,924	6	6.45	1,009,308	4
SLC+6″ (0%)	6.57	1,478,219	6	995,034	12	6.95	892,474	15
SLC+12″ (0%)	7.15	1,365,086	13	859,531	24	7.49	767,265	27
SLC-6″ (4%)	5.11	1,619,741	-3	1,238,094	-10	5.35	1,198,507	-14
SLC-2″ (4%)	5.66	1,563,927	0	1,152,342	-2	5.97	1,078,318	-3
SLC+2″ (4%)	6.28	1,467,296	6	1,040,168	8	6.49	1,001,573	4
SLC+6″ (4%)	6.69	1,426,595	9	963,269	15	7.00	879,016	16
SLC+12″ (4%)	7.26	1,317,903	16	829,566	26	7.61	743,706	29

* Results are from HSW 2011

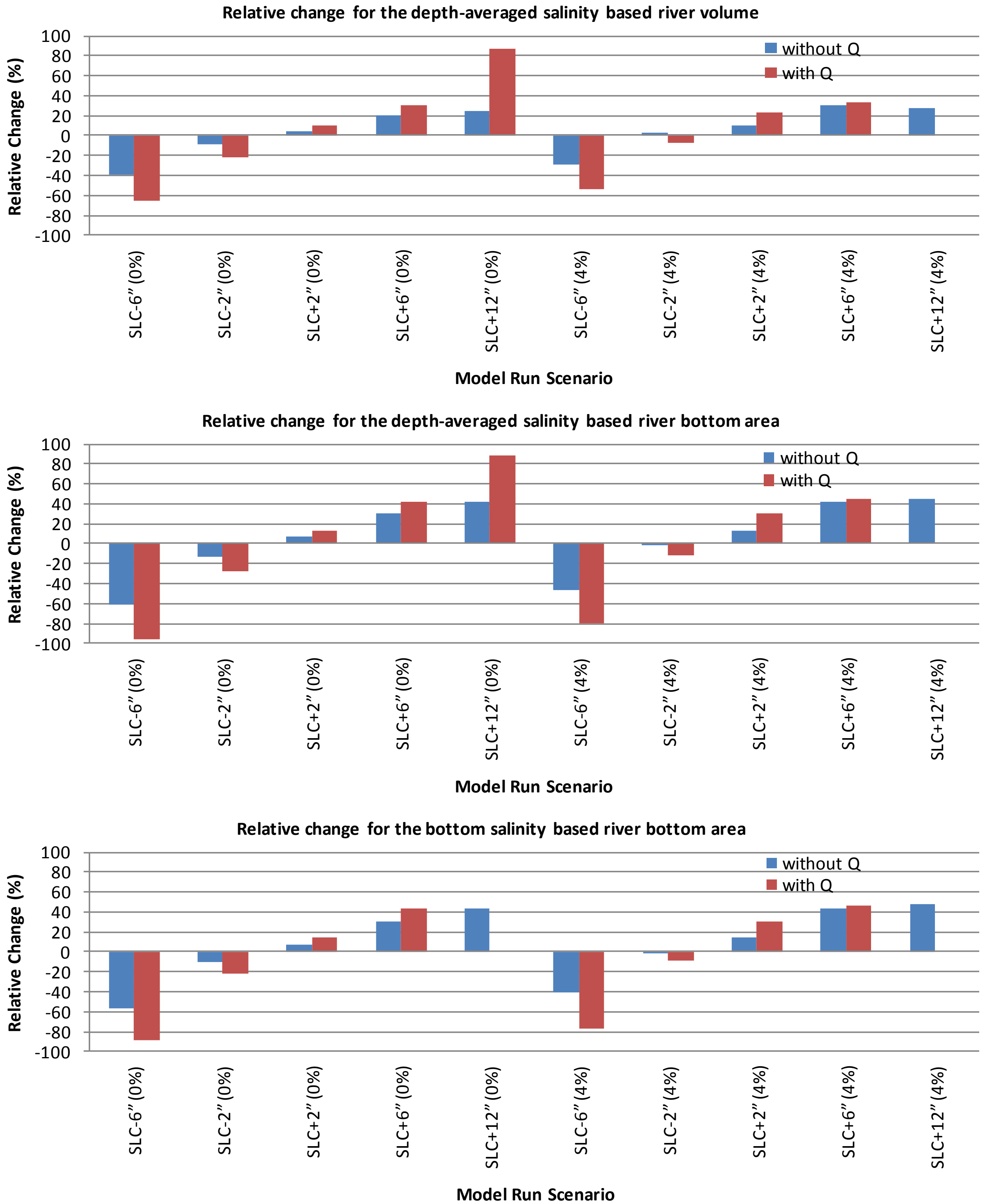


Figure 3. Comparisons of relative changes of river volumes and bottom areas for selected sea level changes (SLC) and flow reductions (0% or 4%) for the 3-psu isohaline with and without considering spring flow change (Q) due to sea level change

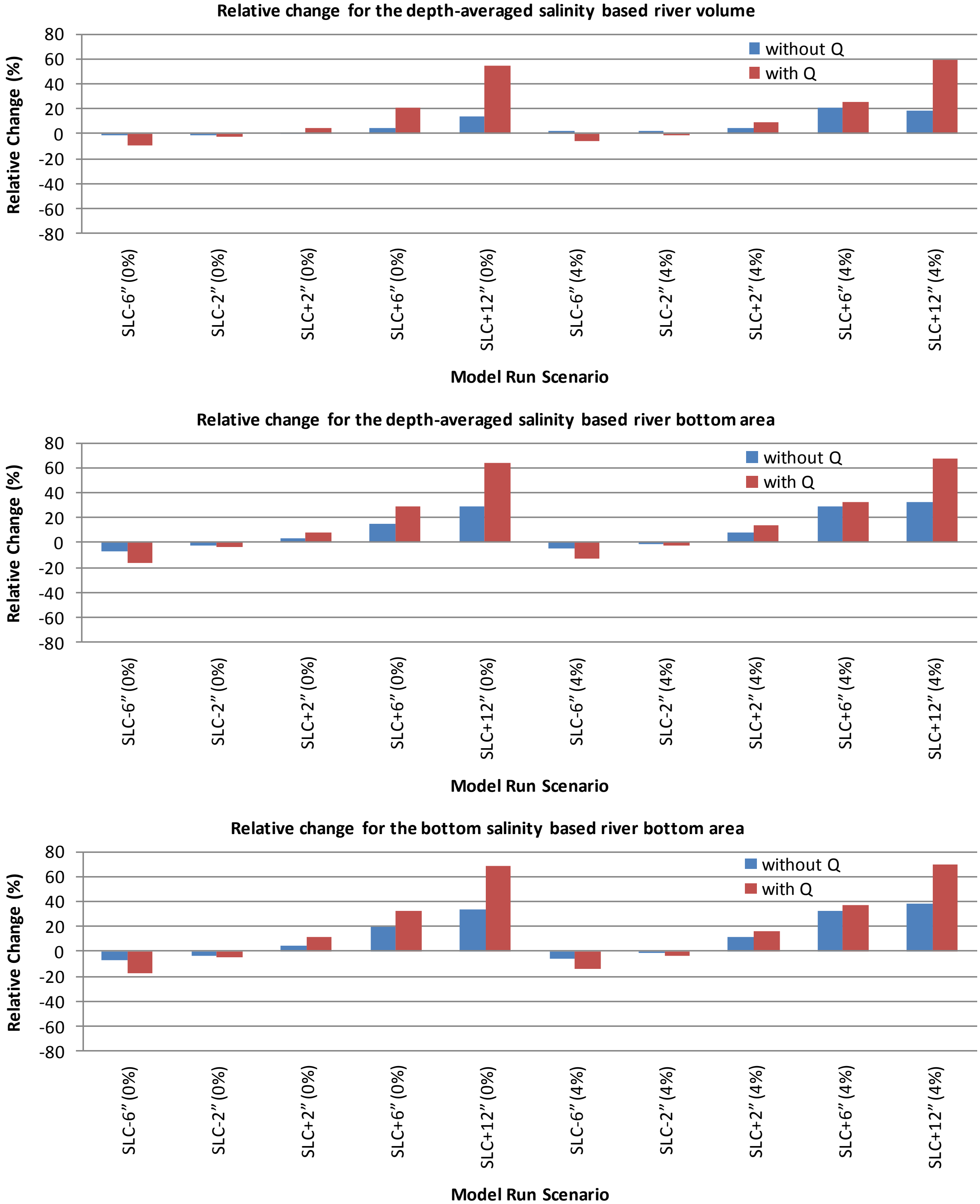
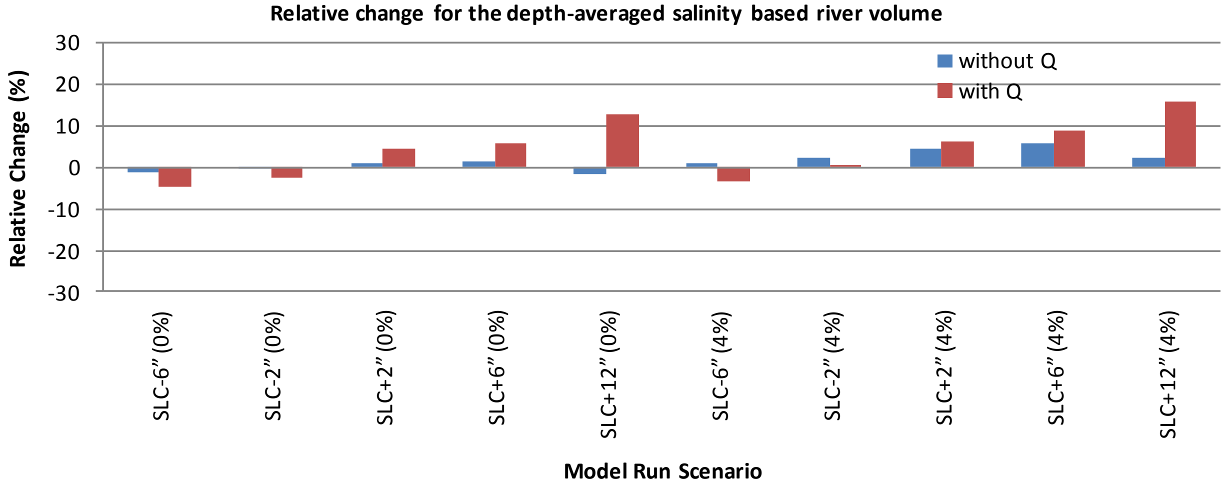
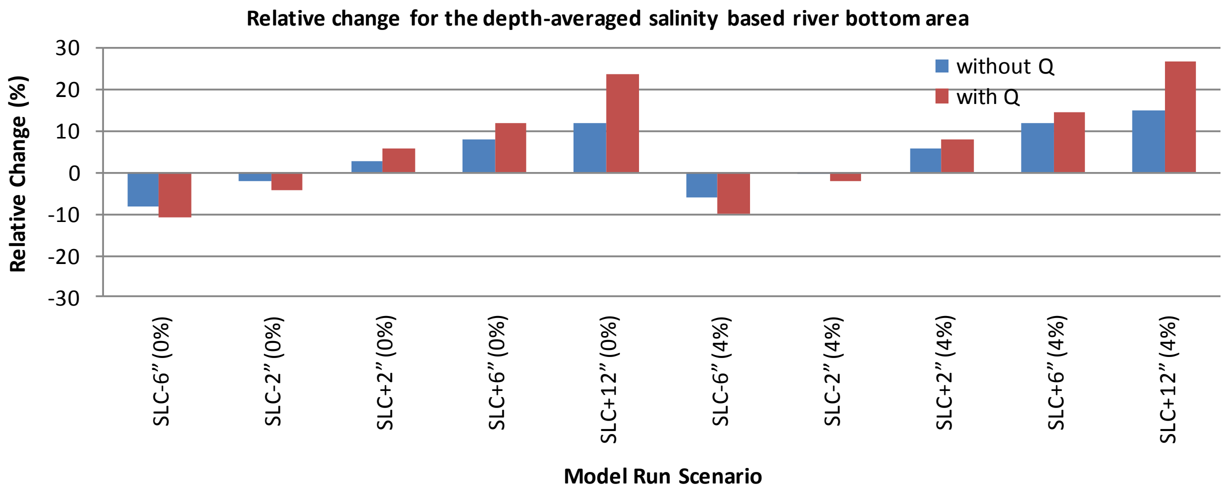


Figure 4. Comparisons of relative changes of river volumes and bottom areas for selected sea level changes (SLC) and flow reductions (0% or 4%) for the 5-psu isohaline with and without considering spring flow change (Q) due to sea level change





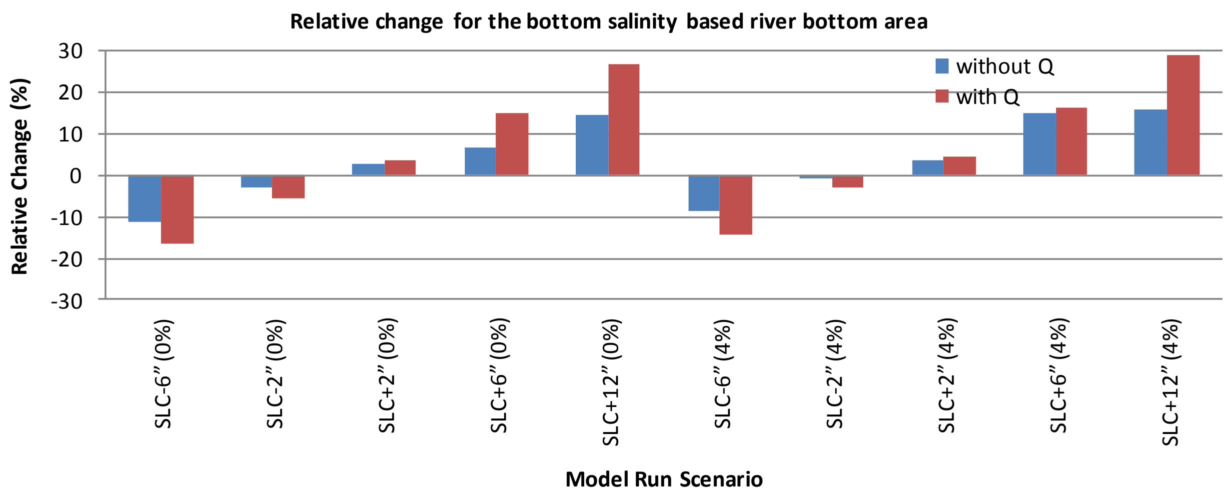


Figure 5. Comparisons of relative changes of river volumes and bottom areas for selected sea level changes (SLC) and flow reductions (0% or 4%) for the 12-psu isohaline with and without considering spring flow change (Q) due to sea level change

Appendix Z

Watson, K.W. and Yang, L. 2011. Memorandum to Mr. Douglas A. Leeper, Southwest Florida Water Management District, dated November 7, 2011. Regarding: use of hydrodynamic and empirical models for evaluating salinity regimes in the Homosassa River in support of MFLs development, P.O. 11POSOW0482. HSW Engineering, Inc. Tampa, Florida.

MEMORANDUM

To: Mr. Douglas A. Leeper, Chief Environmental Scientist
Southwest Florida Water Management District

From: Ken W. Watson, Ph.D., Principle Hydrologist
Lei Yang, Ph.D., P.E., Project Engineer
HSW Engineering, Inc.

Date: November 7, 2011

Re: Use of the hydrodynamic and empirical models for evaluating salinity regimes in the Homosassa River in support of MFLs development
P.O. 11POSOW0482

Hydrodynamic and isohaline empirical models were developed for the Homosassa River (HSW, February 2011) for the Southwest Florida Water Management District (SWFWMD) to assist with developing Minimum Flows and Levels (MFLs). One objective of developing these models is to associate specific isohaline river kilometer (RKM) locations with aquatic habitats, which are defined as river bottom area, water volume, and shoreline length upstream of particular isohalines. For this current study, the effects of potential sea level rise (SLR) on salinities and associated aquatic habitats in the Homosassa River were evaluated using both the hydrodynamic and regression models.

Details regarding the data and methods used are presented in the model documentation and report (HSW, February 2011) and additional analyses associated with potential sea level rise are provided in a subsequent memorandum (HSW, May 2011). For this application of the hydrodynamic and empirical models, the following scenarios were evaluated:

1. Hydrodynamic models, year 2007 – three sea level rise scenarios (SLRs) (1.9, 3.2 and 7.3 inches), 6 MFL spring flow reduction scenarios (0, 1, 2, 3, 4, and 5%), and 2 spring flow reduction scenarios related to SLR (no flow reduction and flow reduction) for a total of 36 scenarios. The SLRs affect the stage boundary condition at the downstream end of the model domain and the change in spring flow affects the upstream flow boundary conditions at Homosassa Springs at Homosassa, Southeast (SE) Fork Homosassa Spring at Homosassa, and Halls River. The SLRs were developed for model year 2007 using projections for year 2030 based on planned updates to the methodology used by the United States Army Corps of Engineers (USACOE 2009) for evaluating SLR and coastal projects. The planned updates to the methodology were provided to Mr. Doug Leeper (SWFWMD) by Dr. Kathleen White, Senior Lead with the USACOE Global and Climate Change Institute for Water Resources, on June 16, 2001. The MFL flow reduction scenarios are simple percent

flow reductions applied at the upstream boundaries. The SLR-induced flow reduction scenarios are based on the United States Geological Survey (USGS) rating curves (which incorporate a tide-stage variable) associated with the springs, and a linear relationship between spring flow and Halls River flow.

2. Empirical models, year 2007 – three SLRs (1.9, 3.2 and 7.3 inches), 6 MFL spring flow reduction scenarios (0, 1, 2, 3, 4, and 5%), and 2 spring flow reduction scenarios related to SLR (no flow reduction and flow reduction) for a total of 36 scenarios. The SLRs and spring flow reductions affect the stage data for the Homosassa gauge and the total spring flow data used as inputs to the empirical models.

3. Empirical models, period of record (POR) (1995 – 2009) - three SLRs (low, medium, and high), 6 spring flow reduction scenarios (0, 1, 2, 3, 4, and 5%), and 2 spring flow reduction scenarios related to SLR (no flow reduction and flow reduction) for a total of 36 scenarios. The low, medium and high sea level rise scenarios are based on the estimated sea level rise over a 21 year period from a particular year (e.g., 1995 to 2016,…, 2009 to 2030).

The 3, 5, and 12 psu isohaline locations, defined by surface, depth-averaged, and bottom salinities, were considered in this study. The river water volume is associated with a depth-averaged salinity, river bottom area associated with both bottom and depth-averaged salinities, and shoreline associated with surface salinities that are less than or equal to the isohaline values. The hydrodynamic model was used only for the calendar year 2007 and the empirical models were applied for both the calendar year 2007 and the POR estimates.

Stage-Area-Volume Relationship

Stage-area-volume relationships were used to quantify the river bottom area and water volume for salinity zones upstream of particular isohaline locations. Six sets of stage-area-volume relationships were developed to reflect the six different SLRs in this study.

Low (1.9 inches), medium (3.2 inches) and high (7.3 inches) SLRs estimates developed using the revised USACOE methods and provided by SWFWMD were used to determine the stage-area-volume relationships for assessing the impacts of SLRs during year 2007. Low, medium, and high SLRs were also estimated for each year of the POR (Table 1). The medians corresponding to these low, medium, and high SLRs over the 15-year POR, i.e., 1.7, 2.6, and 5.6 inches, respectively, were used to determine the stage-area-volume relationships for assessing the impacts of SLRs for the POR. The six SLRs are referenced to zero-NAVD88.

The method used for calculating water volume and bottom area under different SLRs is the same as discussed in Appendix C of the model report (HSW, February 2011). An add-in area of 29,034 m^2 and an add-in volume of 30,050 m^3, based on information developed by the District and Wetland Solutions, Inc. (2010), were used to account for regions of the Homosassa main spring bowl and run (Figure 1), and were added on the established bottom area and volume versus RKM relationships (Figures 2 to 3).

For the six sets of stage-area-volume relationships, greater water volume and bottom area correspond to higher sea level at the same river location (Figures 2 and 3). The difference in volume and area among the SLRs at the same location diminishes from downstream to upstream. These relationships were used to determine the river volumes and bottom areas associated with 3, 5, and 12 psu isohalines under the combined conditions of SLRs and flow reductions.

Natural Shoreline Data

Natural shoreline data (Figure 4) were provided by SWFWMD (via Mr. Doug Leeper on July 1, 2011), and was used to quantify the natural shoreline lengths associated with 3, 5, and 12 psu surface isohalines under the combined SLRs and flow reduction scenarios. Steeper change in shoreline was approximately downstream of RKM 7.5. Upstream of this location there are some zones where there is no natural shoreline, and consequently the change is relatively small (Figure 4).

Tide and Spring Flows

For the hydrodynamic model, the tide is the same as that used in the calibrated model (HSW, February 2011) with offsets that take into account the sea level changes. Spring flows are the flows at Homosassa Springs at Homosassa, SE Fork Homosassa Spring at Homosassa, and Halls River. Each MFL flow reduction was applied proportionately to flows at these three locations.

For the empirical models, the tide is the daily mean tidal stage, as reported for the Homosassa River gauge. Mean monthly tide data were used in the models when daily mean tide at Homosassa gauge was unavailable for the POR model applications. Spring flow is defined as the sum of the mean daily spring flow, as reported for Homosassa Springs at Homosassa and SE Fork Homosassa Spring at Homosassa. A linear relationship between Homosassa Springs and SE Fork flow data was used to supplement the missing records when one record was available. No total spring flow value was estimated when no spring flow data were available.

Six flow reductions of 0, 1, 2, 3, 4, and 5% were applied in combination with the sea level rise scenarios. Spring flow change associated with the SLRs was considered for both hydrodynamic and empirical models for the calendar year 2007 and the POR (empirical models only). The technique used to adjust spring flow due to SLRs involves using the rating curve for each spring and was documented in detail in a previous memorandum "Use of a hydrodynamic model for evaluating sea level change on salinities in the Homosassa River in support of MFLs development" (HSW, May 2011). The baseline condition for each model application is habitat associated with the modeled 0% flow reduction for each sea level rise scenario.

Results

Sea Level Rise Analysis based on Hydrodynamic Model

The 3-hour interval cell-by-cell salinity output for each model run was processed by extracting the surface, middle, and bottom salinities and calculating the depth-averaged salinity for the centerline cells. An isohaline location is represented by the centerline channel distance upstream from the mouth that was assigned using ArcGIS. The 3, 5, and 12-psu surface, bottom, and depth-averaged isohaline locations were then interpolated for each output time step (i.e., 3-hour interval). The medians of interpolated 3, 5, and 12-psu surface, depth-averaged, and bottom isohaline locations under each SLRs for the calendar year 2007 were then calculated (Tables 2 to 7).

The shoreline lengths, bottom area and water volume were determined using the relationships between RKM and the three habitat measures (Tables 2 to 7). Relative change from baseline (i.e., 0% flow reduction) for shoreline, bottom area and water volume were also calculated (Tables 2 to 7).

Sea level rise would shift the isohaline locations upstream and therefore decrease the shoreline, bottom area and water volume upstream of the isohalines. Sea level rise may also cause reduced spring flow, although the dynamics are complicated. The magnitude of the change was simply estimated using the empirical USGS rating curves. This approach may overestimate the magnitude of SLR-induced spring flow reduction, as increased potentiometric head pressure in the Floridan aquifer system as a result of SLR could be expected to counteract the effects of higher tide stages. A reduction in spring flow also will result in reduced habitat. However, SLR would also increase the water volume and, to a lesser extent, bottom area universally over the river course compared with baseline by increasing the total river bottom area and water volume. Therefore, the combination of SLR and flow reduction would have a combined effect on the amount of habitat, i.e., change in habitat would essentially reflect a net balance of sea level rise and spring flow change.

The net effect of sea level rise and flow reduction is the upstream shift of isohalines (i.e., increasing RKMs) and associated decrease in shorelines, water volumes and bottom areas (Tables 2 to 7). In general, a higher SLR resulted in less shoreline, bottom area and water volume habitat for a given flow reduction and for the same isohaline (Tables 2 to 7).

Greater relative change from baseline generally is observed for the 3-psu isohaline compared to the other two isohalines under the same SLR scenario. The 3-psu isohaline is very near to the spring area, particularly the bottom and depth-averaged isohaline, and even a small change in the habitat metrics will cause a relatively large change in habitat. For the 3-psu isohaline, the 3.2-inch sea level change would cause a 15% or greater change in bottom area and water volume when the flow reductions are 4 and 5%, respectively (Table 3, Figures 6 and 8). For 5 and 12 psu isohalines, none of the scenarios would cause a habitat change of more than 9%.

Sea Level Rise Analysis based on Isohaline Empirical Models

Isohaline regression models were developed to estimate daily isohaline locations for the calendar year 2007 and the POR (1995 - 2009) with and without considering spring flow change directly associated with the SLR. For year 2007, empirical models runs were performed to address effects of potential sea level changes (1.9, 3.2, and 7. 3 inches) on the position of the 3, 5, and 12 psu isohalines and associated habitats in the Homosassa River. For the POR, the sea level change scenarios reflect estimated low, medium and high sea level increases by 2030.

The empirical model output is a data set that includes the input data and the locations, in river kilometers, of the surface and bottom isohalines. The average water column location of a specific isohaline is defined as the average location of the surface and bottom isohaline. Shoreline lengths, associated with surface isohalines, bottom areas, associated with depth-averaged and bottom salinity isohalines, and volumes, associated with water column isohalines, were then calculated using the shoreline versus RKM and area/volume versus RKM relationships that accounted for the increased area and volumes associated with the particular seal level rise scenario.

In general, for the 2007 data, the greatest relative habitat changes were associated with the 3 psu and 12 psu isohalines, particularly when not considering spring flow reduction that may be associated with SLR (Tables 8, 9, and 11). Natural shoreline habitat associated with the 12 psu isohaline was reduced by over 15% with 5% flow reductions under low and medium SLRs conditions (Figure 9). Because none of the shoreline at some RKM locations is natural, the change in natural shoreline habitat associated with a potential flow reduction can be quite small (e.g., Figure 9, 5 psu). Bottom area habitat change associated with the 3 psu isohaline also exceeded 15% (Figures 10 and 12) for low and medium SLR scenarios with withdrawals of 4 to 5%.

For the POR data, the relative change of several 3 psu related habitats exceeded 15%, particularly the bottom area. Greater than 15% reductions for bottom areas with salinities of 3 psu or less were associated with flow reductions of 2 to 5% (Tables 14 to 19; Figures 14 and 16). The most sensitive modeled responses, i.e., the greatest decreases in this habitat were associated with the scenarios involving SLR-induced reductions in spring flow, and may be confounded by issues involved in the determination of SLR-induced flow reductions. On a volumetric basis, flow reductions of 4 to 5% were associated with greater than 15% changes in 3 psu habitat (Tables 14 to 19; Figure 15). The 3 psu isohaline is very near the upstream end of the river and even a small change in area or volume can result in a relatively large relative reduction. The 12 psu shoreline change (Table 19, Figure 13) and 5 psu bottom area change (Tables 16 to 18, Figure 16) exceeded 15% for one or more scenarios involving flow reductions of 4 or 5%.

Deliverable Summary

Twenty-one data files are provided in Microsoft Excel 2007 format along with this memorandum and 36 sets of EFDC hydrodynamic model run files:

a. Three files containing stage-area-volume relationships, shoreline, and SLR induced spring flow reductions for year 2007 and POR:

   "Stage_Area_Volume_Shoreline.xlsm"
   "SLR_Spring Q Change_2007.xlsx"
   "SLR_Spring Q Change_POR.xls"

b. Three files contain the hydrodynamic model results for the calendar year 2007, each corresponding to one SLR scenario, coupled with six flow reduction scenarios:

   "Hydrodynamic Modeling+1.9inches_2007.xlsm"
   "Hydrodynamic Modeling+3.2inches_2007.xlsm"
   "Hydrodynamic Modeling+7.3inches_2007.xlsm"

c. Three files contain the hydrodynamic model results for the calendar year 2007, each corresponding to one SLR scenario, coupled with six flow reduction scenarios and with considering spring flow change:

   "Hydrodynamic Modeling+1.9inches_2007_Qadjusted.xlsm"
   "Hydrodynamic Modeling+3.2inches_2007_Qadjusted.xlsm"
   "Hydrodynamic Modeling+7.3inches_2007_Qadjusted.xlsm"

d. Three files contain empirical modeling results for the calendar year 2007, each corresponding to one SLR scenario, coupled with six flow reduction scenarios:

   "Regression Modeling+1.9inches_2007.xlsm"
   "Regression Modeling+3.2inches_2007.xlsm"
   "Regression Modeling+7.3inches_2007.xlsm"

e. Three files contain empirical modeling results for the calendar year 2007, each corresponding to one SLR scenario, coupled with six flow reduction scenarios and with considering of spring flow change:

   "Regression Modeling+1.9inches_2007_Qadjusted.xlsm"
   "Regression Modeling+3.2inches_2007_Qadjusted.xlsm"
   "Regression Modeling+7.3inches_2007_Qadjusted.xlsm"

f. Three files contain empirical modeling results for the POR, corresponding to low, medium, and high SLR scenario, coupled with six flow reduction scenarios:

   "Regression Modeling_Low_POR_Mod1.xlsm"
   "Regression Modeling_Medium_POR_Mod1.xlsm"
   "Regression Modeling_High_POR_Mod1.xlsm"

g. Three files contain empirical modeling results for the POR, corresponding to low, medium, and high SLR scenario, coupled with six flow reduction scenarios and with considering of spring flow change:

“Regression Modeling_Low_POR_Qadjusted_Mod1.xlsm”
“Regression Modeling_Medium_POR_Qadjusted_Mod1.xlsm”
“Regression Modeling_High_POR_Qadjusted_Mod1.xlsm”

Reference

HSW Engineering, Inc. (HSW). A modeling study of the relationships of freshwater flow with the salinity and thermal characteristics of the Homosassa River, February 2011. Prepared for the Southwest Florida Water Management District.

HSW Engineering, Inc. (HSW). Use of a hydrodynamic model for evaluating salinities in the Homosassa River in support of MFL development, February 2011. Technical Memo. Prepared for the Southwest Florida Water Management District.

HSW Engineering, Inc. (HSW). Use of a hydrodynamic model for evaluating sea level change on salinities in the Homosassa River in support of MFLs development, May 2011. Technical Memo. Prepared for the Southwest Florida Water Management District.

USACOA (United States Army Corps of Engineers). 2009. Water resource policies and authorities incorporating sea-level change considerations in civil works programs. Circular No. 1165-2-211. Washington, D.C.

Wetlands Solution, Inc. 2010. An ecosystem-level study of Florida’s springs. Final report, prepared for the Florida Fish and Wildlife Conservation Commission, St. Johns River Water Management District, Southwest Florida Water Management District, Florida Park Service, Florida Spring Initiative, and Three River Trust, Inc.

FIGURES AND TABLES

Table 1. Sea level rise estimates for the period of record (1995 - 2009)

Year	Low (inches)	Medium (inches)	High (inches)
1995	1.72	2.32	4.24
1996	1.72	2.37	4.43
1997	1.72	2.41	4.62
1998	1.72	2.46	4.80
1999	1.72	2.50	4.99
2000	1.72	2.55	5.18
2001	1.72	2.59	5.36
2002	1.72	2.64	5.55
2003	1.72	2.68	5.74
2004	1.72	2.73	5.92
2005	1.72	2.77	6.11
2006	1.72	2.82	6.30
2007	1.72	2.86	6.48
2008	1.72	2.91	6.67
2009	1.72	2.95	6.86
Median	1.72	2.64	5.55

Notes: Low, medium, and high sea level rises represent estimates using the historical trend, adjusted NRC modified I, and adjusted NRC modified III methods, respectively. Data were provided by Mr. Doug Leeper of SWFWMD on July 1, 2011.

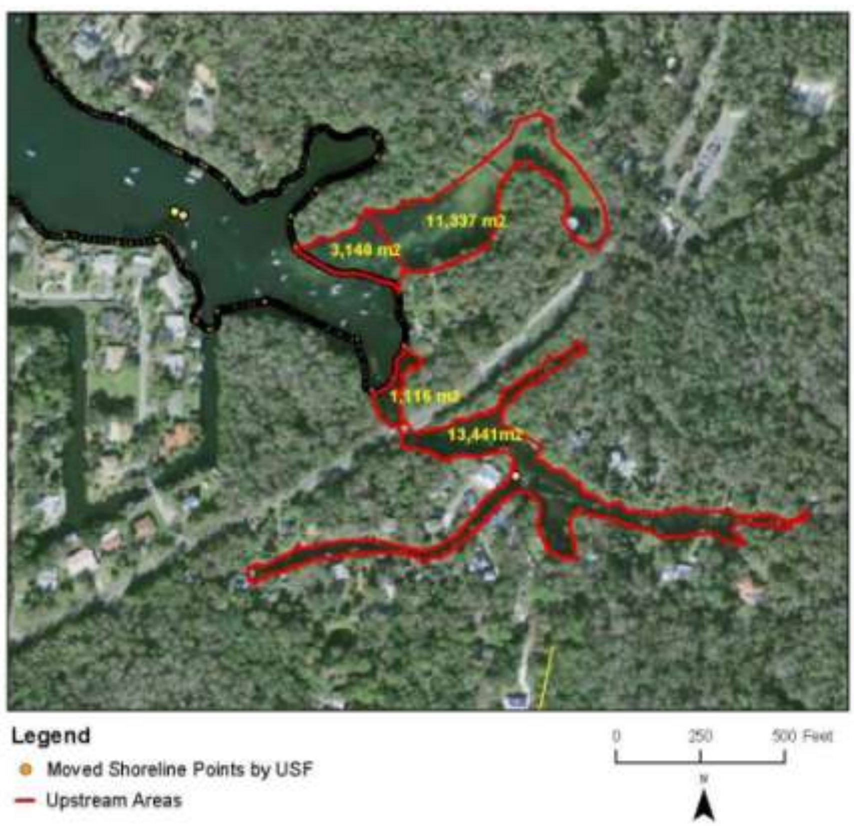


Figure 1. Upstream springhead areas of the Homosassa River System (Provided by Mr. Doug Leeper of SWFWMD on July 1, 2011)

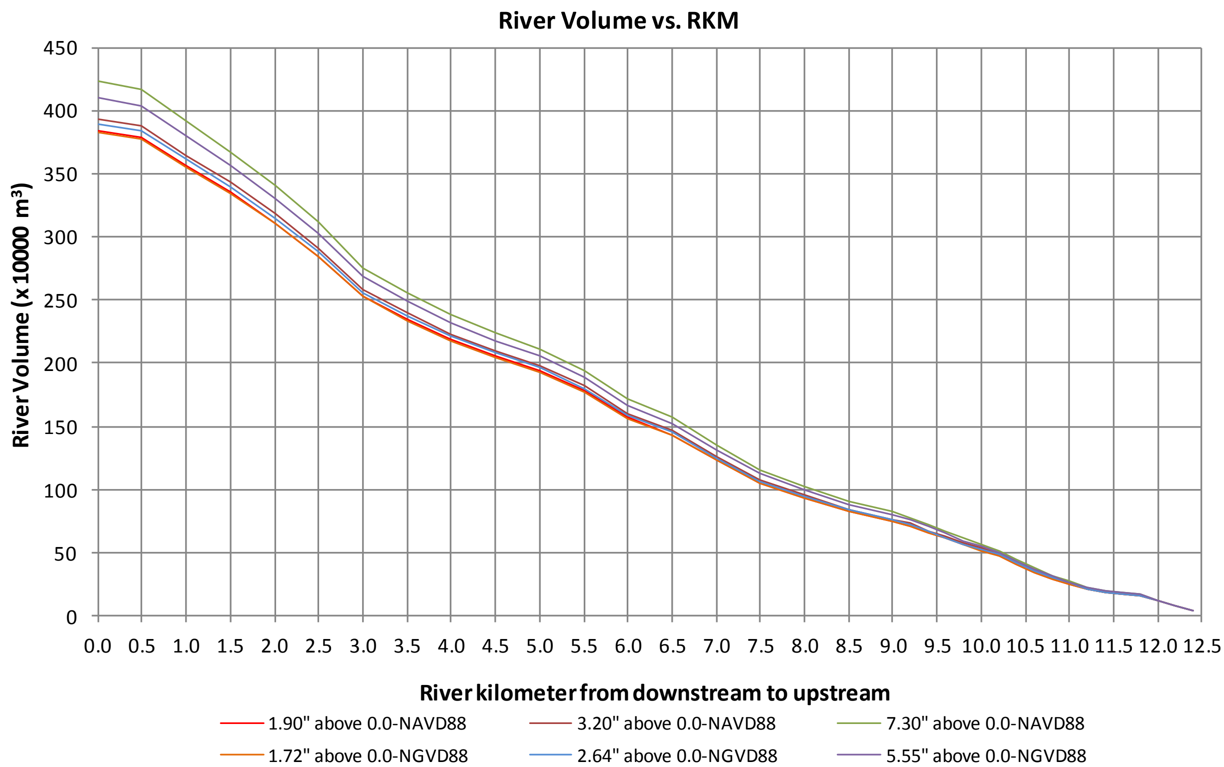


Figure 2. Homosassa River volume vs. river kilometer for six sea level rise conditions

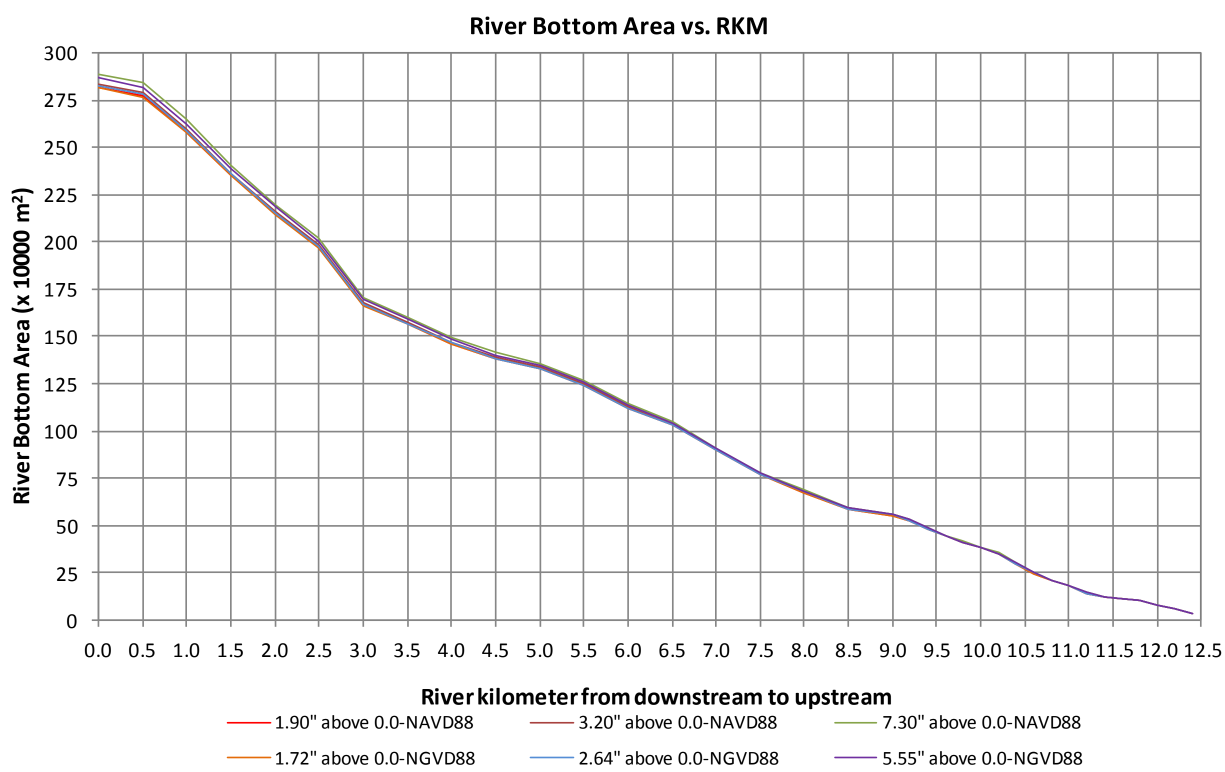


Figure 3. Homosassa River bottom area vs. river kilometer for six sea level rise conditions

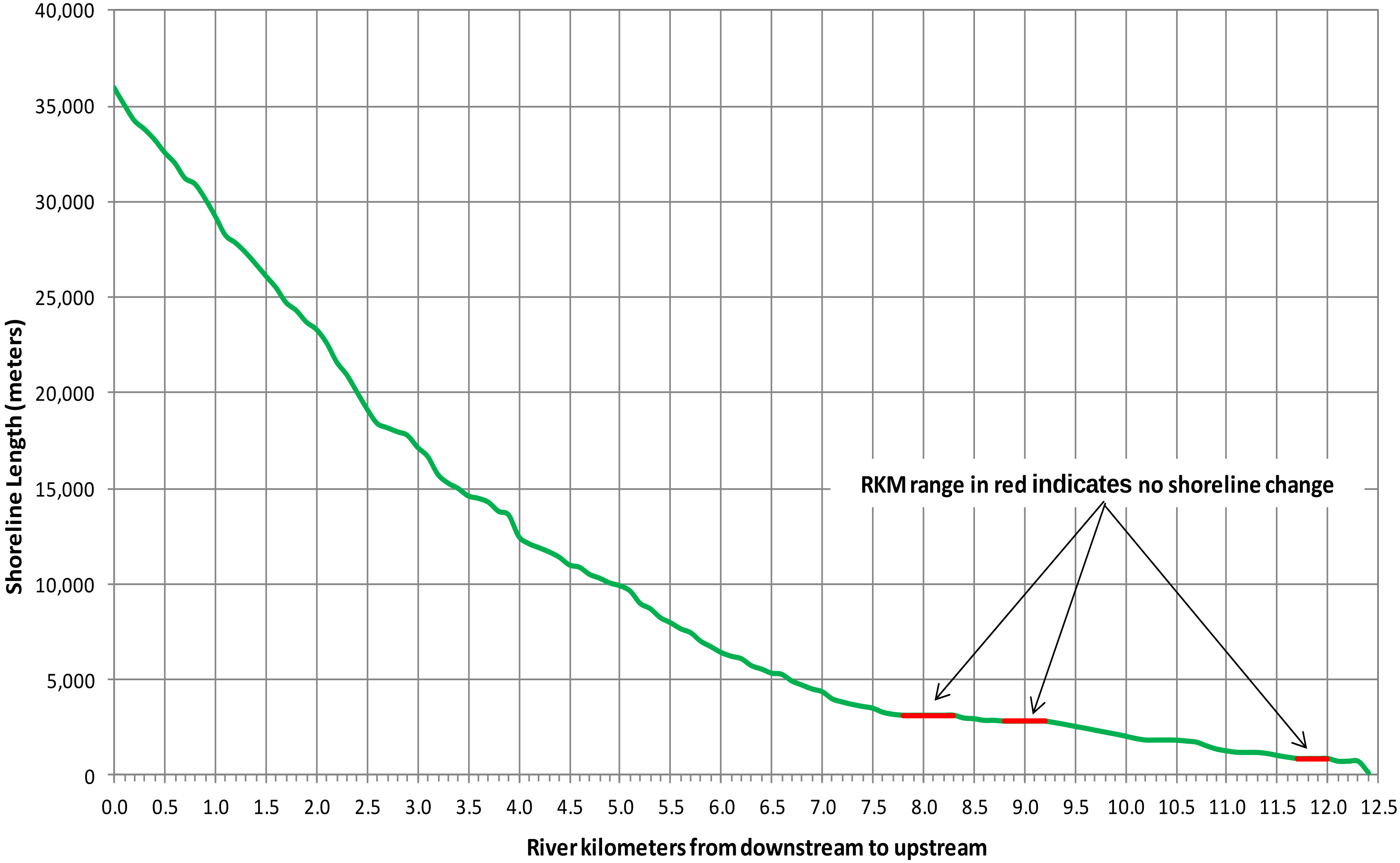


Figure 4. Homosassa River natural shoreline versus river kilometer (data were provided by Mr. Doug Leeper on 7/1/2011)

Table 2. Hydrodynamic model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 1.9-inch sea level rise and 6 flow reductions without considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	10.95	1,326.6	–	3psu_avg_0%	10.98	182,826	–	257,629	–	3psu_bot_0%	11.01	179,268	–
3psu_top_1%	10.96	1,311.2	1	3psu_avg_1%	11.00	179,945	2	253,781	1	3psu_bot_1%	11.02	176,674	1
3psu_top_2%	10.99	1,288.3	3	3psu_avg_2%	11.02	177,469	3	250,810	3	3psu_bot_2%	11.04	172,581	4
3psu_top_3%	10.99	1,282.0	3	3psu_avg_3%	11.02	176,534	3	249,688	3	3psu_bot_3%	11.05	171,744	4
3psu_top_4%	11.02	1,265.4	5	3psu_avg_4%	11.05	171,652	6	243,829	5	3psu_bot_4%	11.07	167,401	7
3psu_top_5%	11.03	1,253.3	6	3psu_avg_5%	11.06	168,673	8	240,254	7	3psu_bot_5%	11.09	164,222	8
5psu_top_0%	9.06	2,834.3	–	5psu_avg_0%	9.18	529,301	–	714,487	–	5psu_bot_0%	9.26	514,160	–
5psu_top_1%	9.09	2,834.3	0	5psu_avg_1%	9.21	523,875	1	707,976	1	5psu_bot_1%	9.29	507,220	1
5psu_top_2%	9.12	2,834.3	0	5psu_avg_2%	9.24	517,922	2	701,403	2	5psu_bot_2%	9.32	499,874	3
5psu_top_3%	9.13	2,834.3	0	5psu_avg_3%	9.25	515,979	3	699,259	2	5psu_bot_3%	9.33	497,003	3
5psu_top_4%	9.18	2,834.3	0	5psu_avg_4%	9.30	504,437	5	686,517	4	5psu_bot_4%	9.39	483,787	6
5psu_top_5%	9.21	2,829.0	0	5psu_avg_5%	9.33	498,025	6	679,439	5	5psu_bot_5%	9.42	476,895	7
12psu_top_0%	5.66	7,540.0	–	12psu_avg_0%	5.96	1,127,658	–	1,584,732	–	12psu_bot_0%	6.39	1,048,199	–
12psu_top_1%	5.68	7,498.9	1	12psu_avg_1%	6.01	1,117,158	1	1,567,025	1	12psu_bot_1%	6.40	1,046,219	0
12psu_top_2%	5.70	7,453.9	1	12psu_avg_2%	6.05	1,109,143	2	1,555,040	2	12psu_bot_2%	6.41	1,043,691	0
12psu_top_3%	5.71	7,428.6	1	12psu_avg_3%	6.06	1,106,738	2	1,551,443	2	12psu_bot_3%	6.42	1,042,793	1
12psu_top_4%	5.74	7,274.5	4	12psu_avg_4%	6.15	1,090,893	3	1,527,747	4	12psu_bot_4%	6.44	1,038,675	1
12psu_top_5%	5.76	7,173.1	5	12psu_avg_5%	6.18	1,085,388	4	1,519,514	4	12psu_bot_5%	6.45	1,036,935	1

Table 3. Hydrodynamic model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 3.2-inch sea level rise and 6 flow reductions without considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	11.00	1,276.8	–	3psu_avg_0%	11.03	175,075	–	251,688	–	3psu_bot_0%	11.06	169,944	–
3psu_top_1%	11.02	1,264.1	1	3psu_avg_1%	11.05	171,843	2	247,718	2	3psu_bot_1%	11.07	167,221	2
3psu_top_2%	11.03	1,252.8	2	3psu_avg_2%	11.06	169,108	3	244,358	3	3psu_bot_2%	11.09	163,715	4
3psu_top_3%	11.04	1,248.4	2	3psu_avg_3%	11.07	168,173	4	243,210	3	3psu_bot_3%	11.10	162,582	4
3psu_top_4%	11.07	1,230.3	4	3psu_avg_4%	11.17	148,872	15	219,500	13	3psu_bot_4%	11.20	143,465	16
3psu_top_5%	11.11	1,205.5	6	3psu_avg_5%	11.19	144,474	17	214,097	15	3psu_bot_5%	11.21	141,632	17
5psu_top_0%	9.15	2,834.3	–	5psu_avg_0%	9.27	511,566	–	708,329	–	5psu_bot_0%	9.39	484,912	–
5psu_top_1%	9.18	2,834.3	0	5psu_avg_1%	9.31	503,946	1	699,686	1	5psu_bot_1%	9.42	478,198	1
5psu_top_2%	9.20	2,832.1	0	5psu_avg_2%	9.34	496,917	3	691,713	2	5psu_bot_2%	9.46	471,169	3
5psu_top_3%	9.21	2,825.5	0	5psu_avg_3%	9.35	493,938	3	688,334	3	5psu_bot_3%	9.47	468,864	3
5psu_top_4%	9.26	2,787.9	2	5psu_avg_4%	9.40	482,518	6	675,380	5	5psu_bot_4%	9.53	457,657	6
5psu_top_5%	9.28	2,766.4	2	5psu_avg_5%	9.44	475,429	7	666,773	6	5psu_bot_5%	9.56	451,898	7
12psu_top_0%	5.73	7,333.6	–	12psu_avg_0%	6.14	1,098,145	–	1,565,298	–	12psu_bot_0%	6.44	1,042,938	–
12psu_top_1%	5.75	7,243.0	1	12psu_avg_1%	6.17	1,092,702	0	1,557,114	1	12psu_bot_1%	6.46	1,040,646	0
12psu_top_2%	5.77	7,128.7	3	12psu_avg_2%	6.21	1,086,220	1	1,547,368	1	12psu_bot_2%	6.47	1,038,494	0
12psu_top_3%	5.78	7,091.0	3	12psu_avg_3%	6.22	1,084,129	1	1,544,223	1	12psu_bot_3%	6.47	1,037,432	1
12psu_top_4%	5.83	6,928.6	6	12psu_avg_4%	6.27	1,075,752	2	1,531,627	2	12psu_bot_4%	6.49	1,033,727	1
12psu_top_5%	5.85	6,855.4	7	12psu_avg_5%	6.29	1,071,507	2	1,525,243	3	12psu_bot_5%	6.51	1,029,596	1

Table 4. Hydrodynamic model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 7.3-inch sea level rise and 6 flow reductions without considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	11.21	1,196.8	–	3psu_avg_0%	11.24	141,672	–	219,725	–	3psu_bot_0%	11.26	138,635	–
3psu_top_1%	11.22	1,196.8	0	3psu_avg_1%	11.24	140,832	1	218,715	0	3psu_bot_1%	11.28	137,051	1
3psu_top_2%	11.23	1,196.8	0	3psu_avg_2%	11.25	139,825	1	217,504	1	3psu_bot_2%	11.29	135,542	2
3psu_top_3%	11.23	1,196.8	0	3psu_avg_3%	11.26	139,284	2	216,853	1	3psu_bot_3%	11.30	134,613	3
3psu_top_4%	11.24	1,196.8	0	3psu_avg_4%	11.29	136,327	4	213,297	3	3psu_bot_4%	11.35	129,370	7
3psu_top_5%	11.26	1,196.8	0	3psu_avg_5%	11.31	133,946	5	210,433	4	3psu_bot_5%	11.38	126,761	9
5psu_top_0%	9.37	2,684.1	–	5psu_avg_0%	9.60	448,697	–	671,560	–	5psu_bot_0%	9.70	431,427	–
5psu_top_1%	9.40	2,660.6	1	5psu_avg_1%	9.64	442,701	1	661,082	2	5psu_bot_1%	9.71	430,636	0
5psu_top_2%	9.44	2,621.5	2	5psu_avg_2%	9.67	436,992	3	651,079	3	5psu_bot_2%	9.78	419,687	3
5psu_top_3%	9.45	2,610.0	3	5psu_avg_3%	9.68	434,944	3	647,491	4	5psu_bot_3%	9.80	416,362	3
5psu_top_4%	9.51	2,549.0	5	5psu_avg_4%	9.70	432,277	4	642,819	4	5psu_bot_4%	9.92	397,840	8
5psu_top_5%	9.54	2,518.6	6	5psu_avg_5%	9.71	431,343	4	641,183	5	5psu_bot_5%	9.96	392,379	9
12psu_top_0%	6.02	6,387.3	–	12psu_avg_0%	6.42	1,062,837	–	1,595,597	–	12psu_bot_0%	6.76	976,925	–
12psu_top_1%	6.07	6,284.6	2	12psu_avg_1%	6.43	1,060,701	0	1,592,338	0	12psu_bot_1%	6.79	969,023	1
12psu_top_2%	6.12	6,196.6	3	12psu_avg_2%	6.44	1,058,373	0	1,588,787	0	12psu_bot_2%	6.83	959,002	2
12psu_top_3%	6.14	6,179.8	3	12psu_avg_3%	6.45	1,057,581	0	1,587,580	1	12psu_bot_3%	6.84	956,011	2
12psu_top_4%	6.19	6,102.5	4	12psu_avg_4%	6.47	1,053,577	1	1,581,472	1	12psu_bot_4%	6.88	945,181	3
12psu_top_5%	6.24	5,965.0	7	12psu_avg_5%	6.48	1,050,598	1	1,576,929	1	12psu_bot_5%	6.90	939,925	4

Table 5. Hydrodynamic model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 1.9-inch sea level rise and 6 flow reductions with considering spring flow change

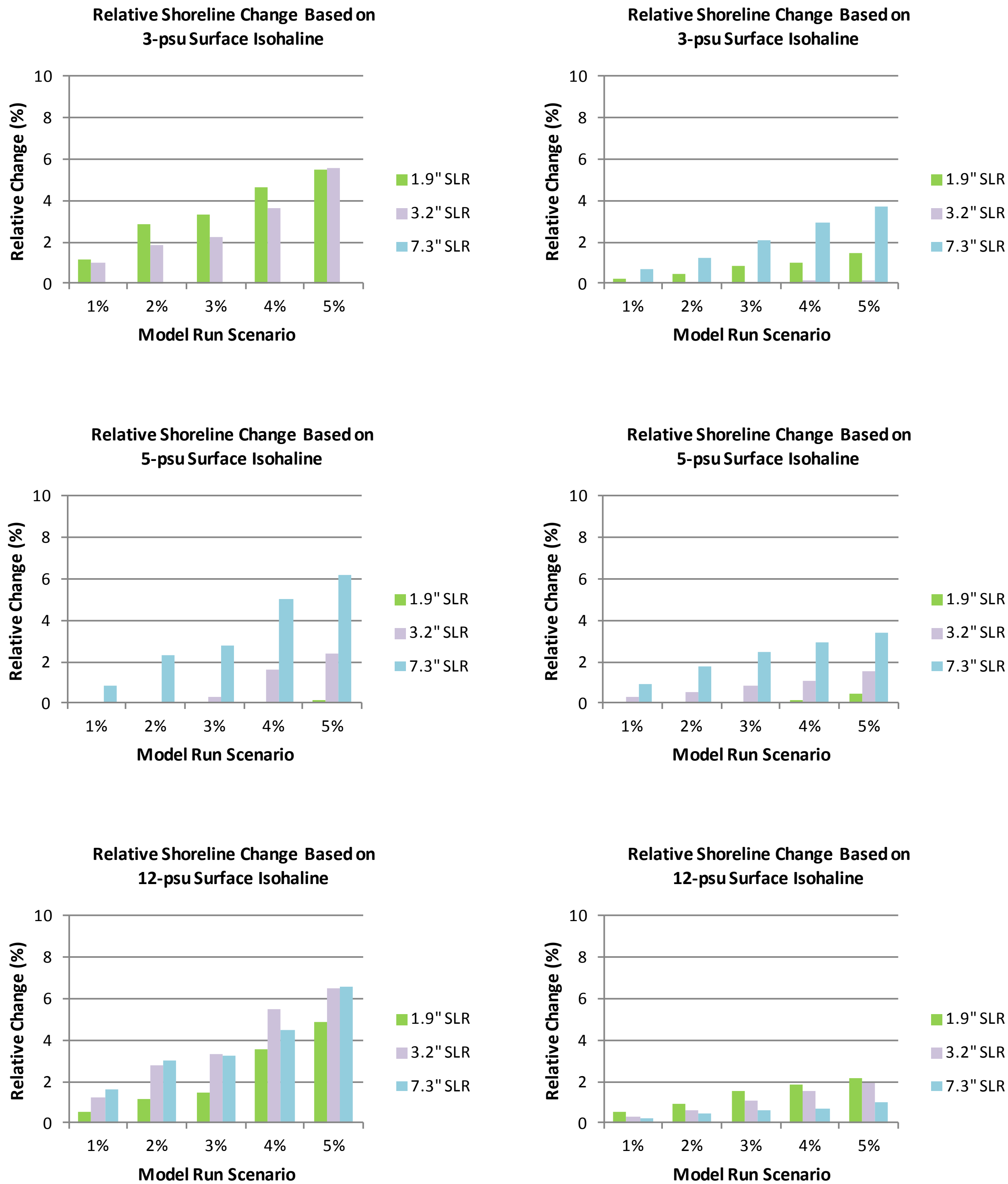
Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m2)	Area Change from Baseline (%)
3psu_top_0%	11.01	1,269.2	–	3psu_avg_0%	11.04	172,928	–	245,360	–	3psu_bot_0%	11.06	168,433	–
3psu_top_1%	11.01	1,266.3	0	3psu_avg_1%	11.05	171,877	1	244,100	1	3psu_bot_1%	11.07	167,582	1
3psu_top_2%	11.02	1,263.4	0	3psu_avg_2%	11.05	171,157	1	243,235	1	3psu_bot_2%	11.07	166,800	1
3psu_top_3%	11.03	1,258.7	1	3psu_avg_3%	11.05	170,398	1	242,324	1	3psu_bot_3%	11.08	165,828	2
3psu_top_4%	11.03	1,256.2	1	3psu_avg_4%	11.06	169,330	2	241,043	2	3psu_bot_4%	11.09	164,306	2
3psu_top_5%	11.04	1,250.3	1	3psu_avg_5%	11.07	167,939	3	239,373	2	3psu_bot_5%	11.09	163,253	3
5psu_top_0%	9.17	2,834.3	–	5psu_avg_0%	9.29	505,651	–	687,857	–	5psu_bot_0%	9.38	485,530	–
5psu_top_1%	9.18	2,834.3	0	5psu_avg_1%	9.30	503,040	1	684,975	0	5psu_bot_1%	9.39	483,200	0
5psu_top_2%	9.19	2,834.3	0	5psu_avg_2%	9.31	501,557	1	683,338	1	5psu_bot_2%	9.40	481,171	1
5psu_top_3%	9.20	2,834.3	0	5psu_avg_3%	9.32	499,621	1	681,201	1	5psu_bot_3%	9.41	479,285	1
5psu_top_4%	9.21	2,829.2	0	5psu_avg_4%	9.33	496,611	2	677,877	1	5psu_bot_4%	9.42	476,368	2
5psu_top_5%	9.21	2,822.3	0	5psu_avg_5%	9.34	494,763	2	675,837	2	5psu_bot_5%	9.43	474,048	2
12psu_top_0%	5.73	7,304.0	–	12psu_avg_0%	6.13	1,094,202	–	1,532,695	–	12psu_bot_0%	6.44	1,039,691	–
12psu_top_1%	5.74	7,266.4	1	12psu_avg_1%	6.15	1,091,462	0	1,528,597	0	12psu_bot_1%	6.44	1,038,941	0
12psu_top_2%	5.75	7,235.2	1	12psu_avg_2%	6.16	1,089,229	0	1,525,258	0	12psu_bot_2%	6.44	1,038,501	0
12psu_top_3%	5.76	7,191.9	2	12psu_avg_3%	6.17	1,087,693	1	1,522,961	1	12psu_bot_3%	6.45	1,037,573	0
12psu_top_4%	5.76	7,167.4	2	12psu_avg_4%	6.18	1,085,569	1	1,519,784	1	12psu_bot_4%	6.45	1,037,462	0
12psu_top_5%	5.77	7,143.8	2	12psu_avg_5%	6.19	1,083,567	1	1,516,790	1	12psu_bot_5%	6.45	1,036,385	0

Table 6. Hydrodynamic model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 3.2-inch sea level rise and 6 flow reductions with considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Change from Baseline Area (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	11.18	1,198.6	–	3psu_avg_0%	11.20	142,589	–	211,816	–	3psu_bot_0%	11.22	140,588	–
3psu_top_1%	11.18	1,198.3	0	3psu_avg_1%	11.21	142,304	0	211,489	0	3psu_bot_1%	11.23	140,041	0
3psu_top_2%	11.19	1,198.0	0	3psu_avg_2%	11.21	141,842	1	210,961	0	3psu_bot_2%	11.23	139,647	1
3psu_top_3%	11.19	1,197.4	0	3psu_avg_3%	11.22	141,456	1	210,520	1	3psu_bot_3%	11.23	139,480	1
3psu_top_4%	11.20	1,197.1	0	3psu_avg_4%	11.22	141,205	1	210,233	1	3psu_bot_4%	11.24	139,158	1
3psu_top_5%	11.20	1,196.8	0	3psu_avg_5%	11.22	140,944	1	209,935	1	3psu_bot_5%	11.24	138,995	1
5psu_top_0%	9.32	2,733.3	–	5psu_avg_0%	9.48	465,925	–	655,210	–	5psu_bot_0%	9.60	443,621	–
5psu_top_1%	9.33	2,725.3	0	5psu_avg_1%	9.49	463,964	0	652,824	0	5psu_bot_1%	9.61	441,783	0
5psu_top_2%	9.34	2,719.2	1	5psu_avg_2%	9.51	461,948	1	650,371	1	5psu_bot_2%	9.62	439,690	1
5psu_top_3%	9.35	2,710.0	1	5psu_avg_3%	9.51	460,517	1	648,630	1	5psu_bot_3%	9.63	438,082	1
5psu_top_4%	9.35	2,703.2	1	5psu_avg_4%	9.52	458,392	2	646,045	1	5psu_bot_4%	9.64	436,365	2
5psu_top_5%	9.37	2,691.1	2	5psu_avg_5%	9.53	456,317	2	643,519	2	5psu_bot_5%	9.66	434,593	2
12psu_top_0%	5.89	6,751.4	–	12psu_avg_0%	6.33	1,064,074	–	1,514,066	–	12psu_bot_0%	6.55	1,019,730	–
12psu_top_1%	5.90	6,732.0	0	12psu_avg_1%	6.34	1,062,884	0	1,512,278	0	12psu_bot_1%	6.56	1,017,977	0
12psu_top_2%	5.90	6,710.8	1	12psu_avg_2%	6.34	1,061,407	0	1,510,057	0	12psu_bot_2%	6.57	1,014,356	1
12psu_top_3%	5.91	6,680.9	1	12psu_avg_3%	6.35	1,060,628	0	1,508,886	0	12psu_bot_3%	6.58	1,012,554	1
12psu_top_4%	5.92	6,646.2	2	12psu_avg_4%	6.36	1,058,929	0	1,506,331	1	12psu_bot_4%	6.59	1,009,723	1
12psu_top_5%	5.93	6,622.4	2	12psu_avg_5%	6.37	1,057,044	1	1,503,496	1	12psu_bot_5%	6.60	1,007,126	1

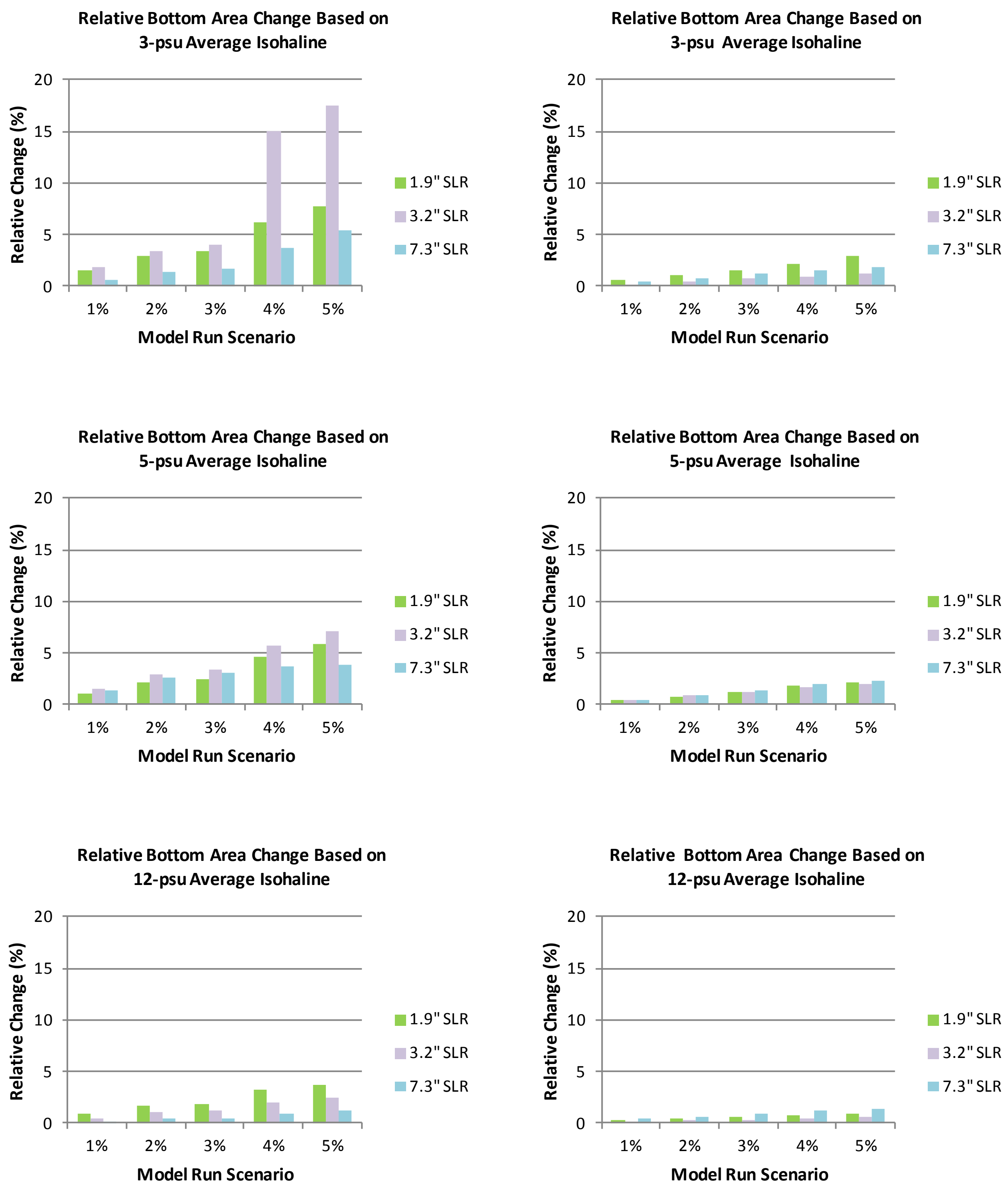
Table 7. Hydrodynamic model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 7.3-inch sea level rise and 6 flow reductions with considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	11.45	1,085.2	–	3psu_avg_0%	11.54	116,554	–	188,831	–	3psu_bot_0%	11.61	112,720	–
3psu_top_1%	11.46	1,077.7	1	3psu_avg_1%	11.55	116,005	0	188,125	0	3psu_bot_1%	11.61	112,255	0
3psu_top_2%	11.47	1,071.7	1	3psu_avg_2%	11.55	115,589	1	187,587	1	3psu_bot_2%	11.62	112,038	1
3psu_top_3%	11.48	1,062.4	2	3psu_avg_3%	11.56	115,159	1	187,033	1	3psu_bot_3%	11.63	111,633	1
3psu_top_4%	11.48	1,053.6	3	3psu_avg_4%	11.57	114,770	2	186,531	1	3psu_bot_4%	11.64	111,072	1
3psu_top_5%	11.49	1,045.1	4	3psu_avg_5%	11.58	114,336	2	185,971	2	3psu_bot_5%	11.64	110,691	2
5psu_top_0%	9.87	2,184.2	–	5psu_avg_0%	10.09	371,385	–	544,349	–	5psu_bot_0%	10.27	336,081	–
5psu_top_1%	9.89	2,163.5	1	5psu_avg_1%	10.11	369,444	1	541,207	1	5psu_bot_1%	10.28	334,565	0
5psu_top_2%	9.91	2,145.1	2	5psu_avg_2%	10.12	368,082	1	539,002	1	5psu_bot_2%	10.29	332,967	1
5psu_top_3%	9.92	2,130.4	2	5psu_avg_3%	10.13	365,981	1	535,599	2	5psu_bot_3%	10.29	331,165	1
5psu_top_4%	9.93	2,120.1	3	5psu_avg_4%	10.14	363,996	2	532,385	2	5psu_bot_4%	10.30	329,593	2
5psu_top_5%	9.94	2,110.6	3	5psu_avg_5%	10.15	362,575	2	530,084	3	5psu_bot_5%	10.31	327,547	3
12psu_top_0%	6.43	5,482.9	–	12psu_avg_0%	6.77	975,520	–	1,453,522	–	12psu_bot_0%	7.04	902,964	–
12psu_top_1%	6.44	5,472.2	0	12psu_avg_1%	6.78	971,594	0	1,447,048	0	12psu_bot_1%	7.04	902,048	0
12psu_top_2%	6.44	5,459.1	0	12psu_avg_2%	6.79	969,618	1	1,443,790	1	12psu_bot_2%	7.05	900,752	0
12psu_top_3%	6.45	5,451.1	1	12psu_avg_3%	6.80	966,812	1	1,439,164	1	12psu_bot_3%	7.05	900,365	0
12psu_top_4%	6.45	5,443.6	1	12psu_avg_4%	6.81	964,324	1	1,435,060	1	12psu_bot_4%	7.05	899,623	0
12psu_top_5%	6.46	5,428.8	1	12psu_avg_5%	6.82	961,458	1	1,430,334	2	12psu_bot_5%	7.05	899,240	0



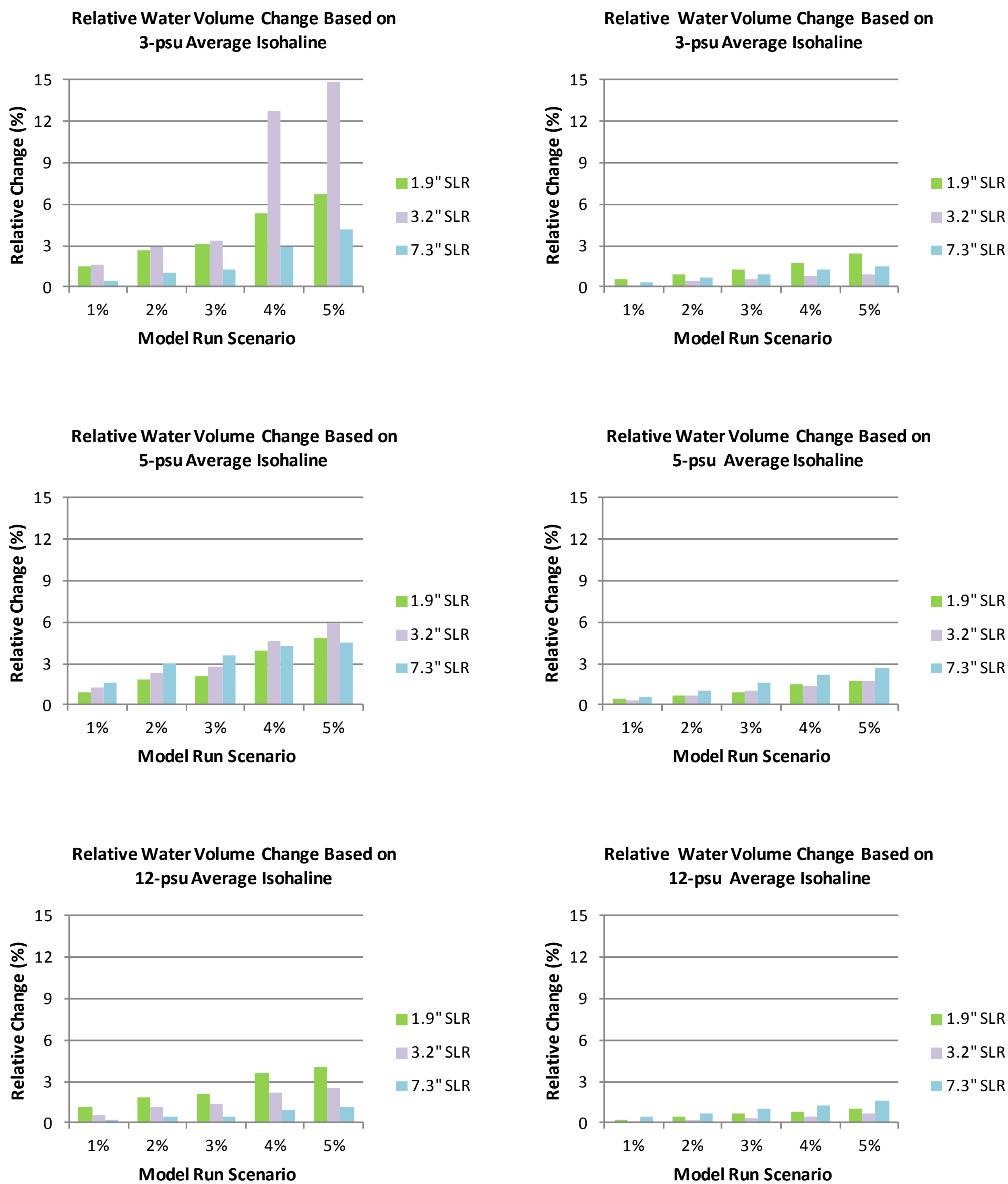
Left: Without considering spring flow change | Right: With considering spring flow change

Figure 5. Hydrodynamic model comparisons of relative changes of surface salinity based shoreline over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines



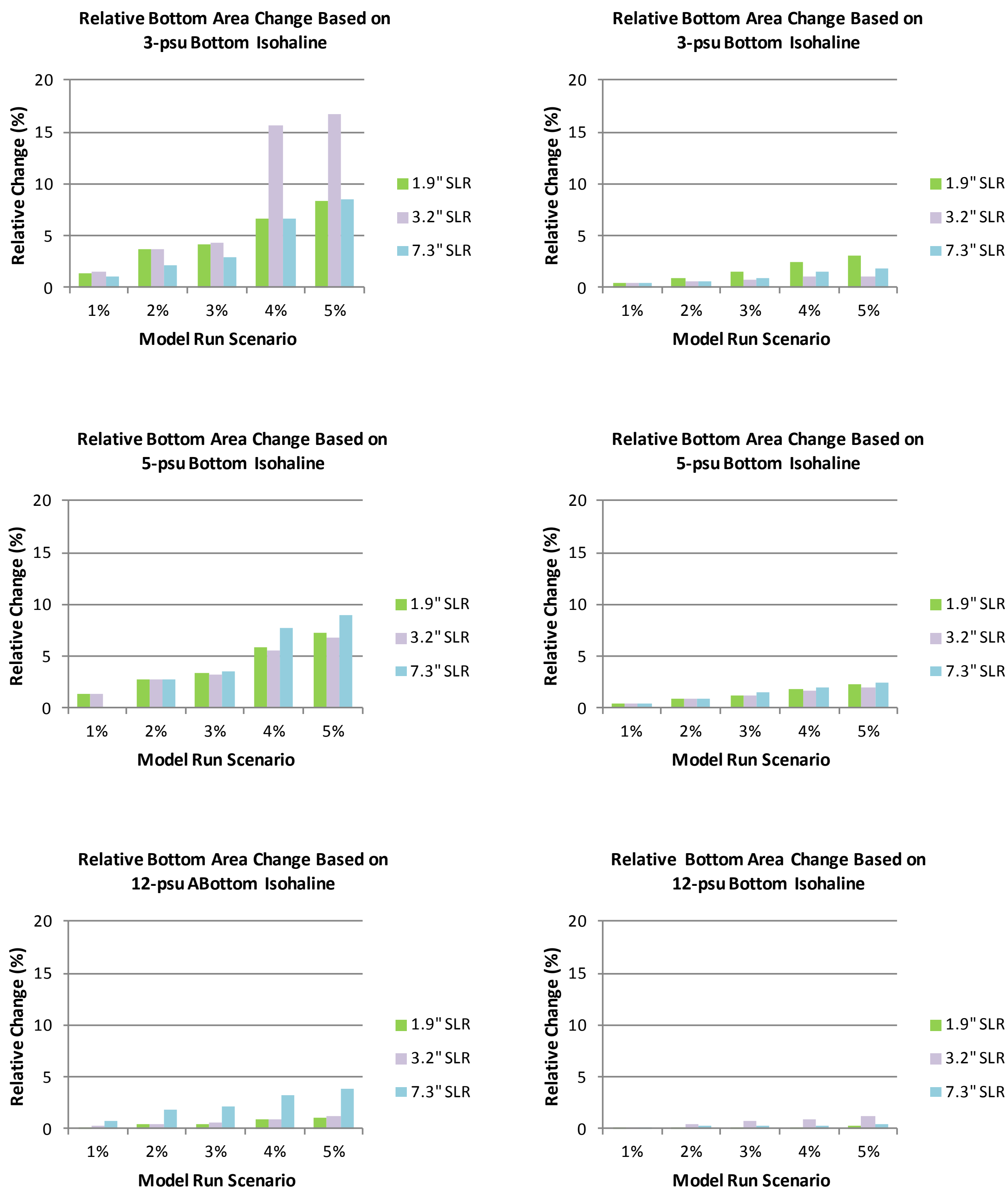
Left: Without considering spring flow change Right: With considering spring flow change

Figure 6. Hydrodynamic model comparisons of relative changes of average-salinity based bottom area over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines



Left: Without considering spring flow change Right: With considering spring flow change

Figure 7. Hydrodynamic model comparisons of relative changes of average-salinity based water volume over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines



Left: Without considering spring flow change Right: With considering spring flow change

Figure 8. Hydrodynamic model comparisons of relative changes of bottom-salinity based river bottom area over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines

Table 8. Regression model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 1.9-inch sea level rise and 6 flow reductions without considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	9.78	2,278.1	–	3psu_avg_0%	10.40	300,192	–	412,388	–	3psu_bot_0%	11.01	178,952	–
3psu_top_1%	9.83	2,227.5	2	3psu_avg_1%	10.43	291,302	3	401,332	3	3psu_bot_1%	11.04	172,361	4
3psu_top_2%	9.87	2,183.9	4	3psu_avg_2%	10.48	279,982	7	387,240	6	3psu_bot_2%	11.08	165,769	7
3psu_top_3%	9.91	2,142.4	6	3psu_avg_3%	10.52	267,909	11	372,210	10	3psu_bot_3%	11.11	159,178	11
3psu_top_4%	9.96	2,093.5	8	3psu_avg_4%	10.55	260,508	13	362,996	12	3psu_bot_4%	11.15	152,587	15
3psu_top_5%	9.98	2,068.6	9	3psu_avg_5%	10.58	253,254	16	353,966	14	3psu_bot_5%	11.18	145,995	18
5psu_top_0%	8.56	2,908.0	–	5psu_avg_0%	9.23	519,746	–	703,418	–	5psu_bot_0%	9.91	394,016	–
5psu_top_1%	8.59	2,885.3	1	5psu_avg_1%	9.25	515,530	1	698,763	1	5psu_bot_1%	9.92	392,298	0
5psu_top_2%	8.61	2,874.2	1	5psu_avg_2%	9.27	509,710	2	692,338	2	5psu_bot_2%	9.93	390,404	1
5psu_top_3%	8.64	2,874.2	1	5psu_avg_3%	9.29	505,161	3	687,316	2	5psu_bot_3%	9.94	388,657	1
5psu_top_4%	8.67	2,874.2	1	5psu_avg_4%	9.31	500,612	4	682,294	3	5psu_bot_4%	9.96	386,911	2
5psu_top_5%	8.69	2,874.2	1	5psu_avg_5%	9.33	496,063	5	677,272	4	5psu_bot_5%	9.97	385,165	2
12psu_top_0%	5.43	8,171.7	–	12psu_avg_0%	5.81	1,164,416	–	1,647,665	–	12psu_bot_0%	6.19	1,083,829	–
12psu_top_1%	5.52	7,919.3	3	12psu_avg_1%	5.90	1,143,054	2	1,611,091	2	12psu_bot_1%	6.23	1,077,396	1
12psu_top_2%	5.61	7,638.7	7	12psu_avg_2%	5.96	1,127,191	3	1,583,932	4	12psu_bot_2%	6.26	1,070,963	1
12psu_top_3%	5.70	7,440.2	9	12psu_avg_3%	6.03	1,113,149	4	1,561,031	5	12psu_bot_3%	6.31	1,062,902	2
12psu_top_4%	5.78	7,076.8	13	12psu_avg_4%	6.06	1,107,770	5	1,552,986	6	12psu_bot_4%	6.35	1,055,849	3
12psu_top_5%	5.84	6,885.2	16	12psu_avg_5%	6.10	1,099,929	6	1,541,260	6	12psu_bot_5%	6.39	1,048,094	3

Table 9. Regression model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 3.2-inch sea level rise and 6 flow reductions without considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	9.82	2,231.9	–	3psu_avg_0%	10.44	289,231	–	405,979	–	3psu_bot_0%	11.06	170,592	–
3psu_top_1%	9.88	2,181.4	2	3psu_avg_1%	10.48	280,308	3	394,603	3	3psu_bot_1%	11.09	163,977	4
3psu_top_2%	9.92	2,135.7	4	3psu_avg_2%	10.52	268,961	7	380,138	6	3psu_bot_2%	11.13	157,363	8
3psu_top_3%	9.96	2,091.1	6	3psu_avg_3%	10.57	256,858	11	364,709	10	3psu_bot_3%	11.16	150,749	12
3psu_top_4%	10.00	2,041.9	9	3psu_avg_4%	10.60	249,439	14	355,250	12	3psu_bot_4%	11.19	144,135	16
3psu_top_5%	10.03	2,014.9	10	3psu_avg_5%	10.63	243,843	16	347,426	14	3psu_bot_5%	11.23	140,125	18
5psu_top_0%	8.62	2,874.2	–	5psu_avg_0%	9.30	506,685	–	702,792	–	5psu_bot_0%	9.98	384,891	–
5psu_top_1%	8.64	2,874.2	0	5psu_avg_1%	9.31	502,458	1	697,998	1	5psu_bot_1%	9.99	383,167	0
5psu_top_2%	8.67	2,874.2	0	5psu_avg_2%	9.34	496,624	2	691,381	2	5psu_bot_2%	10.00	381,230	1
5psu_top_3%	8.70	2,874.2	0	5psu_avg_3%	9.36	492,064	3	686,209	2	5psu_bot_3%	10.02	379,378	1
5psu_top_4%	8.72	2,865.6	0	5psu_avg_4%	9.38	487,505	4	681,037	3	5psu_bot_4%	10.03	377,527	2
5psu_top_5%	8.75	2,855.0	1	5psu_avg_5%	9.40	482,945	5	675,865	4	5psu_bot_5%	10.04	375,675	2
12psu_top_0%	5.56	7,783.7	–	12psu_avg_0%	5.94	1,140,032	–	1,631,919	–	12psu_bot_0%	6.31	1,068,057	–
12psu_top_1%	5.65	7,549.0	3	12psu_avg_1%	6.02	1,120,035	2	1,598,214	2	12psu_bot_1%	6.34	1,061,517	1
12psu_top_2%	5.75	7,247.5	7	12psu_avg_2%	6.09	1,108,056	3	1,580,201	3	12psu_bot_2%	6.38	1,054,977	1
12psu_top_3%	5.84	6,896.1	11	12psu_avg_3%	6.15	1,096,076	4	1,562,188	4	12psu_bot_3%	6.42	1,046,782	2
12psu_top_4%	5.92	6,663.3	14	12psu_avg_4%	6.18	1,090,608	4	1,553,965	5	12psu_bot_4%	6.46	1,039,612	3
12psu_top_5%	5.98	6,489.0	17	12psu_avg_5%	6.23	1,082,637	5	1,541,979	6	12psu_bot_5%	6.51	1,031,260	3

Table 10. Regression model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 7.3-inch sea level rise and 6 flow reductions without considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	9.97	2,078.6	–	3psu_avg_0%	10.59	254,282	–	380,686	–	3psu_bot_0%	11.21	144,603	–
3psu_top_1%	10.02	2,020.5	3	3psu_avg_1%	10.63	246,962	3	369,983	3	3psu_bot_1%	11.24	140,996	2
3psu_top_2%	10.06	1,967.8	5	3psu_avg_2%	10.67	238,294	6	356,986	6	3psu_bot_2%	11.28	137,389	5
3psu_top_3%	10.11	1,921.4	8	3psu_avg_3%	10.72	229,048	10	343,123	10	3psu_bot_3%	11.31	133,782	7
3psu_top_4%	10.15	1,886.3	9	3psu_avg_4%	10.75	223,380	12	334,625	12	3psu_bot_4%	11.35	130,174	10
3psu_top_5%	10.17	1,868.4	10	3psu_avg_5%	10.78	217,825	14	326,297	14	3psu_bot_5%	11.38	126,567	12
5psu_top_0%	8.79	2,838.0	–	5psu_avg_0%	9.50	468,910	–	697,997	–	5psu_bot_0%	10.21	353,282	–
5psu_top_1%	8.82	2,834.3	0	5psu_avg_1%	9.51	465,371	1	693,369	1	5psu_bot_1%	10.22	350,269	1
5psu_top_2%	8.84	2,834.3	0	5psu_avg_2%	9.54	460,487	2	686,983	2	5psu_bot_2%	10.23	346,949	2
5psu_top_3%	8.87	2,834.3	0	5psu_avg_3%	9.56	456,670	3	681,991	2	5psu_bot_3%	10.24	343,887	3
5psu_top_4%	8.90	2,834.3	0	5psu_avg_4%	9.58	452,853	3	676,999	3	5psu_bot_4%	10.26	340,825	4
5psu_top_5%	8.92	2,834.3	0	5psu_avg_5%	9.60	449,036	4	672,008	4	5psu_bot_5%	10.27	337,764	4
12psu_top_0%	5.99	6,457.2	–	12psu_avg_0%	6.33	1,079,821	–	1,621,499	–	12psu_bot_0%	6.67	1,000,900	–
12psu_top_1%	6.08	6,265.0	3	12psu_avg_1%	6.42	1,062,790	2	1,595,525	2	12psu_bot_1%	6.71	991,326	1
12psu_top_2%	6.17	6,130.2	5	12psu_avg_2%	6.49	1,050,144	3	1,576,237	3	12psu_bot_2%	6.74	981,752	2
12psu_top_3%	6.26	5,859.0	9	12psu_avg_3%	6.55	1,033,667	4	1,549,405	4	12psu_bot_3%	6.79	969,754	3
12psu_top_4%	6.35	5,649.1	13	12psu_avg_4%	6.58	1,025,661	5	1,536,203	5	12psu_bot_4%	6.83	959,258	4
12psu_top_5%	6.40	5,542.5	14	12psu_avg_5%	6.62	1,013,991	6	1,516,961	6	12psu_bot_5%	6.87	947,716	5

Table 11. Regression model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 1.9-inch sea level rise and 6 flow reductions with considering spring flow change

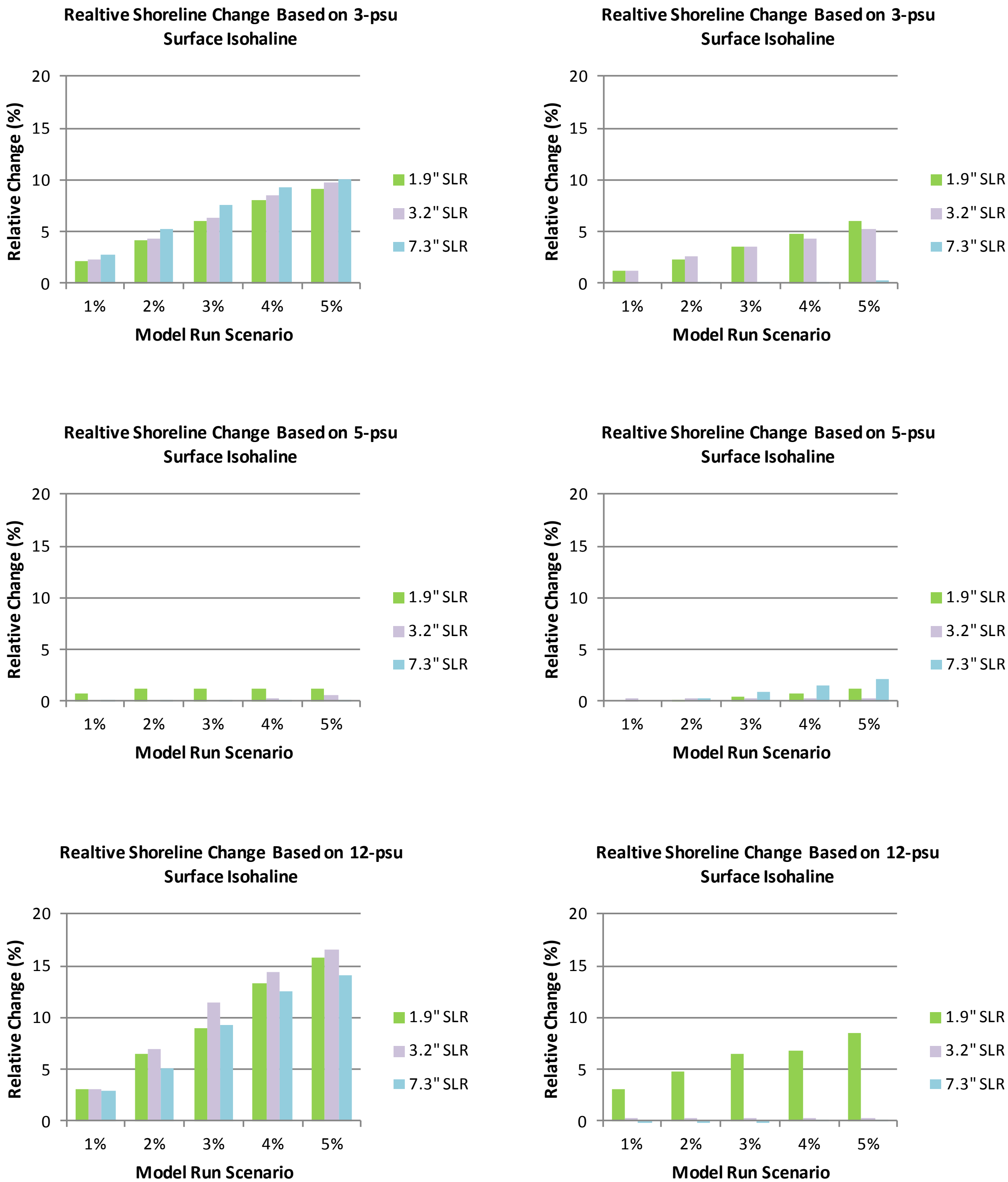
Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	9.95	2,102.6	–	3psu_avg_0%	10.54	262,822	–	365,877	–	3psu_bot_0%	11.14	154,690	–
3psu_top_1%	9.97	2,077.4	1	3psu_avg_1%	10.57	255,836	3	357,180	2	3psu_bot_1%	11.17	148,341	4
3psu_top_2%	9.99	2,053.5	2	3psu_avg_2%	10.60	248,850	5	348,483	5	3psu_bot_2%	11.20	142,105	8
3psu_top_3%	10.01	2,028.1	4	3psu_avg_3%	10.62	243,376	7	341,044	7	3psu_bot_3%	11.23	138,810	10
3psu_top_4%	10.04	2,002.1	5	3psu_avg_4%	10.65	238,080	9	333,753	9	3psu_bot_4%	11.27	135,515	12
3psu_top_5%	10.06	1,976.1	6	3psu_avg_5%	10.68	232,784	11	326,462	11	3psu_bot_5%	11.30	132,219	15
5psu_top_0%	8.66	2,874.2	–	5psu_avg_0%	9.31	502,417	–	684,287	–	5psu_bot_0%	9.95	387,523	–
5psu_top_1%	8.68	2,874.2	0	5psu_avg_1%	9.33	498,032	1	679,447	1	5psu_bot_1%	9.96	385,839	0
5psu_top_2%	8.71	2,870.7	0	5psu_avg_2%	9.34	493,647	2	674,606	1	5psu_bot_2%	9.98	384,088	1
5psu_top_3%	8.73	2,860.6	0	5psu_avg_3%	9.36	489,262	3	669,765	2	5psu_bot_3%	9.99	382,475	1
5psu_top_4%	8.76	2,850.4	1	5psu_avg_4%	9.38	484,877	3	664,924	3	5psu_bot_4%	10.00	380,793	2
5psu_top_5%	8.78	2,840.3	1	5psu_avg_5%	9.40	480,514	4	660,099	4	5psu_bot_5%	10.01	379,028	2
12psu_top_0%	5.77	7,158.3	–	12psu_avg_0%	6.06	1,107,919	–	1,553,209	–	12psu_bot_0%	6.33	1,058,418	–
12psu_top_1%	5.82	6,933.1	3	12psu_avg_1%	6.08	1,103,766	0	1,546,998	0	12psu_bot_1%	6.37	1,051,850	1
12psu_top_2%	5.87	6,809.8	5	12psu_avg_2%	6.14	1,092,505	1	1,530,158	1	12psu_bot_2%	6.42	1,042,803	1
12psu_top_3%	5.91	6,695.4	6	12psu_avg_3%	6.18	1,086,468	2	1,521,130	2	12psu_bot_3%	6.45	1,036,520	2
12psu_top_4%	5.91	6,676.4	7	12psu_avg_4%	6.22	1,078,321	3	1,508,946	3	12psu_bot_4%	6.49	1,030,236	3
12psu_top_5%	5.96	6,553.6	8	12psu_avg_5%	6.27	1,070,443	3	1,497,164	4	12psu_bot_5%	6.52	1,022,004	3

Table 12. Regression model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 3.2-inch sea level rise and 6 flow reductions with considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	10.05	1982.5	–	3psu_avg_0%	10.66	237,231	–	338,129	–	3psu_bot_0%	11.27	135,969	–
3psu_top_1%	10.07	1957.2	1	3psu_avg_1%	10.69	232,061	2	330,858	2	3psu_bot_1%	11.30	132,720	2
3psu_top_2%	10.09	1931.8	3	3psu_avg_2%	10.71	226,890	4	323,587	4	3psu_bot_2%	11.33	129,470	5
3psu_top_3%	10.12	1912.9	4	3psu_avg_3%	10.74	221,720	7	316,317	6	3psu_bot_3%	11.37	126,221	7
3psu_top_4%	10.14	1896.1	4	3psu_avg_4%	10.77	216,550	9	309,046	9	3psu_bot_4%	11.40	122,971	10
3psu_top_5%	10.16	1879.3	5	3psu_avg_5%	10.79	211,379	11	301,775	11	3psu_bot_5%	11.43	121,109	11
5psu_top_0%	8.78	2842.4	–	5psu_avg_0%	9.42	478,800	–	670,875	–	5psu_bot_0%	10.05	373,550	–
5psu_top_1%	8.80	2834.3	0	5psu_avg_1%	9.44	475,252	1	666,558	1	5psu_bot_1%	10.07	371,812	0
5psu_top_2%	8.83	2834.3	0	5psu_avg_2%	9.45	471,704	1	662,241	1	5psu_bot_2%	10.08	370,001	1
5psu_top_3%	8.85	2834.3	0	5psu_avg_3%	9.47	468,155	2	657,924	2	5psu_bot_3%	10.09	368,336	1
5psu_top_4%	8.88	2834.3	0	5psu_avg_4%	9.49	464,607	3	653,607	3	5psu_bot_4%	10.10	366,599	2
5psu_top_5%	8.90	2834.3	0	5psu_avg_5%	9.51	461,059	4	649,289	3	5psu_bot_5%	10.11	364,861	2
12psu_top_0%	6.02	6379.8	–	12psu_avg_0%	6.29	1,070,510	–	1,523,744	–	12psu_bot_0%	6.56	1,016,471	–
12psu_top_1%	6.05	6323.0	1	12psu_avg_1%	6.32	1,065,653	0	1,516,441	0	12psu_bot_1%	6.60	1,007,535	1
12psu_top_2%	6.07	6284.3	1	12psu_avg_2%	6.37	1,057,109	1	1,503,594	1	12psu_bot_2%	6.63	998,598	2
12psu_top_3%	6.09	6247.5	2	12psu_avg_3%	6.40	1,050,677	2	1,493,923	2	12psu_bot_3%	6.66	989,662	3
12psu_top_4%	6.09	6248.8	2	12psu_avg_4%	6.42	1,047,446	2	1,489,064	2	12psu_bot_4%	6.70	980,726	4
12psu_top_5%	6.11	6208.8	3	12psu_avg_5%	6.44	1,043,924	2	1,483,768	3	12psu_bot_5%	6.73	971,790	4

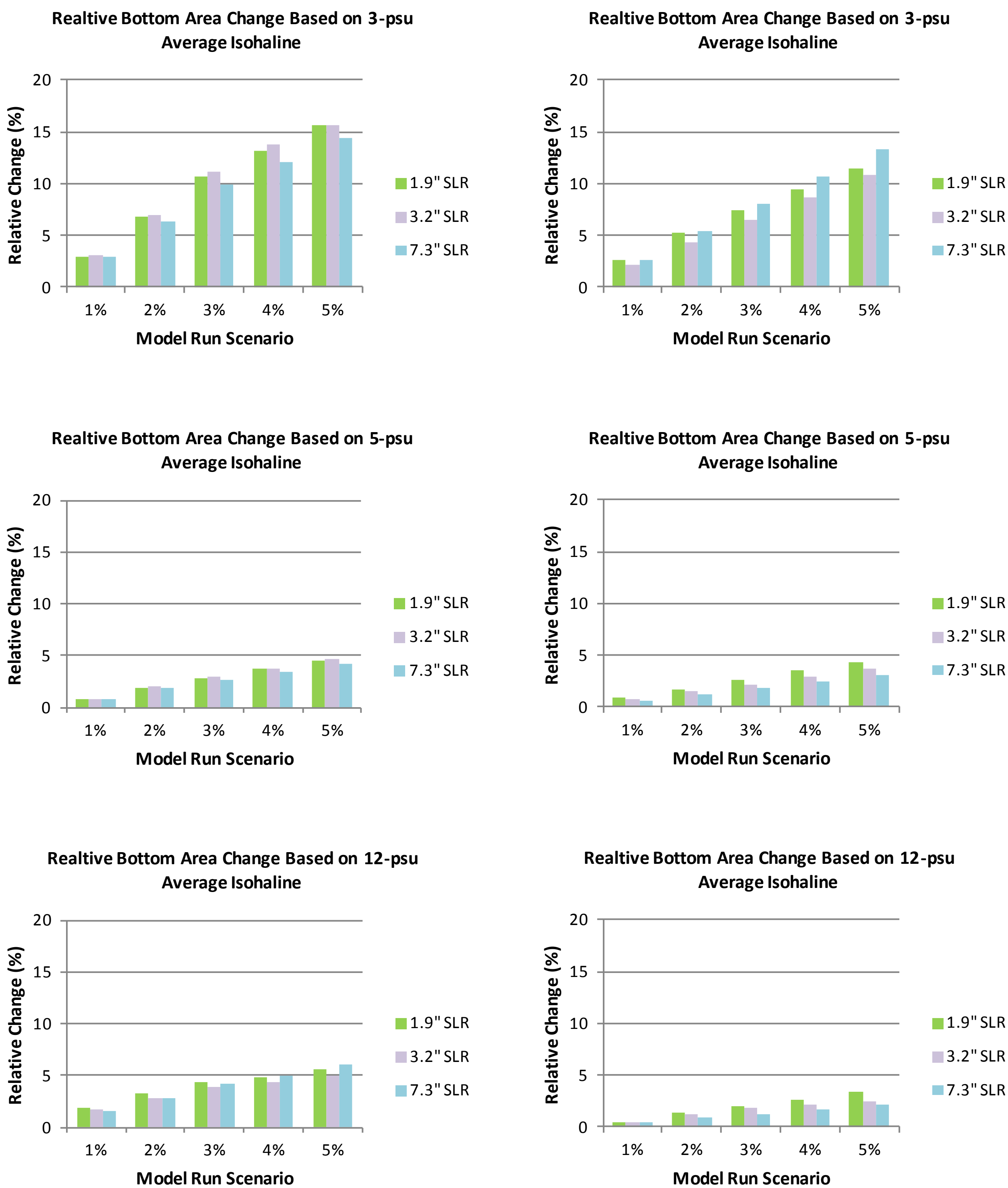
Table 13. Regression model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the 7.3-inch sea level rise and 6 flow reductions with considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	10.38	1845.7	–	3psu_avg_0%	11.04	177,565	–	266,598	–	3psu_bot_0%	11.69	107,994	–
3psu_top_1%	10.40	1845.7	0	3psu_avg_1%	11.06	172,820	3	260,344	2	3psu_bot_1%	11.72	106,414	1
3psu_top_2%	10.42	1844.7	0	3psu_avg_2%	11.08	168,076	5	254,090	5	3psu_bot_2%	11.75	104,835	3
3psu_top_3%	10.43	1843.5	0	3psu_avg_3%	11.11	163,331	8	247,836	7	3psu_bot_3%	11.78	103,255	4
3psu_top_4%	10.45	1842.2	0	3psu_avg_4%	11.13	158,587	11	241,583	9	3psu_bot_4%	11.81	100,903	7
3psu_top_5%	10.47	1841.0	0	3psu_avg_5%	11.16	153,842	13	235,329	12	3psu_bot_5%	11.84	97,317	10
5psu_top_0%	9.16	2834.3	–	5psu_avg_0%	9.77	420,568	–	622,304	–	5psu_bot_0%	10.38	310,137	–
5psu_top_1%	9.19	2834.3	0	5psu_avg_1%	9.79	417,800	1	617,455	1	5psu_bot_1%	10.39	307,503	1
5psu_top_2%	9.21	2826.7	0	5psu_avg_2%	9.80	415,109	1	612,883	2	5psu_bot_2%	10.40	304,751	2
5psu_top_3%	9.23	2808.4	1	5psu_avg_3%	9.82	412,618	2	609,045	2	5psu_bot_3%	10.41	302,223	3
5psu_top_4%	9.25	2790.1	2	5psu_avg_4%	9.84	410,127	2	605,207	3	5psu_bot_4%	10.42	299,564	3
5psu_top_5%	9.28	2771.8	2	5psu_avg_5%	9.86	407,636	3	601,369	3	5psu_bot_5%	10.43	296,905	4
12psu_top_0%	6.54	5313.5	–	12psu_avg_0%	6.90	941,034	–	1,396,655	–	12psu_bot_0%	7.23	851,786	–
12psu_top_1%	6.54	5314.8	0	12psu_avg_1%	6.91	937,072	0	1,390,122	0	12psu_bot_1%	7.26	843,606	1
12psu_top_2%	6.54	5316.1	0	12psu_avg_2%	6.93	933,110	1	1,383,589	1	12psu_bot_2%	7.29	835,427	2
12psu_top_3%	6.54	5313.8	0	12psu_avg_3%	6.94	929,149	1	1,377,057	1	12psu_bot_3%	7.32	827,247	3
12psu_top_4%	6.56	5304.4	0	12psu_avg_4%	6.96	925,187	2	1,370,524	2	12psu_bot_4%	7.35	819,067	4
12psu_top_5%	6.55	5305.6	0	12psu_avg_5%	6.97	921,226	2	1,363,992	2	12psu_bot_5%	7.39	810,887	5



Left: Without considering spring flow change Right: With considering spring flow change

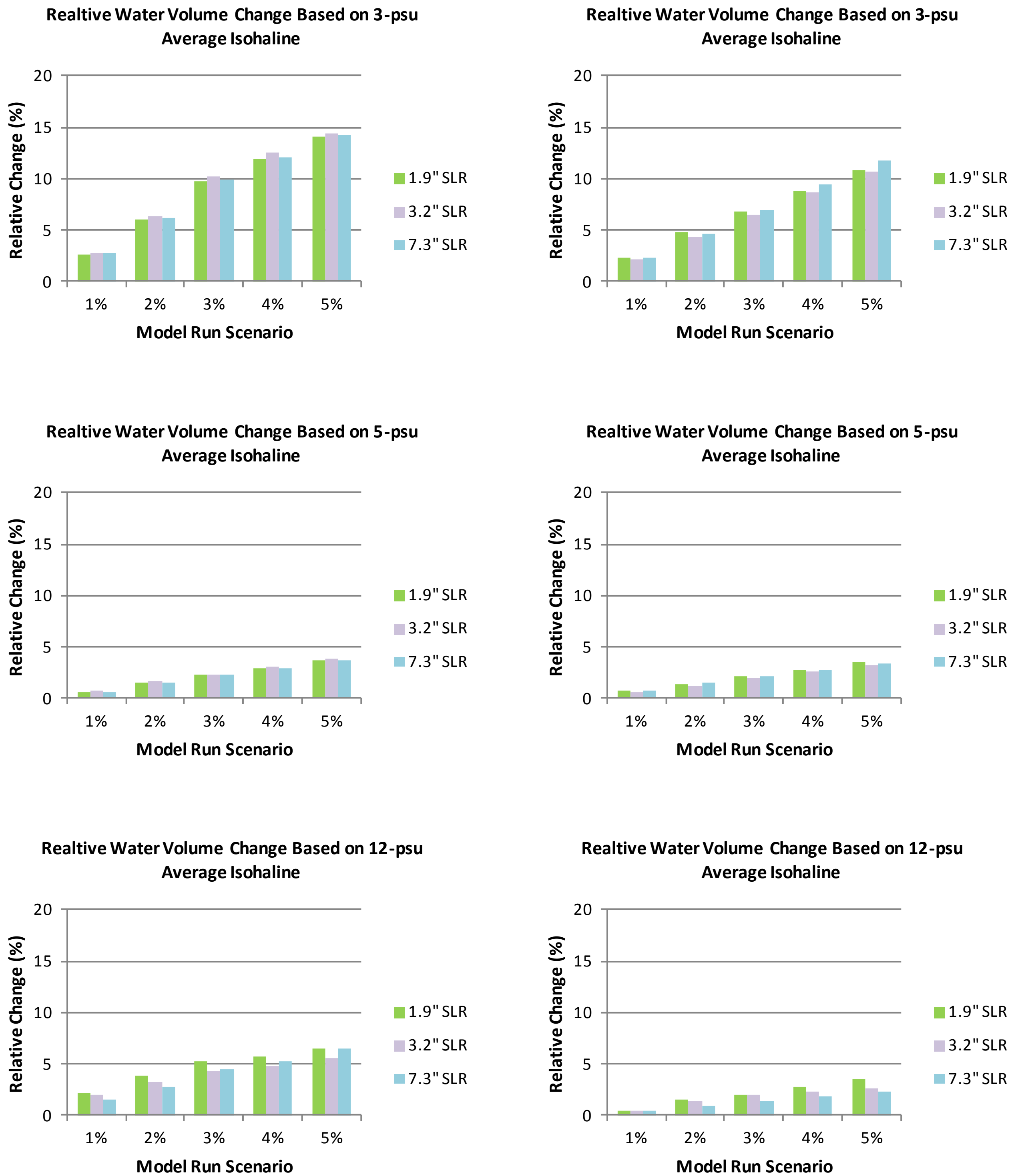
Figure 9. Regression model comparisons of relative changes of surface salinity based shoreline over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines for year 2007



Left: Without considering spring flow change

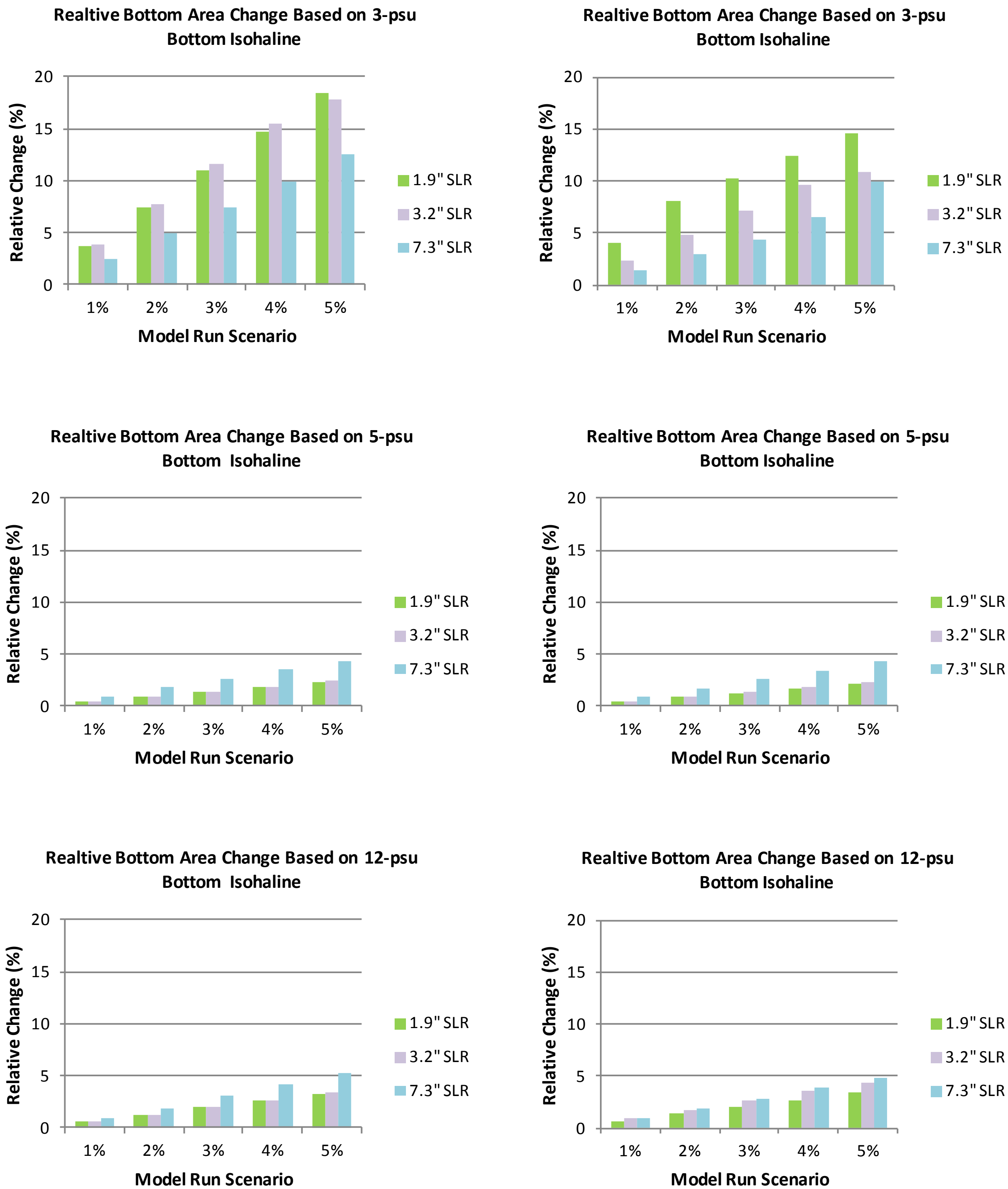
Right: With considering spring flow change

Figure 10. Regression model comparisons of relative changes of average salinity based bottom area over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines for year 2007



Left: Without considering spring flow change Right: With considering spring flow change

Figure 11. Regression model comparisons of relative changes of average salinity based water volume over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines for year 2007



Left: Without considering spring flow change   Right: With considering spring flow change

Figure 12. Regression model comparisons of relative changes of bottom salinity based bottom area over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines for year 2007

Table 14. Regression model result summary for POR: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the low sea level rise and 6 flow reductions without considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	8.88	2,834.3	–	3psu_avg_0%	9.29	505,965	–	686,290	–	3psu_bot_0%	9.70	426,277	–
3psu_top_1%	8.94	2,834.3	0	3psu_avg_1%	9.39	483,695	4	661,798	4	3psu_bot_1%	9.82	407,268	4
3psu_top_2%	9.01	2,834.3	0	3psu_avg_2%	9.48	464,697	8	639,589	7	3psu_bot_2%	9.93	389,940	9
3psu_top_3%	9.08	2,834.3	0	3psu_avg_3%	9.57	446,844	12	618,459	10	3psu_bot_3%	10.05	372,173	13
3psu_top_4%	9.15	2,834.3	0	3psu_avg_4%	9.67	430,554	15	594,055	13	3psu_bot_4%	10.17	353,864	17
3psu_top_5%	9.22	2,816.9	1	3psu_avg_5%	9.77	415,048	18	568,700	17	3psu_bot_5%	10.29	326,560	23
5psu_top_0%	7.70	3,189.1	–	5psu_avg_0%	8.53	655,371	–	906,804	–	5psu_bot_0%	8.12	585,379	–
5psu_top_1%	7.78	3,151.8	1	5psu_avg_1%	8.67	637,228	3	884,106	3	5psu_bot_1%	8.22	576,490	2
5psu_top_2%	7.85	3,140.8	2	5psu_avg_2%	8.80	619,086	6	861,408	5	5psu_bot_2%	8.32	567,603	3
5psu_top_3%	7.93	3,140.8	2	5psu_avg_3%	8.93	600,943	8	838,711	8	5psu_bot_3%	8.42	558,697	5
5psu_top_4%	8.00	3,140.8	2	5psu_avg_4%	9.07	585,762	11	817,865	10	5psu_bot_4%	8.53	544,844	7
5psu_top_5%	8.07	3,140.8	2	5psu_avg_5%	9.20	578,897	12	802,221	12	5psu_bot_5%	8.63	525,806	10
12psu_top_0%	4.01	12,447.0	–	12psu_avg_0%	4.25	1,419,160	–	2,111,602	–	12psu_bot_0%	4.47	1,383,971	–
12psu_top_1%	4.11	12,075.4	3	12psu_avg_1%	4.37	1,400,250	1	2,081,351	1	12psu_bot_1%	4.60	1,368,648	1
12psu_top_2%	4.22	11,850.3	5	12psu_avg_2%	4.49	1,381,341	3	2,051,100	3	12psu_bot_2%	4.73	1,354,628	2
12psu_top_3%	4.32	11,615.5	7	12psu_avg_3%	4.60	1,368,365	4	2,023,454	4	12psu_bot_3%	4.86	1,341,086	3
12psu_top_4%	4.43	11,280.5	9	12psu_avg_4%	4.72	1,356,197	4	1,996,163	5	12psu_bot_4%	5.00	1,327,139	4
12psu_top_5%	4.53	10,951.6	12	12psu_avg_5%	4.84	1,344,029	5	1,968,872	7	12psu_bot_5%	5.13	1,303,359	6

Table 15. Regression model result summary for POR: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the medium sea level rise and 6 flow reductions without considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	8.91	2,834.3	–	3psu_avg_0%	9.32	499,441	–	688,719	–	3psu_bot_0%	9.74	420,971	–
3psu_top_1%	8.98	2,834.3	0	3psu_avg_1%	9.42	477,897	4	664,259	4	3psu_bot_1%	9.85	402,580	4
3psu_top_2%	9.05	2,834.3	0	3psu_avg_2%	9.51	459,424	8	642,015	7	3psu_bot_2%	9.97	385,290	8
3psu_top_3%	9.12	2,834.3	0	3psu_avg_3%	9.61	441,276	12	619,387	10	3psu_bot_3%	10.09	366,939	13
3psu_top_4%	9.19	2,834.3	0	3psu_avg_4%	9.71	425,734	15	593,671	14	3psu_bot_4%	10.21	347,510	17
3psu_top_5%	9.25	2,790.4	2	3psu_avg_5%	9.80	410,422	18	568,360	17	3psu_bot_5%	10.33	317,548	25
5psu_top_0%	7.74	3,170.3	–	5psu_avg_0%	8.16	648,772	–	910,575	–	5psu_bot_0%	8.58	583,447	–
5psu_top_1%	7.81	3,140.8	1	5psu_avg_1%	8.27	630,378	3	887,297	3	5psu_bot_1%	8.72	574,281	2
5psu_top_2%	7.89	3,140.8	1	5psu_avg_2%	8.37	611,984	6	864,018	5	5psu_bot_2%	8.86	565,115	3
5psu_top_3%	7.96	3,140.8	1	5psu_avg_3%	8.47	593,590	9	840,740	8	5psu_bot_3%	8.99	556,167	5
5psu_top_4%	8.04	3,140.8	1	5psu_avg_4%	8.58	583,821	10	823,010	10	5psu_bot_4%	9.12	538,710	8
5psu_top_5%	8.11	3,140.8	1	5psu_avg_5%	8.68	576,919	11	807,193	11	5psu_bot_5%	9.26	515,288	12
12psu_top_0%	4.10	12,107.0	–	12psu_avg_0%	4.33	1,412,019	–	2,123,119	–	12psu_bot_0%	4.55	1,379,558	–
12psu_top_1%	4.21	11,877.7	2	12psu_avg_1%	4.45	1,392,506	1	2,091,643	1	12psu_bot_1%	4.68	1,365,270	1
12psu_top_2%	4.31	11,636.7	4	12psu_avg_2%	4.57	1,377,309	2	2,062,479	3	12psu_bot_2%	4.82	1,351,379	2
12psu_top_3%	4.42	11,314.5	7	12psu_avg_3%	4.69	1,365,050	3	2,034,913	4	12psu_bot_3%	4.95	1,337,337	3
12psu_top_4%	4.53	10,960.2	9	12psu_avg_4%	4.80	1,352,705	4	2,007,153	5	12psu_bot_4%	5.08	1,317,098	5
12psu_top_5%	4.63	10,744.0	11	12psu_avg_5%	4.92	1,340,351	5	1,979,372	7	12psu_bot_5%	5.22	1,293,154	6

Table 16. Regression model result summary for POR: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the high sea level rise and 6 flow reductions without considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	9.02	2,834.3	–	3psu_avg_0%	9.43	479,573	–	694,883	–	3psu_bot_0%	9.84	408,376	–
3psu_top_1%	9.09	2,834.3	0	3psu_avg_1%	9.52	461,158	4	671,514	3	3psu_bot_1%	9.96	390,716	4
3psu_top_2%	9.16	2,834.3	0	3psu_avg_2%	9.62	443,209	8	647,264	7	3psu_bot_2%	10.08	372,408	9
3psu_top_3%	9.23	2,810.2	1	3psu_avg_3%	9.71	427,755	11	620,751	11	3psu_bot_3%	10.20	353,737	13
3psu_top_4%	9.30	2,754.3	3	3psu_avg_4%	9.81	412,493	14	594,845	14	3psu_bot_4%	10.32	323,492	21
3psu_top_5%	9.37	2,689.7	5	3psu_avg_5%	9.90	398,826	17	574,296	17	3psu_bot_5%	10.44	292,839	28
5psu_top_0%	7.87	3,140.8	–	5psu_avg_0%	8.30	630,048	–	923,996	–	5psu_bot_0%	8.74	577,616	–
5psu_top_1%	7.94	3,140.8	0	5psu_avg_1%	8.40	611,073	3	899,131	3	5psu_bot_1%	8.87	568,423	2
5psu_top_2%	8.02	3,140.8	0	5psu_avg_2%	8.51	593,103	6	874,881	5	5psu_bot_2%	9.01	558,819	3
5psu_top_3%	8.09	3,140.8	0	5psu_avg_3%	8.62	585,953	7	858,196	7	5psu_bot_3%	9.14	540,344	6
5psu_top_4%	8.16	3,140.8	0	5psu_avg_4%	8.72	578,925	8	841,795	9	5psu_bot_4%	9.28	514,489	11
5psu_top_5%	8.24	3,140.8	0	5psu_avg_5%	8.82	571,823	9	825,223	11	5psu_bot_5%	9.41	483,123	16
12psu_top_0%	4.41	11,373.3	–	12psu_avg_0%	4.61	1,390,433	–	2,151,898	–	12psu_bot_0%	4.82	1,368,531	–
12psu_top_1%	4.51	10,986.0	3	12psu_avg_1%	4.73	1,377,879	1	2,123,457	1	12psu_bot_1%	4.95	1,354,228	1
12psu_top_2%	4.61	10,823.7	5	12psu_avg_2%	4.85	1,365,294	2	2,094,947	3	12psu_bot_2%	5.08	1,334,039	3
12psu_top_3%	4.72	10,460.6	8	12psu_avg_3%	4.97	1,352,262	3	2,065,426	4	12psu_bot_3%	5.21	1,310,141	4
12psu_top_4%	4.83	10,231.1	10	12psu_avg_4%	5.08	1,333,573	4	2,029,230	6	12psu_bot_4%	5.35	1,285,691	6
12psu_top_5%	4.94	9,999.8	12	12psu_avg_5%	5.21	1,311,688	6	1,988,475	8	12psu_bot_5%	5.48	1,261,888	8

Table 17. Regression model result summary for POR: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the low sea level rise and 6 flow reductions with considering spring flow change

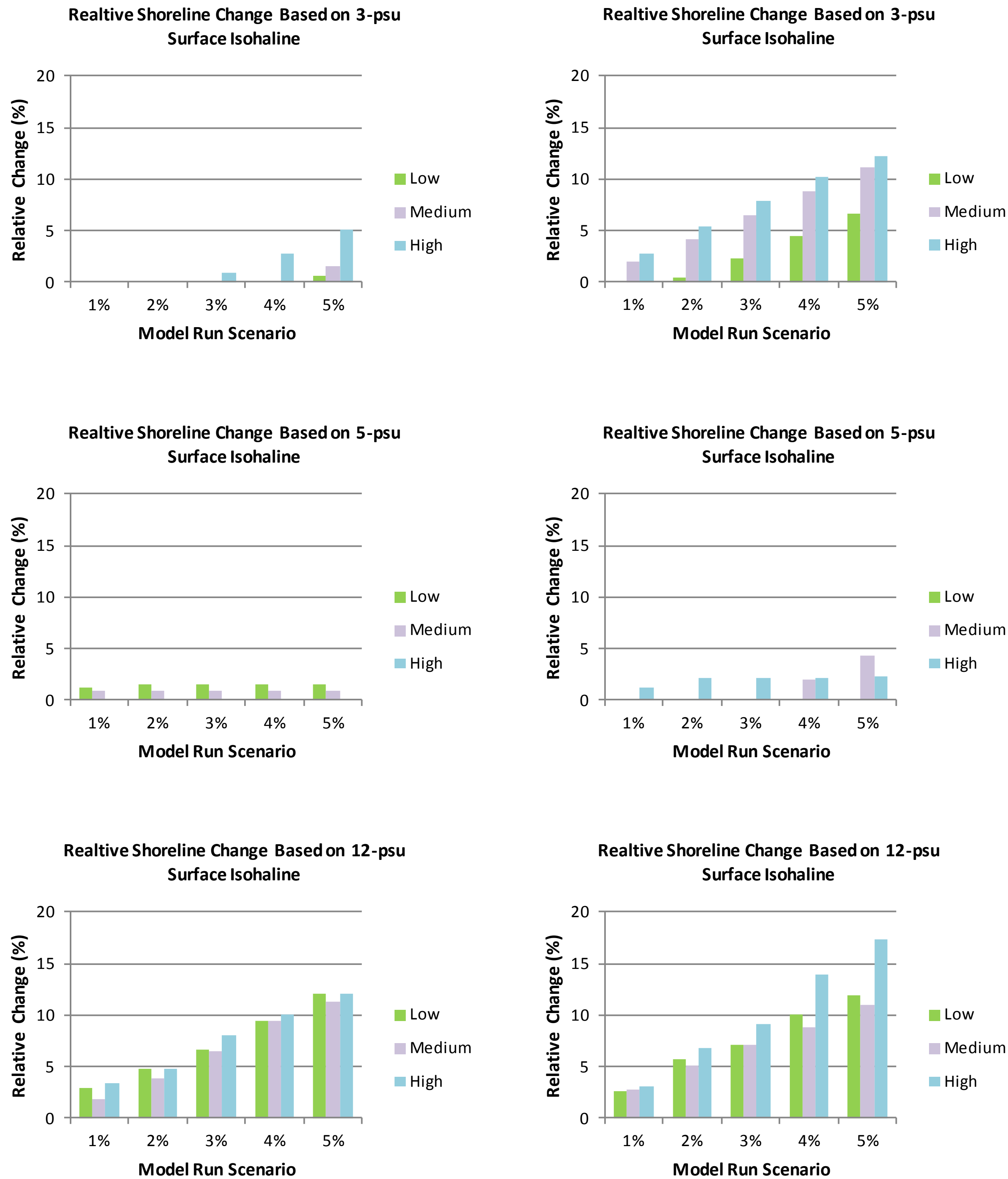
Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	9.08	2,834.3	–	3psu_avg_0%	9.57	448,234	–	620,104	–	3psu_bot_0%	10.05	372,946	–
3psu_top_1%	9.14	2,834.3	0	3psu_avg_1%	9.66	432,172	4	596,701	4	3psu_bot_1%	10.16	355,179	5
3psu_top_2%	9.21	2,824.3	0	3psu_avg_2%	9.75	417,116	7	572,082	8	3psu_bot_2%	10.28	329,606	12
3psu_top_3%	9.28	2,769.4	2	3psu_avg_3%	9.84	403,243	10	550,739	11	3psu_bot_3%	10.39	300,453	19
3psu_top_4%	9.35	2,709.4	4	3psu_avg_4%	9.94	389,787	13	531,617	14	3psu_bot_4%	10.51	270,978	27
3psu_top_5%	9.41	2,645.7	7	3psu_avg_5%	10.02	376,560	16	512,509	17	3psu_bot_5%	10.63	243,058	35
5psu_top_0%	7.92	3,140.8	–	5psu_avg_0%	8.42	601,095	–	838,901	–	5psu_bot_0%	8.93	558,972	–
5psu_top_1%	8.00	3,140.8	0	5psu_avg_1%	8.52	586,025	3	818,465	2	5psu_bot_1%	9.06	546,310	2
5psu_top_2%	8.07	3,140.8	0	5psu_avg_2%	8.62	579,365	4	803,289	4	5psu_bot_2%	9.19	528,666	5
5psu_top_3%	8.14	3,140.8	0	5psu_avg_3%	8.72	572,705	5	788,113	6	5psu_bot_3%	9.32	499,787	11
5psu_top_4%	8.21	3,140.8	0	5psu_avg_4%	8.82	566,045	6	772,937	8	5psu_bot_4%	9.45	471,049	16
5psu_top_5%	8.27	3,140.8	0	5psu_avg_5%	8.92	559,649	7	758,364	10	5psu_bot_5%	9.57	448,571	20
12psu_top_0%	4.32	11,628.1	–	12psu_avg_0%	4.60	1,368,467	–	2,023,683	–	12psu_bot_0%	4.86	1,341,474	–
12psu_top_1%	4.42	11,323.0	3	12psu_avg_1%	4.72	1,356,663	1	1,997,209	1	12psu_bot_1%	4.99	1,328,303	1
12psu_top_2%	4.52	10,968.8	6	12psu_avg_2%	4.83	1,344,859	2	1,970,734	3	12psu_bot_2%	5.12	1,306,154	3
12psu_top_3%	4.62	10,796.4	7	12psu_avg_3%	4.94	1,333,055	3	1,944,260	4	12psu_bot_3%	5.24	1,283,921	4
12psu_top_4%	4.72	10,450.3	10	12psu_avg_4%	5.06	1,317,259	4	1,913,052	5	12psu_bot_4%	5.37	1,261,003	6
12psu_top_5%	4.83	10,232.1	12	12psu_avg_5%	5.17	1,297,278	5	1,876,885	7	12psu_bot_5%	5.51	1,237,427	8

Table 18. Regression model result summary for POR: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the medium sea level rise and 6 flow reductions with considering spring flow change

Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	9.23	2,812.9	–	3psu_avg_0%	9.75	418,889	–	582,345	–	3psu_bot_0%	10.27	332,010	–
3psu_top_1%	9.29	2,758.6	2	3psu_avg_1%	9.84	404,791	3	560,246	4	3psu_bot_1%	10.39	303,312	9
3psu_top_2%	9.36	2,696.9	4	3psu_avg_2%	9.93	391,673	6	541,344	7	3psu_bot_2%	10.50	273,843	18
3psu_top_3%	9.43	2,632.1	6	3psu_avg_3%	10.02	378,259	10	521,766	10	3psu_bot_3%	10.62	245,667	26
3psu_top_4%	9.49	2,563.3	9	3psu_avg_4%	10.11	364,691	13	501,117	14	3psu_bot_4%	10.73	223,838	33
3psu_top_5%	9.56	2,500.9	11	3psu_avg_5%	10.18	353,090	16	483,462	17	3psu_bot_5%	10.81	207,935	37
5psu_top_0%	8.08	3,140.8	–	5psu_avg_0%	8.63	580,336	–	815,024	–	5psu_bot_0%	9.18	530,495	–
5psu_top_1%	8.15	3,140.8	0	5psu_avg_1%	8.73	573,758	1	799,948	2	5psu_bot_1%	9.31	502,044	5
5psu_top_2%	8.22	3,140.8	0	5psu_avg_2%	8.83	567,175	2	784,858	4	5psu_bot_2%	9.44	473,783	11
5psu_top_3%	8.29	3,140.8	0	5psu_avg_3%	8.93	560,507	3	769,576	6	5psu_bot_3%	9.57	449,548	15
5psu_top_4%	8.34	3,078.2	2	5psu_avg_4%	9.01	553,995	5	756,095	7	5psu_bot_4%	9.68	430,648	19
5psu_top_5%	8.39	3,007.0	4	5psu_avg_5%	9.06	546,936	6	746,482	8	5psu_bot_5%	9.73	422,590	20
12psu_top_0%	4.57	10,907.3	–	12psu_avg_0%	4.87	1,346,094	–	1,992,287	–	12psu_bot_0%	5.16	1,304,624	–
12psu_top_1%	4.67	10,609.1	3	12psu_avg_1%	4.98	1,334,313	1	1,965,796	1	12psu_bot_1%	5.28	1,282,283	2
12psu_top_2%	4.77	10,359.0	5	12psu_avg_2%	5.09	1,315,676	2	1,930,909	3	12psu_bot_2%	5.41	1,259,370	3
12psu_top_3%	4.87	10,127.3	7	12psu_avg_3%	5.20	1,295,983	4	1,895,014	5	12psu_bot_3%	5.54	1,234,494	5
12psu_top_4%	4.97	9,950.8	9	12psu_avg_4%	5.32	1,276,129	5	1,858,825	7	12psu_bot_4%	5.67	1,202,877	8
12psu_top_5%	5.07	9,713.5	11	12psu_avg_5%	5.43	1,255,593	7	1,821,395	9	12psu_bot_5%	5.79	1,172,758	10

Table 19. Regression model result summary for POR: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3, 5, and 12 psu isohalines associated with the high sea level rise and 6 flow reductions with considering spring flow change

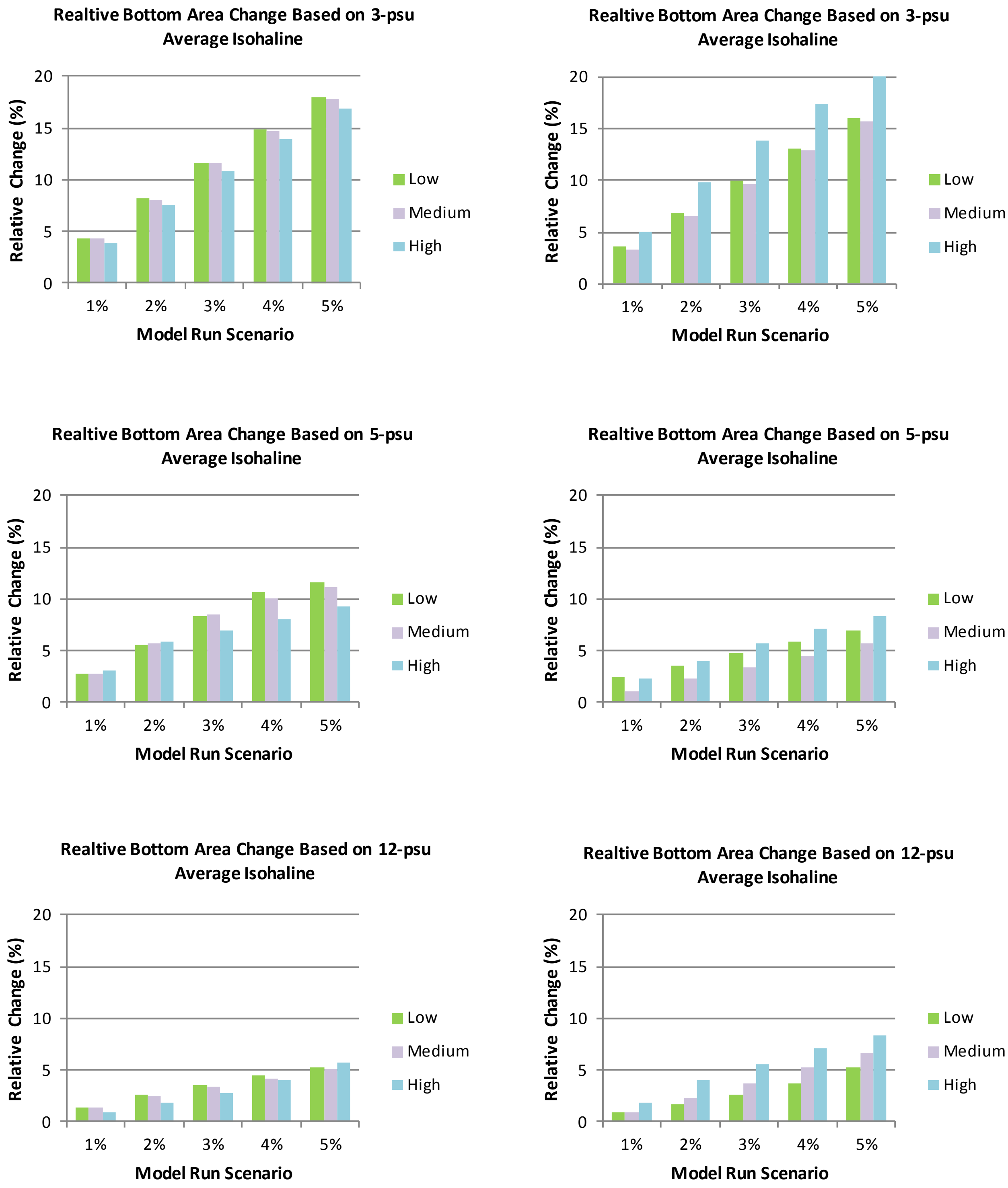
Surface Isohaline	RKM	Shoreline (m)	Shoreline Change from Baseline (%)	Depth-averaged Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)	Water Volume (m^3)	Volume Change from Baseline (%)	Bottom Isohaline	RKM	Bottom Area (m^2)	Area Change from Baseline (%)
3psu_top_0%	9.66	2,398.3	–	3psu_avg_0%	10.29	329,337	–	471,861	–	3psu_bot_0%	10.93	193,586	–
3psu_top_1%	9.72	2,332.9	3	3psu_avg_1%	10.36	313,065	5	450,467	5	3psu_bot_1%	10.99	184,181	5
3psu_top_2%	9.79	2,270.2	5	3psu_avg_2%	10.42	297,126	10	429,438	9	3psu_bot_2%	11.05	174,341	10
3psu_top_3%	9.85	2,207.9	8	3psu_avg_3%	10.47	283,644	14	411,523	13	3psu_bot_3%	11.09	165,530	14
3psu_top_4%	9.90	2,154.6	10	3psu_avg_4%	10.52	271,921	17	395,947	16	3psu_bot_4%	11.14	156,477	19
3psu_top_5%	9.95	2,106.3	12	3psu_avg_5%	10.56	262,443	20	383,353	19	3psu_bot_5%	11.17	149,296	23
5psu_top_0%	8.53	2,936.1	–	5psu_avg_0%	9.21	529,610	–	754,833	–	5psu_bot_0%	9.90	398,681	–
5psu_top_1%	8.57	2,900.9	1	5psu_avg_1%	9.26	517,332	2	740,236	2	5psu_bot_1%	9.94	392,743	1
5psu_top_2%	8.61	2,874.2	2	5psu_avg_2%	9.30	508,687	4	729,959	3	5psu_bot_2%	9.98	387,054	3
5psu_top_3%	8.65	2,874.2	2	5psu_avg_3%	9.34	499,568	6	719,118	5	5psu_bot_3%	10.01	382,699	4
5psu_top_4%	8.69	2,874.2	2	5psu_avg_4%	9.37	492,102	7	710,243	6	5psu_bot_4%	10.04	378,717	5
5psu_top_5%	8.72	2,866.1	2	5psu_avg_5%	9.40	485,304	8	702,155	7	5psu_bot_5%	10.05	375,837	6
12psu_top_0%	5.41	8,209.6	–	12psu_avg_0%	5.73	1,201,203	–	1,787,293	–	12psu_bot_0%	6.07	1,123,023	–
12psu_top_1%	5.50	7,959.6	3	12psu_avg_1%	5.83	1,178,158	2	1,746,212	2	12psu_bot_1%	6.17	1,103,937	2
12psu_top_2%	5.60	7,656.3	7	12psu_avg_2%	5.93	1,153,871	4	1,702,918	5	12psu_bot_2%	6.25	1,087,777	3
12psu_top_3%	5.69	7,463.5	9	12psu_avg_3%	6.01	1,133,425	6	1,667,057	7	12psu_bot_3%	6.34	1,071,310	5
12psu_top_4%	5.79	7,065.2	14	12psu_avg_4%	6.10	1,116,045	7	1,640,696	8	12psu_bot_4%	6.40	1,059,939	6
12psu_top_5%	5.88	6,784.4	17	12psu_avg_5%	6.18	1,101,337	8	1,618,387	9	12psu_bot_5%	6.47	1,046,111	7



Left: Without considering spring flow change

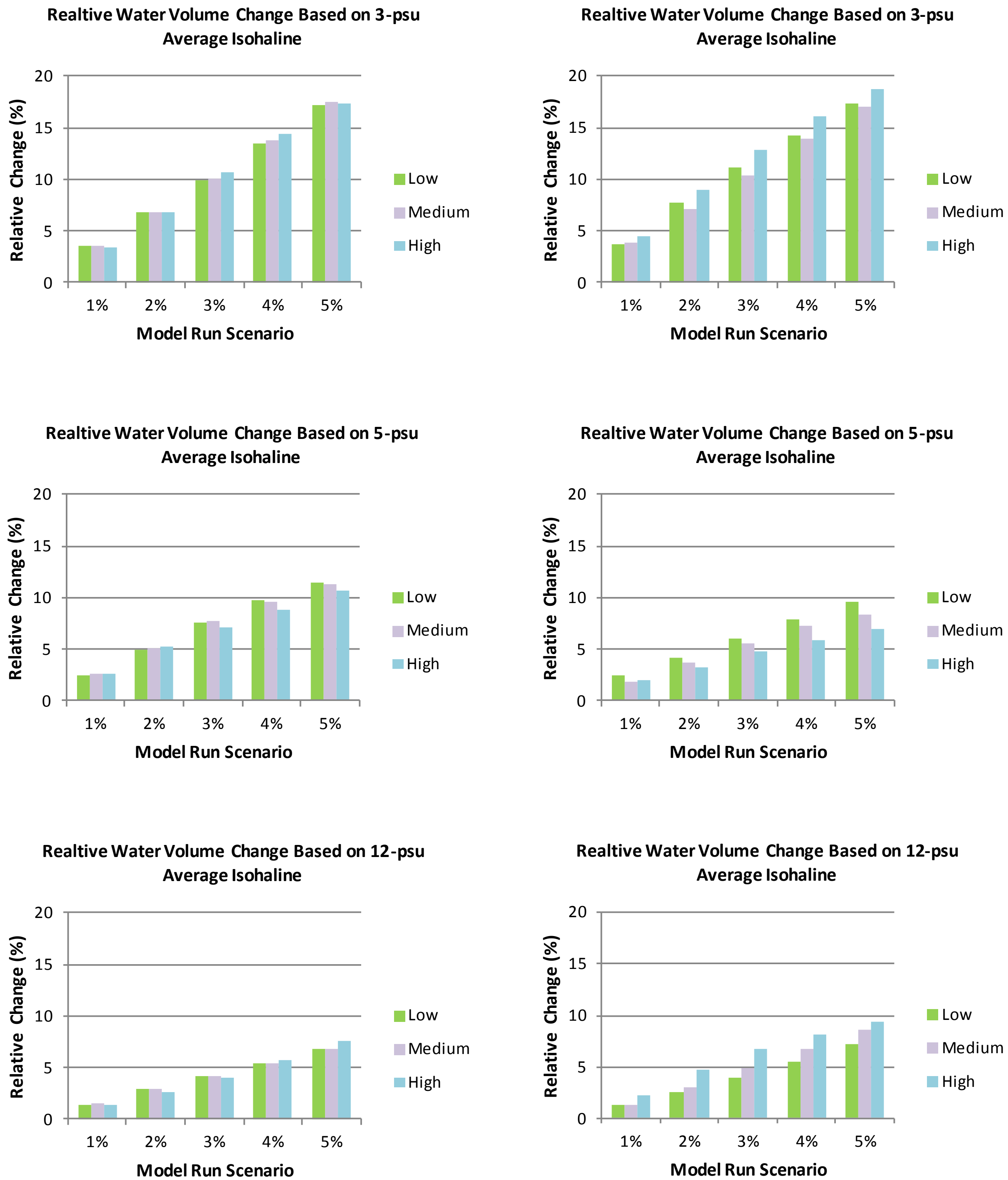
Right: With considering spring flow change

Figure 13. Regression model comparisons of relative changes of surface salinity based shoreline over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines for POR



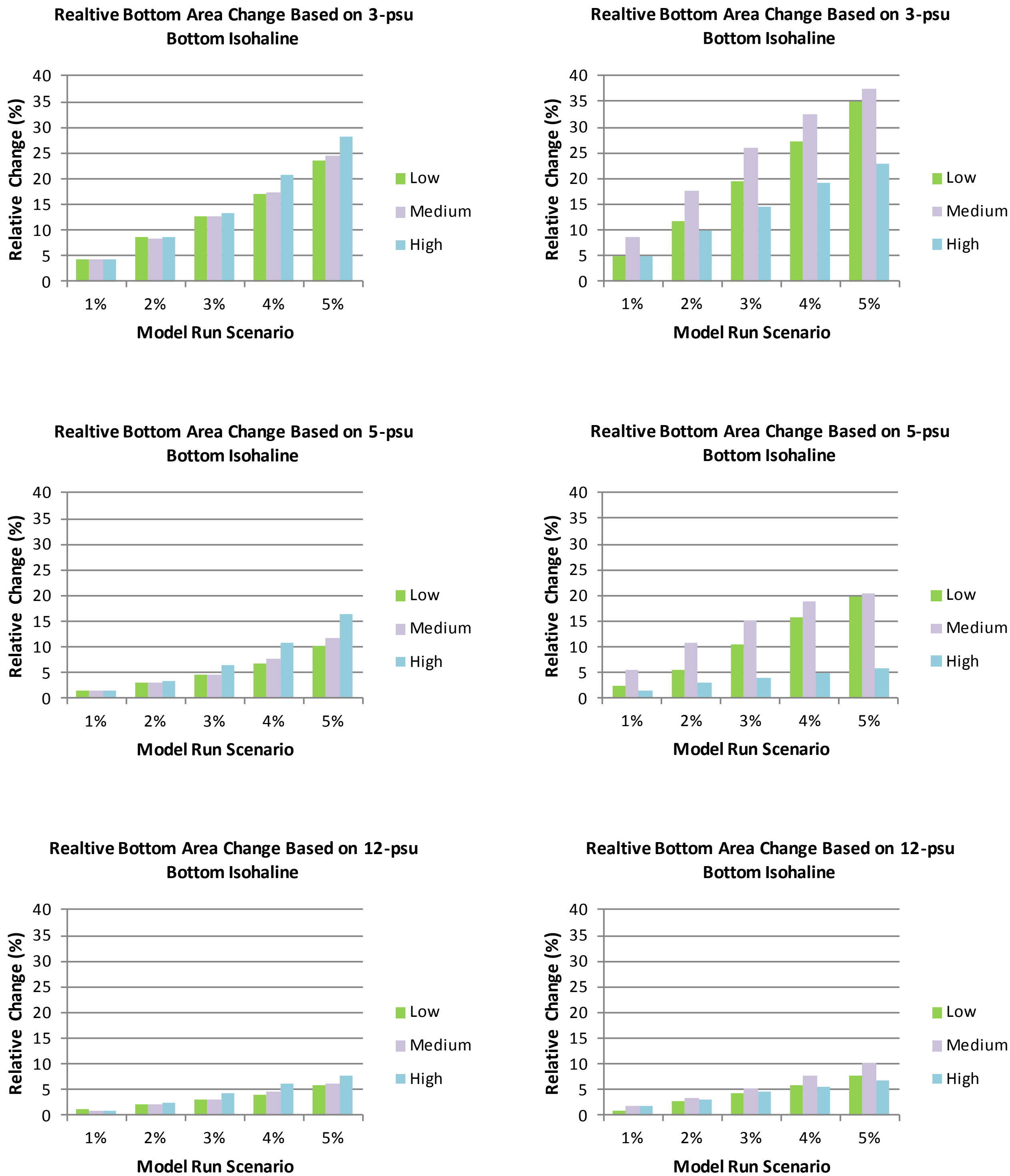
Left: Without considering spring flow change Right: With considering spring flow change

Figure 14. Regression model comparisons of relative changes of average salinity based bottom area over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines for POR



Left: Without considering spring flow change   Right: With considering spring flow change

Figure 15. Regression model comparisons of relative changes of average salinity based water volume over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines for POR



Left: Without considering spring flow change

Right: With considering spring flow change

Figure 16. Regression model comparisons of relative changes of bottom-salinity based bottom area over combined SLRs and flow reduction scenarios for the 3, 5, and 12-psu isohalines for POR

Appendix AA

Heyl, M.G. 2012. Technical memorandum to file, dated Februry 29, 2012 (updated April 6 and October 24, 2012). Regarding: impact of flow on NO_3+NO_2 concentrations in seven Florida spring discharges. Southwest Florida Water Management District. Brooksville, Florida.

Southwest Florida Water Management District

Technical Memorandum

To: File

From: M. Heyl, Chief Environmental Scientist, Springs and Environmental Flows

Date: February 29, 2012 (Updated April 6 and October 24, 2012)

RE: Impact of flow on NO_3+NO_2-N concentration in seven Florida spring discharges.

The relationship between water quality, particularly nitrite and nitrate nitrogen, and minimum flows and levels (MFLs) was raised by Dr. R. Knight at the October 26, 2011 Springs Coast Stake-Holder's meeting[1]. Increases in nitrate (NO_3-N) plus nitrite (NO_2-N) nitrogen concentrations in spring systems within the St. Johns River Water Management District and the Southwest Florida Water Management District (District) have been documented and the source attributed mostly to inorganic fertilizer application (Phelps 2004. Jones et al. 1997). In addition to increases in nitrate+nitrite nitrogen (NO_X-N) concentrations, the discharge of many Florida spring systems have been declining since the 1960s. The initial [2]evaluation was undertaken to determine if there is a relationship between spring flow and NO_X-N concentrations in the Chassahowitzka River, Homosassa River and Silver River systems. The primary source of water for these three systems is groundwater discharging from the Upper Floridan aquifer, which is at, or near land surface over much of the respective groundwater basins. Nutrients introduced at land surface can percolate directly into the aquifer and become entrained in groundwater movement relatively unimpeded. The Chassahowitzka and Homosassa are in the Coastal Springs Groundwater Basin (Knochenmus and Yobbi 2001) while Silver Springs is in a separate groundwater basin. In addition, this technical memorandum responds to several other flow related issues.

Flow

Spring flow in these three systems is directly related to potentiometric difference with the Floridan aquifer. The discharge estimates reported by the United States Geologic Survey (USGS) for many of the spring systems along the west coast of Florida are derived from Upper Floridan water level (potentiometric surface) measured at the Weeki Wachee Well (USGS 28320108231561). Water level in the Upper Floridan aquifer is directly related to rainfall. Figure 1 illustrates the cumulative annual departure from the long-term (1910-2007) rainfall average (56.3 inches) at the Chinsegut Hill National Oceanographic Atmospheric Administration weather station at Brooksville. Compared to the long-term average, the cumulative annual rainfall has been gradually declining at this station since the 1960s. Annual springflow for the three systems and the Weeki Wachee River, another area spring-dominated system, was normalized (divided

[1] http://www.swfwmd.state.fl.us/files/database/site_file_sets/2053/BKnight_-_Spring_MFLs_Workshop_Slides_26oct2011[1].pdf

[2] Weeki Wachee, Gum Springs, Southeast Fork Homosassa and Rainbow were subsequently added.

by respective1967-2007 averages) and superimposed on the rainfall departure and presented as Figure 2. This plot indicates that the spring discharge patterns very closely mirrors the rainfall departure. Declines in flow during 1967-2007 were statistically significant for all systems shown (p values for linear declines: Chassahowitzka = 0.008, Weeki Wachee = 0.004, Rainfall – 0.009 and Silver river = 0.000).

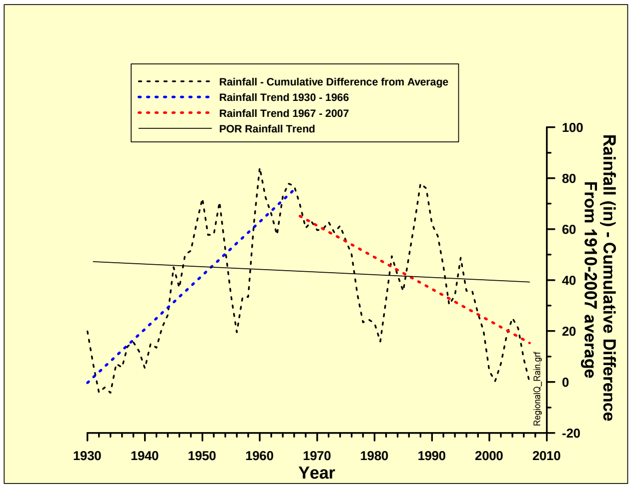


Figure 1. Annual rainfall – cumulative departure from long-term average. Trends shown: 1930 – 1966 and 1967 – 2010.

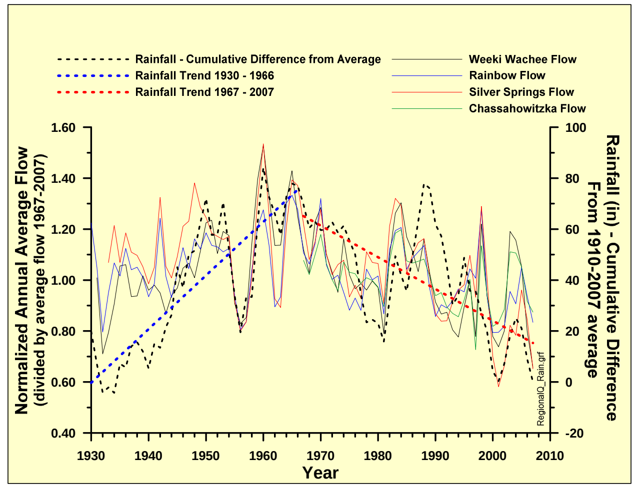


Figure 2. Normalized springflows and cumulative rainfall departure.

It should be noted that rainfall departures from average are not linearly related to discharge departures from average. Recently it has been suggested that the difference is due to withdrawals. In a report to the Florida Fish and Wildlife Conservation Commission on Gum Slough Springs Wetland Solutions, Inc. (2011) notes:

> *". . . since the installation of the USGS gauge, flows in Gum Slough have experienced a more than 50% decline. To further examine these changes in flow the long-term rainfall since installation of this gauge was evaluated. . . . Base on LOESS smoothed monthly rainfall, decrease in rainfall have been approximately 15% over the same period. The spring appears to respond quickly to rainfall events with increased spring flows evident within one to two months after a large rainfall event. However, the difference between the estimated decline in rainfall and flow indicates that groundwater withdrawals have contributed to reductions in flow in Gum Slough during the existing period-of-record". (*page 16)

This line of reasoning ignores a major hydrologic component, namely evapotranspiration. In 1994, Leopold wrote about the importance of evapotranspiration when discussing the impact of declining rainfall on streamflow:

"Suppose the rainfall in a certain year is 40 inches, which would be typical for a location such as Washington, D.C. Evaporation and transpiration might take 20 inches during the year, leaving 20 inches to be carried off by streamflow. Suppose that in the following year the precipitation is 30 inches, 25 percent less than in the previous year. If evaporation and transpiration are the same, which is quite possible, streamflow would be only 10 inches, or 50 percent of that which occurred in the year previous. Thus, a 25 percent change in precipitation becomes a 50 percent change in runoff – a demonstration of the sensitivity of streamflow to changes in rainfall."
(page 96)

In Leopold's first example, runoff (and/or recharge) accounts for 50% of the rainfall. For comparison, annual rainfall in the spring coast is approximately 55 inches and evapotranspiration is approximately 34 inches per year, making the runoff component an even smaller fraction (38%) of the rainfall. Thus, the decline in runoff (or recharge) is even more sensitive to declines in rainfall.

Flows in the Chassahowitzka, Homosassa and Silver River systems have been declining since the 1960s and the Homosassa and Silver River system flows declined over the period for which NO_X-N data is available. On the other hand, flow in the Chassahowitzka since NO_X-N monitoring began in 1993 has been cyclic but with a slight overall positive trend. Figure 3 compares the long-term flow with the flow on dates corresponding to NO_X-N sampling near the main spring vent in the Chassahowitzka River.

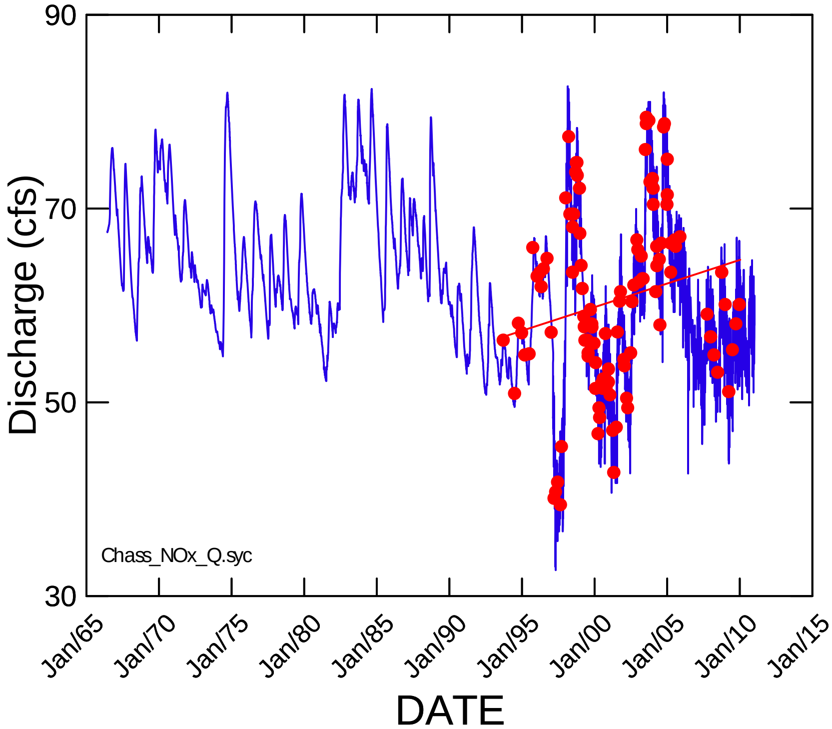


Figure 3. Chassahowitzka discharge (cfs). Red dots indicate NO_X-N sample dates and red line is flow trend for these dates. [Three day moving average applied from 1997 – 2012 to reduce noise.]

Data Sources

Flows for present evaluation were taken from USGS reported values for the Chassahowitzka River (02310650), and the Homosassa River (02310678). Annual flow values for Silver River were taken directly from a Microsoft Excel spreadsheet prepared by Wetland Solutions Inc. (WSI) and electronically transmitted by R. Clarke to Dr. Sonny Hall of the St. John's River Water Management District on February 8, 2012.

Nitrate-nitrite concentrations for the Homossassa River were obtained from the District's Water Management Information System (WMIS[3]) and represent data collected and analyzed by the District. Results were limited to samples collected from within spring vents. The Homosassa results represent samples taken from the following vents Homossassa 1, Homosassa 2, and Homosassa 3 spring vent. Six Homosassa results (1% of total samples) marked as "*Estimated value, value not accurate*.' were excluded from the evaluation. The following analytes were combined without modification a) nitrite+nitrate –N (total), b) nitrite+nitrate – N (dissolved), c) nitrate-N (total), and d) nitrate-N (dissolved). Three hundred and thirty three results were analyzed.

Annual average concentrations for the Silver River evaluation were taken without modification from the WSI spreadsheet previously identified. Fifty-four annual average values were analyzed.

The results for the Chassahowitzka River were obtained from a variety of sources including a) Mote Marine Laboratory, b) University of Florida (T. Frazer) and c) WMIS. All samples were collected in the Main vent, or immediately downstream. All reported results were above the reporting limit for the respective laboratories. The University of Florida collected three samples from right bank to left bank across the river and these were averaged by transect prior to use. One hundred and fifty four results were analyzed.

Methods

In addition to the significant flow trends in each system, the NO_X-N concentrations are also increasing in each system. Consequently, in order to fully evaluate the observed changes, each trend must be evaluated in the context of the other. The question is whether the change in NO_X-N (response variable) is the result of a change in flow or time (both candidate predictor variables). Thus, it is necessary to systematically remove the influence of one predictor variable before testing the other predictor variable.

Figure 4 illustrates the relationship of discharge and NO_X-N concentration during the NO_X-N sampling period for the Chassahowitzka River. NO_X-N was specified as the response variable,

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[3] http://www18.swfwmd.state.fl.us/ResData/Search/ExtDefault.aspx

discharge was selected as the predictor variable and a LOWESS (Helsel and Hirsch 1992) smooth calculated. The output includes the observed NO_X-N values, the predicted NO_X-N values and the difference termed 'residuals'. The residuals represent the concentration of NO_X-N that cannot be explained by flow. In essence, the 'effect' of flow was removed from the time series of NO_X-N values. The residuals were then plotted against time (Figure 5, left panel). A statistically significant trend (Spearman's rho = 0.500, p=0.0000 and Tau-b =0.342, p = 0.0000) resulted indicating that the NO_X-N concentration that cannot be explained by flow is statistically increasing with time.

Time was then selected as the predictor variable and the evaluation repeated. In this case, the variation in NO_X-N that can be explained by time was removed and the residuals tested for a

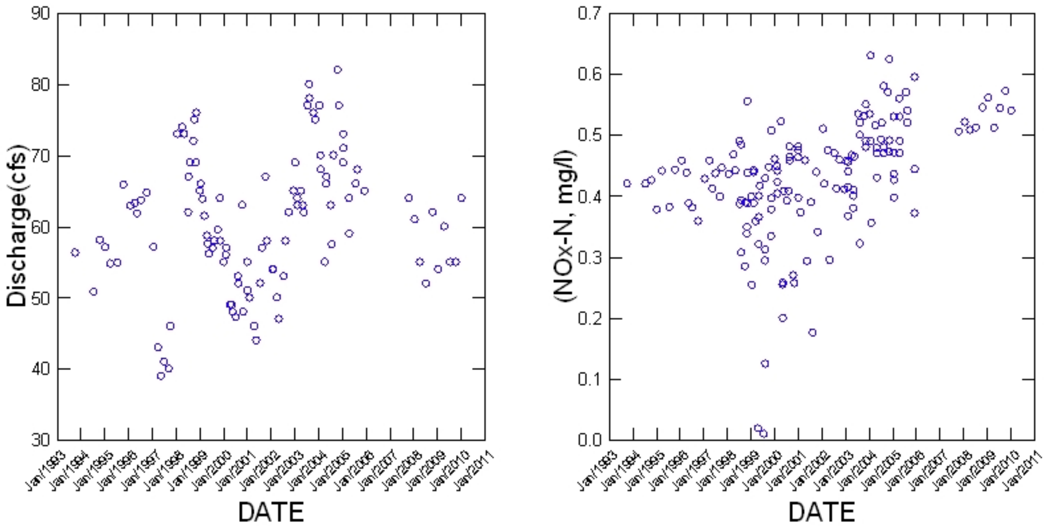

Figure 4. Chassahowitzka River discharge (left panel) and NOx-N (right panel) as function of date.

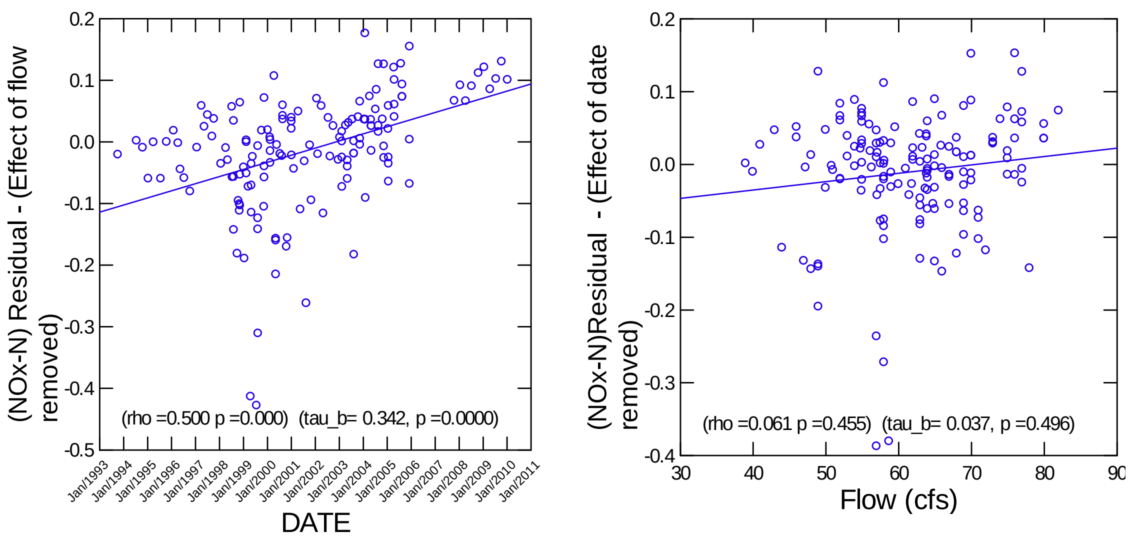

Figure 5. Chassahowitzka residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) while concentration unaccounted for by date is not significantly related to flow (right panel).

significant relationship with flow. The results (Figure 5, right panel) indicate that once the time effect has been removed from concentration, the relationship with flow is not significant (p = 0.455 for Spearman test, p = 0.496 for Tau-b test).

The series of tests were repeated using the Homosassa River data, beginning with the relationship of NO_X-N to flow and time (Figure 6). When the effect of flow was removed, the concentration residuals were significantly (p=0.000 for Spearman test, p = 0.000 for Tau-b test) related to time, but when the effect of time was removed first there was no significant

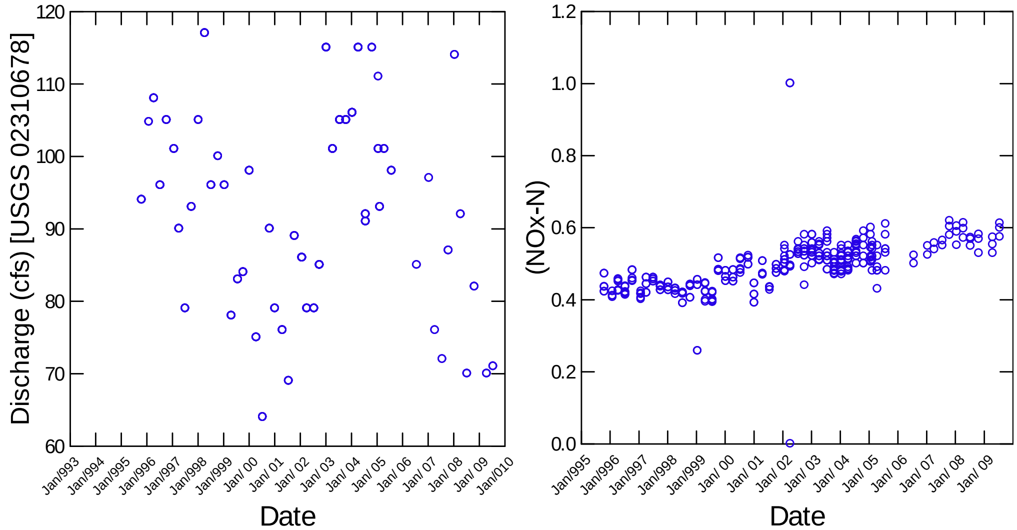

Figure 6. Homosassa Spring discharge (left panel) and NOx-N (right panel) as a function of date.

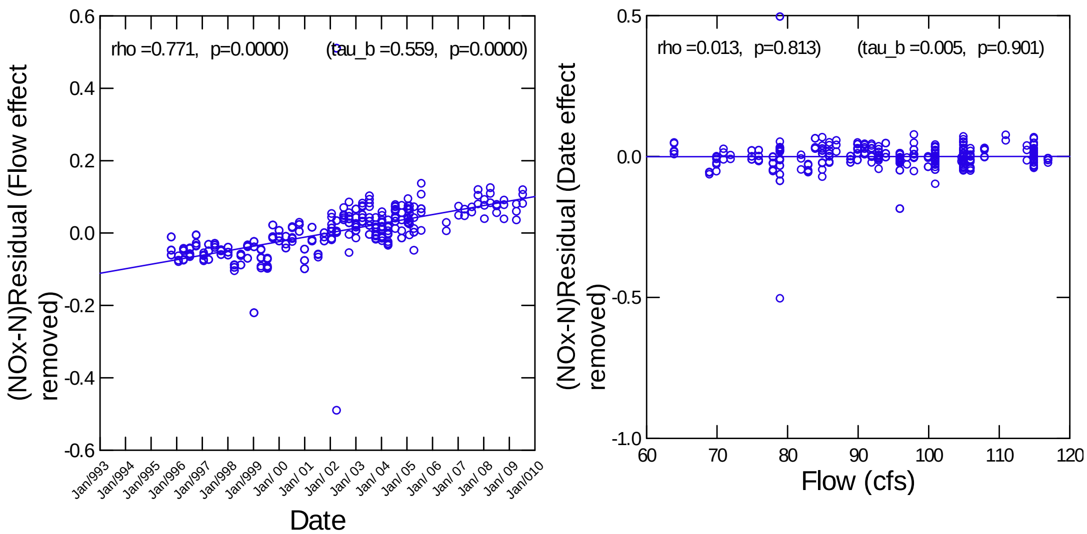

Figure 7. Homosassa residual plots. Concentration unaccounted for by flow is significantly related to date (left panel), while concentration unaccounted for by date is not significantly related to flow (right panel).

relationship of concentration with flow (p = 0.813 for Spearman test, p= 0.901 for Tau-b test). Figure 7 illustrates these relationships.

Lastly, the series of tests were repeated using the Silver Springs data. Exploratory relationships are shown in Figure 8. When the effect of flow was removed, the concentration residuals were

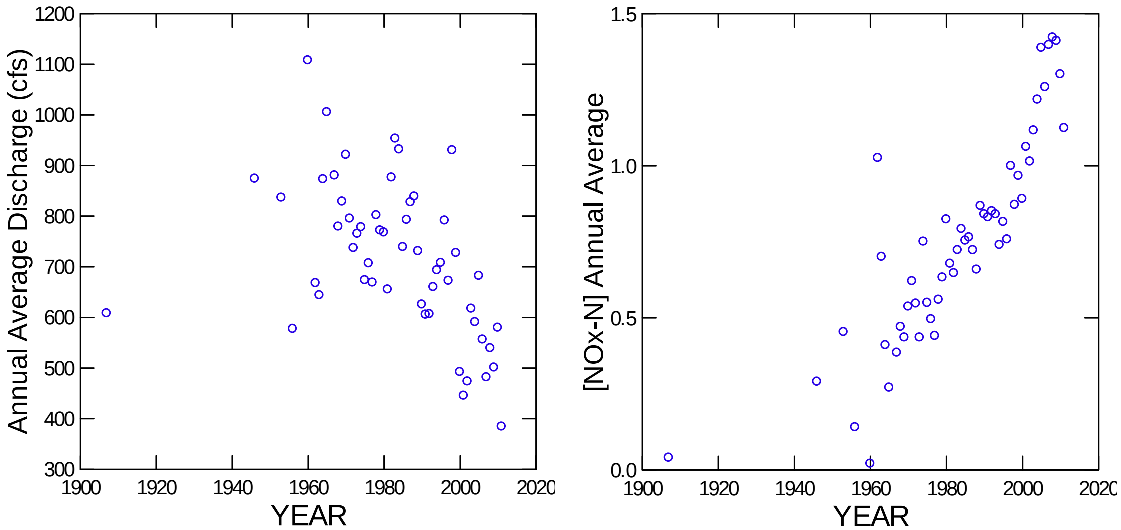

Figure 8. Silver Springs discharge (left panel) and NO_X-N (right panel) as a function of date.

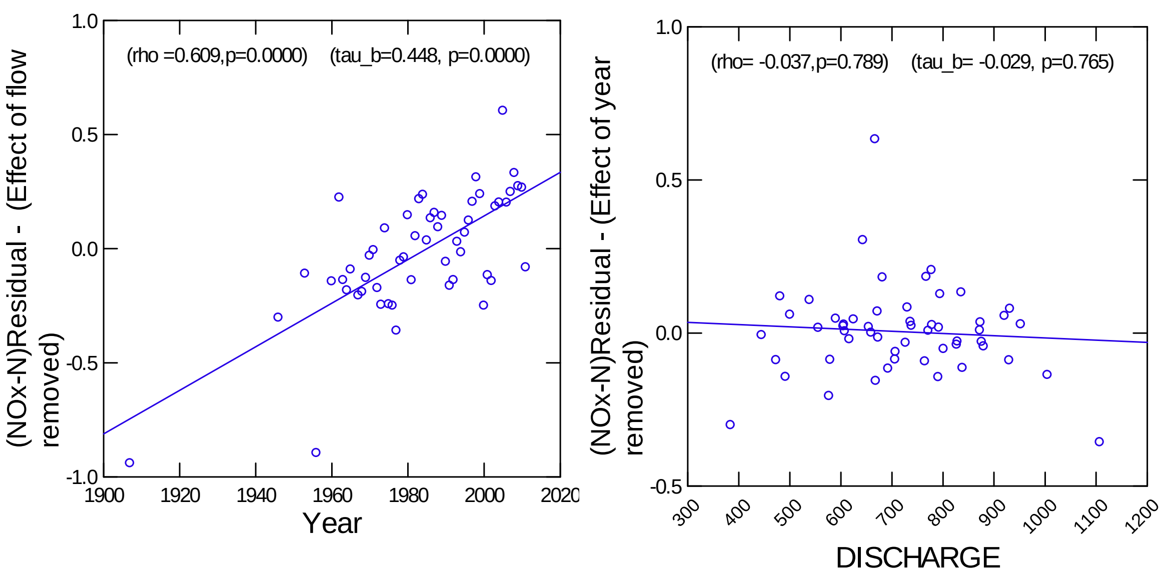

Figure 9. Silver Springs residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) while concentration unaccounted for by date is not significantly related to flow (right panel).

significantly ($p=0.000$ for Spearman test, $p = 0.000$ for Tau-b test) related to time, but when the effect of time was removed first there was no remaining significant relationship of concentration with flow ($p = 0.789$ for Spearman test, $p= 0.765$ for Tau-b test). Figure 9 illustrates the relationships.

Discussion

Flow in the Chassahowitzka, Homosassa and Silver River systems has declined since the 1960s, closely following a pattern of declining rainfall. Rainfall deficits are not linearly related to discharge declines and small changes in rainfall translate into large declines in discharge.

NO_X-N concentration is increasing in the three systems investigated. The relationship between discharge and NO_X-N concentration in each of these systems was evaluated using standard statistical techniques. In all three systems, the increase in concentration was found to be independent of flow but strongly dependent on time.

Literature Cited

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Jones, G.W., S.B. Upchurch, K.M.Champion and D.J. Dewitt. 1997. Water-Quality and Hydrology of The Homosassa, Chassahowitzka, Weeki Wachee, and Aripeka Spring Complexes, Citrus and Hernando Counties, Florida. Origin of Increasing Nitrate Concentrations. Prepared by the Ambient Ground-Water Quality Monitoring Program. Southwest Florida Water Management District.

Knochenmus, L.A. and D.K. Yobbi. 2001. Hydrology of the Coastal Springs Ground-Water Basin and Adjacent Parts of Pasco, Hernando, and Citrus Counties, Florida. U.S. Geological Survey Water-Resources Investigation Report 01- 4230.

Leopold, L.B. 1994. A View of the River. Harvard University Press. Cambridge, Mass.

Phelps, G. G. 2004. Chemistry of Ground Water in the Silver Springs Basin, Florida, with an Emphasis on Nitrate: U.S. Geological Survey Scientific Investigation Report 2004-5144, 54 p.

Wetland Solutions, Inc. 2011. An Ecosystem-Level Study of Florida's Springs – Part II – Gum Slough Springs Ecosystem Characterization. 104 p.

Updated April 6, 2012

Subsequent to release of this technical memorandum on February 29, 2012, similar analyses were conducted for springs (Pumphouse and Trotter) contributing to the Southeast Fork of the Homosassa, Gum Springs (vents 1, 2, 3, 4, Main and Gum Springs nr Holder) and Weeki Wachee. In all cases, the water quality data was obtained from the District's WMIS database and the discharge data was obtained directly from the USGS. The discharge stations used were 02310688, 02312764, and 02310525 respectively. The graphic results are presented on the following pages. The results of the springs contributing to the Southeast Fork and Gum Springs were consistent with the Chassahowitzka, Homosassa springs and Silver River. Weeki Wachee results were unusual, and indicate that NO_X is significantly related to both time and flow.

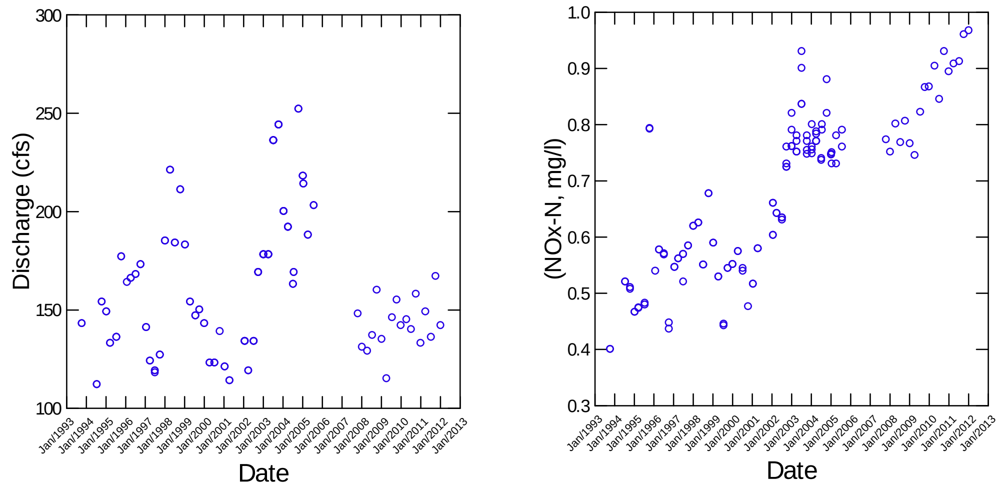

Figure 10. Weeki Wachee discharge (left panel) and NOx-N (right panel) as function of date.

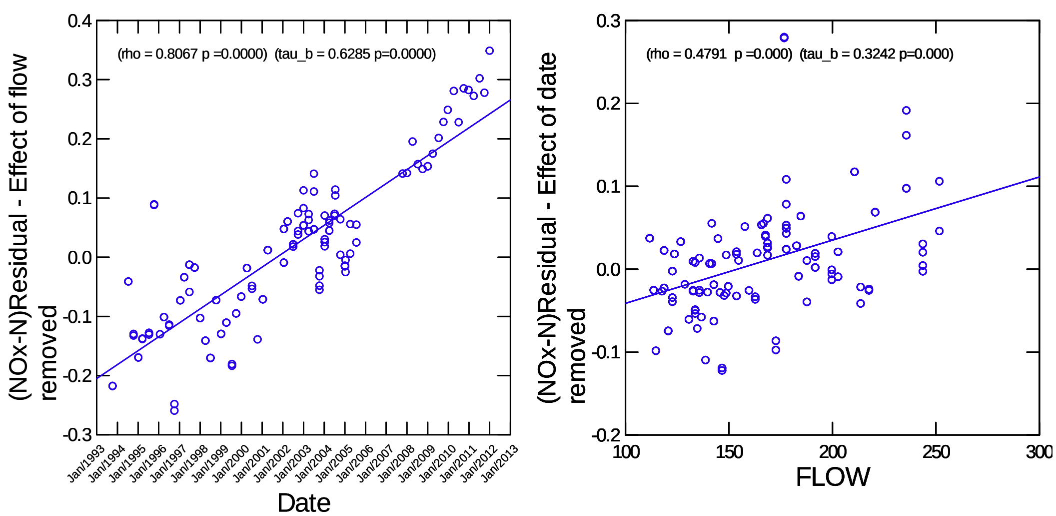

Figure 11. Weeki Wachee residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) and concentration unaccounted for by date is also significantly related to flow (right panel).

Pump House and Trotter Springs vs. Southeast fork discharge.

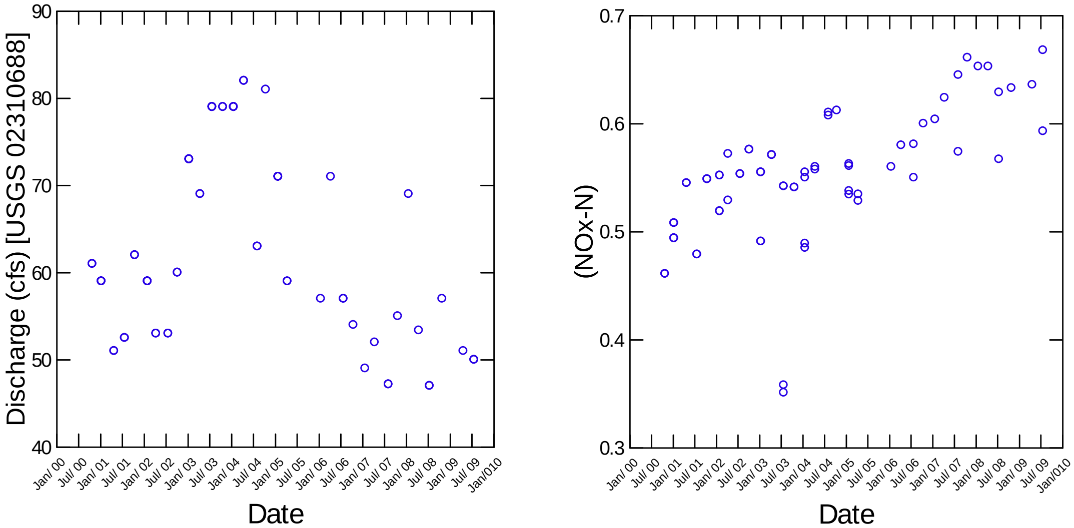

Figure 12. Southeast Fork discharge (left panel) and NO_X-N (right panel) as function of date.

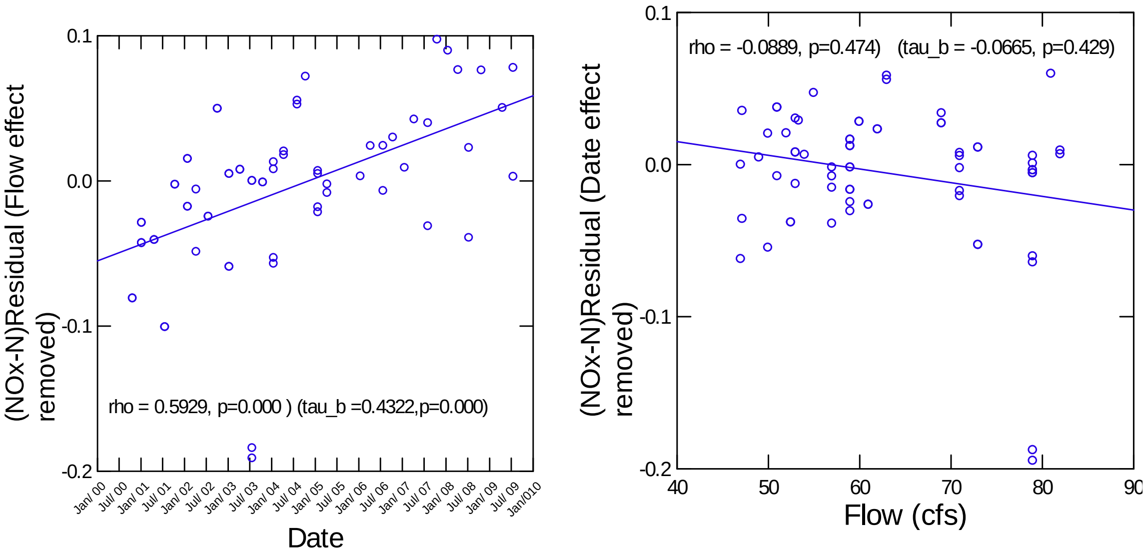

Figure 13. Southeast Fork residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) while concentration unaccounted for by date is not significantly related to flow (right panel).

Gum Springs Main, #1, #2, #3, #4 and Gum Springs nr Holder.
(2003_10_16 through 2012_01_30) WMIS download 2012_03_07

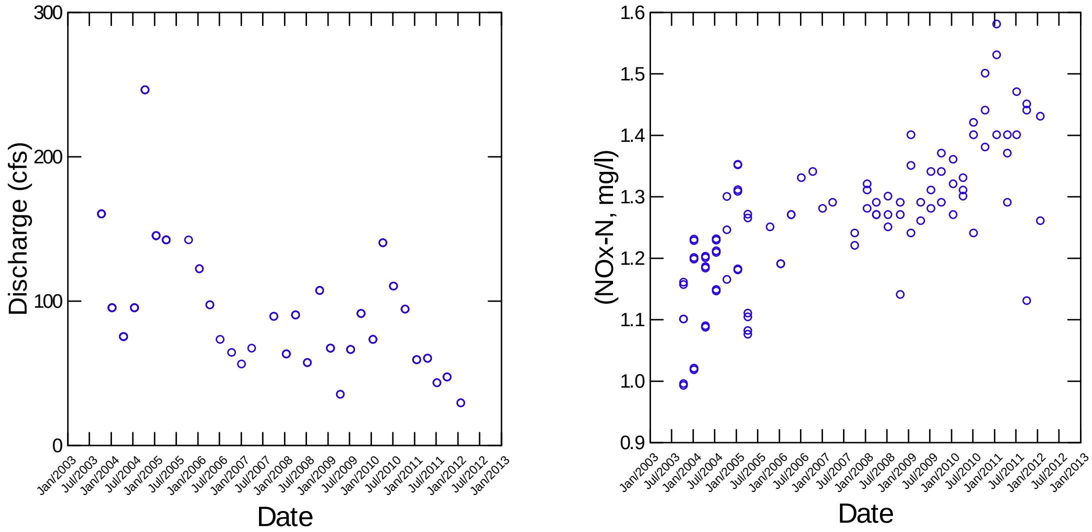

Figure 14. Gum Springs discharge (left panel) and NOx-N (right panel) as function of date.

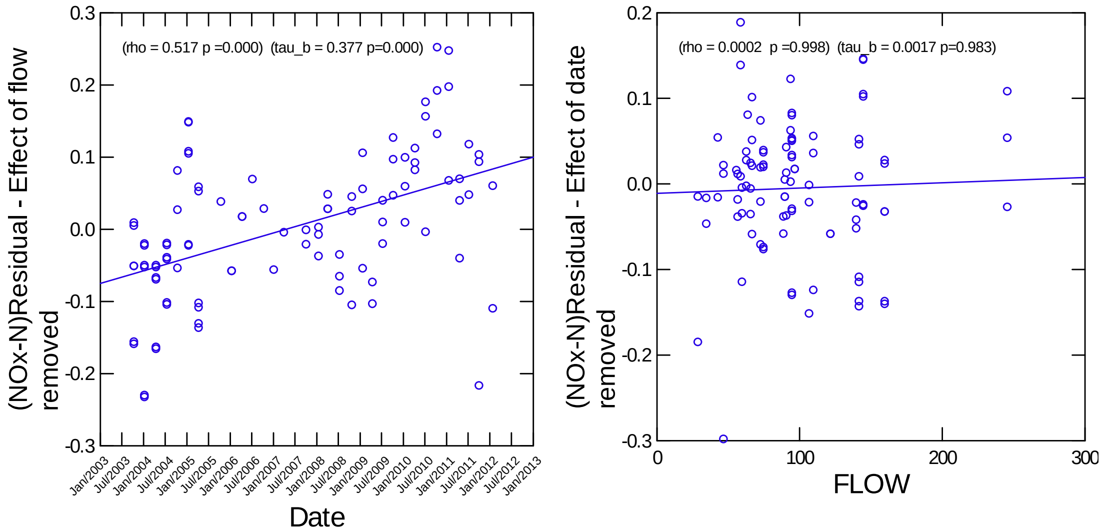

Figure 15. Gum Springs residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) while concentration unaccounted for by date is not significantly related to flow (right panel).

Updated October 24, 2012

Subsequent to release of this technical memorandum on February 29, 2012 and updates on April 6, similar analyses were conducted for the Rainbow River using nitrogen data obtained from SWFWMD WMIS (downloaded 10/21/2012) and USGS flow data (0231300- Rainbow River at Dunnellon) downloaded from NWIS on 10/23/2012. Both approved and provisional flow data were used and the following Rainbow River stations were grouped for analysis.

Rainbow River Springs Included in Analysis.		
Rainbow 1, 2, 3, 4, 5, 7, 8.	Rainbow Bridge Seep North	Bubbling Spring
Rainbow East Seep Spring	Rainbow River at Dunnellon	Seep 1A Spring
Waterfall Spring		

The graphic results are presented on the following page. The results indicate that increase in nitrogen is unrelated to flow, but that the concentration is increasing with time. These findings are consistent with the other six springs evaluated and are partially in agreement with Weeki Wachee. Weeki Wachee results were unusual, and indicate that NO_X is significantly related to both time and flow... Results are summarized in the following table.

Summary of Flow, Date and NOx in Florida Springs		
System	**Effect of Flow Removed NOx Residuals vs. Date**	**Effect of Date Removed NOx Residuals vs. Flow**
Chassahowitzka	Significant	Not Significant
Homosassa	Significant	Not Significant
Pump House & Trotter	Significant	Not Significant
Silver Springs	Significant	Not Significant
Gum Springs 1, 2, 3 & 4	Significant	Not Significant
Weeki Wachee	Significant	Significant
Rainbow River	Significant	Not Significant

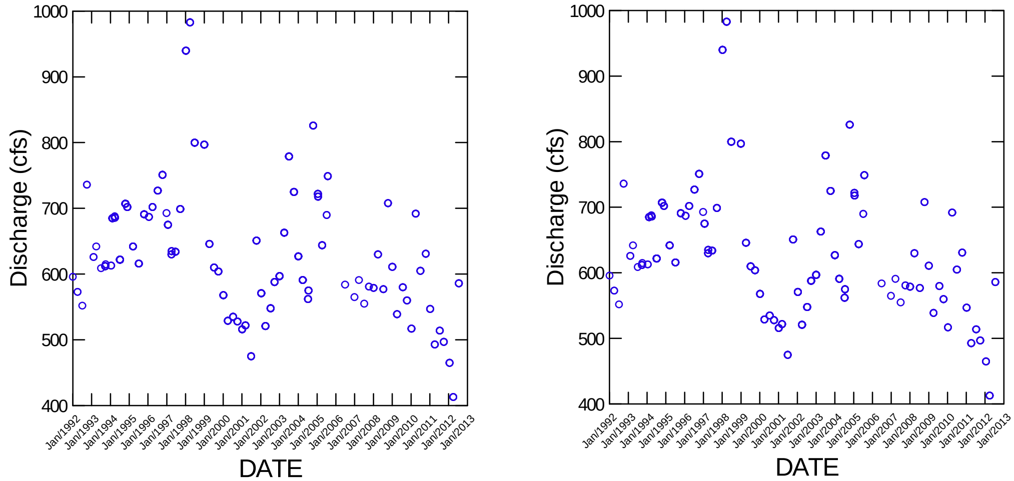

Figure 16 Rainbow River discharge (left panel) and NOx-N (right panel) as function of date.

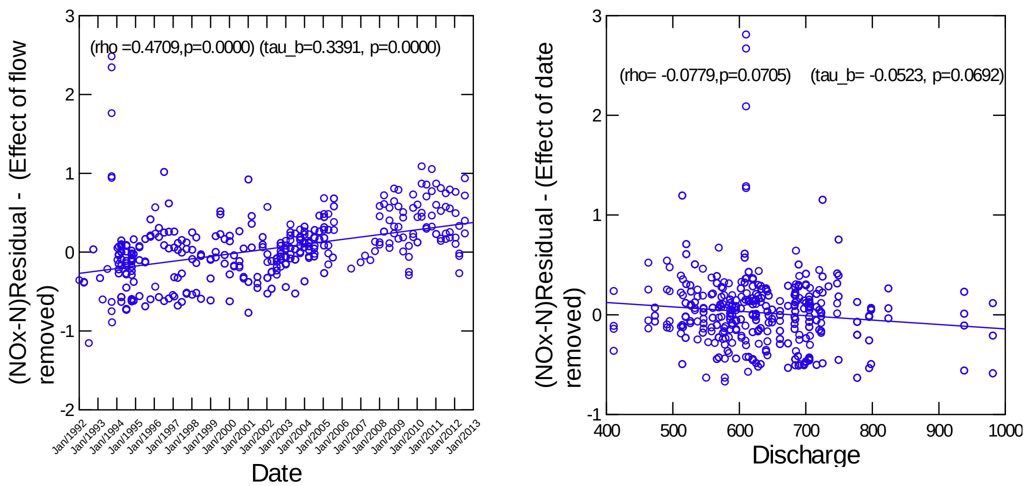

Figure 17. Rainbow River residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) while concentration unaccounted for by date is not significantly related to flow (right panel).

Appendix AB

Watson, K.W., and Yang, L. 2012. Memorandum to Mr. Douglas A. Leeper, Southwest Florida Water Management District, dated May 2, 2012. Regarding: use of the Homosassa hydrodynamic model for evaluating the 3 psu isohaline salinity regime through use of an adjusted flow record associated with a 3.2 inch sea level rise in support of MFLs development, PO 12P00000667. HSW Engineering, Inc. Tampa, Florida.

MEMORANDUM

To: Mr. Douglas A. Leeper, Chief Environmental Scientist
Southwest Florida Water Management District

From: Ken W. Watson, Ph.D., Principle Hydrologist
Lei Yang, Ph.D., P.E., Project Engineer
HSW Engineering, Inc.

Date: May 2, 2012

Re: Use of the Homosassa River hydrodynamic model for evaluating the 3 psu isohaline salinity regime through use of an adjusted flow record associated with a 3.2 inch sea level rise in support of MFLs development
P.O. 12P00000667

A hydrodynamic model was developed for the Homosassa River (HSW, February 2011) for the Southwest Florida Water Management District to assist with developing Minimum Flows and Levels. One objective of developing this model is to associate specific isohaline river kilometer (RKM) locations with aquatic habitats, which are defined as river bottom area, water volume, and shoreline length upstream of particular isohalines (HSW, February, May and November 2011). For this current investigation, the adjusted baseline condition is defined as the baseline flow record plus 1% of baseline flow to account for existing groundwater withdrawal effects on flow, and a modified 2007 tide stage boundary condition that reflects a 3.2 inch sea level rise (SLR). The impact of flow reductions of 3 to 6% on the 3 psu isohaline salinity regime and associated aquatic habitats in the Homosassa River were evaluated by comparing with the reduced flow scenarios with the adjusted baseline scenario.

Results

The adjusted baseline model results and those associated with 3 to 6% flow reductions with a SLR of 3.2 inches (Figure 1 and Table 1) are consistent with previously developed model results (HSW, May and November 2011). For the 3-psu isohaline, the RKM location is further downstream for surface salinity than for bottom salinity for the same flow reduction (Figure 1). Changes on salinity zones associated with shoreline, bottom area and water volume do not exceed 6% for up to 4% flow reduction for surface, depth-averaged and bottom salinities (Table 1 and Figure 2). When the flow reduction is increased to about 5%, a greater than 15% change in bottom area is estimated based on both depth-average and bottom salinities (Table 1 and Figure 2).

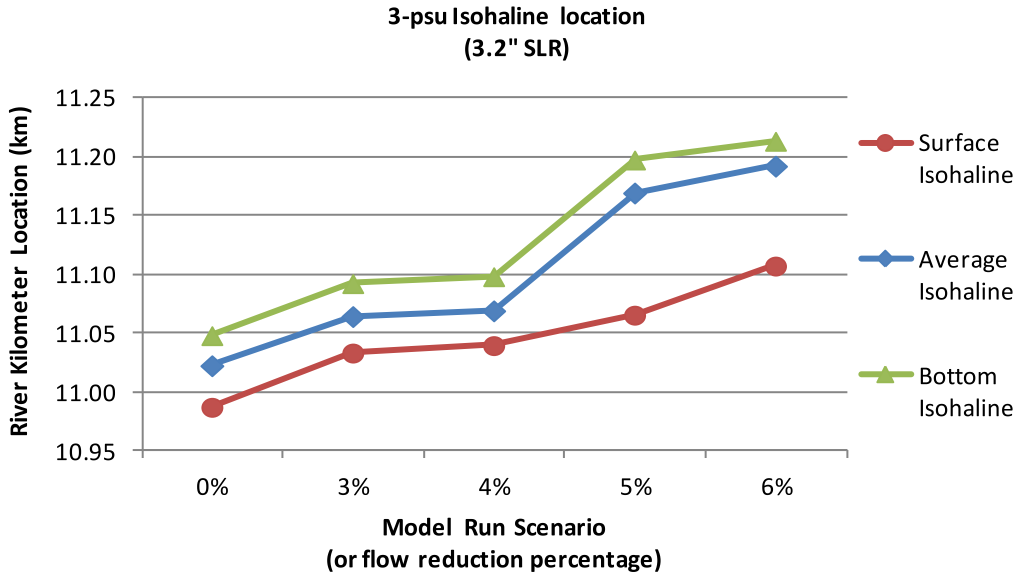

Figure 1. 3-psu surface, depth-averaged, and bottom isohaline locations for adjusted baseline and different flow reduction scenarios

Table 1. Hydrodynamic model result summary for year 2007: River kilometer location, shoreline, water volume, and bottom area and their relative changes from baseline for 3-psu isohaline associated with the 3.2-inch sea level rise and 4 flow reductions from adjusted baseline flow

Depth and Flow Reduction Scenario	RKM	Shoreline (m)	Bottom Area (m^2)	Water Volume (m^3)	Shoreline Change from Baseline (%)	Area Change from Baseline (%)	Volume Change from Baseline (%)
top_0%	10.99	1,288			—		
top_3%	11.03	1,253			3		
top_4%	11.04	1,248			3		
top_5%	11.07	1,230			5		
top_6%	11.11	1,206			6		
avg_0%	11.02		177,165	254,256		—	—
avg_3%	11.06		169,108	244,358		5	4
avg_4%	11.07		168,173	243,210		5	4
avg_5%	11.17		148,872	219,500		16	14
avg_6%	11.19		144,474	214,097		18	16
bot_0%	11.05		172,238			—	
bot_3%	11.09		163,715			5	
bot_4%	11.10		162,582			6	
bot_5%	11.20		143,465			17	
bot_6%	11.21		141,632			18	

Note: shaded cells indicate no data; "—" indicates not applicable.

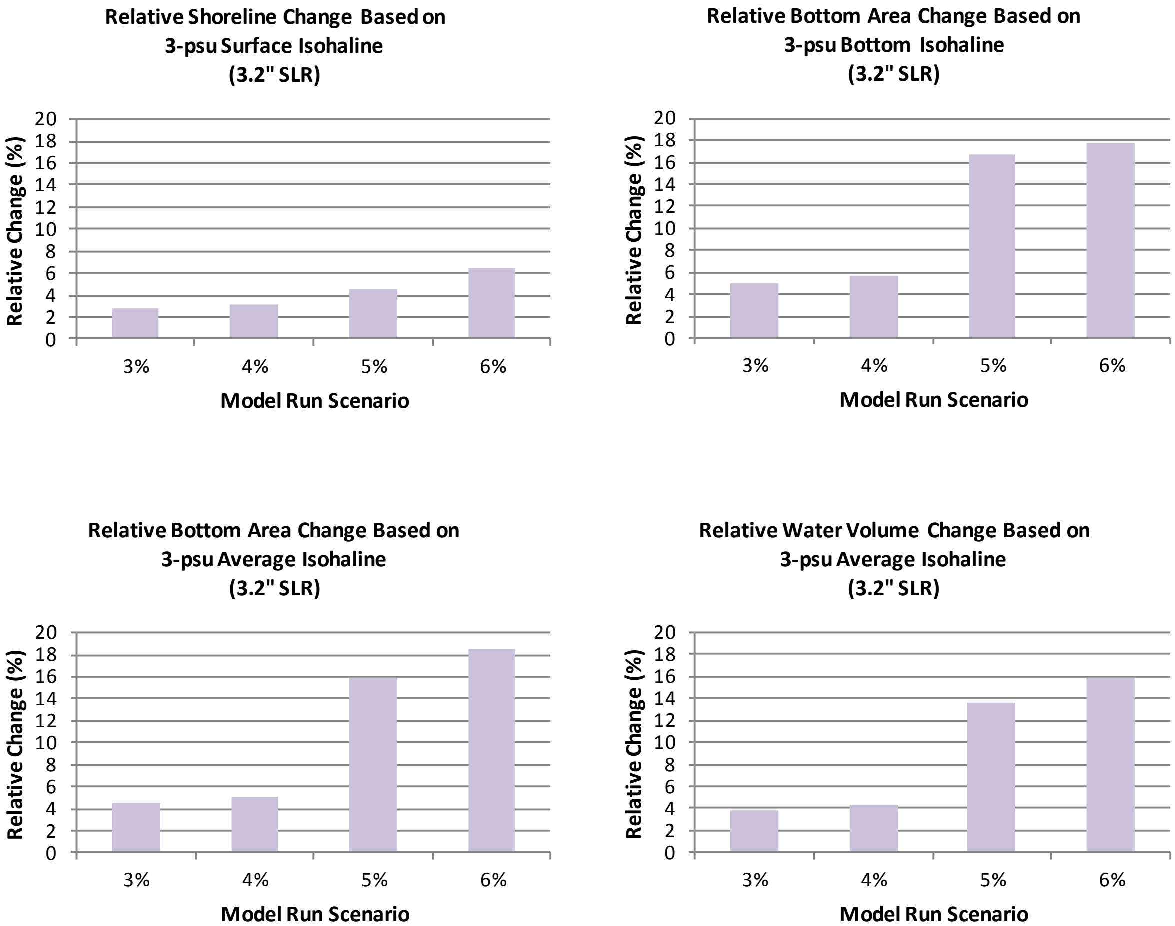

Figure 2. Comparisons of relative changes for shoreline, bottom area, and water volume associated with the 3-psu isohaline for different flow reduction scenarios

Deliverable

One data file is provided in Microsoft Excel 2007 format along with this memorandum and one set of EFDC hydrodynamic model run files.

Reference

HSW Engineering, Inc. (HSW). A modeling study of the relationships of freshwater flow with the salinity and thermal characteristics of the Homosassa River, February 2011. Prepared for the Southwest Florida Water Management District.

HSW Engineering, Inc. (HSW). Use of a hydrodynamic model for evaluating salinities in the Homosassa River in support of MFL development, February 2011. Technical Memo. Prepared for the Southwest Florida Water Management District.

HSW Engineering, Inc. (HSW). Use of a hydrodynamic model for evaluating sea level change on salinities in the Homosassa River in support of MFLs development, May 2011. Technical Memo. Prepared for the Southwest Florida Water Management District.

HSW Engineering, Inc. (HSW). Use of a hydrodynamic and empirical models for evaluating salinity regimes in the Homosassa River in support of MFLs development, November 7, 2011. Technical Memo. Prepared for the Southwest Florida Water Management District.