Antioch-217

Environmental and Ecological Sciences Group

Exponent®

Expert Report of Susan C. Paulsen, Ph.D., P.E.: Availability of Water in Old River, Sacramento-San Joaquin Delta, During Drought Conditions

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Prepared for

Somach, Simmons & Dunn
500 Capitol Mall, Suite 1000
Sacramento, CA 95814

Prepared by

Exponent
70 S. Lake Ave
Pasadena, CA 91101

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Acronyms and Abbreviations

BBID	Byron-Bethany Irrigation District
BDCP	Bay Delta Conservation Plan
CDEC	California Data Exchange Center
CCWD	Contra Costa Water District
CVP	Central Valley Project
DICU	Delta Island Consumptive Use
DSM2	Delta Simulation Model 2
DWR	California Department of Water Resources
ECCID	East Contra Costa Irrigation District
ED	electrical conductivity
HEC-DSS	Hydrologic Engineering Center Data Storage System
HYDRO	DSM2 Hydrodynamic Module
NAVD88	North Atlantic Vertical Datum 1988
NBID	Naglee-Burke Irrigation District
NGVD29	National Geodetic Vertical Datum
PTM	DSM2 Particle Transport Module
QUAL	DSM2 Water Quality Module
SWP	State Water Project
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
WSID	West Side Irrigation District
WY	Water Year

1 Qualifications

This report was prepared by Susan C. Paulsen, Ph.D., P.E. Dr. Paulsen is a Registered Professional Civil Engineer in the State of California (License # 66554). Dr. Paulsen's educational background includes a Bachelor of Science in Civil Engineering with Honors from Stanford University (1991), a Master of Science in Civil Engineering from the California Institute of Technology ("Caltech") (1993), and a Doctor of Philosophy (Ph.D.) in Environmental Engineering Science, also from Caltech (1997). Dr. Paulsen's education included coursework at both undergraduate and graduate levels on fluid mechanics, aquatic chemistry, surface and groundwater flows, and hydrology, and she served as a teaching assistant for courses in fluid mechanics and hydrologic transport processes. Appendix G includes a copy of Dr. Paulsen's curriculum *vitae*.

Dr. Paulsen's Ph.D. thesis was entitled, "A Study of the Mixing of Natural Flows Using ICP-MS and the Elemental Composition of Waters," and the major part of her Ph.D. research involved a study of the mixing of waters in the Sacramento-San Joaquin Bay-Delta (the Delta). Dr. Paulsen collected composite water samples at multiple locations within the Delta, and used the elemental "fingerprints" of the three primary inflow sources (the Sacramento River, the San Joaquin River, and the Bay at Martinez), together with the elemental "fingerprints" of water collected at two interior Delta locations (Clifton Court Forebay and Franks Tract) and a simple mathematical model, to establish the patterns of mixing and distribution of source flows within the Delta during the 1996–1997 time period. Dr. Paulsen also directed model studies to use the chemical source fingerprinting to validate the volumetric fingerprinting simulations using Delta models (including the Fischer Delta Model (FDM) and the Delta Simulation Model (DSM)).

Dr. Paulsen is currently am a Principal and Director of the Environmental and Earth Sciences practice of Exponent, Inc. ("Exponent"). Prior to that, she was the President of Flow Science Incorporated, in Pasadena, California, where she worked for 20 years, first as a consultant (1994-1997), and then as an employee in various positions, including President (1997-2014). Dr. Paulsen has 25 years of experience with projects involving hydrology, hydrogeology, hydrodynamics, aquatic chemistry, and the environmental fate of a range of constituents. She have knowledge of California water supply issues, including expertise in California's Bay-Delta estuary. Dr. Paulsen's expertise includes designing and implementing field and modeling studies to evaluate groundwater and surface water flows, and contaminant fate and transport. She has designed studies using one-dimensional hydrodynamic models, three-dimensional computational fluid dynamics models, longitudinal dispersion models, and Monte Carlo stochastic models, and she has directed modeling studies and utilized the results of numerical modeling to evaluate surface and ground water flows.

Dr. Paulsen has designed and implemented field studies in reservoir, river, estuarine, and ocean environments using dye and elemental tracers to evaluate the impact of pollutant releases and treated wastewater, thermal, and agricultural discharges on receiving waters and drinking-water intakes. She has also designed and managed modeling studies to evaluate transport and mixing, including the siting and design of diffusers, the water quality impacts of storm water runoff, irrigation, wastewater and industrial process water treatment facilities, desalination brines and cooling water discharges, and groundwater flows. She has designed and directed numerous field studies within the Delta using both elemental and dye tracers, and she has designed and directed numerous surface water modeling studies within the Delta.

2 Executive Summary

Background. On July 20, 2015, the State Water Resources Control Board (SWRCB) issued an Administrative Civil Liability (ACL) complaint against the Byron-Bethany Irrigation District (BBID) (Enforcement Action ENF01951) for diverting approximately 2,067 acre-feet of water from the intake channel to the Banks Pumping Plant from June 13 to June 25, 2015. On July 16, 2015, the SWRCB issued a Cease and Desist Order (CDO) to the West Side Irrigation District (WSID) for unauthorized diversions of water from Old River (Enforcement Action ENF01949). Exponent was retained by Somach, Simmons and Dunn (SSD) to assist in their representation of BBID and to assist counsel for WSID during the administrative proceedings regarding ENF01951 and ENF01949. Specifically, Exponent was retained to describe flow and salinity conditions within the Sacramento-San Joaquin River Delta (Delta) over time; to review the historical diversion practices of BBID and WSID; to analyze the "availability" of water to satisfy BBID's intake demands in June 2015 according to its pre-1914 appropriative water rights; and to analyze the "availability" of water to satisfy WSID intake demands between May 1, 2015, and July 16, 2015, according to its post-1914 appropriative water rights. As used herein, the term "availability" refers to both the quantity and quality of the water diverted.

Summary. As detailed in this report, Exponent concludes that water was "available" for diversion by BBID between June 13 and 25, 2015, that water was "available" for diversion by WSID throughout the irrigation season of 2015, and that the availability of water to BBID and WSID at these times was independent of the operations of the SWP and CVP. Exponent further concludes that, because full natural flows are determined far upstream of the Delta, they would not be available for diversion for weeks to months—i.e., for the time required for water to travel from a full natural flow measurement location into and through the Delta, and to diversion locations in the south Delta—and in the meantime, water in the Delta would consist of flows that had entered the Delta in prior months. Although the relationship between full natural flow and "availability" within the Delta could be determined using model simulations, it would be inappropriate to use full natural flow as a real-time indicator of water availability in the Delta. Exponent formed these conclusions in consideration of the configuration, hydrodynamics, residence time, and quality of water within the Delta; the historical record that describes the diversion practices of BBID and WSID, and the quality of water available at the intakes of BBID and WSID; and an analysis of the salinity and the source, both in terms of location and time, of water available for diversion by BBID and WSID.

The Delta and water availability. The Sacramento-San Joaquin River Delta (Delta) is the transition zone between the San Francisco Bay and its watershed. The salinity of water within the Delta results primarily from the balance between freshwater flows into the Delta and higher salinity water that enters the Delta from San Francisco Bay as a result of tidal action; freshwater flows into San Francisco Bay and agricultural return flows within the Delta also affect Delta salinity. Freshwater flows into the Delta typically peak in winter and spring in response to precipitation and snowmelt. Freshwater flows into the Delta are lowest, and exports and diversions of water from the Delta are highest, during the warm and dry summer and fall months.

Because Delta channels are below sea level, water is always present within the Delta. As noted by DWR, "Because the Delta is open to the San Francisco Bay complex and the Pacific Ocean and its channels are below sea level, it never has a shortage of water. If the inflow from the Central Valley is insufficient to meet the consumptive needs of the Delta, saline water from the bay fills the Delta from the west. Thus, the local water supply problem in the Delta becomes one of poor water quality, not insufficient quantity" (DWR 1978). Because water will always be present in the Delta, our analysis of availability focused on the quality of water, specifically the salinity of water, and the source of water within the Delta.

Flows within the Delta are strongly tidal. During dry conditions, tidal variations in stage and bi-directional ("sloshing") flows occur throughout the Delta, including at the upper extent of the Delta (e.g., in the Sacramento River at Sacramento). Tidal variations in flow rate, particularly in the western Delta and during dry conditions, are often much larger than the net outflow, and large volumes of water enter and leave the Delta on a single tidal cycle. Water quality within the Delta is a function of the complex hydrodynamics and geometry of the system, and salinity intrusion from the Bay into the Delta is greatest during the dry season of dry years.

The volume of water within the Delta is large (the Delta contains approximately 1.2 million acre-feet (MAF) of water), and the residence time, or length of time water remains in the Delta before it flows out of or is pumped from the Delta, varies greatly. The residence time of water within the Delta varies from a few days during the winter of wet years to as long as three months during the summer and fall of dry years.

DWR computes a “water year index” that is used to classify the hydrologic condition in each water year (the period from October through the following September). DWR also calculates the unimpaired runoff, also known as “full natural flow.” The full natural flow is defined by the California Data Exchange Center (CDEC) as “the natural water production of a river basin, unaltered by upstream diversions or storage, or by export or import of water to or from other watersheds” (DWR 2011). Table ES-1 presents summary statistics for the ten driest water years in the historical record (1906–2015), as ranked by the amount of full natural flow; the water year classification is also shown, and is “critically dry” or “dry” for each of these years. As detailed in Table ES-1, WY 2015 was the seventh-driest year on record in terms of the full natural flow, the fourth-driest year on record in terms of the Sacramento Valley water year index, and the driest year on record in terms of the San Joaquin Valley index. In terms of the amount of full natural flow, water years 1977, 1924, 1931, 2014, 1976, and 1994 were drier than 2015. Exponent’s analysis of availability focused on water years 2015, 1931, and 1977, and on historical conditions prior to 1917.

Table ES-1. Top ten water years between 1906 and 2015 ranked by lowest runoff in the Sacramento and San Joaquin Valleys (Eight-River FNF)

Sacramento and San Joaquin Valleys					
Water Year	Unimpaired Runoff (Sacramento & San Joaquin Valleys) (MAF)	Sacramento Valley WY Index	Sacramento Valley Year Type	San Joaquin Valley WY Index	San Joaquin Valley Year Type
1977	6.2	3.11	C	0.84	C
1924	7.2	3.87	C	1.42	C
1931	7.8	3.66	C	1.2	C
2014	9.2	4.08	C	1.16	C
1976	10.2	5.29	C	1.57	C
1994	10.3	5.02	C	2.05	C
2015 [1]	10.7	4	C	0.7	C
1934	10.9	4.07	C	1.44	C
1939	11.1	5.58	D	2.2	D
1929	11.2	5.22	C	2	C

[1] 2015 water year index and classification are forecasted values from May 2015; final 2015 data not currently available (1-13-16).

Data from CDEC, accessed at http://cdec.water.ca.gov/

Historical data: pre-1917. An abundance of evidence indicates that, prior to the early 1900s, water in the Delta was predominantly fresh. Changes in the Delta landscape since the mid-1800s have included the reclamation and removal of freshwater tidal marshes and levee construction, both of which increased salinity within the Delta. Freshwater diversion projects for storage and irrigation also increased salinity within the Delta, particularly during the summer and fall irrigation seasons. Salinity intrusion began to increase markedly in about 1918, when “the urge of war had encouraged heavy plantings of rice and other crops in the Sacramento Valley, result[ing] in the penetration of salt water into the Delta for a longer time and to a greater distance upstream than ever known before” (Means 1928). However, prior to that point in time, water within the Delta had been sweet (fresh). Historical data indicate that prior to about 1917, water at the (future) location of the BBID and WSID intakes would have been fresh year-round during all hydrologic year types.

Historical data: 1917 to 1944. Salinity levels began to be monitored in the Delta by DWR and its predecessor organizations (collectively referred to as "DWR" in this report) in about 1920 (DWR 1960). Historical measurements collected by DWR form the basis for the widespread (but inaccurate) belief that salinity levels observed within the Delta after 1917 represented the historical or natural condition. Salinity measurements made between 1920 and 1944 describe the conditions within the Delta after salinity intrusion had become pronounced due to changes in the Delta landscape and water management practices, but prior to the construction of the Central Valley Project (CVP) and the State Water Project (SWP) (the Projects).

Measured salinity data are available at several locations in the Delta, as are records of the volume of water diverted from the Delta each month, for the time period 1929–1944. Of the 544 diversions recorded in DWR's Bulletin 23 from 1931, twelve diversions, including diversions by BBID and WSID, were located in Old San Joaquin River (Old River). DWR data indicate that BBID and WSID diverted water from the Delta throughout this time period, including during the months of March through October in the critically dry water years of 1924, 1929, 1931, and 1934.

As detailed in this report, 1931 is the year with the lowest Sacramento River flow index in the pre-Project time period; because this year occurred during the pre-CVP/SWP time period, conditions during 1931 are most representative of the drought conditions that would occur today if the CVP and SWP did not exist. As shown in Table ES-2, both BBID and WSID (along with other diverters in Old River) diverted water during the months of June, July, and August 1931; the amount of water diverted during June–August 1931 did not vary appreciably from the amount of water diverted during June, July, and August of other years in this time period.

Salinity measurements[1] made near the BBID intake indicate that water at this location remained fresh throughout the month of June 1931, began to rise in July 1931, reached a level of

[1] Historically, salinity in the Delta was measured as chloride (mg/L Cl^-) or total dissolved solids (mg/L TDS). Most modern salinity measurements are expressed as electrical conductivity (EC). Guivetchi (1986) used historical measurements of all three quantities to develop linear relationships among chloride, TDS, and EC, and these mathematical equations are commonly used to convert one form of salinity measurement to another. For additional detail, see Section 4.5 of this report.

1000 mg/L as chloride in early September 1931, peaked at about 1300 mg/L chloride in late September 1931, and fell below 1000 mg/L in late October 1931. Measured chloride data also demonstrate that chloride concentrations of 1000 mg/L or greater were observed at the BBID intake location only twice (in the fall of 1931 and 1934) and at the WSID intake only once (in the fall of 1931). Both BBID and WSID diverted water from Old River throughout this period.

Table ES-2. 1931 BBID diversions, WSID diversions, total diversions from Old River (values in acre-feet, AF)

Month	BBID Diversion (AF)	WSID Diversion (AF)	Total Diversion from Old River (AF)[1]
Mar	1176	1394	5735
Apr	3485	4900	17,099
May	1888	2125	10,400
Jun	2469	1958	9245
Jul	2847	3910	14,125
Aug	2652	2808	10,854
Sep	1139	1019	3522
Oct	140	27	389

Diversion data from DWR Bulletin 23, 1931 edition (DWR 1932)

[1] Including BBID and WSID diversions in the total

Available data show that during June 13–25, 1931 (i.e., during critically dry conditions without the operation of the CVP and SWP), water was present at the BBID intake location, water was fresh, and water was diverted by BBID. Similarly, for WSID, throughout the irrigation season of 1931, water was present at the WSID intake location, water was of suitable quality for use, and water was diverted by WSID. Thus, by any measure, water was “available” to BBID and WSID during a critically dry year, even without the influence of the CVP and SWP (which had not been constructed in 1931), and even without curtailment of diversions within and upstream of the Delta (as occurred during 2015).

Historical data: 1944 to present. The largest reservoir of the CVP, Lake Shasta, was completed in 1945, and the largest reservoir of the SWP, Lake Oroville, was completed in 1968. The total water storage capacity of the SWP is 5.8 MAF, and that of the CVP is about 11 MAF.

The Projects capture and store water in reservoirs upstream of the Delta during the winter and spring, and release flows from upstream reservoirs during the summer and fall months. Thus, the Projects have changed the timing of freshwater inflows to the Delta, generally reducing winter and spring inflows and increasing summer and fall inflows. In addition, water is exported by the Projects from the South Delta, which has changed both the flow rates in Delta channels and the distribution of water and salinity within the Delta. Note that when the SWP was constructed, the BBID intake location was moved to the intake channel of the State Water Project, between Banks Pumping Plant and Clifton Court Forebay.

Diversion data for BBID and WSID were examined for 1977, 2014, and 2015, which as shown in Table ES-1, were among the driest years on record. Monthly diversion data for BBID and WSID for these years are shown in Table ES-3.

Table ES-3. BBID diversions and WSID diversions in 1977, 2014, and 2015 (values in acre-feet, AF) (source: BBID, WSID, U.S. Bureau of Reclamation)

Month	BBID Diversion (AF)			WSID Diversion (AF)		
	1977 [1]	2014 [2]	2015 [2]	1977 [4]	2014 [4]	2015 [4]
Jan	1042	2301	148			
Feb	3373	921	481	654		
Mar	3834	2005	2520	4699	1819	
Apr	6386	2848	3453	5566	1859	2309
May	5049	4298	3939	4462	3073	1176
Jun	8685	4842	4243	5885	1350	909
Jul	9074	4017	343 [3]	8876	1023	592
Aug	8182	2871	923 [3]	6950	1017	412
Sep	3993	2792	1787	3820	401	255
Oct	1919	2657	1383	1346	173	146 [5]
Nov	0	612	183	16		0 [5]
Dec	0	160	121			0 [5]

[1] Diversion data from BBID

[2] Diversion data from U.S. Bureau of Reclamation.

[3] Transferred water, not diverted from the Delta (Source: BBID communication)

[4] Diversion data from WSID for License 1381

[5] Reported value was amount anticipated to be diverted

The data in Table ES-3 confirm that BBID and WSID diverted water from the Delta throughout the irrigation season during the critically dry years of 1977 and 2014, and through most months of 2015 (with the exception of transferred water obtained by BBID after the 2015 curtailment notice was issued). Measured salinity data (shown in Section 4.5) demonstrate that water in Old River at Clifton Court Forebay and near Tracy, close to the BBID and WSID intake locations, respectively, remained fresh during WY 2014 and WY 2015 (average EC in Old River at Tracy between January 2014 and December 2015 was approximately 1020 µS/cm, while the maximum EC was 1636 µS/cm; average EC at Clifton Court Forebay during the same time period was approximately 640 µS/cm with a maximum of 1020 µS/cm).

The State of California pursued litigation against BBID, among others, for diverting 17,256 acre-feet of water in July and August of 1977. Testimony, documents, and court rulings relating to this litigation provide useful information regarding the quantity and quality of the water diverted by BBID during historical drought conditions. Specifically, the information indicates that BBID had sufficient quantity and quality of water available for its use during the 1976–1977 historical drought.

Model simulations: source of water in the Delta in 1931. Although it has been asserted that the operations of the SWP and the CVP are responsible for the presence of fresh water in the south Delta during the summer of 2015, neither historical data (from the critically dry pre-Project year of 1931) nor model results support this view. Exponent used the DSM2 model to simulate hydrodynamics, salinity, and the source of water within the Delta during 1931. Model results were validated by comparing modeled salinity (modeled as EC and converted to chloride concentration) to measured chloride results for 1931. The DSM2 model was able to simulate the intrusion of salinity from the Bay into the Delta well, as shown by comparisons of model results to measured salinity at Antioch. In the south Delta, the model captured the timing of salinity increases reasonably well but showed differences in the magnitude of peak concentrations, a common occurrence with DSM2 that is likely due to difficulties in accurately simulating salinity impacts from agricultural return flows. Both measured and modeled chloride data indicate that fresh water was present near the BBID intake during June 13–25, 1931—i.e., measured chloride concentrations were 120 mg/L or less near the BBID intake during June 13–25, 1931 (measured at Mansion House). The water at the WSID intake would have had lower chloride concentrations than water at the BBID intake, and thus would have remained fresh through the month of June 1931; chloride concentrations over the irrigation season at the WSID intake peaked at about 1,000 mg/L in September 1931. The fact that water was diverted and used at these chloride concentrations demonstrates that water quality was sufficient for use.

Source fingerprinting was used to assess the source of water present at the BBID intake location during 1931. Figure ES-1a presents results at the BBID intake location, and shows that the San Joaquin River was the dominant source of water during December 1930–March 1931, while the Sacramento River and agricultural runoff were the dominant sources of water in the summer months. Figure ES-1b divides the source fingerprints for the Sacramento River to show the month during which water entered the Delta from the Sacramento River. The figure shows that

Sacramento River water present at the BBID intake in June 13–25, 1931, entered the Delta during the months of February–May 1931.

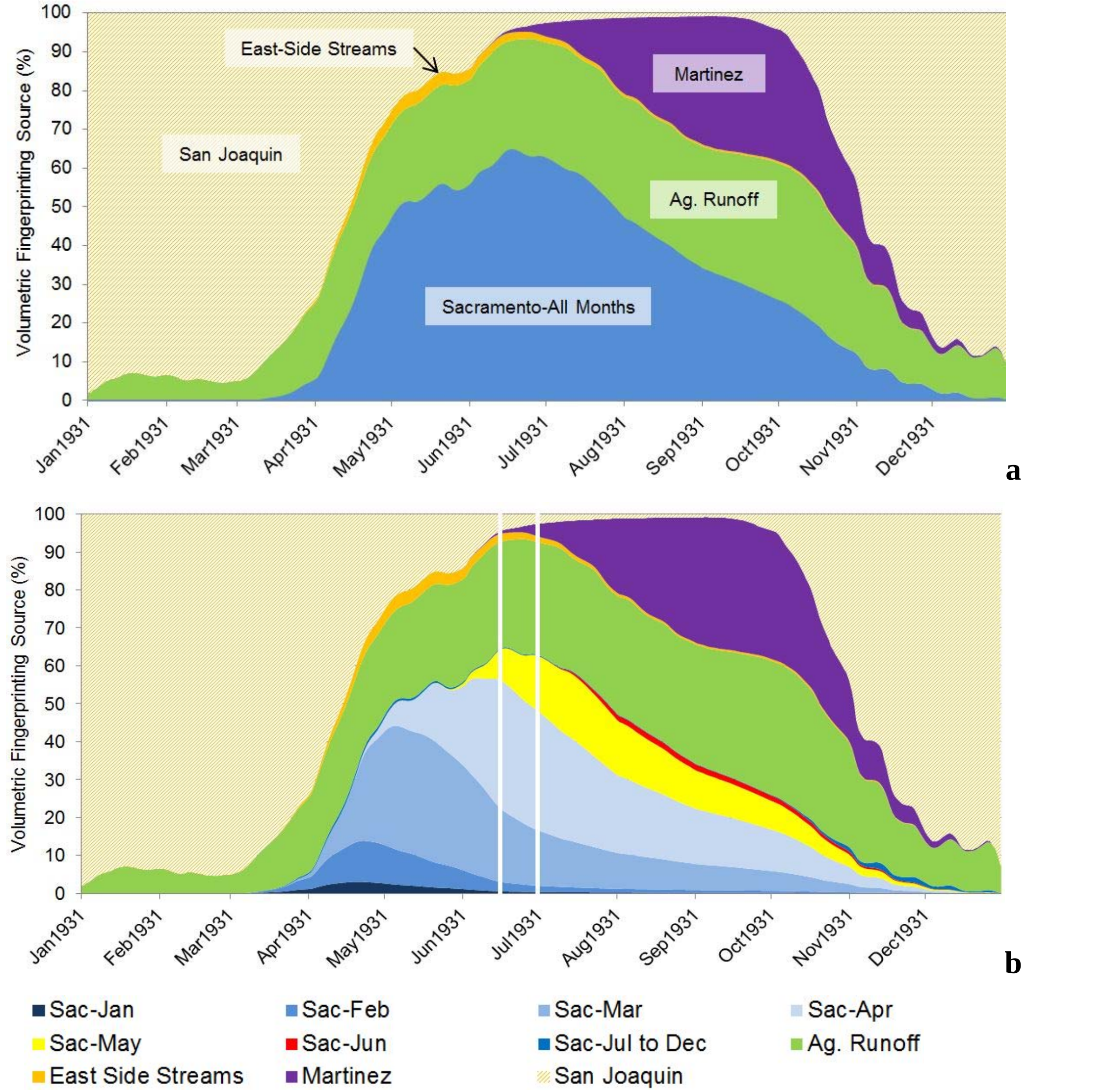


Figure ES-1 Volumetric fingerprint at the BBID intake for 1931 shown with Sacramento River inflow as one source (a), and Sacramento River inflow separated to show the month that water entered the Delta (b)

Figure ES-2a presents volumetric fingerprinting results from 1931 at the WSID intake location, which are similar to results at the BBID intake location. At the WSID intake, the San Joaquin River was the dominant source of water during the winter months, while the Sacramento River and agricultural runoff were the dominant source of water in the summer months. Agricultural runoff, which is some portion of the water diverted from the channels for irrigation that flows back into Delta channels, comprises a larger portion of the water available at the WSID intake location than at the BBID intake location. Figure ES-2b shows that water at the WSID intake location in the irrigation season was a mix of water from the Sacramento River (which entered the Delta primarily in February, March, April, and May), agricultural runoff, and San Joaquin River water.

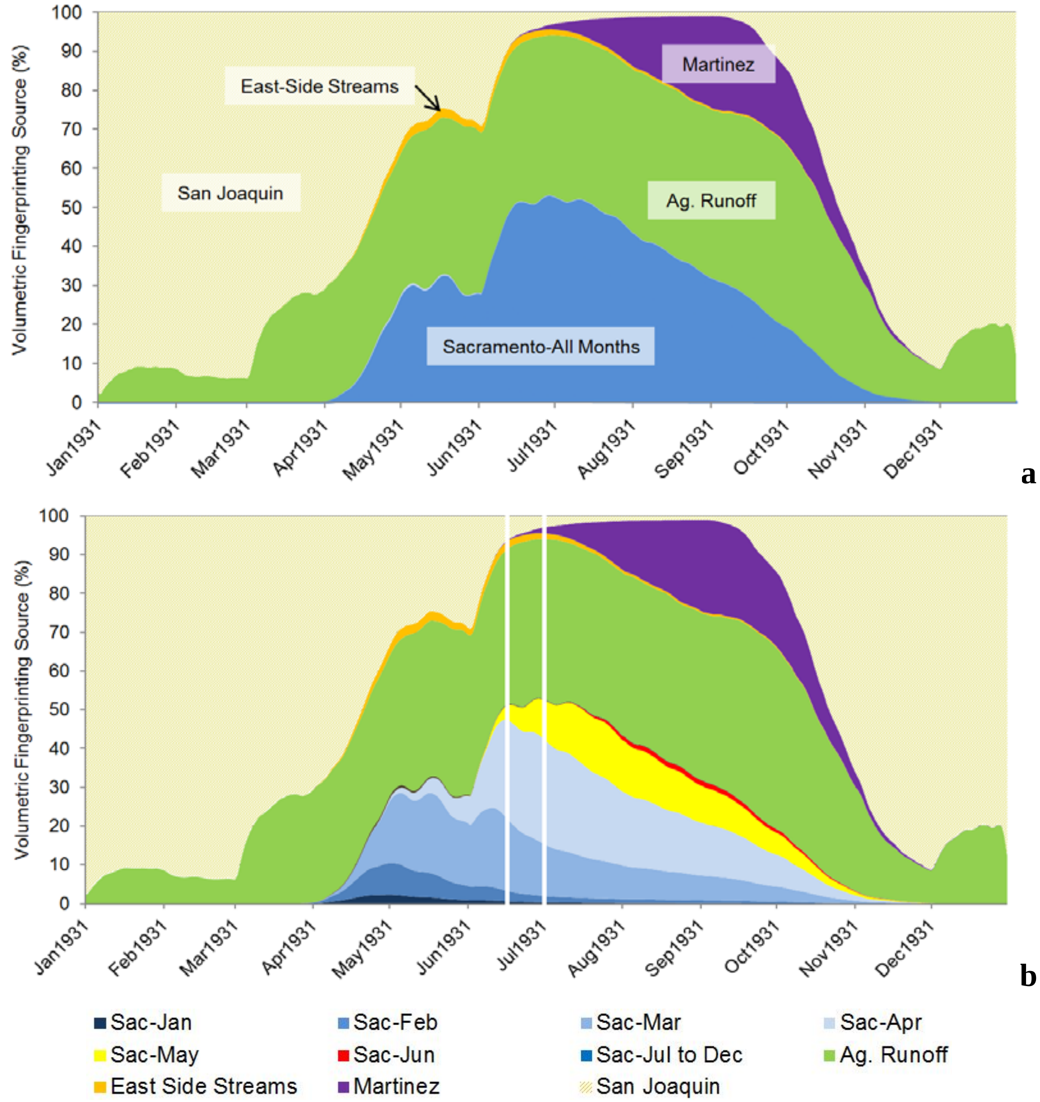
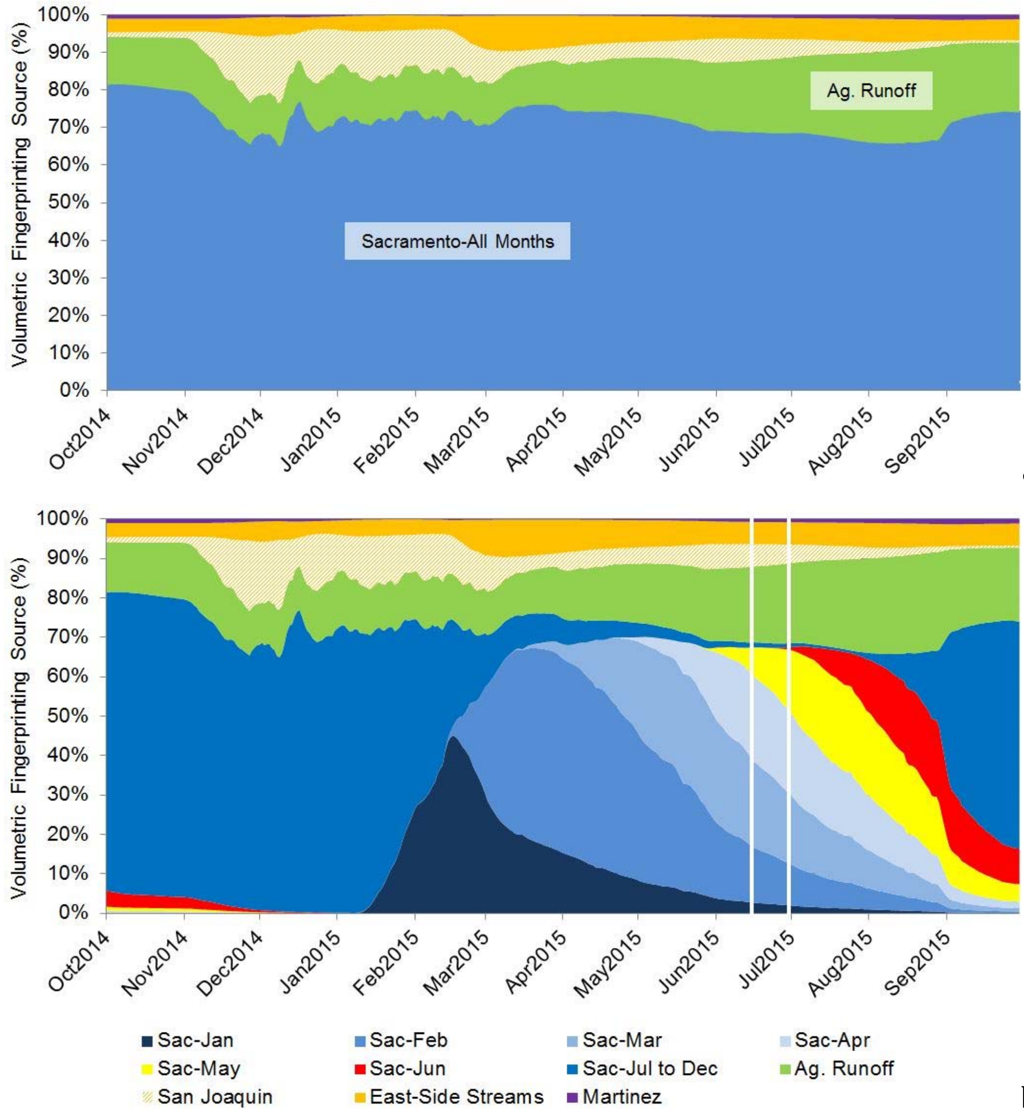


Figure ES-2 Volumetric fingerprint at the WSID intake for 1931 shown with Sacramento River inflow as one source (a), and Sacramento River inflow separated to show the month that water entered the Delta (b)

Model simulations: 2015. Source fingerprinting was also used to identify the source of water present at the BBID intake in 2015. As shown in Figure ES-3a, approximately 65% to 75% or more of the water present at Clifton Court Forebay (through which water was diverted by BBID) originated from the Sacramento River throughout 2015. Figure ES-3a shows that the Projects have changed the distribution of water within the Delta markedly, such that the Sacramento River is the primary source of water in the south Delta year-round, and not just during the summer months. Figure ES-3b shows the month during which water at the BBID intake entered the Delta from the Sacramento River. During the period June 13–25, 2015, water at the BBID intake consisted primarily of Sacramento River water that entered the Delta during the months of February through May 2015. As noted in Section 5.3, it can be estimated that water that entered the Delta from the Sacramento River consisted of full natural flow prior to about April 20, 2015, and consisted of both full natural flow and stored water beginning on about April 20, 2015 (when the flow rates released from Shasta Dam surpassed than the full natural flow in the Sacramento River at Bend Bridge); Figure ES-3b shows that less than about 20% of the water at Clifton Court Forebay in late June 2015 flowed into the Delta from the Sacramento River after April 20, 2015, and only a fraction of that water would have been stored water released from reservoirs upstream of the Delta. In addition, it should be recognized that the Projects captured and stored water during the winter and early spring months of 2015 that otherwise would have flowed into the Delta, thus reducing the quantity of Sacramento River water that otherwise would have been present in the south Delta during the spring and summer months of 2015.

Source fingerprinting performed using the DSM2 model demonstrates that the majority of the water diverted by BBID during June 13–25, 2015, consisted of the full natural flow of the Sacramento River that entered the Delta many months prior to that time.



a

b

Figure ES-3 Source fingerprints for water at Clifton Court for water year 2015 (a), and showing the month when Sacramento River water entered the Delta (b)

Figure ES-4a shows that approximately 65% to 75% or more of the water present at the WSID intake during the irrigation season in 2015 originated from the Sacramento River or from agricultural return waters (i.e., return flows from irrigation water diverted from Old River); during the irrigation season, the majority of Sacramento River water at the WSID intake had entered the Delta during the months of February through May 2015. As was the case at the BBID intake, source fingerprinting indicates that the majority of the water diverted by WSID during the irrigation season in 2015 consisted of the full natural flow of the Sacramento River that entered the Delta many months prior to that time.

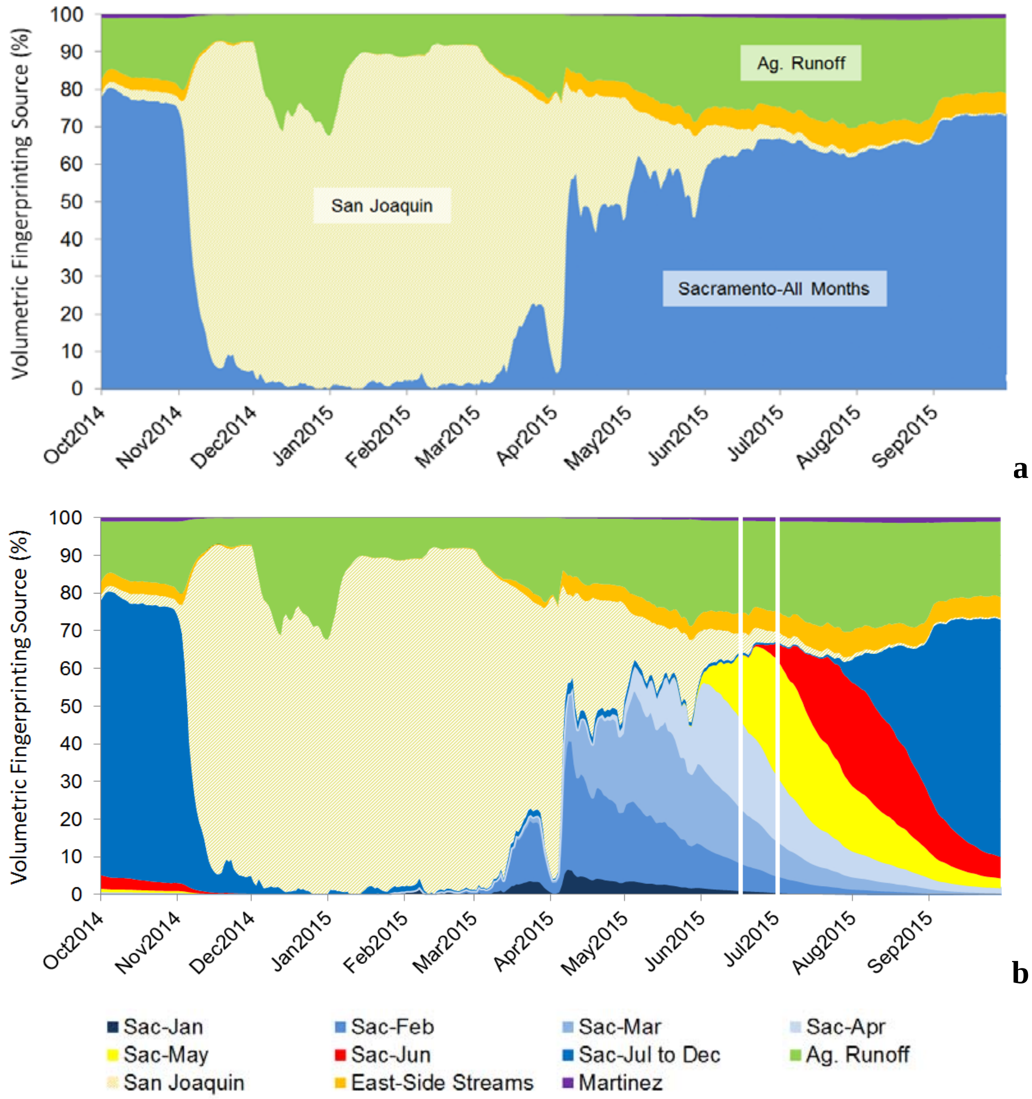


Figure ES-4 Source fingerprints for water at the WSID intake for water year 2015 (a), and showing the month when Sacramento River water entered the Delta (b)

3 Background

On June 12, 2015, the SWRCB issued a "Notice of Unavailability of Water and Need for Intermediate Curtailment for Those Diverting Water in the Sacramento-San Joaquin River Watersheds and Delta with a Pre-1914 Appropriative Claim Commencing During or After 1903," which notified water users with pre-1914 appropriative water rights that they must stop diverting water from the Sacramento-San Joaquin Delta (Delta). On July 20, 2015, the State Water Resources Control Board (SWRCB) issued an Administrative Civil Liability (ACL) complaint against the Byron-Bethany Irrigation District (BBID) (Enforcement Action ENF01951) for diverting approximately 2,067 acre-feet of water from the intake channel to the Banks Pumping Plant from June 13 to June 25, 2015.

On May 1, 2015, the SWRCB issued a "Notice of Unavailability of Water and Immediate Curtailment for Those Diverting Water in the Sacramento River Watershed with a Post-1914 Appropriative Right," which notified water users with post-1914 appropriative water rights that there was insufficient water supply to meet those demands and that they must immediately stop diverting water from the Sacramento River watershed. On July 16, 2015, the SWRCB issued a Cease and Desist Order (CDO) to the West Side Irrigation District (WSID) for unauthorized diversions of water from Old River (Enforcement Action ENF01949).

The Byron-Bethany Irrigation District (BBID) is an agricultural water district in the South Delta region (west of the San Joaquin River and Tracy) that was established to provide irrigation supplies for farmers in the San Joaquin Valley. Prior to the construction of Clifton Court Forebay in 1967, BBID diverted water from the intersection of Old San Joaquin River and Italian Slough. At present, BBID diverts water from the intake channel of the H.O. Banks Pumping Plant and transports it north and south in distribution canals for use throughout the District. Currently, BBID provides water for various uses within a 30,000-acre service area (47 square miles), including for residential use in the community of Mountain House (BBID, bbid.org, accessed 1-7-16).

BBID's pre-1914 appropriative water rights were established on May 18, 1914, when a notice of appropriation was filed under the Byron-Bethany Irrigation Association. An irrigation project in the Byron and Bethany area had been conceived by landowners as early as 1913, and by 1915, the landowners organized to form the Byron-Bethany Irrigation Company, to support and execute a large-scale irrigation project (DPW 1929). By 1917, a pumping plant had been built and construction had begun on a canal that diverted water from a slough near the San Joaquin River and transported it for use in the District. The Byron-Bethany Company then formed into an irrigation district in 1921 and began operating as a public entity at that time (DPW 1929). From 1924 to 1927, the District diverted between 14,187 and 21,749 acre-feet of water from the slough, and by 1929, at least five pumping plants and 4.5 miles of canals were in use for water diversion and transport (DPW 1929). BBID has continued to operate as an irrigation district and maintains a contract with the Bureau of Reclamation and Central Valley Project (CVP) to extract a maximum of 20,600 acre-feet of water per year (Contract no. 14-06-200-785, expiration in 2030); BBID diverts water under this contract most years, but in 2014 and 2015, the Bureau of Reclamation did not allocate any water to agricultural contractors in the Delta. In addition to providing irrigation supplies for agriculture in the San Joaquin Valley, BBID provides water to municipal and industrial customers, including the residential community of Mountain House.

The West Side Irrigation District (WSID) is an agricultural irrigation district located in the San Joaquin Valley near Tracy (east of BBID and both west and east of Tracy). WSID covers an area of approximately 6,000 acres and delivers 20,000 to 40,000 acre-feet of water per year that is extracted primarily from Old River. The district was formed on October 12, 1915, and began making its first water deliveries in 1919. WSID diverts water from the Delta for irrigation under both a license from the SWRCB (License 1381, issued in 1933 with a water priority date of 1916) and a contract with the U.S. Bureau of Reclamation/Central Valley Project (CVP) (Contract No. 7-07-20-W0045, established in 1977, expiration in 2030). WSID obtains most of its water supply from an intake channel off of Old River under the SWRCB license; up to 82.5 cubic feet per second (cfs) can be extracted from April 1 to October 31 each year under this authorization. WSID supplements this supply during peak irrigation months or as needed with water extracted from the Delta-Mendota Canal under the Reclamation/CVP contract. Up to

5,000 acre-feet per year can be extracted under the Reclamation/CVP agreement (personal communication from Jeanne Zolezzi, Herum, Crabtree, and Suntag, on January 5, 2016).

Exponent was retained by Somach, Simmons and Dunn (SSD) to assist in their representation of BBID and to assist counsel for WSID during the administrative proceedings regarding ENF01951 and ENF01949. Specifically, Exponent was retained to describe flow and salinity conditions within the Delta over time, to analyze the "availability" of water to satisfy BBID's intake demands in June 2015 according to their pre-1914 appropriative water rights, to analyze the "availability" of water to satisfy WSID intake demands between May 1, 2015, and July 16, 2015, according to its post-1914 appropriative water rights, and to review the historical diversion practices of BBID and WSID.

4 Introduction to the Bay-Delta System

4.1 Geography

The Sacramento-San Joaquin River Delta (Delta) is the transition zone between the San Francisco Bay and its watershed, which is a 16.3-million-ha (62,900-square-mile) basin that occupies roughly 40% of California's land area (Jassby and Cloern 2000). The Delta includes a network of interconnected channels that comprise 26,000 ha (100 square miles) of open-water habitat; Delta channels range in depth from less than 1 m to greater than 15 m (Jassby and Cloern 2000), and flow within the Delta is complex. As the SWRCB has stated, "[t]hese delta channels form a network of waterways through which the water flows sometimes one way and sometimes another, depending upon the respective stages of the various main tributaries – Sacramento, San Joaquin and Mokelumne Rivers – and the influence of tides" (SWRCB 1926). The network of channels is complex due to the natural processes of sediment erosion and deposition, and human activities such as dredging and historical levee construction.

The Delta is fed by fresh water from the Sacramento River and San Joaquin River basins and east-side streams, and is connected to the San Francisco Bay through Suisun and San Pablo Bays (Figure 4-1). Under this definition, the Delta's "total area is about 738,000 acres or more than 1100 square miles" (SWRCB 1971). "The water surface is over 75 square miles or approximately 48,000 acres" and "[t]here are approximately 700 miles of waterways with an aggregable length in excess of 550 miles" (SWRCB 1971).

The Delta boundary was officially defined in 1959, with passage of the Delta Protection Act in Section 12220 of the California Water Code. The boundary to the north extends to Sacramento and to the south past Tracy. The western boundary is Chipps Island, while the eastern boundary is approximately at Highway 5 (DWR undated).

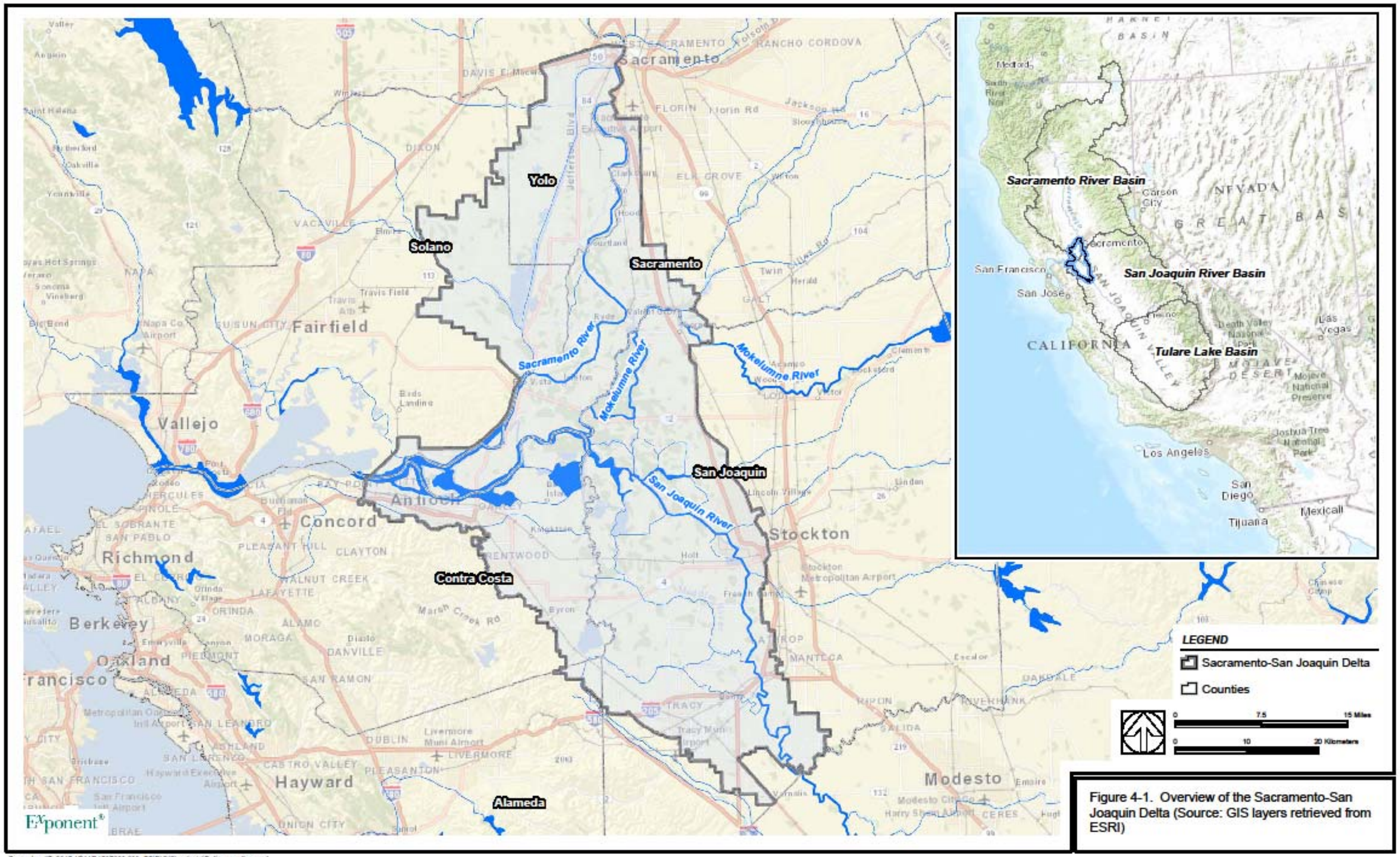


Figure 4-1. Overview of the Sacramento-San Joaquin Delta (Source: GIS layers retrieved from ESRI)

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4.2 Delta Hydrodynamics

4.2.1 Basic Delta Hydrodynamics and Delta Inflows

Fresh water flows into the Delta from three primary sources: the Sacramento River, the San Joaquin River, and east-side streams. In addition, the salinity of water within the Delta is influenced by freshwater flows to Suisun Bay and San Francisco Bay, which affect the salinity of water at the western boundary of the Delta, and by agricultural return flows within the Delta. The Sacramento River (and Yolo Bypass) provide approximately 60% to 80% of total inflow to the Delta (depending on hydrologic year type), the San Joaquin River provides about 13% to 17 % of total inflow, and the east-side streams, including the Calaveras, Cosumnes, and Mokelumne Rivers, constitute approximately 3% to 4% of total inflow (DWR 2005b, 2009). The total annual inflow to the Delta during an average precipitation year is approximately 25 million acre-ft (MAF), but inflows vary significantly during wet or dry years.

As stated in Jackson and Peterson (1977):

> The great rivers of California's Central Valley basin, the Sacramento and the San Joaquin, after draining more than one-third of the state, flow into the complex network of interconnecting channels that comprise the Delta, before entering the shallow waters of Suisun Bay on their way to the Pacific Ocean. Stretching from Mount Shasta to Kern County and from the crest of the Sierra to the Golden Gate, the waters of the Central Valley Basin and the partially overlapping San Francisco Bay tidal basin form one massive hydraulic system, part saline and part fresh, the boundary between the two varying in response to changes in the system as a whole. (Jackson and Peterson 1977)

At the western boundary of the Delta, water typically has salinity levels that are intermediate between freshwater and ocean water. The salinity at the western Delta boundary results from the mixing of saltwater that enters San Francisco Bay through the Golden Gate from the Pacific Ocean, and freshwater flows both from the Delta and from stream and river flows that enter San

Francisco Bay west of the Delta. Freshwater outflow from the Delta typically meets higher salinity water at an interface near Suisun Marsh. However, the location of this transitional zone is not fixed but rather fluctuates depending on freshwater flows and tidal action. Tidal energy from the Pacific Ocean is an important determinant of Delta water quality, because the tidal range is as much as 6 ft at Martinez, and salt water and fresh water “slosh” back and forth with the tides multiple times daily. During periods of low river inflows, the action of the tides on river stage can be seen far upstream of the Golden Gate—tidal variations in stage are observed during low-flow periods in late summer and fall as far inland as the I Street Bridge on the Sacramento River and the Mossdale Bridge on the San Joaquin River (CALFED 2007).

Salinity in the western Delta is a function of both season and year type. Salinity levels in the western Delta are typically low in the winter and spring months, when river outflows are higher as a result of winter rains and spring snowmelt, and higher in summer and fall months. During wet years, the Delta is dominated by fresh water flows, and the saltwater-freshwater interface may be pushed into San Francisco Bay to the west of the Delta. During dry years, river flows are much lower than in wet years, and the saltwater-freshwater interface may extend into the Delta.

The salinity of water within the Delta results from the balance of freshwater flows into the Delta and higher salinity water that enters the Delta from the west as a result of tidal action. However, it is important to note that even if there was no freshwater inflow into the Delta, water would be present in the Delta as the bottom elevation of most Delta channels is below sea level—i.e., even if there were no freshwater flows into the system, water from San Francisco Bay would flow into the system, and water would be present. As noted by DWR,

> Because the Delta is open to the San Francisco Bay complex and the Pacific Ocean and its channels are below sea level, it never has a shortage of water. If the inflow from the Central Valley is insufficient to meet the consumptive needs of the Delta, saline water from the bay fills the Delta from the west. Thus, the local water supply problem in the Delta becomes one of poor water quality, not insufficient quantity. (DWR 1978)

Salinity patterns within the Delta have changed markedly over time in response to changes in the configuration of the Delta and flows to the Delta. As discussed in detail in Section 5, the Delta was naturally and historically a fresh waterbody, and the saltwater-freshwater interface intruded into the western Delta only during dry months of dry years. However, changes in flow patterns (including the diversion and storage of flows upstream of the Delta) and changes in the geomorphology of the Delta (including the channelization of the Delta and the loss of tidal marsh areas) between the late 1800s and the mid-1900s changed the salinity distribution within the Delta, resulting in the movement of the freshwater-saltwater interface farther inland into the Delta.

The complexity of flow in Delta channels has long been recognized. As the SWRCB, Division of Water Rights has explained:

> It is difficult if not impossible to estimate the influence of a diversion at any one point in these delta channels upon the available water supply at other points or the influence of a diversion from one of the tributary streams upon the available water supply at any particular point in the delta. The fact is that the delta channels form a vast reservoir through which the drainage from Sacramento and San Joaquin Rivers pours to form a barrier in the upper end of San Francisco Bay, Suisun Bay and the lower delta against the salt water which would otherwise enter Golden Gate and San Francisco Bay. (SWRCB 1926)

Two large-scale water management projects, the California State Water Project (SWP) and the Central Valley Project (CVP), include various dams, canals, and pumping stations that store and transport fresh water throughout California. The SWP and CVP (together, “the Projects”) have exerted significant control on Delta hydrodynamic processes and have altered the distribution and flow of water through the system over time. The CVP is a federal project managed by the U.S. Bureau of Reclamation and is chiefly designed to transport fresh water to the Central Valley for irrigation and municipal supply. The CVP was established with the construction of Lake Shasta and dam in 1945. The CVP’s water storage and delivery capacity exceeds that of the SWP (SWP facilities and operations have a combined water storage capacity of 5.8 million acre-feet and deliver an average of 3 million acre-feet/year, while CVP has a storage capacity of approximately 11 million acre-feet and delivers an average of 7 million acre-feet/yr; CA DWR data accessed online[2]). Major CVP operations in the Delta include the Delta Cross Channel (DCC), which diverts water from the Sacramento River to the south Delta, and the C.W. Bill Jones Pumping Plant, which is located northwest of Tracy in the South Delta and lifts water into the Delta-Mendota Canal for delivery south of the Delta.

The SWP is managed by the California Department of Water Resources (DWR) and includes reservoirs, lakes, storage tanks, canals, tunnels, pipelines, and pumping and power plants located upstream, within, and downstream of the Delta.[3] The SWP was initiated when the Oroville Dam and Lake were constructed in 1968. The principal SWP facilities in the Delta currently include the North Bay pumping plants, which pump water out of the Sacramento River into the North Bay Aqueduct, and the pumping plants near Clifton Court Forebay (H.O. Banks Pumping Plant and South Bay Pumping Plant), which pump water out of the South Delta estuary into the California and South Bay Aqueducts.

The Projects capture and store water in reservoirs upstream of the Delta during the winter and spring, and release flows from upstream reservoirs during the summer and fall months. Thus, the Projects have changed the timing of freshwater inflows to the Delta, generally reducing winter and spring inflows, and generally increasing summer and fall inflows, into the Delta. In addition, water is exported by the Projects from the South Delta, which has changed both the flow rates and direction of flow in Delta channels and the distribution of water and salinity within the Delta.

Deep water channels that were dredged for shipping and navigation purposes also affect Delta hydrodynamics and flow. Channels were widened and deepened to create the Stockton and Sacramento Deep Water Ship Channels, which changed freshwater flow dynamics in the Sacramento and San Joaquin Rivers and subsequently altered tidal flow volumes and increased seawater dispersion by increasing the volume of water in the Delta (CCWD 2010).

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2 CA DWR data accessed online at http://www.water.ca.gov/swp/cvp.cfm

3 Information obtained online from: http://www.swc.org/issues/state-water-project

Delta hydrodynamics are also influenced to a lesser extent by operable or seasonal gates and barriers. For instance, operable gates at the Delta Cross Channel allow water from the Sacramento River to be re-routed to the central and south Delta by way of the Mokelumne River, and are typically closed during high-water flood periods and opened during low river flows (CALFED 2007). These channel "cross-cuts" can also serve to increase the efficiency of tidal flow through the Delta by enhancing the interconnectedness of flow paths (CCWD 2010).

Delta hydrodynamics have been studied and verified through data recorded throughout the system by various agencies, including DWR and the U.S. Geological Survey (USGS). DWR maintains a database (the California Data Exchange Center, or CDEC) that compiles data regarding current and historical flows, full natural flow, water quality, river stage, temperature, and other measured parameters. Figure 4-2 shows locations of monitoring stations and other significant landmarks within the Delta boundary relevant to this report.

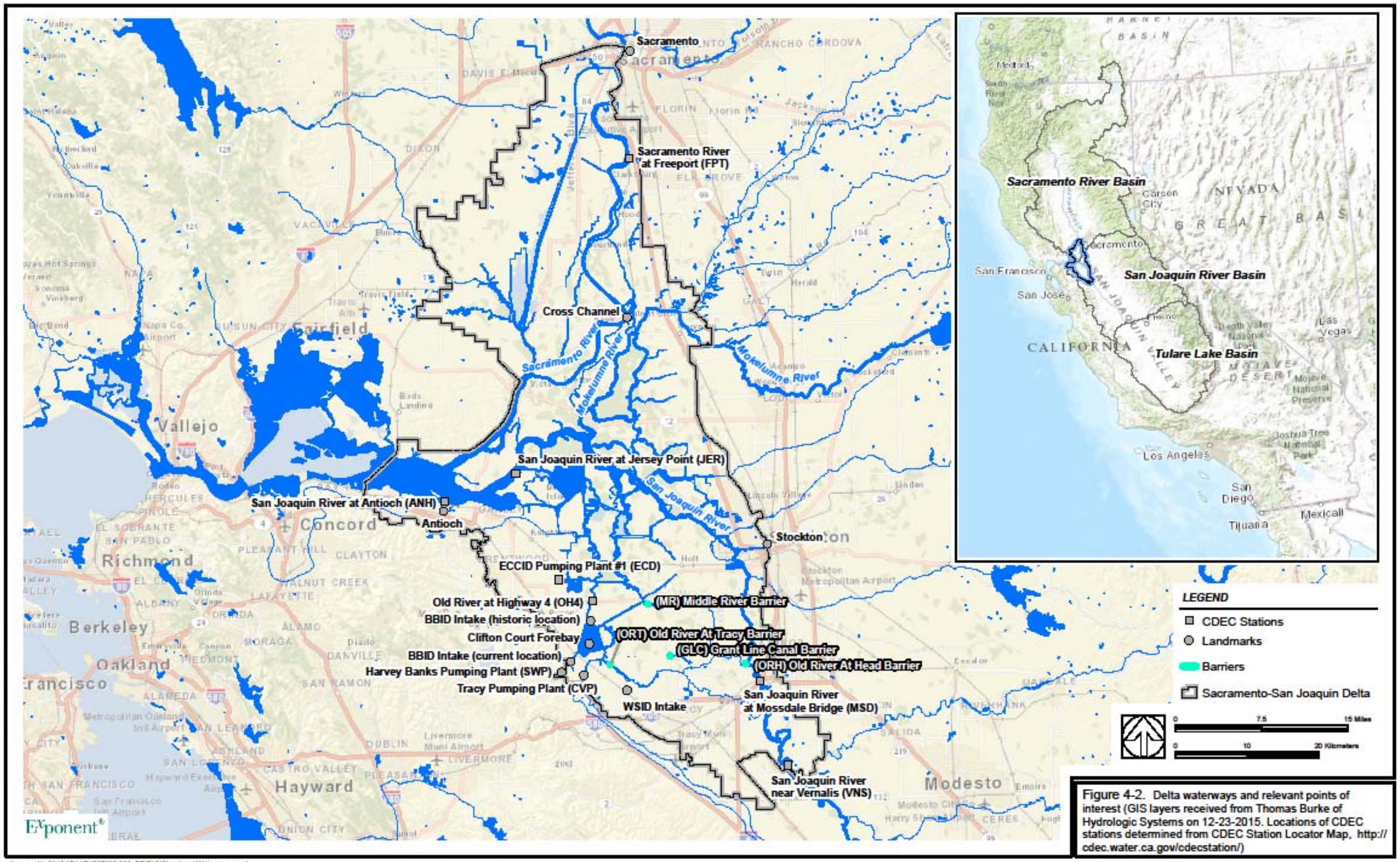

Figure 4-2. Delta waterways and relevant points of interest (GIS layers received from Thomas Burke of Hydrologic Systems on 12-23-2015. Locations of CDEC stations determined from CDEC Station Locator Map, http://cdec.water.ca.gov/cdecstation/)

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4.2.2 Delta Outflows

Water leaves the Delta through both natural and manmade flow pathways. In 1971, the SWRCB explained that "Delta outflow is a calculated quantity determined from measurements of river inflows, estimates of use, evaporation and soil absorption or releases within the Delta, and measurements of quantities pumped out of the Delta for export" (SWRCB 1971). As a long-term historical average, about 70% of the outflow is through Suisun Bay to the Pacific Ocean, approximately 14% is exported to the California Aqueduct through Banks Pumping Plant, 9.5% is exported to the CVP, 6.5% is diverted and used within the Delta, 0.5% is diverted by the Contra Costa Water District (CCWD), and approximately 1% to 2% is exported through the North Bay Aqueduct (California Water Plan Update 2005; DWR 2005b) (Figure 4-3). However, outflows and exported quantities vary significantly depending on the year and hydrologic conditions. As detailed in Section 4.2.3, in many parts of the Delta, net flows (i.e., tidally-averaged flows) are much lower than tidal flows. Figure 4-4 shows the typical maximum Delta tidal flows over a 25-hour cycle in the summer (numbers shown on the figure are in cubic feet per second, cfs).

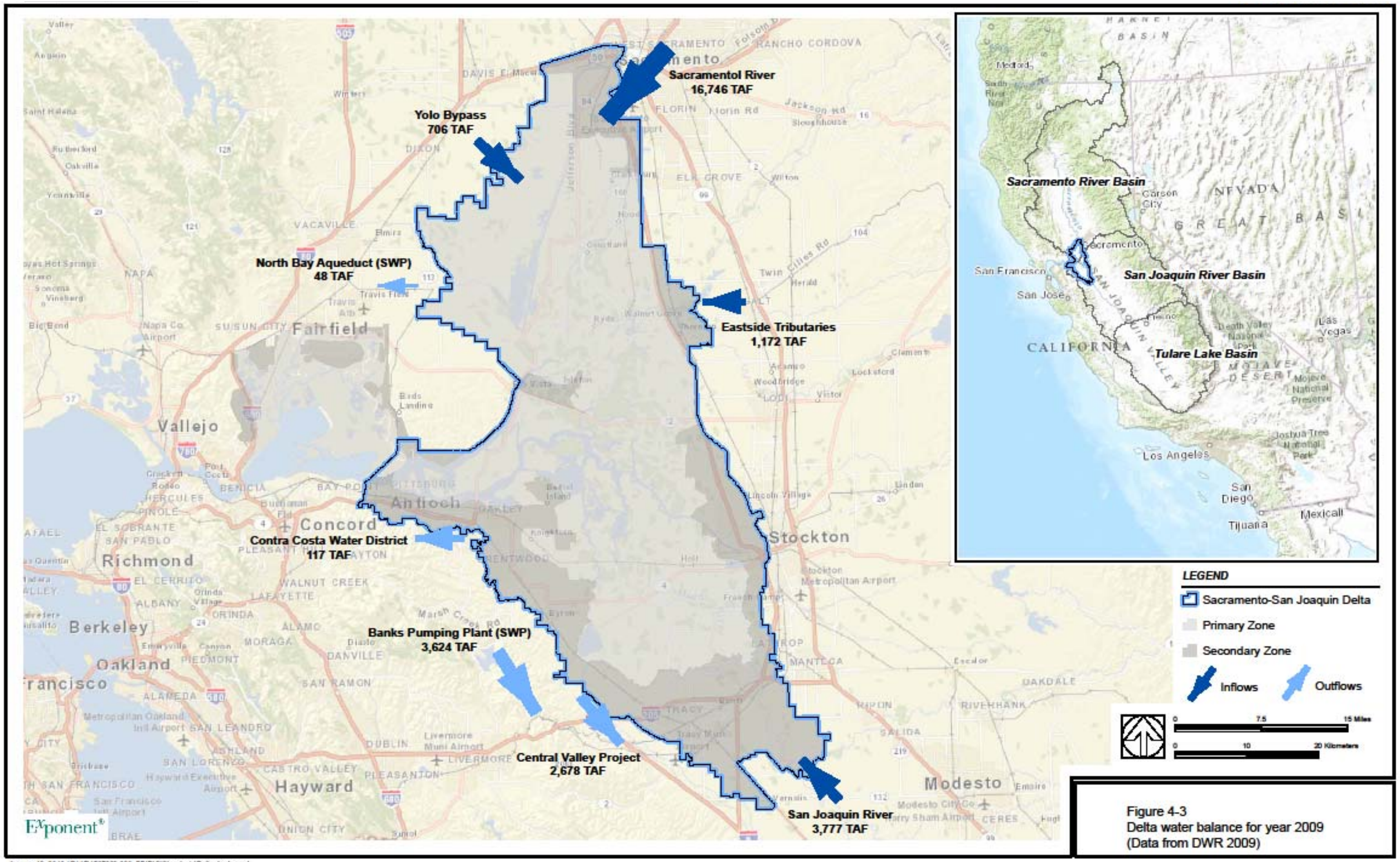

Figure 4-3
Delta water balance for year 2009
(Data from DWR 2009)

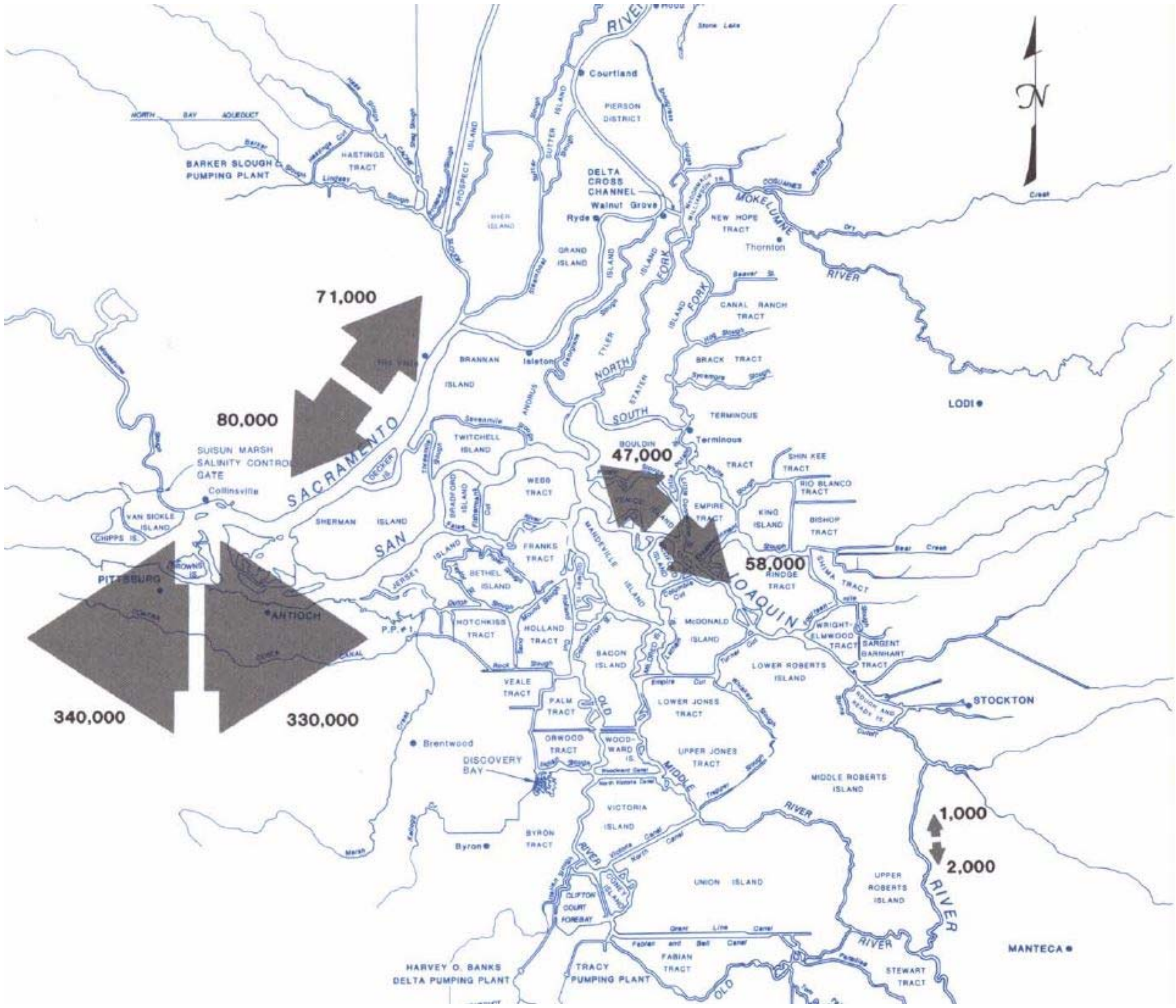

Figure 4-4. Typical maximum Delta tidal flows over a 25-hour cycle in summer conditions (values in cubic feet per second, cfs) (Image from DWR 1995b)

4.2.3 Tidal Behavior of Flow

Figure 4-6 illustrates that tidal flows are often much larger than net (tidally-averaged) flows within the Delta. Tidal influences are strongest in the western portion of the Delta, where Delta outflows enter San Francisco Bay, but extend throughout the Delta. The magnitude of tidal effects within the Delta varies according to tidal cycle, Delta location, and season. Figure 4-5 shows the river stage over a single day in June 2015 in the South Delta (graph A) and North Delta (graph B) at Martinez, at three monitoring locations in the South Delta, and at two locations in the North Delta. The data in Figure 4-5 show that peak tidal stage occurs first at Martinez, then propagates upstream, with a delay of about 3 hours to the San Joaquin River at Jersey Point, 6 hr to Old River at Highway 4, and about 7.5 hours to the San Joaquin River at Mossdale Landing. On the Sacramento River, high tides above the Delta Cross Channel and at Freeport occur about 4 and 5.5 hours after high tide at Martinez, respectively. The river stage varies by as much as 6 ft over the course of a day, depending upon location. The tidal range (i.e., the difference between the water surface elevations at high and low tides) decreases as a function of distance from the Bay, such that the tidal range is greatest at Martinez in the western Delta and decreases as one moves upstream into the rivers that enter and flow through the Delta.

Flow rates throughout the Delta are also strongly influenced by the tides. Figure 4-6 presents river flow rates at selected Delta locations in March and June 2015. Flow rates in the San Joaquin River at Jersey Point (in the Western Delta near the mouth of the San Joaquin River) during this period ranged from about 150,000 cfs in both the upstream and downstream directions, with net flow rates on the order of 2500 to 3200 cfs (see Figure 4-6, C and D). By contrast, flow rates in the Sacramento River at Freeport ranged from 640 to 15,600 cfs (average 9616 cfs) during the first week of March 2015, and from –4130 to 14,600 cfs (average 6436) on June 16, 2015 (Figure 4-6, A and B). Flow reversals and "sloshing flow" also occurred in the San Joaquin River at Mossdale Bridge and in Old River at Highway 4 (Figure 4-6, A and B).

Note that tidally-driven fluctuations in stage do not necessarily correspond to reversals in flow direction; as shown in Figure 4-6, B and D, stage in the Sacramento River at Freeport varied by about 3 feet, but flow in the river was uniformly in the downstream direction during early March 2015 (Figure 4-7). In addition, flow reversals caused by tidal forcing do not mean that salinity from the Bay is present at these locations—even though the Sacramento River at Freeport experiences frequent "flow reversals" during periods of low daily river flow, it remains a freshwater river at this location year-round.

Because water flows within the Delta respond to changes in water surface elevation, hydrodynamics within the interior Delta are complex.

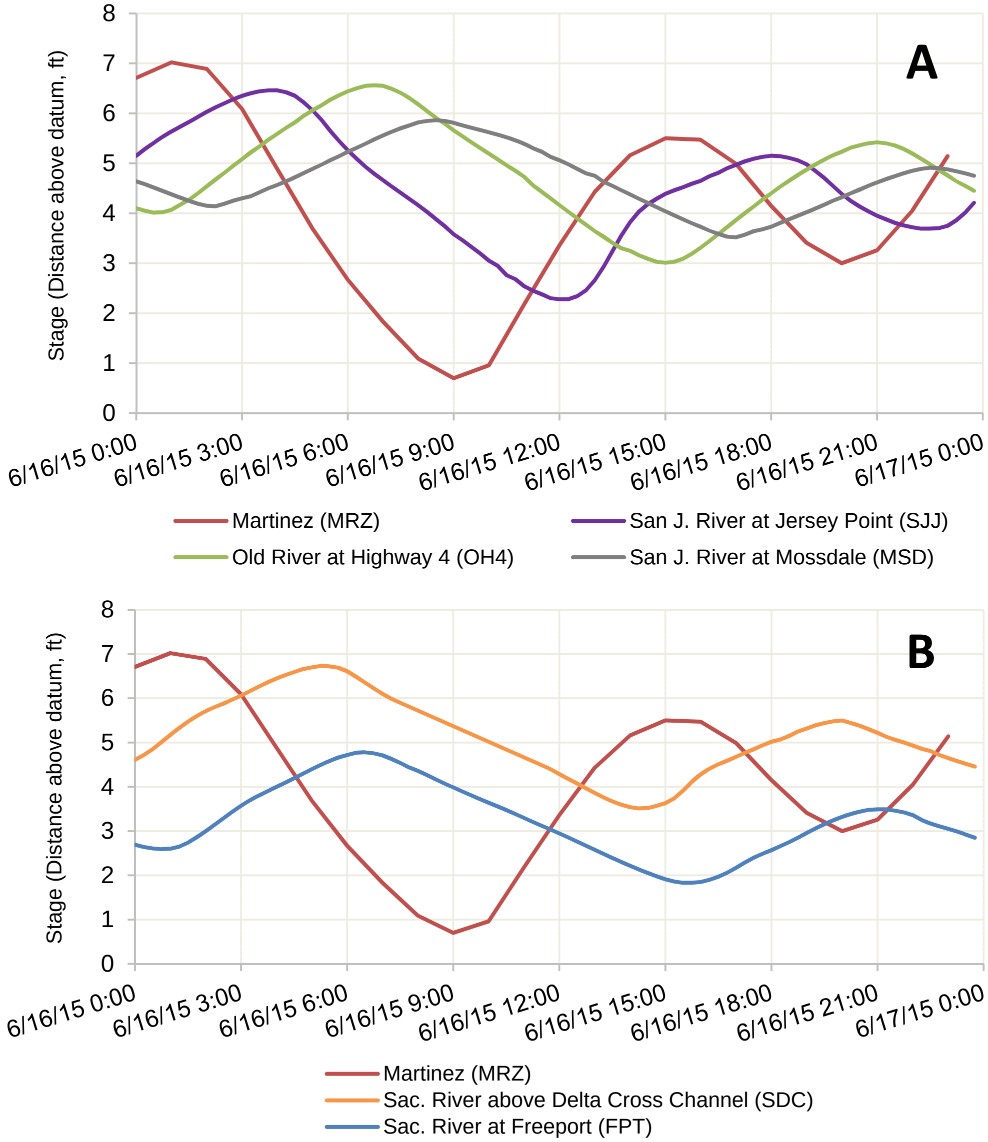

Figure 4-5. River stage over a single day in the South Delta (A) and North Delta (B) (Data from CDEC, accessed online 1-4-2016).

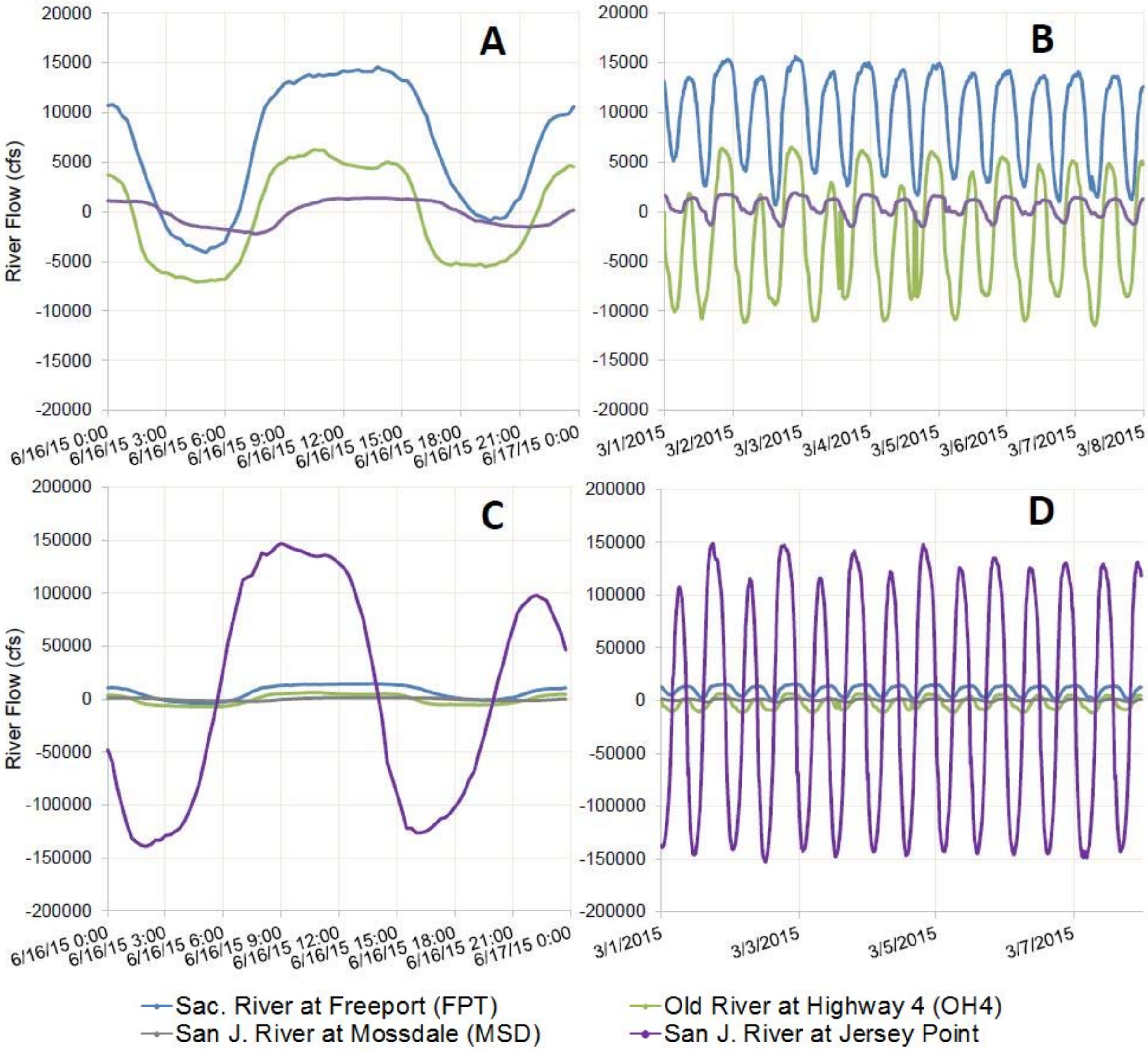

Figure 4-6. Flow rates measured on June 16, 2015 (A) and from March 1 to 7, 2015 (B) at multiple locations in the Delta. Graphs B and C include flow in the San Joaquin River at Jersey Point. Note the scales of graphs B and C are 10 times greater than the scales of graphs A and B. Flow data were not available at the Martinez station (Data from CDEC, accessed online 1-4-2016).

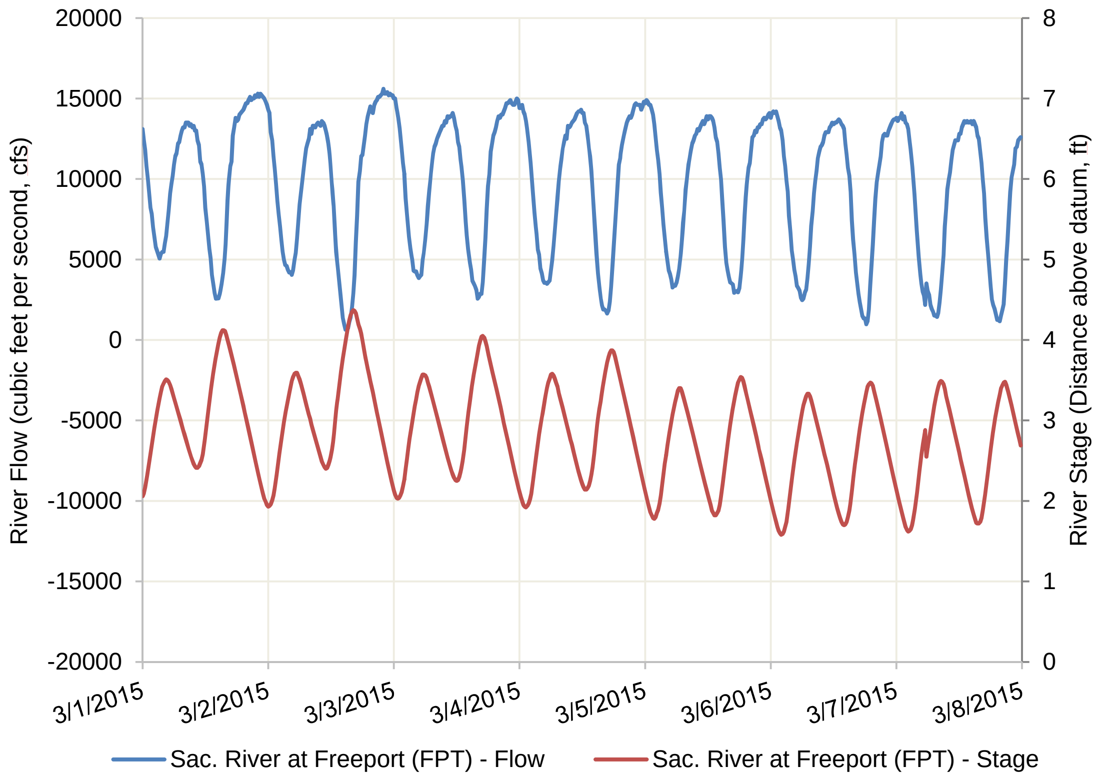

Figure 4-7. Flow rate and stage at Freeport from March 1 to 7, 2015 (Data from CDEC, accessed online 1-4-2016).

4.3 Variations in Hydrology

Multiple drought periods have occurred over the last century. Water years are classified according to the volume of runoff received and are designated as either wet, above normal, below normal, dry, or critical. DWR calculates a water index number, which accounts for both the hydrology of the current year and the previous year's hydrology and index. Extreme drought years are classified as critical with a water index number less than 5.4 (Sacramento Valley) or 2.1 (San Joaquin Valley). Critical water years in the Sacramento River Valley included 1924, 1929, 1931, 1933, 1934, 1939, 1976, 1977, 1988, 1990–1992, 1994, 2008, 2014-2015 (CDEC, data accessed online 1-6-16). The ten years from the period 1906 to 2015 that had the lowest indices on the Sacramento and San Joaquin Rivers are shown in Table 4-1 (note that the index value for 2015 is an estimated value, as final calculations for WY 2015 are not yet available). Water year indices and classifications for the entire 1906 to 2015 period are included in Appendix C.

As shown in Table 4-1, WY 2015 is the 4th ranked year in terms of the Sacramento Valley index, and the 1st ranked year in terms of the San Joaquin Valley index.

Table 4-1. Ten water years between 1906 and 2015 with the lowest water year indices for the Sacramento and San Joaquin Valleys

Sacramento Valley				San Joaquin Valley			
Water Year	Index	Type	Unimpaired Runoff (Sacramento & San Joaquin Valleys) (MAF)[1]	Water Year	Index	Type	Unimpaired Runoff (Sacramento & San Joaquin Valleys) (MAF)
1977	3.11	C	6.2	2015	0.7	C	10.7
1931	3.66	C	7.8	1977	0.84	C	6.2
1924	3.87	C	7.2	2014	1.16	C	9.2
2015[2]	4	C	10.7	1931	1.2	C	7.8
1992	4.06	C	11.4	1961	1.38	C	14.1
1934	4.07	C	10.9	1924	1.42	C	7.2
2014	4.08	C	9.2	1934	1.44	C	10.9
1991	4.21	C	11.6	1988	1.48	C	11.7
1933	4.63	D	12.3	1990	1.51	C	11.7
1988	4.65	C	11.7	1992	1.56	C	11.4

[1] Value is the total unimpaired runoff (measured by eight-river FNF) in the Sacramento and San Joaquin Valleys

[2] 2015 water year index and classification are forecasted values from May 2015; final 2015 data not currently available (1-13-16).

Data from CDEC, accessed at http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

Full natural flow (FNF) is defined by the California Data Exchange Center (CDEC) as “the natural water production of a river basin, unaltered by upstream diversions or storage, or by export or import of water to or from other watersheds” (DWR 2011). The term FNF is often taken to be synonymous with unimpaired flow (UF), unimpaired runoff, natural flow, or natural runoff and typically varies according to weather patterns and hydrologic conditions; FNF increases in the winter and spring months when there is greater precipitation and snow melt. However, distinctions between FNF and UF have been made in Bay-Delta office reports, where FNF is defined as a theoretical flow in a pre-development state, and UF is an estimated natural flow assuming consistent river configurations and the same groundwater accretion and depletion as in the historical condition (DWR 2011). FNF into the Delta is defined by the 8-river index, which is the sum of runoff from major rivers of the Sacramento and San Joaquin Valleys. For the Sacramento River basin, FNF includes flows in the Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake. FNF in the San Joaquin River basin is calculated as the sum of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake (WSIHIST Report).[4] FNF data for individual rivers, as well as the eight-river runoff composite, are available on the CDEC website. CDEC reports the eight-river runoff value as a water year sum (i.e., the sum of runoff in the Sacramento Valley and in the San Joaquin Valley). Table 4-3 presents the ten water years between 1910 and 2015 that have the lowest WY runoff sum in the Sacramento and San Joaquin Valleys (i.e., as defined by the eight-river FNF). WY 2015 is the 7th ranked year according to total runoff in both valleys (Table 4-2).

Table 4-2. Top ten water years between 1906 and 2015 ranked by lowest runoff in the Sacramento and San Joaquin Valleys (Eight-River FNF)

Sacramento and San Joaquin Valleys					
Water Year	Unimpaired Runoff (Sacramento & San Joaquin Valleys) (MAF)	Sacramento Valley WY Index	Sacramento Valley Year Type	San Joaquin Valley WY Index	San Joaquin Valley Year Type
1977	6.2	3.11	C	0.84	C
1924	7.2	3.87	C	1.42	C
1931	7.8	3.66	C	1.2	C
2014	9.2	4.08	C	1.16	C
1976	10.2	5.29	C	1.57	C
1994	10.3	5.02	C	2.05	C
2015[1]	10.7	4	C	0.7	C
1934	10.9	4.07	C	1.44	C
1939	11.1	5.58	D	2.2	D
1929	11.2	5.22	C	2	C

[1] 2015 water year index and classification are forecasted values from May 2015; final 2015 data not currently available (1-13-16).

Data from CDEC, accessed at http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

[4] http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

The 1931 water-year indices are the lowest on record in the Sacramento and San Joaquin Valleys prior to implementation of the CVP (1945) and the SWP (1968). The 1931 water year is considered to be similar to that of 2015 based on water-year index and classification (Table 4-3). It is useful to evaluate the hydrologic processes and water quality that occurred in 1931, because they would be similar to those that would have occurred in 2015 if the CVP and SWP were not operating (i.e., 1931 is representative of a "2015 without Project" scenario). Although the 1977 water year had the lowest Sacramento River Basin water year index in recorded history (1906–2014), freshwater releases from the CVP and SWP reservoirs mitigated salinity intrusion into the Delta during the drought conditions (2015 water year was forecasted to have lowest water year index for San Joaquin Basin). The 1977 water year is therefore useful for examining water quality conditions in the Delta during drought periods where water projects periodically prevented or minimized salt water intrusion by releasing fresh water from upstream reservoirs.

Table 4-3. Comparison of runoff (Eight-River FNF), water year indices, and water year classifications in the Sacramento and San Joaquin Valleys in 1931, 1977, and 2015.

	Sacramento Valley		San Joaquin Valley		Unimpaired Runoff (Sacramento & San Joaquin Valleys) (MAF)
Water Year	Index	WY Type	Index	WY Type	
1931	3.66	Critical	1.2	Critical	7.8
1977	3.11	Critical	0.84	Critical	6.2
2015[1]	4	Critical	0.7	Critical	10.7

[1] 2015 water year index and classification are forecasted values from May 2015; final 2015 data not currently available (1-13-16).

Data from CDEC, accessed at http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

4.4 Residence Time of Water in the Delta

Residence time is a measure of the amount of time that water spends within a system; residence time is a function of the amount of water present in the system and the flow rate of water into (or out of) the system. The residence time can be estimated as follows:

$$Residence\ time = \frac{Volume\ of\ water}{Flow\ rate\ into\ system} = \frac{Volume\ of\ water}{Flow\ rate\ out\ of\ system}$$

During high flow conditions, residence times are shorter, while during low flow (drought) conditions, residence times are longer.

Jassby and Cloern (2000) estimated that the waterways within the Delta have a surface area of approximately 230 million m^2 (57,000 acres, or 2.5 billion ft^2) and a water depth ranging from less than 1 m (3.3 ft) to greater than 15 m (49 ft). Assuming an average depth of 6 m (20 ft), the volume of water in the Delta at any point in time would be 1.4 billion m^3 (1.2 million acre-feet). Assuming a mean inflow of 1700 m^3/s (1.37 acre-feet/s, or 60,000 cfs) during the winter, and 540 m^3/s (0.44 acre-feet/s, or 19,000 cfs) during the summer (Jassby and Cloern 2000, 1968-1995), the average residence time of water in the Delta would be approximately 10 days during the winter and 30 days during the summer.

DWR has used modeling to perform more detailed estimates of residence time. Specifically, DWR calculated the residence time of fresh water in the Delta using particle tracking simulations modeled with the DSM2 HYDRO software (Mierzwa et al. 2006a, 2006b, and Wilde et al. 2006c). Mierzwa et al. (2006a and 2006b) simulated the residence time of water in the Delta between 1990 and 2004 by tracking water that entered the system at Freeport (on the Sacramento River) and at Vernalis (on the San Joaquin River). The residence time was defined as the number of days required for 75% of the particles injected over a 24-hour period at a specific location (e.g., Freeport) to leave or be removed from Delta channels. The particles were assumed to have left Delta channels when they passed (i.e., were detected) at the following locations: SWP and CVP pumps, CCWD and North Bay Aqueduct intakes, Delta island diversions, and the Sacramento River at Chipps Island. Mierzwa et al. (2006a and 2006b) determined the average 75% particle residence time for each month (e.g., every February, every October) between 1990 and 2004, and then calculated a long-term mean for each month with those averages. The long-term mean monthly residence times are shown in Table 4-4, together with minimum and maximum monthly residence times during the 1990–2004 time period.

The monthly average residence times of Sacramento River inflows ranged from an average of 16 days during February (minimum of 3 days and maximum of 38 days), to 51 days during October (minimum of 37 days and maximum of 74 days). Monthly average residence times for San Joaquin River flows ranged from an average of 16 days during January (minimum of 6 days and maximum of 38 days), to 33 days during April (minimum of 8 days and maximum of 54 days). As expected, residence times were longer during dry years than during wet years; minimum residence times for Sacramento inflows occurred during 1997 and 1998, which were wet years, while maximum residence times occurred during 1992, a critically dry year.

Because 2015 was drier than 1992 in the Sacramento and San Joaquin Valleys (see Tables 4-1 and 4-2, and Appendices B and C), the residence time of water in the Delta during 2015 would have exceeded the maximum residence times estimated by the DWR particle tracking studies (e.g., residence times in October 2015 would have been greater than the residence time of 74 days that was estimated for Sacramento River water that entered the Delta in October 1992).

As detailed in Section 6.2, DSM2 model results were used to create animations of model results. Animations were created for WY 1931 and WY 2015 where “source fingerprinting” was used to tag the Sacramento River water that entered the Delta during the months of March and April. These animations demonstrate that, during WY 1931 and WY 2015, some fraction of the Sacramento River that entered the Delta in March and April 2015 remained in the Delta for approximately six months. These animations are discussed in greater detail in Section 6, and select images from the movie files are included in Appendix E.

Table 4-4. Average monthly residence times (in days) between 1990 and 2004 for flow entering the Delta from the Sacramento River at Freeport and from the San Joaquin River at Vernalis. Calculated residence times assume that 75% of simulated particles have left or were removed from Delta channels (Data from Mierzwa et al. 2006b).

Month	Freeport			Vernalis		
	Min	Mean	Max	Min	Mean	Max
January	3	21	56	6	16	28
February	3	16	38	6	17	27
March	4	22	58	7	21	46
April	5	34	89	8	33	54
May	5	39	87	13	29	49
June	6	38	80	9	18	25
July	16	35	70	6	17	27
August	22	40	71	7	16	29
September	25	49	82	17	28	62
October	37	51	74	18	31	70
November	19	40	70	18	32	60
December	6	28	64	12	21	42

4.5 Variations in Salinity within the Delta

The salinity of water in the Delta has historically been expressed as electrical conductivity (EC), total dissolved solids (TDS), or chloride. Many salinity measurements in the Delta are made using EC because the analysis is more cost-effective and quicker than measuring TDS or chloride, and an EC measurement can be taken *in situ*, making it useful for grab sampling or continuous monitoring. EC is thus widely used as a surrogate for salinity (Guivetchi 1986). Guivetchi (1986) also derived linear relationships between EC, TDS, and chloride, generating mathematical equations for various locations in the Delta that can be used to convert one type of salinity measurement to another. (Table 4-5 provides salinity conversions derived using the methods of Guivetchi (1986).).

Table 4-5 Conversion between salinity measurements at Clifton Court and Chipps Island according to the methods developed in Guivetchi 1986

Electrical Conductivity (EC) µS/cm	Clifton Court Intake [1]		Chipps Island [2]	
	Total Dissolved Solids [3] (TDS) mg/L	Chloride [3] (Cl^-) mg/L	Total Dissolved Solids [3] (TDS) mg/L	Chloride [3] (Cl^-) mg/L
200	125	11	63	~0
500	284	84	247	66
1000	548	207	554	233
1500	812	329	861	401
5000	NA	NA	3011	1574
10000	NA	NA	6082	3250
20000	NA	NA	12224	6602

[1] Station CHWST0 (West Canal at mouth of Clifton Court Intake) in Guivetchi 1986

[2] Station RSAC075 (Sacramento River at Old Railroad Bridge South of Chipps Island) in Guivetchi 1986

[3] Water Year type "All" was used for salinity measurement conversions (Guivetchi 1986)

NA indicates that the EC exceeds the maximum value used for development of conversion relationship

The EC (salinity) of freshwater inflows to the Delta is lower than that of sea water or water from San Francisco Bay. For example, in 2015, averaged measured EC in the Sacramento River at Freeport was 168 µS/cm (equivalent to TDS of 103 mg/L using the method of Guivetchi 1986) and ranged from approximately 109 to 281 µS/cm (TDS from 72 to 163 mg/L). Average EC in the San Joaquin River at Vernalis was 595 µS/cm (343 mg/L TDS), ranging from 99 to 1323 µS/cm (48 to 776 mg/L TDS), and average EC at Martinez (downstream boundary of Delta) was 26,384 µS/cm (17,882 mg/L TDS), ranging from 11,501 to 47,204 µS/cm (7440 to 32,490 mg/L TDS) (CDEC, data accessed online 1-6-15, Figure 4-8). By contrast, the salinity of seawater is approximately 50,000 µS/cm (35,000 mg/L TDS).

Agricultural return flows are also a source of salinity to the Delta. Agricultural return flows have elevated salinity levels as a result of the concentration of salts from soils, from fertilizers used within the Delta, and from evaporation of water applied for irrigation. Although there are many sources of agricultural return flows, few have been characterized with respect to salinity levels or flow rates. It has been estimated that, in the San Joaquin River at Vernalis, agricultural surface runoff occurring upstream of Vernalis accounts for up to 43% of total salt loading in the San Joaquin River at Vernalis[5] (CALFED 2007, based on historical data 1977–1997). The Delta Island Consumptive Use (DICU) parameters used in the DSM2 model assume a constant seasonal salinity pattern in Delta diversions and return flows, and assume that this salinity pattern is the same for all water-year types (i.e., wet or dry year). Variation in salinity of agricultural runoff or in-Delta flows that may occur during a wet or dry year is therefore not captured in the model. The EC used in the DICU ranges from approximately 340 to 1840 µS/cm (34 to 420 mg/L chloride), with lowest EC values in July and highest values in EC January (Jung 2000, DWR 1995a). Because agricultural return flows occur at hundreds of locations within the Delta, return flows may significantly affect the salinity of water within the Delta. The extent to which agricultural return flows increase salinity levels at specific locations within the Delta is a function of the amount of flushing that occurs at those locations—i.e., the salinity impacts of agricultural return flows are greatest when net flows past a specific location are lowest (equivalent to high residence times).

Wastewater treatment plants are also sources of salinity to the Delta. In the Sacramento River, wastewater treatment plant effluent constitutes approximately 7% of the salt load at Hood (CALFED 2007). Although flows of treated wastewater are typically a small fraction of freshwater river inflows, the percent contribution increases in dry years. In 2015, effluent discharge from the Sacramento Regional Wastewater Treatment Plant had an average salinity of 925 µS/cm, with a range of 660 to 1000 µS/cm, and discharge flow rates averaged 116 MGD (California Integrated Water Quality System online database, accessed 1-6-16).

The largest source of salinity to the western Delta is sea water from the San Francisco Bay, which is brought into the Delta by tidal action. As freshwater flow rates of rivers fall, salinity from the Bay can intrude into the Delta, degrading water quality from west to east over time.

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5 Salt loading to rivers and tributaries far upstream of the Delta from agricultural practices in the Central Valley may exacerbate and increase the salt loads into the Delta.

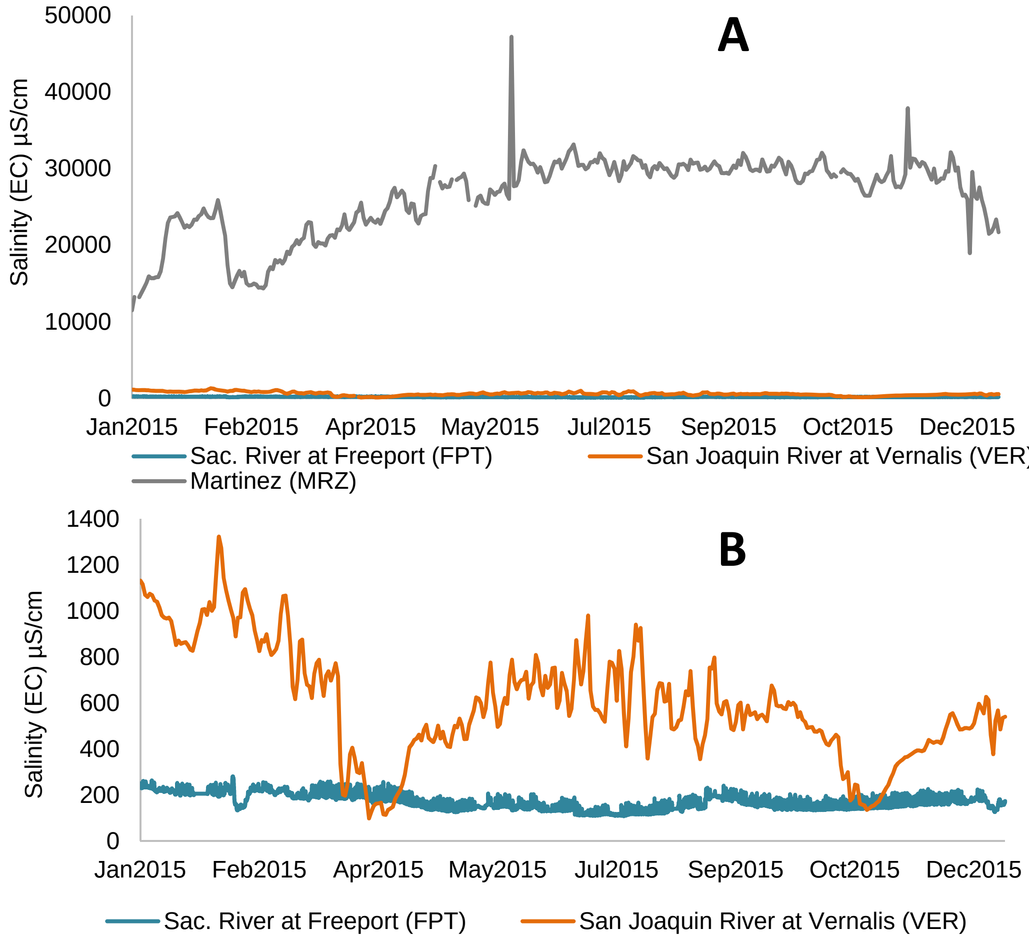


Figure 4-8. Salinity concentrations (measured as EC) in the Sacramento River at Freeport, the San Joaquin River at Vernalis, and at Martinez in 2015. Graph B has a lower y-axis scale than graph A to show EC at Freeport and Vernalis. (Data from CDEC, accessed online 1-6-2016).)

The CVP and SWP release water from reservoirs far upstream of the Delta, particularly during the end of summer and fall, which augments freshwater flows within the Delta during the drier months of the year. Releases during the summer and fall result in higher river inflows and fresher conditions (i.e., lower salinity) in the Delta (CALFED 2007; Enright and Culberson 2009; see also Section 5 below). In contrast, the CVP and SWP store runoff during the winter and spring months, such that freshwater inflows to the Delta during winter and spring are typically lower than would occur without the operation of the CVP and SWP; winter and spring project operations result in an increase in salinity in the Delta during the winter and spring months relative to salinity levels that would occur without the Projects (CALFED 2007; Enright and Culberson 2009; see also Section 5).

The deepwater ship channels can also affect salinity within the Delta, because the increased depth and width (volume) of the channels increase salinity intrusion from the Bay by allowing for increased tidal flow through the channels and salt mixing within the channels (CCWD 2010).

Salinity levels within the Delta are a complex function of freshwater inflows, flushing and residence times within the Delta, and salinity from the Bay that enters the Delta as a function of tidal action.

Salinity (EC) is measured in the Old River north of Tracy, to the east of the intakes of BBID and WSID (data reported on CDEC) (Figure 4-9). In 2014 and 2015, Old River north of Tracy remained relatively fresh. Average daily EC between January 1, 2014 and December 30, 2015, was approximately 1020 µS/cm (ranging from about 500 µS/cm to a maximum of 1636 µS/cm). At the Banks Pumping Plant and Clifton Court Forebay (i.e., near the BBID intake), EC ranged from approximately 380 to 1000 µS/cm in 2014 and 2015. At Clifton Court, EC ranged from approximately 410 to 1020 µS/cm, with an average daily value of about 639 µS/cm.

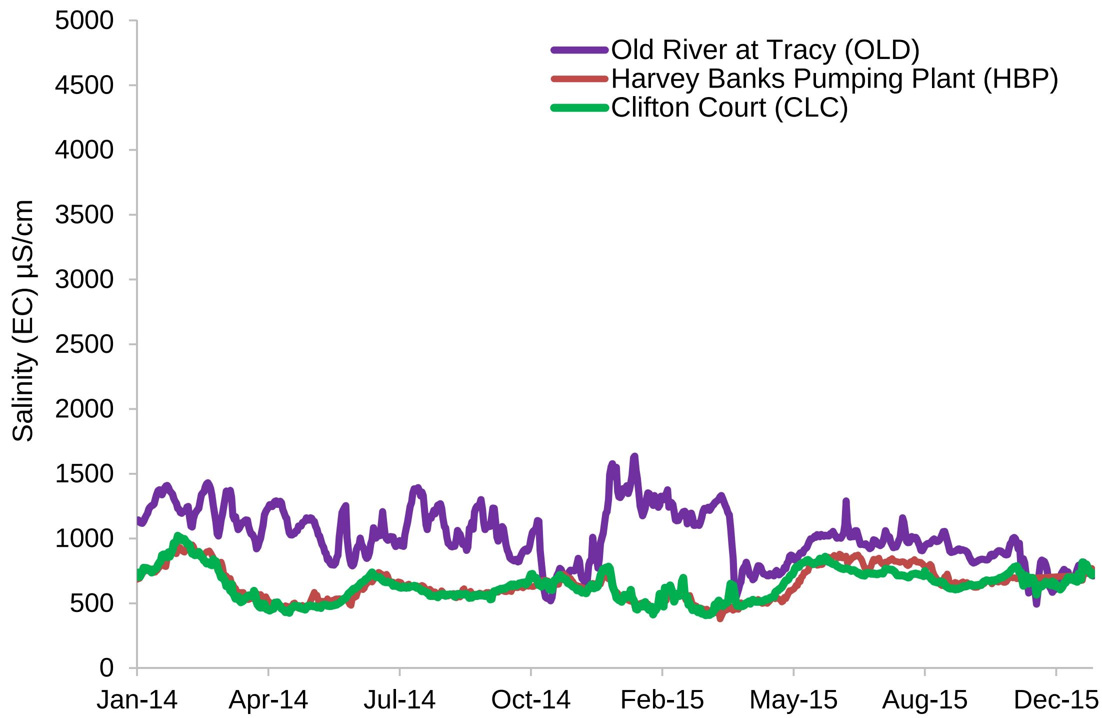


Figure 4-9 Salinity concentrations (measured as EC) in Old River at Tracy, Harvey Banks Pumping Plant (HBP), and Clifton Court (CLC) in 2014 and 2015 (Data from CDEC, accessed on 1-16-16).

4.6 Source Fingerprints

Because waters entering the Delta have different "source fingerprints," the source of flow within the Delta can be determined either by using water samples collected throughout the Delta or by modeling. Source fingerprints can be used to determine both the location and time at which freshwater flows entered the Delta. Dr. Paulsen conducted work of this nature using water samples collected from five key locations in the Delta; specifically, Dr. Paulsen used the elemental "fingerprints" of the three primary inflow sources (the Sacramento River, the San Joaquin River, and the Bay at Martinez), together with the elemental "fingerprints" of water collected at two interior Delta locations (Clifton Court Forebay and Franks Tract) and a simple mathematical model, to establish the patterns of mixing and distribution of source flows within the Delta during the 1996–1997 time period (Paulsen 1997). Dr. Paulsen's work was later used to validate the source fingerprinting determined using Delta models (e.g., DSM2, the FDM).

DSM2 has been widely used by the California DWR to analyze the source of water within the Delta for various time periods and conditions, and for both observed and hypothetical conditions (e.g., to evaluate the impacts of potential operational changes). Five inflows are typically considered in the DSM2 model for fingerprinting purposes: the Sacramento River, San Joaquin River, east-side streams, agricultural return flows, and flows from the Bay at Martinez. For a given date and location, the DSM2 model can be used to calculate the percentage contribution from each of the respective inflow sources.

Figure 4-10 presents the results of volumetric fingerprinting analyses performed by DWR to evaluate the source of water (top panel) and the source of salinity (bottom panel) within the Delta between October 2014 and February 2015 (2015 DWR data online at http://www.water.ca.gov/waterquality/drinkingwater/public_docs, accessed 1-8-16). Figure 4-10 (top) shows that, during this time period, approximately 75% or more of the water present in Old River at Highway 4 entered the Delta from the Sacramento River. Figure 4-10 also shows that even though only a small fraction of the water at this location originated from Martinez (top panel), water from Martinez was the largest source of EC (salinity) at this location (bottom panel).

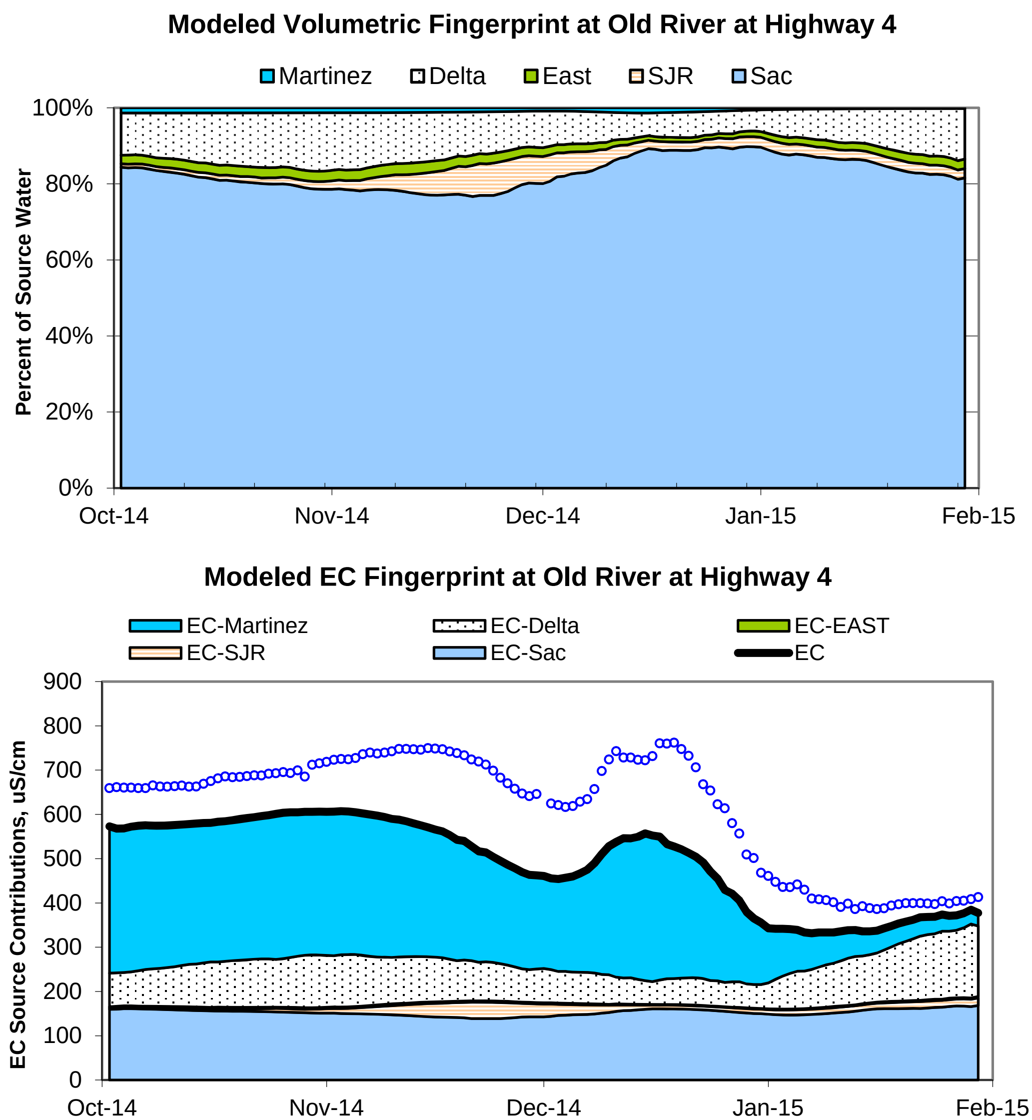
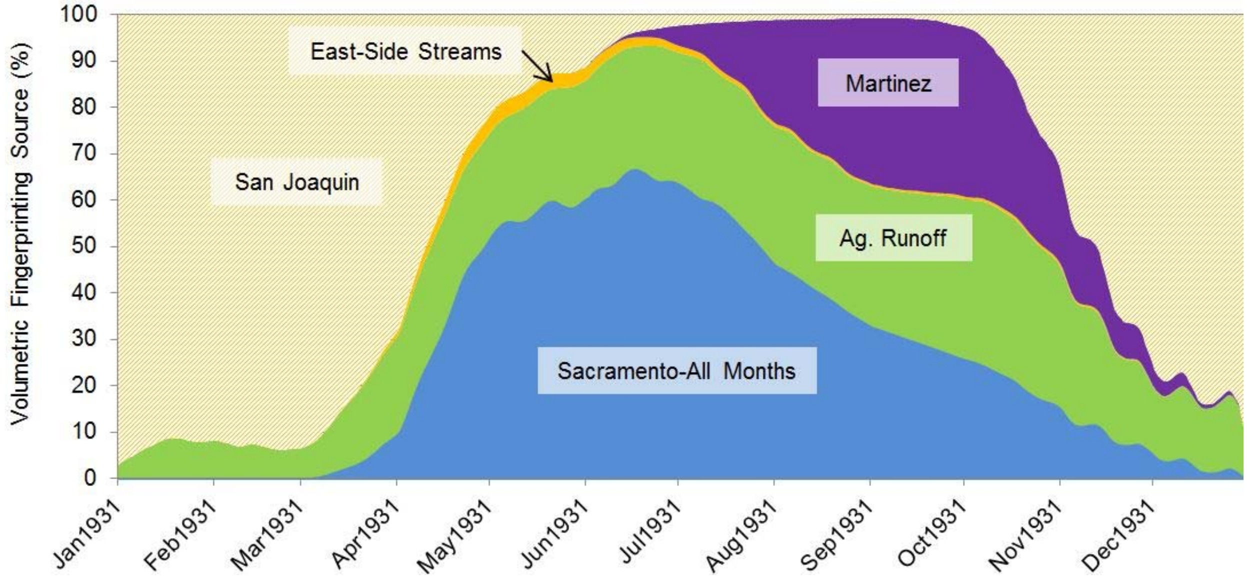


Figure 4-10. Source fingerprinting by volume (top) and EC (bottom) in Old River at Highway 4 between October 2014 and February 2015 (Data collected and plotted by DWR; obtained online at www.water.ca.gov on 1-6-2016)

Volumetric fingerprinting can also be used to show how the distribution of water has changed within the Delta over time. Figure 4-11 presents the source of water in Old River at Highway 4 during 1931 (a pre-Project condition) and during 2015 (current, post-Project conditions); the model runs used to obtain the source fingerprints in Figure 4-11 are described in Section 6. As shown in Figure 4-11 (top), San Joaquin River water was the primary source of water in Old River in the months of November to April (i.e., the wet season), while Sacramento River water was the primary source at this location in the months of May to September 1931. By contrast, and consistent with Figure 4-10, Sacramento River water comprised 75% of the water present in Old River at Highway 4 in 2015 during all months. Thus, it is clear that the Projects and other changes within the system have changed the distribution of freshwater within the Delta significantly.

In addition to calculating the location at which water interior to the Delta entered the estuary, the DSM2 model can also be used to identify the time period when the source water at a given location entered the Delta. For example, at Old River (near Highway 4), the fingerprinting analysis can determine what percent of the water originated from each of the five different inflows (Sacramento River, San Joaquin River, east-side streams, agricultural return flows, and flows through Martinez), and the approximate time period when the source flow entered the Delta (e.g., Sacramento River in June). The source makeup of water in the Delta varies according to location and time. The results of the volumetric fingerprinting work are presented in Section 6.



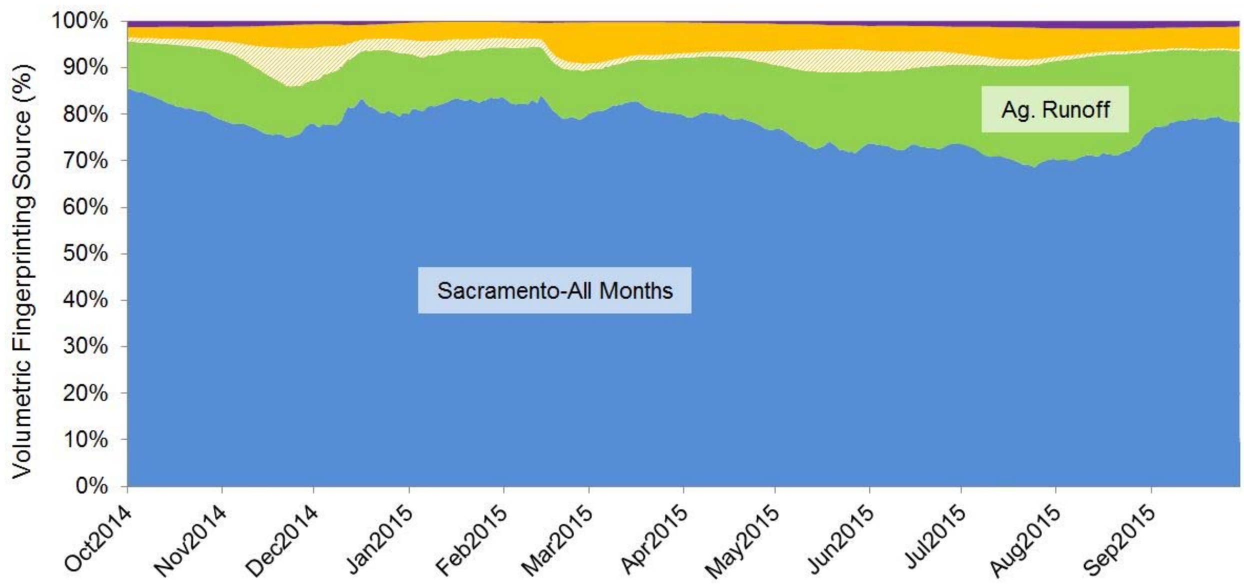


Figure 4-11. Source fingerprinting by volume in Old River at Highway 4 during 1931 (top) and 2015 (bottom). Fingerprinting was conducted for this study using DSM2 modeling.

5 Historical Hydrodynamics, Salinity Intrusion, and Pumping Practices Review

To understand historical hydrodynamic processes and salinity conditions in the Delta and to assess the impacts of pumping and water projects on flow and water quality, it is instructive to examine three historic time periods: 1) pre-1917 Delta conditions, 2) drought periods after 1917 but prior to construction of the SWP and the CVP (i.e., post-1917/pre-SWP and CVP), and 3) drought periods after construction of SWP and CVP (i.e., Post-SWP and CVP). Because BBID and WSID hold water rights that were appropriated prior to 1917 (in 1914 and 1916 for BBID and WSID, respectively), examining the historical salinity conditions and pumping practices in the Delta helps understand the supply that was historically available to the districts and the impacts that the CVP and SWP have had on hydrodynamics and salinity within the Delta.

5.1 Pre-1917 Conditions

An abundance of evidence indicates that, prior to the early 1900s, water in the Delta was predominantly fresh, and water at the BBID intake would have been fresh during all year types and all times of year. After about 1917, water and land-use practices changed salinity levels within the Delta from a principally fresh condition to a much more saline condition. Coincidentally, salinity levels began to be monitored by the California Department of Water Resources and its predecessor organizations (collectively referred to in this report as “DWR”) in about 1920 (DWR 1960). Historical measurements collected by DWR form the basis for the widespread (but inaccurate) belief that salinity levels observed after 1917 represented the historical or natural condition.

Seawater intrusion into the upper Delta has historically been reported and occurs as a result of natural cyclical processes (e.g., Spanish explorers reported salty water in upper Suisun Bay in 1775, and an American expedition reported saline water near Antioch in 1841 [DPW 1931; DWR 1960]). However, fresh water was present farther downstream for longer portions of the year prior to 1917 than in recent times under hydrologically similar conditions. The change in salinity conditions within the Delta has resulted primarily from a substantial increase in water management activities (e.g., diversions for irrigation and storage) and physical transformations (e.g., reclamation and erosion) that occurred in the early 1900s. In addition, a series of dry years occurred in the region after 1918, during which time the Delta grew increasingly salty in water bodies that had previously remained fresh (DPW 1931).

The Delta landscape has experienced significant physical changes since the mid-1800s, and many of these transformations have increased the salinity of the Delta waters. The reclamation and removal of freshwater tidal marshes by European settlers in the 1800s through levee construction resulted in increased salinity in the upper Delta by allowing for greater tidal energy, and subsequent mixing and dispersion of saline water, within the Delta. In fact, the amount of tidal marsh decreased from nearly 346,000 acres in the 1870s to less than 25,000 acres in the 1920s (CCWD 2010). As a result of the loss of tidal marsh, a lower volume of freshwater flood flows during winter and spring months were stored and retarded in the upper Delta (Means 1928). Hydraulic mining for gold in the 1800s caused increased erosion and sediment deposition in various Delta channels and in Suisun Bay, which was followed by a marked increase in erosion and net sediment loss in Suisun Bay during the period 1887–1920 (CCWD 2010). The deepening of the Bay and upper channels caused by erosion increased the volume of water in the Delta channels and resulted in greater salinity intrusion from the Bay (CCWD 2010). The construction of the Stockton and Sacramento Deep Water Ship Channels (DWSC), which were created by major dredging projects, also increased the channel volume within the Delta, altering the distribution of fresh and saline waters within the Delta (CCWD 2010). The salinity regime has shifted as a result of each of these factors; tidal energy now carries seawater farther into the Delta without the protection that the tidal marsh lands once provided, and the erosional environment in Suisun Bay, in conjunction with deepening of channels within the Delta, facilitated mixing and dispersive transport of saline waters into the estuary (CCWD 2010).

Early water management and diversion activities upstream of and within the Delta may have had a more significant impact on saltwater intrusion than land transformations. Prior to the large-scale reservoir projects constructed beginning in the 1940s, freshwater diversion projects for storage and irrigation increased salinity in the Delta, especially during the summer and fall irrigation seasons (CCWD 2010; Means 1928). In 1928, Thomas Means, a consulting engineer for the Association of Industrial Water Users, wrote "Salt Water Problem" and used pre-1928 records and observations to evaluate the historical water quality condition of the Delta. Means wrote (1928), "If the water now diverted for irrigation and held in storage were released, natural conditions would be brought about," and "[t]he dry year of 1918, in which the urge of war had encouraged heavy plantings of rice and other crops in the Sacramento Valley, resulted in the penetration of salt water into the Delta for a longer time and to a greater distance upstream than ever known before." A bulletin published in 1931 by the California Department of Public Works (DPW, which became the Department of Water Resources [DWR]) also noted that the diversion of river water upstream of the Delta for food production caused an increase in salt water intrusion: "The dry years of 1917 to 1919, combined with increased upstream irrigation diversions, especially for rice culture in Sacramento River Valley, had already given rise to invasions of salinity into the upper bay and lower delta channels of greater extent and magnitude than had ever been known before" (DPW 1931).

Although fewer salinity monitoring data are available in the Delta prior to 1920 than in more recent periods, numerous historical records confirm that the Delta was significantly less saline before 1920. Means (1928) noted that the natural boundary between salt and freshwater in the Delta was located around Carquinez Strait: "Under natural conditions, Carquinez Straits marked, approximately, the boundary between salt and fresh water in the upper San Francisco Bay and delta region of the two tributary rivers—the Sacramento and San Joaquin" (Means 1928). Means observed that Suisun Bay contained primarily freshwater vegetation, while the tidal marshes of San Pablo Bay contained saltwater vegetation, indicating that Suisun Bay was predominantly a freshwater body. He also noted that, even under dry years, if all flow from the Sacramento and San Joaquin Rivers, including major tributaries, was allowed to reach the head of Suisun Bay, "salt water would have penetrated no farther in this extremely dry period than Antioch, and then only for a few days at a time" (Means 1928). Means ultimately concluded, "The definite statement that salt water under natural conditions did not penetrate higher upstream than the mouth of the river, except in the driest years, and then only for a few days at a time, is warranted." (Means 1928)

Operational logs kept by the California and Hawaiian Sugar Company (C&H), located in Crockett, provide insight into the salinity conditions in the Delta as early as 1908 (Means 1928; DPW 1931; Jackson and Paterson 1977). When fresh water was not available at Crockett, C&H sent barges upstream into the Sacramento and San Joaquin Rivers to collect the fresh water that was needed for sugar refining. C&H recorded both the distance traveled by barge to collect the water and the salinity of the water at various points during travel (Means 1928, Table 1; Jackson and Paterson 1977).

A comparison of the reported C&H salinity conditions to salinity data collected between 1966 and 2004 indicate that C&H barges would have to travel up to 19 miles farther upstream to reach fresh water (<50 mg/L chloride) during the recent period than in the early 1900s (CCWD 2010). The historical C&H records also show that fresh water persisted in the western Delta farther downstream and for longer periods of time each year between 1908 and 1917 than under more recent years with similar hydrologic conditions (i.e., wet or dry year) (CCWD 2010).

The California DWR has also estimated historical salinity conditions around Antioch in the early 1900s (DWR 1960). The CA DWR estimated that, under “natural” Delta conditions (i.e., without water management or water exports), water that was less than 350 ppm chloride would be available at Antioch approximately 85 to 90 percent of the time (DWR 1960). DWR (1960) estimated that in 1900, fresh water was available 80 percent of the time at Antioch, and that the decline in fresh water availability from natural conditions was due to upstream diversions of the fresh water (DWR 1960). The DWR also estimated that by 1920, the availability of fresh water had decreased to approximately 70 percent due to an increase in the number of diversions that occurred between 1900 and 1920 (DWR 1960).

Documentation from a 1920 water rights lawsuit filed by the City of Antioch against an upstream irrigation district (*Town of Antioch v. Williams Irrigation District*) also describes the increased salinity conditions and saltwater intrusion the city experienced in the early 1900s (Antioch 2010, CCWD 2010). In that lawsuit, Antioch claimed that the diversion of water for irrigation upstream of the Delta caused an increase in the salinity of their water intake supply in the western Delta (CCWD 2010). Testimony from both the plaintiffs (Antioch) and defendants (irrigators) indicated that Antioch was able to pump fresh water from the San Joaquin River until at least 1915, but that the water was often brackish at low tide or during summer and fall months (Antioch 2010; CCWD 2010). Testimony from Antioch indicated that, prior to 1918, fresh water was available in the river during dry years and during the summer and fall months (Antioch 2010). Antioch recorded the concentration of salinity in the river in August or September from 1913 to 1917 and noted that the salinity more than doubled over the four-year period between 1913 and 1917 (66 ppm recorded in September 1913 [dry year]; 141.6 ppm recorded in September 1917 [wet year]) (Antioch 2010). Additional detail can be found in Antioch (2010), which is attached to this report in Appendix D.

In 2010, the Contra Costa Water District (CCWD) produced a report that reviewed the historical record of salinity in the Delta, as well as various published studies on the Delta's water quality condition, and concluded that "…the Delta is now managed at a salinity level much higher than would have occurred under natural conditions. Human activities, including channelization of the Delta, elimination of tidal marsh, and water diversions, have resulted in increased salinity levels in the Delta during the past 150 years" (CCWD 2010). CCWD found that conditions in the Delta in the early 1900s were much "fresher than current conditions for hydrologically similar periods" and that the diversion of water and construction of large water storage projects has been a significant contributor to salt water intrusion. Although salinity management efforts have reduced the expected concentration of salt in the Delta during certain periods of the year, the salinity levels still surpass those that were observed before 1900 (CCWD 2010).

In summary, available data and information indicate clearly that the salinity regime of the Delta shifted in the early 1900s as a result of upstream water management practices and changes to the configuration of the Delta. Prior to about 1917, the water that was present at the (future) locations of the BBID and WSID intakes would have been fresh for the full range of hydrologic conditions, including those that would have occurred during the month of June in critically dry years.

5.2 Post-1917 and Pre-CVP/SWP Conditions

5.2.1 Full Natural Flow

Prior to development of the SWP/CVP, diversions from the Old San Joaquin River (Old River) occurred year-round, despite multiple historical drought periods within this time. The California Department of Public Works Division of Water Resources released the Sacramento-San Joaquin Water Supervisor's Report (Bulletin 23) annually from 1929 through 1962; these reports included measured data from as early as 1924. Bulletin 23 reported river discharge rates, Delta return flows, total volume of diversions, irrigated acreage, salinity data, and other related information, typically as average monthly values. Bulletin 23 data show that BBID and WSID, along with other irrigation districts in the south Delta, were able to divert and use water year-round from their intake, even during the driest months of the driest years on record (DWR 1932).

During the pre-project critical water years, the FNF, as determined by the eight-river index, peaked in the spring as a result of increased runoff from snowmelt. Figure 5-1 shows the monthly average FNF from Bulletin 23 documents for 1924, 1929, 1931, and 1934, which were classified as critical water years. In general, FNF increased from December through the winter months to spring, and then declined in late spring and early summer into the fall. As discussed in Section 4, this pattern corresponds with typical weather patterns, as rainfall in the winter and spring, as well as springtime snowmelt increase flows into the Delta.

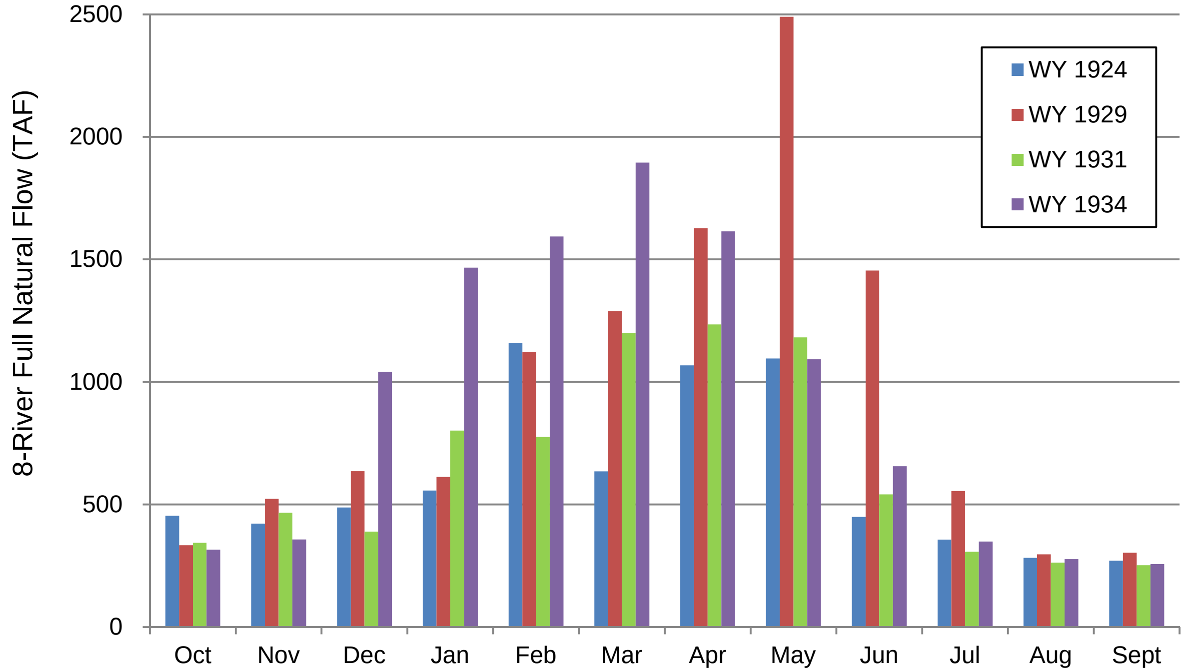


Figure 5-1. 8-River index FNF during pre-CVP/SWP critical water years (Data from DWR Bulletin 23 documents; DWR 1930a, DWR 1930b, DWR 1932, DWR 1935)

5.2.2 Diversion Operations

5.2.2.1 BBID and WSID Historical Diversion Operations

Diversion data for BBID and WSID from DWR Bulletin 23 documents were reviewed to provide context for understanding BBID and WSID operations during the pre-CVP/SWP period. Historical monthly measurements and records of diversions are available from the Sacramento River and its tributaries within the valley floor, as well as from tributaries in the Delta Uplands from Cache Slough, Old River, Tom Paine Slough, and San Joaquin River. Diversions on the Stanislaus, Tuolumne, Merced, and San Joaquin Rivers and Dry Creek were obtained in connection with the return water measurements. Of the 544 diversions recorded in the 1931 Bulletin 23 (DWR 1932), twelve diversions were located on the Old San Joaquin River, including diversions by BBID and WSID. Most diversion volumes were estimated within

Bulletin 23 from records of electric power consumption by diversion pumps and pump discharge flow rates (DWR 1932).

BBID and WSID diverted water continuously through historical droughts during the pre-CVP/SWP years. Figures 5-2 and 5-3 show BBID and WSID monthly diversions from March through October for critical water years 1924, 1929, 1931, and 1934. BBID diversions typically peaked between May and July, and dropped significantly in September and October. In 1931, BBID diverted approximately 2500 acre-feet of water in June, 2850 ac-ft in July, and 2650 ac-ft in August. Clearly, water was available for diversion by BBID, and water was diverted by BBID, throughout the summer of critically dry year 1931, including during the period of June 13-25, 1931. As will be shown in Section 6, the fresh water pumped by BBID during June 1931 was primarily Sacramento River water that had entered the Delta between February and May 1931.

Similarly, WSID diversions were typically high through the summer and into the fall for years 1924 and 1929. In 1931, WSID diverted about 1960 ac-ft of water in June, 3900 ac-ft in July, and 2800 ac-ft in August. Water was available for diversion by WSID, and water was diverted by WSID, throughout the irrigation season of critically dry year 1931.

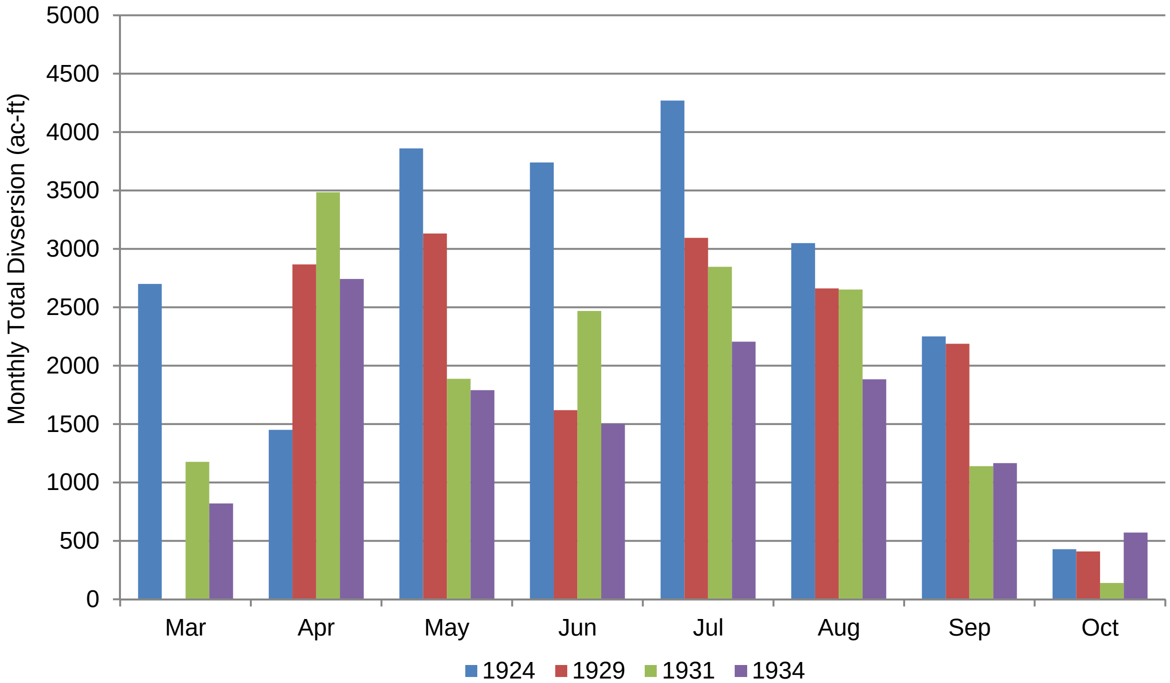


Figure 5-2. BBID total monthly diversion during pre-Projects critical water years (data from DWR Bulletin 23; DWR 1930a, DWR 1930b, DWR 1932, DWR 1935)

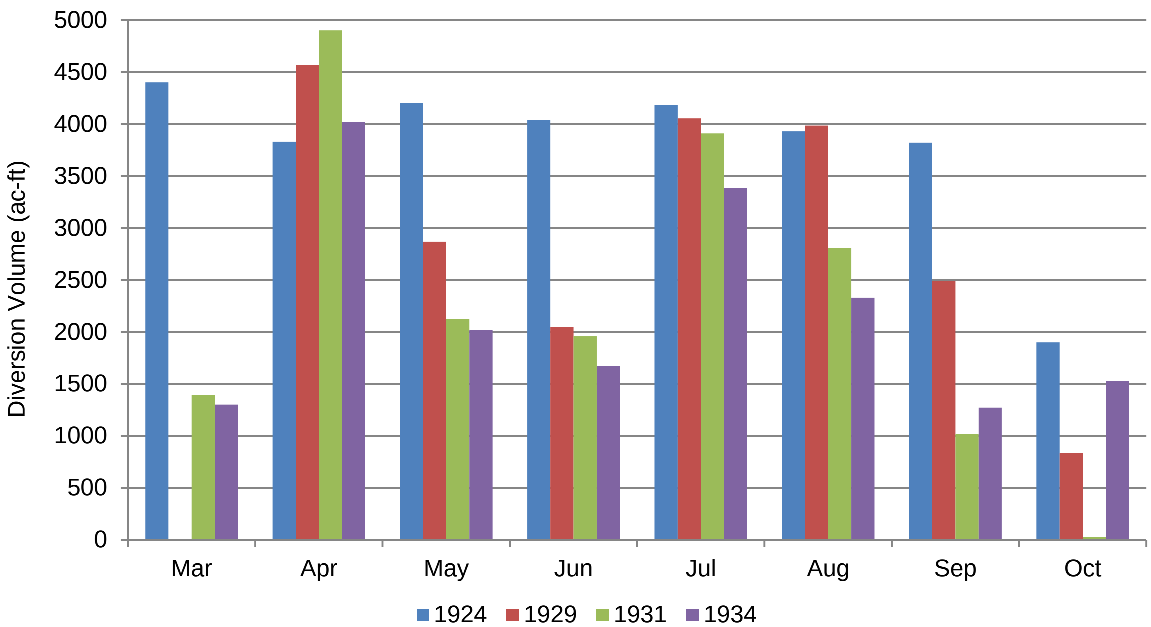


Figure 5-3. WSID total monthly diversion during pre-Projects critical water years (data from DWR Bulletin 23; DWR 1930a, DWR 1930b, DWR 1932, DWR 1935)

5.2.2.2 Historical Diversions from Old River

BBID and WSID historically diverted water from Old River, along with a small group of others. In 1931, 12 diversions from Old River were recorded in DWR Bulletin 23 reports, and by 1942, 13 diversions were reported (DWR 1943). Figure 5-4 shows the total monthly average amount of water diverted from the Old River in 1931 for the months of March through October, as well as the amount diverted by BBID and WSID. Total monthly diversions peaked in April 1931 at about 17,100 ac-ft, and about half of that was attributed to BBID and WSID together. Figure 5-5 shows monthly total diversions by the four primary diverters (BBID, WSID, East Contra Costa Irrigation District [ECCID], and Naglee-Burke Irrigation District [NBID]) and the total amount pumped by smaller diverters between 1924 and 1944 for the months of June, July, and August.

Historical data clearly indicate that BBID, WSID, and other diverters pumped water from Old River in the Delta throughout the summer of even critically dry years prior to construction of the CVP and SWP, including during the critical period of June 13-25. In 1931, the volume of total diversions from the Delta (March to October) was approximately 1.17 MAF (DWR 1932). Available data clearly indicate even during the critically dry conditions that occurred prior to the construction of the Projects, water was “available” for diversion, and water was diverted, by BBID and other diverters in Old River. Water also continued to be diverted by a large number of other parties throughout the system, and this water obviously could not have been provided by stored water released by the CVP and SWP, since they had not yet been constructed in 1931.

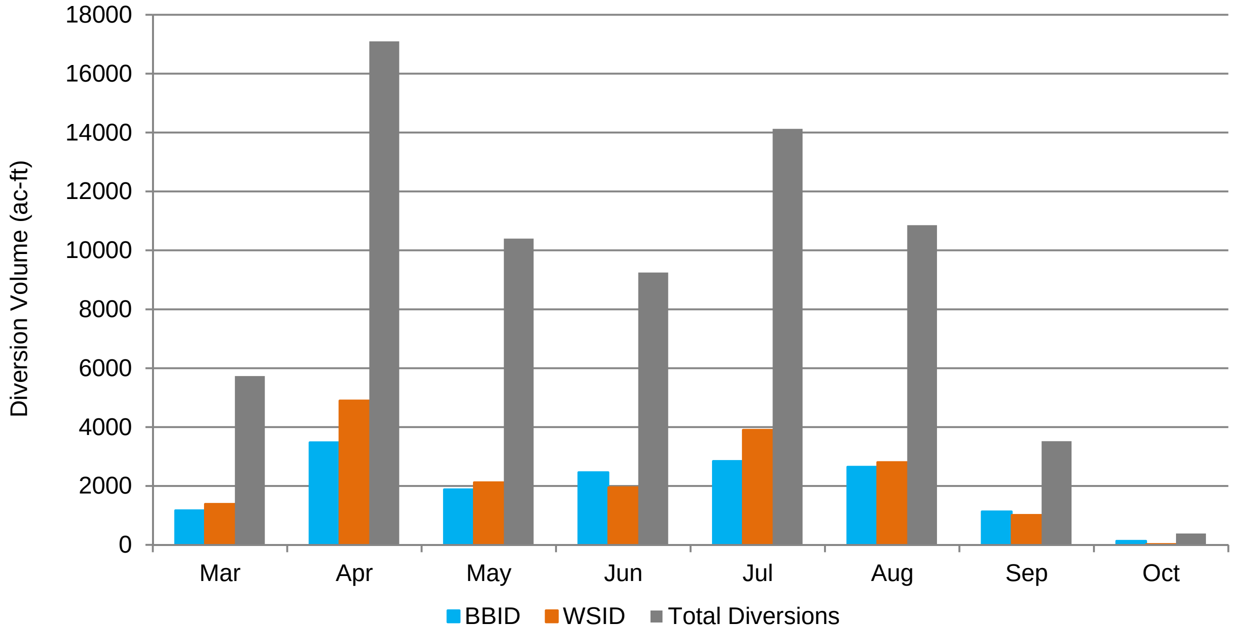


Figure 5-4. Total monthly diversions in 1931 from BBID, WSID, and combined total from the 12 diverters pumping water from Old River (Data from DWR 1931 Bulletin 23, DWR 1932)

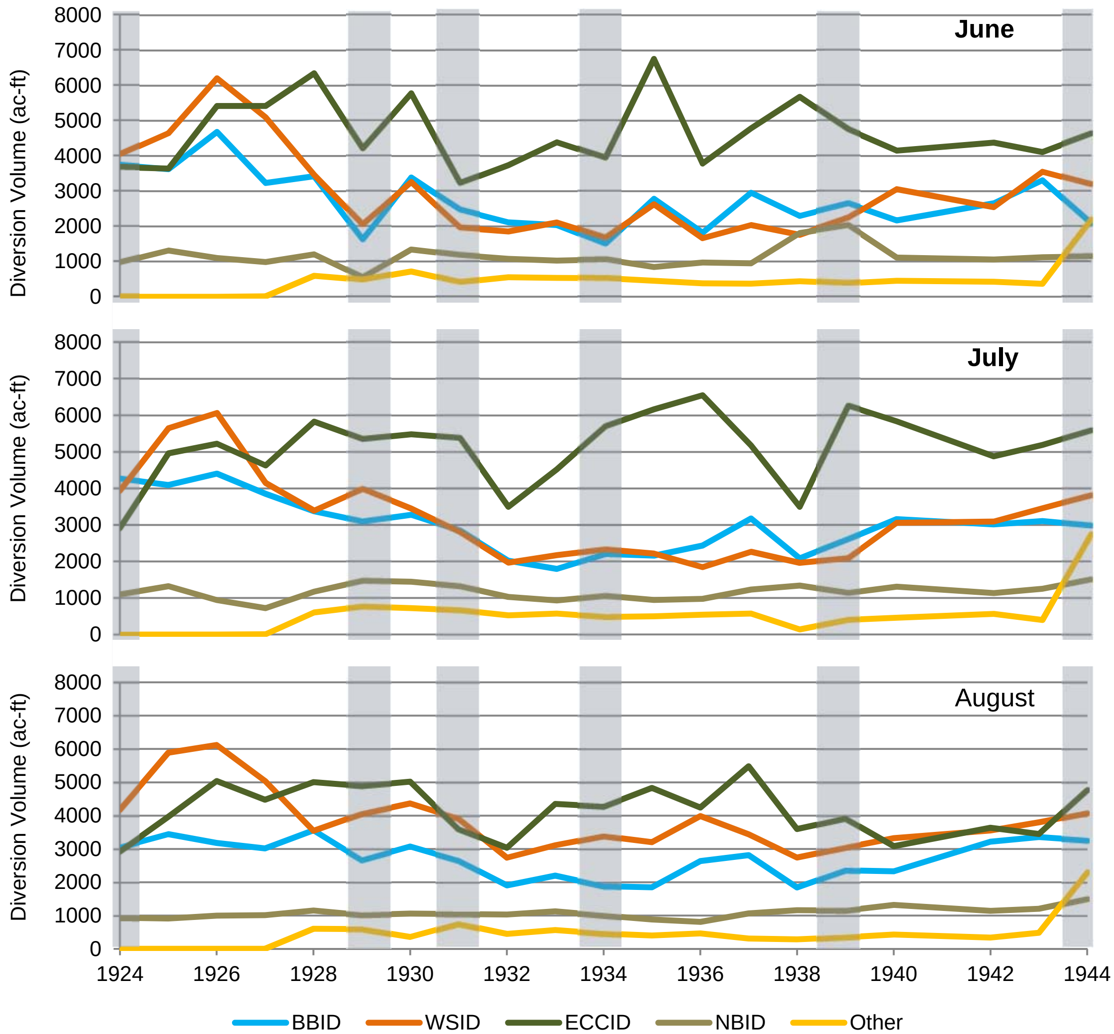


Figure 5-5. Total monthly diversions from Old River between 1924 and 1944, with critical water years shaded in gray (data from DWR 1929 to 1944 Bulletin 23, DWR 1930a, DWR 1930b, DWR 1931, DWR 1932, DWR 1933, DWR 1935, DWR 1936, DWR 1937, DWR 1938, DWR 1939, DWR 1940, DWR 1941, DWR 1942, DWR 1943, DWR 1944, DWR 1945)

5.2.3 Salinity in the Delta between 1917 and 1942

As discussed in Section 5.1, water within the Delta was predominantly fresh throughout the year prior to about 1917. However, after about 1917, a saline front from Suisun Bay propagated into the Delta in the late summer; the eastward extent of the saline front was a function of freshwater flows, and was greater in dry years than in wet years.

Figure 5-6 shows chloride concentrations measured at Clifton Court Ferry and Mansion House and reported in Bulletin 23, together with monthly BBID and WSID diversions, for calendar year 1931 (DWR 1932). Figure 5-6 shows that chloride concentrations increased at both locations beginning near the end of July 1931 and reached peak values in early October 1931. Chloride concentrations at Clifton Court Ferry, the location nearest the BBID intake, reached a level of 1000 mg/L on about September 6 1931, peaked at about 1300 mg/L on about September 22, 1931, and fell below 1000 mg/L on about October 22, 1931. By the end of December 1931, chloride concentrations had decreased to the baseline value of approximately 100 mg/L. Because Mansion House is located nearer to the Bay than Clifton Court Ferry, salinity increases occurred sooner and reached higher peak concentrations than were observed at Clifton Court Ferry to the south. Peak chloride concentrations at Mansion House in 1931 were about 2,400 mg/L chloride, while chloride concentrations at Clifton Court Ferry reached about 1,300 mg/L chloride.

Chloride concentrations at the WSID intake were lower than concentrations measured at the BBID intake, because the WSID intake is farther from the Bay than either Mansion House or Clifton Court Ferry. Salinity levels of 1,000 mg/L chloride or greater have reached as far as Clifton Court Ferry only twice in the pre-CVP/SWP historical record: in the fall of 1931 and the fall of 1934. Only once, in September 1931, has that salinity threshold been reached at the location of WSID’s intake. Figure 5-7 shows the extent of salinity intrusion into the Delta during pre-CVP/SWP years.

The historical record shows that only rarely did saline waters reach the BBID and WSID diversion locations in the south Delta. During the most severe droughts and without releases from CVP/SWP reservoirs, BBID and WSID were able to use, and did use, water from their intakes year-round, including during the period of June 13-25, 1931. Bulletin 23 data demonstrate that water was pumped and used continuously by BBID, WSID, and other Old River diverters throughout the summer of 1931, even when chloride concentrations were elevated, indicating that water at these locations was “available” and was used during this time period.

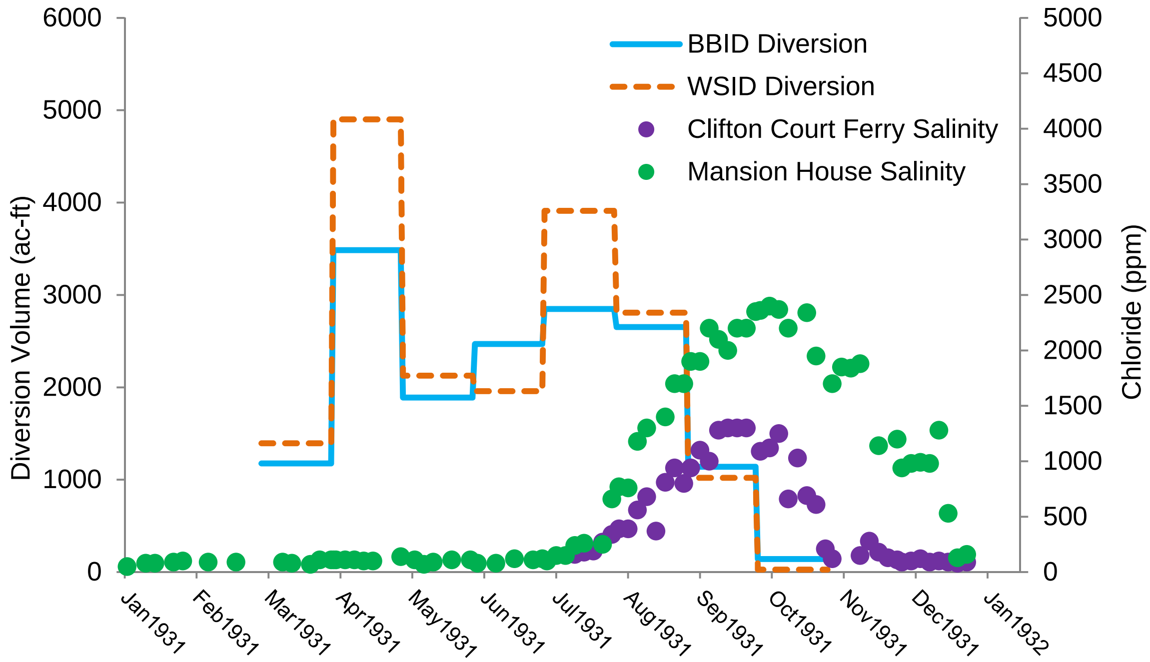


Figure 5-6. Comparison of salinity concentration at Clifton Court Ferry and Mansion House to volume of water diverted by WSID and BBID in 1931 Salinity began to rise at Clifton Court Ferry, near the BBID intake, in July 1931. Chloride levels were not measured prior to July 1931 at Clifton Court Ferry, but during the period of June 13-25, 1931, chloride concentrations averaged 250 mg/L at Mansion House; BBID pumped water throughout the irrigation season in 1931. (Data from DWR 1931 Bulletin 23, DWR 1932)

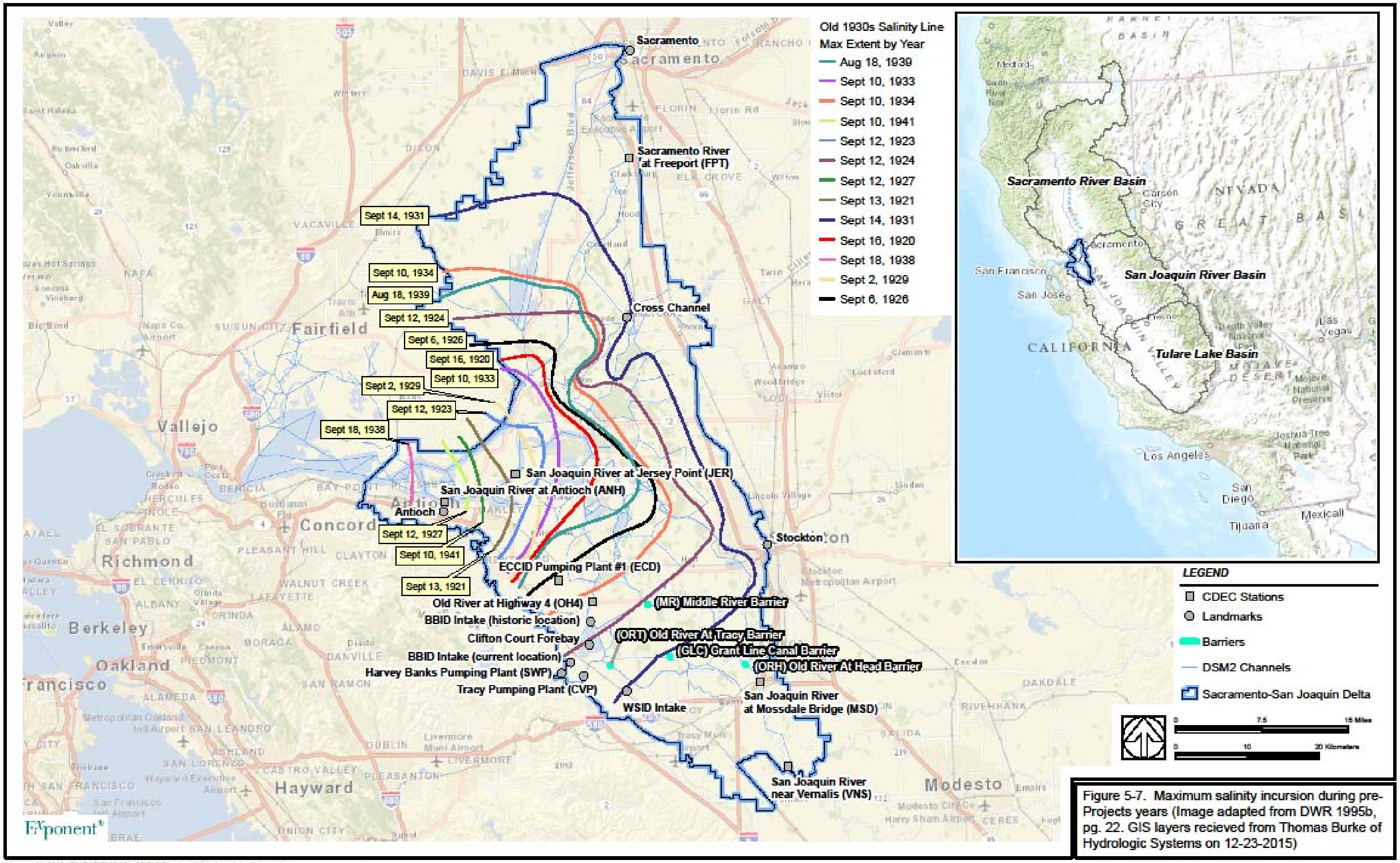


Figure 5-7. Maximum salinity incursion during pre-Projects years (Image adapted from DWR 1995b, pg. 22. GIS layers recieved from Thomas Burke of Hydrologic Systems on 12-23-2015)

January 06, 2016 / P:\15\1507982.000_BBID\GIS\projects\Historic_salinity_lines.mxd

5.3 Post-CVP/SWP Conditions

5.3.1 Storage and Diversion during Post-CVP/SWP years

Water storage, diversion, and export projects in the Delta continued to increase in size and number through the mid- to late 1900s, exacerbating the saltwater intrusion that began in the early 1900s. The reservoir capacity in the Sacramento and San Joaquin River basins increased significantly (up to approximately 15 and 28 MAF, respectively) from 1915 through the 1980s, which accommodated an increase in irrigated acreage in the Central Valley (up to approximately 9 million acres by 1985) (CCWD 2010). The largest reservoir of the Central Valley Project (CVP), Lake Shasta, was completed in 1945, while the largest reservoir of the State Water Project, Lake Oroville, was completed in 1968 (CCWD 2010). In total, the water projects increased storage capacity from 1 MAF in 1920 to more than 30 MAF by 1979 (CCWD 2010). Total annual average diversions from the Delta System are estimated to be on the order of 15 MAF per year (CCWD 2010). This storage, export, and diversion of water has a significant effect on the timing and magnitude of salinity intrusion, and serves to further alter and significantly increase the influx and mixing of saline waters in the Delta (CCWD 2010).

5.3.2 Full Natural Flow

Eight-river index monthly average FNFs for WY 1977, 2014, and 2015 are presented in Figure 5-8. FNF values were generally lower in 1977 than in 2014 or 2015. In 1977, the highest monthly FNF was just over 900 TAF (in May 1977), while peak monthly FNF for WY2014 was 2052 TAF in March, and 2905 in December of WY2015. The total volumes of FNF in WYs 1977, 2014, and 2015 were 6174, 9186, and 10,672 TAF, respectively. A comparison of FNFs from 1931 and 2015 (Figure 5-9) shows a similar magnitude of flow in all months of the year except December and February (where 2015 FNF exceeded 1931 values for those months by a total of 3970 TAF) and March, April, and May (where 1931 FNF exceeded 2015 values by a total of 1180 TAF). Based on FNFs, 1931 and 2015 are comparable.

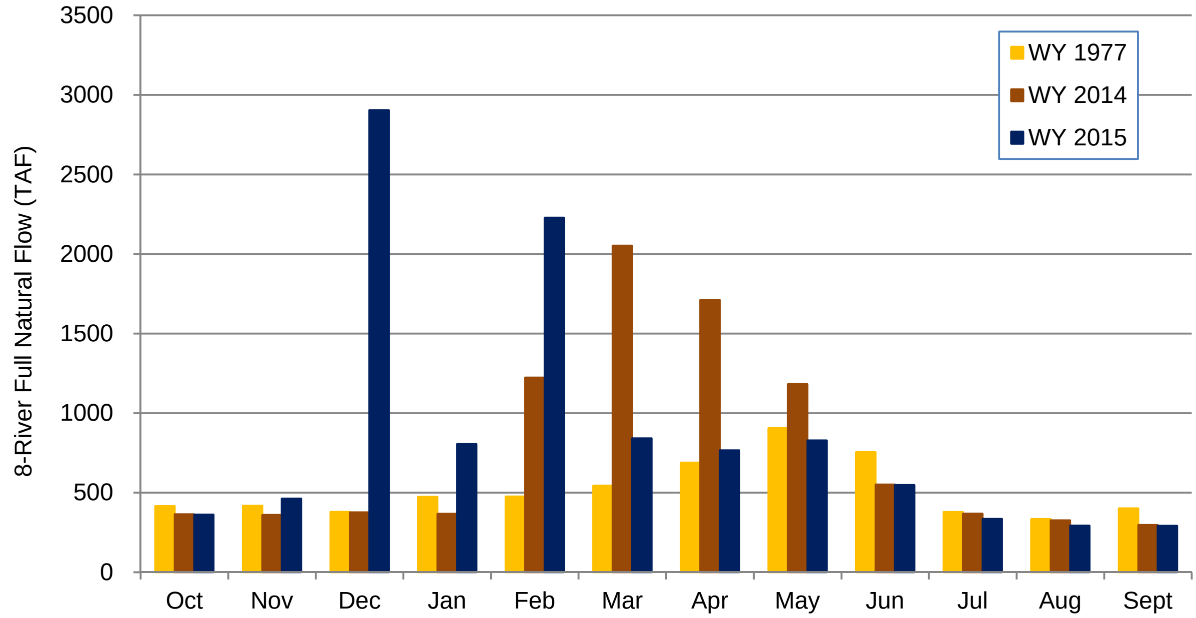


Figure 5-8. 8-River index FNF during post-CVP/SWP critical water years (Data from http://cdec.water.ca.gov and Kenneth Hennemen [personal communication] for 1910 through 2014. FNF for 2015 was calculated as the sum of flow from Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, American River inflow to Folsom Lake, Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake. 2015 data retrieved from http://cdec.water.ca.gov/cgi-progs/reports/FNFSUM.2015 and accessed 12-30-2015)

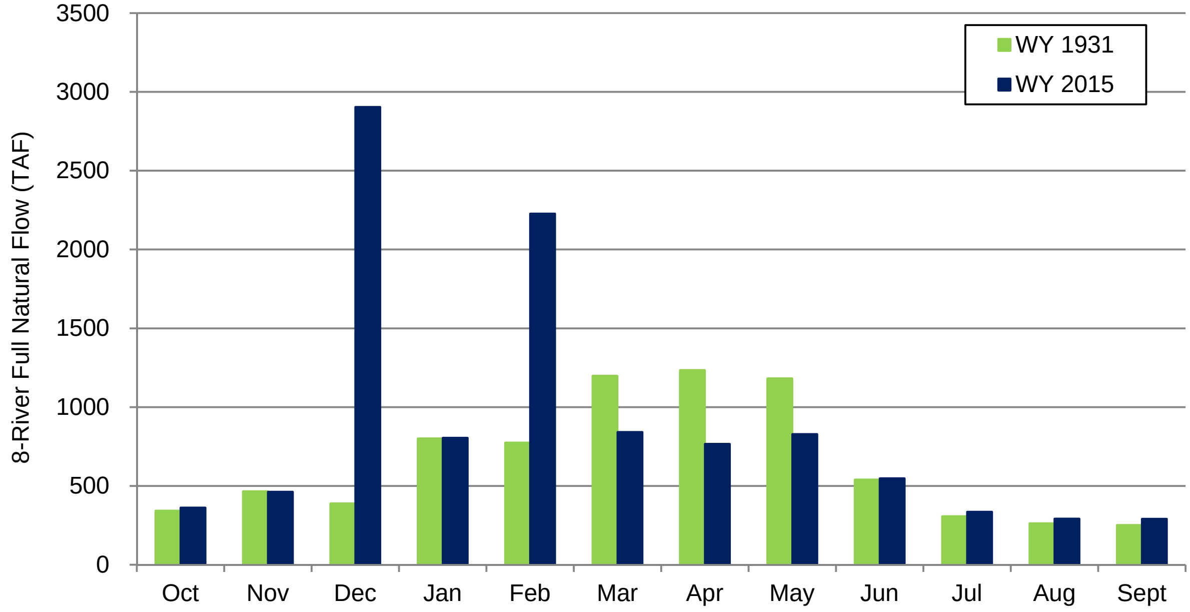


Figure 5-9. 8-River index FNF comparison of 1931 and 2015 (Data for 1931 retrieved from http://cdec.water.ca.gov and Kenneth Henneman. FNF for 2015 was calculated as the sum of flow from Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, American River inflow to Folsom Lake, Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake. 2015 data retrieved from http://cdec.water.ca.gov/cgi-progs/reports/FNFSUM.2015 and accessed 12-30-2015)

5.3.3 Reservoir Releases and FNF

Figure 5-10 compares three flows for the 2014-2015 water year: Shasta Reservoir outflow, Sacramento River FNF at Bend Bridge, and the Sacramento River flow at Freeport. As shown in Figure 5-10 A, peaks flows, which occurred in response to precipitation events, are evident in December and February 2015 in both FNF at Bend Bridge and Sacramento River flows at Freeport; peak flow rates illustrate that the travel time from Bend Bridge to Freeport (a distance of about 210 river miles) is about four to five days during these river flow conditions.[6] Figure 5-10 shows that releases from Shasta Dam were low during the winter months (ranging from 214 to 4950 cfs between November 1, 2014, and February 28, 2015), when water is captured and

6 River miles retrieved from http://www.sacramentoriver.org/access_site.php?access_site_id=102

stored behind Shasta Dam. Beginning around April 1, 2015, dam releases from Shasta Dam increased, and on about April 20, 2015, releases of water from Shasta Dam were greater in magnitude than the FNF at Bend Bridge. Thus, it can be estimated that April 20, 2015 marks the approximate point in time when water in the Sacramento River was a combination of FNF and reservoir releases.

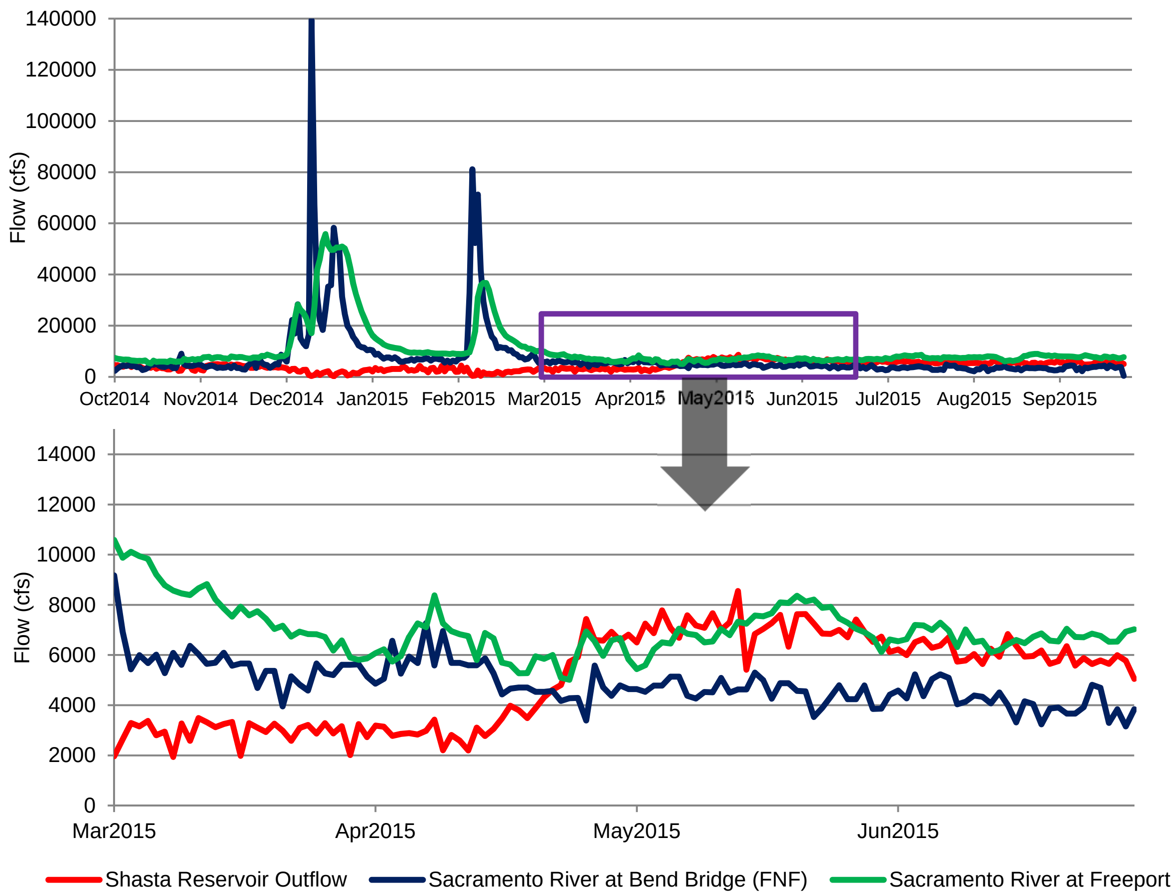


Figure 5-10. Shasta Reservoir outflow, Sacramento River FNF at Bend Bridge, and Sacramento River at Freeport during the 2014/2015 water year (top), and the same comparison focused on the point where reservoir outflow surpasses FNF at Bend Bridge (bottom). Note the change in scales on x and y-axes between top and bottom graphs (FNF Data and Shasta Reservoir Outflow from CDEC, accessed online 1-5-2015)

5.3.4 Diversion OperationsOperations

As with the pre-Project period prior to 1944, diversion data from the post-Project time period show that BBID and WSID have diverted water from the Delta throughout the irrigation season. Figure 5-11 presents monthly BBID diversion volumes from 1977 and from 2011-2015. Diversion data for BBID and WSID are also included in Tables 5-1 and 5-2. These measured data show that BBID diverted more than 50,000 ac-ft of water in 1977 (a critical year), about 30,000 ac-ft in both 2013 and 2014 (dry and critical years, respectively), and about 19,400 ac-ft, the lowest amount on record, in 2015 (a critical year). WSID diverted up to approximately 5000 ac-ft per month during the irrigation season of 1977 (a critical year).

Although the 1977 water year has the lowest water year index in recorded history (1906 to 2014), BBID was still able to divert, and did divert, water as it had in the past. The State of California pursued litigation against, among others, BBID for its diversion of 17,256 acre feet of water in July and August 1977 through its pumps at the Clifton Court intake channel, claiming that it was entitled to compensation for the quantity and quality of the water diverted based on the State's releases of project water. (*State of California v. Contra Costa County Water Agency et al.*, California Superior Court, City and County of San Francisco Case No. 765 609 (1977 Litigation).) Specifically, BBID diverted 9,074 acre-feet of water in July of 1977, and diverted 8,182 acre-feet of water in August 1977.

In 1977, BBID was the sole diverter of water from the California Intake Channel prior to the water reaching the base of the California Aqueduct pumps, which lift the water into the Aqueduct Canal on its journey south over the Tehachapis and into Riverside County. In the 1977 Litigation, BBID explained that it diverted the water in July and August 1977 because water was available at its location in the Delta (in contrast to supply on upstream rivers), just as it had been every other year. BBID further explained that it used the water during that drought, because it was of usable quality for application to its crops.

In addition, the data show that the amount of water diverted by BBID during the months of February through September was lower in the 2011-2015 time period than in 1977. Since 2011, the amount of water diverted by BBID in the driest months of the year has been relatively constant, despite monthly and annual differences in rainfall and runoff between years.

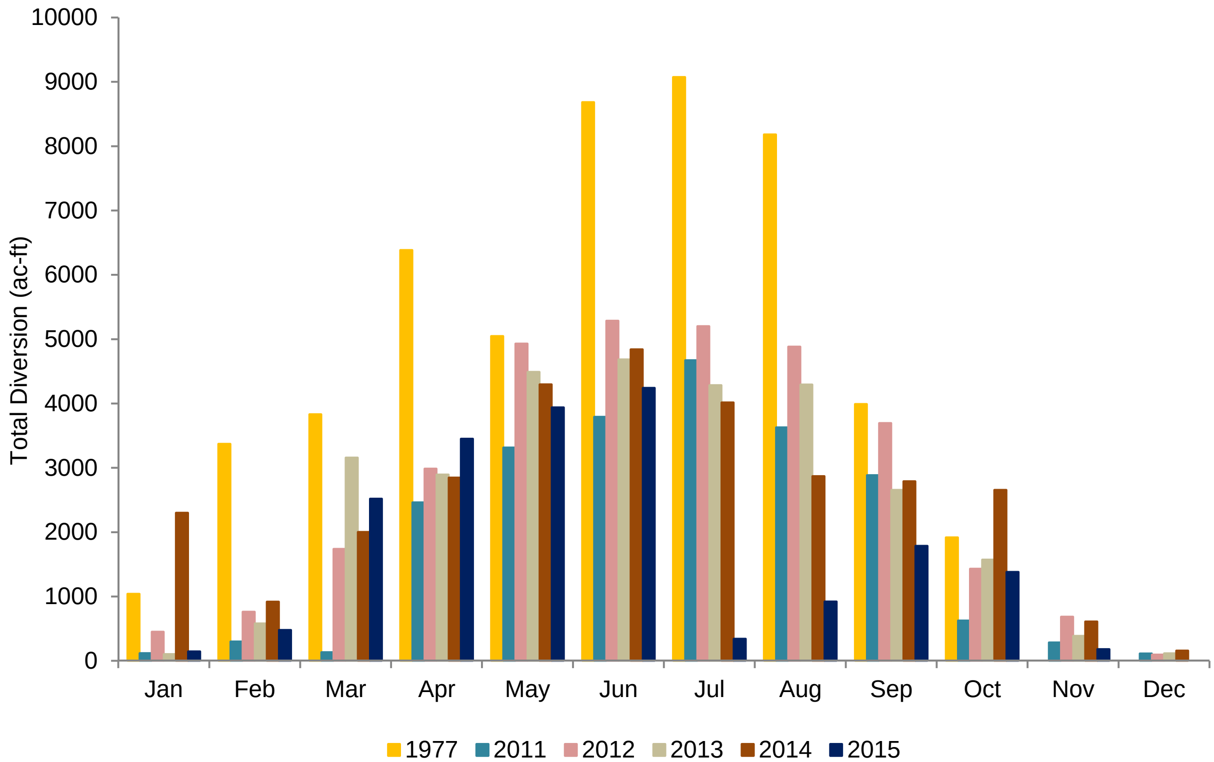


Figure 5-11. BBID total monthly diversions in 1977 and from 2011 to 2015 (Data from 1977 and from 2011 to 2014 received directly from BBID by email through Kenneth Henneman on 12-23-2015. Data from 2015 retrieved from U.S. Bureau of Reclamation on 12-30-2015 at http://www.usbr.gov/mp/cvo/pmdoc.html)

Table 5-1. BBID total monthly diversions in 1977, and from 2011 through 2015 (Data from 1977 and 2011 to 2014 received directly from BBID by email through Kenneth Henneman on 12-23-2015. Data from 2015 retrieved from U.S. Bureau of Reclamation on 12-30-2015 at http://www.usbr.gov/mp/cvo/pmdoc.html.)

Month	BBID Diversions (AF)					
	1977	2011	2012	2013	2014	2015
Hydrologic year classification	C	W	BN	D	C	C
January	1042	119	452	104	2301	148
February	3373	303	764	583	921	481
March	3834	134	1741	3160	2005	2520
April	6386	2464	2987	2895	2848	3453
May	5049	3316	4933	4492	4298	3939
June	8685	3793	5287	4686	4842	4243
July	9074	4673	5204	4286	4017	343 [1]
August	8182	3630	4884	4295	2871	923 [1]
September	3993	2885	3697	2659	2792	1787
October	1919	626	1433	1574	2657	1383
November	0	286	687	389	612	183
December	0	115	99	117	160	121
Total	51537	22345	32168	29241	30325	19524

[1] Transferred water, not diverted from the Delta (Source: BBID communication)

Table 5-2 Monthly WSID diversions (Data from WSID)

Month	WSID Diversion (AF)		
	1977 [1]	2014 [1]	2015 [1]
Hydrologic Year Classification	C	C	C
Jan			
Feb	654		
Mar	4699	1819	
Apr	5566	1859	2309
May	4462	3073	1176
Jun	5885	1350	909
Jul	8876	1023	592
Aug	6950	1017	412
Sep	3820	401	255
Oct	1346	173	146 [2]
Nov	16		0 [2]
Dec			0 [2]

[1] Diversion data from WSID for License 1381

[2] Reported value was amount anticipated to be diverted

6 Hydrodynamic and Water Quality Modeling

Hydrodynamic and water quality modeling was conducted to understand the source of water, and its distribution within the Delta, during the conditions that occur in critically dry years. During dry and critically dry years, water has a residence time in the Delta of weeks to months (see Section 4), and fresh water that entered the Delta during wetter winter and spring months remains in the Delta during drier months. As shown in Sections 4 and 5, the amount and quality of water present in the Delta is more relevant to the issue of availability than full natural flow (FNF) values calculated using flow measurements at locations far upstream of the Delta. Although modeling tools such as the DSM2 have been available and in widespread use for decades, it does not appear that the SWRCB used modeling tools to analyze whether water was available to users in the Delta.

Numerical models are useful tools for understanding water flow and quality in complex systems. DWR has developed and refined a model to simulate conditions in the Delta, called the Delta Simulation Model II (DSM2). The DSM2 model simulates stage and tidal flows, water quality, and particle movement in the Delta. The model can be used to simulate both actual (observed) conditions and hypothetical conditions.

Exponent used the DSM2 model for three primary purposes in this investigation: to understand the movement of water within the Delta estuary; to simulate salinity levels throughout the estuary, including salinity intrusion from the Bay; and to determine the source of water within the Delta. The source of water analysis was used to assess the fraction of water at the BBID intake in June 2015 that originated from the Sacramento River, the San Joaquin River, and other sources, and to calculate when that water entered the Delta.

Exponent performed model simulations for two conditions. First, Exponent simulated water year (WY) 1931, the driest year on record prior to the construction of the SWP and CVP. WY1931 was simulated as representative of the conditions that would likely have occurred during WY2015 had the CVP and SWP not been constructed—i.e., WY1931 is the pre-Project water year most hydrologically similar to WY2015. Measured salinity data were used to understand model outputs for salinity, and the DSM2 was used to calculate source fingerprints for water at key locations within the Delta for 1931.

Second, Exponent simulated WY2015 using model input data corresponding to actual WY2015 conditions. As with the WY1931 run, salinity measurements from key locations within the Delta were compared to DSM2 model output to understand and interpret model results. The 2015 model runs were used to calculate hydrodynamics and salinity as a function of time, to evaluate Delta conditions during June 2015, and to determine both the location and the time at which water in the interior of the Delta entered the estuary.

Finally, Exponent used the results of the 1931 and 2015 model runs, together with historical information and measurements describing salinity within the Delta, to develop opinions regarding the conditions that would have existed during WY 2015 if the CVP and SWP had not been operating.

6.1 DSM2 Model

The Delta Simulation Model, DSM2 (Version 8.1.2) is a one-dimensional (with branched-channels) tidal hydrodynamic model used to simulate stage and tidal flows, water quality, and particle tracking in the Sacramento–San Joaquin Delta (Delta). The model was developed by California Department of Water Resources (DWR) (CH2MHill 2009). The model domain extends to the Sacramento River at I Street to the north and to the San Joaquin River at Vernalis to the south, and the model includes inflows from east-side streams (the Cosumnes, Mokelumne, and Calaveras Rivers) (Figure 6-1). The downstream (western) boundary is located at Martinez.

The DSM2 model has three separate components: HYDRO, QUAL, and PTM. HYDRO simulates flows in all the channels defined in the DSM2 Grid, and channel stages for the specified Delta channel geometry and for dynamic tidal boundary elevations at Martinez. QUAL simulates the concentrations of conservative (i.e., no decay or growth) variables such as EC (electrical conductivity) and salinity, and non-conservative (decay or growth) variables such as temperature and turbidity, given the inflows and tidal flows in the Delta channels simulated by HYDRO. The particle tracking model (PTM) simulates mixing and transport of neutrally buoyant (suspended) particles based on the channel geometry and tidal flows simulated by HYDRO. In addition, the DSM2 model includes a feature called “volumetric fingerprinting,” which tracks inflows to the Delta throughout the model domain. Volumetric fingerprinting can be used to “tag” inflows to the Delta and to determine the source of water within the estuary. This feature was used to determine the location and time that flows from various sources entered the Delta. The DSM2 modules used for the analyses and fingerprinting presented in this report include HYDRO, QUAL, and PTM.

DSM2 users must specify a series of input parameters to operate the model, including inflows from the Sacramento River, San Joaquin River, Cosumnes River, Mokelumne River, and Calaveras River; the stage at Martinez; DICU flows and electrical conductivity; conductivity at Martinez and Freeport; and conductivity of the east-side streams and the San Joaquin River. Diversions and exports must also be specified in the model. Model inputs can be taken either from measured data (e.g., stage at Martinez, river inflows, salinity at model boundaries, measured diversions, and exports) or from synthetic data sets (e.g., data from Dayflow, a computer program maintained by DWR that uses daily river inflows, water exports, rainfall, and agricultural depletions to estimate daily average Delta outflow).

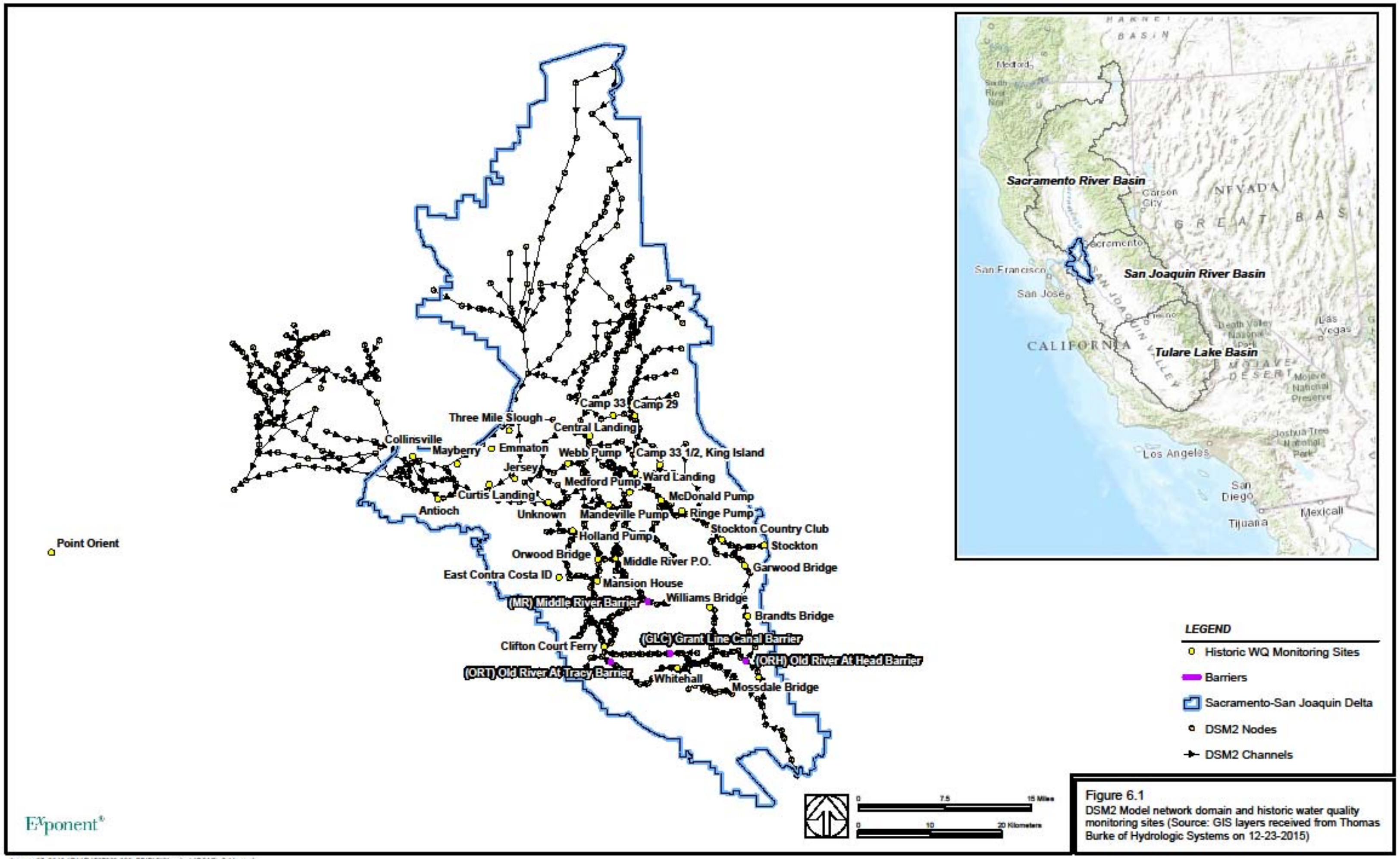


Figure 6.1
DSM2 Model network domain and historic water quality monitoring sites (Source: GIS layers received from Thomas Burke of Hydrologic Systems on 12-23-2015)

The DSM2 code has been calibrated and validated by DWR and others for a range of timeframes and conditions. Calibration exercises have been used to refine the model parameters that describe Delta channels and the flow of water. Calibration for Version 8.1 of DSM2 was performed in 2013. The calibration aimed to improve model convergence, refine channel geometries, convert the model datum to NAVD88, and correct Martinez EC boundary conditions. The 2013 calibration results were very close to prior calibration results, but some improvements were seen within HYDRO and QUAL. Improvements were not seen with regard to flows in the Franks Tract area or EC simulation in the south Delta; both these areas are acknowledged by DWR as areas still requiring development.[7] The DSM2 webpage includes detailed information on three recent calibration exercises.[8]

Figure 6-2 shows the most recent EC (salinity) calibration results at Antioch. The calibration at Antioch is characterized by a high degree of certainty, with a coefficient of correlation R^2 of 0.9696. The EC calibration results at Clifton Court Forebay are acceptable as well, but show that the model underestimates peak salinity values (Figure 6-3). As noted in DWR (2013a), the DSM2 model predictions of EC in the south Delta are poorer than at other locations. Poor salinity predictions in the south Delta are likely to be related primarily to a lack of granular information about the magnitude and salinity of return flows (i.e., DICU model parameters), and changes in those quantities during different year types. As noted in Section 4.5, the DSM2 DICU model input assumes a repeating pattern of salinity that is constant over all hydrologic year types.

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[7] DWR 2013a. Memorandum: DSM2 Version 8.1 Calibration with NAVD88 datum. Prepared by Lianwu Liu for Tara Smith. September 3, 2013.

[8] 1998–2003 calibration and validation http://www.water.ca.gov/dsm2pwt/calibrate/index.cfm; 2009 BDCP calibration http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/BDCP/DSM2_Recalibration_102709_doc.pdf; 2013 DSM2 V8.1.2 Calibration https://dsm2ug.water.ca.gov/library/-/document_library/view/163187

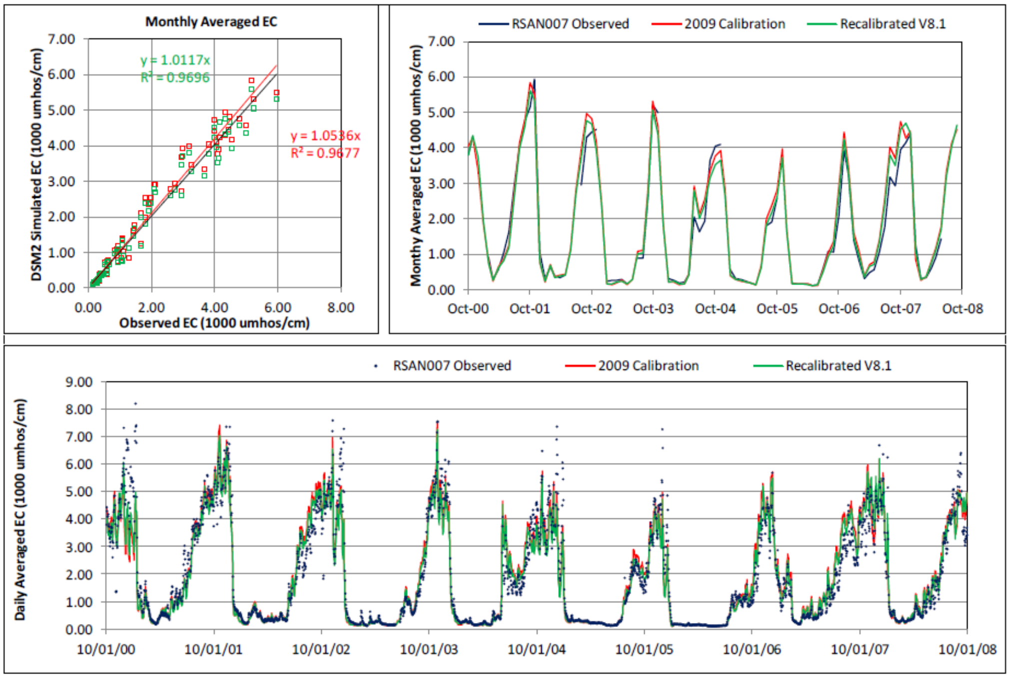

Figure 6-2 DSM2 EC calibration results at Antioch (DWR 2013a and 2013b)

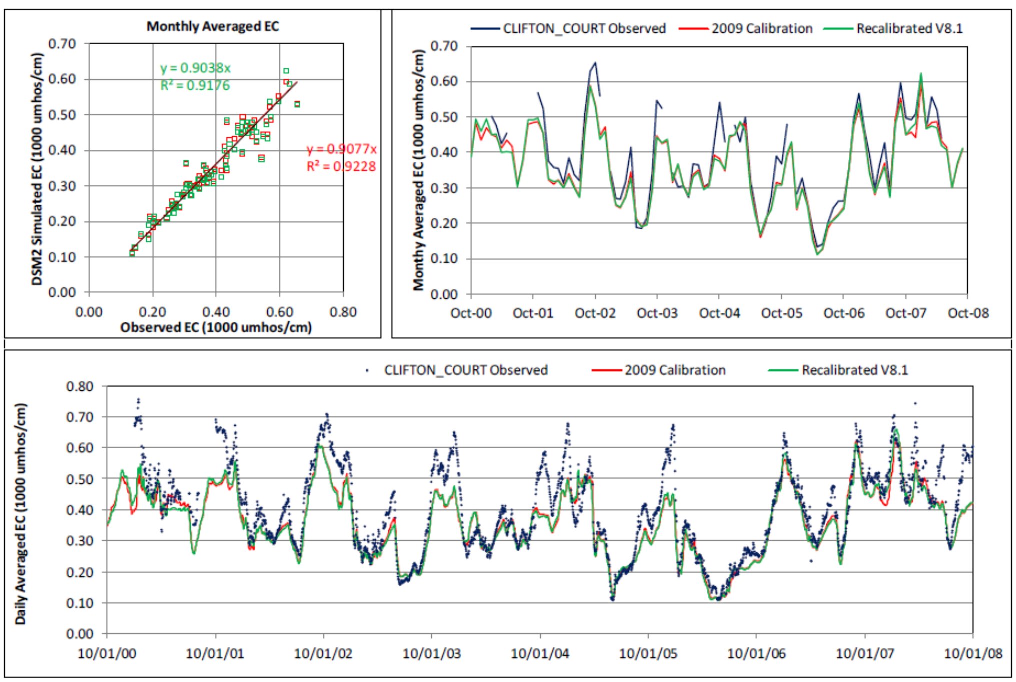

Figure 6-3. DSM2 EC calibration results at Clifton Court (DWR 2013a and 2013b)

6.2 Hydrodynamics, Salinity, and Source Fingerprints for a Critically Dry, Pre-Project Year (1931)

6.2.1 Model Run Description

As detailed in Section 4.3, WY1931 was one of the driest years on record, with a water-year index of 3.66; the water-year index for 2015 was forecast in the May 2015 Bulletin 120 (DWR 2015) to be 4.0, and FNF from these two years is comparable . Thus, WY 1931 is the pre-Project water year that is most similar, hydrologically, to 2015. Exponent used the DSM2 model to simulate hydrodynamics, salinity, and source fingerprints for WY 1931 to approximate the conditions that would have occurred in the Delta during WY 2015 in a no-Project condition. Specifically, WY 1931 was used to calculate water quality, and to determine the source of water at BBID and WSID intakes, during June of 1931.

Flow and stage information used to describe the model boundary conditions, and the sources of those data, are presented in Table 6-1 and described in further detail in Appendix A. Exponent also altered the DSM2 grid to remove features that did not exist in 1931 (Clifton Court Forebay and associated gates, the south Delta barriers, Franks Tract, and the Delta Cross Channel). Exponent simulated hydrodynamics, salinity, and source fingerprints for WY1931 (the simulation ran from October 1, 1929, through December 21, 1935) to understand the conditions that would occur within the Delta during a critically dry year that was not influenced by the construction and operation of the CVP and DWP.

Table 6-1. Input data and data sources for the 1931 simulation

Input Data	Data Source
Sacramento River Inflow	Dayflow
San Joaquin River Inflow	Dayflow
Cosumnes River Inflow	Dayflow
Mokelumne River Inflow	Dayflow
Calaveras River Inflow	Dayflow
Stage at Martinez	DWR
BBID Diversion	DWR Bulletin 23 (1931)
Delta Island Consumption Use (DICU)	DWR
Electrical Conductivity at Martinez, Freeport, Mossdale	DWR Bulletin 23 (1931)
Electrical Conductivity of DICU	DWR
Electrical Conductivity of east-side rivers, SJR	Assumed Constant

6.2.2 Model Validation for WY1931

Chloride concentrations were measured at several locations within the Delta during WY1931, and these data were used to evaluate DSM2 model performance for WY 1931 (i.e., for a critically dry year before the CVP and SWP were constructed). The DSM2 output data, expressed as EC, were converted to chloride concentrations for comparison with measured chloride data.[9] For reference, Table 4-5 in Section 4 presents chloride, EC, and TDS values that are equivalent at the BBID intake location (Clifton Court); conversions were made using the relationship of Guivetchi (1986). Figure 6-4 presents measured chloride data (DWR 1931 Bulletin 23; DWR 1932) for three locations (the San Joaquin River at Antioch, Old River at Mansion House [near Highway 4], and Clifton Court Ferry) together with DSM2 model results (for EC converted to chloride concentration) for calendar year 1931. Modeled and measured EC match well at Antioch through the entire year. The modeled EC from Old River at Highway 4 slightly overestimates measured salinity at Mansion House, and shows peak salinity arriving a few weeks earlier than the measured data (Figure 6-4 [middle]). A similar deviation from measured data is observed at Clifton Court Ferry, where modeled salinity is nearly double the measured salinity (Figure 6-4 [bottom]). However, the DSM2 model is able to capture generally both the timing and magnitude of salinity increases in the South Delta.

[9] Guivetchi, K. 1986. Salinity unit conversion equations. Memorandum. California Department of Water Resources. Sacramento, CA.

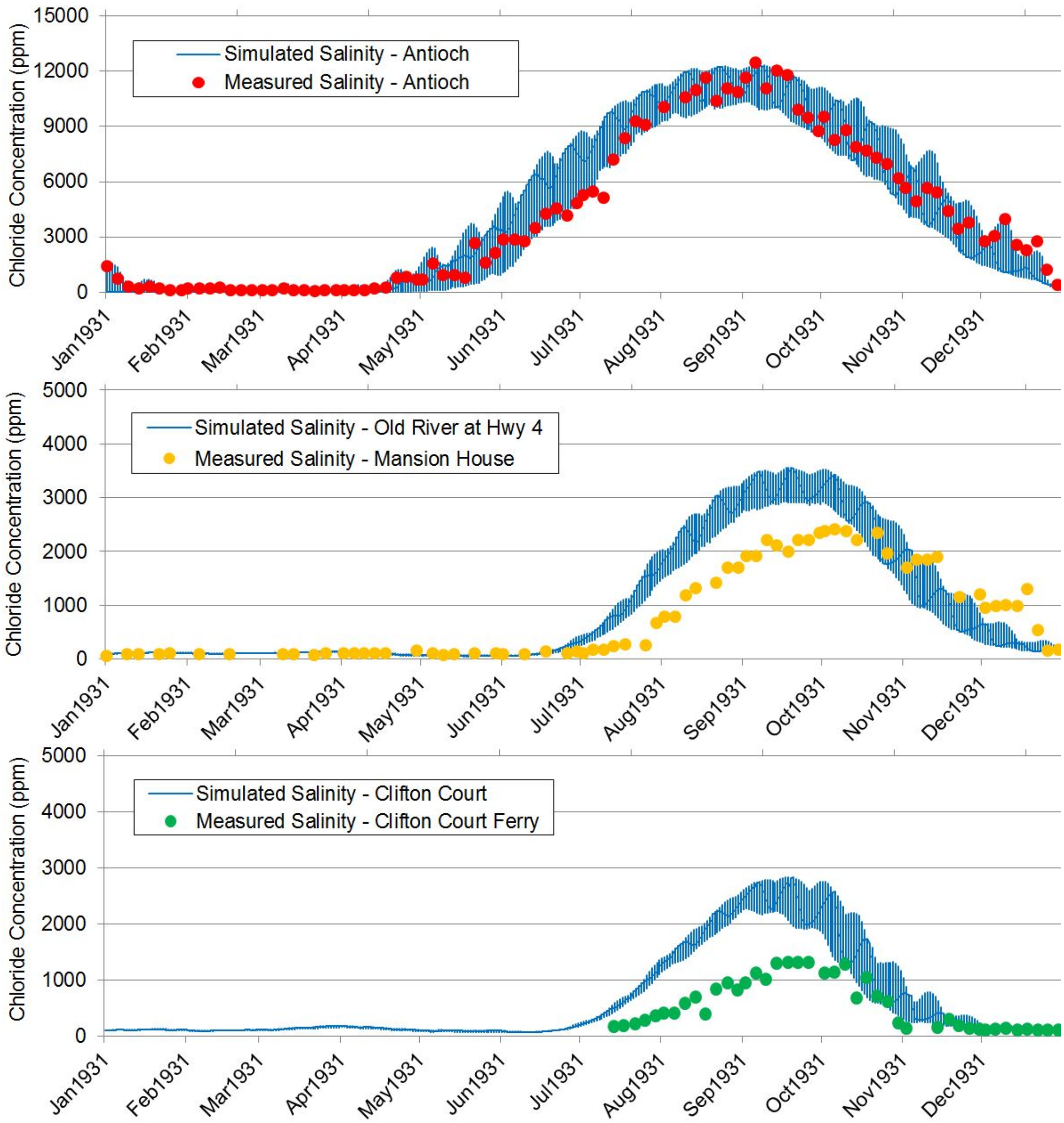

Figure 6-4. Comparison of measured and modeled salinity at Antioch (top), Old River at Highway 4 (middle), and Clifton Court Ferry (bottom) (measured data from DWR 1931 Bulletin 23, DWR 1932)

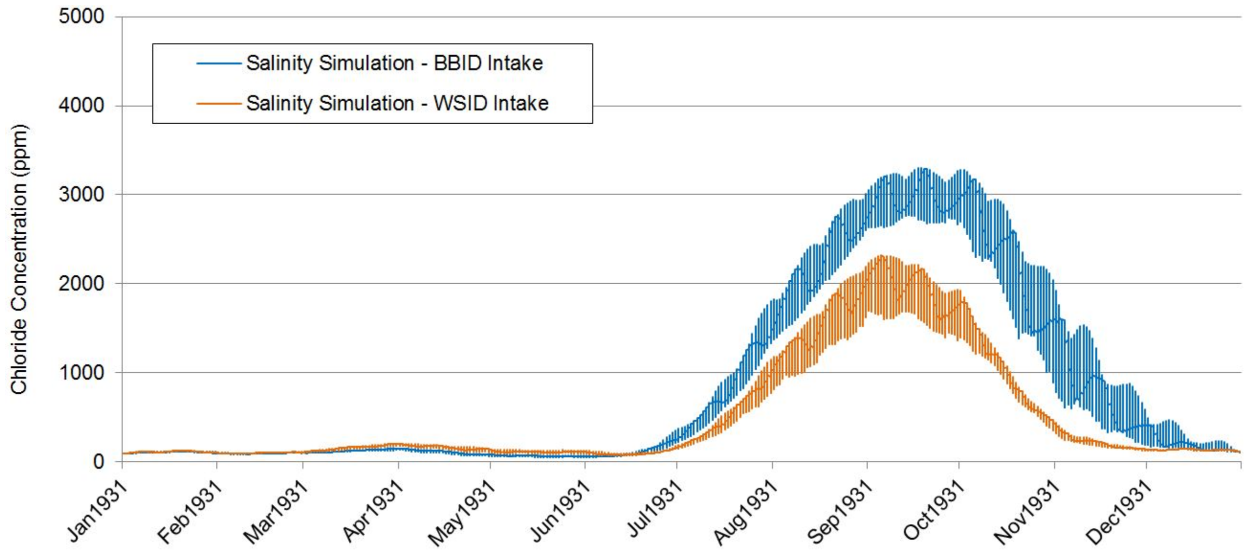

Figure 6-5. Simulated chloride concentrations at the BBID and WSID intakes

6.2.3 Model Results for Salinity in WY1931

As described above, the DSM2 model was used to simulate EC throughout the Delta for WY 1931; modeled EC was converted to chloride concentrations for comparison with measured data. DSM2 model results and measured data indicate that chloride concentrations in the San Joaquin River at Antioch increased from a baseline value near 100 mg/L in May 1931 to values as high as 12,000 mg/L by the beginning of September 1931. High chloride concentrations also propagated into the south Delta. At Old River at Highway 4, modeled salinity began increasing in July, and the measured data peaked at approximately 2,500 mg/L chloride in October. At Clifton Court Ferry on Old River, measured chloride concentrations reached a peak of nearly 1,300 mg/L toward the end of September. Both modeled and measured data show that water was fresh at the BBID intake (near Clifton Court Ferry) during the period June 13–25, 1931. DSM2 model results were used to generate animations describing the variation in salinity in the Delta as a function of time. For WY1931, daily average EC was calculated from 15-minute DSM2 model output at every DSM2 model node and used to generate a map on which the color of each node was proportional to the salinity level. Maps for each day in the simulation periods were compiled into a single animation file to show changes in salinity within the Delta over time during WY 1931. Digital copies of this and other animations are included in the report submittal packet.

6.2.4 Volumetric Fingerprinting

Figures 6-6, 6-7, and 6-8 show the source fingerprints for Old River at Highway 4, the BBID intake, and the WSID intake for the calendar year of 1931. Due to the proximity of these locations, the source fingerprints are similar. Simulation results show that over 90% of the water in Old River during winter 1931 entered the Delta from the San Joaquin River. In the summer, the Sacramento River provided as much as 60% of the flow, with a significant contribution from agricultural return flows. (Note that agricultural return flows consist of water diverted from the channels (i.e., predominantly Sacramento River water during the irrigation season) and returned to the Delta channels as drainage.) Between June 13 and 25, 1931, the water present at BBID's intake would have been approximately 60% to 65% Sacramento River water, 30% agricultural return flows, and 5% to 10% water from other sources.

Because Sacramento River inflows to the Delta are on the order of five to six times greater than the San Joaquin River inflows, the bulk of the water within the Delta originates from the Sacramento River. The bottom panels of Figures 6-6, 6-7, and 6-8 subdivide the Sacramento River fingerprint by month to when Sacramento River water within the Delta entered the system. These figures show that most of the water present in June 1931 entered the Delta months before. Approximately 60% of the water present at the BBID intake between June 13 and 25, 1931, originated from the Sacramento River, and more than 80% of that Sacramento River water entered the Delta in April 1931 or earlier. Consistent with the long residence times of water within the Delta during dry years (see Section 4.4), none of the Sacramento River water present at the BBID intake location in June 1931 entered the Delta in June 1931.

During the summer of 1931, the water present at WSID's intake consisted of approximately 35% to 50% Sacramento River water and about 40% agricultural return flows, with the remainder from other sources. The Sacramento River water present at the WSID intake in summer 1931 entered the Delta primarily during the months of February through May 1931.

Animations were generated from the volumetric fingerprinting using the same methods described in Section 6.2.3. The animations show Sacramento River inflow from March 1931 and April 1931 as it propagates through the Delta. These animations were generated by "tagging" Sacramento River inflows with a concentration of 100% during the month of March (or April) 1931, and tracking the concentration of March (or April) Sacramento River inflow within the Delta over time. These animations provide visual confirmation that some portion of the water that entered the Delta from the Sacramento River in April 1931 remained in the Delta through the end of the year (December 1931), when the San Joaquin River flushed the south Delta. The aminations will be provided electronically and a series of images from the animations are provided in Appendix E.

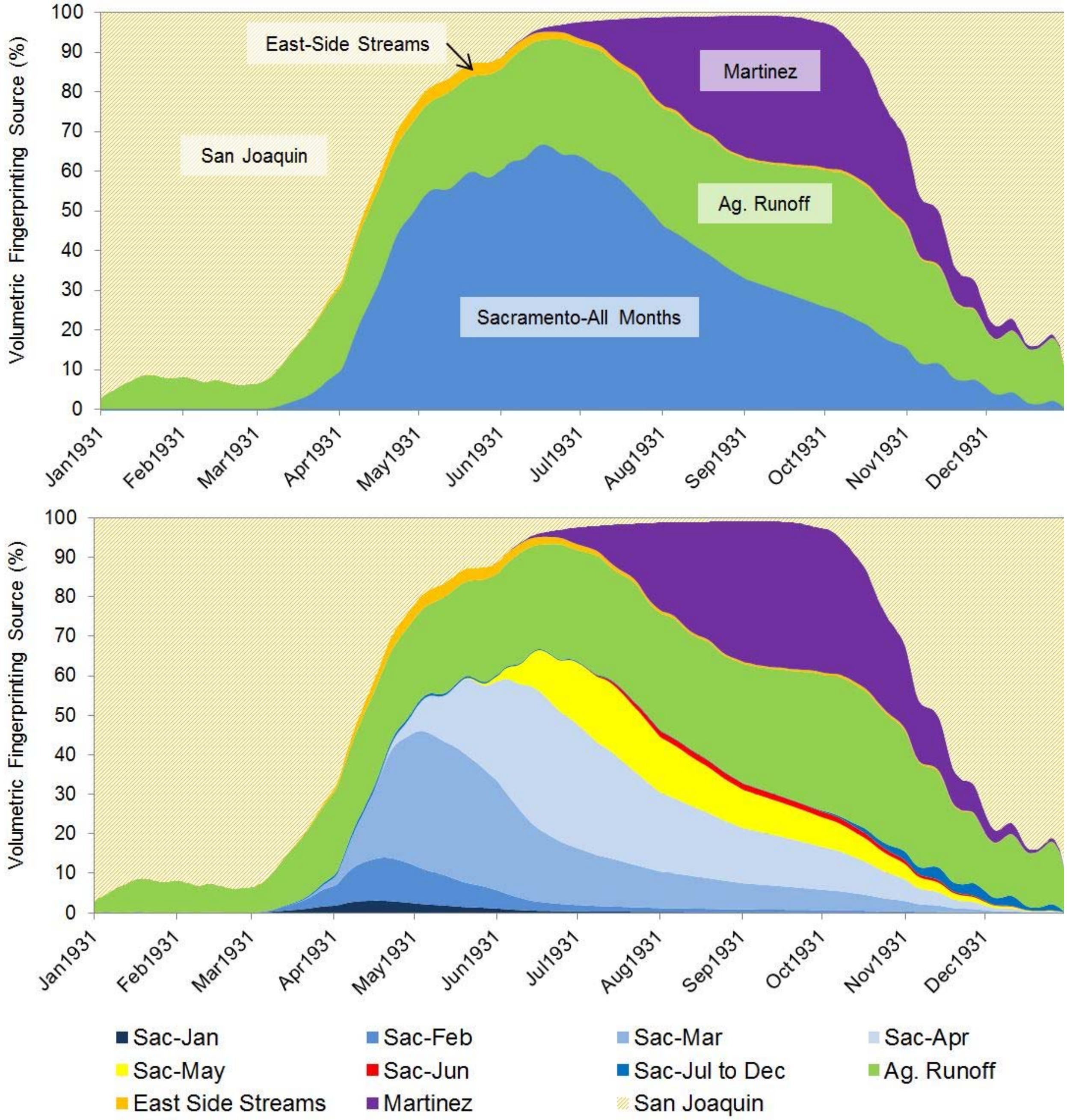

Figure 6-6. Volumetric fingerprint in Old River at Highway 4 for 1931 shown with Sacramento River inflow as one source (top), and Sacramento River inflow separated according to month (bottom)

Antioch-217

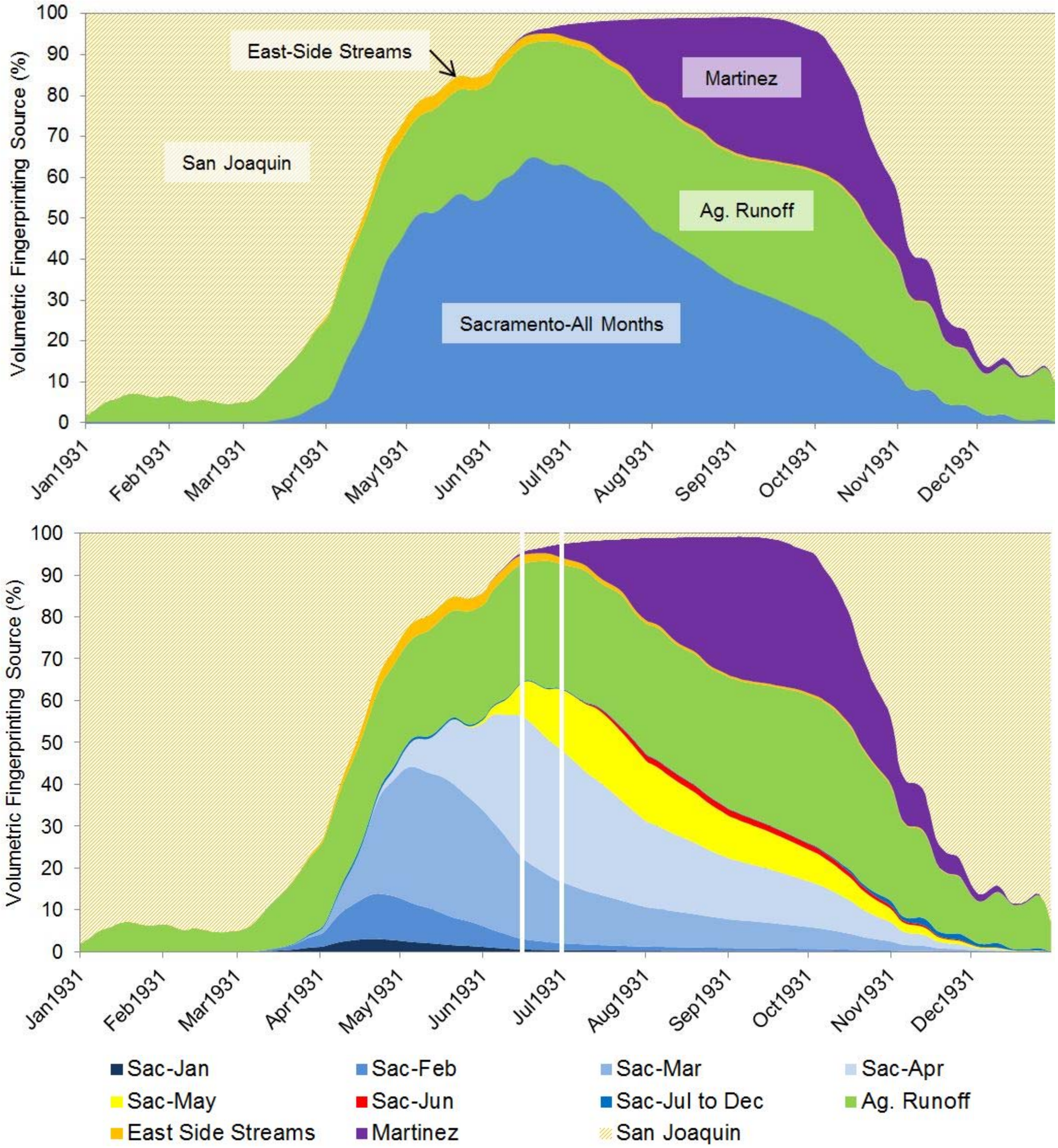

Figure 6-7. Volumetric fingerprint at the BBID intake for 1931 shown with Sacramento River inflow as one source (A), and Sacramento River inflow separated according to month (B)

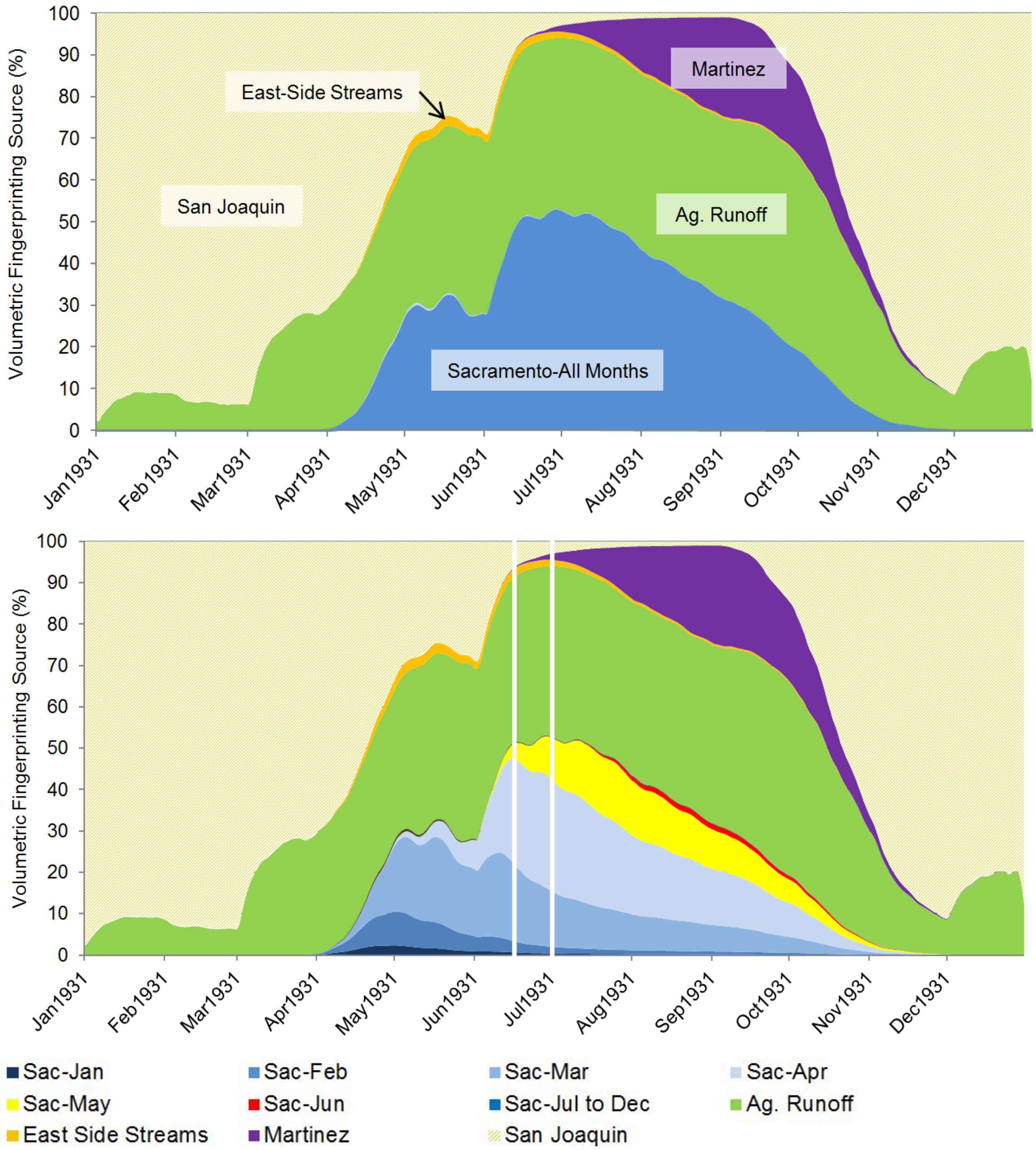

Figure 6-8 Volumetric fingerprint at the WSID intake for 1931 shown with Sacramento River inflow as one source (A), and Sacramento River inflow separated according to month (B).

6.3 Hydrodynamics, Salinity, and Source Fingerprints for 2015

6.3.1 Model Run Description

Exponent modeled Delta conditions for WY2015 to evaluate salinity, hydrodynamics, and source fingerprints. This model run was developed to simulate actual conditions in the Delta throughout WY 2015, including during June 2015. Unlike the 1931 simulation, when the CVP and SWP were absent and when no gates were in operation by DWR and USBR, water exports at Harvey Banks Pumping Plant and Tracy Pumping Plant, and the gate operations, were included in the 2015 run.

For the 2015 model run, Exponent used the DSM2 to simulate electrical conductivity (EC) over the period October 1, 2010, through September 30, 2015. Model runs were performed for WY 2011–2015, but results and output are presented for WY 2015 only. The model boundary conditions and sources of data and information for the WY 2015 simulation are presented in Table 6-2 and discussed in Appendix A.

Table 6-2. Input data and data sources for the 2015 simulation

Input Data	Data Source
Sacramento River Inflow	Dayflow (- 2014), CDEC (2015), USGS
San Joaquin River Inflow	Dayflow (- 2014), CDEC (2015)
Cosumnes River Inflow	Dayflow (- 2014), CDEC (2015)
Mokelumne River Inflow	Dayflow (- 2014), CDEC (2015)
Calaveras River Inflow	Dayflow (- 2014), CDEC (2015)
Stage at Martinez	CDEC
BBID Diversion	DWR (estimated), USBR (actual)
Delta Island Consumption Use—DICU	DWR
Electrical Conductivity of Inflows	CDEC
Electrical Conductivity of DICU	DWR
Gate Operation Records	DWR & USBR
Pumping Stations	CDEC & USBR
Inflow and EC at Clifton Court	CDEC & USBR

6.3.2 Model Validation

DSM2 model output was validated by comparison with measured data. Figure 6-9 shows modeled and measured electrical conductivity data at Antioch and at Clifton Court Forebay for WY 2015. Both modeled results and salinity measurements for WY 2015 are expressed as EC and use the units µS/cm. As shown in Table 4-5, salinity conversions for Clifton Court Forebay are provided to allow conversion between EC, chloride concentration, and total dissolved solids (TDS); for reference, an EC value of 550 µS/cm is equivalent to about 100 ppm chloride at Clifton Court (note that unit conversion relationships are specific to location, according to relationships developed in Guivetchi 1986).

Model results for EC match measured data well at Antioch (Figure 6-9, top panel). By contrast, model results for EC match measured data reasonably well at Clifton Court Forebay for WY 2011 and 2012 (results not shown), but the deviation between modeled and measured salinity was greater for the WY 2013–2015 time period. Even though peak measured EC values are greater than peak modeled EC in WY 2015, the model captures the overall patterns of EC at this location in WY 2015 reasonably well. DSM2 model results for EC at this location are, however, generally consistent with the 2013 DWR DSM2 EC calibration results. Differences between modeled and measured salinity values in the vicinity of the BBID intake are likely due to inaccuracies in the values of DICU used in the model (see Sections 4.5 and 6.2 for further discussion).

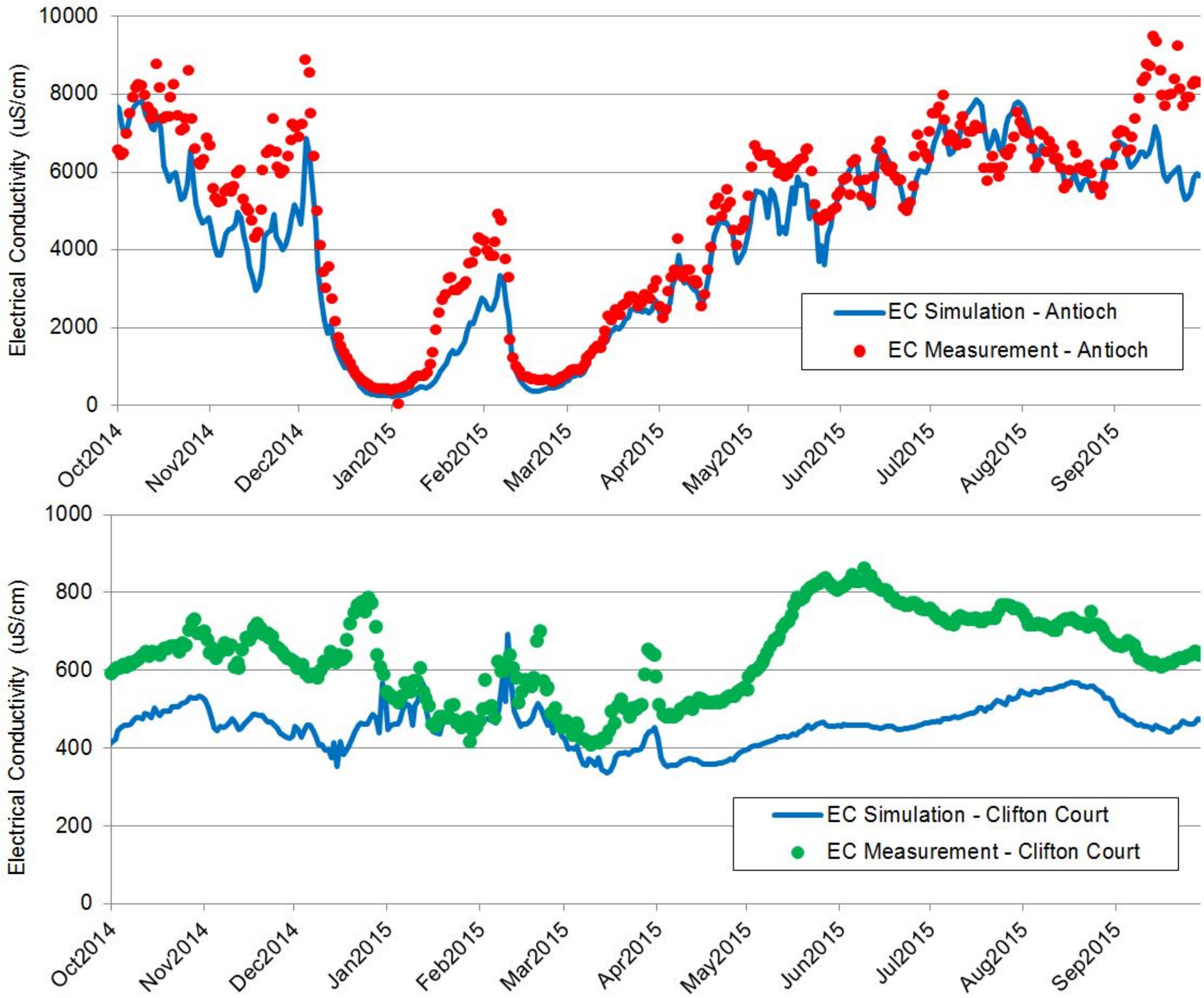

Figure 6-9. Modeled and measured EC at Antioch (a) and at Clifton Court Forebay (b) during WY 2015 (measured data from CDEC, accessed 11-20-2015)

6.3.3 Salinity

Salinity measurements and modeled data show different trends in 2015 relative to the 1931 data, due to the presence of the Projects. Instead of a smooth curve indicating salinity intrusion in the late summer, multiple smaller salinity spikes are apparent throughout the year, and the salinity baseline is higher throughout the year than in the pre-Project condition. The maximum measured EC at Clifton Court Forebay between 2011 and 2015 was 1000 µS/cm (~215 mg/L chloride); by contrast, in 1931, the salinity peaked at nearly 1,300 mg/L chloride. Similarly, EC at Antioch peaked at 9500 µS/cm (~3000 mg/L chloride) in September of 2015, while in 1931, concentrations as high as nearly 12,000 mg/L were observed. During June 2015, measured salinity at Clifton Court Forebay ranged from 500 µS/cm (~90 mg/L chloride) to 740 µS/cm (~150 mg/L chloride). On June 13, 2015 the measured salinity in Clifton Court Forebay was 821 µS/cm (~160 mg/L chloride), and on June 25, 2015 the salinity was 769 µS/cm (~150 mg/L chloride). This indicates that fresh water was present at the BBID intake through the entire month of June 2015.

As shown in Section 4.0, fresh water was also present near the WSID intake throughout the summer of 2015 (Figure 4.9). From June 1, 2015 to August 31, 2015, measured EC concentrations in Old River near Tracy averaged approximately 1000 µS/cm and peaked at 1290 µS/cm.

As with the WY 1931 model simulation, an animation was prepared to show daily average salinity throughout the Delta for WY 2015. Compared to WY 1931, baseline salinity levels in WY 2015 were higher, but peak salinity levels in the Delta were generally lower throughout the year. Aminations are provided electronically.

6.3.4 Volumetric Fingerprinting

Volumetric fingerprinting was used within DSM2 to calculate the source of the water present in Old River and at the BBID intake location during WY 2015, including from June 13 to 25, 2015. Figure 6-10 shows that approximately 75% or more of the water in Old River at Highway 4 originated from the Sacramento River. Figure 6-10 (bottom panel) separates the Sacramento River source fingerprint by month; the graph shows that virtually all of the Sacramento River water present in Old River at Highway 4 from June 13 to 25, 2015, entered the Delta in February, March, April, and May 2015. Figure 6-11 (top panel) presents a similar volumetric fingerprint graph for Clifton Court Forebay, illustrating that model results demonstrate that more than 70% of the water at Clifton Court Forebay throughout WY 2015 was from the Sacramento River. Figure 6-11b shows that the majority of Sacramento River water present at Clifton Court Forebay from June 13 to 25, 2015, entered the Delta between February and May 2015. As shown in Section 5.3, it can be estimated that only after about

April 20, 2015, can water in the Sacramento River be considered to consist of both full natural flows and stored water. Thus, the modeling analysis demonstrates clearly that the majority of water present at the BBID intake from June 13 to 25, 2015, was not stored water released from upstream reservoirs.

The impact of the CVP and SWP on the composition of water in the Delta can clearly be seen by comparing source fingerprints from 1931 to those from WY 2015. Whereas water in the Clifton Court area consisted primarily of San Joaquin River water in winter and Sacramento River water in summer during WY 1931, about 70% or more of the water present at Clifton Court Forebay year-round in 2015 is Sacramento River water. It is also important to note that the Project reservoirs upstream of the Delta captured and stored some portion of the runoff that occurred during WY 2015, including some portion of the pulses of flow that occurred in response to precipitation events in December 2014 and February 2015; had this water not been captured by the projects, that water would have entered the Delta, and, given the high Delta residence times during dry conditions, would have remained in the Delta and available for diversion in subsequent months.

Two animations were generated from the volumetric fingerprinting data using the same techniques described in Section 6.2.3. The animations show Sacramento River inflow from March and April (independently) propagating through the Delta. The aminations will be provided electronically.

As discussed in Section 4.5, the DSM2 is also used by DWR to compute source fingerprints for water within the Delta. The 2015 source fingerprints simulated by Exponent, as shown in Figures 6-10 and 6-11, are very similar to those produced by DWR (see Figure 4-10 for comparison).

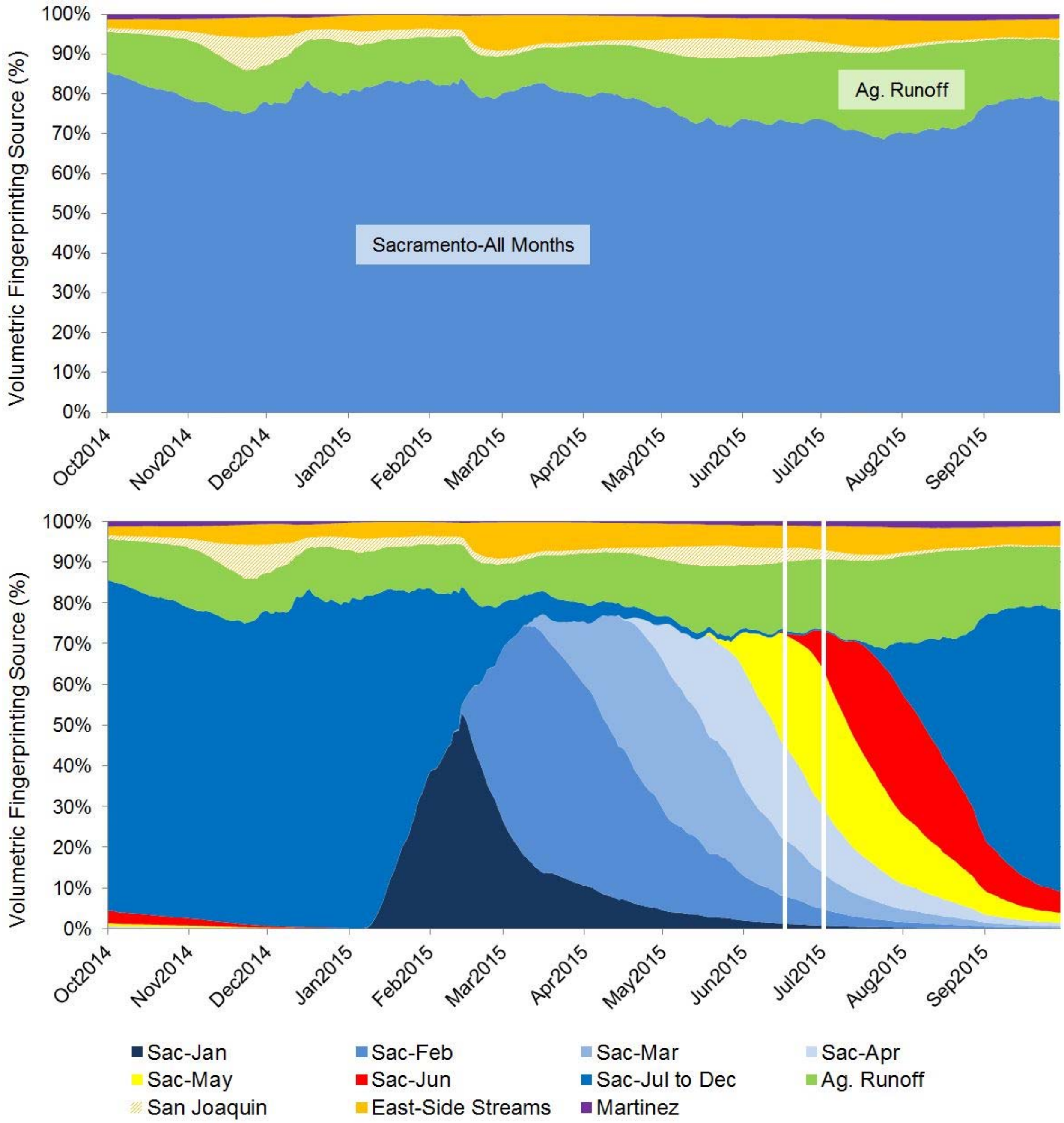

Figure 6-10. Source fingerprints for water in Old River at Highway 4 for water year 2015 (a), and showing the month when Sacramento River water entered the Delta (b)

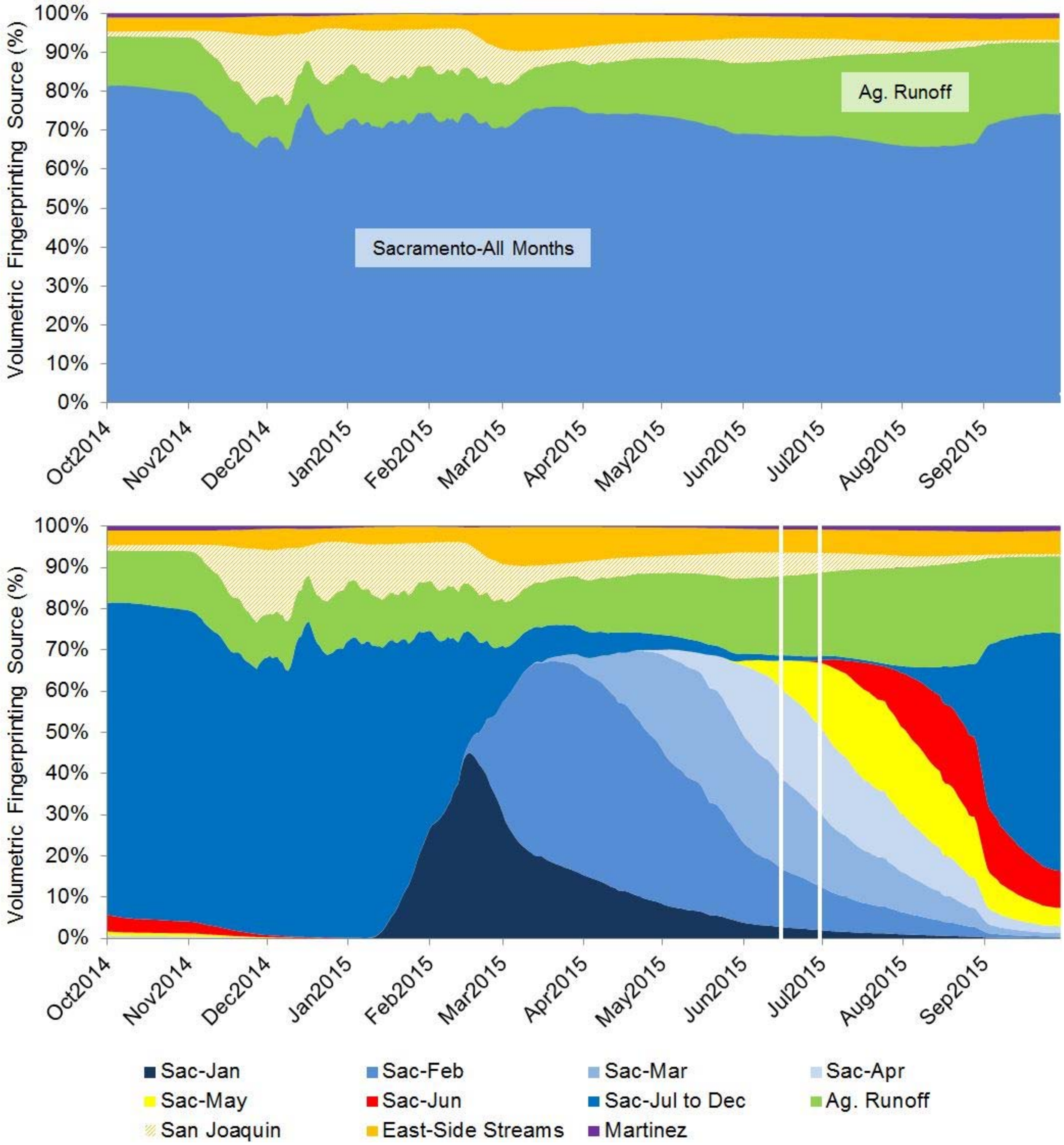

Figure 6-11. Source fingerprints for water at Clifton Court for water year 2015 (a), and showing the month when Sacramento River water entered the Delta (b)

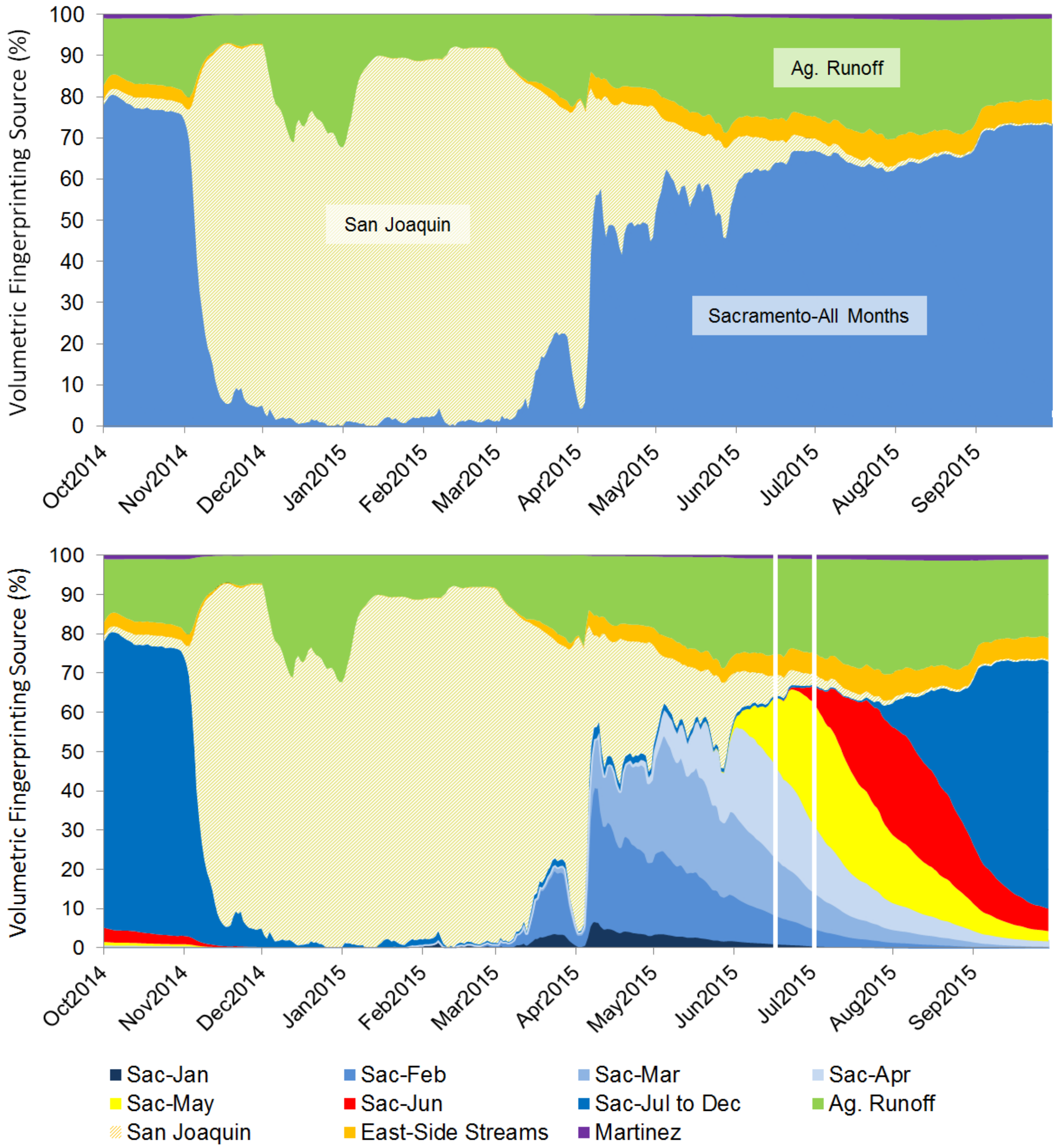

Figure 6-12 Source fingerprints for water at WSID intake for water year 2015 (a), and showing the month when Sacramento River water entered the Delta (b)

6.4 Conditions in the Delta in 2015 without the CVP and SWP

As detailed in Section 4.3, 1931 represents the conditions that would likely have occurred within the Delta during 2015 had the CVP and SWP not been constructed. However, diversions during 1931 were likely greater than in 2015 in the period after May 1 (when post-1914 rights holders were curtailed) and after June 12 (when pre-1914 rights holders were curtailed). In addition, two significant pulses of inflow occurred during WY 2015 (in December 2014 and in February 2015) that were not observed during WY 1931, and source fingerprinting shows that Sacramento River water that entered the Delta in February 2015 was still present in the Delta between June 13 and 25, 2015. Of note, had the Projects not captured and stored water upstream of the Delta in WY 2015, the amount of natural that entered the Delta in response to these flow pulses would have been greater, increasing the amount of Sacramento River water from winter 2015 that would have remained in the Delta later in the year.

Although it is difficult to simulate the conditions that would have occurred during WY 2015 without the operation of the CVP and SWP, it is my opinion that the conditions measured in WY 1931, and the simulations results that correspond to WY 1931, are similar to the conditions that would have occurred during WY 2015 without the CVP and SWP. Both measured and modeled results for WY 1931 demonstrate that water was present at the BBID intake location from June 13 to 25, 1931 (as it always would be, because the bottoms of the channels at this location are below sea level). Both measured data and model results indicate that fresh water was present at the BBID intake location during June 13–25, 1931; salinity levels did not begin to rise until July 1931. Also, historical records indicate that BBID and WSID (and other diverters in the same area of the Delta) diverted water throughout the irrigation season, including both during the period June 13–25, 1931, and later in the summer, when salinity levels rose.

Additionally, source fingerprinting performed using the DSM2 model demonstrates that, for WY 1931, water that was present at the BBID intake location consisted primarily of Sacramento River water that had entered the Delta during the months of February–May 1931. Similarly, water that was present at the WSID intake location in summer 1931 consisted primarily of a mixture of Sacramento River water (from February-May 1931) and agricultural return flows.

Sacramento River water that flowed into the Delta during June 1931 did not reach the BBID and WSID intake locations until later in the summer of 1931, after the June 13–25, 1931 time period.

Finally, source fingerprinting confirms that because the residence time of water in the Delta is several months during dry flow conditions, it takes a significant amount of time for river water to flow into and to propagate through the system. Because full natural flows are determined far upstream of the Delta, they would not be available for diversion for weeks to months—i.e., for the time required for water to travel from a full natural flow measurement location into and through the Delta, and to diversion locations in the south Delta—and in the meantime, water in the Delta would consist of flows that had entered the Delta in prior months. Although the relationship between full natural flow and "availability" within the Delta could be determined using model simulations, it would be inappropriate to use full natural flow as a real-time indicator of water availability in the Delta.

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Appendix A

Input Data for DSM2 Model Runs

DSM2 Model Input Parameters

DWR has developed and refined a model to simulate conditions in the Delta, called the Delta Simulation Model (DSM2). Exponent used the DSM2 model to simulate hydrodynamics, water quality, and source fingerprints within the Delta in order to understand the flow and source of water within the Delta during key timeframes, and to understand the distribution of salinity within the Delta, including the intrusion of salinity from the Bay.

DSM2 users must specify a series of input parameters to operate the model, including inflows from the Sacramento River, San Joaquin River, Cosumnes River, Mokelumne River, and Calaveras River, the stage at Martinez, DICU flows and electrical conductivity, conductivity at Martinez and Freeport, and conductivity of the east side streams and the San Joaquin River. Diversions and exports must also be specified in the model. Model inputs can be taken either from measured data (e.g., stage at Martinez, river inflows, salinity at model boundaries, measured diversions and exports) or from synthetic datasets such as Dayflow (maintained by DWR). The input parameters for the WY1931 and WY2015 model runs as described in Section 6 of the body of the report are shown in the following sections.

WY1931 Model Run

The following tables and figures describe DSM2 model input parameters for the WY1931 model run. The simulation was run for October 1, 1929, through December 21, 1935, but the following figures present input for WY1931. Table A-1 lists the required input data and the sources of these input data.

Table A-1 WY1931 Input Parameters and Sources

Input Data	Data Source
Sacramento River Inflow	Dayflow[1]
San Joaquin River Inflow	Dayflow[1]
Cosumnes River Inflow	Dayflow[1]
Mokelumne River Inflow	Dayflow[1]
Calaveras River Inflow	Dayflow[1]
Stage at Martinez	DWR[2]
BBID Diversion	Bulletin 23 Report (1931)
Delta Island Consumption Use (DICU)	DWR[2]
Electrical Conductivity at Martinez, Freeport, Mossdale	Bulletin 23 Report (1931)
Electrical Conductivity of DICU	DWR[2]
Electrical Conductivity of east side rivers	Assumed Constant

[1]Data downloaded from http://www.water.ca.gov/dayflow/output/Output.cfm for stations SAC, SJR, CSMR, MOKE, CALR

[2]Data included in DSM2 download package from DWR (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm)

As shown in Table A-1, boundary flow data were downloaded from the Dayflow web site (http://www.water.ca.gov/dayflow/output/Output.cfm). Flow rates for the Sacramento, San Joaquin, Cosumnes, Calaveras and Mokelumne Rivers for WY1931 are shown in Figures A-1 and A-2. The stage, or surface water elevation, at Martinez is shown in Figure A-3, and was included in the DSM2 package downloaded from the DWR website. Also included in the downloaded package were the Delta Island Consumptive Use (DICU) flow data. The total DICU flow, shown as instantaneous values recorded for the end of each month, are presented in Figure A-4. The assumed DICU EC is shown in Figure A-5. Figures A-6 and A-7 present the EC boundary conditions at Martinez and Mossdale Bridge. Table A-2 lists the assumed constant EC values for the eastside streams (the Calaveras, Cosumnes, and Mokelumne Rivers) to describe the salinity of inflows to the Delta. Constant values were used because this methodology was used in prior DWR simulations and because the EC of the east-side streams is relatively constant. DWR Bulletin 23 observed data were used to obtain the EC values for Sacramento River at Freeport and Yolo Bypass.

Antioch-217

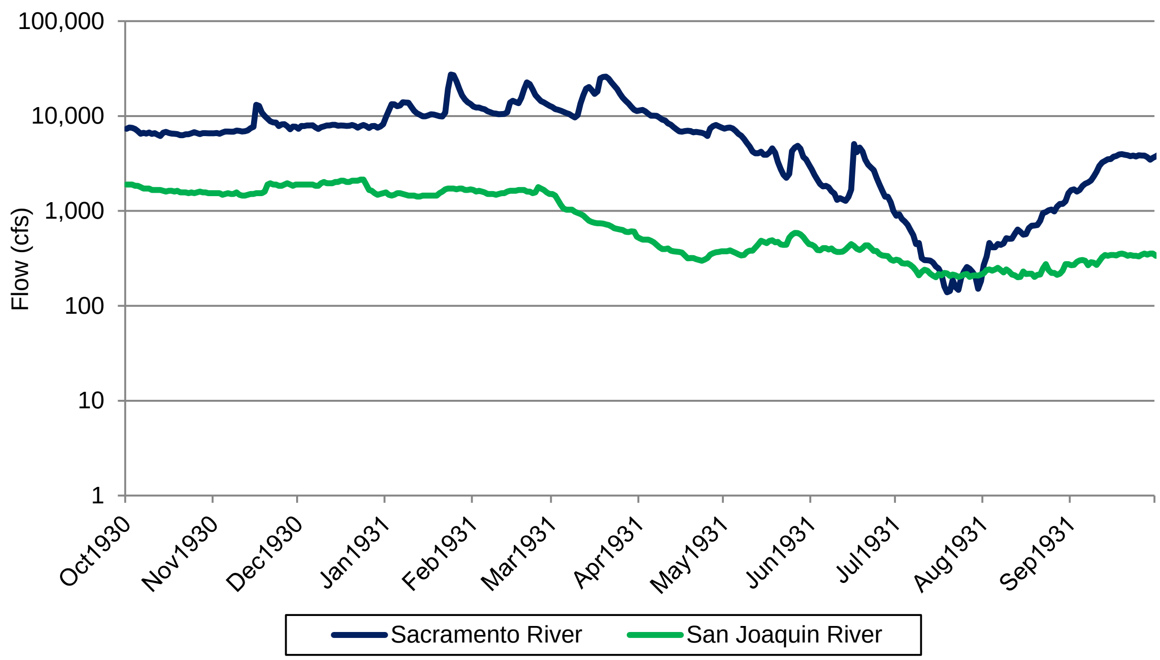


Figure A-1. Sacramento River flows at Freeport and San Joaquin River flows at Vernalis from October 1930 through January 1932 (Source: Dayflow [1930-1939]). Note the log-scale.

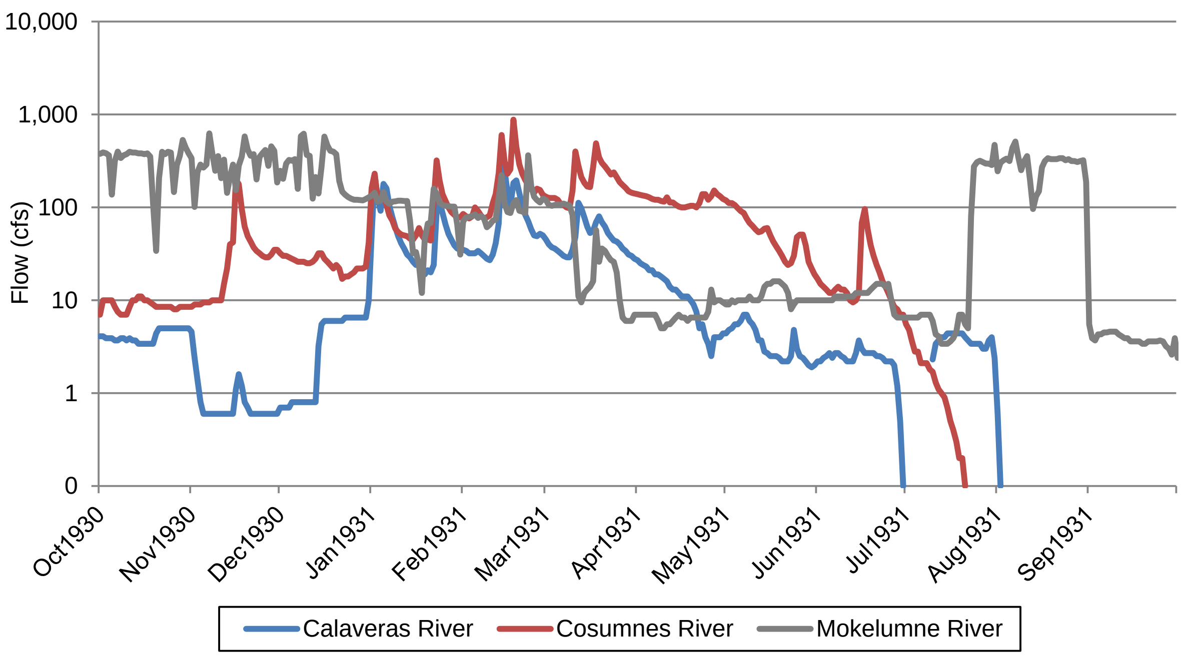


Figure A-2. Calaveras River, Cosumnes River, and Mokelumne River flows from October 1930 through January 1932 (Source: Dayflow [1930-1939]). Note the log-scale.

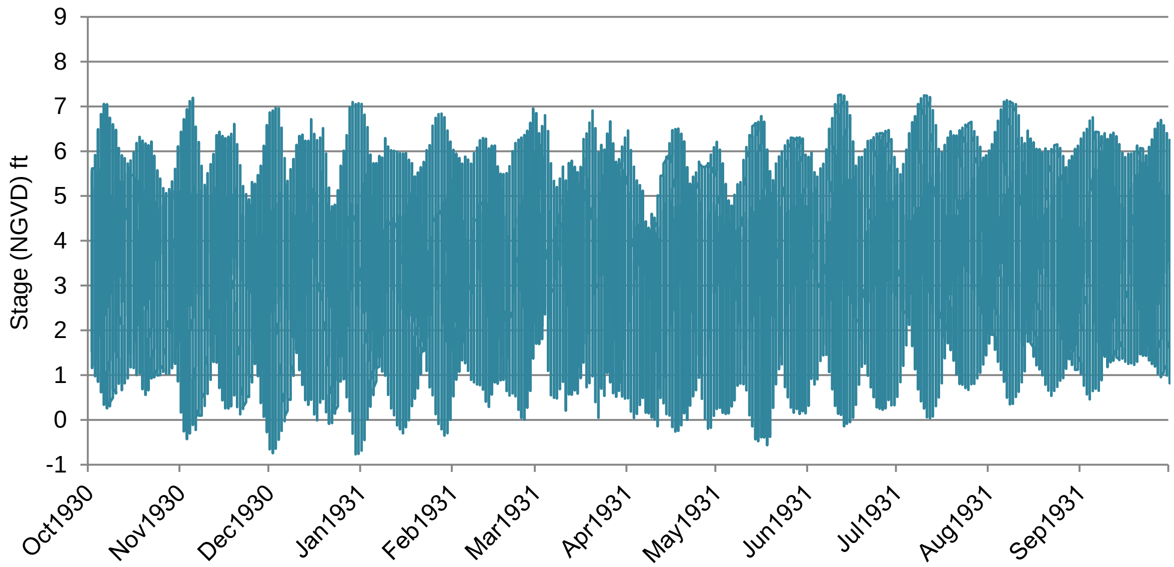


Figure A-3. Stage at Martinez from October 1930 through January 1932 (Source: DWR DSM2 package, downloaded on 2015/1/30. Note the datum was converted from NGVD 29 to NAVD 88.

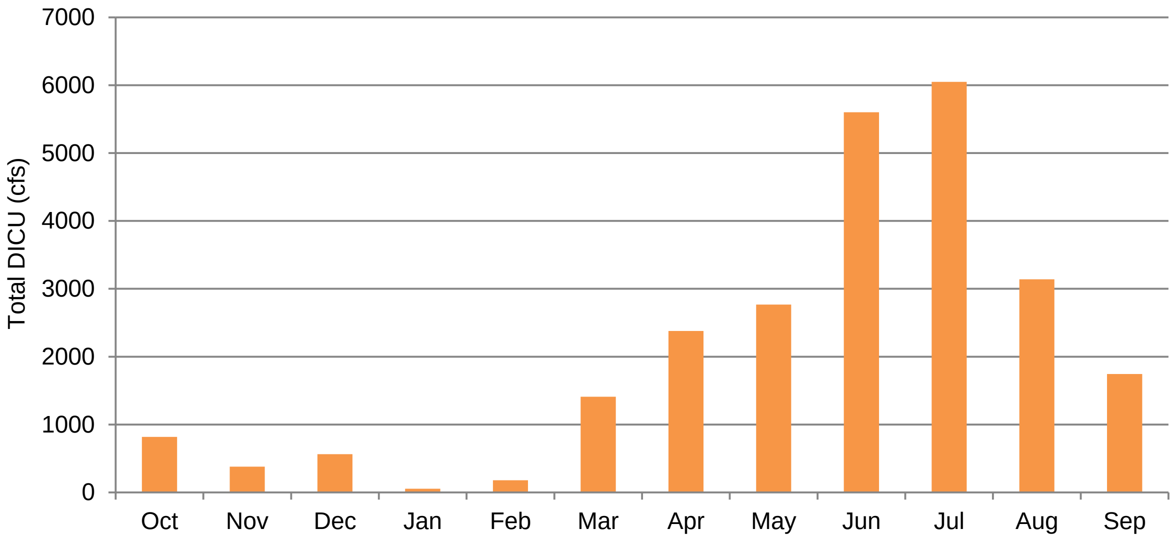


Figure A-4. Daily average DICU flows from the end of each month for WY1931 (Source: DWR DSM2 package, downloaded on 2015/1/30)

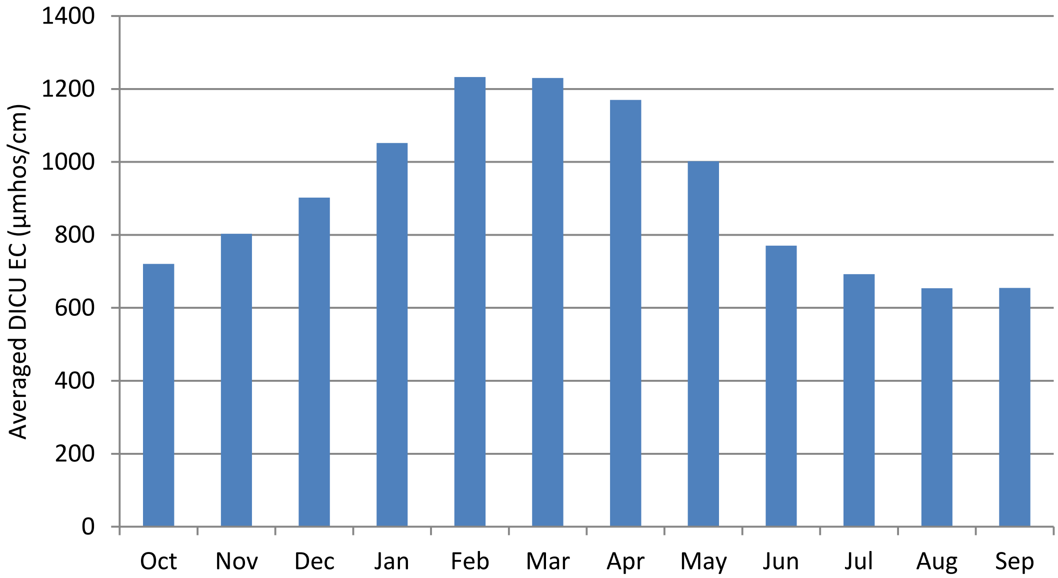


Figure A-5. Averaged EC values used in DICU by month
(Source: DWR DSM2 package, downloaded on 2015/1/30).

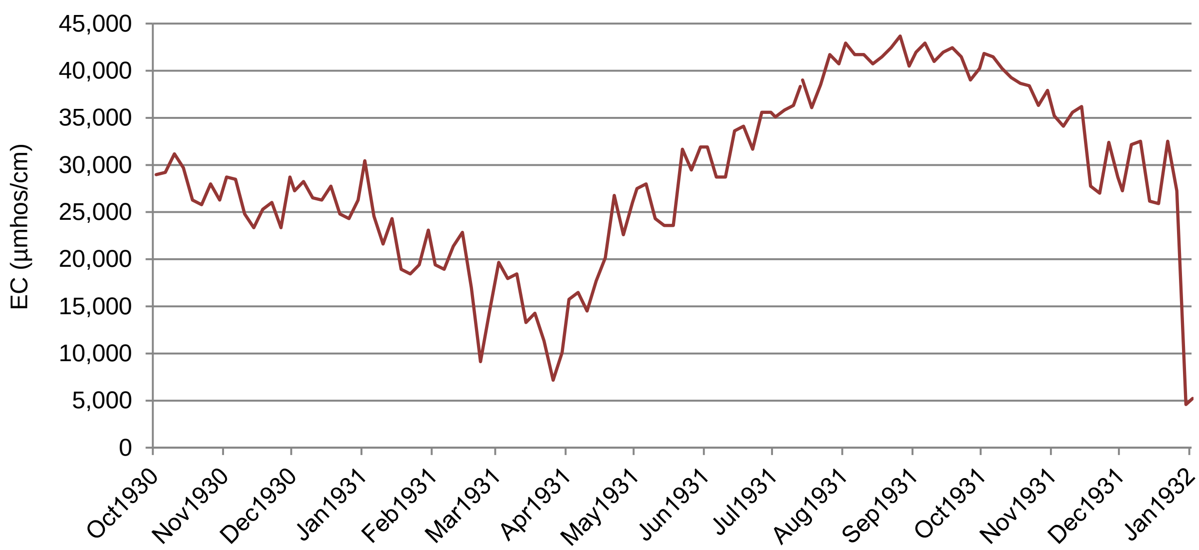


Figure A-6. EC values at Martinez (Source: Bulletin 23 Report [1930,1931])

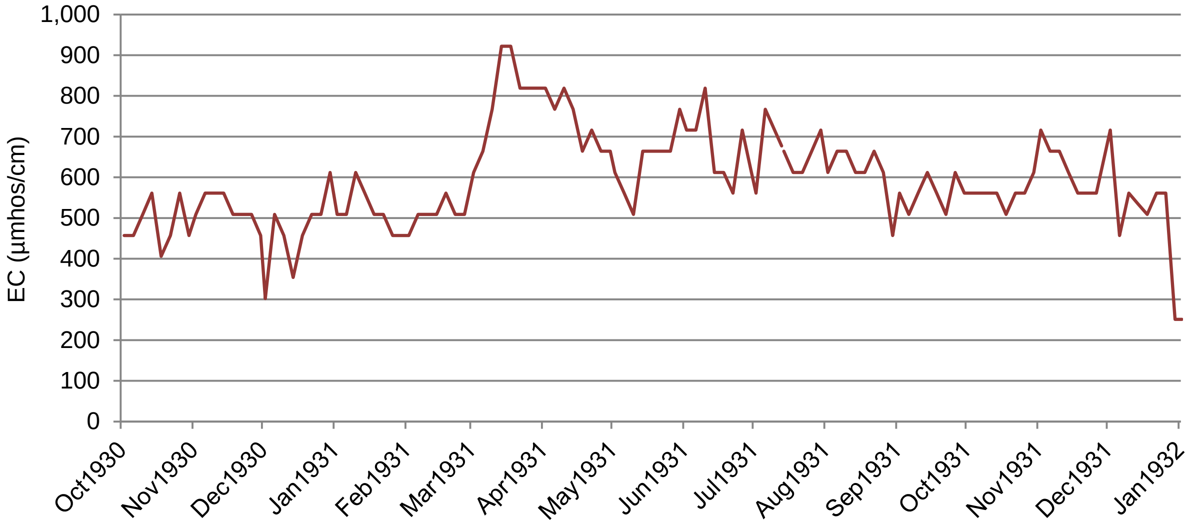


Figure A-7. EC values at Mossdale Bridge (Source: Bulletin 23 Report [1930,1931])

Table A-2. Assumed Constant EC values

Inflows	Constant EC (µmhos/cm)
Calaveras	75
Cosumnes	75
Mokelumne	75

WY2015 with Projects Model Run

The following tables and figures describe DSM2 model input parameters for the WY2015 model run. Table A-3 lists the input data and the sources of the input data. The following figures show input data for WY2015, although the simulation was run from WY2011-WY2015, and for certain parameters multiple data sources were required to cover the multi-year time frame.

Table A-3 WY2015 Input Parameters and Sources

Input Data	Data Source
Sacramento River Inflow	Dayflow[1] (- 2014), CDEC[2] (2015), USGS
San Joaquin River Inflow	Dayflow[1] (- 2014), CDEC[2] (2015)
Cosumnes River Inflow	Dayflow[1] (- 2014), CDEC[2] (2015)
Mokelumne River Inflow	Dayflow[1] (- 2014), CDEC[2] (2015)
Calaveras River Inflow	Dayflow[1] (- 2014), CDEC[2] (2015)
Stage at Martinez	CDEC
BBID Diversion	DWR[3] (estimated), USBR (actual)
Delta Island Consumption Use – DICU	DWR[3]
Electrical Conductivity of Inflows[4]	CDEC
Electrical Conductivity of DICU	DWR[3]
Gate Operation Records	DWR & USBR
Pumping Stations	CDEC & USBR
Inflow and EC at Clifton Court	CDEC & USBR

[1]Dayflow data downloaded from http://www.water.ca.gov/dayflow/output/Output.cfm for stations SAC, SJR, CSMR, MOKE, CALR.

[2] Flow and EC data dowloaded from CDEC at http://cdec.water.ca.gov/cgi-progs/selectQuery for stations SAC, SJR, CSMR, MOKE, CALR, MTZ.

[3]Data included in DSM2 download package from DWR (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm)

[4] EC downloaded from CDEC for Martinez, Sacramento River at Freeport, and San Joaquin River at Vernalis

Boundary inflows from the Sacramento River at Freeport, the San Joaquin River at Vernalis, and the east-side streams (Cosumnes, Calaveras and Mokelumne Rivers) used in the model simulation are shown for WY2015 in Figures A-8 and A-9 (note these are plotted on a log-scale). The substantial precipitation events of December 2014 and February 2015 are notable in Figure A-8. Figures A-10 through A-12 present the stage (the tidal forcing function) at Martinez, flow diversions at BBID, and total DICU inflow, respectively. Figures A-13 through A-15 present the EC boundary conditions at Martinez, Sacramento, Yolo, and the San Joaquin River at Vernalis. Similar to the 1931 simulation, constant EC boundary values were assumed for the east-side steams (Table A-4). In contrast to the 1931 run, water exports to CVP and SWP were considered in the 2015 run and are presented in Figure A-16 along with recorded diversions from BBID.

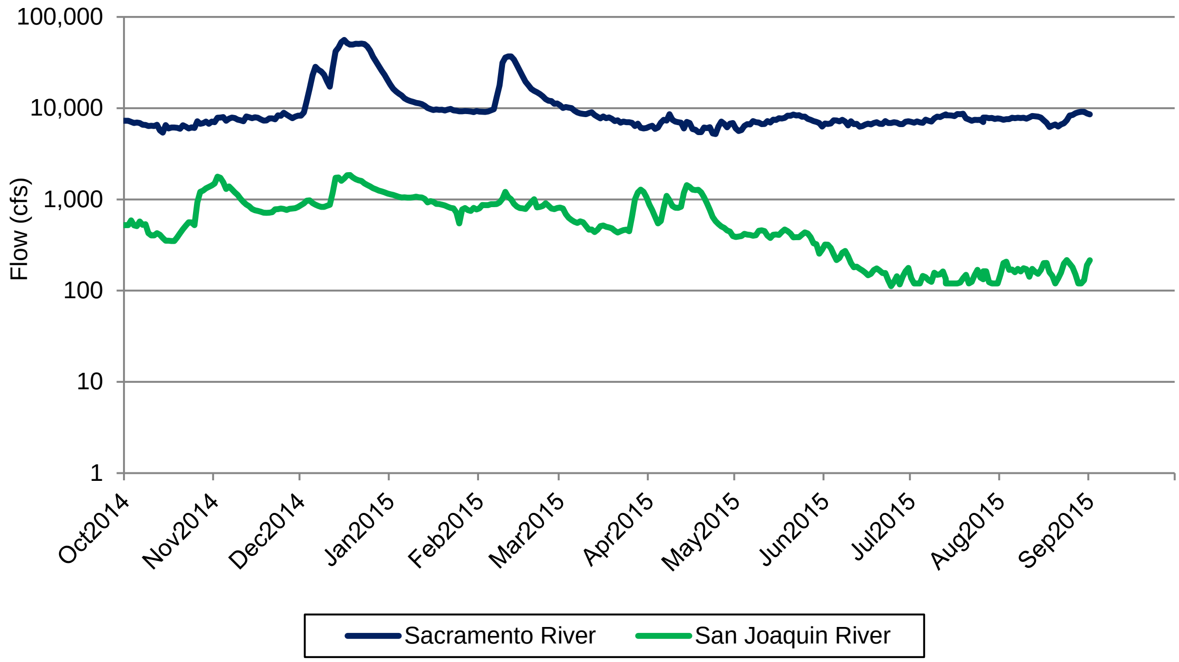


Figure A-8. Sacramento River flow at Freeport and San Joaquin River flow at Vernalis (Source: Dayflow [2011-2014], CDEC [2015], USGS). Note the log-scale.

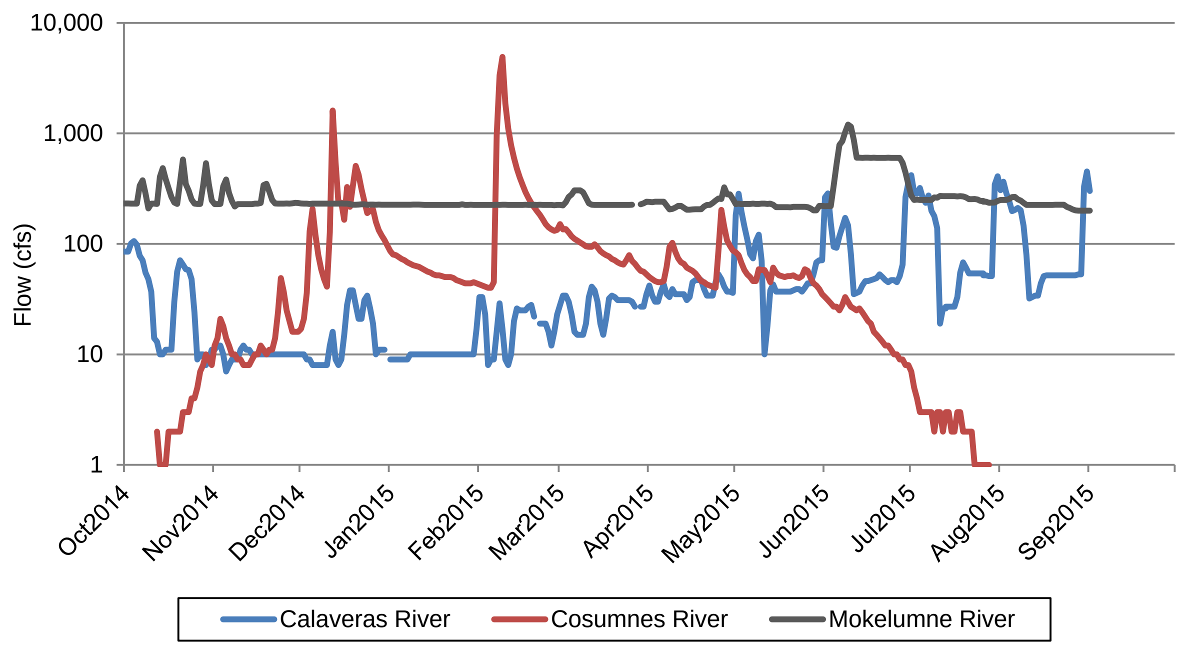


Figure A-9 Boundary inflows at the Sacramento, San Joaquin, Cosumnes, Calaveras and Mokelumne Rivers for WY2015 (Source: Dayflow [2011-2014], CDEC [2015]). Note the log-scale.

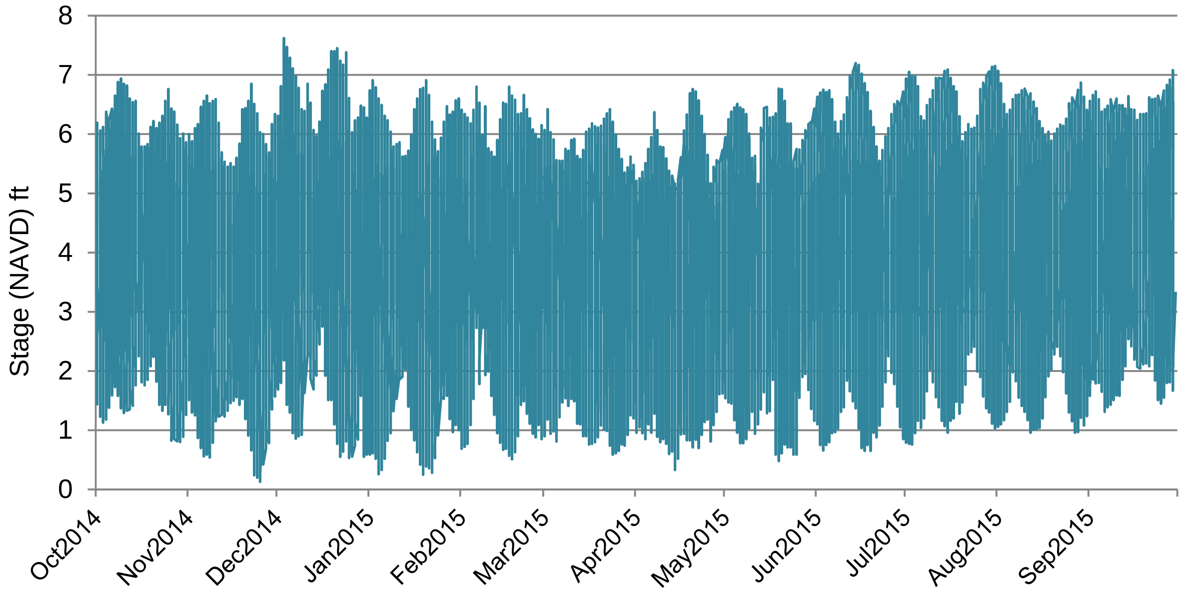


Figure A-10 Stage (NAVD) at Martinez for WY2015 (Source: CDEC)

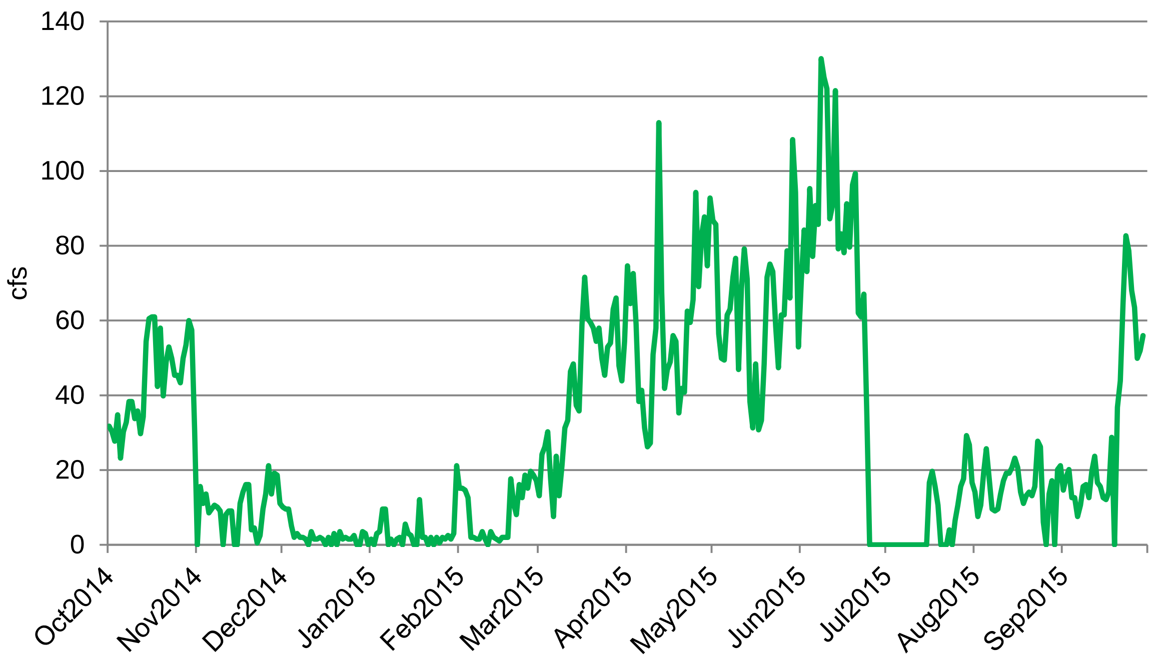


Figure A-11 BBID diversions from WY2015 (Source: USBR)

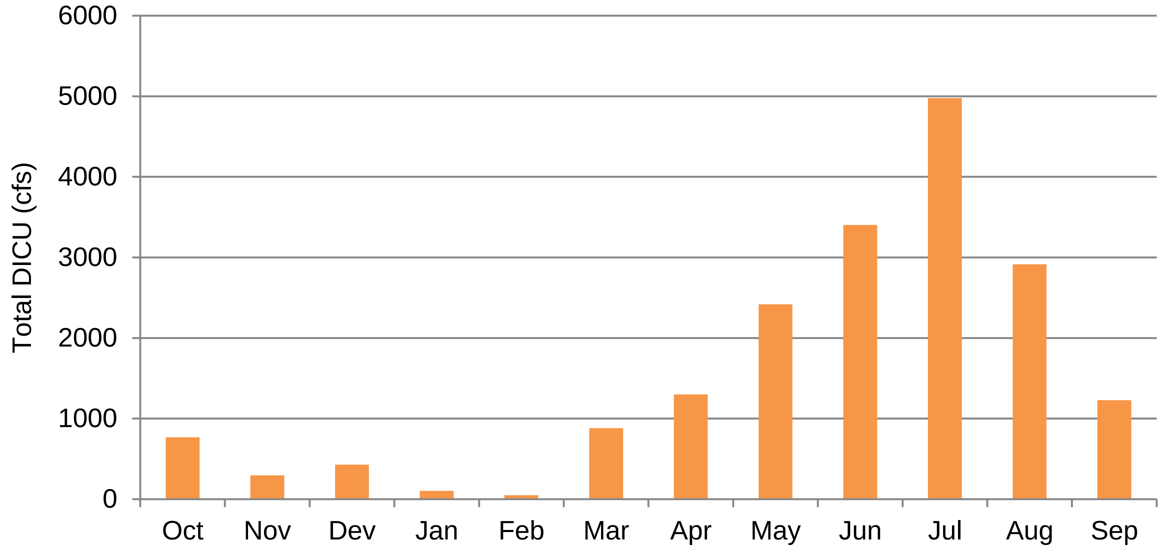


Figure A-12 Daily average DICU flows from the end of each month for WY2015 (Source: DWR received on 2015/11/18)

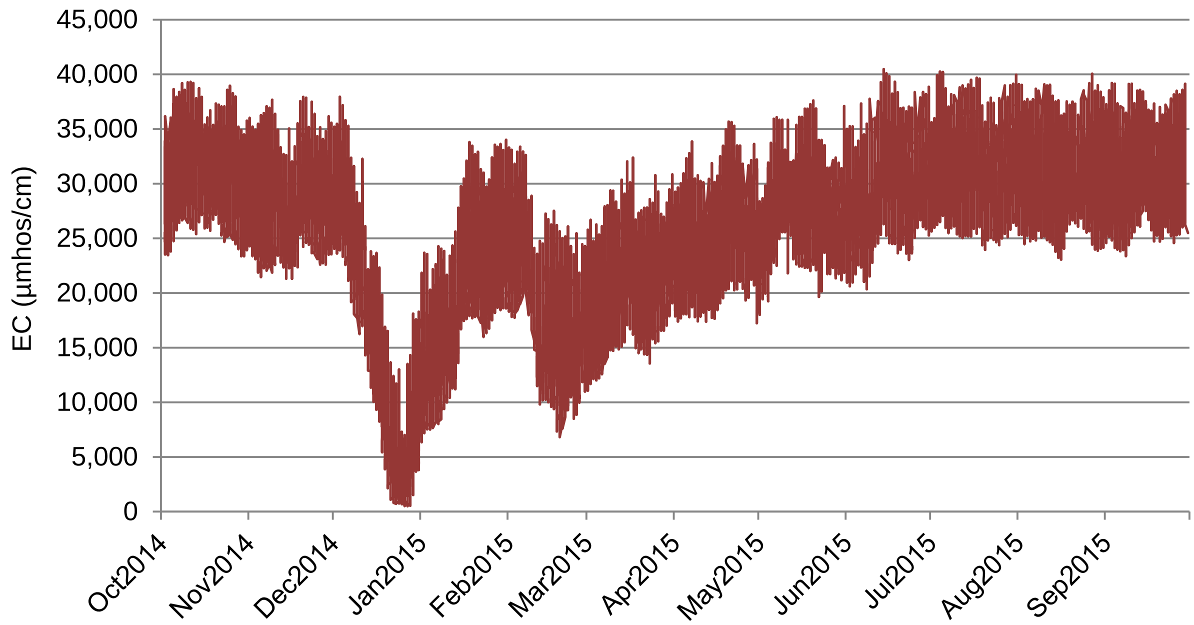


Figure A-13 EC at Martinez for WY2015 (Source: CDEC)

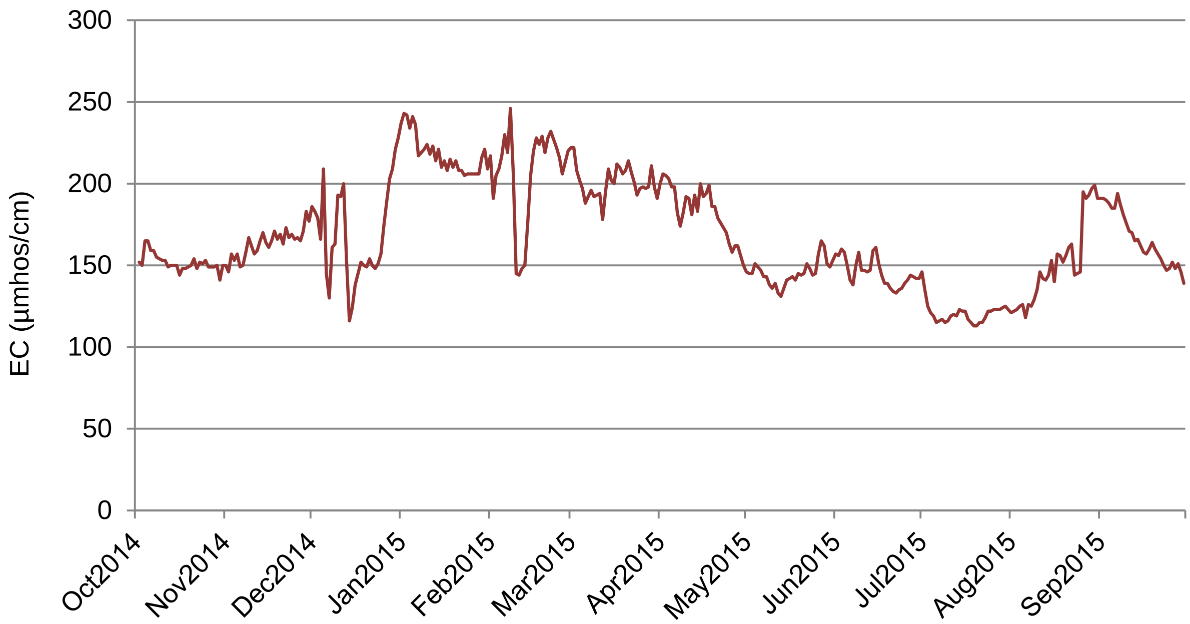


Figure A-14 EC of Sacramento River at Freeport and Yolo Bypass (Source: CDEC)

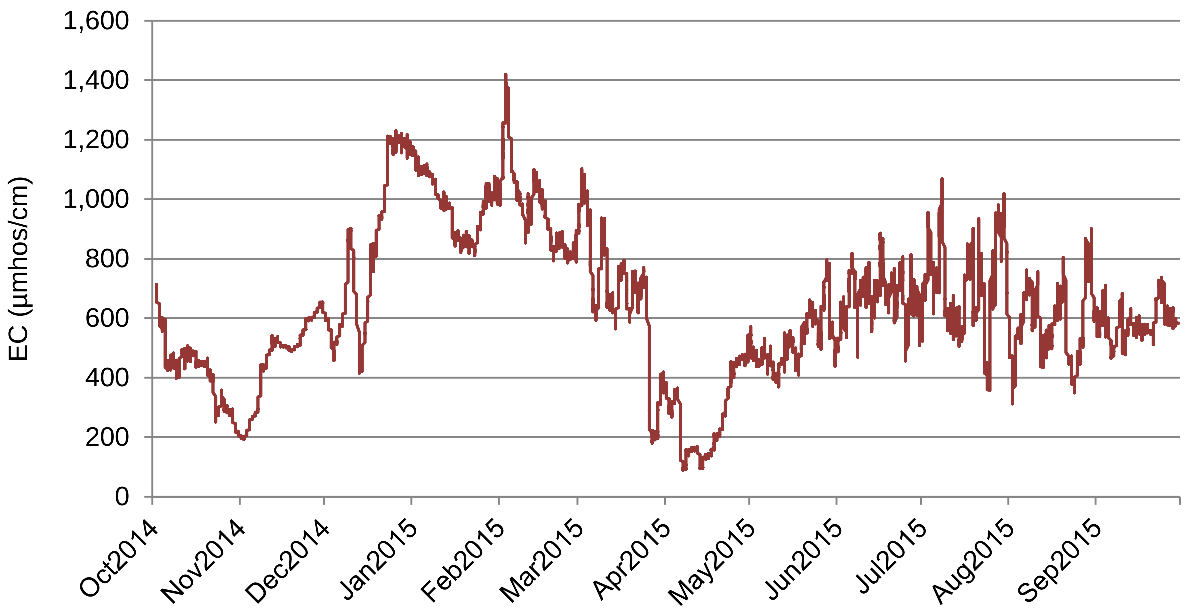


Figure A-15 EC of San Joaquin River at Vernalis for WY2015 (Source: CDEC)

Table A-4. Assumed EC values for 2015 model runs

Inflows	Constant EC (µmhos/cm) assumed[1]
Calaveras	125
Cosumnes	125
Mokelumne	125

[1]The same EC values were used as DWR's historical run (1999-2012)

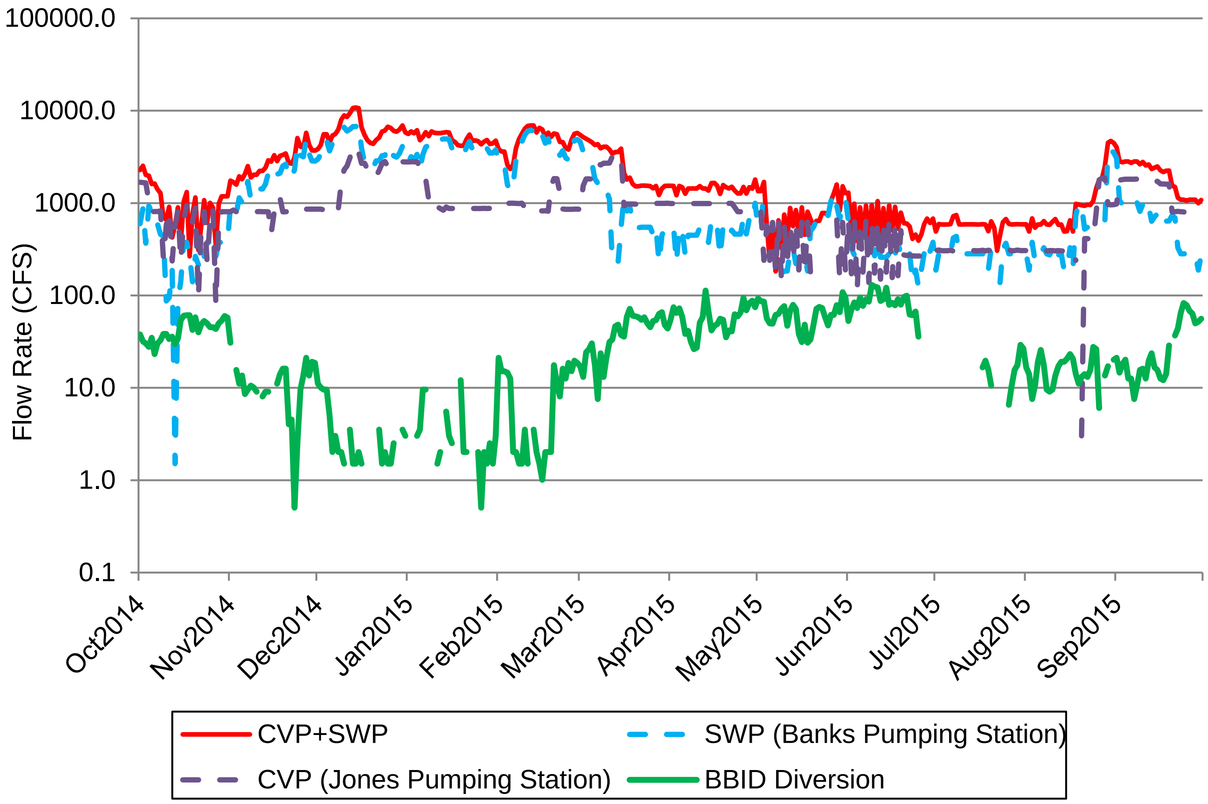


Figure A-16. CVP and SWP exports, and BBID diversions for WY2015 (Source: USBR). Note the log-scale.

Appendix B

Eight-River Unimpaired Runoff

Eight-River Unimpaired Runoff Index by Month from 1910 to 2015 (Data from CDEC and Kenneth Henneman, personal communication). Values are in Thousand-acre feet (TAF)

Water Year	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)
1910	632	1980	3086	2899	2546	4843	4206	3302	1460	768	528	512
1911	491	654	1152	4113	3612	5877	6358	5709	6029	2544	791	531
1912	520	557	555	1197	944	1609	1579	3334	2487	815	509	515
1913	427	1029	767	1602	1010	1320	2814	3307	1669	838	596	463
1914	385	675	1719	8499	3989	4180	5046	5280	3632	1790	777	532
1915	558	556	764	1860	5429	3539	4431	6383	3972	1578	672	520
1916	481	567	1520	3752	4892	5711	5032	4440	3358	1555	687	530
1917	690	666	1276	1008	3127	2146	4289	4365	4010	1311	588	448
1918	398	469	704	566	1217	2990	3090	2525	2018	653	435	516
1919	747	676	680	1203	3127	2743	3889	4062	1201	607	436	381
1920	404	404	679	566	584	1710	2579	3203	1754	663	405	342
1921	482	2359	2896	4337	3146	4216	3298	4011	3034	1020	494	407
1922	386	484	1163	1072	2625	2405	3661	6676	4848	1379	559	401
1923	433	673	2032	1747	1198	1510	3383	3659	2072	1110	479	423
1924	454	422	488	557	1158	635	1068	1096	449	357	282	270
1925	370	809	924	940	4993	2175	3822	3705	2043	868	477	373
1926	405	511	670	763	3182	1733	3790	2175	915	472	329	306
1927	349	1984	2006	2217	6054	3527	4823	4276	3113	1103	489	393
1928	398	1426	1096	1374	1944	5688	3731	3020	1170	576	372	334
1929	334	523	636	613	1123	1289	1628	2490	1455	555	297	303
1930	290	315	2372	1412	1841	2777	2639	2287	1581	582	344	329
1931	343	466	389	802	775	1199	1235	1182	541	307	263	252
1932	337	385	1684	1326	1837	2499	2730	4159	2988	1046	438	315
1933	306	324	419	700	580	1892	1966	2363	2453	648	335	292
1934	315	357	1041	1466	1593	1895	1615	1092	656	349	277	257
1935	321	856	795	1872	1559	2127	6177	4738	2944	858	429	323
1936	381	401	510	3221	5035	2770	3827	3712	2357	890	409	324

Water Year	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)
1937	323	328	449	542	2364	3277	3771	4919	2392	811	378	306
1938	396	1709	4814	1857	5268	7495	5978	7339	5044	1905	749	508
1939	601	645	797	792	814	1906	2259	1471	723	418	319	339
1940	437	365	677	3877	5682	6224	4612	3773	1905	682	408	380
1941	443	624	3407	4281	5074	4718	4617	5749	3339	1579	676	508
1942	505	676	3576	4182	5096	2230	4640	4759	4167	1647	657	482
1943	488	1076	1828	4666	2835	5328	4233	3590	2268	1086	567	437
1944	466	500	547	781	1442	1939	1880	3336	1811	881	424	346
1945	413	1202	1505	1073	4132	2170	2817	3818	2593	1065	502	373
1946	686	1357	4603	2639	1312	2292	3450	3681	1732	756	461	381
1947	453	939	1063	636	1569	2509	2205	2050	1200	487	361	334
1948	699	585	504	1911	701	1556	4343	4511	3318	957	474	405
1949	415	505	660	529	920	3322	3267	3386	1525	524	378	332
1950	349	423	435	1822	2545	2457	3735	3727	2103	727	405	367
1951	1010	4591	5950	3395	3517	2662	2807	3149	1596	695	451	377
1952	509	988	3362	3476	4026	3679	6352	7512	4557	2089	801	552
1953	490	520	1923	5397	1517	2064	3248	3379	3398	1418	585	497
1954	490	853	798	2203	2836	3660	4560	3266	1456	690	477	438
1955	438	780	1355	1162	961	1274	1973	3220	1893	646	406	376
1956	376	633	9144	7525	3713	3067	3509	5241	3547	1596	682	525
1957	657	615	607	794	2653	3409	2360	3851	2469	800	480	480
1958	846	860	1625	2388	7613	4706	6041	6736	4186	1675	810	582
1959	533	541	582	2249	2499	1980	2274	1820	1070	525	387	568
1960	426	393	474	904	3147	3221	2498	2389	1321	512	373	356
1961	392	727	1360	860	2137	1933	2016	2160	1226	480	415	363
1962	399	587	1189	781	4083	2390	3887	3142	2526	926	453	365
1963	2594	740	1897	1704	4656	2101	5604	4988	2664	1205	591	488
1964	589	1679	851	1548	1013	1147	1919	2436	1580	583	385	333
1965	386	907	8661	5613	2255	1972	4737	3809	2778	1356	836	456
1966	465	1464	1044	1854	1562	2525	3327	2516	917	500	392	362

Water Year	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)
1967	366	1304	2981	3345	2517	4091	3819	6256	5444	2589	818	512
1968	517	550	851	1494	3710	2554	2168	2153	1092	553	522	411
1969	515	887	1765	7913	4731	3359	5438	7340	4278	1765	742	537
1970	637	658	3298	10681	3021	3119	1823	2766	1911	810	512	431
1971	481	1927	3259	3045	1834	3725	3403	4177	3333	1213	580	503
1972	557	693	1191	1395	1731	3298	2520	2610	1537	573	408	484
1973	624	1211	1835	4076	3657	3271	3080	4757	2258	768	514	463
1974	668	4556	3685	6933	2097	6176	5070	4688	3187	1364	675	519
1975	535	622	859	1013	2924	4650	2891	5403	4076	1238	636	566
1976	916	858	763	648	877	1342	1351	1436	607	425	500	450
1977	416	418	379	475	476	545	689	906	755	378	335	402
1978	356	473	1898	5907	3478	5357	4398	4701	3782	1740	685	793
1979	430	522	535	1445	2102	2897	2674	4504	1747	708	438	390
1980	668	886	1242	6885	5927	3618	3108	3673	2906	1724	602	555
1981	488	453	917	1571	1760	2476	2323	2113	1007	474	377	353
1982	616	4326	5582	3505	5568	4740	8048	5682	3334	1760	797	866
1983	1303	1888	3694	4248	6459	10569	4869	6964	7101	3454	1349	794
1984	782	3773	6717	2851	2287	3081	2504	3600	1989	903	516	482
1985	648	1858	1196	842	1210	1593	2786	2135	1013	474	389	498
1986	546	749	1255	2617	11548	7095	3193	3562	2581	1030	541	609
1987	573	444	529	779	1476	2596	1730	1475	645	435	340	331
1988	364	472	1701	1835	1008	1260	1478	1587	932	459	325	288
1989	323	1048	720	851	987	6173	3587	2216	1196	493	355	432
1990	771	566	445	1272	875	1840	1798	1772	1241	503	322	317
1991	314	354	338	370	445	2636	1946	2404	1628	595	319	298
1992	378	428	474	579	2414	1991	2168	1335	567	515	303	294
1993	397	395	1247	4058	3125	5705	4327	5235	3688	1378	602	434
1994	512	430	777	776	1229	1486	1567	1790	806	366	280	328
1995	391	631	1056	8110	3115	10194	5609	7178	5467	3354	1121	642
1996	498	447	1716	2466	6253	4249	3973	5504	2407	991	548	455

Water Year	Oct (TAF)	Nov (TAF)	Dec (TAF)	Jan (TAF)	Feb (TAF)	Mar (TAF)	Apr (TAF)	May (TAF)	Jun (TAF)	Jul (TAF)	Aug (TAF)	Sep (TAF)
1997	507	1293	6836	12146	2742	2446	2697	2960	1641	683	513	467
1998	566	988	1183	5187	7441	5106	4528	5532	6411	3174	968	739
1999	699	1436	1884	2598	4585	3672	3261	4272	2633	948	575	537
2000	559	710	654	2548	5486	4077	3550	3618	1840	728	511	516
2001	578	550	667	866	1503	2390	2035	2486	715	457	375	376
2002	392	944	2499	2704	1744	2308	2819	2603	1372	521	395	363
2003	348	777	3242	3400	1663	2524	3268	4817	2436	715	556	434
2004	419	549	2137	1900	3980	3474	2636	2293	1136	584	390	354
2005	692	636	1558	2489	2006	3746	3182	7228	3613	1538	608	464
2006	477	667	5829	5158	3415	5380	8559	6844	3636	1422	637	500
2007	510	673	1320	873	2140	2065	1737	1667	657	436	363	351
2008	498	401	696	1700	1808	1787	1894	2681	1211	483	336	270
2009	377	690	571	964	2321	3637	2395	4215	1406	637	411	339
2010	662	411	710	2478	2306	2313	3245	3696	4151	1214	499	405
2011	875	917	4313	2095	1957	6198	5230	4943	5589	2668	869	546
2012	717	589	488	960	736	3033	3696	2273	848	506	410	340
2013	407	1228	4091	1337	1076	1712	2020	1429	802	432	358	344
2014	365	361	377	368	1224	2052	1712	1182	552	369	327	298
2015	362	463	2905	806	2228	842	767	829	549	336	293	292

Appendix C

Sacramento Valley and San Joaquin Valley Historical Water Year Classification

Water year indices and classifications in the Sacramento and San Joaquin Valleys from 1906 to 2015 (Data from CDEC, accessed online 1-11-16).

	Sacramento Valley					San Joaquin Valley				
Water Year	Runoff (MAF)			Index	Year Type	Runoff (MAF)			Index	Year Type
	Oct-Mar	Apr-Jul	WY Sum			Oct-Mar	Apr-Jul	WY Sum		
1906	12.57	12.92	26.71	11.76	W	2.53	9.24	12.43	6.7	W
1907	18.96	13.45	33.7	14.07	W	3.67	7.61	11.82	6.2	W
1908	8.29	5.6	14.77	7.73	BN	0.98	2.17	3.32	2.4	D
1909	20.61	8.98	30.68	12.1	W	2.85	5.91	8.97	4.59	W
1910	13.12	6.11	20.12	9.38	W	2.87	3.62	6.64	3.65	AN
1911	12.27	13.12	26.38	11.74	W	3.63	7.52	11.48	5.97	W
1912	4.84	5.65	11.41	6.71	BN	0.54	2.57	3.21	2.55	BN
1913	5.72	6.29	12.85	6.24	D	0.44	2.34	3	2	C
1914	16.72	10.08	27.81	10.92	W	2.72	5.67	8.69	4.35	W
1915	11.41	11.42	23.86	10.99	W	1.29	4.95	6.4	4.1	W
1916	14.25	8.89	24.14	10.83	W	2.67	5.5	8.38	4.65	W
1917	7.25	9.14	17.26	8.83	AN	1.66	4.84	6.66	4.13	W
1918	5.27	4.89	10.99	6.19	D	1.07	3.4	4.59	3.08	BN
1919	8.12	6.77	15.66	7	BN	1.06	2.99	4.09	2.62	BN
1920	3.63	4.91	9.2	5.15	C	0.72	3.29	4.09	2.64	BN
1921	15.47	7.52	23.8	9.2	AN	1.97	3.84	5.9	3.23	AN
1922	6.63	10.57	17.98	8.97	AN	1.51	5.99	7.68	4.54	W
1923	6.21	6.27	13.21	7.06	BN	1.39	3.95	5.51	3.55	AN
1924	3.27	1.94	5.74	3.87	C	0.45	1.03	1.5	1.42	C
1925	8.76	6.51	15.99	6.39	D	1.45	3.93	5.51	2.93	BN
1926	6.37	4.79	11.76	5.75	D	0.89	2.56	3.49	2.3	D
1927	14.34	8.75	23.83	9.52	W	1.8	4.56	6.5	3.56	AN
1928	10.24	5.86	16.76	8.27	AN	1.69	2.64	4.37	2.63	BN
1929	4	3.84	8.4	5.22	C	0.52	2.29	2.84	2	C
1930	8.24	4.65	13.52	5.9	D	0.76	2.44	3.25	2.02	C
1931	3.52	2.09	6.1	3.66	C	0.46	1.18	1.66	1.2	C
1932	6.28	6.24	13.12	5.48	D	1.79	4.69	6.63	3.41	AN
1933	3.73	4.66	8.94	4.63	C	0.49	2.77	3.34	2.44	D
1934	5.68	2.45	8.63	4.07	C	0.98	1.26	2.28	1.44	C
1935	6.27	9.69	16.59	6.98	BN	1.26	5.03	6.41	3.56	AN
1936	10.32	6.41	17.35	7.75	BN	2	4.38	6.49	3.74	AN
1937	5.5	7.24	13.33	6.87	BN	1.78	4.66	6.53	3.9	W
1938	17.96	12.93	31.83	12.62	W	3.58	7.33	11.24	5.89	W
1939	4.56	3.04	8.18	5.58	D	1	1.83	2.9	2.2	D
1940	14.78	6.93	22.43	8.88	AN	2.49	4.04	6.59	3.36	AN
1941	16.32	9.77	27.08	11.47	W	2.22	5.51	7.93	4.43	W
1942	14.33	9.93	25.24	11.27	W	1.93	5.28	7.38	4.44	W
1943	13.37	6.9	21.13	9.77	W	2.86	4.28	7.28	4.03	W
1944	4.81	4.93	10.43	6.35	D	0.87	2.97	3.92	2.76	BN
1945	8.42	5.92	15.06	6.8	BN	2.07	4.37	6.6	3.59	AN
1946	10.89	5.97	17.62	7.7	BN	1.99	3.65	5.73	3.3	AN
1947	5.9	3.83	10.39	5.61	D	1.26	2.12	3.42	2.18	D
1948	5.39	9.55	15.75	7.12	BN	0.56	3.58	4.21	2.7	BN
1949	5.73	5.59	11.97	6.09	D	0.62	3.12	3.79	2.53	BN
1950	7.01	6.72	14.44	6.62	BN	1.02	3.57	4.65	2.85	BN
1951	16.77	5.42	22.95	9.18	AN	4.35	2.83	7.25	3.14	AN
1952	13.86	13.68	28.6	12.38	W	2.18	6.84	9.3	5.17	W
1953	10.84	8.26	20.09	9.55	W	1.07	3.18	4.35	3.03	BN
1954	9.74	6.81	17.43	8.51	AN	1.1	3.16	4.3	2.72	BN
1955	5.19	5.07	10.98	6.14	D	0.78	2.67	3.5	2.3	D
1956	20.32	8.6	29.89	11.38	W	4.14	5.29	9.67	4.46	W

Water Year	Sacramento Valley Runoff (MAF) Oct-Mar	Apr-Jul	WY Sum	Index	Year Type	San Joaquin Valley Runoff (MAF) Oct-Mar	Apr-Jul	WY Sum	Index	Year Type
1957	7.72	6.29	14.89	7.83	AN	1.02	3.19	4.29	3.01	BN
1958	16.37	12.24	29.71	12.16	W	1.67	6.4	8.36	4.77	W
1959	7.4	3.84	12.05	6.75	BN	0.98	1.85	2.98	2.21	D
1960	7.72	4.65	13.06	6.2	D	0.85	2.07	2.96	1.85	C
1961	6.87	4.39	11.97	5.68	D	0.54	1.5	2.1	1.38	C
1962	8.17	6.23	15.11	6.65	BN	1.26	4.24	5.61	3.07	BN
1963	12.01	10.09	22.99	9.63	W	1.68	4.37	6.24	3.57	AN
1964	5.9	4.37	10.92	6.41	D	0.93	2.14	3.14	2.19	D
1965	16.59	8.13	25.64	10.15	W	3.2	4.55	8.13	3.81	W
1966	7.42	4.84	12.95	7.16	BN	1.49	2.42	3.98	2.51	BN
1967	12.14	11.01	24.06	10.2	W	2.46	7.09	9.98	5.25	W
1968	8.66	4.12	13.64	7.24	BN	1.02	1.85	2.94	2.21	D
1969	15.33	10.68	26.98	11.05	W	3.84	8.14	12.29	6.09	W
1970	18.87	4.35	24.06	10.4	W	2.55	2.96	5.61	3.18	AN
1971	12.71	8.9	22.57	10.37	W	1.56	3.23	4.91	2.89	BN
1972	7.61	5.02	13.43	7.29	BN	1.25	2.22	3.57	2.16	D
1973	12.8	6.38	20.05	8.58	AN	1.87	4.48	6.47	3.5	AN
1974	21.69	9.78	32.5	12.99	W	2.43	4.53	7.12	3.9	W
1975	9.24	8.95	19.23	9.35	W	1.37	4.65	6.18	3.85	W
1976	4.63	2.75	8.2	5.29	C	0.78	1.07	1.97	1.57	C
1977	2.49	1.93	5.12	3.11	C	0.22	0.8	1.05	0.84	C
1978	14.9	8.12	23.92	8.65	AN	2.57	6.5	9.65	4.58	W
1979	6.06	5.64	12.41	6.67	BN	1.87	3.99	5.98	3.67	AN
1980	15.49	6	22.33	9.04	AN	3.74	5.41	9.47	4.73	W
1981	6.81	3.63	11.1	6.21	D	0.85	2.29	3.22	2.44	D
1982	20.56	11.82	33.41	12.76	W	3.78	7	11.41	5.45	W
1983	22.75	13.66	37.68	15.29	W	5.42	8.73	15.01	7.22	W
1984	15.98	5.52	22.35	10	W	3.51	3.48	7.13	3.69	AN
1985	6.24	4	11.04	6.47	D	1.11	2.41	3.6	2.4	D
1986	19.45	5.45	25.83	9.96	W	4.36	4.92	9.5	4.31	W
1987	5.85	2.8	9.27	5.86	D	0.55	1.48	2.08	1.86	C
1988	5.78	2.9	9.23	4.65	C	0.86	1.55	2.48	1.48	C
1989	9.03	5.07	14.82	6.13	D	1.07	2.42	3.56	1.96	C
1990	4.94	3.72	9.26	4.81	C	0.83	1.59	2.46	1.51	C
1991	3.9	4.01	8.44	4.21	C	0.56	2.57	3.2	1.96	C
1992	5.41	2.93	8.87	4.06	C	0.86	1.66	2.58	1.56	C
1993	12.44	8.98	22.21	8.54	AN	2.49	5.65	8.38	4.2	W
1994	4.55	2.73	7.81	5.02	C	0.66	1.8	2.54	2.05	C
1995	19.83	13.6	34.55	12.89	W	3.67	8.01	12.32	5.95	W
1996	13.05	8.37	22.29	10.26	W	2.57	4.51	7.22	4.12	W
1997	20.22	4.39	25.42	10.82	W	5.75	3.59	9.51	4.13	W
1998	17.65	12.54	31.4	13.31	W	2.82	7.11	10.43	5.65	W
1999	12.97	7.26	21.19	9.8	W	1.9	3.85	5.91	3.59	AN
2000	12.06	5.96	18.9	8.94	AN	1.98	3.78	5.9	3.38	AN
2001	5.64	3.46	9.81	5.76	D	0.92	2.23	3.18	2.2	D
2002	9.32	4.57	14.6	6.35	D	1.27	2.75	4.06	2.34	D
2003	10.71	7.74	19.31	8.21	AN	1.25	3.49	4.87	2.81	BN
2004	10.95	4.4	16.04	7.51	BN	1.51	2.25	3.81	2.21	D
2005	8.4	9.28	18.55	8.49	AN	2.73	6.28	9.21	4.75	W
2006	18.06	13.09	32.09	13.2	W	2.86	7.37	10.44	5.9	W
2007	6.59	3.04	10.28	6.19	D	0.99	1.46	2.51	1.97	C
2008	5.9	3.82	10.28	5.16	C	0.99	2.45	3.49	2.06	C
2009	7.05	5.3	13.02	5.78	D	1.51	3.35	4.94	2.72	BN
2010	7.45	7.78	16.01	7.08	BN	1.43	4.53	6.08	3.55	AN

Water Year	Sacramento Valley Runoff (MAF)			Sacramento Valley		San Joaquin Valley Runoff (MAF)			San Joaquin Valley	
	Oct-Mar	Apr-Jul	WY Sum	Index	Year Type	Oct-Mar	Apr-Jul	WY Sum	Index	Year Type
2011	12.68	11.53	25.21	10.54	W	3.68	6.9	10.99	5.58	W
2012	5.69	5.46	11.84	6.89	BN	0.83	1.86	2.76	2.18	D
2013	8.52	3.01	12.19	5.83	D	1.33	1.67	3.05	1.71	C
2014	4.29	2.6	7.47	4.08	C	0.46	1.21	1.72	1.16	C
2015 [a]				4.0	C				0.7	C

[a] 2015 water year index and classification are forecasted values from May 2015; final 2015 data not currently available (1-13-16).

Appendix D

Historical Antioch Testimony

Antioch-217

Testimony by City of Antioch

For SWRCB Delta Flow Criteria
Informational Proceeding

Submitted February 16, 2010

For hearings beginning March 22, 2010

Antioch-217

Overview

- Antioch has taken fresh drinking water from the Delta since the 1860s
- Infrastructure and flow diversions have changed distribution and timing of freshwater flows
- Historic conditions were far fresher than current conditions
- Quality of water at Antioch has declined markedly

Antioch-217

Why Is This Important ?

- Characterizations of the Delta as "historically saline" are false
- Native species are adapted to historical conditions, so historic salinity and flow patterns must be considered in establishing appropriate flow and salinity standards

Antioch-217

What Should Happen ?

- SWRCB should review and incorporate historic salinity data into its analyses
- SWRCB should use historic data to establish an historic baseline of water quality and flows for both fisheries and drinking water quality standards

Antioch-217

What Should Happen ?

- SWRCB should ensure that flows are not reduced, nor salinity increased, beyond levels assured by D-1641 and current X2 requirements
- In fact, the City of Antioch asks the SWRCB to establish flow and salinity standards in line with the Delta's historic fresh condition
- SWRCB should state that characterizations of the Delta as "historically saline" are false
- SWRCB should consider using Antioch's gauging station as a 'point of interest' to gauge flow and salinity conditions

Systemic Changes Have Influenced Flows and Salinity

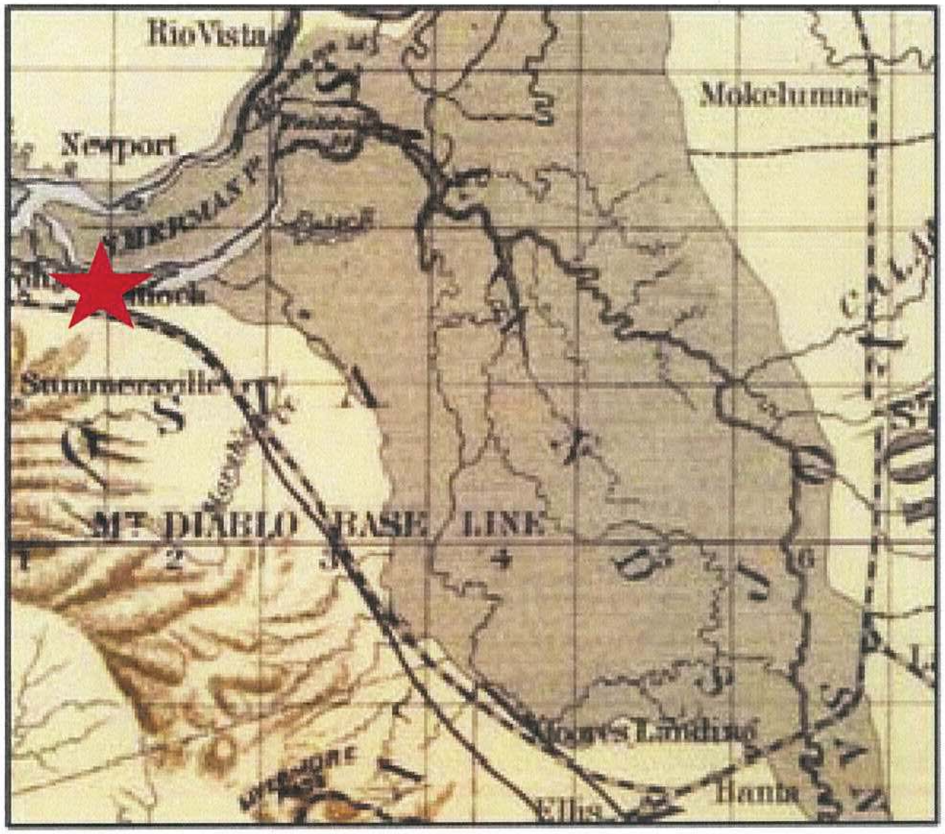
Factors Influencing Salinity

- Hydrology
- Changes to the Delta landscape
- Water Management
  - Exports
  - Diversions
  - Reservoir Storage

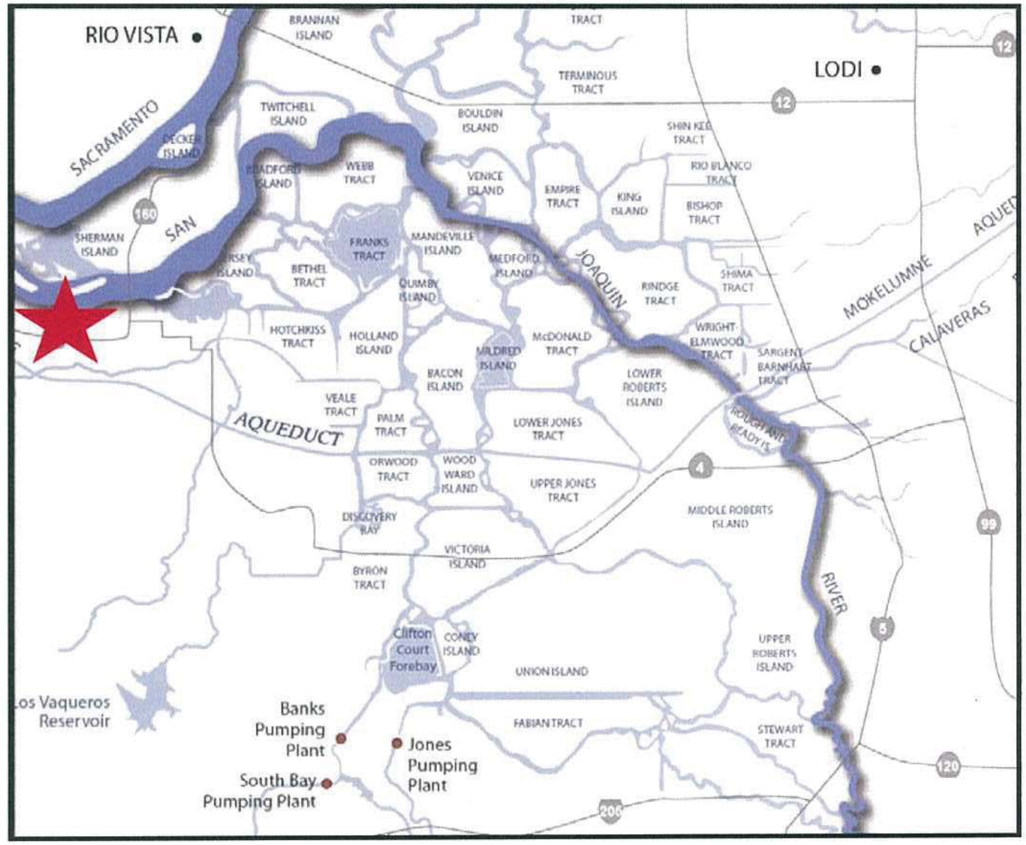
Antioch-217

The Delta Landscape is Dramatically Different

1873



2010

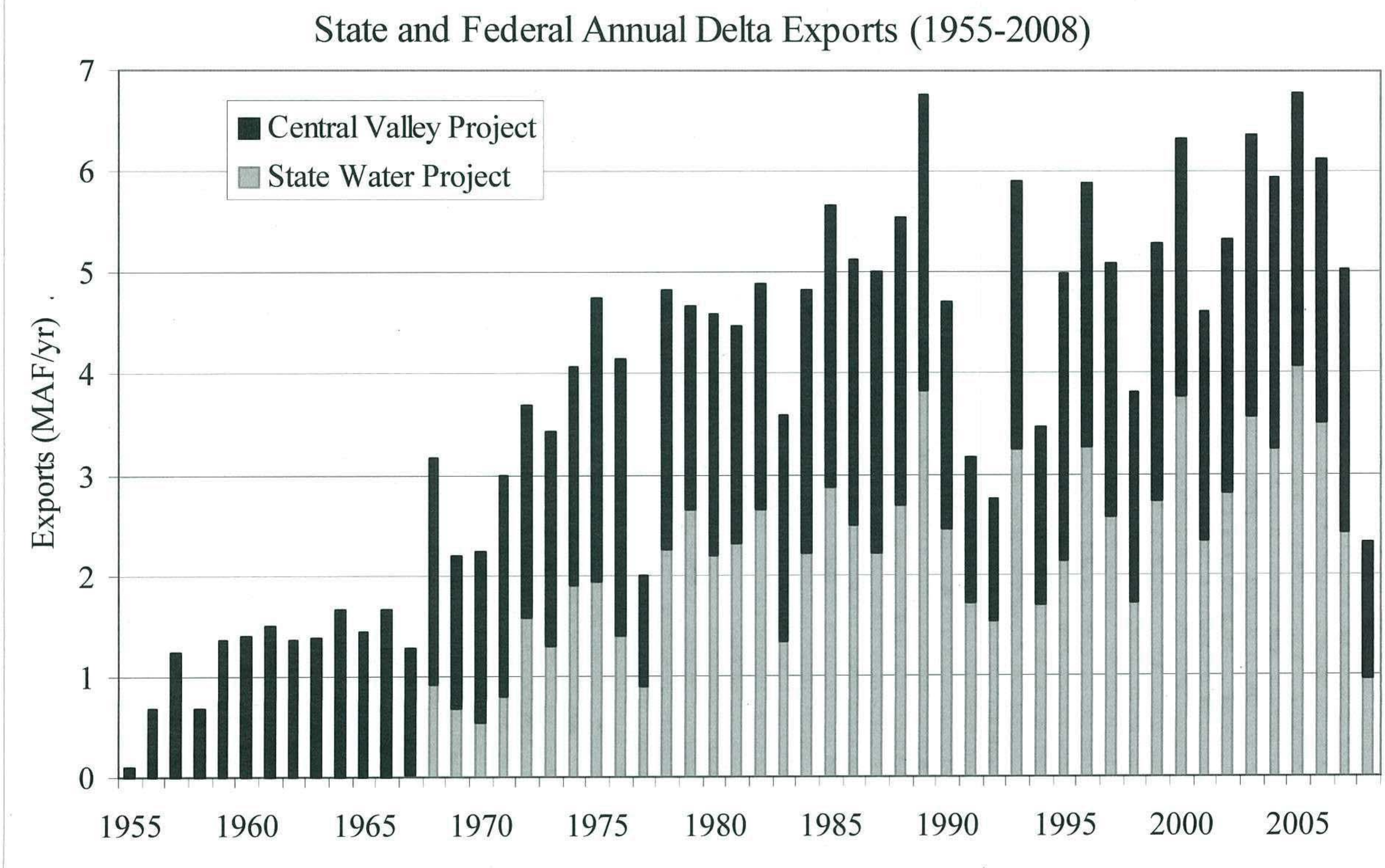


Approximate location of City of Antioch's water intake

Source: left panel: DWR archives presented to Delta Vision (2008) final report; right panel: Delta Vision (2008)

Antioch-217

Water Exports Have Increased and Remove Fresh Water from Delta



Data from IEP's DAYFLOW Program

Antioch-217

Pre-1918, Fresh Water was Available in Western Delta Nearly Year-round

Location	Quotation
Antioch, CA	"*From early days, Antioch has obtained all or most of its domestic and municipal water supply from the San Joaquin River immediately offshore from the city… However, conditions were fairly satisfactory in this respect until 1917, when the increased degree and duration of saline invasion began to result in the water becoming too brackish for domestic use during considerable periods in the summer and fall.*" (DPW, 1931, pg. 60)
Western Delta	"*The dry years of 1917 to 1919, combined with increased upstream irrigation diversions, especially for rice culture in the Sacramento Valley, had already given rise to invasions of salinity into the upper bay and lower delta channels of greater extent and magnitude than had ever been known before.*" (DPW, 1931, pg. 22) "*It is particularly important to note that the period 1917-1929 has been one of unusual dryness and subnormal stream flow and that this condition has been a most important contributing factor to the abnormal extent of saline invasion which has occurred during this same time.*" (DPW, 1931, pg. 66)
Carquinez Strait (Western Delta)	"*Under natural conditions, Carquinez Straits marked, approximately, the boundary between salt and fresh water in the upper San Francisco Bay and delta region…*" (Means, 1928, pg. 9) "*For short intervals in late summer of years of minimum flow, salt water penetrated at lower river and delta region, and in wet seasons the upper bay was fresh, part of the time, to the Golden Gate.*" (Means, 1928, pg. 9 & pg. 57)

DPW (1931). Bulletin No. 27. State of California, Department of Public Works, See http://www.archive.org/details/variationcontrol27calirich
Means, T. (1928). Salt Water Problem: San Francisco Bay and Delta of Sacramento and San Joaquin Rivers, San Francisco, California, April 1928. A report prepared for the Association of Industrial Water Users of Contra Costa and Solano Counties.

Antioch-217

Pre-1918, Fresh Water was Available in Western Delta Nearly Year-round

Location	Quotation
Benicia, CA (Suisun Bay)	"*In 1889, an artificial lake was constructed. This reservoir, filled with fresh water from Suisun Bay during the spring runoff of the Sierra snow melt water* …" (Dillon, 1980, pg. 131) "*…in 1889, construction began on an artificial lake for the* [Benicia] *arsenal which would serve throughout its remaining history as a reservoir, being filled with fresh water pumped from Suisun Bay during spring runoffs of the Sacramento and San Joaquin Rivers which emptied into the bay a short distance north of the installation.*" (Cowell, 1963, pg. 31)
Pittsburg, CA	"*From 1880 to 1920, Pittsburg (formerly Black Diamond) obtained all or most of its domestic and municipal water supply from New York Slough [near Pittsburg at the confluence of the Sacramento and San Joaquin Rivers] offshore.*" (DPW, 1931, pg. 60) "*There was an inexhaustible supply of river water available in the New York Slough* [near Pittsburg at the confluence of the Sacramento and San Joaquin Rivers], *but in the summer of 1924 this river water showed a startling rise in salinity to 1,400 ppm of chlorine, the first time in many years that it had grown very brackish during the dry summer months.*" (Tolman and Poland, 1935, pg. 27)

Cowell, J. W. 1963. History of Benicia Arsenal: Benicia, California: January 1851 – December 1962. Berkeley, Howell-North Books
Dillon, R. 1980. Great Expectations: The Story of Benicia, California, Fresno, California. 241 pp.
Tolman, C. F. and J. F. Poland. 1935. *Investigation of the Ground-Water Supply of the Columbia Steel Company Pittsburg, California*. Stanford University, California, May 30, 1935

Testimony from Antioch Lawsuit: Pre-1918, Fresh Water was Available at Antioch Year-round

- Antioch lawsuit in 1920: Town of Antioch [plaintiff] v. Williams Irrigation District et al. [defendants] (1922, 188 Cal. 451)

- Plaintiff alleged that the upstream diversions were causing increased salinity intrusion at Antioch

- Testimony from defendants in the Antioch lawsuit (from the supporting Supreme Court record on file at the State Archives) (CCWD, 2010)
    - In the late 1800s, water at Antioch was known to be brackish at high tide during certain time periods.
    - Antioch was able to pump fresh water at low tide throughout the year, with the possible exception of the fall season during one or two dry years.
    - Water at Antioch was apparently fresh at low tide at least until around 1915 (when the pumping plants started pumping continuously, regardless of tidal stage).

Antioch-217

Testimony from Antioch Lawsuit: Pre-1918, Fresh Water was Available at Antioch in Fall

Testimony from plaintiff in the Antioch lawsuit (from the supporting Supreme Court record on file at the State Archives)

- Antioch's freshwater supply was obtained directly from the western Delta from about 1866 to 1918 (pg. 47-48).

- Prior to 1918, freshwater was available at Antioch even during dry years and in the fall (pg. 23-24).

Date	Location	Salinity (ppm)
1913 (Sept; a dry year)	Antioch	66
1916 (Aug. 5th; wet year)	Antioch	22.3
1916 (Aug. 9th; wet year)	Antioch	12.3
1916 (Sept. 19th; wet year)	Antioch	101.3
1917 (Sept. 14th; wet year)	Antioch	141.6

Antioch-217

Testimony from Antioch Lawsuit: Post-1918, Upstream Diversions Drastically Increased Salinity Intrusion

Testimony from plaintiff in the Antioch lawsuit (continued)

- After 1918, salinity abruptly increased during irrigation (rice cultivation) season, and returned to a potable level after irrigation ceased (pg. 18-20)

Date	Location	Salinity (ppm)
1918 (Sept. 25th; dry year)	Antioch	1360
1920 (mid-July; critical year)	Pittsburg, CA	4500
1920 (end-July; critical year)	Pittsburg, CA	6000
1920 (mid-Aug.; critical year)	Pittsburg, CA	9500
1920 (end-Sept.; critical year)	Pittsburg, CA	2500
1920 (during rice irrigation; critical year)	Antioch	12,500
1920 (end-Oct, after irrigation; critical year)	Pittsburg, CA	fresh

Measurements at Pittsburg, CA, are from the Great Western Electro Chemical Co.

- Information on the effect of upstream diversions is also confirmed by records in the plaintiff's testimony from C&H Sugar (see CCWD 2010).

Testimony from Antioch Lawsuit: Water at Antioch is from Sacramento River

- Testimony from <u>plaintiff</u> in the Antioch lawsuit (continued)

  - Plaintiff testimony asserted that in 1920 "the amount of water which the San Joaquin carried was dependent entirely upon the amount of water in the Sacramento," and that "the San Joaquin itself carried practically no water at all. In other words, it was demonstrated that the amount of fresh water which came into the San Joaquin and down as far as the Town of Antioch was practically all Sacramento River water." (pg. 15)

  - Water was delivered to the San Joaquin River from the Sacramento River via two main conduits: Georgiana Slough and Three Mile Slough. 1920 flow rates in these sloughs were the basis of the assertion quoted above.

Antioch-217

Testimony from Antioch Lawsuit: Water at Antioch is from Sacramento River

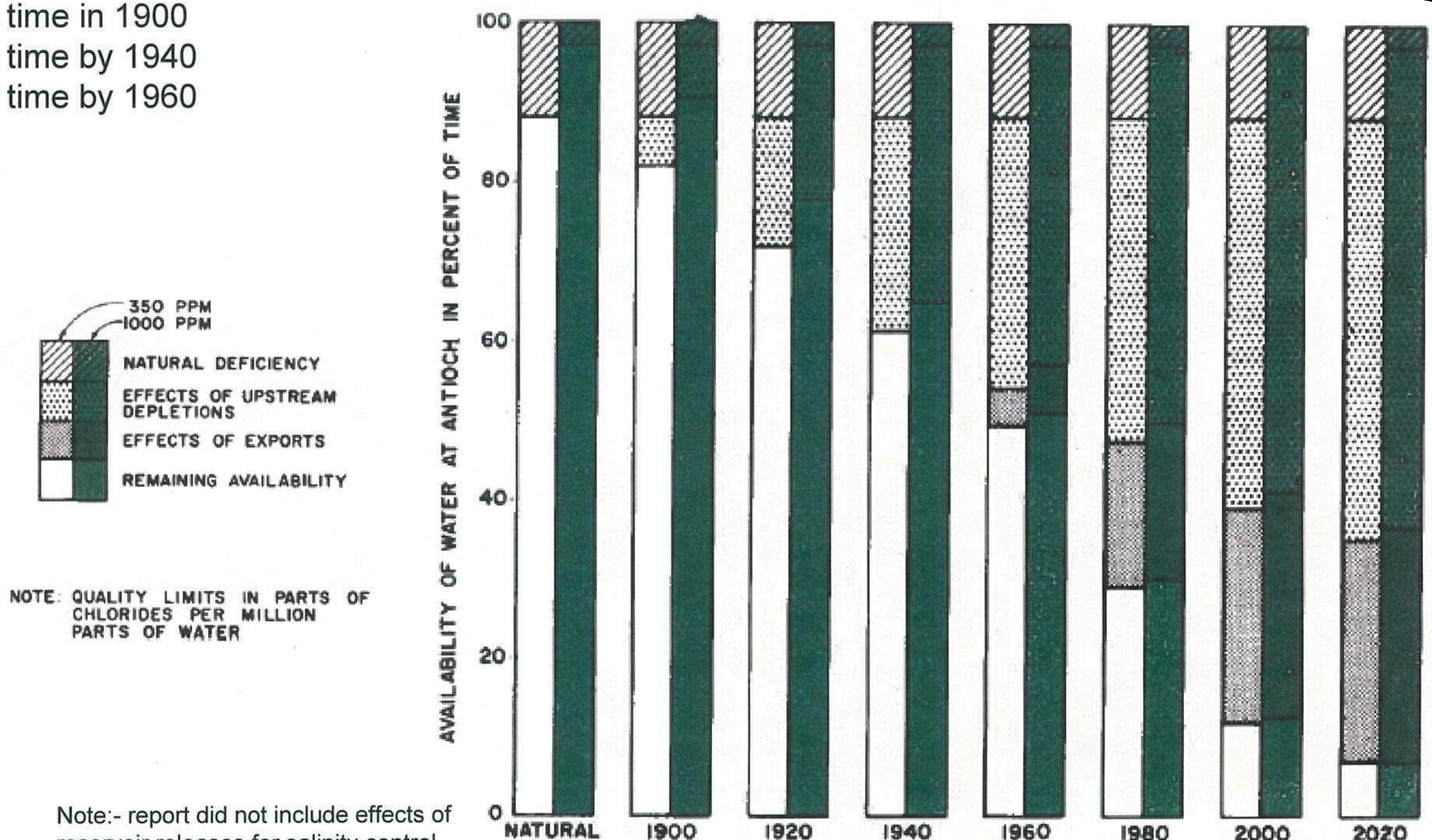
- “It is necessary here to state some additional facts to explain how this pollution comes about and why diversions from the Sacramento River may or do affect the volume and quality of the water flowing down the San Joaquin River . . . From the Sacramento River at two points, one about eight [Three Mile] and the other about twenty - three miles [Georgiana] above its mouth, sloughs diverge, into which parts of its waters escape and flow through the said sloughs and into the San Joaquin River at points several miles above the place of the diversion by the city of Antioch.” Town of Antioch v. Williams Irrigation District et al. (1922) 188 Cal. 451, 455

Antioch-217

Freshwater Availability has Declined

DWR (1960, pg. 13) found that freshwater was available at San Joaquin River at Antioch:

- •85% of the time under “natural” conditions
- •80% of the time in 1900
- •60% of the time by 1940
- •50% of the time by 1960



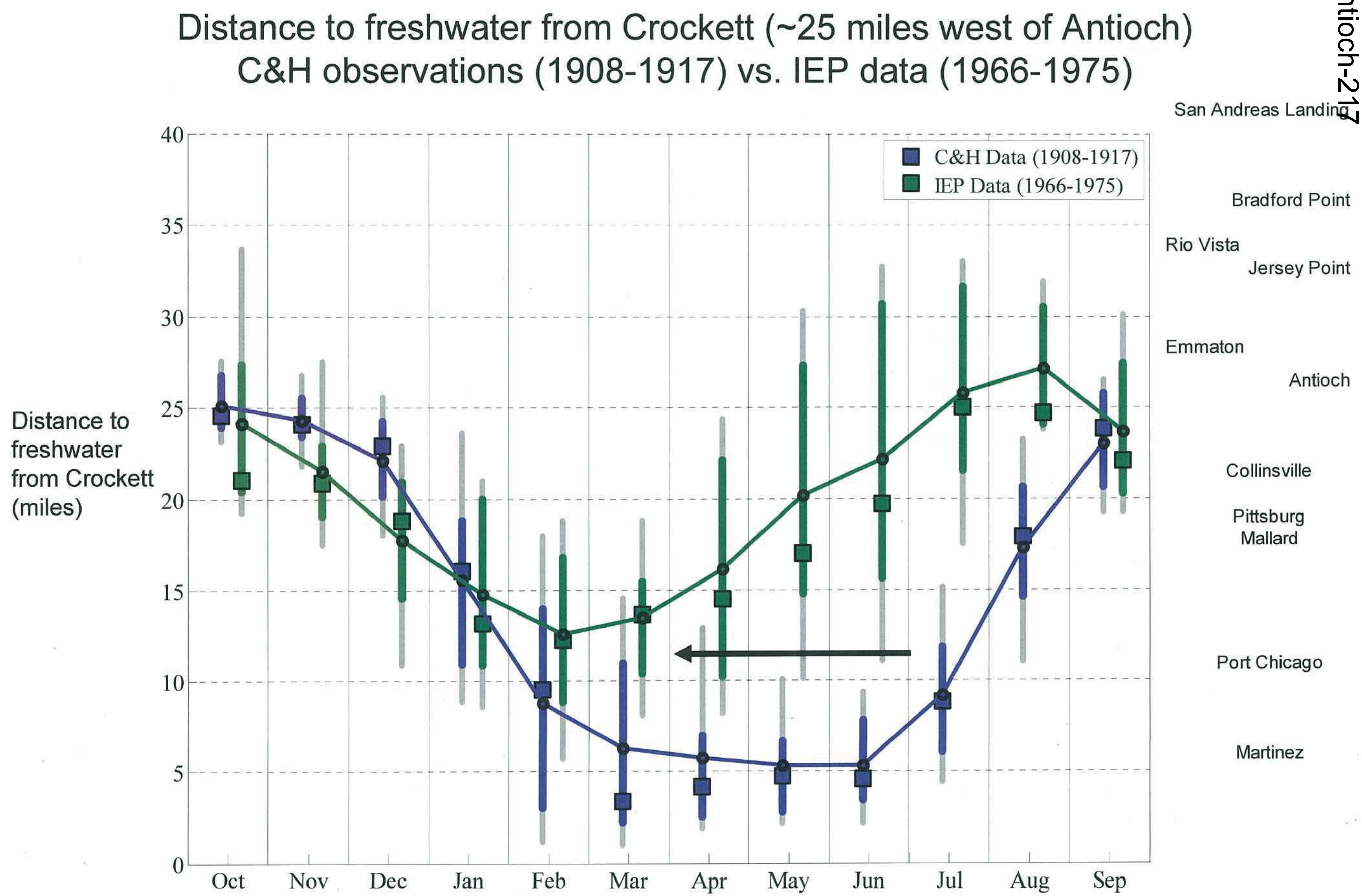
DELTA WATER QUALITY WITHOUT SALINITY CONTROL

Note:- report did not include effects of reservoir releases for salinity control

DWR (1960). Bulletin No. 76. State of California. See http://www.deltacorridors.com/uploads/Bulletin_No._76_Delta_Water_Facilities-Color.pdf

Antioch-217

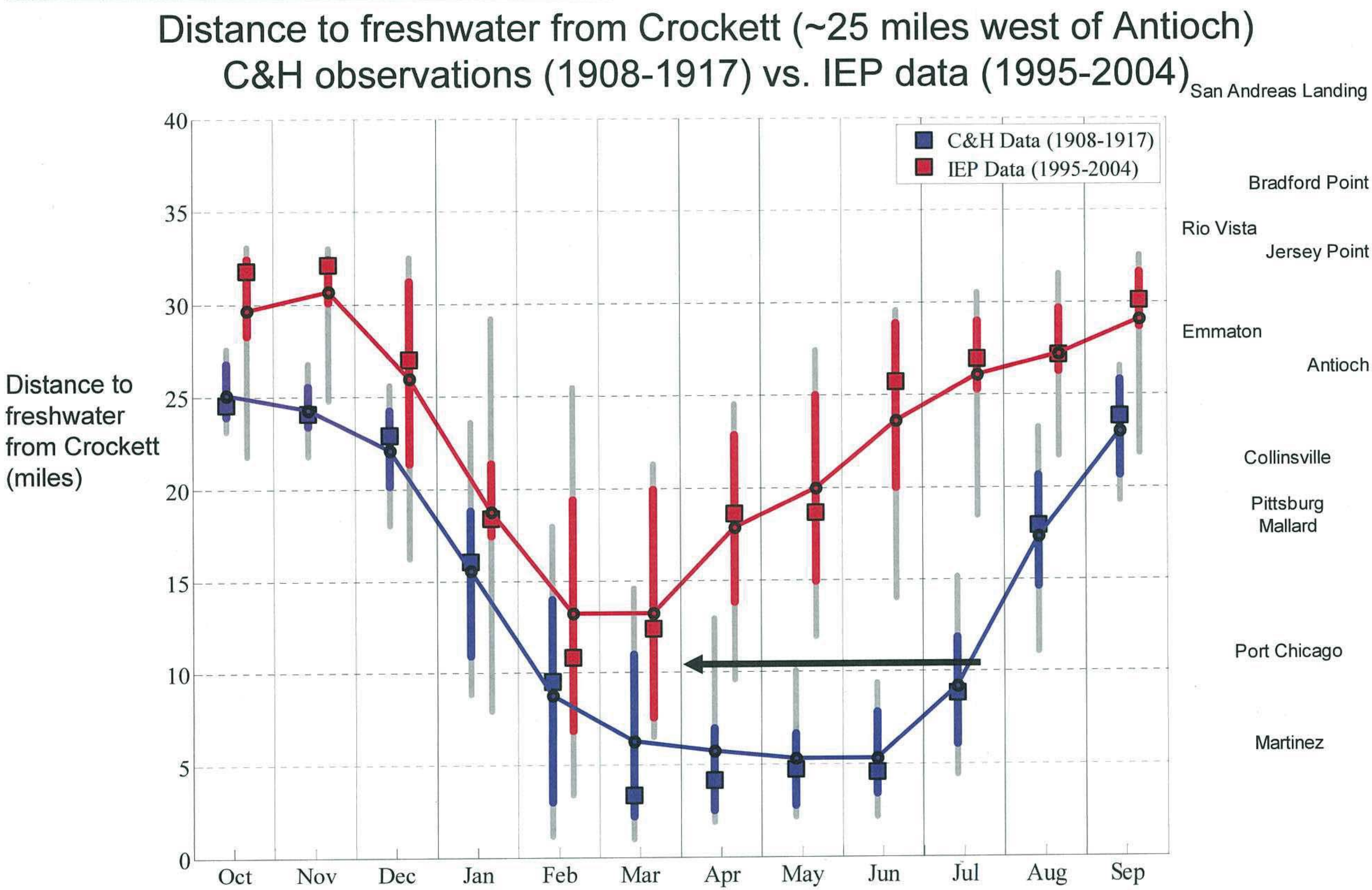
Salinity Intrusion Occurred Earlier by 1975



Source: CCWD Salinity Report (2010)

Antioch-217

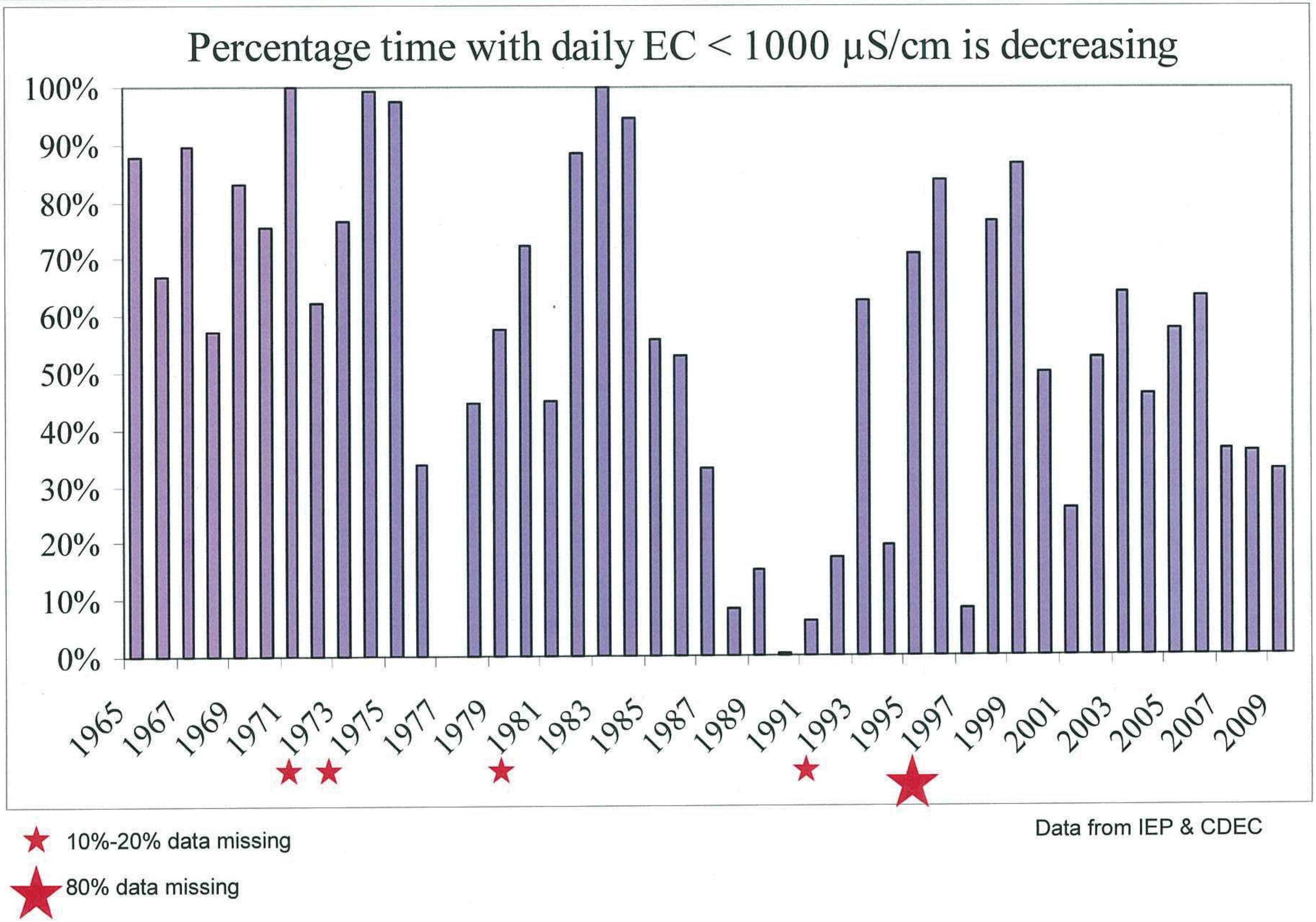
Salinity Intrusion Occurred Even Earlier and Extended Farther by 2004



Source: CCWD Salinity Report (2010)

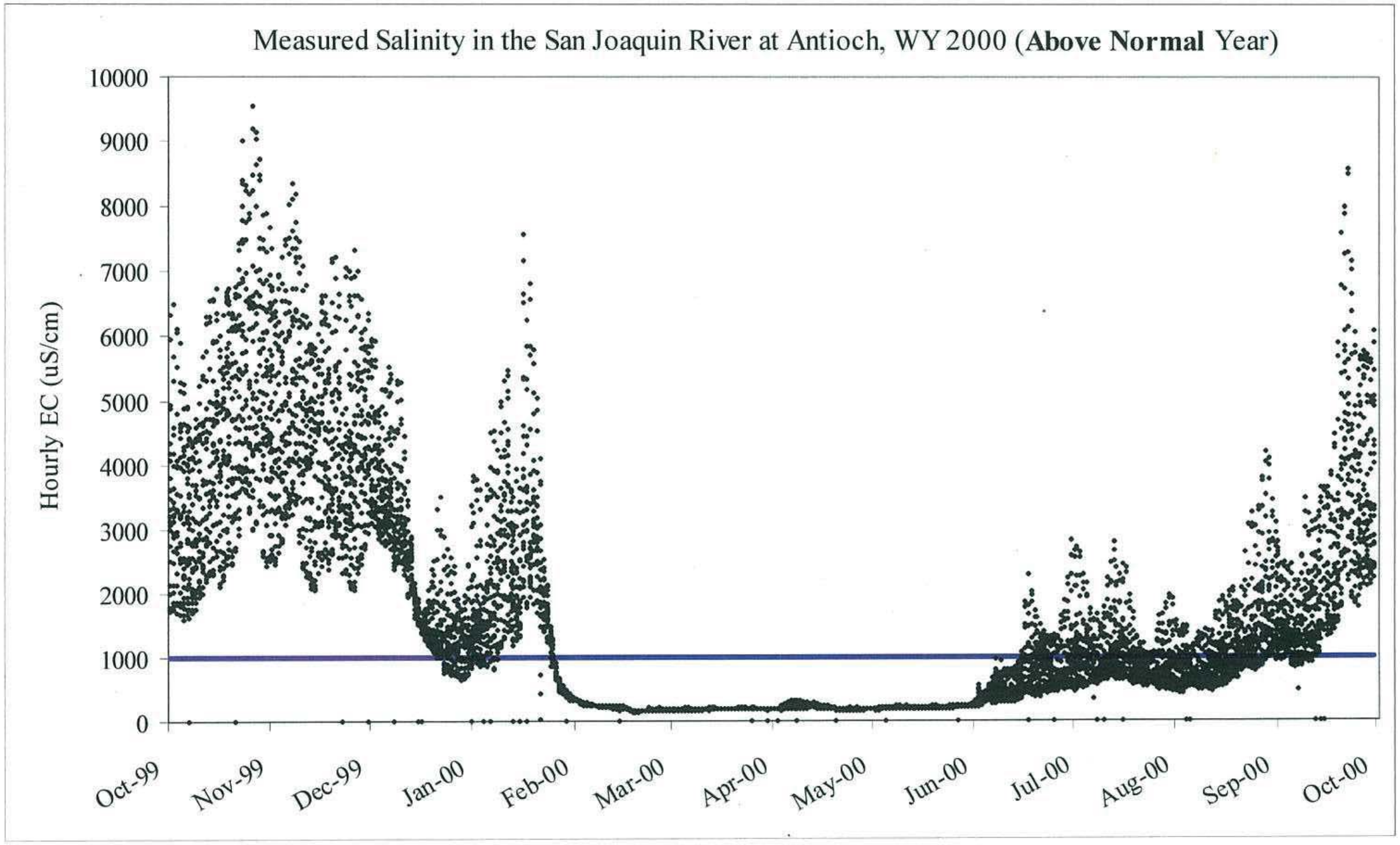
Antioch-217

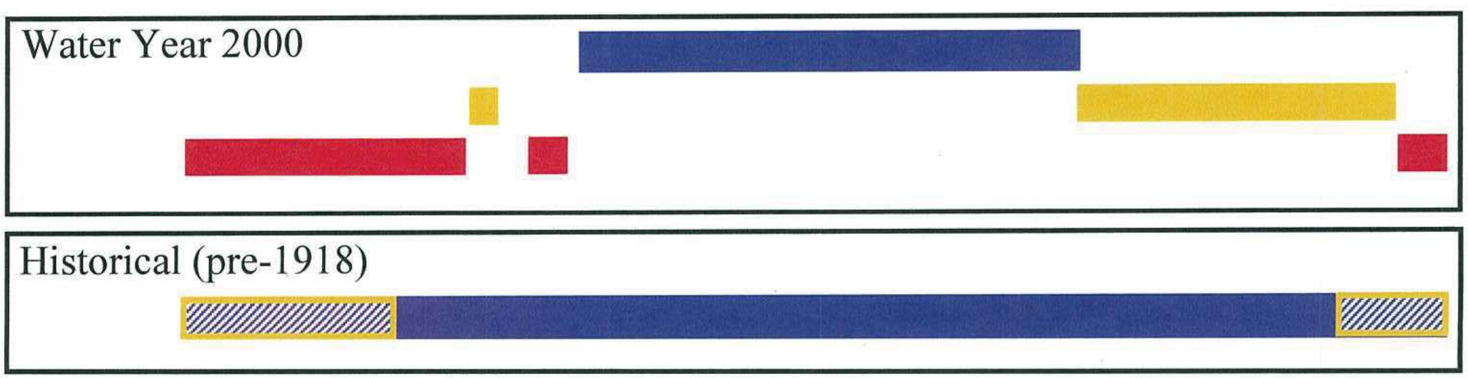
Freshwater Availability at Antioch Continues to Decline



Antioch-217

Even in Above Normal Years, Freshwater is Now Unavailable in Summer/Fall

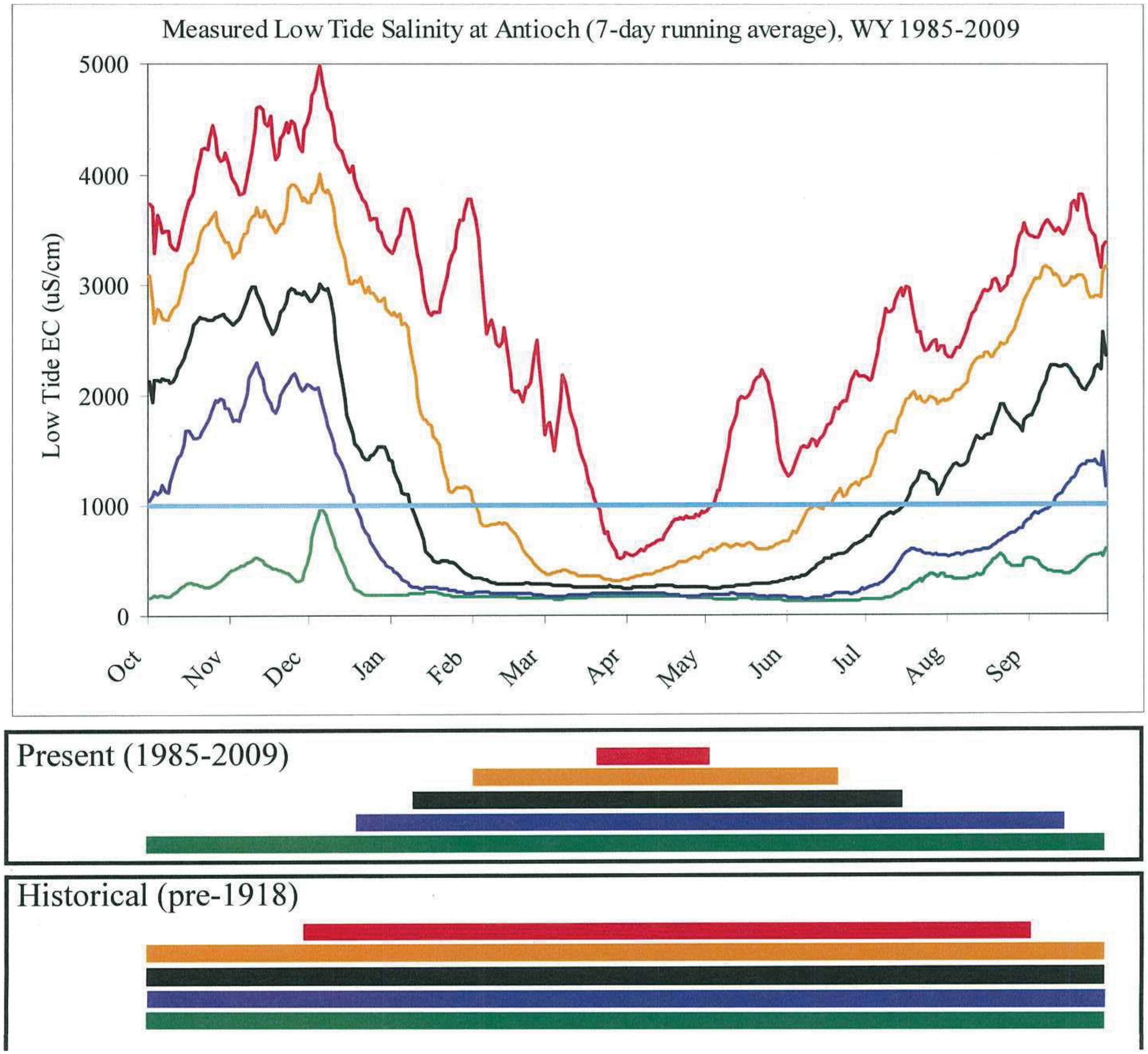




Data from CDEC

Antioch-217

Freshwater is Now Available at Antioch Far Less Often



Driest 10%

Driest 25%

Median

Wettest 25%

Wettest 10%

Pre-1918, freshwater was available year-round at low tide in all but driest years

Data from CDEC

Summary: The Western Delta was Historically Fresher

- Pre-1918, freshwater was almost always available at least at low tide.
- Between 1918 and the late 1930s, drought conditions, upstream water diversions, and channelization increased the salinity of water at Antioch.
- By 1940 the drought receded, but salinity at Antioch remained elevated.
- Salinity continues to increase in recent years at Antioch.
- The fraction of time that water at Antioch is suitable for use (when salinity is < 250 mg/L chlorides or 1000 µS/cm EC) has declined significantly.
- “Historic” Delta was significantly fresher than the current Delta.

Conclusions

Consider historic fresh conditions to:

Establish Delta outflows and inflows to protect species adapted to these conditions.

Establish the criteria (volume, timing, quality) required by SB 7X 1.

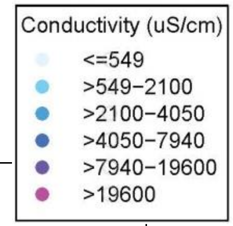
Establish drinking water quality standards for the Delta.

Appendix E

Images from DSM2 Model Animations

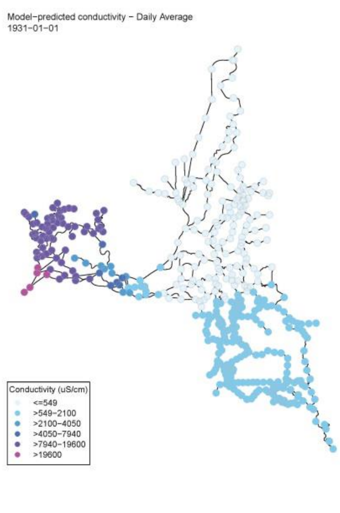
Antioch-217

Appendix E - Images from DSM2 Model Animations, page 1

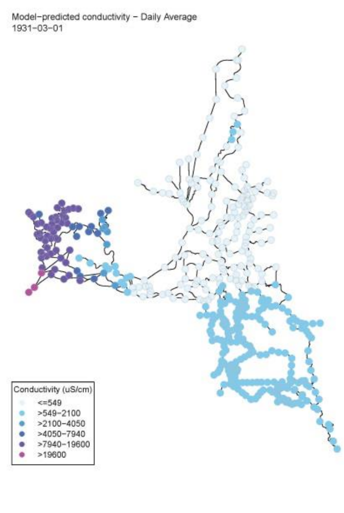


1. Concentration of salinity (electrical conductivity [EC], μS/cm) in 1931

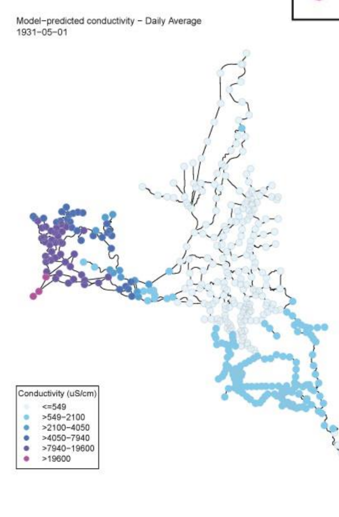
January 1, 1931



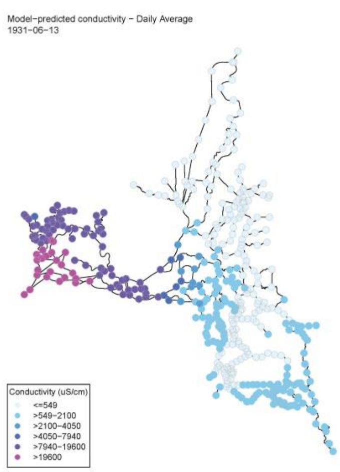
March 1, 1931



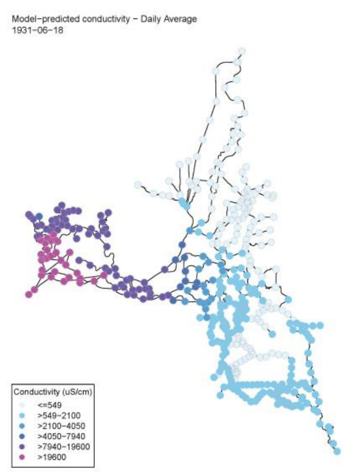
May 1, 1931



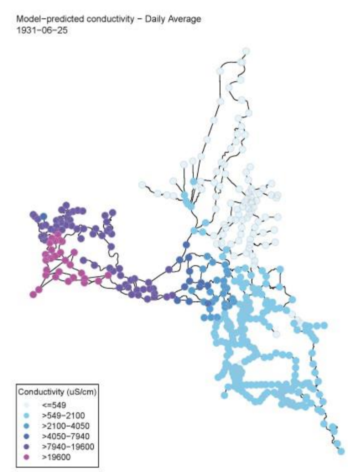
June 13, 1931



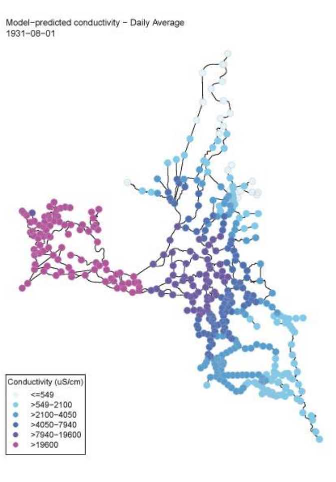
June 18, 1931



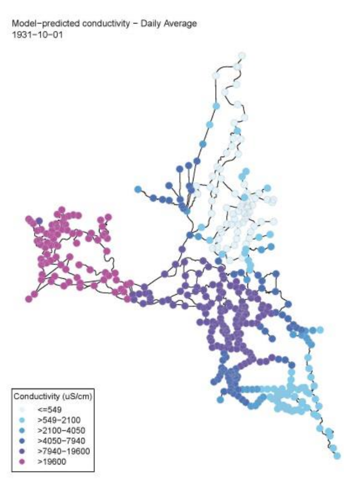
June 25, 2013



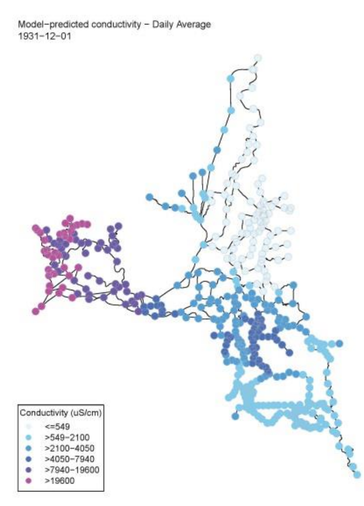
August 1, 1931



October 1, 1931



December 1, 1931



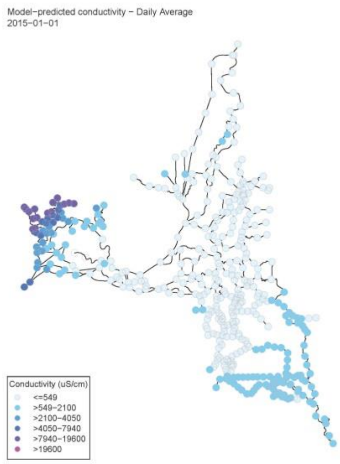
Antioch-217

Appendix E - Images from DSM2 Model Animations, page 2

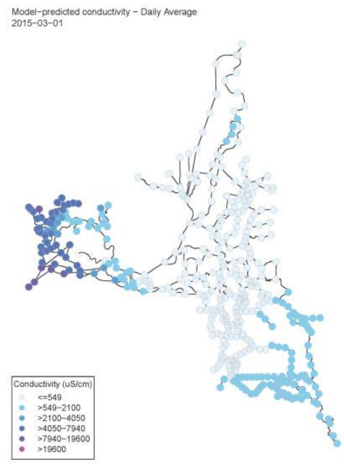
Conductivity (uS/cm)
- <=549
- >549–2100
- >2100–4050
- >4050–7940
- >7940–19600
- >19600

2. Concentration of salinity (electrical conductivity [EC], µS/cm) in 2015.

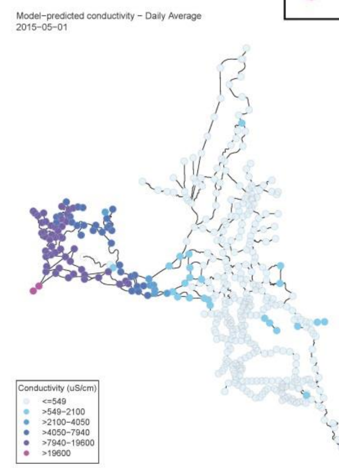
January 1, 2015



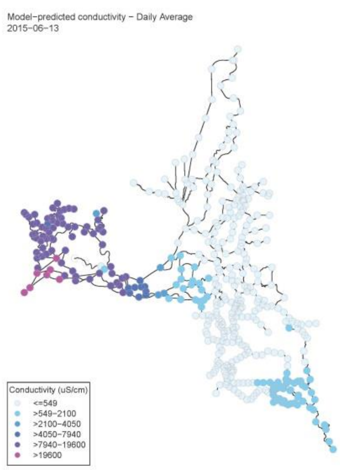
March 1, 2015



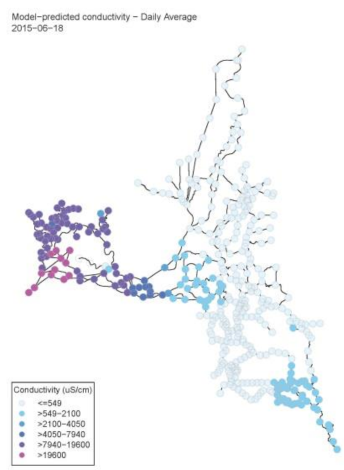
May 1, 2015



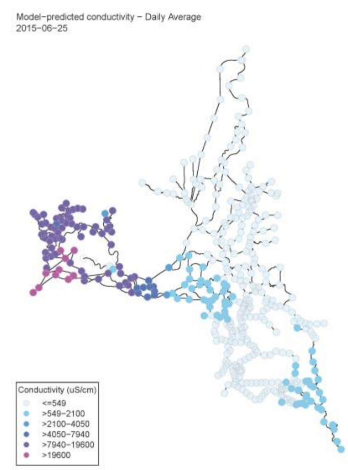
June 13, 2015



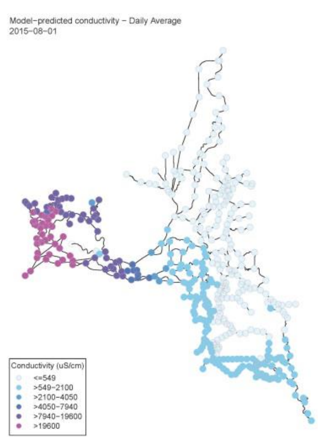
June 18, 2015



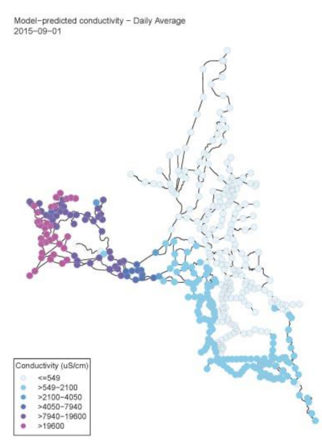
June 25, 2015



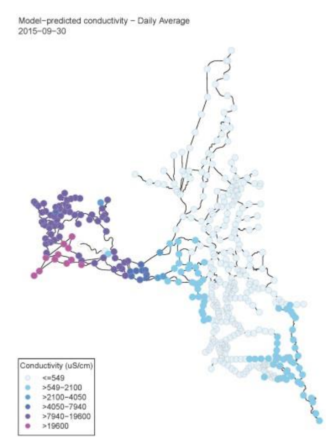
August 1, 2015



September 1, 2015



September 30, 2015



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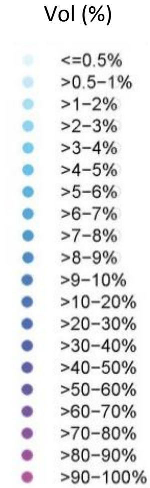
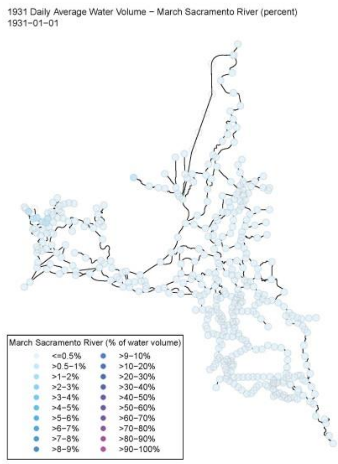
Appendix E - Images from DSM2 Model Animations, page 3

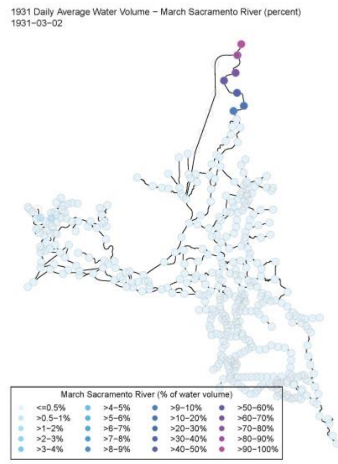


3. Volume of Sacramento River water that entered the Delta in March 1931 (in percent)

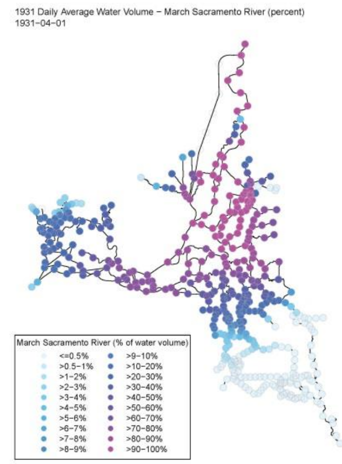
January 1, 1931



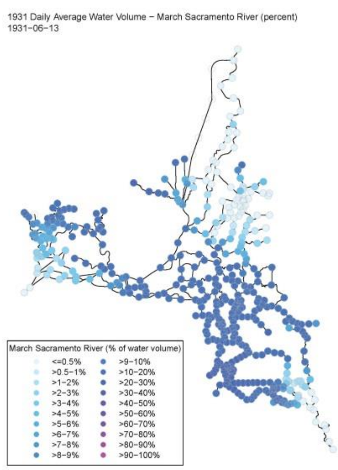
March 2, 1931



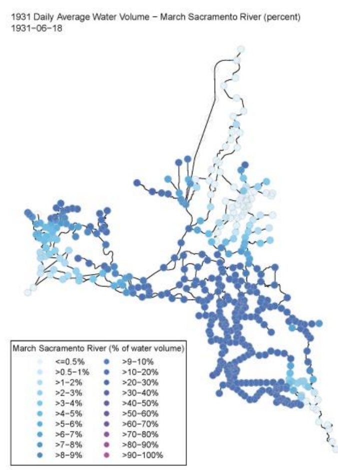
April 1, 1931



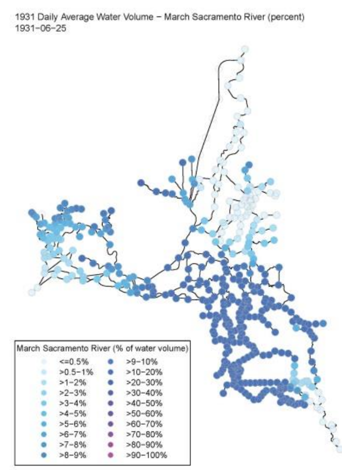
June 13, 1931



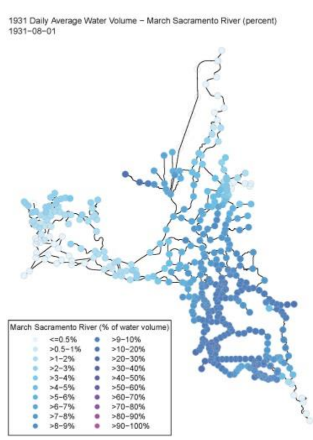
June 18, 1931



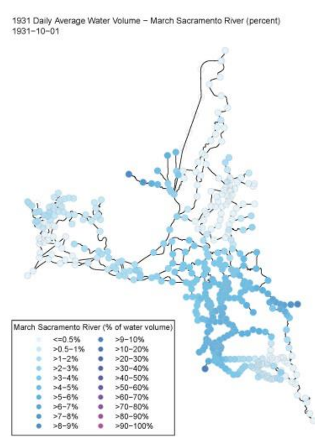
June 25, 1931



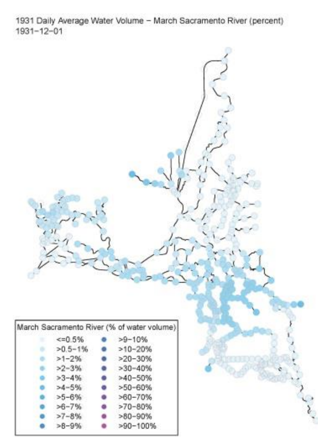
August 1, 1931



October 1, 1931



December 1, 1931



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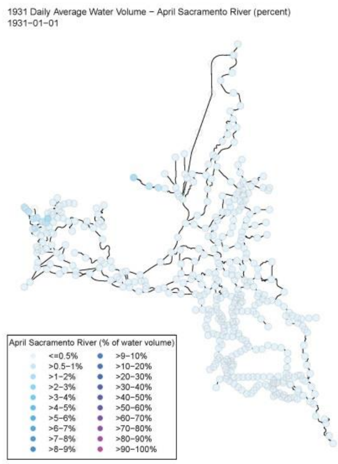
Appendix E - Images from DSM2 Model Animations, page 4

Vol (%)

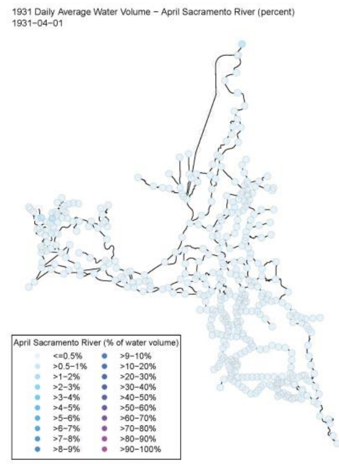
<=0.5%
>0.5–1%
>1–2%
>2–3%
>3–4%
>4–5%
>5–6%
>6–7%
>7–8%
>8–9%
>9–10%
>10–20%
>20–30%
>30–40%
>40–50%
>50–60%
>60–70%
>70–80%
>80–90%
>90–100%

4. Volume of Sacramento River water that entered the Delta in April 1931 (in percent)

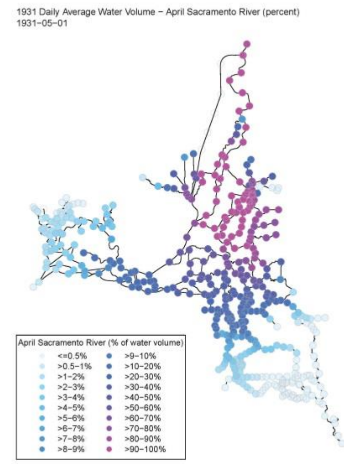
January 1, 1931



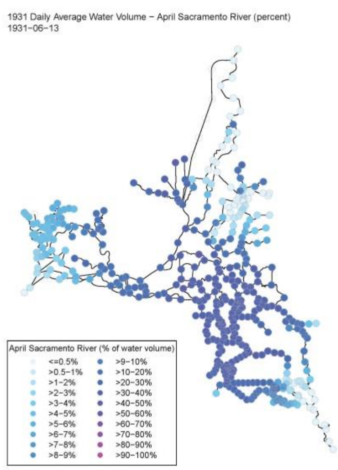
April 1, 1931



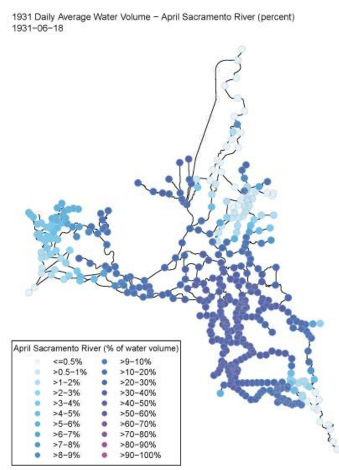
May 1, 1931



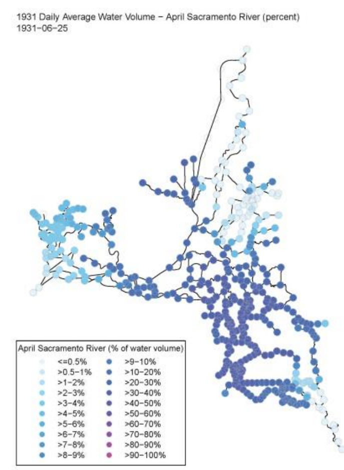
June 13, 1931



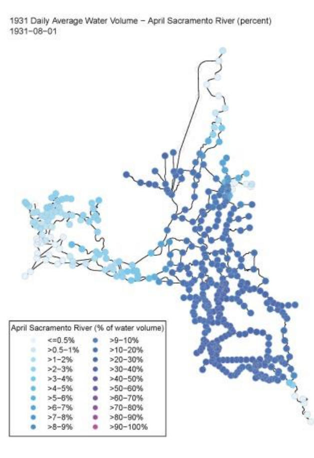
June 18, 1931



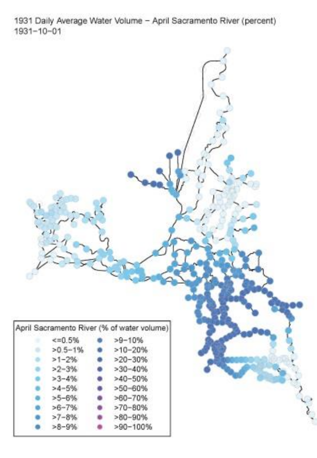
June 25, 1931



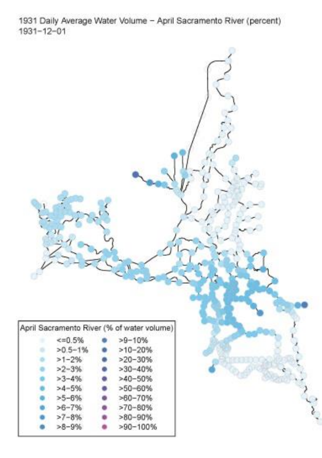
August 1, 1931



October 1, 1931



December 1, 1931



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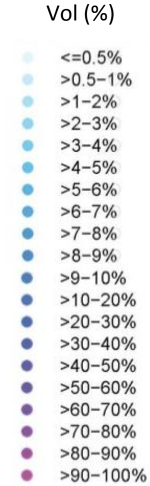
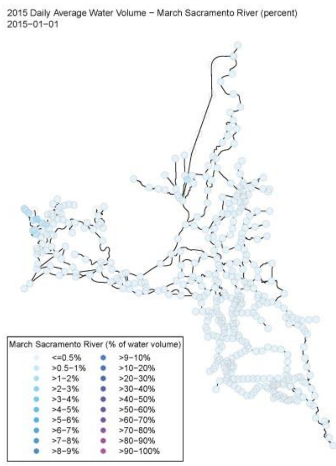
Appendix E - Images from DSM2 Model Animations, page 5

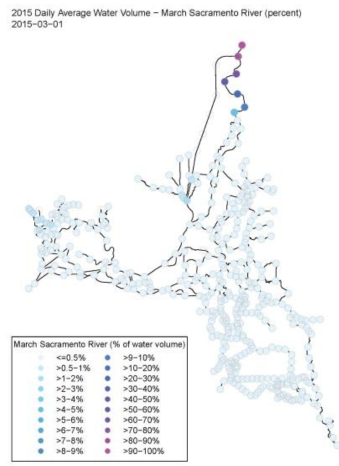


5. Volume of Sacramento River water that entered the Delta in March 2015 (in percent)

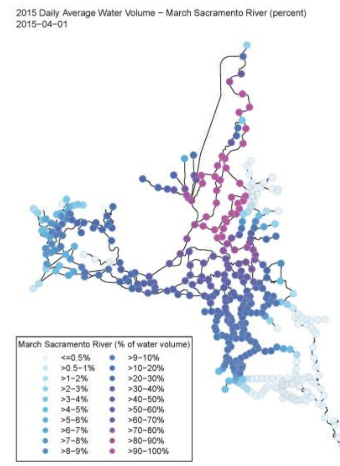
January 1, 2015



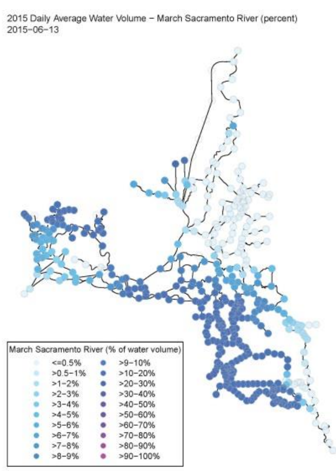
March 1, 2015



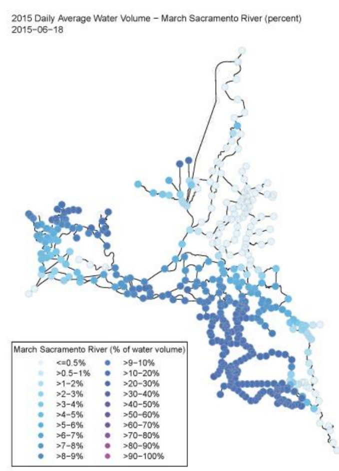
April 1, 2015



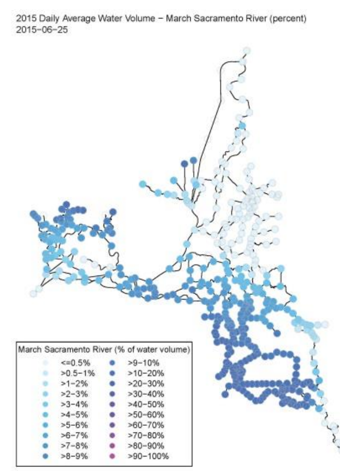
June 13, 2015



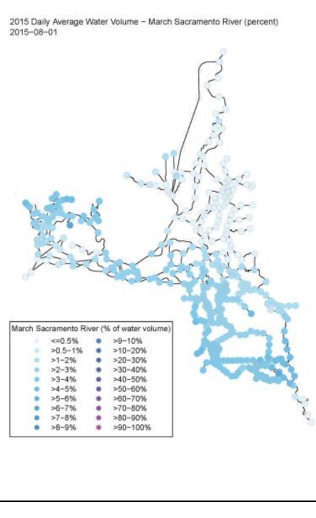
June 18, 2015



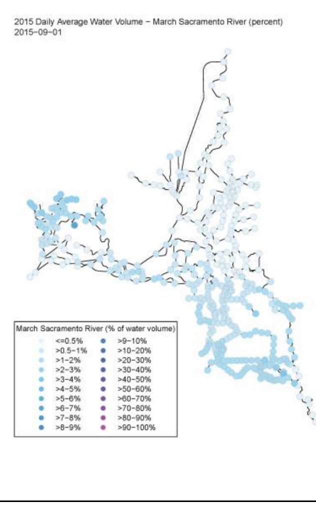
June 25, 2015



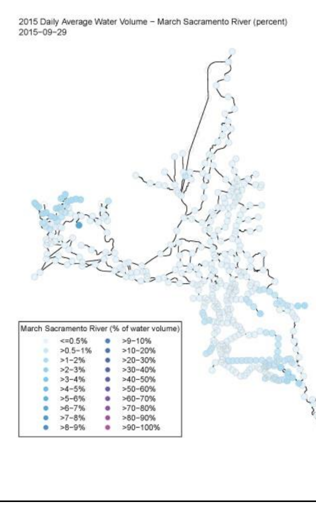
August 1, 2015



September 1, 2015



September 29, 2015



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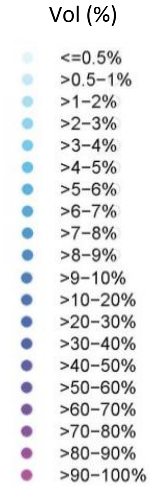
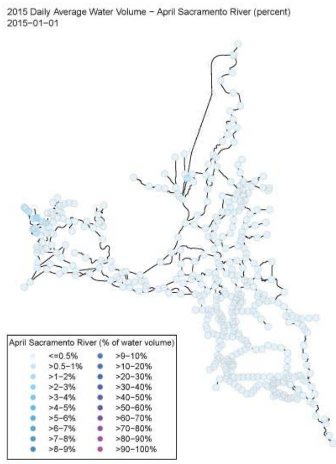
Appendix E - Images from DSM2 Model Animations, page 6

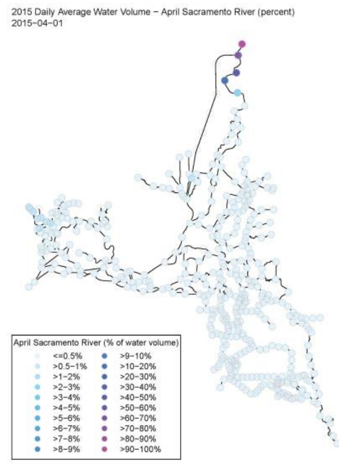


6. Volume of Sacramento River water that entered the Delta in April 2015 (in percent)

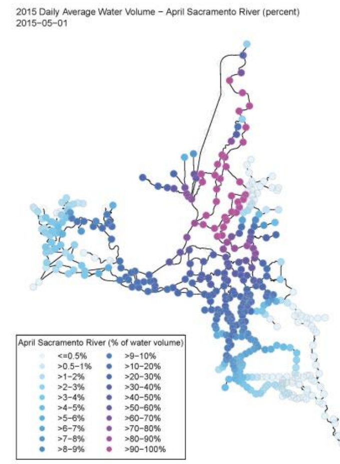
January 1, 2015



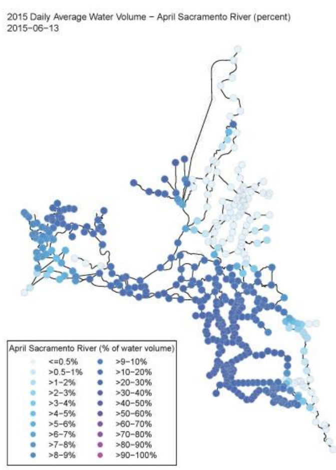
April 1, 2015



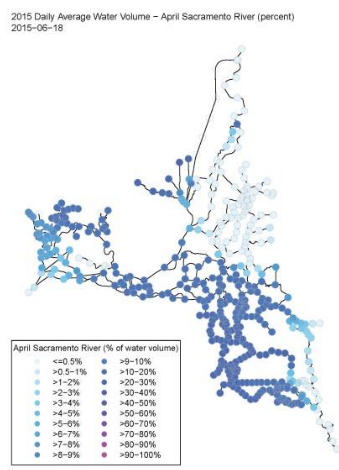
May 1, 2015



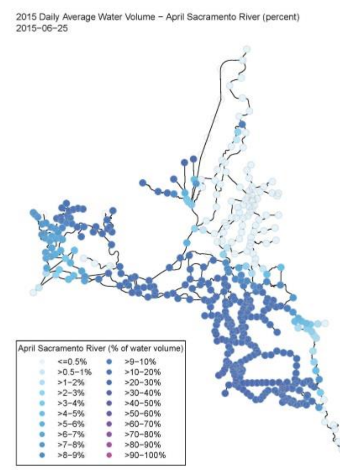
June 13, 2015



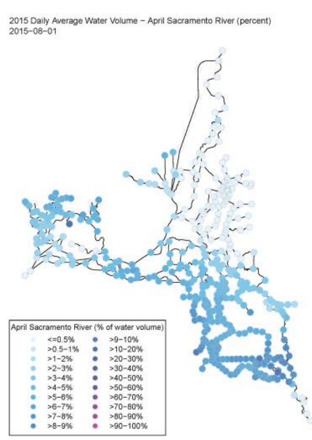
June 18, 2015



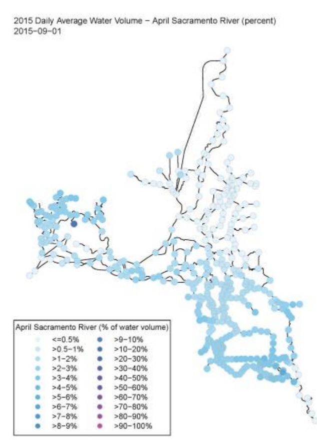
June 25, 2015



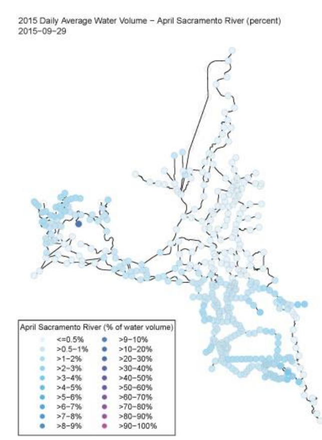
August 1, 2015



September 1, 2015



September 29, 2015

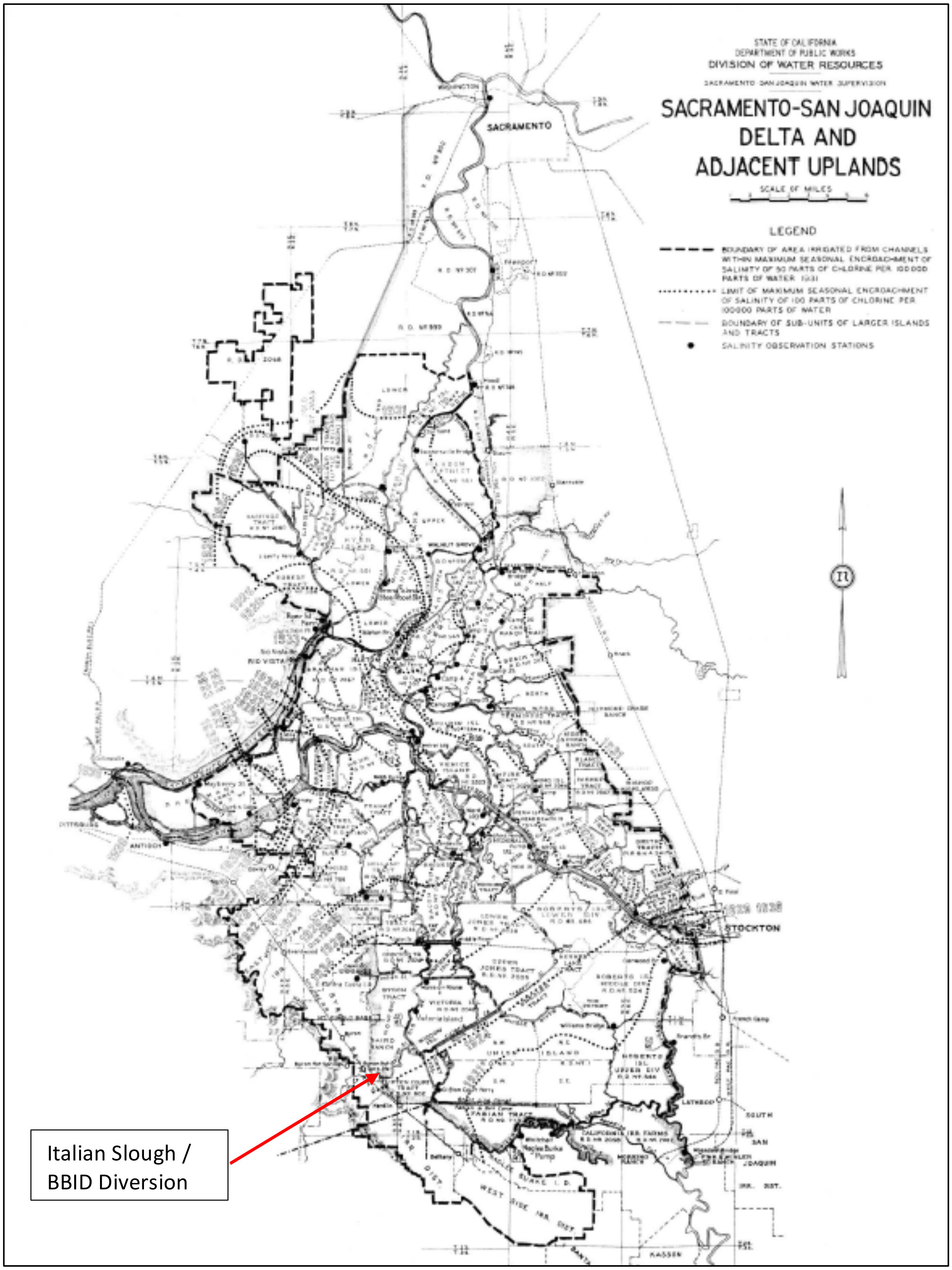


Appendix F

Supplemental Historical Information

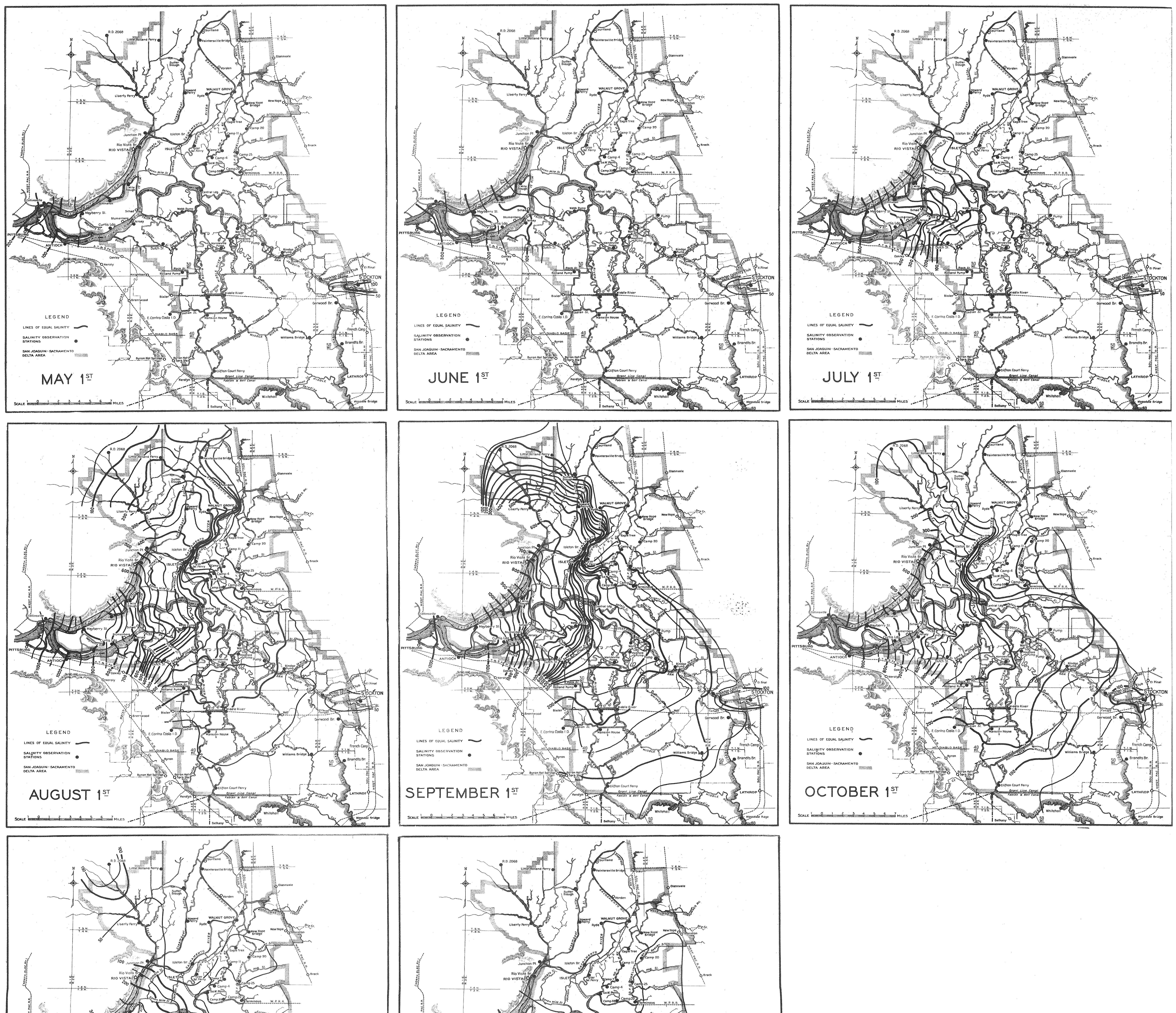
Antioch-217

Figure 1. Maximum Seasonal Encroachment of Salinity of 100 parts chloride per 100,000 parts of water (From Plate 2, DWR Bulletin 29, 1939 edition)



Maximum Seasonal Encroachment of Salinity of 100 parts chloride per 100,000 parts of water (From Plate 2, DWR Bulletin 29, 1939 edition)

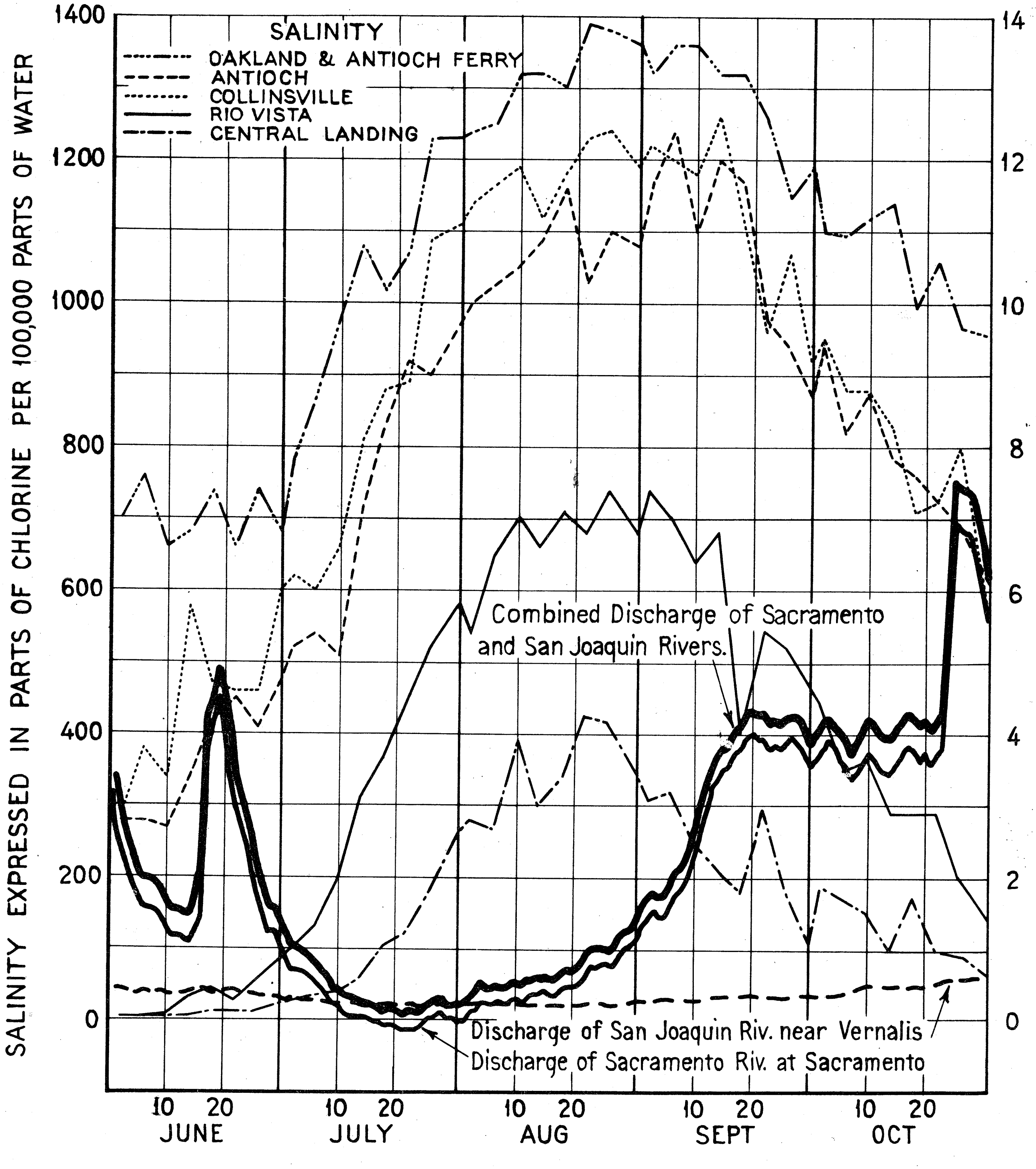
Figure 2. Timing of Salinity Intrusion (Source: DWR Bulletin 23, 1931 Edition)



VARIATION OF SALINITY
SACRAMENTO-SAN JOAQUIN DELTA
MAY TO DECEMBER 1931
AS SHOWN BY
LINES OF EQUAL SALINITY AT INTERVALS OF
50 PARTS OF CHLORINE PER 100000 PARTS OF WATER

PLAT

Figure 3. Extent of Salinity Intrusion in 1931 (Source: DWR Bulletin 23, 1931 edition). Note: image has been modified from its original version by the addition of red text.



COMPARISON OF RIVER DISCHARGE AND SALINITY AT BAY AND DELTA STATIONS 1931

PLATE 9

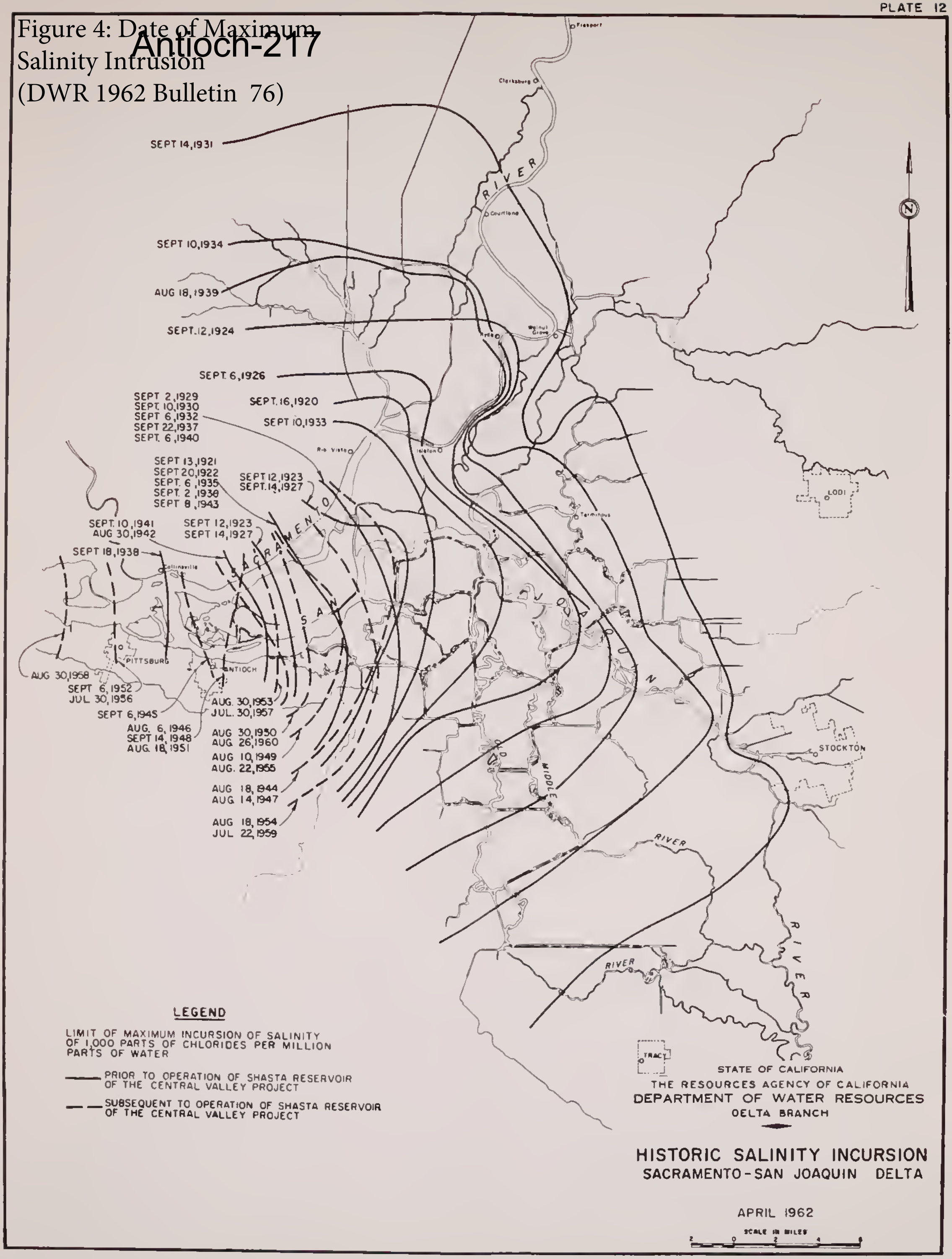


Figure 4: Date of Maximum Salinity Intrusion (DWR 1962 Bulletin 76)

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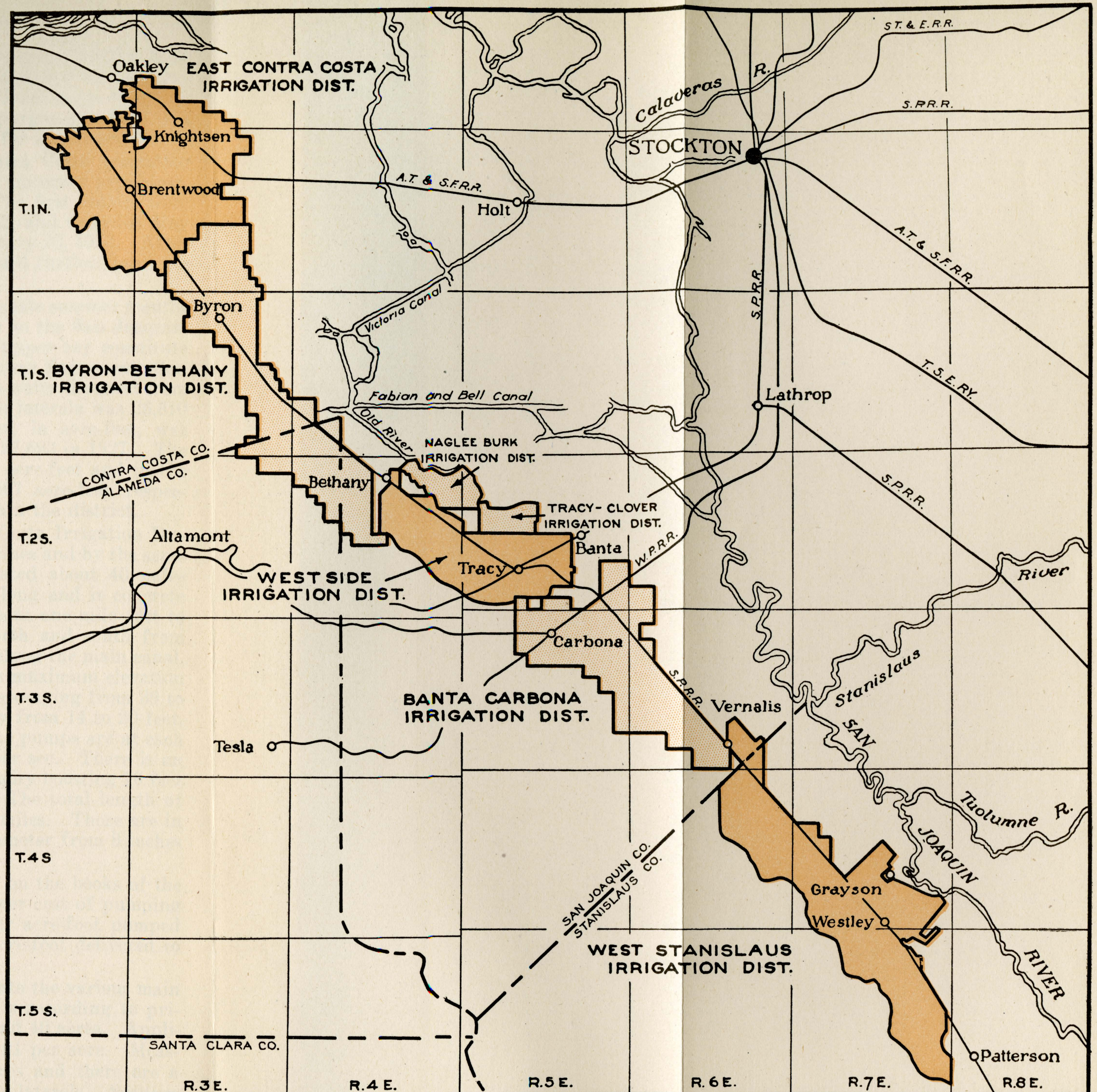
Antioch-217

Figure 5a: History of BBID (Source: DWR Bulletin 21, 1929)



Location and boundary map of irrigation districts on west side of lower San Joaquin Valley.

Figure 5b: History of BBID (Source: DWR Bulletin 21, 1929)

Antioch-217

amount delivered into the main laterals in 1927, and ranging from 9.7 to 52.5 per cent in the different main laterals. The lining of additional canals or substitution of pipes to lessen seepage is under way. The district has computed from the pumping records the quantity of water used per acre in 1927 for each crop. A tabulation of their results, showing an average application of 1.08 acre-feet per acre, is given in the summary below:

Crops	*Acre-feet*	*Acres irrigated*	*Average acre-foot per acre*
Alfalfa	6,123.7	4,125	1.48
Trees	4,155.3	4,652	.89
Vegetables	3,269.2	3,224	1.01
Trees and vegetables	708.9	870	.81
Vines	400.1	589	.67
Trees and vines	294.3	349	.84
Grain	31.2	25	1.24
	14,982.7	13,834	1.08

The water toll of $4 per acre-foot encourages economy of application.

Bonds.—Bonds outstanding after retirement of January 1, 1928, total $1,288,000, of which $637,000 are against lands in the original Knightsen District, $514,000 against lands in the original Brentwood District, and $137,000 against lands in the original Lone Tree District. The total of all bonds authorized by the three districts is $1,324,000. The first series of Knightsen District bonds, amounting to $13,000, have been retired, in addition to the $23,000 of Lone Tree bonds canceled in 1925. Other bonded indebtedness against lands in the district is estimated to total $118,250, divided as follows: elementary school bonds, $40,550; union high school bonds, $5,600; county bonds, $42,100; bonds of Water District No. 1, $20,000.

Assessments and water tolls.—For assessment purposes the three original irrigation districts are treated separately, although in 1927–28 the assessed valuations were the same, the valuation in each being $190 per acre on good farm land and $160 to $175 on land with rough topography. The total assessed valuation in 1927–28 was $3,615,344. The assessment rate per $100 of valuation in 1926–27 varied from $3.73 in the Brentwood area to $5.23 in the Lone Tree area. In 1927–28 the rate was uniform throughout, being $2.60 for bond interest and retirement and $1.40 for general fund, a total of $4. The total levy in 1927–28 was $145,508. Water tolls within the district in 1927 were $4 per acre-foot, all water used being charged for at that rate. Total water tolls collected in 1927 amounted to $59,934.

BYRON-BETHANY

Location: west side of San Joaquin Valley, between San Joaquin River and the hills on the west, in Contra Costa, San Joaquin, and Alameda counties. (Pl. XVII.)

Date of organization election: December 22, 1919.

Gross area: 17,200 acres; **area assessed 1927:** 17,200 acres.

Principal town: Byron.

Post office: Byron.

Railroad transportation: main line of Southern Pacific railroad.

History.—Surveys were started to outline an irrigation project for the land in the neighborhood of Tracy, Byron, and Bethany about 1913, but were not completed. About 1914 a local committee considered the promotion of a project to cover a large area and divert water near the

Figure 5c: History of BBID (Source: DWR Bulletin 21, 1929)

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site of the old river landing known as San Joaquin City. By the following year, the landowners around Byron and Bethany had decided to work independently of the areas around Tracy and to the south, and proceeded to organize a cooperative irrigation company. Prior to the organization of this company a local surveyor had estimated the cost of the system at $5 per acre, but when reviewed by the county surveyor his estimate was increased to $5.88 per acre. Stock in the water company was sold at $10 per acre and money was borrowed from various banks.

Construction was started and a pumping plant erected and part of the canal built by the beginning of the irrigation season of 1917. The proposed source of water was a dredged cut leading to a slough near the junction of San Joaquin, Contra Costa, and Alameda counties. No right of access to the slough had, however, been obtained, and the owners refused to grant one. This was during the war period, and an effort was made through the State Council of Defense to have this right of way granted, but without success. Thereupon the company obtained from the Railroad Commission a certificate of public convenience and necessity, and with this it was able to proceed by condemnation to acquire the needed right of way, their action having been brought in June, 1918. By this time the company had expanded or incurred debts amounting to $115,630 and were confronted with additional estimated expenditures of $194,330. Shares in the company had been sold to the number of 6288 at $10 per share. By September 1, 1919, the expenditures had totalled $203,707.62, or at a rate per acre about five times the estimate on which the cooperative company had organized several years earlier. The company then had notes payable to the amount of $57,000, and accounts payable, less current assets, to the amount of $12,051. Water had been made available to about 8000 acres, or only approximately half of the area in which the company was interested.

With the conditions previously outlined facing them, the landowners finally reached the conclusion that the only feasible method of procedure was through an irrigation district, and this they proceeded to organize by a vote of 173 to 14. An engineer was employed to make a thorough study and cost estimate, and after revision by the assistant state engineer this called for a total expenditure of $632,370. This included $265,000 for the assets of Byron-Bethany Irrigation Company, which had been appraised at $357,067, and $358,095 for new works. The original estimate made by the district engineer calling for $550,000 was approved by the Irrigation Bond Commission and bonds to that amount were voted. Later an additional $100,000 bond issue had to be sold and a further amount of about $130,000 for construction raised from district taxes. Finally, on August 2, 1927, a special assessment of about $37,000, to be used chiefly for concrete canal lining and replacement of some canals with concrete pipe, was passed by a narrow margin of 73 to 70.

The district took over the works of the Byron-Bethany Company on March 5, 1921, at a total price, including interest and reimbursement of expenditures since January 1, 1920, of $302,392. Since that date the district has been on an operating basis.

Soils and topography.—The prevailing soil classifications are Yolo clay loam and adobe and Antioch clay loam and clay.* North of Byron

* U. S. Dept. of Agr., Bureau of Soils, Reconnoissance Soil Survey of the Lower San Joaquin Valley, California.

Figure 5d: History of BBID (Source: DWR Bulletin 21, 1929)

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elevations vary from a few feet to 75 feet above sea level. In this portion the surface is generally smooth, with sufficient slope to aid irrigation. The southwest is more rough, with over 2000 acres above the district canals. From 2000 to 3000 acres along the rim of the old flood plain of San Joaquin River shows alkali. East of the concrete highway north of Byron the water table is within a few feet of the surface, but west of the highway it is 10 to 25 feet below the surface, and 10 to 40 feet below the surface south of Byron. Drainage wells are being used north of Byron to reduce the ground water level. Thus far the adobe soil south of Byron has not produced sufficiently to make irrigation attractive.

Development.—There are now about 250 farm holdings, averaging 46 acres. Three large holdings have 736, 745, and 810 acres. The population of Byron is about 300 and of the remainder of the district about 700. A concrete highway passing through the district connects with San Francisco and Oakland by way of either Martinez, Walnut Creek, or Livermore.

Water supply.—The water rights of the district are based on a notice of appropriation filed in the name of Byron-Bethany Irrigation Association on May 18, 1914, for 40,000 miner's inches, and on subsequent use. Construction was started in 1915 and some water was used in 1917. Diversion is from San Joaquin River at the junction of Indian Slough and Old River. The entire supply is pumped. Records kept by the Sacramento-San Joaquin water supervisor show diversions in acre-feet during the past four years as follows: 1924, 21,749; 1925, 14,187; 1926, 20,576; 1927, 16,237. The largest diversion thus far has been that of 1924.

Salinity from upper San Francisco Bay has been looked upon as a potential hazard in the general region of diversion by the district, but thus far there has been no apparent damage from this source to lands in this district.

Works.—The irrigation system of Byron-Bethany Irrigation District is somewhat similar to the systems of East Contra Costa, Westside, Banta-Carbona, and West Stanislaus districts, which, with Byron-Bethany Irrigation District, irrigate the west-side area from Patterson north through Brentwood. It consists of successive pump lifts from San Joaquin River, with distribution canals reaching north and south. Because Byron-Bethany District is more rolling than the others to the north and south, the pumping lifts are scattered along the north and south main canals and laterals, rather than along a main canal running westerly through the center of the district.

There are five pumping plants with capacities ranging from 125 down to 10 cu. ft. per sec. A dredged cut about one mile long conveys water from Indian Slough to pumping plant No. 1, which discharges through 1100 feet of 60-inch concrete pipe into the main distributing canal, the lift being 45 feet. The water flows for about one-half mile through a lined canal to the point where Byron Canal turns north and Bethany Canal turns south, the areas under these two canals being nearly equal. Most of the land supplied through Byron Canal is irrigated without further lift. At pump 4, north of Byron, however, 25 cu. ft. per sec. is lifted an additional 55 feet into a highline canal, which runs near the northern boundary of the district; also, booster pump 5 lifts 10 cu. ft. per sec. against a head of 75 feet to supply a

Figure 5e: History of BBID (Source: DWR Bulletin 21, 1929)

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small area above pumping station 4. After leaving Byron Canal, Bethany Canal flows south about one mile to pumping station 2, which, with a capacity of 75 cu. ft. per sec., lifts water 30 feet into the canal which supplies the southeastern areas. A branch from this latter canal leading to pumping station 3 serves the higher southern land. Pumping station 3 boosts water by means of two 14-inch pumps to the 160-foot level and by means of a 22-inch pump to the 126-foot level. Very little land is irrigated under the higher lift. The maximum lift in the district is 175 feet.

Altogether the district operates 4.5 miles of canals, of which 3.5 miles are lined; 0.5 mile of main pipe line 30 inches to 40 inches in diameter, and 0.5 mile of 30-inch concrete lateral pipe. Many of the original canal structures were of wood, but concrete replacements are being made as funds are available. In addition to the irrigation works the district operates for drainage purposes three well turbines with rated capacities of 800 g.p.m. each, but the drainage water pumped is not used for irrigation. To further assist in controlling ground water, about one-half mile of canal is being replaced with concrete pipe to decrease seepage. While additional expenditures must be made for drainage in the near future, it is believed by the district that the water table can be controlled with comparative ease by means of well pumps and the lining of certain canals in which seepage is excessive.

The total amount invested in works to December 31, 1927, was $741,569.46, from which $97,231.79 has been written off for depreciation, leaving a net present worth of $644,337.67. Besides the system of Byron-Bethany Irrigation Company, the district purchased for $24,500 the town water supply system of Byron.

Use and delivery of water.—The district undertakes to deliver water to each 160-acre tract, and deliveries are either measured over weirs, through orifices, or are estimated by the ditchtenders. Records of deliveries have not been tabulated, but the quantities delivered have been estimated from water tolls charged as follows for the past four years: 1924, 15,300 acre-feet; 1925, 9570 acre-feet; 1926, 11,120 acre-feet; 1927, 9470 acre-feet. For purposes of operation the district is divided into Byron and Bethany divisions, each of which is in charge of a water master reporting to the general manager. The rules provide that water shall be delivered to irrigators only through measuring devices approved and installed by the district. Water users are required to file applications for water not less than 48 hours prior to the time it is desired, these applications to be made on blanks furnished by the district, and to be accompanied by an advance payment of 50 cents per acre. Deliveries are made in rotation from each lateral, beginning at the diversion point, except as agreed otherwise by the users. The district undertakes to make water available during the irrigation season every 15 days, provided a sufficient number of irrigators apply for water to justify the run.

Bonds.—The district has authorized bond issues of $550,000 and $100,000. On January 1, 1928, $25,000 had been retired. Other bonds against the district total $30,100, divided as follows: elementary school, $2,600; high school, $3,000; Contra Costa County, $20,000; San Joaquin County, $2,000; Alameda County, $2,500.

Figure 5f: History of BBID (Source: DWR Bulletin 21, 1929)

Assessments and water tolls.—Income is derived from both district assessments and water tolls. About 4000 acres of the best land north of Byron is assessed for district purposes at $200 per acre and the good land south of Byron at $130 per acre. Lands of somewhat poorer grade are assessed at $75 to $100 per acre and alkali 'rim' lands at $10 to $50 per acre. Lands above the canals, totaling 2766 acres, are assessed at $1 per acre. The total district valuation for 1927–28 was $1,720,644 and the amount of the levy for that year was $70,546. The assessment rate per $100 valuation for the past five years has ranged from $3.20 to $4.40. Water tolls are charged at the rate of $3.50 per acre-foot, the amount of the tolls collected in 1927 having been $33,145.

WEST SIDE

Location: west side of San Joaquin Valley surrounding Tracy, in San Joaquin County. (Pl. XVII.)
Date of organization election: October 25, 1915.
Gross area: 11,828 acres; **area assessed 1927:** 11,828 acres.
Principal town: Tracy.
Post office: Tracy.
Railroad transportation: Southern Pacific railroad, with main line of Western Pacific railroad nearby.

History.—The first recent movement to supply irrigation water for the lands around Tracy was made about 1913 when surveys were started at the instance of local merchants and landowners. These surveys were not completed, but about 1914 a committee of landowners in the area extending generally from Banta on the south to Byron on the north tentatively proposed construction of a canal from San Joaquin River, to head near the old abandoned townsite of San Joaquin City. Later the landowners around Tracy began working independently, with the result that West Side District was formed.

Soils and topography.—West Side Irrigation District extends from Bethany, a station on the main valley line of the Southern Pacific railroad, to about 2 miles east of Tracy, a distance of about 8 miles, and lies below elevation 107 and above the 17-foot contour, U. S. G. S. datum. The soils are classed as Yolo loams, clay loams, and adobes.* The surface is generally even, but slopes toward the north at a rate of 15 to 35 feet per mile. North of Tracy, in sections 19, 20, 21 and 22, the water table in April, 1928, was 2 to 4 feet below the surface, but in the southern section, roughly along the 75-foot contour, it stands about 15 feet below the surface.

Development.—The Tracy area has always been a strong producer of grains, although subject from time to time to deficient rainfall. All of the land in the district was in crop when the district was formed, with the exception of minor scattered areas and rights of way. The crop census for 1927 showed 8513 acres in alfalfa, 469 acres in trees and vines, 141 acres in truck crops, 1085 acres in grain, 1163 in pasture and grain hay, 219 acres in industrial use, and 158 acres in residential tracts. Out of the 11,761 acres assessed in 1927, 10,415 acres was irrigated. There are 174 farms averaging 65 acres, this including one holding of 1500 acres, one of 723 acres, one of 547 acres, and one of 197 acres. The estimated assessed value of land in the district for county purposes for 1927 was $900,000.

* U. S. Dept. of Agr., Bureau of Soils, Reconnoissance Soil Survey of the Lower San Joaquin Valley, California.

Figure 6: Unimpaired flow from the 8-River Index (Source: CDEC and DWR Bulletin 120 [2015])

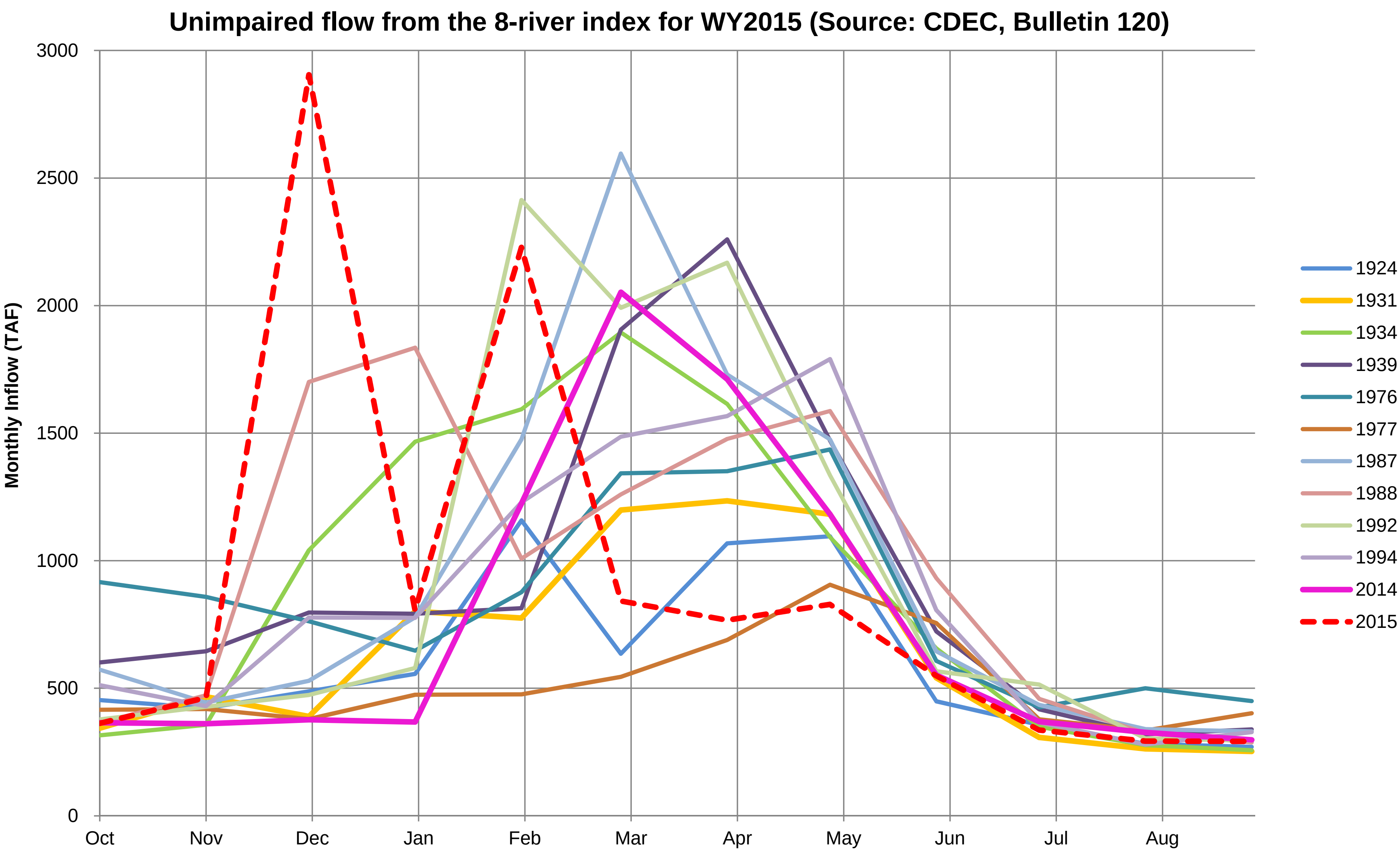

Figure 7: Unimpaired flow from the 8-River Index (Source: CDEC and DWR Bulletin 120 [2015])

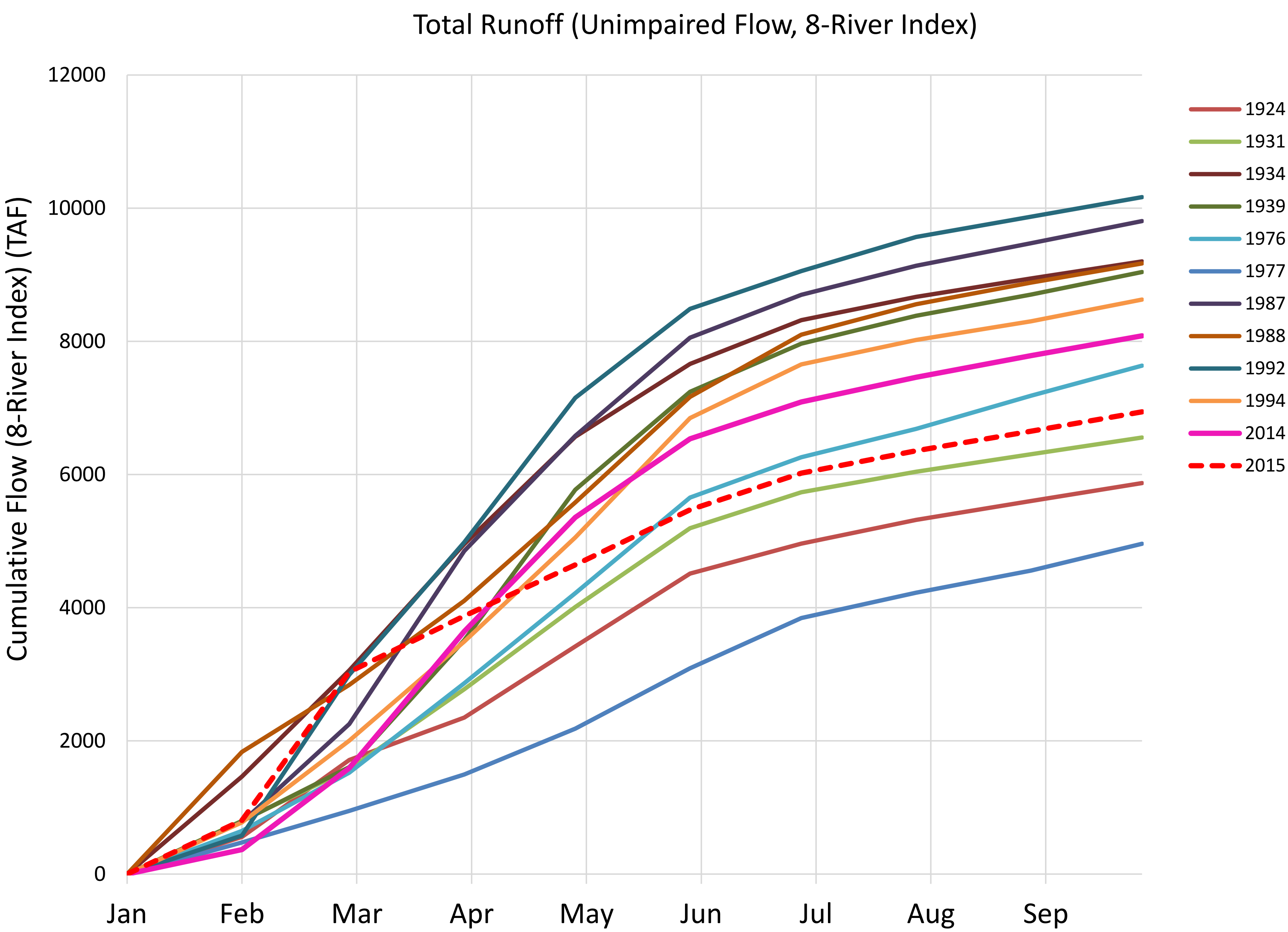

Figure 7: Old River Stage and flow rate, and BBID diversion rate in May and June, 2015 (Source: CDEC, US Bureau of Reclamation)

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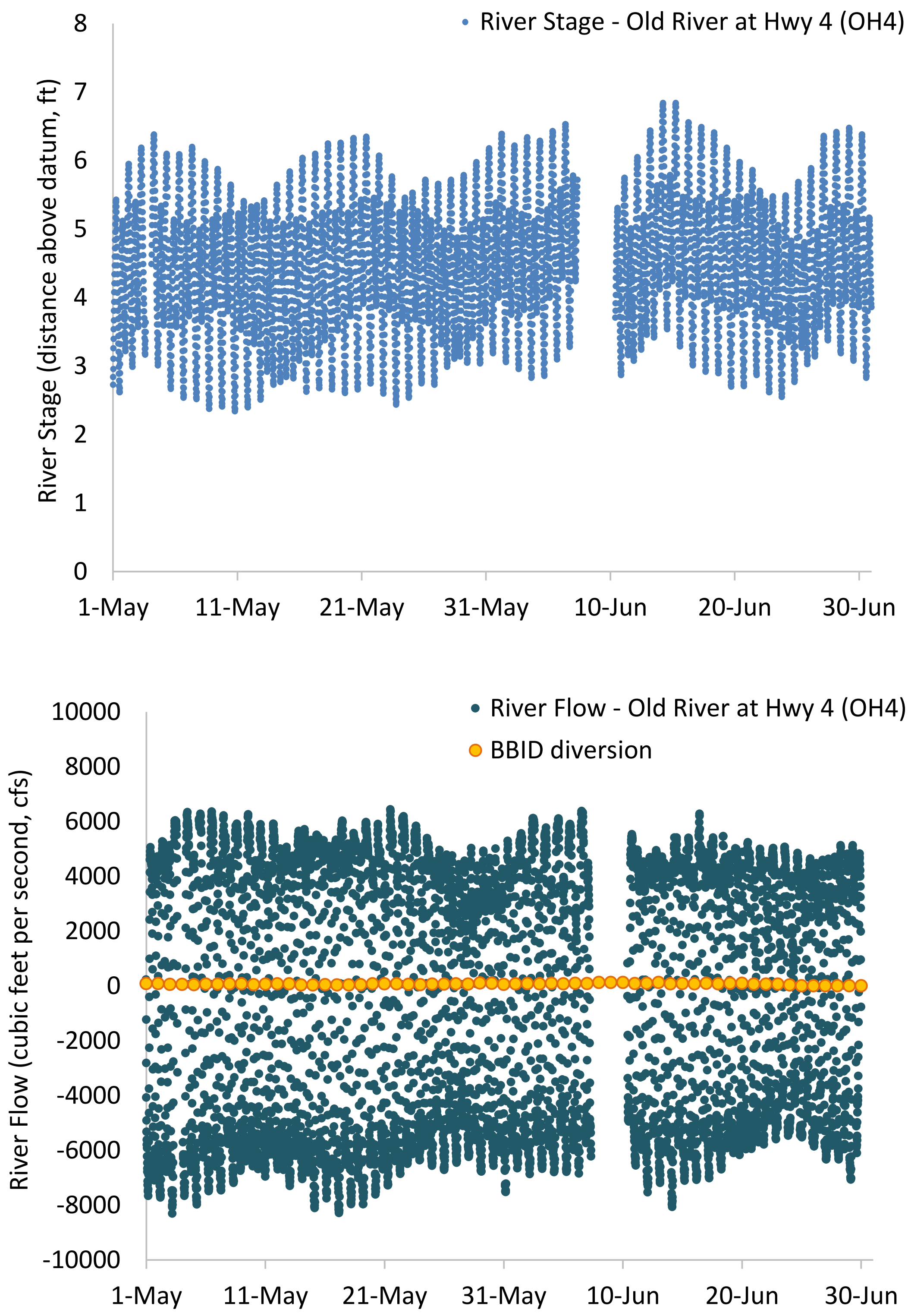

Figure 7. River stage in Old River at Highway 4 (top) and river flow in Old River at Highway 4 (bottom) as well as BBID diversion flow rate (bottom) in May and June 2015. BBID diversion flow ranged between 0 and 130 cfs from May 1, 2015 to June 30, 2015.

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Figure 8. Old River Stage, Clifton Court inflow, and BBID diversion rate in May and June, 2015 (Source: CDEC, US Bureau of Reclamation)

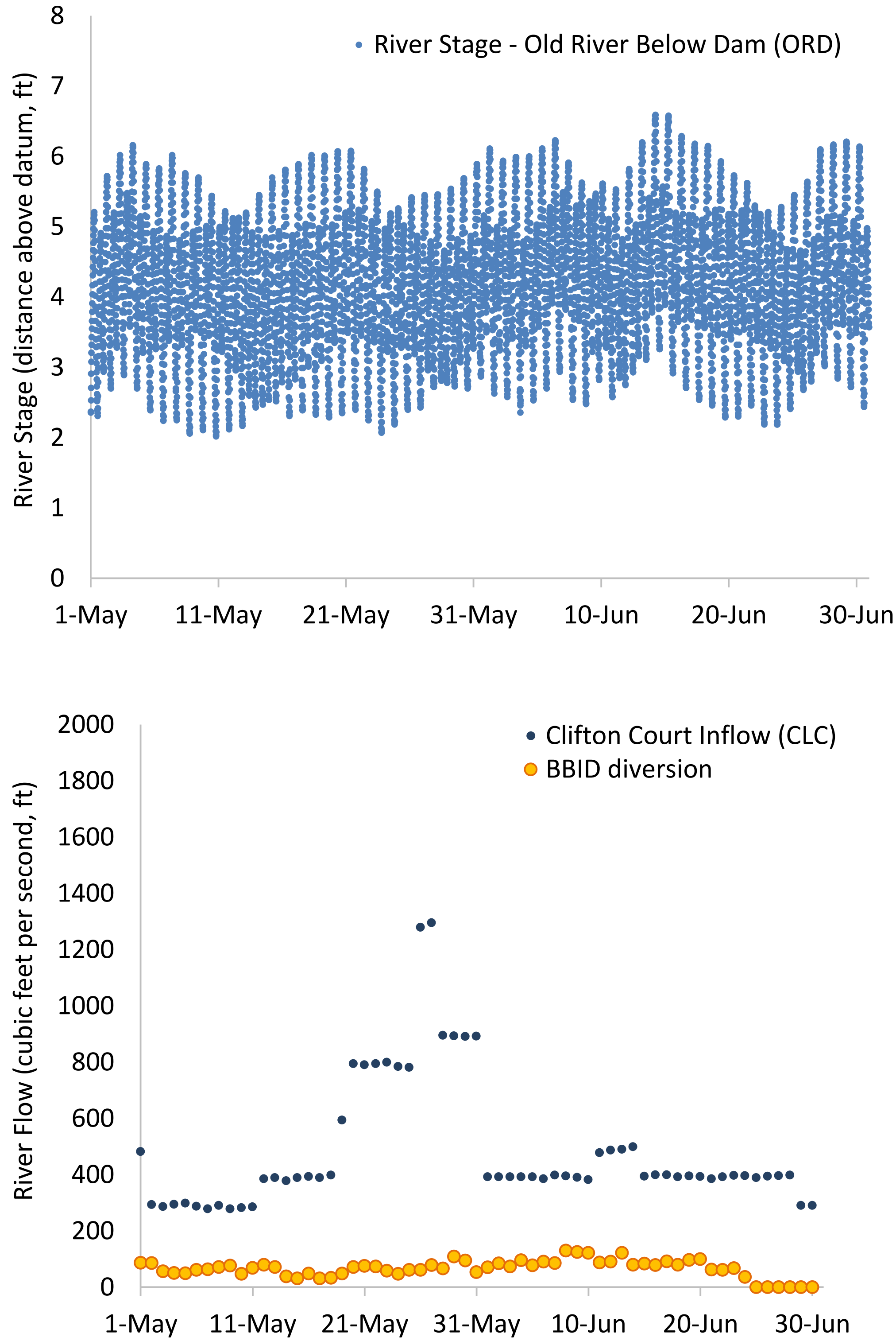

Figure 8. River stage in Old River below the dam (top) and inflow to Clifton Court (bottom) as well as BBID diversion flow rate (bottom) in May and June 2015. BBID diversion flow ranged between 0 and 130 cfs from May 1, 2015 to June 30, 2015.

Appendix G

Curriculum Vitae of Susan Paulsen

Exponent®

Susan C. Paulsen, Ph.D., P.E.
Principal Scientist & Practice Director

Professional Profile

Dr. Susan Paulsen is a Principal Scientist and the Director of Exponent's Environmental and Earth Sciences practice. Dr. Paulsen has 24 years of experience with projects involving hydrodynamics, aquatic chemistry, and the environmental fate of a range of constituents. She has provided expert testimony on matters involving the Clean Water Act and state water quality regulations, and she also provides scientific and strategic consultation on matters involving Superfund (CERCLA) and Natural Resources Damages (NRD). She has expertise designing and implementing field and modeling studies of dilution and analyzing the fate and transport of organic and inorganic pollutants, including DDT, PCBs, PAHs, copper, lead, and selenium, in surface and groundwater and in sediments.

Dr. Paulsen has designed and implemented field studies in reservoir, river, estuarine, and ocean environments using dye and elemental tracers to evaluate the impact of pollutant releases and treated wastewater, thermal, and agricultural discharges on receiving waters and drinking-water intakes. Dr. Paulsen has designed and managed modeling studies to evaluate transport and mixing, including the siting and design of diffusers, and has evaluated water quality impacts of stormwater runoff, irrigation, wastewater and industrial process water treatment facilities, and desalination brines. Dr. Paulsen has extensive knowledge of California water supply issues, including expertise in California's Bay-Delta estuary, the development of alternative water supplies, and integration of groundwater basins into supply and storage projects.

Dr. Paulsen has designed studies using one-dimensional hydrodynamic models (including DSM2 and DYRESM), three-dimensional CFD modeling, longitudinal dispersion modeling, and Monte Carlo analysis. Dr. Paulsen has participated in multi-disciplinary studies of the fate and transport of organic and inorganic pollutants, including DDT, PCBs, PAHs, copper, lead, selenium, and indicator bacteria in surface waters, groundwaters, and/or sediments. She has worked on matters involving both CERCLA and NRDA, including several involving the fate and transport of legacy pollutants, and she has evaluated the impacts of oil-field operations on drinking-water aquifers.

Dr. Paulsen has broad expertise with water quality regulation through the Clean Water Act and state regulations in California, Washington, Hawaii, and other states, and has worked on temperature compliance models, NPDES permitting, permit compliance and appeals, third-party citizens' suits, and TMDL development. She has evaluated the importance of background and natural sources on stormwater and receiving-water quality and the development of numeric limits for storm flows and process-water discharges. Dr. Paulsen is the author of multiple reports describing the history and development of water quality regulations and has provided testimony on regulatory issues, water quality, and water rights.

Academic Credentials and Professional Honors

Ph.D., Environmental Engineering Science, California Institute of Technology, 1997
M.S., Civil Engineering, California Institute of Technology, 1993
B.S., Civil Engineering, Stanford University (with honors), 1991

Licenses and Certifications

Registered Professional Civil Engineer, California, #66554

Languages

Italian (Conversational)
German (Conversational)

Selected Publications and Presentations

Byard JL, Paulsen SC, Tjeerdema RS, Chiavelli D. DDT, Chlordane, Toxaphene and PCB Residues in Newport Bay and Watershed: Assessment of Hazard to Wildlife and Human Health. Reviews of Environmental Contamination and Toxicology 2015; 235.

California Council for Environmental and Economic Balance (CCEEB); authored by Paulsen SC. A Clear Path to Cleaner Water: Implementing the vision of the State Water Board for improving performance and outcomes at the State Water Boards. CCEEB: San Francisco, CA. 2013. Available at www.cceeb.org.

South Orange Coastal Ocean Desalination (SOCOD) Project; authored by Expert Panel Member Paulsen SC. Expert Panel Report: Offshore Hydrogeology/Water Quality Investigation Scoping, Utilization of Slant Beach Intake Wells for Feedwater Supply. Municipal Water District of Orange County (MWDOC): Fountain Valley, CA. 2012. Available at http://www.mwdoc.com/filesgallery/FINAL_Expert_Panel_Rept_10_9_2012.pdf.

Paulsen SC, Goteti G, Kelly BK, Yoon VK. Automated flow-weighted composite sampling of stormwater runoff in Ventura County, CA. Proceedings, Water Environment Federation 2011.12 (2011): 4186-4203. Also published as automated flow-weighted composite sampling of stormwater runoff. Water Environment Laboratory Solutions 2012; 19(2):1–6.

Paulsen SC, List EJ, Kavanagh KB, Mead AM, Seyfried R, Nebozuk S. Dynamic modeling and field verification studies to determine water quality and effluent limits downstream of a POTW discharge to the Sacramento River, California. Proceedings, Water Environment Federation 2007; 12:5695–5721.

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Paulsen SC, List EJ, Santschi PH. Modeling variability in 210Pb and sediment fluxes near the Whites Point Outfalls, Palos Verdes Shelf, California. Environmental Science & Technology 1999; 33:3077–3085.

Paulsen SC, List EJ, Santschi PH. Comment on “In situ measurements of chlorinated hydrocarbons off the Palos Verd es Peninsula, California.” Environmental Science & Technology 1999; 33:3927–3928.

Paulsen SC, List EJ. A study of transport and mixing in natural waters using ICP-MS: Water-particle interactions. Water, Air, and Soil Pollution 1997; 99:149–156.

Paulsen SC, List EJ. Tracing discharges in ocean environments using a rare earth tracer. Presented at the 27th IAHR Congress, San Francisco, CA, August 1997.

Prior Experience

- Various positions including President, Flow Science Incorporated, Pasadena, California, 1997–2014
- Consultant to Flow Science Incorporated, Pasadena, California, 1994–1997
- Staff Engineer, Dames & Moore, Civil Design Group, San Francisco, California, 1990-1992
- Graduate Research and Teaching Assistant, Hydrologic Transport Processes and Fluid Mechanics, California Institute of Technology, Pasadena, California, 1993–1997
- Research Engineer, Fraunhofer Institute for Atmospheric Environmental Research, Garmisch-Partenkirchen, Germany (West), 1989
- Instructor, Technical Communications Program (joint Business School/School of Engineering program), Stanford University, Stanford, CA, 1989–1990

Professional Affiliations

- American Society of Civil Engineers—ASCE
- Member, National Ground Water Association

Depositions (last 4 years)

City of Cerritos, et al., v. Water Replenishment District of Southern California, Case No. BS128136, in the Superior Court of the State of California, County of Los Angeles. November 24, 2014.

The Boeing Company et al. v. State of Washington, Department of Ecology, Appeal of the 2010 Industrial Stormwater General Permit, Pollution Control Hearings Board, State of Washington. Case No. 09-140. 2011.

Puget Soundkeeper Alliance v. BNSF Railway Co., Case No. C09-1087-JCC, in the United States District Court, Western District of Washington at Seattle. 2011.

Trials and Hearings (last 4 years)

The Boeing Company et al. v. State of Washington, Department of Ecology, Appeal of the 2010 Industrial Stormwater General Permit, Pollution Control Hearings Board, State of Washington. Case No. 09-140. 2011.