

APPENDIX J  
HYDRAULICS AND HYDROLOGY REPORT  
(2010)

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**Sacramento River Deep Water Ship Channel  
Limited Reevaluation Study**

**Hydrologic, Hydraulic & Hydrodynamic  
Without-Project Baseline Conditions  
Final Report**



**Prepared For:  
U.S. Army Corps of Engineers  
San Francisco District**



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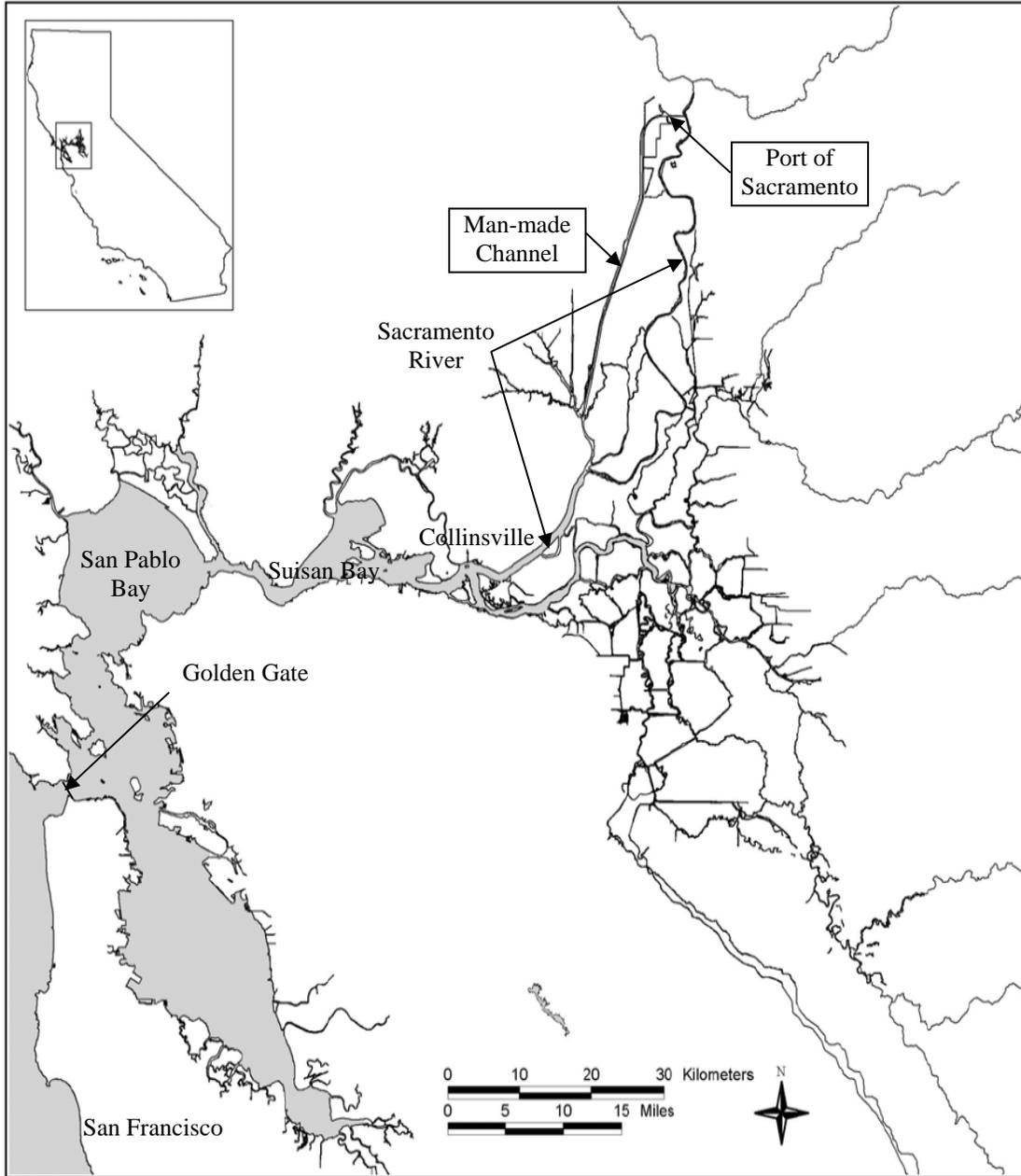
## 1.0 INTRODUCTION

A Limited Reevaluation Study for deepening the Sacramento River Deep Water Ship Channel (SRDWSC) is being undertaken by the Corps of Engineers - San Francisco District. The SRDWSC project begins at Collinsville in Sacramento River through the man-made channel near Rio Vista and reaches its terminus at the Port of Sacramento, as shown in **Figure 1**. This navigation-related channel-deepening project is located in the Sacramento-San Joaquin Delta region of northern California.

### 1.1 Project Background

The 46.5-mile Sacramento River Deep Water Ship Channel was originally authorized by the River and Harbor Act (Public Law 525, 79<sup>th</sup> Congress, 2<sup>nd</sup> Session) on July 24, 1946. Construction of a 30-foot deep channel was completed in 1963. In response to resolutions adopted on 10 July, 1968 and 11 December, 1969 by the House of Representatives Committee on Public Works, the Board of Engineers for Rivers and Harbors was requested to review reports pertinent to the Sacramento River Deep Water Ship Channel, and recommend any modifications of the existing navigational project. In July 1980, a combined report of a feasibility study and Environmental Impact Statement (EIS) for navigation and related purposes was prepared. The report recommended deepening and widening of the existing channel. The SRDWSC channel deepening project was subsequently authorized for construction by Public Law 99-88 in 1985.

This Authorization was reiterated in Section 202(a) of Public Law 99-662, the Water Resources Development Act of 1986 (WRDA, 1986). A General Design Memorandum (GDM) and a Supplemental Environmental Impact Statement were prepared in March 1986 that presented the selected plan for channel modifications between New York Slough and the Port of Sacramento. A supplement study to the 1986 GDM was performed in May 1988 to reduce the overall construction costs. Construction of a 35-foot deep channel referenced to the Mean Lower Low Water (MLLW) datum was initiated in 1989, but work was suspended in 1990 at the request of the Port of Sacramento due to the inability to continue financing their share of the project cost. Only about 8 miles of channel deepening from River Miles 35 to 43 had been completed at the time of the project suspension.



Source: DWR

Figure 1. Project Location

In 1998, Congress directed the Corps to initiate a reevaluation process of the incomplete project that would serve as a basis for a possible recommendation to resume construction (Bill Number HR 4060 and the Energy and Water Appropriations Act of 1999).

*“The conferees direct the Corps of Engineers to complete a reevaluation report of the Sacramento River Deepwater Ship Channel, California, project using available funds.”*

Negotiations were held between the Port of Sacramento and the Sacramento District of the Corps to develop an acceptable scope and budget for the project. Work was initiated to conduct a Limited Reevaluation Study on a cost-shared (75 Federal/25 Non-Federal) in July 2002. The major engineering features (design) of the project are to remain essentially unchanged from the previously approved documents. Environmental considerations have, however, changed with new endangered species, availability of dredge material disposal sites, and heightened water quality concerns. A joint Supplemental Environmental Impact Statement/Subsequent Environmental Impact Report (SEIS/SEIR) will therefore be required to accompany a Limited Reevaluation Report (LRR) for the study.

In 2005, the Port of Sacramento requested that the study be suspended as the Port addressed its financial priorities. In 2007 the Port, in cooperation with the Port of Oakland, renewed its interest to again support the study and ultimately resume construction of the 35-foot channel as soon as possible. The San Francisco District received funds in February 2008 and resumed work on the project in March 2008.

## 1.2 Previous Studies

### 1.2.1 Previous Studies by the Corps of Engineers

A combined report of the feasibility study and Environmental Impact Statement (EIS) was prepared in July 1980 (USACE-SAD, 1980) to evaluate the feasibility of deepening a navigational channel in Sacramento River extending from the John F. Baldwin Ship Channel in Suisan Bay near Collinsville to the Port of Sacramento. Various potential measures were analyzed and evaluated to determine a preferred alternative, based on engineering design, environmental concerns, and economic considerations. The factors affecting channel dimensions include the size and maneuverability of a vessel, vessel speed, current velocity and direction, river stages, wind speed and direction, and physical characteristics of channel bottom and banks. The economically justified alternative consisted of a navigational channel that is 35 feet deep at the MLLW level with a 250 to 350 -foot width and a side slope of either 1 to 3 (vertical to horizontal) or 1 to 4.

A General Design Memorandum (GDM) and a Supplemental Environmental Impact Statement were subsequently prepared in March 1986 (USACE-SAD, 1986), which formulated the engineering plans for channel deepening between Collinsville in

Sacramento River and the Port of Sacramento via a man-made channel. A supplement addendum to the 1986 GDM was also prepared in May 1988 (USACE-SAD, 1988) to reduce the overall construction costs of this navigational project. As a result of the project cost reduction, the design channel width at Miles 18.60 to 21.42, 21.62 to 25.65, 26.11 to 35.45 and 35.88 to 40.16 was narrowed from 250 feet to 200 feet. Also, a salinity monitoring program for the pre-deepened ship channel was conducted from 1987 to 1993 (USACE-SAD & USACE-SFD, 2004).

Upon request by Congress in 1998 to prepare a reevaluation study for a possible recommendation to resume the channel deepening construction after the project suspension in 1990, a Project Management Plan (PMP) (USACE-SFD, 2008) was prepared in 2008 to outline the scope of work, overall schedule, and itemized budgets for a Limited Reevaluation Study. The PMP detailed the technical requirements for the work tasks including engineering analyses, cost estimating, economic evaluation and environmental consideration.

### 1.2.2 Previous Studies by Others

To optimize future planning and management of water usage within the Sacramento-San Joaquin Delta, various studies have been prepared and a number of monitoring programs have been implemented to assess Delta issues related to water deliveries and water quality since the 1987-1992 drought period. CALFED (<http://calwater.ca.gov/calfed/index.html>) which is comprised of four federal agencies (the Environmental Protection Agency, Bureau of Reclamation, National Marine Fisheries Service and Fish and Wildlife Service) and the State of California have commissioned numerous studies including field monitoring within the Delta. The monitored hydrologic parameters such as river stage, water velocity, flow discharge rate, salinity, and water quality constituents including chlorophyll, dissolved oxygen, and PH have been and are continuously being collected in Sacramento River (<http://cdec.water.ca.gov/>). The California Department of Water Resources (DWR) has also developed a Delta Modeling system (<http://baydeltaoffice.water.ca.gov/modeling>) to assess Delta hydrodynamics, water quality and transport of various constituents in the entire Bay-Delta environment. Annual reports have continuously been prepared since 1992 (<http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/annualreports.cfm>).

## 2.0 PYHSICAL SETTING

### 2.1 Channel Setting

The Sacramento River Deep Water Ship Channel (SRDWSC) lies within Contra Costa, Solano, Sacramento, and Yolo Counties and serves the marine terminal facilities at the Port of Sacramento as shown in Figure 1. The 46.5-mile long federally maintained channel provides navigational access from approximately Collinsville, near the Contra Costa county line to the Port of Sacramento in West Sacramento, Sacramento County. This ship channel joins the San Francisco Bay to the Stockton Deep Water Ship Channel

at New York Slough, thereby affording access from the Port of Sacramento to harbors in the Bay and via the Golden Gate to the Pacific Ocean. At a confluence location near Rio Vista, the Steam Boat Slough and the downstream reach of the SRDWSC merge to the Sacramento River that discharges into Suisan Bay. Just north of Miner Slough, the SRDWSC forks to the north from the natural SRDWSC, includes a man-made navigational channel, and reaches its terminus at the Port of Sacramento. The man-made portion of the SRDWSC comprises approximately two-thirds of the entire ship channel.

The entire deep water ship channel is divided into 5 specific reaches based on each respective geographic setting, as listed in **Table 1**. Reach 1, which is relatively short and in a general west-east alignment, begins at Collinsville and ends at a channel location immediately northeast of Sherman Lake. Reach 2 that orientates toward northeast extends for about 10 miles along the Sacramento River upstream to the confluence of the Steam Boat Slough. Reach 3 that is also a short reach continues from the confluence to the beginning of the man-made channel that was constructed specifically for the navigational purpose. Reach 4 extending for approximately 17 miles covers the entire man-made channel orienting almost toward north. Reach 5 begins at the location where the channel deepening and widening has been completed and ends at the Port of Sacramento. Dimensions of the existing channel configuration are presented in **Table 2** for the entire deep water ship channel. The design depth of the SRDWSC is currently at 30 feet, MLLW, except for the channel reach between Miles 35 and 43 where it was deepened to 35 feet under the original navigational project that was constructed in the 1980's. **Figure 2** shows the channel mile locations along the deep water ship channel.

Table 1. Discretization of Channel Reaches

Reach	beginning	ending
1	Sta. 0+00 (Channel Mile 0)	Sta. 211+20 (Channel Mile 4.0)
2	Sta. 211+20 (Channel Mile 4.0)	Sta. 761+25 (Channel Mile 14.418)
3	Sta. 761+25 (Channel Mile 14.418)	Sta. 983+98 (Channel Mile 18.636)
4	Sta. 983+98 (Channel Mile 18.636)	Sta. 1848+00 (Channel Mile 35.0)
5	Sta. 1848+00 (Channel Mile 35.0)	Sta. 2290+33 (Channel Mile 43.377)



the Oregon border to the Sacramento-San Joaquin Delta. The Sacramento Valley, which forms the core of the region, is bounded to the east by the crest of the Sierra Nevada and southern Cascades and to the west by the crest of the Coast Range and Klamath Mountains. The watershed that drains the northern part of California's prominent Central Valley into the middle and lower reaches of the Sacramento River includes the eastern slopes of the Coast Ranges and Mount Shasta, the western slopes of the southernmost region of the Cascades, and the Northern section of the Sierra Nevada. The primary tributaries of the Sacramento River are the Pit, Feather, Yuba McCloud and American Rivers. The Pit River is the longest of these tributaries, but the Feather and American Rivers carry larger volumes of water. The Sacramento River joins the San Joaquin River in the Sacramento – San Joaquin Delta, which empties into Suisun Bay, the northern extension of San Francisco Bay.

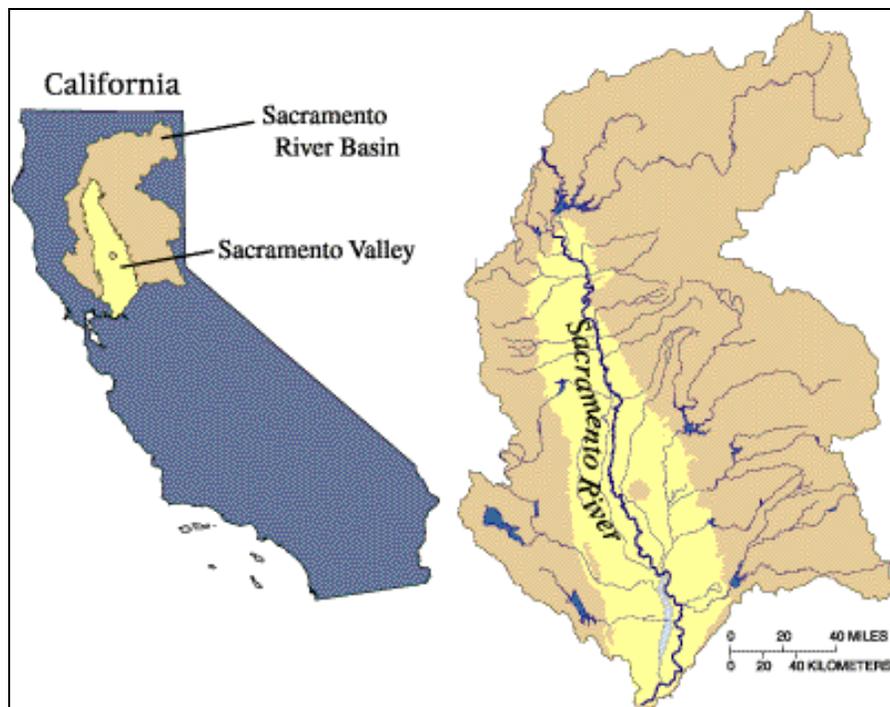


Figure 3. Sacramento River Watershed

Water levels are significantly influenced by both tides and inflows. Most of the precipitation feeding the Sacramento River falls in winter and spring as frontal systems roll in from the Northern Pacific. The river experiences higher inflows in the winter and spring due to these rainfalls and snowmelt. Inflows are controlled by upstream reservoirs which damp peak flows for flood control and storage. These reservoirs release water in the summer and fall to meet agricultural and municipal demands, within and beyond the Sacramento River watershed. Significant amounts of water are directed south for export to Southern California.

### 2.3 Sediment

The primary source of sediment within the ship channel is from the sediment yield of the Sacramento River watershed. Sediment on the ship channel bottom is primarily comprised of silt, clay and fine sand with a relative large percentage of fine sediments whose median grain size is smaller than 0.063 mm. Analysis of a grain size distribution from the past maintenance dredging indicates that a large percent of bottom sediment is either silt or clay. Due to the buoyancy effect of silt and clay, the settling duration of these fine sediments can be in hours or even days. In addition, re-suspension is also likely to occur owing to ship wakes or other agitation. As a consequence, there will be an increased level of turbidity for any maintenance-dredging activities as compared to a site with more sand material.

## 3.0 HYDROLOGIC CHARACTERISTICS

### 3.1 Regional Climate

Winters in the hydrologic region of the Sacramento River are cool and moist with fogs that may last for a week or more; summers are clear, hot, and dry. Summer hot spells that drive daytime temperatures into triple digits are relieved by cooling “Delta breezes” that carry moist air from San Francisco Bay eastward through the Delta and into the basin areas. Average temperatures in July (a summer month) and January (a winter month) in the basins are 75°F and 45°F, respectively.

Rainfall is frequent in the winter, but snowfall is unusual because temperatures, particularly in the daytime, normally remain well above freezing except in the high desert plateau areas or mountain terrains. About ninety percent of runoff-producing precipitation occurs during the period from November to April. Precipitation characteristics in the hydrologic region are significantly affected by topography. Annual precipitation at Sacramento Airport averages 17.9 inches; whereas annual precipitation at Redding in the northern part of the Sacramento Valley averages 33.5 inches. In the high mountainous areas of the Sierra Nevada, average precipitation can be as high as 80 to 90 inches per year. **Table 3** presents the monthly average precipitation at Sacramento and Redding as well as in the Sacramento River hydrologic region.

Table 3. Average Precipitation in the Sacramento River Watershed

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Precipitation in inches													
Region	6.68	6.42	5.81	2.45	1.62	0.65	0.2	0.26	0.87	2.07	4.79	5.40	37.4
Sacramento	3.84	3.54	2.80	1.02	0.53	0.20	0.05	0.06	0.36	0.89	2.19	2.45	17.9
Redding	6.50	5.49	5.15	2.40	1.66	0.69	0.05	0.22	0.48	2.18	4.03	4.67	33.5

### 3.2 Astronomical Tides

Astronomical tides in the San Francisco Bay area are of the mixed, semi-diurnal type, with two highs and two lows of unequal height occurring each lunar day (the duration of which averages 24.4 hours). The largest water level excursion typically occurs as the tide falls from higher high to lower low water, a process that generally requires 7 to 8 hours.

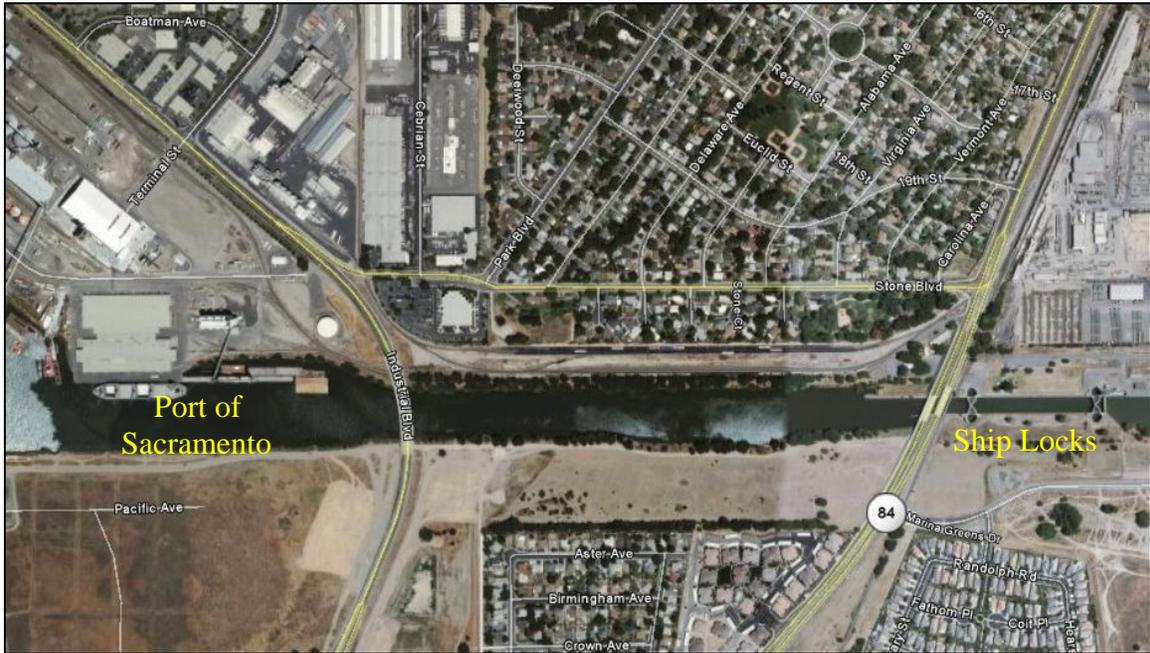
As ocean tidal waters propagate along the Sacramento-San Joaquin Delta and continue into the Sacramento River, a muting effect of lowering the amplitude of tidal range occurs. The muting effect is primarily due to man-made flood protection devices or natural barriers, which inhibit the exchange of waters between the river channels and the ocean. Table 4 respectively presents the mean tidal range, spring tidal range and Mean tide level in San Francisco bay, along the John F. Baldwin Ship Channel and the Sacramento River, and at the Port of Sacramento. It appears that no definite muting trend can be observed along the river. Spatial variation along the river may be due to the geographic setting of the delta and river that damps the tidal ranges at one downstream location, but amplifies it at an upstream location. A tide gage was recently installed at Marker 54 (i.e., 38°15'21.2", 121° 39' 59.1") that is located near the downstream end of the man-made channel. The measured tidal ranges can be as high as 5 feet, which is even higher than the downstream locations at Rio Vista and Pittsburg in Suisan Bay, and as low as one foot only, based on tide measurements from July 2008 to January 2009.

Table 4. Tidal Ranges along Navigational Channels

Station Location	Mean Tidal Range (ft)	Spring Tidal Range (ft)	Mean Tide Level (ft)
Golden Gate Bridge	4.10	5.84	3.18
Pinole Point (San Pablo Bay)	4.40	6.00	3.20
Crockett (Carquinez Strait)	4.40	5.94	3.17
Pittsburg (Suisan Bay)	3.02	4.14	2.13
Sacramento River			
Collinsville	2.89	3.96	2.03
Threemile Slough	3.01	4.05	2.08
Rio Vista	3.25	4.31	2.20
Sacramento near I Street	2.30	2.90	1.40
Port of Sacramento	4.73*	-	-
*. Based on the predicted tides of 2009 Source: NOAA, 2009			

It should be noted that the average tidal range derived from the predicted high and low tides in 2009 at the Port of Sacramento is about 4.73 feet, which is greater than those at various downstream channel locations. This may be attributed to a resonant-like effect induced by the William G. Stone Ship Locks that are located on the east end of the Port

of Sacramento, as shown in **Figure 4**. The ship locks, shown in **Figure 5**, separate the deep water ship channel from the Sacramento River and are currently out of commission.



Source: Google Earth

Figure 4. Location of William G. Stone Ship Locks



Source: DWR

Figure 5. William G. Stone Ship Locks

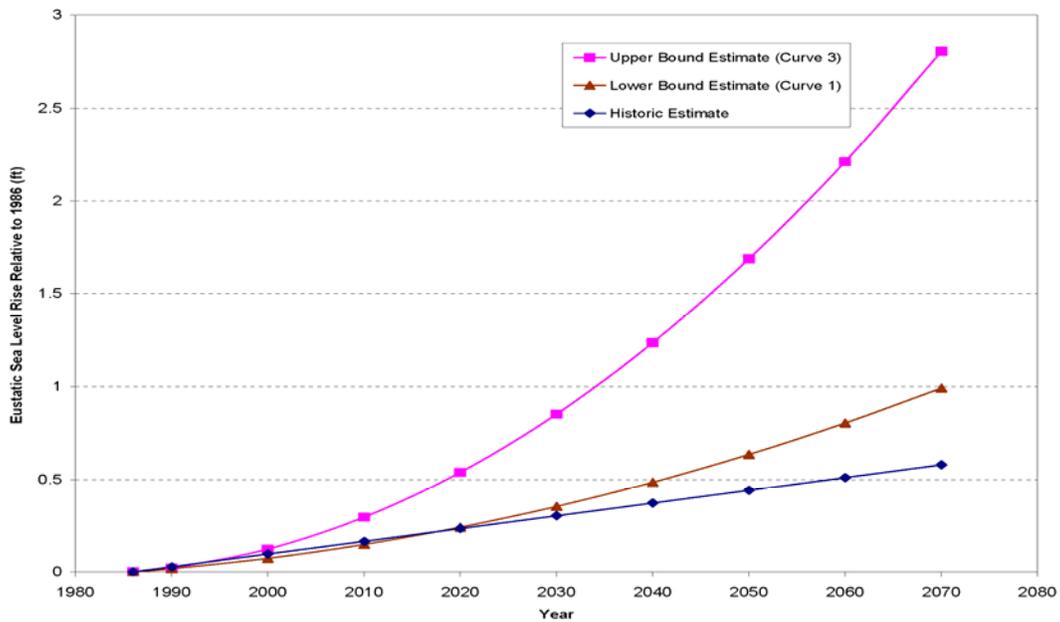
### 3.3 Sea Level Rise

Long-term changes in the elevation of sea level relative to the land can be engendered by two independent factors: (1) global changes in sea level, which might result from influences such as global warming, and (2) local changes in the elevation of the land, which might result from subsidence or uplift.

The ocean level has never remained constant over geologic time, but has risen and fallen relative to the land surface. A trendline analysis of yearly Mean Sea Level (MSL) data recorded at Golden Gate in San Francisco Bay from 1854 to 1999 indicates that the MSL upward trend is approximately 0.055 inches per year. However, the trend increases to 0.0069 feet per year from 1906 to 1999 (NOS, 2001), which is indicative of an acceleration of sea level rising rate. Based on the deduced rate, the sea level at the Golden Gate Bridge is currently 7 inches higher than it was in 1920.

Several notable studies were prepared to predict the increasing rates of future sea level rise due to greenhouse gas emission (National Academy Press, 1987, Titus, 1995, IPCC, 2007, PPIC, 2008). The trend of warmer global temperatures will accelerate melting of glaciers, which will consequently release more water into the oceans (Meier, et. al, 2007). In addition, warmer ocean temperatures cause the water to expand, further raising the sea level. These predictions that are sensitive to the modeling assumptions have various degrees of uncertainty. The predicted future sea level rises can range from about 0.3 to 0.6 feet between 2000 and 2050 (IPCC, 2007). The CALFED Independent Science Board suggests that sea level is likely to rise at least 2.3 to 3.2 feet by 2100, and even greater (6.5 feet or more) if the ice cap melting accelerates (Healey, 2007).

A report issued by National Research Council in 1987 (NRC, 1987) presented the estimated sea level rise rates for three different projected scenarios. These curves that were modified by the Corps of Engineers in 2009 (USACE, 2009) serve as the guideline for Corps' planning studies. **Figure 6** shows the upper (Curve 3) and lower (Curve 1) bound estimates based on the base year of 1986. The Corps of Engineers has adapted a policy to use the upper bound curve (Curve 3) as the maximum estimate for this SRDWSC reevaluation study. On the other hand, the water level upward trend with a constant rate of 0.0069 ft/yr that was deduced from the Golden Gate tide gage data between 1906 and 1999 is designated to be the minimum future sea level rise rate. The sea level rise relative to 1986, based on the minimum rate, is also plotted in the figure for comparison. Assuming that the base year (i.e. Year 0) is set to be in 2012, the resultant sea level rises at the end of 50-year project life (i.e., 2062) will respectively range from a minimum of 0.35 feet to a maximum of 1.97 feet.



Sources: NRC, 1987 & NOAA, 2001

Figure 6. Estimated Sea Level Rise Rates

### 3.4 Sedimentation

Periodic maintenance dredging of sediment within the deep water ship channel has been required since the completion of channel construction in 1963. The temporal fluctuation of dredging quantity depends primarily on the hydrologic conditions within the Sacramento River watershed. However, the sediment yield has continuously decreased in recent years. Many factors contribute to the decreasing sediment yield. These factors may include depletion of erodible sediment from hydraulic mining, sediment impoundments by reservoirs and riverbank protection.

**Table 5** presents the historical dredging record within the ship channel on a yearly basis, while **Figure 7** shows the graphic presentation. Sedimentation occurs primarily between Miles 3.5 and 14 as well as from Miles 33 to 42. The channel condition in the man-made reach from Miles 14 to 33 appears to be relatively stable. Annual average of maintenance dredging over 43 years (1966 to 2009) is approximately 327,100 cubic yards. However, the average dredged volume is merely 171,200 cy/yr since 2000, which is indicative of a long-term reduction trend of sediment yield in the lower reaches of the Sacramento River watershed.

Table 5. Maintenance Dredging Record in SRDWSC

Year	Volume (cy)						
1966	2,220,000	1977	-	1988	-	1999	220,000
1967	183,800	1978	270,500	1989	-	2000	525,000
1968	-	1979	-	1990	-	2001	286,400
1969	890,600	1980	-	1991	-	2002	35,300
1970	-	1981	1,372,000	1992	-	2003	93,100
1971	712,000	1982	1,212,000	1993	238,000	2004	-
1972	146,000	1983	-	1994	-	2005	351,000
1973	-	1984	1,432,000	1995	103,800	2006	240,000
1974	1,065,300	1985	544,000	1996	-	2007	1,000*
1975	314,300	1986	940,000	1997	815,600	2008	125,000
1976	-	1987	-	1998	-	2009	55,000

Note: \* Dredging activity was suspended due to the delta Smelt related issue.

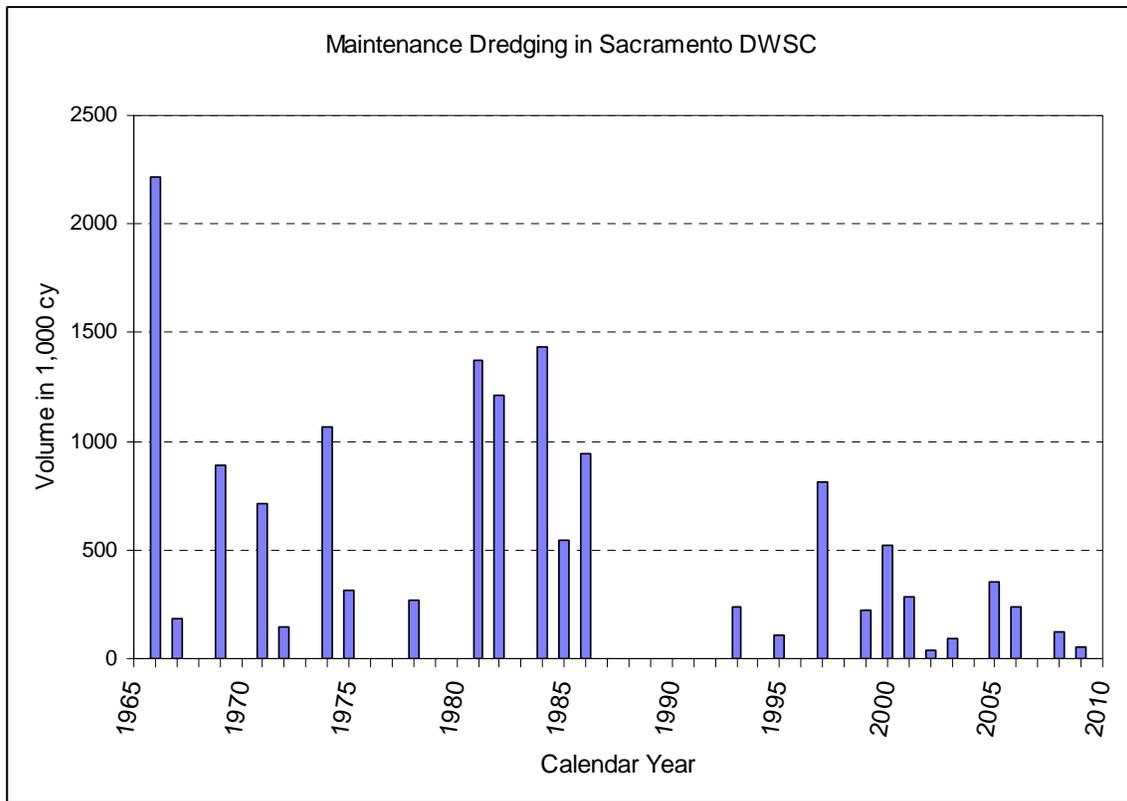


Figure 7. Historical Maintenance Dredging in Sacramento DWSC

### 3.5 Groundwater

The Sacramento River hydrologic region is heavily groundwater reliant. Groundwater provides about 31 percent (DWR, 2003) of the water supply for urban and agricultural uses in the regions, and has been developed in both the alluvial basins and the hard rock uplands and mountains. The Sacramento Valley is geologically a large trough filled with sediments having variable permeability; as a result, well yields are good and range from one-hundred to several thousand gallons per minute. Groundwater extraction for agriculture use primarily supplements surface waters that are in-flowed from the watershed and have been abundant in the Sacramento Valley.

Seawater intrusion in shallow aquifers can be a problem in the coastal groundwater basins. No apparent observation regarding saltwater intrusion into the aquifers along the Sacramento River was documented.

## 4.0 HYDROLOGIC PARAMETERS IN DEEP WATER SHIP CHANNEL

The California Data Exchange Center (CDEC) collects, stores, disseminates, and exchanges hydrologic and meteorological data and related information with other public agencies. Currently, numerous Federal, State, and local agencies collect data from hundreds of meteorological data such as rain, snow, temperature, wind, atmospheric pressure, and humidity, hydrological data including river stage, water turbidity, river discharge rate and flow velocity, and water quality data of salinity, chlorophyll, PH, etc. The data enables users to assess various issues of flood, water supply, and water quality. **Table 6** provides a matrix list of the available gage stations (CDEC, 2009) along the SACRDSWC and the hydrologic parameters that were or/and are continuously being collected. **Figures 8** and **9** illustrate the approximate locations of the listed gages along the SRDWSC. Hydrologic parameters, including river stage, water velocity, river discharge and salinity, at these gage stations were extracted in different months consisting primarily of two distinguished wet (winter) and dry (summer) periods. Temporal and spatial comparisons were made to provide the basic hydrologic characteristics in the ship channel.

### 4.1 River Stage

River Stage represents the combined influence of upstream freshwater inflows and tide-driven ocean water intrusion. River stages at six different stations along the deep water ship channel, as tabulated in Table 6, have been measured for different periods starting as early as the late 1980's with most of them being in the 2000's. The data exhibits the spatial variation as well as temporal changes of water level along the SRDWSC. **Figures 10** through **13** show water levels at applicable stations for four winter months in 1995, 2000, 2005 and 2008, respectively, while **Figures 14** to **17** illustrate the same parameter for the summer months in different years spanning over 14 years.

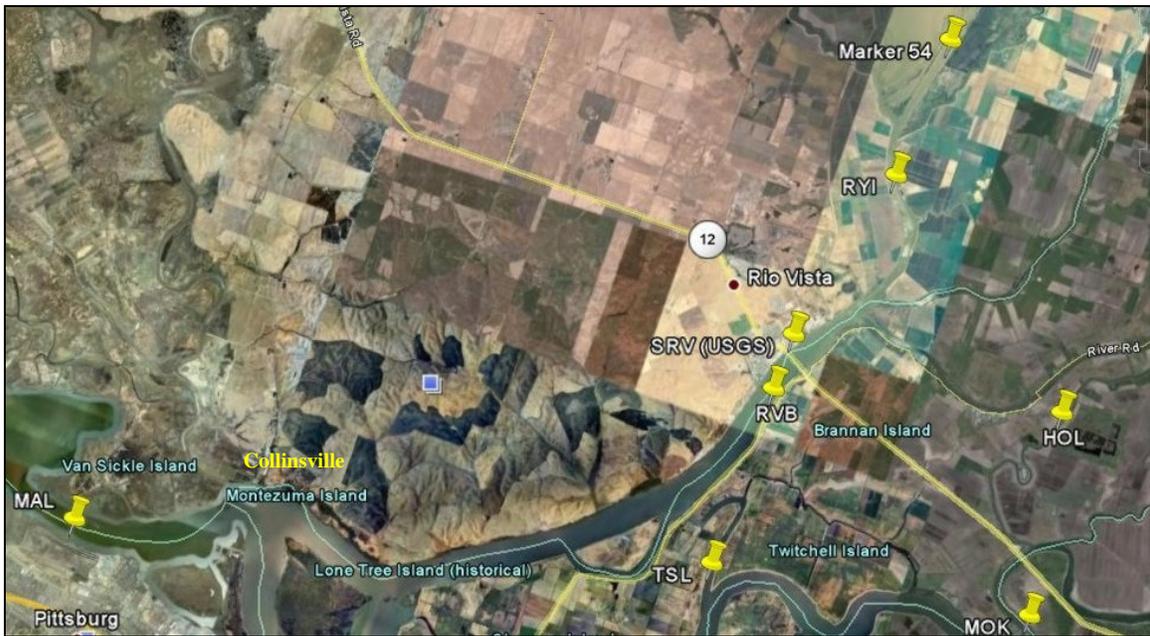
Table 6. Gage Stations along SRDWSC and Collected Hydrologic Parameters

Station ID	Coordinates	River Stage	Water velocity	River Discharge	Salinity
MAL	38.0440°N, 121.9190°W	X	-	-	X*
RVB	38.1500°N, 121.7000°W	X	-	-	X*
SRV	38.1600°N, 121.6860°W	X	X	X	-
RYI	38.2128°N, 121.6692°W	X	X	X	-
Marker 54	38.2558°N, 121.6664°W	X	-	-	-X
LIS	38.4750°N, 121.5870°W	X	X	X	-

Notes: MAL - Sacramento River at Mallard Island  
 SRV - Sacramento River at Rio Vista  
 LIS - Yolo Bypass at Lisbon

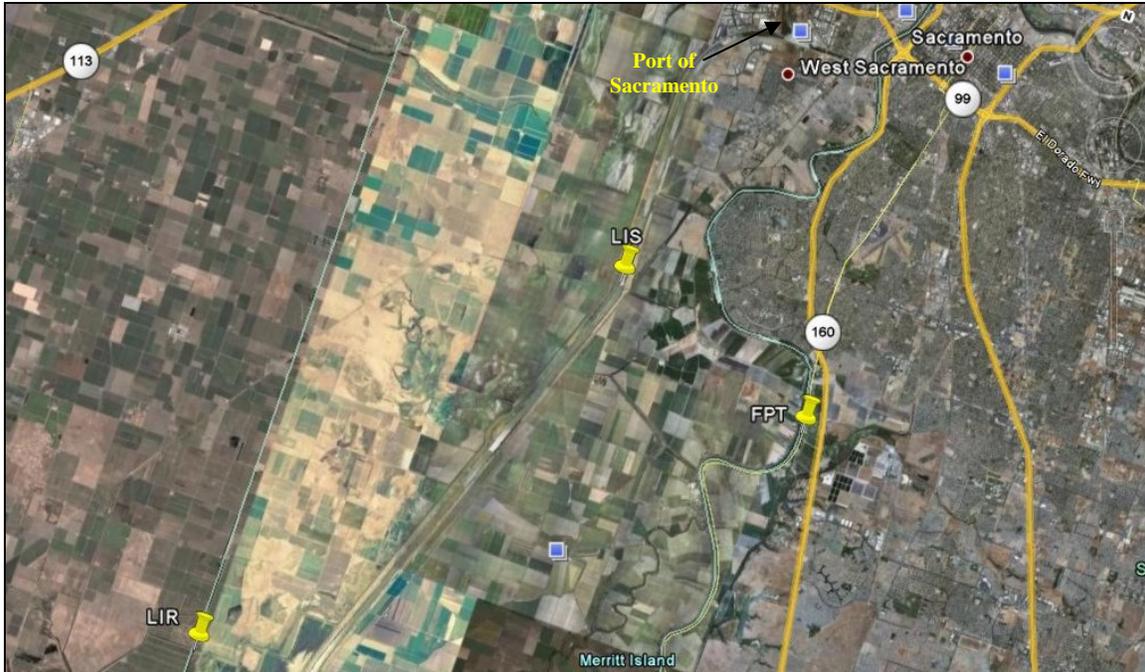
Sources: CDEC, 2009

RVB - Sacramento River at Rio Vista Bridge  
 RYI - Sacramento River at Ryer Island  
 \* - Measured as conductivity



Source: Google Earth Map

Figure 8. Gage Locations at MAL, RVB, SRV RYI & Marker 54



Source: Google Earth Map

Figure 9. Gage Location at LIS

In general, the further upstream the gage station is located, the higher the river stage is during the same temporal period, based on an identical vertical datum. It is also indicative that the river stages in the upstream region (e.g., Station LIS) are significantly influenced by localized inflows into the channel during wet winter months. The river stages at Station LIS were respectively elevated in days during the months of January 1995 (see Figure 10), February 2000 (see Figure 11) and December 2005 (see Figure 12) as a direct consequence of rainfalls occurring during these periods. The tidal influence in the upstream region during these periods was significantly muted; and water level oscillations during flood/ebb cycles were not visible.

Contrarily, river stages that were measured at the six gages for the month of December 2008 without substantial rainfall-related inflows into the upstream region all showed a similar fluctuation in water level that somewhat corresponded to the cyclic flood and ebb tides. **Figure 18**, illustrating the river stages measured in March 1995, indicates that the river stage was once again influenced by tidal cycles after rainfall stopped and river inflows diminished.

During the summer months (July 1995, July 2000, July 2005 & August 2008), river stages recorded at various gage stations in different periods all exhibited a similar behavior of a cyclic fluctuation as the volume of the freshwater inflows is insignificant as compared to the tidal-induced water volume. In addition, it appears that no definite long-term trend of river stage over the 14-year period from 1995 to 2008 can be determined from the gage data.

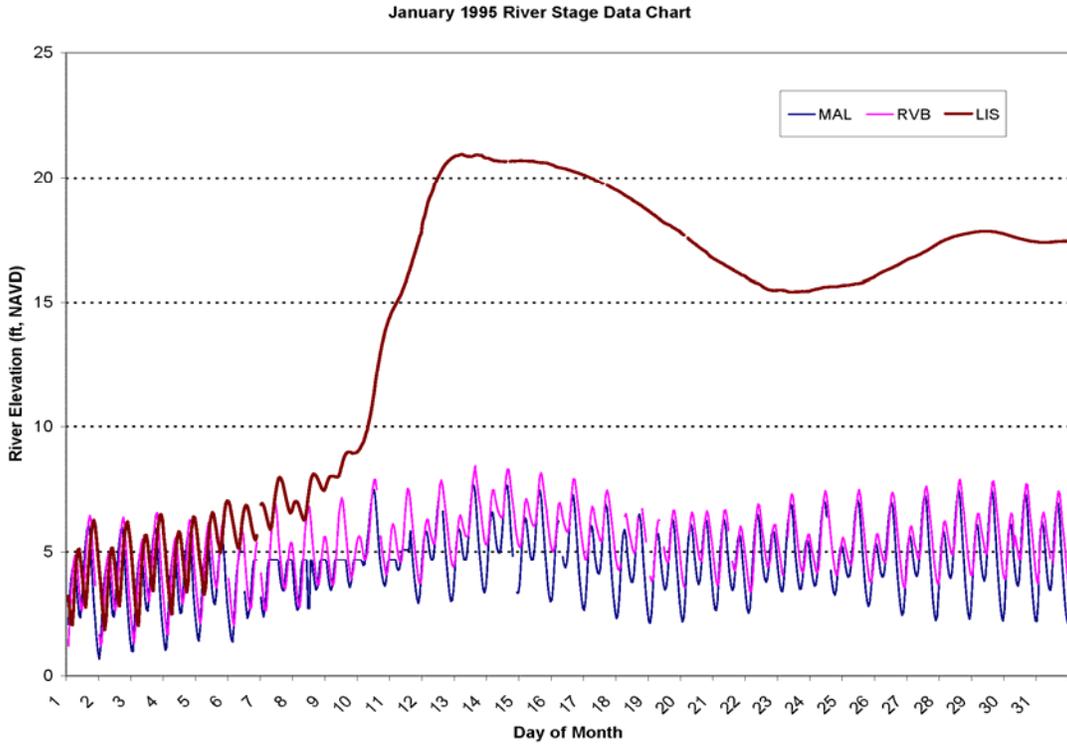


Figure 10. Measured River Stages in January 1995

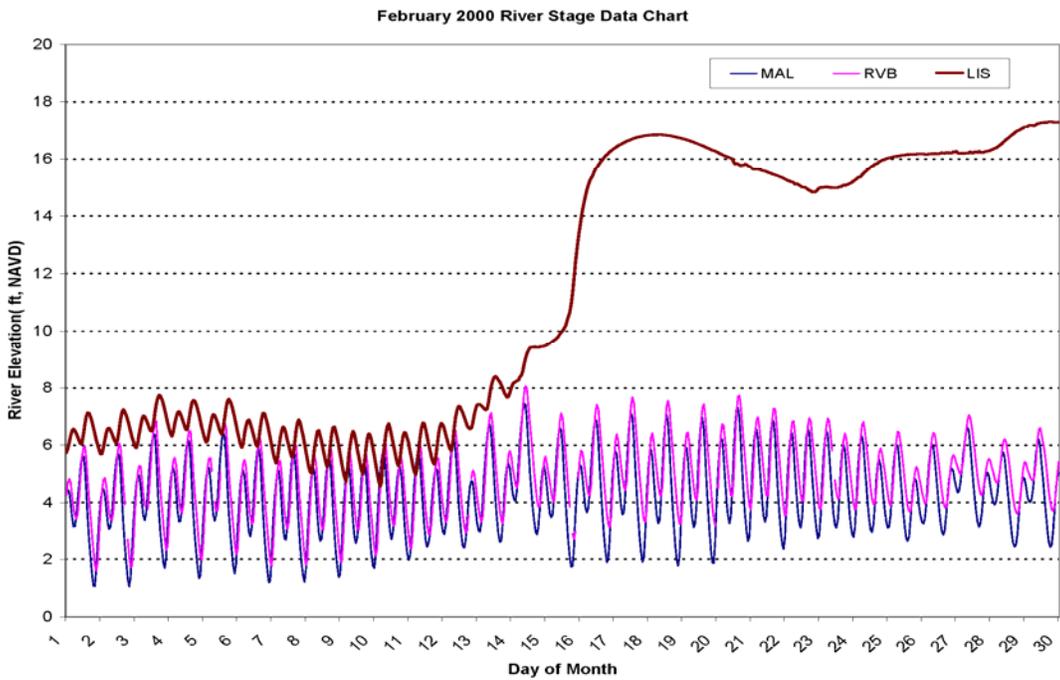


Figure 11. Measured River Stages in February 2000

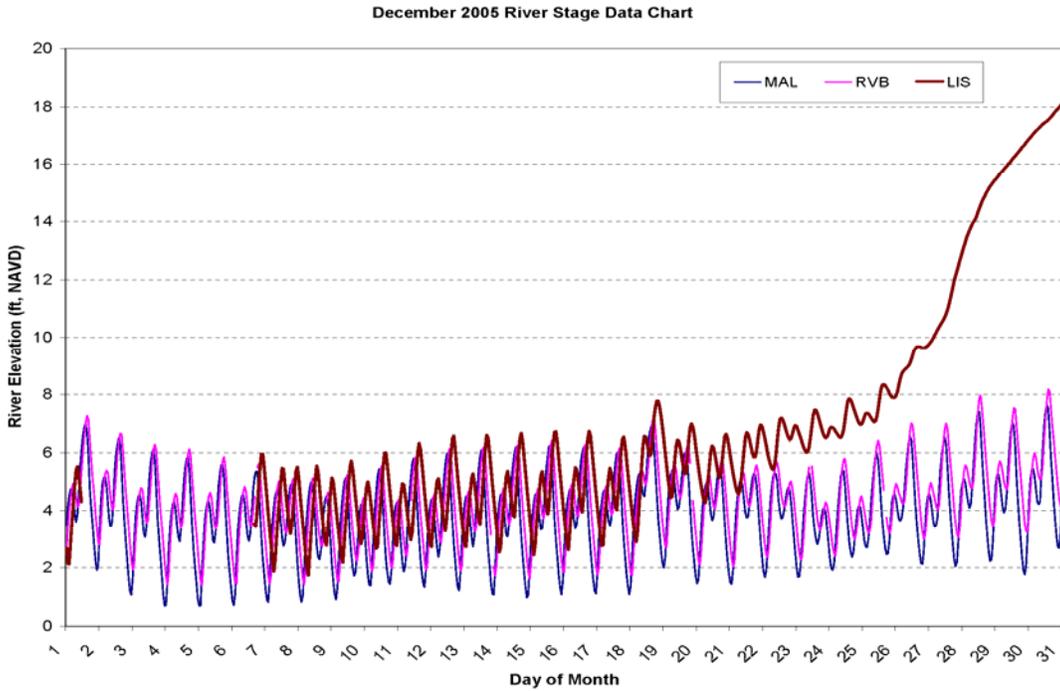


Figure 12. Measured River Stages in December 2005

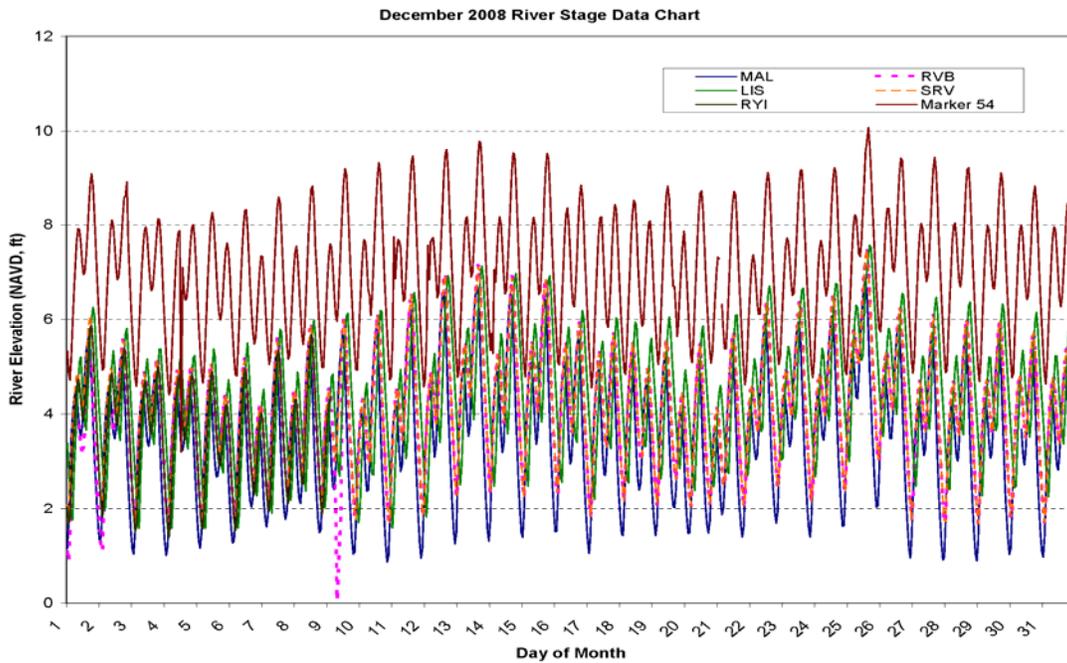


Figure 13. Measured River Stages in December 2008

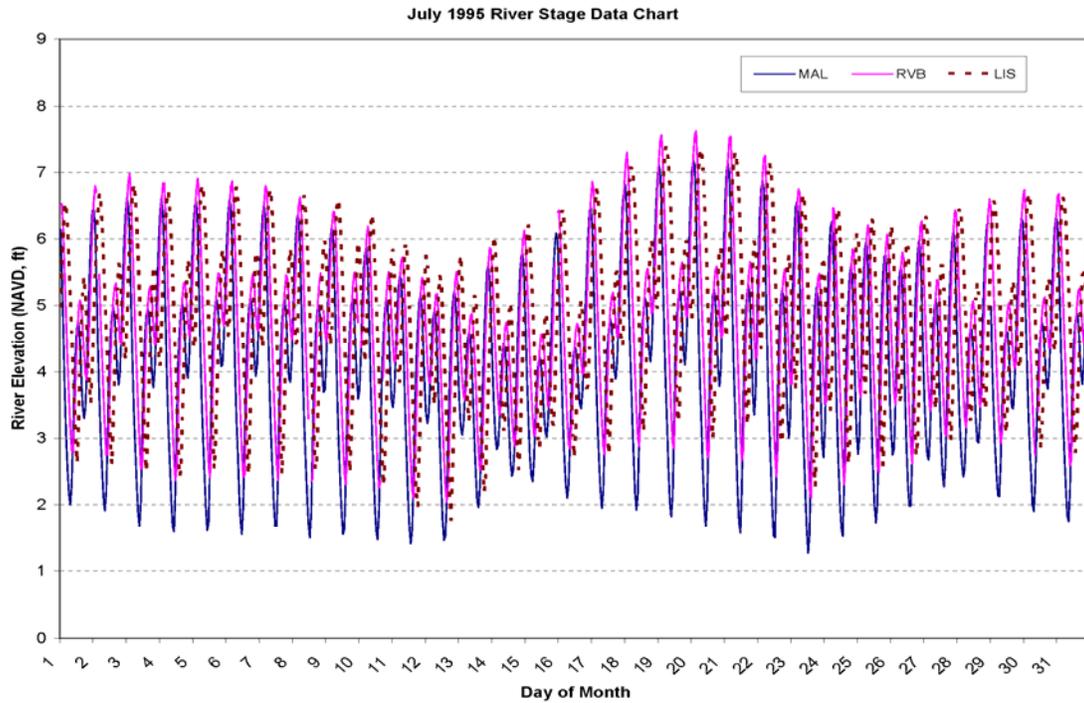


Figure 14. Measured River Stages in July 1995

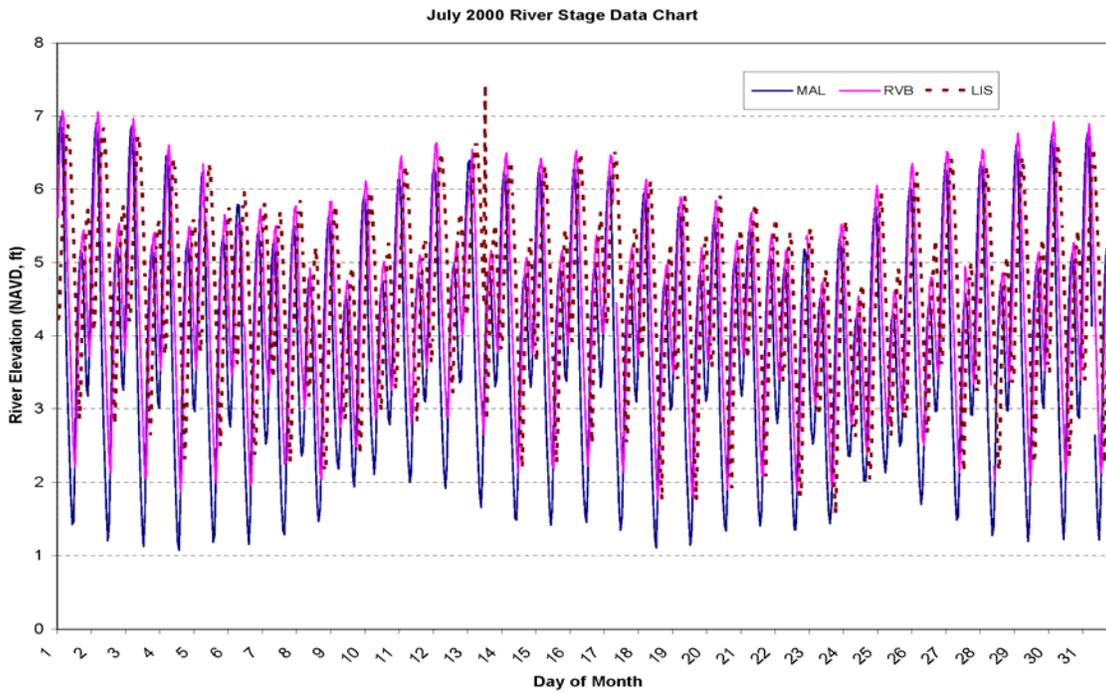


Figure 15. Measured River Stages in July 2000

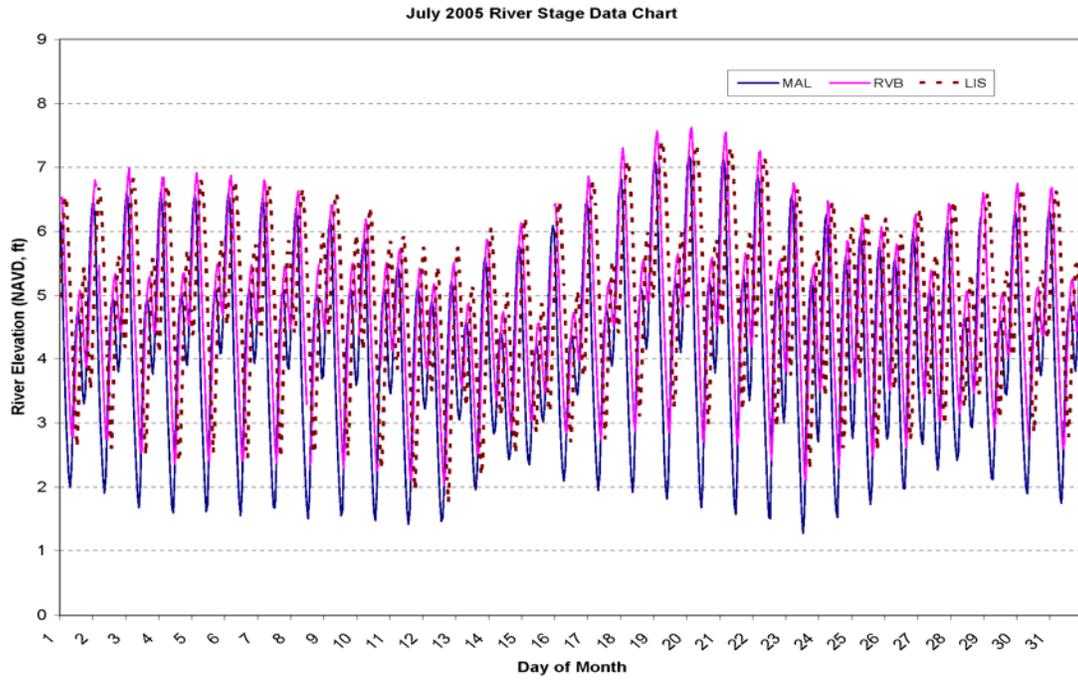


Figure 16. Measured River Stages in July 2005

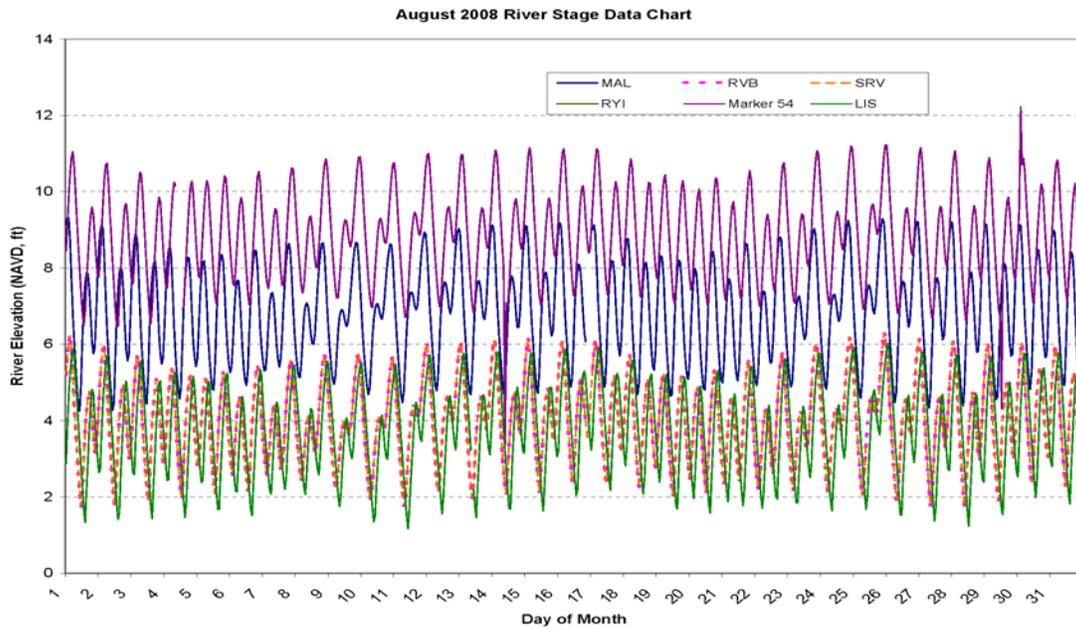


Figure 17. Measured River Stages in August 2008

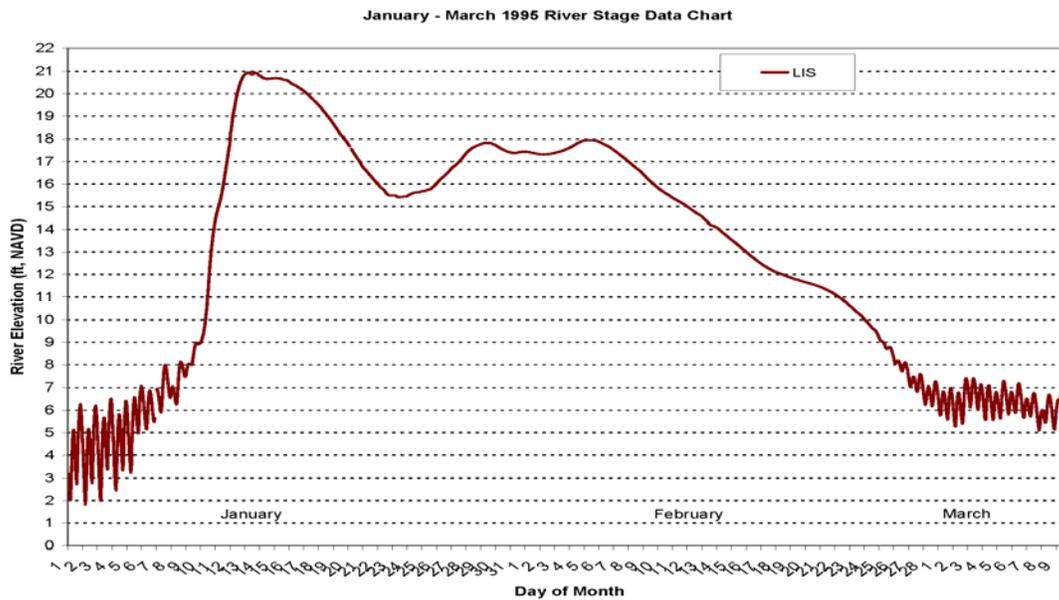


Figure 18. Measured River Stages from January 1 to March 9, 1995 at Gage LIS

#### 4.2 Flow Velocity

The excursion of water particles in the SRDWSC can be either toward upstream during flood tides or vice versa in the ebb-tide periods, particularly in the downstream regions. However, the flow pattern and velocity may be altered in the upstream regions as river inflows play a more significant role of defining the flow field in the ship channel. Flow velocities were measured at three available gage stations: one in the man-made channel (i.e., LIS) and two are in the downstream regions (SRV & RYI). **Figures 19** through **21** illustrate the measurements of wave velocity in three different winter months (December 2006, January 2008 & January 2009) at these three gage stations, while **Figures 22** to **24** show the velocity conditions for three separate summer months (June 2006, August 2007 & August 2008) at the same gage stations. A positive value indicates the downstream particle moving direction and vice versa for a negative value. The measured peak flow velocities in the downstream regions (i.e., Gages SRV & RYI) were approximately 2-3 feet per second with no distinguished seasonal variation in magnitude, while the peak velocities varied significantly in the man-made channel region (i.e., LIS) between the wet and dry seasons ranging from over 3 ft/sec during one of the rainfall periods to much slower than one foot per second in the summer months.

As river inflows increase during the winter raining months, flows in the upstream regions can become unidirectional (i.e., toward downstream), as seen in Figures 19 to 21. The tidal influence during these periods is overshadowed by the precipitation-induced river inflows. The alternation of the particle moving direction is no longer evident, even though the tide-related fluctuation of flow velocity is still visible. On the contrary, as river inflows diminish in the summer months, the flow pattern in the upstream regions

corresponds more or less to the flood/ebb tidal cycles in moving upstream during flood tides and downstream in ebbs, as illustrated in Figures 22 to 24. In addition, water particle velocities in the upstream regions appear to be substantial slower than that in the downstream regions during the summer months.

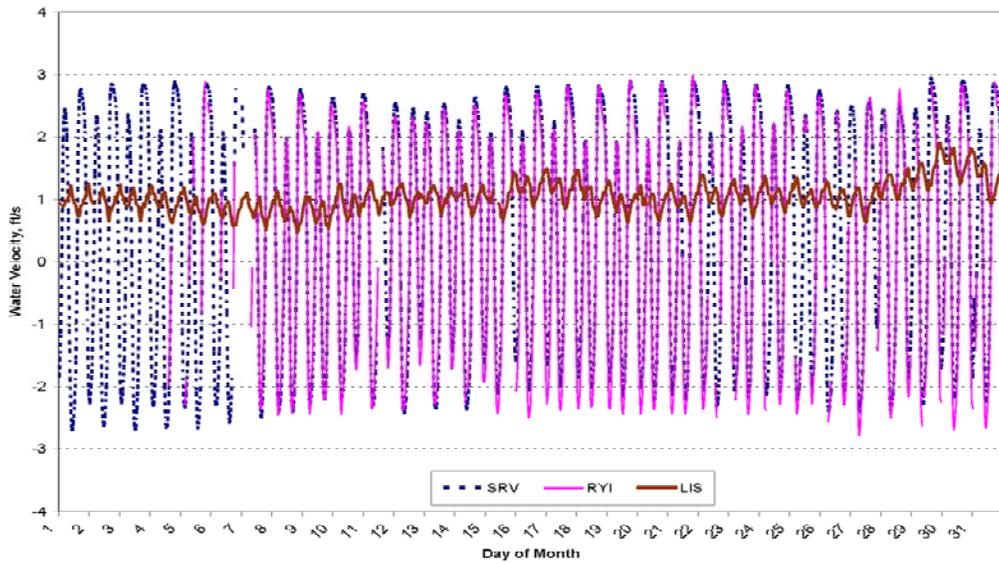


Figure 19. Measured Water Velocities in December 2006

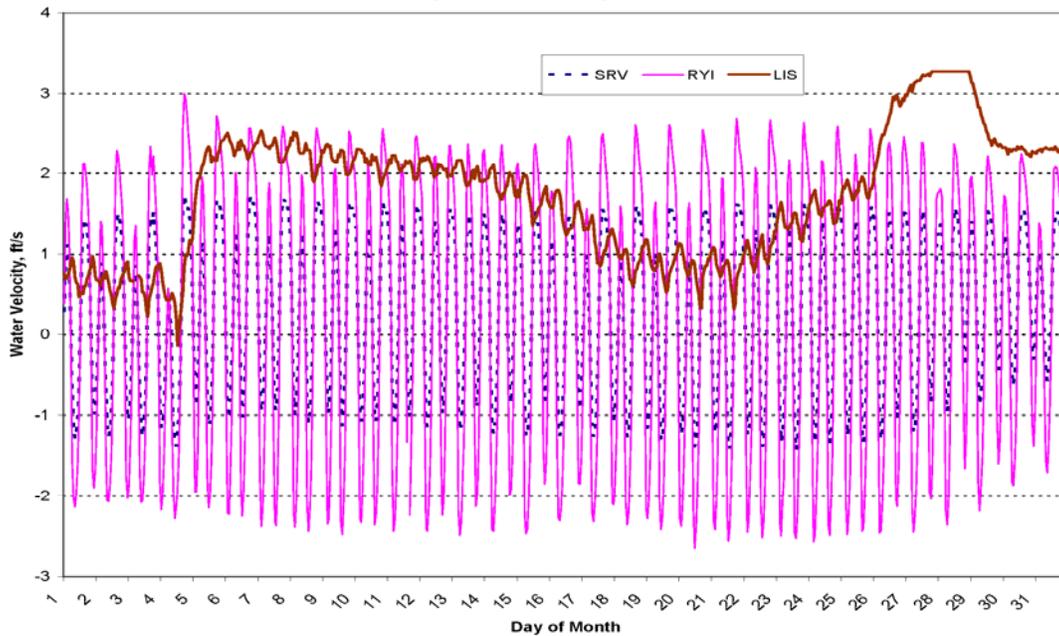


Figure 20. Measured Water Velocities in January 2008

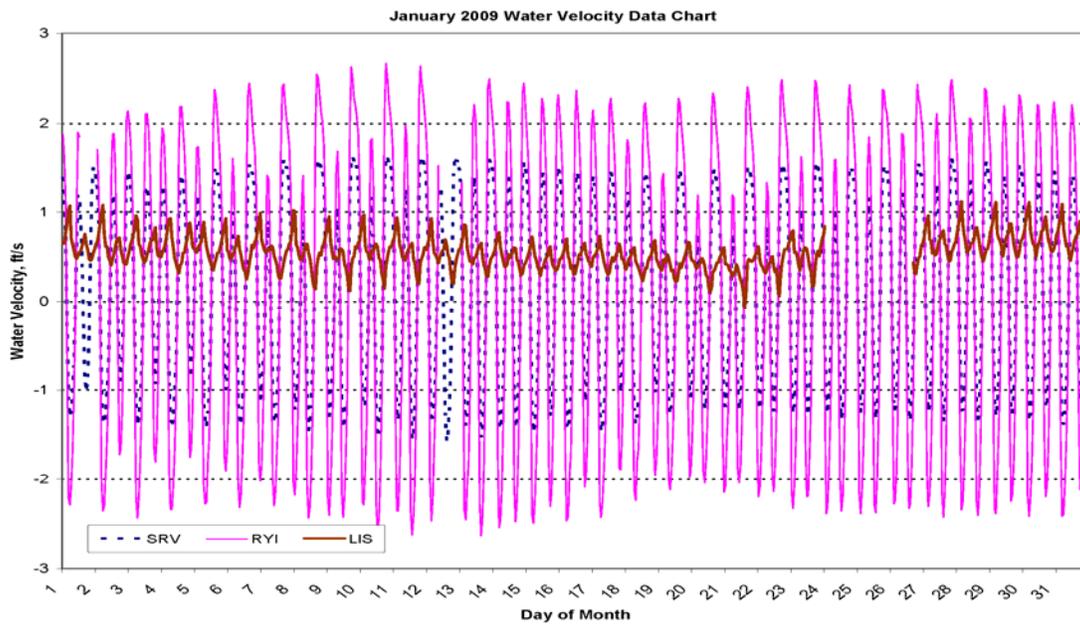


Figure 21. Measured Water Velocities in January 2009

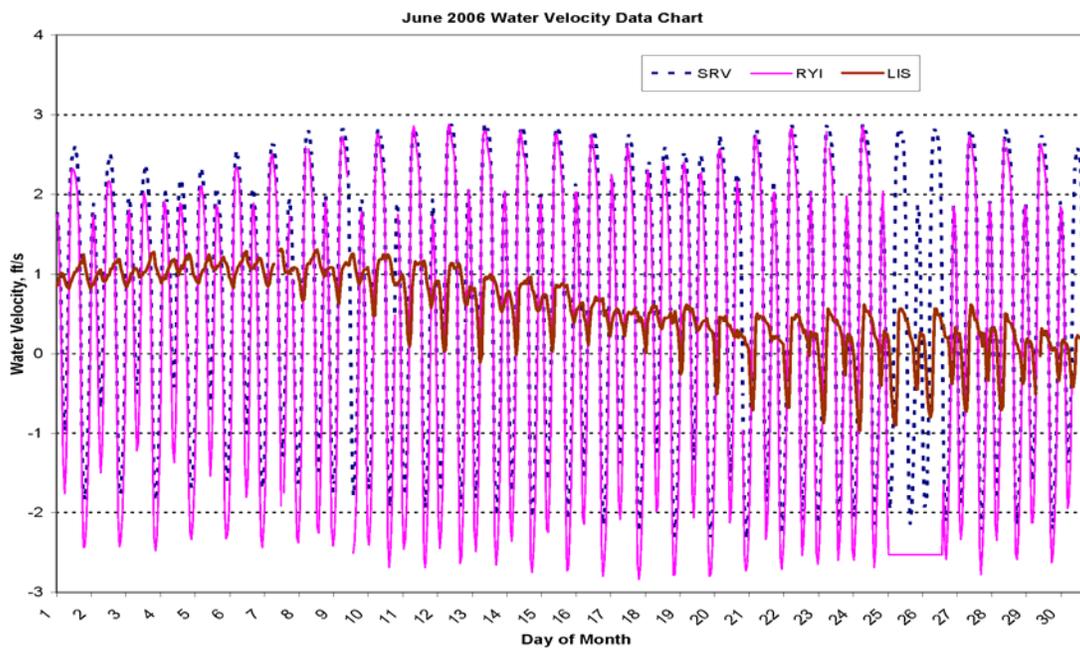


Figure 22. Measured Water Velocities in June 2006

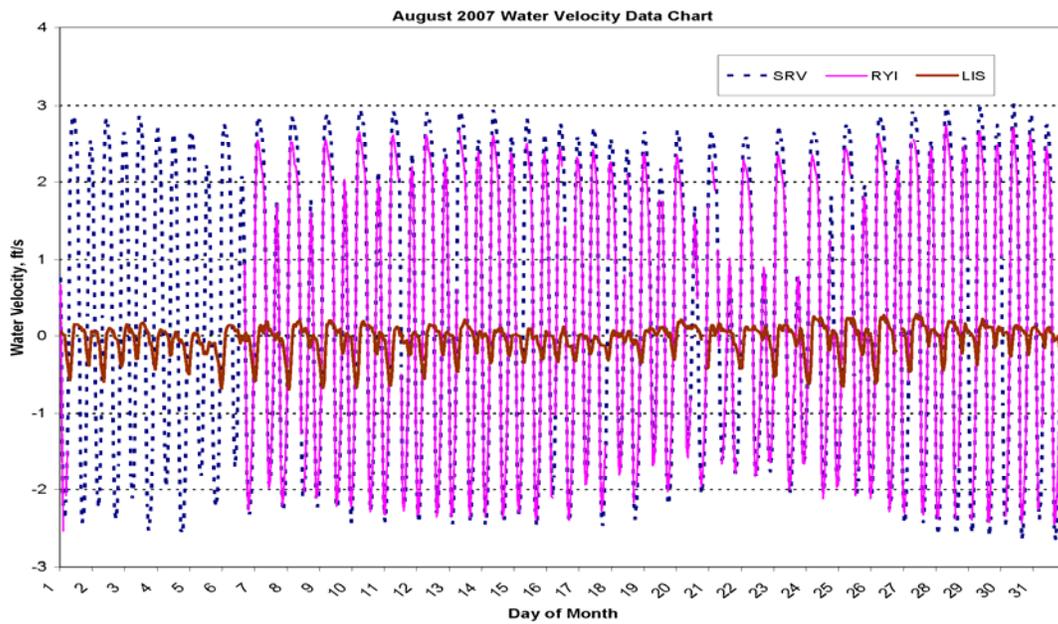


Figure 23. Measured Water Velocities in August 2007

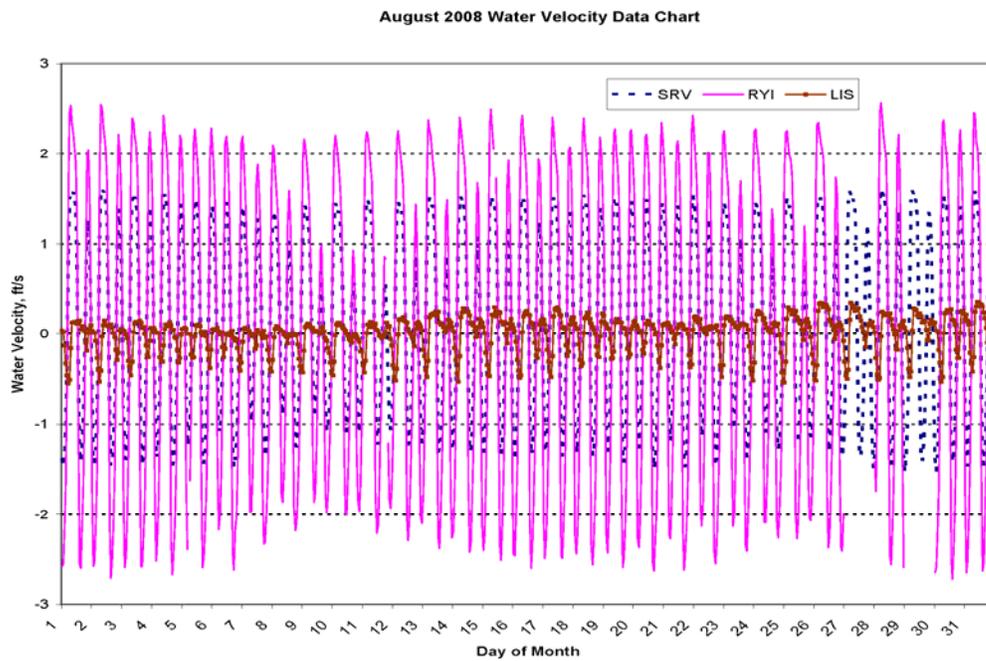


Figure 24. Measured Water Velocities in August 2008

### 4.3 Flow Discharge Rate

The flow discharge rate at a particular river location can be directly computed from the average flow velocity multiplied by the river cross-section area at the location. The CDEC also provides the flow discharge rates at the same three gage stations (i.e., SRV, RYI & LIS) where flow velocities were measured. **Figures 25** through **27** present the flow discharge rates in three different winter months (January 2007, January 2008 and January 2009), while **Figures 28** to **30** illustrate the discharge rates in three separate summer months (June 2006, August 2007 and August 2008). It can be seen in these figures that the discharge rates are significantly reduced from Gage SRV, which is located downstream of the confluence of the Sacramento River and its tributaries, to Gage LIS located near the upstream end of the man-made channel. It appears that no significant seasonal variation in discharge rate for the two downstream gages. At Gage LIS, the discharge rates can vary in response to the magnitude of rainfall-induced water inflows from the drainage basins, particularly in winter months.

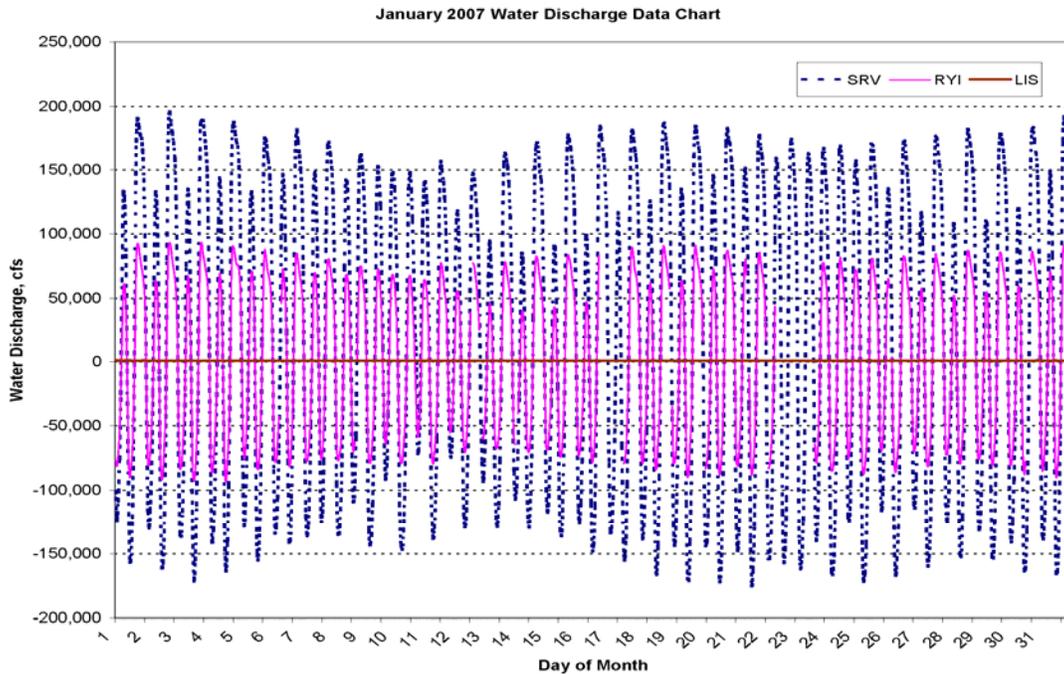


Figure 25. Estimated Flow Discharge Rates in January 2007

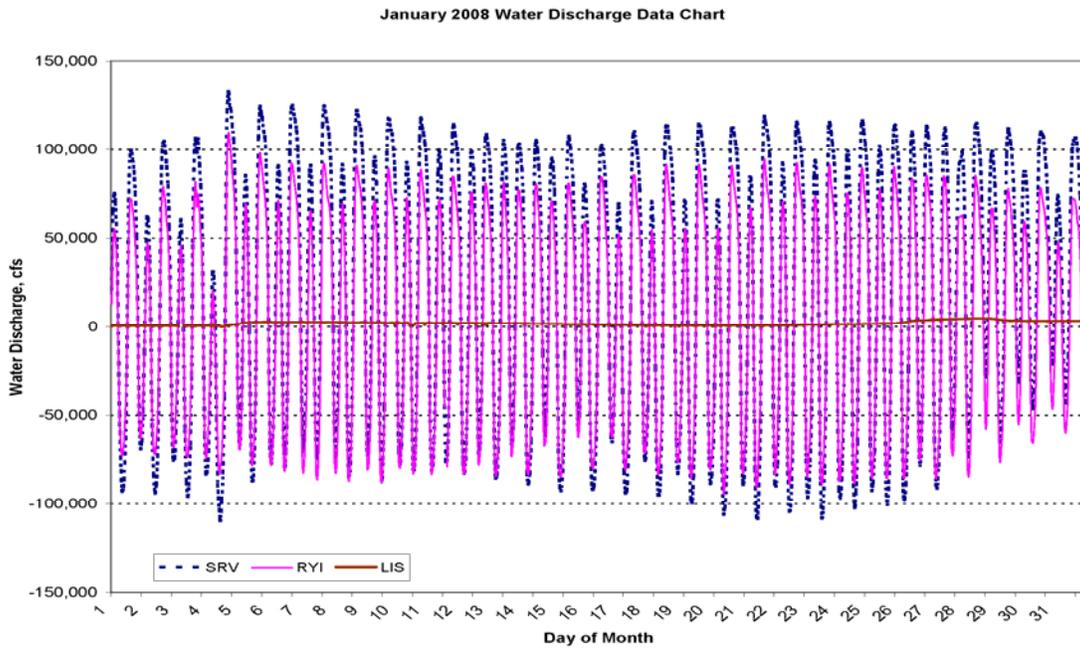


Figure 26. Estimated Flow Discharge Rates in January 2008

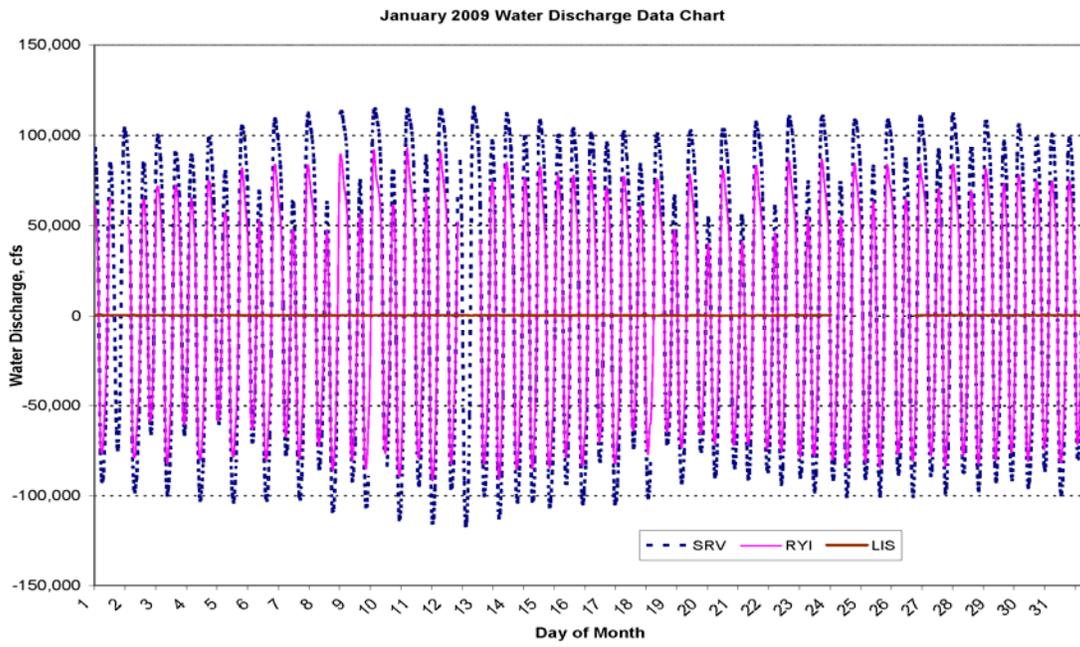


Figure 27. Estimated Flow Discharge Rates in January 2009

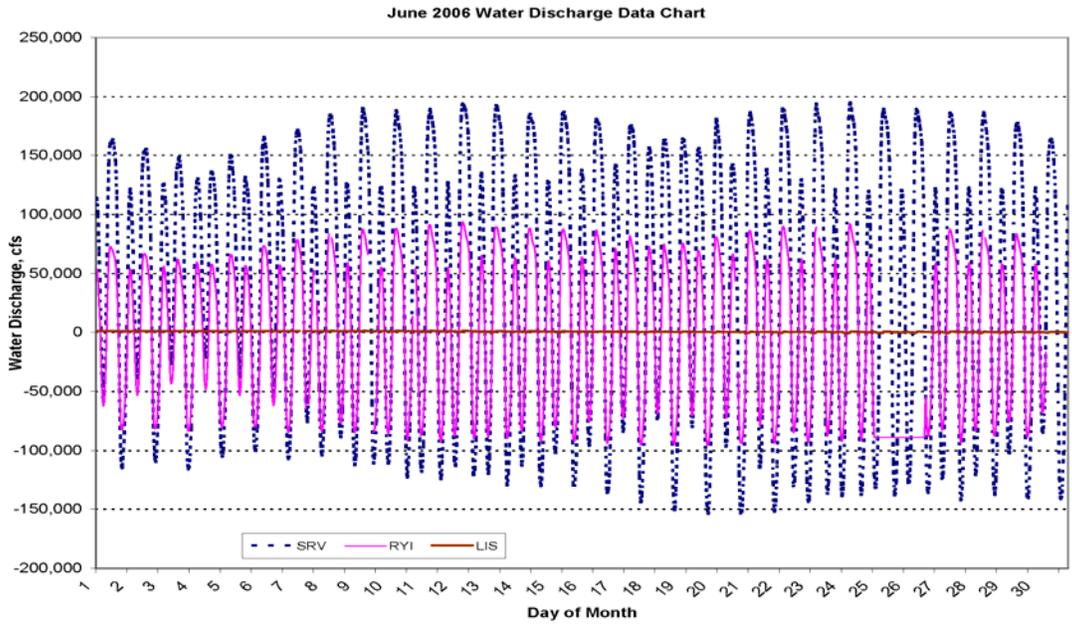


Figure 28. Estimated Flow Discharge Rates in June 2006

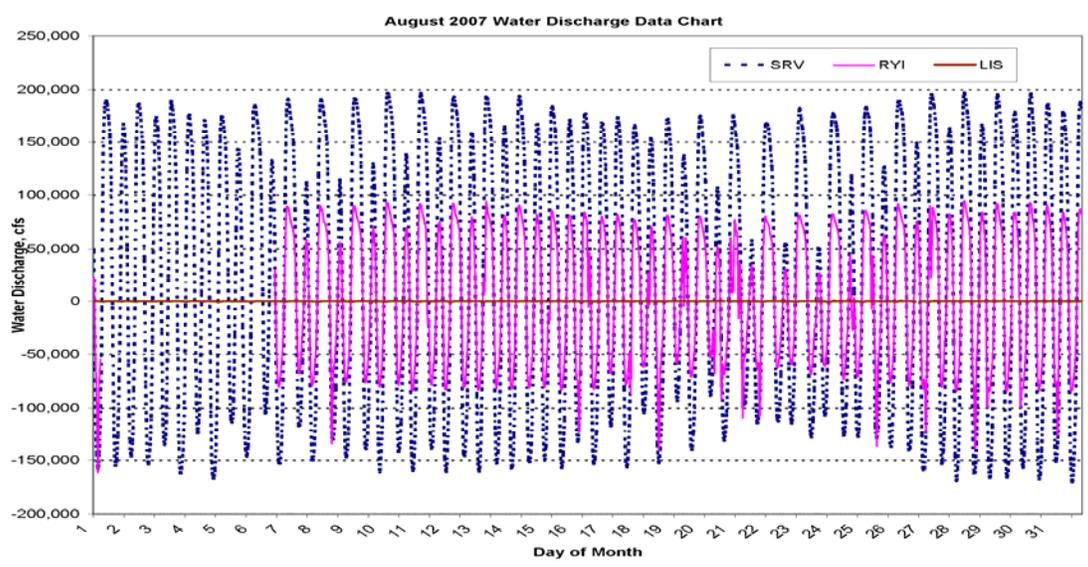


Figure 29. Estimated Flow Discharge Rates in August 2007

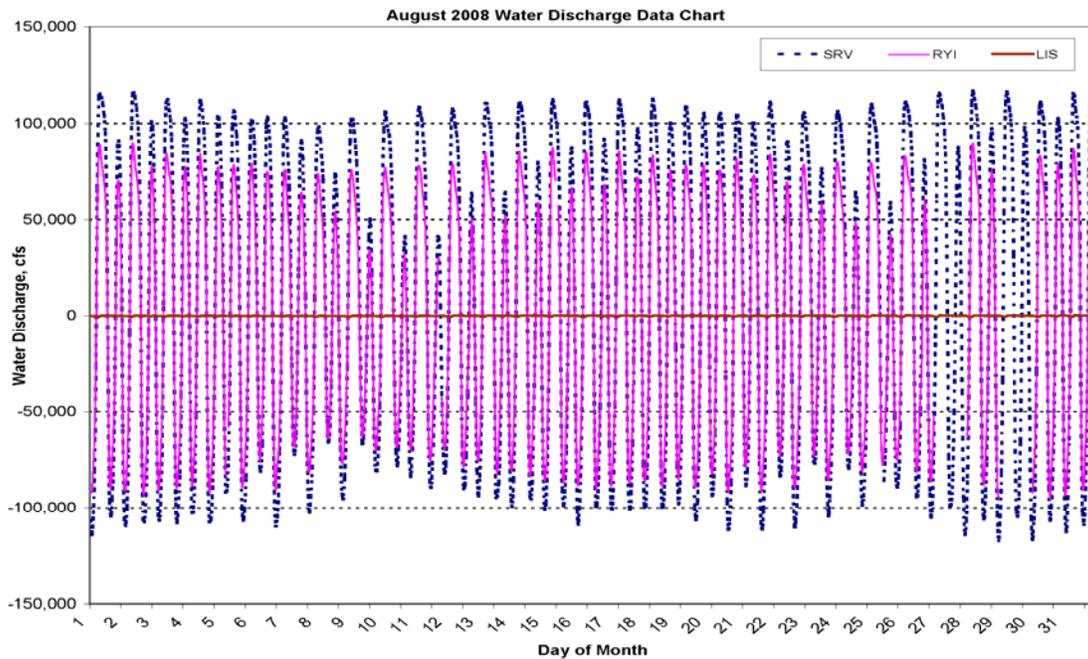


Figure 30. Estimated Flow Discharge Rates in August 2008

#### 4.4 Salinity

Salinity conditions are of important in the Delta for several reasons. Water agencies such as the Department of Water Resource (DWR) and the U. S. of Reclamation who supply water for municipal and agricultural uses are required to insure the exported water from the Delta being below a certain salinity condition as well as to satisfy the requirement based on the biological opinions respectively issued by the U.S. Fish and Wildlife Service and National Marine Fisheries Service. Typically, salinities in the river generally range from approximately 64 ppm (virtually in freshwater levels) to 704 ppm.

Salinity conditions vary temporally and spatially in correspondence with the flood and ebb tide cycles in the ship channel as ocean water passing through the Golden Gate entrance via the John F. Baldwin channel into the SRDWSC. As the relatively heavier salt water moves beneath the lighter fresh water discharged from the Sacramento River, the bottom residual salinity is always higher than the surface residual salinity. Salinity in the ship channel is also impacted by freshwater inflows from the Sacramento River. The salinity concentration in the ship channel tends to be lower in the winter months/wet periods as compared to the summer season/drought periods.

Electrical Conductivity (EC) representing as an indicator of salinity was periodically measured at two gages (MAL & RVB) along the ship channel. **Figures 31** and **33** respectively illustrate the converted salinities from the measured ECs at the two stations for three different months (January 2009, February 2008, and August 2008). The

three figures showing the spatial variation of salinity along the ship channel indicate the degree of saltwater intrusion along the ship channel. The readings at the downstream gage (MAL) are much higher than the SRV gage that is located at Rio Vista. A more detailed delineation of salinity within the SRDWSC is provided in the next section, based on the river hydrodynamic and salinity numerical simulations.

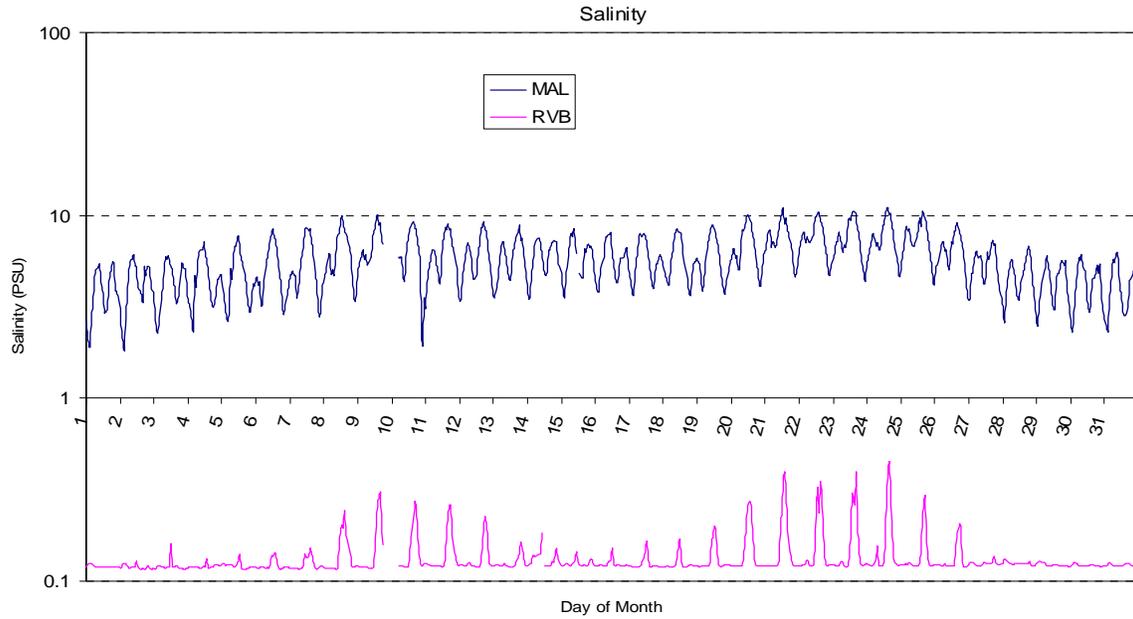


Figure 31. Converted Salinities from EC Measurements in January 2009

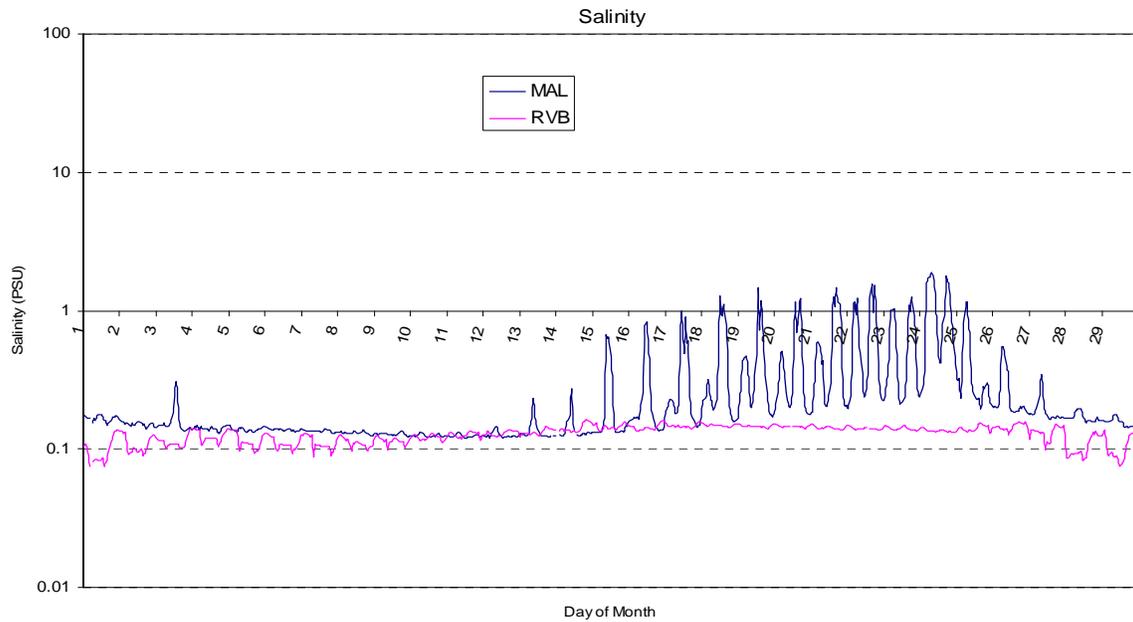


Figure 32. Converted Salinities from EC measurements in February 2008

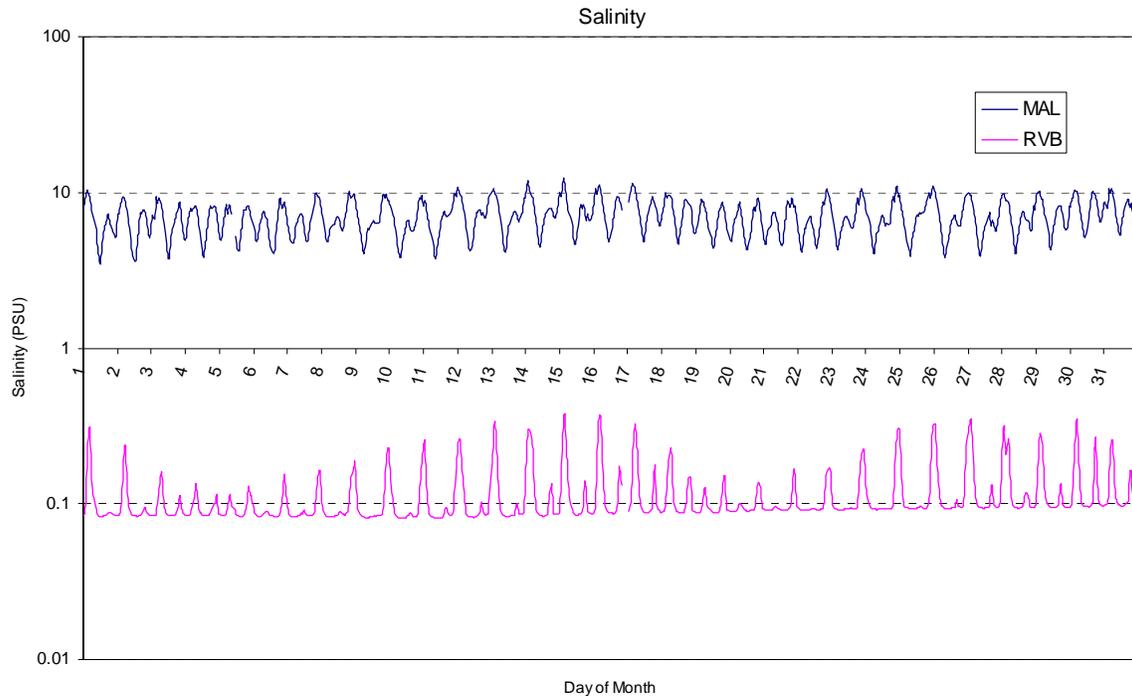


Figure 33. Converted Salinities from EC Measurements in August 2008

## 5.0 CURRENTLY MAINTAINED HYDRODYNAMIC CONDITIONS (YEAR 0)

An extensive 3-D modeling effort using the UnTRIM numerical model was performed to quantify the hydrodynamic conditions including river stage, flow field and salinity in the SRDWSC under the without-project base year (Year 0) conditions (MacWilliams et al., 2009 and MacWilliams & Gross, 2010). The base year (Year 0) without any proposed project implementation is designated as the year in Year 0 during which the currently maintained conditions, including channel bathymetry, regional hydrology and water inflow/export operations in the SRDWSC, are defined. The water inflow/export operations incorporate the biological opinions respectively issued by the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS).

The current base year conditions were developed from the CALSIM II simulations (DWR, 2009a) to provide the best currently-available representation of expected inflows to the Delta and exports from the Delta subject to the most recent operational representation of the current regulatory requirements for the base year (2011/2012) conditions. The output of the CALSIM simulations establishes the “Year 0” boundary conditions for the Sacramento-San Joaquin Delta. In the CALSIM II simulations, the hydrologic sequence of simulated years was based on historic precipitation and runoff patterns for water years 1922 through 2003 (i.e., 82 years) (DWR, 2009a), but with current delta operations, flow management requirements, and water quality standards.

For the base year (Year 0) conditions, a single year from April 1, 1994 through April 1, 1995 within the 82-year record was selected to define the delta inflow, export, and barrier operation conditions. The 1994-1995 simulation period spans across historical water years 1994 and 1995. Water year 1994 (from October 1, 1993 through September 30, 1994) was classified as a “critical” year with the low flows recorded in both the Sacramento and San Joaquin Rivers. Water Year 1995 (from October 1, 1994 through September 30, 1995) was classified as a “wet” year with the highest flow classification on both the Sacramento River and San Joaquin River (DWR, 2009b). Thus, the selection of the 1994-1995 period for the Year 0 conditions provides an opportunity to evaluate the impacts of the DWSC deepening scenarios under both extremely low flow and extremely high flow conditions.

In addition to the hydrologic and water operation conditions as described above, the bathymetric conditions within the SRDWSC follow the design depths with a 2-foot overdepth throughout all discretized reaches (see Tables 1 and 2) ranging from 32 feet in Reaches 1, 2, 3 and 4 to 37 feet in Reach 5 at the MLLW level. The Pacific Ocean water level was specified using observed 1994-1995 water levels at Fort Point without any inclusion of sea level rise. **Table 7** presents the physical, hydrologic, and water operation characteristics in the without-project base year for the SRDWSC. A detailed description of the Year 0 conditions was provided in the UnTRIM modeling report (MacWilliams et al., 2010).

Table 7. General Characteristics of Without-Project Base Year (Year 0)

<i>Baseline Year( Year 0) Conditions</i>	<i>Description</i>
Calendar base year (Year 0)	2011-2012
Hydrologic conditions	Historical precipitation & runoff patterns recorded from April 1, 1994 to April 1, 1995
Water inflows, exports and operations	Delta inflow, export and barrier operation conditions based on the application of CALSIM II model to develop the scenario for current conditions including biological opinions respectively issued by USFWS & NMFS
Deep water ship channel bathymetric conditions	Channel depth with a 2-foot overdepth allowable to the design depth (i.e., 32 feet for Reaches 1 to 4 and 37 feet for Reach 5)
Pacific Ocean Water Level	Observed 1994-1995 water levels at Fort Point, San Francisco Bay without sea level rise

River stages, flow rates and salinities at various locations along the SRDWSC are obtained from the UnTRIM numerical simulations to exhibit the spatial variation of these three hydrologic and water quality parameters. **Figure 34** shows the locations where the modeled results were extracted.

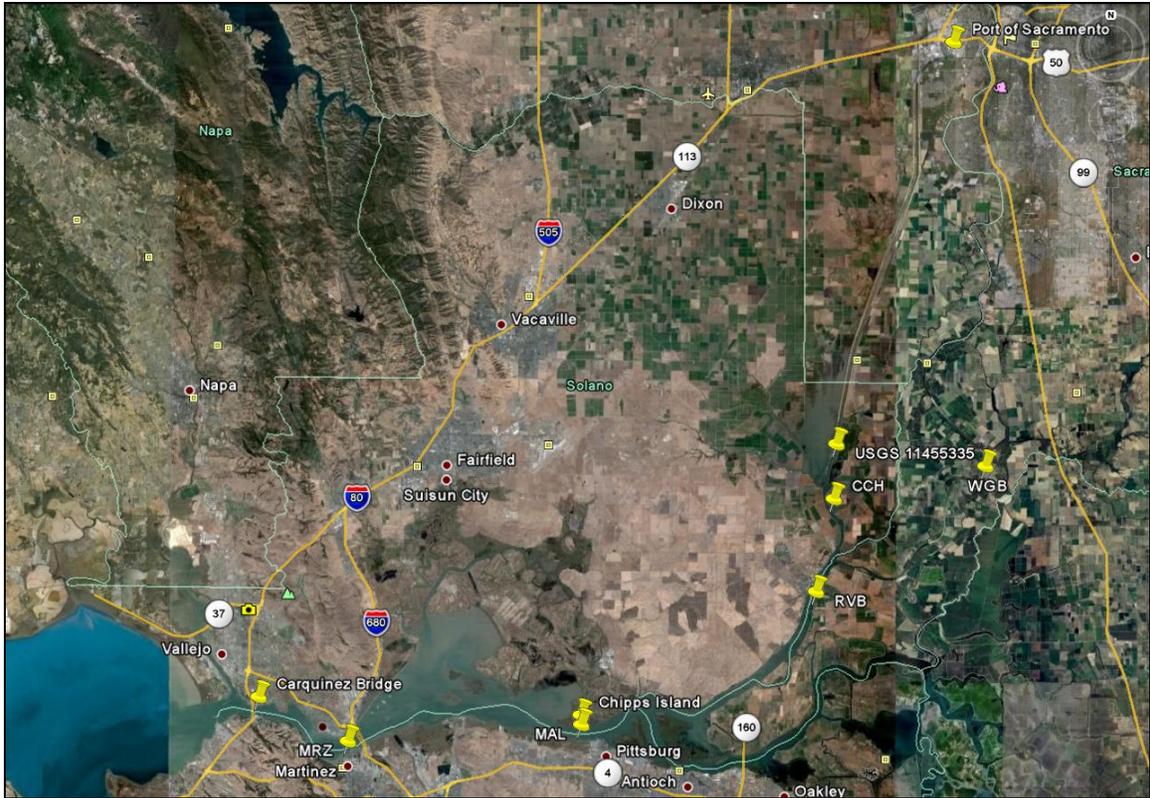


Figure 34. Hydrologic and Water Quality Channel Locations

### 5.1 Predicted River Stage

Seven selected locations from downstream to upstream along the John F. Baldwin Ship Channel (JFBSC) and SRDWSC to exhibit the predicted river stages are at Martinez (MRZ), Mallard Island (MAL), Rio Vista (RVB), Ryer Island (CCH), the USGS station in the man-made channel, and the Port of Sacramento. A river location at Georgiana Slough in the Sacramento River is also selected. It should be noted that the period represents a designated duration using the hydrologic conditions recorded in 1994-1995 and other parameters to establish the Year 0 conditions (i.e., 2011/2012). **Figures 35 to 41** present the temporal river stages for a two-week period from June 15 to June 30 in Year 0 at the seven selected locations. In general, the predicted river stages exhibit cyclic fluctuations in accordance with the flood/ebb tides. The fluctuating river stages synchronize spatially with a slight phase shift along the channel locations. Higher river stages were predicted at upstream locations (e.g., the Port of Sacramento), while a slight attenuation of tidal range due to the muting effect was modeled at Georgiana Slough in the Sacramento River. The daily-averaged stages are also presented in each figure for the entire simulation year. As expected, high daily-averaged river stages occur during the wet months between December and March.

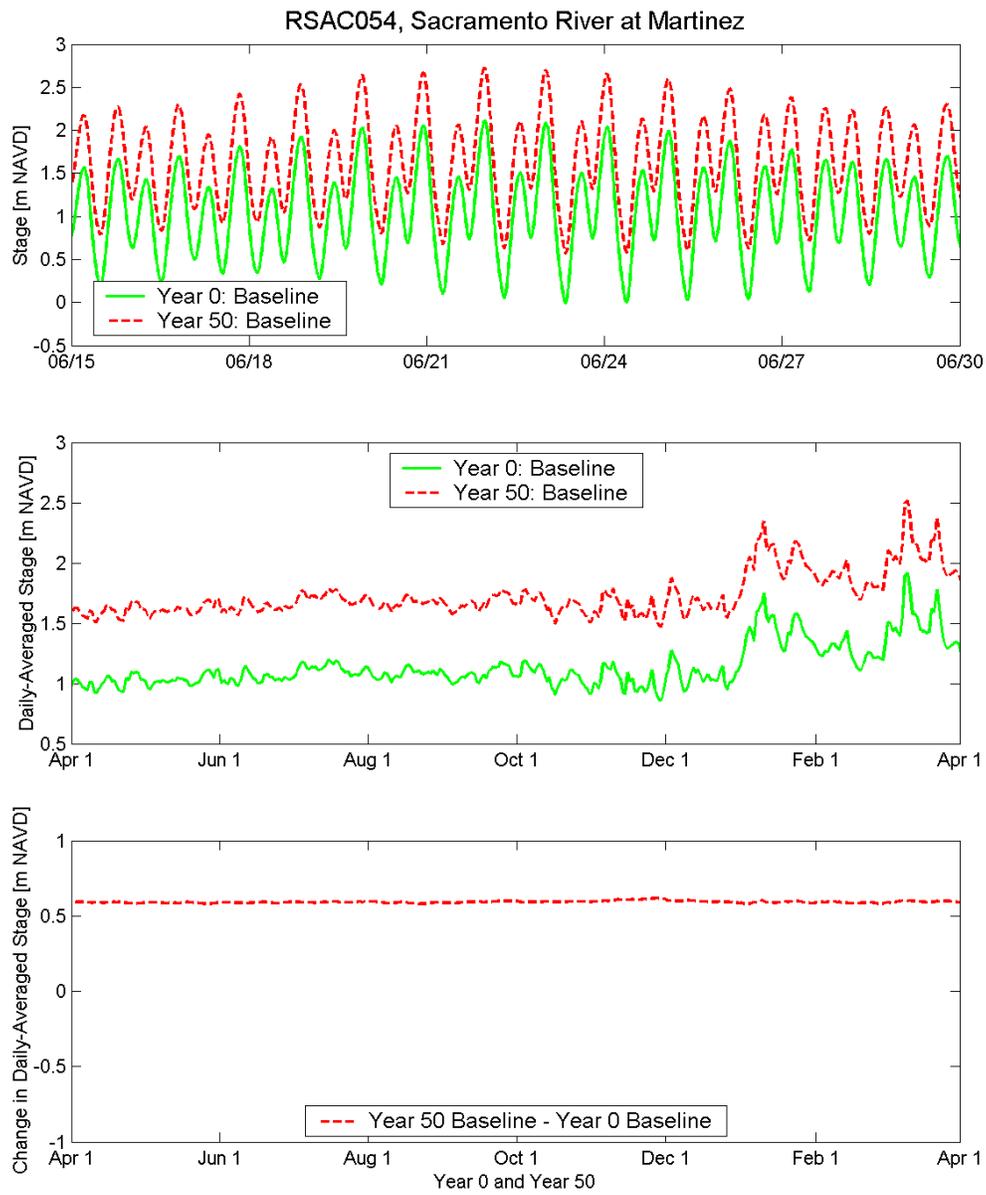


Figure 35. Predicted River Stages at Martinez in JFBSC

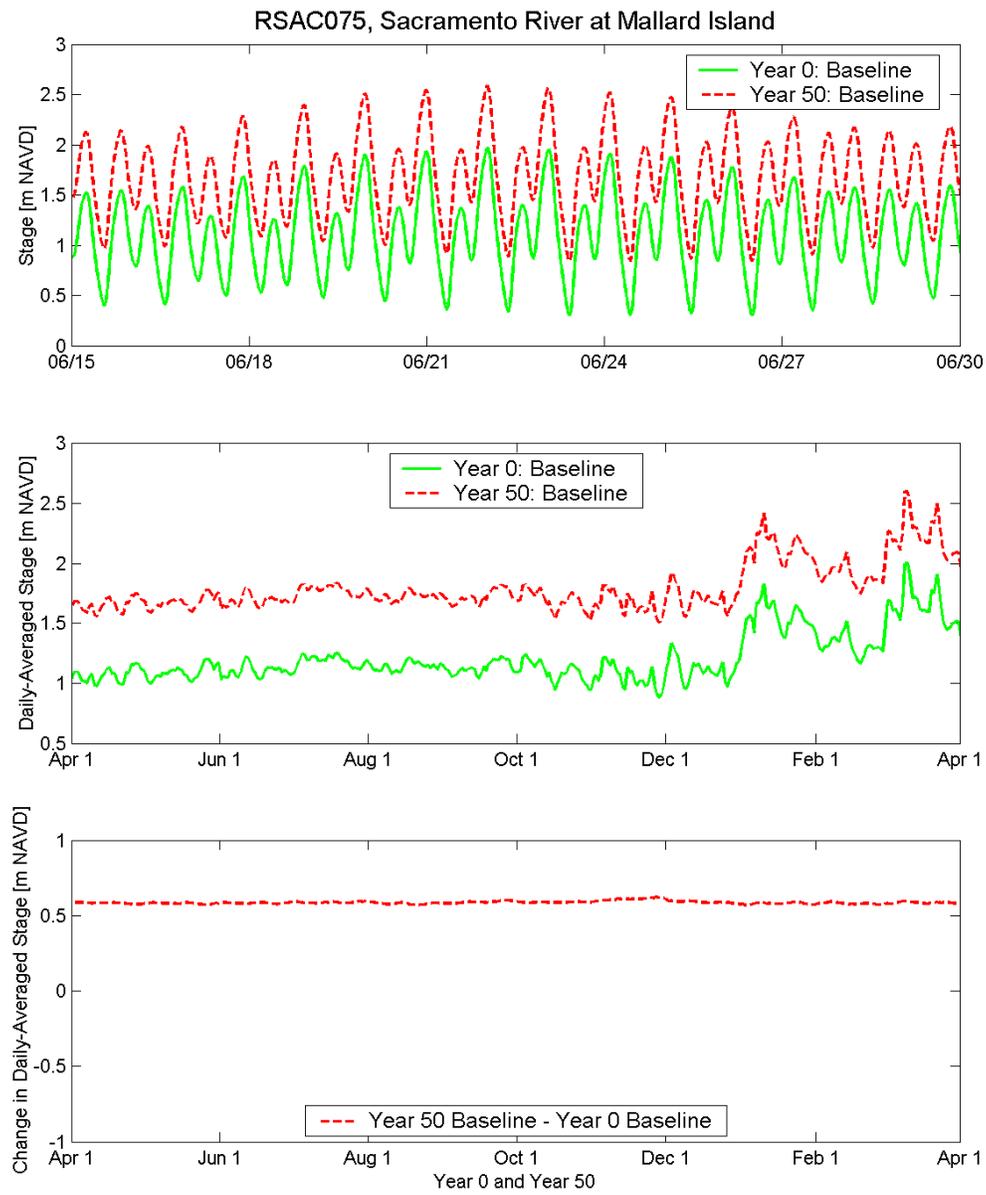


Figure 36. Predicted River Stages at Mallard Island in JFBS

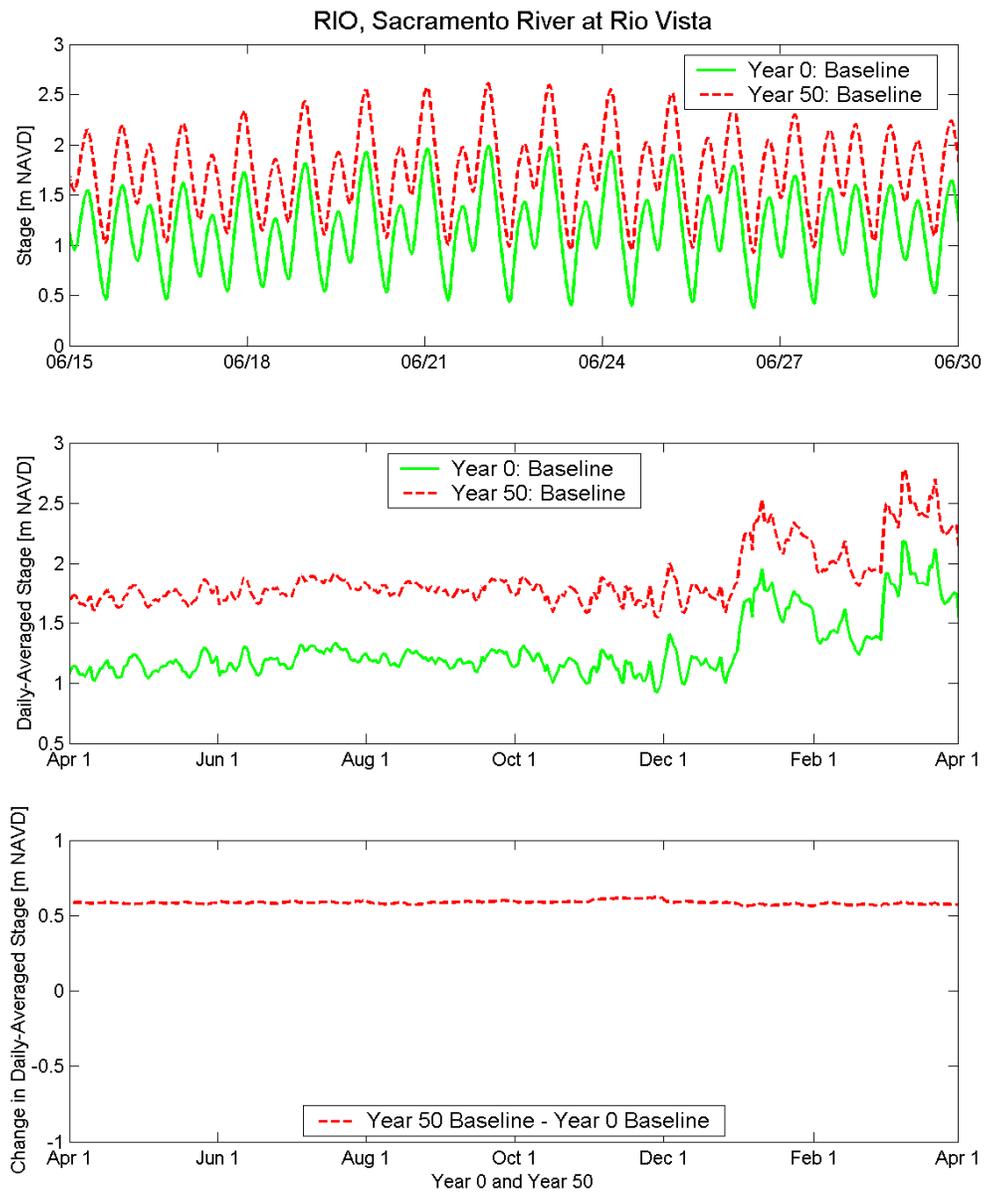


Figure 37. Predicted River Stages at Rio Vista in SRDWSC

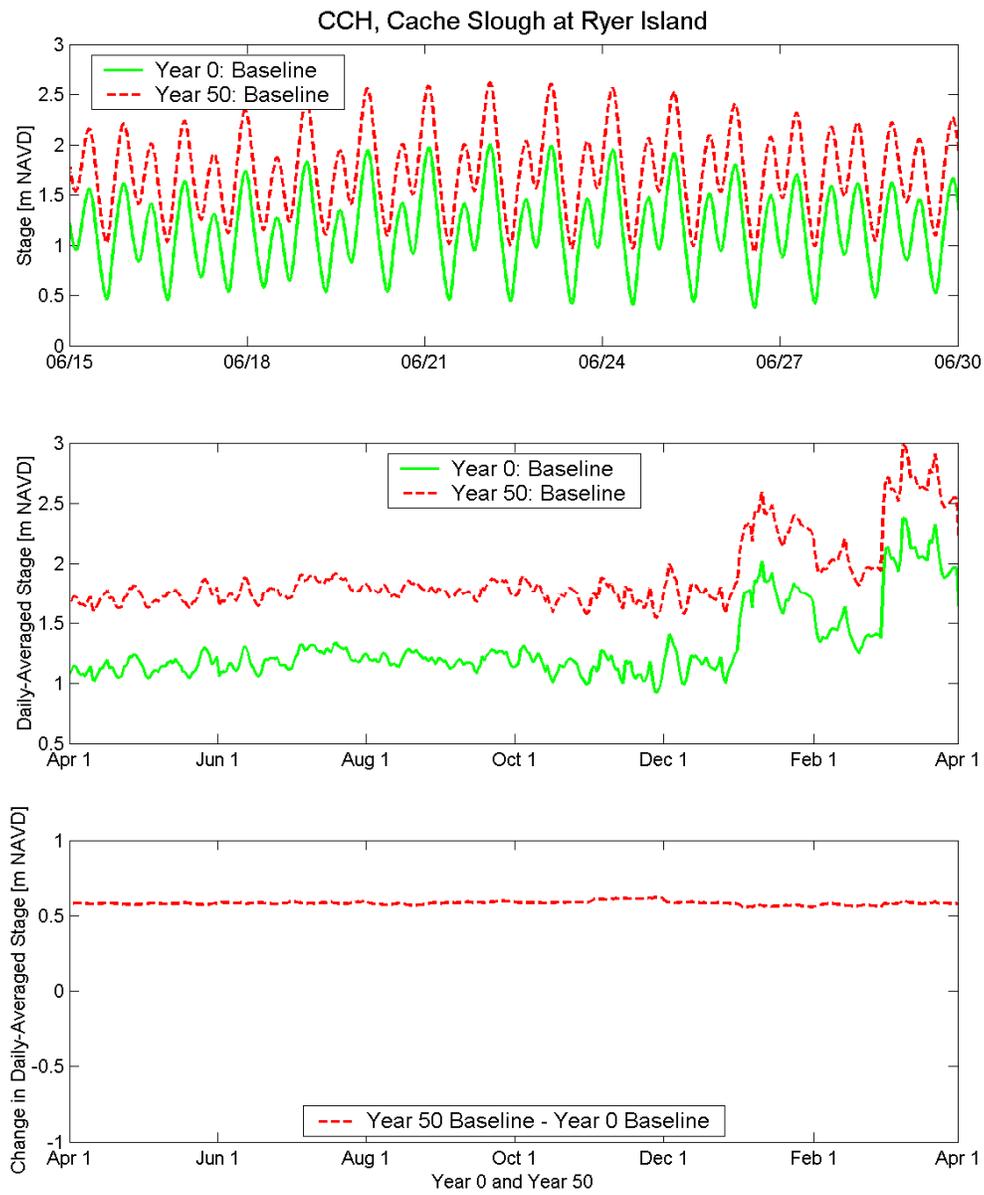


Figure 38. Predicted River Stages at Ryer Island in SRDWSC

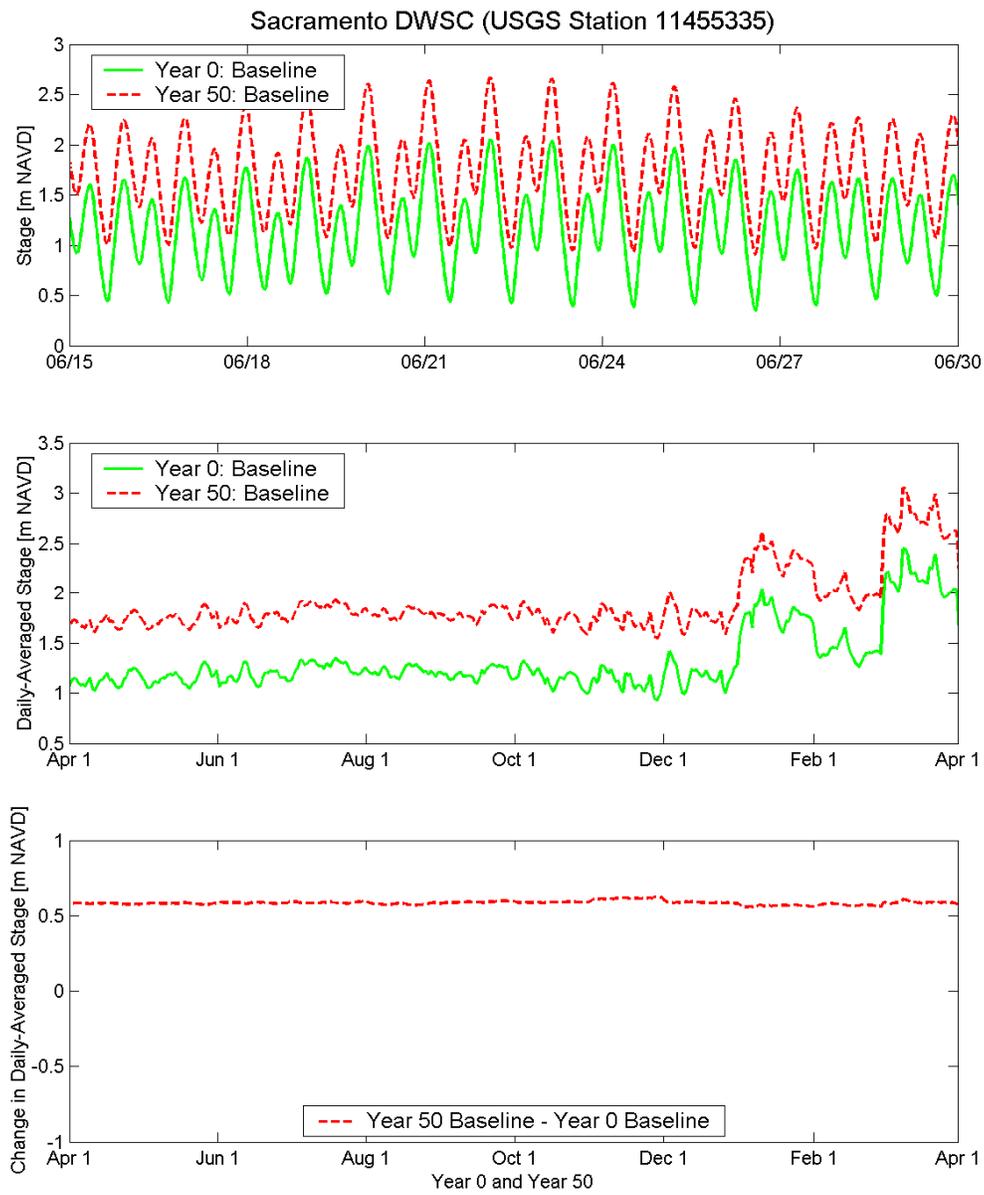


Figure 39. Predicted River Stages at USGS Station 11455335 in SRDWSC

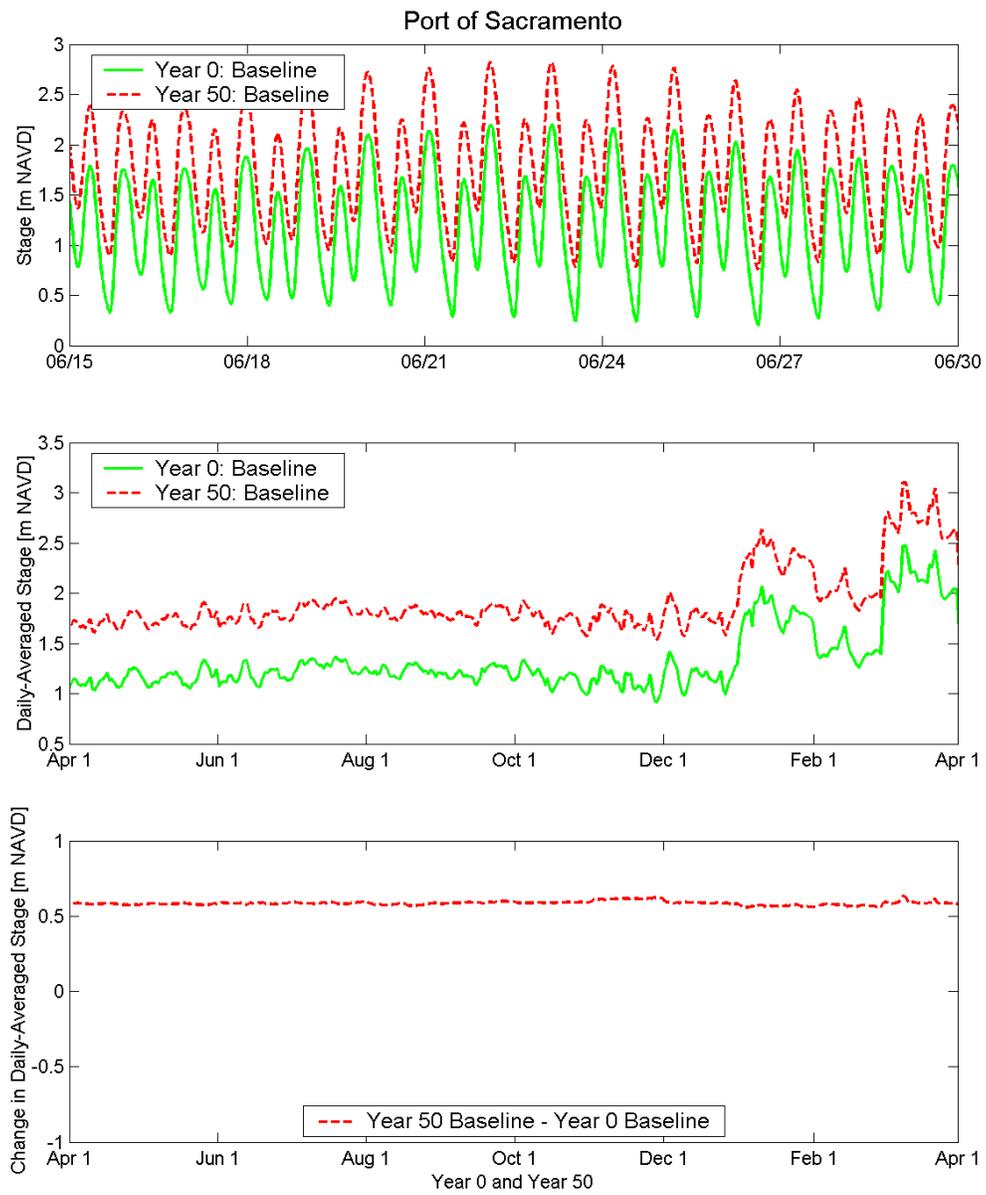


Figure 40. Predicted River Stages at the Port of Sacramento

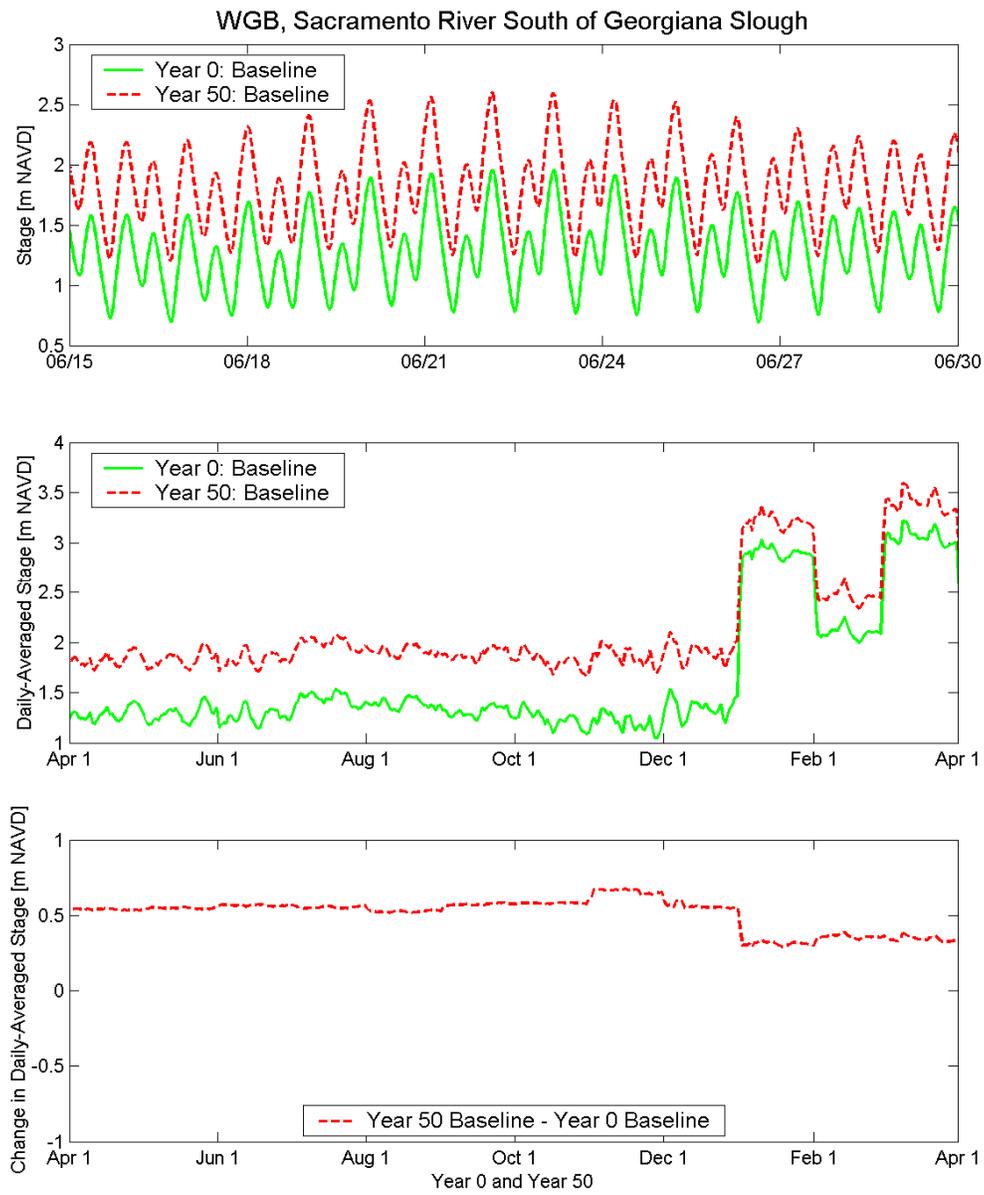


Figure 41. Predicted River Stages at Georgiana Slough in Sacramento River

## 5.2 Predicted Flow Rate

Six selected locations from downstream to upstream along the JFBSC and SRDWSC to exhibit the predicted flow rates are at Carquinez Bridge, Chipps Island, Rio Vista (RVB), Ryer Island (CCH), the USGS station in the man-made channel, and a river location at Georgiana Slough in the Sacramento River. **Figures 42 to 47** show the predicted temporal flow rates at these six locations for the same two-week period as for the river stage. The positive values indicate a downstream flow direction and vice versa for the negative values. These figures also illustrate the daily-averaged flow rates for the entire simulated period under the currently managed water operations.

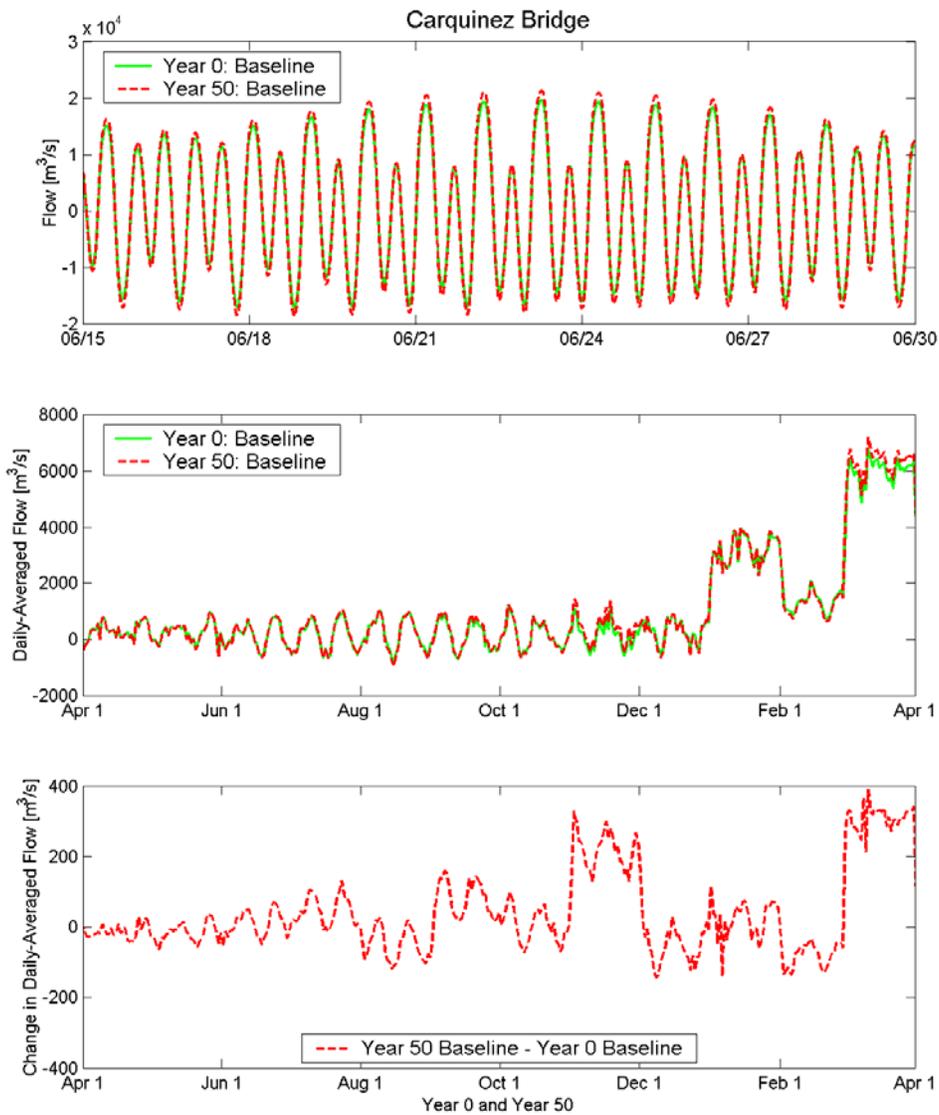


Figure 42. Predicted Flow Rates at Carquinez Bridge in JFBSC

The simulated flow rates exhibit more frequent net downstream flow conditions (see the mid graph of each figure) as a result of continuous water inflows into the entire Delta. At Georgiana Slough in the Sacramento River, the net daily-averaged flows (see Figure 47) are always toward downstream, an indication of significant influence from the water inflows at this location. The daily-averaged stage plots show that high daily-averaged flow rates occur during the wet months between December and March.

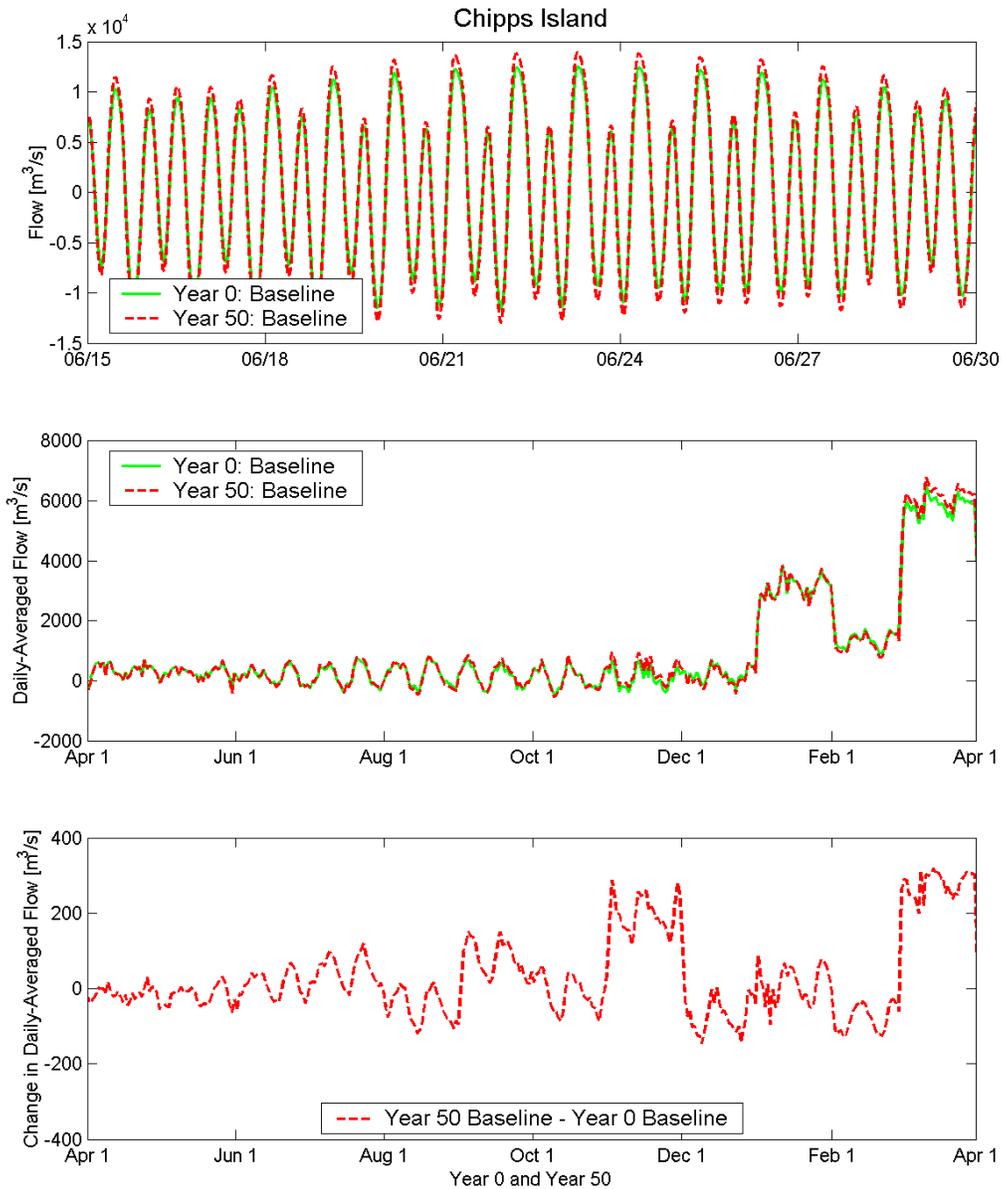


Figure 43. Predicted Flow Rates at Chipps Island in JBFSC

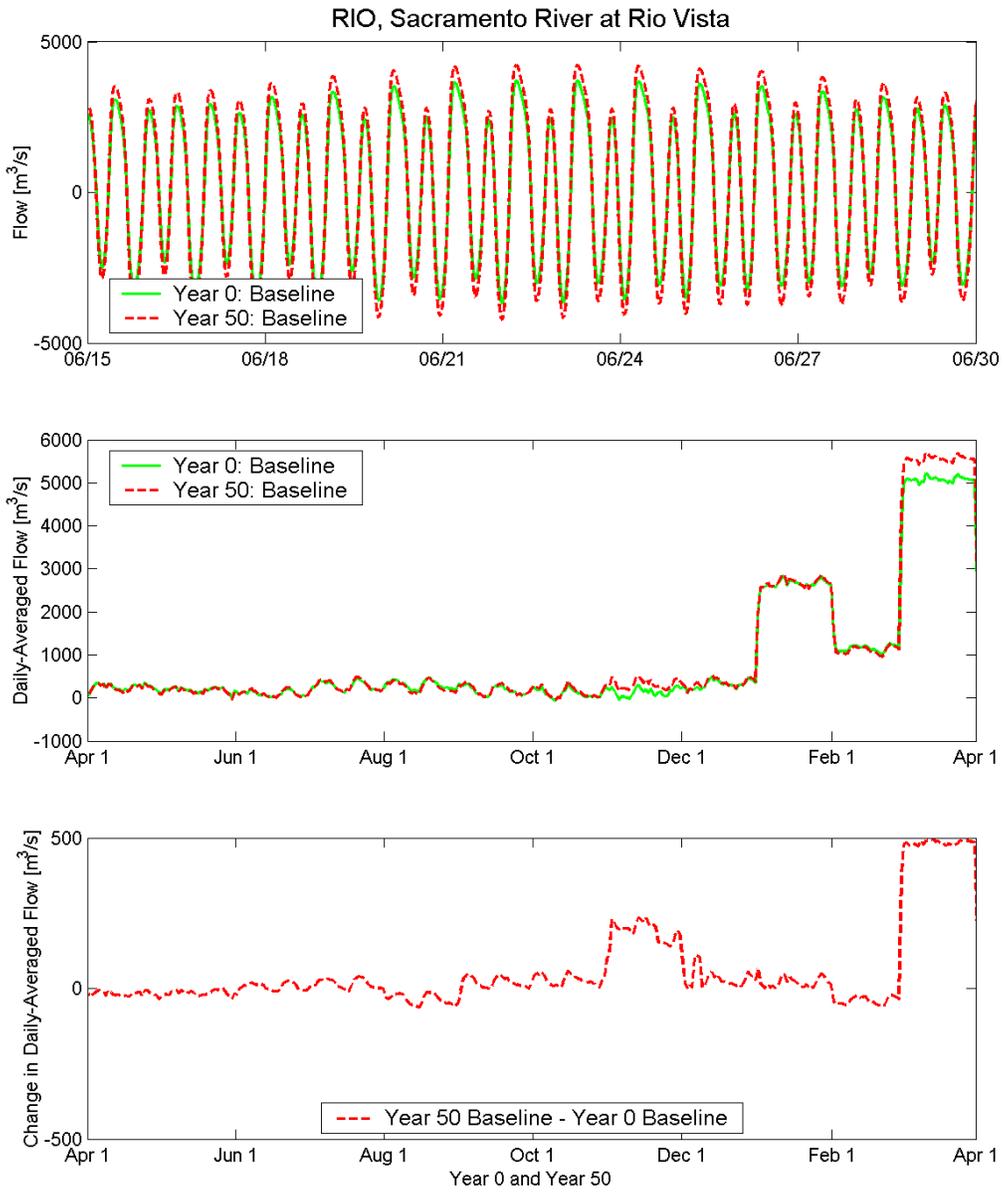


Figure 44. Predicted Flow Rates at Rio Vista in SRDWSC

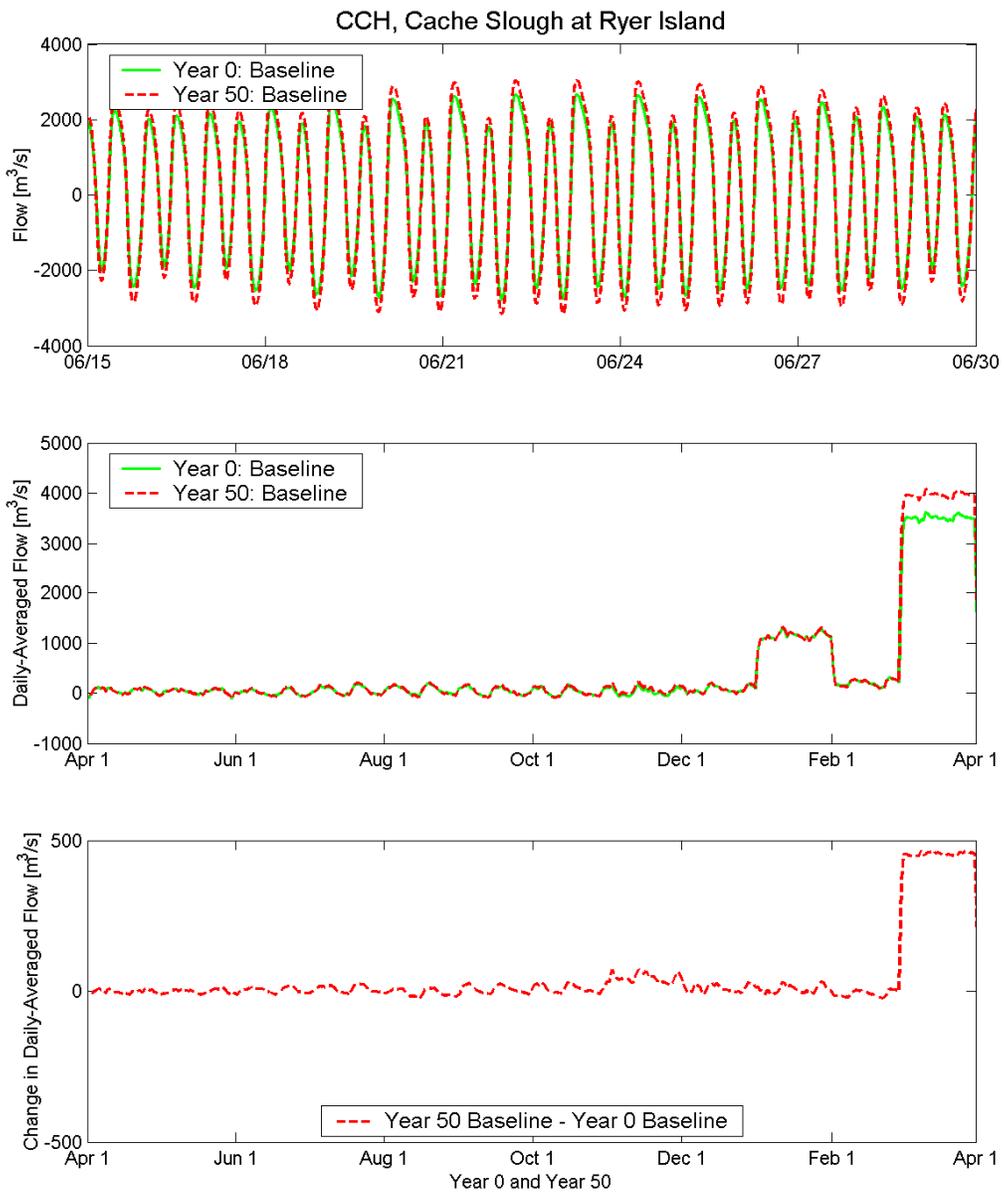


Figure 45. Predicted Flow Rates at Ryer Island in SRDWSC

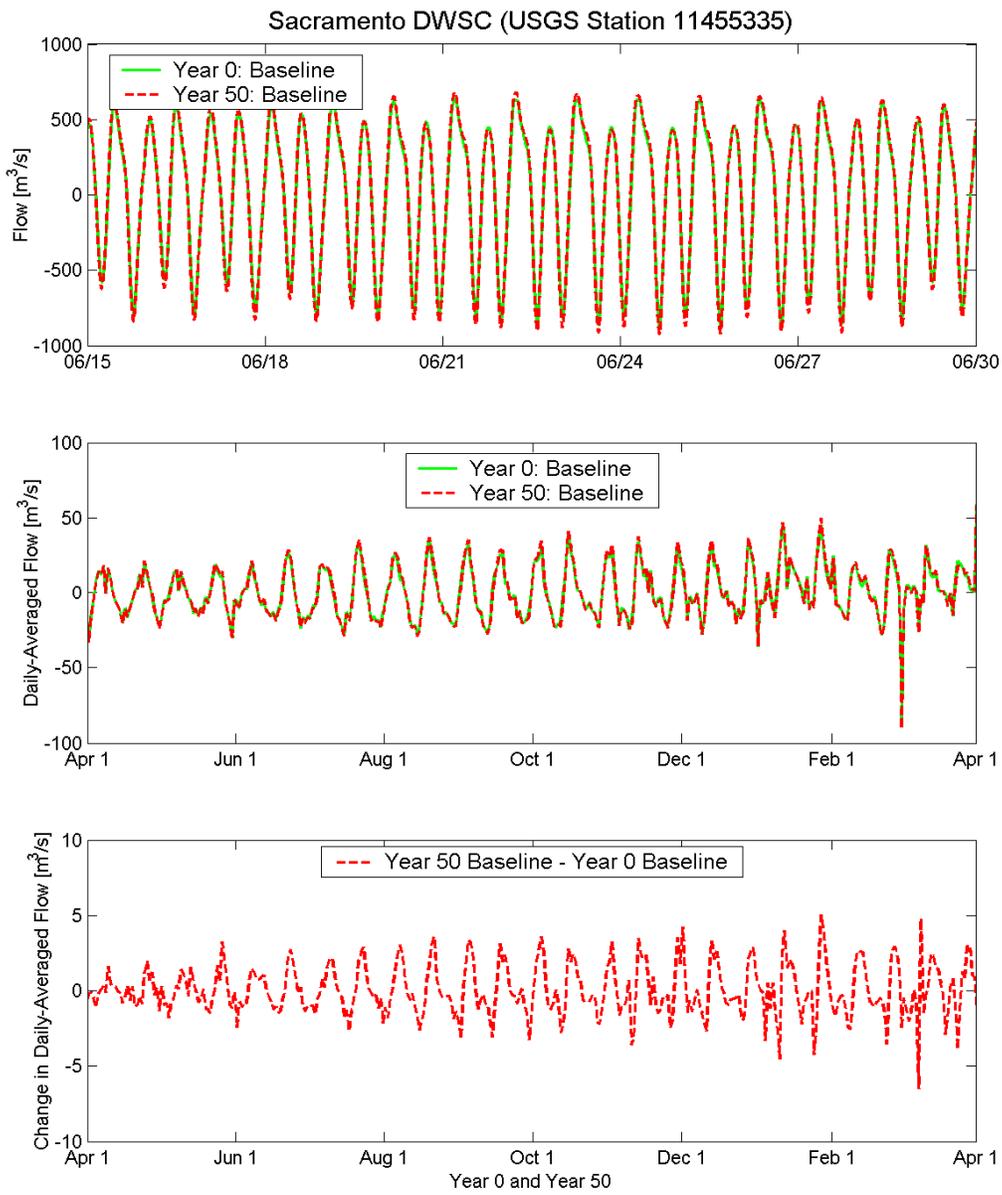


Figure 46. Predicted Flow Rates at USGS Station 11455335 in SRDWS

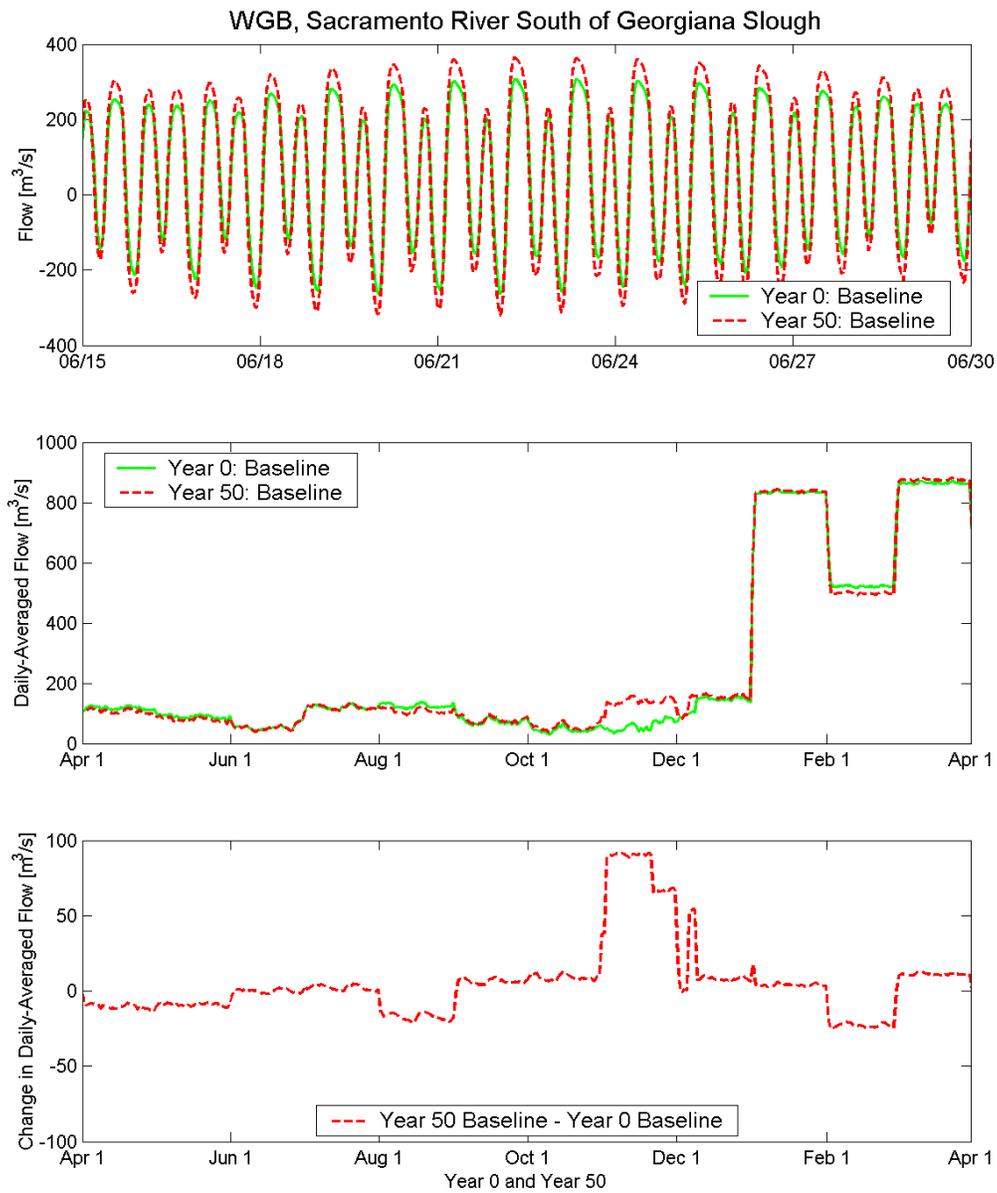


Figure 47. Predicted Flow Rates at Georgiana Slough in Sacramento River

### 5.3 Predicted Salinity

Four selected locations from downstream to upstream along the JFBSC and SRDWSC to exhibit the predicted salinities are at Martinez Bridge, Mallard, Rio Vista (RVB), and the Port of Sacramento. **Figures 48 to 51** show the predicted temporal salinities at these four locations for the same two-week period as for the river stages. The figures also illustrate the daily-averaged salinities for the entire simulated period under the currently managed water operations. The spatial variation of salinity ranging

10-15 psu at Martinez (downstream) to 0.15 psu at the Port of Sacramento (upstream) indicates that the reduction of salinity toward upstream locations occurs as more freshwater injected into the river and ship channel.

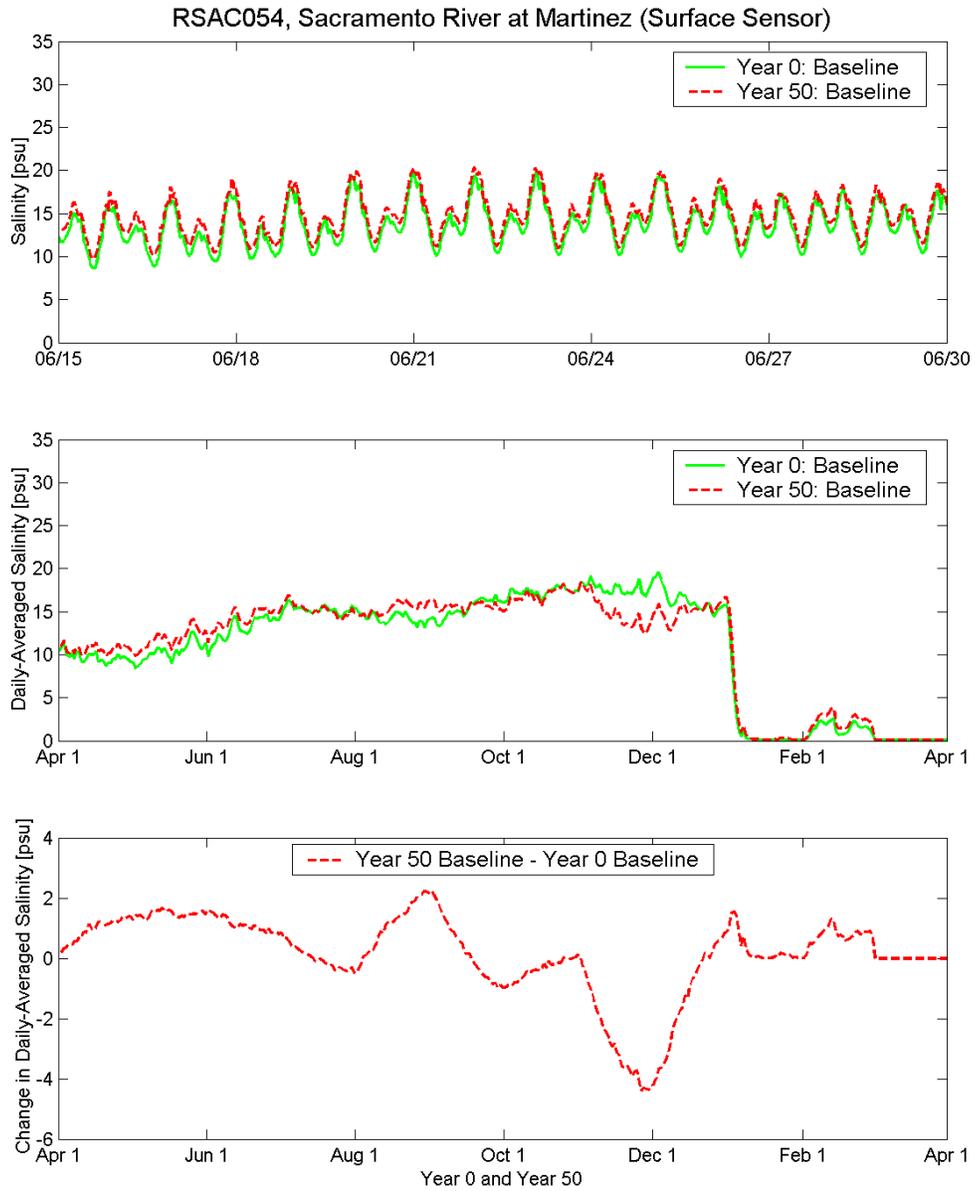


Figure 48. Predicted Salinity at Martinez in JDBSC

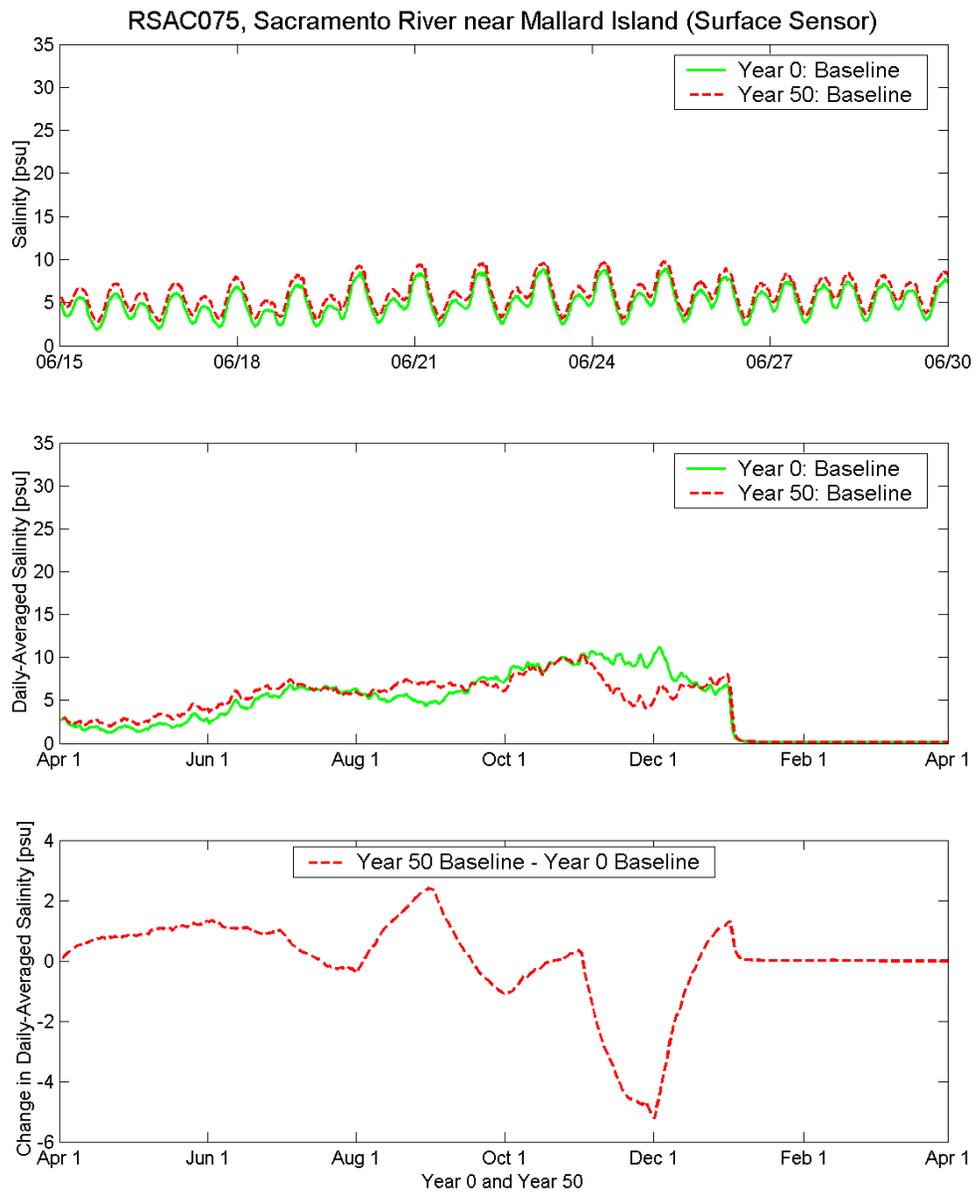


Figure 49. Predicted Salinity at Mallard Island in JFBS

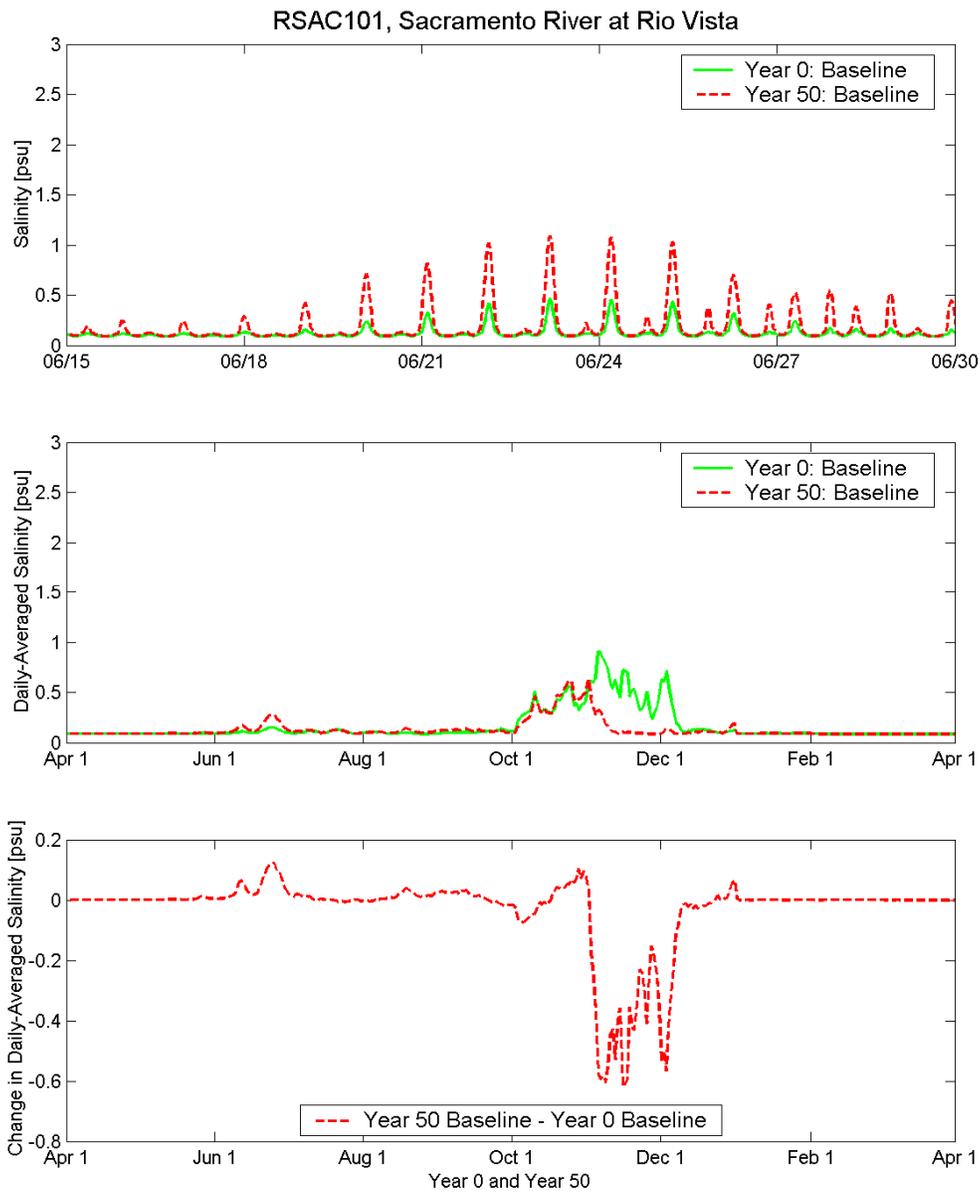


Figure 50. Predicted Salinity at Rio Vista in SRDWSC

By definition, X2 is the distance from the Golden Gate to the tidally-averaged near-bed 2-psu isohaline. It was established to determine the degree to which salinity is allowed to penetrate up-estuary so as to be controlled via Delta outflows (IEP, 2009). **Figures 52 to 55** present the predicted daily-averaged salinity profile along the JFBSC and SRDWSC on four separate dates (April 1, July 1, October 1 & January 1) to represent conditions in four different seasons. **Figure 56** illustrates the X2 location along the designated channel alignment in the SRDWSC. The X2 location gradually migrates

upstream from the spring season (e.g., April) to the dry summer months (e.g., October), as the freshwater inflows reduce. A reverse trend begins in December as a result of winter rainy season arrives.

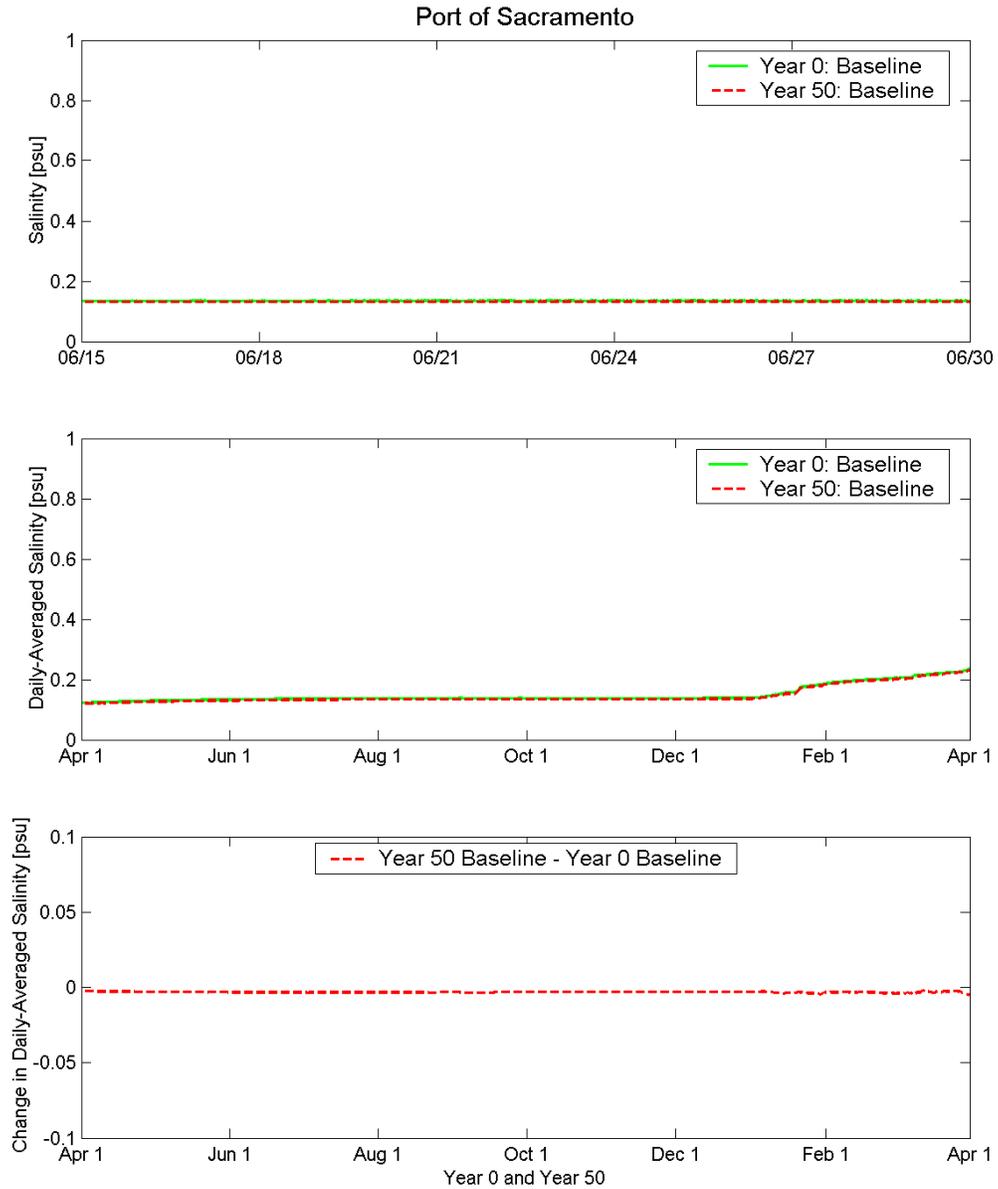


Figure 51. Predicted Salinity at Port of Sacramento

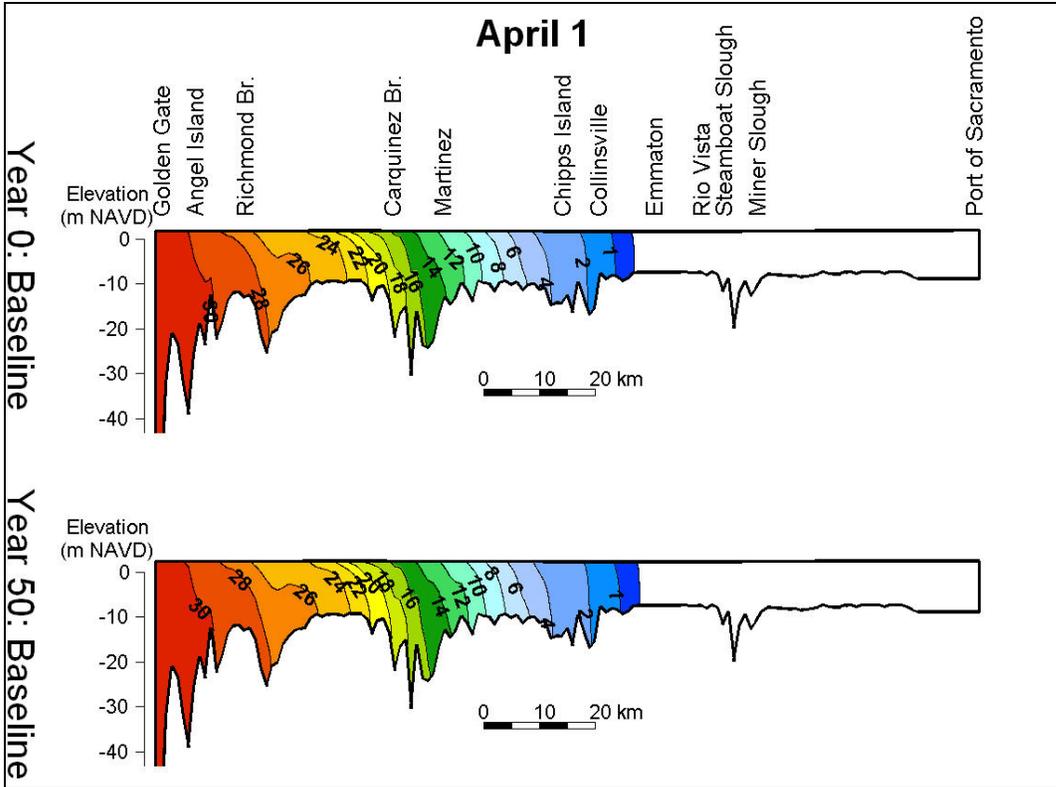


Figure 52. Predicted Daily-Averaged Salinity Profile on April 1

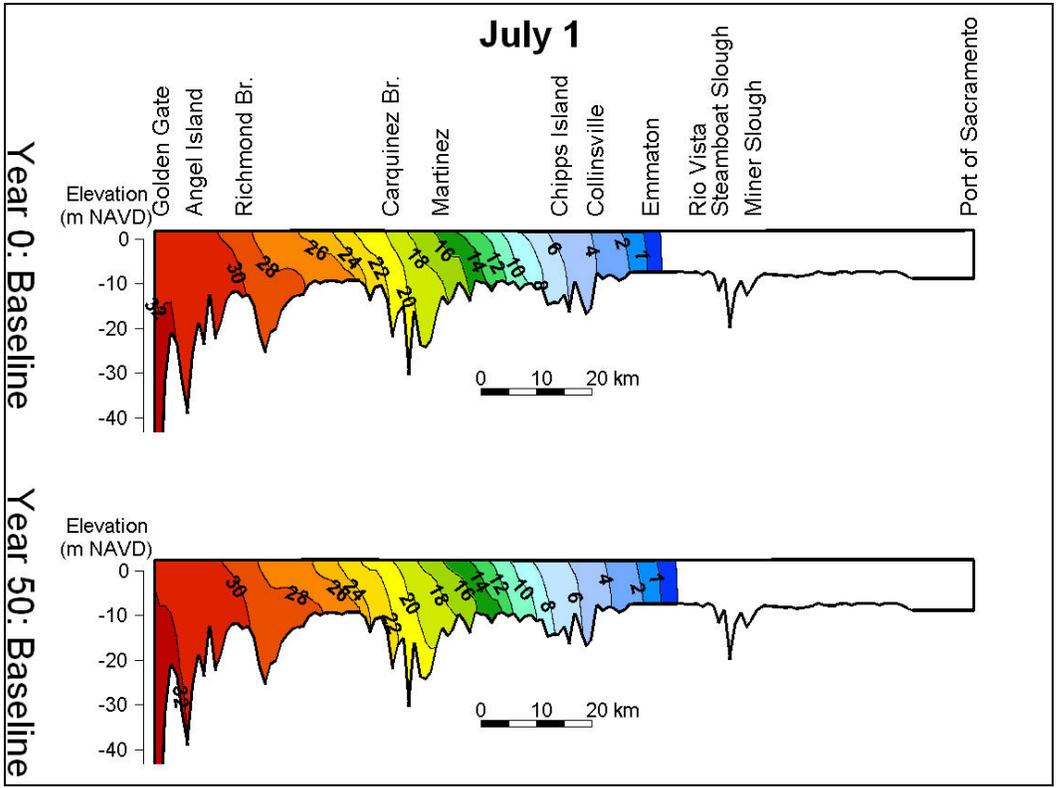


Figure 53. Predicted Daily-Averaged Salinity Profile on July 1

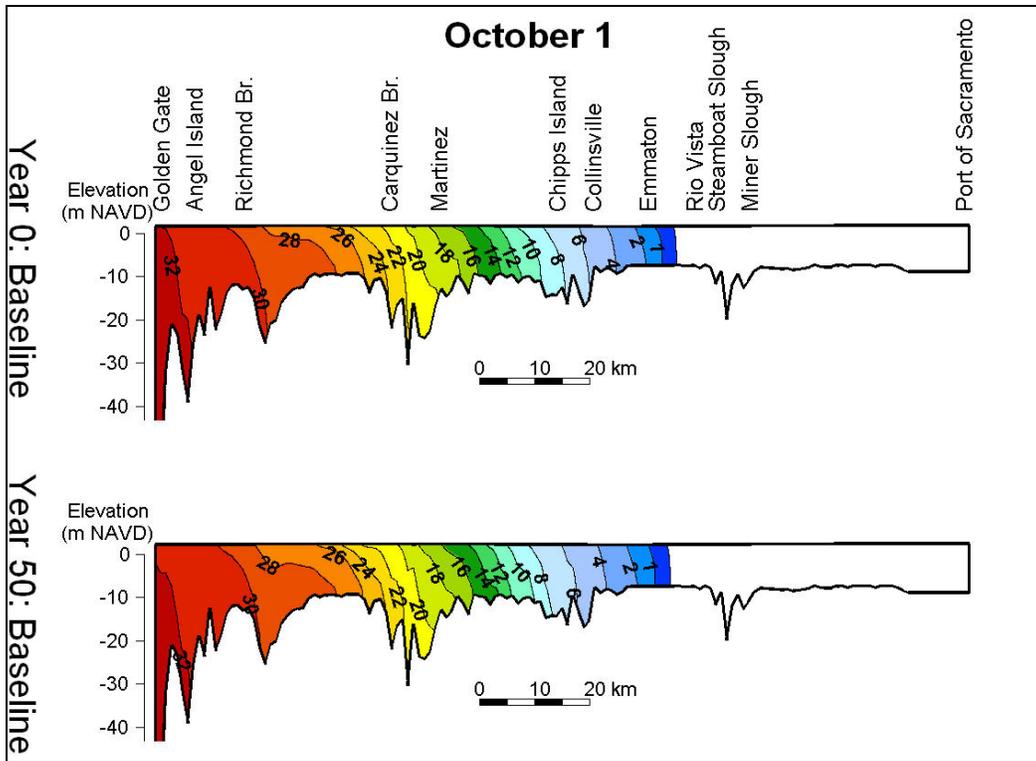


Figure 54. Predicted Daily-Averaged Salinity Profile on October 1

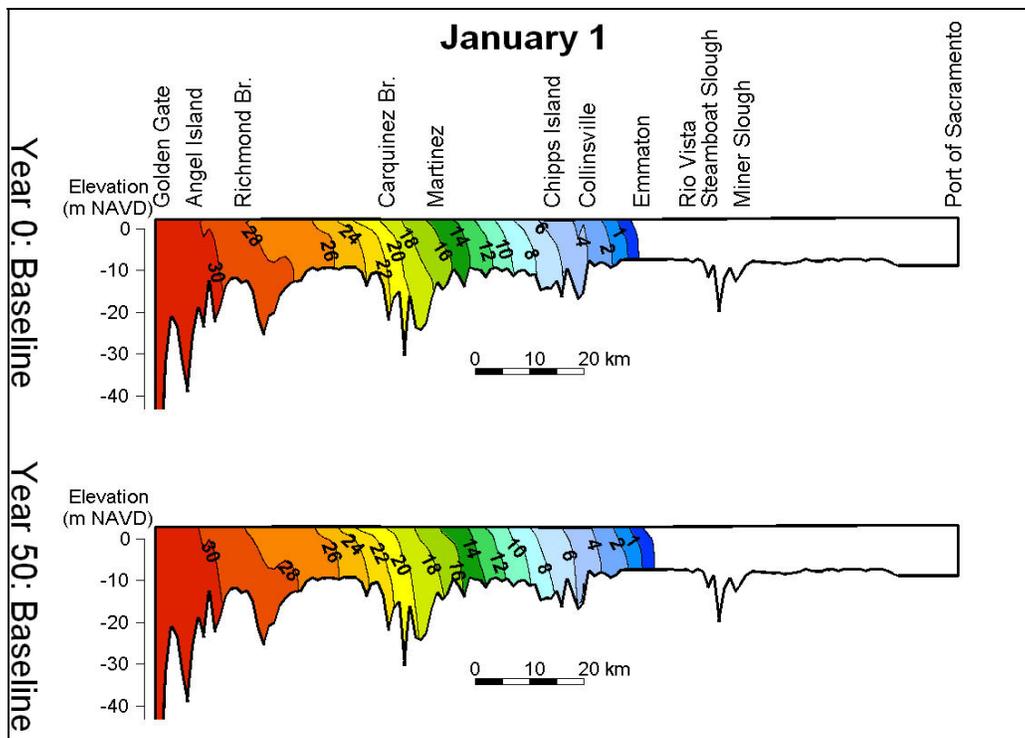


Figure 55. Predicted Daily-Averaged Salinity Profile on January 1

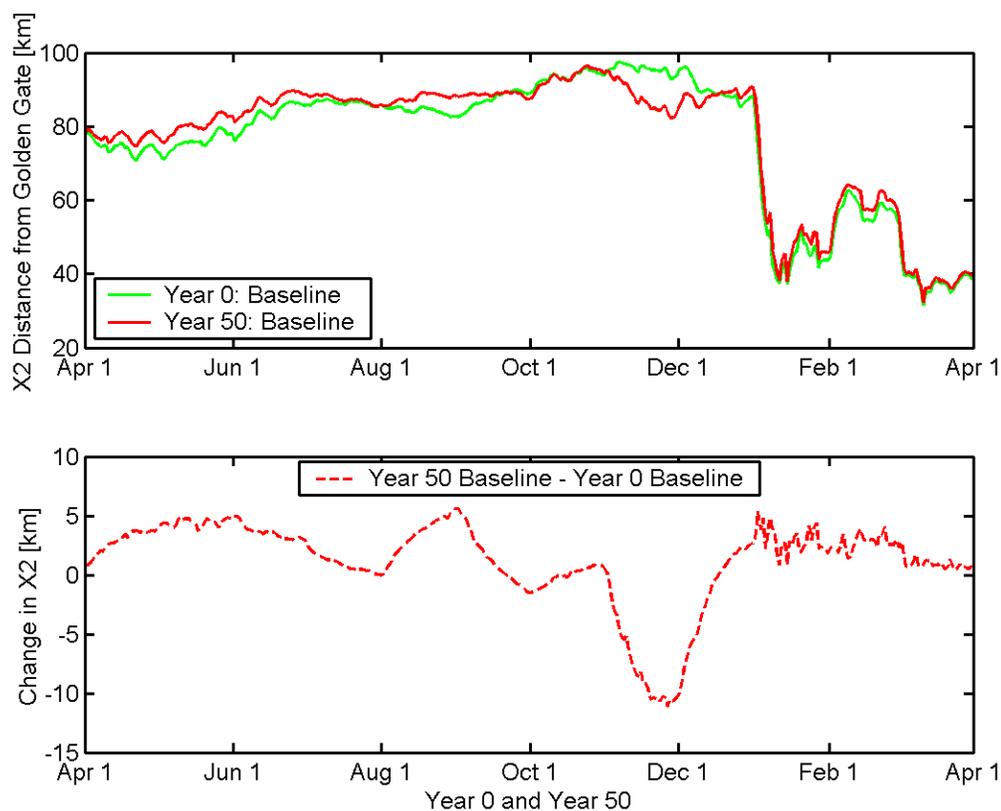


Figure 56. Predicted X2 Distance Location from Golden Gate to SRDWSC

## 6.0 FUTURE WIHTOUT-PROJECT HYDRODYANMIC CONDITIONS (YEAR 50)

The future without-project conditions were characterized as the Year 50 conditions and are referenced to the calendar year of 2061/2062. It was formulated under the projected hydrologic, bathymetric and water operation conditions in the SRDWSC. For the Year 50 conditions, a single year spanning from April 1, 1994 to April 1, 1995 was also selected. This is the same one-year period used in the Year 0 analysis, however the delta inflows, exports, and operations are different from “Year 0” and are based on future level of land use, water demand, climate change, and sea level rise.

Future water inflows, exports and operations in the Delta were formulated from 1) the CALSIM II predictions of the future conditions in 2029 with climate change, which assumes only 1 foot sea level rise (DWR, 2009a); and 2) the MPI-ECHAM5 climate change model and A2 greenhouse gas emissions with an anticipated level in 2050 (MacWilliams et al., 2010). However, future sea level rise (SLR) rates to be considered in this study were based on the USACE's guidance (EC 1165-2-211) for incorporating the direct and indirect physical effects of projected future sea level change in civil work programs (USACE, 2009). Based on the specific guideline, it is suggested that a low

limit of the local historic trend of 0.36 feet and an upper limit of 1.97 feet over 50 years be used, based on the modified NRC curve #3, if local subsidence is insignificant. Therefore, for the future conditions (Year 50), a sea level rise of 1.97 feet was applied to the Pacific Ocean water level that was recorded in the 1994-1995 year at Fort Point. The bathymetric conditions along the Sacramento DWSC remain unchanged under the future (Year 50) without-project conditions. **Table 8** summarizes the physical, hydrologic, and water operation characteristics in the future year (Year 50) for the SRDWSC. A detailed description of the Year 50 conditions was provided in the UnTRIM modeling report (MacWilliams et al., 2010).

Table 8. General Characteristics of future Year Without Project (Year 50)

<i>Baseline Year 50 Conditions</i>	<i>Description</i>
Calendar year (Year 50)	2061-2062
Hydrologic conditions	Historical precipitation & runoff patterns recorded from April 1, 1994 to April 1, 1995
Water inflows, exports and operations	Delta inflow, export and barrier operation conditions from April 1, 1994 to April 1, 1995, based on CALSIM II predictions considering the global warming effect as well as biological opinions issued by USFWS & NMFS
Deep water ship channel conditions	Channel depth with 2 feet overdepth allowable to the design depth (i.e., 32 feet for Reaches 1 to 4 and 37 feet for Reach 5)
Pacific Ocean Water Level	Observed 1994-1995 water levels at Fort Point, San Francisco Bay with an addition of 1.97 feet to account for sea level rise

## 6.1 Predicted River Stage

Seven identical stations, as chosen for the Year 0 simulation, along the JFBSC and SRDWSC are selected to exhibit the predicted river stages. The temporal river stages for a two-week period from June 15 to June 30 at the seven selected locations are also illustrated in Figures 35 to 41. In general, the predicted trend of river stage is similar to those simulated for the Year 0 conditions with elevated river stages of about 1.97 feet (0.6 meters) that is equivalent to the increase of sea level rise in Year 50 under the without-project conditions. Higher river stages were predicted at upstream locations (e.g., the Port of Sacramento), while a slight attenuation of tidal range due to the muting effect was also predicted at Georgiana Slough in the Sacramento River. As a result, the increase of river stage at Georgiana Slough between Year 0 and Year 50 predictions is slightly less than 1.97 feet, which is the increase of sea level rise. During the wet winter months from December to March, elevated daily-averaged river stages were predicted throughout the JFBSC and SRDWSC and the Sacramento River as a direct consequence of more freshwater inflows being discharged into the Delta.

## 6.2 Predicted Flow Rate

Six identical locations at Carquinez Bridge, Chipps Island, Rio Vista (RVB), Ryer Island (CCH), the USGS station in the man-made channel, and a river location at Georgiana Slough in the Sacramento River are selected to exhibit the predicted flow rates, as also shown in Figures 42 to 47. The predicted Year 50 (2061/2062) flow rates under the without-project conditions follow the similar trend as for the results in Year 0 (2011/2012). These figures also illustrate the daily-averaged flow rates for the entire simulated year under the future water operation scenario. Greater ranges of flow rate for Year 50 (see the top graph of each figure) are attributed to the increased sea level resulting in a greater tidal prism with more water exchanges between flood and ebb tides.

The simulated flow rates exhibit more frequent net downstream flow conditions (see the mid graph of each figure) as a result of continuous water inflows into the entire Delta. At Georgiana Slough in the Sacramento River, the net daily-averaged flows (see Figure 47) are always toward downstream, an indication of significant influence from the water inflows at this location. As expected, high daily-averaged flow rates will occur during the wet months between December and March. Changes in daily-averaged flows between Year 0 and Year 50 vary monthly typically with a lesser range between April and June and a greater difference from November to the following April. These changes are primarily attributed to the alteration of inflows, exports, water operations between these two simulated years, based on climate change and biological opinions that were issued for river habitats by various public agencies.

## 6.3 Predicted Salinity

Four identical locations as chosen for the Year 0 simulation are selected to exhibit the predicted salinities. The predicted temporal salinities at these four locations for the same two-week period are also illustrated in Figures 48 to 51. The figures also illustrate the daily-averaged salinities for the entire simulated year (Year 50) under the future managed water operations that account for climate change and sea level rise. Salinities predicted in Year 50 generally are higher than those simulated in Year 0. The sea level rise in Year 50 results in more salt water intrusion into the SRDWSC. The predicted daily-averaged salinity profiles along the JFBSC and SRDWSC for Year 50 (Figures 52 to 55) also show the same upstream encroachment trend for these four selected dates, particularly during the summer/fall months (e.g., October). The temporal variation of the X2 location as shown in Figure 56 also exhibits a similar trend of which the X2 locations are further upstream from the Golden Gate during the summer months.

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