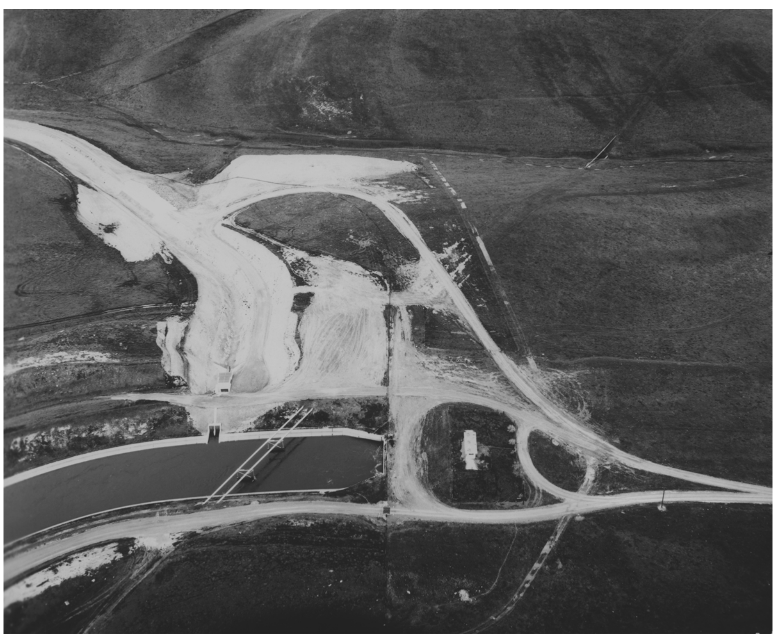
Factors Affecting the Composition & Salinity of Exports from the South Sacramento-San Joaquin Delta

Memorandum Report
February 2004

State of California
The Resources Agency
Department of Water Resources
Division of Operations and Maintenance
Environmental Assessment Branch

The intake of the California Aqueduct at Italian Slough (center bottom) prior to the creation of the Clifton Court Forebay (circa 1967). Note Bethany Forebay (upper center) before it was enlarged and renamed Bethany Reservoir.



Intake of the State's South Bay Aqueduct at the Headworks of Tracy Pumping Plant on the Delta Mendota Canal (circa 1962). Water was conveyed west and pumped into Bethany Forebay.

Cover: Satellite photograph of the south Delta, circa 1991.

State Water Project of California Department of Water Resources The Resources Agency

OFFICE MEMO

TO: Dan Peterson	DATE: February 25, 2004
FROM: Barry Montoya, Staff Environmental Scientist	SUBJECT: Memo Report: **Factors Affecting the Composition and Salinity of Exports from the South Sacramento-San Joaquin Delta**

Summary

The goal of this report is to identify factors affecting the composition and salinity of exports from the south Sacramento-San Joaquin Delta. Composition is defined here as sources of salt such as rivers and seawater. Specific objectives are to

- identify factors determining the export of cross-Delta flow versus the San Joaquin River – the two immediate sources of water flowing to the State Water Project (SWP) and Central Valley Project (CVP) export sites in the south Delta; and
- identify long-term salinity trends in SWP exports and factors affecting them.

Factors Affecting Export Composition

Cross-Delta flow is predominantly low-salinity water from the Sacramento River that picks up salt as it flows through the Delta to the export sites. The two export sites are located at the Clifton Court Forebay (CCF) gates and Tracy Pumping Plant (Tracy). The other immediate source of water is the San Joaquin River flowing directly to the export sites via south Old River and Grant Line Canal. Several factors determine which is exported.

High San Joaquin River Flow

- When San Joaquin River flow was above ~3,400 cfs, water at Tracy was mostly from the San Joaquin River with little or no influence from cross-Delta flow. This can occur 48 percent of the time during the first half of any given year and 18 percent during the second half.

- When San Joaquin River flow was above ~7,400 cfs, water at the CCF gates was mostly from the San Joaquin River with little or no influence from cross-Delta flow. This can occur 27 percent of the time during the first half of any given year and 5 percent during the second half.

Tide

- The composition of water at the export sites can oscillate between cross-Delta flow, the San Joaquin, or a mixture of both on an hourly basis. San Joaquin water is drawn to the export sites during ebb tide and pushed back by cross-Delta flow during flood tide. Since the San Joaquin typically exhibits a higher salinity than cross-Delta flow, it was usually responsible for the crests of the resulting conductivity oscillations.

- When these oscillations are occurring, the composition and salinity of water at the CCF gates and Tracy depends on the time of day. These oscillations continued down the Delta-Mendota Canal; therefore, the composition and salinity of inputs to O'Neill Forebay from the Delta-Mendota Canal would also depend on time of day when these oscillations are occurring.

- Factors affecting these oscillations included certain south Delta temporary barriers, San Joaquin flow, and total export rate.

- These oscillations were more common at Tracy than at the CCF gates. One consequence of this was that CVP exports usually exhibited a higher salinity than SWP exports.

Clifton Court Forebay

- Conductivity between the CCF gates and Banks was significantly different (higher or lower) during roughly half of the months between 1990 and 2002, possibly due to gate operations. For most other months, there was no statistical difference in conductivity between these stations.

- Sump pumps around CCF are high in salt and can increase salinity at Banks during infrequent periods when exports are low and local rainfall is high. The sump discharges are relatively insignificant but could erroneously portray water in the south Delta as having elevated salinity when exports are low and local rainfall is high.

- When pumping at Banks decreases, residence time through CCF increases. As a result, water pumped into the Aqueduct can be a composite of water admitted to CCF from the south Delta over a period of days or weeks. Low-salinity water that can accompany high flow conditions in the south Delta during the winter and spring may not be immediately reflected at Banks. Longer residence times are most likely during late winter and early spring when pumping at Banks has been historically lowest.

Delta Cross Channel Gates

Conductivity at Banks was roughly correlated with total Delta inflow (from Dayflow) when the Delta Cross Channel gates were left open. Gates are typically left open from June 15 to October.

Long-Term Salinity Trends

Annual conductivity at Banks

- was well correlated with water year indices for the Sacramento and San Joaquin Rivers;
- has varied by about 370 µS/cm between any given year (excluding 1977); and
- has neither increased nor decreased over the last 33 years.

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1. Introduction

Objectives

The goal of this report is to identify factors affecting the composition and salinity of exports from the south Sacramento-San Joaquin Delta. Composition is defined here as sources of salt such as rivers and seawater.

The individual objectives are to

(1) review south Delta export composition studies;
(2) describe salinity trends in cross-Delta flow and the San Joaquin River – the two immediate sources of water flowing to the SWP and CVP export sites in the south Delta;
(3) identify factors determining the export of cross-Delta flow versus the San Joaquin River; and
(4) describe long-term salinity trends in SWP exports from the south Delta and factors affecting them.

This study relied heavily on the Department of Water Resources' (DWR) water quality monitoring programs. The Division of Operations and Maintenance has been monitoring SWP exports from the south Delta since 1962. In 1982, DWR's Municipal Water Quality Investigations Program began routine water quality monitoring throughout the Delta. Further, the "Data Vaults" on the Interagency Ecological Program's Web site made a vast array of historical data easily accessible. Data from other sources such as the U.S. Geological Survey and the Bureau of Reclamation were also used.

Problem Description

Salinity is a concern to SWP municipal water supply contractors (Bookman-Edmonston Engineering, Inc. 1999). Salinity in municipal drinking water causes several problems. Salinity

(1) corrodes plumbing and home appliances;
(2) produces an undesirable taste in potable water at sufficiently high levels;
(3) prohibits the use of recycled water for groundwater recharge or crop irrigation when the cycling of potable water for residential, commercial, or industrial uses concentrates salinity to elevated levels;
(4) reduces the effectiveness of laundry detergents due to the presence of calcium and magnesium; and
(5) can be directly correlated with bromide, an element that is associated with unwanted disinfection by-products.

The Metropolitan Water District of Southern California established a blending program to reduce salt in its municipal water supply. SWP water from the East Branch of the California Aqueduct is blended with higher salinity water from the Colorado River to achieve a total dissolved solids goal of 500 mg/L – the secondary Maximum Contaminant Level for drinking water. Achieving this goal is problematic because salinity in the California Aqueduct is variable. Further, when salinity increases, costs to produce drinking water can go up along with possible losses in water supply.[1] Salinity reductions and forecasting capabilities are desired to help with the blending program.

Although salinity can also cause problems for agriculture, conductivity in the California Aqueduct rarely approaches levels known to affect crops in the San Joaquin Valley, where water from the Aqueduct can be used for irrigation. Over 70 percent of the crops irrigated in the San Joaquin Valley are capable of tolerating

1 Aqueduct blending issues are detailed in Bookman-Edmonston Engineering, Inc., 1999.

salinities ranging from 1,500 µS/cm (almond/pistachios) to 7,700 µS/cm (cotton) before yield begins to decline (DWR 1998b, Maas 1984). The remaining 30 percent of irrigated crops in the San Joaquin Valley not specifically identified in DWR 1998b were lumped into broad categories such as "other truck" or "other field." Regardless of the potential for these crops to be more salt-sensitive, the least salt tolerant plants identified in Maas 1984 (strawberries, carrots, and turnips) began showing a decrease in yield when conductivity reached 1,000 µS/cm. This threshold has rarely been exceeded in SWP exports. The exception was during the last 6 months of 1977 when conductivity at Banks ranged from 1,000 to 1,300 µS/cm. This was an isolated event and the only year when conductivity at Banks exceeded 1,000 µS/cm. Therefore, conductivity in SWP exports has rarely been above levels that cause problems for salt-sensitive plants.

One component of salinity that is especially harmful to plants is the trace mineral boron. Boron is needed by plants in small amounts but levels above 1 mg/L in irrigation water can be toxic to boron-sensitive plants such as citrus trees (Hem 1985). Boron levels in SWP exports typically range between 0.1 and 0.3 mg/L, well below this toxic level. Irrigation water with boron levels below 0.33 mg/L is considered to be "excellent" for boron-sensitive plants (USSLS 1954).

Exports by the CVP at Tracy Pumping Plant were included because of their influence on the Aqueduct further downstream. Water from the CVP's Delta-Mendota Canal can be pumped into the joint-use stretch of the California Aqueduct at O'Neill Forebay. These inputs are significant and have contributed a majority of the salt load to the California Aqueduct (DWR 2001).

2. Background

Mineralogy and Salinity

Salinity is the combined influence from dissolved minerals such as the positively charged cations calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), and the negatively charged anions sulfate (SO_4), chloride (Cl), and bicarbonate (HCO_3). The sum of these electrolytes determines the salinity of natural waters.

Two major sources of high salt in exports – the San Joaquin River and seawater from San Francisco Bay – exhibit different mineralogies.[2] In seawater, the chloride/sulfate ratio is 7, while in the San Joaquin, this ratio averages around 1. Therefore, chloride makes up more of the anionic content in seawater than sulfate, and in the San Joaquin, chloride and sulfate are, on average, equal in terms of their concentration (the 99 percent confidence interval of the chloride/sulfate ratio in the San Joaquin was 0.57 to 1.4).

To further discern the mineralogical differences between these two major sources of salt, water from the San Joaquin and seawater was diluted with water from the Sacramento River.[3] In the dilutions of the Sacramento and San Joaquin, the anionic components sulfate and chloride increased with increasing percentages of San Joaquin water (Figure 1). The average mineralogy of Salt Slough was also shown in Figure 1 because of its influence on the San Joaquin. In the Sacramento/seawater dilutions, the anionic content increased in chloride and decreased in sulfate with increasing percentages of seawater. All samples collected at Banks and Tracy exhibited anionic characteristics that generally fell within the boundary of the dilution points presented in Figure 1.

These dilution data also illustrate the difference between volumetric percentages of water versus gravimetric percentages of salt. Small volumes of seawater contributed disproportionately to the salt content of the Sacramento/seawater dilutions. Seawater accounted for 24 percent of the salt content in the 0.1 percent dilution with Sacramento water (Figure 2A). In the 2 percent dilution, seawater accounted for 83 percent of the salt content. Note that in this dilution, chloride made up about 82 percent of the total anionic content (see Figure 1). Chloride at Banks has never exceeded 80 percent of the total anionic content, indicating that seawater, or water with seawater-like characteristics, has never volumetrically composed more than 2 percent of SWP exports.

The San Joaquin accounted for 17 percent of the salt content in the 5 percent dilution with Sacramento water and 61 percent of the salt content in the 20 percent dilution (Figure 2B). In this last dilution, the San Joaquin contributed a majority of the salt while composing only a fifth of the volume. San Joaquin mineralogy can change dramatically, so these numbers will depend on specific conditions in that river. Mineralogy in the Sacramento is not as variable, so specific conditions in that river are not as important for these analyses.

The preceding analysis illustrates how mineralogy can be used to identify salt sources. The position of the anionic marker on a ternary diagram or Piper graph could estimate composition with respect to seawater, the San Joaquin, and the Sacramento. Figure 3 shows the anionic content of various mixtures of these waters

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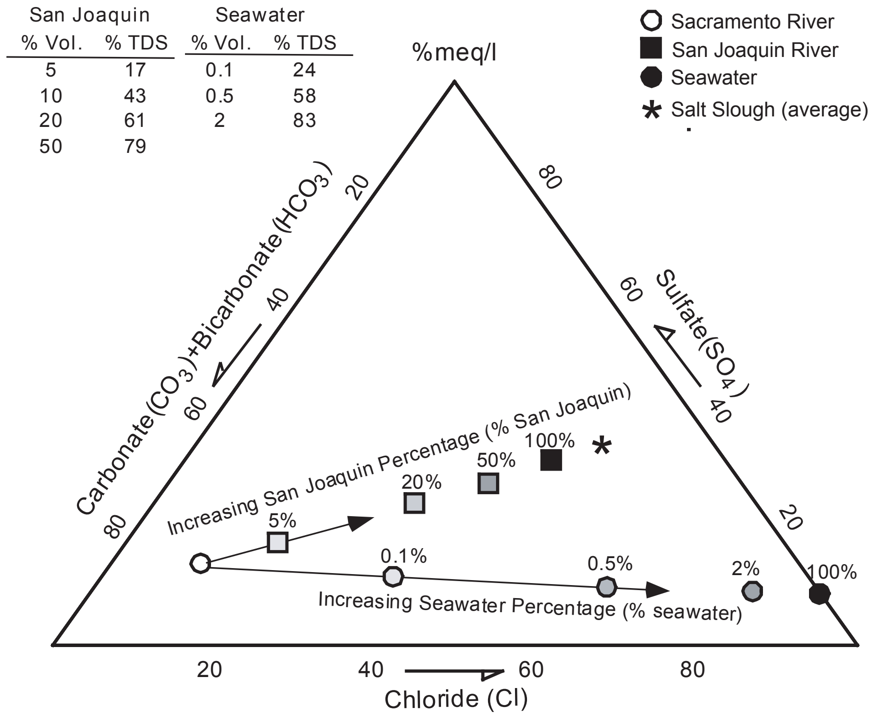
2 Other sources such as Delta island drainage also influence export mineralogy (DWR 1990, Brown and Caldwell 1995). However, the mineralogy of these discharges can reflect that of diluted seawater or the San Joaquin River (DWR 1994). This is because the salt content is sometimes a direct consequence of water applied to the islands for irrigation (DWR 2001).

3 Samples collected in the fall of 2000.



San Joaquin % Vol.	San Joaquin % TDS	Seawater % Vol.	Seawater % TDS
5	17	0.1	24
10	43	0.5	58
20	61	2	83
50	79		

Figure 1. *Anionic content of Sacramento River water mixed with various amounts of water from the San Joaquin River and seawater (see Appendix B for an explanation of a ternary diagram and Piper graph). Percentages in the figure represent increasing volumes of seawater and San Joaquin River water diluted with water from the Sacramento River. The table in the upper left hand corner shows the volumetric and gravimetric percentages of these dilutions. Gravimetric percentages are represented as percent of Total Dissolved Solids (% TDS).*

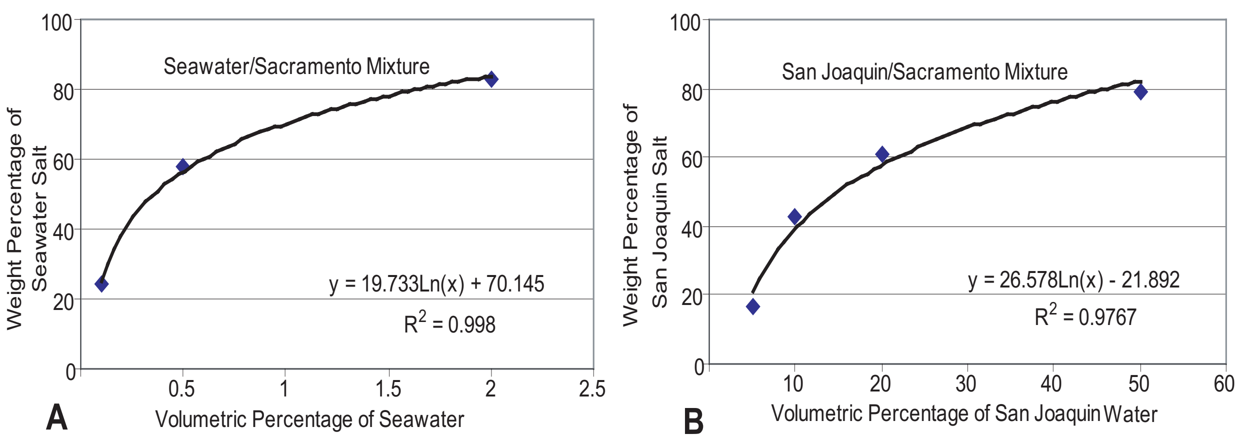


Figure 2. *Relationship between the volumetric content of San Joaquin River water and seawater diluted with Sacramento River water versus the gravimetric percentages of salt in these dilutions.* **2A** *shows 0.1, 0.5, and 2 percent seawater diluted with Sacramento River water. Data used in these dilutions were collected in the fall of 2000;* **2B** *shows volumetric dilutions of 5, 10, 20, and 50 percent San Joaquin River water with Sacramento River water.*

calculated from the previous dilution data. The black and white circles show calculated dilutions (volumetric) of 0.02-0.73 percent seawater, 12-68 percent San Joaquin water, and the remainder Sacramento water. The black and white boxes show calculated dilutions of 0.02-1.7 percent seawater, 0.03-49 percent San Joaquin water, and the remainder Sacramento water. As stated before, San Joaquin mineralogy is variable, so the accuracy of this method would rely on recent mineral data. Further, this type of analysis does not specifically identify influence from other sources of salt such as Delta island drainage.

The slope of the conductivity/sulfate line is another technique that can be used to differentiate influence from seawater versus the San Joaquin. Using the previous dilution data, the linear slope of conductivity with sulfate in the Sacramento/San Joaquin dilutions was 0.14, while in the Sacramento/seawater dilutions, it was 0.04 (Figure 4A). A greater slope indicates more influence from the San Joaquin (or waters with a similar mineralogy) than seawater, and vice versa. This relationship is evident at Banks where the conductivity/sulfate relationship is widely dispersed, suggesting influence from both sources (Figure 4B). The mineralogical associations presented above were used to identify factors affecting salinity trends in south Delta exports. In this report, conductivity rather

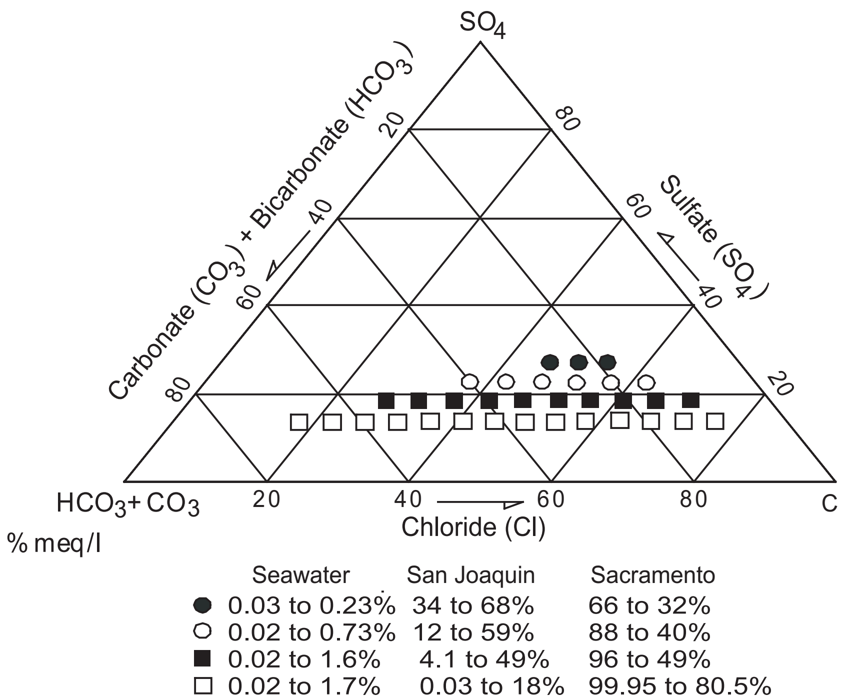


Figure 3. *Anionic content of various mixtures of water from the Sacramento River, San Joaquin River, and seawater. The percentages at the bottom indicate how much water from each source is represented by the rows of icons. See Appendix B for an explanation of a ternary diagram.*

than total dissolved solids (TDS) was used to represent salinity. The method for measuring conductivity has not changed since its inception. As long as the meter is properly calibrated, there is little potential to introduce variability. This is not always the case for TDS (see documentation in Appendix A). A rough estimate of TDS can be obtained by multiplying conductivity by 0.6.

Conductivity has historically been termed specific conductance in units of micromhos/cm (e.g., the Maximum Contaminant Level for this parameter is listed as such). However, both the term and units have changed. In the late 1980s, the Committee on the International System of Units changed the units from micromhos to micro Siemens; they are numerically equivalent. In 1991, the Standard Methods Committee approved the term conductivity over specific conductance (Anonymous 1995). Therefore, conductivity will be used consistently in this report to represent salinity in units of micro Siemens per centimeter, or µS/cm.

State Water Project Operations

The SWP currently operates in accordance with the State Water Resources Control Board's Decision 1641 (D-1641), adopted in 1999, which contains water quality, flow, and operational criteria for exports from the south Sacramento-San Joaquin Delta. SWP operations are coordinated with those of the CVP as specified in the 1986 Coordinated Operations Agreement to balance total exports with Delta flow and fishery needs. Criteria contained within D-1641 are conditioned by water year type, generally becoming less stringent during water years with less precipitation. SWP and CVP operations are also

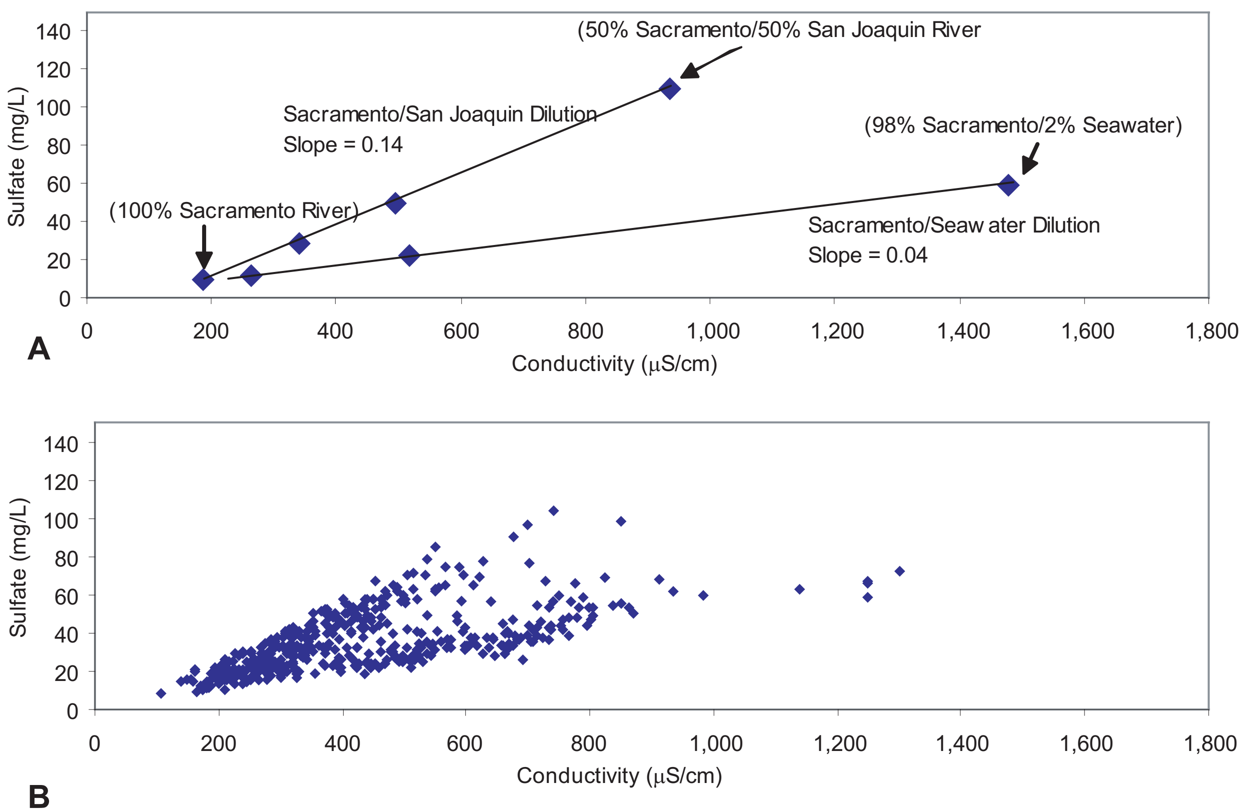


Figure 4. 4A *shows the relationship between conductivity and sulfate in dilutions with water from the Sacramento River, San Joaquin River, and seawater;* **4B** *shows the same relationship with data collected at Banks Pumping Plant.*

directed by various objectives of the 1995 Bay-Delta Plan, Central Valley Improvement Act, San Joaquin River Agreement, California Bay-Delta Authority (CALFED), and biological opinions for fish species listed under State and federal endangered species acts. In addition, an Environmental Water Account is maintained for the protection of listed fish species as mandated under CALFED's Record of Decision and coordinated by DWR, the Bureau, Department of Fish and Game, and U.S. Fish and Wildlife Service. Lastly, a U.S. Army Corps of Engineers Section 10 permit under the River and Harbor Act of 1899 requires the SWP to maintain the navigability of waters in the south Delta by restricting exports if necessary.

3. Review of Export Composition

Modeling Studies

Models have been used to estimate export composition under a variety of conditions (DWR and USBR 1990, ENTRIX, Inc., and Resource Insights 1996). One particular modeling run estimated export composition for a critical water year (Orlob 1991).[4] CVP exports were composed of 12 percent San Joaquin water and 60 percent Sacramento water in July of a critical water year (Table 1). The remainder was made up by tidal boundary (17 percent) and in-Delta agriculture return flow (11 percent). For SWP exports during the same month and water year type, the composition was 1 percent San Joaquin water and 68 percent Sacramento water followed by tidal boundary (bay water) and in-Delta agriculture. Export composition was also estimated for May and September of a critical year. For May, CVP/SWP exports were 34/2 percent San Joaquin water and 43/67 percent Sacramento water, respectively. For September, CVP/SWP exports were 30/1 percent San Joaquin water and 52/73 percent Sacramento water, respectively. San Francisco Bay water and in-Delta agriculture made up the rest. In all of these runs, the San Joaquin composed 2 percent or less of SWP exports.

More recently, DWR's Delta Simulation Model estimated that from May to October 1996 (a wet year), the San Joaquin accounted for 48 percent of the conductivity in SWP exports and the Sacramento, 31 percent (DWR 2001). Tidal boundary water and in-Delta agricultural discharges made up the remainder (5 and 13 percent, respectively).

[4] Export composition from the Sacramento River, San Joaquin River, tidal boundary (seawater intrusion), and in-Delta agriculture was estimated without south Delta barriers.

Water Quality Studies

Other methods have been used to determine export composition. On March 2 1989, selenium was 6 µg/L in the lower San Joaquin and <1 µg/L in cross-Delta flow[5] just north of the export sites (DWR 1990a). On the same day, selenium was <1 µg/L in both SWP and CVP exports. Consequently, exports were thought to be largely from cross-Delta flow with less-than-detectable influence from the San Joaquin flowing to the export sites via Grant Line Canal and south Old River (DWR 1990). Four months later, using mineral data such as chloride, sulfate, etc., it was estimated that SWP exports contained mostly cross-Delta flow while CVP exports were a mixture of cross-Delta flow and San Joaquin River water. This same observation was made in 1990 using chloride and bromide levels (CUWA 1995).

These water quality studies used a particular point in time and a particular indicator to fingerprint export composition. The concept is similar to a tracer dye study but uses minerals as a tracer and is capable of tracking more than one source. This concept was used to expand the understanding of export composition with respect to cross-Delta flow and the San Joaquin. A review of salinity trends in cross-Delta flow and the San Joaquin is presented first.

[5] Cross-Delta flow is defined here as water from Old and Middle Rivers that merge into West Canal, just north of the export sites.

Table 1. Estimated Export Composition Percentages[1] in a Critical Water Year Type[2]

Source	May		July		September	
	CVP	*SWP*	*CVP*	*SWP*	*CVP*	*SWP*
San Joaquin River	34	2	12	1	30	1
Sacramento River	43	67	60	68	52	73
Seawater Intrusion	13	21	17	20	14	20
Delta Agriculture	10	11	11	11	4	6

[1]Percent of total
[2]from Orlob, 1991

4. Salinity in Cross-Delta Flow and the San Joaquin River

Most of the data presented in this report was collected from stations identified in Figure 5.

Cross-Delta Flow

Cross-Delta flow is water from the central Delta that approaches the export sites from the north. It is predominantly low-salinity water from the Sacramento that picks up salt as it moves through the Delta (Figure 5). Sources of salt can include the San Joaquin River, in-Delta agriculture, and seawater from the San Francisco Bay. When this flow reaches Old and Middle Rivers, just north of the export sites, the conductivity isignificantly higher ($p<0.005$) than in the Sacramento River (Figure 6).[6] Conductivity in cross-Delta flow (Old and Middle Rivers combined) just north of the export sites averaged around 400 µS/cm, roughly two-and-a-half times higher than the Sacramento River average of 160 µS/cm. Conductivity in Old and Middle Rivers was usually above 200 µS/cm, while in the Sacramento it was usually below 200 µS/cm. Therefore, cross-Delta flow can have a completely different mineralogy than the Sacramento as exhibited by conductivity.

A test using same-day data[7] indicated that Old River had a statistically higher conductivity than Middle River ($p<0.001$). This difference was more apparent when looking at seasonal trends.

Conductivity in Old River, just north of the export sites, was generally highest during fall and early winter. Monthly averages ranged from 517 to 601 µS/cm during October through February and from 364 to 457 µS/cm during the other months (Figure 7). Conductivity in Old River was lowest and least variable during March through May, overlapping a period when pumping at Banks has been historically lowest (discussed later). For Middle River, monthly conductivity trends were less distinct; however, variability within and between months was lower than in Old River. Further, similar to Old River, levels in Middle River exhibited an increase during October through December.

Water from Middle River can flow to the export sites via Victoria Canal.[8] Victoria Canal and Old River meet at West Canal, the main channel that conveys water from the western and central Delta to the export sites. When water in West Canal moves south towards the SWP and CVP export sites, it can mix with, or displace water from, the San Joaquin flowing west to the export sites via south Old River and Grant Line Canal.

The San Joaquin River

Conductivity in the San Joaquin generally declines with increasing flow in a curvilinear fashion (Figure 8).[9] Flow in this river is typically lowest during the summer and early fall months, coinciding with conductivities that are usually highest. However, under certain flow conditions there is a relative increase in conductivity during the winter and spring months.

Figure 9 shows monthly conductivity separated between eight different flow regimes in the San Joaquin ranging from less than 1,000 cfs to more than 20,000 cfs. In the lowest regime (<1,000 cfs), conductivity was highest during July and August. However, in all flow regimes greater than 1,000 cfs, conductivity was highest during January through April. These trends are relative

6 Kruskal-Wallis one-way ANOVA.

7 Same-day data (n=57) was used in the Wilcoxon matched-pair signed-ranks test to eliminate any possible bias due to database size.

8 Victoria Canal was used here to also represent North Canal that runs parallel to it.

9 Field or laboratory measurements from the Department, USGS, or Storet retrieval.

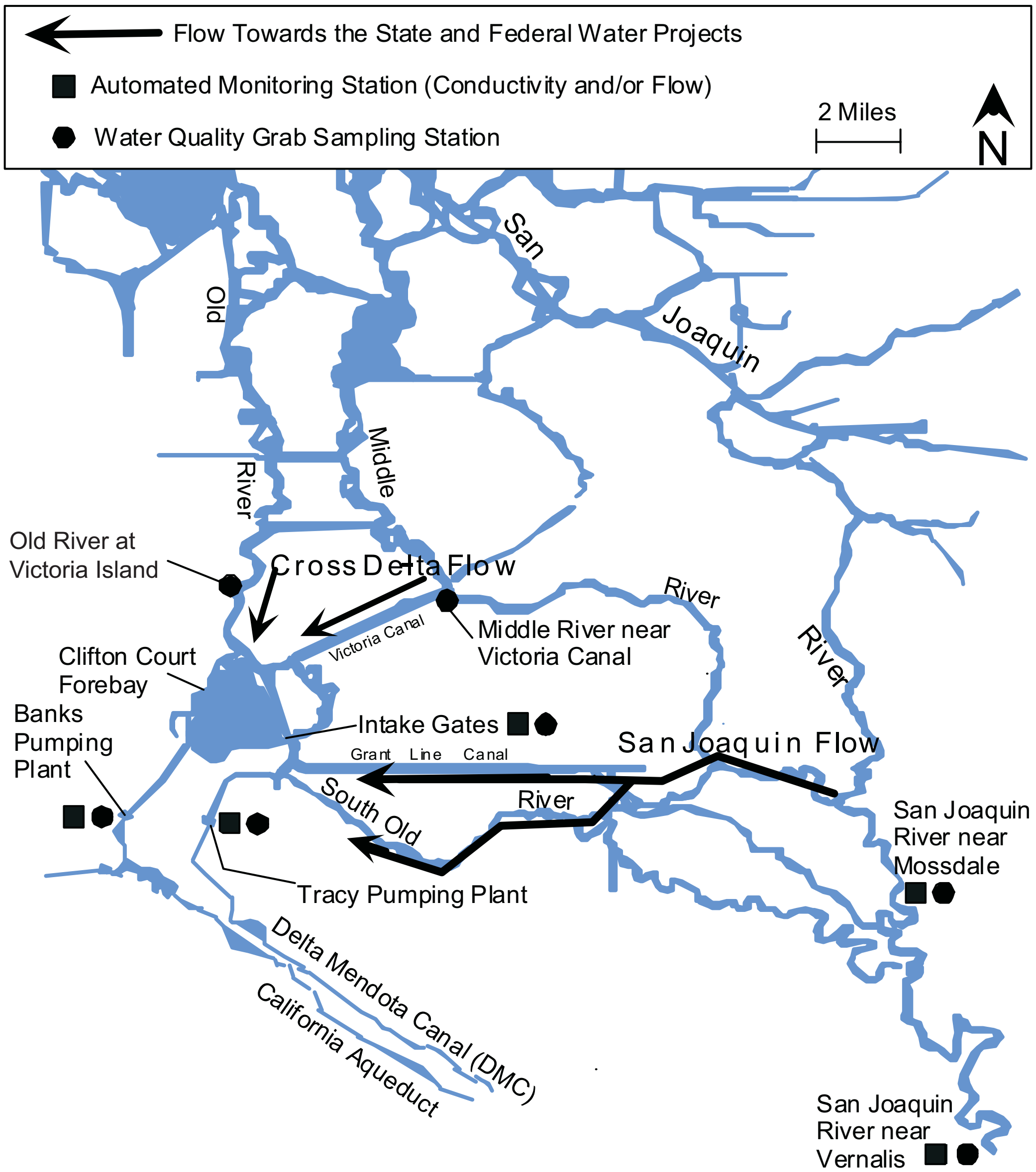


Figure 5. *The map above depicts water flow towards the export sites and water quality monitoring stations. Most data used in this report were collected at these stations.*

to flow (note the scale in Figure 9B is is lower than in 9A) so, although levels during these months were usually lower than during the summer months of low flow periods, they were highest relative to the other months under the same flow regime. The same trend, discussed later, was observed at Banks under similar high flow conditions.The higher relative conductivities during January through April could be due to pre-irrigation in the San Joaquin Valley.

Pre-irrigation of agricultural fields in the San Joaquin Valley is done to remove salts accumulated in the soil during the previous growing season and to prepare the soil for planting (DWR 1974a). Pre-irrigation during winter and spring takes advantage of high San Joaquin River flow for dilution purposes (DWR 1960). This method of dilution is one of the recommended strategies for meeting San Joaquin River water quality objectives year-round (SWRCB 1995). Pre-irrigation discharges to the San Joaquin usually start peaking between January and March – earlier during wet water years, and later during critical water years (DWR 2001). These discharges, along with low-salinity runoff from the Sierra Nevada, can make conductivity in the San Joaquin highly variable during winter and spring

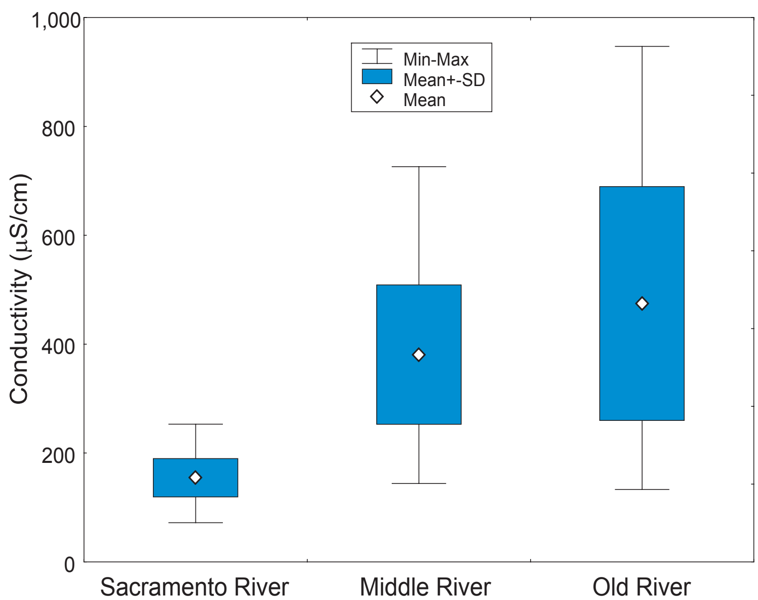


Figure 6. *Conductivity in the Sacramento River (Greene's Landing to Hood), Old River (near Victoria Island), and Middle River (near Victoria Canal) from 1990 through 1999 is depicted. Samples were collected at all three stations during most of this time period, assuring less bias in the comparison.*

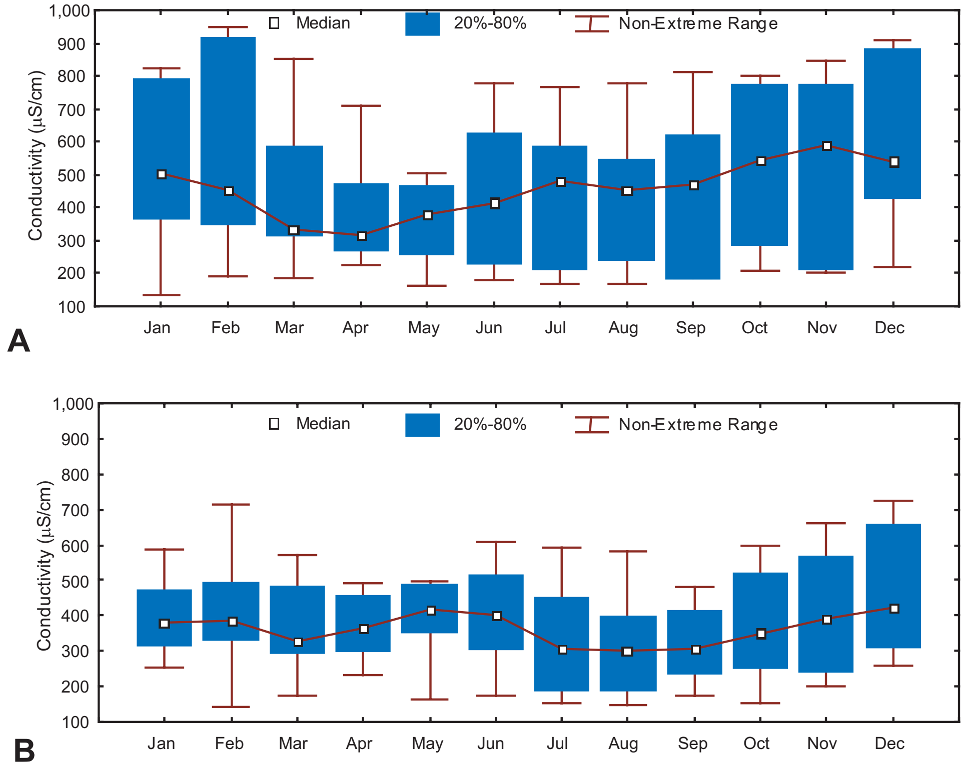


Figure 7. *Monthly conductivity trends in Old River (**A**) and Middle River (**B**) from 1990 through 1999 are shown. Samples were collected at both stations during most of this period.*

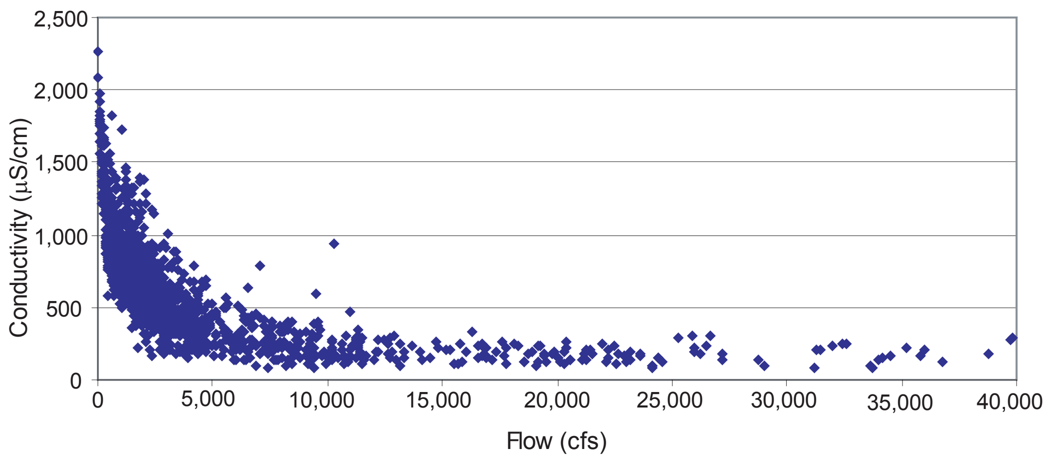


Figure 8. *This graph depicts the relationship between flow and conductivity in the San Joaquin River.*

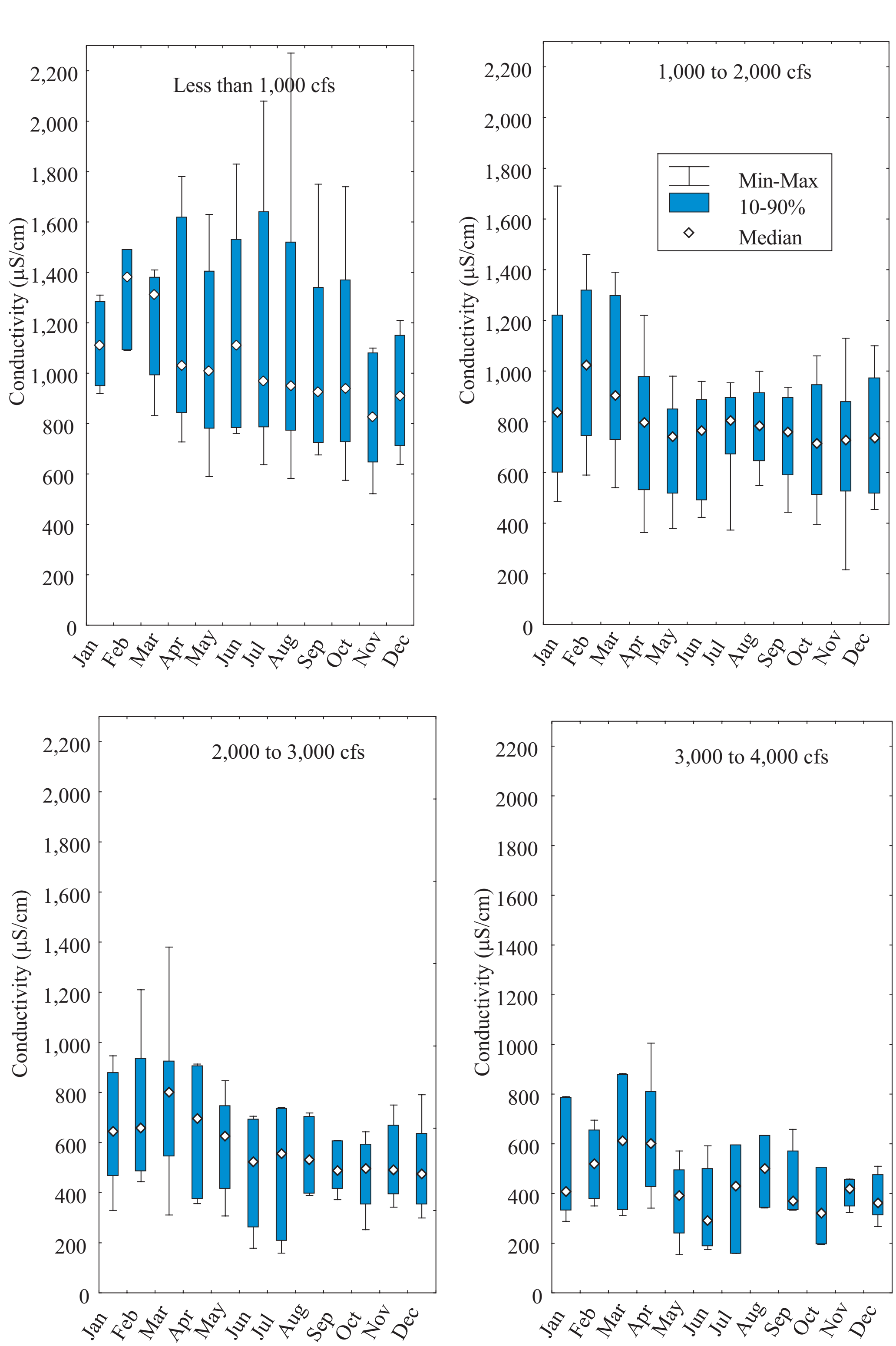


Figure 9A. *Monthly conductivity trends in the San Joaquin River is shown for four flow ranges, from less than 1,000 cfs to a maximum of 4,000 cfs.*

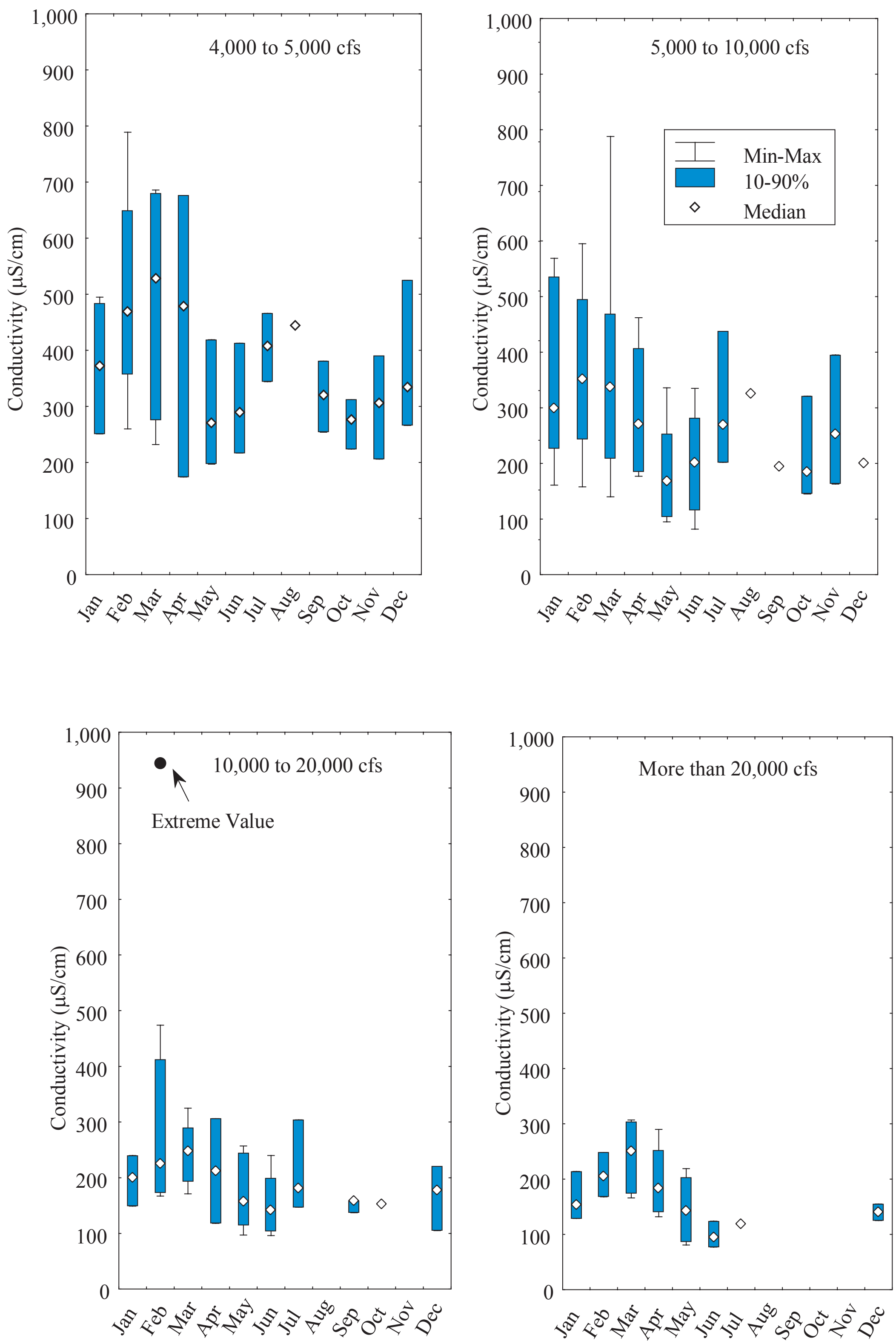


Figure 9B. *Monthly conductivity trends in the San Joaquin River is shown for four flow ranges, from more than 4,000 cfs to more than 20,000 cfs.*

5. Factors Affecting Export Composition

High San Joaquin River Flow

When flow in the San Joaquin River was greater than 3,350 cfs,[10] conductivity at Tracy and in the San Joaquin was similar based on samples collected from both sites within one day of each other. The correlation was significant with a Spearman Rank of 0.94 ($p<0.001$) and an r-squared of 0.72 (Figure 10A). The correlation quickly decayed when using paired conductivity values associated with lower flow. This infers that under certain high flow conditions (>~3,350 cfs), water at Tracy was mostly from

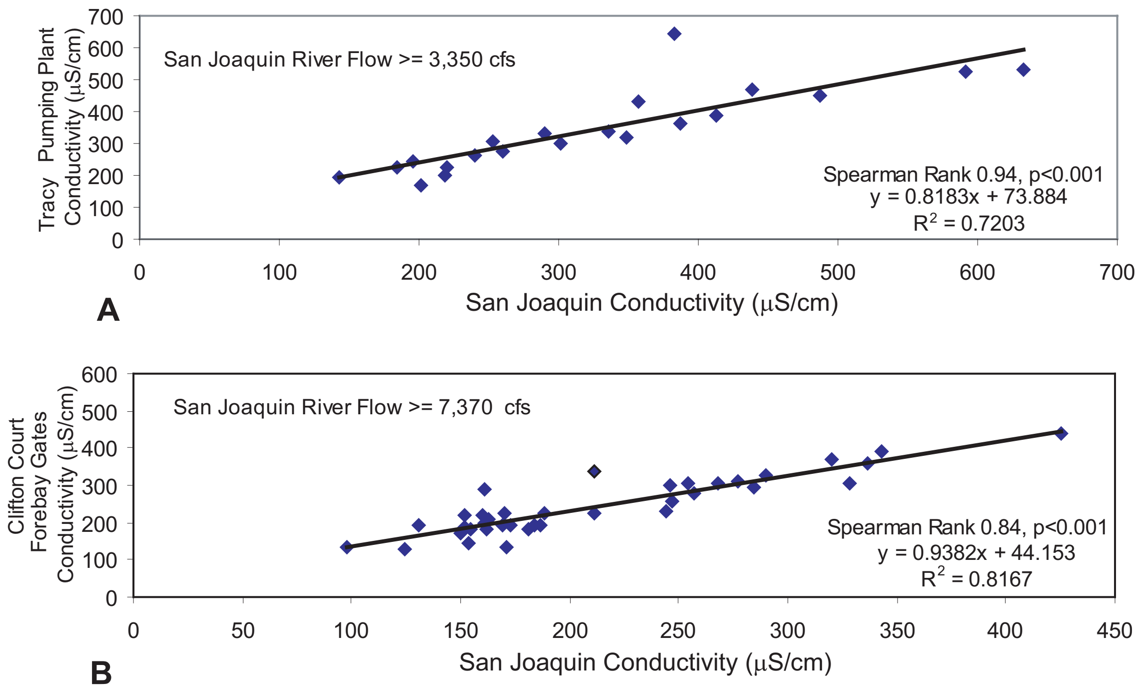


Figure 10. 10A *shows the correlation in conductivity between the San Joaquin River and Tracy Pumping Plant when river flow was 3,350 cfs or more.* **10B** *shows the correlation in conductivity between the San Joaquin River and the Clifton Court Forebay gates when river flow was 7,370 cfs or more. Conductivity values for the paired stations in each graph were measured within one day of each other.*

[10] This was flow on the day paired water quality samples were collected. It is not intended to be the specific flow above to which conductivity in the San Joaquin and at Tracy correlate. There probably is no one number but a range around this value. This also applies to the flow provided for the CCF gates. All samples were collected without the barrier at the head of Old River or the barrier combination of Grant Line Canal and south Old River near Tracy.

the San Joaquin flowing via Grant Line Canal and south Old River with little or no influence from cross-Delta flow.

A similar relationship was found for water at the CCF gates. When flow in the San Joaquin was 7,370 cfs or more, the conductivity in the San Joaquin and at the CCF gates was significantly correlated based on samples collected at both sites within one day of each other (see footnote 10) (Figure 10B). This indicates that under certain high flow conditions (>~7,370 cfs), water at the CCF gates was mostly from the San Joaquin. The r-squared values for both relationships increased to more than 0.90 when one or two data points were removed which indicates that other factors, such as travel time, can affect the correlations.

For the above correlations to hold, conductivity in the San Joaquin would have to remain relatively stable for the duration of travel to the export sites via Grant Line Canal and south Old River. This duration ranges from hours to days depending on flow and barrier placement (Oltmann 1999). If mineralogy in the lower San Joaquin were to change during this travel time, samples collected at the export sites and in the San Joaquin on the same day would be dissimilar, thus affecting the above correlations. Regardless, the San Joaquin, exclusive of cross-Delta flow, is expected to have a major presence at the export sites under certain high flow conditions.

The same association could not be made at Banks, possibly due to operation of the CCF gates and residence times through CCF (discussed later). However, using other analytical techniques, water at Banks was, on average, mineralogically similar to the San Joaquin when the river's flow was greater than 7,370 cfs.

When San Joaquin flow was over 7,370 cfs, the average anionic dominance at Banks shifted from bicarbonate to chloride/sulfate with increasing conductivity (Figure 11). Chloride increased from 32 percent of the average anionic content in the lowest conductivity range (100-200 µS/cm) to 46 percent in the highest

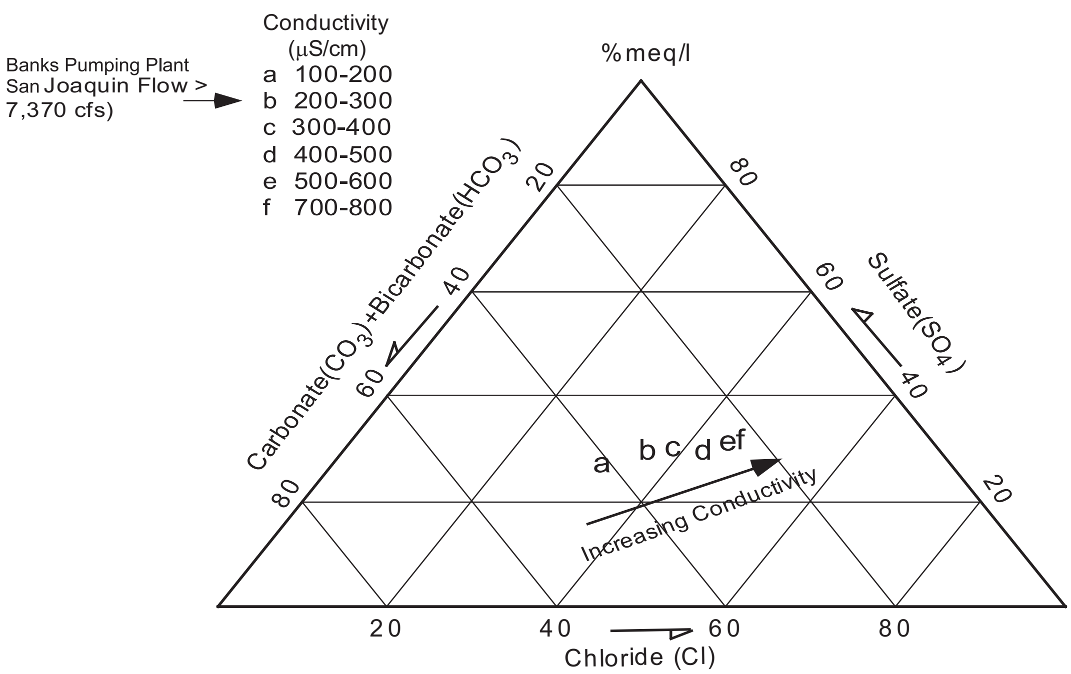


Figure 11. *Changes in anionic mineralogy with increasing conductivity at Banks Pumping Plant under certain high flow conditions. Mineral data used in this graph was collected at Banks Pumping Plant when flow in the San Joaquin River was 7,370 cfs or more.*

conductivity range (700-800 µS/cm). The change in sulfate content was smaller – 27 to 30 percent over the same conductivity range. These anionic changes were similar to those observed in water influenced by the San Joaquin (see Background). This is indirect evidence that water at Banks was, on average, from the San Joaquin under the same high flow conditions (>~7,370 cfs). This was supported by assessing the slope of the conductivity/sulfate relationship which was not statistically different (p=0.021)[11] than that of the San Joaquin River under the same high flow conditions. These analyses were not as strong as the earlier associations made with same-day conductivity values at Tracy and the CCF gates. They are, however, supported from the standpoint that a flow of 7,370 cfs in the San Joaquin could be high enough to produce positive flow in Old River (south to north) and past the CCF gates. One last analysis of conductivity at Banks supports this.

Using data from the previous paragraph (samples at Banks collected while flow in the San Joaquin was >7,370 cfs), conductivity at Banks was seasonally highest during the winter and early spring, mimicking trends in the San Joaquin under the same flow conditions (Figure 12). As discussed earlier, seasonal increases in San Joaquin conductivity during January through April may be related to pre-irrigation discharges in the San Joaquin Valley (see Salinity in Cross-Delta Flow and the San Joaquin River).

Although seasonal trends were similar between these two sites, conductivity was consistently higher at Banks than in the San Joaquin (Figure 12). Both the average and maximum conductivity at Banks was higher during the winter and spring months with the exception of one value in February. It is possible that the salt content of the San Joaquin was augmented as it flowed to the export sites via south Old River and Grant Line Canal. There are numerous sources of salt along this route.

The City of Tracy operates a wastewater treatment plant that discharges to south Old River just upstream from the bifurcation with Grant Line Canal (Figure 13). Design flow is 9.0 million gallons per day with an average conductivity of approximately 1,700 µS/cm (PMC 2001). Other sources of salt include about 40 agricultural sump pumps along south Old River and

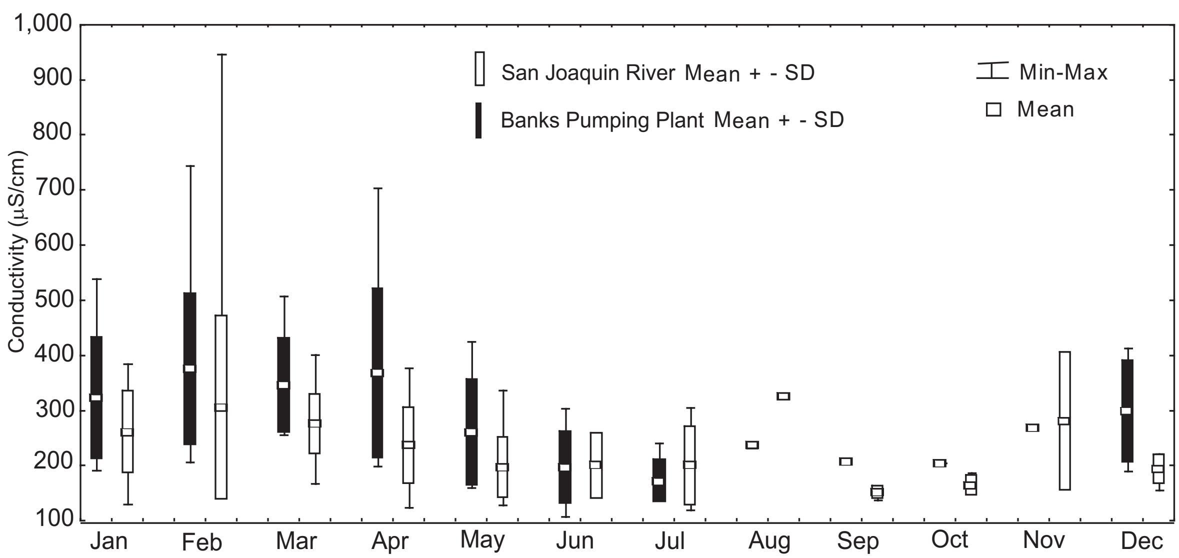


Figure 12. *Monthly conductivity trends at Banks Pumping Plant and in the San Joaquin River under certain high flow conditions. Conductivity data used in this graph was collected at Banks Pumping Plant and in the San Joaquin River when flow in that river was 7,370 cfs or more.*

[11] Hollander nonparametric test for parallelism of two regression lines.

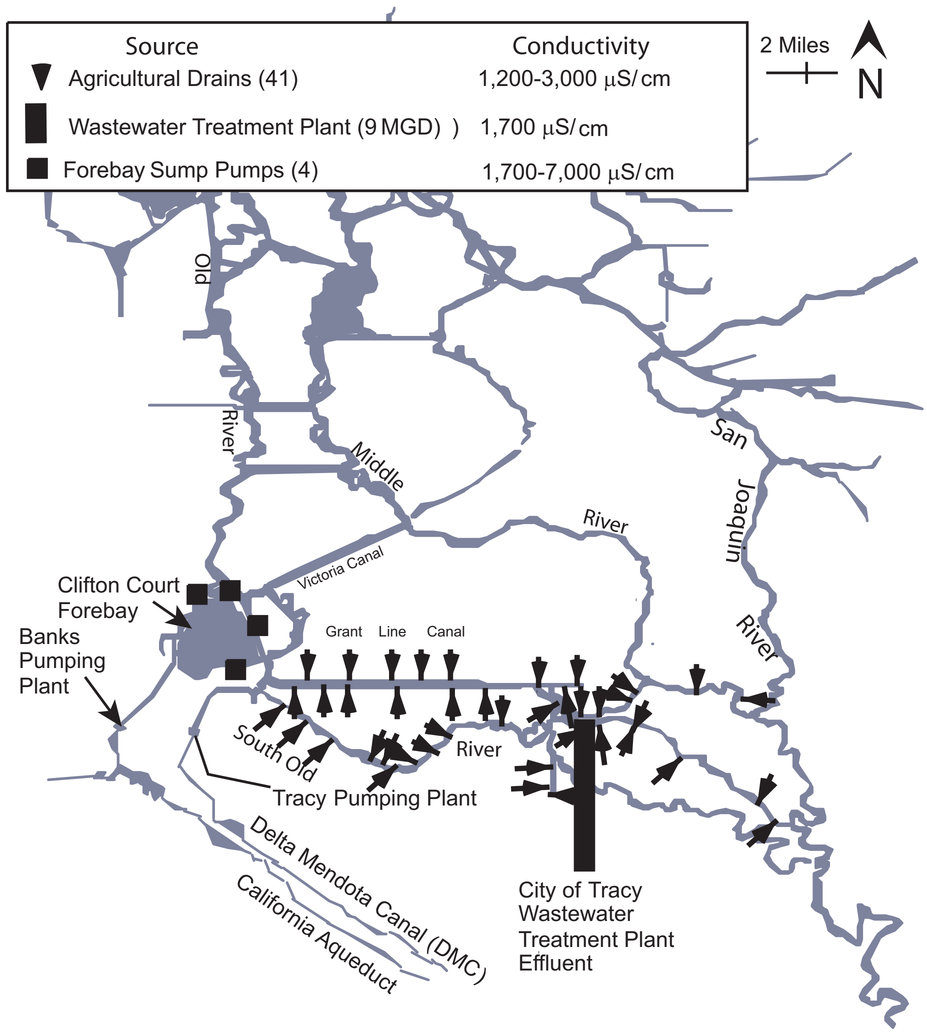


Figure 13. *The locations of several potential sources of salt in the south Delta are shown above.*

Grant Line Canal (DWR 1995). Several of the sumps exhibited conductivities ranging from 1,200 to 3,000 µS/cm (DWR 1994, CVRWQCB 1989). Similar to west-side farmland in the San Joaquin Valley, Delta islands can be pre-irrigated during winter (DWR 1990a). Collectively or individually, wastewater and Delta island discharges may measurably influence water flowing to the export sites via south Old River and Grant Line Canal. Another source of salt includes several sump pumps around CCF (discussed later).

Flow in the San Joaquin River was assessed to identify periods of greatest influence on exports. San Joaquin River flow was over 3,350 cfs from 38 to 57 percent of the time during January-June (Table 2).[12] These percentages dropped to between 8 and 31 percent during the second half of the year (July-December). This, and the pre-

12 Daily automated station data from 1950 to 1999 (USGS and the Department). The cutoff date of 1950 was chosen due to the completion of Friant Dam in 1947, and subsequent deliveries via the Friant-Kern Canal in 1949. The year 1950 was the first full year the San Joaquin River water from Millerton Lake was delivered to the Tulare Lake Basin for irrigation (SWRCB 1987).

ceding analysis, indicate that water at Tracy can be largely from the San Joaquin an average of 48 percent of the time during the first half of any given year and an average of 18 percent during the second half (see footnote 10 regarding temporary barriers). These percentages represent the minimum predicted frequency when water at Tracy can be mostly from the San Joaquin River: the San Joaquin can also be present when flow is lower than 3,350 cfs (discussed later).

San Joaquin River flow was above 7,370 cfs from 19 to 33 percent of the time during January-June and from 2 to 9 percent during July-December (Table 2). Based on this and the previous analysis, water at the CCF gates can be mostly from the San Joaquin an average of 27 percent of the time during the first half of any given year and an average of 5 percent during the second half (see footnote 10 regarding temporary barriers). These percentages represent the minimum predicted frequency when San Joaquin River water is prevalent at the CCF gates: the San Joaquin can also flow directly to the gates when flow is lower than 7,370 cfs (discussed later).

Monthly frequencies were also calculated for different water year classifications. San Joaquin River flow was over 3,350 cfs from 66 to 95 percent of the time during January-June of a wet water year (Figure 14A). These values ranged from 29 to 99 percent during the same months of an above-normal year. Thus, there is a good chance that water at Tracy will be mostly from the San Joaquin River during January-June of a wet water year and, to a lesser degree, the same period of an above-normal year. Percentages generally declined with dryer water years. The exception was during October-December. For December alone, percentages remained above 40 percent across 3 water year classifications from above-normal to dry. Therefore, the frequency of San Joaquin River flow above 3,350 cfs was not necessarily dependent on water year classification during those months.

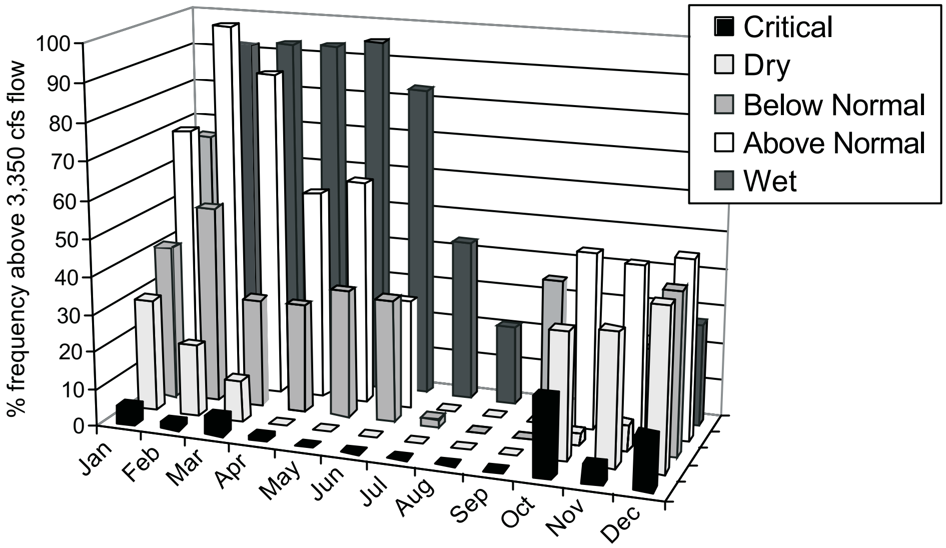
The frequency of San Joaquin River flow over 7,370 cfs ranged from 28 to 69 percent during January-June of a wet year (Figure 14B), indicating an approximate 28-69 percent chance that water at the CCF gates will be from the San Joaquin during the first half of a wet year. During an above-normal year, these percentages ranged from 36 to 75 during January-March, then declined dramatically (Figure 14B). During July-December of a wet and above-normal water year, these percentages dropped to between 0 and 21 percent. Flow in the San Joaquin was infrequently above 7,370 cfs during a below-normal water year and almost never above it during a dry or critical water year.

Table 2. Monthly Percent Frequency When San Joaquin River Flow Was Above 3,350 and 7,370 cfs, 1950-99

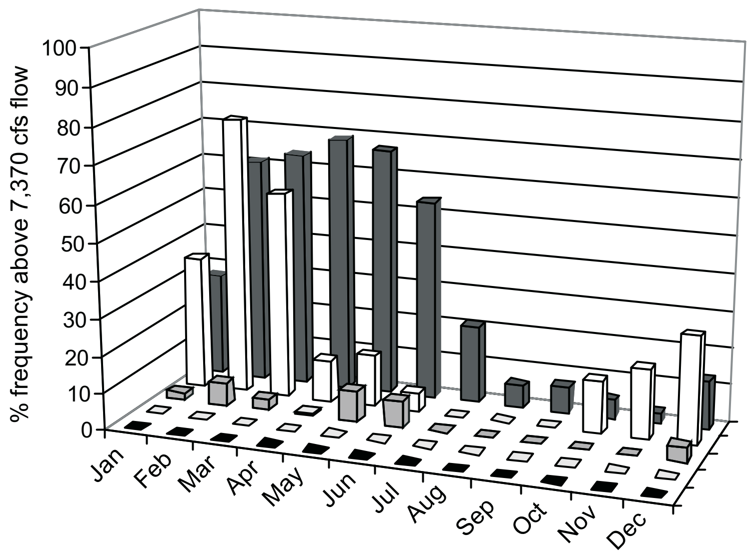
	Percent Frequency											
San Joaquin Flow	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Above 3,350 cfs	44	57	52	46	47	38	16	8	19	22	18	31
Above 7,370 cfs	19	33	31	27	28	21	8	2	2	4	3	9

Tide

Under lower flow conditions in the San Joaquin River, the composition and salinity of exports can change on an hourly basis with the tide. Figure 15 shows conductivity and tidal stage at the CCF gates during a 4-day period in June 1996. Conductivity began increasing with low-low tide, reached a crest, and then decreased before, or just after, high-high tide. During the same 4-day period, conductivity averaged 175 µS/cm in cross-Delta flow (Old and Middle Rivers combined) and 695 µS/cm in the San Joaquin. Therefore, it appears that San Joaquin River water was drawn to the CCF gates during ebb tide (outgoing or falling tide) and mixed with cross-Delta water, increasing conductivity for a few



A



B

Figure 14. 14A *shows the monthly percent frequencies when flow in the San Joaquin River was 3,350 cfs or more during different water year types. The percentages represent the chance that water at Tracy Pumping Plant will be largely from the San Joaquin River during any given month of any given water year.* **14B** *shows the monthly percent frequencies when flow in the San Joaquin River was 7,370 cfs or more during different water year types. It represents the chance that water at the Clifton Court Forebay gates will be largely from the San Joaquin River during any given month of any given water year.*

hours. As the tide came back in, cross-Delta flow gradually displaced San Joaquin River water and lowered conductivity. The oscillations were sometimes bimodal during the 25-hour tidal cycle, with conductivity increasing on both the high-low and low-low tides. This phenomenon, also observed at Tracy, was supported with mineral data.

In June 1996, conductivity at Tracy was oscillating between 200 and 550 µS/cm, increasing to levels observed in the San Joaquin and decreasing to those in cross-Delta flow (Figure 16). When hourly conductivity neared its crest on June 13, mineralogy at Tracy was more like the San Joaquin than either Old or Middle Rivers (Figure 17). At other times, water collected during conductivity troughs had a mineralogy that was more like the Old or Middle Rivers. This demonstrates that the composition of water at Tracy and the CCF gates can shift between the San Joaquin River and cross-Delta flow on an hourly basis with the tide. During these periods, the mineralogy and salinity of samples collected at these sites would depend on the tide. Water at the CCF gates and at Tracy could reflect the composition and salinity of cross-Delta flow, the San Joaquin, or various mixtures of both, depending on the time of day.

Tidally induced conductivity (or composition) oscillations observed at Tracy were also

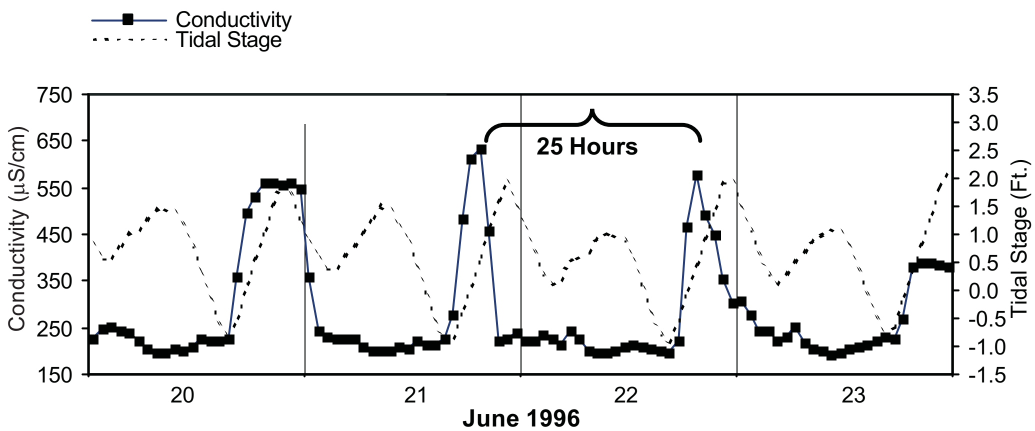


Figure 15. *Hourly conductivity and tidal stage trends at the Clifton Court Forebay gates are shown for June 20 through 23, 1996.*

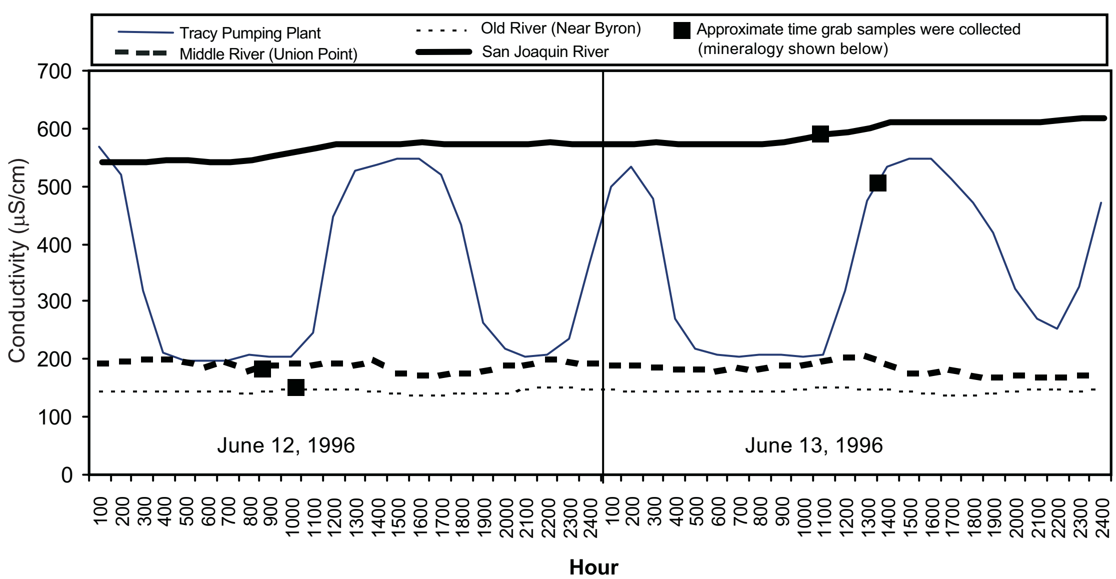


Figure 16. *Hourly conductivity trends at Tracy Pumping Plant during June 12 through 13, 1996. Conductivity there was oscillating between lower levels in Old and Middle Rivers, just north of the export site, and higher levels in the San Joaquin River. The black boxes show when grab samples were collected for mineral analysis (mineral data shown in next figure).*

observed nearly 70 miles down the Delta Mendota Canal near O'Neill Forebay where water can be pumped from the canal into the California Aqueduct. The continuation of these oscillations down the Delta-Mendota Canal makes sense considering that pumping at Tracy is usually continuous. Some mixing and dampening-out of crests and troughs during this transport process is likely. Regardless of this dampening effect, when these oscillations are occurring, the mineralogy and salinity of water entering O'Neill Forebay from the canal would depend on the time of day. Tidally induced conductivity oscillations observed at the CCF gates did not continue down the California Aqueduct because of gate operations (discussed later).

The oscillations discussed above were common at both Tracy and the CCF gates. An analysis quantified this and identified any seasonal trends. If conductivity was clearly oscillating between levels in cross-Delta flow and the San Joaquin for at least a week during any given month, it was counted in the "Oscillations Observed" column in Figure 18. Months with no clear evidence of oscillations for the entire month were counted in the "Oscillations Not Observed" column. Months when neither of these trends could be discerned were counted in

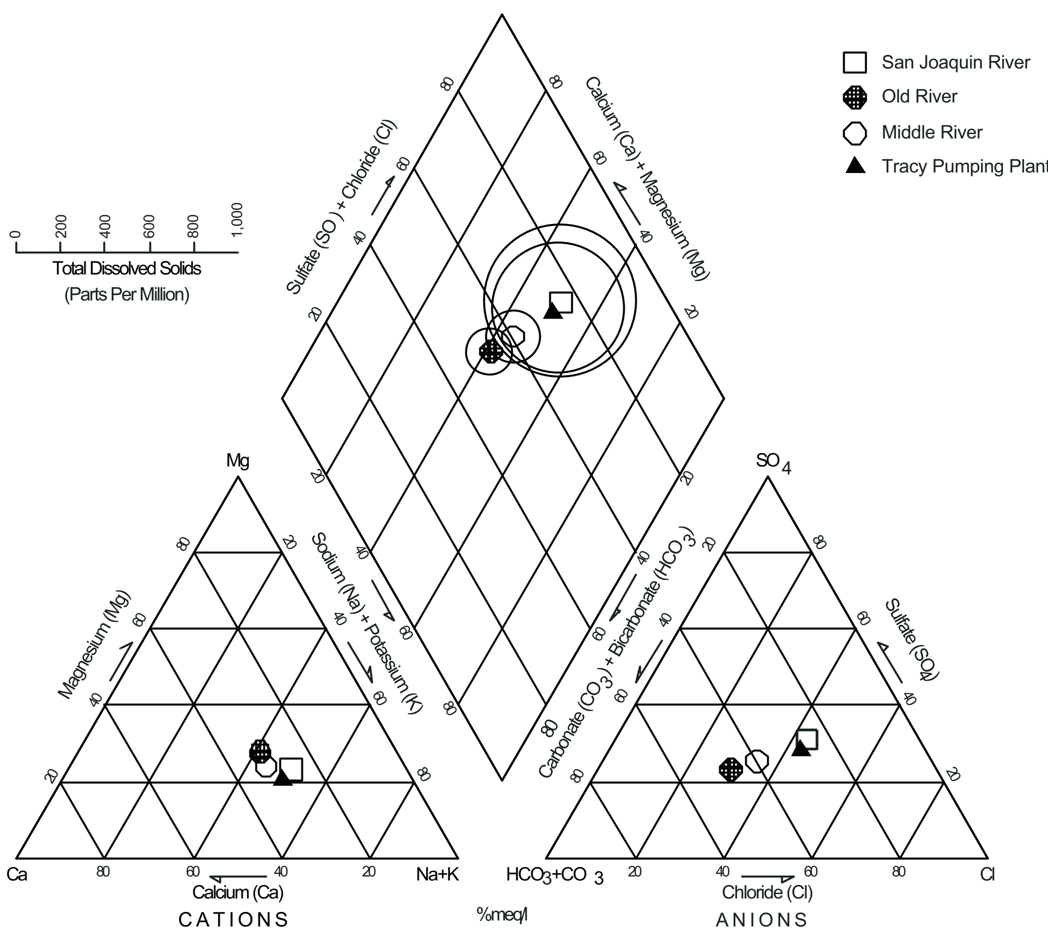


Figure 17. *This Piper graph depicts mineralogy at Tracy Pumping Plant and in the Old, Middle, and San Joaquin Rivers during June 12 and 13, 1996. A description of a Piper graph can be found in Appendix B.*

the "Unclear" column. Although this approach appears biased towards detecting oscillations, the purpose was not to quantify duration, but the presence or absence of the oscillations in any given month.

At the CCF gates, January had the highest incidence of oscillation detection. Oscillations were observed for at least a week, during 10 of the 13 Januarys between 1990 and 2002 (Figure 18A). For the other 3 Januarys, the data was ambiguous as to whether oscillations occurred. This last category ("Unclear") was needed because of the following factors:

(1) Conductivity in cross-Delta flow and the San Joaquin River was similar, making it difficult to determine which was influencing water at the CCF gates.
(2) Conductivity data was missing from one or more of the stations.
(3) Conductivity data was unexplainable or suspected to be inaccurate.

Assuming the probability of recording any month as "Unclear" is random, and the "Unclear" category exhibited no apparent trends, Figure 18A would indicate that conductivity oscillations at the CCF gates were most frequently observed during January and, to a lesser extent, during November through April. During these months between 1990 and 2002, oscillations were more common than not. The reverse was true for July and September, when oscillations were not observed more frequently than observed. One explanation for fewer oscillation detections during summer/fall is that declining San Joaquin River flow and temporary barriers during this period could reduce flow into south Old River and Grant Line Canal and, therefore, less water is available to be drawn to the CCF gates with outgoing tide. In August, oscillations were observed as frequently as not. For May, and to some extent October, there were too many "Unclear" observations to draw any conclusions.

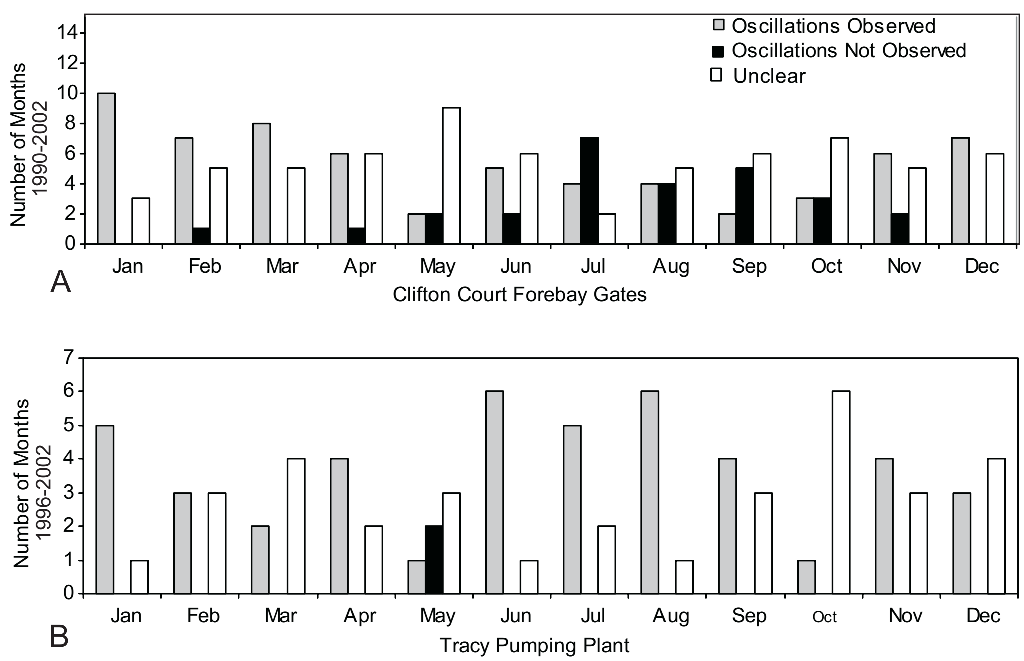


Figure 18. 18A *shows the number of months that conductivity oscillations from tidally induced composition changes were, or were not, observed for at least a week at the Clifton Court Forebay gates. The third category, "unclear", was needed because no determination could be made one way or the other for some months.* **18B** *is the same analysis done at Tracy Pumping Plant.* **18A** *represents 13 years of available hourly conductivity data and* **18B** *represents 6-7 years of available hourly data.*

The same assessment for Tracy was limited by less available data: hourly conductivity data in electronic format was only available back to June 1996. Regardless, the existing data shows conductivity oscillations were more common at Tracy than at the CCF gates. May was the only month when oscillations were clearly not observed, and oscillations were observed more often than not in all months (Figure 18B).

Conductivity oscillations were observed at Tracy a total of 44 months during the 6 to 7 year period, compared with only 2 months when they were not observed. Therefore, oscillations were observed 22 times more frequently than not (44 observed, 2 not observed). This is compared with oscillations at the CCF gates where they were observed two-and-a-half times more frequently than not (64 observed, 27 not observed). The composition of water at Tracy was shifting with tide from that of cross-Delta flow to the San Joaquin more frequently than at the CCF gates (22 times more frequently versus 2.5 times). This indirectly illustrates the greater influence of the San Joaquin on water at Tracy. This greater influence of the San Joaquin was supported by comparing salinity between SWP and CVP exports.

Table 3 shows median daily conductivity at Tracy and Banks between 1986 and 2002.[13] Banks was chosen rather than the CCF gates because gate operations can sometimes affect salinity trends in the Aqueduct (discussed later). Conductivity was statistically higher at Tracy than at Banks for 12 of the 17 years between 1986 and 2002 (Table 3). Conductivity was statistically higher at Banks for 3 of the remaining years, and no statistical difference was found for the other 2 years. Therefore, for a majority of the years during this period, annual conductivity was higher at Tracy than at Banks. The higher conductivity did not appear to be strongly related to water year classification since conductivity was statistically higher at Tracy during wet, dry, above-normal, and critical water years.

The higher salinity at Tracy was not unexpected because conductivity in the San Joaquin is usu-

Table 3. Water Year Classification and Median Conductivity at the Clifton Court Forebay Gates and Tracy Pumping Plant

	Water Year Classification		Median Conductivity		
Water Year	*Sacramento*	*San Joaquin*	*Tracy Pumping Plant*	*Banks Pumping Plant*	**Station Siginficantly Higher[2]**
1986	wet	wet	366	293	Tracy***
1987	dry	critical	652	474	Tracy***
1988	critical	critical	665	629	Tracy***
1989	dry	critical	551	462	Tracy***
1990	critical	critical	657	644	NS
1991	critical	critical	571	547	Tracy**
1992	critical	critical	727	713	Tracy*
1993	above normal	wet	503	435	Tracy***
1994	critical	critical	583	557	Tracy***
1995	wet	wet	330	241	Tracy***
1996	wet	wet	371	291	Tracy***
1997	wet	wet	420	368	Tracy**
1998	wet	wet	286	300	Banks*
1999	wet	above normal	379	400	Banks**
2000	above normal	above normal	372	345	Tracy**
2001	dry	dry	442	485	Banks***
2002	dry	dry	430	417	NS

[1]Observations for at least 1 week
[2]Station with a significantly higher conductivity (Mann-Whitney U Test).
*** = Very significant (p<0.001)
** = Significant (p<0.05)
* = Somewhat significant (p<0.1)
NS = Not significant

13 The period of record for the Banks automated station.

ally higher than in cross-Delta flow. Figure 19 shows average conductivity in the San Joaquin and cross-Delta flow (Old and Middle Rivers).[14] In this figure, conductivity in the San Joaquin averaged 25 percent higher than in Old River, and 46 percent higher than in Middle River. Because of the San Joaquin's greater influence at Tracy versus the CCF gates, CVP exports would be expected to reflect these higher levels. The San Joaquin flows to Tracy more frequently with outgoing tide than to the CCF gates. San Joaquin River water was present at Tracy more often and for a greater period of time. Because conductivity in the San Joaquin is usually higher than in cross-Delta flow, salinity at Tracy, and presumably in CVP exports, was often higher than that of SWP exports at Banks.

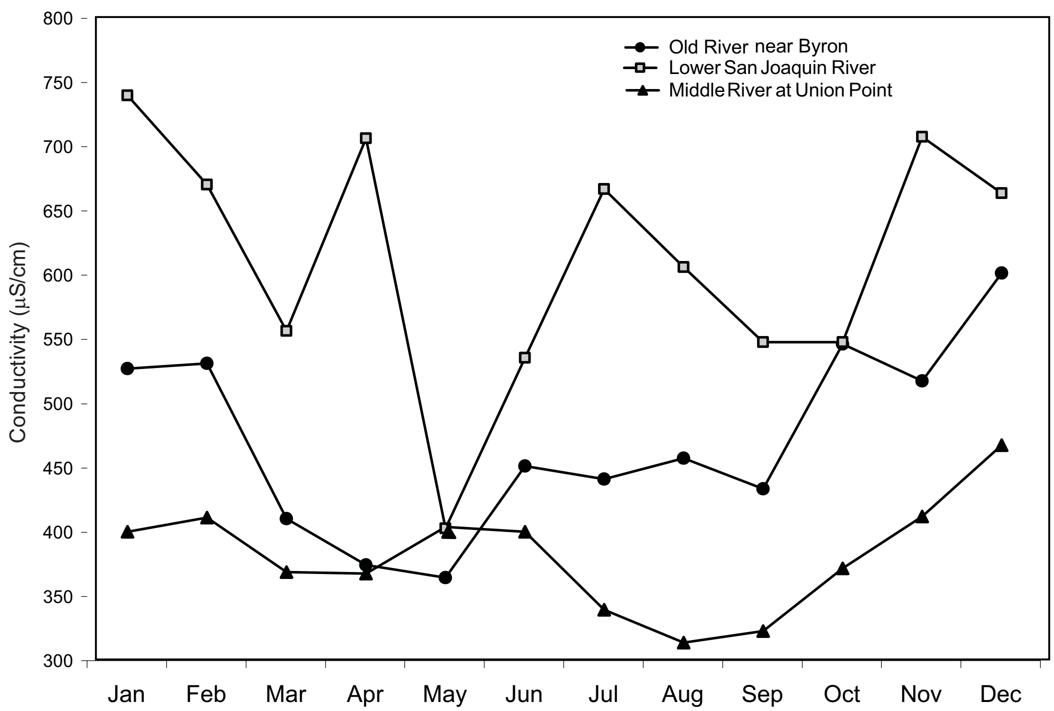


Figure 19. *Average monthly conductivity in the Old, Middle, and San Joaquin Rivers is graphed from 1990 to 1999. Samples were collected at all three stations during most of the time period, assuring less bias in the comparison.*

South Delta Temporary Barriers

One factor affecting conductivity oscillations was south Delta barriers. Conductivity oscillations at the CCF gates sometimes stopped with the installation of certain south Delta temporary barriers. In June 1997, oscillations virtually ceased after barriers on south Old River and Grant Line Canal were completely installed on June 4 (Figure 20). Conductivity was 500-600 µS/cm in the San Joaquin, the source of the conductivity crests at the CCF gates, and 250-350 µS/cm in cross-Delta flow, the source of the conductivity troughs. Therefore, installation of the barriers coincided with a reduction or elimination of water flow from the San Joaquin drawn to the CCF gates with tide. The result was that most of the water at the gates was cross-Delta flow with little or no influence from the San Joaquin River flowing directly to the export site via south Old River and Grant Line Canal. The 4-day average before installation was 405 µS/cm, and 361 µS/cm after – an

14 Field or lab values during 1990-99: a time period when samples were mostly available for all three stations.

11 percent decline. In this case, oscillations ceased after complete installation of the second barrier. In other instances, the cessation occurred prior to the completion date of barrier installation (it can take several days to install a barrier). A similar effect was sometimes observed with installation of the barrier at Old River at Head. This conflicts with one modeling study that predicted barrier installation increased the amount of San Joaquin River water in SWP exports (Orlob 1991).

At Tracy during the same period (June 1997), conductivity oscillations were only slightly reduced by the barriers. Of the two bimodal conductivity crests observed at Tracy during the 25-hour tidal cycle, only one was slightly reduced after barrier installation, resulting in a 6 percent decline in the before and after 4-day average (Figure 21). In this instance, installation of the barriers only reduced the influence of the San Joaquin at Tracy. Continued oscillations meant that the San Joaquin was still strongly prevalent at Tracy during the tidal cycle. This is another indirect example of the San Joaquin's greater influence at Tracy than at the CCF gates. Hourly data for Tracy only extended to 1996, so a definitive analysis of barrier installation on conductivity was not completed. However, the reduction of the influence of the San Joaquin at Tracy with barrier installation was supported by one modeling study (Orlob 1991).

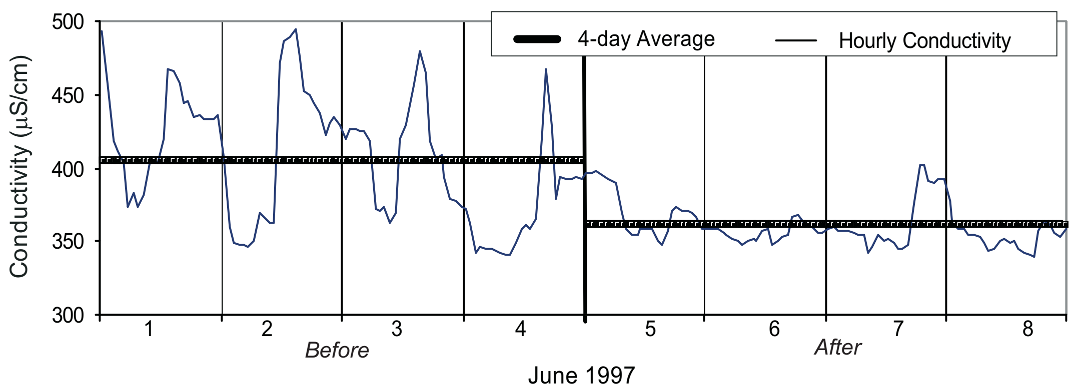


Figure 20. *Hourly conductivity trends at the Clifton Court Forebay gates during June 1-8, 1997. The 4-day average, calculated before and after installation of temporary barriers on both Grant Line Canal and south Old River, was completed on June 4.*

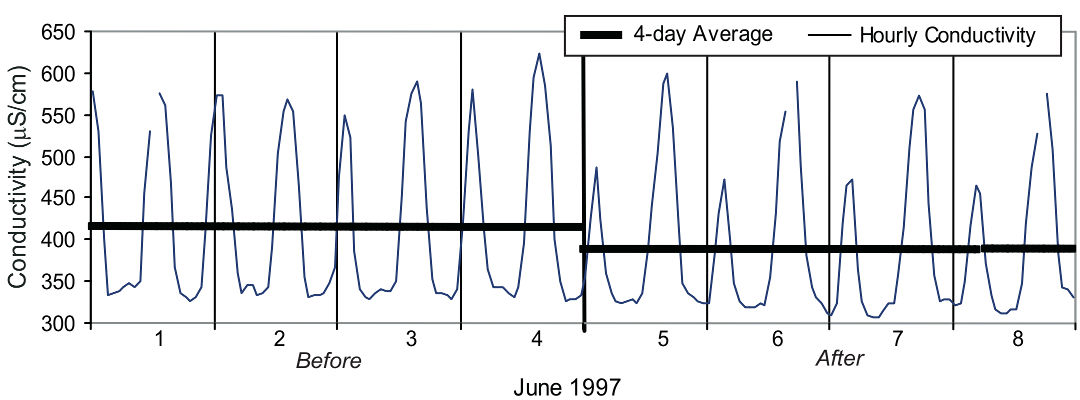


Figure 21. *Hourly conductivity trends at Tracy Pumping Plant during June 1-8, 1997. The 4-day average, calculated before and after installation of temporary barriers on both Grant Line Canal and south Old River, was completed on June 4.*

The timing and duration of south Delta barrier installation and removal has varied from year-to-year. Barriers on Grant Line Canal and south Old River have been installed as early as April and removed as late as November, depending on the year. These last two barriers are installed to improve water circulation and levels in the south Delta during the agricultural irrigation season. The Old River at Head barrier has been installed in the fall and spring, in part to help with upstream and downstream salmon migration, respectively (DWR 2003). During some years, south Delta barriers have not been installed due to high San Joaquin flow, or as requested by the Department of Fish and Game.

San Joaquin River Flow-to-Export Ratio

Another factor that sometimes affected tidally-induced conductivity oscillations was San Joaquin flow relative to south Delta exports. When San Joaquin flow was high relative to total export volume (SWP and CVP), conductivity oscillations at the CCF gates were usually more frequent. Confirmation of this relationship was qualitatively determined by observing the frequency of oscillations when they occurred. For example, when the San Joaquin River flow-to-export ratio was greater than 0.3, conductivity oscillations were more frequent, often two crests and troughs a day, than if this ratio was closer to 0.1. Therefore, higher ratios resulted in more influence from the San Joaquin at the CCF gates. The effect of this ratio was only observable when the following conditions applied:

(1) Temporary barriers on Old River at Head or the combination of barriers on Grant Line Canal and south Old River were not installed. As discussed before, these barriers sometimes resulted in the cessation of conductivity oscillations at the CCF gates.
(2) The conductivity differential between cross-Delta flow and the San Joaquin River were such that an adequate distinction could be made between them.
(3) The difference in conductivity between stations was obviously not due to precision errors or a difference in conductivity between Middle and Old Rivers, north of the CCF gates.
(4) The ratio was stable for several consecutive days.
(5) Data for all automated conductivity stations was available.

Because of these conditional requirements, the influence of the San Joaquin River flow-to-export ratio on conductivity oscillations at the CCF gates was infrequently discernable over the timeframe of available automated station data (since 1987). Hourly electronic conductivity data for Tracy was only available to June 1996, and no determination was made between the San Joaquin River flow-to-export ratio on conductivity oscillations there.

Clifton Court Forebay Gate Operations

The CCF gates are generally operated to avoid diversions during the low-low and rising high-high tides.[15] This strategy is intended to help circulation and keep water levels high enough in the South Delta for agricultural diverters (DWR and USBR 1990). Gate operations can have an affect on salinity in the California Aqueduct.

Gates were sometimes open when conductivity was lowest (Figure 22). During the 4-day period in June 1996, described previously in Figure 15, conductivity at the CCF gates averaged 34 percent lower when gates were open than when they were closed. As described before, conductivity was oscillating between higher levels in the San Joaquin and lower levels in cross-Delta flow. In this example, gate operations favored the admission of lower-salinity cross-Delta flow

15 Procedures for operating the CCF gates are detailed in the Department's Division of Operations and Maintenance Standing Operating Order Number 200.7-A. The operating schedule is ranked in order of three priorities. Gates are open longer with each successive priority.

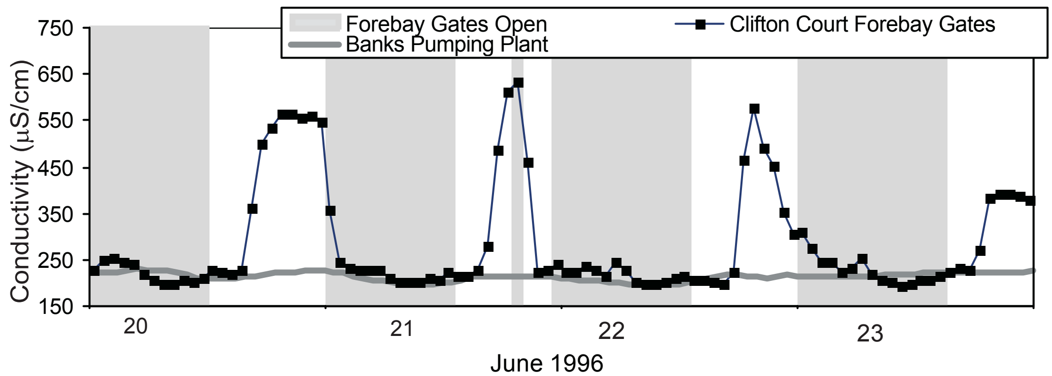


Figure 22. *Hourly conductivity trends at the Clifton Court Forebay gates and Banks Pumping Plant are shown during June 20-23, 1996. The shaded areas show periods when the forebay gates were open. Conductivity data for Banks Pumping Plant was confirmed or adjusted with lab values.*

to CCF rather than water from the San Joaquin. Therefore, gate operations provided a net benefit to Aqueduct salinity by accepting water on the ebb tide. This effect has been described before (Orlob 1991) and was generally stated as one of the advantages of gate operations (Brown & Caldwell 1990, DWR 2001).

However, when the CCF gates were open mostly during conductivity crests, higher salinity water was admitted to CCF. This usually occurred when conductivity in cross-Delta flow was higher than in the San Joaquin. In December 1996, conductivity oscillations at the CCF gates were bimodal, rising to higher levels in cross-Delta flow (average of 426 µS/cm) and dropping to lower levels in the San Joaquin (average of 170 µS/cm) (Figure 23). Conductivity crested on the backside, or ebb, of both high tides and was lowest on the front side, or flood tide. This was opposite the trends shown in Figure 15 where conductivity crests occurred on the front side of the high tides. Because gates are typically opened on the backside of high tides, gate operations favored the admission of the higher salinity water to CCF in this example. Conductivity averaged 24 percent higher when gates were open rather than when they were closed during the 4-day period; this was reflected at Banks (Figure 24). Since gates are usually opened on ebb tide when water from cross-Delta flow is present, during periods of tidally induced conductivity oscillations, water admitted to the CCF was of higher average conductivity than when the gates were closed.

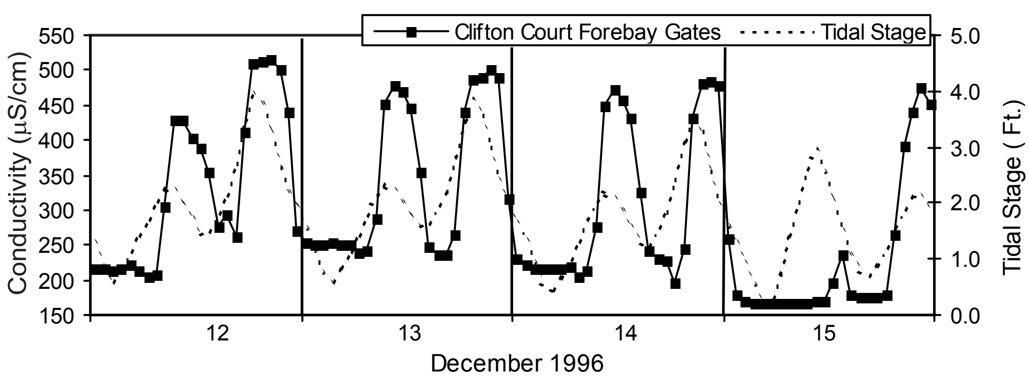


Figure 23. *Hourly conductivity and tidal stage trends at the Clifton Court Forebay gates are shown during December 12 through 15, 1996*

Conductivity at the CCF gates and Banks was compared to determine if there was a net increase or decrease between these sites, possibly indicating the effects of gate operations. Table 4 shows median conductivity at both stations and any statistical differences. Conductivity was statistically higher at the CCF gates for 5 of the 16 years during 1987 to 2002. All 5 years occurred during dry or critical water years, suggesting salinity reductions were greater during drier years. Conductivity was statistically higher at Banks for 1 year (1997) and the remaining years exhibited no significant difference between stations.

The strong statistical differences detected in 1987-89 may not be reflective of current conditions because of changes made to one south Delta channel. In compliance with the South Delta Agreement to improve conditions for agricultural diverters (DWR 1986), approximately 100,000 cubic yards of sediment were removed from the channel of Tom Paine Slough by October 1986 (DWR 1990b). In mid 1989, four siphons with single direction flap-gates were installed on the gated dike located at the confluence of Tom Paine Slough and Sugar Cut, a tributary of south Old River. This was done to increase the amount of water going into Tom Paine Slough, but not out.

During the period from late 1986 to mid 1989, a greater volume of water in the south Delta was available to move downstream towards the export sites with the tide. The San Joaquin River, which would be the largest source of water entering Tom Paine Slough, could have influenced exports more during this period compared to other years. A larger volume of water in the south Delta was available to provide hydrostatic pressure to force water to the export sites during outgoing tide. It is possible that this resulted in more frequent conductivity oscillations, providing an explanation of why conductivity was strongly different between the CCF gates and Banks only during 1987-89.

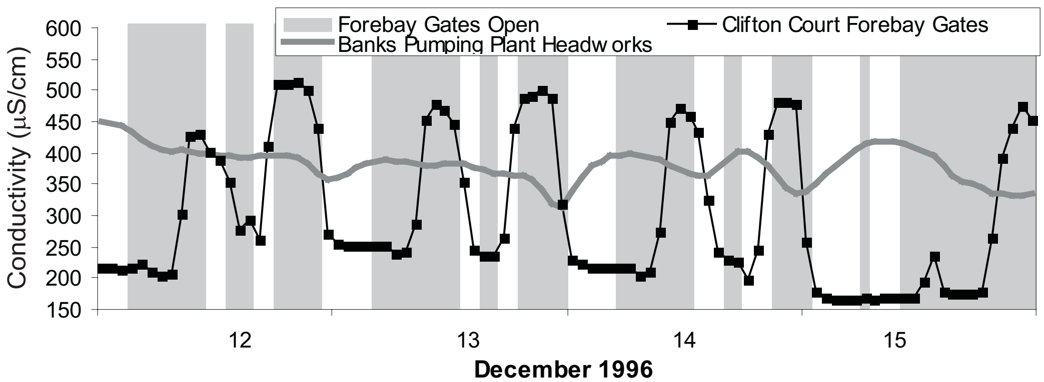


Figure 24. *Hourly conductivity trends at the Clifton Court Forebay gates and Banks Pumping Plant are shown during December 12-15, 1996. The shaded areas show periods when the forebay gates were open. Conductivity data for Banks Pumping Plant was confirmed or adjusted with lab values.*

The San Joaquin's greater influence during 1987-89 was supported by the following:

(1) A qualitative analysis of hourly conductivity at the CCF gates is evidence of more frequent conductivity oscillations from 1987 to mid 1989 compared to later years. During this period, conductivity crests were usually elevated to levels observed in the San Joaquin rather than cross-Delta flow.

Table 4. Water Year Classification and Median Conductivity at the Clifton Court Forebay Gates and Banks Pumping Plant

Water Year	Water Year Classification		Median Conductivity		Station Siginficantly Higher[1]
	Sacramento	*San Joaquin*	*Clifton Court Forebay*	*Banks Pumping Plant*	
1987	dry	critical	545	467	CCF**
1988	critical	critical	690	581	CCF**
1989	dry	critical	652	535	CCF**
1990	critical	critical	540	573	NS
1991	critical	critical	646	572	NS
1992	critical	critical	689	680	NS
1993	above normal	wet	551	514	NS
1994	critical	critical	487	481	CCF*
1995	wet	wet	354	393	NS
1996	wet	wet	262	255	NS
1997	wet	wet	312	352	Banks**
1998	wet	wet	482	512	NS
1999	wet	above normal	347	357	NS
2000	above normal	above normal	359	351	NS
2001	dry	dry	508	488	NS
2002	dry	dry	460	422	CCF*

[1]Station with a significantly higher conductivity (Mann-Whitney U Test).
** = Very significant ($p<0.006$)
* = Somewhat significant ($p<0.1$)
NS = Not significant
CCF = Clifton Court Forebay

(2) As previously discussed, conductivity differences between the CCF gates and Banks were very significant for only those 3 years in the 16-year analysis. It would not appear coincidental considering that several other dry or critical water years followed.

(3) If hydrological conditions in the south Delta had remained the same, a significant difference between stations should have also been observed during 1990-92, the second half of the 1987-92 drought. This difference was not observed.

Although the dredging of Tom Paine Slough in 1986 may have increased the influence of the San Joaquin at the CCF gates, it was countered by installation of the siphons at its mouth with Sugar Cut. Evidence infers that this feature indirectly reduced the amount of San Joaquin water available to flow to the gates with tide after mid 1989, resulting in a net reduction in the influence of the San Joaquin on SWP, and probably CVP, exports.

Considering this information, Table 4 does not provide convincing evidence that CCF gate operations consistently affect export salinity. Excluding the 1987-89 period, there were only 2 years when salinity was higher at the CCF gates and 1 year when Banks had significantly higher conductivity. For the other 10 years, there was no significant difference between stations. It would appear that over a period of a year, conductivity is not that different between sites, or it is higher at one or the other station during different times of the year. To better define this and identify any seasonality, the same analysis was made for each month during 1990-02.

Conductivity was not statistically different between Banks and the CCF gates for 80 of the 140 months (57 percent) between 1990 and 2002 (some months were excluded because of the paucity of data for one or both stations). Conductivity was higher at Banks than the CCF gates during 29 months and the reverse was observed for the remaining 31 months. Therefore, there was no difference between stations for a majority of months (57 percent) during this period; for the remaining 43 percent, the station with the higher conductivity was about evenly split. This infers that gate operations have altered conductivity between the CCF gates and Banks about 40 percent of the time.

Seasonal trends in conductivity differences between Banks and the CCF gates were not that strong. Conductivity was higher at the CCF gates than at Banks for 5 of the 12 Aprils between 1990-02 (data at both stations was not available for one April), compared to only two when the reverse was true (Figure 25). Conductivity was usually higher at Banks than the CCF gates during September and October. However, the total number of months when there was a statistical difference either way was not very large, i.e., 3 to 5 per month compared to 3 to 9 per month with no statistical difference. Other factors such as pumping trends at Banks and sump pumps around the CCF can sometimes affect conductivity between stations regardless of gate operations (discussed below). Therefore, a longer period of time is needed to conclude whether there are months when conductivity is seasonally higher at either station. Figure 25 does illustrate that conductivity at Banks and the CCF gates was not statistically different for a little more than half of the months during any given year.

Sump Discharges to Clifton Court Forebay

Four sump pumps were included in the original design of CCF (DWR 1974b) (see Figure 5). Three of these pump seepage and rainfall runoff into CCF between the original levee and the CCF embankment, and the fourth pump removes runoff from agricultural land on the south side of CCF. Although the drainage areas are relatively small, the sump water is fairly saline. A recent dry weather survey of the sumps measured conductivities ranging from 1,400 to 7,000 µS/cm. These inputs have measurably increased salinity at Banks during certain low-export, high-rainfall, periods.

Pumping at Banks was curtailed for several months in early 1998 to repair structures throughout the SWP. As a result, very little water was admitted to CCF via the CCF gates. On two occasions in April, a small amount of water was pumped from CCF into the Aqueduct, coinciding with conductivity spikes near 750 µS/cm at Banks (see arrows in Figure 26). The spikes were not caused by water admitted to CCF via the gates because conductivity at the gates outside CCF was ranging between 150 and 350 µS/cm. The low levels were the result of high flow in the San Joaquin that had inundated several south Delta channels with low salinity water (represented by diamonds in Figure 26). Also, the spikes were not caused by water admitted to CCF prior to April; conductivity at the CCF gates remained well below 750 µS/cm during the 3 preceding months. Input from the sump pumps was the only other possible source of salt. A mineralogical analysis supports this.

Between March and April 1998, the mineralogy at Banks became more like that of sump water around CCF. The April sample, collected after the first conductivity spike, had a higher content

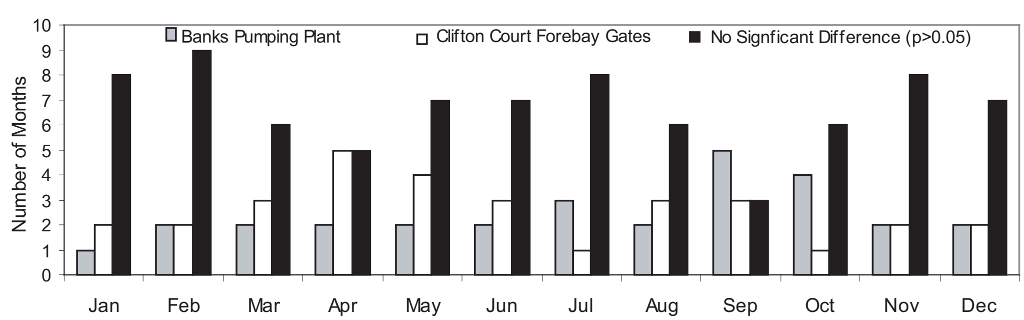


Figure 25. *The number of months when conductivity was statistically higher at Banks Pumping Plant, the Clifton Court Forebay gates, or neither (no statistical difference at p>0.05) are shown from 1990 through 2002.*

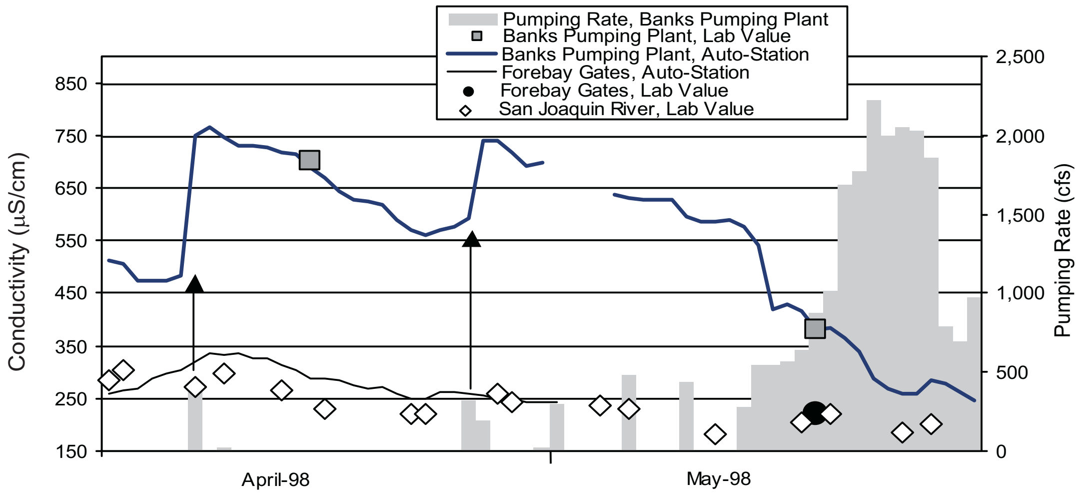


Figure 26. *Daily conductivity trends at Banks Pumping Plant, the Clifton Court Forebay gates, and in the San Joaquin River are shown during April and May, 1998. Shaded areas show the pumping rate at Banks Pumping Plant.*

of sodium and chloride than the preceding month's sample (see circles in Figure 27). Sump pumpage was a possible source since the average cationic content of the sumps was dominated by sodium (and possibly potassium) and the average anionic content of the sumps was dominated by chloride (see gray diamonds in Figure 27). SWP operations and rainfall records confirm the sumps as the most probable source of salt causing the increase in chloride and sodium at Banks between March and April.

Ten inches of rain was recorded near CCF during March through April 1998, resulting in an increase in sump pumpage to CCF. In early March, around 14,000 af were pumped at Banks to draw down levels in CCF for gate repairs. After that, exports came to a virtual halt for 2 months. Records show pumping from the surrounding sumps was above normal for March and early April. Because of the repair work, very little water was in, or admitted to, CCF. A sub-normal volume of water was available to dilute the sump discharges. When a small amount of this mixture was pumped from CCF into the Aqueduct in early April, conductivity at Banks increased from 475 µS/cm to more than 750 µS/cm. Bromide and organic carbon – two other constituents elevated in the surrounding sumps – also increased at Banks, which further implicated sump water as the cause of the conductivity spikes. The mineralogy of water at the CCF gates and in the San Joaquin during May was shown in Figure 27 for comparison (data was not available for April). When exports resumed on a daily basis in May, conductivity at Banks began declining as low salinity water at the CCF gates began diluting the higher salinity water in CCF.

The entire episode resulted in elevated salinity at Banks that did not match conditions in the Delta – salinity at Banks was up to three times higher. A similar episode occurred in February 1995, when heavy local rainfall coincided with pumping curtailments due to floodwater damage in the San Luis Canal. Without accounting for these factors, studies assessing water quality at Banks during these months might have erroneously concluded that salinity in the south Delta was elevated during the high flow period of a wet year.

Long periods of no pumping at Banks have not been consistent from year-to-year. Figure 28 shows the number of days of no pumping per-month between 1990-02. In 1995, there were 4 months when no pumping occurred for 15 days or more in each month (not necessarily consecutive days). The highest number of days of no pumping was in 1998, when pumping ceased for 25 days or more during each of 3 consecutive months (February through April).

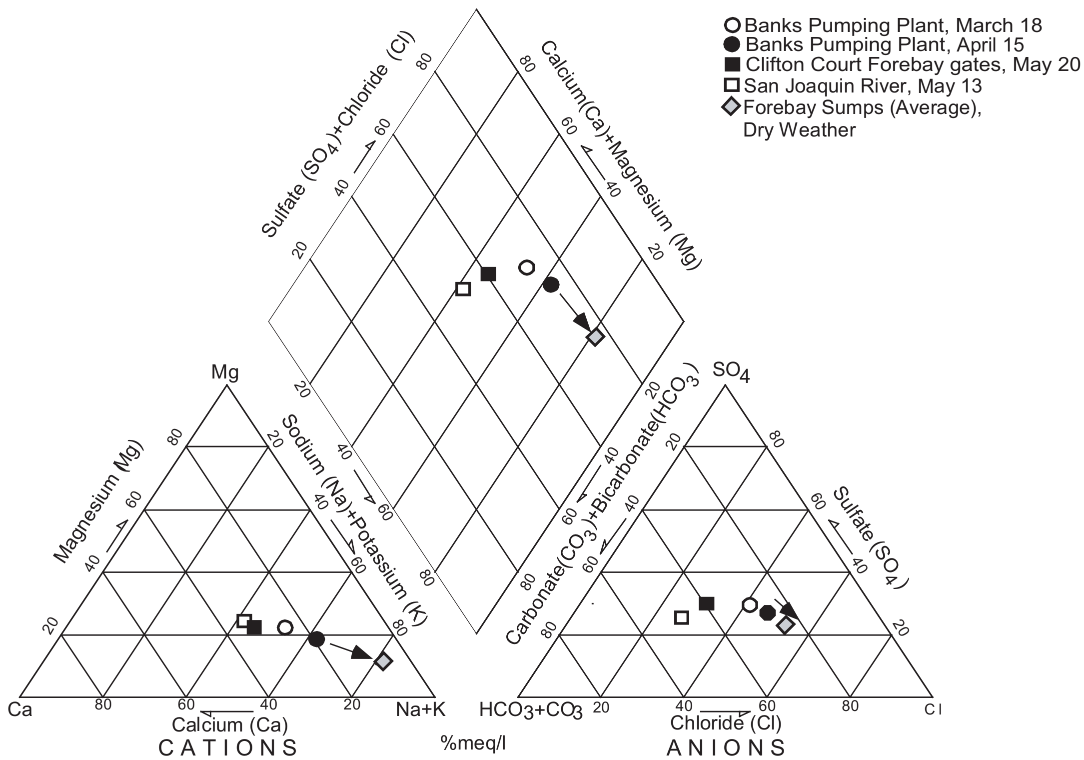


Figure 27. *Piper graph mineralogy is demonstrated at Banks Pumping Plant for March and April, 1998. The arrows show that, between March and April, the mineralogy at Banks Pumping Plant became more like that of the forebay sumps. The mineralogy at the Clifton Court Forebay gates and in the San Joaquin River is shown for May 1998 (April data was not available).*

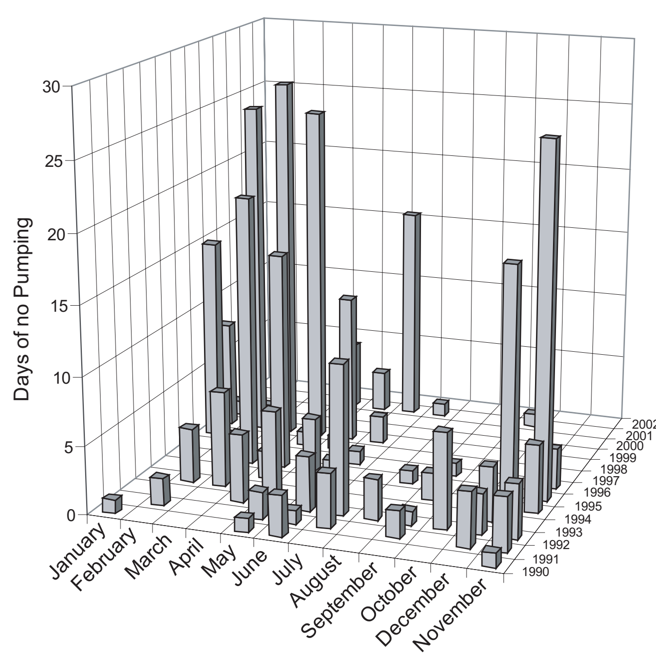


Figure 28. *This chart depicts the number of days per month of no pumping at Banks Pumping Plant from 1990 through 2002.*

In 1995 and 1998 there were 84 and 98 days of no pumping at Banks, respectively (Figure 29). These 2 years contrast with 2000 and 2002, when at least some pumping occurred every day of the year. Both 1995 and 1998 were classified as wet, and pumping was stopped due, in part, to flooding and repair work around the SWP. Pumping at Banks has also been halted for reasons other than flooding and repairs (as reported in Appendix E of DWR's Bulletin 132). These include

- pondweed abatement spraying in CCF
- aqueduct leaks
- maintenance of Rock Slough standard
- other Delta water quality concerns
- high numbers of winter-run-sized salmon, Delta smelt, or splittail salvage
- maintenance of Delta QWEST flow standard
- either scheduled or unscheduled outages at Banks or Skinner Fish Facility

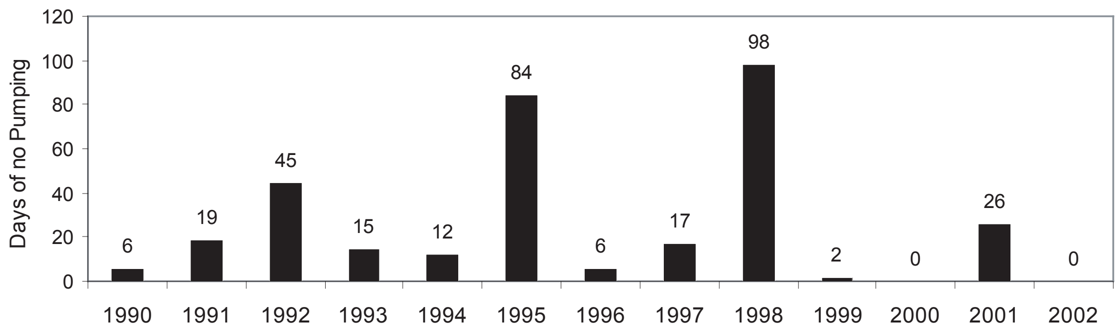


Figure 29. *This chart depicts the number of days per year of no pumping at Banks Pumping Plant from 1990 through 2002*

Although the number of no pumping days at Banks has not been consistent from year to year, sump discharges are consistently higher during wetter years. Figure 30 shows annual sump pumpage was well correlated with annual local rainfall. Consequently, sump discharges are expected to be higher during wetter seasons.

Monthly discharge volumes from all four sump pumps ranged from 18 to 434 af between mid 1986 and 1999, the period of record (estimated from electricity use). The highest volumes were recorded during winter and spring. Discharge volumes were relatively minor compared to what is normally pumped at Banks. Average monthly sump discharges composed from 0.011 to 0.066 percent of the average monthly export volume at Banks (Figure 31). Therefore, sump discharges, on average, composed only a fraction of the total volume of water typically exported at Banks. Figure 31 also shows that sump discharges are most likely to influence conductivity at Banks during February, April, and May, when average sump pumpage was highest relative to pumping at Banks.

Although there have been months when sump discharges have appeared to be significant compared to export volumes – sump discharges made up 7.6 percent of exports in April 1998, and an estimated 28 percent of the salt load – overall salt contributions were actually relatively small. The volume of water pumped at Banks during April 1998 (1,871 acre-feet) was the lowest ever recorded, and well below the average April volume of 126,240 af. The volume of water and the contribution of salt that month were actually very small compared to what is usually sent down the California Aqueduct. The significance of these sumps as sources of unwanted constituents was illustrated with load estimates.

Salt loads were calculated using average sump discharges for April, when sump pumpage has been highest relative to pumping at Banks.

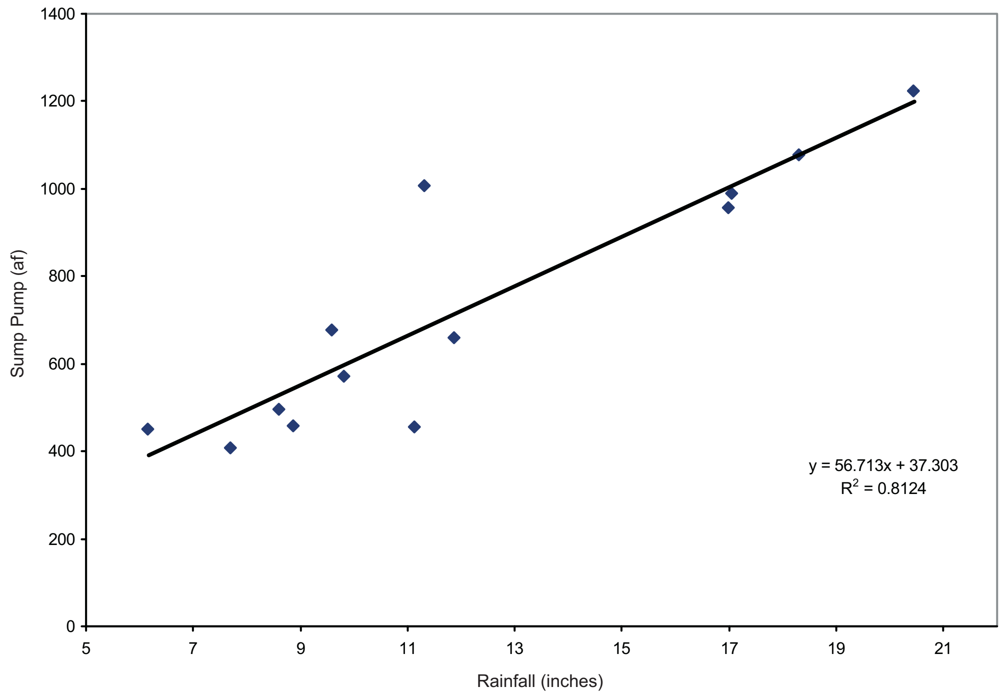


Figure 30. *The relationship between annual rainfall at Tracy Pumping Plant and annual sump pumpage to Clifton Court Forebay is demonstrated.*

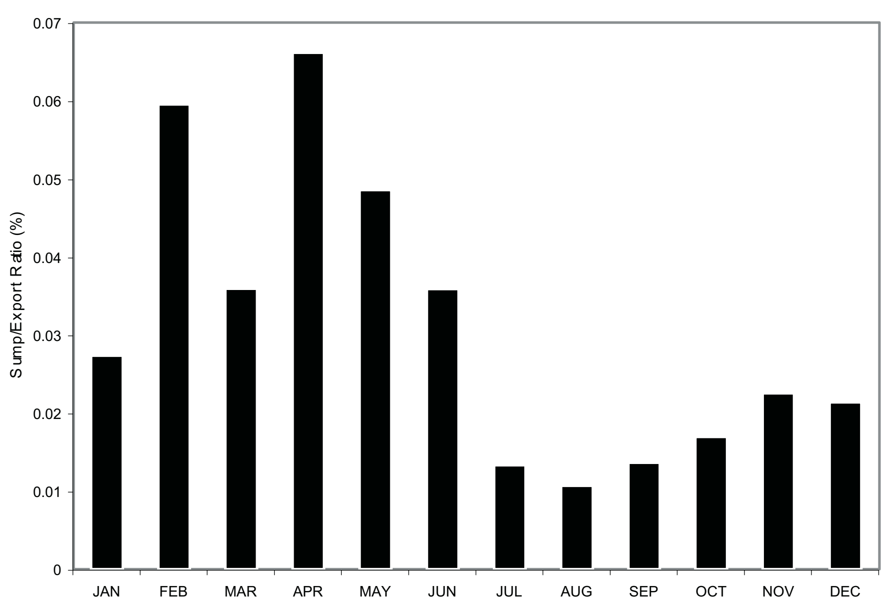


Figure 31. *The monthly average ratio of sump pumpage to Banks Pumping Plant exports is shown in percent.*

Loads were both concentration and flow-weighted since approximately 90 percent of all discharges came from two of the lowest salinity sumps (1,400 and 2,800 µS/cm). Calculations show that the discharges would, on average, increase conductivity at Banks in April by about 2 µS/cm, or 0.3 to 1.2 percent, depending on background levels. This level is near the accuracy claimed by many meter manufacturers. Consequently, during a month when these discharges are expected to be greatest relative to exports, their contribution would be relatively minor. Further, sump discharges during the winter and spring would likely exhibit lower conductivities than those used in these calculations (summer levels) due to dilution from rainfall. This would further reduce their significance as a source of salt and possibly other water quality constituents. However, sump contributions could confound trend analyses at Banks when long periods of limited or no pumping coincide with heavy local rainfall.

Residence Time Through Clifton Court Forebay

In addition to stoppages at Banks, pumping reductions can also influence salinity trends there because of residence time through CCF.

As pumping rates decrease, residence time through CCF increases. As a result, water pumped into the California Aqueduct can be a composite of water admitted to CCF over a period of days or weeks. Similar to stoppages, this can result in a disparity between salinity at Banks and in the south Delta. The May data from Figure 26 illustrates this.

On May 20, 1998, Banks was exporting around 900 cfs (see Figure 26). With capacity information from a 1999 survey of the CCF's bed (Gage 2000, e-mail communication) and a tide of +1 to +1.5 feet, the residence time of water through the CCF was 8 days (at 900 cfs). As export rates increased to 2,000 cfs several days later, the residence time decreased to 4 days. The higher salinity water in CCF was slowly diluted by lower salinity water entering through the CCF gates. So, even though pumping was continuous, more than a week passed before conductivity at Banks matched that at the CCF gates (see Figure 26). During this period, water at Banks represented various mixtures of water from both inside and outside CCF.

Longer residence times can result in greater differences between salinity at Banks and in the south Delta. Because conditions in the south Delta can change rapidly, salinity at Banks at any given time may not be representative of that in the south Delta. Low-salinity water that can accompany high flow conditions in the south Delta during the winter and spring may not be immediately reflected at Banks.

Conductivity at Banks and in the south Delta would be most similar during periods of elevated pumping. Residence time is about 1 day with a sustained tide of +1 foot and a pumping rate of about 6,600 cfs. Therefore, salinity trends at Banks would be most representative of those at the CCF gates when pumping is highest. Pumping at Banks has generally been highest during July through March (Figure 32). Although pumping rates can change dramatically within any given month, the effects of residence time through CCF would be most likely during months of lowest average pumping (April-June). Residence times calculated above may not apply for all years since sedimentation and periodic dredging would alter the capacity of, and thus travel rates through, CCF.

Pumping at Banks has been reduced for a variety of reasons other than those reported above for stoppages (Appendix E of DWR's Bulletin 132). These include

- fisheries experiments
- Bay-Delta Plan spring pulse flow restrictions (April through June)
- Vernalis Adaptive Management Plan restrictions (mid April to mid May)
- maintenance of X2 compliance
- exports generally limited to 35 percent of Delta inflow (February through June)

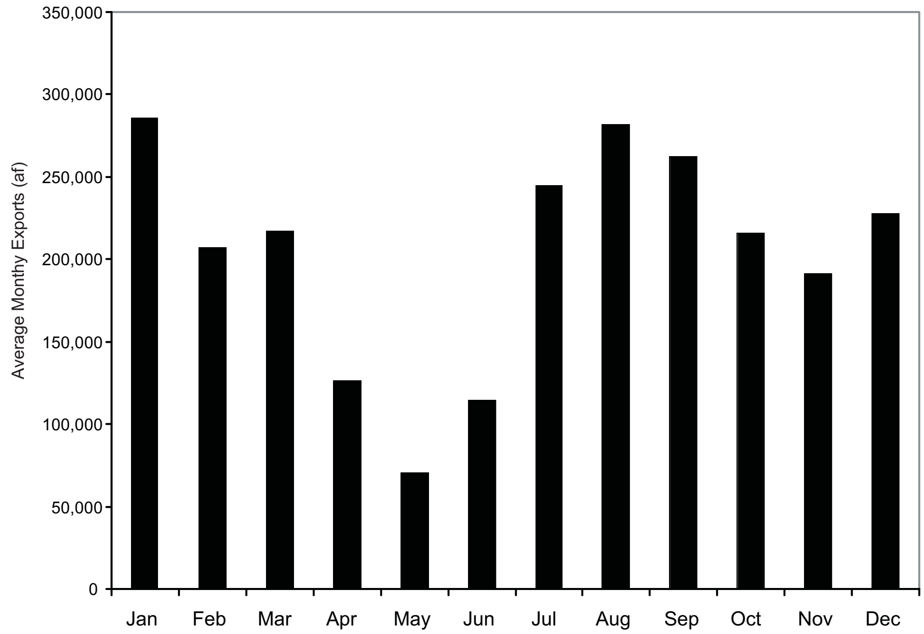


Figure 32. *The average monthly export rate is shown for Banks Pumping Plant from 1990 through 2002.*

Delta Cross Channel Gates

Monthly salinity at Banks was roughly correlated with total Delta inflow during months when the Delta Cross Channel gates are usually open. Gates are typically open from June 15 to October unless conditions such as high flow in the Sacramento River are encountered (SWRCB 1995). Conductivity declined with increasing Delta inflow in a curvilinear relationship (Figure 33A).[16] This curvilinear relationship between salinity and Delta inflow has also been determined at a number of different locations in the Delta (DPW 1931). Several of the lowest conductivity measurements were made when San Joaquin River flow was above 7,370 cfs, inferring that exports were largely composed of water from that river. Since this relationship was shown earlier, these values were removed from the graph. Plotting the remaining data with log-transformed Delta inflow values to induce linearity, the linear relationship was statistically significant ($p<0.05$) (Figure 33B).

This relationship makes sense from two standpoints. First, pumping reductions and stoppages would be least likely when export demand is high – summer and fall. As a result, the CCF gates would be operated to maximize exports, increasing the potential for salinity at Banks and in the south Delta to be similar due to the shorter residence times through CCF. Secondly, with limited closure of the Delta Cross Channel gates, flow conditions across the Delta may be allowed to stabilize, eliminating another potential variable affecting conductivity trends system-wide.

16 Total Delta inflow estimates from DWR's Dayflow database.

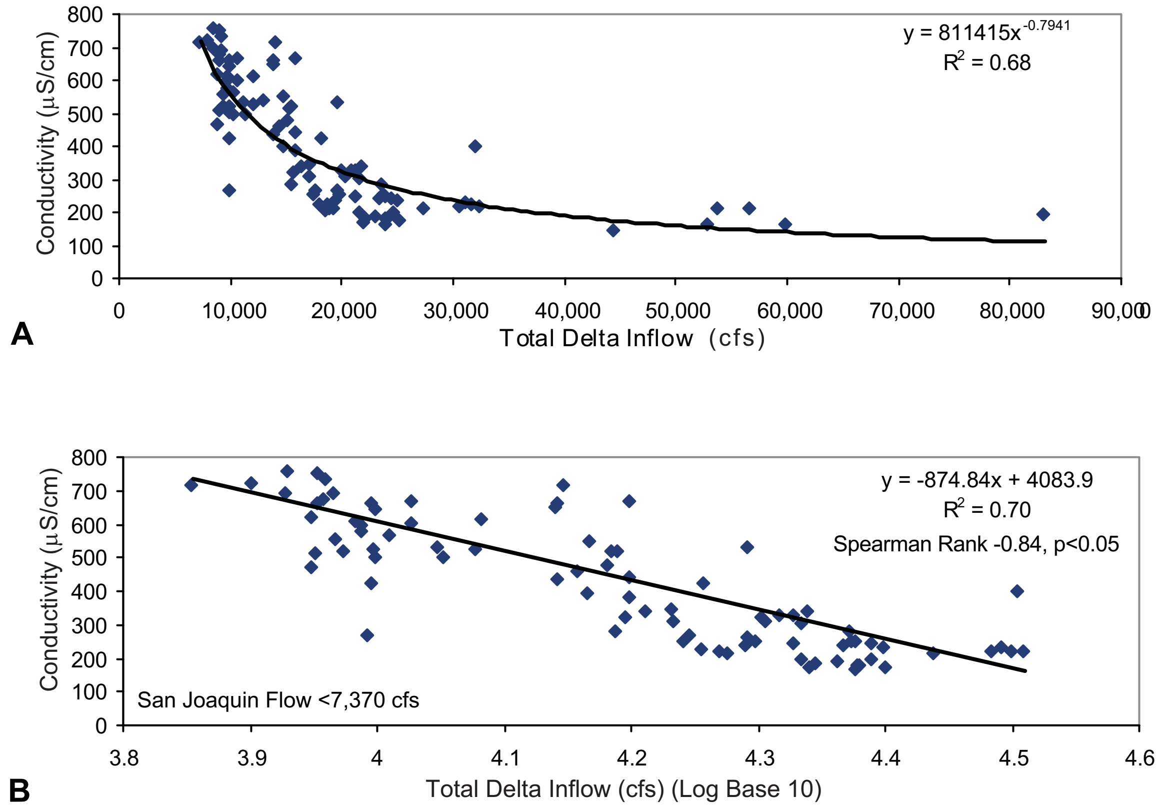


Figure 33. 33A *shows the relationship between conductivity at Banks Pumping Plant and total Delta inflow (from Dayflo). Conductivity data used in this graph was collected between June 15 and the end of October (1990 through 2002). The Delta Cross Channel gates are typically kept open during this time of the year.* **33B** *is a log-transformed version of the same relationship excluding data collected when San Joaquin River flow was 7,370 cfs or more.*

6. Long-Term Conductivity Trends in State Water Project Exports

The SWP began exporting water from the South Delta in 1962 for the South Bay Aqueduct and in 1967 for the California Aqueduct. Figure 34 shows monthly conductivity over a 41-year period from 1962 to 2002. The most striking feature is the high conductivity measured in 1977 when California experienced the driest season of record (DWR 1981).

Salinity intrusion during the summer and fall of 1977 induced rising conductivity in exports as freshwater inflow to the Delta dwindled. Freshwater inflow is inversely correlated with salinity in the Delta and, along with tide, is a major factor governing salinity intrusion events (DPW 1931). During the first few months of 1977, it was apparent that upstream storage was insufficient to meet regulatory standards in the Delta that year while leaving enough carryover for minimum Delta needs the following year (DWR 1981). Regulatory standards had to be changed twice during that year to accommodate the unusually high salinity levels. A third and final set of standards – Water Right Decision 1485 – was approved the following year and remained in place for almost 22 years, when it was succeeded by D-1641 in December 1999.

Although 1977 was the driest year of record, there were 6 years between 1920 and 1940 when

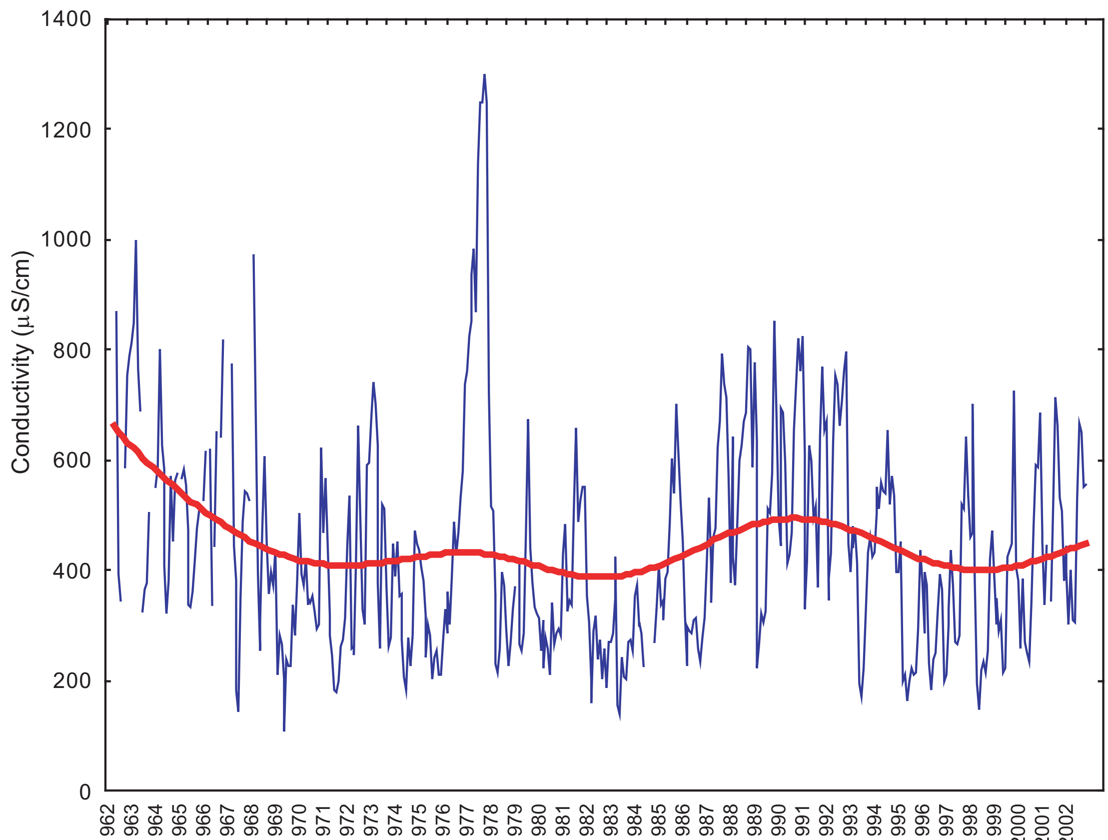


Figure 34. *Monthly average conductivity in State exports is shown from 1962 through 2002.*

salinity intrusion was greater than in 1977. The most extreme salinity intrusion event occurred in 1931 when the 1,000 mg/L chloride line – an indicator of maximum salinity intrusion – went as far east as Stockton, about 8 miles further into the Delta than in 1977 (DWR 1995).

Enlargement of the Delta's tidal prism, the volume of water in the basin between the levels of high and low tides, was thought to contribute to these earlier salinity intrusion events (DPW 1931, DWR 1991). Tidal prism enlargement was the indirect result of a series of dredging projects and flooding events between 1910 and 1933, including:

- extensive widening and deepening of the Sacramento River between Collinsville and Isleton, in part for improved shipping access;
- removal of a Panama Canal-sized portion of soil to straighten out the Sacramento River at Horseshoe Bend, just downstream from Rio Vista;
- dredging to create the San Joaquin River Deep Water Ship Channel;
- dredging in the Sacramento River between the Delta and Sacramento for flood protection and land reclamation (dredging was undertaken, in part, to remove debris deposited from hydraulic mining conducted in the late 1800s); and
- flooding of lower Sherman Island and another island near Dutch Slough in the west Delta.

Tidal flow into the Delta gradually increased during this period (1910-1933). A greater volume of bay water flowed into the Delta with incoming tide. Mixing at the salt/fresh-water interface (tidal diffusion) also increased. Salinity intrusion began occurring earlier in the season at any given location within the Delta. Before these dredging projects and flooding events, the extent of tidal action on the Sacramento River was observed as far upstream as river mile 42. After these events, the extent of tidal action was observed as far upstream as river mile 79, 20 river miles upstream from Sacramento.

Sediment deposition has since decreased the capacity of some channels in the Delta (DWR 1991). Conversely, various dredging projects around the Delta (e.g., creation of the Sacramento Deep Water Ship Channel in 1963) and natural scour have increased the capacity of other channels.

Another important factor contributing to these earlier intrusion events was a reduction in freshwater inflow to the Delta. Upstream agricultural diversions in the Sacramento and San Joaquin Valleys increased from 2.8 to 5.1 million af between 1910 and 1929 due, in part, to increased rice growing in the Sacramento Valley (DPW 1931). During the same period, upstream reservoir capacity in the combined river system increased more than 10-fold to 4.1 million af. These diversions resulted in an estimated net decrease in Delta inflows during summer and early fall, increasing the extent and degree of salinity intrusion in the Delta (DPW 1931). This was compounded by 11 dry or critical water years between 1920 and 1940, resulting in an extended period of subnormal river flow in the Sacramento Valley, the largest source of freshwater to the Delta (Figure 35). The combined effect of upstream diversions and low runoff was a substantial reduction in freshwater inflow to the Delta during this period. Salinity intrusion in the Delta was roughly equal to, or greater than, that occurring in 1977 during 14 of the 21 years from 1920 through 1940 (DWR 1995).

Smoothed line analysis shows extended periods of relatively high conductivity in SWP exports during the early 1960s and 1990s (see Figure 34). SWP exports began in 1962, a below normal water year following 3 dry or below-normal years in the Sacramento Valley (Figure 35). Conductivity gradually declined through the mid 1970s as the Sacramento Valley experienced a series of wet water years. Conductivity in SWP exports was highest in 1977, the second of two back-to-back critical water years. However, 1976 and 1977 were preceded and followed by a number of wet or above normal water years, resulting in a relatively short period of high conductivity. Another period of relatively high

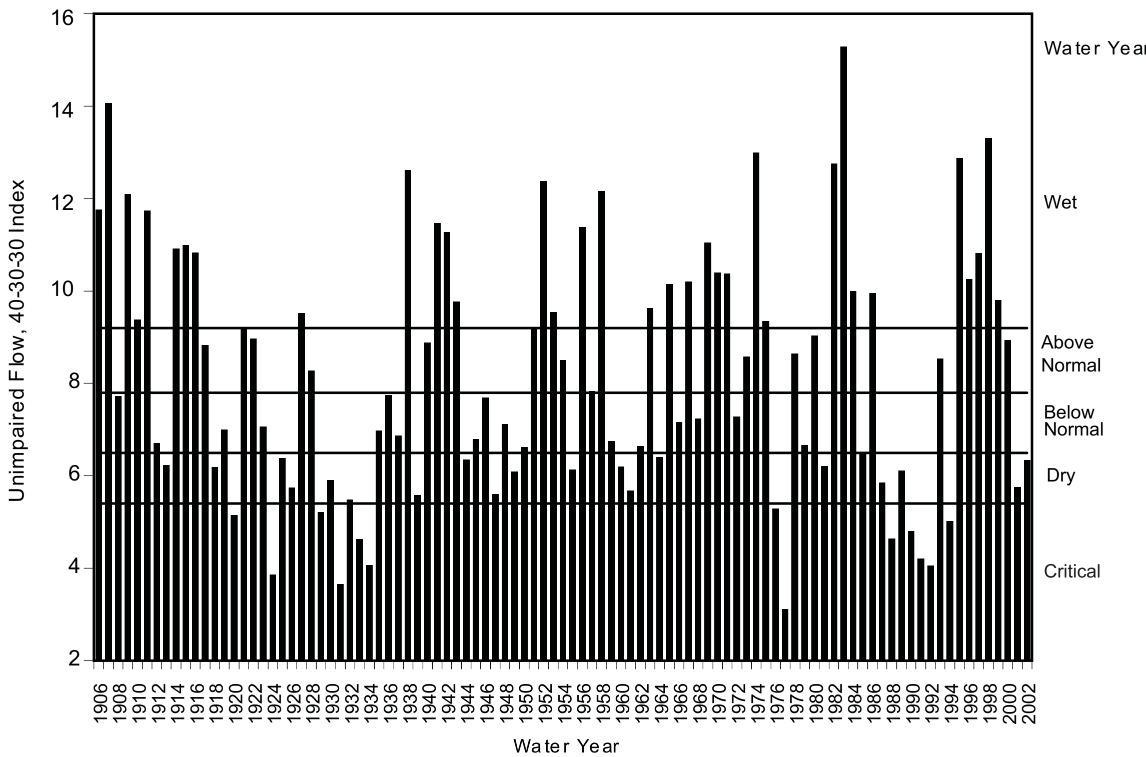


Figure 35. *The Sacramento Valley 40-30-30 Index from 1906 to 2002. The index is the sum of 40 percent of the current year's April-July unimpaired runoff, 30 percent of the current year's October-March unimpaired runoff, and 30 percent of the previous years Index with a cap of 10.0 million acre-feet.*

conductivity occurred during 1987-92 when the Sacramento Valley experienced 6 consecutive dry or critical water years, almost identical to conditions observed between 1929 and 1934 (Figure 35). Although this 40-year analysis represents the entire duration of SWP exports, the intake location was changed twice prior to 1970, potentially affecting salinity trends.

SWP exports down the South Bay Aqueduct were initially diverted from the Delta-Mendota Canal at the headworks of Tracy (see photo inside front cover). After completion of the Delta Pumping Plant in 1967 (later named H. O. Banks Pumping Plant), Italian Slough was the interim intake location pending completion of CCF in December 1969 (DWR 1974b) (see photo inside front cover). Salinity trends prior to this date may not be comparable to current ones due to the potential for hydrodynamic differences and gate operations to affect salinity trends.

Monthly salinity trends at Banks were assessed using data from 1970 to 2002. Median monthly conductivity exhibited a declining trend for the first 6 months from 446 µS/cm in January to 305 µS/cm in July (Figure 36). Median conductivity generally increased after July reaching a high of 536 µS/cm in December.

The previous figure shows the highest conductivities and some of the widest percentile ranges were measured in September through December. This is significant since water year, as opposed to calendar year, starts on October 1. If a wet water year follows an especially dry one, the first few months of the wet year could exhibit uncharacteristically high salinities. The reverse could also occur. For example, the highest conductivities ever measured at Banks occurred during October through December 1977, the first 3 months of a wet water year. This effect was observed when assessing annual salinity trends at Banks.

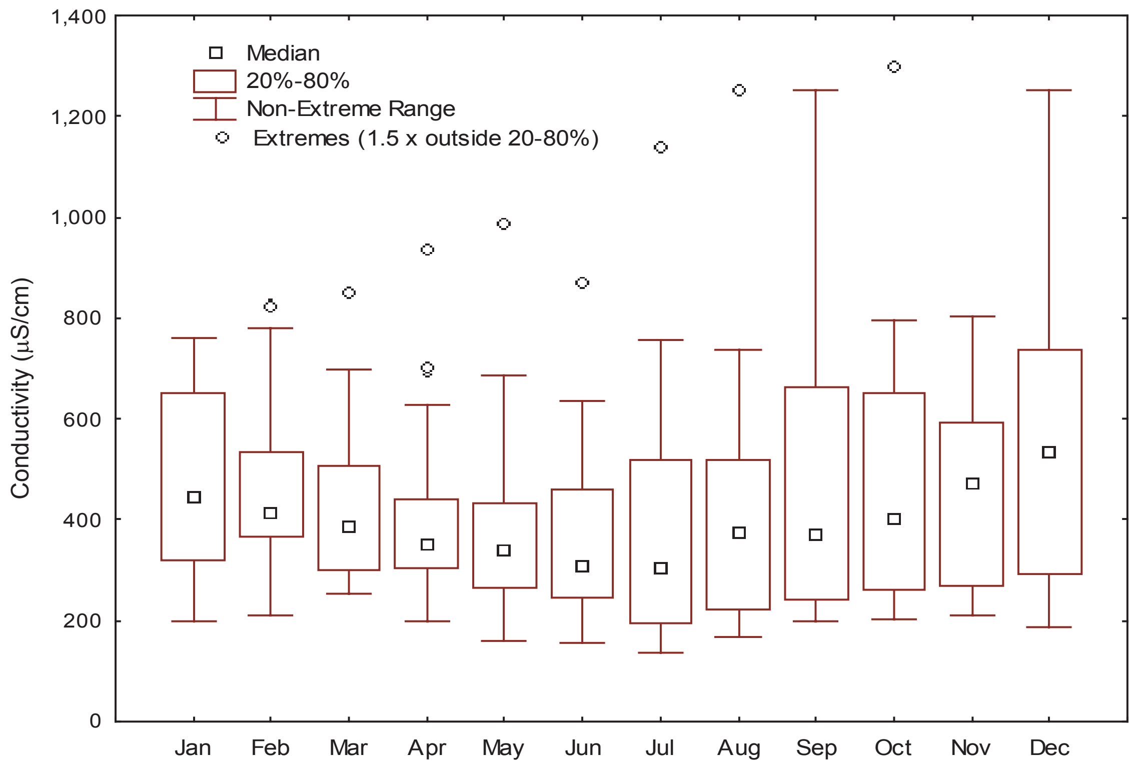


Figure 36. *Monthly conductivity trends at Banks Pumping Plant are shown from 1970 through 2002.*

Long-term salinity trends at Banks were assessed from 1970 to 2002 using annual averages to remove seasonal effects. Annual conductivity at Banks, calculated by calendar year, was well correlated with the sum of the water year indices for the Sacramento and San Joaquin Rivers (Figure 37A). Water year indices are calculated using a formula that incorporates both unimpaired runoff from major watersheds and the preceding year's index (DWR 2003). Calendar year conductivity averages (January through December) were better correlated with water year indices than water year averages (October through September). This is probably due to the higher salinity levels that can be measured at the end of a dry water year during October through December, the start of the next water year. A log-transformed graph of the same, to induce linearity, was statistically significant (Figure 37B). This last figure shows that annual average conductivity at Banks has varied by about 370 µS/cm between any given year, excluding 1977.

Linear regression of the annual data with time shows a positive slope of 0.585, possibly indicating a slight increase in conductivity over the 33-year period from 1970 to 2002 (Figure 38). However, the slope of the line was not statistically different from a slope of zero ($p>0.1$).[17] Consequently, there is little convincing evidence that annual salinity in SWP exports have either increased or decreased between 1970 and 2002.

17 Theil's Method

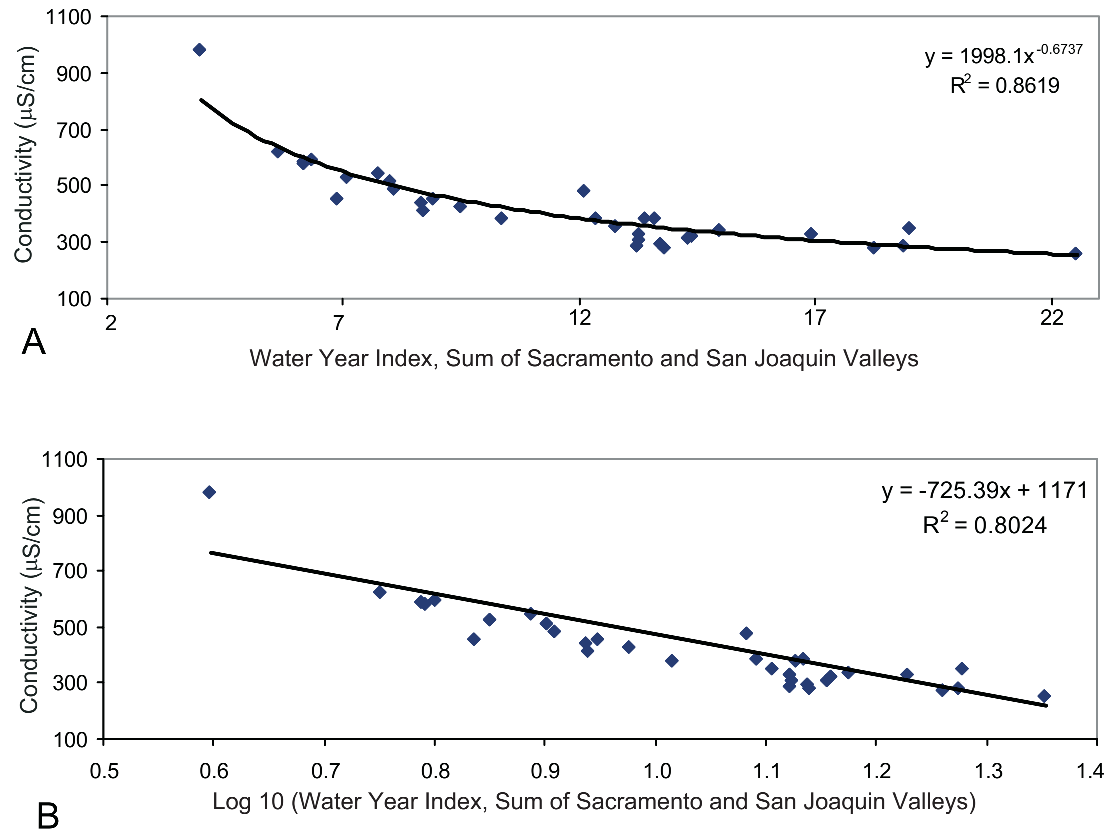


Figure 37. 37A *shows the relationship between the sum of the Sacramento and San Joaquin Valley indices and annual average conductivity at Banks Pumping Plant from 1970 through 2002.* **37B** *shows the same relationship with a log transformed x-axis and least-squares regression.*

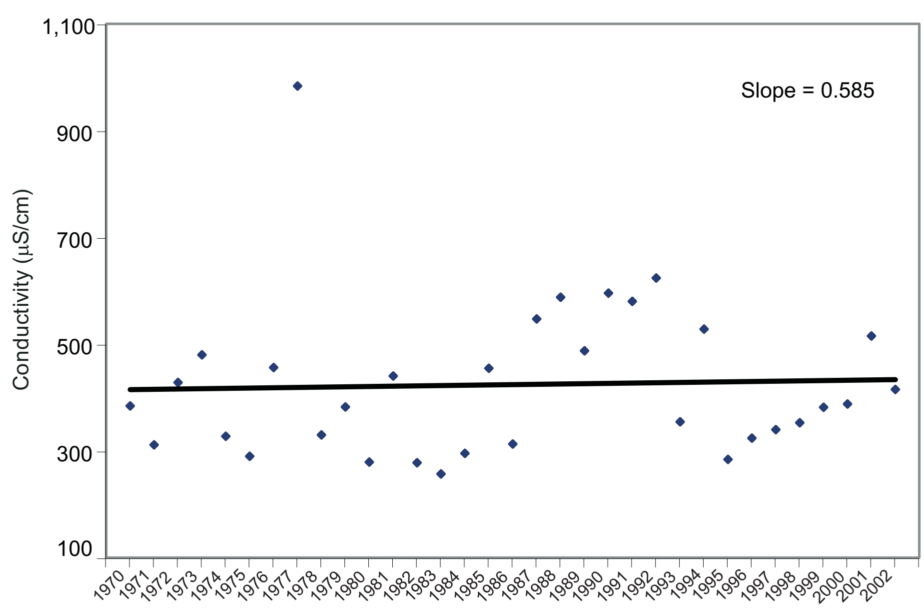


Figure 38. *Annual average conductivity at Banks Pumping Plant from 1970 through 2002. The slightly positive slope of the least-squares regression was not statistically different from a slope of zero.*

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Appendix A

Salinity in fresh water is often expressed as total dissolved solids, or TDS. Although TDS is useful for calculating loads, the measurement can be prone to numerous sources of variability. Measuring mass by drying and weighing may volatilize some ionic components such as carbonates (Anonymous 1995). Further, DWR has been desiccating TDS samples at 180 degrees C since 1960. Prior to this, it was 105 degrees C. Although the latter samples could simply be eliminated, such a complete history of methodology does not exist for non-DWR data. Variability can also be introduced during filtration.

Non-electrolytes, like silica and metallic colloids, can pass through filters and become part of the TDS measurement (Hem 1985). This could explain why the linear relationship between conductivity – a physically calibrated measure of ionic solutes – and TDS at Castaic Lake exhibits an r-squared value of 0.83. In other words, 17 percent of the variability in Castaic Lake TDS is not explained by salinity. Further, TDS is defined as the portion of solids that pass through 2.0 microns or less (Anonymous 1995). Although most present-day samples are filtered at 0.45 micron, filtering information for historical data does not always exist. Different filter sizes would make samples incomparable. Lastly, filter material has changed over the years, potentially affecting actual pore size and clogging rate. The most precise way to measure salinity is conductivity (Anonymous 1995).

Appendix B

Piper graphs are useful for comparing the mineralogical characteristics of different water bodies. Streams and groundwater usually exhibit a unique content of minerals such as sulfate, chloride, and bicarbonate. Figure B-1 shows the average mineral characteristics of three different water bodies – Salt Creek drainage to the San Luis Canal, south Delta water pumped at Banks, and Feather River water at Thermalito Afterbay. A histogram of the six major minerals and TDS is converted to three points on a Piper graph for each station (plot in Figure B-1). The central diamond plot accounts for all cation/anion combinations together. The circle surrounding each icon is TDS (calculated) on a scale that is provided in the mid-upper left. The larger the circle, the greater it reflects TDS. The two ternary diagrams on the bottom represent the anions (right) and cations (left) in percent of the total ionic equivalent concentration.

The individual anions chloride, sulfate, and bicarbonate are shown in the lower right ternary diagram. At Banks, chloride composes 40 percent of the anionic content followed by bicarbonate (36 percent) and sulfate (24 percent). This compares with Thermalito Afterbay where bicarbonate composes almost 90 percent of the anionic content and Salt Creek in which sulfate is the dominant anion with over 80 percent. The cationic content as shown in the lower left ternary diagram was not as dramatic, with the exception of Thermalito Afterbay, that is dominated by calcium as opposed to the other two water bodies that had similar proportions of sodium+potassium and calcium.

A Piper graph can be used to determine the influence of one water body on another. If there are two icons, A and B, representing two water bodies, then the icon of the mixture will be positioned between A and B. This assumes no chemical interactions upon mixing that might result in the precipitation of any salts. If equal amounts of water from two different water bodies are mixed, the icon of the resulting mixture would be positioned in a straight line between the two source icons in all three diagrams.

Figure B-1
Explanation of a Trilinear Plot.