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Department of Water Resources Comments to the State Water Resources Control Board Regarding Information On the Southern Delta Salinity and San Joaquin River Flow Objectives and Their Program of Implementation

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Department of Water Resources Comments to the State Water Resources Control Board regarding Information on the Southern Delta Agricultural Salinity and San Joaquin River Flow Objectives and Program of Implementation

The State Water Resources Control Board (State Water Board) has asked for detailed information regarding potential amendments or revisions to the southern Delta salinity and San Joaquin River flow objectives included in the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta) (2006 Bay-Delta Plan).

In 1978, the State Water Board adopted the southern Delta agricultural salinity objectives and the three compliance locations based on environmental conditions, crops, and irrigation practices at that time. In 2004, the State Water Board conducted a workshop on the salinity objectives that provided information supporting a need to have additional review on the sources, concentrations, loads, effects, and methods of control of salinity in the southern Delta. In 2007, the State Water Board requested that participants focus on the salinity objectives, their corresponding program of implementation and provide information to evaluate whether additional studies should be undertaken that could support an amendment to the 2006 Bay-Delta Plan. At this time, the State Water Board is seeking to gather scientific information to consider and base potential amendments to the southern Delta salinity and San Joaquin River flow objectives and the program of implementation for those objectives.

As requested in the February 13, 2009, Notice, the Department of Water Resources' (DWR) presentation will include information on the following:

- water use in the southern Delta;
- factors affecting salinity in the San Joaquin River Basin and southern Delta;
- protection of agricultural beneficial uses in the southern Delta related to salinity;
- reasonableness of existing salinity objectives; and
- recommendations on what the program of implementation for the southern Delta salinity objectives should be.

Much of the information presented below has been submitted to the State Water Board at different times and in different proceedings. However, DWR believes that the information is still relevant and, where appropriate, it has been, or will be, updated to reflect current conditions. Importantly, DWR's presentation may not address all the questions that the State Water Board and its staff may have of DWR. Specifically, at this time DWR is not recommending any particular changes to the San Joaquin River flow objectives or their program of implementation. In addition, some of DWR's information may be considered as preliminary or as background on certain issues. Thus, DWR expects that the Board may request more information as the review process moves forward and DWR intends to continue working, in cooperation with the State Water Board and other parties, to provide additional information the Board may need.

In review of information regarding the water quality objectives in the southern Delta, the State Water Board should consider what, in its judgment, is required to "ensure the reasonable protection of beneficial uses." (Water Code Section 13241.) In addition, when reviewing information that would support a revised objective that is "reasonably protective" of the use, the State Water Board must consider information regarding:

- Past, present and probable future beneficial uses of water.
- Environmental characteristics of the hydrographic unit under consideration, including the quality of water available thereto.
- Water quality conditions that could reasonably be achieved through the coordinated control of all factors that affect water quality in the area.
- Economic considerations.

(Wat. Code Section 13241.)

During the upcoming workshops and any subsequent workshops and meetings, DWR looks forward to reviewing and discussing information provided by all the interested parties that may help the State Water Board determine a reasonable method of protection for southern Delta agriculture based on the above criteria.

DWR's comments include; A. Background on Development of Agricultural Salinity Objectives, and B. Specific Information on the following topics:

1. Overview of the Delta, SWP and CVP facilities
2. Historic salinity levels in the southern Delta.
3. Salinity variation
4. Effects on salinity from SWP and CVP operations as shown by historical data and modeling.
5. Monitoring data and maps of in-Delta discharges
6. Cropping patterns and irrigation intakes in the southern Delta
7. Status and effects of the Temporary Barrier Program and the proposed permanent operable gates
8. Summary of information needed for further evaluation of southern Delta salinity objectives and methods of implementation
9. Recommendations on changes to Program of Implementation.

A. Background on Development of Agricultural Salinity Objectives

About thirty years ago, during hearings to develop the 1978 Water Quality Control Plan and Decision 1485, parties presented information on irrigation needs of agricultural lands in the southern Delta. The objectives then established were based on the University of California "Guidelines for the Interpretation of Water Quality for Agriculture" (U.C. Guidelines). (1978 WQCP, at VI-19.) In the 1978 WQCP the State Water Board noted that "ongoing research by the U.C. Cooperative Extension in the southern Delta may produce information which will show a need for future revision of these water quality criteria." (Id.) Table VI-1 of the 1978 WQCP provided values for the southern Delta agricultural objectives of 0.7 mmhos/cm during April through August and 1.0 mmhos/cm from September through March, measured as a 30-day running average of mean daily electrical conductivity (EC). The Plan also indicated that the values were to become effective "only upon the completion of suitable circulation and water supply facilities." (1978 WQCP at VI-29.)

After litigation regarding D-1485, the State Water Board held workshops and hearings to prepare a new water quality control plan and water right decision. A Southern Delta Agriculture Work Group was

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formed to evaluate the irrigation water quality requirements for agriculture in the South Delta (See SDWA presentation at March 2005 Workshop, SDWA Exhibit No. 103 prepared for 1987 State Water Board water right hearings.). On January 4, 1982, the Committee submitted a final report, authored by Hoffman, Prichard and Meyer, to the State Water Board and interested parties. The report reviewed southern Delta soil types, permeability of those soils, and water quality requirements for various crops grown in the area. The report provides data and graphs of water quality (in EC and mg/l of salt) applied to certain crops and the effects of leaching on crop yields. In general, the report shows that for a greater total amount of water passing, or leaching, through the crop root zone (the leaching fraction), crop yield can be maintained with a higher salt concentration in the applied irrigation water. (Hoffman, Prichard, and Meyer, "Water Quality Considerations for the South Delta Water Agency," Jan. 4, 1982, Figures 1 and 2.) The Committee report noted that some crops may be more sensitive during emergence than during later stages of growth. (Id. at 4.) The Committee made no recommendation as to an appropriate water quality value for the southern Delta. It concluded that the "biggest uncertainty in this information is the leaching fractions which can reasonably be achieved for the various combinations of soils, crops, and management options suitable for the South Delta." (Id. at 10.) The Committee recommended "that the concerned parties sponsor a more extensive field study of the leaching fractions being achieved in the South Delta." In the 1991 and 1995 WQCPs, the State Water Board made no changes to the southern Delta agricultural objectives.[1]

For the past two decades, the State Water Board, DWR, U.S. Bureau of Reclamation, and South Delta Water Agency (SDWA) have been relying on a physical solution of permanent operable gates installed in three channels of the southern Delta. The parties have studied this solution and agree that operable gates in the southern Delta would improve circulation, water levels and water quality for agricultural uses. The gate program has been the preferred solution and there has not been an assessment of other methods that could help implement the objectives for protecting agricultural uses. Although the permanent gates may continue to be the preferred method of implementing the southern Delta agricultural objectives, information provided to the State Water Board during the Decision 1641 water rights hearings showed that the gates will not effectively control salinity under dry conditions of some years and will not have significant effect on water quality at the Brandt Bridge compliance location. In addition, the schedule for the installation of the permanent gates has been significantly delayed due to additional monitoring and analysis required by the National Marine Fisheries Service. Therefore, the State Water Board should consider including in the Water Quality Control Plan (WQCP) and its Program of Implementation additional methods other than the operable gates to achieve the objectives.

B. Specific Information

Below is a summary of the information that DWR has at this time to present to the State Water Board on southern Delta salinity. DWR anticipates that additional information will be developed and will be presented at subsequent workshops.

1. Overview of the Delta, SWP and CVP Facilities

Many water projects have been developed in the watershed of the Sacramento-San Joaquin Delta/San Francisco Bay. The two largest projects are the federally-owned Central Valley Project (CVP)

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[1] In the 1991 WQCP, the State Water Board adopted the same southern Delta objectives because members of the Agricultural Workgroup did not reach consensus on a recommendation for revised objectives. (1991 WQCP at 5-12; 1991 WQCP Table 6-3 at 4.) In the 1995 WQCP, the Board did not revisit issues related to the southern Delta agricultural objectives, instead it focused on fish and wildlife issues, although it did extend the deadline for the effective date to December 31, 1997. (1995 WQCP at 2; 1995 WQCP Table 2 at 17.)

and the state-owned State Water Project (SWP) (the CVP and SWP may be referred to individually as "Project" or, collectively, as "Projects"). Both Projects have multiple purposes, but their chief purpose is to store excess runoff which occurs during the wet season and divert it to municipal and agricultural water agencies throughout California.

The CVP has three main storage facilities on tributaries north of the Delta. The principal storage facility is Lake Shasta on the Sacramento River north of Redding. The other storage facilities are Trinity Lake on the Trinity River and Folsom Lake on the American River. The main storage facilities on tributaries south of the Delta are New Melones Reservoir on the Stanislaus River and Millerton Lake on the San Joaquin River. The SWP has one main storage facility, Lake Oroville on the Feather River, north of the Delta. The Projects jointly own and operate an off- stream storage facility called San Luis Reservoir for storage on the west side of the San Joaquin Valley. Both Projects have major diversion facilities in the south Delta, the CVP's Tracy Pumping Plant and the SWP's Clifton Court Forebay/Banks Pumping Plant. The SWP has no on-stream storage facilities on the San Joaquin River System,

Both the SWP and CVP divert water from the Delta to serve the majority of their contracts with California water agencies located south of the Delta and the city of Tracy. The CVP's Tracy Pumping Plant pumps directly from the Delta's southern waterways into the Delta-Mendota Canal (DMC). The SWP's Clifton Court Forebay/Banks Pumping Plant is operated in a different manner. Water is diverted from the Delta through five large operable radial gates at the entrance to the Forebay. In general, the gates are open when water levels inside the Forebay are lower than those outside of the gates (typically during the high tide) and closed when water levels are lower outside of the Forebay (typically during low tides). Water stored in the Forebay is then pumped at Banks Pumping Plant into the California Aqueduct.

The diversion into the Forebay is generally limited to 6,680 cfs over a three-day period. It may be increased above this limit by 500 cfs during July through September to transfer water for fishery purposes and from mid-December through mid-March when it can be increased by one-third of the flow amount of the San Joaquin River if that flow exceeds 1000 cfs. SWP diversions are usually minimized during low tide periods. CVP diversions are taken during both high and low tide periods. Because of the Forebay operations, the SWP diversions have less of an effect on southern Delta water levels than those of the CVP.

The service areas for both projects include water agencies located north of the Delta and south of the Delta. Many of the north-of-Delta contractors have pre-project rights to water and have negotiated settlement contracts that provide equivalent water supplies. Both projects also deliver the majority of their water supplies to south-of-Delta water agencies. The south-of-Delta service areas of both water projects are a combination of municipal/industrial water agencies and agricultural irrigation agencies. The CVP's south-of-Delta contractors are dominantly agricultural agencies, while the majority of the SWP's south-of-Delta contractors are municipal/industrial agencies. Many of the CVP contractors in the San Joaquin River Valley have surface or subsurface agricultural drainage that reaches the San Joaquin River either directly or indirectly. Oak Flat Water District with a relatively small contracted amount of 5,700 acre-feet per year is the only SWP water agency whose agricultural drainage flows into the San Joaquin River.

The CVP and SWP are operated in close coordination pursuant to the 1986 Coordinated Operations Agreement that spells out how the projects share water released from each project's storage facilities and excess waters which originate within the Delta's watershed. Joint point of diversion (JPOD) is the term which describes either projects ability to share in the use of Delta diversion facilities at Tracy and Banks Pumping Plants. The use of JPOD is dependent on the availability of unused or excess pumping capacity at a project's diversion facility by the project owning the facility. Because Banks Pumping Plant has a

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higher maximum pumping capability than the Tracy Pumping Plant, it is much more common for the CVP to use some of Banks capacity than it is for the SWP to use some of Tracy's capacity. The use of JPOD can be used to minimize the entrainment of fish if larger amounts of fish are being taken at one facility as opposed to the other facility.

One concept advocated by various interests over the last several years is to increase flow in the San Joaquin River at Vernalis through "recirculation." Recirculation, as defined herein, is the concept of diverting water at Project Delta diversion facilities that is then released either simultaneously or, at some future time, into the San Joaquin River to augment existing San Joaquin River flows. The water could be released to the river via the CVP's Westley or Newman Wasteway. This water could be water stored in San Luis Reservoir or pumped from the Delta and released directly from the CVP's Delta-Mendota Canal.

2. Historic Salinity Levels in the Southern Delta[2]

Data on historic salinity levels in the southern Delta is fairly limited. Some data is available from the Sacramento-San Joaquin Water Supervisor Reports, and Bulletin 27, Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay, 1931 published by the Division of Water Resources (predecessor to the Department of Water Resources). The table in Appendix A provides some of the data from these reports at various Delta stations. The first extensive investigation of Delta salinity was initiated in 1920 following the dry years of 1917 and 1919 which, combined with increased upstream diversion as a result of increased agricultural development, resulted in upstream invasion of salinity of a greater extent and magnitude than ever previously recorded (Bulletin 27, p. 22). Figure 1 below developed from Sacramento-San Joaquin Water Supervisor Reports shows the maximum seasonal salinity encroachment of 1000 ppm chlorine (about 3 to 4 times the current agricultural objective in the South Delta) during dry and critical years from 1920 through 1943 prior to the development of the Shasta and Friant elements of the CVP (1945) and SWP Delta pumping (1967). Available records show some level of degradation due to salinity in the southern Delta in certain critical years prior to the development of the projects. In addition, available flow reaching the Delta was insufficient to meet the consumptive use demands within the Delta. Crop losses in the Delta in 1931 from both saline irrigation water and lack of supply far exceeded those seen in any year since the development of the CVP or SWP, including those in the driest year of record, 1977. (DWR Bulletin 132-89, Appendix E, p xiii). Evidence of salinity intrusion and significant crop losses in critical years prior to development of the projects supports the consideration of flexible southern Delta salinity objectives during drier year types, as has been developed for other water quality objectives at other locations within the Delta.

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[2] This report includes many different measures of salinity. Ocean salinity is about 35,000 pmm Total Dissolved Solids (TDS). A dominant ion in sea water is the chloride ion . Chloride in sea water is about 19,400 ppm. During the early 1900's a measure of ocean salinity was 1000 ppm which is about 5% seawater. More recently salinity in the Delta is measured in terms of Electrical Conductivity. This can be expressed as either mmhos/cm or µSiemens/cm (µS/cm). 1000 µS/cm is 1.0 mmhos/cm and 700 µS/cm is 0.7 mmhos/cm. The water quality objectives are expressed in mmhos/cm or mS/cm while many of the measurements are taken in µS/cm. 1000 ppm Chloride is about 2.8 mmhos/cm.

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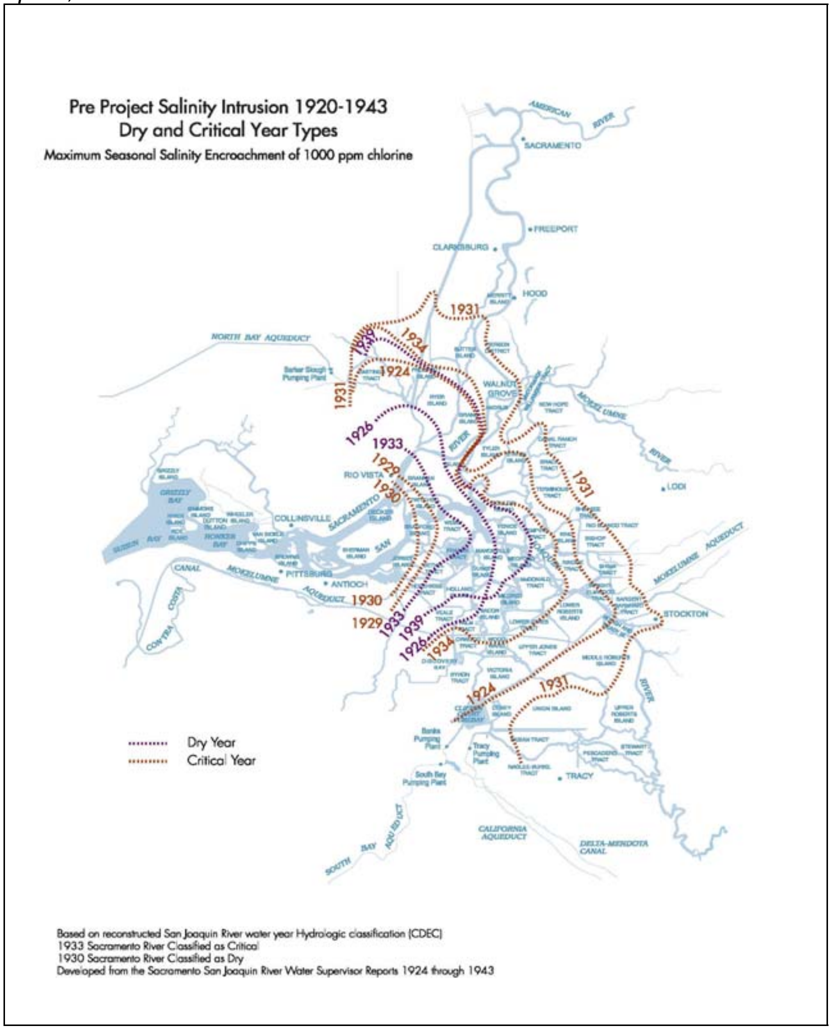

Pre Project Salinity Intrusion 1920-1943
Dry and Critical Year Types
Maximum Seasonal Salinity Encroachment of 1000 ppm chlorine

Based on reconstructed San Joaquin River water year Hydrologic classification (CDEC)
1933 Sacramento River Classified as Critical
1930 Sacramento River Classified as Dry
Developed from the Sacramento San Joaquin River Water Supervisor Reports 1924 through 1943

Figure 1. Historical Salinity Intrusion in Dry and Critical Year Types)

3. Salinity Variation

Salinity in the southern Delta varies greatly dependent on the location, basin hydrology, tidal influences and inflows per diversions within the localized area. The principal inflow into the south Delta comes from the San Joaquin River at Vernalis. Water flowing from the northern part of the Delta is also conveyed into the south Delta by the Mokelumne River and flow through the CVP's Delta Cross Channel. Other, smaller tributaries also carry water into the south Delta region. The diversions in the south Delta include about 130 privately-owned agricultural diversions for irrigation of farmland, the CVP and SWP diversion facilities and the diversions by the Contra Costa Water District at Rock Slough and the intake to Los Vaqueros Reservoir. If the sum of diversions in the south Delta is greater than the inflow to the south Delta, the remaining flow is provided by the mixture of both fresh and salt water on the lower San Joaquin River near Jersey Point.

Therefore, predicting the salinity at any given location and time in the southern Delta is very complicated because of the mixture of out-of basin land derived salts, local in-basin agricultural drainage return flows and ocean salts.

Salinities in the southern Delta generally range from about 100 mmhos/cm EC (or 0.1 mmhos/cm EC) (virtually freshwater levels) to 1100 mmhos/cm EC (or 1.1 mmhos/cm EC). Salinities vary within the four south Delta locations or stations (e.g. Vernalis, Brandt Bridge, Old River near Middle River and

Old River near Tracy Road Bridge) plus or minus 200-300 mmhos/cm EC. These differences reflect the direct impact that local drainage returns can has on one or more of the southern Delta stations. DWR Modeling described below provides some understanding of the effects of various sources of salinity on water quality in the southern Delta.

Currently, compared to historical pre-CVP and SWP operations, southern Delta salinities are usually higher in the late fall and winter months and lower in the spring and summer months, reflecting both the natural occurrence of freshwater runoff from the melting snowpack as well as the overlying standards for fish protection (e.g. X2 and VAMP) and the requirements for lower salinity during the irrigation season, which are currently set at 700 mmhos/cm EC from April through August.

4. Effects on Salinity from SWP and CVP Operations Demonstrated by Modeling

The Delta is a complex system and water quality can be affected very differently at different locations. To illustrate, the three water quality stations in the southern Delta are affected by different influences than those stations in the Western Delta. For stations in the western Delta, water quality can be controlled by releasing fresher Sacramento flow or reducing exports. The reason is primarily because these stations are located downstream of the flows and the exports, and will respond to the changes in the system. By increasing the flow or reducing the exports, less ocean salinity makes its way into the Delta. In the southern Delta, the natural flow, without exports, is the flow from the San Joaquin River making its way towards the ocean through the San Joaquin, Old and Middle Rivers. The agricultural water quality stations are upstream of exports and do not naturally receive water from the Sacramento River. Exports pull water that contains a mixture of different sources of water, including the usually fresher Sacramento River, upstream towards the southern Delta area but the exports are still downstream of the South Delta Water Quality locations and cannot control the salinity at those southern Delta stations. Some water can be “moved” upstream into the southern Delta area by the use of the temporary agricultural barriers that work with the tides; however the water from the Sacramento side, during the majority of time is not transported far enough upstream to affect the three locations. Some improved movement upstream is achieved with the addition of the barrier in Old River where it diverges from the San Joaquin River (Head of Old River) and much greater circulation upstream can be provided with the permanent gates but with both the temporary barriers and the permanent gates, Brandt Bridge is not affected.

Historical and modified historical Delta Simulation Model 2 (DSM2) studies were made to demonstrate how water quality is affected in the southern Delta. Some of that work was presented in Exhibit 20 at the 2005 Cease and Desist Hearings (and included in Appendix G of this document) and additional analysis is presented in the attached Appendix B of these comments. The work presented for the Cease and Desist hearings investigated the following areas:

- Degradation of water quality from Vernalis to Brandt Bridge (using observed data).
- Long term (1991 – 2005) historical simulation of flows and water quality in the Delta
- Long term (1991-2005) modified historical simulations, reduction and increase of SWP exports by 500 cfs (with barriers)
- Shorter term (2002, 2003) modified historical simulations, with a total elimination of SWP exports (with barriers)

These studies showed that SWP exports could affect, but could not control the water quality at the three agricultural objectives locations. When affected, the water quality sometimes improved and sometimes degraded with the reduction of exports. Of the three stations, Old River at Tracy was the only station that showed any significant effect.

The work presented in the Appendix B of these Comments focuses on the following areas:

- 2002 Historical DSM2 Simulation of flows and water quality in the southern Delta
- 2002 modified historical simulations with no SWP exports from Jan – Aug and no South Delta Barriers installed
- 2002 modified historical simulations with no SWP and no CVP pumping from January through August and no South Delta Barriers installed
- Historical 2002 conditions with an additional 5000 cfs flow in the Sacramento River from April – August (decreasing Oroville down to minimum level by August)

These simulations validate the previous understanding of the system and provide additional information on the circulation in the southern Delta with and without temporary barriers. The additional Sacramento flow does not significantly affect the water quality at the three locations and the elimination of exports demonstrates the natural flow pattern of the San Joaquin River through the Delta. Details on the modeling and the resulting data are provided in Appendix B.

To further illustrate how Projects operations affect the salinity in the southern Delta, particle tracking simulations were completed and animations of flow movement were made to help provide a better understanding. A description of the studies is provided in the following paragraphs and copies on CD are available upon request.

Particle Tracking Model (PTM) Animations for Southern Delta Analysis. A set of four PTM animations have been assembled to show whether any changes in SWP operations (Sacramento River flow and/or pumping) or in CVP pumping affect the water quality in the southern Delta. In each PTM animation, two maps of the Delta are shown side by side. On the right side, the particles are released into the San Joaquin River, and on the left side, the particles are released into the Sacramento River. The particles essentially represent the movement of the water in the two major rivers. The purpose of these animations is to increase the understanding of the mixing of water sources that take place in the southern Delta. All four animations are recorded in AVI format, and can be viewed via Windows Media Player, available on all Windows based Computers.

Table 1 has a summary of assumptions reflected in each scenario. The hydrology assumed in each scenario is generic, and does not represent an actual historical event. The Delta Cross Channel Gate and the barrier at the head of Old River (HOR Barrier) are assumed to be open for all four scenarios.

Table 1. Summary of Modeling Assumptions

PTM Animation	South Delta Gates	Sacramento River flow(cfs)	San Joaquin River flow (cfs)	SWP pumping (cfs)	CVP Pumping (cfs)
1	Temporary	15,000	1,500	6,680	4,600
2	Temporary	15,000	1,500	1,500	1,000
3	Temporary	20,000	1,500	0	0
4	Permanent	15,000	1,500	3,000	3,000

PTM Animation 1 (High Pumping). In this scenario, it is demonstrated that a big fraction of particles released in Sacramento River travel south toward the pumps, however, very few particles make it upstream of the temporary barriers to help dilute the water in the southern Delta region. Based on the PTM animation, 0.5% of the particles released in Sacramento River make it upstream of the temporary barriers. To put that in perspective, this roughly means that under the conditions simulated, about 0.5% of Sacramento River flow (about 75 cfs) makes it upstream of the temporary barriers. This amount is not enough to provide the dilution required at times when water quality in the southern Delta is poor. Basically, the particles in the southern Delta region, including the main-stem of San Joaquin River, are predominantly the ones which were released into the San Joaquin River.

PTM Animation 2 (Low Pumping). In this scenario, pumping (both SWP and CVP) was curtailed dramatically. As expected, a smaller fraction of Sacramento River particles reach the pumps and, in fact, it takes longer for the particles to get to the pumps. However, similar to the first animation, few Sacramento River particles make it past the temporary barriers, to help dilute the water in the southern Delta. Based on the PTM animation, 0.4% of the particles released in Sacramento River make it upstream of the temporary barriers.

PTM Animation 3 (Zero Pumping + Increase Sacramento River Flow by 5000 cfs). In this scenario, both SWP and CVP pumps are turned off completely, and Sacramento River flow is increased by 5000 cfs. Again, as expected very few particles make it to the southern Delta. In fact, 0% of the particles released in Sacramento River make it upstream of the temporary barriers. The most noticeable difference here is that a bigger portion of the Delta is affected by the San Joaquin River.

The following are a few observations based on the results of the first three animations:

- The southern Delta area (San Joaquin River to Turner Cut, and the area west of head of Old River extended to the temporary barriers) is predominantly affected by San Joaquin River.
- Reducing pumping (CVP or SWP) or increasing Sacramento River flow has little influence on providing dilution in the southern Delta area (upstream of the barriers).
- In general, increasing pumping tends to bring a bigger portion of Sacramento River flow toward the southern Delta. Although, it is not directly shown in the animations, one can conclude that, assuming there is no salinity intrusion from the ocean, the water quality in the southern Delta (Downstream of the barriers) will usually be improved with increased pumping.

Based on the above observations, one can draw a general conclusion that the portion of the southern Delta Shown in Figure 2 is predominantly dominated by San Joaquin River[3].

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[3] The Zone of influence(s) shown in the temporary barriers figure located in the main text are slightly different than the ones in Appendix B – due to different hydrology and different methods of assessing the zone. The main text's figure is a more general figure taken from where the particles moved to in the animation. Appendix B looked at several fingerprinting results at several locations and detailed contour lines were drawn showing the percentage of SJR water at the locations in the south Delta.

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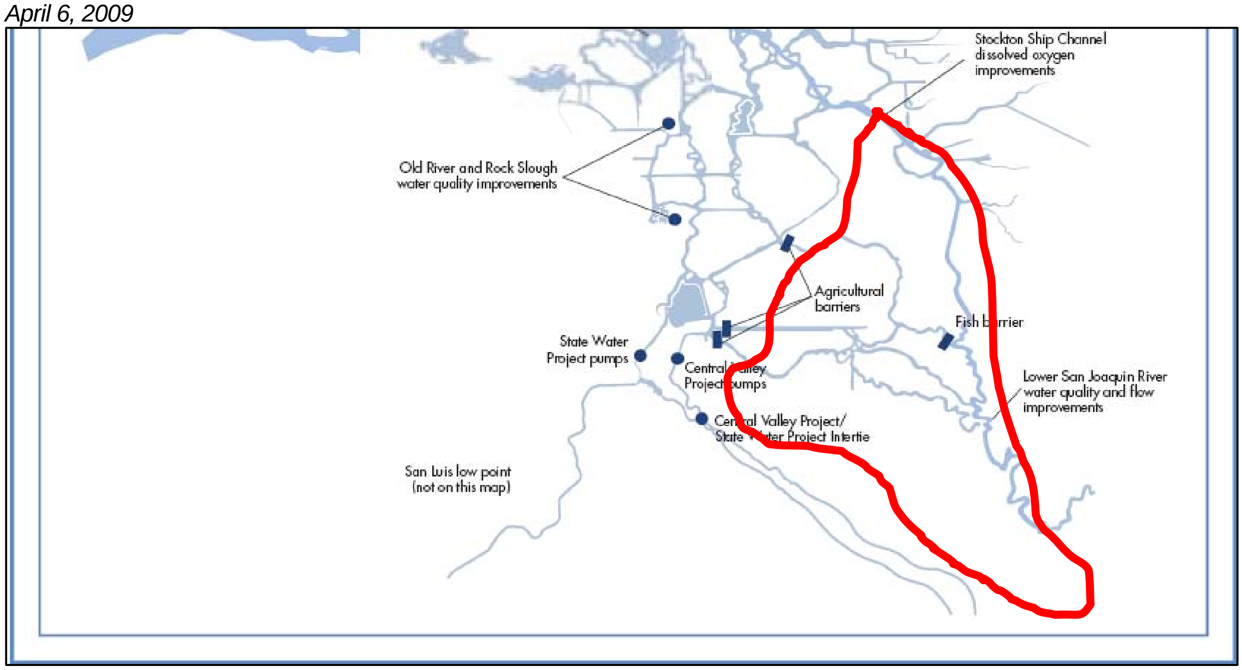

Figure 2. Zone of San Joaquin River Dominance Under Temporary Barriers

PTM Animation 4 (Medium Pumping + Permanent Gates). In this scenario, the temporary barriers are replaced with permanent gates, and a portion of Middle River is dredged (as described in the EIR/EIS for the South Delta Improvements Program (SDIP)). It is assumed that the gates operate according to "Modified Plan C" operation, consistent with the SDIP EIR/EIS studies. Basically, it is assumed that all the three gates are open during flood tide. During the ebb tide, the gates on Middle River and Old River are closed, forcing the water to circulate around and return toward the pumps via Grant Line Canal. These gates rely on the tidal energy to circulate a portion of the better quality water originating from Sacramento River water in the interior southern Delta. This PTM animation illustrates the mechanics of how the permanent gates can be used to improve water quality in the interior southern Delta. Based on this animation, 1.4% of the particles released in Sacramento River make it to the upstream of the permanent gate. This is about 1% higher than what occurred with the temporary barriers, which, under the conditions simulated, translates to about 150 cfs of additional water for dilution in the interior southern Delta. It should be noted that none of the particles released in Sacramento River made it to the main-stem of San Joaquin River (upstream of Turner Cut), illustrating that permanent gates will have little influence in solving the water quality problems at Brandt Bridge.

Based on the results from this animation, it can be concluded permanent gates have the potential to improve water quality in the interior southern Delta, thus reducing the area of the southern Delta that is predominantly affected by San Joaquin River, as shown in Figure 3.

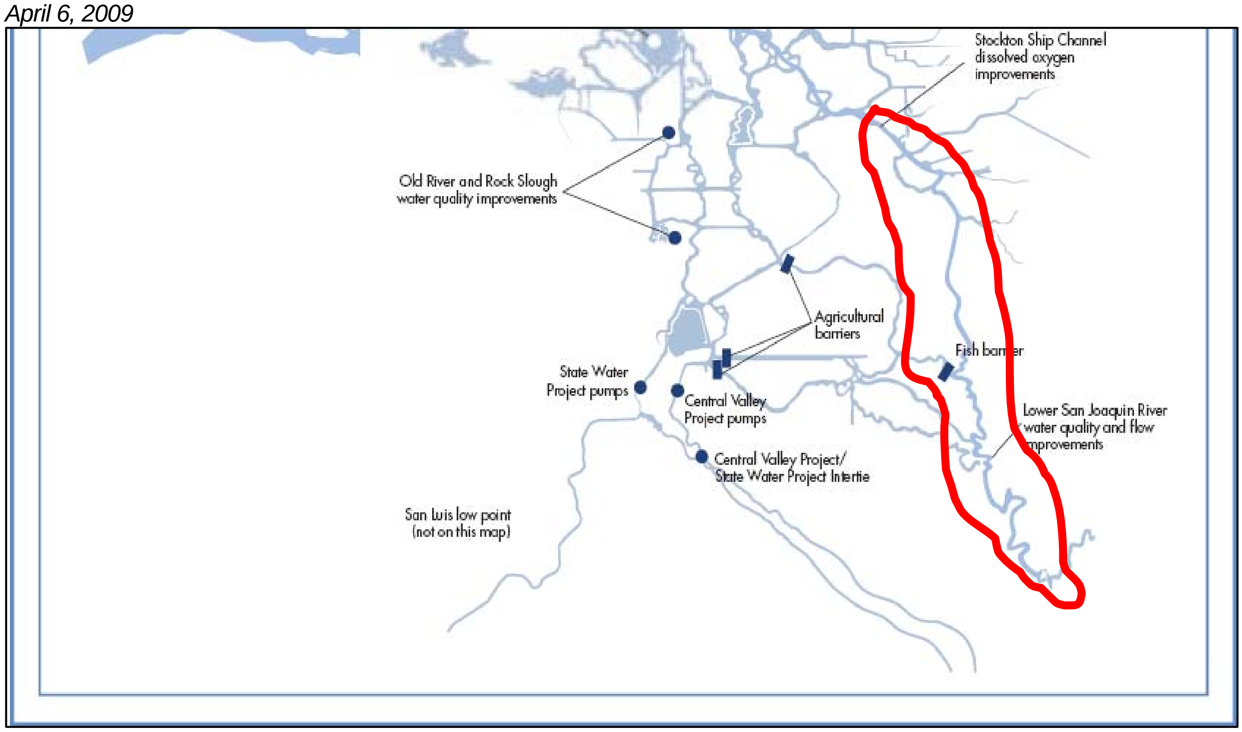

Figure 3. Zone of San Joaquin River Dominance Under Permanent Gates

5. Monitoring Data and Maps of In-delta Discharges

Monitoring Data and New Locations of Monitoring Stations

In the spring of 2006, the Department of Water Resources began installing additional EC stations in the southern Delta. A total of six new water quality stations were established, four in the San Joaquin River and two adjacent to Pescadero Tract. Only one of these new stations is telemetered to CDEC (SJR below Old River near Lathrop), however the data are downloaded monthly. Evaluation of the information we obtain from the additional monitoring is expected to identify areas where significant degradation is occurring.

In-Delta Discharges

Local discharges from agricultural, municipal and industrial uses affect water quality available to the southern Delta. DWR's Environmental Assessment Branch has investigated sources of salinity in the southern Delta. This investigation, entitled Sources of Salinity in the South Sacramento-San Joaquin Delta and attached as Appendix C, has identified approximately 74 discharge sites on waterways flowing to the State and federal export sites in the southern Delta. Most are agricultural, followed by treated sewage, urban runoff, and groundwater effluence. The waterways include south Old River, Grant Line Canal and the San Joaquin River between Vernalis and the head of Old River. The discharges are relatively saline and appear to be cumulatively raising the salinity of water approaching the export sites via these waterways. The report characterizes the discharges and their potential contribution to salinity between Vernalis and the export sites.

An upstream/downstream comparison of salinity was made between Vernalis on the San Joaquin River and Old River at Tracy Boulevard Bridge. Monthly average conductivity was consistently highest at the Old River station with the exception of a few relatively short duration periods. Differences in conductivity between stations were highest between April and November. During this 8-month period, conductivity at the Old River station was often 100 to 185 µS/cm (median values) higher than at Vernalis. A similar comparison between the Vernalis and Grant Line Canal stations also showed increases but to a lesser degree.

A number of factors have been provided to explain why conductivity consistently increases between the Vernalis and Old River stations. However, the sheer number of diversions and saline discharges situated between these two stations provides strong rational for causative effects. The Old River station appears to be especially influenced by saline outflows from Tom Payne Slough and possibly Paradise Cut as well as saline groundwater effluence to several urban/agricultural drainage channels. This is evidenced by a statistically higher conductivity in Old River versus Grant Line Canal during most of the year. Further, the intake of the Old River station appears to be located in the plume of a nearby saline discharge or discharges.

Agricultural Discharges. This section describes the potential contribution of agricultural drainage to the degradation of water quality throughout the Delta. Agricultural drainage is runoff water from agricultural fields. In different Delta areas, the drainage has different origins. Not only is the source water different, agricultural drainage quality is dependant on the soil types and the depth of the soil from which the drainage water is captured. Water quality of runoff water affects the water quality of Delta channels. In this way, discharges from farmers can affect water quality necessary for other farmers. At Figure 4 is a map showing agricultural discharge locations in the south Delta. This map is based on surveys done by DWR in 1999.

The following data is from two primary sources: the Central Valley Regional Water Board Agricultural Discharge Waiver Monitoring Program and the New Jerusalem Drain (NJD) automated monitoring station on California Data Exchange Center (CDEC). Figure 5 is a map showing the locations of the many sample sites referred to in this paper. Appendix D contains the data and charts from the Waiver monitoring program and Appendix E is a chart of the New Jerusalem Drainage CDEC data.

This data was submitted for the 2007 Delta Salinity Workshop and will be updated. The submitted data is limited in quantity and history. Some sites have very few reported sampling events. Because the agricultural waiver program is still rather new, the oldest data under this program dates back to 2003. Because both 2005 and 2006 water years were above normal, the water quality data from agricultural discharges is likely skewed in the lower Electrical Conductivity (EC) range compared to a longer history with drier year types.

In the more interior portions of the Delta, many of the islands are below mean sea level. Consequently, many of the fields have drain canals that serve to drain water below the root zone to prevent water logging of the roots. Water from these drain canals contain the salts in the irrigation water the plants will not use. Drainage canals from peat soils also contain organic material from the soils.

In upland areas and areas to the east of the San Joaquin River, agricultural runoff is predominantly surface water runoff and is not associated with dewatering root zones.

Because of the sporadic nature of the sampling, it is difficult to determine any specific trends across the Delta. Sampling is done for a year or two and is then stopped. Another drain nearby is then sampled, again, for a year or two. Even within any sampling period, it is rare to see data over a majority of months throughout the year, so an annual trend can not be discerned. As of 2007, no sampling of drainage water is reported in the problem areas of the south Delta, such as in Old River near Tracy Road Bridge, or near compliance stations for State Water Resources Control Board Decision 1641.

It is fairly clear that upland areas served by water coming from the eastern side do not contribute to any excursions above salinity goals within the Delta. And it is fairly clear that west side drains downstream of Vernalis and upstream of Old River have significant potential to degrade south Delta water quality.

If sampling were to stabilize, a pattern in south delta drains may show that leaching of agricultural lands occurs during the winter months which can contribute to excursions above salinity goals within the southern Delta.

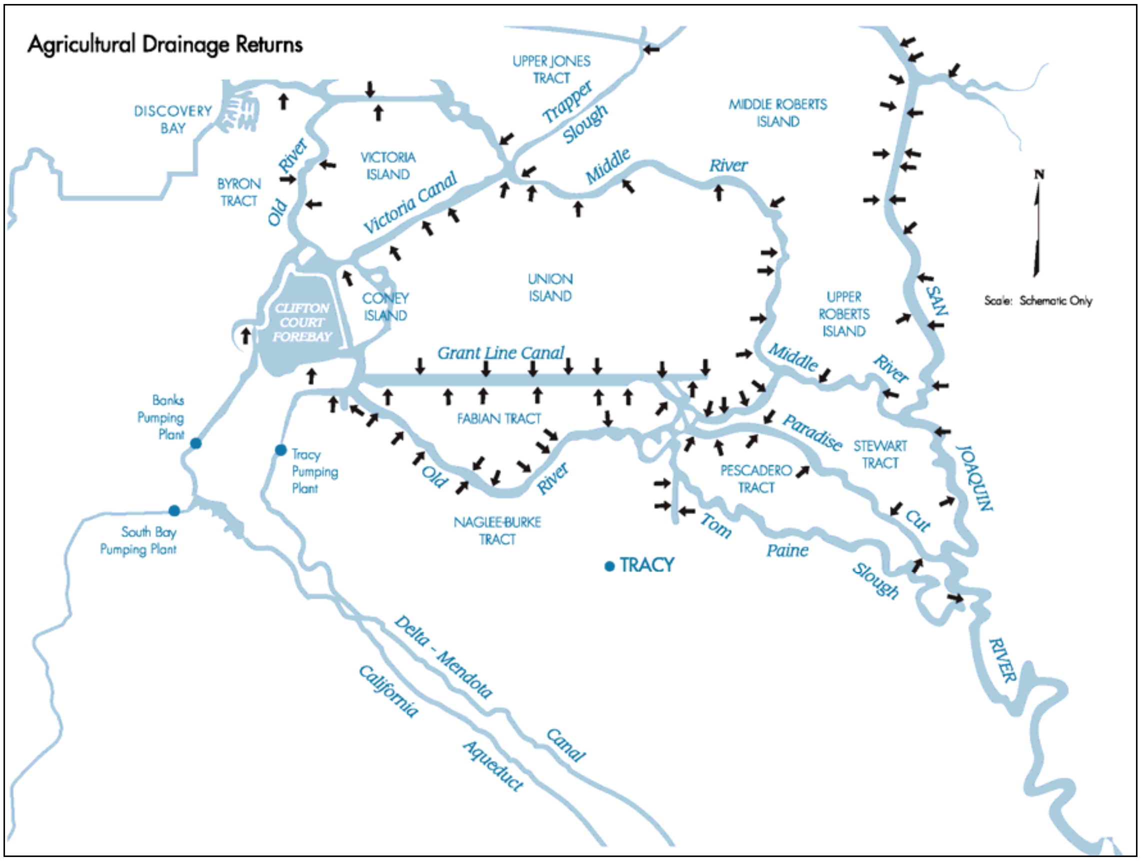

Figure 4. Agricultural Discharges in the South Delta

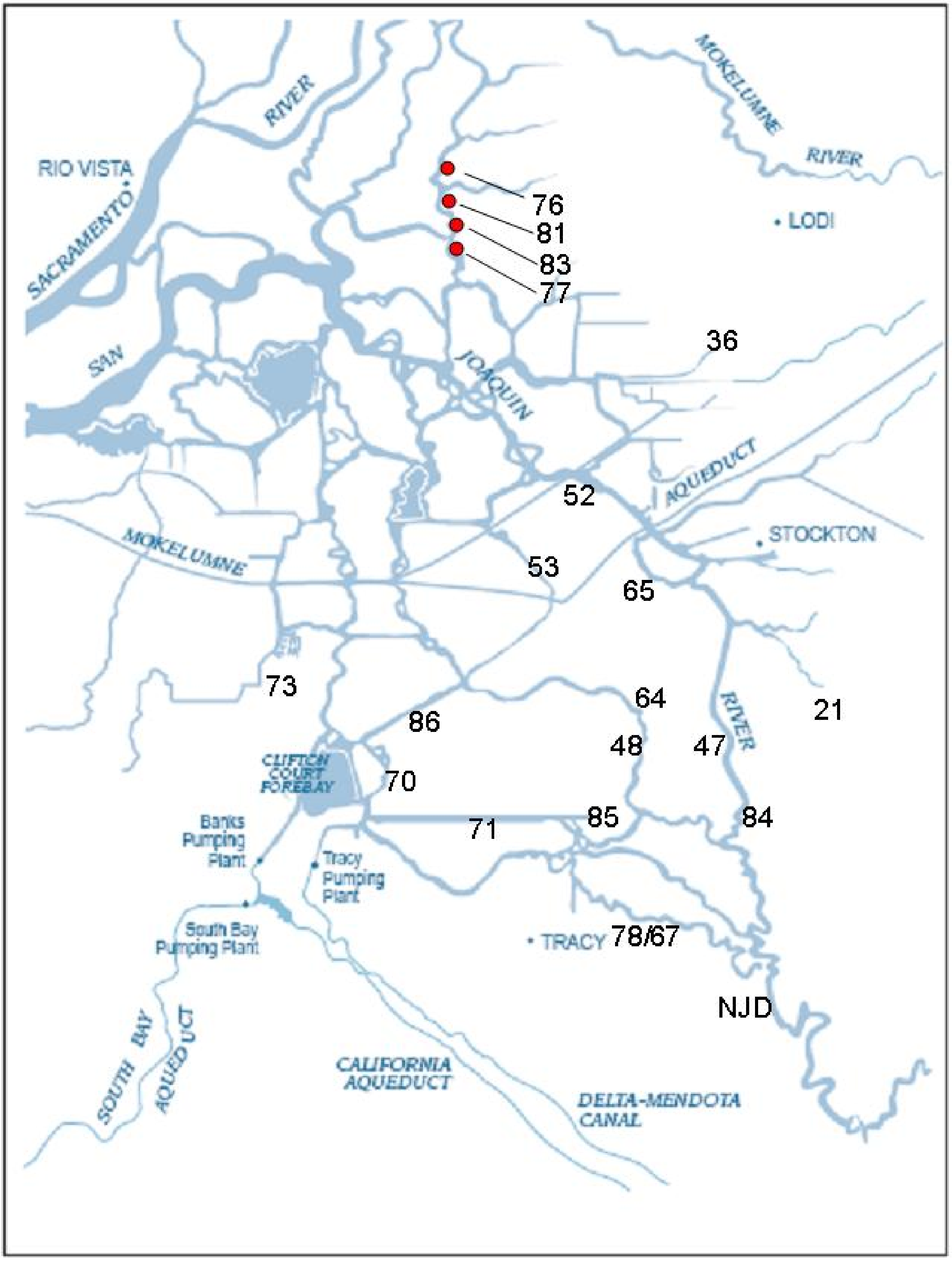

Figure 5. Map of the water quality sampling sites from the Agricultural Drainage Waiver Monitoring Program and the New Jerusalem Drain (NJD) CDEC Station.

Details of 2007 North Delta Data. Most northern Delta drainage affects the Sacramento River water quality which, in turn, affects water diverted in the central Delta and water diverted by the Projects in the southern Delta. In the northern portions of the Delta, agricultural drain water quality is likely most affected by source water quality. The lower elevation drains may also contain water flushed from the root zone.

Agricultural Waiver Program monitoring indicates the water salinity levels in the northern Delta are generally in the 500 – 1000 uS/cm range. As of 2007, four sampling sites within two miles of each other were reported in the monitoring program. All four drains ultimately discharge to Potato Slough. One drain, Number 83, has EC levels up to 1800 uS/cm, while drain number 77 has EC levels more characteristic of East Side Drains. Drains 83 and 81 report drain water quality for 2005 and 2006. Drain 77, reports water quality for 2004 through 2006. Drain 76 only reports water quality for 2004. All water quality data used from the agricultural Drainage Waiver program is included in Appendix D. Figure 6 identifies the relative location of the drains.

East Side Tributarie as of 2007s. Although there are many East Side Tributaries that are sampled for the monitoring program, most of the monitoring locations were more than a few miles from the Delta channels. Two drains were selected to represent water quality of the irrigation return flow of east side agriculture. One station is on French Camp Slough near Lathrop (#21). The other station is on Pixley Slough near Bishop Tract (#36) south of Lodi. These drains are typically low in salinity averaging EC less than 200 uS/cm. The Pixley Slough discharge data spans 2004 and 2005 and is often less than 100 uS/cm. French Camp Slough data is from 2005 and 2006 and ranges from 100 to 250 uS/cm. Salinity this low indicates that these lands are probably irrigated with water captured outside of the Delta. Discharges at this salinity level are not a threat to exceeding Delta Salinity Criteria.

San Joaquin River as of 2007. A total of four sites are discussed here to represent discharges to the San Joaquin River. Starting from the upstream location at the New Jerusalem Drain and proceeding downstream to a drain from Lower Roberts Island northwest of Stockton. The New Jerusalem Drain is monitored by a California Data Exchange Center station which started collecting information in 2005. The remainder of the data is gathered through the Agricultural Drainage Waiver monitoring program. These three sites, in downstream order, # 47, # 65, and # 52, are all on Roberts Island. The New Jerusalem Drainage (NJD) data is reported in 15 minute intervals. Daily averages of this data are reported on the New Jerusalem Drain chart (Exhibit E). The New Jerusalem Drain discharges to the San Joaquin River downstream of the Banta Carbona canal which is several miles downstream of the Vernalis water quality monitoring station. With the exception of about six weeks over the 18 month data set, the NJD is generally greater than 2000 uS/cm and is often very near or greater than 2500 uS/cm. Water quality criteria at Vernalis are 700 uS/cm during the irrigation season and 1000 uS/cm the remainder of the year. The water quality criteria is typically met at Vernalis, but the water quality is then degraded by this discharge of nearly 2500 uS/cm. Since this data history only reaches back to 2005, all of this history is during wet water year types when water quality in the source water has been typically much better than the water quality criteria. New Jerusalem Drain water may be significantly higher during an extended drought. However we do not yet have data regarding this possibility.

Drainage water quality data from the upper portion of Roberts Island, Station # 47, is from 2003 only. Four sampling events indicate water quality ranges between nearly 1300 uS/cm and nearly 4000 uS/cm. 2003 was an average water year. The 2005 and 2006 drainage from Middle Roberts, Station #65, and Lower Roberts Island, Station # 52, are much lower than the upper portion. Data for this area has typically been under 1000 uS/cm for the past couple of years.

South Delta. Drainage data from 2003 along Middle River averages around 900 uS/cm during much of the year, as seen in the data from Monitoring Station # 48. The drain monitored by station # 48 drains a portion of Union Island. Another drain monitored along Middle River is # 64 which drains a part of Roberts Island. The data for monitoring Station # 64 averages about 380 uS/cm for 2005, the only year of data on record prior to 2007. Further north on Middle River, in the Central Delta and also a Roberts Island drain, there are two data points in 2006. In Mid-May of 2006 Monitoring Station # 53 reported an EC of 736 uS/cm, whereas a month later the Drain EC was 1811 uS/cm.

West of the temporary barriers in the South Delta are two monitoring stations, # 86 along Victoria Canal and #70 at the west end of Union Island. The discharge into Victoria Canal was just under 1000 uS/cm in the summer of 2004 and increased to just under 2000 uS/cm during the next winter (January/February 2005). Over at the west end of the island, the discharge was at a similar level in February and March of 2005 (about 1700 uS/cm) which dropped off during the irrigation season to under 400 uS/cm. Between these two data sets, it is evident that winter discharges are higher than irrigation season discharges suggesting that the fields were being leached at this time.

More in the interior of the south delta, drains on Grant Line Canal and Tom Paine Slough show a variety of discharge patterns. The discharge into the east end of Grant Line Canal (Station # 85) was just over 1000 uS/cm in the summer of 2004 and increased to 2000 uS/cm during the next winter (January/February 2005), also suggesting leaching of the soils. But Monitoring Station # 71 on Grant Line Canal was much more varied, although still showing signs of leaching in February and March of 2005 and March and April of 2006. During the irrigation season of 2005 this drain averaged over 800 uS/cm. Drainage on Tom Paine Slough was sampled in the irrigation season of 2003 and generally had EC above 1400 uS/cm. West Side Drainage, Station # 73, near Discovery Bay has a varied discharge pattern ranging from about 200 uS/cm to over 1400 uS/cm.

References. California Data Exchange Center Station NJD (New Jerusalem Drain), 2005 and 2006. Central Valley Regional Water Board Agricultural Discharge Waiver Monitoring Program, San Joaquin County & Delta Water Quality Coalition (SJCDWQC), data as of December 2006

Municipal and Industrial Discharges. For the information submitted to the State Water Board in their 2007 review of the salinity objectives, DWR presented some information from the Regional Water Quality Control Boards of local municipal and industrial discharges. Some of these discharges flow into the San Joaquin River between Vernalis and Brandt Bridge. For example, the Central Valley Regional Quality Control Board issued a Waste Discharge Requirement to the City of Manteca requiring that the City not discharge greater than 1.0 EC to the San Joaquin River, at Highway 120 near Mossdale. (This location is upstream of the confluence of the San Joaquin River and Old River.) (CVRWQCB WDR Order R5-2004-0028.) Table 2 below shows the existing municipal dischargers within the southern Delta region. The discharge locations are shown on Figure 6. As can be seen from Table 2, each of the discharges exceeds the current WQCP salinity objectives of 1.0 EC (September through March) and 0.7 EC (April through August) during the data collection periods. At times, the Discovery Bay summer discharges exceed the summer objective by up to three times. Only one of the discharger's NPDES permits contains a limit for EC, the City of Manteca. Manteca's discharge exceeds the current objective but it has plans to change water supplies which will reduce the salinity level. Although the discharges may be small compared to total stream flow, the impact to water quality could be significant when the discharges are located near monitoring stations or within the vicinity of seasonal null zones. DWR recommends that the Regional Boards require that the dischargers' NPDES permit conditions be consistent with the Bay/Delta water quality objectives.

Table 2. Major Dischargers in the South Delta*

Discharger	Permitted Flow (mgd)	Permitted Flow (cfs)	Average EC (mmhos/cm)	Data Collection	Receiving Water	Outfall Location
City of Tracy	9	14	1.7	2002 - 2004	Old River	37.8047N, 121.4008W
Mountain House CSD	0 [2]	8	1.1	2004 - 2005	Old River	37.7977N, 121.5223W
City of Stockton	55	85	1.1	2002	San Joaquin River	37.9375N, 121.3347W
City of Manteca	8.11	12	1.1 [3]	2000 - 2002	San Joaquin River	37.7792N, 121.3000W
Discovery Bay CSD	2.1	3	1.9 - 2.3	2000 - 2002	Old River	37.8883N, 121.5750W

1. Information on NPDES dischargers in the South Delta area was provided to DWR by the Central Valley Regional Water Quality Control Board in December 2006.
2. Will begin discharging approx. 3 mgd in 2007. Permitted flow expected to be 5.4 mgd. CFS shown for permitted flow.
3. New permit includes monthly average effluent limitation of 1.0 EC (mmhos/cm). City of Manteca is changing water supplies to meet new limit.

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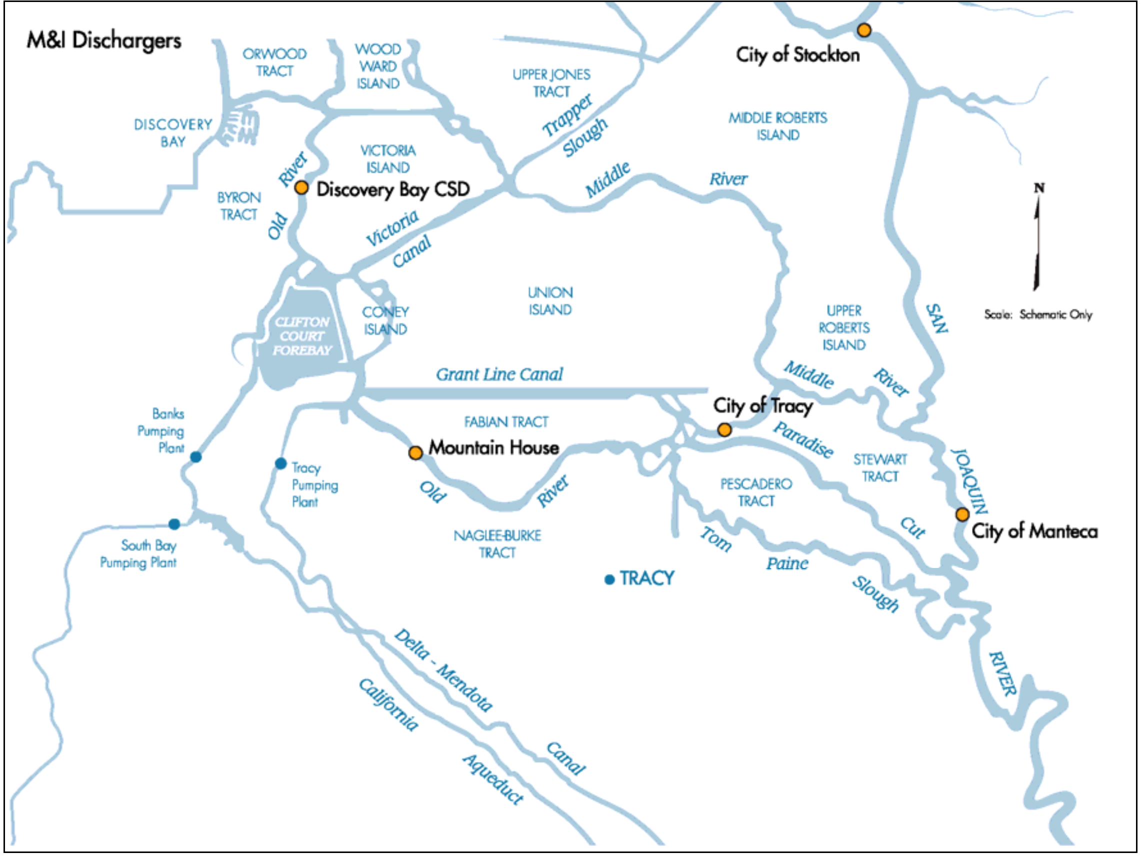

Figure 6. Municipal and Industrial NPDES Dischargers in the South Delta

6. Cropping Patterns and Irrigation Intakes in the Southern Delta

Cropping Patterns in the South Delta

DWR has surveyed locations of Delta crops in the past, and has provided a brief report to the SWRCB in October 2005, which is at Appendix G, DWR Exhibit 21 "Agriculture in the Southern Delta."

Range of Channel Water Salinity Available for Irrigation

The State Water Board currently mandates that salinity levels of 0.7 mmhos/cm EC or less be met from April through August and that 1.0 mmhos/cm EC or less be met from September through March for south Delta irrigation. From December 1999 to April 2005, the objective was 1.0 EC year-round. The objective was not in effect prior to December 1999. The salinity levels are specified at four south Delta compliance stations: (1) Vernalis, (2) Brandt Bridge, (3) Old River near Middle River, and (4) Old River near Tracy Road Bridge.

The Table shown below displays the maximum, minimum and average daily measurements of irrigation water quality at the four south Delta stations during the irrigation season (April through August) for years 2000 through 2008.

Over the nine-year period shown, the maximum salinity at Vernalis was 1.100 EC in 2007, the minimum was 0.100 EC in both 2005 and 2006 and the average was about 0.500 EC. At Brandt Bridge, the maximum was 1.205 EC in 2007, the minimum was 0.081 EC in 2005 and the average was about 0.600 EC. At Old River near Middle River (Union Island), the maximum was 1.110 EC in 2007, the minimum was 0.099 EC in 2006 and the average was about 0.450 EC. At Old River near Tracy Road

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Bridge, the maximum was 1.301 EC in 2007, the minimum was 0.127 EC in 2006 and the average was about 0.600 EC.

Table 3. Salinity in South Delta Channels (mmhos/cm EC)

	Brandt Bridge			Union Island			Old River			Vernalis		
Year	**Max**	**Min**	**AVG**	**Max**	**Min**	**AVG**	**Max**	**Min**	**AVG**	**Max**	**Min**	**AVG**
2000	0.746	0.271	0.458	0.699	0.306	0.498	0.800	0.410	0.531	0.730	0.220	0.462
2001	0.889	0.279	0.619	0.914	0.328	0.614	0.990	0.420	0.785	0.930	0.250	0.577
2002	1.002	0.393	0.692	0.979	0.350	0.635	1.020	0.560	0.726	0.930	0.270	0.545
2003	1.081	0.406	0.608	0.962	0.399	0.573	1.050	0.480	0.650	0.900	0.360	0.544
2004	0.786	0.323	0.542	0.895	0.382	0.622	NA	NA	NA	0.780	0.290	0.558
2005	0.567	0.081	0.286	0.663	0.101	0.321	0.634	0.129	0.377	0.630	0.100	0.297
2006	0.502	0.102	0.245	0.471	0.099	0.225	0.580	0.127	0.307	0.480	0.100	0.205
2007	0.889	0.356	0.659	0.856	0.256	0.616	1.076	0.486	0.777	0.820	0.560	0.690
2008	1.205	0.320	0.725	1.110	0.420	0.865	1.301	0.420	0.865	1.100	0.290	0.660

7. Status and Effects of Temporary Barriers Program and the Proposed Permanent Operable Gates

Temporary Barriers

Background. The Temporary Barriers Project (TBP, initiated in 1990, provides for the seasonal installation of three flow control rock barriers and one fish control rock barrier in south Delta channels. The purpose of the TBP is to improve water levels for the benefit of agriculture and at times improve water quality at some locations in the south Delta, and improve conditions for migrating San Joaquin River Chinook salmon.

Three flow control barriers (agricultural barriers) are designed to help maintain water levels and improve circulation in the southern Delta channels during the irrigation season so that southern Delta farmers can adequately divert water. These agricultural barriers mitigate for the adverse impacts to local water levels caused by SWP and CVP Delta exports. However, low water levels in the area are also influenced by low San Joaquin River inflows, local agricultural channel depletions, natural tidal variations, fluctuating barometric pressure, local wind velocities and direction, and limited channel capacity.

The fourth barrier is a fish control rock barrier that helps improve migration conditions in the south Delta for chinook salmon smolts emigrating down the San Joaquin River in the spring and helps improve dissolved oxygen in the San Joaquin River for immigrating adults in the fall. The fish barrier is located at the Head of Old River (HOR), which is on Old River near its divergence from the San Joaquin River.

These barriers collectively have been installed to test the feasibility of the permanent operable gates (known also as operable barriers or flow control structures) now proposed by DWR under its South Delta Improvements Program (SDIP).

Figure 7 shows the number of agricultural diversions in the southern Delta area that are effected by the barriers. DWR surveyed the diversions in this area initially in early 1999. Diversions are mostly turbine pumps but there are a few siphons, especially at the west end of Union Island, where lower land elevations relative to the channel water levels make siphons workable.

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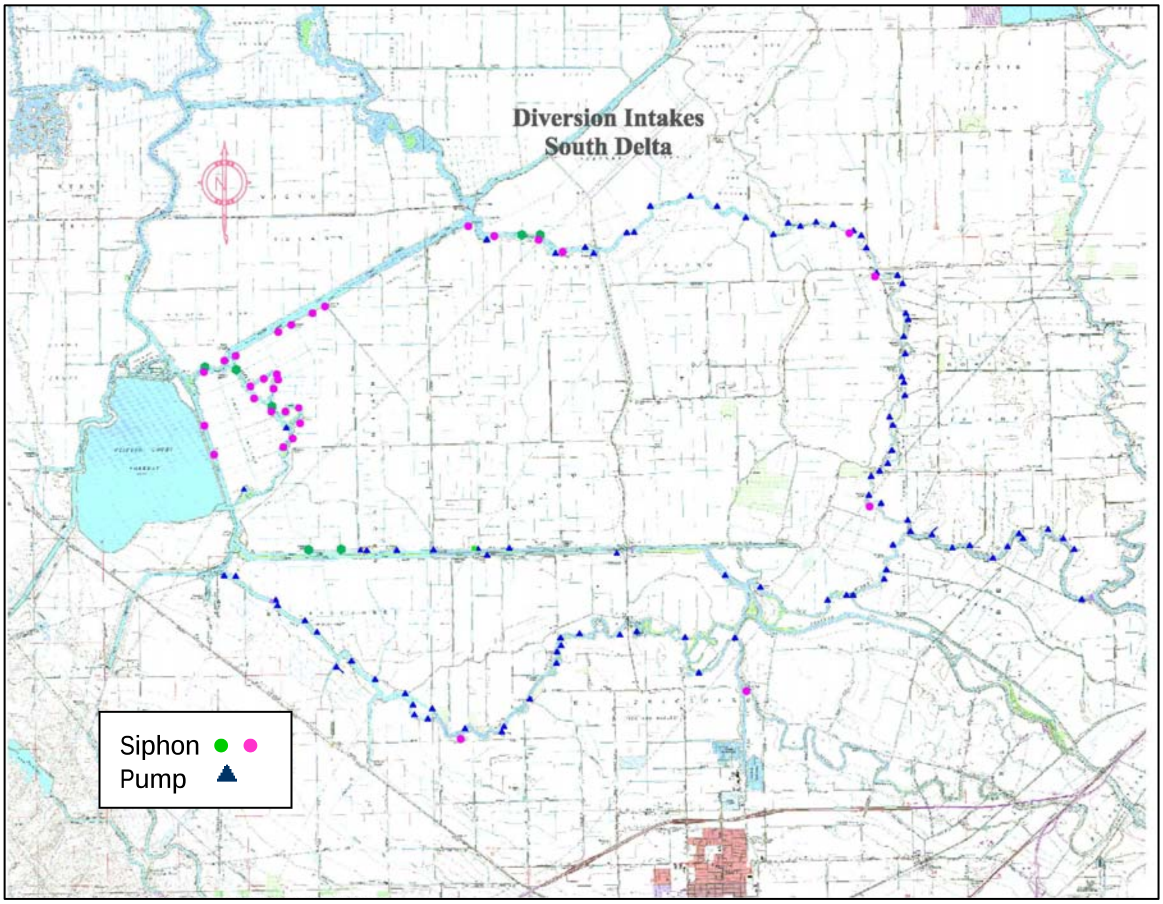

Figure 7. South Delta Agricultural Diversions

Figure 8 shows a map of the south Delta area with the temporary barrier sites shown in red. The three agricultural barriers are located in the Middle River, the Old River near Tracy Pumping Plant, and the east end of Grant Line Canal. The permanent operable gates proposed to be constructed under the SDIP are to be at approximately the same locations except for the Grant Line Canal barrier. The location of the permanent gate on Grant Line Canal, indicated in green, is proposed to be on the west end of the canal instead of the east end.

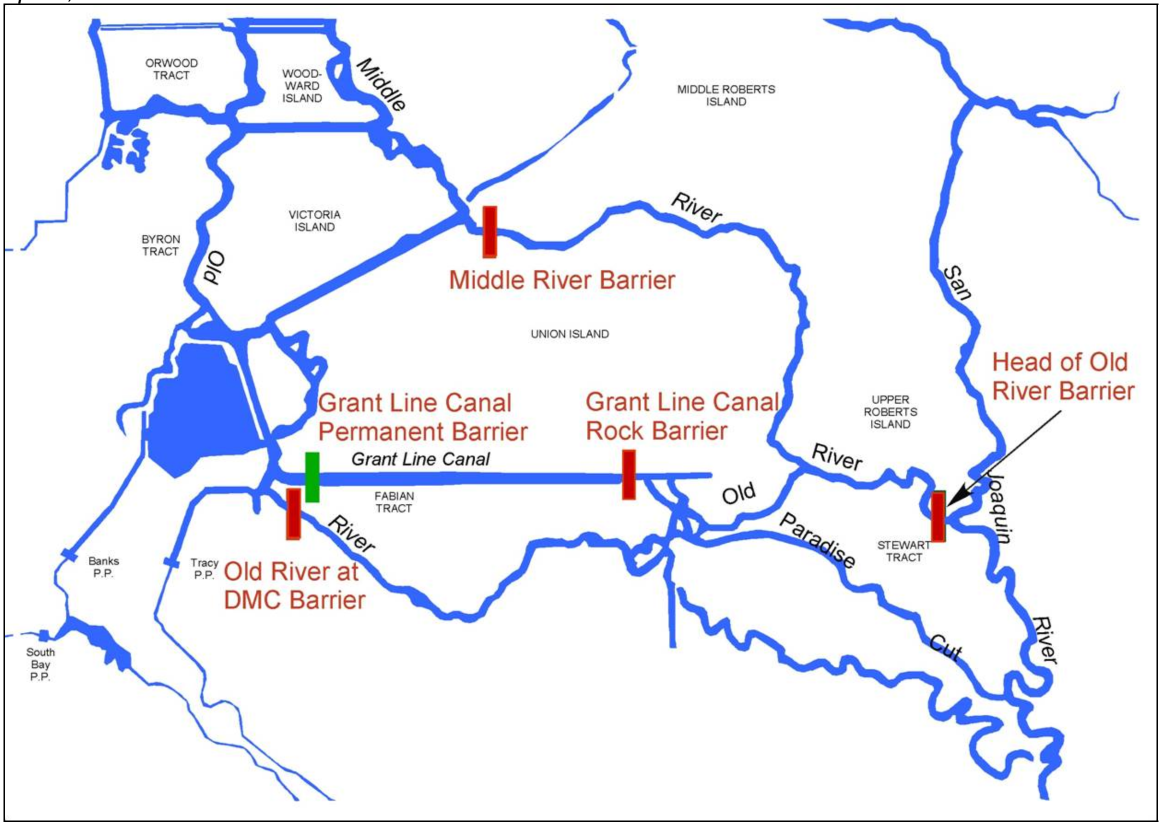

Figure 8. Temporary Barriers Location

Installation History. The temporary barriers are rock structures placed across the channel with culverts placed through the rock near the low water levels. DWR has been installing and operating temporary barriers to assist diversions by farmers within the South Delta Water Agency in the southern Delta since 1989. The fall Head of Old River barrier has been installed at the request of the Department of Fish and Game (DFG) since 1968 to benefit migrating adult Chinook salmon. The Spring HOR barrier has been installed since 1992 for the benefit of migrating salmon smolts to keep the smolts in the main channel of the San Joaquin River. DWR is presently permitted to operate the barriers through the year 2010. Installation and removal of the barriers is also covered through 2010 except with the U.S. Fish and Wildlife Service (USFWS). ESA consultation with the USFWS for the installation and removal of the barriers for years 2009 and 2010 is expected to be completed very soon. We are committed to continuing the temporary barriers program until such time as permanent, fully operable gates are constructed.

Operations. Typically, each year the barriers are installed from April 15 to about November 15. While the agricultural barriers operate partially or wholly throughout this time, the spring HOR barrier operates from April 15 to May 15, and sometimes until May 30 if requested by the fish agencies and then is removed for the summer. The annual installation of the Spring HOR barrier is dependent upon its potential affect on delta smelt, which is determined by the USFWS. The Fall HOR barrier is then installed about mid-September, when requested by DFG, and operates until mid-November. As required by our US Army Corps of Engineers Permit and biological opinions for constructing the barriers, all the barriers must be removed from the channels by November 30. This minimizes impacts to fish and prevents the barriers from being an impediment to higher river flows in the winter and spring.

Historical Water Quality Measurements. Water quality in the southern Delta is influenced by many factors— the quality of incoming San Joaquin River flows, salt water intrusion from San Francisco Bay, local agricultural drainage, poor circulation in southern Delta channels (“null zones”), and CVP and

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SWP Delta exports. Figure 9 shows water quality measurements taken in 2003 from three monitoring locations for the Temporary Barriers Project. These locations are along Old River from the Delta Mendota Canal to the HOR. This example shows how water quality generally improves when the temporary barriers are operating. There are a number of reasons why this improvement happens. First, the San Joaquin River flows are much higher when the HOR barrier is operated in April/May in support of the Vernalis Adaptive Management Plan experiment. Although the HOR barrier was in place during this time, considerable flow from the San Joaquin River enters Old River via culverts in this barrier. Higher flows improve the water quality entering the southern Delta area, which is generally San Joaquin River water during this time. Second, during the summer months, when the HOR barrier isn't operating and San Joaquin River flows are low and poorer quality; the three agricultural barriers reduce the amount of San Joaquin River flows entering the southern Delta and change circulation dynamics. Lastly, the barriers hold a greater volume of water in the channels upstream of the barriers than would be present without them. Higher volumes provide greater dilution of salt from upstream and agricultural sources.

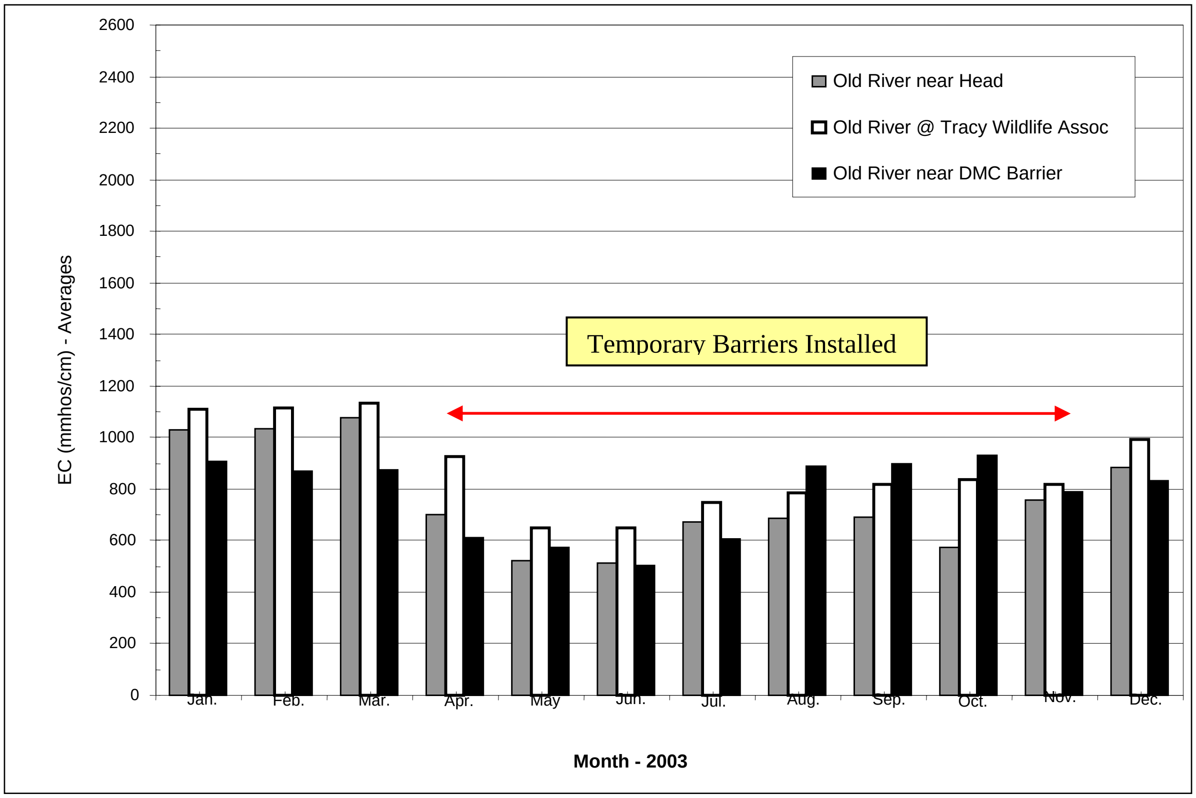

Figure 9. Water Quality Improvements During Temporary Barriers Installation

Permanent Operable Gates

On December 15, 2006, DWR and the U.S. Bureau of Reclamation (Reclamation) certified the Final EIR/EIS on the proposed South Delta Improvements Project (SDIP). The Final EIR/EIS may be viewed at the DWR website: http://sdip.water.ca.gov/documents/final_eis_eir.cfm The SDIP includes two components: (1) a physical/structural component describing the construction and operation of the permanent gates, and (2) an operational component describing increased pumping at the State Water Project (SWP) Delta pumps. Because of uncertainties regarding recent declines in pelagic organisms in the Delta, including the endangered Delta Smelt, the second component of SDIP is not being considered for approval at this time. Therefore, DWR's comments herein summarize the physical/structural component involving the permanent operable gates. Additional details and analysis of this component is available in the FEIR/EIS at DWR's website cited above.

Design and Operation of the Permanent Operable Gates. DWR and Reclamation are proposing to install permanent operable gates to replace the four temporary rock barriers that have been installed seasonally since about 1990. The proposed gates are a bottom hinge design (See Figure 10). Bottom hinge gates have the following advantages:

- They lay flat on the river bottom during floods and do not cause an obstruction to flood water or debris;
- In-stream abutments are not necessary, the channel does not need to be widened and levees set back to accommodate flood flow; and
- The gates all operational flexibility and can pass river traffic effectively.

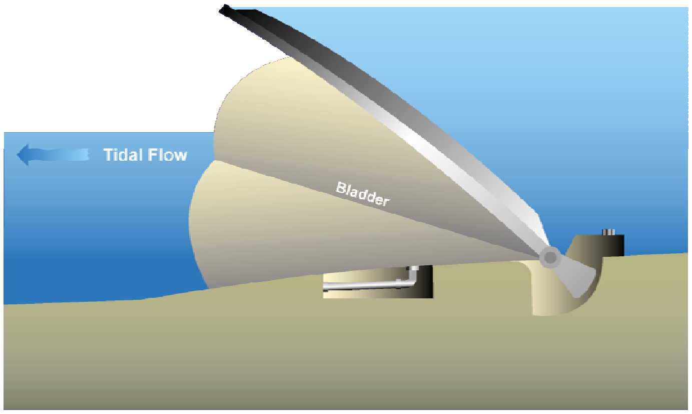

Figure 10. Depiction of a Bottom Hinged Gate

Improved Circulation / Improved Water Quality

Three of the permanent gates will operate to raise water levels and to induce circulation in the southern Delta channels. The permanent gate will operate to achieve improvements in water levels and circulation by capturing tidal flows on the high tide. By capturing the high tide on Middle River and Old River and setting a lower gate elevation at the Grant Line Canal, water is forced to flow from Middle River and Old River into Grant Line Canal, thus inducing circulation of water in the south Delta channels. During modeling of the gate operations, the height of the gate on Grant Line Canal is set at a 0.0 feet mean sea level, allowing high waters to flow over it. Under some conditions, it is best to slightly restrict San Joaquin River water flowing into Old River by slightly raising the gate to have it function as a weir.

DWR has studied the effects of the proposed permanent gate operations compared to the effects of the temporary barriers on water quality in the south Delta. Modeling has shown that the gate operations induce circulation in the south Delta and result in significant water quality improvements as measured by EC. We have compared days exceeding the 1000 µS/cm level in DSM2 model runs for both existing conditions (with the temporary barriers in place) and with the proposed permanent operable gates.

Under existing conditions with the seasonal installation of temporary barriers, the modeling of a16-year period shows that the EC values at the Middle River compliance location would exceed the 1000 EC 386 days and at the Old River compliance location would exceed the 1000 EC 181 days. Under the proposed permanent gate operations, the same modeling of the 16-year period shows the EC values did not exceed 1000 EC at either station. Figure 11 illustrates the potential average water quality

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improvements available by using the proposed permanent gate operations (Final SDIP EIS/EIR, November 2006).

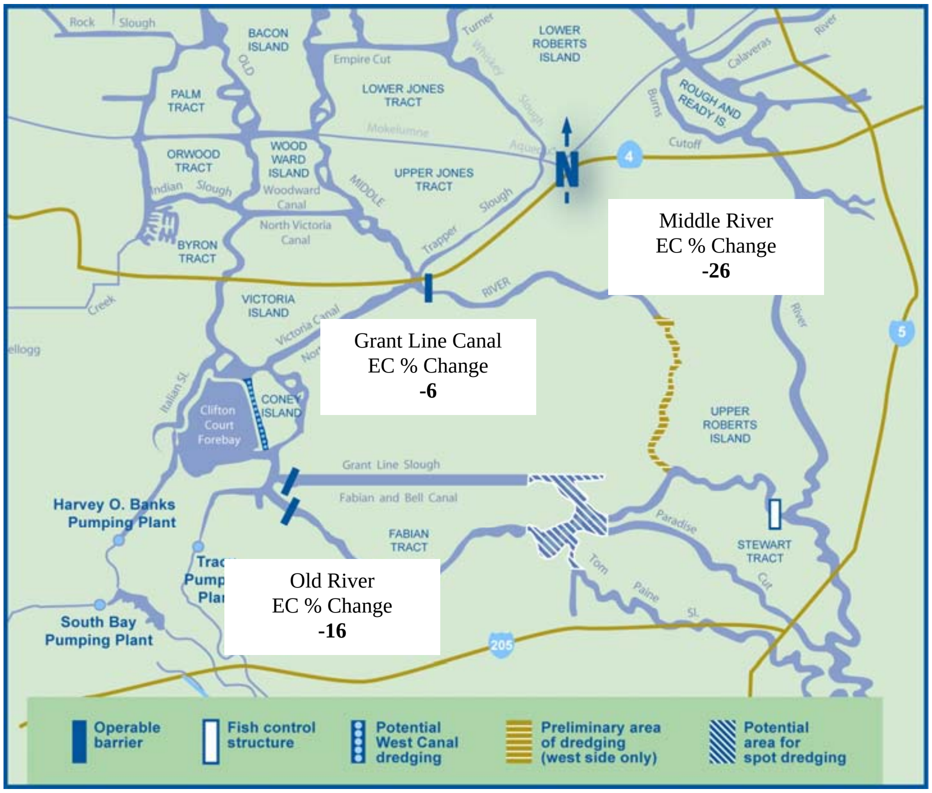

Figure 11. Average Reductions in Salinity Using Permanent Operable Gates

Status of the SDIP Implementation

ESA consultation for operation of the SDIP gates has been incorporated into the ESA consultation for the operation of the CVP and SWP (the CVP and SWP Operations Criteria and Plan (OCAP)). The FWS' OCAP Biological Opinion allows for the operations of the SDIP gates but requires the operation to be approved by FWS with respect to protecting delta smelt. The completion date for the NMFS OCAP Biological Opinion is June 2009. The draft biological opinion from NMFS was made available to the public in mid-December 2008. It concludes the SDIP gates will degrade the designated critical habitat for Central Valley steelhead and the additional actions are needed to prevent fish from entering Turner Cut and Columbia Cut.

DWR staff has met several times with NMFS' staff where they have indicated that further evaluation is required to address potential salmonid predation impacts associated with the gates. DWR is having three-dimensional hydraulic models of the gates prepared. These models will be used to evaluate the near-field effects of the gates and modify the designs to minimize fishery impacts. In addition, NMFS has proposed that the study of predation at the temporary barriers be used to estimate the potential predation impacts of the SDIP gates. The predation study is currently required for the temporary barriers as part of the U.S. Army Corps of Engineers Section 404 permit and is scheduled to begin in April 2009. It is a two-year study and results are not expected until the beginning of calendar year 2011. Given the time needed to conduct the NMFS' evaluation, it is apparent the gates will not be operable by 2012. Once the final NMFS OCAP biological opinion is issued, the magnitude of the delays

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will be determined and a revised schedule for constructing the operable gates developed.

8. Summary of Information Needed for Further Evaluation of Southern Delta Objectives and Methods of Implementation

The SWRCB established the salinity objective of 0.7 mmhos/cm EC to provide adequate water quality during the summer irrigation season (April-August) based on the salt sensitivity and growing season of beans; while the 1.0 mmhos/cm EC objective was established for the winter irrigation season based on alfalfa crop requirements. DWR believes that analyses of agricultural experts and others described in the reports listed below suggest that the 1.0 mmhos/cm objective in the southern Delta may reasonably protect agricultural crop production during the summer season. This information would be useful in considering changes to the objectives or to methods of implementation. For example, if the SWRCB were to consider a summer objective of 1.0 EC during dryer year types, it might find this is a reasonable method of implementation as well as reasonably protective of the beneficial use because studies show the effects on crops to be minimal. DWR recommends that the SWRCB include in its studies on southern Delta salinity a review of the following reports:

- “Establishing Water Standards that are Protective for Agricultural Crop Production,” Report to DWR by Dr. John Letey, Oct. 14, 2005 (concluding that an EC standard of 1.0 mmhos/cm EC is protective of agricultural production in the south Delta).
- “An Approach to Develop Site-Specific Criteria for Electrical Conductivity to Protect Agricultural Beneficial Uses that Accounts for Rainfall,” Dr. Isidoro Ramirez, and Dr. Steve Grattan, UC Davis Department of Land, Air and Water Resources, 2004 (concluding that an EC objective of 1.1 mmhos/cm EC is adequate to protect agricultural beneficial uses in the Delta).
- “Concerning Southern Delta Electrical Conductivity Water Quality Objectives,” Mr. William Johnston, P.E., 2005. (discussing the evolution of the existing Southern Delta EC Objectives, research and crop changes that have taken place since the existing objectives were established, and recommendations on whether or not changes should be made to the existing objectives, based on updated research and current cropping patterns).
- Dr. James R. Brownell presentation for March 2005 SWRCB Workshop (concluding that there is no agricultural reason supporting the 0.7 mmhos/cm objective for Agricultural Water Quality Objective in the South Delta and recommending 1.1 mmhos/cm based on the more recent work of Hoffman, Grattan and his co-workers, and himself).

As part of future studies of southern Delta water quality needs, DWR recommends that the State Water Board re-assess the analysis and information of the reports listed above as well as continue to work with Dr. Hoffman as he conducts a technical review of all evidence presented on the irrigation water quality needs of the southern Delta. After Dr. Hoffman has completed the thorough review of the available information, DWR trusts that he should be prepared to make a recommendation to the State Water Board as to an appropriate value that would reasonably protect agricultural production in the southern Delta under various hydrologic conditions.

In addition, DWR recommends that the State Water Board retain a consultant to evaluate sources of water quality degradation within the southern Delta. The purpose of such an evaluation would be to determine what sources may be a significant cause of increased salinity that degrades water quality in the area.

DWR obtained information of local salinity contributions by municipal discharges and permitted agricultural runoff drains, discussed below and in Section 4 above. Local groundwater accretions, and local agricultural surface discharges are more difficult to estimate due to the numerous points of discharges. A detailed study is needed to quantify these contributions. However, based on existing data,

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DWR estimates that such contributions are substantial, especially in terms of surface agricultural drainage discharges.

In 1987, DWR performed a land survey mapping over 1,800 agricultural irrigation diversions in the Delta (see figure 12).

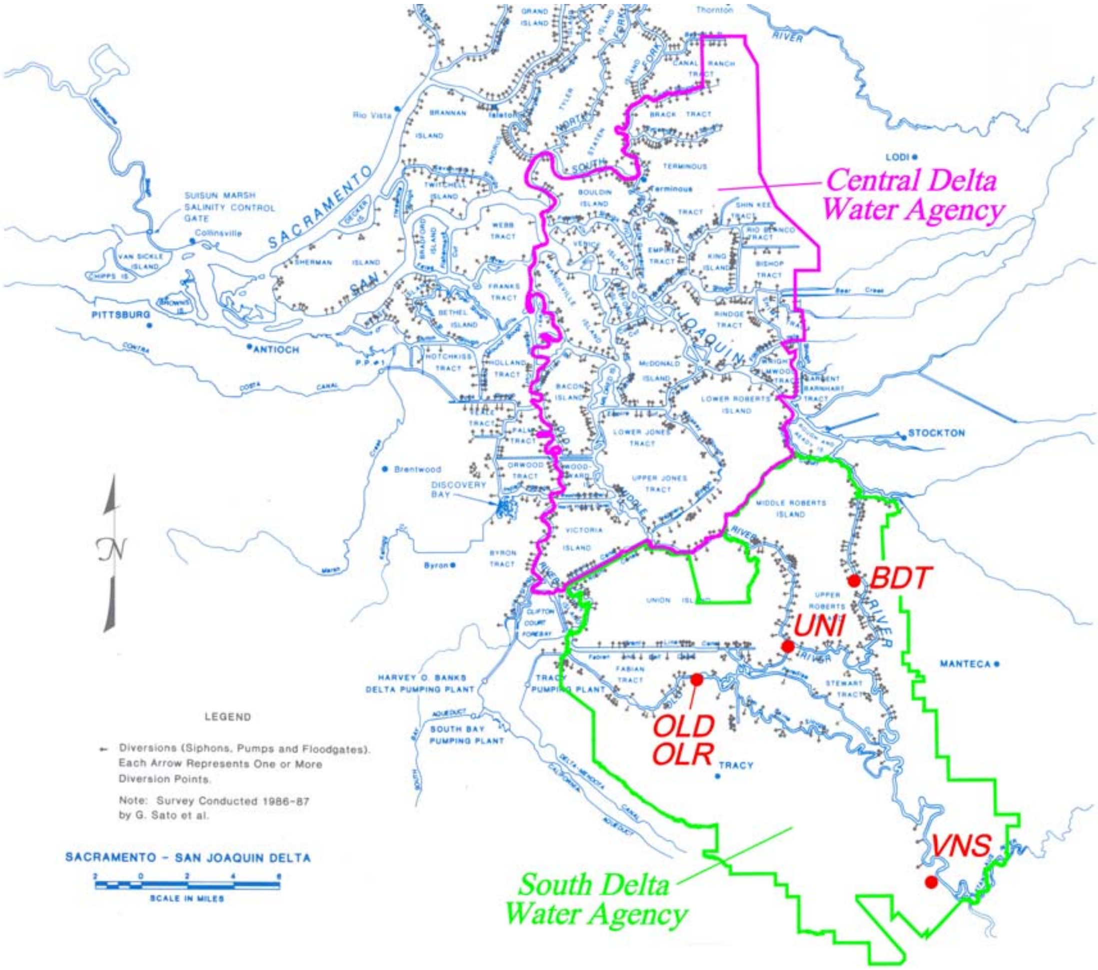

Figure 12. Agricultural Diversions in the Delta

At the time of this mapping effort, the principal crops grown were corn, sugarbeets, grains, alfalfa, tomatoes, asparagus, fruit, safflower, and nuts. The survey estimated that during the peak of the summer irrigation season, the diversions exceed 4,000 cfs. The survey also mapped the location of hundreds of agricultural drainage returns in the Delta (see Figure 13). The discharges from the drainage returns result from the natural evapotranspiration process of plants and run-off after irrigation, which leaves salts in the soils, and from the fact that most agricultural areas in the Delta are near or below sea level. Drainage is needed to prevent plant root waterlogging and to remove excess salts from the soils. Typically irrigated agriculture in the Delta can produce a threefold increase in salt concentrations in the tailwater, compared to water that was pumped from the channel irrigation. In addition, salt concentrations from subsurface irrigation drains (tilewater) are much higher than agricultural surface drainage returns. Both types of discharges are pumped from the islands and discharged into Delta channels. These agricultural drainage returns often exceed salinity levels of 2 mmhos/cm EC, which, in turn, degrades water quality in the Delta channels. Total combined agricultural discharge flows into the Delta are estimated to range between 500

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cfs and 1,000 cfs during the peak discharge season. Permitted municipal and agricultural dischargers (New Jerusalem Drain) may add as much as 165 cfs, with EC levels ranging from 0.7 to 2 mmhos/cm.

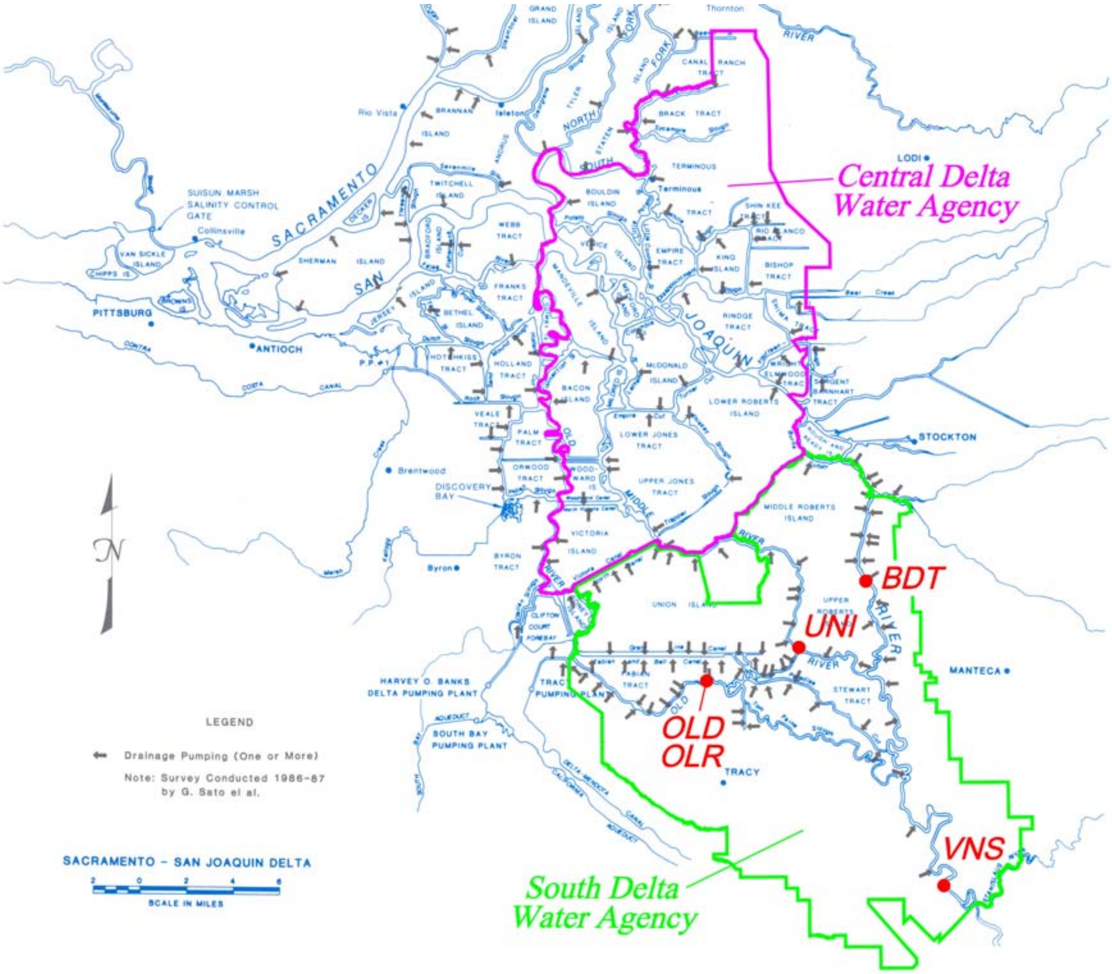

Figure 13. Agricultural Returns in the Delta

An example of the amount of water required for dilution flows needed in order to achieve the 0.7 mmhos/cm EC objective helps to show if such flows are reasonable. For example, to reduce the salt concentration in 100 cfs at 2 mmhos/cm EC (1240 mg/l) to 0.7 mmhos/cm EC, additional flows of 195 cfs of distilled water (25 ppm) would be needed. Or, using a more realistic water salinity of 0.5 mmhos/cm EC (320 ppm) would require an added 650 cfs. The State Water Board should include in its southern Delta salinity studies, an investigation on requirements for dilution flows to help determine if such flows would be reasonable.

In addition, in order to reasonably achieve a summer water quality objective of 0.7 mS, DWR recommends that the State Water Board quantify the respective share of salt contributions from specific sources and determine if there are reasonable methods of reducing such contributions. A land use and irrigation survey similar to the one performed in 1987 by DWR is needed to provide updated information for the southern Delta and locations of sources of salinity.

Investigating Effectiveness of Current and Future Salinity Controls on South Delta Salinity

The following is a summary of actions that DWR recommends the State Water Board investigate to control salinity in the southern Delta. These actions occur, or would occur, upstream and downstream of Vernalis, effecting salinity in the San Joaquin River and the southern Delta.

Actions Upstream of Vernalis Controlling Salinity in the San Joaquin River:

- Provide fresh water to dilute saline discharges and to increase flows upstream of Vernalis through flow releases from New Melones Reservoir, through the Vernalis Adaptive Management Program (VAMP) provided under the San Joaquin River Group Agreement, and through the release of water from the Central Valley Project via the Westley or Newman Wasteways; and
- Control discharge of saline water into the San Joaquin River upstream of Vernalis.

Measures Upstream of Vernalis Controlling Discharges in the San Joaquin River:

- On-farm management activities to reduce subsurface drainage,
- Real-time water quality management to maximize the assimilative capacity of the San Joaquin River,
- Efforts to improve water quality of wetlands discharges, and
- Implementation of TMDLs.

Specific information regarding methods to provide on-farm drainage management activities are discussed below.

On-farm Drainage Management Activities. Drainage management activities involving source control have proven to be effective in reducing salt loads in the San Joaquin River. These activities include:

- Irrigation Water Conservation such as use of improved irrigation systems; tiered block water pricing, shallow groundwater management, and best irrigation management practices.
- Agricultural tailwater and tilewater control and recycling.
- Agricultural subsurface drainage water reuse through the San Joaquin River Improvement Project.
- Development of integrated regional water quality management plans and operations through Proposition 50.

DWR additionally supports the recommendations of the San Joaquin River Management Group in its report for controlling salinity in the San Joaquin River. Recommendations include:

- fully implementing the West Side Regional Drainage Plan,
- further evaluating and pursuing managed wetland drainage management actions to mitigate impacts of February through April drainage releases, and
- developing a real-time water quality management coordination group involving Lower San Joaquin River (LSJR) tributaries, LSJR drainers and DWR to coordinate reservoir release and SWP/CVP Project operations (Head of Old River Barrier and New Melones operations) to realize opportunities to improve water quality and increase the utility of stored water releases.

The San Joaquin River Water Quality Management Group has merged into the Water Quality Subcommittee of the San Joaquin River Management Plan (SJRMP) with the purpose of implementing the above recommendations. DWR is a lead agency for the SJRMP.

DWR also refers the State Water Board to information in the Report on San Joaquin Drainage Programs prepared by Jose Faria for DWR in October 2005, and recently updated, which is attached as

Appendix F. This report includes additional information on work done in the San Joaquin River upstream of Vernalis to reduce salinity and discharges. This work has reduced the amount of releases from New Melones reservoir required in the past to dilute salinity to achieve the 0.7 mmhos/cm EC at Vernalis.

9. Recommendations on changes to Objectives and the Program of Implementation

DWR believes that the State Water Board should investigate several alternatives that could be applied separately or in combination for implementing the southern Delta objectives. At this time, DWR is providing a possible list of implementation methods, shown below. After the workshops and meetings, the methods could be more fully developed based on facts gathered by the State Water Board during these workshops.

- Varying the southern Delta salinity objective based on San Joaquin River water-year hydrologic classifications that are defined in Figure 3 of the 2006 Bay-Delta Plan. This method would be similar to variations in the salinity objectives based on the Sacramento River water-year classifications as shown for the Western Delta and Interior Delta on Table 2, footnote 3 of the 2006 Bay-Delta.
- Assign the responsibility for achieving the objective among several entities shown to affect southern Delta salinity.
- Implement the objectives in phases based on the schedule for constructing a physical solution, achieving waste discharge requirements, or other methods proposed for implementing the objectives.
- Provide protection of agricultural beneficial uses by a narrative objective instead of numeric objectives, similar to protection provided to brackish tidal marshes of Suisun Bay on Table 3 of the 2006 Bay-Delta Plan.

Summary

In summary, DWR's modeling and particle tracking studies demonstrate that the SWP cannot effectively control salinity in the southern Delta through changes in its Delta exports or changes in flow from the Sacramento River. This modeling also shows the zone of influence of the San Joaquin River on the southern Delta under varying export conditions when the temporary barriers or permanent gates are operating. DWR has also provided information obtained from the Regional Water Quality Control Boards on the locations and amounts of discharges by agricultural, municipal, and industrial water users in the area. DWR also reviewed information on the historic salinity patterns and cropping patterns in the southern Delta. The information, however, on specific agricultural practices and current crops in the south Delta is limited and the State Water Board may need to obtain additional information to better consider reasonable objectives for protecting the agricultural uses in the area.

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APPENDICES

Appendix A. Historic Salinity Data from Bulletin 27

Appendix B. Central Valley Project and State Water Project Operations' Effect on Variability of Salinity in the Southern Delta & Impact of SWP and CVP Operations on Delta-wide Circulation and South Delta Water Quality

Appendix C Sources of Salinity in the South Sacramento-San Joaquin Delta

Appendix D. Data and Charts from the Waiver Monitoring Program

Appendix E. New Jerusalem Drainage CDEC Data

Appendix F. Report on San Joaquin Drainage Programs

Appendix G DWR Exhibits from State Water Board 2005 Cease and Desist Order Hearings: DWR 21 (Establishing Salinity Water Standards that are Protective for Ag Crops, Oct 7, 2005), DWR 22 (Establishing Salinity Water Standards that are Protective for Agricultural Crop Production), DWR 20 (Investigation of the Factors affecting Water Quality at Brandt Bridge, Middle River at Union Point, and Old River at Tracy), DWR 20A (Fingerprinting Methodology), and DWR 20C (Description of historical DSM2 Particle Tracking Animation With Temporary Barriers Installed in South Delta)

APPENDIX A

HISTORIC DELTA SALINITY DATA (PPM CHLORIDE)

The data represented in the table below (above) was obtained from the Sacramento-San Joaquin Water Supervisor Reports, 1924-1943, and was expressed as parts of chloride per 100,000 part of water. The data was converted to ppm (mg/l) to be consistent with units used to express current water quality objectives (municipal). Conversion to EC is inexact and dependent on the composition of salts in the water source at a particular location. Based on analysis of chlorides vs EC at a location on Old River at Bacon Island (using water quality data from December 1998 through July 2003), DWR has estimated for previous hearings before the SWRCB that 150 mg/l chloride is approximately 0.7 EC, and 250 mg/l approximately 1.0 EC. Actual values at any particular location can vary.

Station	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
Middle River	1860	130	690		210	170	130	270	120	180	1080	110	120	160	130	600	550
Mansion House	1480	110	690		160	160	110	240			900						
Victoria Island																350	
Stockton Country Club	1080		480			360	180	1220			440						
Clifton Court Ferry	800		240			230		130			400					190	
Stockton Country Club						2000	1200	1320	720	660	760					320	
Garwood Bridge								920			380						
Brandts Bridge								430			210						
Williams Bridge	420		180			120		1180			430						
Naglee Burke Pump																140	
Whitehall						150		310			120						
Mossdale Bridge	140					160	100	120	140	130	250	120	140	120	120	160	140
Durham Ferry Bridge								100									

Figures represent maximum recorded salinity at selected locations in southern Delta
Source: Sacramento-San Jaoquin Water Supervisor Reports 1924-1943

Middle River	Middle River, east bank, at Santa Fe RR crossing
Mansion House	Victoria Island, Old River, east bank, at junction with North Victoria Canal
Victoria Island	Old River at Borden Hwy crossing
Stockton	On Lindley Cut-off (San Joaquin R.), north bank, aobut 3/4 mi above Burns cut-off junction
Clifton Court Ferry	Old River just below junction with Grant Line Canal
Stockton	Near head of Stockton Channel at wharf of California Trans Co. (1931)
Garwood Bridge	San Joaquin River at drawbridge 1 mi above Santa Fe RR crossing
Brandts Bridge	San Joaquin River at drawbridge 6 mi above Santa Fe RR crossing
Williams Bridge	Middle River about 4 mi below Salmon Slough junction
Naglee Burke Pump	Old River at Naglee Burke pump (102.5 mi from GGB)
Whitehall	Old River west of junction of Salmon Slough & Paradise cut due north of Tracy (104.8 mi from GGB)
Mossdale Bridge	San Joaquin River at Lincoln Hwy crossing about 3 mi SW of Lathrop
Durham Ferry Bridge	San Joaquin River 1/2 mi below San Joaquin City

APPENDIX B

Central Valley Project and State Water Project Operations’ Effect on Variability of Salinity in the Southern Delta

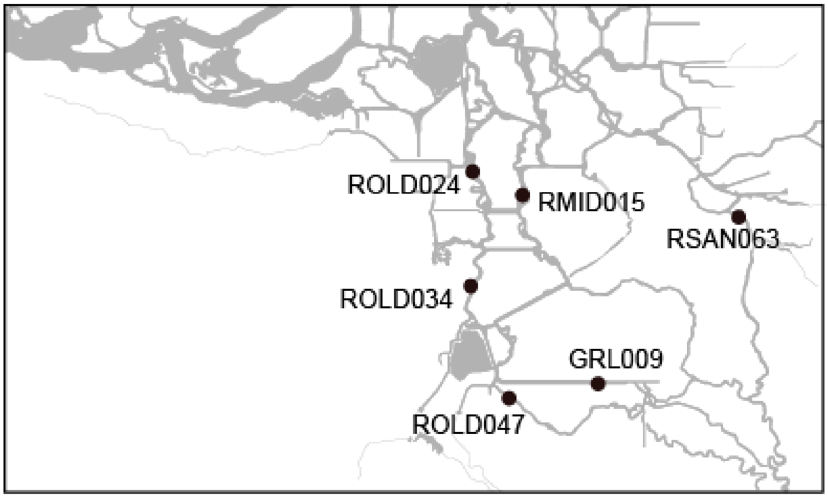
Salinity in south Delta channels is a result of the mixing of several sources of water with variable water quality. CVP and SWP operations affect Delta inflows, and these inflows, along with SWP and CVP exports, tides, and agriculture diversions, in turn affect general Delta circulation patterns. One important factor for determining salinity in south Delta channels is the relative contribution of the San Joaquin and Sacramento rivers as sources of water; the Sacramento River flowing into the Delta tends to be significantly less salty than the San Joaquin River. A second important determinant of salinity in the south Delta is the local circulation of water within the south Delta. South Delta channels at times receive significant amounts of agricultural drainage which can be two or three times more salty than the water in the receiving channels. Salt tends to buildup in channel reaches with relatively stagnant flow while salt from agricultural discharges tends to be flushed out with better circulation. This circulation in the south Delta, in part a result of Delta tides, inflows, exports, and agricultural activities, can also be significantly affected by the installation of temporary rock barriers. General Delta circulation patterns drive the relative contribution of the Sacramento and San Joaquin rivers as sources of water in the vicinity of the south Delta, and local circulation patterns determine how these sources are mixed and to what extent agricultural discharges are diluted. Thus, SWP and CVP operations which may affect salinity in the south Delta include SWP and CVP exports, Delta inflow, and the installation of temporary barriers.

In order to aid the understanding of the effects of SWP and CVP operations on south Delta salinity, Delta hydrodynamics and salinity have been simulated assuming modified historical 2002 Delta conditions. While San Joaquin River inflow and electrical conductivity (EC) were held fixed at historical levels, different CVP and SWP exports, Sacramento River inflow, and south Delta barrier installations were considered. CVP and SWP effects on south Delta salinity were evaluated using simulated Delta flows, EC, and ‘fingerprints” of the Sacramento and San Joaquin rivers’ contributions to the source of water throughout the Delta. Study results indicate that, when San Joaquin River flow into the Delta is fixed at historical values, changing localized circulation through different installations of south Delta barriers has more impact on salinity at the three compliance locations in the south Delta than does changing Delta-wide circulation patterns through changing SWP and CVP exports and Sacramento River inflow.

General Approach to Analysis

Simulated historical and modified 2002 Delta conditions were used as a basis for evaluating the effects of SWP and CVP operations on Delta circulation patterns and south Delta salinity. This year was selected to be consistent with the evidence provided by DWR in November of 2005 at SWRCB’s hearing on draft Cease and Desist Order Nos. 262.31-16 and 262.31-17 (exhibit 20). The Delta simulation model, DSM2, was used to simulate Delta hydrodynamics and water quality. In order to show the model’s ability to reproduce 2002 historical conditions, model and measured daily average flow at six locations in the Delta (Figure 1) are presented in Figure 2 and EC model and measured daily average EC are presented at the three compliance locations in Figure 3. At the time of this report, processed measured flow data from 2002 was immediately available only through June. Figure 3 indicates that DSM2 reproduces 2002 historical EC at the compliance locations fairly well with a tendency to underestimate, particularly at the Old River at Tracy Road Bridge site (ROLD047). Considering that the measured EC at the Old River at Tracy site in 2002 tended to be higher than the EC at the other two sites, the DSM2 simulation failed to account for a source of additional salt here. This underestimation is possibly due to failing to capture poorly circulating water and the build up of salt from agriculture drains or due to errors in the quality and quantity of local agricultural return flows estimated in DSM2.

Figure 1. Locations 2002 daily average measured and DSM2-simulated flow are compared.



Consistent with the presentation of historical simulations in DWR's South Delta Temporary Barriers reports, 15-minute Delta flows are averaged over periods for which Delta inflows and exports are fairly constant and the combined presence of south Delta barriers is fixed (Table 1). To accompany period-average flows, simulated Sacramento and San Joaquin rivers "fingerprints" and EC at the end of periods of time are presented. By using the fingerprinting method, relative contributions of water sources to the volume are estimated at any location. Volumetric fingerprinting can be thought of as taking a bucket of water at a particular location and being able to know what percentage of that water came from each inflow source. For this analysis, fingerprinting output is generated at several locations and from these results the fingerprints are displayed as contours delineating the extent 75% and 90% of Delta channel water originating from either the Sacramento or San Joaquin rivers. EC at the Old River near Middle River compliance location was not simulated for all alternatives in this study; EC at RMID041, approximately one mile downstream in Middle River from this site, is instead presented in order to be able to compare the effects of different SWP and CVP operations and different barrier configurations. Also presented is the EC in Old River just upstream of the temporary barrier location ("Old River near DMC") in order to better understand the different roles that Delta-wide circulation patterns and localized south Delta circulation patterns play in determining the salinity in the south Delta. The periods from 2002 that are presented for each simulation are: April 1-14, April 15-30, May 1-24, June 7-30, July 1-31, and August 1-31 (Table1).

A description of the results for the historical 2002 simulation is contained within the discussion of the results of variations from the historical conditions.

Figure 2. Comparison of measured daily average flow to DSM2-simulated daily average flow, 2002.

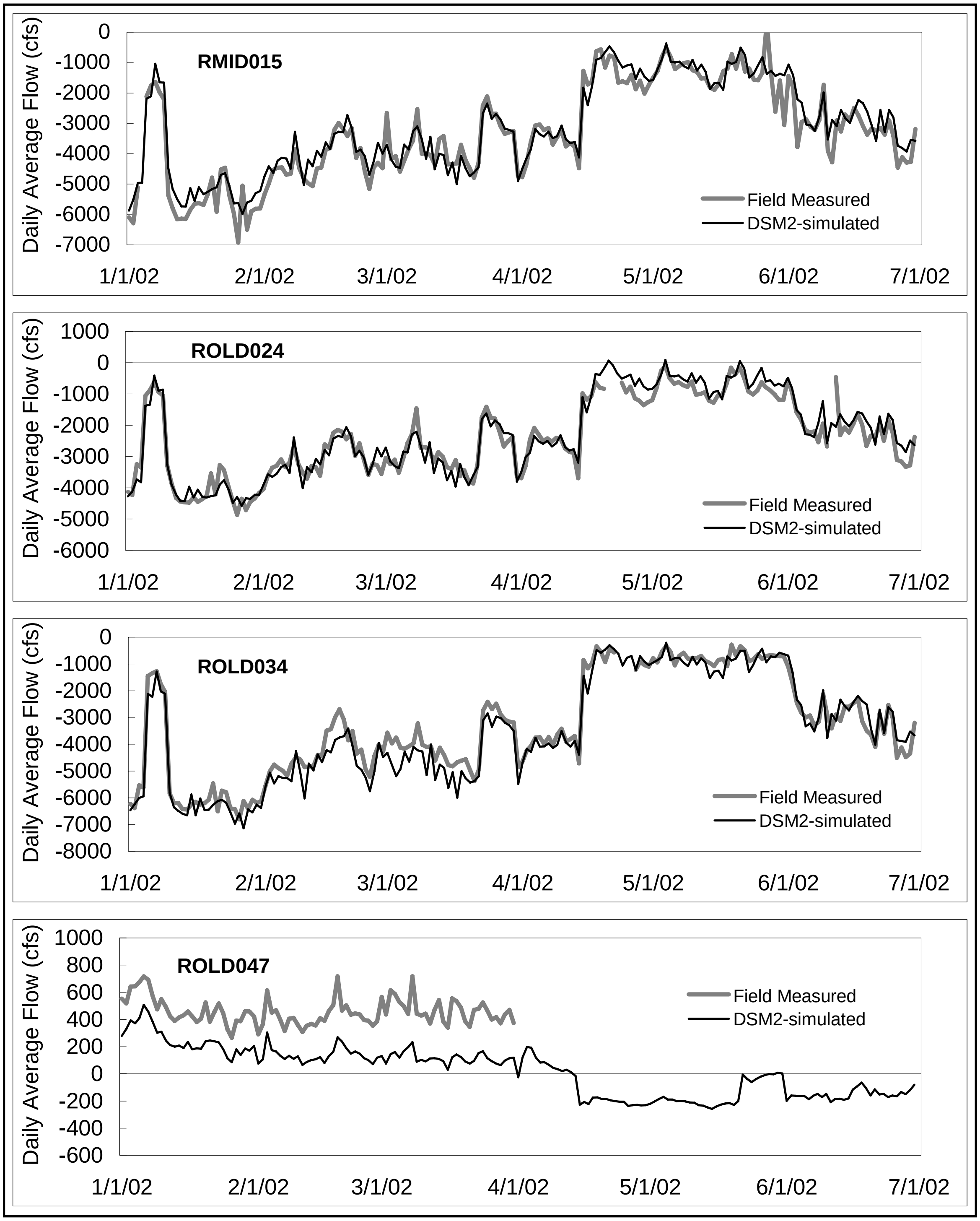


Figure 2 (cont.). Comparison of measured daily average flow to DSM2-simulated daily average flow, 2002.

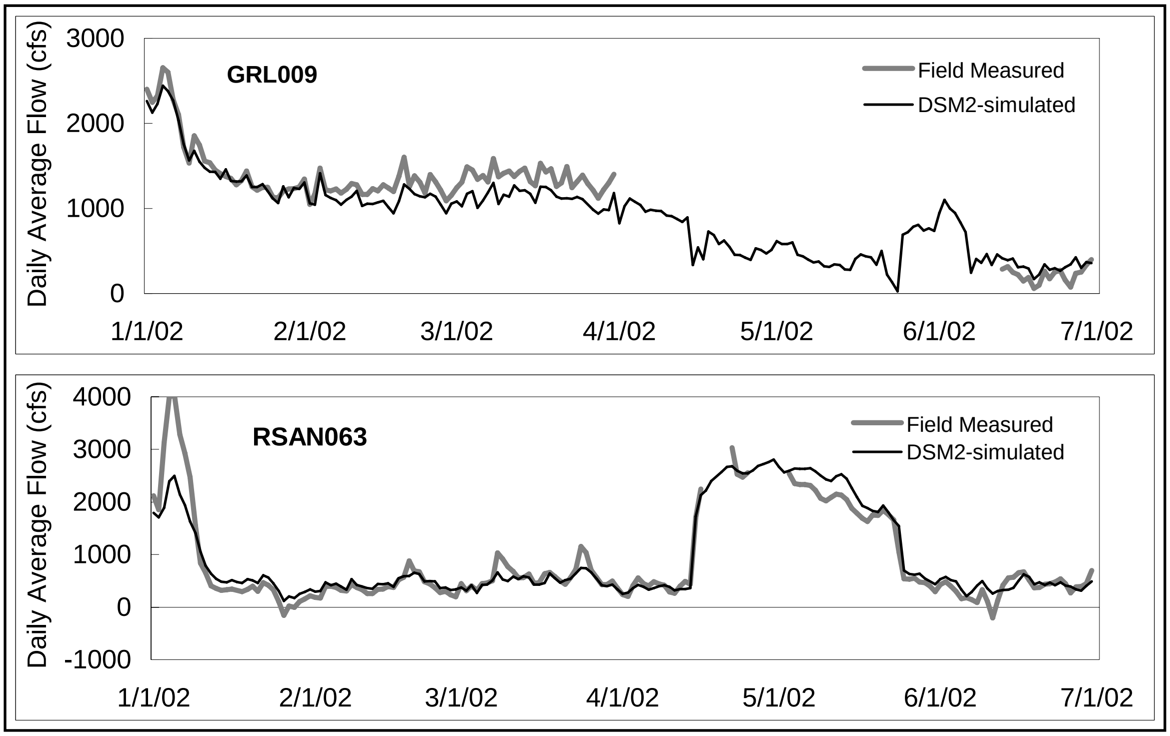
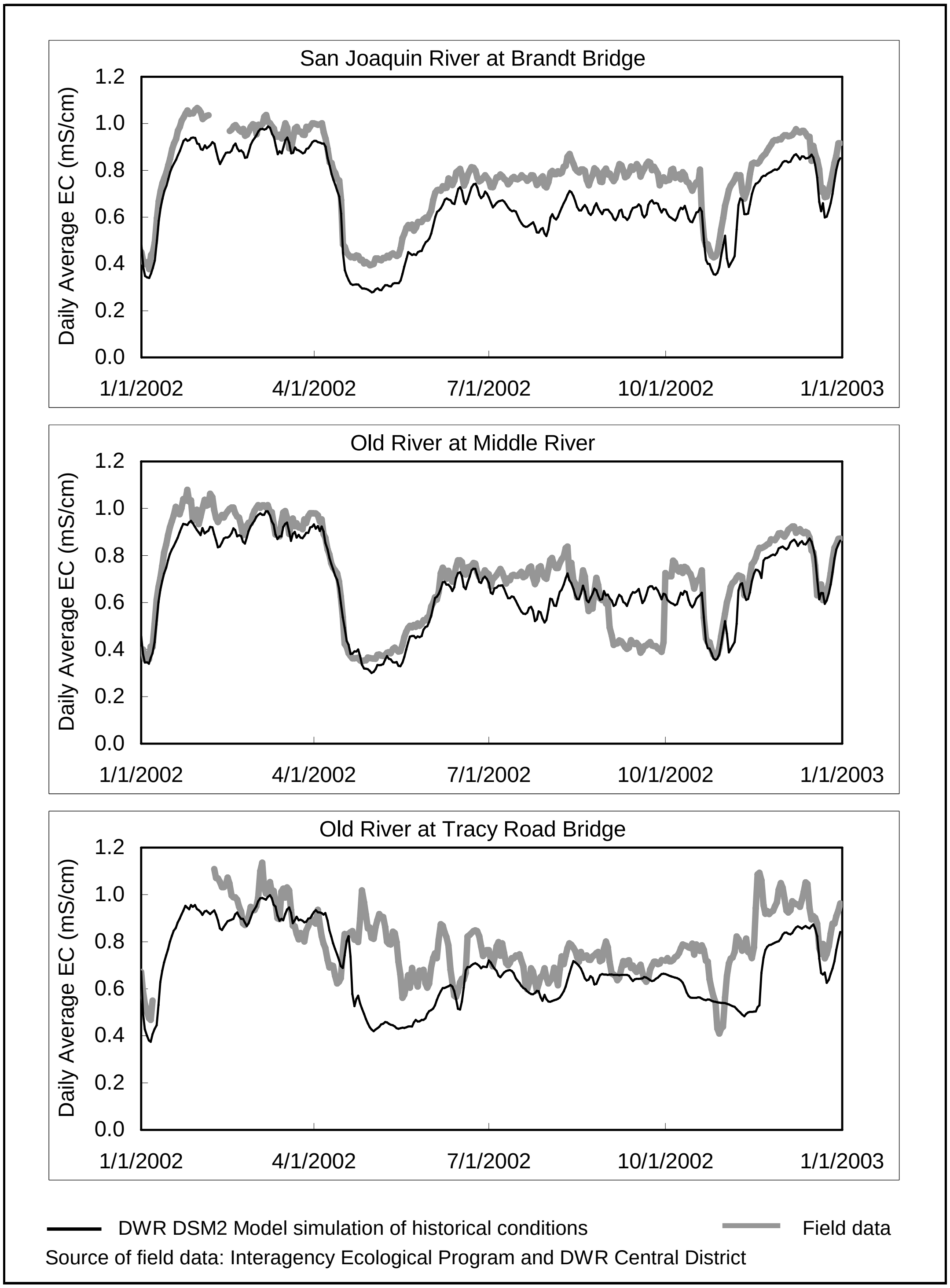


Figure 3. Comparison of DSM2-simulated and measured EC at the three south Delta agriculture compliance locations, 2002.



Source of field data: Interagency Ecological Program and DWR Central District

Table 1. Partitioning of historical 2002 simulation for presentation of results into periods of stable inflows and exports and constant south Delta barrier installation.

Period		Period Average Flows				Period Barrier Status			
		Sac River + Yolo Bypass (cfs)	San Joaquin River (cfs)	DMC Pumping (cfs)	SWP Pumping (cfs)	MR	OR	GLC	ORH
JAN	1 - 4	52,468	4,849	4,044	8,012	--	--	--	--
	5 - 10	83,533	3,839	4,117	2,581	--	--	--	--
	11 - 31	30,316	1,968	4,172	7,268	--	--	--	--
FEB	1 - 28	18,238	1,895	3,601	4,941	--	--	--	--
MAR	1 - 22	21,846	2,121	4,149	4,630	--	--	--	--
	23 - 31	20,139	2,157	4,209	2,091	--	--	--	--
APR	1 - 14	16,321	1,822	3,501	3,986	--	--	--	--
	15 - 30	13,355	3,218	1,097	693	IN	IN	--	IN
MAY	1 - 24	12,694	3,000	836	573	IN	IN	--	IN
	25 - 31	15,098	2,107	922	805	IN	IN	--	--
JUN	1 - 6	12,653	1,676	3,267	1,580	IN	IN	--	--
	7 - 30	14,105	1,368	2,427	2,331	IN	IN	IN	--
JUL	1 - 31	18,817	1,275	4,348	6,222	IN	IN	IN	--
AUG	1 - 31	16,959	1,150	4,329	6,733	IN	IN	IN	--
SEP	1 - 30	13,554	1,161	4,278	4,131	IN	IN	IN	--
OCT	1 - 3	11,707	1,176	4,321	2,202	IN	IN	IN	--
	4 - 20	9,772	1,306	4,286	1,039	IN	IN	IN	IN
	21 - 31	9,709	2,069	3,698	2,665	IN	IN	IN	IN
NOV	1 - 10	11,913	1,669	2,626	2,196	IN	IN	IN	IN
	11 - 20	13,245	1,712	4,114	4,703	IN	IN	IN	IN
	21 - 28	11,161	1,493	4,254	2,628	IN/--	IN/--	IN/--	--
	29 - 30	21,960	1,411	4,264	2,153	--	--	--	--
DEC	1 - 13	11,406	1,425	3,346	2,063	--	--	--	--
	14 - 31	44,904	2,379	3,312	5,844	--	--	--	--

Impact of SWP and CVP Operations on Delta-wide Circulation and South Delta Water Quality

To demonstrate the effect of SWP and CVP operations on Delta-wide circulation patterns and south Delta EC, three scenarios were simulated to compare to the historical 2002 simulation: 1) no SWP pumping from January through August and no south Delta barriers installed, 2) no SWP and no CVP pumping from January through August and no south Delta barriers installed, and 3) historical 2002 conditions including barrier installation with an additional 5,000 cfs in Sacramento River inflow. When SWP or CVP pumping was eliminated, Sacramento River was reduced the same amount to maintain the same Delta outflow. For the scenario with additional Sacramento River inflow, the downstream boundary EC was modified to reflect higher Delta outflow.

Figures 4a – 4f show for the historical 2002 simulation the Delta-wide period-average flow directions and the end-of-period volumetric fingerprints of the Sacramento River and San Joaquin rivers displayed as contours of 75% and 90% contribution. The daily average EC at the four locations in the south Delta on the last day of the period is also presented. These figures indicate that period-average flows in Old and Middle rivers downstream of the south Delta tend to be in the upstream direction towards the SWP and CVP pumps. When combined SWP and CVP pumping is low (April 15-30 and May 1-24), the area of high portion of Sacramento River water remained in the Sacramento River and lower San Joaquin River. However, when combined SWP and CVP pumping range from 7,400 cfs to 4,700 cfs (in the April 1-14 and June 7-30 periods), the region for which Sacramento River is an important source of water moves up Old River towards the pumps. In July and August, with combined SWP and CVP pumping exceeding 10,500 cfs, average flows in the lower San Joaquin River are upstream and the contour of 90% Sacramento River water by volume moves further upstream Old River and dominates Middle River. In July and August of 2002, Delta-wide circulation brings Sacramento River-source water into the vicinity of the south Delta barriers on Middle and Old rivers. This is reflected in the relatively low EC at Old River near the DMC (0.3 mS/cm) compared to the other sites which have a daily average EC of 0.6 mS/cm.

In contrast to the region of Sacramento River water influence, the area of influence of the San Joaquin River in 2002 varies far less over the study period. The source water at the three compliance stations usually exceeds 90% from the San Joaquin River. The exception for this is in July and August at Brandt Bridge because most of the San Joaquin River during these times flows down the head of Old River, allowing more Sacramento River-source water to move up the San Joaquin River. Still, the EC at the three compliance stations at the end of the periods is either equal to or greater than the EC at Vernalis, further demonstrating the dominance of the San Joaquin River as the source of water at the sites.

Figures 5a-5f present the results of simulating the scenario for no SWP pumping from January through August and no barriers installed. Without SWP pumping, period-average flow is in the downstream direction for Old and Middle rivers when CVP pumping is near or less than 1,000 cfs. As CVP pumping exceeds 2,000 cfs, net reverse flows in Old and Middle rivers are seen with an accompanying moving of Sacramento River-source water up Old and Middle rivers; however, Sacramento River-source water fails to penetrate into the south Delta to the extent that is seen in the historical simulation. The region dominated by the San Joaquin River tended to move further downstream the San Joaquin River than in the historical simulation, the three compliance locations once again falling within the 90% source contour and the EC here equal to or exceeding the EC at Vernalis.

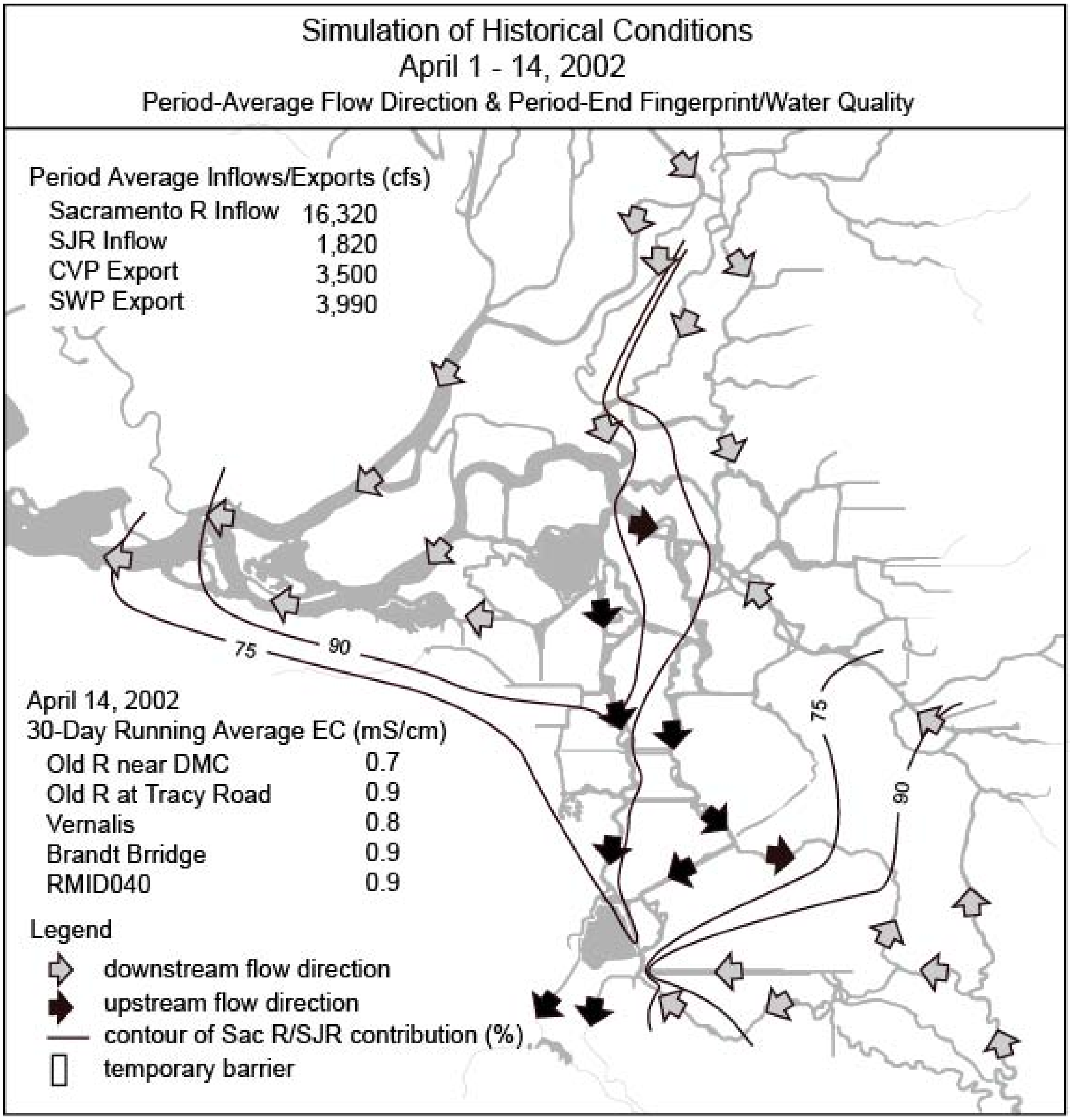
Figures 6a-6f present the results of simulating the scenario of no SWP and CVP pumping from January through August and no barriers installed. Without the project exports in the south Delta, period-average flow direction in Old and Middle rivers is downstream with the exception of Middle River from June through August. From April through May, period-average San Joaquin River inflows exceeds 1,800 cfs and the region dominated by the San Joaquin River extends down the San Joaquin River and somewhat down Old River. From June through August, with San Joaquin River inflows below 1,400 cfs and Delta agricultural water use higher, the extent of San Joaquin River influence recedes to a region similar to the previous two scenarios. The compliance locations again fall within the region of dominance of the San Joaquin River and EC at these locations again equal or exceed the EC at Vernalis.

Figures 7a-7f present the results of simulating the scenarios of historical conditions with an additional 5,000 cfs flowing down the Sacramento River from April through August. The circulation patterns, regions of dominance by the Sacramento and San Joaquin rivers, and the EC at the compliance locations are all very similar to those from the historical simulation. The area for which the Sacramento River is the dominant source does tend to move down the Sacramento River somewhat when compared to the area from the historical simulation. In addition, some more Sacramento River-source water tends to move upstream Old River when compared to the historical simulation; however, the three compliance sites remain well within the dominance of the San Joaquin River.

Figure 8 presents the daily average EC at the four study sites for the four scenarios. The EC at the Old River near DMC site, which is downstream of the Old River at Tracy Road site, is substantially increased by eliminating SWP and CVP pumping and removing barriers. This is due to replacing some of the water originating from the Sacramento River with saltier water from the San Joaquin River, as is reflected in the area of San Joaquin River dominance moving downstream Old River. For the same reason, the EC at Old River near DMC decreases for additional Sacramento River flow in July and August because more of the water here at these times originates from the Sacramento River. At both Old River at Tracy Road and RMID040, some decrease in EC in April and May is shown for the scenarios of eliminating SWP pumping and both SWP and CVP pumping. Since, when compared to the historical simulation, the EC downstream at Old River near DMC either remained the same as the historical simulation (for the No SWP Pumping, No Barriers scenario) or increased (for the No SWP, CVP Pumping, No Barriers scenario), the improvement in EC isn’t attributable to Delta-wide circulation patterns. Instead, the south Delta barriers at times can reduce the circulation in Old River, allowing local agricultural drainage to accumulate and increasing salinity levels. More discussion of south Delta circulation patterns follows in the next analysis. Finally, the EC at Brandt Bridge remains essentially unchanged under the different scenarios. Overall, Figure 8 indicates that increasing Sacramento River flow by 5,000 cfs for the historical 2002 simulation does not dramatically change Delta-wide circulation patterns, the Delta regions dominated by the Sacramento and San Joaquin Rivers, or the EC at the compliance sites. Reducing or eliminating SWP and CVP pumping does significantly change general Delta circulation patterns, but these changes, in themselves, do not affect EC at the compliance sites.

The next section focuses on the impact on south Delta EC of inducing different circulation patterns within the south Delta by changing barrier installation strategies.

Figure 4a. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, historical conditions, April 1-14, 2002.



Simulation of Historical Conditions
April 1 - 14, 2002
Period-Average Flow Direction & Period-End Fingerprint/Water Quality

Period Average Inflows/Exports (cfs)

Sacramento R Inflow	16,320
SJR Inflow	1,820
CVP Export	3,500
SWP Export	3,990

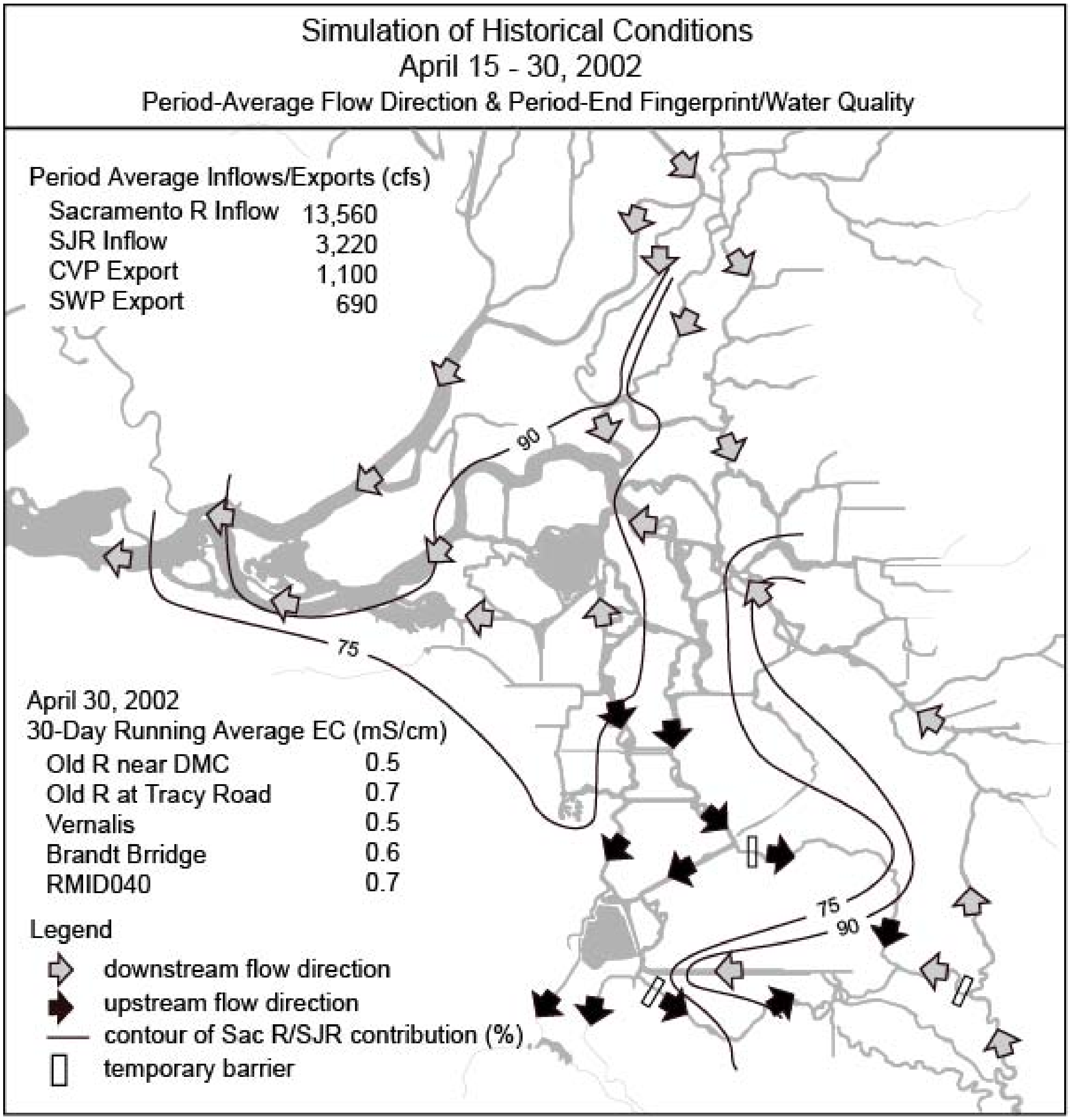
April 14, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.7
Old R at Tracy Road	0.9
Vernalis	0.8
Brandt Brridge	0.9
RMID040	0.9

Legend

⇨	downstream flow direction
➡	upstream flow direction
—	contour of Sac R/SJR contribution (%)
▯	temporary barrier

Figure 4b. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, historical conditions, April 15-30, 2002.



Simulation of Historical Conditions
April 15 - 30, 2002
Period-Average Flow Direction & Period-End Fingerprint/Water Quality

Period Average Inflows/Exports (cfs)

Sacramento R Inflow	13,560
SJR Inflow	3,220
CVP Export	1,100
SWP Export	690

April 30, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.5
Old R at Tracy Road	0.7
Vernalis	0.5
Brandt Brridge	0.6
RMID040	0.7

Figure 4c. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, historical conditions, May 1-24, 2002.

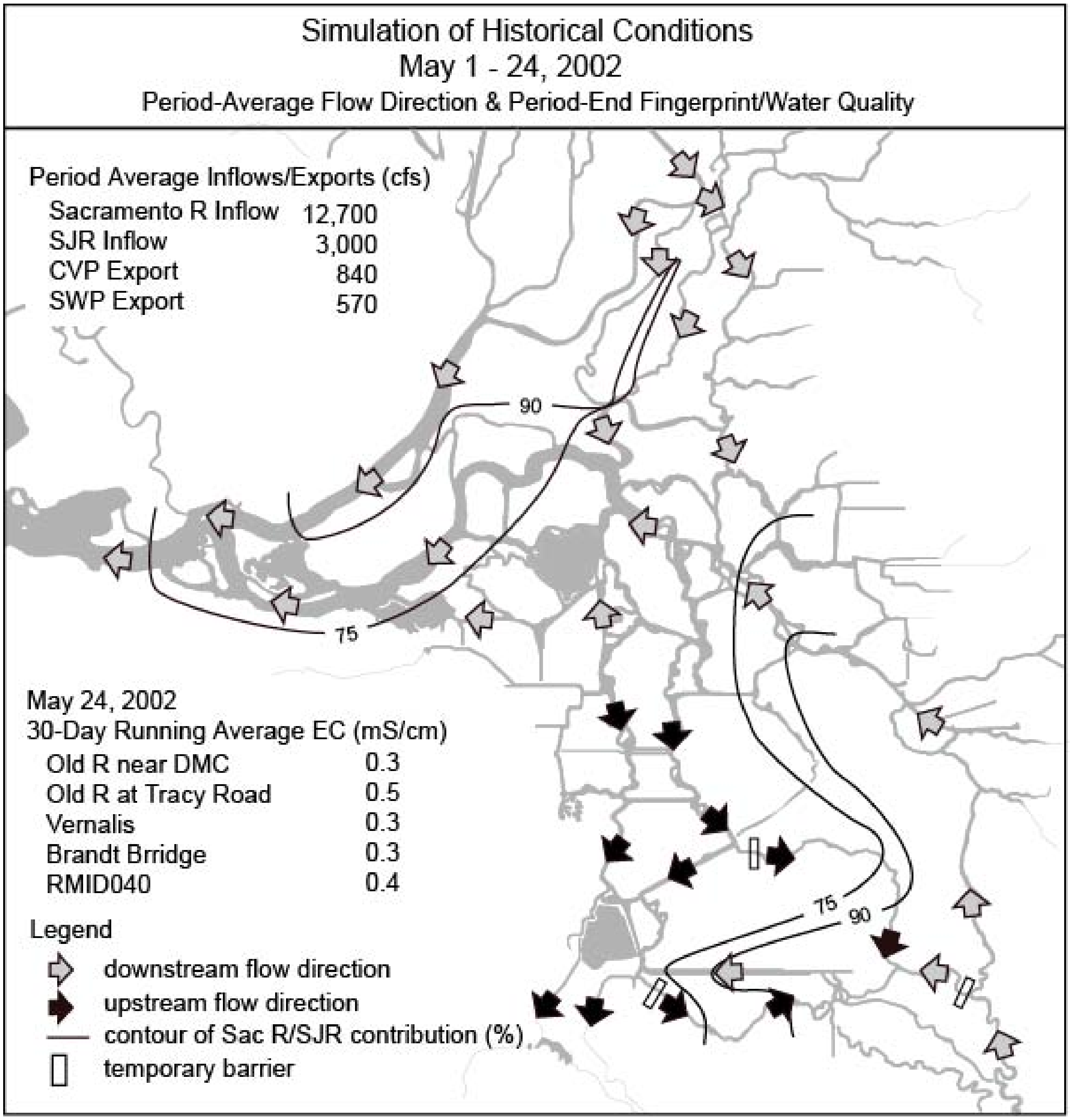
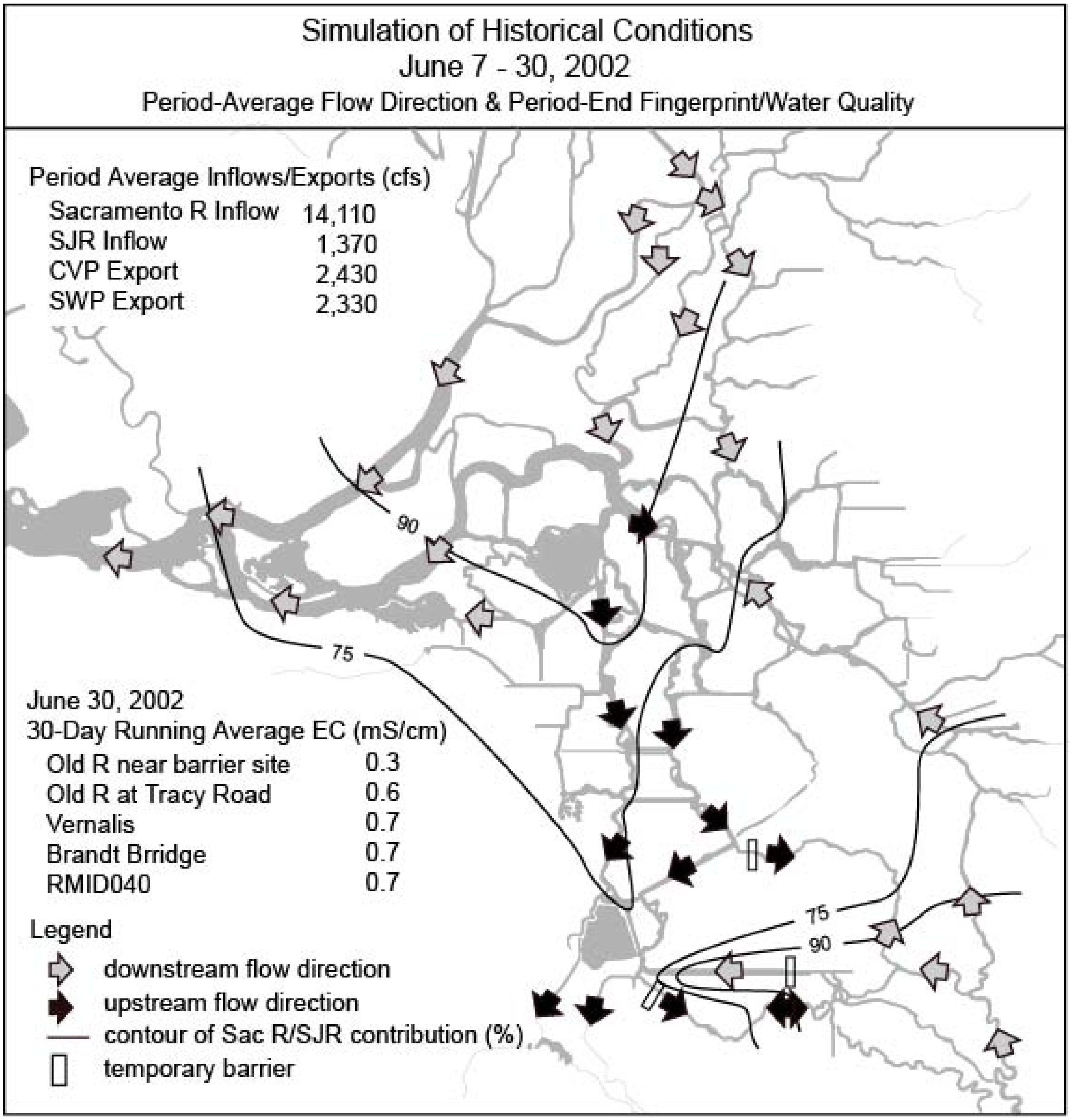


Figure 4d. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, historical conditions, June 7-30, 2002.



Simulation of Historical Conditions
June 7 - 30, 2002
Period-Average Flow Direction & Period-End Fingerprint/Water Quality

Period Average Inflows/Exports (cfs)

Sacramento R Inflow	14,110
SJR Inflow	1,370
CVP Export	2,430
SWP Export	2,330

June 30, 2002
30-Day Running Average EC (mS/cm)

Old R near barrier site	0.3
Old R at Tracy Road	0.6
Vernalis	0.7
Brandt Brridge	0.7
RMID040	0.7

Figure 4e. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, historical conditions, July 1-31, 2002.

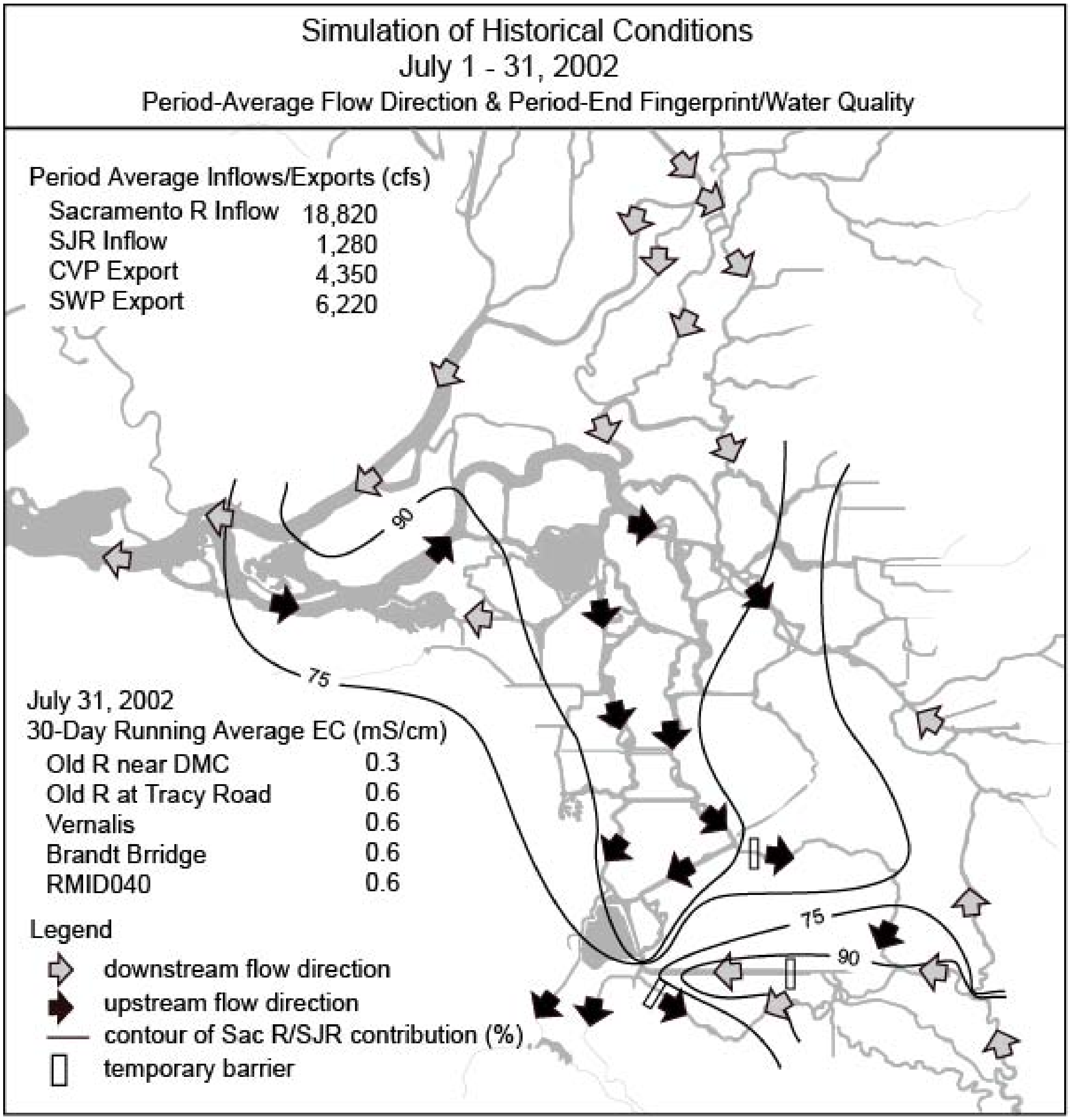
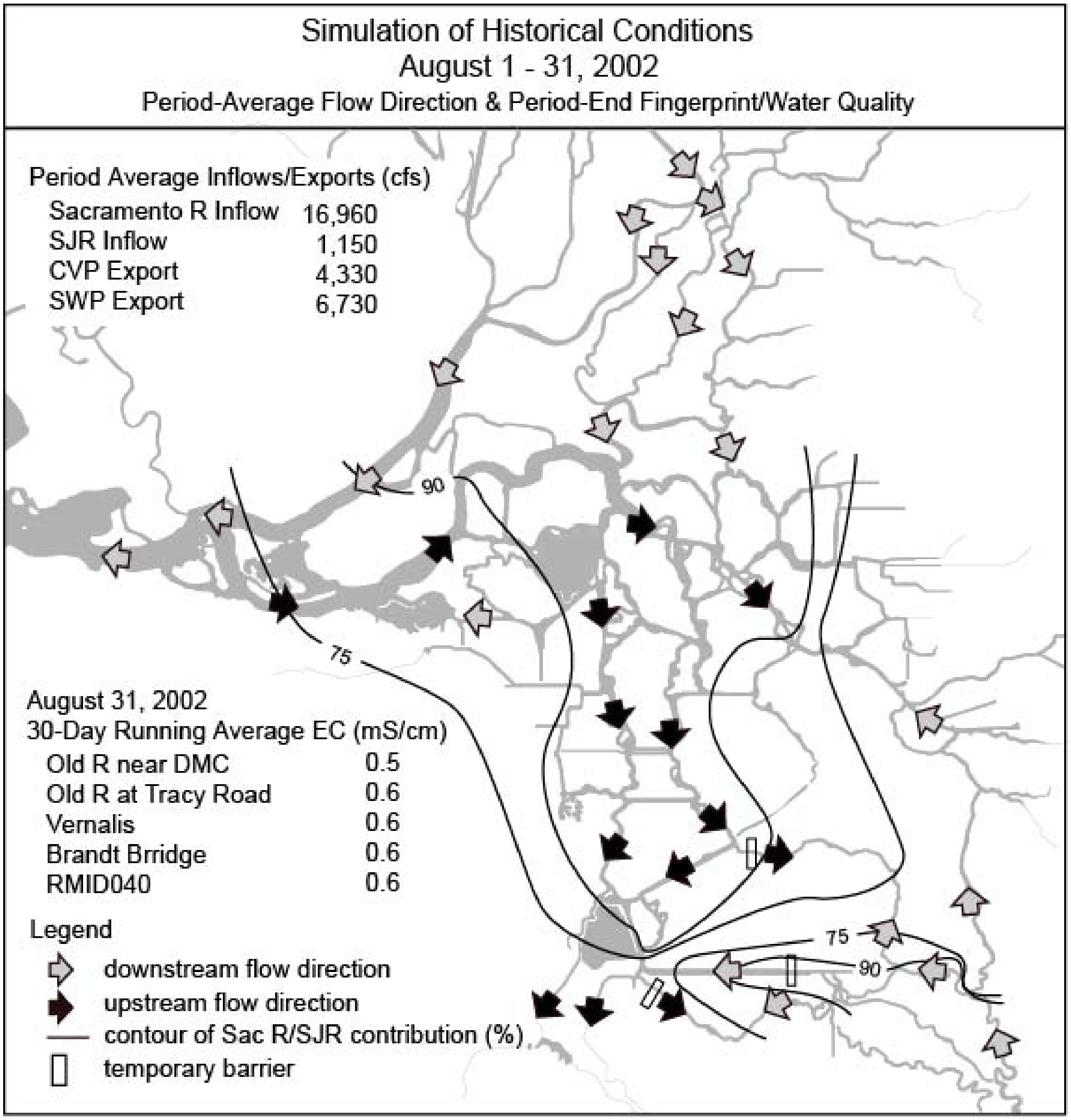


Figure 4f. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, historical conditions, August 1-31, 2002.



Simulation of Historical Conditions
August 1 - 31, 2002
Period-Average Flow Direction & Period-End Fingerprint/Water Quality

Period Average Inflows/Exports (cfs)

Sacramento R Inflow	16,960
SJR Inflow	1,150
CVP Export	4,330
SWP Export	6,730

August 31, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.5
Old R at Tracy Road	0.6
Vernalis	0.6
Brandt Brridge	0.6
RMID040	0.6

Figure 5a. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping and no barriers scenario, April 1-14, 2002.

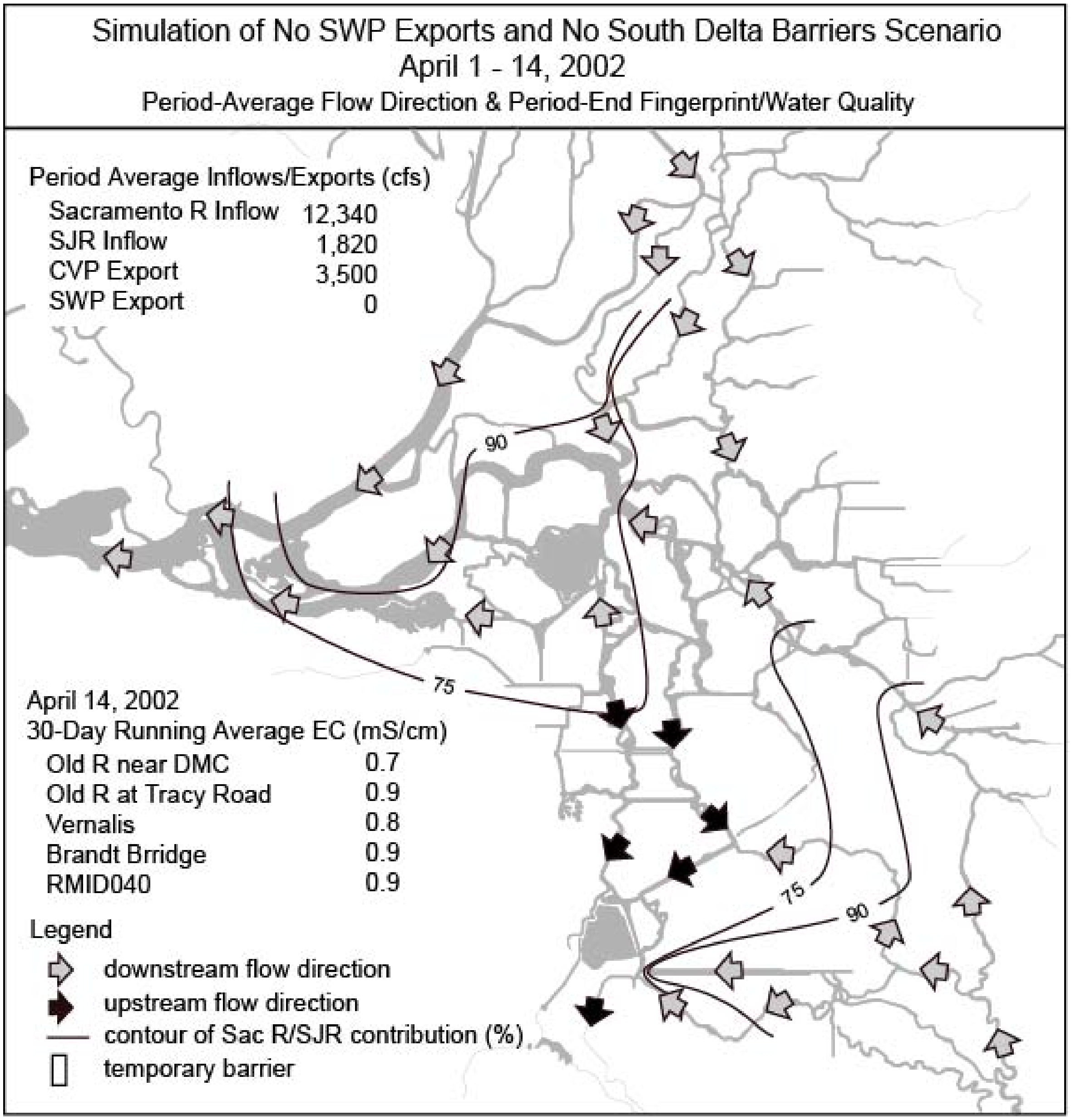


Figure 5b. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping and no barriers scenario, April 15-30, 2002.

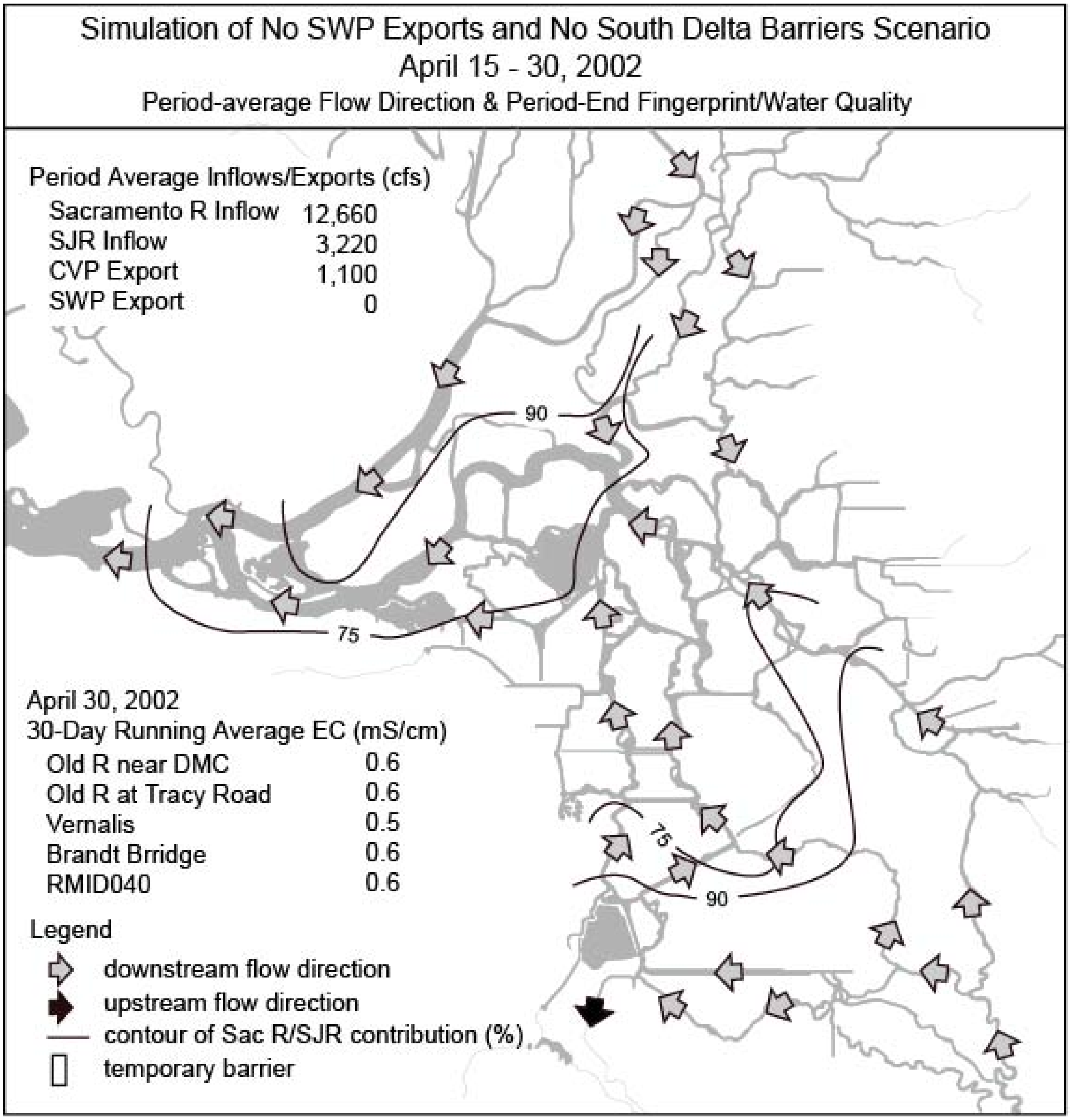


Figure 5c. DSM2-simulated period-average Delta-wide flow patterns and period- end fingerprints and EC, No SWP pumping and no barriers scenario, May 1-24, 2002.

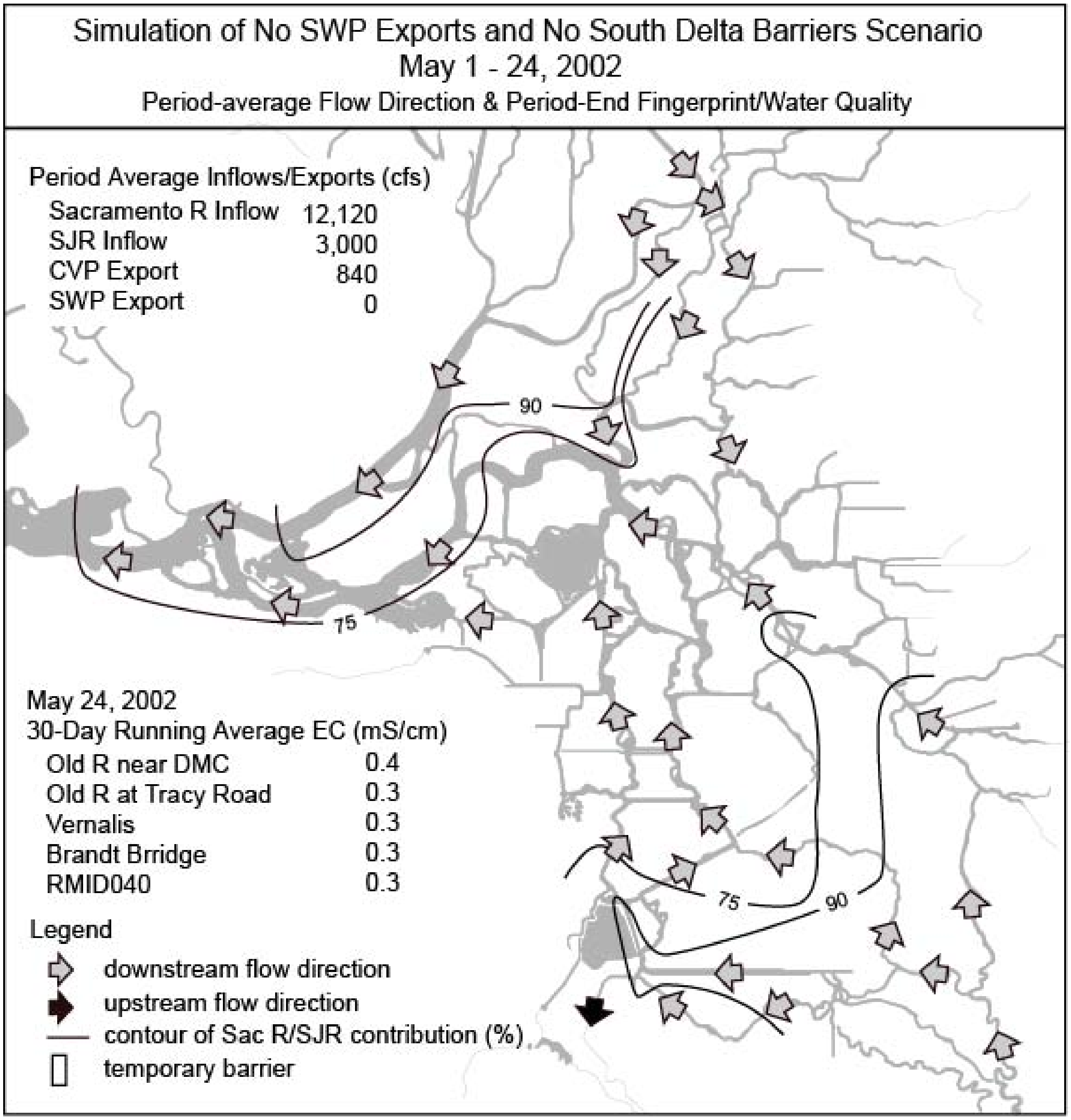
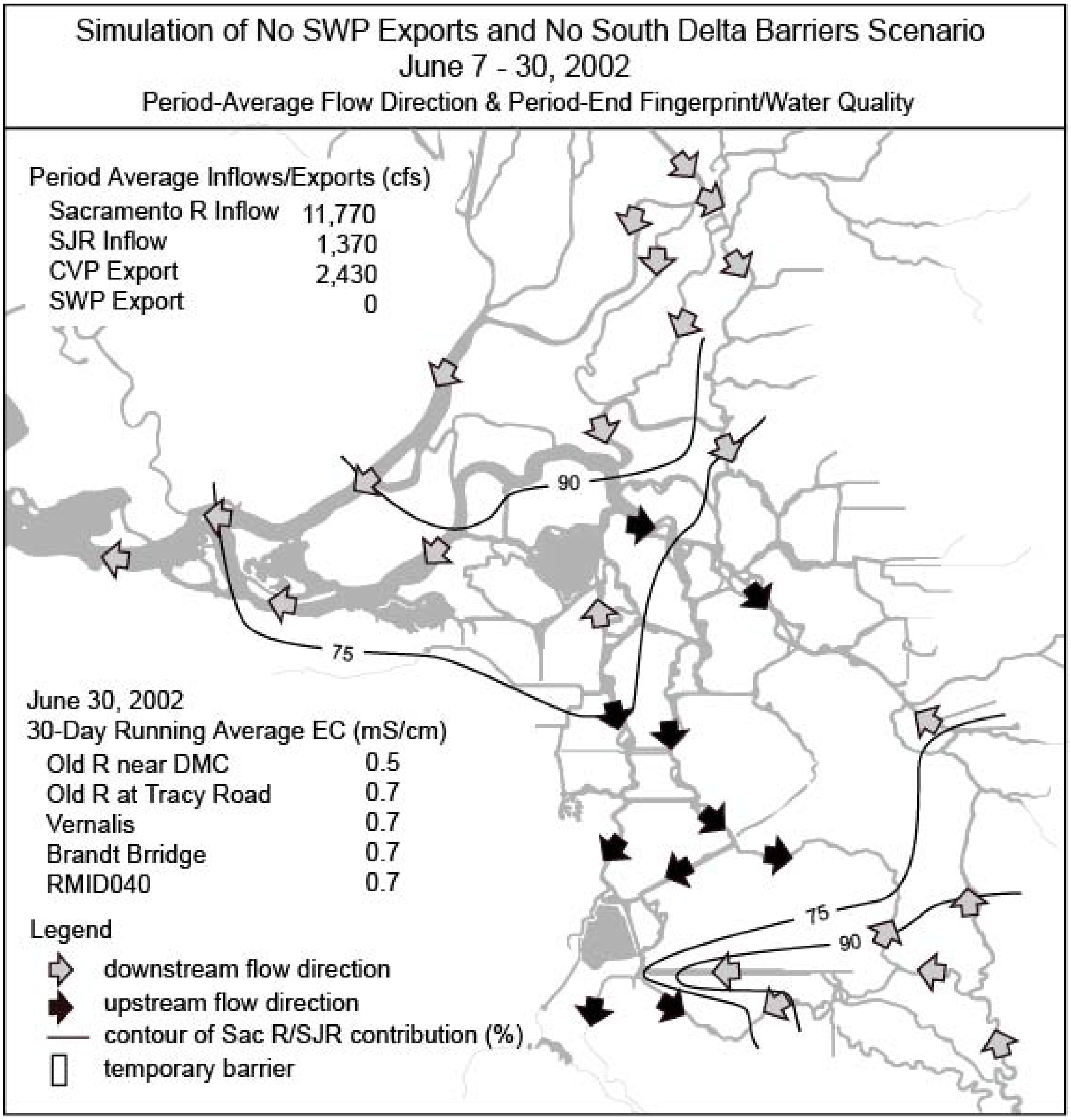


Figure 5d. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping and no barriers scenario, June 7-30, 2002.



Period Average Inflows/Exports (cfs)

Sacramento R Inflow	11,770
SJR Inflow	1,370
CVP Export	2,430
SWP Export	0

June 30, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.5
Old R at Tracy Road	0.7
Vernalis	0.7
Brandt Brridge	0.7
RMID040	0.7

Figure 5e. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping and no barriers scenario, July 1-31, 2002.

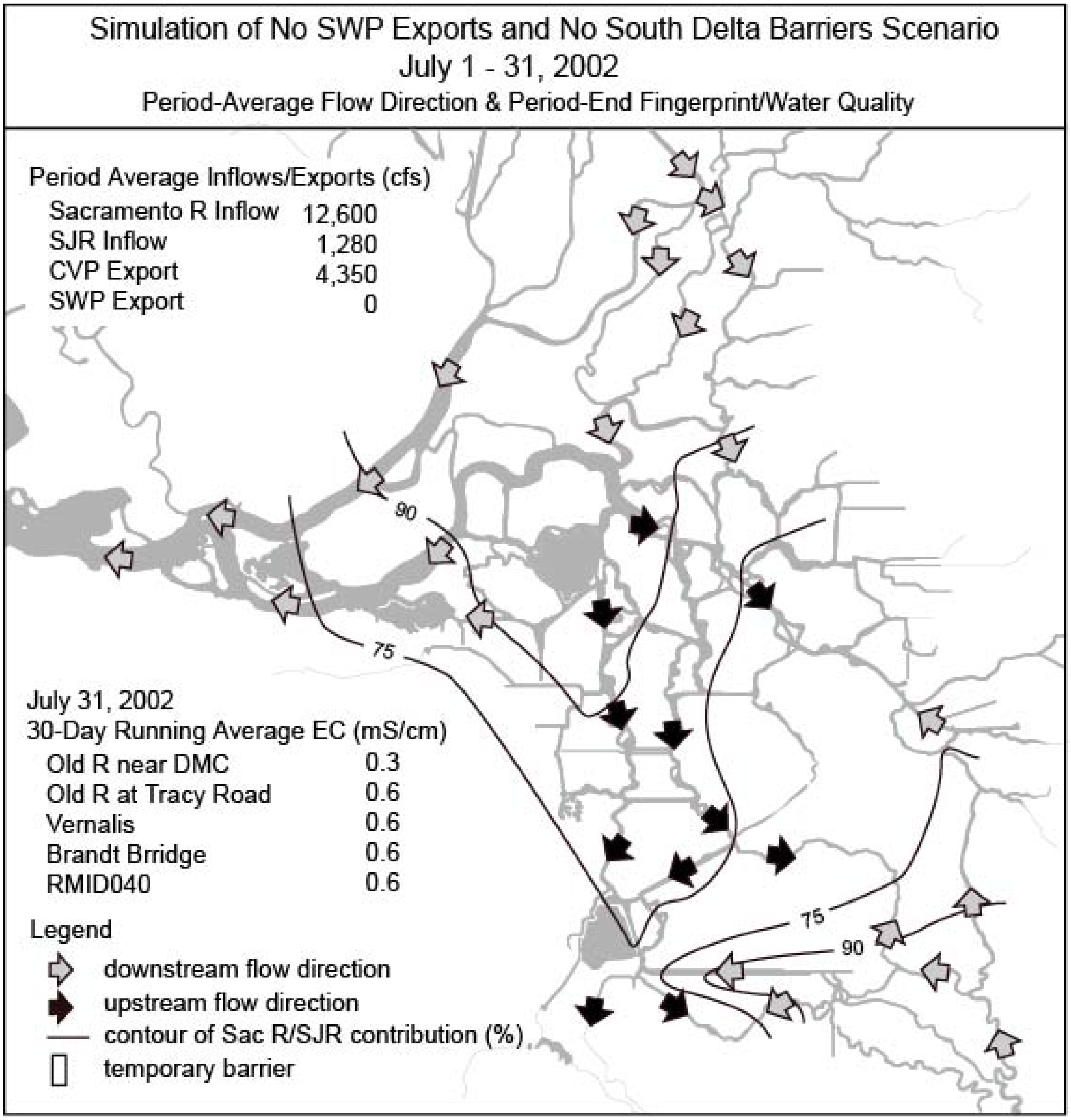
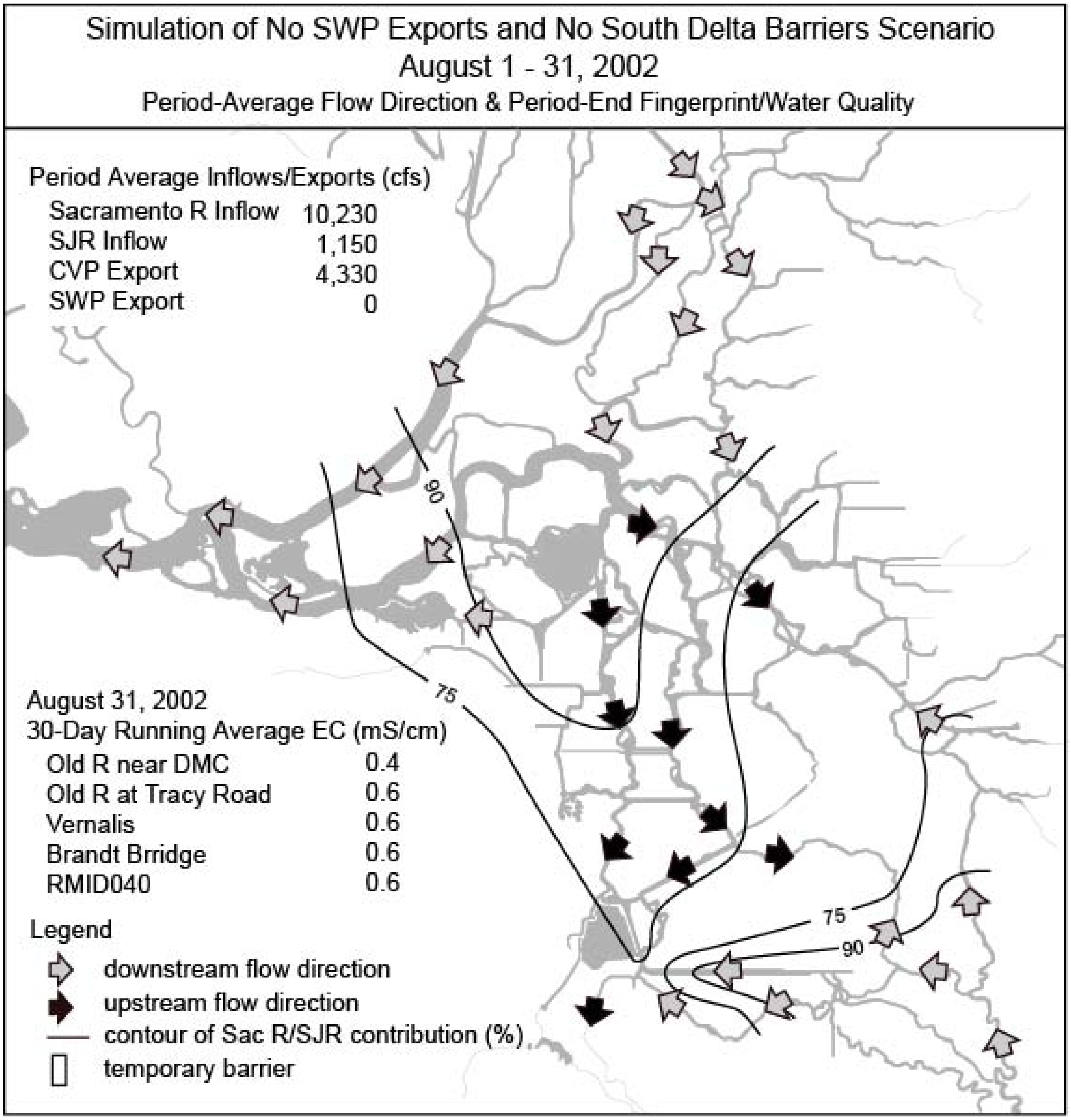


Figure 5f. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping and no barriers scenario, August 1-31, 2002.



Simulation of No SWP Exports and No South Delta Barriers Scenario
August 1 - 31, 2002
Period-Average Flow Direction & Period-End Fingerprint/Water Quality

Period Average Inflows/Exports (cfs)

Sacramento R Inflow	10,230
SJR Inflow	1,150
CVP Export	4,330
SWP Export	0

August 31, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.4
Old R at Tracy Road	0.6
Vernalis	0.6
Brandt Brridge	0.6
RMID040	0.6

Legend

⇨	downstream flow direction
➡	upstream flow direction
—	contour of Sac R/SJR contribution (%)
▯	temporary barrier

Figure 6a. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping, No CVP pumping, and no barriers scenario, April 1-14, 2002.

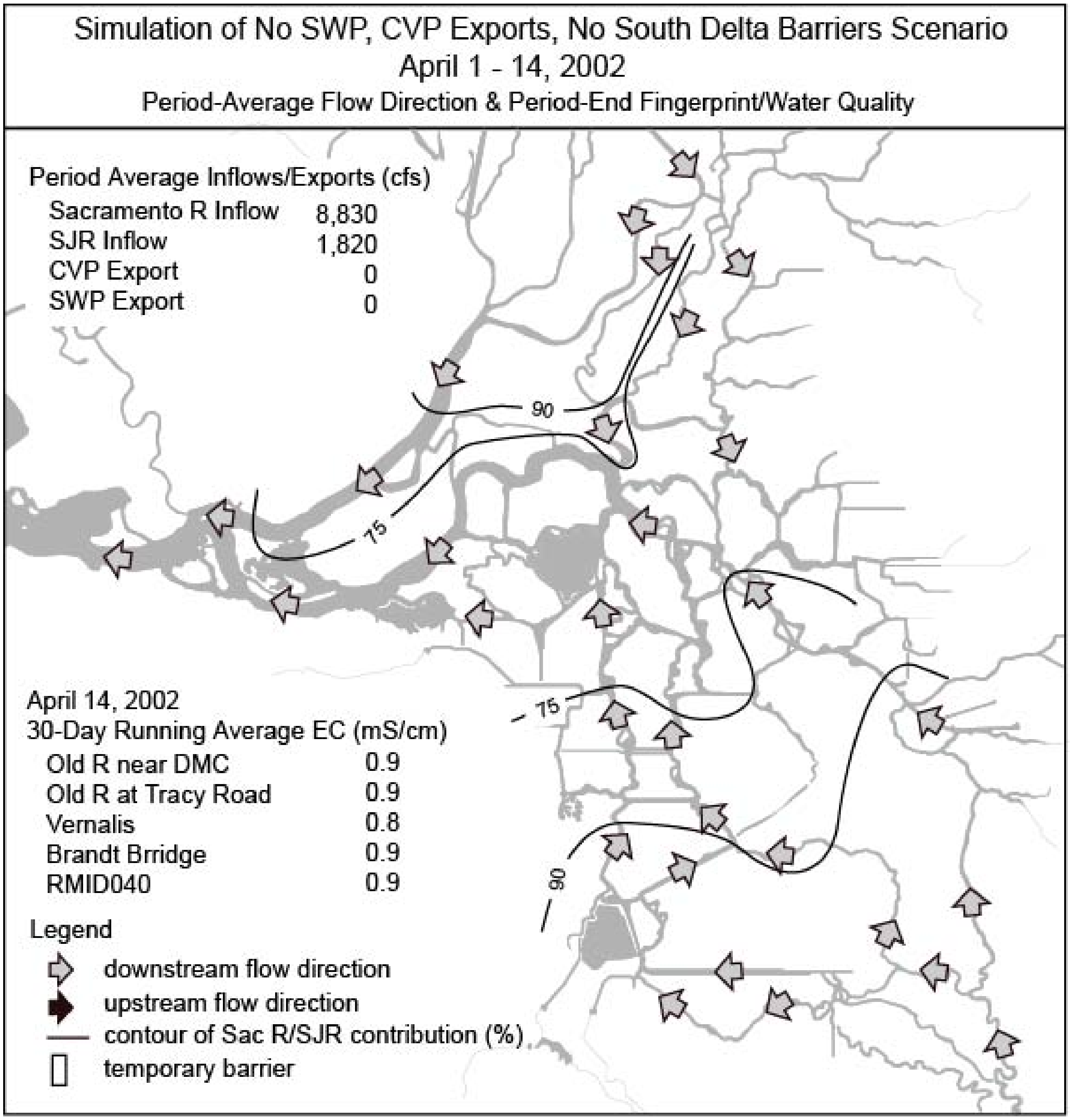
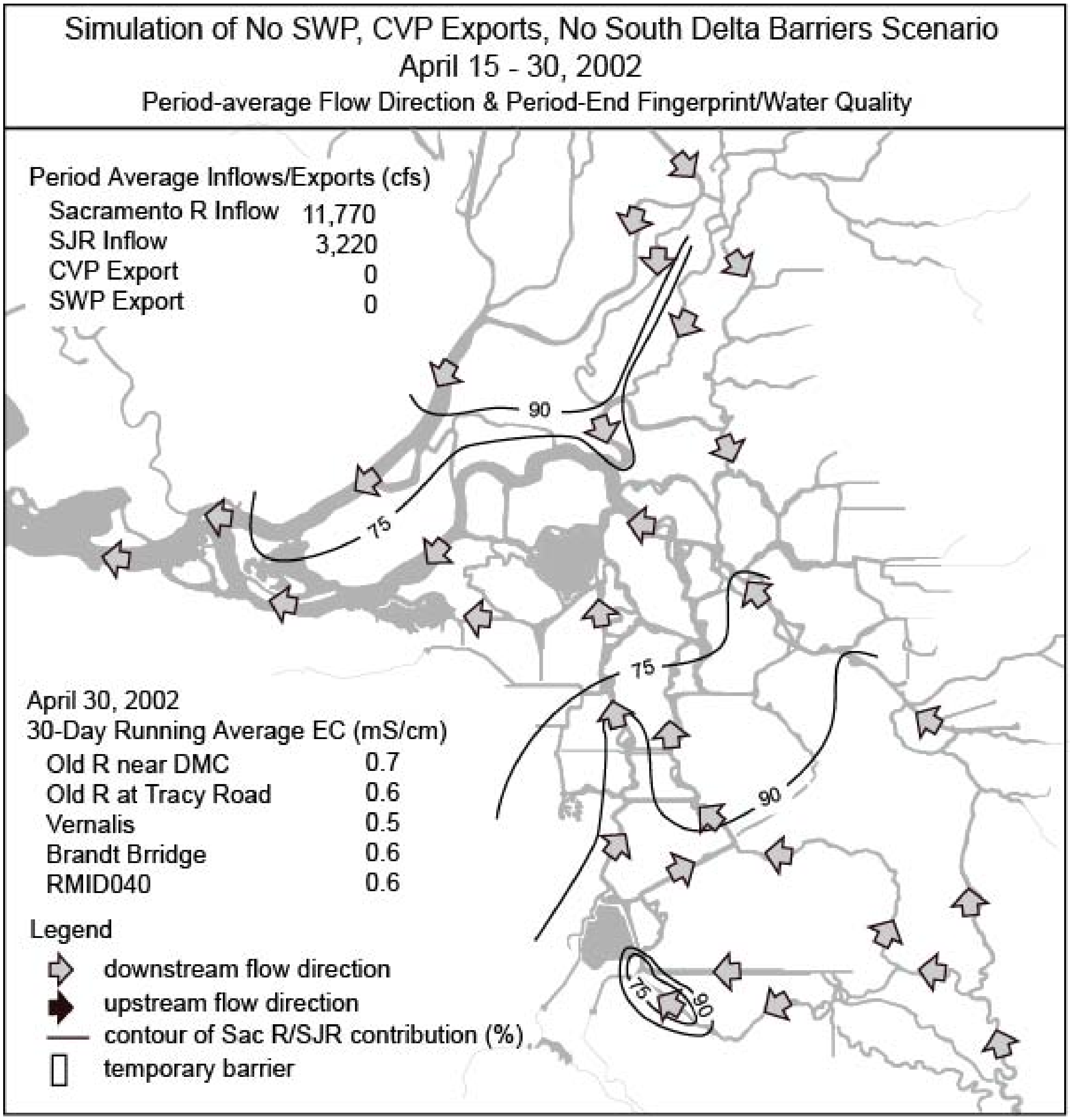


Figure 6b. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping, No CVP pumping, and no barriers scenario, April 15-30, 2002.



Simulation of No SWP, CVP Exports, No South Delta Barriers Scenario
April 15 - 30, 2002
Period-average Flow Direction & Period-End Fingerprint/Water Quality

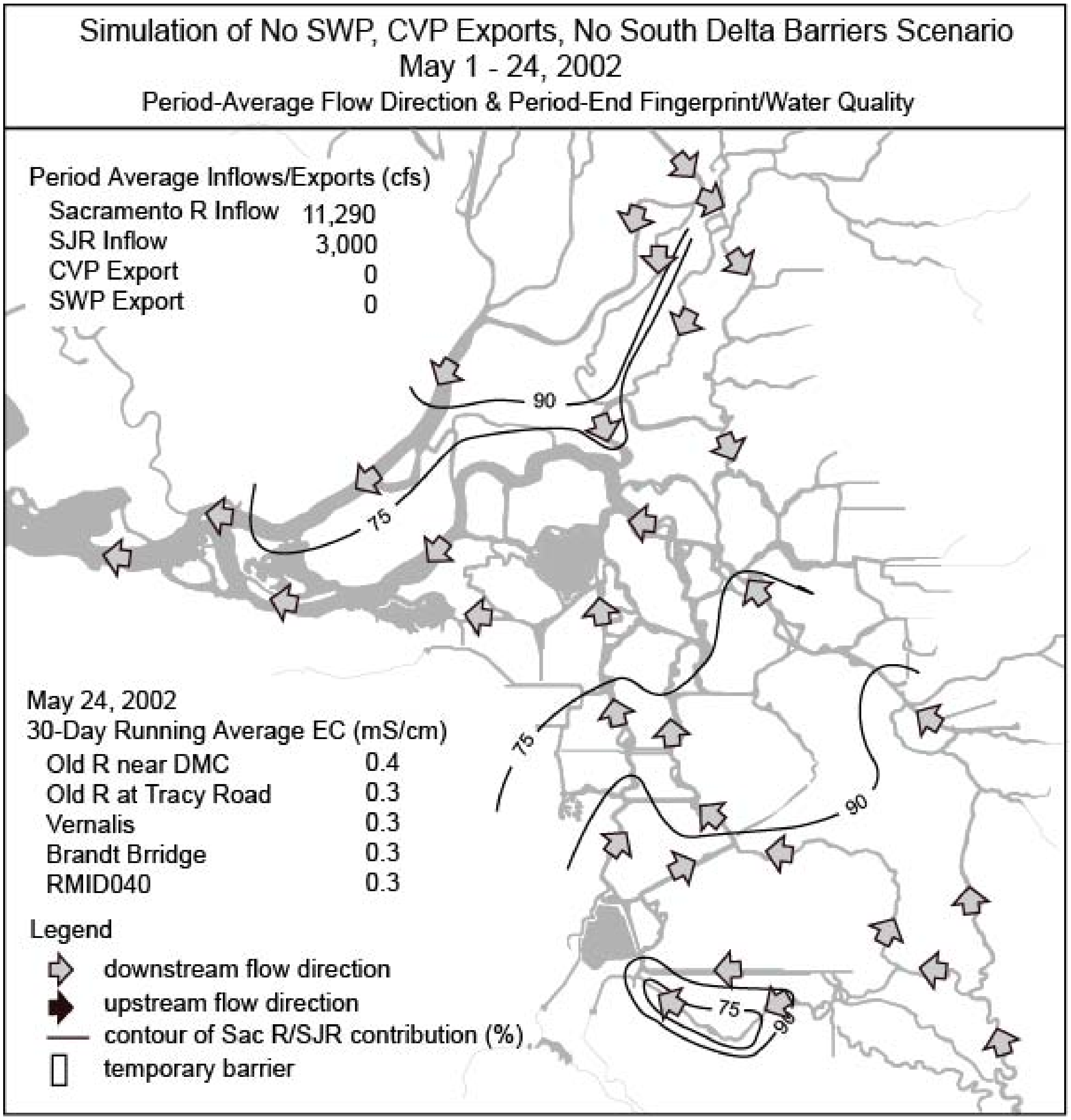
Period Average Inflows/Exports (cfs)

Sacramento R Inflow	11,770
SJR Inflow	3,220
CVP Export	0
SWP Export	0

April 30, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.7
Old R at Tracy Road	0.6
Vernalis	0.5
Brandt Brridge	0.6
RMID040	0.6

Figure 6c. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping, No CVP pumping, and no barriers scenario, May 1-24, 2002.



Simulation of No SWP, CVP Exports, No South Delta Barriers Scenario
May 1 - 24, 2002
Period-Average Flow Direction & Period-End Fingerprint/Water Quality

Period Average Inflows/Exports (cfs)

Sacramento R Inflow	11,290
SJR Inflow	3,000
CVP Export	0
SWP Export	0

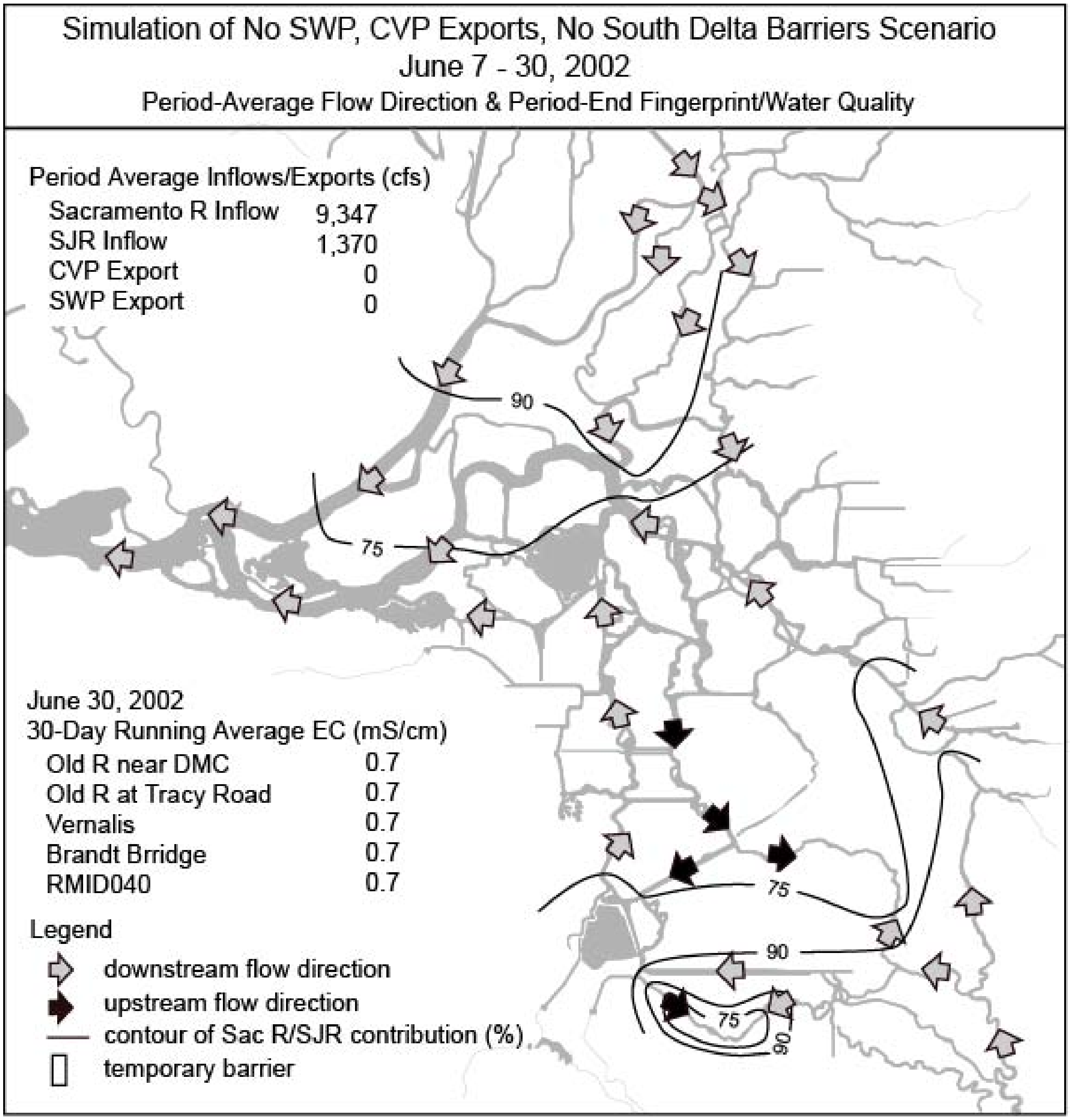
May 24, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.4
Old R at Tracy Road	0.3
Vernalis	0.3
Brandt Brridge	0.3
RMID040	0.3

Legend

⇨	downstream flow direction
➡	upstream flow direction
—	contour of Sac R/SJR contribution (%)
▯	temporary barrier

Figure 6d. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping, No CVP pumping, and no barriers scenario, June 7-30, 2002.



Simulation of No SWP, CVP Exports, No South Delta Barriers Scenario
June 7 - 30, 2002
Period-Average Flow Direction & Period-End Fingerprint/Water Quality

Period Average Inflows/Exports (cfs)

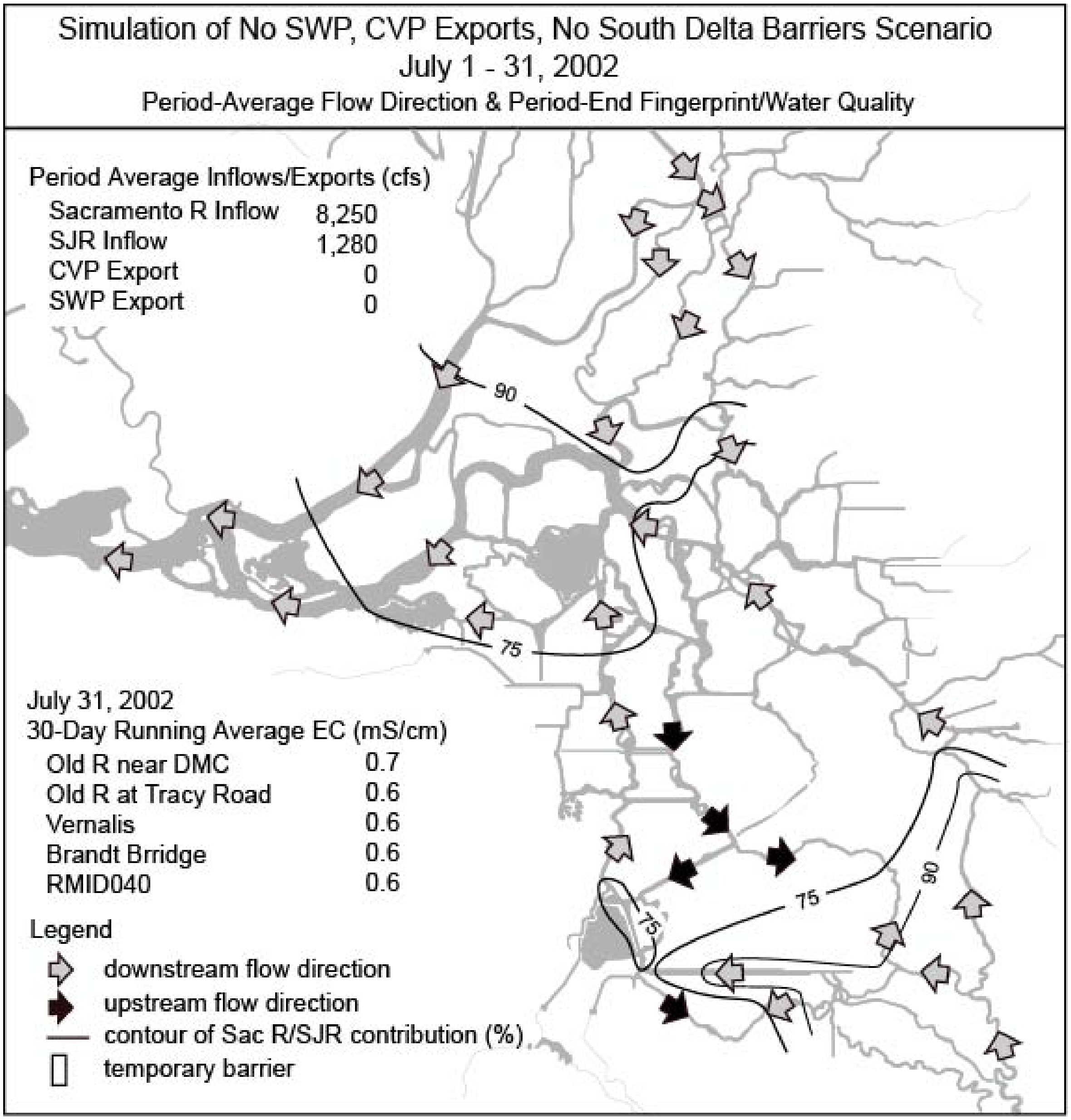
Sacramento R Inflow	9,347
SJR Inflow	1,370
CVP Export	0
SWP Export	0

June 30, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.7
Old R at Tracy Road	0.7
Vernalis	0.7
Brandt Brridge	0.7
RMID040	0.7

Legend

Figure 6e. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping, No CVP pumping, and no barriers scenario, July 1-31, 2002.



Simulation of No SWP, CVP Exports, No South Delta Barriers Scenario
July 1 - 31, 2002
Period-Average Flow Direction & Period-End Fingerprint/Water Quality

Period Average Inflows/Exports (cfs)

Sacramento R Inflow	8,250
SJR Inflow	1,280
CVP Export	0
SWP Export	0

July 31, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.7
Old R at Tracy Road	0.6
Vernalis	0.6
Brandt Brridge	0.6
RMID040	0.6

Figure 6f. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, No SWP pumping, No CVP pumping, and no barriers scenario, August 1-31, 2002.

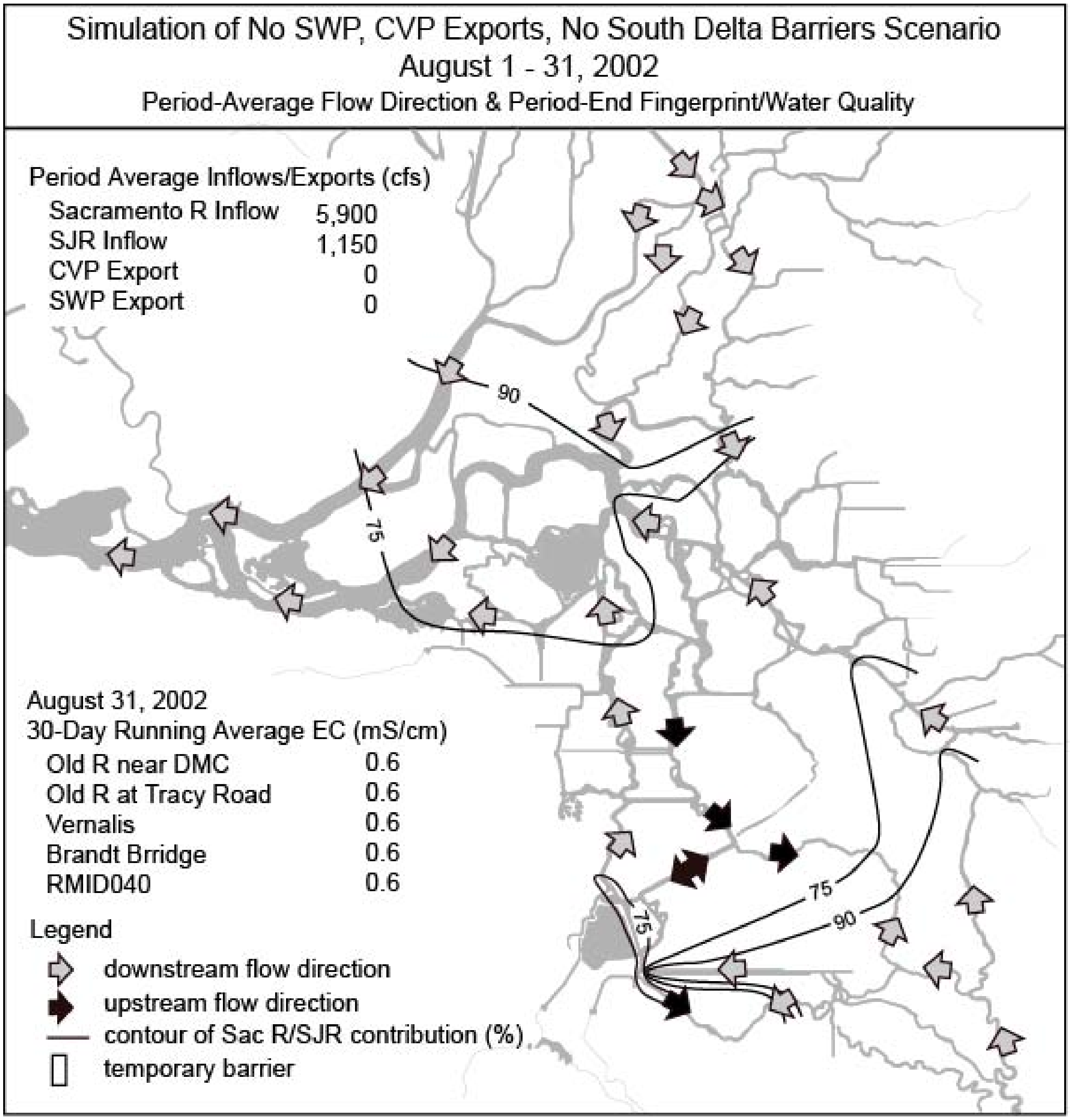
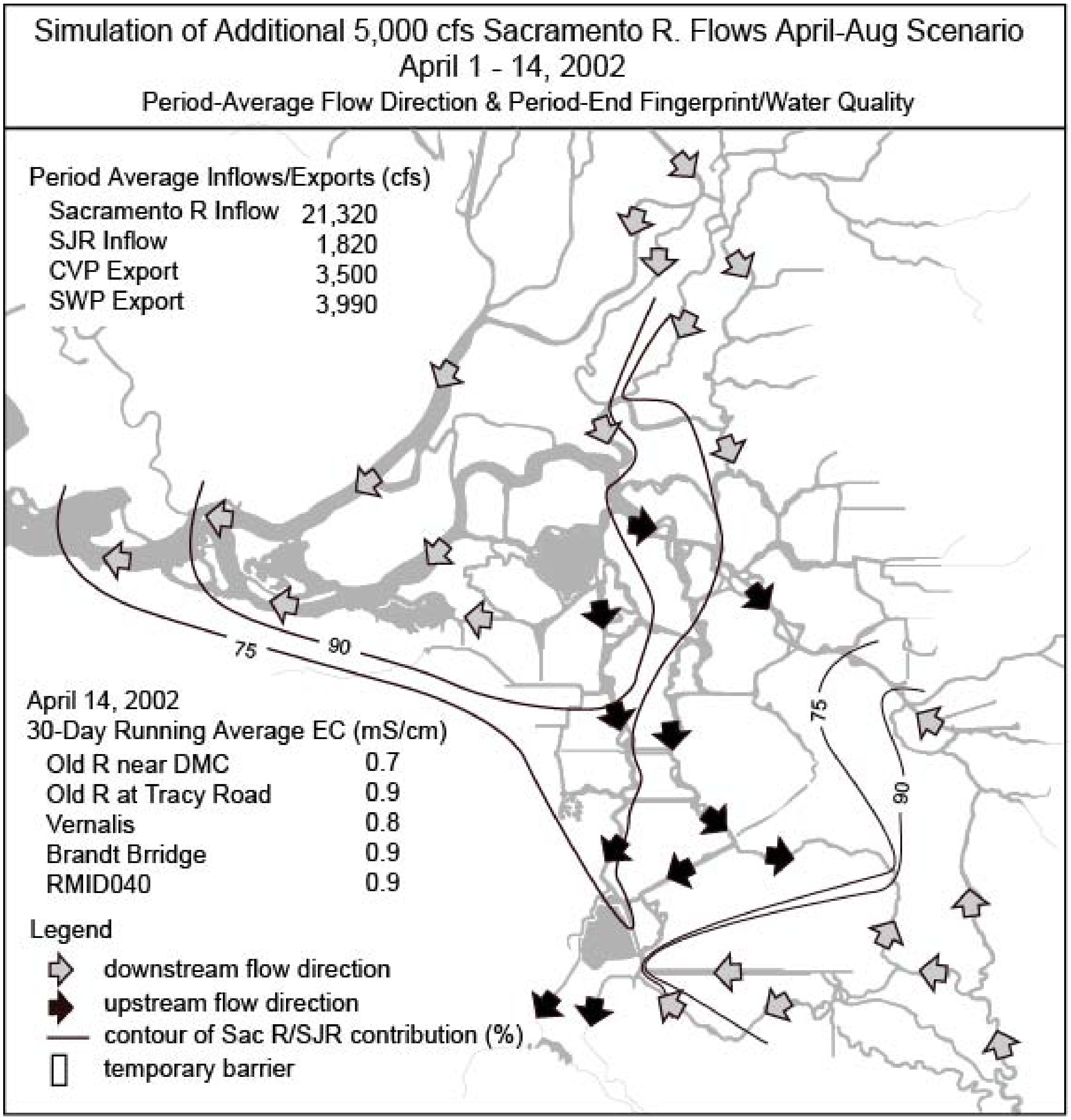


Figure 7a. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, additional Sacramento River flows scenario, April 1-14, 2002.

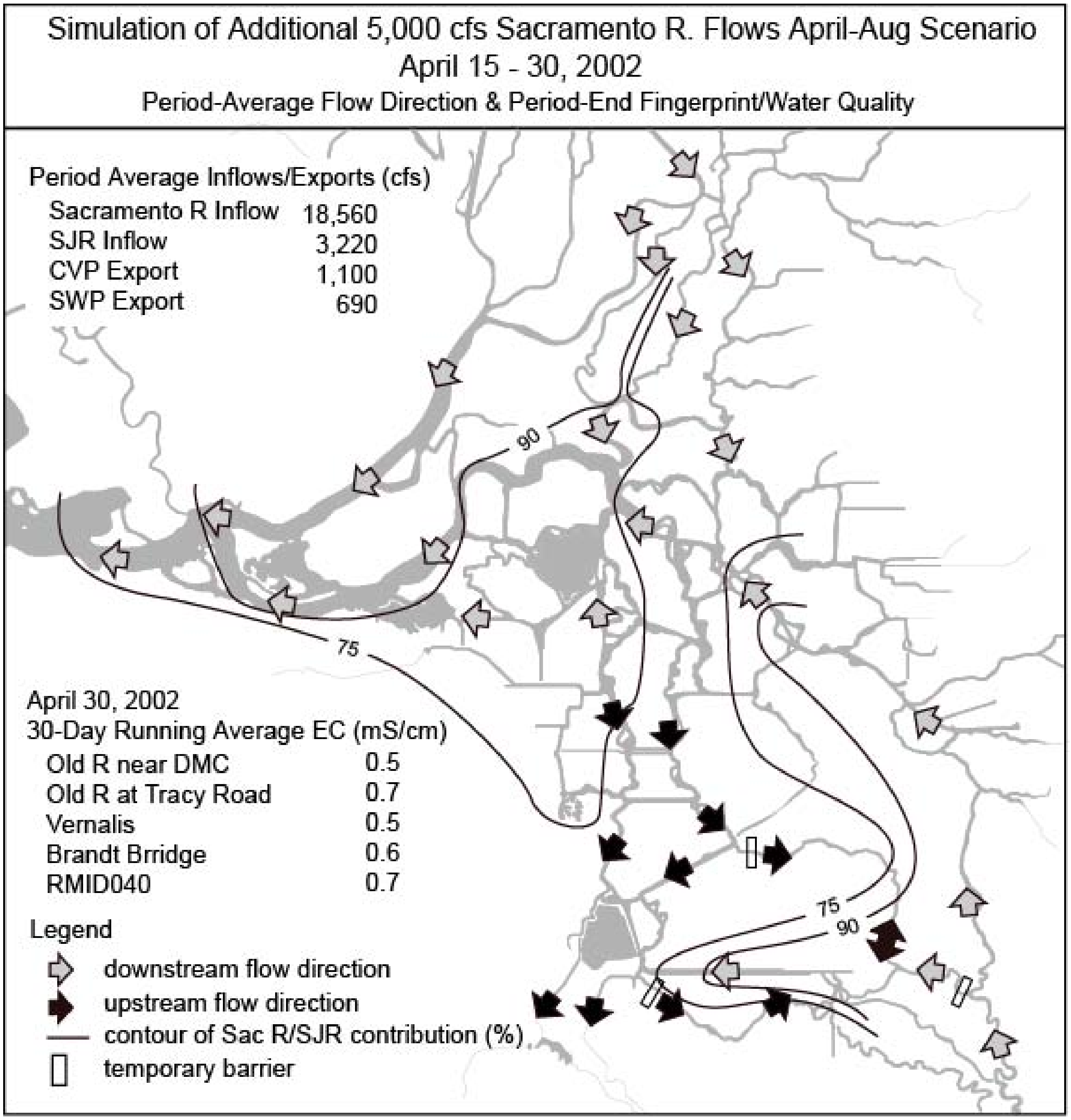


Simulation of Additional 5,000 cfs Sacramento R. Flows April-Aug Scenario
April 1 - 14, 2002
Period-Average Flow Direction & Period-End Fingerprint/Water Quality

Period Average Inflows/Exports (cfs)	
Sacramento R Inflow	21,320
SJR Inflow	1,820
CVP Export	3,500
SWP Export	3,990

April 14, 2002 30-Day Running Average EC (mS/cm)	
Old R near DMC	0.7
Old R at Tracy Road	0.9
Vernalis	0.8
Brandt Brridge	0.9
RMID040	0.9

Figure 7b. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, additional Sacramento River flows scenario, April 15-30, 2002.



Period Average Inflows/Exports (cfs)

Sacramento R Inflow	18,560
SJR Inflow	3,220
CVP Export	1,100
SWP Export	690

April 30, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.5
Old R at Tracy Road	0.7
Vernalis	0.5
Brandt Brridge	0.6
RMID040	0.7

Figure 7c. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, additional Sacramento River flows scenario, May 1-24, 2002.

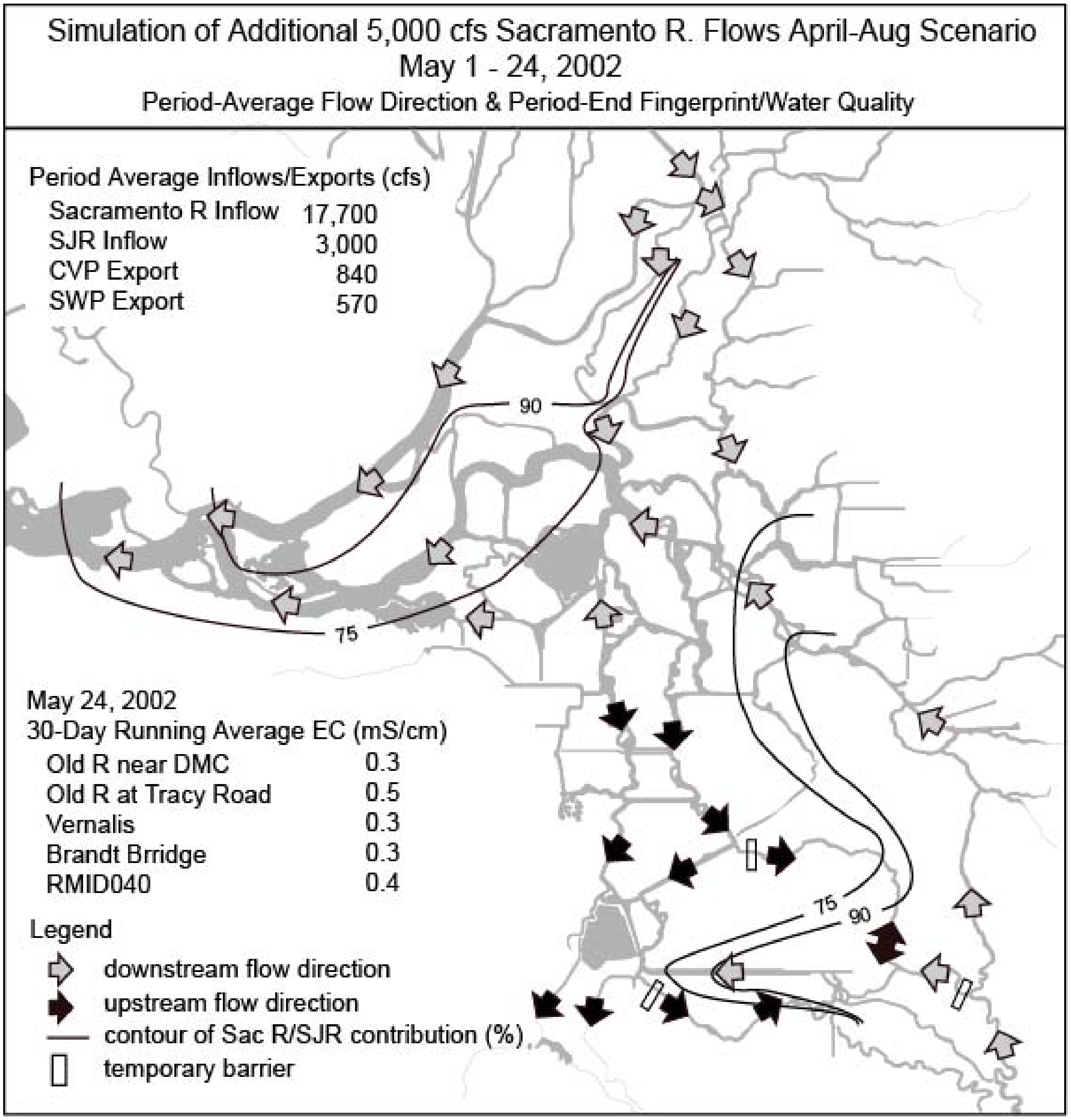
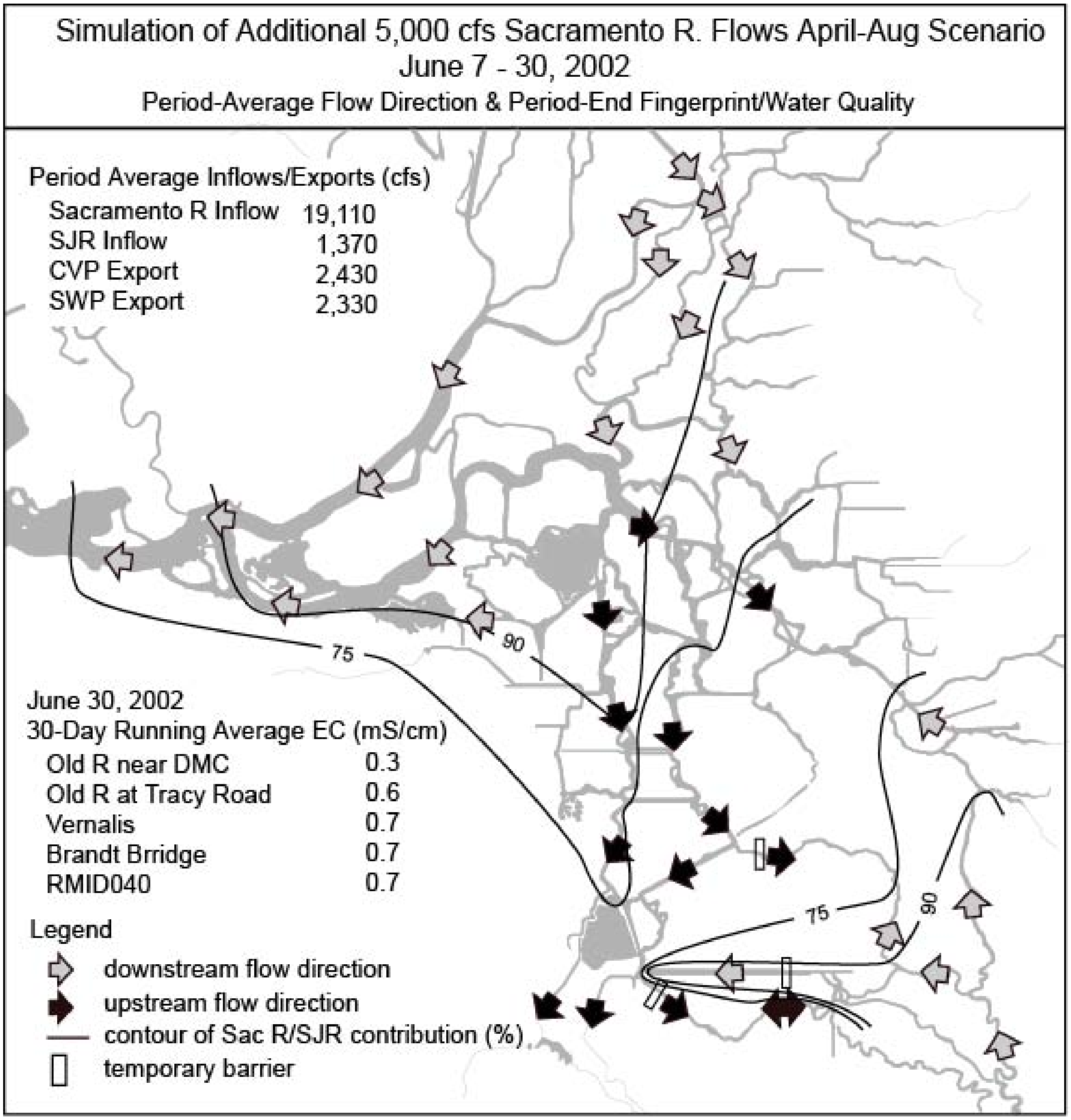


Figure 7d. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, additional Sacramento River flows scenario, June 7-30, 2002.



Simulation of Additional 5,000 cfs Sacramento R. Flows April-Aug Scenario
June 7 - 30, 2002
Period-Average Flow Direction & Period-End Fingerprint/Water Quality

Period Average Inflows/Exports (cfs)

Sacramento R Inflow	19,110
SJR Inflow	1,370
CVP Export	2,430
SWP Export	2,330

June 30, 2002
30-Day Running Average EC (mS/cm)

Old R near DMC	0.3
Old R at Tracy Road	0.6
Vernalis	0.7
Brandt Brridge	0.7
RMID040	0.7

Figure 7e. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, additional Sacramento River flows scenario, July 1-31, 2002.

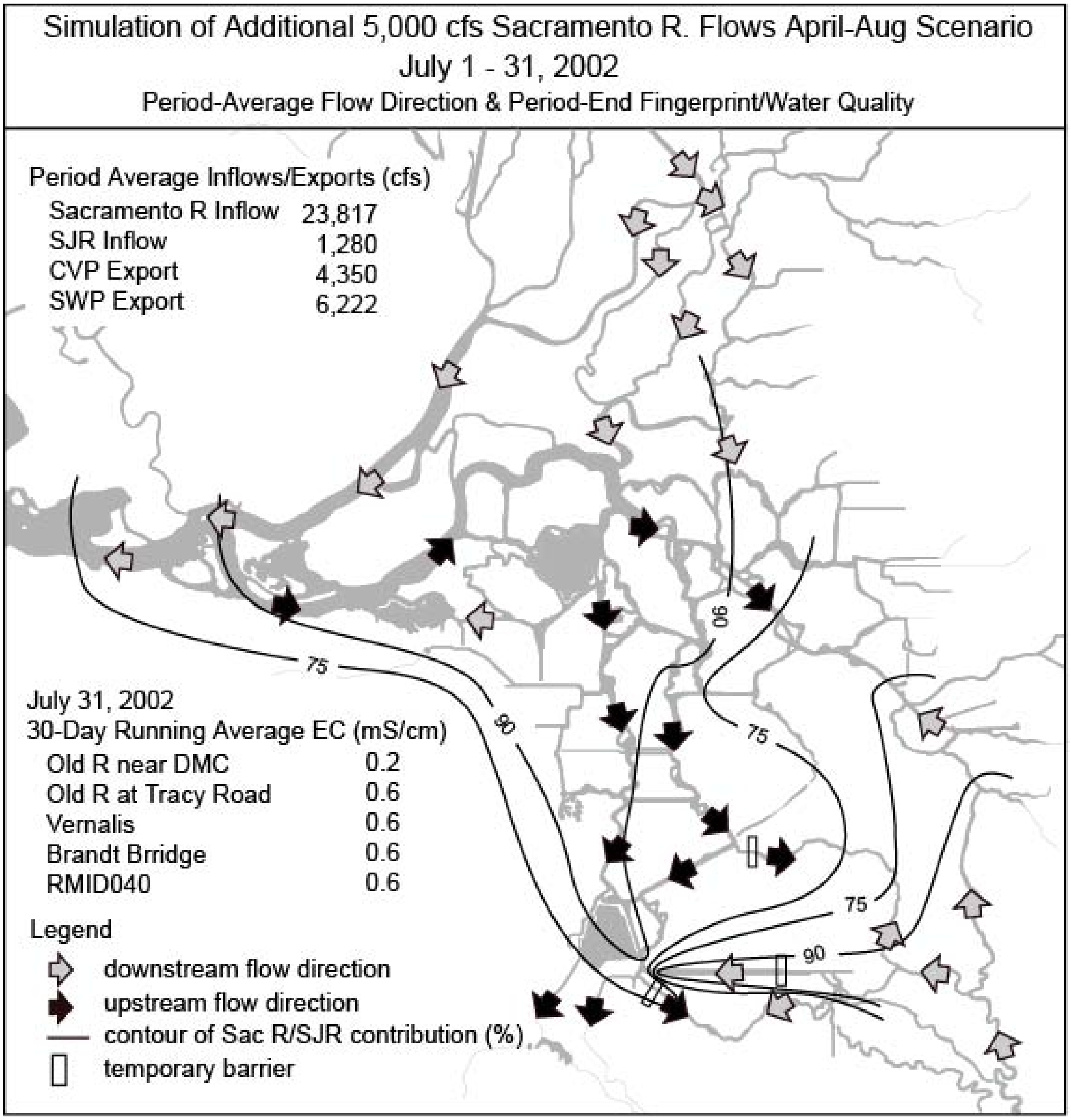


Figure 7f. DSM2-simulated period-average Delta-wide flow patterns and period-end fingerprints and EC, additional Sacramento River flows scenario, August 1-31, 2002.

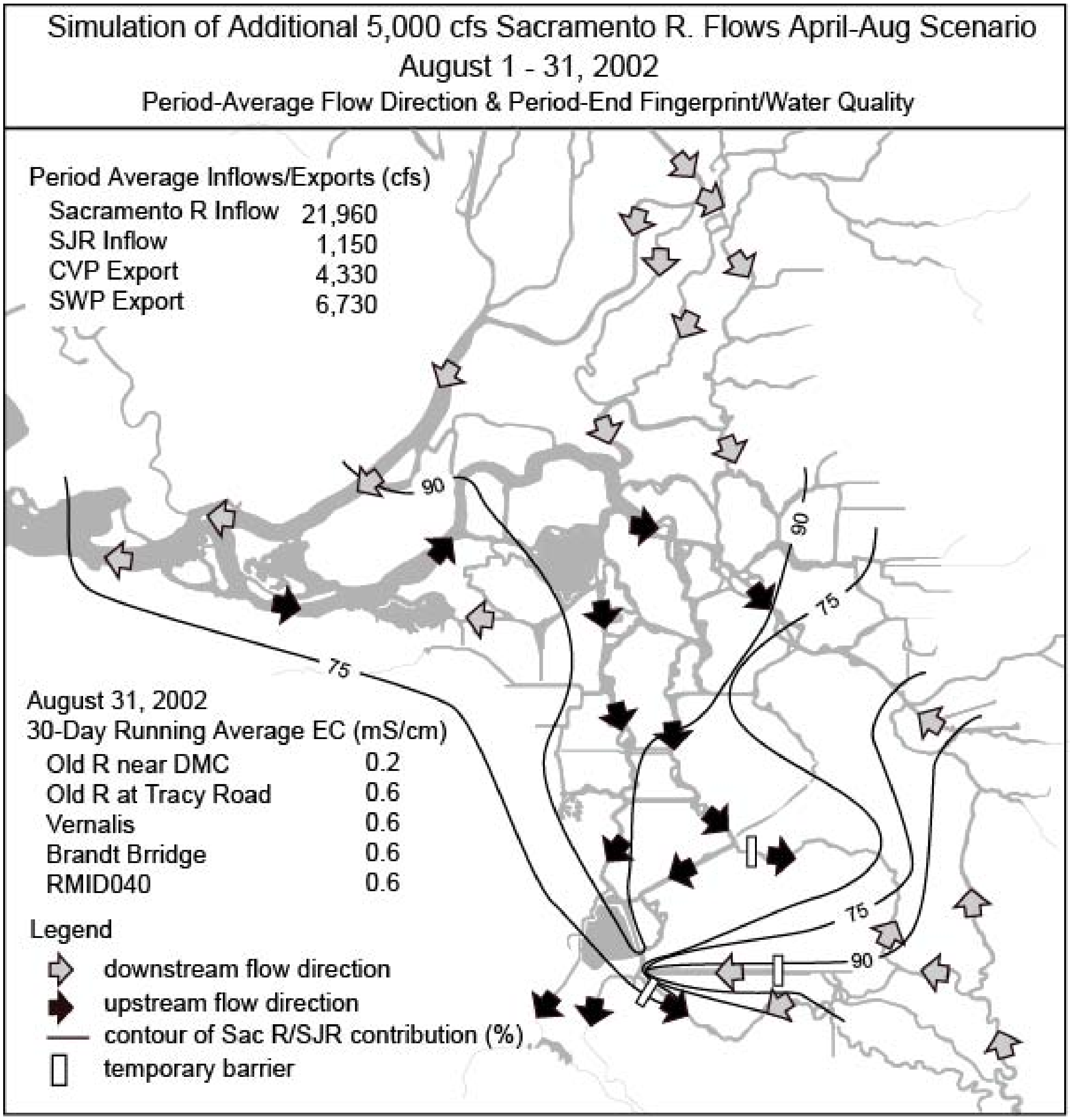
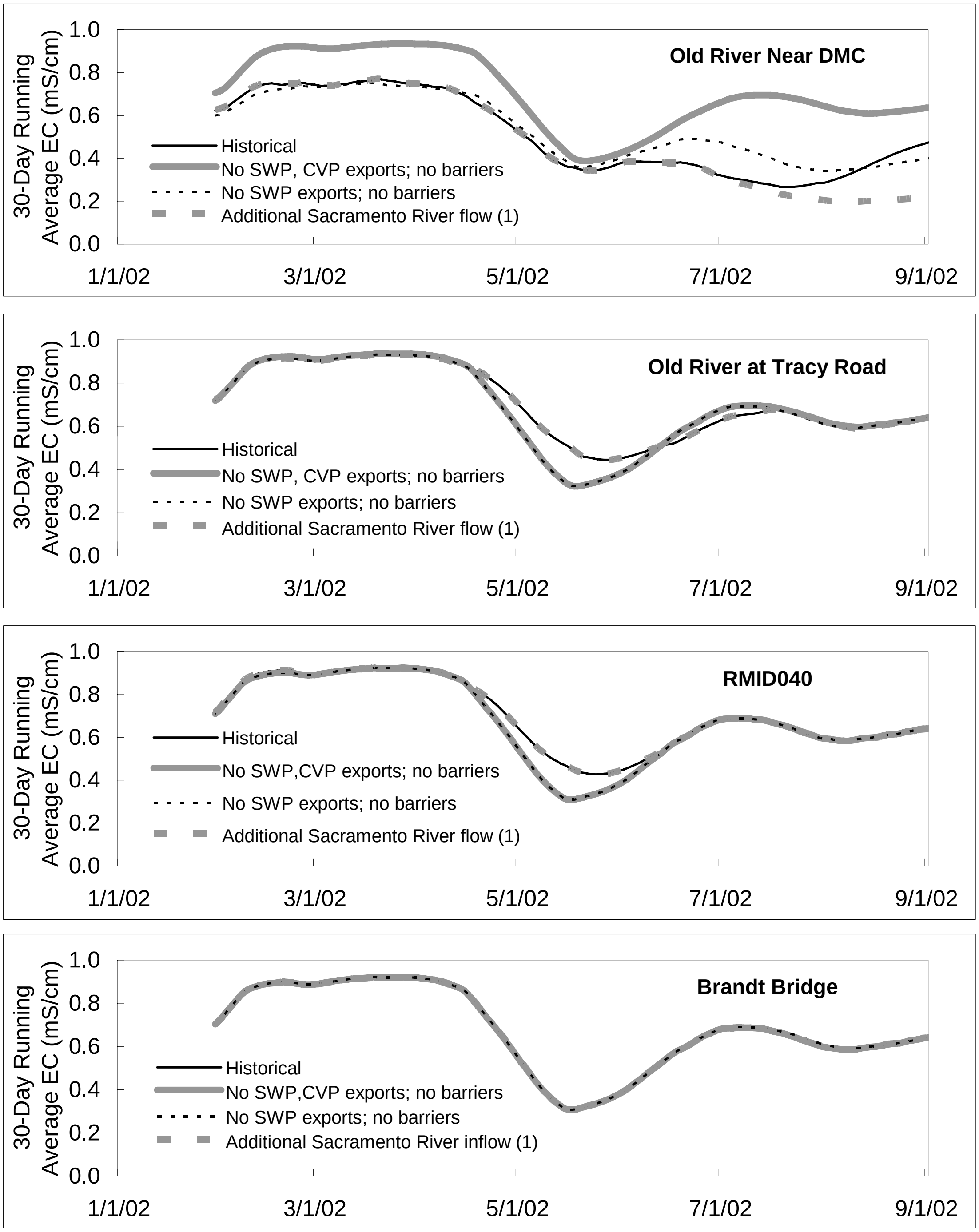


Figure 8. DSM2-simulated daily average EC under scenarios inducing significant changes in Delta-wide flow patterns.



(1) Sac River inflow increased 5,000 cfs over historical flow for April - Sep of 2002.

Impact of South Delta Barrier Installation on South Delta Circulation and Water Quality

To demonstrate the effect of south Delta barrier installation on south Delta circulation patterns and south Delta EC, two scenarios were simulated to compare to the historical 2002 simulation. The first scenario assumes no barriers installed. This scenario maximizes using San Joaquin River inflow to create favorable circulation in the south Delta. The second scenario assumes the installation of the barriers at Old River, Middle River, and Old River at Head during the entire April 1 – October 30 period. This scenario maximizes circulating water originating from the Sacramento River through the south Delta channels. Since SWP and CVP pumping and Sacramento River inflow in these simulations are the same as for the historical simulation, the focus of the analysis is more on EC and local circulation of water, specifically the direction and magnitude of period-average flows in the south Delta. When the barrier at the Head of Old River is installed in this analysis, it is assumed 6 culverts are open to allow some of the San Joaquin River to flow down Old River.

Figures 9a-9f shows the period-average flows with flow direction and end-of-period daily average EC at the study sites for the historical 2002 simulation and the scenarios maximizing circulation of San Joaquin River-source water and Sacramento River-source water. In general terms, when no barriers are installed in the south Delta, a large portion of the water entering the south Delta via the San Joaquin River flows down Grant Line Canal. When the water flowing down Old and Middle River are more than enough to meet local agricultural diversion along the rivers, period-average flows tend to be downstream. As agricultural demands along a river reach increase, period average flows on the boundary of the reach may converge. When period-average flow in Middle River near Old River compared to the flow in Middle River near the barrier site and in Old River near DMC compared the flow in Old River at the Tracy Road Bridge converge, relatively poor circulation is indicated and less salt from agricultural return flows is being flushed out of the reach. Installing the temporary rock barriers in the south Delta can greatly complicate circulation. The barriers in Old and Middle rivers allow water to move upstream with the flood tide and then restrict downstream flow during the ebb tide. This results in average flow immediately upstream of these two barriers being in the upstream direction. If the net flow is sufficiently high and there is no constraint of flow down Grant Line Canal, water can potentially circulate up Old and Middle rivers and down Grant Line Canal. However, the barriers can also induce poor circulation by restricting downstream flow, especially when the Grant Line Canal barrier is installed to restrict flow down this natural outlet.

For the 2002 historical simulation, the Old River, Middle River, and Old River at Head barriers are assumed installed from April 15 through May 24., and from June 7 through October, the Old River, Middle River, and Grant Line Canal barriers are assumed installed. Under historical conditions, circulation in Middle and Old rivers appears to be persistently unfavorable when the Old River, Middle River, and Grant Line Canal barriers are simultaneously installed. Significantly better circulation seems to occur when the Old River, Middle River, and Old River at Head barriers are all installed. However, because the flow and EC in the San Joaquin River and the SWP and CVP pumping is different under these different barrier configurations, comparing EC in the 2002 historical simulation between different periods is not informative. Therefore the results of the two other scenarios are presented.

Not installing south Delta barriers results in more San Joaquin River water flowing down the head of Old River. However unfavorable circulation patterns persist in Old and Middle Rivers from June through August due to channel characteristics and agricultural diversions. Water in the south Delta channels then can be expected to originate mostly from the San Joaquin River with some local agricultural drainage significantly contributing when circulation is particularly poor.

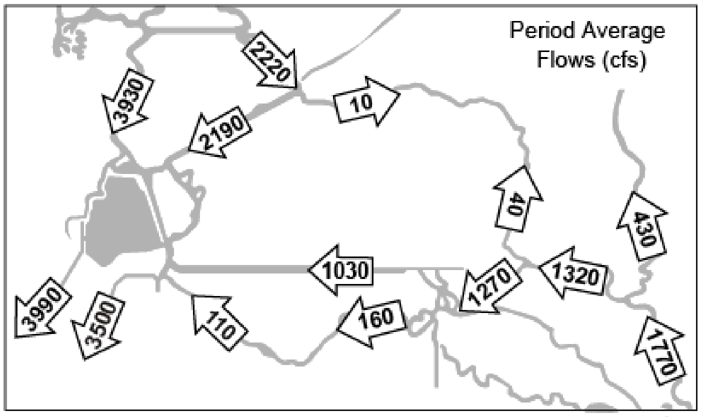
Installing the Old River, Middle River, and Old River at Head barriers results in desirable circulation in Old River from April through August and Middle River from April through May. The circulation pattern in Old River under this scenario indicates that water downstream of the Old River barrier, with at times a significant portion of water originating in the Sacramento River, can be significantly lower in EC than the San Joaquin River inflow. Thus, this barrier configuration has the potential of not only moving agricultural salts out of the south Delta channels, but this circulation is induced with better quality water than if the San Joaquin River is used to flush Old River.

Figure 10 compares the EC at the study sites under simulated historical 2002 conditions and the two scenarios. Maximizing San Joaquin River water circulating in south Delta channels increases the EC in Old River near DMC because without the Old River barrier, less Sacramento River-source water is retained in this vicinity. At Old River at Tracy Road and RMID040, maximizing San Joaquin River water circulating lowers the EC in May. This corresponds to the better circulation pattern mentioned above. The increase in EC from Vernalis to Old River at Tracy Road (0.2 mS/cm) and Vernalis to RMID040 (0.1mS/cm) seen in the historical 2002 simulation for May 24th, is absent when the barriers are removed. Removing the barriers also results in a significant decrease in EC at Brandt Bridge in July and August. This is due to inducing reverse flows in the upper San Joaquin River, bringing more water of Sacramento origin to the vicinity of Brandt Bridge. Figure 10 shows that installing the Old River, Middle River, and Old River at Head barriers on April 1 provides additional improvement to EC at Old River at Tracy Road and RMID040 on April 30 compared to waiting until April 15 as in the historical simulation. The EC at Old River at Tracy Road and RMID040 under the scenario maximizing Sacramento-source water circulation is significantly lower when than the historical simulation when the Grant Line Barrier is installed, which is consistent with the improved circulation discussed above.

Figure 9a. DSM2-simulated period-average south Delta flows and period-end EC, historical, maximizing San Joaquin River for circulation, and maximizing San Joaquin River circulation scenarios, April 1-14, 2002.

April 1-14, 2002

Historical Conditions



Key Simulation Information

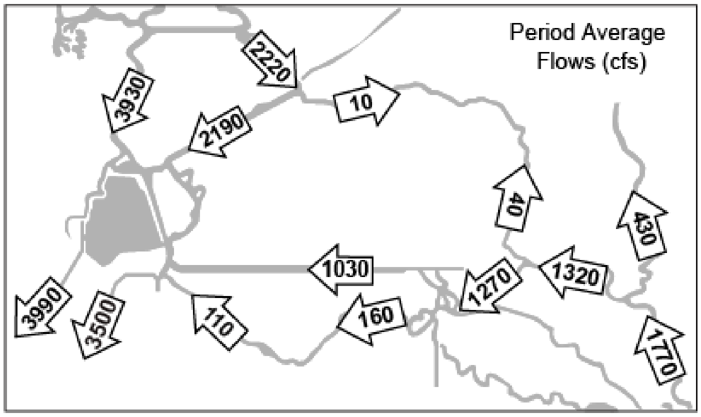
No barriers installed

SJR Inflow (avg)	1,820 cfs
CVP Export (avg)	3,500 cfs
SWP Export (avg)	3,990 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.7
Old R at Tracy Road	0.9
Vernalis	0.8
Brandt Brridge	0.9
RMID040	0.9

Maximizing San Joaquin River as Source (no barriers installed)



Key Simulation Information

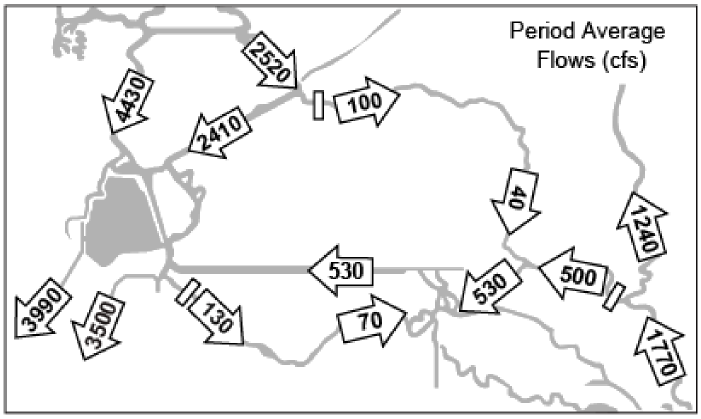
No barriers installed

SJR Inflow	1,820 cfs
CVP Export	3,500 cfs
SWP Export	3,990 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.7
Old R at Tracy Road	0.9
Vernalis	0.8
Brandt Brridge	0.9
RMID040	0.9

Maximizing Sacramento River as Source
(Old River, Old River at Head, Middle River barriers installed)



Key Simulation Information

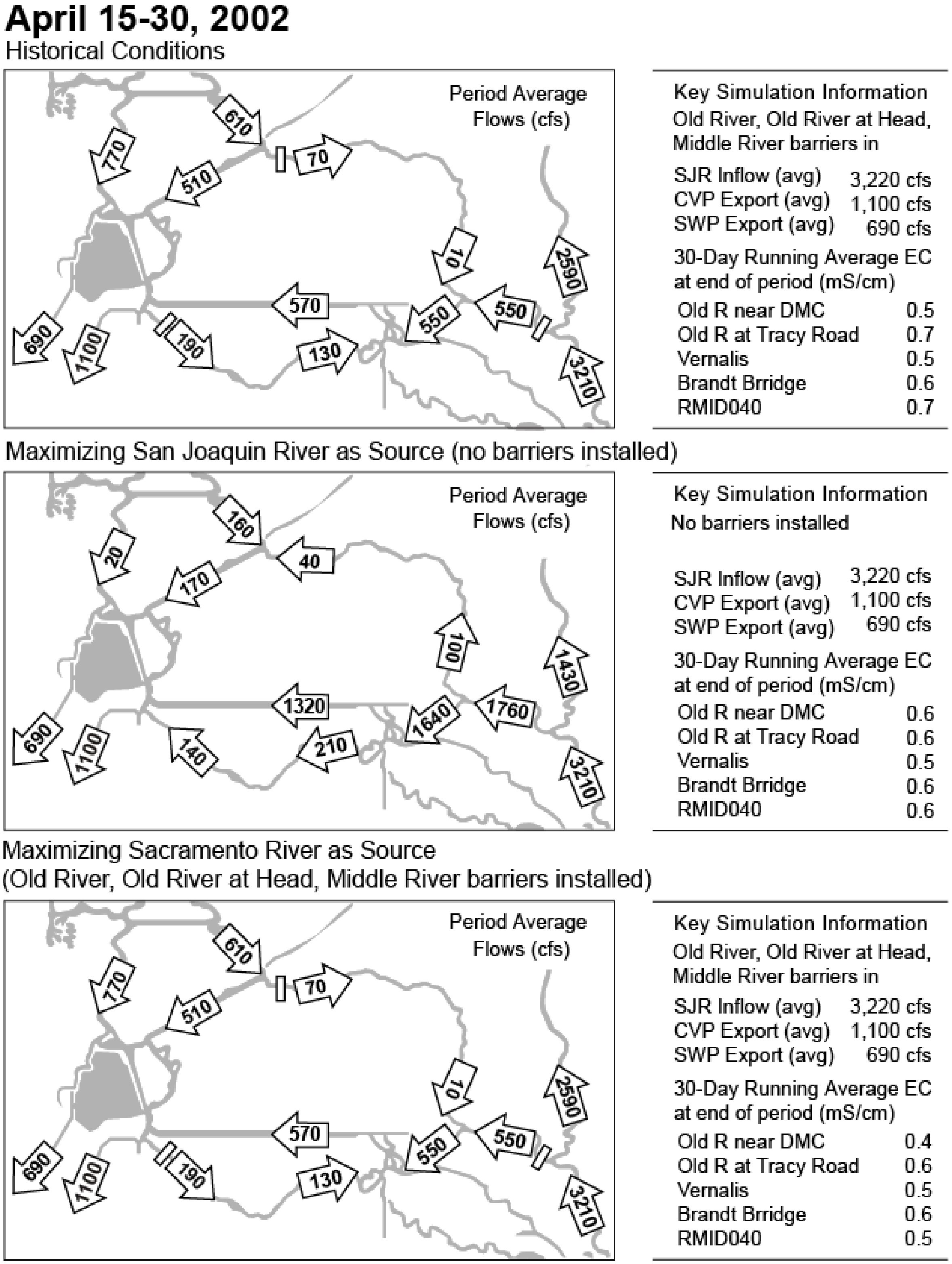
Old River, Old River at Head, Middle River barriers in

SJR Inflow	1,820 cfs
CVP Export	3,500 cfs
SWP Export	3,990 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.6
Old R at Tracy Road	0.8
Vernalis	0.8
Brandt Brridge	0.9
RMID040	0.8

Figure 9b. DSM2-simulated period-average south Delta flows and period-end EC, historical, maximizing San Joaquin River for circulation, and maximizing San Joaquin River circulation scenarios, April 15-30, 2002.



April 15-30, 2002

Historical Conditions

Key Simulation Information

Old River, Old River at Head, Middle River barriers in

SJR Inflow (avg)	3,220 cfs
CVP Export (avg)	1,100 cfs
SWP Export (avg)	690 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.5
Old R at Tracy Road	0.7
Vernalis	0.5
Brandt Brridge	0.6
RMID040	0.7

Maximizing San Joaquin River as Source (no barriers installed)

Key Simulation Information

No barriers installed

SJR Inflow (avg)	3,220 cfs
CVP Export (avg)	1,100 cfs
SWP Export (avg)	690 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.6
Old R at Tracy Road	0.6
Vernalis	0.5
Brandt Brridge	0.6
RMID040	0.6

Maximizing Sacramento River as Source
(Old River, Old River at Head, Middle River barriers installed)

Key Simulation Information

Old River, Old River at Head, Middle River barriers in

SJR Inflow (avg)	3,220 cfs
CVP Export (avg)	1,100 cfs
SWP Export (avg)	690 cfs

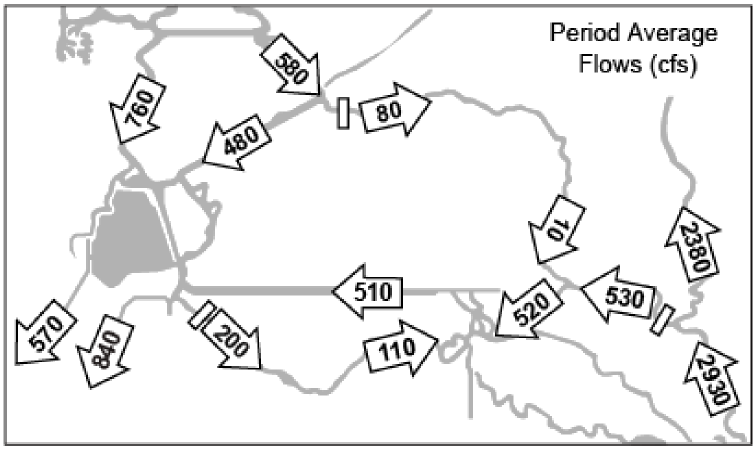
30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.4
Old R at Tracy Road	0.6
Vernalis	0.5
Brandt Brridge	0.6
RMID040	0.5

Figure 9c. DSM2-simulated period-average south Delta flows and period-end EC, historical, maximizing San Joaquin River for circulation, and maximizing San Joaquin River circulation scenarios, May 1-24, 2002.

May 1-24, 2002

Historical Conditions



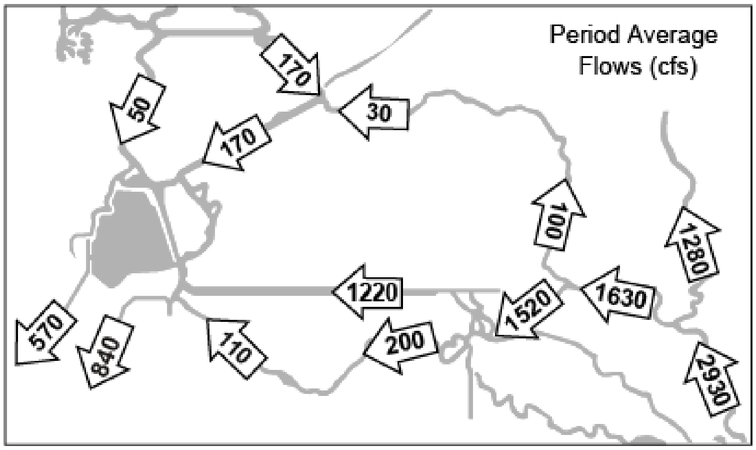
Key Simulation Information
Old River, Old River at Head, Middle River barriers in

SJR Inflow (avg)	3,000 cfs
CVP Export (avg)	840 cfs
SWP Export (avg)	570 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.3
Old R at Tracy Road	0.5
Vernalis	0.3
Brandt Brridge	0.3
RMID040	0.4

Maximizing San Joaquin River as Source (no barriers installed)



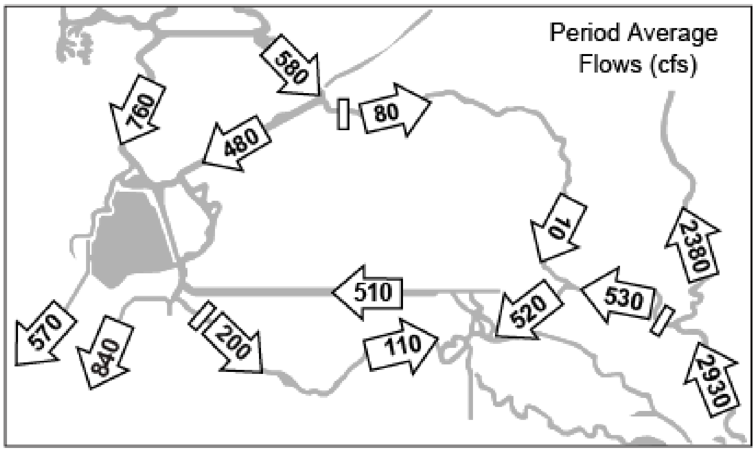
Key Simulation Information
No barriers installed

SJR Inflow (avg)	3,000 cfs
CVP Export (avg)	840 cfs
SWP Export (avg)	570 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.4
Old R at Tracy Road	0.3
Vernalis	0.3
Brandt Brridge	0.3
RMID040	0.3

Maximizing Sacramento River as Source
(Old River, Old River at Head, Middle River barriers installed)



Key Simulation Information
Old River, Old River at Head, Middle River barriers in

SJR Inflow (avg)	3,000 cfs
CVP Export (avg)	840 cfs
SWP Export (avg)	570 cfs

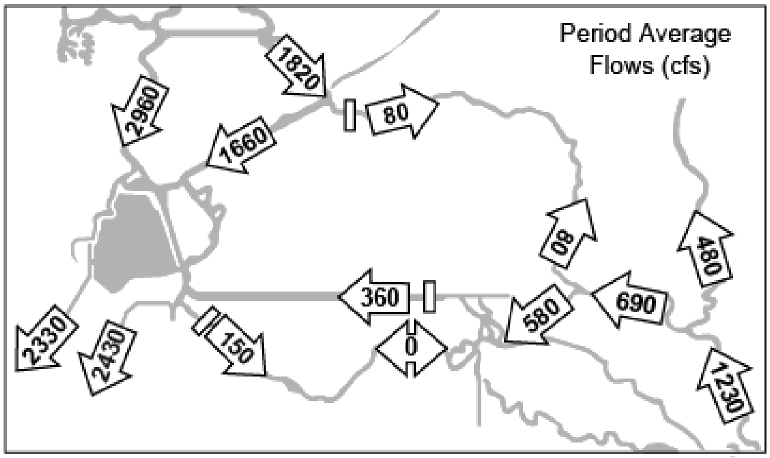
30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.4
Old R at Tracy Road	0.5
Vernalis	0.3
Brandt Brridge	0.3
RMID040	0.5

Figure 9d. DSM2-simulated period-average south Delta flows and period-end EC, historical, maximizing San Joaquin River for circulation, and maximizing San Joaquin River circulation scenarios, June 7-30, 2002.

June 7-30, 2002

Historical Conditions



Key Simulation Information

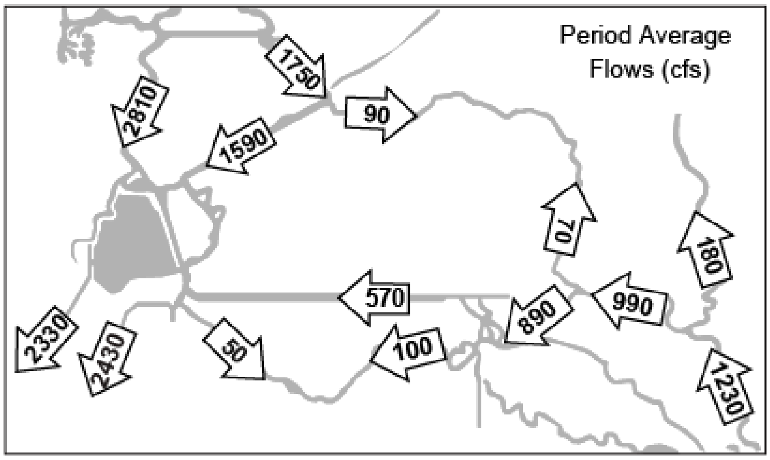
Old River, Grantline Canal, Middle River barriers in

SJR Inflow (avg)	1,370 cfs
CVP Export (avg)	2,430 cfs
SWP Export (avg)	2,330 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.3
Old R at Tracy Road	0.6
Vernalis	0.7
Brandt Brridge	0.7
RMID040	0.7

Maximizing San Joaquin River as Source (no barriers installed)



Key Simulation Information

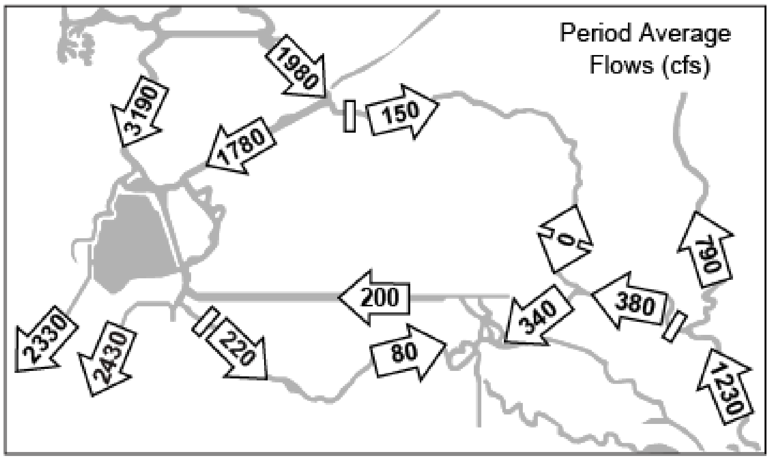
No barriers installed

SJR Inflow (avg)	1,370 cfs
CVP Export (avg)	2,430 cfs
SWP Export (avg)	2,330 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.5
Old R at Tracy Road	0.7
Vernalis	0.7
Brandt Brridge	0.7
RMID040	0.7

Maximizing Sacramento River as Source
(Old River, Old River at Head, Middle River barriers installed)



Key Simulation Information

Old River, Old River at Head, Middle River barriers in

SJR Inflow (avg)	1,370 cfs
CVP Export (avg)	2,430 cfs
SWP Export (avg)	2,330 cfs

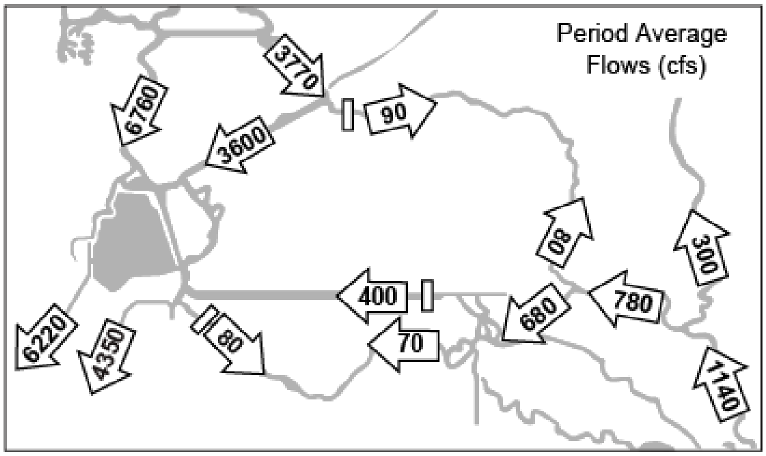
30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.3
Old R at Tracy Road	0.5
Vernalis	0.7
Brandt Brridge	0.7
RMID040	0.6

Figure 9e. DSM2-simulated period-average south Delta flows and period-end EC, historical, maximizing San Joaquin River for circulation, and maximizing San Joaquin River circulation scenarios, July 1-31, 2002.

July 1-31, 2002

Historical Conditions



Key Simulation Information

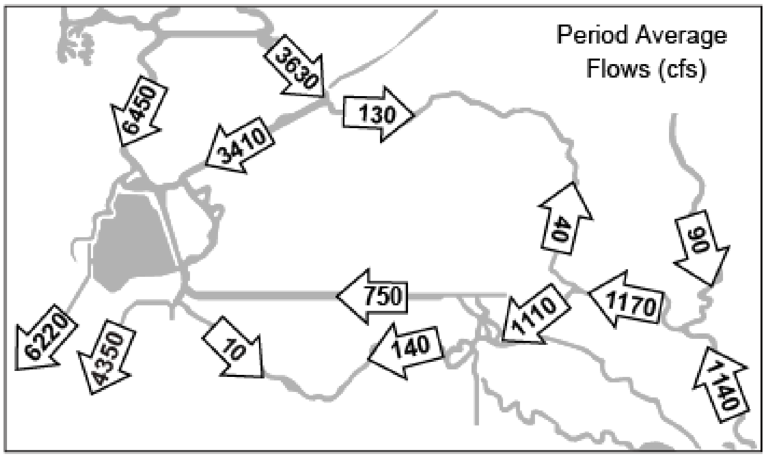
Old River, Grantline Canal, Middle River barriers in

SJR Inflow (avg)	1,280 cfs
CVP Export (avg)	4,350 cfs
SWP Export (avg)	6,220 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.3
Old R at Tracy Road	0.6
Vernalis	0.6
Brandt Brridge	0.6
RMID040	0.6

Maximizing San Joaquin River as Source (no barriers installed)



Key Simulation Information

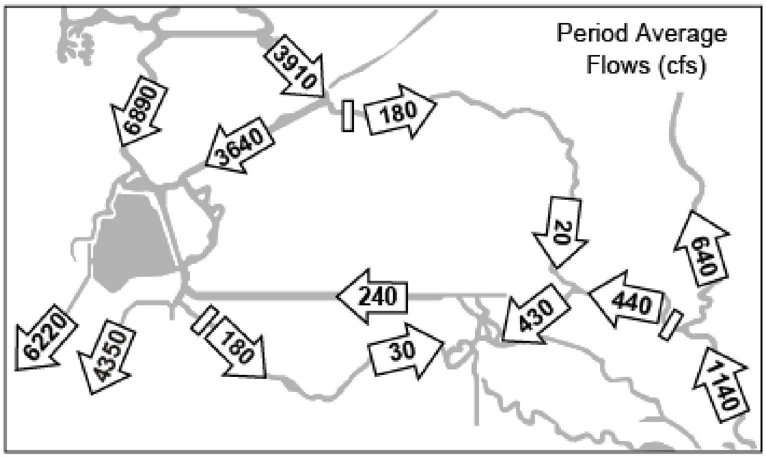
No barriers installed

SJR Inflow (avg)	1,280 cfs
CVP Export (avg)	4,350 cfs
SWP Export (avg)	6,220 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.4
Old R at Tracy Road	0.6
Vernalis	0.6
Brandt Brridge	0.6
RMID040	0.6

Maximizing Sacramento River as Source
(Old River, Old River at Head, Middle River barriers installed)



Key Simulation Information

Old River, Old River at Head, Middle River barriers installed

SJR Inflow (avg)	1,280 cfs
CVP Export (avg)	4,350 cfs
SWP Export (avg)	6,220 cfs

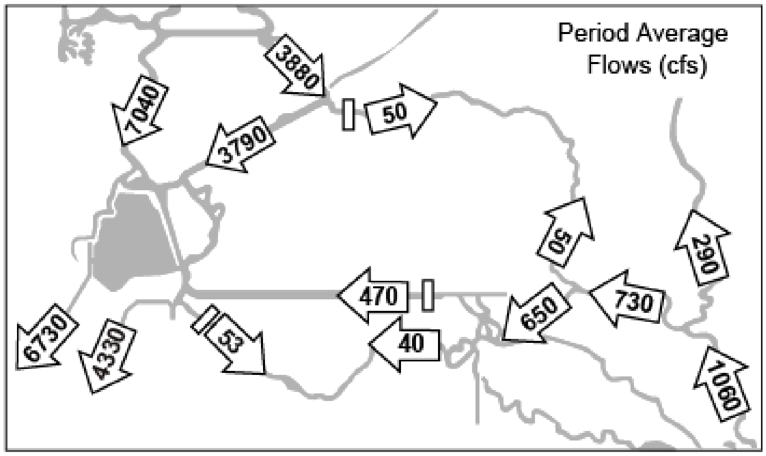
30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.3
Old R at Tracy Road	0.4
Vernalis	0.6
Brandt Brridge	0.6
RMID040	0.4

Figure 9f. DSM2-simulated period-average south Delta flows and period-end EC, historical, maximizing San Joaquin River for circulation, and maximizing San Joaquin River circulation scenarios, August 1-31, 2002.

August 1-31, 2002

Historical Conditions



Key Simulation Information

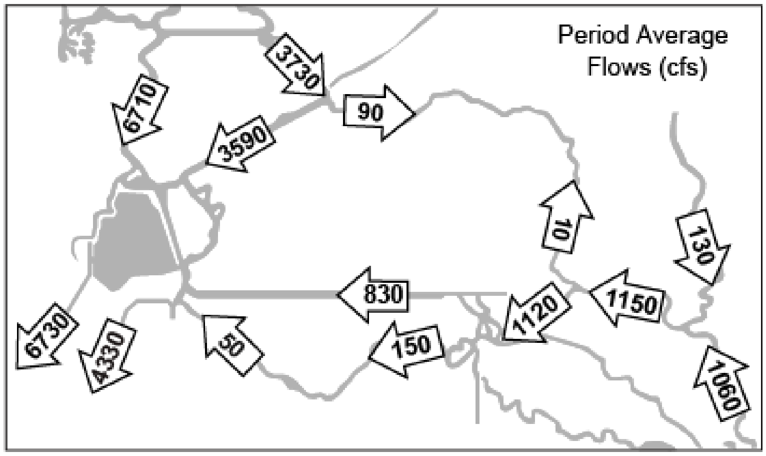
Old River, Grantline Canal, Middle River barriers installed

SJR Inflow (avg)	1,150 cfs
CVP Export (avg)	4,330 cfs
SWP Export (avg)	6,730 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.5
Old R at Tracy Road	0.6
Vernalis	0.6
Brandt Brridge	0.6
RMID040	0.6

Maximizing San Joaquin River as Source (no barriers installed)



Key Simulation Information

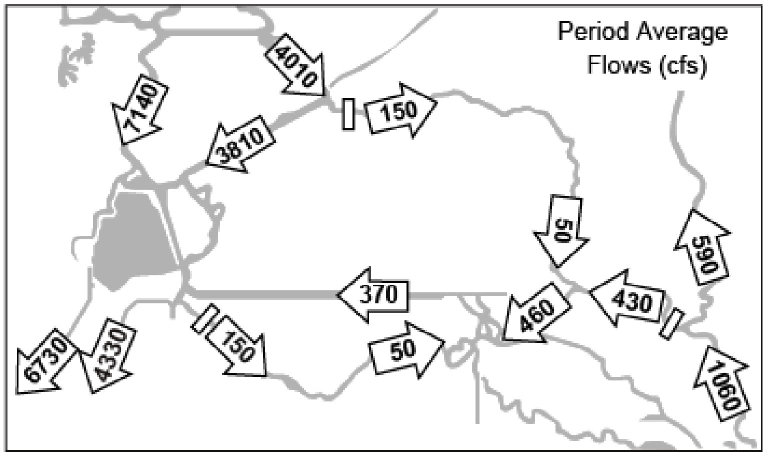
No barriers installed

SJR Inflow (avg)	1,150 cfs
CVP Export (avg)	4,330 cfs
SWP Export (avg)	6,730 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.5
Old R at Tracy Road	0.6
Vernalis	0.6
Brandt Brridge	0.3
RMID040	0.6

Maximizing Sacramento River as Source
(Old River, Old River at Head, Middle River barriers installed)



Key Simulation Information

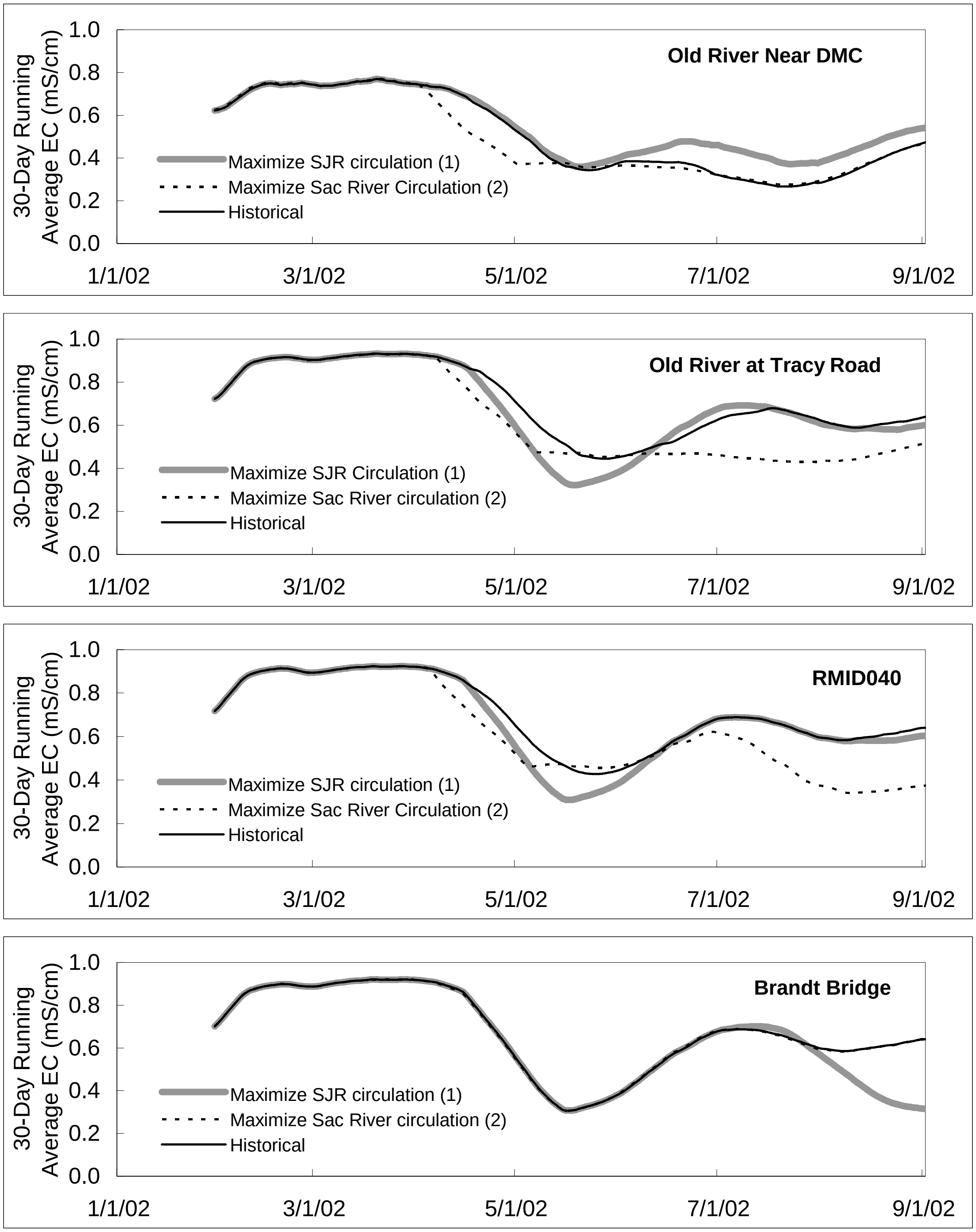
Old River, Old River at Head, Middle River barriers installed

SJR Inflow (avg)	1,150 cfs
CVP Export (avg)	4,330 cfs
SWP Export (avg)	6,730 cfs

30-Day Running Average EC at end of period (mS/cm)

Old R near DMC	0.5
Old R at Tracy Road	0.5
Vernalis	0.6
Brandt Brridge	0.6
RMID040	0.4

Figure 10. DSM2-simulated daily average EC under scenarios inducing significant changes in south Delta circulation.



(1) No barriers installed (2) Old River, Old River at Head, and Middle River barriers in Apr-Oct.

Summary of Study Results

Table 2 summarizes the changes in date-specific daily average EC with respect to the historical simulation at the four study sites. When the flow and EC in the San Joaquin River is held fixed compared to historical 2002 conditions, the most potential control over EC in the south Delta appears to be in varying the strategy of installing the south Delta barriers rather than in reductions in SWP or CVP pumping or increased Sacramento River inflows. This is due in part to the dominance of the San Joaquin River as the source of water in the south Delta regardless of SWP and CVP pumping and Sacramento River inflow. However, different barrier configurations in the south Delta have the potential of better circulating water locally thus reducing the concentrating of agricultural drainage with its higher salinity. Improvements are maximized when the water being circulated through south Delta channels has been captured by the Old and Middle River barriers.

Table 2. Summary of changes in EC from historical conditions for various scenarios of Delta-wide and south Delta circulation as simulated by DSM2.

RMID040						
	30-Day RA EC (mS/cm)	Change in 30-Day Running Average EC from Historical Simulation (mS/cm)				
		Modified General Delta Circulation			Modified Barrier Installation	
Date	Historical Simulation	No SWP & No Barriers	No SWP No CVP No Barriers	Additional Sac River Flows(1)	Maximize Sac River Circulation(2)	Maximize SJR Circulation(3)
Apr 14	0.87	0	0	0	**-0.1**	0
Apr 30	0.67	**-0.1**	**-0.1**	0	**-0.1**	**-0.1**
May 24	0.43	**-0.1**	**-0.1**	0	0	**-0.1**
Jun 30	0.68	0	0	0	**-0.1**	0
Jul 31	0.60	0	0	0	**-0.2**	0
Aug 31	0.64	0	0	0	**-0.3**	**0.0**

(1) Additional 5,000 cfs in April through September.
(2) Old River, Old River at Head, and Middle River barriers installed April through October.
(3) No barriers installed.

Table 2 (cont). Summary of changes in EC from historical conditions for various scenarios of Delta-wide and south Delta circulation as simulated by DSM2.

Old River at Tracy Road Bridge

Date	30-Day RA EC (mS/cm)	Change in 30-Day Running Average EC from Historical Simulation (mS/cm)				
		Modified General Delta Circulation			Modified Barrier Installation	
	Historical Simulation	No SWP & No Barriers	No SWP No CVP No Barriers	Additional Sac River Flows(1)	Maximize Sac River Circulation(2)	Maximize SJR Circulation(3)
Apr 14	0.9	0	0	0	**-0.1**	0
Apr 30	0.7	**-0.1**	**-0.1**	0	**-0.1**	**-0.1**
May 24	0.4	**-0.1**	**-0.1**	0	0	**-0.1**
Jun 30	0.6	0	0	0	**-0.2**	**0.1**
Jul 31	0.6	0	0	0	**-0.2**	0
Aug 31	0.6	0	0	0	**-0.1**	0

Brandt Bridge

Date	30-Day RA EC (mS/cm)	Change in 30-Day Running Average EC from Historical Simulation (mS/cm)				
		Modified General Delta Circulation			Modified Barrier Installation	
	Historical Simulation	No SWP & No Barriers	No SWP No CVP No Barriers	Additional Sac River Flows(1)	Maximize Sac River Circulation(2)	Maximize SJR Circulation(3)
Apr 14	0.9	0	0	0	0	0
Apr 30	0.6	0	0	0	0	0
May 24	0.3	0	0	0	0	0
Jun 30	0.7	0	0	0	0	0
Jul 31	0.6	0	0	0	0	0
Aug 31	0.6	0	0	0	0	**-0.3**

(1) Additional 5,000 cfs in April through September.
(2) Old River, Old River at Head, and Middle River barriers installed April through October.
(3) No barriers installed.

Table 2 (cont.). Summary of changes in EC from historical conditions for various scenarios of Delta-wide and south Delta circulation as simulated by DSM2.

Old River near DMC						
	30-Day RA EC (mS/cm)	Change in 30-Day Running Average EC from Historical Simulation (mS/cm)				
		Modified General Delta Circulation			Modified Barrier Installation	
Date	Historical Simulation	No SWP & No Barriers	No SWP No CVP No Barriers	Additional Sac River Flows(1)	Maximize Sac River Circulation(2)	Maximize SJR Circulation(3)
Apr 14	0.7	0	**0.2**	0	**-0.1**	0
Apr 30	0.5	0	**0.2**	0	**-0.2**	0
May 24	0.3	0	0	0	0	0
Jun 30	0.3	**0.2**	**0.3**	0	0	**0.1**
Jul 31	0.3	**0.1**	**0.4**	**-0.1**	0	**0.1**
Aug 31	0.5	**-0.1**	**0.2**	**-0.3**	0	**0.1**

(1) Additional 5,000 cfs in April through September.
(2) Old River, Old River at Head, and Middle River barriers installed April through October.
(3) No barriers installed.

APPENDIX D

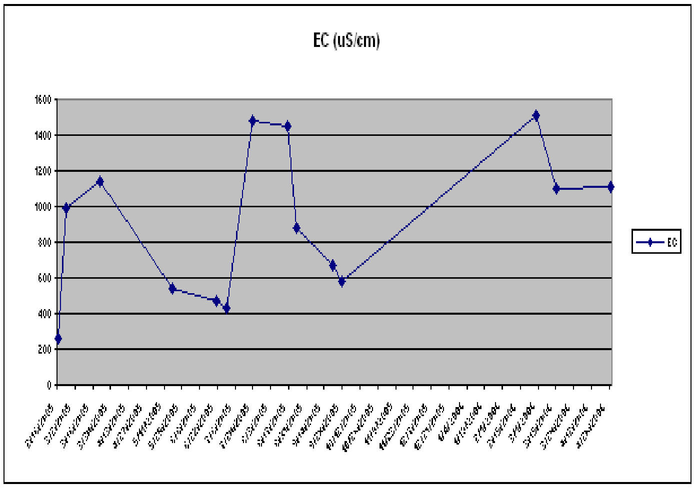
Data and Charts from the Waiver Monitoring Program

Data from the Agricultural Drainage Waiver Program

Kellogg Creek @ Hwy 4
544XKCHWF

73 West Side Drainage

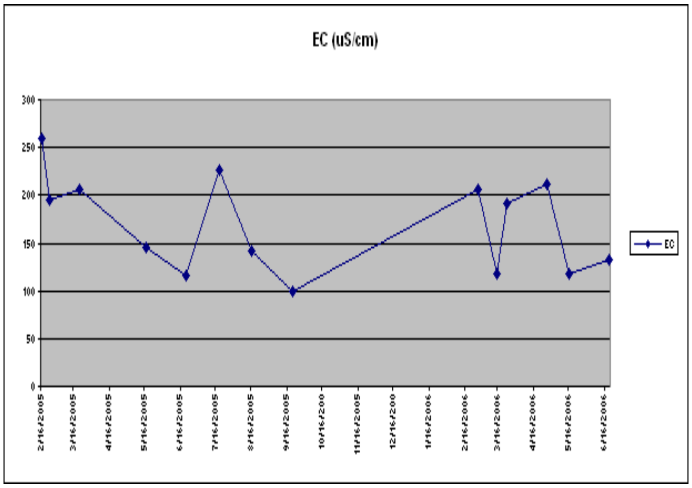
Date	EC	Time
16-Feb-05	259	12:40
23-Feb-05	990	13:40
21-Mar-05	1136	13:20
17-May-05	544	12:00
21-Jun-05	470	12:10
29-Jun-05	435	9:00
19-Jul-05	1485	11:00
16-Aug-05	1447	13:00
23-Aug-05	885	12:00
20-Sep-05	667	10:30
27-Sep-05	582	11:20
27-Feb-06	1512	11:20
15-Mar-06	1097	10:30
27-Apr-06	1112	9:40



French Camp Slough
531SJC504

21 East Side Drainage

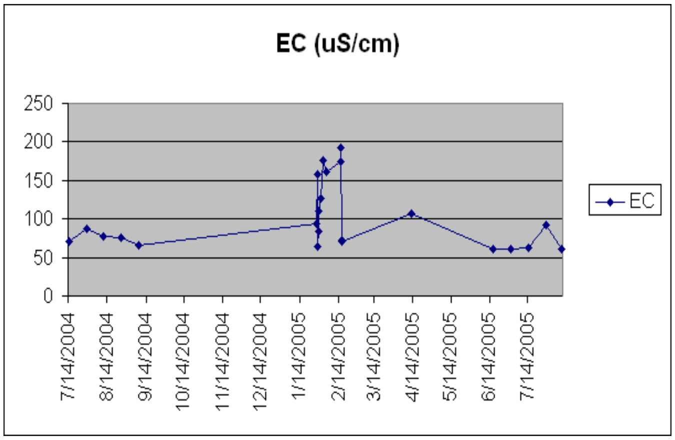
Date	EC	Time
16-Feb-05	259	16:00
23-Feb-05	195.4	11:30
21-Mar-05	207	16:50
17-May-05	145.5	15:00
21-Jun-05	116.2	13:40
19-Jul-05	226	13:40
16-Aug-05	142.1	15:20
20-Sep-05	99.4	14:10
27-Feb-06	206	15:00
15-Mar-06	118.6	13:40
24-Mar-06	192.3	9:40
27-Apr-06	211	11:50
16-May-06	118.6	16:10
20-Jun-06	131.8	17:00



Pixley Slough @ 8 Mile Road
531XNSJ28

#36 East Side Drainage

Date	EC	Time
14-Jul-04	70.1	10:20
28-Jul-04	87.9	10:30
11-Aug-04	77.1	10:00
25-Aug-04	75.4	9:30
8-Sep-04	66.2	9:30
27-Jan-05	93.5	19:10
27-Jan-05	93.7	13:00
28-Jan-05	157.1	10:00
28-Jan-05	64.2	15:00
29-Jan-05	83.3	17:00
29-Jan-05	109.9	11:00
30-Jan-05	126.4	16:00
30-Jan-05	127.3	10:00
1-Feb-05	175.7	13:00
4-Feb-05	161.2	9:50
15-Feb-05	174.1	17:00

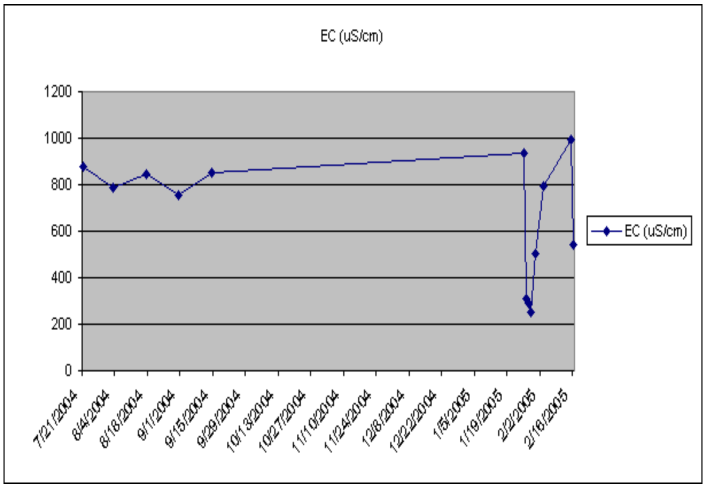


15-Feb-05	193	11:00
16-Feb-05	72.7	10:50
16-Feb-05	70.1	16:50
12-Apr-05	106.4	8:30
16-Jun-05	60.4	9:10
30-Jun-05	60.1	7:50
14-Jul-05	62	9:20
28-Jul-05	92	9:20
10-Aug-05	60.8	7:10

Drain to San Joaquin River
544XXXD01

84 San Joaquin River Drainage

Date	EC (uS/cm)	Time
21-Jul-04	878	8:40
3-Aug-04	786	9:00
17-Aug-04	845	9:30
31-Aug-04	757	10:00
14-Sep-04	853	10:50
26-Jan-05	938	17:50
27-Jan-05	311	10:30
28-Jan-05	290	10:40
29-Jan-05	252	11:00
31-Jan-05	505	10:10
3-Feb-05	791	11:00
15-Feb-05	991	10:10
16-Feb-05	543	10:00



Mid Roberts Island Drain
544SJC517

65 San Joaquin River Drainage

Date	EC	Time
14-Jul-05	852	8:20
28-Jul-05	-88	8:30
10-Aug-05	724	9:20

Roberts Island
544RIDAHR

52   San Joaquin River Drainage

Date	EC	Time
16-May-06	356	9:10
20-Jun-06	1060	8:50

San Joaquin at Bowman
544DABWMR

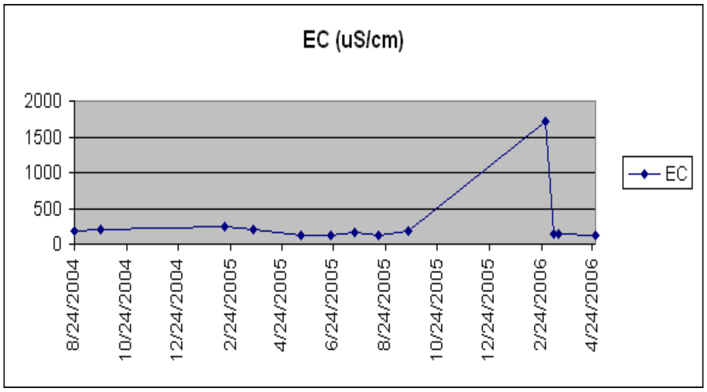
47   San Joaquin River Drainage

Date	EC	Time
1-Apr-03	3030	14:40
27-May-03	3971	13:30
12-Jun-03	2386	9:45
3-Jul-03	1289	10:00

544RIDAHT

53   Central Delta Drainage

Date	EC	Time
16-May-06	736	8:00
20-Jun-06	1811	9:50



Potato Slough @ Hwy 12
544XPSAHT

77 North Delta Drainage

Date	EC	Time
24-Aug-04	191	9:00
23-Sep-04	196.1	9:30
16-Feb-05	243	8:00
21-Mar-05	195.5	8:00
17-May-05	124.8	7:30
21-Jun-05	121.5	7:50
19-Jul-05	160.5	7:20
16-Aug-05	125.9	8:50
20-Sep-05	174.1	8:00
27-Feb-06	1724	11:00
10-Mar-06	149.7	10:30

15-Mar-06	146.8	9:10
27-Apr-06	114.3	9:20

Potato Slough at WoodBridge
544XNSJ03

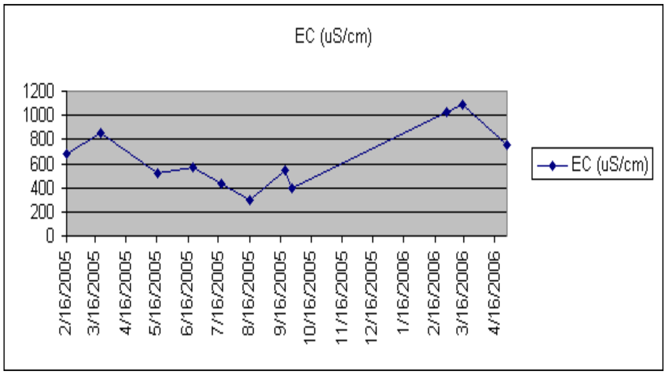
76 North Delta Drainage

Date	EC	Time
14-Jul-04	720	12:10
28-Jul-04	626	13:30
11-Aug-04	555	11:20
25-Aug-04	804	8:20
8-Sep-04	1060	8:30

Terminous Tract 544XTTGLR Delta Drain-

81 North Delta Drainage

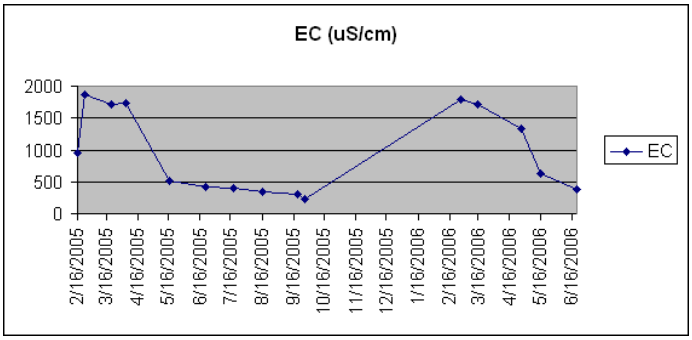
Date	EC (uS/cm)	Time
16-Feb-05	684	9:20
21-Mar-05	848	9:10
17-May-05	515	8:30
21-Jun-05	567	8:50
19-Jul-05	429	9:00
16-Aug-05	294	9:10
20-Sep-05	543	10:50
27-Sep-05	394	9:10
27-Feb-06	1030	8:20
15-Mar-06	1091	7:00
27-Apr-06	754	8:00



Terminous Tract
544XTTHWT

83 North Delta Drainage

Date	EC	Time
16-Feb-05	950	9:50
23-Feb-05	1868	9:50
21-Mar-05	1705	9:00
4-Apr-05	1742	8:30
17-May-05	515	9:00
21-Jun-05	411	8:40
19-Jul-05	398	8:00
16-Aug-05	348	9:40
20-Sep-05	314	9:00
27-Sep-05	235	10:10
27-Feb-06	1781	9:50
15-Mar-06	1720	8:20
27-Apr-06	1325	8:40
16-May-06	634	8:00
20-Jun-06	382	7:20

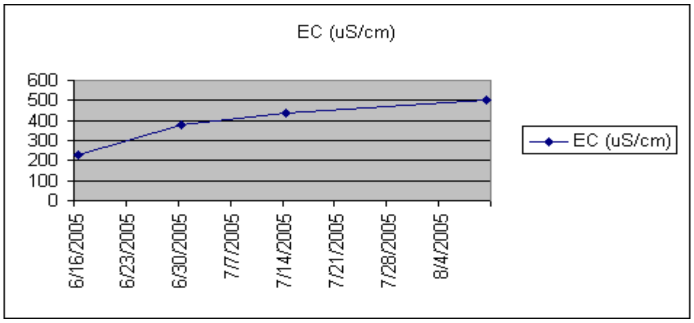


Interior South Delta

Howard Road
544SJC516 Unnamed Canal at Howard Road

64 South Delta Drainage

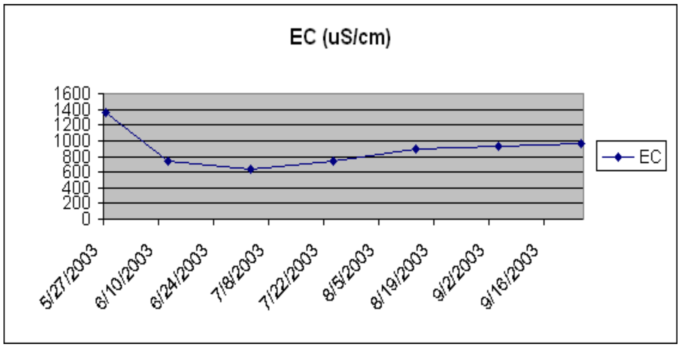
Date	EC (uS/cm)	Time
16-Jun-05	229	7:30:00
30-Jun-05	379	12:00:00
14-Jul-05	436	7:30:00
28-Jul-05	-88	7:40:00
10-Aug-05	500	9:50:00



Middle River Wing Levee
544DRAWLR

48 South Delta Drainage

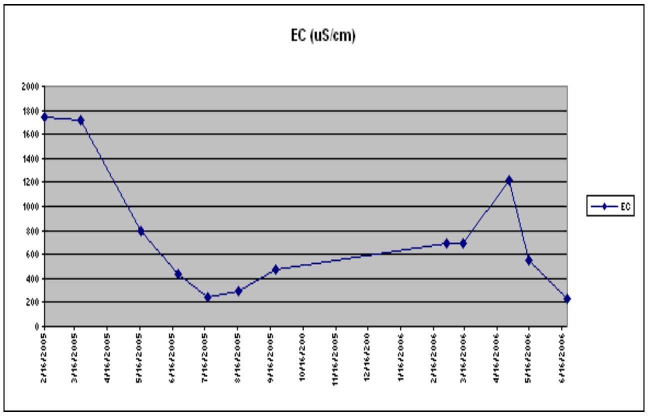
Date	EC	Time
27-May-03	1357	12:00
12-Jun-03	742	11:00
3-Jul-03	628	12:10
24-Jul-03	735	14:00
14-Aug-03	890	11:40
4-Sep-03	937	12:30
25-Sep-03	959	13:00



Grant Line at Clifton Court
544XGLCAA

70 South Delta Drainage

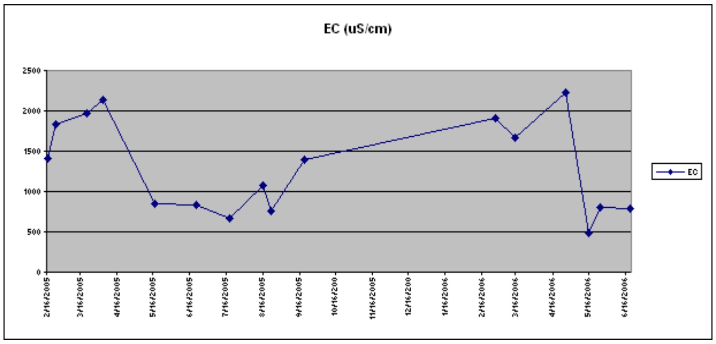
Date	EC	Time
16-Feb-05	1743	14:40
21-Mar-05	1715	16:10
17-May-05	801	15:30
21-Jun-05	442	14:30
19-Jul-05	243	13:20
16-Aug-05	290	15:20
20-Sep-05	477	13:00
27-Feb-06	693	13:50
15-Mar-06	693	12:40
27-Apr-06	1214	11:00
16-May-06	553	16:50
20-Jun-06	225	15:50



Grant Line at Calpack Rd
544XGLCCR

71 South Delta Drainage

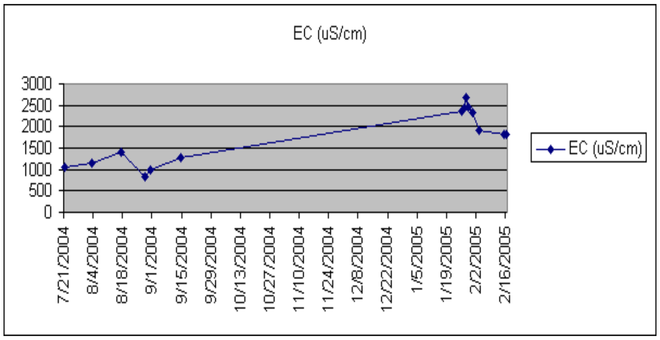
Date	EC	Time
16-Feb-05	1412	13:50
23-Feb-05	1834	12:30
21-Mar-05	1970	15:20
4-Apr-05	2140	11:30
17-May-05	847	14:10
21-Jun-05	835	13:40
19-Jul-05	673	12:40
16-Aug-05	1077	14:20
23-Aug-05	759	11:10
20-Sep-05	1390	12:00
27-Feb-06	1910	13:00
15-Mar-06	1660	12:00
27-Apr-06	2220	10:30
16-May-06	490	15:50
25-May-06	806	9:50
20-Jun-06	791	14:50



Grant Line Drainage
544XXXD02 Drain to Grant Line Canal off Wing

85 South Delta Drainage

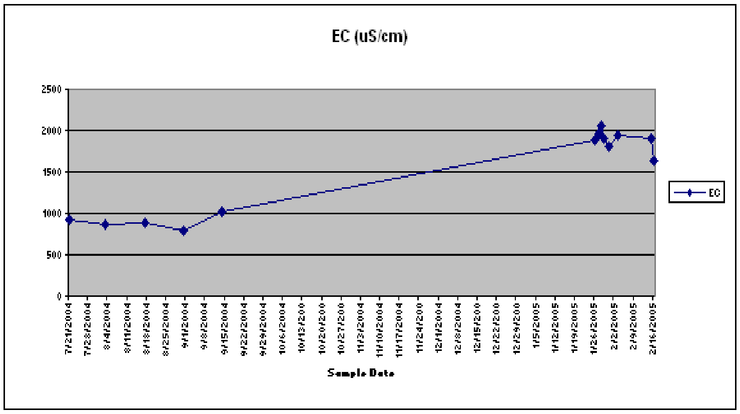
Date	EC (uS/cm)	Time
21-Jul-04	1063	9:40:00
3-Aug-04	1153	10:30
17-Aug-04	1392	11:00
28-Aug-04	821	15:05
31-Aug-04	995	11:20
14-Sep-04	1265	11:30
26-Jan-05	2370	12:20
27-Jan-05	2410	12:50
28-Jan-05	2680	14:00
29-Jan-05	2470	12:30
31-Jan-05	2330	12:00
3-Feb-05	1916	11:30
15-Feb-05	1805	12:00
16-Feb-05	1833	11:30



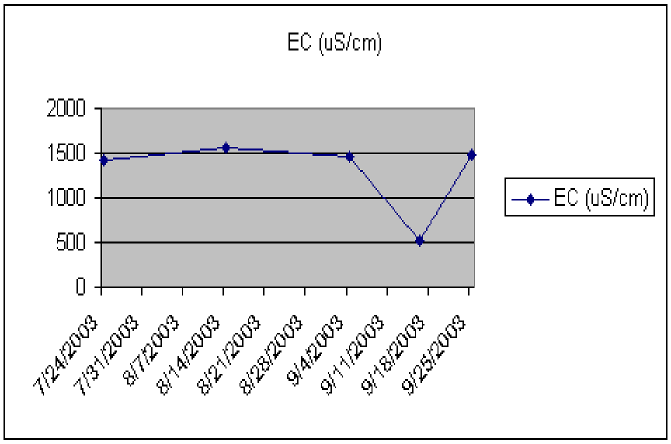
North Canal

Date	EC	Time

544XXXD03	21-Jul-04	932	10:50
	3-Aug-04	867	13:30
	17-Aug-04	880	12:20
# 86 South Delta Drainage	31-Aug-04	795	12:20
	14-Sep-04	1010	12:50
	26-Jan-05	1892	16:20
	27-Jan-05	1962	14:20
	28-Jan-05	2060	16:50
	29-Jan-05	1913	14:30
	31-Jan-05	1815	13:20
	3-Feb-05	1939	12:30
	15-Feb-05	1903	13:20
	16-Feb-05	1627	12:50

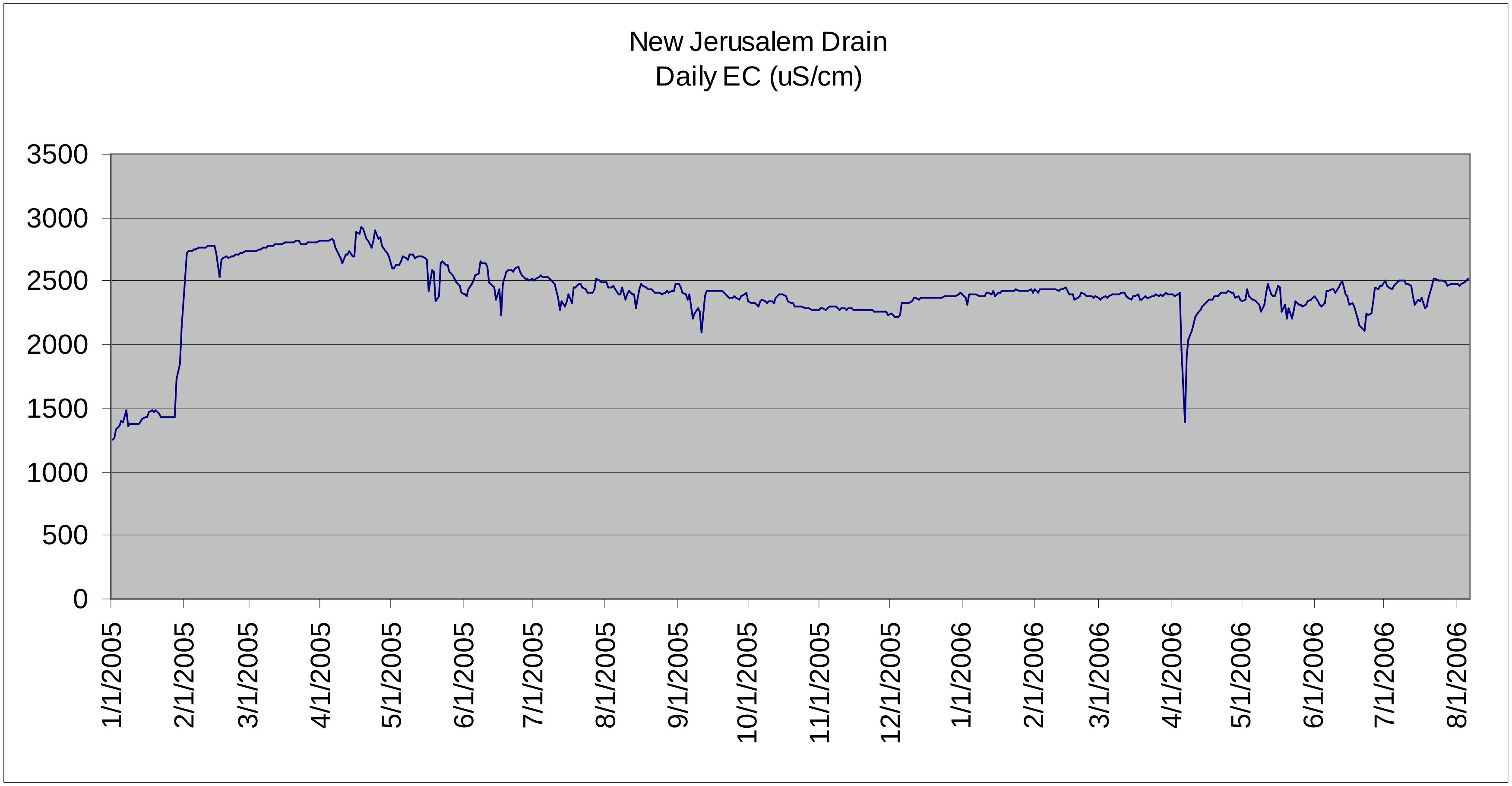


Tom Paine Slough	Date	EC	Time
544XSED07	27-Aug-04	607	18:30
	Date	EC (uS/cm)	Time
544TPSELR	24-Jul-03	1421	10:20
	14-Aug-03	1558	10:00
	4-Sep-03	1457	10:00
	16-Sep-03	522	0:00
# 67 South Delta Drainage	25-Sep-03	1475	10:30



APPENDIX E

New Jerusalem Drainage CDEC Data



APPENDIX F

DWR actions to control salinity in the San Joaquin River upstream of Vernalis

This report summarizes the many programs and extensive funding that the Department of Water Resources (DWR) has engaged in to order to reduce the volume and concentration of saline discharges to the San Joaquin River. This information demonstrates the actions that DWR in cooperation with the United States Bureau of Reclamation (USBR) and local agencies have taken and plan to take to help achieve water quality standards in the Lower San Joaquin River Delta. The State Water Resources Control Board (SWRCB) should consider this information when determining if DWR and Reclamation have taken actions within their control to meet the Delta standards.

In D-1641, the SWRCB allocates responsibility for the Vernalis flow and salinity requirements to USBR because it is one of the largest diverters of water from the San Joaquin River (SJR) and because the Central Valley Project (CVP) exports Delta water to farmers on the west side of the San Joaquin Valley. The reduction in San Joaquin River flows from tributaries streams in combination with discharges of saline surface and subsurface drainage water results in increases of salt loads in the river at Vernalis. Although DWR is not responsible for meeting Vernalis standards established by the State Water Resources Control Board (SWRCB), it was given responsibility for meeting salinity standards at the Brandt Bridge and other South Delta stations. Improvements in San Joaquin River water quality help achieve water quality standards at these locations.

Many agencies with interests in the Delta recognize the value of improving SJR water quality. The CALFED Bay-Delta Program includes actions to address drainage problems in the San Joaquin Valley to improve downstream water quality (CALFED ROD, August 28, 2000, p.66-67). In December 1991, the USBR , U.S. Fish and Wildlife Service (FWS), U.S. Natural Resources Conservation Service (NRCS), U.S. Geological Survey (USGS), the California Department of Fish and Game (DFG), California Department of Food and Agriculture (DFA), the SWRCB and DWR signed a Memorandum of Understanding (MOU) to implement a management plan for agricultural subsurface drainage and related problems in the Westside of the San Joaquin Valley (SWRCB 1995 WQCP, p. 30). The plan outlined in the "Rainbow Report" was updated in 2000. Many actions have been funded subsequent to the MOU. These and other actions are described in the attached DWR report.

It is important to note historical hydrologic conditions for the SJR near Vernalis. Figure 1 data from the Central Valley Regional Water Quality Control Board (CVRWQCB) graphs the 30-day running average electrical conductivity respectively for the SJR near Vernalis while Figure 2 illustrates the annual average flow and the10-year average annual flow for the same location. Figure 1 also demonstrates that, in general, the USBR has complied with salinity objectives since 1995, with the exception of the drought years 1987 to 1992. Figures 1 and 2 clearly indicate that hydrological conditions directly affect the water quality and flow regime of the river; however, water quality objectives apply regardless of hydrological conditions. Since 1995, salinity conditions have improved partly due to improved hydrologic conditions and because of additional measures taken by DWR, USBR, and many collaborating agencies. These measures include: 1) Providing fresh water to dilute saline discharges and to increase flows upstream of Vernalis from Goodwin Dam (Table 1) and through the Vernalis Adaptive Management Program (VAMP) agreement (Table 2) and 2) controlling discharge of saline water into the SJR upstream of Vernalis.

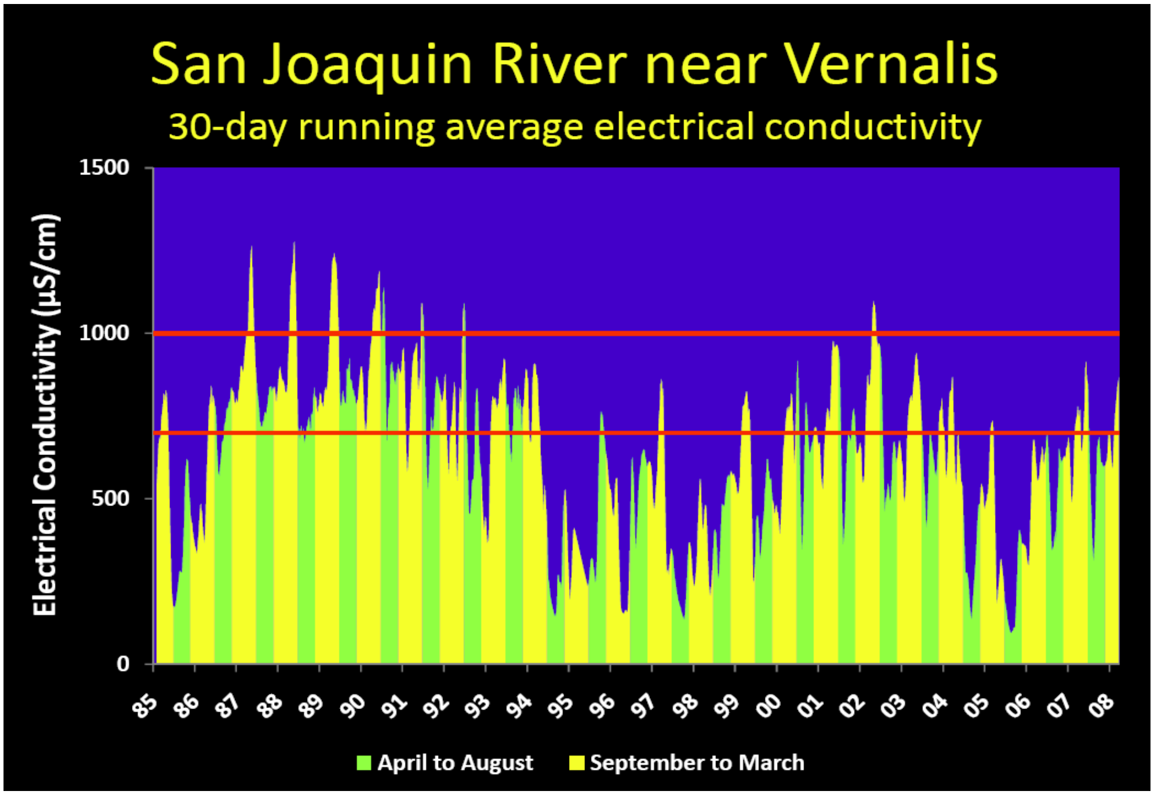


Figure 1. San Joaquin River at Vernalis, Electrical Conductivity

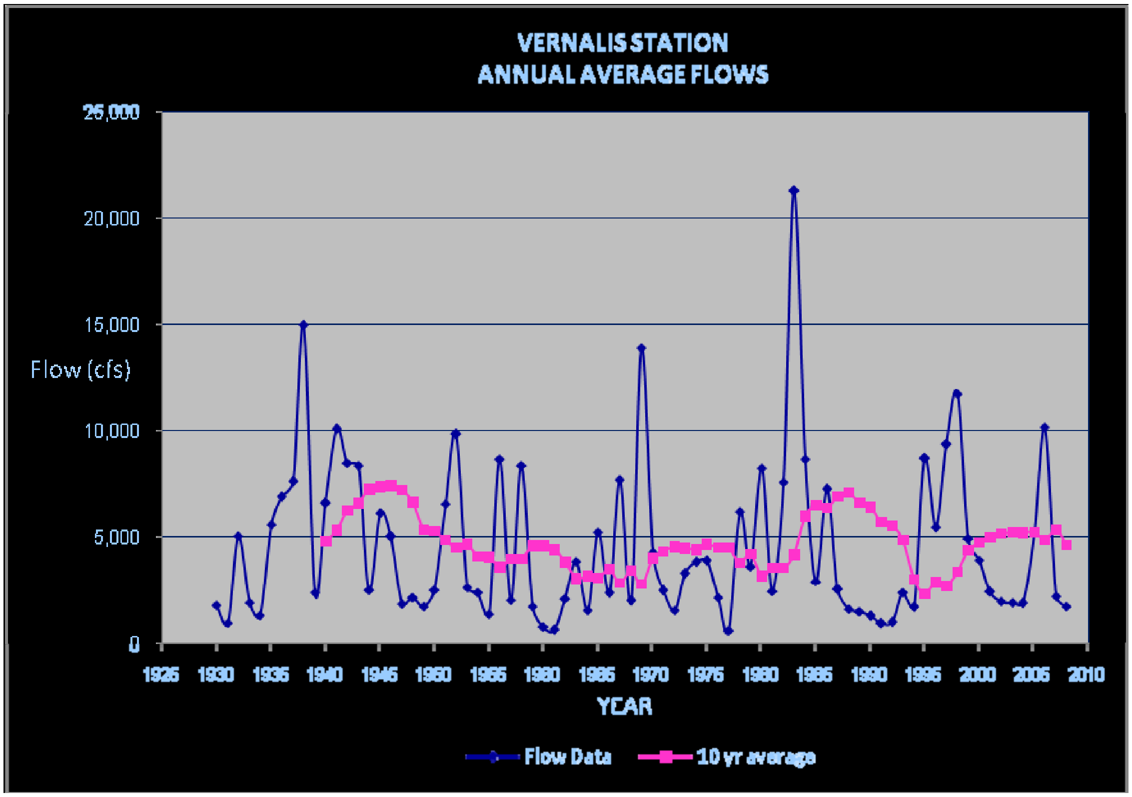


Figure 2 San Joaquin River Average Annual Flows at Vernalis

Table 1
Goodwin Dam – 1991-2008
Average Monthly Flow Releases to Meet Salinity and Flow Objectives at Vernalis

WQ Release	AF/Month
January	166
February	2,988
March	8,818
April	9,087
May	4,742
June	16,276
July	11,966
August	5,579
September	1,851
October	125
November	0
December	0
TOTAL	61,598 AF
Average monthly release	5,133 AF

Table 2
Vernalis Adaptive Management Plan 2000-2008

Year	VAMP Pulse Period	Target Vernalis/Export Flows	Observed Vernalis/Export Flows	VAMP Supplemental Water
		(cfs)	(cfs)	(acre-feet)
2000	4/15-5/15	5,700/2,250	5,869/2,155	77,680
2001	4/20-5/20	4,450/1,500	4,224/1,420	78,650
2002	4/15-5/15	3,200/1,500	3,301/1,430	33,430
2003	4/15-5/15	3,200/1,500	3,235/1,446	58,065
2004	4/15-5/15	3,200/1,500	3,155/1,331	65,591
2005	5/1-5/31	>7,000/2,250	10,390/2,986	0
2006	5/1-5/31	>7,000/1,500	26,220/1,559	0
2007	4/22-5/22	3,200/1,500	3,263/1,486	33,330
2008	4/22-5/22	3,200/1,500	3,163/1,520	75,250

Source: San Joaquin River Agreement-VAMP technical report

1. **Measures to provide fresh water for dilution of saline flows above Vernalis**

Goodwin Dam releases plus the VAMP flow contributions averaged about 108,500 acre-feet per year. The San Joaquin River Agreement (SJRA) commits DWR to fund water purchases to meet flow requirements on the SJR for VAMP. Under the SJRA; the USBR and DWR agreed to spend up to $3 million and $1 million, respectively, per year to purchase VAMP water. Figure 3 shows the water quality benefits of Goodwin Dam and VAMP flow releases at Vernalis when compared with other upstream SJR stations.

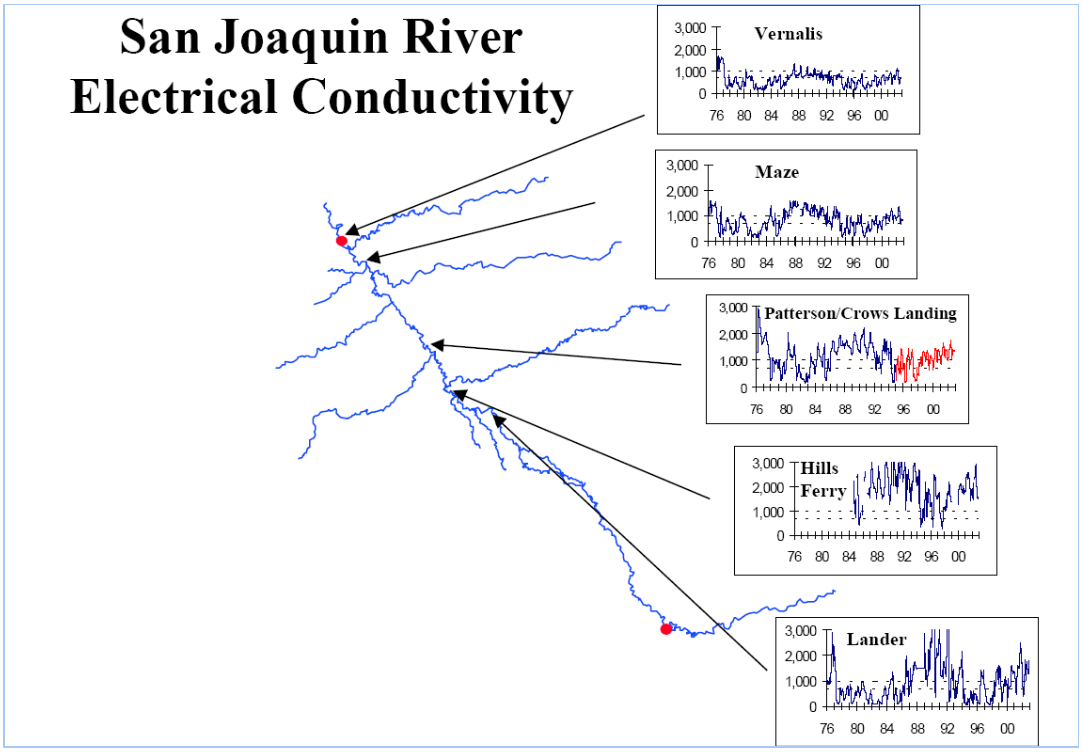


Figure 3. San Joaquin River Electrical Conductivity at Vernalis and Other Stations
Source: Central Valley Regional Water Quality Control Board

2. Measures to control salinity in the San Joaquin River upstream of Vernalis

In D1641, the SWRCB recognizes that regional management of drainage water is the preferred method to meet the SJR objectives (page 84). Department of Water Resources, USBR, the CVRWQCB as well as many local, public and private agencies have made tremendous efforts to achieve salinity objectives in this area. A significant amount of public and private money has been, and continues to be invested in salinity reduction efforts for the SJR. In order to understand the salinity reduction measures taken, it is important to describe the sources of the salt load that averages one million tons per year in the SJR at Vernalis. In an average year, CVP water supplies carry more than 800,000 tons of salt into the northern portion of the San Joaquin Valley. Most of this salt load originates from the Delta and approximately 350,000 tons of this salt load are ultimately recycled back to the Delta through agricultural surface and subsurface returns and wetland discharges (Water Facts: Salt Balance in the San Joaquin Valley, Jan 2001). Tables 3 and 4 contain CVRWQCB information describing the sources of salt and the corresponding loads, while Figure 4 defines the Lower San Joaquin River (LSJR) areas that contribute salts.

Table 3
San Joaquin River at Vernalis

Approximate Sources of Salt	Load
Sierra Nevada Tributaries	18%
Groundwater	28%
Agricultural Surface Returns	26%
Agricultural Subsurface Returns	17%
Managed Wetlands	9%
Municipal and Industrial	2%

Table 4
San Joaquin River at Vernalis

Approximate Sources of Salt	Area of Contribution
I SJR Upstream Salt Slough	9%
II Merced	
III Tuolumne	
IV Stanislaus	
Total SJR Tributaries Streams:	19%
V East Valley Floor	5%
VI Northwest Side	30%
VII Grasslands	37%

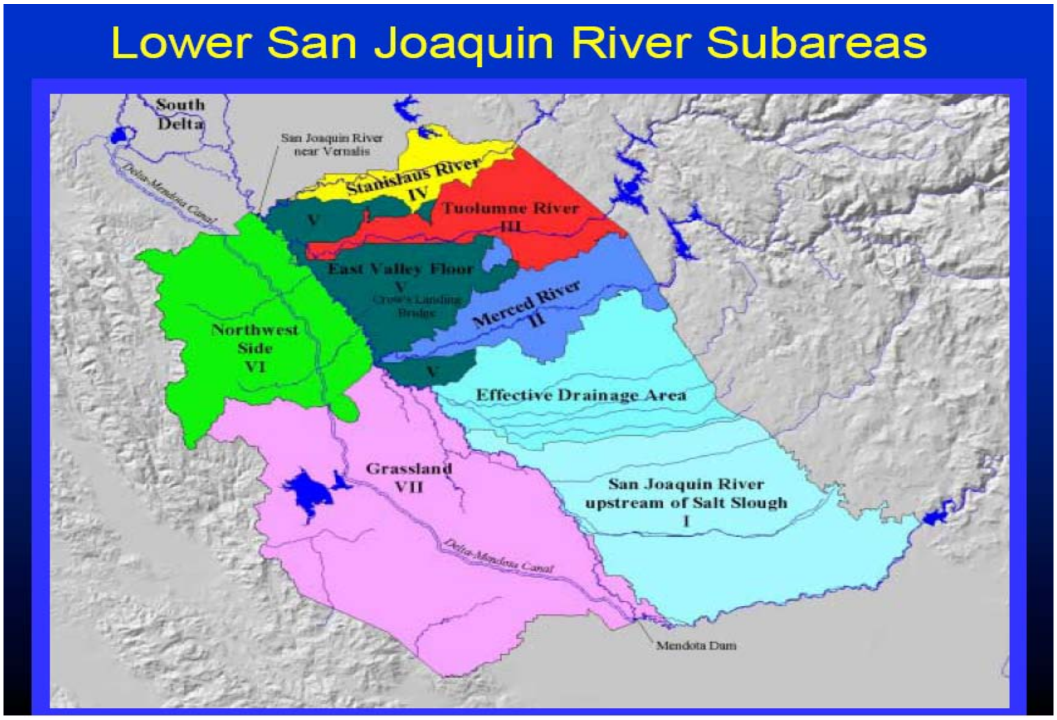


Figure 4. Salt Source Contribution Areas of the Lower San Joaquin River
Source: Central Valley Regional Water Quality Control Board

Measures to control salinity upstream of Vernalis include: (a) On-farm management activities to reduce subsurface drainage, (b) Real-time water quality management to maximize the assimilative capacity of the SJR, (c) Efforts to improve wetlands discharges.

a) On-Farm Drainage Management Activities

Drainage management activities involving source control have proven to be effective in reducing salt loads in the San Joaquin River. These measures include:

- Irrigation Water Conservation such as use of improved irrigation systems;
- Tiered Water Pricing, based on increased water cost for increased water use;
- Agricultural tailwater and tilewater control and recycling and;
- Agricultural subsurface drainage water reuse by blending it with source water and through irrigation of the San Joaquin River Improvement Project Crops.

A good example of the effectiveness of these measures has been demonstrated by the efforts of the Grasslands Area farmers as a part of the Grasslands Bypass Project (GBP). Figures 5 and 6 shows the reductions achieved in terms of volume of discharge and salt loads. Since the implementation of the GBP, drainage discharges have decreased from 58,000 AF to about 16,000 AF and salt loads have been reduced from 237,000 tons to 66,000 tons. Funding sources and expenditures for implementation of the components of the GBP are outlined in Table 5. Table 6 summarizes some of the DWR grants targeting drainage source control in the Grasslands Area. Many components of the Grasslands Bypass Project, including the San Joaquin River Improvement Project, are also a part of the Westside Regional Drainage Plan. Recently, DWR provided a Proposition 50 grant of $25 Million to the San Luis Delta Mendota Water Authority to help implement key components of the West Side Regional Drainage Plan, which include acquisition of additional land for reuse and a treatment system to reduce discharges of subsurface drainage water to the San Joaquin River to or near zero.

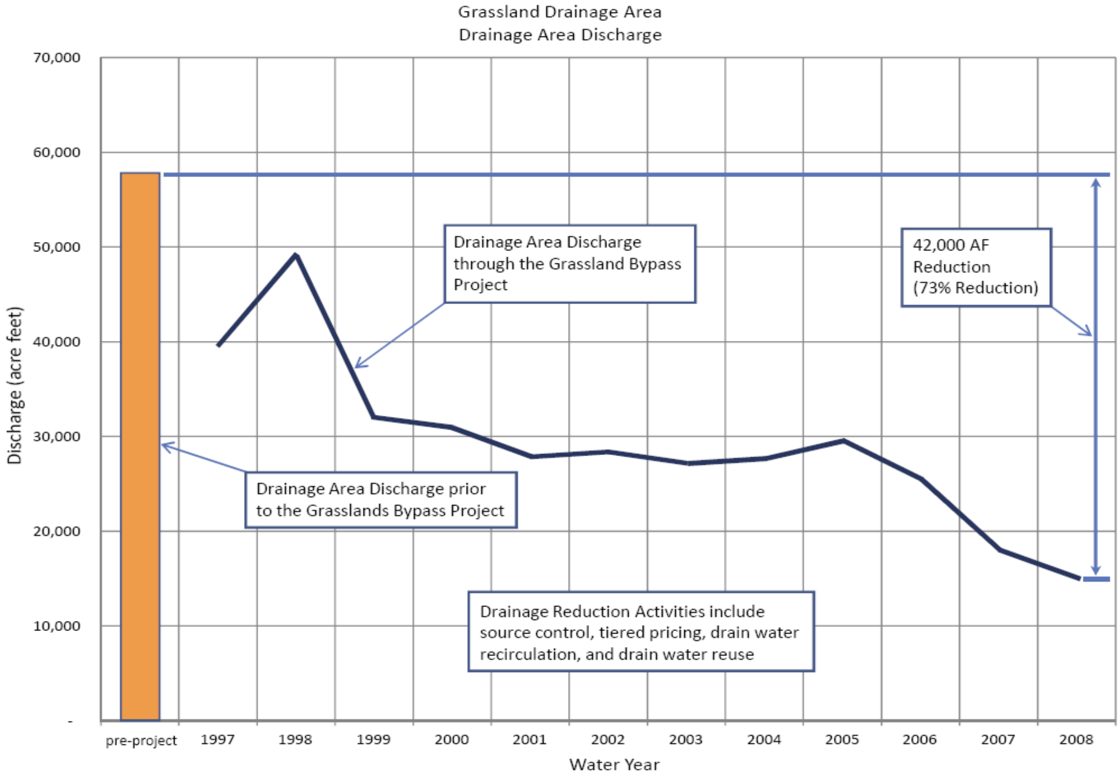


Figure 5. Grasslands Drainage Area, Drainage Discharges

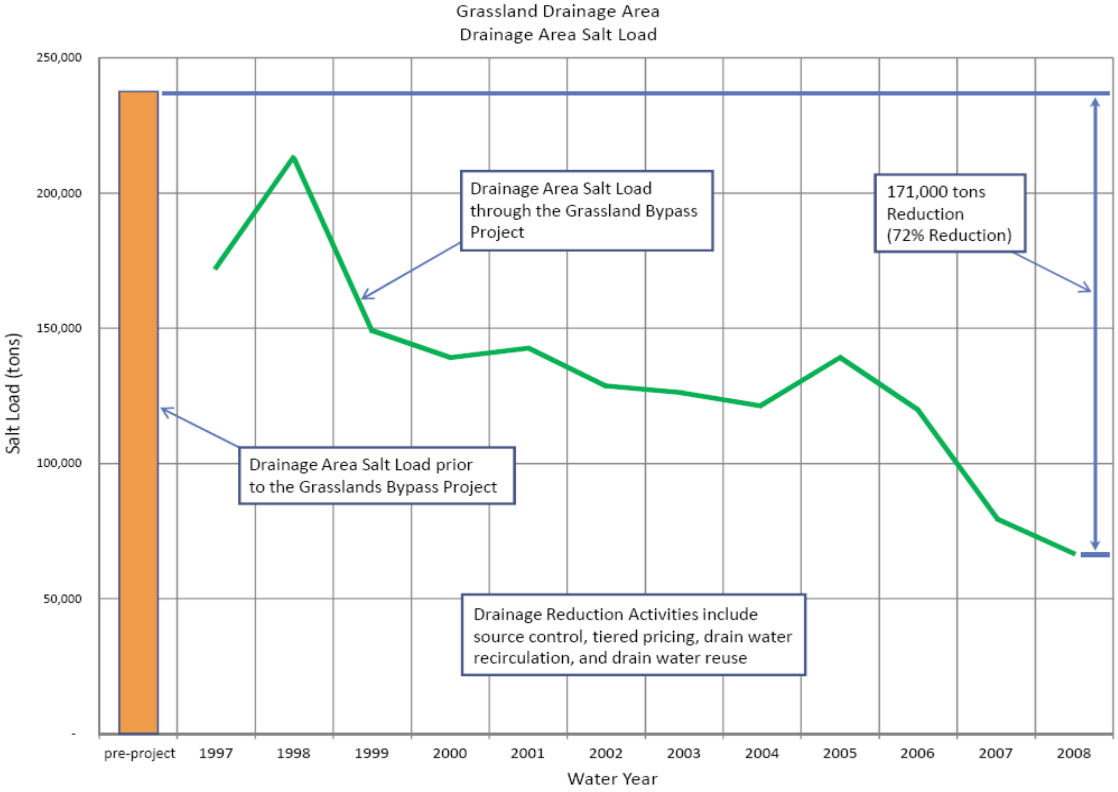


Figure 6. Grasslands Drainage Area, Drainage Salt Load

Table 5

Grassland Drainage Area

Previous Funding for the In-Valley Drainage Solution

Project	Funding Source	Grant Funding	Loan Funding	District Funding	Total
Grassland Bypass Construction	SWRCB State Revolving Fund		$ 600,000		$ 600,000
Charleston D.D. Recirculation System	SWRCB State Revolving Fund		$ 320,000		$ 320,000
Charleston D.D. Recirculation System : CH-3	Charleston D.D.			$ 71,200	$ 71,200
Firebaugh Canal W.D. Recirculation Systems	Firebaugh Canal W.D.			$ 271,100	$ 271,100
Pacheco W.D. Drainwater Recirculation System	SWRCB State Revolving Fund		$ 1,375,000		$ 1,375,000
Panoche W.D. Drainwater Recirculation System	SWRCB State Revolving Fund		$ 4,228,000		$ 4,228,000
Pacheco W.D. Acquisition of Improved Irrigation Eq.	SWRCB State Revolving Fund		$ 737,500		$ 737,500
Panoche D.D. Acquisition of Improved Irrigation Eq.	SWRCB State Revolving Fund		$ 4,997,294		$ 4,997,294
Panoche D.D. Road Watering Project	Panoche D.D.			$ 12,000	$ 12,000
San Joaquin River Improvement Project (SJRIP)					
Land Purchase & Initial Development	Prop 13 (Directed Action)	$ 17,500,000			$ 17,500,000
2004-05 Development Project	USBR	$ 904,100		$ 95,900	$ 1,000,000
Halophyte Development Project	USBR	$ 290,000		$ 15,000	$ 305,000
Grassland Integrated Drainage Management Proj.	Prop 13	$ 987,200		$ 246,800	$ 1,234,000
PE-5 Pump Station	Panoche D.D.			$ 13,200	$ 13,200
Algal-Bacterial Selenium Reduction Proj. (ABSR)	USBR/DWR/CalFed	$ 3,352,000		$ 225,000	$ 3,577,000
USBR: RO Pilot Plant		$ 440,000		$170,000	$ 610,000
	Subtotal	**$ 23,473,300**	**$ 12,257,794**	**$ 1,120,200**	**$ 36,851,294**
March 2005 Update:					
Panoche D.D. SJRIP Reuse Development Project	SWRCB - Prop 50	$ 389,500		94,800	$ 484,300
SJRIP Reuse Expansion Project	USBR	$ 890,000			$ 890,000
Panoche W.D. Ag Drainage Loan Project - Irri. Impr.	SWRCB		$ 1,800,000		$ 1,800,000
	Subtotal	**$ 24,752,800**	**$ 14,057,794**	**$ 1,215,000**	**$ 40,025,594**

Source Summers Enginnering

Even though the San Joaquin Valley Drainage Implementation Program (SJVDIP) has been idled since 2003, DWR continues to implement many of its recommendations through its Agricultural Drainage program and working in partnership with California Universities, CALFED, USBR, Resource Conservation Districts, Watershed groups, Water and Drainage Districts and many other Local, State and Federal entities. These activities include:

a) providing grants for control of agricultural drainage water and reduction of its toxic elements using (Propositions 13, 50, 204 and in the near future 84) and DWR own project fund monies,
b) developing, educate, and promote the use Integrated On-Farm Drainage Management Systems (IFDM) in the San Joaquin Valley,
c) providing technical assistance and collaborating with water and drainage districts, and local entities to reduce and control surface subsurface agricultural drainage water,
d) maintaining research and demonstration projects to develop drainage reuse systems, including development of cost effective salt tolerant crops, drainage treatment and disposal technologies, and salt separation and utilization,
e) monitoring the quality and distribution of shallow groundwater water levels in drainage impaired areas of the San JoaquinValley.

Table 6 summarizes grants directly and indirectly related to the activities described above. To date, more than 72 million dollars in grants have been distributed by DWR through Project Funds and bond money from Propositions 13, 50, and 204 (drainage sub-account).

Additional efforts proposed to control saline water discharges into the San Joaquin River include the West Side Regional Plan, USBR's San Luis Drainage Feature Reevaluation to provide drainage service to the San Luis Unit of the Central Valley Project and the Integrated On-Farm Drainage Management Program that DWR and collaborating agencies maintain. In addition, the

San Joaquin River Management Group, of which DWR is a member, completed its report controlling salinity in the San Joaquin River. Recommendations include:

1. Fully implementing the West Side Regional Drainage Plan.
2. Further evaluating and pursuing managed wetland drainage management action to mitigate impacts of February through April drainage releases.
3. Developing a real-time water quality management coordination group involving LSJR tributaries, LSJR drainers and DWR to coordinate reservoir release and SWP/CVP Project operations (head of Old River barrier and New Melones operations) to realize opportunities to improve water quality and increase the utility of stored water releases.

TABLE 6
DWR Grants

2001	Westside RCD	Prop. 13	Total Utilization of Drainage & Minimization of Evaporation	$111,280
2001	USDA/Ag. Research Serv.	Prop. 13	Salt-Tolerant Crops Evaluation	$69,600
2001	San Joaquin Valley Drainage Auth	Prop. 13	SW Stanislaus Co. Regional Drainage Water Mgt.	$616,200
2001	Stanislaus RCD, West	Prop. 13	Irrigation Mgmt. & Dormant Spray Reduction	$160,523
2001	WaterTech	Prop. 13	Irrigation Scheduling	$200,000
2001	Columbia Canal Co.	Prop. 13	On-farm Irrigation System Improvements	$152,823
2001	Panoche Water District	Prop 13	Grassland Integrated Drainage Management Proj.	$987,200
2002	Panoche Water District	Prop. 13	Herndon Avenue Lateral Feasibility Study. Modernization Feasibility	$54,545
2002	Banta Carbona Irrigation District	Prop. 13	Banta-Carbona Irrigation District Modernization Feasibility Study	$99,204
2002	Westlands Water District	Prop. 13	Water Measurement Enhancement Project	$82,500
2004	Patterson Irrigation District	Prop. 50	Agricutural Water Reuse Best Management Practices to	$1,053,000
2004	California State University - Fresn	Prop. 50	Improve District-Level Irrigation Efficiency	$1,027,779
2004	Modesto Irrigation District	Prop. 50	Ditch pipeline to Improve Water Quality	$500,000
2004	Oakdale Irrigation District	Prop. 50	Irrigation District Tailwater Recovery Program	$731,500
2004	USDA	Prop. 50	Improved Water Use Efficiency for Vegetables grown in the SJV	$248,000
2004	San Joaquin County RCD	Prop. 50	Expanded Mobile Irrigation Lab and Irrigation Workshops	$60,000
2005	San Joaquin RIver Exchange Con	Prop. 50	Upper San Joaquin River Conceptual Restoration Plan - Integrated Regional Water Management Plan	$499,952
2000	Vernalis Adaptive Managenemt Plan		Purchase water for pulse flows to meet SWRCB standards	$5,000,000
2000	Friant Water Users Authority and	Prop. 13 C	San Joaquin River Restoration Program	$15,700,000
2000	Panoche Drainage District	Prop. 13 C	San Joaquin River Water Quality Improvement Project	$17,500,000
2000	Environmental Water Account	Prop. 13 C	Water Transfers	$6,250,000
2000	San Luis & Delta Mendota WA *	Prop. 13 C	Water Transfer	$6,250,000
2000	Westlands Water District	Prop. 13 C	Irrigation Systems Improvement Project: On farm irrigation improve	$5,000,000
2000	San Luis Water District	Prop. 13 C	Relift Canal Lining Project	$1,000,000
2000	Del Puerto Water District	Prop. 13 C	Irrigation Systems Improvement Project: On farm irrigation improve	$500,000
2000	UC Riverside	Prop. 204 (	IFDM Present Status and Further Research	$51,303
2000	DWR	Prop. 204 (	Red Rock Ranch IFDM Monitoring	$317,000
2000	UC Davis	Prop. 204 (	Producing Forage Crops Using Drainage	$45,990
2000	Westside Resources Conservatio	Prop. 204 (	Various IFDM Start-Up Proposals	$267,797
2000	SJV Drainage Authority	Prop. 204 (	Planning and Design for Grasslands Drainage Reuse	$150,000
2000	DWR	Prop. 204 (	Conceptual Planning and Design for Grasslands Drainage Reuse	$60,000
2000	DWR-USFWS	Prop. 204 (	Development of IFDM Wildlife Management Criteria	$75,000
2000	DWR	Prop. 204 (	Monitoring Wildlife Impacts at IFDM Demonstration Projects	$105,000
2000	Buena Vista Water Storage Distric	Prop. 204 (	Buena Vista Desalination Pilot Demonstration	$100,000
2000	DWR-WRCD	Prop. 204 (	Water and Salt Recovery Through Solar Distillation	$120,000
2000	UC-Davis	Prop. 204 (	Investigate systems of salt separation, utilization, and purification	$60,000
2000	UC-Davis	Prop. 204 (	Salt Utilization in Glass Making	$33,000
2000	DWR	Prop. 204 (	Survey of Location and Acreage of Westside SJV Irrigation Method	$75,000
2000	DWR	Prop. 204 (	Contracts and Program Management/Fund Administration	$160,000
2000	DWR	Prop. 204 (	Contribution to SJV Drainage Implementation Program (2001 and 2	$44,000
2001	UC Davis	Prop. 204 (	Using Forages and Livestock to Manage Drainage Water in the San	$169,950
2001	USDA	Prop. 204 (	Crop Production with In-situ Use of Shallow Saline Groundwater	$402,600
2001	WRCD	Prop. 204 (	Expanded Demonstration Projects for Integrated On-Farm Drainag	$335,000
2001	UC Berkeley	Prop. 204 (	Grassland Drainage Area Algal-Bacterial Selenium Removal Facility	$125,000
2002	CSU-Fresno	Prop. 204 (	Evaluate cumulative water use (ET) for salt tolerant forages in RRR	$90,030
2002	Westlands Water District	Prop. 204 (	Removal of Selenium from Drainage water in lined reduction channe	$100,000
2002	Tulare Lake Drainage DIstrict	Prop. 204 (	Develop biological design criteria for a wetland located within the T	$120,000
2002	Patterson Water District	Prop. 204 (	Compare and contrast salinity mass balance on Patterson WD and	$121,000
2002	DWR-UTEP	Prop. 204 (	Feasibility of Salinity Gradient Solar Pond Technology in San Joaqui	$180,000
2002	USDA	Prop. 204 (	Biofuels - Biofuel and Se-enriched forage from Canola	$65,500
2002	UC Davis	Prop. 204 (	Utilizing the saline biomass for energy and producing value-added pr	$175,346
2002	UC Davis	Prop. 204 (	Develop a mass balance on water and Se on TLDD and Lost Hills E	$202,500
2002	DWR	Prop. 204 (	Real Time Water Quality Measurements in the San Joaquin River	$87,226
2002	UC Riverside	Prop. 204 (	A comparative economic analysis of implementing an evaporation p	$36,196
2003	UC Daviis - CSU Fresno	Prop. 204 (	Evaluate yield and animal acceptability of forages grown under irriga	$247,272
2003	UC Davis	Prop. 204 (	Evaluate the efficacy of reducing Se load by intensive harvest of brin	$176,588
2003	UCLA	Prop. 204 (	Evaluate drainage water quality for membrane desalination process	$167,456
		Prop. 204 (	Construct and test ion exchange processes in a pilot on farm ion exc	$93,500
2005	UCLA	Prop. 204 (	Concentration of Mineral Salts from Membrane Desalting of Agricult	$159,116
2005	UC Merced	Prop. 204 (	Wetland drainage management technology development in support	$199,807
2005	UC Davis	Prop. 204 (	Predicting water use, crop growth,and quality of Bermuda grass und	$175,533
2000	UC Davis	DWR- Proj	Mycrophyte-Mediated Se Bigeochemistry and its role in Bioremediati	$134,200
2000	UC Davis	DWR- Proj	TLDD - Flow trough Wetland Systems for the removal of Se in Irrigat	$60,000
2000	UC Davis	DWR- Proj	In Situ Se. Volatilization and From Measurements at SJV Evaporatio	$14,200
2000	UC Davis	DWR- Proj	Assesing the Efficacy of Macroinvertebrate Harvest and Algal Se Vol	$159,000
2000	UC Davis	DWR- Proj	Recovery of Sodium Sulfate from Drainage Water	$50,000
2000	UC Davis	DWR- Proj	Utilization of Agricultural Drainage Salt in Textile Processing	$50,000
2000	UC Davis	DWR- Proj	Recovery, purification, and utilization of salts from agricultural subsu	$155,616
2001	Broadview Water District	DWR- Proj	Active Land Managemet Program to Reduce Drainage Water	$130,000
2003	USDA	DWR- Proj	Direct ET Determination of Grass and Truckload crops by lysimeter	$110,000
2003	Buena Vista Water Storage Distric	DWR- Proj	Buena Vista Ag Drainage Desalination Pilot Demonstration	$270,000
2000	UCLA	DWR- Proj	Optimizing processes for desalination of Agricultural Drainage Water	$300,000
			TOTAL	$70,380,832

TABLE 6 (Continuation)

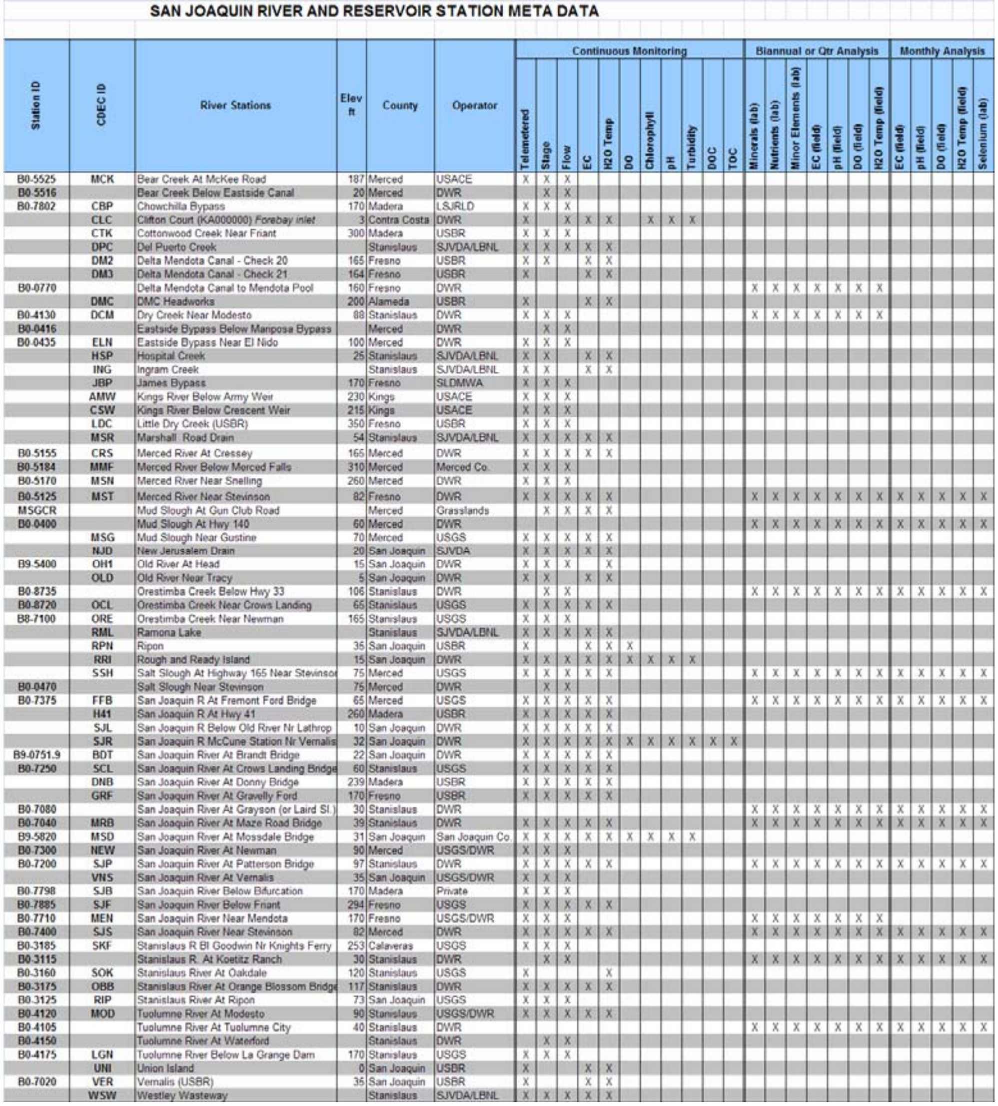
Year Begun	Local Agency	Project Title	Total Cost	Objective
1988	Westlands Water District	Demonstration of Emerging Irrigation	$552,408	Demonstrate the potential of emerging irrigation technologies to reduce the volume of drainage water in the western San Joaquin Valley.
1988	Westlands Water District & Broadview Water District	Demonstration of Improved Furrow Irrigation	$568,000	Demonstrate advanced technologies, innovative concepts to improve on-farm irrigation efficiencies, and irrigation uniformities while maintaining or increasing the yield.
1991	Central California Irrigation District	Grasslands Drainage Basin Water Conservation Coordinator	$64,286	Provide technical expertise, educate water users, improve irrigation management, and decrease subsurface drainage.
1987	Panoche Water & Drainage District	Irrigation Efficiency & Regional Subsurface Drainage Flow on the Westside of the San Joaquin Valley	$171,000	Evaluate whether the discharge of selenium and other toxic trace elements in the drainage water could be reduced by improving on-farm irrigation practices and drainage management.
1990	Panoche Water & Drainage District	Relationship between Contaminant Loads & Drain Flows for Drainage Systems on the Westside of the San Joaquin Valley	$175,000	Evaluate the hydrologic interaction between the load (or mass) of salt, boron, selenium, and molybdenum and the volume of water removed by agricultural drains, taking into consideration different soils and crops.
1988	USGS	Groundwater Quantity & Quality into the San Joaquin River	$140,000	Identify the quality of groundwater flows to the San Joaquin River.
1988	Broadview Water District	Tiered-Block Water Pricing	$175,000	Test the effectiveness of tiered-block water pricing in reducing irrigation water use without reducing crop yield.
1988	Westlands Water District	Agroforestry Systems for Sequential Reuse of Drainage Water	$324,863	Use agroforestry systems to lower a high water table, reuse saline drainage water, and remove salts and trace elements from irrigation land.
1992	Broadview Water District	Shallow Groundwater Management	$175,000	Develop subsurface drainage design and irrigation and drainage management criteria to maximize the use of shallow groundwater during the growing season, while minimizing agricultural drainage pollutant load and impacts on crop yield.
1995	USDA	Growth and Water Relations of Plant Species Suitable for Saline Drainage Water Reuse Systems	$218,800	Determine the crop/water production functions for eucalyptus trees under different salinity and boron treatments, the ion-loading characteristics of a selected eucalyptus genotype and the ion interactions that contribute to foliar injury.
1995	Regents of UC	Selenium Management in Integrated On-Farm Drainage Management Systems through Volatilization	$107,741	Determine the extent which selenium (Se) is removed to the atmosphere through biological volatilization from different components of Integrated On-Farm Drainage Management systems.
N/A	Regents of UC	Boron Accumulation and Toxicity in Integrated On-Farm Drainage Management	$40,000	Determine the long term impacts of soil boron accumulation with Integrated On-Farm Drainage Management systems in the San Joaquin Valley.
N/A	CSU, Fresno	Survey of Linear Move Irrigation Systems in California	$6,000	Conduct a survey of growers using linear move irrigation systems, identify the costs and benefits associated with the systems, and determine if any systems were used to mitigate agricultural drainage problems.
1998	Pond-Shafter-Wasco RCD	Irrigation Workshops and Training Manuals	$31,770	Workshops targeted specific irrigation districts and regions and were designed to assist farm irrigation managers and workers who perform irrigation operations.
1999	CSU, Fresno	Integrated On-Farm Drainage Management Workshops	$80,000	A series of workshops on Integrated On-Farm Drainage Management.
1996	Regents of UC	Advances in Irrigation Symposium	$8,000	Three symposiums on "Advances in Irrigation".

b) Real-time Water Quality Monitoring Program

The Real-time Water Quality Monitoring Program (RTWQMP) provides information on existing water quality conditions and forecasts flow and water quality conditions to SJR water managers and stakeholders.   The information provided is important for improving management and coordination of reservoir releases, agricultural and wetlands drainage flows, and eastside tributary releases to achieve water quality objectives at the SJR compliance points. In fact, DWR is collaborating with the San Joaquin River Water Quality Management Group to realize opportunities to achieve these goals using the RTWQMP and other stakeholder tools.

DWR operates and maintains 25 river monitoring stations and shares responsibility with USGS for another three stations along the lower San Joaquin River System. For this effort, DWR currently expends over one million dollars. In the early stages, the RTWQMP was funded by USBR and then by CALFED. Currently, DWR has assumed responsibility for funding most of the RTWQMP for the San Joaquin River. Table 7 lists the LSJR surface water monitoring stations including DWR stations as well as other cooperating agency stations in the RTWQMP.

Table 7



SAN JOAQUIN RIVER AND RESERVOIR STATION META DATA

Station ID	CDEC ID	River Stations	Elev ft	County	Operator	Continuous Monitoring											Biannual or Qtr Analysis							Monthly Analysis				
						Telemetered	Stage	Flow	EC	H2O Temp	DO	Chlorophyll	pH	Turbidity	DOC	TOC	Minerals (lab)	Nutrients (lab)	Minor Elements (lab)	EC (field)	pH (field)	DO (field)	H2O Temp (field)	EC (field)	pH (field)	DO (field)	H2O Temp (field)	Selenium (lab)
B0-5525	MCK	Bear Creek At McKee Road	187	Merced	USACE	X	X	X																				
B0-5516		Bear Creek Below Eastside Canal	20	Merced	DWR		X	X																				
B0-7802	CBP	Chowchilla Bypass	170	Madera	LSJRLD	X	X	X																				
	CLC	Clifton Court (KA000000) *Forebay inlet*	3	Contra Costa	DWR	X		X	X	X		X	X	X														
	CTK	Cottonwood Creek Near Friant	300	Madera	USBR	X	X	X																				
	DPC	Del Puerto Creek		Stanislaus	SJVDA/LBNL	X	X	X	X	X																		
	DM2	Delta Mendota Canal - Check 20	165	Fresno	USBR	X	X		X	X																		
	DM3	Delta Mendota Canal - Check 21	164	Fresno	USBR	X			X	X																		
B0-0770		Delta Mendota Canal to Mendota Pool	160	Fresno	DWR												X	X	X	X	X	X	X					
	DMC	DMC Headworks	200	Alameda	USBR	X			X	X																		
B0-4130	DCM	Dry Creek Near Modesto	88	Stanislaus	DWR	X	X	X									X	X	X	X	X	X	X					
B0-0416		Eastside Bypass Below Mariposa Bypass		Merced	DWR		X	X																				
B0-0435	ELN	Eastside Bypass Near El Nido	100	Merced	DWR	X	X	X																				
	HSP	Hospital Creek	25	Stanislaus	SJVDA/LBNL	X	X		X	X																		
	ING	Ingram Creek		Stanislaus	SJVDA/LBNL	X	X		X	X																		
	JBP	James Bypass	170	Fresno	SLDMWA	X	X	X																				
	AMW	Kings River Below Army Weir	230	Kings	USACE	X	X	X																				
	CSW	Kings River Below Crescent Weir	215	Kings	USACE	X	X	X																				
	LDC	Little Dry Creek (USBR)	350	Fresno	USBR	X	X	X																				
	MSR	Marshall Road Drain	54	Stanislaus	SJVDA/LBNL	X	X	X	X	X																		
B0-5155	CRS	Merced River At Cressey	165	Merced	DWR	X	X	X	X	X																		
B0-5184	MMF	Merced River Below Merced Falls	310	Merced	Merced Co.	X	X	X																				
B0-5170	MSN	Merced River Near Snelling	260	Merced	DWR	X	X	X																				
B0-5125	MST	Merced River Near Stevinson	82	Fresno	DWR	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X
MSGCR		Mud Slough At Gun Club Road		Merced	Grasslands		X	X	X	X																		
B0-0400		Mud Slough At Hwy 140	60	Merced	DWR												X	X	X	X	X	X	X	X	X	X	X	X
	MSG	Mud Slough Near Gustine	70	Merced	USGS	X	X	X	X	X																		
	NJD	New Jerusalem Drain	20	San Joaquin	SJVDA	X	X	X	X	X																		
B9-5400	OH1	Old River At Head	15	San Joaquin	DWR	X	X	X		X																		
	OLD	Old River Near Tracy	5	San Joaquin	DWR	X	X		X	X																		
B0-8735		Orestimba Creek Below Hwy 33	106	Stanislaus	DWR		X	X									X	X	X	X	X	X	X	X	X	X	X	X
B0-8720	OCL	Orestimba Creek Near Crows Landing	65	Stanislaus	USGS	X	X	X	X	X																		
B8-7100	ORE	Orestimba Creek Near Newman	165	Stanislaus	USGS	X	X	X																				
	RML	Ramona Lake		Stanislaus	SJVDA/LBNL	X	X	X	X	X																		
	RPN	Ripon	35	San Joaquin	USBR	X			X	X	X																	
	RRI	Rough and Ready Island	15	San Joaquin	DWR	X	X	X	X	X	X	X	X	X														
	SSH	Salt Slough At Highway 165 Near Stevinso	75	Merced	USGS	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X
B0-0470		Salt Slough Near Stevinson	75	Merced	DWR		X	X																				
B0-7375	FFB	San Joaquin R At Fremont Ford Bridge	65	Merced	USGS	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X
	H41	San Joaquin R At Hwy 41	260	Madera	USBR	X	X	X	X	X																		
	SJL	San Joaquin R Below Old River Nr Lathrop	10	San Joaquin	DWR	X	X	X	X	X																		
	SJR	San Joaquin R McCune Station Nr Vernalis	32	San Joaquin	DWR	X	X	X	X	X	X	X	X	X	X	X												
B9-0751.9	BDT	San Joaquin River At Brandt Bridge	22	San Joaquin	DWR	X	X	X	X	X																		
B0-7250	SCL	San Joaquin River At Crows Landing Bridge	60	Stanislaus	USGS	X	X	X	X	X																		
	DNB	San Joaquin River At Donny Bridge	239	Madera	USBR	X	X	X	X	X																		
	GRF	San Joaquin River At Gravelly Ford	170	Fresno	USBR	X	X	X	X	X																		
B0-7080		San Joaquin River At Grayson (or Laird Sl.)	30	Stanislaus	DWR												X	X	X	X	X	X	X	X	X	X	X	X
B0-7040	MRB	San Joaquin River At Maze Road Bridge	39	Stanislaus	DWR	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X
B9-5820	MSD	San Joaquin River At Mossdale Bridge	31	San Joaquin	San Joaquin Co.	X	X	X	X	X	X	X	X	X														
B0-7300	NEW	San Joaquin River At Newman	90	Merced	USGS/DWR	X	X	X																				
B0-7200	SJP	San Joaquin River At Patterson Bridge	97	Stanislaus	DWR	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X
	VNS	San Joaquin River At Vernalis	35	San Joaquin	USGS/DWR	X	X	X																				
B0-7798	SJB	San Joaquin River Below Bifurcation	170	Madera	Private	X	X	X																				
B0-7885	SJF	San Joaquin River Below Friant	294	Fresno	USGS	X	X	X	X	X																		
B0-7710	MEN	San Joaquin River Near Mendota	170	Fresno	USGS/DWR	X	X	X									X	X	X	X	X	X	X					
B0-7400	SJS	San Joaquin River Near Stevinson	82	Merced	DWR	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X
B0-3185	SKF	Stanislaus R Bl Goodwin Nr Knights Ferry	253	Calaveras	USGS	X	X	X																				
B0-3115		Stanislaus R. At Koetitz Ranch	30	Stanislaus	DWR		X	X									X	X	X	X	X	X	X	X	X	X	X	X
B0-3160	SOK	Stanislaus River At Oakdale	120	Stanislaus	USGS	X				X																		
B0-3175	OBB	Stanislaus River At Orange Blossom Bridge	117	Stanislaus	DWR	X	X	X	X	X																		
B0-3125	RIP	Stanislaus River At Ripon	73	San Joaquin	USGS	X	X	X																				
B0-4120	MOD	Tuolumne River At Modesto	90	Stanislaus	USGS/DWR	X	X	X	X	X																		
B0-4105		Tuolumne River At Tuolumne City	40	Stanislaus	DWR												X	X	X	X	X	X	X	X	X	X	X	X
B0-4150		Tuolumne River At Waterford		Stanislaus	DWR		X	X																				
B0-4175	LGN	Tuolumne River Below La Grange Dam	170	Stanislaus	USGS	X	X	X																				
	UNI	Union Island	0	San Joaquin	USBR	X			X	X																		
B0-7020	VER	Vernalis (USBR)	35	San Joaquin	USBR	X			X	X																		
	WSW	Westley Wasteway		Stanislaus	SJVDA/LBNL	X	X	X	X	X																		

One important activity of this program is forecasting flow and salinity conditions on the SJR so that decision makers can take advantage of assimilative capacity of the river when available. For this purpose, DWR collects data from the network of stations and inputs it into the San Joaquin River Input-Output Day (SJRIODAY) model. The model forecasts salinity and flow conditions on the River near Vernalis, and other upstream stations on a biweekly basis. DWR publishes the information on its website on a weekly basis. Figure 7 shows an example of the information displayed:

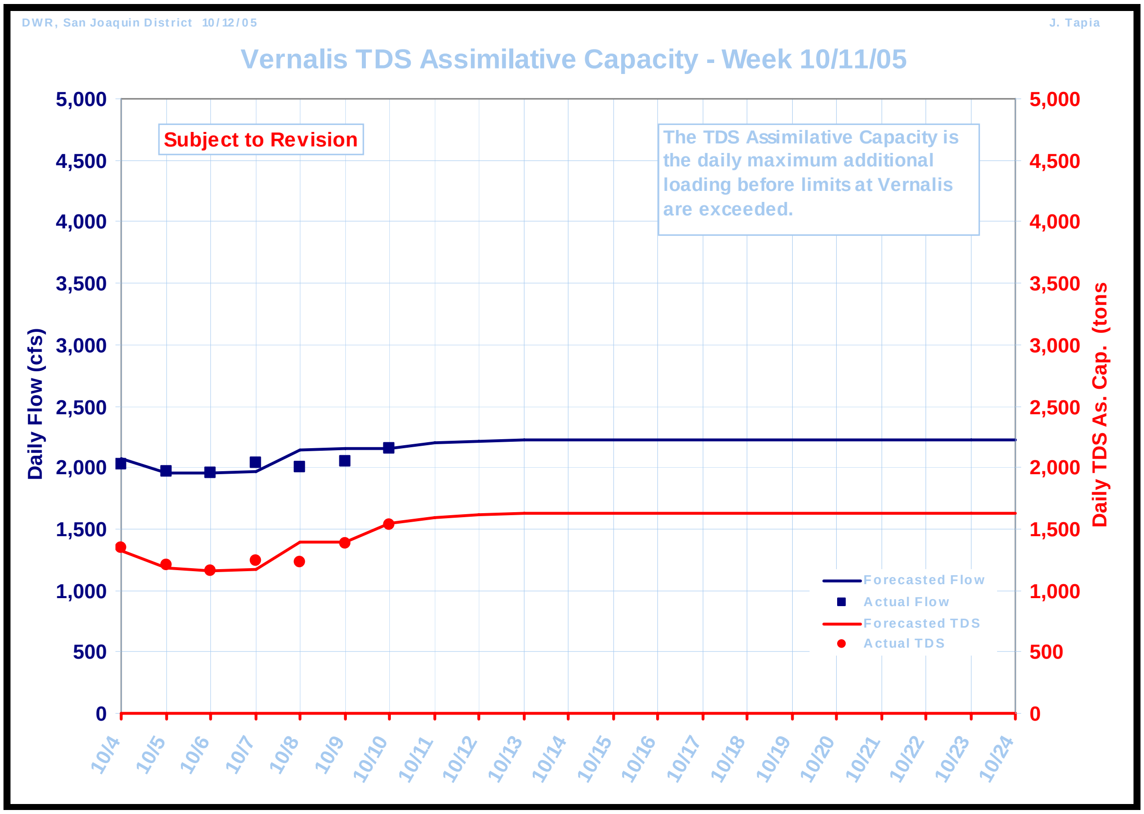
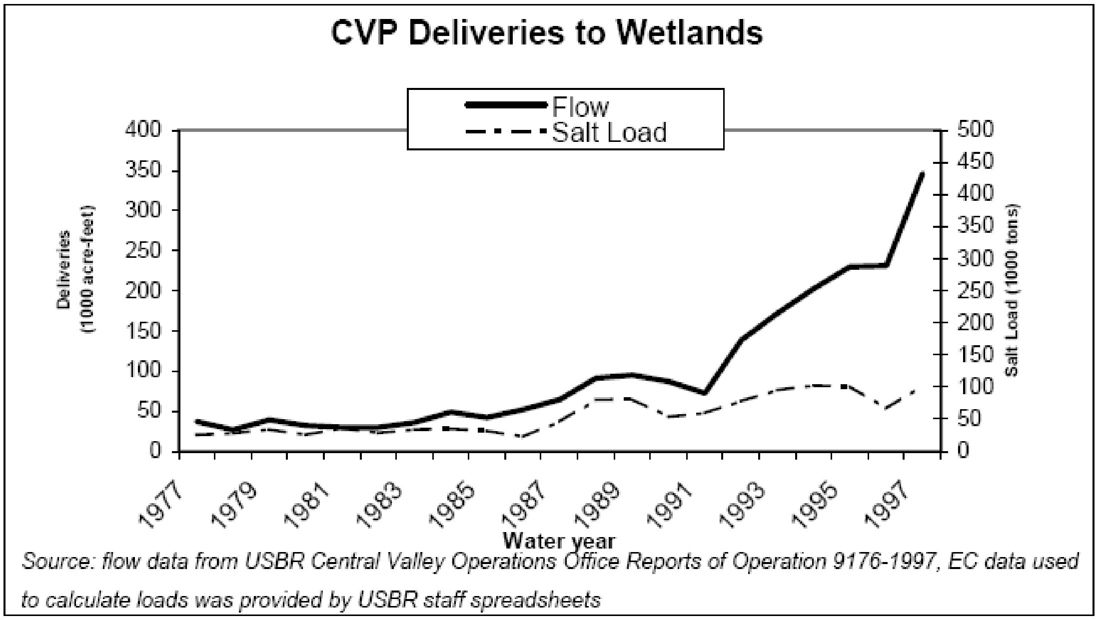


Figure 7. San Joaquin River Input-Output Day Modeling Forecasts

c) Efforts to Improve Wetlands Discharges

As per 1998 data, wetlands discharges contributed about 9% of the total salt load in the San Joaquin River at Vernalis. The contribution is likely to be higher today as additional water supply and land are acquired for wetlands wildlife refuges (Figure 8) through CVPIA, EWA, and other programs. Timing of wetland releases with assimilative capacity of the SJR will result in significant water quality improvements. However, little has been done in this regard due to concerns over disrupting existing, proven wetland management practices.



Source: flow data from USBR Central Valley Operations Office Reports of Operation 9176-1997, EC data used to calculate loads was provided by USBR staff spreadsheets

Figure 8. Central Valley Project Wetlands Water Deliveries
Source: Central Valley Regional Water Quality Control Board

Research is needed to determine if improved wetlands management practices can be achieved for the benefit of both wildlife and SJR water quality. Current research has focused on real-time water quality monitoring and adaptive management. Research goals are to coordinate timing of wetland discharges when assimilative capacity is available. Multiple grants have been provided for these purposes (Table 8).

Table 8
CALFED Grant Funded Projects

Project	Year Funded	Amount	Recipient
Effect of Delayed Wetland Drawdown On Moist Soil Plants	2005	$200,000	California Department of Fish and Game
Adaptive Real-Time Monitoring & Management of Seasonal Wetlands in the San Luis National Wildlife Refuge to Quantify Contaminant Sources & Improve Water Quality in the San Joaquin River	2002	$320,000	Berkeley National Labs
Vernalis Real-Time Water Quality Monitoring Station	2002	$615,000	California Department of Water Resources
Adaptive Real-Time Water Quality Management of Seasonal Wetlands in the Grassland Water District.	2000	$671,900	Grassland Water District
San Joaquin River Real-Time Water Quality Management Program	1997	$931,857	California Department of Water Resources, San Joaquin District

In addition to funds provided by CALFED for the study on the *Effect of Delayed Wetland Drawdown on Moist Soil Plants*, staff from DWR, DFG, and UC Davis are working cooperatively to assess other aspects of delayed wetland drawdown. The study will complement DFG's current wetland drawdown research.

The studies on delayed wetland drawdown are complemented with a study titled "Wetland drainage management technology development in support of San Joaquin River real-time water quality management" funded by DWR under Proposition 204 (drainage sub-account). The study is a part of the Real-time Water Quality Monitoring Program.

The CVRWQCB has also given grants to wetlands operators supported by funds from Propositions 40, and 50. These grants are shown in Table 9.

Table 9

Regional Water Quality Board Funded Projects

Project	Year Funded	Proposition #	Amount	Recipient
Monitoring Constructed Wetlands to Improve Water Quality of Irrigation Return Flows	2005	40	$500,000	UC Davis
Adaptive, Coordinated Real-Time Management of Wetland Drainage	2005	50	$998,029	Grasslands Water District

Degradation of water quality at the San Joaquin River below Vernalis

While salinity objectives are met most of time at Vernalis (Figure 1), SJR water quality is subject to significant degradation from treated sewage discharges from the cities of Manteca, Lathrop, Tracy, and Mountain House, by illegal water diversions and by drainage water discharges from agricultural operations in the South and Central Delta. A DWR analysis performed by the Bay Delta Office indicates that, in average, there is approximately an 8% increase in salinity at the SJR between Vernalis and Brandt Bridge stations. This increase represents an addition of approximately 80,000 tons of salt between these two stations, which are 26 miles apart. A DWR memorandum report titled "Sources of Salinity in the South Sacramento-San Joaquin Delta" presents evidence pointing sources of saline discharges and water diversions that affect river water quality between in the lower San Joaquin River South Delta region.

As with the Grasslands Area farmers, specific salt loads contributions from responsible parties need to be quantified in order to appropriately determine responsibility for water quality objectives compliance. A good example of how this can be accomplished is referenced to the work performed by the CVRWQCB leading to the establishment of proposed TMDLs for Salinity and Boron in the lower SJR. Tables 3 and 4 and Figure 4 show how salt load allocations can be established by type and area.

It is important to note that while the EC 0.7 mmhos/cm objective in the SJR was developed to protect beneficial agricultural uses in the South Delta, farmers in the Grasslands Drainage Area representing Panoche, Pacheco, Charleston, and Firebaugh Canal water districts, have implemented successful measures to reuse tailwater and reduce subsurface drainage discharges by blending tilewater with their irrigation water supply to EC levels near or equal to 1 mmhos/cm. These water districts have received many grants and loans to implement these measures. Table 10 describes the crops these districts raised in 2002. A portion of crops was grown with blended drainage and irrigation water. With careful irrigation management practices, these farmers continue to contribute more than $140 million to the California economy.

Table 10
Crops Grown in Selected Water Districts that Recycle Irrigation Water

Water District:	**Firebaugh Canal**	**Panoche**	**San Luis**	**Charleston**	**Pacheco**
Irrigated Crop Survey 2002	**Acreage**	**Acreage**	**Acreage**	**Acreage**	**Acreage**
Alfalfa	3,890	1,547	1,662	401	1
Almonds/Pistachio	24	622	10,660	26	
Corn	63	3	652	40	
Cotton	10081	15402	10645	2421	732
Cucurbits	2334	5967	3879	547	1487
Dry Beans		128	141		
Grain	846	918	575	242	179
Onions & Garlic	334	1,196	914		108
Other Deciduous Trees	74		1,468		
Other Field Crops	257	128			
Other Truck Crops	2	2335	491	183	217
Pasture	32	167	28	8	
Rice					
Safflower	78	449			100
Sugar Beets	889	509	459		
Tomatoes	2087	6773	4466	433	1325
Vineyard		686	306		
Citrus			261		
Total	**20,991**	**36,830**	**36,607**	**4,301**	**4,149**

Conclusion

Evidence presented in this report demonstrates that DWR has taken proactive measures to help meet water quality objectives at the lower San Joaquin River compliance points. These contributions include the purchase of VAMP flows, implementing recommendations of the interagency San Joaquin Valley Drainage Implementation Program through DWR's Agricultural Drainage Program and working cooperatively with other agencies, and by providing and administering grants monies from its own Project Funds and Propositions 13, 50, and 204 (and 84 in the near future) in projects for salinity control in the SJR. The Department of Water Resources also operates and maintains a network of over 25 real-time water quality monitoring stations along the lower San Joaquin River and provides flow and water quality information to stakeholders. In addition, DWR provides at its website weekly forecasts of the assimilative capacity of the San Joaquin River at key locations. DWR is also participating in, and funding research that could improve management wetlands saline discharges into the SJR. DWR is also actively involved in the San Joaquin River Restoration Program which is a comprehensive long-term effort to restore flows to the San Joaquin River from Friant Dam to the confluence of Merced River and restore a self-sustaining Chinook salmon fishery in the river. The first releases of SJRRP flows from Friant Dam are expected to occur from October through September 2010. Additionally, DWR is also working various watershed groups that among other things work towards improving water quality in the river.

The information also points out that while water quality objectives in the Delta are set at EC 0.7, part of a year to protect agriculture beneficial uses, other water districts upstream the San Joaquin River are irrigating crops with blended tail and tile water at EC's 1 or above in order to meet salt and boron objectives in the SJR. The information provided also points out a clear need to quantify and identify the sources of water quality degradation downstream Vernalis as CVRWQCB did upstream. The information will help regulatory agencies to allocate responsibility for mitigating water quality impacts to the appropriate responsible parties.

DWR - 20

Department of Water Resources
Testimony for SWRCB Hearing on Cease and Desist Order

Investigation of the Factors affecting Water Quality at Brandt Bridge, Middle River at Union Point, and Old River at Tracy

1 Introduction

To gain a better understanding of how the San Joaquin River, in delta uses, the Sacramento River, exports, and temporary barriers affect water quality at Brandt Bridge, Middle River at Union Point, and Old River at Tracy, several analyses using field data and Delta Simulation Model 2 (DSM2) simulation results were made. These analyses include:

- an evaluation of water quality degradation due to in Delta sources using field data at Vernalis, Brandt Bridge, and Mossdale;
- an evaluation of source water at Brandt Bridge, Old River at Tracy and Middle River at Union Point using DSM2 simulations of historical conditions; and
- an evaluation of the effects of State Water Project pumping on water quality at Brandt Bridge, Old River at Tracy, and Middle River at Union Point by varying pumping in DSM2 simulations of otherwise historical simulations.

The results of the studies show that the three locations are heavily dependent on San Joaquin River water and in Delta returns. It can be shown, from the DSM2 historical simulations that water at the Brandt Bridge location is composed entirely of San Joaquin River water and in Delta returns unless there is reverse flow at Brandt Bridge. Analysis using field data indicates the average degradation from Vernalis to Brandt Bridge is approximately 8%. For the Middle River at Union Point Station and the Old River at Tracy Station, the DSM2 historical simulations demonstrated that unless San Joaquin flow is low, the water at those two locations consist entirely of San Joaquin water and in Delta returns when the barriers are not installed. When the barriers are installed, there are a number of factors that potentially can affect the improvement or degradation in water quality and large changes in exports do not always result in a large change in water quality.

2 Historical Simulations and Field Data

2.1 Water Quality Field data and Explanation of Fingerprinting

Water quality and the effects of project operations at Brandt Bridge, Middle River at Union Point and Old River at Tracy (Figure 1) are evaluated in the various sections that follow. The analysis uses both measured field data and DSM2 model simulations. Information about DSM2 and its calibration and validation can be found in Appendix A

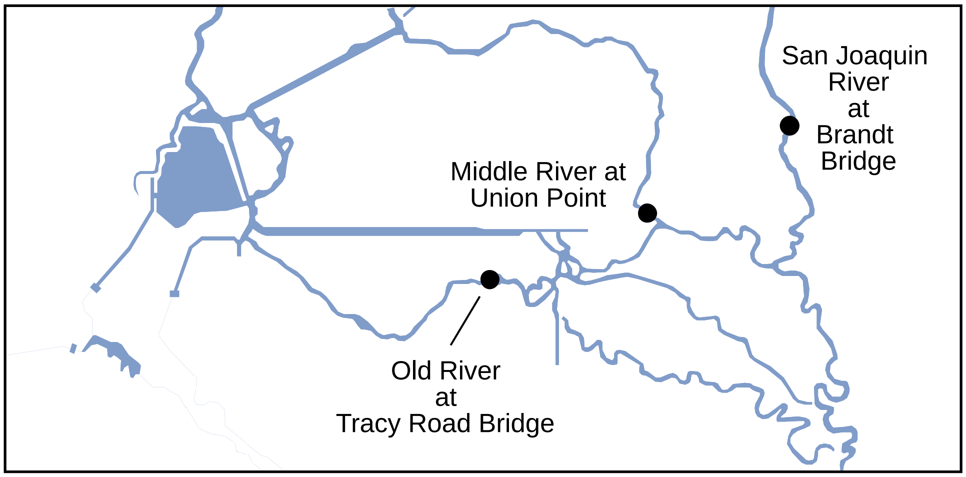


Figure 1. Locations of Water Quality Standards Sites as Modeled by DSM2

Figure 2 shows the field measured electrical conductivity (EC) at the three locations and Vernalis. This report, through various methods will demonstrate the strong effect that the Vernalis water quality and in-Delta returns have on the water quality at the three locations. As Figure 2 indicates, the water quality at the three locations and Vernalis follow predominately similar patterns. Figures 3, 4, and 5 show 30-day running average field measured water quality and DSM2 modeled San Joaquin River and agricultural returns at Brandt Bridge, Middle River at Union Point, and Old River at Tracy Road respectively. Field measured values were obtained from DWR Division of Planning and Local Assistance, Central District and are plotted against the 2005 agricultural standard.

The percentage volume contributions were determined by running historical simulations with the DSM2 Fingerprinting Methodology (Anderson, 2002). By using this method, relative contributions of water sources to the volume can be estimated at any location. Volumetric fingerprinting can be thought of as taking a bucket of water at a particular location and being able to know what percentage of that water came from each source. For the Delta waterways, the sources include the Sacramento River, the ocean, the San Joaquin River, agricultural drainage, or other inflows. Figure 6 shows the historical volumetric fingerprint for Clifton Court Forebay for the period of 2001 through 2002. In this particular plot all sources of water are plotted and all sources sum to 100%. This graph shows that during some months in the spring and early summer, the San Joaquin River dominates and later the Sacramento dominates. In Figures 3, 4 and 5, only the volumetric fingerprint for the combined San Joaquin River and agricultural drainage are shown.

2.2 Brandt Bridge Source Water and Water Quality

Figure 3 shows that there were several periods in the early 1990s when the percentage of San Joaquin River water and agricultural drainage water at Brandt Bridge dropped to approximately 30%. Historically during this time period, reverse flow occurred in the San Joaquin River at Brandt Bridge and other water sources such as the Sacramento River contributed to the volume at Brandt Bridge. Figure 3 also shows that from 1996 through 2004, the water at Brandt Bridge consisted entirely of water from the San Joaquin River passing by Vernalis and agricultural returns. To further show that the source of water at Brandt Bridge is from Vernalis and other in-Delta sources, DSM2 modeled daily average flow at the head of Old River is always flowing away from the San Joaquin River; old River Flow does not contribute to the flow at Brandt Bridge.

Since the historical period covers a variety of different pumping rates, tides, and inflows, it can be concluded from this analysis that unless there is reverse flow in the San Joaquin River, the Brandt Bridge station is fully dependent on Vernalis Water Quality and other returns along the San Joaquin river such as agricultural drainage.

2.3 Degradation of Water Quality from Vernalis to Brandt Bridge

Since the Brandt Bridge water quality is dependent upon the Vernalis water quality and other returns along the San Joaquin River, an analysis was completed quantifying the degradation of water quality from Vernalis to Mossdale and to Brandt Bridge from in-Delta sources. The analysis also provides a relationship to estimate target San Joaquin River EC at Vernalis to ensure that a Brandt Bridge EC standard of 700 μS/cm be met during April - August and 1000 μS/cm be met during September - March. The relationship was developed using monthly averaged historical EC data from year 1994 to 2002. The historical EC data were obtained from the Interagency Ecological Program (IEP) and California Data Exchange Center (CDEC) databases. USBR and DWR are the major collection agencies for EC data at Vernalis, Mossdale and Brandt Bridge.

Figure 7. shows boxplots of monthly averaged historical EC data at Vernalis, Mossdale and Brandt Bridge. Table 1 summarizes some of the basic descriptive statistics of the historical EC data at those periods. Monthly EC data at all three locations showed similar statistical characteristics. Spreads are fairly large and distributed evenly both at lower and higher EC values. There are no outliers.

As shown in the scatter plots Figure. 8, monthly EC at Vernalis and Brandt Bridge are strongly correlated (Pearson's correlation[1] 0.97). The regression analysis of EC showed that Brandt Bridge EC is estimated 1.08 x Vernalis EC, indicating about 8% water quality degradation (measured in term of EC) between Vernalis and Brandt Bridge. Although, the United States Bureau of Reclamation (USBR) cannot control the in-Delta returns, in order to meet the objectives at Brandt Bridge, the Vernalis water quality, in the vast majority of cases would have to be better than the objective.

Using standard error of regression and sum of squares, one can predict the Brandt Bridge EC at a given level of confidence level as a function of Vernalis EC. Figure 9 shows the required Vernalis EC to ensure target Brandt Bridge EC (700 μS/cm during

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[1] The Pearson correlation r, measures the strength of the linear relationship between the X and Y variables. R^2 , the coefficient of determination (a popular measure in regression analysis) is the fraction of the variance explained by the regression. In the least square regression, $R^2 = r^2$.

Apr-Aug and 1000 EC for the rest of the months) at different confidence levels. The numerical values are provided in Table 2.

In general, Vernalis EC can be represented by a dilution mass-balance approach. If additional water were used for dilution purposes between Vernalis and Brandt Bridge, the required volume of water needed would be dependent on the source quality. As a result, lesser volumes of dilution water would be required from a high quality source than from a relatively lower-quality dilution source. The amount of dilution water that would be required to be added to Vernalis flow to conform to the numerical values in Table 2 from a high quality source, such as Goodwin Releases from the Stanislaus River, is probably not insignificant but has not been analyzed.

An attempt was made to break down the salinity (EC) degradation estimate into two components:

a) From Vernalis to Mossdale
b) From Mossdale to Brandt Bridge

Initial analysis indicates an average EC degradation of 7% between Vernalis and Mossdale and 1% between Mossdale and Brandt Bridge. (Figure 10 shows the strong correlation between Vernalis EC and Mossdale EC, with Pearson's correlation of 0.98.)

Upon closer examination, during certain periods EC at Brandt Bridge was actually lower than Mossdale. Typically the only time that one expects lower EC at Brandt Bridge is when there is a reverse net flow at Brandt Bridge. Under this condition, better quality water from the North travels upstream in San-Joaquin River as far as the head of Old River. Reverse net flow at Brandt Bridge usually occurs during low San Joaquin River flows at Vernalis (below 1000 cfs) and high pumping rates. At times field data suggests that EC at Brandt Bridge was lower than the EC at Mossdale even when the San Joaquin River flow at Vernalis was 2000 cfs or higher. This was especially noticeable for the years 1999 and later.

In a separate analysis, the data was divided into two parts, one for the years prior to 1999 and the other for year 1999 and afterwards. The first analysis suggested an average of about 4% EC degradation occurs between Mossdale and Brandt Bridge (which is about half of the total EC degradation between Vernalis and Brandt Bridge). The second data set suggested an average of about 1% EC improvement at Brandt Bridge compared to Mossdale. Developing an accurate estimate for the degradation of water quality in individual reaches requires a fairly accurate data set to within a few percent. Based on the analysis mentioned above, the EC data sets may not have the level of accuracy required for a break-down of the degradation quantity in individual reaches.

However, given the fact Mossdale is about 2.8 miles upstream of the head of Old River, it can be concluded the EC degradation between the head of Old river and Brandt Bridge is less than half the total degradation between Vernalis and Brandt Bridge, and possibly much smaller. The reasons may be attributed to higher tidal flows in the San-Joaquin River downstream of the head of Old River.

From the analysis of field data at Vernalis, Mossdale and Brandt Bridge, there is approximately an average of 8% degradation in EC from Vernalis to Brandt Bridge and the majority of that degradation occurs between Vernalis and Mossdale.

2.4 Middle River at Union Point Source Water and Water Quality

Figure 4 shows the field measured EC and DSM2 simulated percent of water from agricultural diversions and the San Joaquin River at Middle River at Union Point. The water at this station is also heavily dependent upon the flow in the San Joaquin River and in-Delta return sources. Times when the percentage shown in the figures is less than 100% reflect times with the agricultural barriers and/or the Old River at Head fish barrier are installed in the South Delta. Design and timing of the installation of the barriers have varied historically.

Even when the Old River at Head Barrier is installed, San Joaquin River source water can reach this site. Some San Joaquin flow may pass through the barrier culverts or over barrier weir if barrier design allows for it. San Joaquin River flow may be directed into the central Delta and down towards Middle River at Union Point via Turner Cut or Columbia Cut.

Figure 4 shows that the sourcewater makeup at Middle River at Union Point is changed to a small degree by the installation of the temporary barriers; however, the water quality is predominately controlled by the water quality at Vernalis and the water quality of other in-Delta returns. The South Delta Improvements Program, by having the flexibility of operating gates, can change the amount of source water at this location so that this location is not as dependent on Vernalis and agricultural drainage water quality.

2.5 Old River at Tracy Source Water and Water Quality

Figure 5 shows the 30-day running average field measured EC values and DSM2 simulated percent of water from agricultural diversions and the San Joaquin River at Old River at Tracy. This station is further away from the San Joaquin River and is more strongly influenced by the operation of the barriers. When the barriers are not installed, the water quality is primarily a reflection of the Vernalis water quality and the agricultural drainage water quality[2].

As Figure 5 shows, the period of 2001 – 2004 has seen yearly periods when the contribution from the San Joaquin River and agricultural returns dropped to about 20 percent of the source of the water at Old River at Tracy Road. These were times when the agricultural barriers were installed. It may be noticed that the 30-day running average EC does not immediately decrease to coincide with the decrease in San Joaquin River water as the dominant source. This is due to the effect of averaging the EC values over 30 days and because the EC contribution to agricultural returns significantly increases with the installation of the barriers.

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[2] Another DSM2 simulation was made using the historical hydrology but removing all barriers. There were a few time periods where some Sacramento flow was occurring at Old River at Tracy and Middle River at Union Point. These periods reflected times when the San Joaquin River flow was below 1000 cfs.

Since the historical period covers a variety of different pumping rates, tides, and inflows, it can be concluded from this analysis that unless there are barriers in the South Delta or the San Joaquin River Flow is below 1000 cfs, the Middle River at Union Point and the Old River at Tracy station is dependent on Vernalis Water Quality and other returns such as agricultural drainage.

3 Modified Historical Simulations

3.1 Reduction and Increase in State Water Project Exports by 500 CFS

To gain a better understanding of the flow and water quality dynamics in the South Delta, a series of simulations were made to see if the water quality at the three inner Delta locations could be controlled by varying the State Water Project’s export rate. In one simulation, the exports were reduced by 500 cfs over the entire historical time period, to a minimum of zero. To keep the same net delta outflow and more importantly the same historical Martinez boundary salinity, the Sacramento River was also reduced by 500 cfs over the entire time period. In the second simulation, state exports and Sacramento flows were increased by 500 cfs.

Figures 11, 12, and 13 show the results of these simulations. The Figure 11 shows DSM2 simulated monthly averaged historical EC at Brandt Bridge and changes from this EC due to changes in pumping. Except for a few time periods in the early 1990's, the differences in monthly average EC were less than 2 μS/cm. (For a 700 μS/cm objective, the change is less than 0.3%. The change is less than 0.2% for a 1000 μS/cm objective). Additionally, the reduction in exports didn't always result in better water quality and the increase in exports didn't always result in a degradation of water quality.

Figures 12 and 13 show the results of the simulations at Middle River at Union Point and Old River at Tracy Road. Similar to the modeling results at the Brandt Bridge station, the reduction in exports didn't always result in better water quality and the increase in exports didn't always result in a degradation of water quality. The largest difference observed for these two stations occurred at the Middle River station in the winter of 2004. This difference was 45 μS/cm. (For a 1000 μS/cm objective, a 45 μS/cm change is 4.5%). The volumetric fingerprints for this station during the winter of 2004 for the increase and decrease in SWP pumping revealed that the volume was made up of only San Joaquin River water and agricultural drainage water. The relative proportions of those two sources changed.

The conclusions drawn from performing these studies were;

- *Modifying the pumping rate by 500 cfs resulted in at most a 5% change in water quality.*
- *Modifying the pumping rate by 500 cfs had a small effect (less than 5 uS/cm) on the water quality at Brandt Bridge unless there was reverse flow in the San Joaquin River.*
- *There is not a simple relationship between state water project export operations and water quality improvement.*
- *By changing the export level during times without barriers, the relative proportion of San Joaquin River water and agricultural drainage water changes; however, the total volume is still only made up of those two sources.*

3.2 No State Water Project Exports

Two simulations looked at more drastic changes to operations. In these simulations, the SWP exports were eliminated (Figures 14 and 16) during several months in 2002 and 2003. The Sacramento flow was correspondingly adjusted to maintain the same net delta outflow and more importantly the same Martinez salinity boundary condition. Figures 15 and 17 show EC results for two different time periods for Middle River at Union Point, Old River at Tracy, and Brandt Bridge. On each of these graphs, the 2005 agricultural standard is plotted along with the DSM2 modeled historical EC, and the EC as simulated with the State Water Project exports eliminated. During some of this time period, the modeled historical EC tends to under predict the field data at the three locations (Figure 2). Since observed water quality field data is used for the Vernalis boundary in DSM2 and the water at the locations is a combination of San Joaquin River water and in-Delta returns, it appears that the impact of agricultural returns is under represented in the modeling during this period. DSM2 does not have measured consumptive use data as boundary data for the model; instead, consumptive use is determined using the Delta Island Consumptive Use (DICU) model (Mahadevan,1995) which utilizes crop type, precipitation, seepage, evapotranspiration, irrigation, soil moisture storage, leach water, runoff and acreage.

The SWP export reduction ranges from over 8,000 cfs to approximately 1000 cfs between January 6, 2002 and September 9, 2002 and from over 7500 cfs to approximately 1000 cfs between January 4, 2003 and May 30, 2003. For both Figure 15 and Figure 17 and for both Middle River at Union Point and Brandt Bridge, the no SWP export run results follow the electrical conductivity results of the historic runs. There are small differences between the runs that are consistent with the magnitude of differences shown in Figures 11 and 12; however, they are difficult to discern with the scale used.

3.2.1 Old River at Tracy Road No SWP Exports

3.2.1.1 2002 No SWP Export Simulation

The discussion that follows will focus on the results at Old River at Tracy Road and will look at differences between the two simulations. The differences between the no SWP pumping simulation and the historical simulations start to become visible in May of 2002. The larger cuts in exports shown in Figure 14 don’t have a significant effect prior to the middle of April 2002 when three of the temporary barriers have been installed (Table 3). The volumetric fingerprint for the late April time period in Figure 18 shows that some Sacramento source water makes it to Old River at Tracy. The EC fingerprint for the no SWP export shown on the same page indicates that the EC primarily comes from agricultural drainage and San Joaquin River water. Figure 19 indicates that during this time period in the historical simulation, the source water was primarily the San Joaquin River. The slight degradation in water quality shown in Figure 14 is a reflection of the reproportioning of agricultural drainage to San Joaquin water brought on by changes in the exports. Any freshening of the water due to the Sacramento River source was offset by the agricultural drainage source.

Even with the model underpredicting the field EC at Old River at Tracy, the 700 μS/cm 2005 agricultural standard would have been violated with no State Water Project Exports.

Towards the end of June, the water quality improved for the no export simulation. This occurred about the time that the Central Valley Project pumping was increasing, the Grant Line Canal Barrier was installed, and the Old River at Head barrier was removed.

3.2.1.2 2003 No SWP Export Simulation

In the 2003 no export simulation, the water quality started to visibly degrade in late April 2003 (Figure 17) after the barriers were installed. The fingerprinting results during that time period show that some Sacramento water makes it to Old River at Tracy but that proportionally there is more agricultural drainage at that location than in the historical simulation for those stations.

3.2.1.3 Factors controlling the Sacramento Flow into Old River

From these studies, it could not be determined how to operate the SWP exports to improve Water Quality at Old River at Tracy. These studies also demonstrated that drastic reductions in exports did not effectively change the water quality at Brandt Bridge and Middle River, leading to the conclusion that water quality cannot be simply controlled through modifying exports.

To try and develop a better understanding of what might be affecting the water quality at Old River at Tracy, a further examination of the historical hydrology and barrier configuration during a time that a large portion of Sacramento flow made it to Old River at Tracy. (The graphs in Figure 5. showing the percent volume contributions indicate times when the Sacramento River is influencing the water quality at Old River at Tracy). These periods include September 91, May – October 92, April – October 94, September – November 01, October – November 02, and September – October 03. In all periods three of the barriers, Old River near Tracy, Old River at Head, and Middle River were installed either entirely or partially during the time mentioned. In one period the Grant

Line Canal was installed. Looking at the averaged hydrology over the different periods did not reveal a explanatory factor. Total Exports ranged from 2500 – 7300 cfs. The SJR flow ranged from 600-2000 cfs. The Sacramento River flow ranged from 8000 – 11000 cfs. Outflow ranged from 3500 – 6400 cfs. Consumptive use varied from 900 – 2500 cfs. More investigation is needed to determine what combination of factors affect the water quality at Old River at Tracy.

Several factors can influence the flow of Sacramento River water into the southern Delta. The opening of Reclamation's Delta Cross Channel gates allows for Sacramento River water to flow into the interior Delta before being influenced by saltier conditions to the west. Then the interior Delta water is effectively drawn toward the pumping facilities and carrying Sacramento River water quality into the southern Delta environment.

The conclusions drawn from this analysis are

- *Large reductions in SWP exports did not effectively change water quality at Brandt Bridge and Middle River at Union Point.*
- *Large reductions in SWP exports did not effectively change water quality at Old River at Tracy when the temporary barriers were not installed.*
- *Large reductions in SWP exports did not consistently improve water quality. In some situations, water quality was degraded.*
- *More investigation is needed to determine what combination of factors affects the water quality at Old River at Tracy.*

4 Summary and Conclusions

This report contained analyses of water quality and flow in the South Delta using field data and Delta Simulation Model 2 (DSM2) modeled data. From the analysis, the following conclusions were drawn;

- The water quality degradation from Vernalis to Brandt Bridge is on average approximately 8%.
- From DSM2 historical modeling simulations, the makeup of water at Brandt Bridge, Middle River at Union Point, and Old River at Tracy consists of water

coming from the San Joaquin River at Vernalis and in-Delta returns. The only exceptions to this are when there is reverse flow in the San Joaquin River at Brandt Bridge, low San Joaquin River flow, or the temporary barriers are installed.

- Because of the temporary barriers, water at Middle River at Union Point and at Old River at Tracy at times consist of other water sources in addition to water from the San Joaquin and in Delta returns.
- During the times when the volumetric makeup of water consists of only San Joaquin water and in Delta returns, changing State Water Project pumping by 500 cfs results in small changes in water quality. The changes in water quality are primarily a result of a changing proportion of San Joaquin water and in-Delta returns at the three interior Delta locations.
- During the times when the volumetric makeup of water consists of other water sources in addition to the San Joaquin and in-Delta returns, reducing or cutting SWP exports does not always improve the water quality. In some situations, the water quality is degraded.

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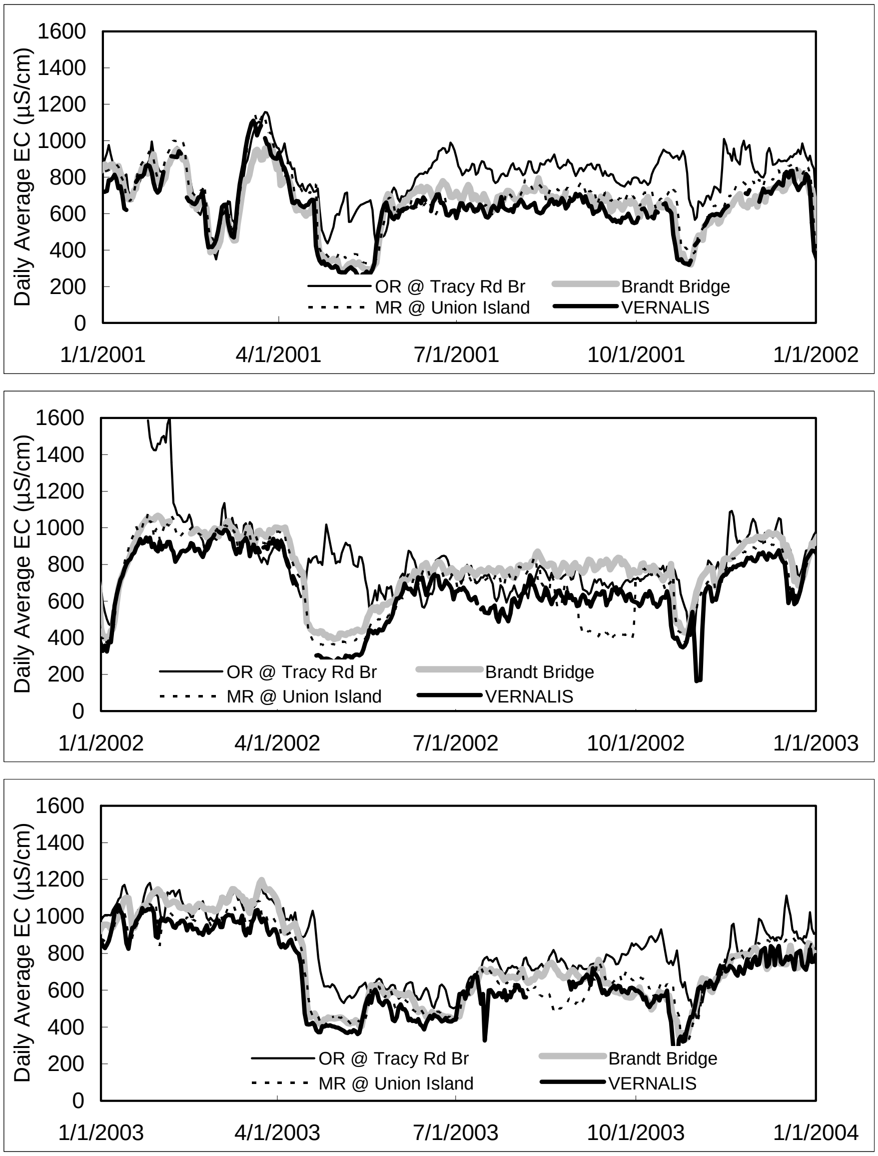
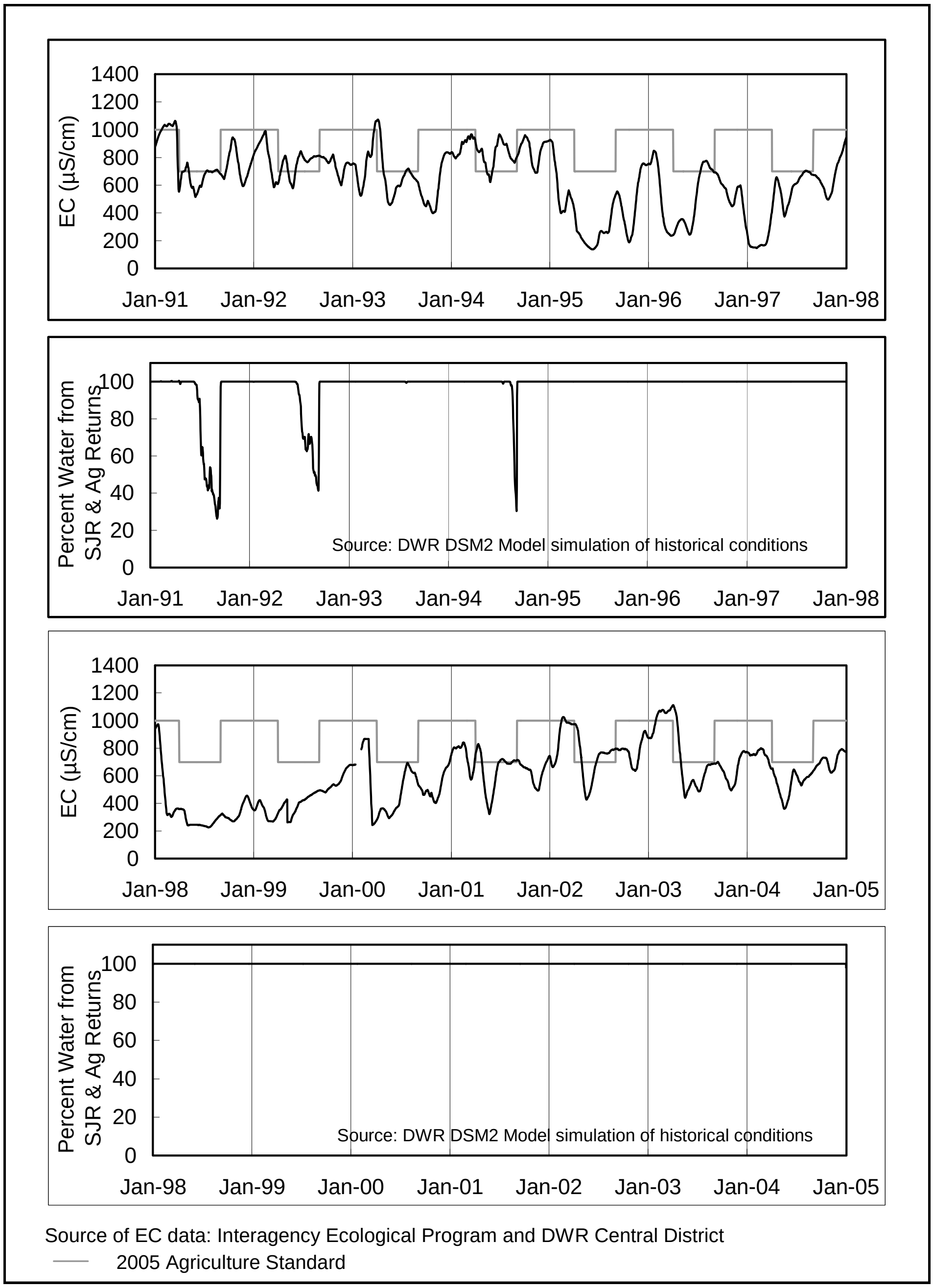


Source of data: Interagency Ecological Program and DWR Central District.

Figure 2. Historical EC at Vernalis, Brandt Bridge, Middle River at Union Point, and Old River at Tracy Road Bridge.



Source of EC data: Interagency Ecological Program and DWR Central District

Figure 3. San Joaquin River at Brandt Bridge 30-Day Running Average EC and Percent Water from San Joaquin River and Agriculture Returns.

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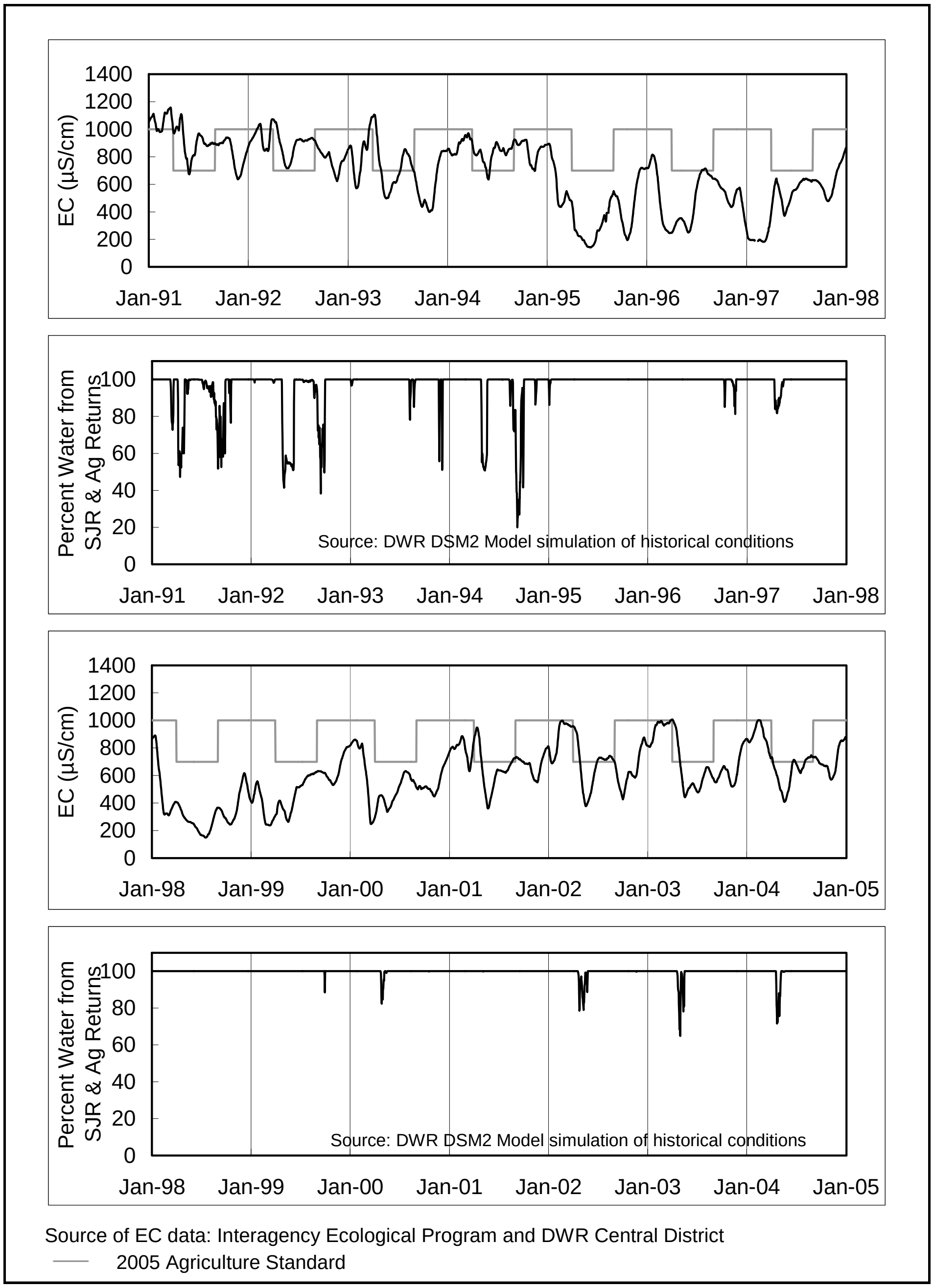

Source of EC data: Interagency Ecological Program and DWR Central District

Figure 4. Middle River at Union Point 30-Day Running Average EC and Percent Water from San Joaquin River and Agriculture Returns.

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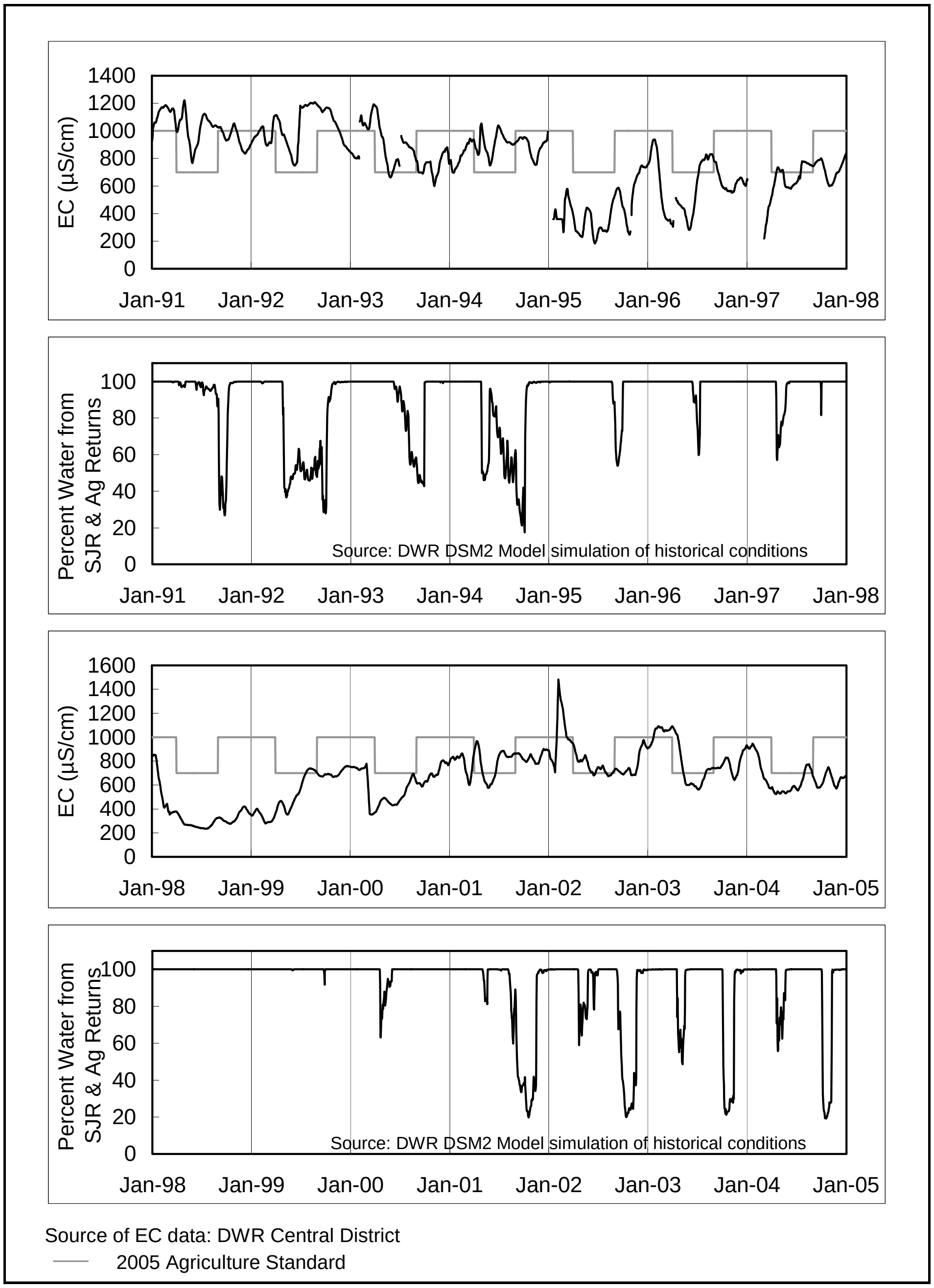

Source of EC data: DWR Central District

Figure 5. Old River at Tracy Road Bridge 30-Day Running Average EC and Percent Water from San Joaquin River and Agriculture Returns.

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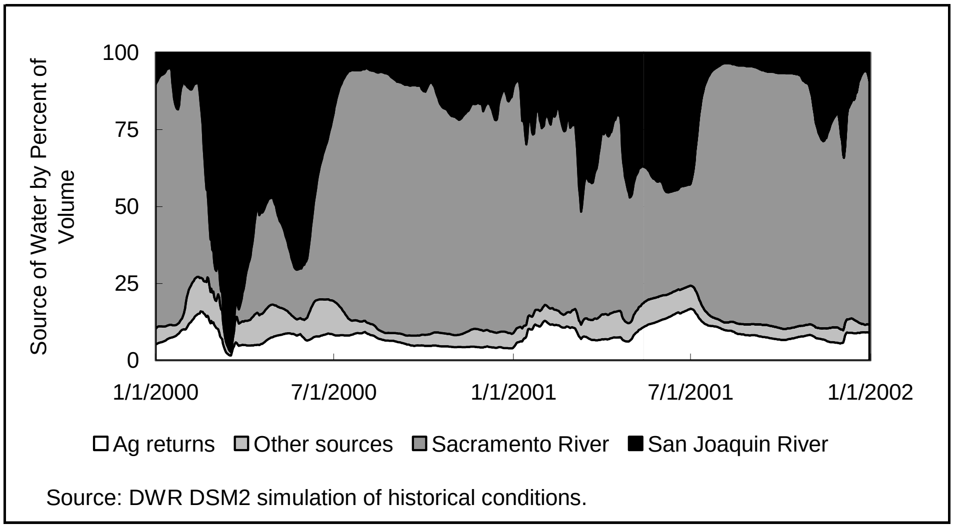

Source: DWR DSM2 simulation of historical conditions.

Figure 6. Volumetric Fingerprint at Clifton Court Forebay for Historical Conditions, 2000 - 2001.

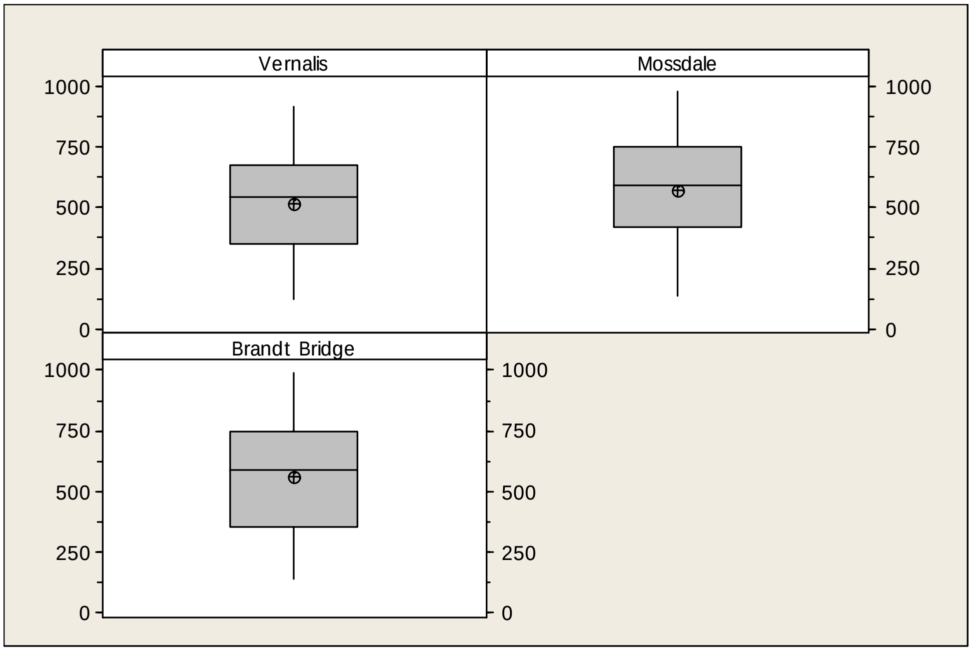

Figure 7: Boxplots of Monthly EC at Vernalis, Mossdale, Brandt Bridge

EC Locations	**Total Non Missising Data Points**	**Mean (μS/cm)**	**Standard Deviation (μS/cm)**	**Range (μS/cm)**	
				Low	**High**
Vernalis	108	518.4	205.6	121.0	916.8
Mossdale	86	570.3	221.5	132.9	982.0
Brandt Bridge	103	565.7	224.8	144.5	990.8

Table 1: Descriptive Statistics of Monthly EC at Vernalis, Mossdale and Brandt Bridge

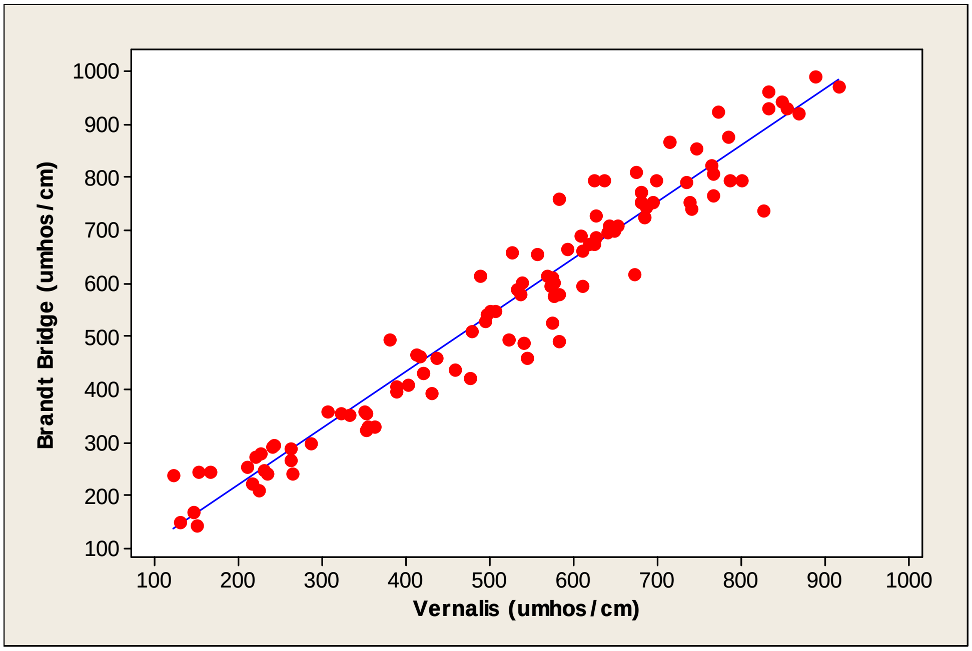

Figure 8: Monthly EC at Brandt Bridge vs. Vernalis

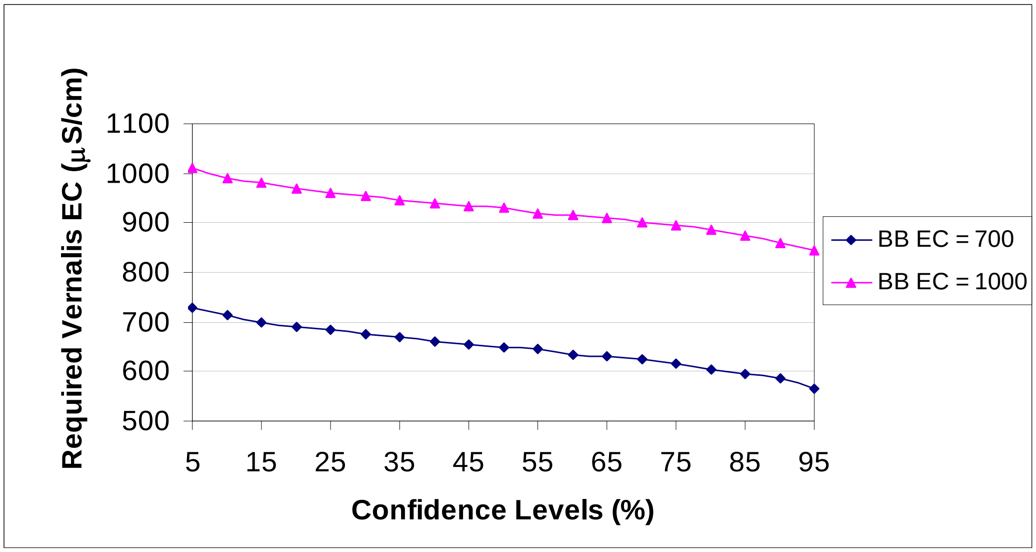

Figure 9: Required Vernalis EC to Ensure Target Brandt Bridge EC at Different Confidences Levels

Confidence levels	**Required Vernalis EC to Ensure**	
	Brandt Bridge **EC = 700 μS/cm**	**Brandt Bridge** **EC = 1000 μS/cm**
95	565	845
90	585	860
85	595	875
80	605	885
75	615	895
70	625	900
65	630	910
60	635	915
55	645	920
50	650	930
45	655	935
40	660	940
35	670	945

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30	675	955
25	685	960
20	690	970
15	700	980
10	715	990
5	730	1010

Table 2: Required Monthly EC at Vernalis to Ensure Brandt Bridge EC Standards

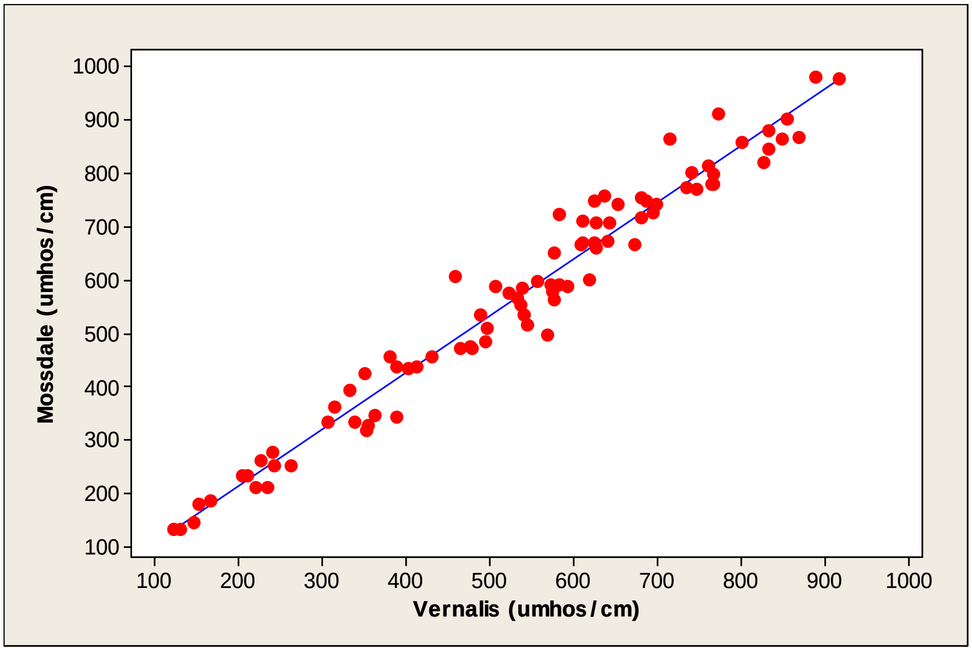

Figure 10: Monthly EC at Mossdale vs. Vernalis

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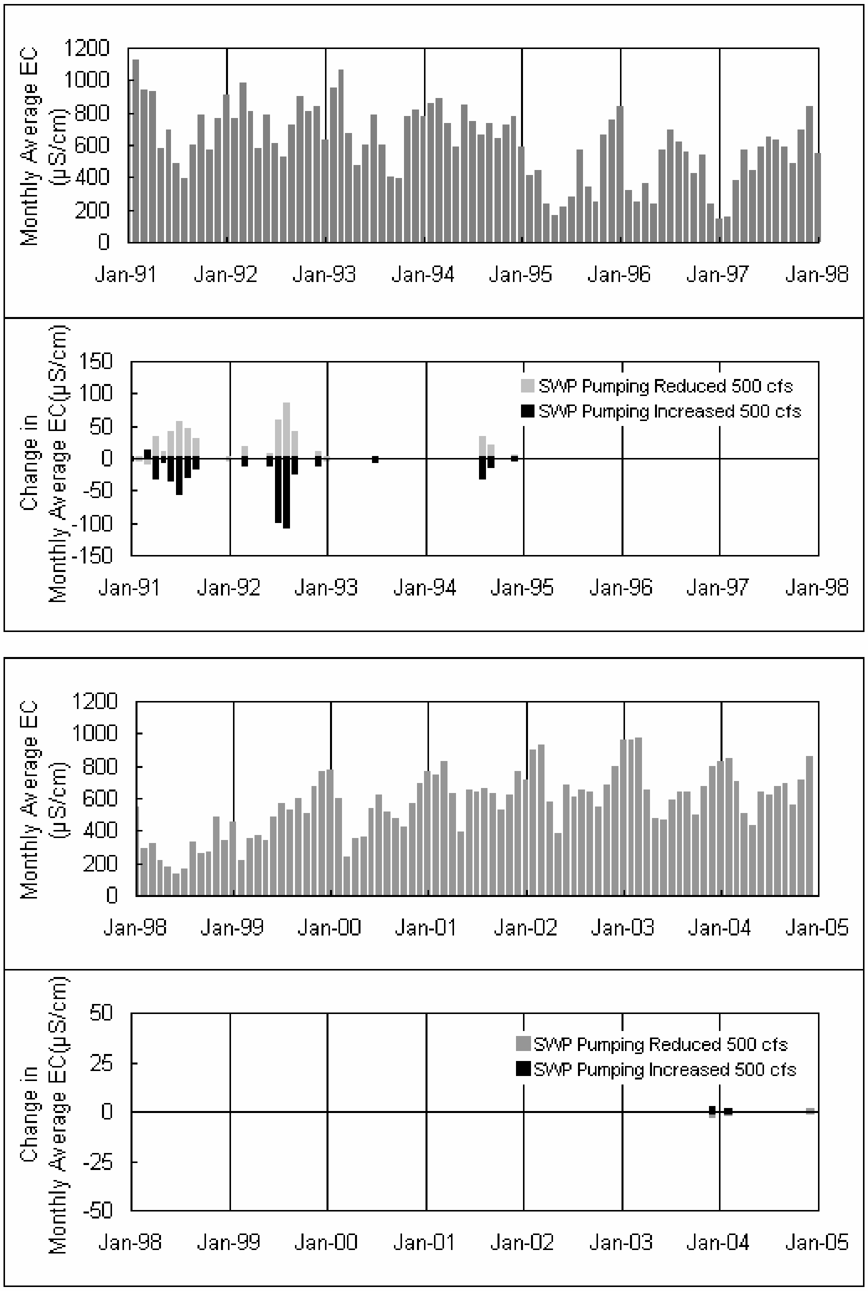

Source of EC data: DWR DSM2 simulation of historical and modified conditions.

Figure 11. San Joaquin River at Brandt Bridge Simulated Historical EC and Change in EC when SWP Pumping Increased/Decreased 500 cfs, 1991 - 2004.

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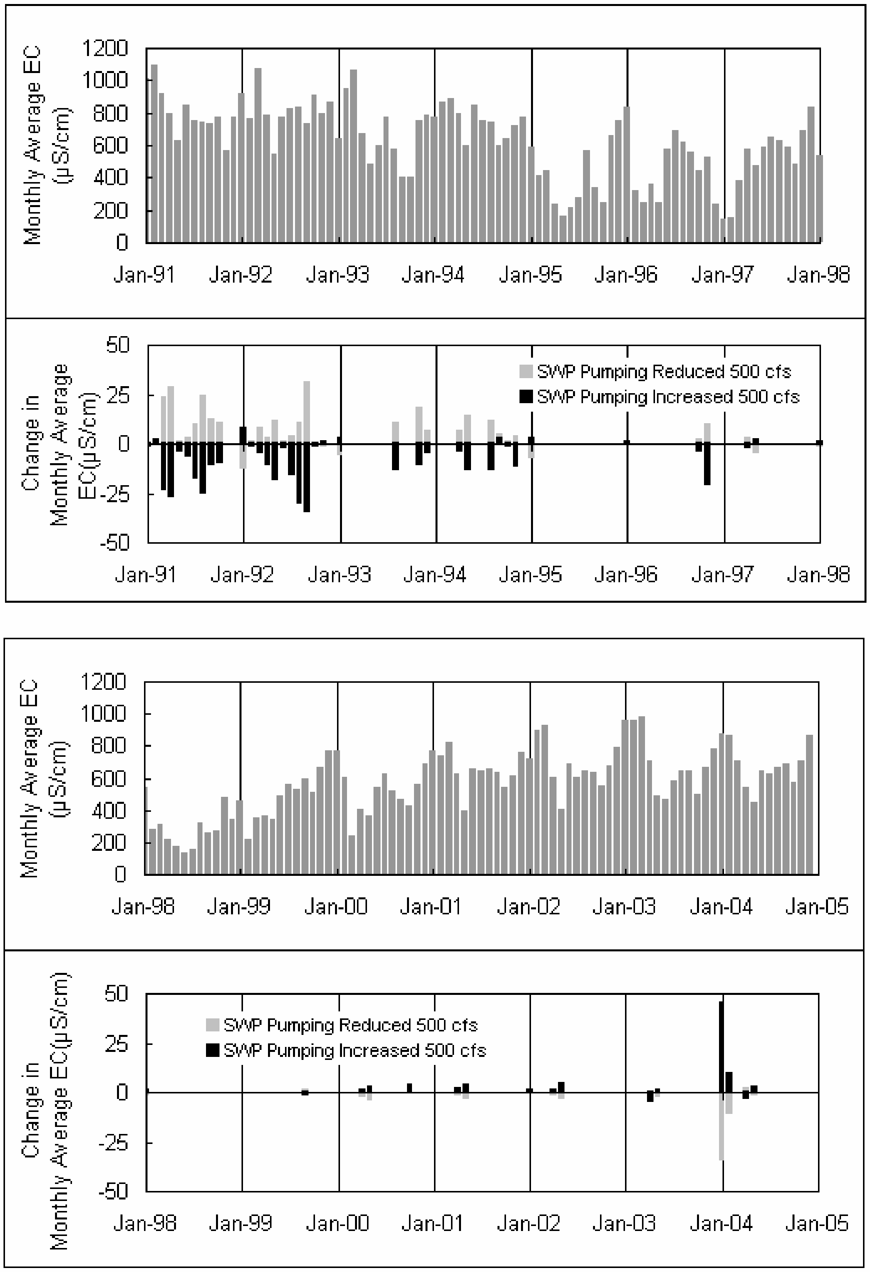

Source of EC data: DWR DSM2 simulation of historical and modified conditions.

Figure 12. Middle River at Union Point Simulated Historical EC and Change in EC when SWP Pumping Increased/Decreased 500 cfs, 1991 - 2004.

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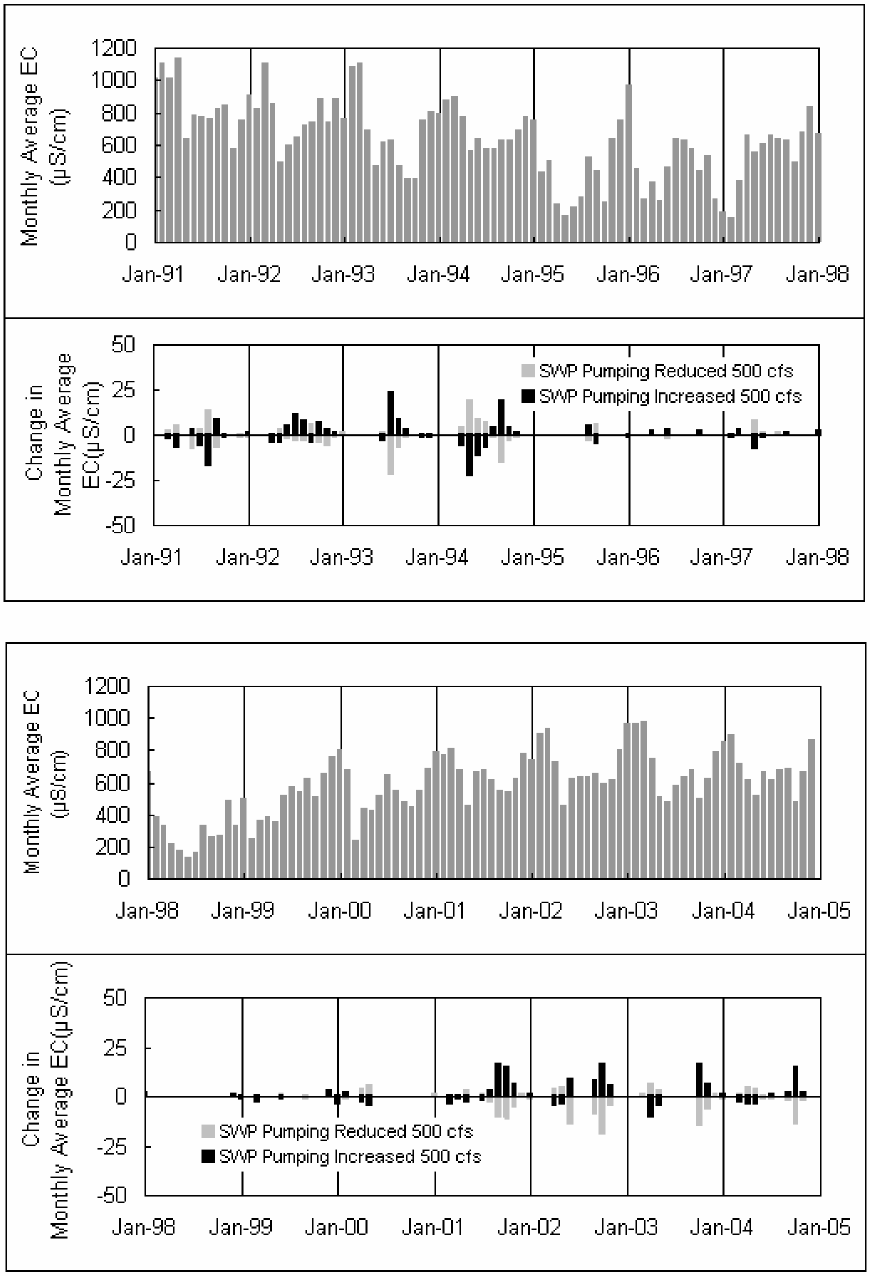

Source of EC data: DWR DSM2 simulation of historical and modified conditions.

Figure 13. Old River at Tracy Road Bridge Simulated Historical EC and Change in EC when SWP Pumping Increased/Decreased 500 cfs, 1991 – 2004.

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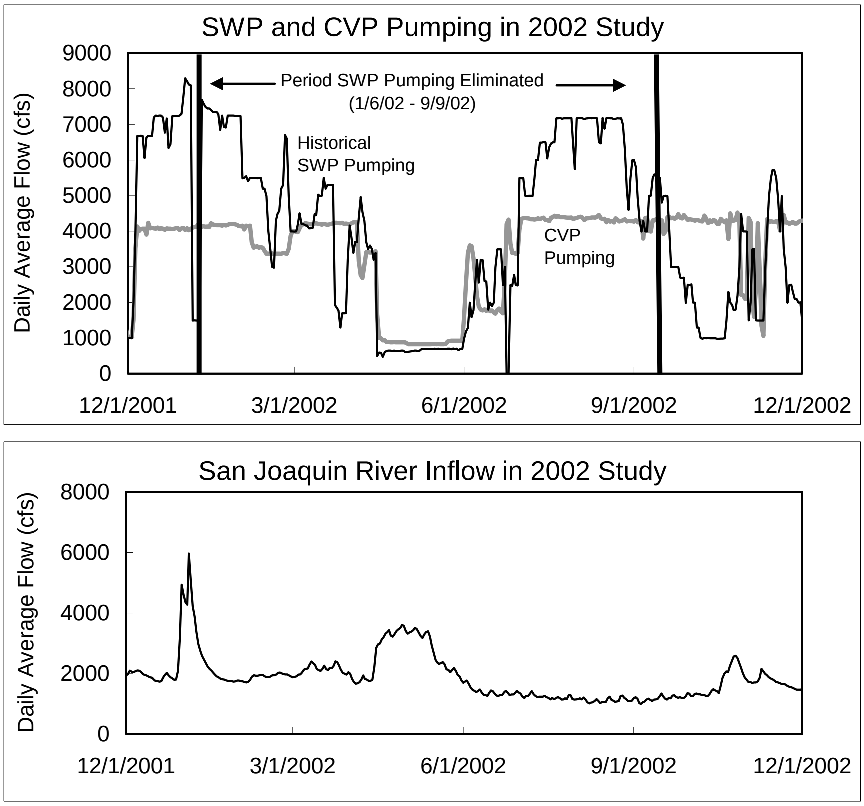

Source of Data: DAYFLOW.

Figure 14. Historical SWP and CVP Pumping and San Joaquin River Inflow in 2002 for Study of Effects on EC in South Delta of Eliminating SWP Pumping.

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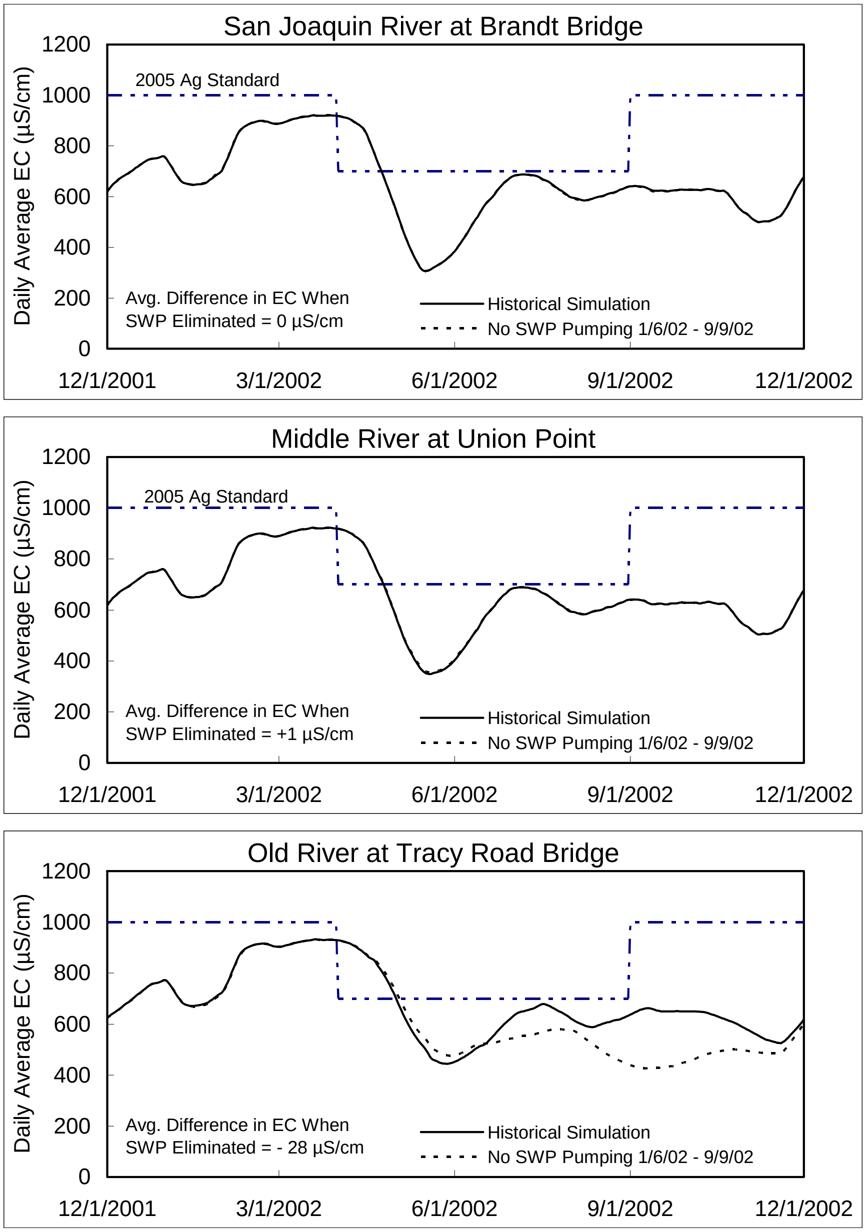

Source of Data: DWR DSM2 simulation of historical and modified conditions.

Figure 15. Effect of Eliminating SWP Pumping for Extended Period on EC at Brandt Bridge, Middle River at Union Point, and Old River at Tracy Road Bridge, 2002.

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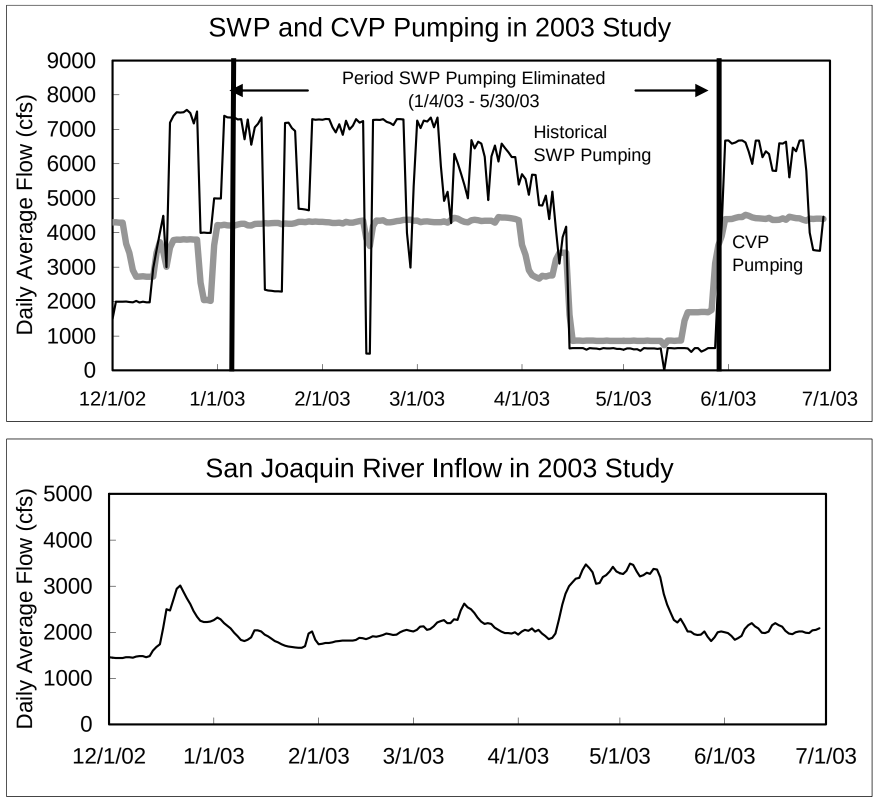

Source of Data: DAYFLOW.

Figure 16. Historical SWP and CVP Pumping and San Joaquin River Inflow in 2002 for Study of Effects on EC in South Delta of Eliminating SWP Pumping.

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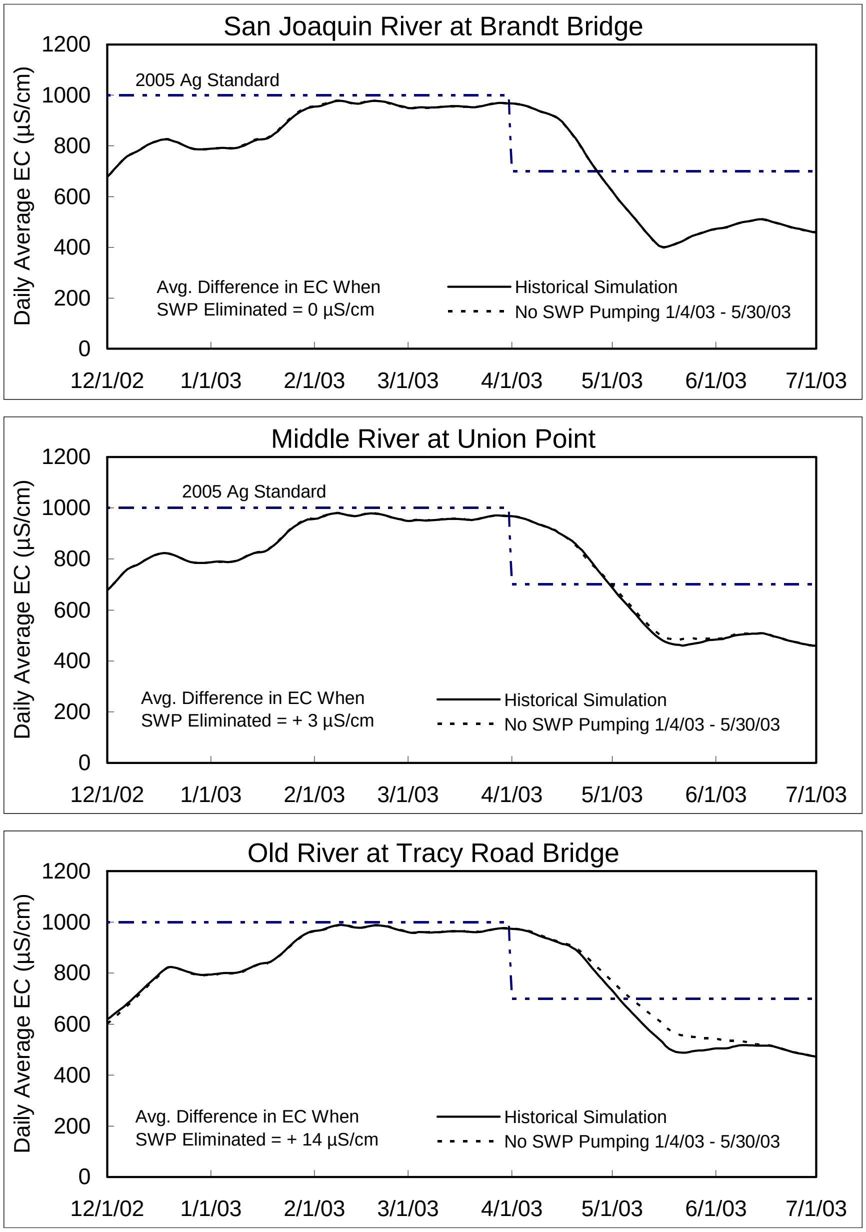

Source of Data: DWR DSM2 simulation of historical and modified conditions.

Figure 17. Effect of Eliminating SWP Pumping for Extended Period on EC at Brandt Bridge, Middle River at Union Point, and Old River at Tracy Road Bridge, 2003.

	Old River Near Tracy	**Old River at Head Spring**	**Old River at Head Fall**	**Middle River**	**Grant Line Canal**
Installation and Removal Complete - 2002	April 18 – November 29	April 18- June 7	October 4- November 21	April 15 – November 23	June 12 – November 25
Installation and Removal Complete - 2003	April 22 – November 25	April 21- June 3	September 18 – November 13	April 23- November 10	April 23 (partial), June 17 completed – November 25

Table 3 – Temporary Barrier Installation Dates

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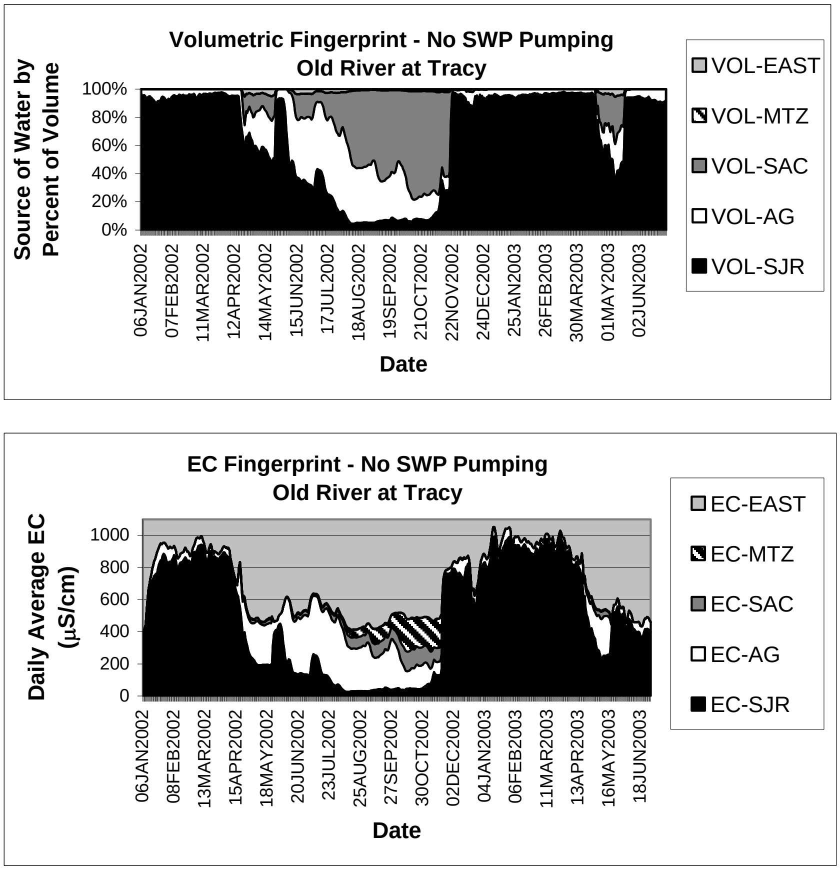

Figure 18: Volumetric and EC Fingerprint at Old River at Tracy for No SWP Pumping Simulation, Jan 2002 – July 2003

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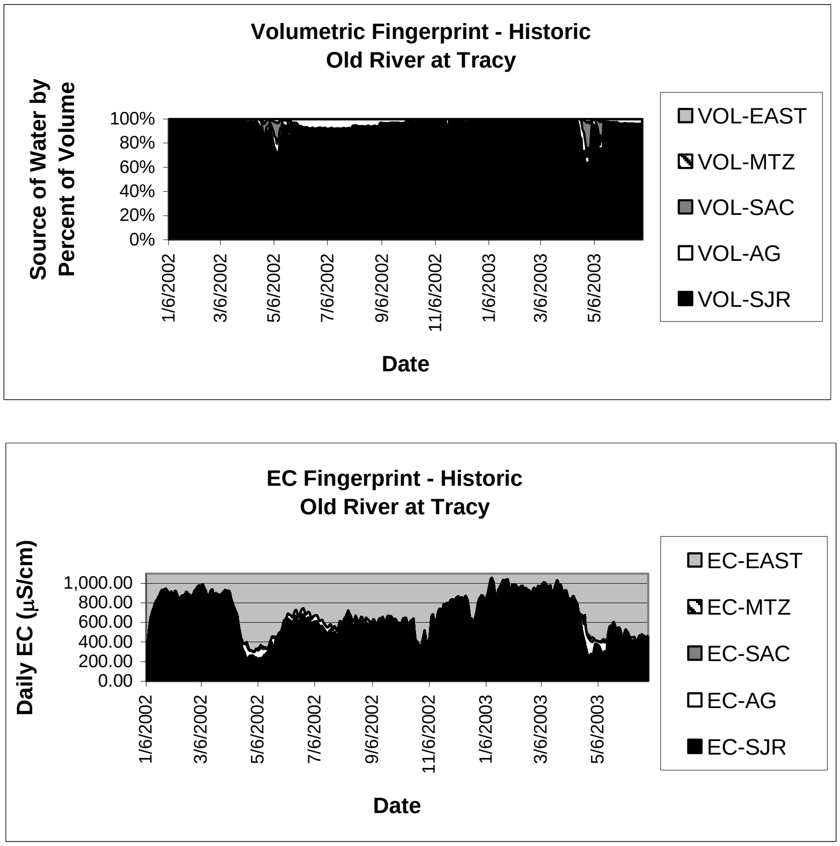


Figure 19: Volumetric and EC Fingerprint at Old River at Tracy for Historic Simulation, Jan 2002 – July 2003

References

Anderson, J. (2002). “Chapter 14: DSM2 Fingerprinting Methodolgy.” *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 23rd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Office of State Water Project Planning. Sacramento, CA.

Mahadevan, N. (1995) *Estimation of Delta Island Diversions and Return Flows.* California Department of Water Resources, Division of Planning, Sacramento, CA.

Appendix A – Delta Simulation Model 2 (DSM2) Description

The Delta Simulation Model 2 (DSM2) is a one-dimensional mathematical model for dynamic simulation of one-dimensional hydrodynamics, water quality and particle tracking in a network of riverine or estuarine channels. DSM2 can calculate stages, flows, velocities, mass transport processes for conservative and non-conservative constituents including salts, water temperature, dissolved oxygen, and trihalomethane formation potential, and transport of individual particles.

DSM2 consists of three modules: HYDRO, QUAL and PTM. HYDRO simulates one-dimensional hydrodynamics including flows, velocities, depth and water surface elevations. HYDRO provides the flow input for QUAL and PTM. QUAL simulates one dimensional fate and transport of conservative and non-conservative water quality constituents give a flow field simulated by HYDRO. PTM simulations a quasi 3-D transport of neutrally buoyant particles based on the flow field simulated by HYDRO.

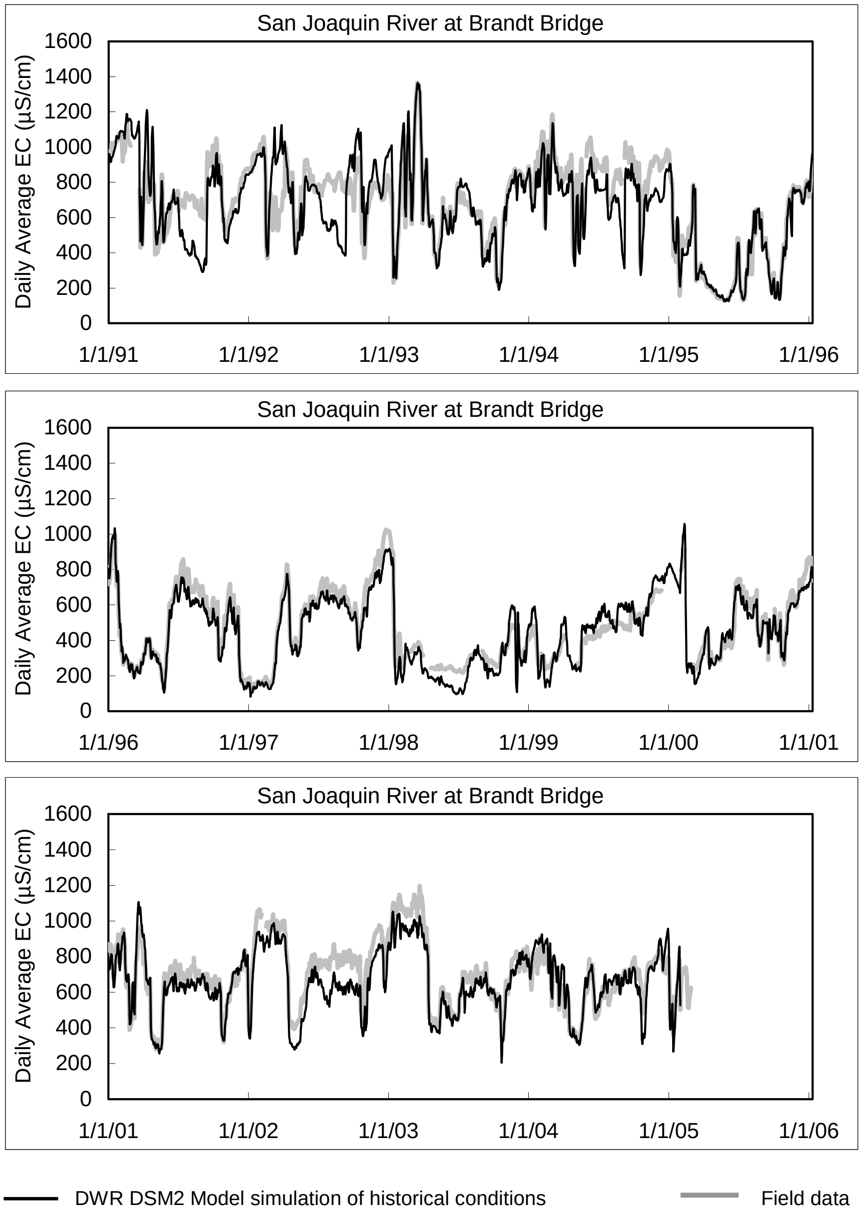
The latest full calibration/validation was completed in 2000 by the DSM2 Project Work Team as part of the Interagency Ecological Program (IEP). Information about this calibration and validation can be found at http://iep/dsm2pwt/dsm2pwt.html

The model is publicly available and can be downloaded from http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm

The model is currently being utilized by various agencies and companies. Those that are running or are using results from DSM2 include:

- California Department of Water Resources (DWR)
- United States Bureau of Reclamation (USBR)
- United States Corps of Engineers (USCOE)
- United States Geological Survey (USGS)
- Metropolitan Water District (MWD)
- Contra Costa Water District (CCWD)
- CH2M HILL
- Jones & Stokes
- Montgomery Watson Harza
- HydroQual
- Surface Water Resources, Inc

A selection of recent validation plots for electrical conductivity are shown below.



Source of field data: Interagency Ecological Program and DWR Central District

Figure A-1. Validation of DSM2 for Simulation of EC at San Joaquin River at Brandt Bridge, 1991 - 2004.

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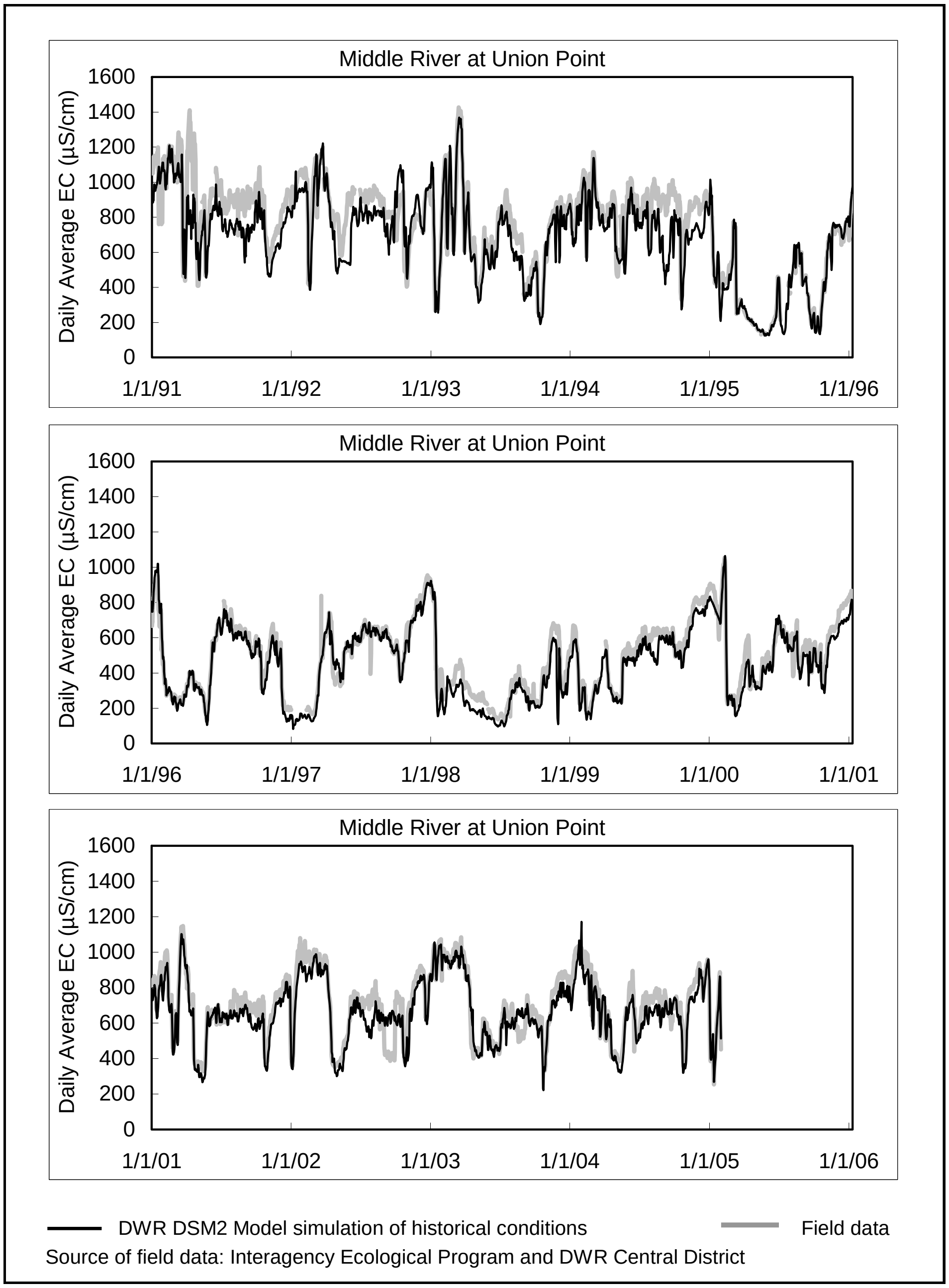
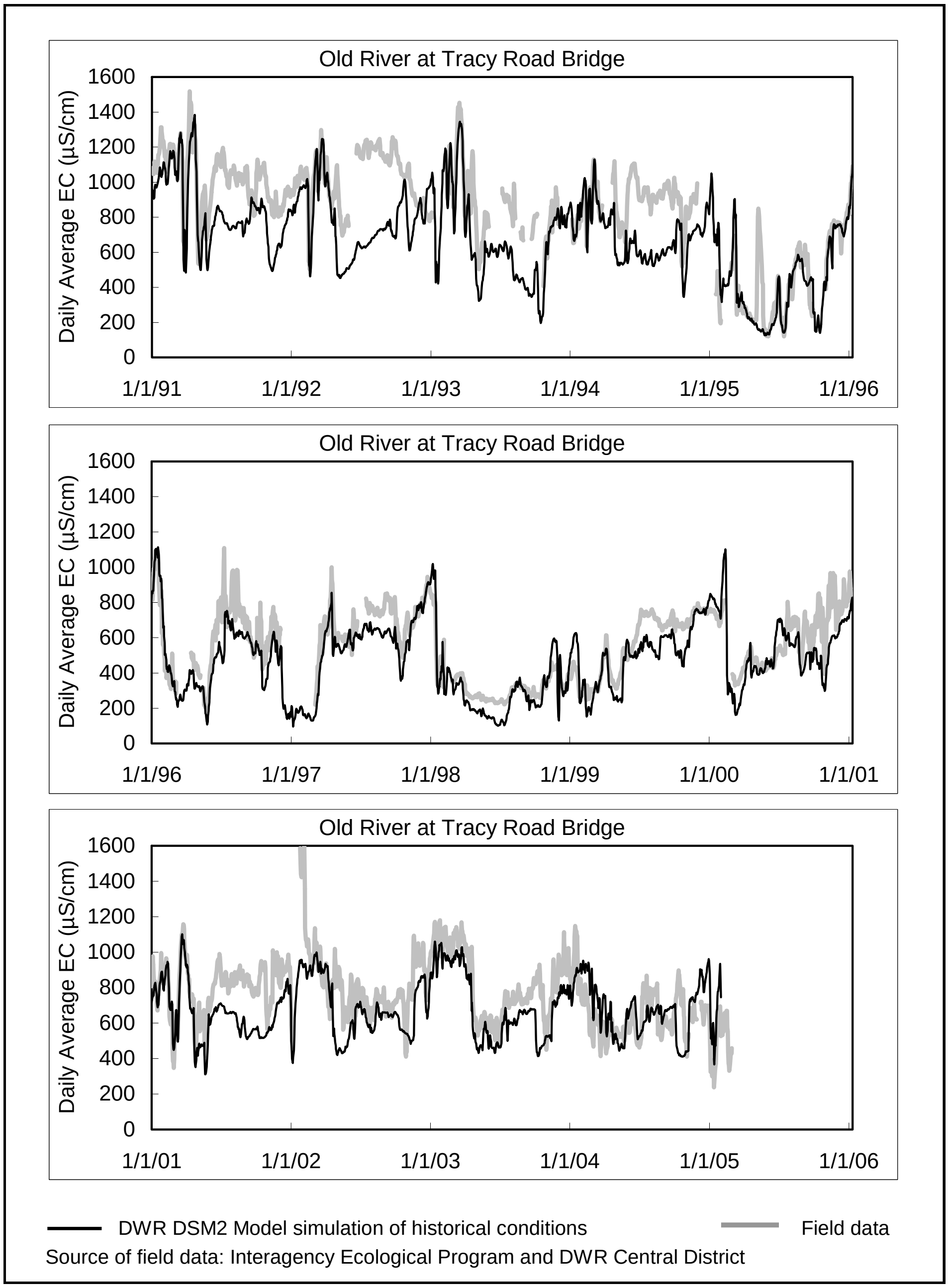


Source of field data: Interagency Ecological Program and DWR Central District

Figure A-2. Validation of DSM2 for Simulation of EC at Middle River at Union Point, 1991 - 2004.



Source of field data: Interagency Ecological Program and DWR Central District

Figure A-3. Validation of DSM2 for Simulation of EC at Old River at Tracy Road Bridge, 1991 – 2004.

DWR – 20A

Fingerprinting Methodology

The attached document is an excerpt from *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 23rd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources, Office of State Water Project Planning. It can also be found at http://modeling.water.ca.gov/delta/reports/annrpt/2002/2002Ch14.pdf

Mahadevan, N. (1995) *Estimation of Delta Island Diversions and Return Flows.* California Department of Water Resources, Division of Planning, Sacramento, CA.

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

23rd Annual Progress Report
June 2002

Chapter 14:
DSM2 Fingerprinting Methodology

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14 DSM2 Fingerprinting Methodology

14.1 Introduction

A methodology has been developed where a single simulation using the Delta Simulation Model 2 (DSM2) can be used to estimate the concentration of any conservative constituent at any specified time and location in the Delta[1]. Transport of conservative tracer constituents is simulated to determine volume contributions from various sources. These volume contributions can then be utilized to estimate concentrations of any conservative constituent. Use of DSM2 in this mode is referred to as fingerprinting. The main methods of applying the fingerprinting technique are:

- **Volume Fingerprinting** - Determine the relative contributions of water sources to the volume at any specified location.
- **Volume and Timing Fingerprinting** - In addition to determining the relative contributions of water sources to the volume at any specified location, the time period during which that water entered the system is also recorded.

Fingerprinting techniques can also be applied to a specific constituent as follows[2]:

- **Constituent Fingerprinting** - Determine the relative contributions of conservative constituent sources to the concentration at any specified location.
- **Constituent and Timing Fingerprinting** - In addition to determining the relative contributions of conservative constituent sources to the concentration at any specified location, the time period during which that constituent entered the system is also recorded.

The volume fingerprinting techniques are the most general. Volume fingerprinting can be used to estimate concentrations of any conservative constituent without rerunning DSM2. Constituent fingerprinting is a more specific method in which the results are valid for the constituent simulated. For constituent fingerprinting, the results are not easily extrapolated to other constituents.

Fingerprinting provides valuable insight into the system being modeled. Applications of fingerprinting include:

Hydrodynamics

- Determine the relative flow contribution of each source at a specified location. For example, how much of the flow at Clifton Court originated from the Sacramento River, the San Joaquin River, eastside streams[3], the ocean, and agricultural return flows? (Volume fingerprinting)

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[1] Parviz Nader-Tehrani in DWR's Delta Modeling Section developed this methodology for volume fingerprinting.

[2] Prior to the development of volume fingerprinting, the Delta Modeling Section has used the superposition principle for specific constituent fingerprinting (see Hutton and Chung, 1992).

[3] Eastside streams include the Mokelumne, Cosumnes, and Calaveras rivers.

- ❑ Determine the relative flow contribution and timing of each source at a specified location. For example, how much of the flow at Clifton Court originated from the Sacramento River, the San Joaquin River, eastside streams, the ocean, and agricultural return flows during the current month, last month, the month before that, etc.?
  (Volume and timing fingerprinting)

Water Quality

- ❑ Estimate conservative water quality constituent concentrations at specified locations using a single DSM2 simulation.
  (Volume fingerprinting)

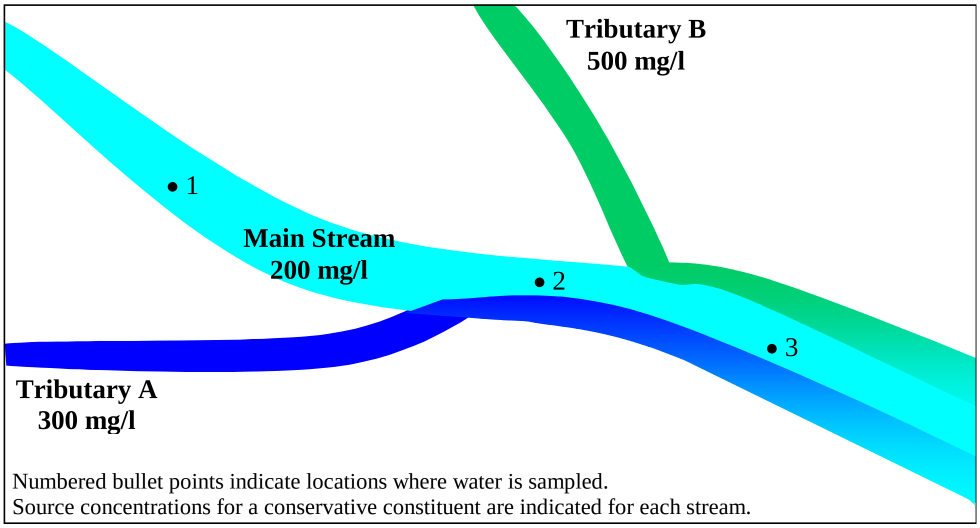
- ❑ Estimate conservative water quality constituent concentrations and timing at specified locations using a single DSM2 simulation.
  (Volume and timing fingerprinting)

- ❑ Determine the relative importance of sources of a water quality constituent at a specified location. For example, how much of the EC at the entrance to Clifton Court Forebay was contributed by each source?
  (Constituent fingerprinting)

- ❑ Determine the relative contributions and timing of each source of a water quality constituent at a specified location. For example, how much of the EC at the entrance to Clifton Court Forebay contributed by each source entered the Delta this month, last month, the month before that, etc.?
  (Constituent and timing fingerprinting)

14.2 Conceptualization of Volume Fingerprinting

To illustrate the concept of volume fingerprinting, consider a stream with two tributaries (Figure 14.1). If a sample of water was removed from the stream at each of the three locations indicated in Figure 14.1, the volume of water in each sample would be made up of contributions from the three streams as shown in Figure 14.2. For illustration purposes, hypothetical relative volume contributions from each source have been indicated. DSM2 fingerprinting can be used to determine the relative volume of water at a given location from specified sources.



Numbered bullet points indicate locations where water is sampled.
Source concentrations for a conservative constituent are indicated for each stream.

Figure 14.1: Conceptualization of a Stream with Two Tributaries.

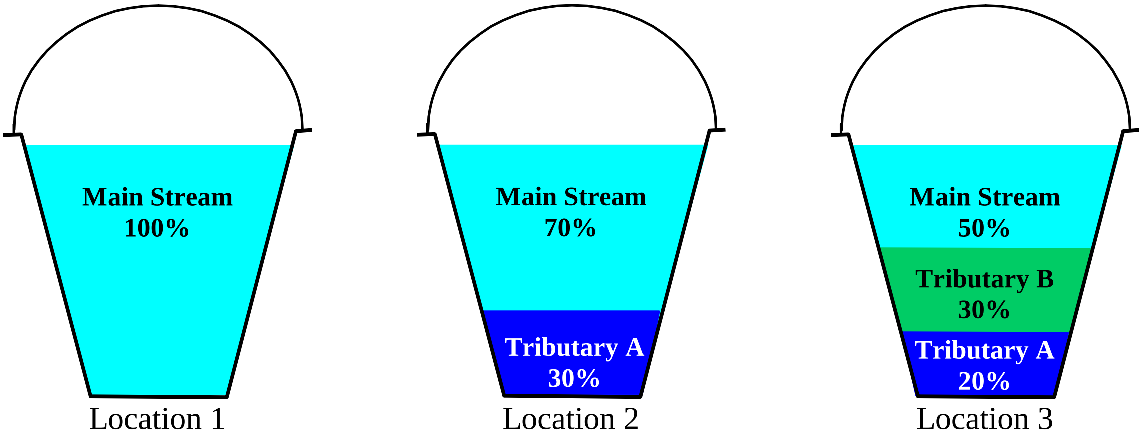


Figure 14.2: Conceptualization of Relative Volume Contributions from each Source for Water Sampled from Three Locations.

From the volume contributions and source concentrations, the concentration of a conservative constituent can be estimated by summing the volume of each source multiplied by the concentration of the constituent associated with that source (Equation 14-1).

$$C_{CC} = \sum_{i=1}^{n} \frac{V_{\% i}}{100} C_i \qquad \text{[Eqn. 14-1]}$$

where,

C_{CC} = concentration of a conservative water quality constituent at a specified location,
C_i = concentration of a conservative water quality from source *i* at the specified location,
n = total number of sources, and
$V_{\% i}$ = percent volume at a specified location contributed by source *i*.

Using the source concentrations from Figure 14.1 and the relative volume contributions from Figure 14.2, the concentration of a conservative constituent for the three sample locations can be estimated using Equation 14-1 as shown in Table 14.1 and Figure 14.3.

Using the volume fingerprinting methodology, the concentration of any conservative constituent can be estimated from the simulated volume contributions if the source concentrations are known. This methodology does not take into account any antecedent conditions. Because of the long residence time in the Delta due to tidal influences, the volume fingerprinting methodology provides a very rough estimate of conservative constituent concentrations. The timing of the sources becomes very important if the source flows or concentrations vary drastically with time. Thus for more accurate conservative constituent concentration estimates, the volume and timing fingerprinting methodology should be utilized.

Table 14.1: Estimation of Conservative Constituent Concentrations using Volume Contributions and Source Concentrations.

Source	**% Volume, $V_{\%}$**	**Source Concentration, C (mg/l)**	**$V_{\%}/100 \times C$ (mg/l)**
Location 1			
Main Stream	100	200	200
Tributary A	0	300	0
Tributary B	0	500	0
Total	*100*		***200***
Location 2			
Main Stream	70	200	140
Tributary A	30	300	90
Tributary B	0	500	0
Total	*100*		***230***
Location 3			
Main Stream	50	200	100
Tributary A	20	300	60
Tributary B	30	500	150
Total	*100*		***310***

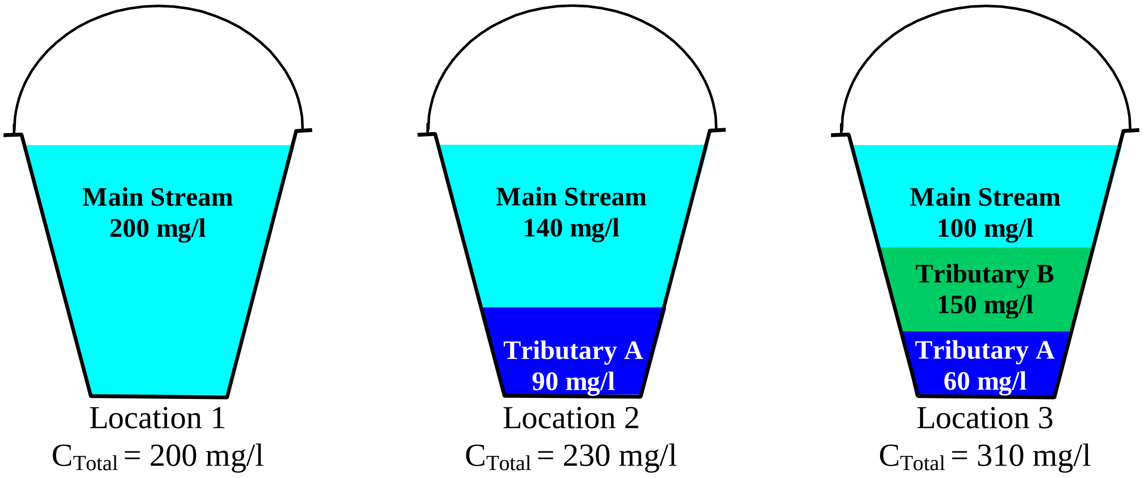


Figure 14.3: Conceptualization of Relative Concentrations Computed from Source Volumes and Source Concentrations for Water Sampled from Three Locations.

14.3 Conceptualization of Volume and Timing Fingerprinting

In some cases, it may be desirable to know not only the source of water, but also to have information of the timing when that water entered the system. In systems with long residence times, such as the Delta, the water from each source in a sample of water at a specified location may consist of water that entered the system at different times with different concentrations. Thus in addition to determining the source of the water in the sample, the timing of when that source entered the system is also useful for more accurate estimates of conservative constituent concentrations.

For illustration purposes, consider a sample of water withdrawn from a system with two sources (Figure 14.4). The sampled water could be divided both by source and by time period of entry into the system (Figure 14.5). For illustration purposes, hypothetical relative volume contributions from each source have been indicated for each time period. The number of time periods represented in the sample is referred to in this document as the system “memory”. The length of the system memory will depend on the hydrologic conditions and the retention time of the system. For this example the system memory is three time periods long.

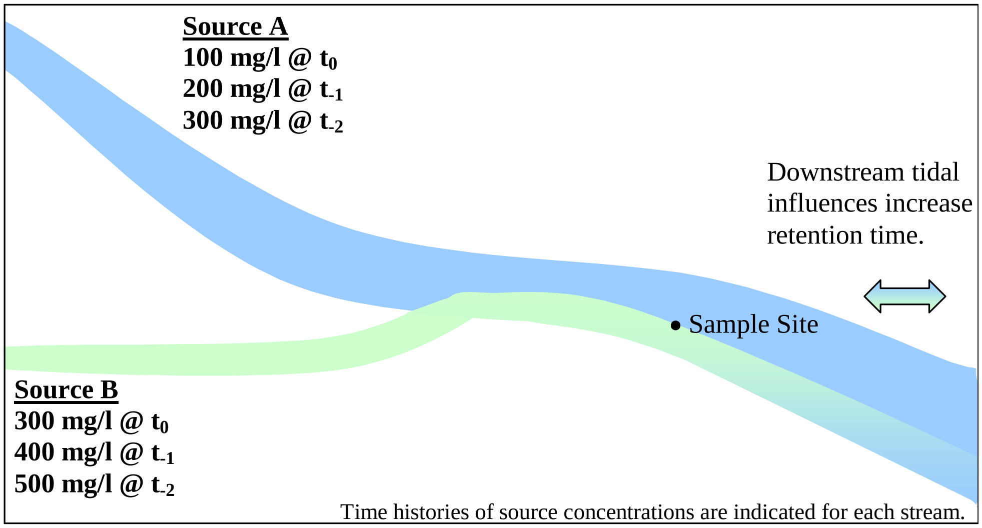


Figure 14.4: Conceptualization of Two Source Streams with a Long Retention Time after their Confluence.

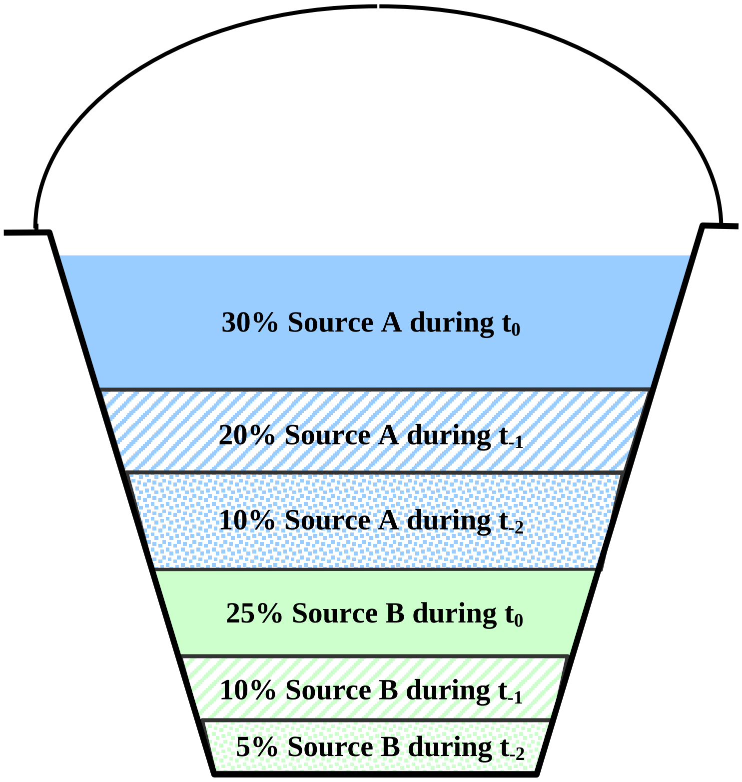


Figure 14.5: Conceptualization of Volume and Timing of Source Contributions in a Water Sample from Two Source Streams with a Long Retention Time.

From the volume contributions, source concentrations, and timing, the concentration of a conservative constituent can be estimated by summing the volume of each source for each time period multiplied by the concentration of the constituent associated with that source for that time period (Equation 14-2).

$$C_{CC}\left(t\right)=\sum_{i=1}^{n}\sum_{j=0}^{m}\frac{V_{\%i,-j}}{100}C_{i,-j} \qquad \text{[Eqn. 14-2]}$$

where,

$C_{CC}(t)$ = concentration of a conservative water quality constituent at a specified location and time,
$C_{i,-j}$ = concentration of a conservative water quality constituent from source i at time $-j$[4],
n = total number of sources,
m = length of the system memory, and
$V_{\%\ i,-j}$ = percent volume at a specified location from source i at time $-j$.

Using the source concentrations from Figure 14.4 and the relative volume contributions from Figure 14.5, the concentration of a conservative constituent for the sample location can be estimated using Equation 14-2 as shown in Table 14.2 and Figure 14.6.

Table 14-2: Estimation of Conservative Constituent Concentrations using Volume Contributions, Source Concentrations, and Source Timing.

Source	**% Volume, $V_{\%}$**	**Source Concentration, C (mg/l)**	**$V_{\%}$/100 x C (mg/l)**
Source A for t_0	30	100	30
Source A for t_{-1}	20	200	40
Source A for t_{-2}	10	300	30
Source B for t_0	25	300	75
Source B for t_{-1}	10	400	40
Source B for t_{-2}	5	500	25
Total	*100*		***240***

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[4] Note that the time periods are counted backwards from the present. t_0 is the present time period, t_{-1} is one time period in the past, etc. Similarly $C_{i,0}$ is the concentration of the constituent from source *i* from the present time, $C_{i,-1}$ is the concentration of the constituent from source *i* from one time period in the past, etc.

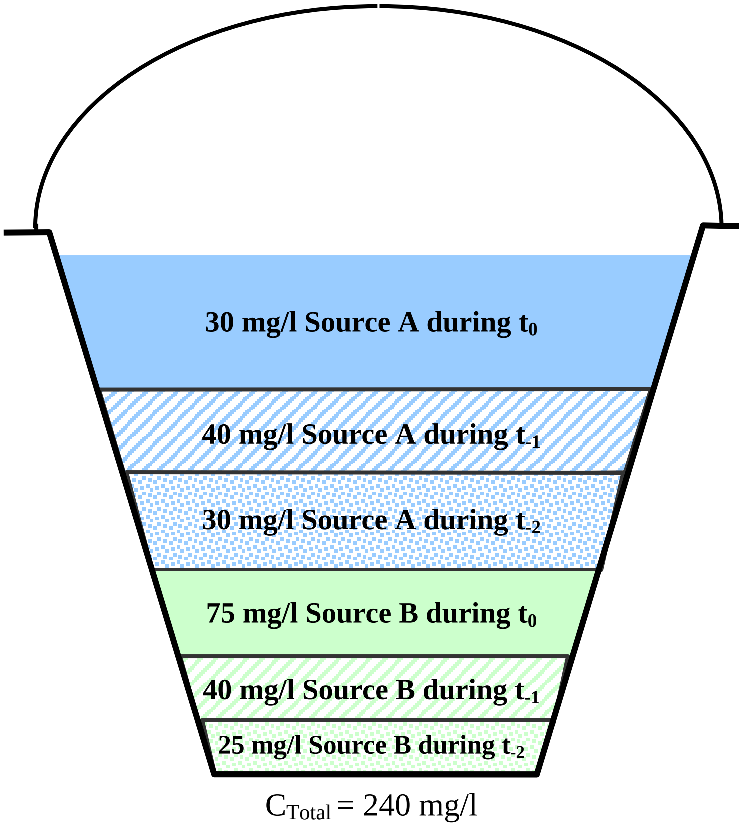


Figure 14.6: Conceptual Relative Concentrations Computed from Source Volumes, Source Concentrations, and Source Timing.

Using the volume and timing fingerprinting methodology, the concentration of any conservative constituent can be estimated from the simulated timed volume contributions if the timed source concentrations are known. The volume and timing fingerprinting method should be used when boundary flows and concentrations vary drastically with time. Because of the long residence time in the Delta due to tidal influences and the varying boundary conditions, this methodology provides a better estimate of conservative constituent concentrations than the volume fingerprinting method.

To further illustrate the two different types of fingerprinting (volume fingerprinting and volume and timing fingerprinting), hypothetical fingerprinting results were generated for the three sample locations for the system shown in Figure 14.1. Pie charts for each type of fingerprinting (Figure 14.7) could represent relative contributions of either water volumes or of conservative constituent concentration depending on the type of analysis that was conducted.

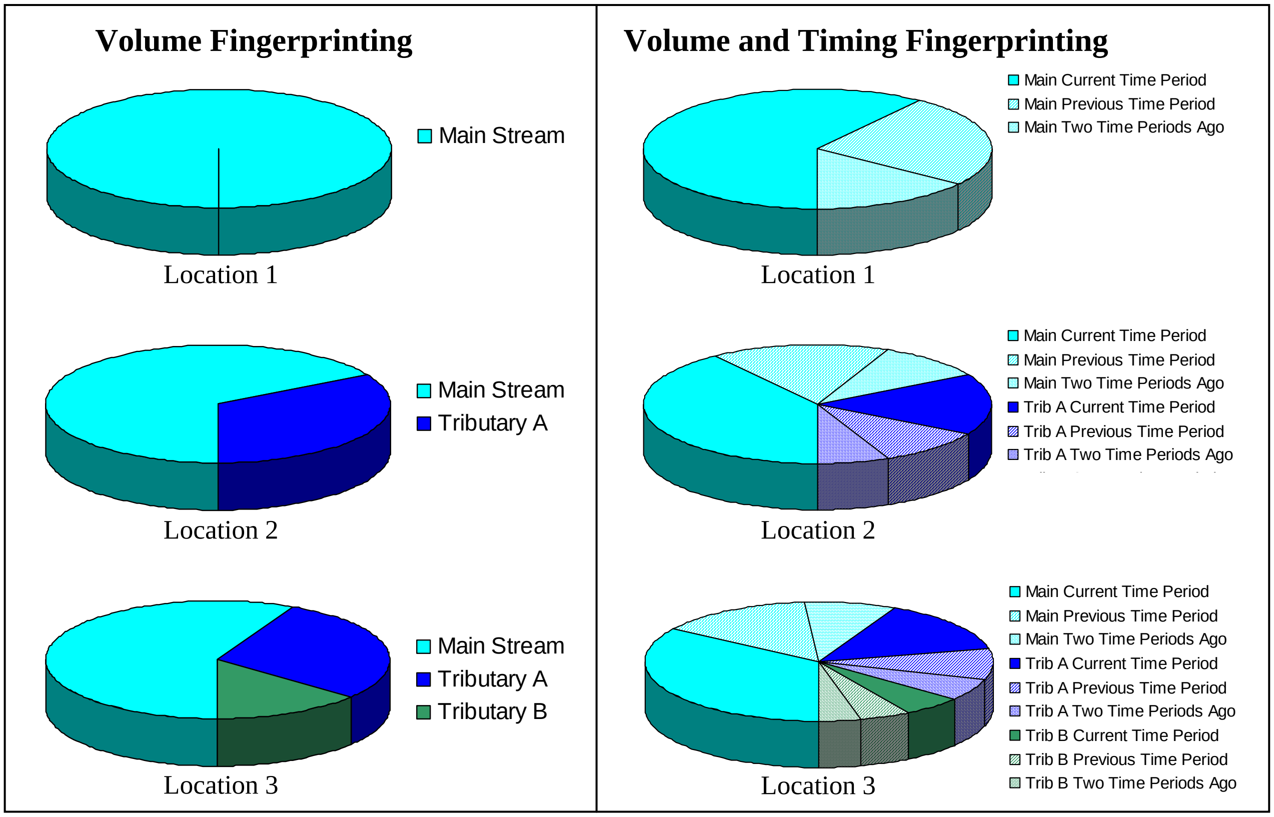


Figure 14.7: Pie Charts of Relative Contributions of Water Volume or of Conservative Constituent Concentrations using Two Fingerprinting Methods.

14.4 Constituent Fingerprinting

The volume fingerprinting methodologies described above provide a general analysis tool for water volumes and conservative constituent concentrations. Constituent fingerprinting is a specialized application of volume fingerprinting or volume and timing fingerprinting in which a specific constituent is utilized instead of a general conservative constituent. Constituent fingerprinting is discussed in more detail in section 14.6.

14.5 Application of Fingerprinting in the Delta using DSM2

Fingerprinting techniques have been utilized in DSM2 to analyze relative sources of flow and conservative constituents in the Sacramento-San Joaquin Delta. Due to the tidal flows in the Delta, the residence time or system “memory” can be up to six months depending on the hydrologic conditions. For fingerprinting studies, six main sources are typically used: the Sacramento River, the San Joaquin River, Martinez, eastside streams (all combined), agricultural drains (all combined), and the Yolo Bypass (Figure 14.9). A sample of water withdrawn from any location in the Delta contains water contributions from these sources (Figure 14.8). Similarly, the concentration of a conservative constituent at any location in the Delta is derived from contributions from these sources. The flow and conservative constituent contributions from the various sources at a given location can be determined by conducting fingerprinting simulations utilizing DSM2.

DSM2 provides various methods for running fingerprinting simulations. These methods fall into two main categories, which are described in this chapter:

- ☐ Modify DSM2-QUAL boundary condition input files to use tracer constituents for fingerprinting analysis. This method can be used for volume fingerprinting, volume and timing fingerprinting, constituent fingerprinting, and constituent and timing fingerprinting.

- ☐ Modify DSM2-QUAL OUTPUTPATHS section to request internally computed fingerprinting results. This method can only be used for constituent or constituent and timing fingerprinting (see section 14.6.3).

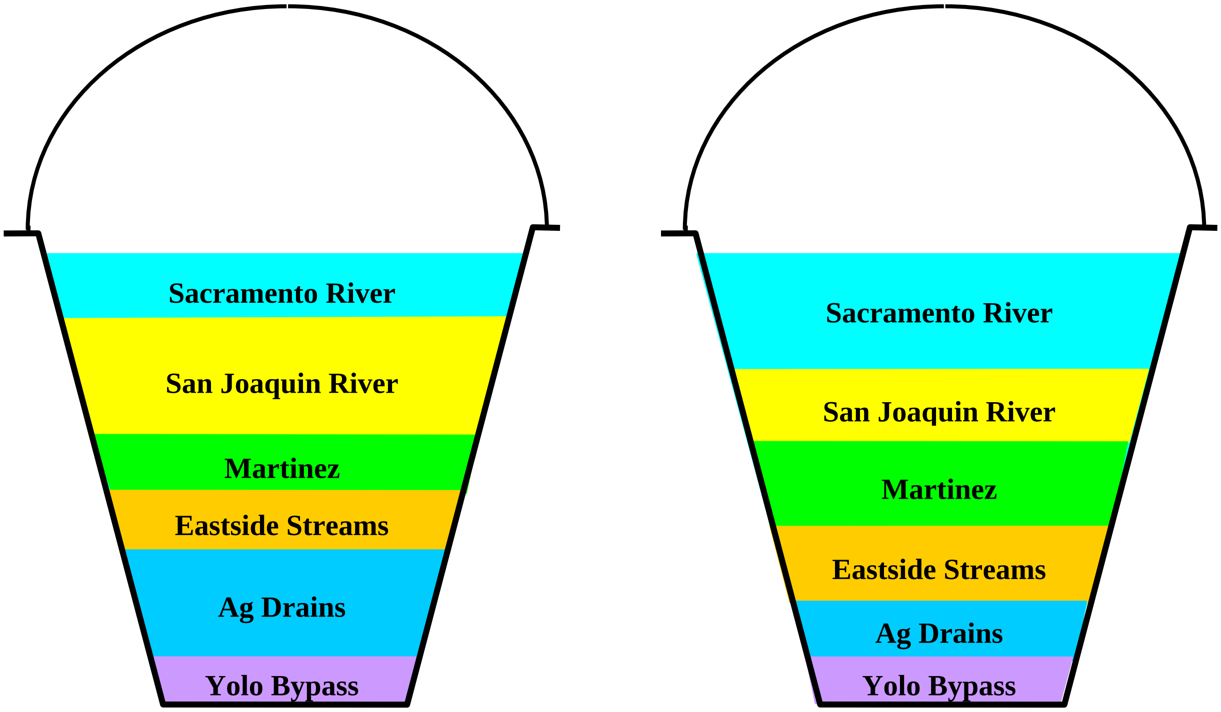
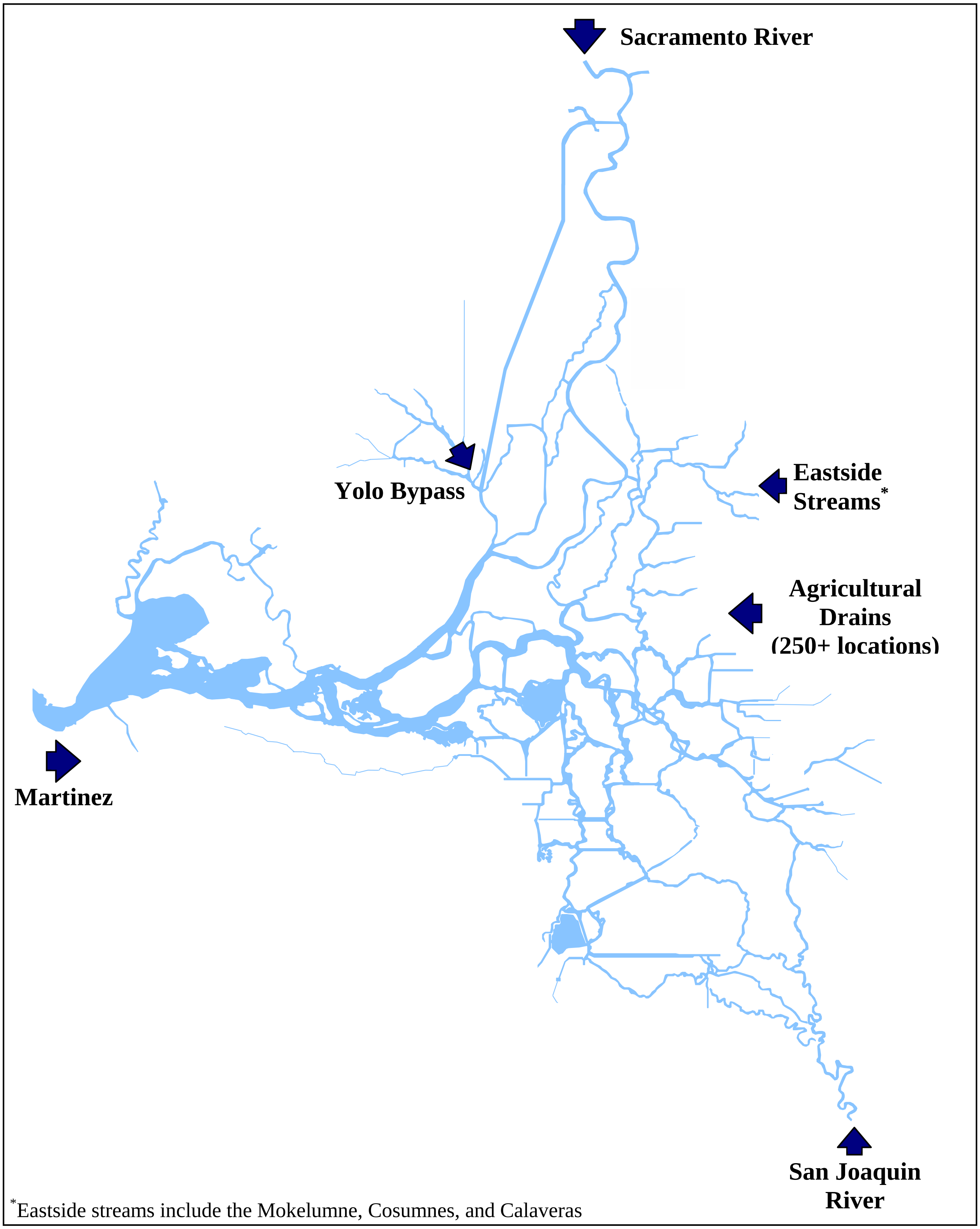


Figure 14.8: Conceptualization of Relative Contributions of Six Sources to Water Samples from Two Different Locations in the Delta.

Note: Relative contributions are for illustrative purposes only. They do not reflect actual results from the Delta.



[*]Eastside streams include the Mokelumne, Cosumnes, and Calaveras

Figure 14.9: Typical Fingerprinting Source Locations for the Sacramento-San Joaquin Delta.

14.5.1 Volume Fingerprinting for Conservative Constituents by using Tracer Constituents in QUAL

Volume fingerprinting indicates the volume of water at a given location and time contributed by each source. For volume fingerprinting simulations, tracer constituents are used to represent contributions from each source. These tracers are arbitrarily defined conservative constituents in DSM2. The concentration of each tracer constituent is set to a constant value at the point of origin of each tracer. The concentration of each tracer constituent is then set equal to zero at all other locations. Thus for the six source locations typically used in DSM2 fingerprinting studies, the tracer concentrations would be set up as illustrated in Table 14.3. In this example, tracer 1 is associated with the Sacramento River, tracer 2 is associated with the San Joaquin River, etc. Additional source locations can be included by adding additional tracer constituents for each new source.

In addition, a tracer for checking mass conservation can be specified. Thus, for a six-source volume fingerprinting simulation of the Delta, seven tracer constituents would be specified: one for each source and one for mass conservation. For the mass conservation tracer, the concentration at each source is set equal to the constant value used for the individual source tracers (Table 14.3). If the same constant value is used at each source, the concentration of the mass conservation tracer will equal that constant value at all locations throughout the system. If mass is conserved, at any time at a specified location the sum of the tracer constituent concentrations should equal the simulated concentration of the mass conservation tracer (Equation 14-3). Although it is not necessary to use a separate mass conservation tracer, it provides a method to check that the simulation was set up correctly.

$$C_{Tmc} = \sum_{i=1}^{n} C_{T\,i} \qquad \text{[Eqn. 14-3]}$$

where,

C_{Tmc} = concentration of the mass conservative tracer at a given location,
C_{Ti} = concentration of tracer constituent i at a given location,
n = total number of sources.

The value assigned for the concentration of each tracer at the source with which it is associated is arbitrary. For convenience in analysis, the same constant value is typically used for each tracer. A concentration of 10,000 is often used because percent contributions are easily determined by dividing by 100. A concentration of 10,000 is also large enough to indicate minor contributions, which can be lost in round off error if smaller values are used.

Table 14.3: Specified Tracer Concentations for Volume Fingerprinting in the Delta.

Location	Tracer 1	Tracer 2	Tracer 3	Tracer 4	Tracer 5	Tracer 6	Tracer 7 to Check Mass Conservation
Sacramento River	Constant value e.g., 10,000	0	0	0	0	0	Constant value e.g., 10,000
San Joaquin River	0	Constant value e.g., 10,000	0	0	0	0	Constant value e.g., 10,000
Martinez	0	0	Constant value e.g., 10,000	0	0	0	Constant value e.g., 10,000
Eastside Streams	0	0	0	Constant value e.g., 10,000	0	0	Constant value e.g., 10,000
Ag Drains	0	0	0	0	Constant value e.g., 10,000	0	Constant value e.g., 10,000
Yolo Bypass	0	0	0	0	0	Constant value e.g., 10,000	Constant value e.g., 10,000

Percent Volume Contributions for Volume Fingerprinting

The volume fingerprinting methodology indicates the volume of water at a given location contributed by each source represented by a tracer constituent. The percent volume contribution of a particular source, *k*, at a given location and time can be determined as shown in Equation 14-4:

$$V_{\%k} = \frac{C_{Tk}}{\sum_{i=1}^{n} C_{Ti}} \times 100\% = \frac{C_{Tk}}{C_{Tmc}} \times 100\% \qquad \text{[Eqn. 14-4]}$$

where,

C_{Ti} = concentration of the tracer constituent *i* at a given location,
C_{Tk} = concentration of the tracer constituent associated with specific source *k* at a given location,
n = total number of sources, and
$V_{\% k}$ = percent volume contribution from source *k* at a specified location.

Conservative Constituent Estimates for Volume Fingerprinting

The concentration of a conservative constituent at a specified location can be estimated from the percent volume contributions from each source if the source concentrations are known (Equation 14-5):

$$C_{CC} = \sum_{i=1}^{n} C_{Ti} \frac{V_{\% i}}{100} \qquad \text{[Eqn. 14-5]}$$

where,

C_{CC} = concentration of a conservative water quality constituent at a given location,
C_{Ti} = concentration of the tracer constituent *i* at a given location,
n = total number of sources, and
$V_{\% i}$ = percent volume contribution from source *i* at a specified location.

Examples of volume fingerprinting results for different analysis periods are given in section 14.5.4.

Once the fraction of water contributed by each source, $\frac{V_{\% i}}{100}$, has been determined, a single DSM2 simulation can be used to estimate the concentration of any conservative constituent from the source concentrations for that constituent. However, Equation 14-5 only approximates the concentration of a conservative water quality constituent for a specific location. Antecedent conditions are not considered. This method does not account for changes in source flows and concentrations. If the residence time of the system is longer than the analysis period for the volume contributions, the volume and timing fingerprinting method provides a more accurate estimate of conservative constituent concentration estimates.

14.5.2 Volume and Timing Fingerprinting for Conservative Constituents by using Tracer Constituents in QUAL

The volume fingerprinting method presented in section 14.5.1 can be expanded to include the timing of the sources. Typically in DSM2, the volume and timing analysis is conducted on a monthly basis. An arbitrarily defined conservative tracer constituent is assigned to each source location for each month out of the year. Since the system memory for the Delta is considered to be six months or less, the volume and timing fingerprinting simulations are simplified by combining tracers for months that are six months apart. In other words, the same tracer is used to represent sources in January and July, February and August, March and September, etc. At the point of origin for each tracer, the concentration of that tracer constituent is set equal to a constant value for the two months represented by that source, and it is set equal to zero for the remaining ten months out of the year. The concentrations of the tracer constituents are set equal to zero at all other locations for all times. Thus for the six source locations typically used in DSM2 fingerprinting studies, the tracer concentrations would be set up as illustrated in Table 14.4. In this example, tracers 1-6 are associated with the Sacramento River, tracers 7-12 are associated with the San Joaquin River, etc. Additional source locations can be included in a volume and timing fingerprinting simulation by adding six additional tracer constituents for each source. An example of the six tracer constituents that would be required to represent a single source in a volume and timing fingerprinting study is shown in Figure 14.10. For a six-source volume fingerprinting simulation of the Delta, thirty-six tracer constituents would be specified: six for each source.

Analysis of volume and timing fingerprinting results can be tricky, especially if the short cut of assigning two source time periods to each tracer is used. If two source time periods are assigned to each tracer, the source time represented by that tracer will depend upon the month for which the simulation results are analyzed. For example, consider a tracer that represents water from a given source entering the system in January and July. Simulated concentrations of that tracer represent the volume contribution by its source during January for simulation results in January through June. However, for simulation results for July through December, that tracer represents the volume contributed by its source during July. To further illustrate this concept, the source months represented by each tracer in Figure 14.10 for each simulation month are summarized in Table 14..

In addition, a tracer for checking mass conservation can be specified. Thus, for a six-source volume fingerprinting simulation of the Delta, forty-two tracer constituents would be specified: six for each source (6x6 = 36) and six for mass conservation (36+6 = 42). For the mass conservation tracer, the concentration at each source for each time period is set equal to the constant value used for the individual source tracers (Table 14.4). If the same constant value is used at each source, the concentration of the mass conservation tracer will equal that constant value at all locations throughout the system. If mass is conserved, at any time at a specified location the sum of the tracer constituent concentrations should equal the sum of the simulated concentration of the mass conservation tracers (Equation 14-6). Although it is not necessary to use a separate mass conservation tracer, it provides a method to check that the simulation was set up correctly.

$$\sum_{j=1}^{m} C_{Tmc,j} = \sum_{i=1}^{n}\sum_{j=1}^{m} C_{T(i,j)} \qquad \text{[Eqn. 14-6]}$$

where,

$C_{Tmc,j}$ = concentration of the mass conservative tracer at a given location for time period j,

$C_{T(i,j)}$ = Concentration of the tracer constituent i at a given location for time period j,

n = total number of sources, and

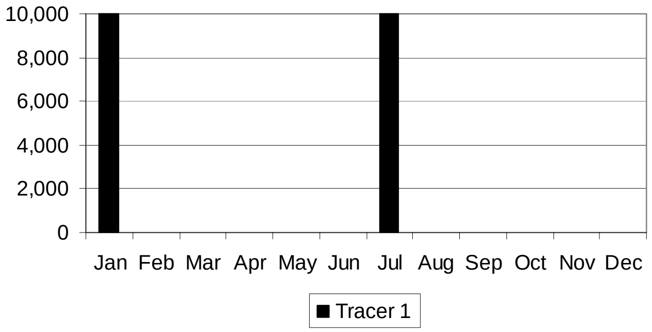
m = total number of time periods based on system memory.

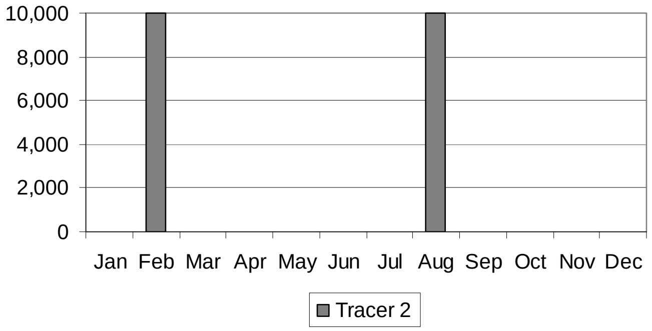
Table 14.4: Specified Tracer Concentations for Volume and Timing Fingerprinting in the Delta.

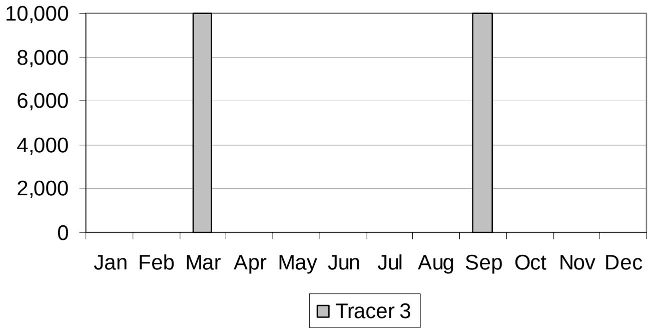
Location	Tracers 1-6	Tracers 7-12	Tracers 13-18	Tracers 19-24	Tracers 25-30	Tracers 31-36	Tracers 37-42 to Check Mass Conservation
Sacramento River	Constant value e.g.,10,000 or zero*	0	0	0	0	0	Constant value e.g.,10,000 or zero*
San Joaquin River	0	Constant value e.g.,10,000 or zero*	0	0	0	0	Constant value e.g.,10,000 or zero*
Martinez	0	0	Constant value e.g.,10,000 or zero*	0	0	0	Constant value e.g.,10,000 or zero*
Eastside Streams	0	0	0	Constant value e.g.,10,000 or zero*	0	0	Constant value e.g.,10,000 or zero*
Ag Drains	0	0	0	0	Constant value e.g.,10,000 or zero*	0	Constant value e.g.,10,000 or zero*
Yolo Bypass	0	0	0	0	0	Constant value e.g.,10,000 or zero*	Constant value e.g.,10,000 or zero*

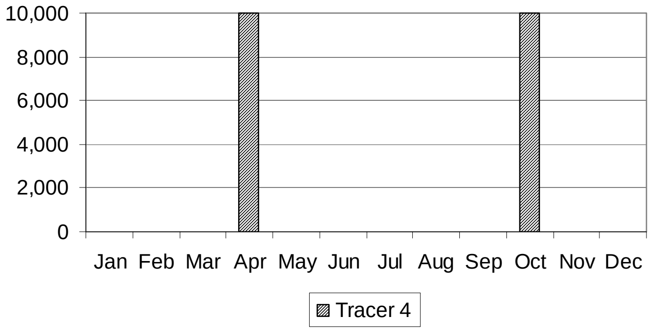
*Tracer is assigned a constant concentration for the two months represented by that tracer, and a value of zero is assigned for all other months.

Similar to the volume fingerprinting method, the value assigned for the concentration of each tracer at the source with which it is associated is arbitrary. For convenience, the same constant value is typically used for each tracer. A concentration of 10,000 is often used because percent contributions are easily determined by dividing by 100. A concentration of 10,000 is also large enough to indicate minor contributions, which can be lost in rounding error if smaller values are used.


10,000
8,000
6,000
4,000
2,000
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
■ Tracer 1


10,000
8,000
6,000
4,000
2,000
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
■ Tracer 2


10,000
8,000
6,000
4,000
2,000
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
□ Tracer 3


10,000
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Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
▨ Tracer 4

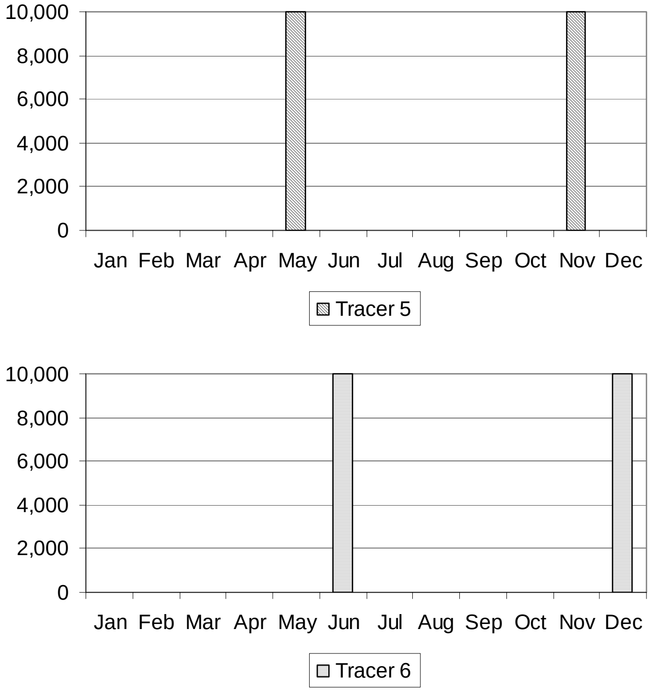

Figure 14.10: Specified Tracer Concentrations for a Single Source for Volume and Timing Fingerprinting in the Delta.

Table 14.5: Source Month Represented by each Tracer for a Specified Month in the Delta.

Simulation Results Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Tracer 1	Jan	Jan	Jan	Jan	Jan	Jan	Jul	Jul	Jul	Jul	Jul	Jul
Tracer 2	Aug	Feb	Feb	Feb	Feb	Feb	Feb	Aug	Aug	Aug	Aug	Aug
Tracer 3	Sep	Sep	Mar	Mar	Mar	Mar	Mar	Mar	Sep	Sep	Sep	Sep
Tracer 4	Oct	Oct	Oct	Apr	Apr	Apr	Apr	Apr	Apr	Oct	Oct	Oct
Tracer 5	Nov	Nov	Nov	Nov	May	May	May	May	May	May	Nov	Nov
Tracer 6	Dec	Dec	Dec	Dec	Dec	Jun	Jun	Jun	Jun	Jun	Jun	Dec

Percent Volume Contributions for Volume and Timing Fingerprinting

The volume and timing fingerprinting methodology indicates the volume of water at a given location contributed by each source from a specified month. At a given location, the percent volume contribution of a particular source, *k*, from a specified time, *t*, can be determined as shown in Equation 14-7:

$$V_{\%(k,t)} = \frac{C_{T(k,t)}}{\sum_{i=1}^{n} C_{T(i,t)}} \times 100\% = \frac{C_{T(k,t)}}{C_{Tmc,t}} \times 100\% \qquad \text{[Eqn. 14-7]}$$

where,

$C_{Tmc,t}$ = concentration of the mass conservative constituent associated with specific source *m* at a given location for a specific time *t*,
$C_{T(k,t)}$ = concentration of the tracer constituent associated with specific source *k* at a given location for a specific time *t*,
$C_{T(i,t)}$ = concentration of the tracer constituent *i* at a given location for a specific time *t*,
n = total number of sources, and
$V_{\%\,(k,t)}$ = percent volume contributed from source *k* at a specified location for a specific time *t*.

For the Delta, six time periods ($n = 6$) represent the six-month “system memory”. Because a single tracer represents two time periods for volume and timing fingerprinting, care must be taken when conducting analyses to ensure that the correct source times are associated with each tracer (see Figure 14.10 and Table 14.).

Conservative Constituent Estimates for Volume and Timing Fingerprinting

The concentration of a conservative constituent at a specified location can be estimated from the percent volume contributions from each source if the source concentrations are known (Equation 14-8):

$$C_{CC} = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{T(i,j)} \frac{V_{\%(i,j)}}{100} \qquad \text{[Eqn. 14-8]}$$

where,

C_{CC} = concentration of a conservative water quality constituent at a specified location for a give time,
n = total number of sources,
m = total number of time periods based on the system memory, and
$V_{\%\,(i,j)}$ = percent volume contributed from source i at a specified location for a specific time *j*.

Once the fraction of water contributed by each source during each time period, $\frac{V_{\%(i,j)}}{100}$, has been determined, a single DSM2 simulation can be used to provide a good estimate of the concentration of any conservative constituent from the source concentrations for that constituent. Because of the long residence times in the Delta and fluctuations in boundary flows and constituent concentrations, using the volume and timing fingerprinting method provides a more accurate estimate of conservative constituent concentration estimates than using the volume fingerprinting method.

14.5.3 Accuracy of Conservative Constituent Concentration Estimates

The accuracy of conservative constituent concentration estimates using fingerprinting depends on various factors. Variations in the source flows and/or concentrations over the analysis period (hourly, daily, monthly) affect the accuracy of constituent concentration estimates using fingerprinting. For example, EC concentrations for the Sacramento River, eastside streams, and Yolo Bypass are relatively constant with time. However, EC concentrations for Martinez, the San Joaquin River, and agricultural drains vary with time. Using fingerprinting methods that include timing of the sources increases the accuracy of the constituent concentration estimates.

The relative importance of errors in a fingerprinting analysis may depend on the application. To illustrate this point, consider volume fingerprinting results for Martinez that are going to be used to estimate constituent concentrations for both EC and DOC at Rock Slough. Typical source concentrations at Martinez for these two constituents are 25,000 umhos/cm for EC and between 1.6 and 7.0 mg/l for DOC.[5] Assume that the fingerprinting analysis found the volume of water from Martinez at Rock Slough to be 2% of the total volume of water at Rock Slough.

To illustrate the impacts of errors in boundary constituent concentrations on estimates of constituent concentrations at other locations in the Delta, consider a 10% error in the Martinez source concentration. For the EC concentration estimate, a 10% error in the Martinez source concentration estimate results in a 2,500 umhos/cm error at the Martinez boundary. Based on the fingerprinting concentration volume contribution at Rock Slough, the original Martinez contribution at Rock Slough would be 500 umhos/cm, while the same contribution with a 10% increase in the Martinez concentration would be 550 umhos/cm. The 50 umhos/cm difference at Rock Slough between these two scenarios is considerably smaller than the 2,500 umhos/cm error at Martinez.

For the DOC concentration estimate, a 10% error in the Martinez source concentration estimate results in a 0.02 to 0.07 mg/l increase in the DOC concentration at Martinez. Based on the fingerprinting volume contribution, the high-end (7 mg/l) contribution at Rock Slough would be 0.14 mg/l, while the same contribution of DOC from Martinez with a 10% increase would be 0.15 mg/l. The 0.01 mg/l difference at Rock Slough is on the same order of magnitude as the difference in DOC at Martinez (0.02 and 0.07 mg/l for the low- and high-end errors).

The significance of an error in a source concentration estimate at a location of interest depends not only upon the magnitude of the error at the boundary, but also depends on the relative concentrations from the other sources and the volume contribution from the source in question. Errors related to a major source of a constituent will have more of an impact on the concentration estimate than errors related to minor sources.

14.5.4 Sample Volume Fingerprinting Results

Results from fingerprinting simulations can be analyzed in several different ways. Results can be examined on different time scales (hourly, daily, monthly, etc). Analyses can be conducted based on hydrologic conditions, such as dividing the simulation results by water year type. To illustrate the wide range of applications of fingerprinting, examples from a volume fingerprinting

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[5] The DOC water quality at Martinez is based on data collected at Mallard Island (Pandey, 2001).

study of historical conditions for water years 1992-1998 are presented below. All results shown are for the entrance to Clifton Court Forebay. In Figure 14.11, monthly percent volume contributions from two sources, the Sacramento and San Joaquin rivers, are shown as a time series plot. Other sources contributed less than 20% and were omitted for illustration purposes. The time series plot indicates that it depends on the time period whether the Sacramento River or the San Joaquin River provides the majority of the volume at the entrance to Clifton Court Forebay.

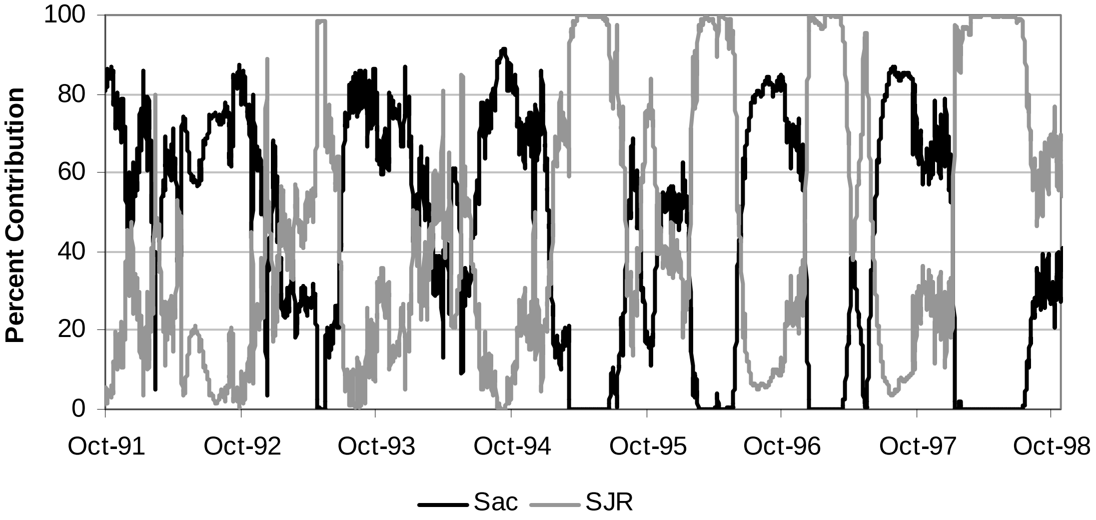


Figure 14.11: Percent Volume Contributions of the Sacramento and San Joaquin Rivers at the Entrance to Clifton Court Forebay.

As an additional analysis, the volume fingerprinting results were examined based on water year types. Pie charts illustrate the relative volume contributions from six sources by water year type (Figure 14.12). These results indicate that at the entrance to Clifton Court Forebay the Sacramento River provide the majority of the water volume during critical years, whereas the San Joaquin River provides the majority of the water volume during wet years.

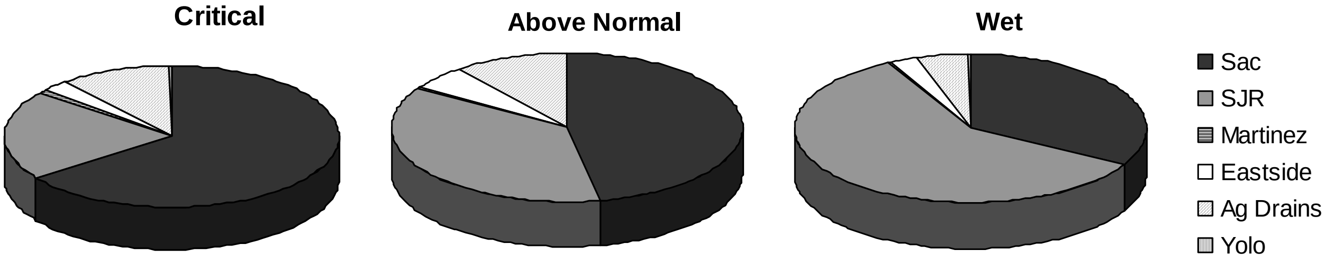


Figure 14.12: Percent Volume Contributions of the Sacramento and San Joaquin Rivers at the Entrance to Clifton Court Forebay based on Water Year Types.

Monthly average volume contributions over the seven-year period were also analyzed. The monthly average results in Figure 14.13 indicate that at the entrance to Clifton Court Forebay the Sacramento River provides the majority of the water volume during dry months, whereas the San Joaquin River provides the majority of the water volume during wet months.

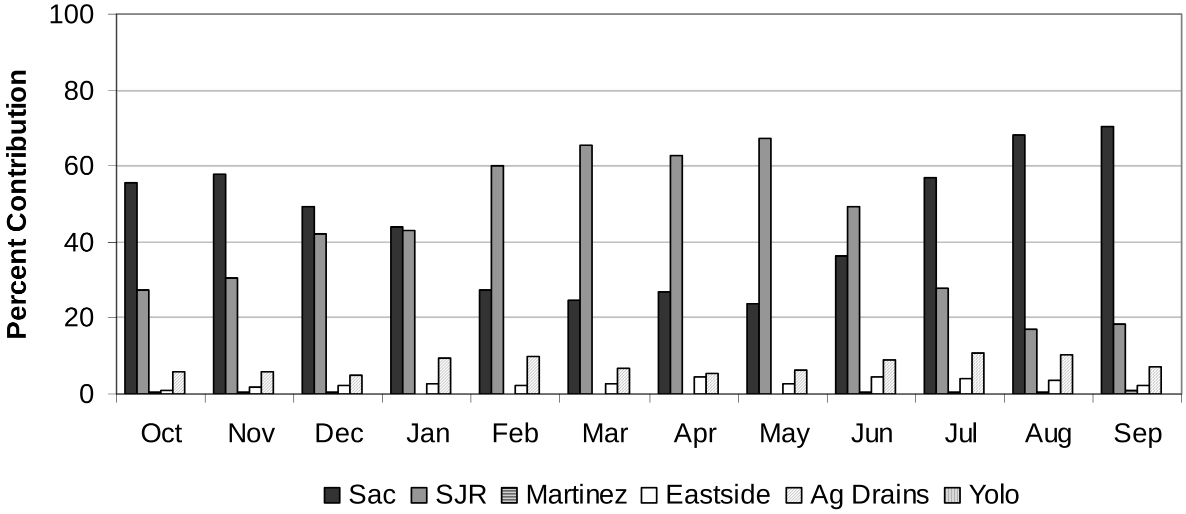


Figure 14.13: Monthly Average Percent Volume Contributions of the Sacramento and San Joaquin Rivers at the Entrance to Clifton Court Forebay.

14.6 Special Applications of Fingerprinting using DSM2

The volume-based fingerprinting methods described in section 14.5 provide a general analysis methodology that can be used to estimate the concentration of any conservative constituent. This section describes adaptations of those techniques when analysis is desired for a specific conservative constituent.

14.6.1 Constituent Fingerprinting

For the volume fingerprinting method, tracer constituents represent any conservative constituent. For the case when fingerprinting analysis is only desired for a specific constituent (e.g., EC), the arbitrary concentration of the tracer constituent (Table 14.3) can be replaced with the source concentrations of the desired constituent (Table 14.). In addition to specifying a tracer constituent for each source, the conservative constituent being investigated (e.g., EC) is simulated as its own constituent in the traditional manner. If mass is conserved, at any time at a specified location the sum of the tracer constituent concentrations should equal the simulated constituent concentration (Equation 14-9). This provides a method to check that the simulation was set up correctly.

$$C_{CC} = \sum_{i=1}^{n} C_{Ti} \qquad \text{[Eqn. 14-9]}$$

where,

C_{CC} = concentration of the conservative constituent to be simulated,
C_{Ti} = concentration of tracer constituent i, and
n = total number of sources.

Table 14.6: Specified Tracer Concentations for Constituent Fingerprinting in the Delta.

Location	Tracer 1	Tracer 2	Tracer 3	Tracer 4	Tracer 5	Tracer 6	Constituent (e.g., EC)
Sacramento River	Observed Values	0	0	0	0	0	Observed Values
San Joaquin River	0	Observed Values	0	0	0	0	Observed Values
Martinez	0	0	Observed Values	0	0	0	Observed Values
Eastside Streams	0	0	0	Observed Values	0	0	Observed Values
Ag Drains	0	0	0	0	Observed Values	0	Observed Values
Yolo Bypass	0	0	0	0	0	Observed Values	Observed Values

Percent Contributions for Constituent Fingerprinting

The constituent fingerprinting methodology indicates the relative contributions of a specified source to the constituent concentration at a given location. The percent contribution of a particular source, *k*, at a given location and time can be determined as shown in Equation 14-10:

$$C_{\%k} = \frac{C_{Tk}}{\sum_{i=1}^{n} C_{Ti}} \times 100\% = \frac{C_{Tk}}{C_{CC}} \times 100\% \qquad \text{[Eqn. 14-10]}$$

where,

$C_{\%k}$ = percent contribution of the conservative constituent from source *k* at a specified location,
C_{Tk} = concentration of tracer constituent *k*, and
n = total number of sources.

14.6.2 Constituent and Timing Fingerprinting

The constituent fingerprinting method described in section 14.6.1 can be extended to constituent and timing fingerprinting also by adding tracer constituents for each desired source location and time. For the case when fingerprinting analysis is only desired for a specific constituent (e.g., EC), the arbitrary concentration of the tracer constituent (Table 14.4) can be replaced with the source concentrations of the desired constituent (Table 14.7).

Table 14.7: Specified Tracer Concentations for Constituent and Timing Fingerprinting in the Delta.

Location	Tracers 1-6	Tracers 7-12	Tracers 13-18	Tracers 19-24	Tracers 25-30	Tracers 31-36	Constituent (e.g., EC)
Sacramento River	Observed values or zero*	0	0	0	0	0	Observed values
San Joaquin River	0	Observed values or zero*	0	0	0	0	Observed values
Martinez	0	0	Observed values or zero*	0	0	0	Observed values
Eastside Streams	0	0	0	Observed values or zero*	0	0	Observed values
Ag Drains	0	0	0	0	Observed values or zero*	0	Observed values
Yolo Bypass	0	0	0	0	0	Observed values or zero*	Observed values

*Tracer is assigned the observed concentration for the two months represented by that tracer, and a value of zero is assigned for all other months.

Percent Contributions for Constituent and Timing Fingerprinting

The constituent and timing fingerprinting methodology indicates the relative contributions of a specified source during a specified month to the constituent concentration at a given location.

Based on Equation 14-10, the percent contribution of a particular source, *k*, from a specified month, *t*, at a given location can be determined as shown in Equation 14-11:

$$C_{\%(k,t)} = \frac{C_{T(k,t)}}{\sum_{i=1}^{n}\sum_{j=1}^{m} C_{T(i,j)}} \times 100\% = \frac{C_{T(k,t)}}{C_{CC}} \times 100\% \qquad \text{[Eqn. 14-11]}$$

where,

$C_{\%(k,t)}$ = percent contribution of the conservative constituent *k* during time *t* at a specified location,
$C_{T(i,j)}$ = concentration of tracer constituent from source *i* at time *j* at a specified location,
$C_{T(k,t)}$ = concentration of tracer constituent *k* at time *t*,
n = total number of sources, and
m = length of the system memory.

14.6.3 Constituent or Constituent and Timing Fingerprinting for Conservative Constituents by using an OUTPUTPATHS Section in the QUAL Input

In addition to the fingerprinting methods described above, DSM2 will internally set up and run fingerprinting simulations by specifying an appropriate OUTPUTPATHS section in the QUAL input. The OUTPUTPATHS section requests fingerprinting results at specified locations. The amount of the constituent contributed by the specified source is then computed internally when QUAL is run in a process that is transparent to the user. Results are only provided for the constituents and sources specified in a QUAL OUTPUTPATHS section.

For constituent fingerprinting, an OUTPUTPATHS section is added to the QUAL input that includes one of the following key words:

☐ FROM_NAME	tracks conservative constituents from a location name
☐ FROM_TYPE	tracks conservative constituents from an accounting type
☐ FROM_NODE	tracks conservative constituents from a node number
☐ FROM_ALL	tracks conservative constituents from all sources[6]

Additional details on OUTPUTPATHS sections in the DSM2 input files can be found in the 1998 annual report (Nader-Tehrani et al., 1998).

Sample Scenario

How much of the EC at various locations in the Delta originated from the ocean (Martinez)?

---

[6] The FROM_ALL computation occurs automatically for any fingerprinting simulation specified by one of the above FROM_XXX keywords. However the results are only provided in the output if the FROM_ALL keyword is specified.

Sample OUTPUTPATHS Section

```
OUTPUTPATHS
NAME FROM_NAME  TYPE  INTERVAL PERIOD  FILENAME
antioch        mtz   ec       1day    ave      output-files/qual.dss
jerseypt       mtz   ec       1day    ave      output-files/qual.dss
victoria       mtz   ec       1day    ave      output-files/qual.dss
cvp            mtz   ec       1day    ave      output-files/qual.dss
END
```

Using the above OUTPUTPATHS section, DSM2 would compute the one-day average contributions of EC from Martinez at the four specified locations (Antioch, Jersey Point, Victoria, and the CVP). The results would be stored in a file called qual.dss located in the output-files directory.

14.7 Summary

Fingerprinting techniques have been used to analyze source contributions of Delta flows and conservative constituent concentrations using DSM2. Fingerprinting studies are conducted by simulating the transport of conservative tracer constituents associated with each source. The two main applications of fingerprinting are volume fingerprinting and volume and timing fingerprinting. Results from fingerprinting analyses provide:

- ☐ A method for using a single DSM2 simulation to estimate the concentration of any conservative constituent at specified locations in the Delta if the source concentrations are known. The volume and timing fingerprinting method provides the best estimate of conservative constituent concentrations.
- ☐ The relative importance of each source.
- ☐ Improved understanding of the Delta.

Use of fingerprinting techniques with DSM2 provides a powerful analysis tool for understanding both hydrodynamics and water quality dynamics in the Delta.

14.8 References

Hutton, P. and F. Chung. (1992). “Simulating THM Formation Potential in Sacramento Delta. Part II.” *Journal of Water Resources Planning and Management.* American Society of Civil Engineers. 118 (5).

Nader-Tehrani, P. and R. Finch. (1998). “Chapter 5: DSM2 Input and Output.” *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 19th Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

Pandey, G. (2001). “Chapter 3: Simulation of Historical DOC and UVA Conditions in the Delta.” *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 22nd Annual Progress Report to the State Water Resources Control Board.* California Department of Water Resources. Sacramento, CA.

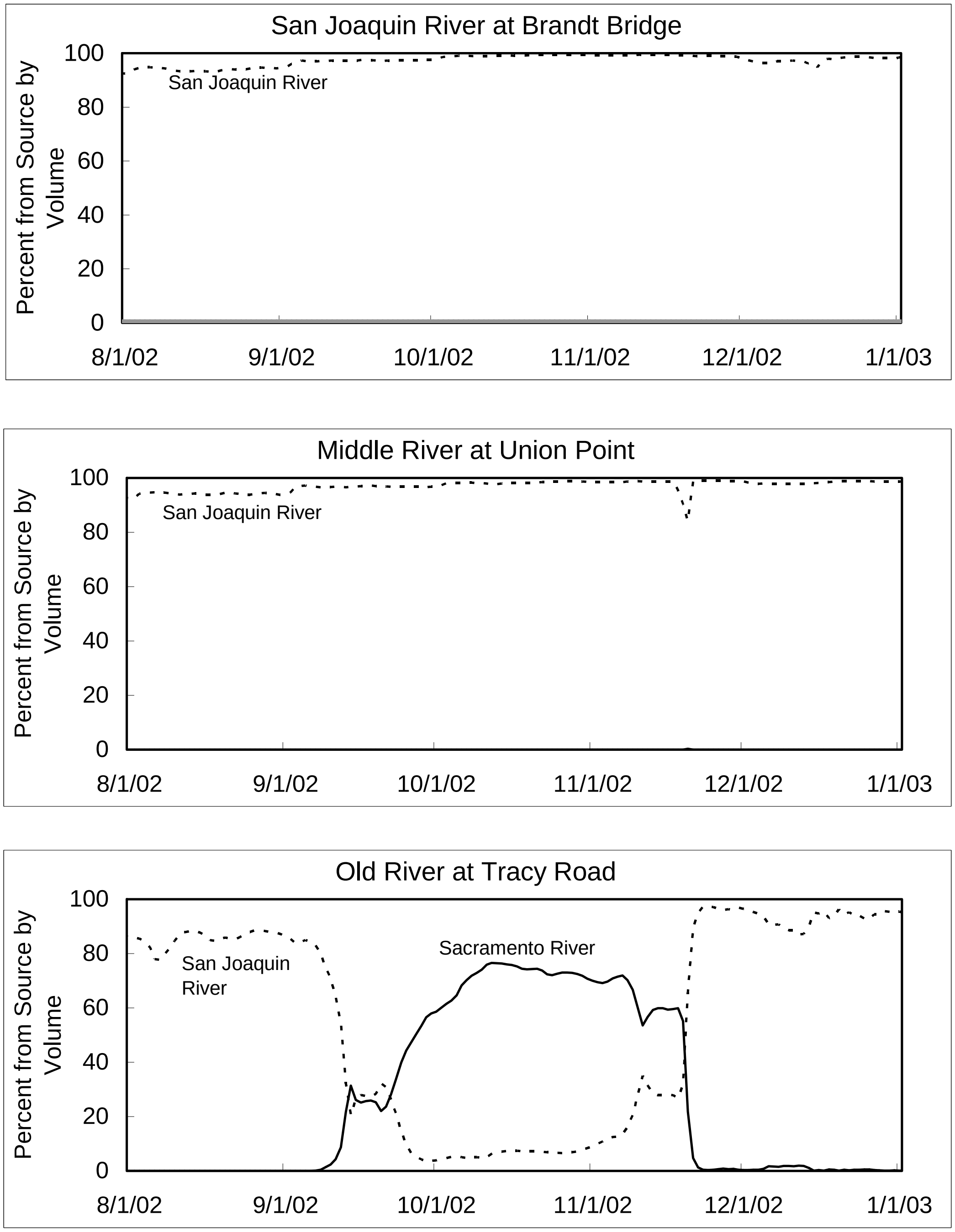
DWR – 20C

Description of historical DSM2 Particle Tracking Animation
With Temporary Barriers Installed in South Delta
October 13, 2005

Results from Particle Tracking Model simulations over historical periods were animated to visually demonstrate the movement of Sacramento River water into the south Delta into the vicinity of Old River at Tracy Road, Middle River at Union Point, and San Joaquin River at Brandt Bridge when the temporary barriers were in place. The two animations inject 10,000 particles on September 1, 2002 and on June 15, 2003, immediately upstream of the Delta Cross Channel and follow the movement of the particles for 90 days. These two periods were compared because the San Joaquin flows and the SWP and CVP exports were comparable. The Particle Tracking Model simulations are shown graphically in Figures 1 and 2, as well in the accompanying animated video.

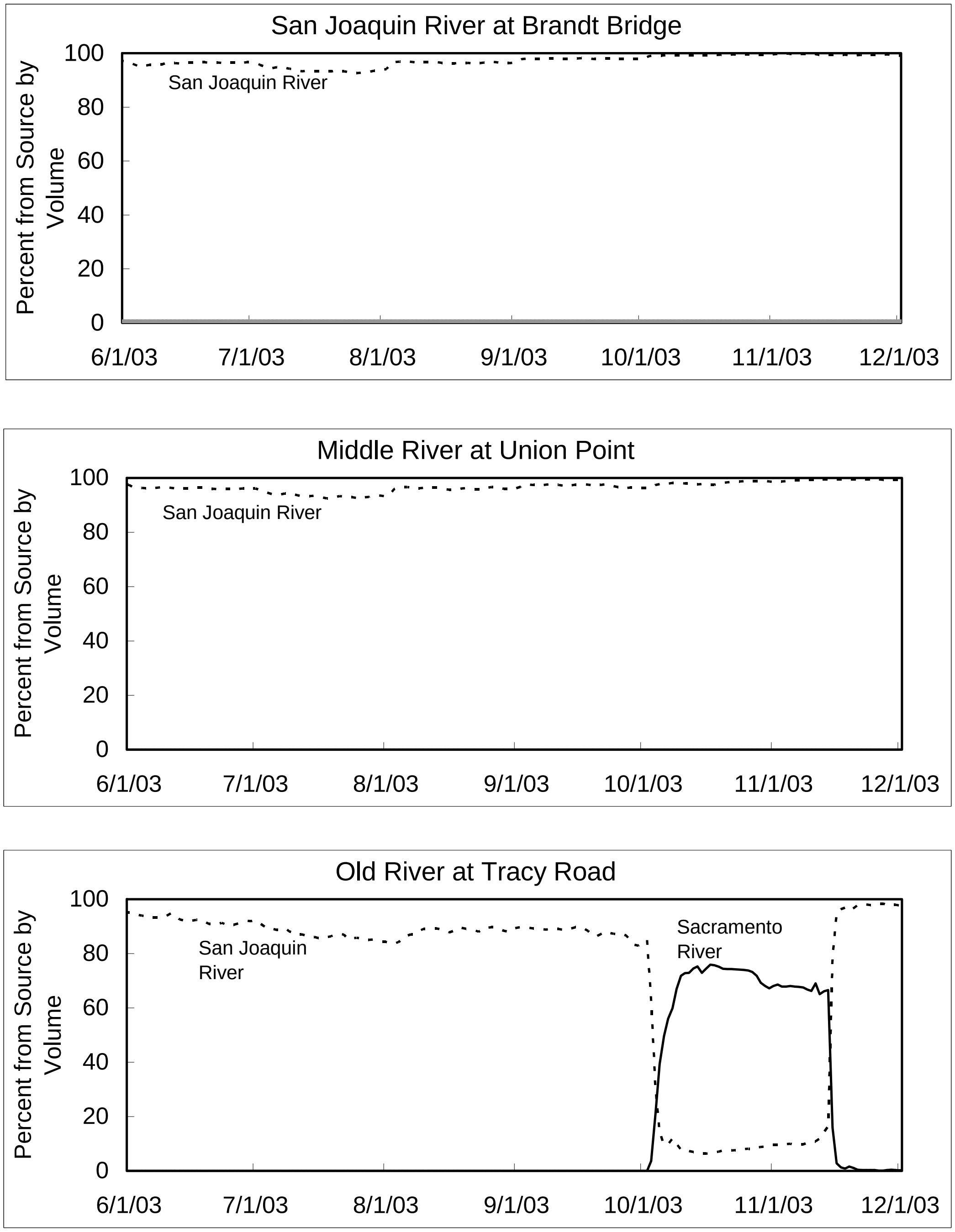
As shown below in Figure 1, the DSM2 volumetric fingerprint of historical 2002 conditions indicates that at San Joaquin River at Brand Bridge and Middle River at Union Point, the source of water remain predominantly the San Joaquin River over the period from September through November. In contrast, while much of the water at Old River at Tracy Road originates from the San Joaquin River for much of July and August, by mid September the Sacramento River starts to become a significant source, quickly replacing the San Joaquin River. This transition occurs during a time of sustained SWP and CVP exports of approximately 5,000 and 4,000 cfs respectively and San Joaquin River inflow at Vernalis of approximately 1,100 cfs and before the barrier at the Head of Old River is installed. The corresponding Particle Tracking 90-day animation for the September 1, 2002 injection shows particles moving from the injection site towards the south Delta. The particles never pass near the San Joaquin River at Brandt Bridge or the Middle River at Union Point sites and only reach the Old River at Tracy Road Bridge site by mid September.

Figure 2, below, shows the DSM2 volumetric fingerprinting of historical 2003 conditions and indicates that for the period of June through September of 2003, the San Joaquin River remained the predominant source of water at the Old River at Tracy Road site, as at the San Joaquin River at Brandt Bridge and Middle River at Union Point sites. The corresponding 90-day Particle Tracking animation for the June 15, 2003 injection shows particles again moving to the south Delta, but this time none reach the Old River at Tracy Road site by the end of September, consistent with Figure 2 that shows no Sacramento River water reaching here by this time. This is despite flows and exports being somewhat similar to 2002 with San Joaquin flows ranging from 1,000 cfs to 2,000 cfs, SWP exports ranging from 4,000-7,000 and CVP exports about 4,300 cfs; however, Figure 1 and 2 show from early October to mid-November that the Sacrament River water was the predominant source of water at Old River at Tracy Road site. This can be attributed to the installation of the Head of Old River barrier. When this barrier is installed, the circulation patterns change and the Sacramento River water usually reaches into Old River at Tracy Road.



Source: DSM2 simulation of historical conditions.

Figure 1. DSM2 Fingerprint of Historical 2002 Conditions Showing Relative Contribution of Sacramento and San Joaquin Rivers in the South Delta.



Source: DSM2 simulation of historical conditions.

Figure 2. DSM2 Fingerprint of Historical 2003 Conditions Showing Relative Contribution of Sacramento and San Joaquin Rivers in the South Delta.

DWR - 21

Department of Water Resources
Testimony for SWRCB Hearing on Cease and Desist Order

Agriculture in the Southern Delta

The southern Delta generally encompasses lands and channels of the Sacramento-San Joaquin Delta southwest of Stockton (See Figure 1). The bulk of the lands in the southern Delta are included within the South Delta Water Agency (SDWA) (Figure 2). Water conditions in the southern Delta are influenced by San Joaquin River inflow; tidal action; water export facilities (primarily water levels and circulation), local pump diversions; agricultural and municipal return flows; channel capacity; and upstream development. The area is irrigated primarily with surface water through numerous local agricultural diversions. A small percentage of SDWA agricultural land is irrigated with groundwater. Average annual rainfall in the southern Delta varies from approximately 8 inches to over 12 inches.

The SDWA area is predominantly mineral soils. The soils within the lowlands in the SDWA tend to be of lower permeability with a higher groundwater table than the upland areas (Figure 3). Most of the upland areas in the SDWA are characterized by soils that are well to moderately well drained and depth to groundwater ranges from 4 to 6 feet during the irrigation season (Figures 4 and 5). The depth to water table information is from the USDA, Natural Resources Conservation Service *Soil Survey of San Joaquin County, California*. The soil survey shows that a large area of the SDWA where beans are grown has a year-round water table that varies in depth from 4 to 6 feet. The depth to the water table could be less than six feet during the growing season. The soil survey does not specify where within this range the water table is located during the growing season. This could vary from one year to another.

Of the nearly 150,000 acres within the SDWA, approximately 120,000 are in agricultural production. The remaining acreage includes urban lands, waterways, berms, channel islands, and levees. Staff in the Department of Water Resources' (DWR) Central District Office have periodically conducted land use surveys of San Joaquin County, most recently in 1982, 1988, and 1996. In the 1996 survey, field crops including alfalfa, grain, corn, beans, hay and pasture, accounted for nearly 70 percent of the agricultural production. Other crops grown within SDWA include permanent crops such as fruits, nuts, and vineyards as well as truck crops.

The southern Delta agricultural salinity objective of 0.7 EC, April through August, is implemented through water right Decision 1641 (D-1641). This objective was initially established in the 1978 Water Quality Control Plan for the Sacramento-San Joaquin River and Suisun March (1978 Bay/Delta Plan). It was based on guidelines from the University of California Agricultural Extension, and

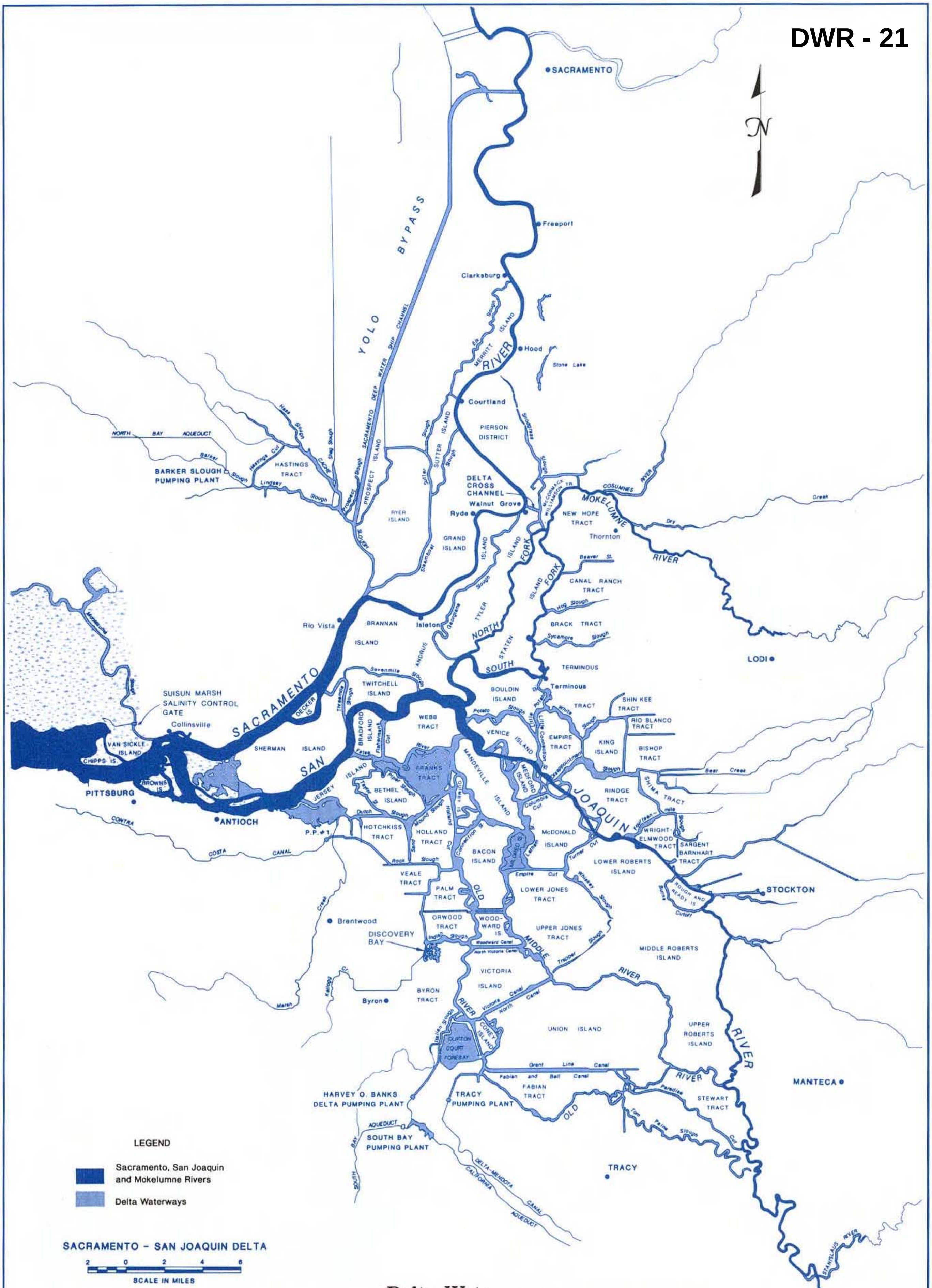
Irrigation and Drainage Paper 29 of the Food and Agriculture Organization of the United Nations (FAO)(Ayers and Westcot). The 0.7 EC objective is intended to be protective of beans which were determined to be an important salt sensitive crop grown in the southern Delta during the summer irrigation season (SWRCB WQCP, p. VI-19 (1978)).

At the time the 1978 Bay/Delta Plan was developed it was estimated that acreage planted in field beans had diminished to approximately 2,400 acres in the southern Delta, generally in the area receiving Delta-Mendota water (SWRCB WQCP, p. VI-18 (1978)). Delta-Mendota water is delivered to Plainview Irrigation District and Banta Carbona Irrigation District along a narrow strip adjacent to the southwest boundary of SDWA. This trend does not appear to have continued through the 1980’s and 1990’s. The net cropped acreage for beans grown in SDWA mapped in the 1982, 1988, and 1996, DWR land use surveys, were approximately 11,800, 7,600, and 8,700 acres, respectively. These acreages do not include acreage planted in beans for any land within the southern Delta outside SDWA, including the lands receiving Delta-Mendota water. The 1982, 1988, and 1996 acreages of beans represent an increase over the 2,400 acres reported at the time the 0.7 EC objective was established.

In the 1996 survey, beans were grown primarily in an area bounded by the San Joaquin River on the east and Old River on the north (Figure 6). The data collected in the 1988 land use survey of San Joaquin County showed a similar regional distribution of cropped acreage for beans (Figure 7). In general the mineral soils in this area have better drainage characteristics and a greater depth to groundwater than those in other parts of SDWA. This would tend to suggest that factors such as soil characteristics and depth to groundwater are a significant factor in cropping decisions.

Prior to adoption of D-1641 in December 1999, the agricultural salinity objective was not implemented. There was no specific water right permit conditions controlling salinity, as measured by EC, in the southern Delta. Other DWR testimony for this hearing has indicated that during the growing season for beans, the EC value in the south Delta channels has often been above the 0.7 EC. Since 1978 when the 0.7 EC objective was adopted in the WQCP, acreage planted to beans in SDWA has appeared to increase. This practical observation raises the question as to whether 0.7 EC is a necessary value to reasonably protect agricultural uses or if other factors, such as leaching fraction, soil type, permeability, depth to groundwater, annual rainfall, and general land management, have more important influences on crop yield than the quality of irrigation water, as long as it is within a reasonable range. DWR believes that SDWA has not provided evidence of yield decrement in beans to counter this observation and it is a fair assumption that existing conditions with water quality in the range of 0.7 to 1.0 EC have not adversely impacted the quantity of beans grown in SDWA.

DWR - 21

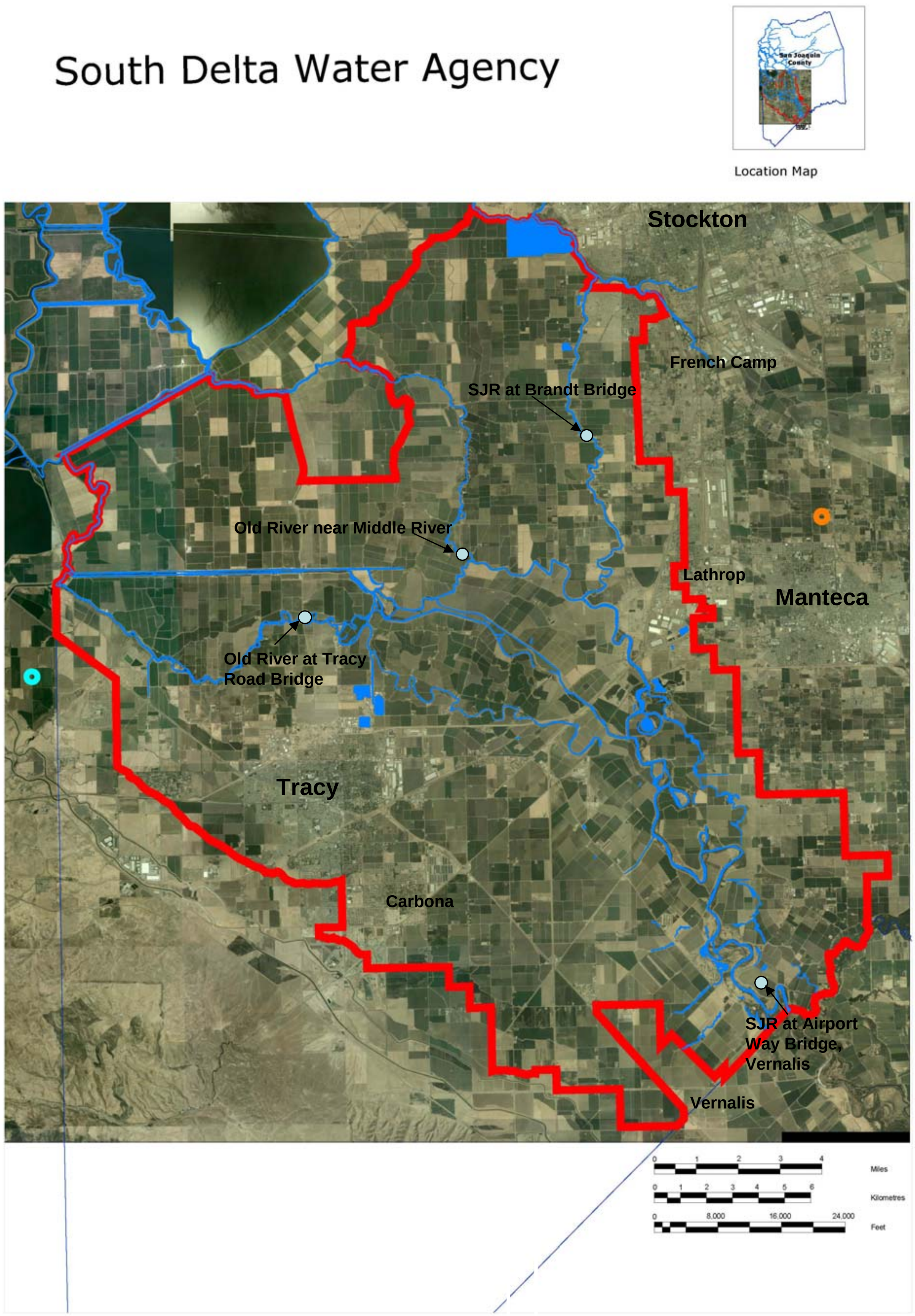


Delta Waterways

Figure 1

DWR - 21

South Delta Water Agency



Legend

- 🟥 South Delta Water Agency (DRAFT Boundary, subject to correction)
- — San Joaquin County Boundary
- ● Manteca CIMIS Weather Station
- ● Tracy Pumping Plant Weather Station
- ○ D1641 Compliance Monitoring Locations

July 2-3, 2004 Aerial Photo
USDA Farm Services Agency

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

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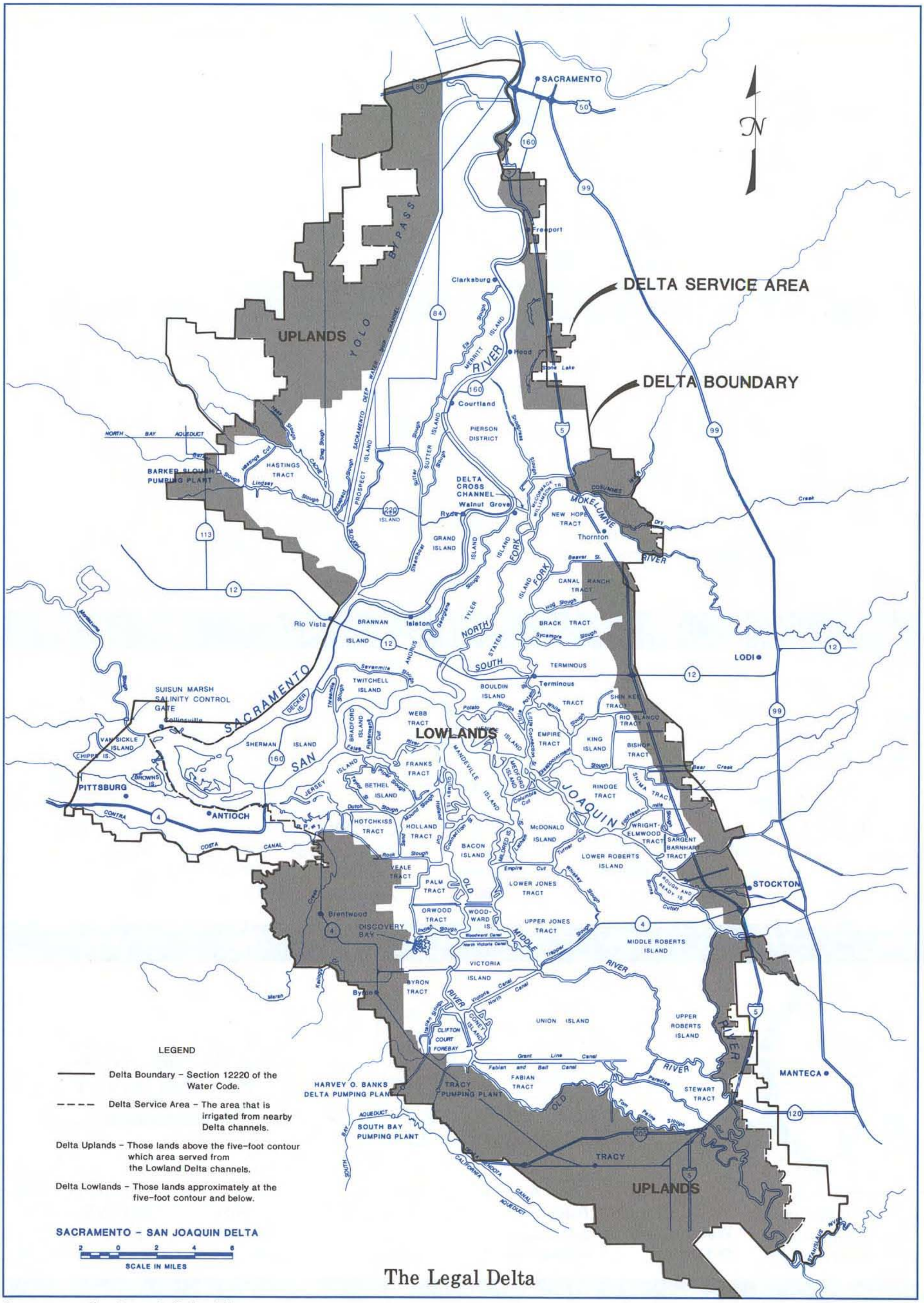
Figure 2



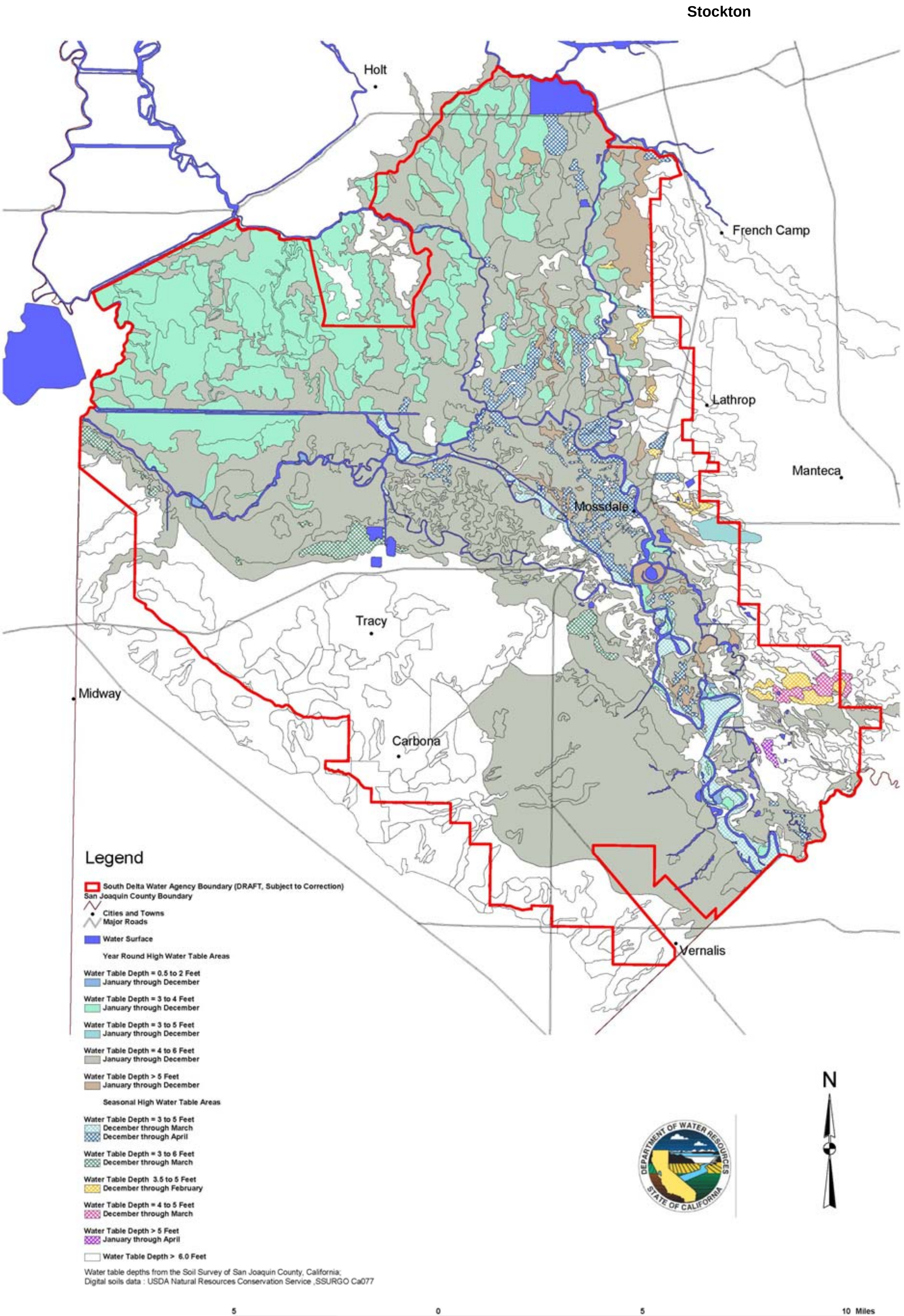
The Legal Delta

Sacramento–San Joaquin Delta Atlas *Department of Water Resources*

Figure 3

DWR - 21

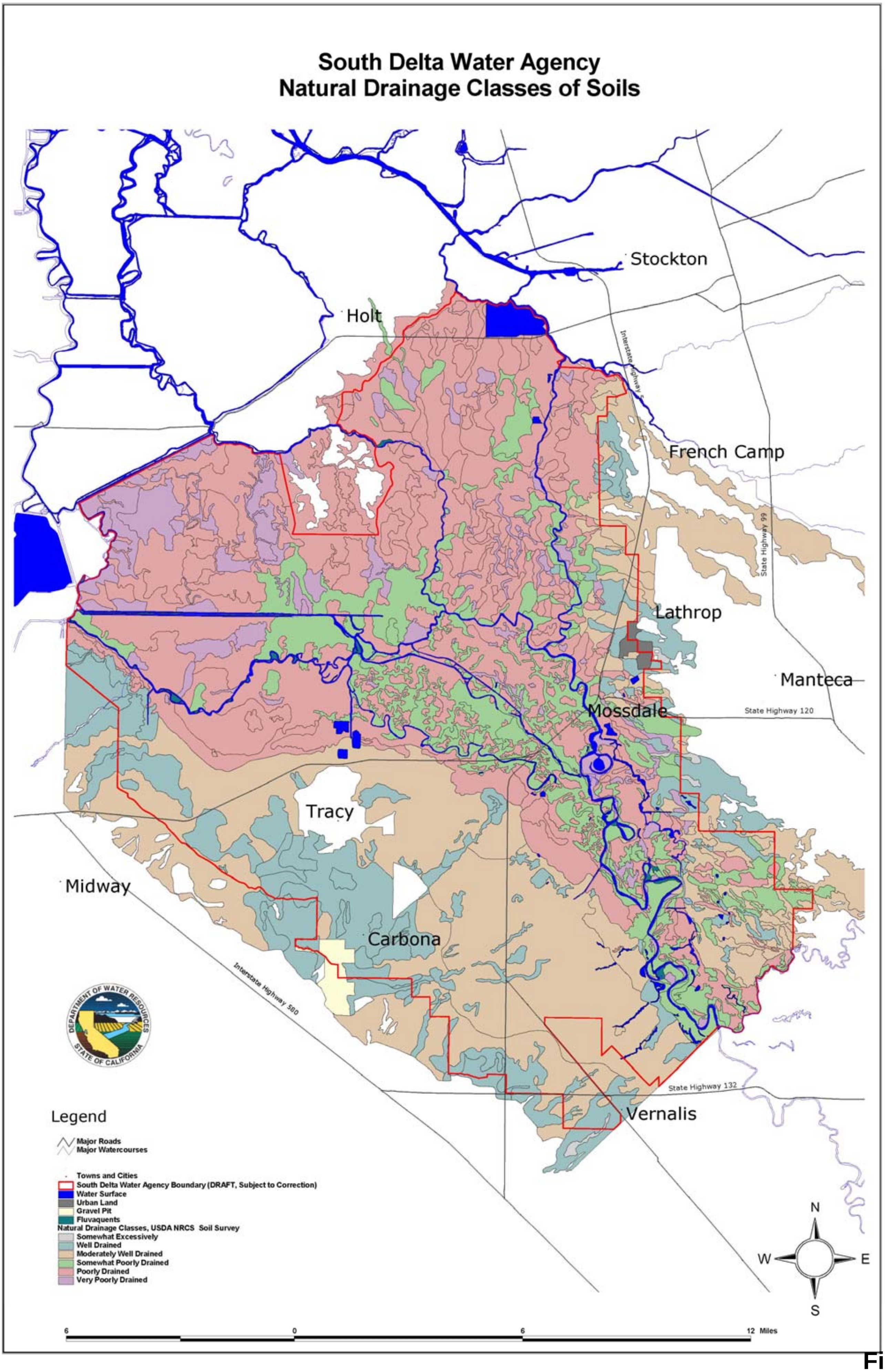
South Delta Water Agency
Depth to Water Table



Water table depths from the Soil Survey of San Joaquin County, California;
Digital soils data : USDA Natural Resources Conservation Service ,SSURGO Ca077

Figure 4

DWR - 21

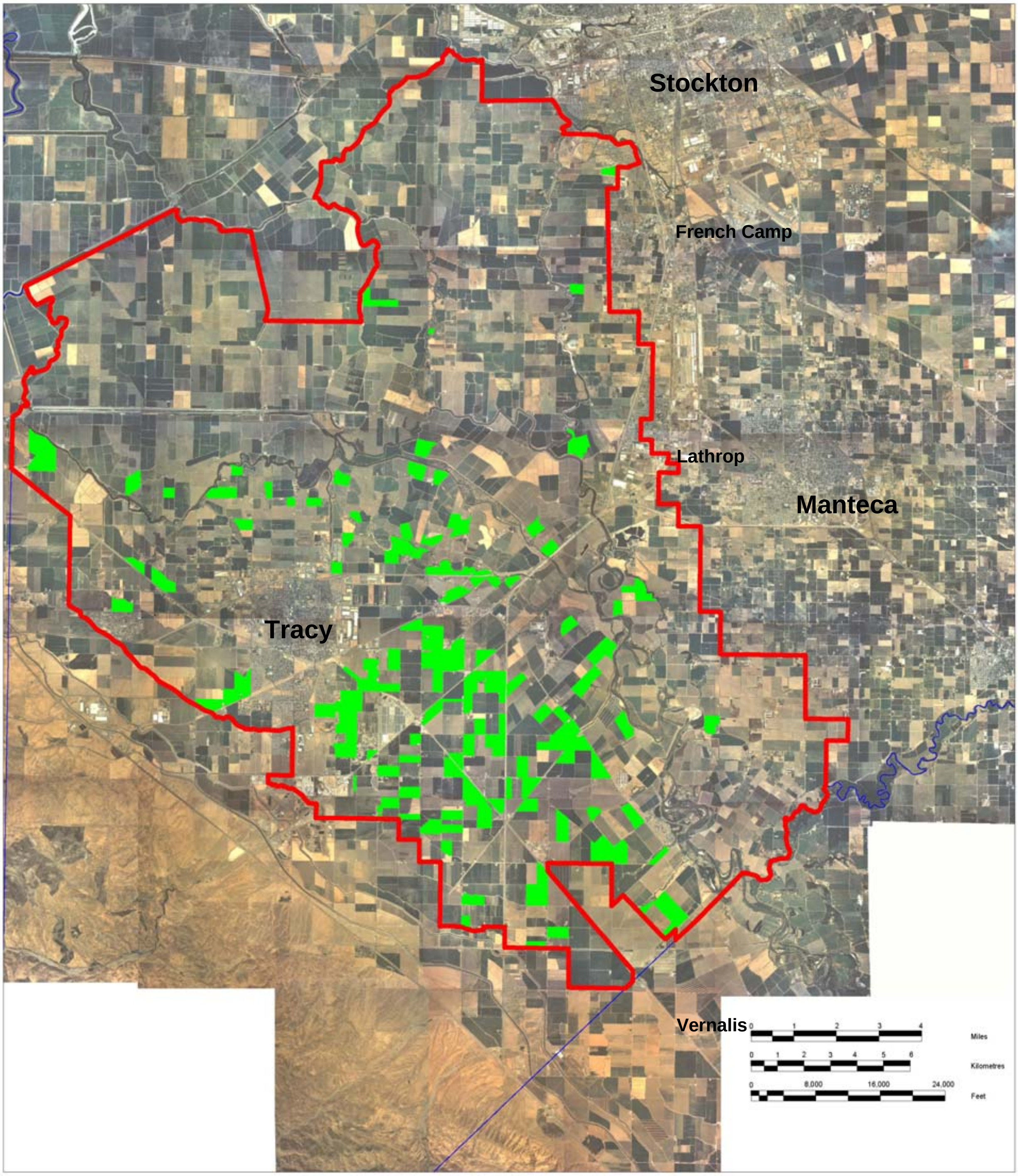


South Delta Water Agency
Natural Drainage Classes of Soils

Figure 5

South Delta Water Agency
1996 Land Use Survey
Bean Fields

Location Map



Legend

- 🟩 Beans Mapped in 1996 Land Use Survey of San Joaquin County
- — South Delta Water Agency Boundary (DRAFT, Subject to Correction)
- — San Joaquin County Boundary

Aerial Photo: June, 1996

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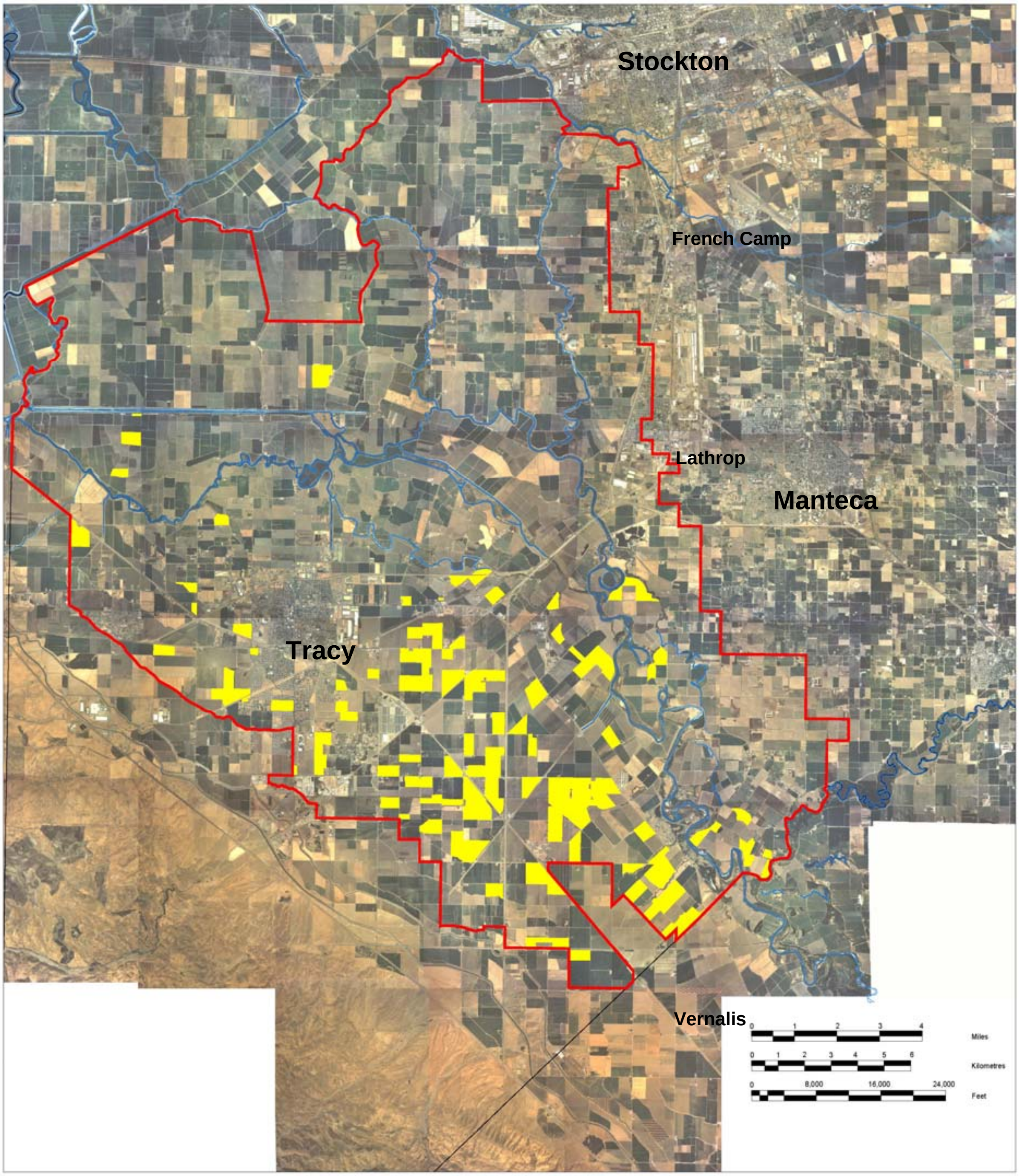
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

Figure 6

DWR - 21

South Delta Water Agency
1988 Land Use Survey
Bean Fields

Location Map



Legend

🟨 Beans Mapped in 1988 Land Use Survey of San Joaquin County
— South Delta Water Agency Boundary (DRAFT, Subject to Correction)
— San Joaquin County Boundary

Aerial Photo: June, 1996

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STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

Figure 7

DWR – 22 rev

Salinity Water Values that are Protective for Agricultural Crop Production

John Letey

October 14, 2005

Introduction

A greater understanding of the dynamic interaction between soil-water, salinity, and plant response has been achieved in recent years. My report will (1) provide a general description of salinity-plant interactions, (2) describe an approach to establish the value of irrigation water salinity that is protective of agricultural crops, (3) identify the rainfall contribution to partially mitigate the impact of water salinity on crop productivity, and (4) conclude that an EC value of 1.0 dS/m is protective of agricultural production.

General Salinity—Plant Interactions

The fact that salts (commonly referred to as salinity) or total dissolved solutes (TDS) in the water can be damaging to crop production has been known for centuries. Furthermore, it is well known that crops have different degrees of tolerance to TDS. The TDS in water is most quickly and easily quantified by measuring the electro-conductivity (EC) of the water. Therefore, the TDS or salinity of the water is usually reported as the EC of the water. For most waters the EC of 1 dS/m is equivalent to a TDS concentration of 640 mg/L. The following symbols will be used in this report. EC_{iw} is the EC of the irrigation water. EC_{sw} is the EC of the water in the soil. EC_e is the EC of the water in the soil when it is saturated with distilled water in the laboratory and extracted for measurement. EC_{sw} is approximately equal to 2 EC_e.

An index that reflects the sensitivity of a given crop to EC is important. Eugene Maas and Glenn Hoffman, scientists at the USDA Salinity Laboratory, found that research reports on crop growth related to EC_e could approximately be characterized by two straight lines as illustrated in Figure 1.

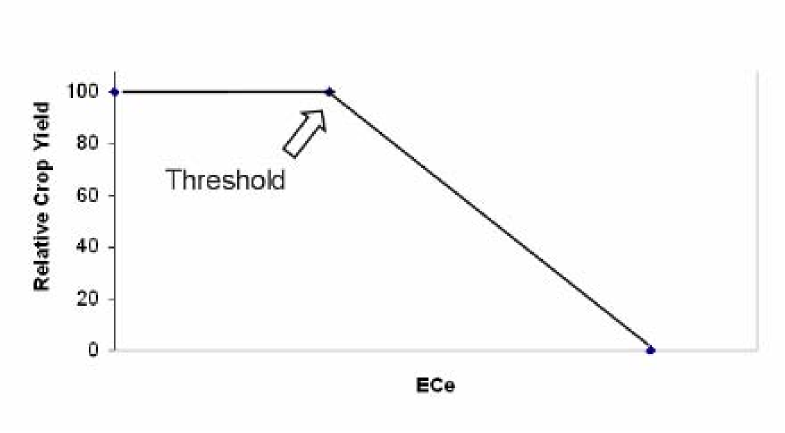


Figure 1. General relationship between relative crop yield and soil salinity.

One line is flat at maximum crop growth at all salinities up to a “threshold” number, but increasing the EC_e beyond this threshold causes a linear decrease in crop growth. The coefficients that would characterize crop tolerance to EC_e are the threshold value and the slope of the curve at values greater than the threshold value. These coefficients have been referred to as the Maas–Hoffmann coefficients and have been reported for numerous crops in various publications. The Maas-Hoffman coefficients for a few selected crops are presented in Table 1. The threshold EC_e of 1.0 dS/m reported for beans represents the lowest threshold EC_e of any vegetable or field crop that have been evaluated.

Table 1. Maas-Hoffman coefficients for some selected crops.

Crop	Threshold ECe dS/m	Slope % per dS/m
Alfalfa	2.0	7.3
Almonds	1.5	19.0
Asparagus	4.1	2.0
Beans	1.0	19.0
Corn	1.7	12.0
Cotton	7.7	5.2
Grapes	1.5	9.6
Tomatoes	2.5	9.9

All irrigation waters add salts as well as water to the soil. The plants extract water and leave most of the salts behind which concentrate in the soil solution. If the EC concentration exceeds the threshold value, some reduction in crop growth will occur. “Extra” water is applied to leach salts from the root zone to prevent their accumulation to detrimental concentrations. Typically the amount of water required depends on the crop tolerance to salinity and the EC of the irrigation water (EC_{iw}). This is the simple straightforward approach to the matter, and these general principles have been successfully used for years. However the quantitative assessment of irrigating with saline waters introduces some complex relationships between the plant and soil-water dynamics.

The long-term water balance equation is

$$AW = ET + DP$$

where AW is the applied water including precipitation that infiltrates the soil, ET is evapotranspiration, and DP is deep percolation (the water that moves below the root zone). The LF (leaching fraction) is defined as deep percolation divided by the applied water. I once assumed that if saline water was applied at amounts less than the amount of evapotranspiration, then there would be no deep percolation to wash the salts out of the root zone, and they would accumulate until they killed the plant. That would be a conclusion readily adopted from the water balance equation. However, I had overlooked another relationship that has been well-supported by research, and that is that evapotranspiration is not only a function of the climate, but also linearly related to plant growth. This reaction sets up a dynamic interaction between the crop and the soil-water system that affects the yield.

If the soil salinity reaches a level that reduces water uptake to a level less than potential transpiration, the leaf stomata close. Closure of the stomata decreases transpiration and preserves water in the leaf to prevent dehydration. Carbon dioxide which is essential for photosynthesis and plant production passes from the atmosphere through the stomata to the cell where photosynthesis occurs. Closure of the stomata decreases carbon dioxide supply to the leaf and consequently reduces photosynthesis and plant growth. This process represents a two-fold mechanism for plant survival. The plant reduces water loss and stops growing and thus reduces the transpiration demand that would occur with larger leaf surface area.

When evapotranspiration is reduced, deep percolation is increased, and the increased deep percolation leaches more salt from the root zone. This is one of nature’s additional protective mechanisms. During the crop-growing season, with irrigation and precipitation, the salt distribution is continuously changing with time and depth in the root zone. The plant naturally integrates all of these dynamic processes and provides “feedback” to the soil-water systems based on the plant growth as described above. This feedback, in turn, modifies the reactions occurring in the soil. The point is that some very complex interactions are occurring which impact the relationships between irrigating with saline waters and crop yield, and some of these relationships can be counter-intuitive.

The crop responds to the salinity in the soil-water surrounding the root (EC_{sw}), and the challenge is to relate EC_{sw} to the EC of the irrigation water (EC_i). The Maas-Hoffman coefficients are used to determine EC_{sw} thresholds for individual crops. (Note that the Maas-Hoffman coefficients are usually reported on EC_e rather than EC_{sw}.) If a reliable approach to relating EC_i to EC_{sw} or EC_e is developed, then the maximum EC in the irrigation water that will not result in a yield reduction can be established for specific crops based upon the Maas-Hoffman coefficients for that specific crop.

“As the soil dries, the plant is also exposed to a continually changing water availability in each portion of the rooting depth since the soil-water content and soil water salinity are both changing as the plant uses water between irrigations. The plant absorbs water, but most of the salt is excluded and left behind in the root zone in a shrinking volume of soil water. Figure 4 shows that following an irrigation, the soil salinity is not constant with depth. Following each irrigation, the soil-water content at each depth in the root zone is near maximum, and the concentration of dissolved salts near the minimum. Each changes, however, as water is used by the crop between irrigations” (Ayers and Westcot (1985)). Figure 4 depicts the measured soil-water salinity at the 40- and 80-cm depths as a function of time for irrigated alfalfa as reported by Rhoades. As described by Ayers and Westcot, the salinity at a given depth increases with time as the crop extracts the water. The irrigation leaches the accumulated salts out of the zone so that the soil salinity starts out at the same concentration after each irrigation, particularly in the upper part of the root zone where most of the roots are.

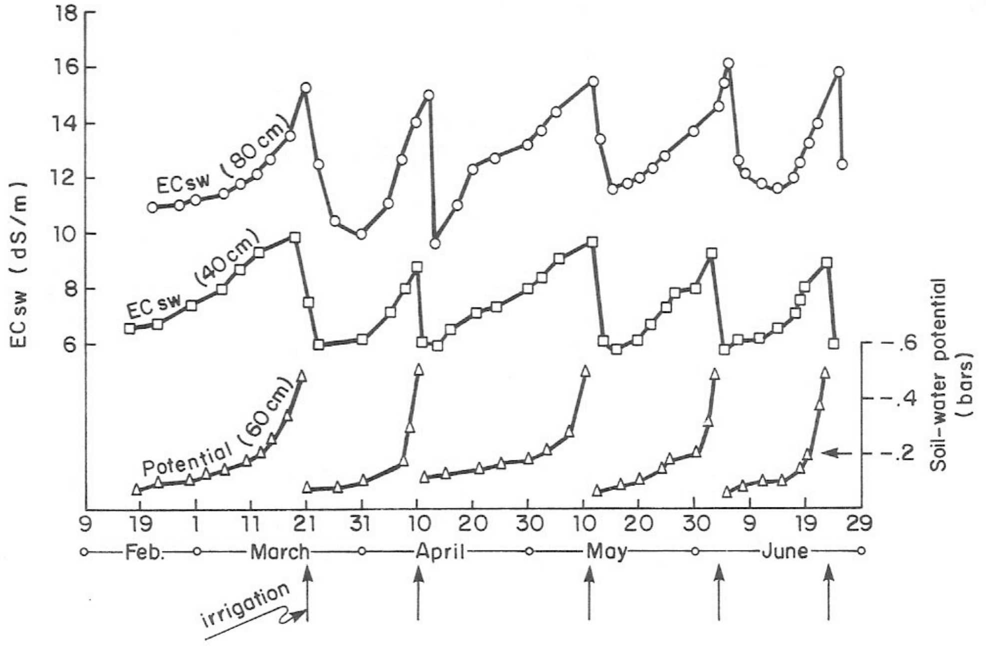


Fig. 4 Change in salinity of soil-water (EC_{sw}) between irrigations of alfalfa due to ET use of stored water (Rhoades 1972)

The magnitude of the salt concentration from immediately after irrigation to immediately before the next irrigation depends on the volumetric water content immediately after and before irrigation. The law of mass conservation dictates that the salt concentrates proportionately to the change in volumetric soil water content when there is no salt dissolution or precipitation. The change in volumetric water content between irrigation depends on the soil-water retention characteristics. For most soil types the volumetric soil water would decrease by less than half between irrigations. Consequently, the soil salinity would concentrate less than two times between irrigations. Therefore, it is logical that if one applies water at one-half the threshold value, the soil-water salinity will not concentrate beyond the threshold value before the next irrigation. For the example in Figure 4, the soil water salinity at the 40-cm depth increased in concentration by a factor of 1.7 between irrigations, which would be expected for many soils.

I would not recommend choosing 1.7 as the concentrating factor for two reasons. First, it leaves no margin for possibly having a soil with more extreme soil-water holding characteristics. Second, the salt transport is assumed to be completely efficient with no bypass. In other words, the soil solution will not be exactly the concentration of the irrigation water, thus a factor of two would be a more conservative approach.

By coincidence computing the irrigation water salinity that can be used to grow a crop with a given Maas-Hoffman threshold salinity is simple. The concentration of salts in the soil water increases by a factor of approximately two between irrigations. The Maas-Hoffman coefficients are based on the salinity of the saturated soil extract, or EC_e, which is approximately equal to ½ of the salinity of the soil-water, or EC_{sw}. Therefore, the irrigation water salinity that can be tolerated is equal to the Maas-Hoffman threshold value when they are reported as EC_e.

The most salt-sensitive crop grown in the area of interest is beans. The Maas-Hoffman threshold EC_e for beans is 1.0 dS/m. Therefore, an irrigation water as high as this value could be used without reduction in yield.

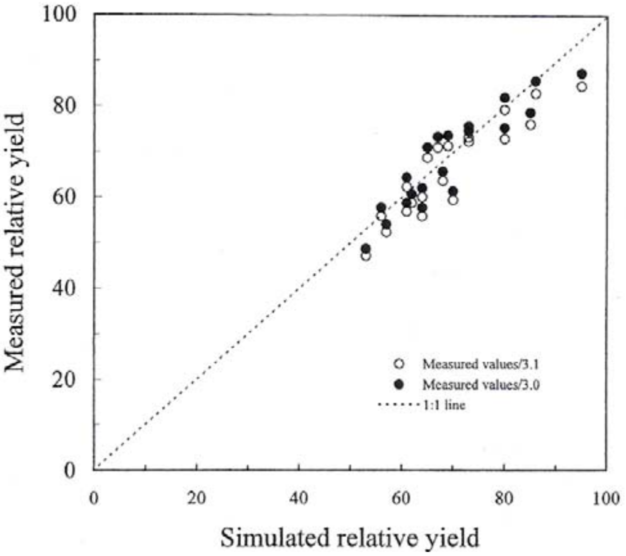
Contribution of rainfall toward reducing salinity effect

The analysis reported above neglected the effects of rainfall. Rain is almost pure water and therefore provides salt-free water to satisfy a portion of the crop need. The challenge is to quantify the contribution of rain towards partially mitigating the impacts of saline irrigation water.

I developed a model in 1985 (Letey et al. 1985) which allowed the computation of relative crop yield and amount of deep percolation based upon the amount and salinity of the applied irrigation water, crop tolerance to salinity, and the potential ET for a nonstressed crop. A comparison of model simulated results to experimental values was reported by Letey and Dinar (1986). One comparison was done with results from an experiment conducted in Utah, where snow and rain contributed to the crop water supply. The computed yields agreed quite well with the experimental yields when the weighted average EC of the rain and irrigation waters was used in the computations. Based on this, the contribution of rain can be estimated based on the weighted average EC of the combined rain and irrigation water.

Although the original seasonal model has great utility, it is limited to conditions where the same irrigation management and crop are continuously followed. Subsequently, I was involved in developing a transient-state model that allows incorporating the time, amount, and salinity of irrigation water applied. This model tracks the soil water content and water salinity as a function of depth and time and allows computation of relative crop yield and deep water percolation (Cardon and Letey, 1992; Pang and Letey, 1998). This model has much greater flexibility to simulate the consequences of a wide array of management practices. Excellent agreement between simulated relative yield and the measured relative yield for an experiment conducted on corn in Israel was achieved (Feng et al. 2003). Figure 3 of the Feng et al. (2003)

publication which illustrates the agreement between measured and simulated relative yields is reproduced below to document the validity of the model.



Comparison of measured and simulated relative yields assuming unstressed yield equal to 3.0 and 3.1 Mg ha^{-1}. (Figure 3, Feng et al. 2003).

The transient-state model can be used to simulate the effect of various cyclic and blending strategies for using non-saline and saline waters for irrigation (Bradford and Letey, 1993). In one case, the model was used to simulate mixing waters before irrigation or intermittently using waters of different qualities for the irrigation of the perennial crop alfalfa. The intermittent applications of saline and non-saline waters were done on alternate irrigations. The periods of use for each type of water varied, and the longest simulation was an annual use of non-saline water followed by an annual use of saline water. The same total amount of water and salts were added to the system in all simulations.

The main finding was that no significant difference in simulated yields occurred whether the waters were mixed prior to application, or were intermittently applied for different lengths of time. In other words, the crop response was to the integrated average EC of the waters regardless of when or how long the individual waters were applied. This result is consistent with Meiri et al. (1986) who conducted a three-year study in Israel to compare crop performance under mixing irrigation waters or intermittently applying them to the soil. They concluded that the crops responded to the weighted mean water salinity regardless of the blending method.

Therefore, both experimental evidence and theoretical model analyses come to the same conclusion. The crop responds to the weighted mean water salinity between rainfall and irrigation water. The amounts and concentrations of irrigation and rainwater that contribute to crop production, including the off-season water penetrating the soil, in addition to the in-season applications, must be included in the analysis such as was done in all of the reported studies.

With this information as background, one can now make quantitative estimates of the contribution of rain to partially mitigate the effects of salinity in the irrigation water in the area of interest. The weighted mean water salinity is calculated by equation 1

[Equation 1] $$C_a = \frac{C_i A_i}{A_i + A_r} \quad or \quad C_i = \frac{C_a (A_i + A_r)}{A_i}$$

where C_a is the weighted mean water salinity, C_i is the irrigation water salinity, A_r is the amount of rainfall, and A_i is the amount of irrigation.

The main uncertainty in making this computation is in properly accounting for the amount of rainfall that contributes to the crop water supply. As previously stated, rainfall during the off-season recharges the soil profile, leaches salts, and therefore contributes to the welfare of the crop.

Based on the factors stated above, I will now compute the contribution of rainfall towards the production of beans in the area of interest for three assumptions on the effective amount of precipitation. The assumptions are 25, 50, or 75% of the total precipitation contributed to the crop production.

The crop ET was calculated by multiplying the ET_o value from the nearest CIMIS station by the appropriate crop coefficient (K_{cr}). The numbers reported in Table 2 are for dry beans or large limas grown from May 1 to August 28. The average annual precipitation at the Tracy Pumping Plant based on a 55-year period of record is 12.24 inches. I will assume that 10% more water than crop ET is applied through a combination of irrigation and rain to accommodate some leaching. Thus, the ET times 1.1 equals 28.4 inches. The amount of irrigation (A_i) will equal 28.4 inches minus the effective precipitation, which will be calculated for 25, 50, and 75% times the total precipitation of 12.24 inches.

The results of these computations are presented in Table 3 for the three assumptions on the effective precipitation. The computed C_a value in the table represents the weighted average EC when the irrigation water salinity is 1.0 dS/m. The C_i number in the table represents the concentration of the irrigation water that could be used if the weighted average EC of the water equal to 1.0 dS/m is protective for producing beans. These calculations were done to illustrate that rainfall can significantly mitigate the impact of irrigation water salinity. If only 25% of the precipitation was effective, an irrigation water salinity of 1.12 rather than 1.0 dS/m could be used without impacting the most salt-sensitive crop.

Table 2. Computed crop ET for beans

	K_{cr}	ET_o in/mo	ET in/mo
May	0.40	6.45	2.58
June	0.97	7.45	7.23
July	1.15	8.02	9.22
Aug	0.96	7.11	6.82
Total			25.85

Table 3. Computed contributions of rainfall to partially mitigating the effects of salty irrigation water.

$A_i + A_r$	A_r	A_i	C_a[1]	C_i[2]
28.4	3.1	25.3	0.89	1.12
28.4	6.1	22.3	0.78	1.28
28.4	9.2	19.2	0.68	1.47

1. Calculation of C_a (weighted mean water salinity) from equation 1 if C_i is 1.0 dS/m.
2. Calculation of C_i (irrigation water salinity) from equation 1 of C_a equal to 1 was adequate crop protection.

Experimental results and the results from theoretical model analyses all come to the same conclusion--that irrigation water with an EC of 1.0 dS/m or slightly higher would be sufficiently protective for the most salt-sensitive crops. Nevertheless, the conclusion should be compared as much as possible to what is actually happening under real farming operations. Equally salt-sensitive crops are being successfully grown in the Coachella and Imperial Valleys of California when irrigated with Colorado River water. The EC of the Colorado River water is approximately 1.25 dS/m. Furthermore, precipitation contributes almost nothing to the crop water demand in these valleys.

Based on all of this documented evidence, I confidently conclude that an irrigation water concentration of 1.0 dS/m is sufficiently protective for even the most salt-sensitive crops.

Conclusions

The most salt-sensitive agricultural crops have a threshold salinity of 1.0 dS/m. Based on the dynamics of water flow, salt transport, and crop-soil water interactions, an irrigation water with an EC of 1.0 dS/m is sufficiently protective of salt-sensitive crops and can be used to irrigate these crops without yield reduction. The contribution of rainfall provides an added margin of safety to this conclusion. Finally, this conclusion is consistent with experience in the Imperial and Coachella Valleys of California, where the salt sensitive crops are being successfully irrigated with Colorado River water with an EC of approximately 1.25 dS/m.

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