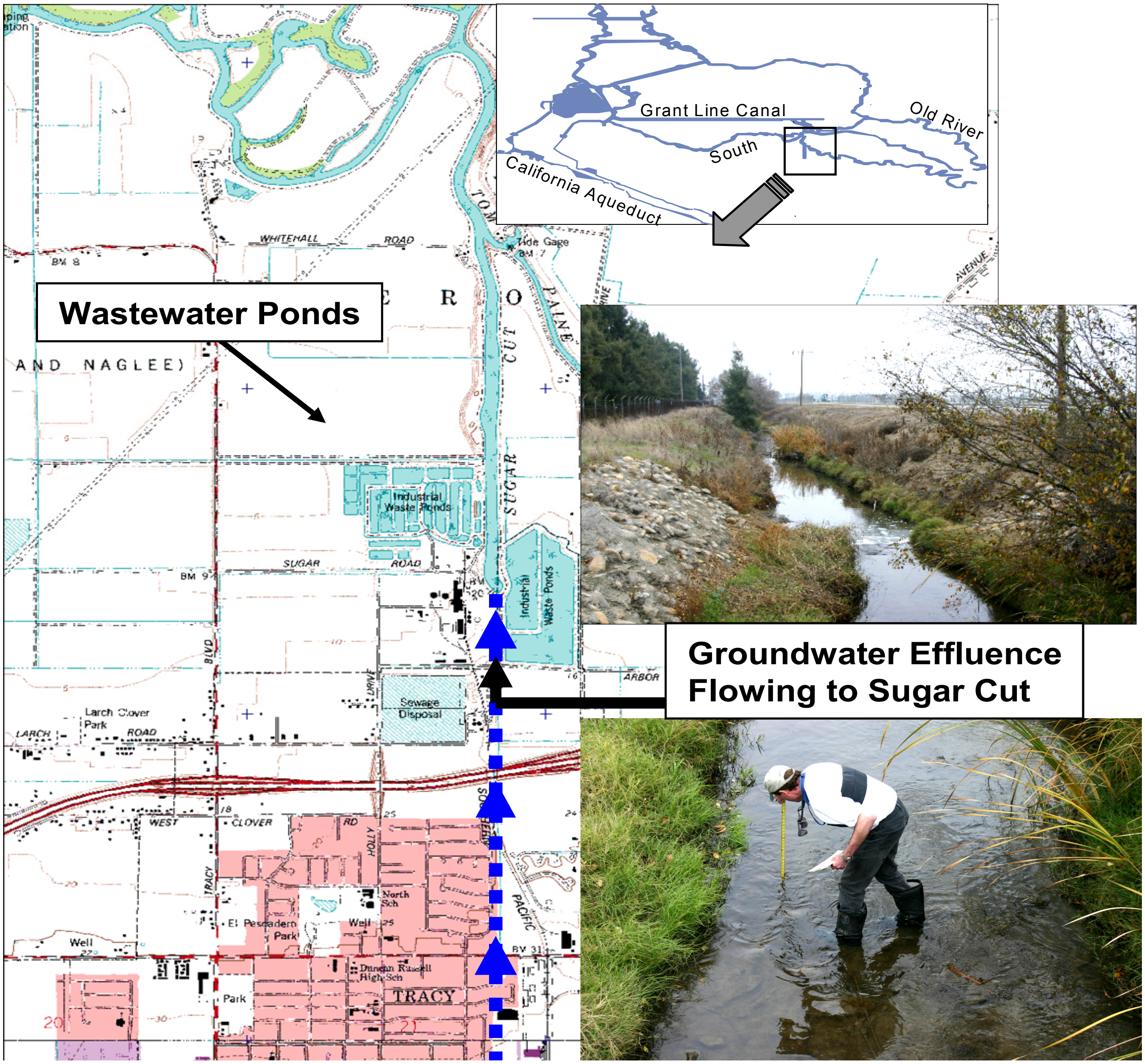
Sources of Salinity in the South Sacramento-San Joaquin Delta

Memo Report
May 2007



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

Cover:
Groundwater effluence flowing to Sugar Cut in an urban runoff channel and accretion from municipal and industrial wastewater ponds are two routes of salt introduction to south Delta waterways. Dry weather conductivity of the groundwater effluence was 2,071 μS/cm.

State of California Department of Water Resources The Resources Agency

OFFICE MEMO

TO: Dean F. Messer, Chief, Environmental Assessment Branch	DATE: 5/30/07
	SUBJECT: Memo Report: **Sources of Salinity in the South Sacramento-San Joaquin Delta**
FROM: Barry L. Montoya, Staff Environmental Scientist	

Summary

Approximately 74 discharge sites are situated along waterways immediately upstream from the State and federal export sites in the south Sacramento-San Joaquin Delta (south Delta). Most are agricultural followed by treated sewage, urban runoff, and groundwater effluence. The discharges are relatively saline and appear to be raising the salinity of water flowing from Vernalis on the San Joaquin River to the export sites via south Old River and Grant Line Canal. This report characterizes the discharges and their influence on salinity between Vernalis and the export sites.

Discharges

Twenty-two agricultural, stormwater, or point-source discharges are located on the 17-mile stretch of San Joaquin River between Vernalis and the head of Old River (James et al. 1989, DWR 1995, National Pollutant Discharge Elimination System [NPDES] permits). From the head of Old River, the distance to Jones (formerly Tracy) Pumping Plant is roughly 21 miles via Old River and 18 miles via Grant Line Canal. Distances to Clifton Court Forebay via both routes are a few miles shorter. Approximately 52 discharge sites are situated along these waterways and their tributaries Tom Paine Slough, Paradise Cut, and Sugar Cut (DWR 1995, Stantec 2003, NPDES permits). Most are agricultural drains with two point-source effluents, four urban runoff outfalls, and groundwater effluence conveyed to Old River in urban/agricultural drainage channels.

Point-Sources: Point-source discharges along the lower San Joaquin River (Vernalis to head of Old River) include municipal wastewater from the cities of Manteca/Lathrop and pit drainage from an historic sand excavation company. Municipal/industrial wastewater from the City of Tracy and Deuel Vocational Institute is discharged to Old River and Paradise Cut, respectively. Discharge volumes from all point-sources average between 0.6 and 5.7 million gallons per day (mgd) with conductivity averages ranging between 1,099 and 1,753 μS/cm (NPDES permits).

Agricultural Drainage: The vast majority of discharge sites along the identified waterways are agricultural. Although agricultural drainage volumes are not routinely reported, two studies measuring or estimating agricultural drainage shows pumping from Delta islands was consistently highest during winter, with a smaller increase during summer (DWR 1956 and 1997). Pumping is increased during winter, in part, to remove precipitation, seepage, and water applied to leach salts. Historic discharge estimates ranged from 0.03 to 0.7 acre-feet per acre during the peak discharge month of January (1955).

Conductivity in south Delta agricultural drains ranges from 350 to 4,500 μS/cm with an overall average of 1,496 μS/cm (Belden et al. 1989, DWR 1990, 1994, and 1999). Agricultural drains in the south Delta are particularly saline compared to others around the Delta (DWR 1967). The extra-saline nature of these drains can be explained by the origin and makeup of the underlying soils. The resident soils in the southernmost portion of the Delta are composed of eroded, heavily mineralized, marine sedimentary rock from the Diablo Range (Davis 1961, DWR 1970).

Groundwater Effluence: Three to four urban/agricultural drainage channels are believed to be conveying saline groundwater to Old River year-round. Groundwater effluence in 3 of these channels exhibited flows between 1 and 2 cubic-feet per second (cfs) and conductivities between 2,100 and 2,600 μS/cm (measurements made for this study).

Upstream/Downstream Salinity

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

A number of factors can explain why conductivity consistently increased between the Vernalis and Old River stations. The sheer number saline discharges (as well as diversions) situated between these two stations provides strong rational for causative effects. The Old River station appears to be especially influenced by saline inputs from Tom Paine Slough, Paradise Cut, and groundwater effluence. This was evidenced by a statistically higher conductivity in Old River than Grant Line Canal during most months of the year. Further, the intake of the Old River water quality station appears to be located in the plume of a nearby saline agricultural discharge(s).

Editorial review: Gretchen Goettl, Supervisor of Technical Publications, and Marilee Talley, Research Writer. Thanks to Dan Peterson and Rob Duvall for their extensive reviews.

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I. Introduction

Background

Water is exported from the south Delta at Banks Pumping Plant and Jones Pumping Plant (Figure 1-1). Water can flow westward to both export sites from the lower San Joaquin River via south Old River (hereafter Old River) and Grant Line Canal. Approximately 74 discharge sites are situated along these and other contributory waterways – most are agricultural drains with a smaller number of point-source, urban runoff, and groundwater inputs. A majority of the discharges are relatively saline and appear to be raising the salinity of water approaching the export sites from the west.

Agricultural drainage within the Delta was recognized as a source of saline water in the inaugural State Water Project (SWP) operations report (DWR 1963). Other more specific water quality observations have suggested that discharges along Old River and Grant Line Canal are increasing the salinity of water flowing to the export sites from the San Joaquin River. Conductivity was consistently higher at Banks Pumping Plant than in the San Joaquin River under certain high flow conditions when State exports were entirely composed of that river (DWR 2004B). The suggested explanation was salinity augmentation by the numerous interjacent agricultural discharges. A similar claim was made in a review of data collected during the 1950s and 1960s concluding that an area of high salinity between Vernalis on the San Joaquin River and the Delta-Mendota Canal was caused principally by agricultural drainage (DWR 1967).

Problem Description

Salinity in south Delta exports is a parameter-of-concern to SWP drinking water contractors. Effects of salt in drinking water above the Maximum Contaminant Level can include hardness, deposits, colored water, staining, or salty taste (USEPA 1992). Although not a major direct concern to human health, salinity can cause other problems for SWP contractors. Elevated salinity in drinking water can:

1. be an indicator of bromide, a disinfection by-product precursor;
2. limit the use of recycled water for groundwater recharge or crop irrigation; and,
3. reduce opportunities for blending with higher-salinity sources.

A list of management actions were developed to promote salinity controls, reductions, and forecasts (Bookman-Edmonston Engineering, Inc. 1999).

Objectives

1. Identify discharges to Old River, Grant Line Canal, and a 17-mile stretch of the San Joaquin River (Vernalis to the head of Old River);
2. Characterize discharge volume and salinity trends; and,
3. Quantify upstream/downstream salinity increases between Vernalis on the San Joaquin River and Old River.

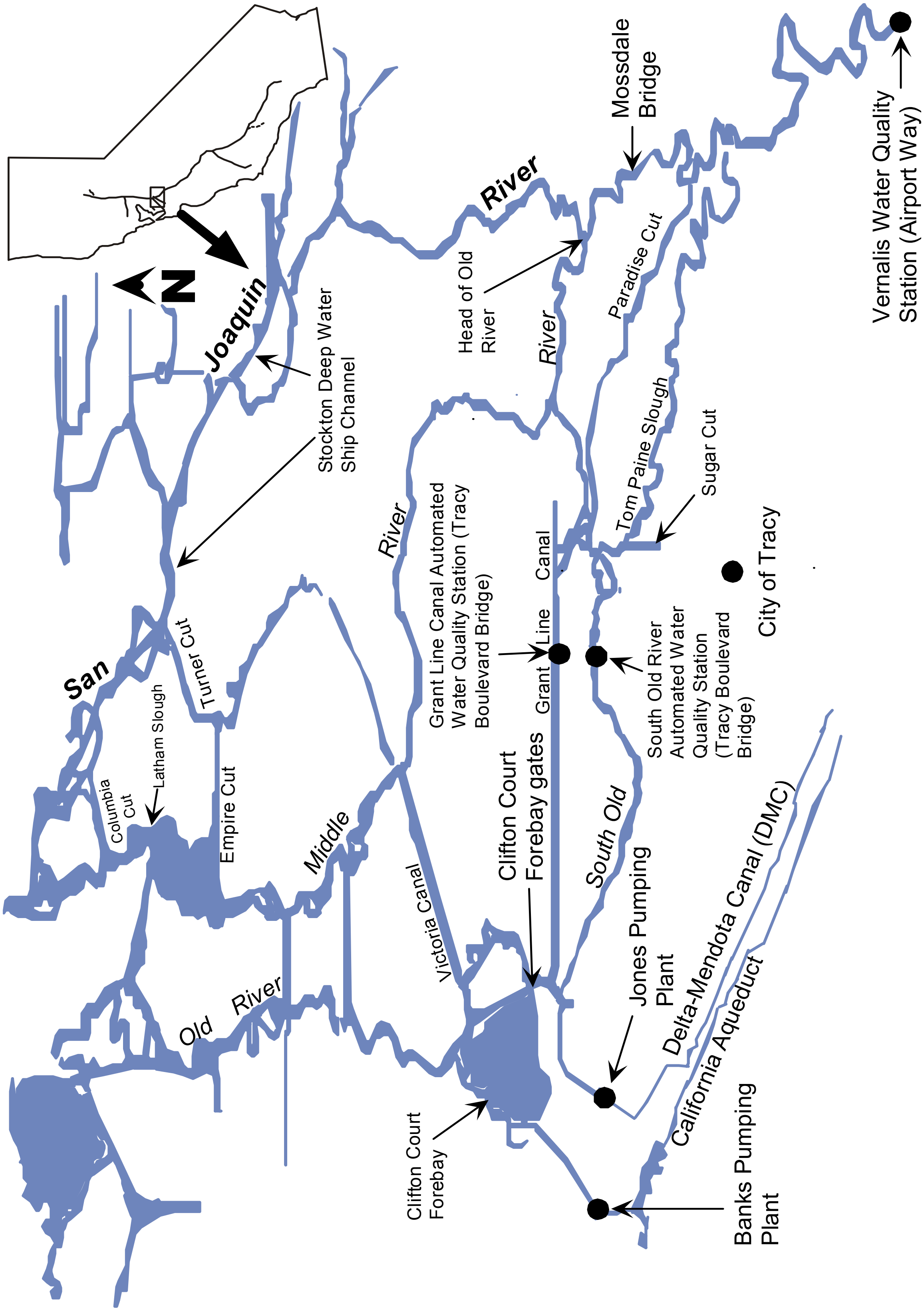


Figure 1-1. Waterways in the south Delta, export sites at Banks Pumping Plant and Jones Pumping Plant, and water quality station locations

II. Discharges

Information on south Delta discharges was obtained largely from existing reports and documents. Discharges to the lower San Joaquin River were separated from those along Grant Line Canal and Old River.

San Joaquin River, Vernalis to the Head of Old River

The distance from Vernalis on the San Joaquin River to the head of Old River is about 17 river miles. Twenty-two discharge sites have been identified along this stretch of river (Figure 2-1 and Table 2-1). Most were described as either stormwater or agricultural with two point-source effluents.

All but two of the agricultural or stormwater discharges were considered relatively insignificant in size, especially when compared to upstream sources (James et al. 1989). The exceptions included two pumps on the east side of the river (station locations SJR13 and SJR16 in Figure 2-1). These 2 pumps discharge surface runoff from about 5,000 acres of agricultural land in Reclamation District No. 2075. Downstream at river mile 63.4, another relatively significant discharge was identified as New Jerusalem Outlet (SJR11). Tile drainage from this source was stated to exceed 25 cubic feet per second (16 million gallons per day [mgd], 1 mgd = 1.55 cfs) throughout most of the year. This drain is particularly saline with conductivities usually above 2,000 μS/cm (CDEC database).

Another potentially major input to the lower San Joaquin River is a watershed of unknown size drained by Walthall Slough (SJR18). The surrounding watershed is mostly agricultural farmland with some minor rural development (from aerial photography at CaliforniaMaps.org). Drainage from Walthall Slough passes through Weatherbee Lake before reaching the San Joaquin River near river mile 57, less than a mile upstream from Mossdale (Figures 1-1 and 2-1 and Table 2-1).

Two point-sources also discharge to the 17-mile stretch of San Joaquin River from Vernalis to the head of Old River. The discharges are relatively saline with conductivities averaging above 1,000 μS/cm. The Cities of Manteca and Lathrop jointly discharge municipal wastewater at river mile 56.8 (SJR19) (Figure 2-1 and Table 2-1). Outflows average 5.72 mgd with a maximum of 6.29 mgd (CVRWQCB 2004B).

A sand excavation company (Brown Sand, Inc.) historically discharged groundwater seepage and excess stormwater to the San Joaquin River from an adjacent mining pit (SJR20) (CVRWQCB 2005A). The discharge is located near the effluent of the previous point-source. Mining operations were idled in 2001 and the excavation pit was converted to Oakwood Lake for a water and mobile home park along with neighboring campgrounds. The discharges continued, however, to maintain water levels in Oakwood Lake. Discharges between January 2001 and December 2004 averaged 6.2 mgd with a maximum of 15.3 mgd.

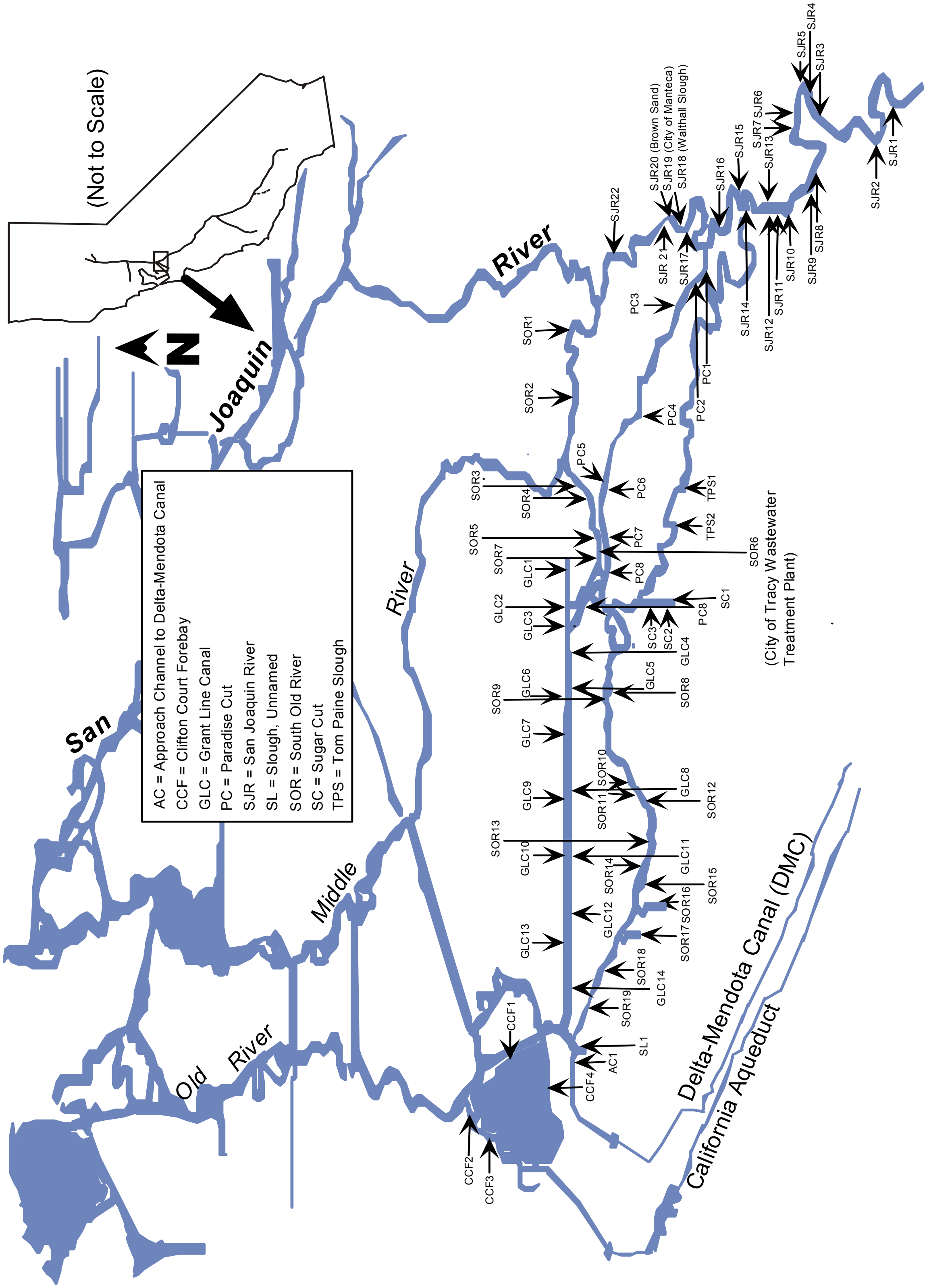


Figure 2-1. Approximate location of discharges on south Delta waterways. Individual discharges are identified and described in alphabetical order in Table 2-1.

Table 2-1. Description of discharges on south Delta waterways

Receiving Water	Discharge Identification	Areal Location Source 1/	Discharge Description 2/	Water Quality Data ?
Approach Channel to Tracy Pumping Plant on the Delta-Mendota Canal	AC1	A	Drainage Pumping (one or more)	-
Clifton Court Forebay	CCF1	B	Drainage Sump Pump between Levee and Forebay Embankment	Y
	CCF2	B	Drainage Sump Pump between Levee and Forebay Embankment	Y
	CCF3	B	Drainage Sump Pump between Levee and Forebay Embankment	Y
	CCF4	B	Agricultural Drainage Sump Pump	Y
Grant Line Canal (or Fabian and Bell Canal)	GCL1	A	Drainage Pumping (one or more)	Y
	GCL2	A	Drainage Pumping (one or more)	Y
	GCL3	A	Drainage Pumping (one or more)	Y
	GCL4	A	Drainage Pumping (one or more)	-
	GCL5	A	Drainage Pumping (one or more)	Y
	GCL6	A	Drainage Pumping (one or more)	-
	GCL7	A	Drainage Pumping (one or more)	Y
	GCL8	A	Drainage Pumping (one or more)	Y
	GCL9	A	Drainage Pumping (one or more)	-
	GCL10	A	Drainage Pumping (one or more)	-
	GCL11	A	Drainage Pumping (one or more)	Y
	GCL12	A	Drainage Pumping (one or more)	-
	GCL13	A	Drainage Pumping (one or more)	Y
	GCL14	A	Drainage Pumping (one or more)	-
Paradise Cut	PC1	F	Deuel Vocational Institute Wastewater Discharge	Y
	PC2	C	Paradise Mutual	Y
	PC3	A	Drainage Pumping (one or more)	-
	PC4	A, C	Pescadero	Y
	PC5	A, C, D	Stewart Tract	Y
	PC6	A, C, D	Pescadero, Pescadero RD pump	Y
	PC7	A, C, D	Pescadero, Pump west of Tom Paine Slough	Y
	PC8	A, C, D	Pescadero, Pescadero RD pump	Y
San Joaquin River	SJR1	E	Natural Drain, RM 72.2	-
	SJR2	E	SJRiver Club Drain, RM 70.0	-
	SJR3	E	Intake Pump & Discharge Pump, RM 68.1	-
	SJR4	E	Drainage Pump, 67.4	-
	SJR5	E	Intake Pump & Drainage Pump, 67.1	-
	SJR6	E	Drainage Pump, 66.4	-
	SJR7	E	Field Drain and & Old Pump Station, RM 66.3	-
	SJR8	E	Tail Water Pump, RM 64.5	-
	SJR9	E	Drainage Discharge Pump, RM 64.5	-
	SJR10	E	Tail Water Pump, RM 63.6	-
	SJR11	E	New Jerusalem Tile Drain, RM 63.4	-
	SJR12	E	Drainage Discharge Pump, RM 63.2	-
	SJR13	E	Discharge Pump, RM 63.1	-
	SJR14	E	Tail Water Pump, RM 62.5	-
	SJR15	E	Intake Pump & Oxbow Lake Drain, RM 62.4	-
	SJR16	E	Discharge Pump, RM 62.0	-
	SJR17	E	Tail Water Drain, RM 57.3	-
	SJR18	E	Weatherbee Lake Discharge (Walthall Slough), RM 57.1	-
	SJR19	G	City of Manteca Wastewater Discharge, RM 56.8	Y
	SJR20	H	Brown Sand Groundwater Dewatering Discharge, D/S RM 56.8	Y
	SJR21	A	Drainage Pumping (one or more)	-
	SJR22	A	Drainage Pumping (one or more)	-
Slough, Unnamed	SL1	A	Drainage Pumping (one or more)	-
South Old River	SOR1	A	Drainage Pumping (one or more)	-
	SOR2	A	Drainage Pumping (one or more)	-
	SOR3	A	Drainage Pumping (one or more)	Y
	SOR4	A	Drainage Pumping (one or more)	Y
	SOR5	A	Drainage Pumping (one or more)	Y
	SOR6	I	City of Tracy Wastewater Discharge	Y
	SOR7	A	Drainage Pumping (one or more)	Y
	SOR8	A, K	Drainage Pumping (one or more)	Y
	SOR9	A	Drainage Pumping (one or more)	Y
	SOR10	A	Drainage Pumping (one or more)	-
	SOR11	A	Drainage Pumping (one or more)	-
	SOR12	A, J	Drainage Pumping (one or more), Urban Runoff	Y
	SOR13	A	Drainage Pumping (one or more)	Y
	SOR14	A	Drainage Pumping (one or more)	-
	SOR15	A	Drainage Pumping (one or more)	-
	SOR16	J, K	Urban Runoff, Groundwater Effluence, Agricultural Drainage	-
	SOR17	K	Urban Runoff, Groundwater Effluence, Agricultural Drainage	Y
	SOR18	A	Drainage Pumping (one or more)	-
	SOR19	A	Drainage Pumping (one or more)	-
Sugar Cut	SC1	J, K	Urban Runoff, Groundwater Effluence, Agricultural Drainage	Y
	SC2	A	Drainage Pumping (one or more)	-
	SC3	A	Drainage Pumping (one or more)	-
Tom Paine Slough	TPS1	D	Pescadero RD	Y
	TPS2	D	RD 1007 / RD 2058	Y

1/ Sources
A: DWR 1995
B: Unpublished DWR Operations & Maintenance surveys
C: DWR 1990, 1994, and 1999 MWQI data query request
D: Belden et al. 1989
E: James et al. 1989
F: CVRWQCB 2004A and 2003
G: CVRWQCB 2004B
H: CVRWQCB 2005A
I: CVRWQCB 2006
J: Stantec 2003
K: Visual Inspection

2/ San Joaquin River miles accordant with U.S.ACE 1984

Head of Old River to the Export Sites

The distance from the head of Old River to Jones Pumping Plant is roughly 21 miles via Old River and 18 miles via Grant Line Canal. Distances to Clifton Court Forebay via both routes are a few miles shorter. Approximately 52 discharge sites are situated along these waterways and their tributaries Tom Paine Slough, Paradise Cut, and Sugar Cut (Figure 2-1 and Table 2-1). Most of the discharges are agricultural with elevated conductivities averaging between 900 and 2,600 µS/cm (discussed in next section).

The location of most agricultural discharge sites were duplicated from DWR 1995 (Delta Atlas). The Delta Atlas footnotes each location as "one or more," and as such, the arrow indicators in Figure 2-1 may represent individual discharge pumps or several in close proximity. Therefore, the number and placement of agricultural discharge sites along the waterways of Old River, Grant Line Canal, and their tributaries in Figure 2-1 are considered approximations.

Three sump pumps are situated around Clifton Court Forebay (CCF1 to CCF3) to remove seepage and accumulated rainfall from between the Delta levees and the forebay embankment (Figure 2-1 and Table 2-1). A fourth pump intercepts farmland runoff from south of the forebay.

The pumps around Clifton Court Forebay, by themselves, have been shown to be relatively minor. Estimated pumpage from electricity records indicate that all four pumps comprised less than 0.5 percent of the monthly pumping at Banks Pumping Plant during all but 5 months between 1986 and 1999 (available data) (Table 2-2). These sumps measurably affected export water quality during April 1998 when sump pumpage composed a period maximum 7.6 percent of the total volume pumped at Banks Pumping Plant (DWR 2004B). An increase in salinity, bromide, and organic carbon was geochemically associated with sump drainage that month. April 1998 was one of several consecutive months when Banks Pumping Plant was rarely idled due to heavy rainfall around the State and an abundance of water sources alternative to south Delta exports. Although unwanted water quality parameters increased at Banks Pumping Plant that month, very little water was moved south, and hence, the accompanying loads were similarly small. Although the forebay sump pumps, by themselves, are relatively minor, they do contribute to the cumulative influence of all sources of salt in the south Delta.

The City of Tracy and Deuel Vocational Institution discharge municipal wastewater to Old River (SOR6) and Paradise Cut (PC1), respectively. Discharges from the City of Tracy average 7.09 mgd with a maximum 9.4 mgd (CVRWQCB 2006A). The city is proposing to increase it's effluent rate to 16 mgd (PMI 2001). Discharges from Deuel Vocational Institution average 0.589 mgd with a wet weather allowable limit of 0.783 mgd (CVRWQCB 2003, 2004A, and 2005B). Both of these point-sources are relatively saline with conductivities ranging from 1,000 to 2,400 µS/cm (discussed in next section).

Table 2-2. Percent of monthly sump pumpage to Clifton Court Forebay (CCF1-4) pumped at Banks Pumping Plant (estimated from electricity records with an efficiency correction)

	Percent of Sump Pumpage at Banks Pumping Plant, %											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1986					0.025	0.017	0.010	0.006	0.006	0.018	0.016	0.027
1987	0.028	0.041	0.027	0.024	0.014	0.032	0.008	0.008	0.011	0.050	0.050	0.015
1988	0.004	0.014	0.008	0.039	0.039	0.030	0.012	0.009	0.022	0.014	0.015	0.013
1989	0.014	0.014	0.014	0.016	0.018	0.029	0.006	0.007	0.004	0.013	0.007	0.015
1990	0.005	0.010	0.012	0.019	0.061	0.244	0.027	0.014	0.017	0.019	0.026	0.019
1991	0.030	0.061	0.015	0.021	0.066	0.064	0.067	0.022	0.021	0.016	0.049	0.045
1992	0.022	0.040	0.008	0.085	0.127	0.053	0.063	0.067	0.050	0.144	0.072	0.051
1993	0.026	0.045	0.095	0.072	0.081	0.034	0.013	0.004	0.011	0.009	0.022	0.010
1994	0.025	0.050	0.084	0.292	0.142	0.198	0.026	0.017	0.014	0.019	0.016	0.020
1995	0.020	0.062	0.151	2.492	0.089	0.022	0.014	0.008	0.029	0.026	0.062	1.711
1996	0.013	0.096	0.162	0.119	0.023	0.017	0.012	0.007	0.012	0.012	0.003	0.036
1997	0.536	0.147	0.066	0.108	0.080	0.030	0.009	0.013	0.009	0.010	0.025	0.011
1998	0.067	4.371	0.690	7.615	0.090	0.066	0.021	0.013	0.017	0.010	0.076	0.019
1999	0.068	0.135	0.033	0.113	0.048	0.067	0.007	0.009	0.008	0.014	0.015	0.020

The Mountain House Community Services District has been given tentative approval to discharge municipal wastewater to Old River (CVRWQCB 2006B). This district is a new residential, commercial, and industrial municipality. The outfall will be located near the SOR18 discharge site. Initial discharge volumes will be 3.0 mgd (phase II) with a proposed future increase to 5.4 mgd (Phase III). Installation of the outfall diffuser in Old River was ongoing at the writing of this report.

Urban runoff from the Mountain House subdivision is conveyed via Mountain House Creek to an unnamed slough hydraulically connected to Old River (SOR17). The size of the watershed drained by Mountain House Creek is about 17 square miles (SWRB 1958). The community is currently under construction and was only partially built-up at the writing of this report. When completed, it will accommodate all the necessary services for up to 43,500 residents.

Urban runoff from the City of Tracy is directed into several drains that flow toward Old River (Stantec 2003). The outfall of one drain is at the end of Sugar Cut (SC1) and the other two are farther west along Old River (SOR12 and SOR16). Both SC1 and SOR16 flow by gravity to dead-end soughs hydraulically connected to Old River. These two channels also serve as conveyances of farmland runoff, tile drainage, and groundwater effluence.

Runoff volumes from urbanized areas vary with a number of factors such as percent imperviousness, watershed size and saturation, rainfall intensity, etc. (CVRWQCB 1987). Flows typically rise and fall with the passage of a storm event. The collection of flow data is not a necessary requirement of a small municipal separate storm sewer General Permit (SWRCB 2003), and none was explicitly proposed in the City of Tracy's Storm Water Management Program (Stantec 2003).

Several of the aforementioned drains also appear to convey saline groundwater to Old River. The urban/agricultural drains SC1, SOR16, and SOR17 flow year-round to dead-end sloughs hydraulically connected to Old River. Groundwater may also be infiltrating a fourth drain flowing to an existing agricultural pumping station on Old River (SOR8).

Baseline, perennial flows in the urban/agricultural drains SC1, SOR16, and SOR17 are believed to be groundwater for several reasons. Flows of 1 to 2 cfs were observed in all three channels in early December 2006, before any appreciable rainfall had fallen during water year 2007 (Figures 2-2 and 2-3). Further, water applications to surrounding farmland were not observed at the time of the field inspections. All three channels are at or below sea level permitting a path of least resistance for the local aquifer or aquifers.

Conductivity in the aforementioned drains ranged between 2,100 and 2,600 µS/cm during the December 2006 inspections. The elevated conductivities are an indication of water in contact with mineralized soils. Water in contact with mineral matter for longer periods of time can take more of this matter into solution. A geochemical analysis presented in the next section provides supporting evidence that these drains are conveying groundwater effluence to Old River.

Groundwater effluence to urban storm drainage channels is not uncommon. Flow in certain storm drains around the City of Sacramento continues year-round. About half of the total outflow from the Sacramento urban storm drainage system was not directly associated with rainfall runoff (CVRWQCB 1987). The water originated, in part, from groundwater permeating into underground sumps, plumbing, and drainage channels. Flow in many of the conveyances continued throughout the summer and fall regardless of water year type.

One relatively large discharge to the previously discussed combination drain flowing to Sugar Cut (SC1) is agricultural drainage from Westside Irrigation District. This district has an agreement with the City of Tracy to pump as much as 35 cfs (22.6 mgd) to the drain about a mile upstream from the confluence with Sugar Cut (Reyna, e-mail communication, 2007).

The wastewater ponds next to Sugar Cut may be one specific source of saline groundwater accretion to Old River. The Leprino Foods Company leases several treatment ponds to process wastewater from its cheese factory (SWRCB 2006B). These ponds are immediately adjacent to Sugar Cut and are situated more than 15 feet above the slough's water level (Figure 2-2). Saline water in the unlined ponds could degrade groundwater (SWRCB 2006B) and, in turn, potentially generate a specific source of saline groundwater accretion to Old River.

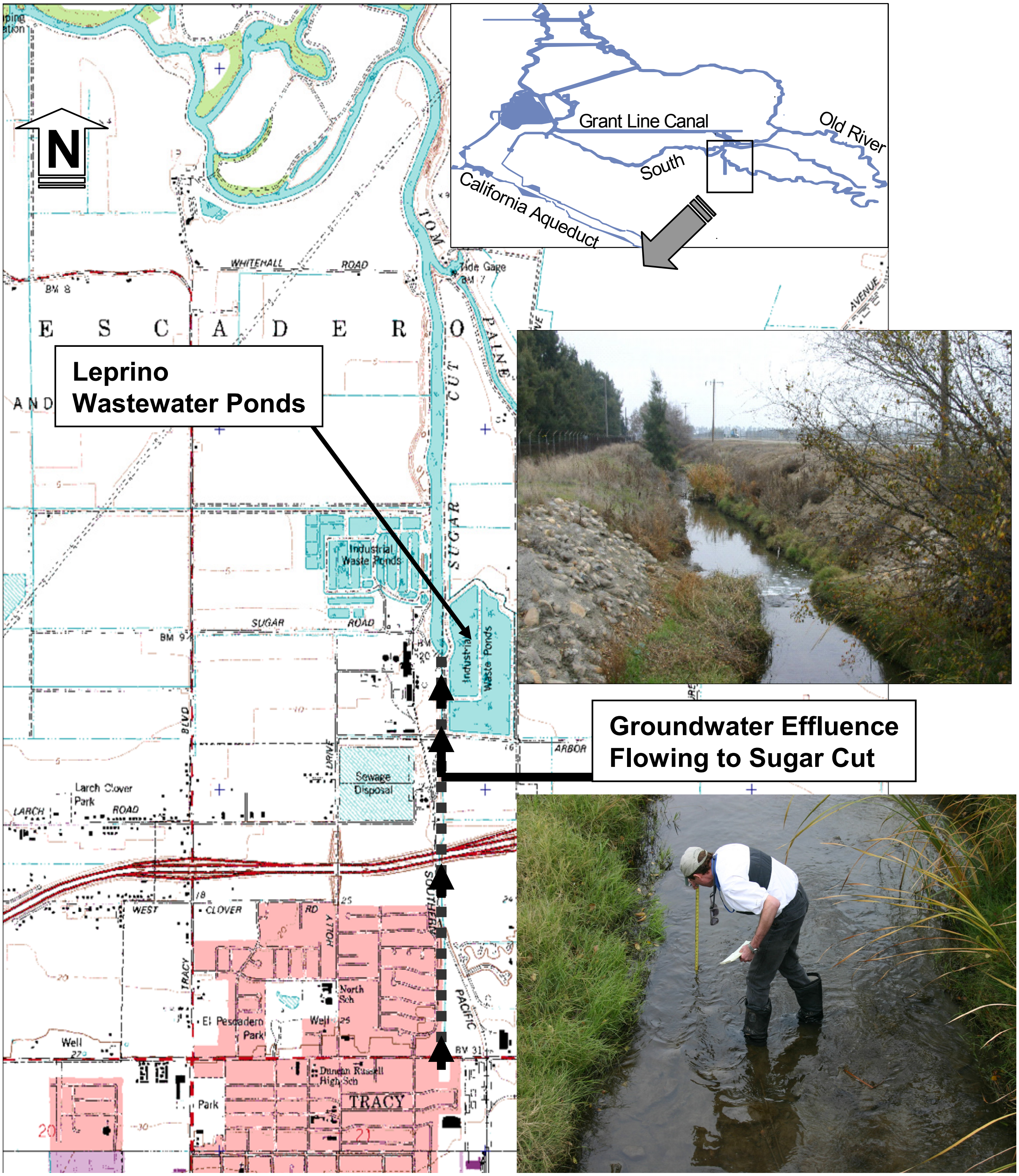
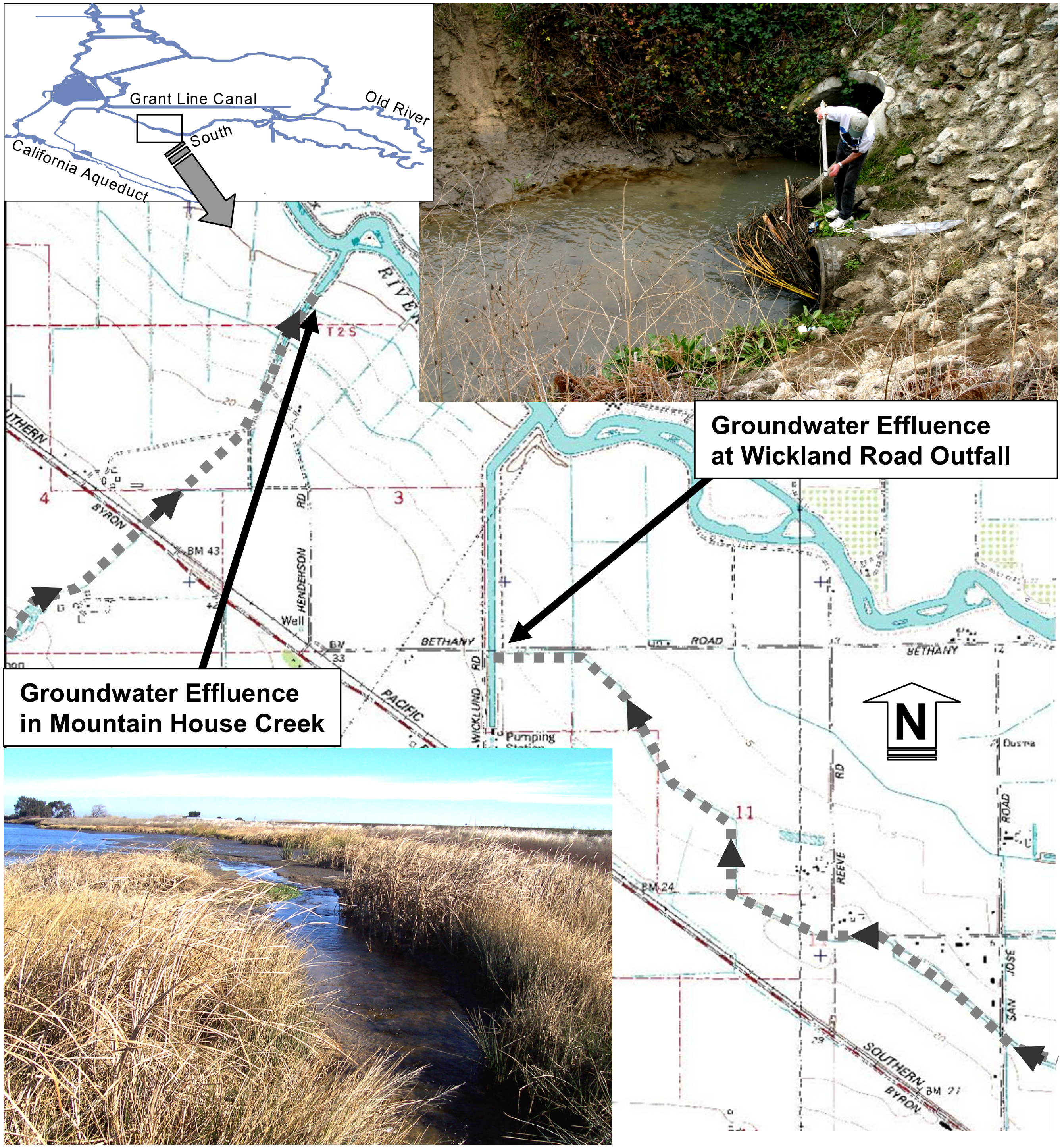


Figure 2-2. Location of groundwater effluence flowing to Sugar Cut in an urban runoff channel. Dry weather conductivity of the groundwater effluence was 2,071 µS/cm.



Groundwater Effluence at Wickland Road Outfall

Groundwater Effluence in Mountain House Creek

Figure 2-3. Location of two groundwater effluence discharge sites along south Old River. Conductivity was 2,566 µS/cm at the Wickland Road Outfall and 2,260 µS/cm in Mountain House Creek.

Delta Island Discharge Trends

Few studies have measured agricultural drainage volumes from Delta islands. One study estimated pumpage from 24 agricultural units making up a sizable portion of the Delta during 1954-1955 (DWR 1956). Many of the pumping plants were equipped with float-actuated sensors to automatically remove water at predetermined levels. Most pumpage was estimated with pump test data and electrical use records. The remainder was obtained by assuming that plant rating factors were similar to comparably measured installations or by correlation with discharge-per-acre values of adjacent lands.

Monthly pumpage was generally highest during the months of June to August and December and January (Figure 2-4A). Increases during the summer growing season were thought (in DWR 1956) to reflect over-application of irrigation water. Pumping during the winter increases to remove (1) precipitation (Figure 2-4B), (2) seepage from the surrounding river channels, and (3) water applied to leach salts built up in the soil over the growing season. Other reasons for intentionally applying water to Delta island farmland outside of the growing season include weed control, residue decomposition, and waterfowl habitat (Zuckerman 1999).

Another study measuring agricultural discharges from Twitchell Island showed a greater disparity in seasonal trends (Figure 2-4C). Pumpage during January to March 1995 was roughly equivalent to that for the remainder of the year.

The preceding graphs indicate that seasonal agricultural drainage trends between Delta islands can be distinct. In fact, discharge-per-acre estimates varied widely around the Delta ranging from 0.03 to 0.7 acre-feet per acre during the high-discharge month of January 1955 (DWR 1956). Relative discharge rates were lowest in the north and south Delta and highest in the central-most portion. The lower relative discharge rates in the north and south Delta were attributed to less channel seepage and more efficient application of irrigation water.

Regardless of the variability, an increase in drainage during winter is expected to be the common thread in Delta island discharge trends. Winter discharges are necessary to remove rainfall, increased seepage from rising water levels, and water applied for salt leaching, weed control, etc. This is significant because winter overlaps the period when Delta island drainage is most saline.

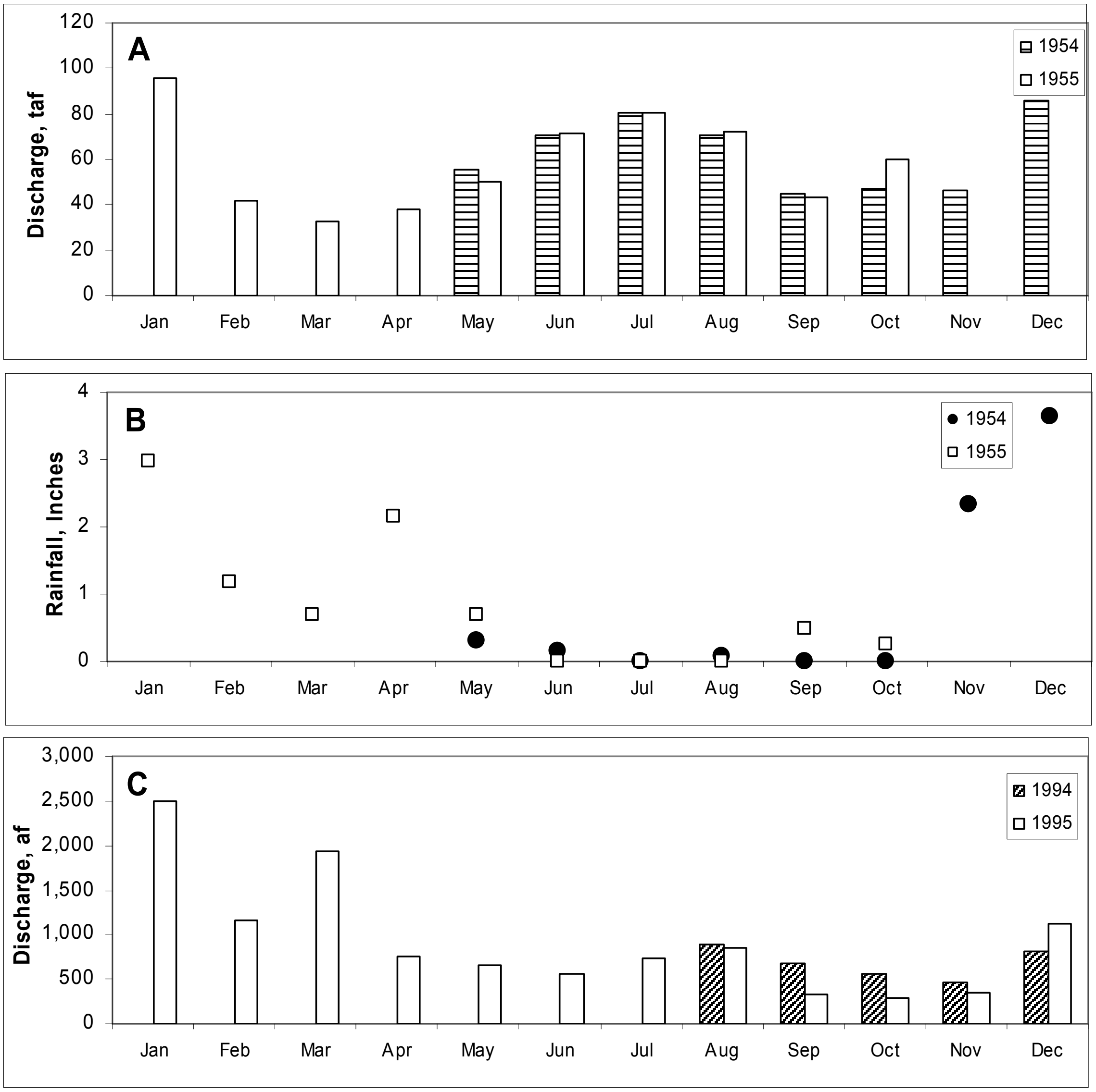


Figure 2-4. Monthly agricultural pumping estimated with rated power consumption and other methods from 24 agricultural drainage units around the Delta in 1954-1955 (A), average monthly rainfall totals from 7 cities around the Delta including Sacramento to the north, Lodi to the south, Stockton to the east, and Antioch to the west during 1954-1955 (B), and measured pumping from an agricultural drain on Twitchell Island during 1994-1995 (C) (sources: DWR 1956 and Templin and Cherry 1997)

III. Discharge Salinity

Agricultural Drainage

Conductivity in several south Delta agricultural drains is summarized in Table 3-1. Most data originated from studies conducted by the Central Valley Regional Water Quality Control Board (CVRWQCB) in 1986 and 1987.

Table 3-1. Summary of conductivity in several south Delta drains

Discharge Location	Minimum	Maximium	Median	Average	Std. Dev.	CV 1/	Sample Size	Date Range	Sources 2/
GLC1	864	2,100	960	1,238	461	37	7	1/86 to 9/87	A
GLC2	810	1,200	950	1,007	160	16	7	1/86 to 9/87	A
GLC3	620	1,500	791	868	296	34	7	1/86 to 9/87	A
GLC5	718	3,230	1,050	1,202	788	66	9	1/86 to 9/87	A
GLC7	820	1,420	1,165	1,096	215	20	8	1/86 to 9/87	A
GLC8	720	1,400	1,100	1,124	235	21	8	1/86 to 9/87	A
GLC11	550	2,600	1,525	1,589	642	40	8	1/86 to 9/87	A
GLC13	550	1,410	1,090	999	367	37	7	1/86 to 9/87	A
PC1	700	2,500	1,150	1,382	733	53	6	1/86 to 9/87	A
PC2	450	2,150	1,405	1,352	566	42	6	1/86 to 9/87	A
PC4	1,400	3,060	1,810	2,037	572	28	11	4/88 to 10/91	B
PC5	710	2,300	1,600	1,641	498	30	9	1/86 to 9/87	A
PC6	1,200	3,160	1,880	1,988	499	25	20	4/87 to 10/91	B
PC6	1,400	2,900	1,550	1,740	494	28	8	1/86 to 9/87	A
PC7	1,230	2,710	1,725	1,798	396	22	18	4/87 to 10/91	B
PC7	1,100	2,600	1,450	1,543	497	32	7	1/86 to 9/87	A
PC8	545	2,680	1,548	1,558	494	32	61	4/87 to 9/97	B
PC8	1,200	2,400	1,700	1,659	419	25	7	1/86 to 9/87	A
SOR3	350	2,550	1,200	1,253	762	61	7	1/86 to 9/87	A
SOR4	750	1,800	960	1,058	377	36	7	1/86 to 9/87	A
SOR5	620	2,500	743	1,009	672	67	7	1/86 to 9/87	A
SOR7	780	2,700	905	1,323	922	70	4	1/86 to 9/87	A
SOR8	1,100	3,880	2,100	2,063	937	45	7	1/86 to 9/87	A
SOR9	920	1,400	1,010	1,076	162	15	8	1/86 to 9/87	A
SOR12	1,200	2,600	1,655	1,785	550	31	8	1/86 to 9/87	A
SOR13	2,400	4,100	2,600	2,779	543	20	8	1/86 to 9/87	A
TPS1	1,300	3,570	1,815	2,238	953	43	8	1/86 to 9/87	A
TPS2	1,100	4,500	2,600	2,597	1,235	48	7	1/86 to 9/87	A
All stations combined (n=28)	350	4,500	1,300	1,496	763	51	285		
Middle River Drains (n=8)	121	3,290	740	947	635	67	56	1/86 to 9/87	A
Victoria Canal Drains (n=5)	350	3,010	620	821	533	65	34	1/86 to 9/87	A
West Delta Drains (n=8)	270	2,800	763	862	440	51	53	1/86 to 9/87	A
South Delta Tile Drainage (n=14)	1,900	4,230	3,100	3,098	704	23	27	6/1/86 and 6/13/86	C
West Delta Tile Drainage (n=14)	780	2,870	1,760	1,822	498	27	20	6/2/86 and 6/16/86	C
CCF1 to CCF4	897	6,970	3,683	3,822	2,821	74	8	6/20/2002	D

1/ Coefficient of Variation

2/ Sources

A: Belden et al. 1989

B: DWR 1990, 1994, and 1999 MWQI data query request

C: Chilcott et al. 1988

D: Unpublished DWR Operations and Maintenance Data

Conductivity in all south Delta drains sampled ranged from 350 to 4,500 μS/cm with a median and average of 1,300 and 1,496 μS/cm, respectively (Table 3-1). Average conductivity was generally highest in the drains along Tom Paine Slough and, to a lesser extent, in those along Paradise Cut (Figure 3-1). The Grant Line Canal drains exhibited the lowest averages and those along Old River ranged from low to high depending on discharge site. Conductivity in all drains was moderately to highly variable with coefficients of variation (CVs) ranging from 15 to 67 percent and an overall CV of 51 percent (Table 3-1).

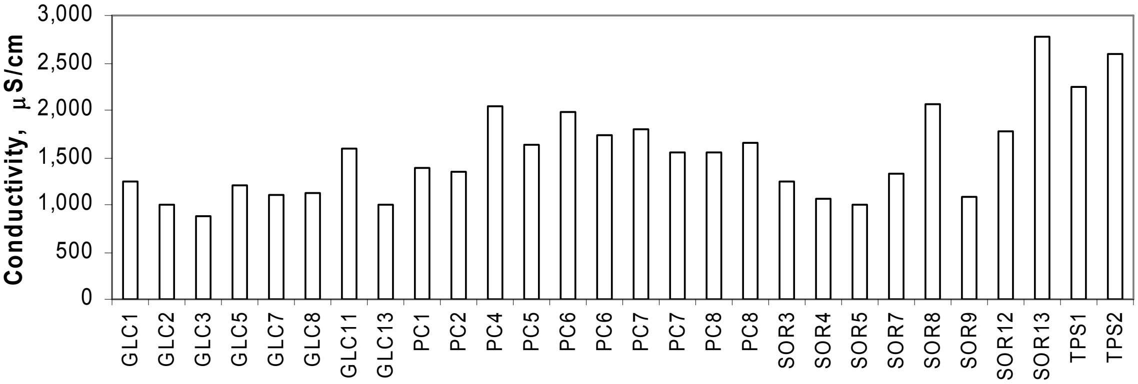


Figure 3-1. Average conductivity in several south Delta drains (see Table 2-1 for station identifiers)

Agricultural drains along Grant Line Canal, Old River, and their tributaries were particularly saline compared to other drains around the Delta. The average conductivity in these south Delta drains (1,496 μS/cm) was 58 to 82 percent higher than the average for several drains located farther north on Middle River, Victoria Canal, and north Old River (821 to 947 μS/cm) (Figure 3-2 and Table 3-1). All drains were sampled within the same period of January 1986 to September 1987, eliminating the possible effects of non-concurrent sampling periods between drains induced by variations in hydrology, operations, etc. (e.g., conductivity during wet versus dry water years). A comparison of tile drainage in the south and west Delta yielded similar results. Conductivity in south Delta tile drains averaged 70 percent higher than tile drainage farther west (Figure 3-2 and Table 3-1).

South Delta drains also exhibited higher salinities than most other island drains in the north, west, and east Delta. Thirteen agricultural drains were sampled between July and November 1964, including some as far north as Clarksburg and as far west as Sherman Island (DWR 1967). Conductivity was lowest in 8 north and east Delta drains with averages ranging from 381 to 879 μS/cm (Table 3-2). The highest conductivities were reported for 2 south Delta drains on Paradise Cut (average = 1,597 μS/cm) and Old River (average = 3,359 μS/cm) (Table 3-2).

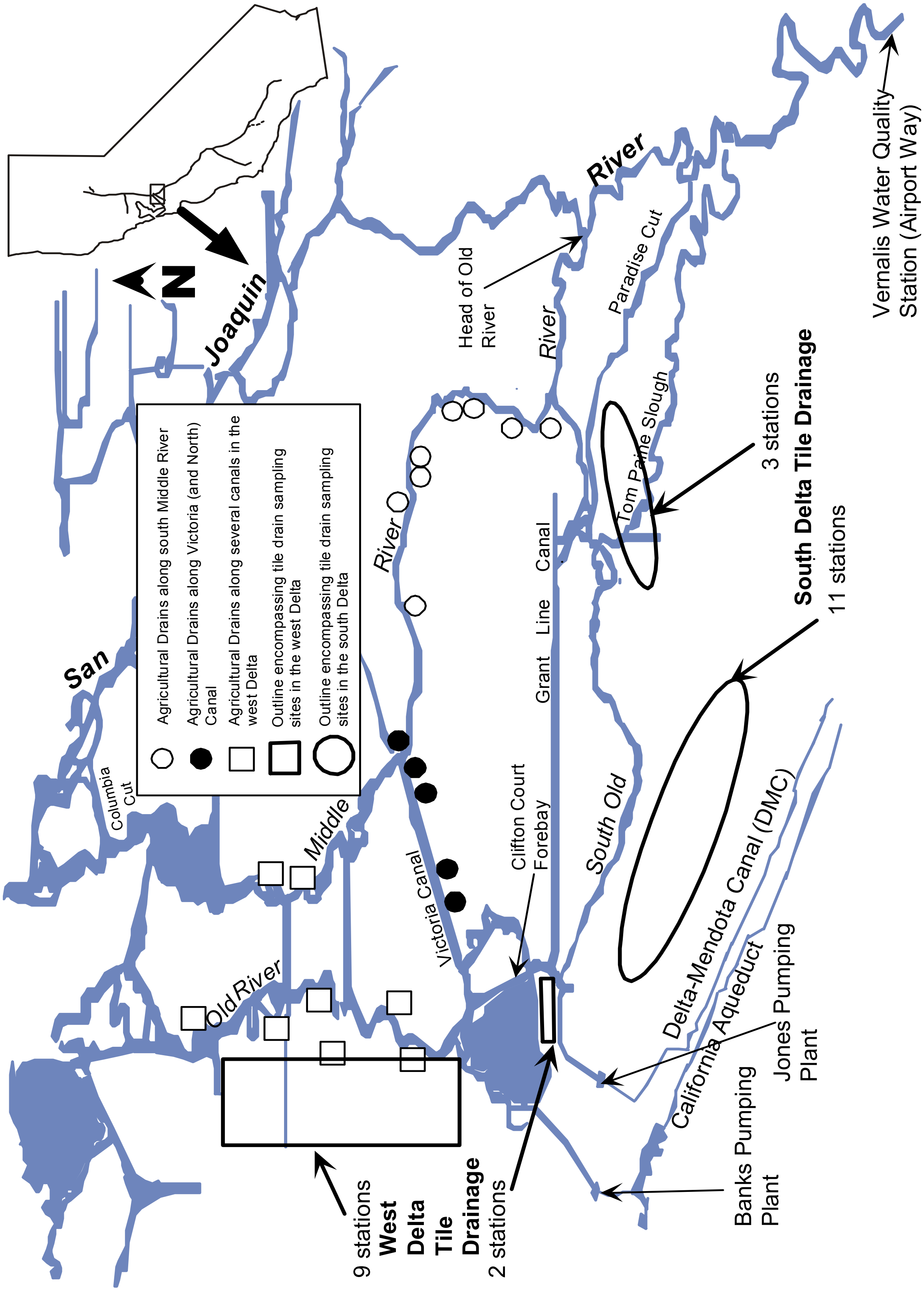


Figure 3-2. Location of agricultural drains on Old and Middle Rivers and Victoria Canal and outlines encompassing tile drain sampling sites (see Table 3-1 for details).

Table 3-2. Summary of conductivity in 13 agricultural drains around the Delta (source: DWR 1967)

Agricultural Drain Location	Delta Orientation	Station Identification 1/	Conductivity (μS/cm) Miniumum	Maximum	Average
Clarksburg	North	2	140	2,010	845
Grand Island at Ryde New Hope Tract	North	5	225	716	381
New Hope Tract	North	6	270	660	428
Staten Island	North	10	320	1,360	720
Terminus Tract	East	11	360	941	556
Hastings Tract	North-West	4	255	622	384
Sherman Island	West	16	819	2,150	1,495
King Island	East	14	380	1,460	879
Roberts Island at Whiskey Slough	East	22	420	1,280	837
Roberts Island at Burns Cut	South-East	24	700	1,770	1,062
Union Island	South	27	640	1,360	1,175
R. D. 2058 at Paradise Cut	South	28	1,250	1,960	1,597
R. D. 1007 near Old River	South	30	1,800	6,170	3,359

1/ Areal location in Attachment A

Conductivity measurements from a drain on Sherman Island were also relatively elevated with an average 1,495 μS/cm and a maximum 2,150 μS/cm (Table 3-2). This island – and others in the west Delta – are periodically affected by seawater intrusion, providing an explanation for the relatively high salinity on Sherman Island.

Unlike the agricultural drain on Sherman Island, those in the south Delta are not likely to be frequently influenced by seawater intrusion. Instead, their saline nature can be explained, in large part, by the makeup and origin of the resident soils.

Based on lithologic maps, much of the surface geology of the Diablo Range immediately up-gradient from the south Delta is generally classified as marine sedimentary rock (Davis 1961). These formations (and others in the Diablo Range) contain an abundance of readily available minerals. Many of the intermittent and ephemeral streams in the Diablo Range exhibit elevated salt concentrations when not heavily diluted by rainfall runoff. Drainage from the Diablo Range contains the usually dominant anions sulfate and bicarbonate and, depending on watershed, a cationic dominance ranging between a combination of sodium, calcium, and magnesium. Chloride is the dominant anion in a small number of Diablo Range watersheds where seawater-like connate waters are known or presumed.

Soils in the southernmost portion of the Delta originated, to varying degrees, from these marine sedimentary rocks. In a major study during the 1950s and 1960s, more than 1,500 20-foot deep holes in the San Joaquin Valley floor were drilled and logged to characterize depth to groundwater, groundwater salinity, and soil stratigraphy (DWR 1970). Detailed logs describe soil characteristics throughout many of the 20-foot bore columns to identify lands that could accommodate irrigation drainage. The information was used to partition the San Joaquin Valley into several general physiographic classifications. Three classifications overlapping the immediate south Delta included alluvial fan material from the Diablo Range, the basin trough, and the basin rim.

Resident soil surrounding the City of Tracy (south, west, east, and just north) was characterized as water-laid sediment forming a slightly sloped alluvial fan. The ancient alluvial fan is composed of eroded material from the Diablo Range. The boundary of the distal end of the alluvial fan (basin rim) generally extends in an east-to-west direction just north of Tracy (the DWR 1970 map was similarly general). The basin rim is a relatively slim band of sedimentary deposits from the Diablo Range with a flat or very slightly sloping topography. From the rim, the basin trough extends to the study boundary at Old River. Soils making up the basin trough are a mixture of sedimentary deposits from the Diablo Range and granitic material from the Sierra Nevada carried into the floodplain during high flow periods.

Therefore, land in the south Delta is bisected with soils of differing types and origins. The alluvial fan material in the southernmost portion of the south Delta originated from the Diablo Range. Studies by the U.S. Geological Survey identified the origin of the ancient alluvium to be the Corral Hollow Creek watershed (Atwater 1982 and Dubrovsky et al. 1991). Groundwater in this alluvium was saltier than other groundwater sources sampled outside of the Diablo Range alluvial fan (Sorenson 1981). These heavily mineralized soils (and accompanying groundwater) provide an explanation for the higher salinities in south Delta agricultural drains. Farther north, the soils transition to a lesser-mineralized mixture of organic deposits, eroded Diablo Range material, and sediment from the Sierra Nevada carried down into the floodplain during heavy runoff. Groundwater in the central and eastern Delta exhibited better quality water with respect to salinity due to these soils (Sorenson 1981). Another more general depiction of Delta lithology shows soils transitioning from a mineral composition at the outer boundary of the Delta to a more organic or peaty composition closer to the core (DWR 1967, see Appendix A).

The salinity of Delta island drainage varies with season and is consistently highest during winter. Figure 3-3A shows monthly conductivity for four south Delta drains with a relatively long history of monitoring (1987 to 1999). Conductivity was generally highest during January to April and October. Data from a drain on Twitchell Island were more extensive and show conductivity was highest during January to March, declined through August then increased into December (Figure 3-3B).

The preceding graphs show that Delta island drainage salinity is highest during the winter and certain fall months. This was supported by studies in the 1950s and 1960s, which concluded that Delta island drainage quality was poorest with respect to conductivity (as well as chloride and nitrogen) during winter and, to a lesser extent, fall (DWR 1956 and 1967). The poor water quality during these seasons was attributed to a build-up of salt in the soils during the growing season and their subsequent leaching after rainfall events or water applications.

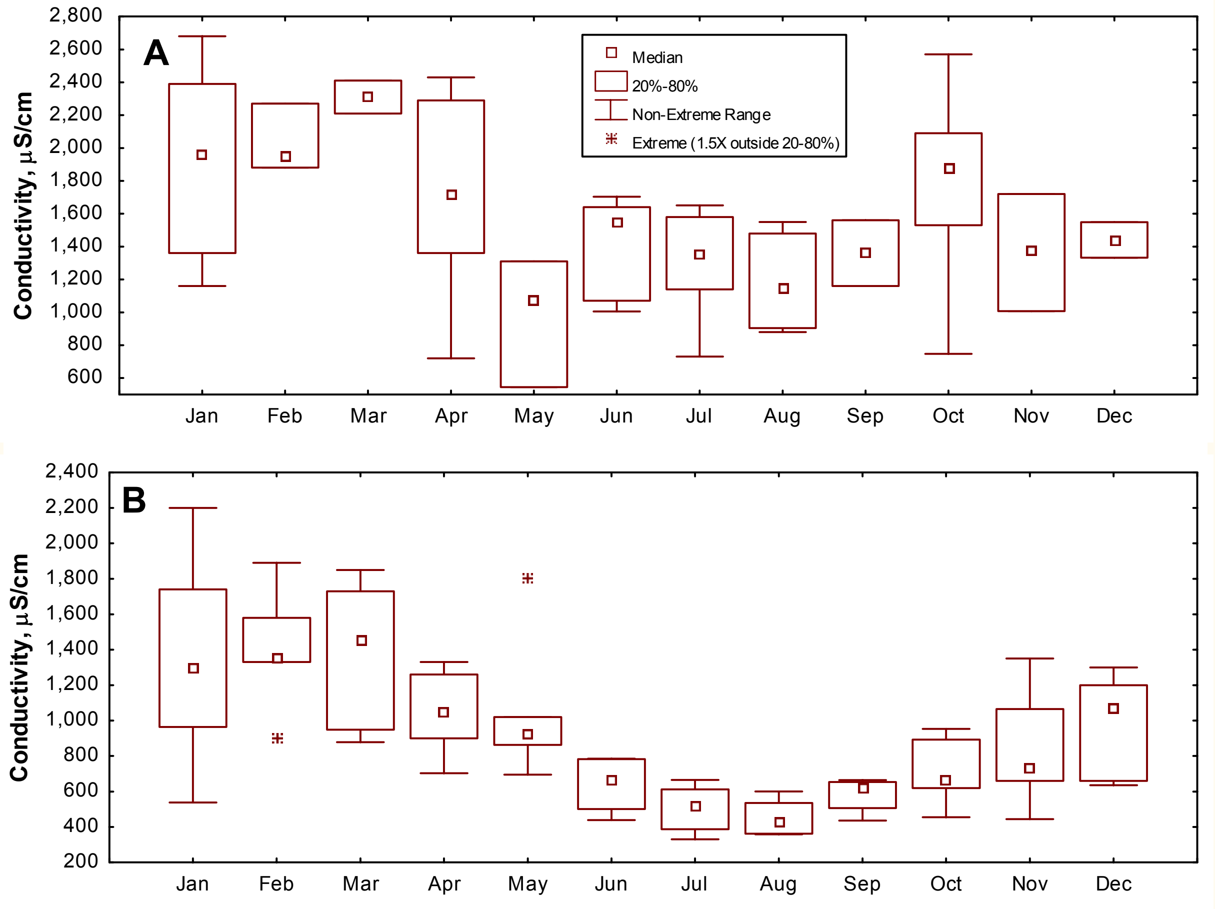


Figure 3-3. Monthly conductivity in 4 agricultural drains discharging to Paradise Cut (stations PC4 and PC6-8 in Table 2-1) (A) and a drain on Twitchell Island (B) from periodic sampling between 1987 and 1999 (sources: DWR 1990, 1994, and 1999)

Point-Sources

The following information was obtained largely from waste discharge requirements (CVRWQCB 2003, 2004A, 2004B, 2005A, 2005B, and 2006B).

The City of Tracy Wastewater Treatment Plant accepts municipal wastewater and pre-treated industrial food processing water from a cheese manufacturer. Effluent conductivity averages 1,753 µS/cm and ranges between 1,008 and 2,410 µS/cm (from Monitoring and Reporting Requirements submittals between July 1998 and December 2004).

The Brown Sand (Inc.) discharge exhibits an average conductivity of 1,167 µS/cm and a range from 683 to 1,930 µS/cm (January 2000 to December 2004).

Discharges from the City of Manteca Wastewater Quality Control Facility exhibit an average conductivity of 1,099 µS/cm with a range between 819 and 1,300 µS/cm

(January 1998 to December 2002). The CVRWQCB issued a Cease and Desist order to this facility in 2004 for violation of the conductivity effluent limit of 1,000 μS/cm.

The Deuel Vocational Institution operates a facility to treat municipal wastewater commingled with industrial wastes, stormwater, and contaminated groundwater. Conductivity in the effluent ranges between 1,600 and 2,400 μS/cm (December 1998 to February 2001). The CVRWQCB issued a Cease and Desist Order to this facility in 2003, in part, for violation of the conductivity limit of 700 μS/cm (maximum daily of 1,600 μS/cm).

Urban Runoff and Groundwater Effluence

Urban runoff from the City of Tracy drains to Old River via four channels. Urban runoff is not expected to be saline because the conductivity of precipitation is typically low (8 to 63 μS/cm, Hem 1985). However, sources of flushable salt may exist from certain commercial, industrial, or residential activities specific to individual urban watersheds. Water quality monitoring was not an explicit component of Tracy's Storm Water Management Plan (Stantec 2003).

As discussed, several of the urban/agricultural drains also appear to be conveying saline groundwater to Old River. These include SC1, SOR16, SOR17, and possibly, SOR8. Conductivity in 3 of the drains (SC1, SOR16, and SOR17) in early December 2006 was 2,100-2,600 μS/cm and flow was 1-2 cfs (measurements made for this study). The measurements were made before any appreciable rainfall had fallen during water year 2007. Further, irrigation activities on the surrounding farmlands were not observed during the field visits. A mineralogical analysis supports the contention that flow in these channels was largely from groundwater effluence at the time of sampling.

The mineralogy of SC1, SOR16, and SOR17 was somewhat similar to groundwater from nearby wells (Figure 3-4). The anionic composition of most samples in Figure 3-4 was either chloride or chloride-sulfate dominant. The cationic dominance of most samples was either sodium or sodium-calcium.

The mineralogy of Mountain House Creek (SOR17) was somewhat dissimilar to that of SOR16 and SC1. Sodium in Mountain House Creek composed 74 percent of the cationic content, whereas in SOR16 and SC1, the percentages were around 50 percent (Figure 3-4). Bicarbonate in Mountain House Creek also made up a larger proportion of the anionic content at the expense of sulfate. The differences in mineralogy between Mountain House Creek and the other two groundwater conveyances can be explained by the proximal origin of the associated aquifers.

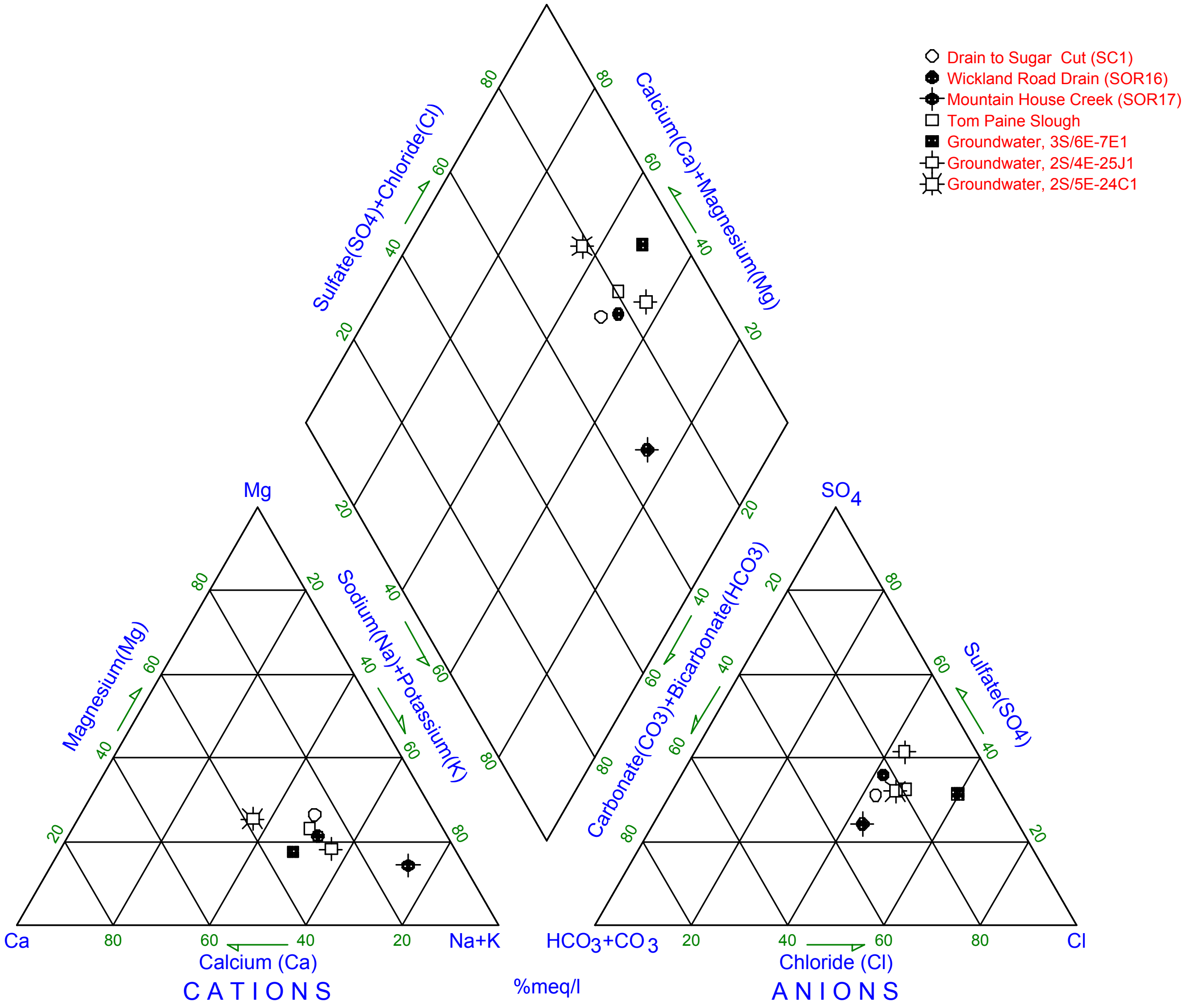


Figure 3-4. Piper graph depiction of several surface and groundwater quality samples collected in the south Delta. The groundwater samples were collected from wells within an approximate 2-mile radius of the center of the City of Tracy. Groundwater was from the semi-confined or upper water-bearing zone (Dubrovsky et al. 1991 and Hotchkiss and Balding 1971).

The groundwater in SC1 and SOR16 emanates from the same Corral Hollow Creek alluvium and is expected to be geochemically dissimilar to that emanating from Mountain House Creek. The quality of groundwater in Mountain House Creek reflects the lithologic makeup of the upstream watershed. This relatively small watershed is several miles north of the Corral Hollow Creek watershed. As discussed, the alluvium in the southernmost portion of the Delta surrounding the City of Tracy originated from the Corral Hollow Creek watershed. The quality of groundwater emanating from Mountain House Creek is expected to be dissimilar to that from Corral Hollow Creek due to the unique geological makeup of individual watersheds (Davis 1961). Although Mountain

House Creek is relatively close to the SOR16 site, the SOR16 drainage channel flows from south-east to north-west with the headwaters extending to the City of Tracy (see Figure 2-3).

A water quality sample was also collected from Tom Paine Slough in early December 2006. The mineralogy of Tom Paine Slough at the time of sampling was nearly identical to SC1 and SOR16 (Figure 3-4). The Diablo Range alluvium controlling the quality of groundwater effluence in these drains also appears to be controlling water quality in Tom Paine Slough. As discussed, several saline agricultural drains discharge to Tom Paine Slough and likely contributed to the slough's mineralogy and high conductivity (2,500 μS/cm) at the time of sampling. It is highly unlikely that these three waterways exhibit nearly identical mineralogies by chance. All six mineral components in the Piper graph (in Figure 3-4) would have to be nearly equal in concentration in all three individual samples. Therefore, the mineralogical similarities between these waterways provide additional evidence that flow in SC1 and SOR16 originated largely from groundwater effluence at the time of sampling.

IV. Diversions

There are more than 100 local irrigation diversions on the subject waterways in the south Delta (DWR 1995). Many of the local diversions were identified as siphons, pumps, or floodgates.

These local diversions can contribute indirectly to channel salinity. The influence of saline discharges is compounded when they co-occur with diversions along the same channels. Diversions remove water that would otherwise be available for in-channel dilution. As such, local diversions indirectly contribute to salinity increases in water flowing to the export sites from the San Joaquin River via Old River and Grant Line Canal.

Studies quantifying local diversions in the Delta have been meager. One study estimated water applications for Delta island irrigation (DWR 1956). Water applications were estimated, in part, from Delta island land use survey data and measured or estimated unit applied-water values for each crop type. Monthly applications during 1954 showed a steady increase from March to July and thereafter a decline through October (Figure 4-1). Total seasonal applications to the 291,667-acre study area amounted to 656,000 acre-feet – an average of 2.25 acre-feet per irrigated acre.

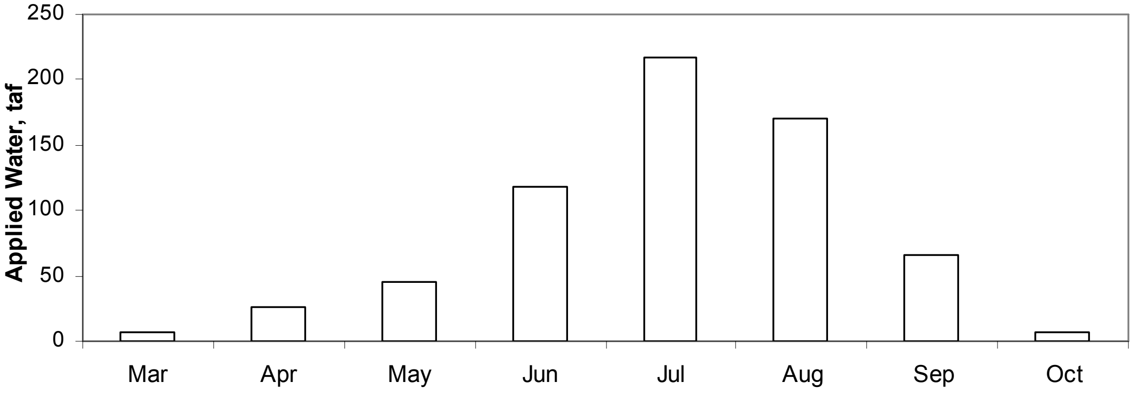


Figure 4-1. Total estimated water applications made to agricultural land in a substantial proportion of the Delta during 1954. The applications were estimated from specific crop use and unit applied-water values (modified from DWR 1956).

Water applications made to Delta islands during November to February were not included in the DWR 1956 study. However, the study stressed that such applications during the non-growing season were necessary to remove salt from the soil. Salt can build up in the root zone during the summer and may adversely affect plant growth the following year. No attempt was made to estimate such applications because leaching practices varied widely. Further, application requirements during fall and winter were considered relatively unimportant because an ample supply of good-quality water was usually available.

One of the larger local agricultural diverters in the south Delta is Banta Carbona Irrigation District. The diversion intake is on the San Joaquin River about 9 river miles below Vernalis, just upstream from the relatively large New Jerusalem Drain (SJR11 in Figure 2-1). The irrigation district delivers water via Banta Carbona Canal to about 16,500 acres of irrigable land and customers such as the City of Tracy (Quinn and Tulloch 2002).

Diversions down Banta Carbona Canal were obtained from Water Master handbooks reported in Quinn and Tulloch (2002). Monthly diversions ranged from 0 to 12,798 acre-feet between 1999 and 2002 and were greatest during May to August (Figure 4-2).

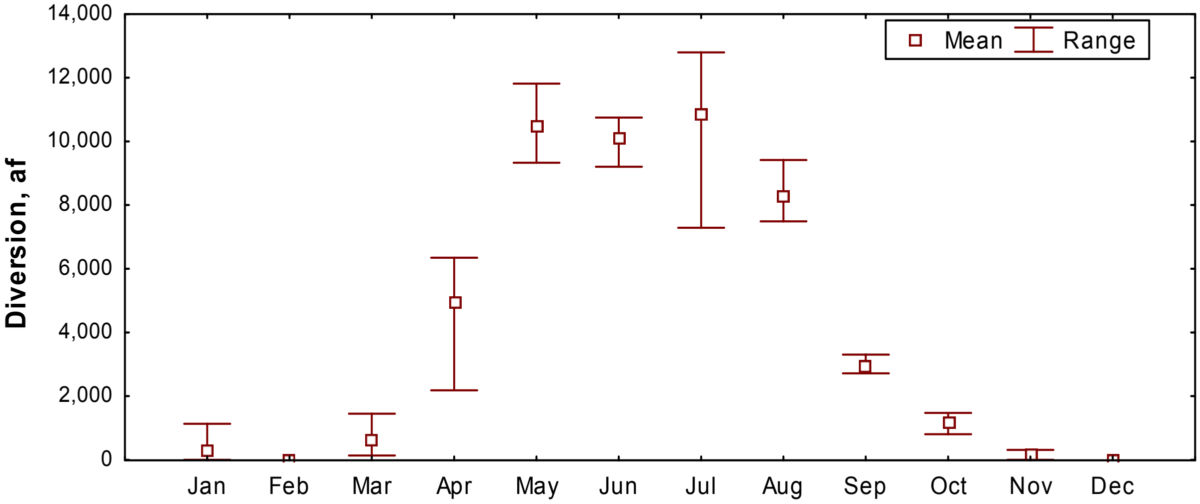


Figure 4-2. Monthly irrigation diversions from the San Joaquin River down the Banta Carbona Canal, 1999 to 2002 (data source: Quinn and Tulloch 2002)

A relatively small amount of water was pumped during October to March (Figure 4-2), possibly indicating little or no water applications for soil leaching. However, soil leaching may be performed with water obtained through other diversion sources such as siphons or gated structures. As noted before, more than 100 diversion sites are along the subject waterways in the south Delta. Using passively operated siphons or gates during months when water is typically most abundant (late fall to winter) would be more economical than pumping.

Data from the same study (Quinn and Tulloch 2002) showed that daily diversions for 2002 reached a maximum of 220 cfs near the end of July (the only year when daily diversions were reported). Flow in the San Joaquin River at Vernalis averaged between 1,100 and 1,300 cfs during the same time. In this case, the peak diversion rate of 220 cfs down Banta Carbona Canal reduced flow in the San Joaquin River by approximately 17 to 20 percent. A diversion rate of 220 cfs is fairly substantial considering that flows below 1,000 cfs in the lower San Joaquin River are not uncommon during drier water years.

Monthly diversions down Banta Carbona Canal during 1972 to 2002 were quite consistent in wet and dry years alike (Quinn and Tulloch 2002). As a result, this individual diversion may induce a greater relative decrease in San Joaquin River flow during drier versus wetter water years in the San Joaquin Valley. Correspondingly, the effect of diversions on downstream salinity due to reduced dilution capacity for co-located saline discharges may also be greatest during drier versus wetter water years.

V. Upstream/Downstream Salinity

Vernalis versus Old River

Upstream/downstream salinity was assessed between Vernalis on the San Joaquin River (SJRV) and Old River at Tracy (Boulevard) Bridge (ORTB) (locations are shown in Figure 1-1). Conductivity from 1990 to mid 2006 was obtained from automated water quality monitoring stations. Conductivity was consistently highest at ORTB with the exception of a few relatively short duration periods (Figure 5-1). These short-term exceptions were most protracted around February 2004 and January 2005.

Based on Figure 5-1, salinity consistently increased as water flowed from SJRV to ORTB. The previously-discussed interjacent discharges and diversions provide ample evidence for causative upstream-to-downstream increases in salinity. Figure 5-1 would also imply that conductivity periodically decreases – although infrequently – as water flows between stations. The potential for an upstream-to-downstream decrease in salinity is considered unlikely based on the existing information. Periods when conductivity at ORTB was lower than at SJRV is most likely associated with the effects of travel-time (discussed later) and simple meter inaccuracy.

Automated water quality meters are often subject to a certain amount of drift between service visits. Conductivity probes and controller assemblages have certain limitations on how long and to what magnitude they will hold a calibration. If drift is not immediately corrected, the data will not reflect accurate salt concentrations even though tracking of relative salinity trends may continue. Inaccuracies of 5 to 10 percent are not uncommon in conductivity data from automated monitoring stations. These percentages can reflect a 10 to 20 percent error difference when comparing data from an upstream/downstream pair of stations that drift in opposing directions.

Other explanations for an actual upstream-to-downstream decrease in conductivity between these stations (other than meter drift) include low-salinity discharges and reverse flow in Old River. Based on studies presented earlier, low-salinity discharges between SJRV and ORTB were scarce. Evidence is lacking that any source or sources could overwhelm the preponderance of saline discharges and produce a measurable decrease in channel salinity. Further, reverse flow in Old River and any subsequent salinity reduction from cross-Delta flow is unlikely. In this scenario, water from the central Delta would flow past both State and federal export sites and east up Old River to the automated station at Tracy Boulevard Bridge. This seems unlikely because it would entail reverse flow in Old River for a distance of at least 8 miles and an elevation rise of approximately 5 feet. An exception to this may be when the Old River barrier is installed. This barrier is equipped with single-direction flap-gates and is predicted to induce reverse flow in Old River (DWR 2007).

Salinity is sometimes legitimately lower at ORTB than SJRV on the same day due to travel time. Figure 5-2 shows conductivity trends at SJRV were observed several days later at ORTB. The delay in rising conductivity trends between stations results in periods

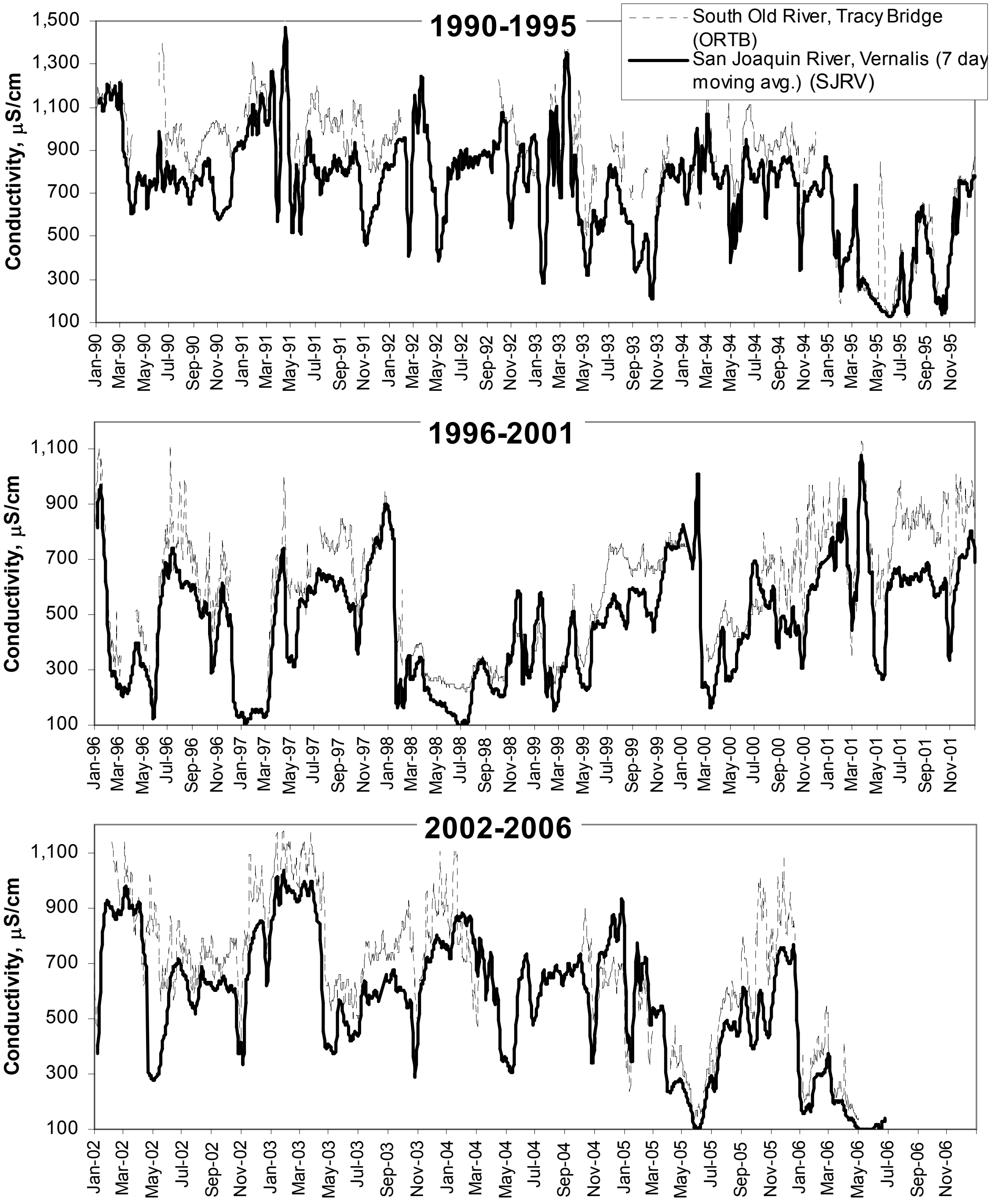


Figure 5-1. Daily automated station conductivity in the San Joaquin River at Vernalis (SJRV, 7-day moving average) and Old River at Tracy (Boulevard) Bridge (ORTB), 1990 to mid 2006 (sources: SWRCB 2006A, HEC-DSS, and CDEC websites accessed June 2006)

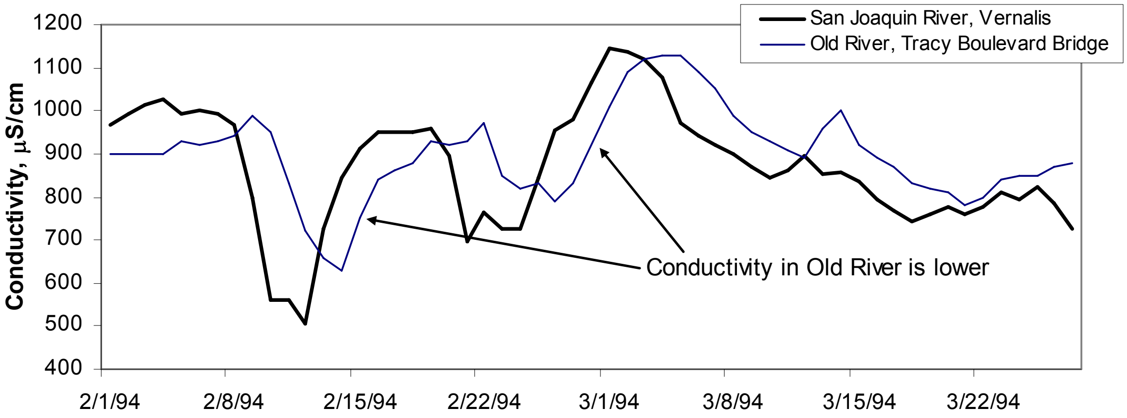


Figure 5-2. Multi-day delay in conductivity trends between the San Joaquin River at Vernalis (SJRV) and Old River at Tracy (Boulevard) Bridge (ORTB). Conductivity fluctuations result in periods of higher or lower conductivity between stations on the same day due to travel time.

when conductivity is lower at ORTB than SJRV on the same day. This artifact of travel time also produces the opposite effect – higher salinity at ORTB than SJRV – not necessarily due to any interjacent augmentation, but to a delay in declining conductivity trends between stations due to travel time.

To reduce the effects of travel time on the upstream/downstream analysis, monthly averages were calculated to quantify salinity increases between SJRV and ORTB and the remainder thereof was plotted in Figure 5-3.

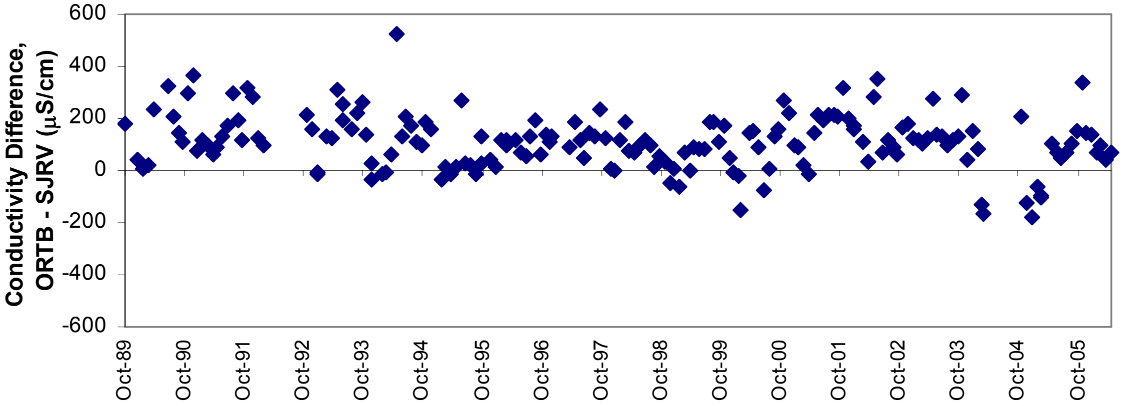


Figure 5-3. Long-term monthly average conductivity differences between the San Joaquin River at Vernalis (SJRV) and Old River at Tracy (Boulevard) Bridge (ORTB), late 1989 to mid 2006

Differences in monthly average conductivity between ORTB and SJRV ranged from -178 to 522 μS/cm with a median of 114 μS/cm. The negative values would imply that conductivity is sometimes lower at ORTB than at SJRV. However, as discussed earlier, a certain amount of error is unavoidable when comparing data from a pair of upstream/downstream automated stations (inaccuracies and travel time effects), and this error is believed to be largely responsible for the negative values.

Differences in conductivity between ORTB and SJRV exhibited seasonal trends. Monthly average conductivity at ORTB was highest relative to SJRV from April to November (Figure 5-4). During this 8-month period, median values ranged from 100 to 185 µS/cm, and during the other 4 months (December to March), median values were lower ranging from 59 to 76 µS/cm (Table 5-1).

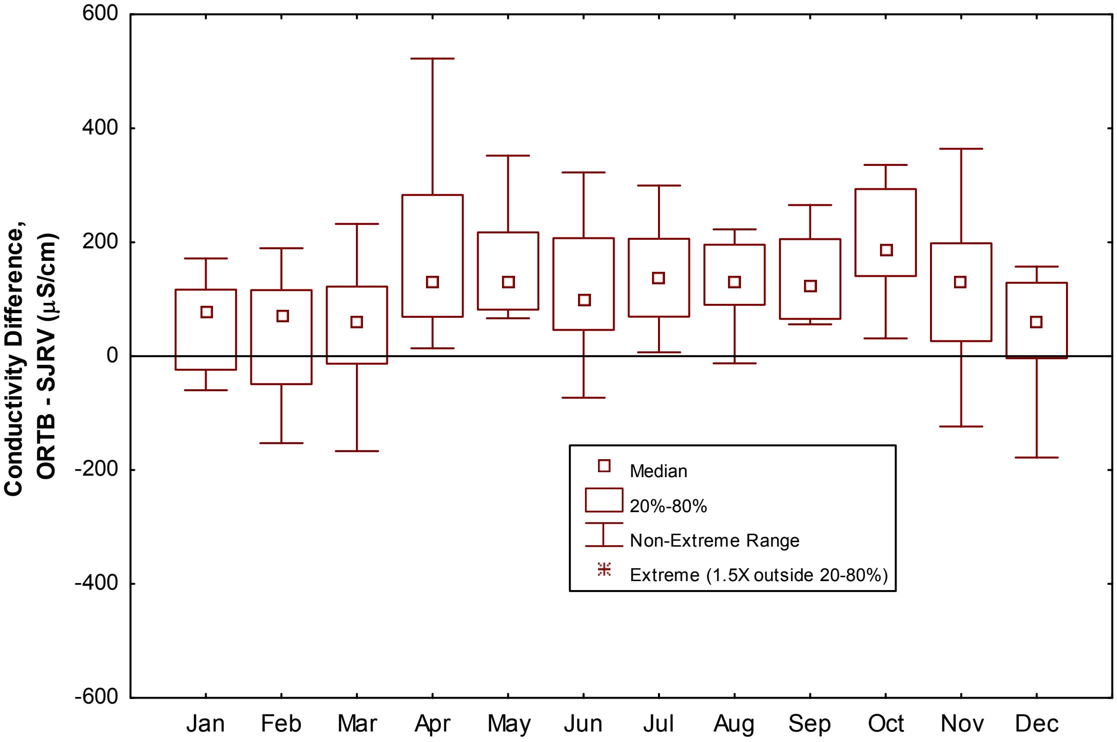


Figure 5-4. Monthly trends in conductivity differences between the San Joaquin River at Vernalis (SJRV) and Old River at Tracy (Boulevard) Bridge (ORTB) and, late 1989 to April 2006

Vernalis versus Grant Line Canal

The same monthly analysis was performed with data from the automated station on Grant Line Canal at Tracy (Boulevard) Bridge (GLCTB). Differences in average monthly conductivity between GLCTB and SJRV ranged from -147 to 544 µS/cm and were generally highest from April to October with median differences ranging between 43 and 87 µS/cm (Figure 5-5 and Table 5-2).

The April-to-November trend observed in the comparison between ORTB and SJRV was not as strongly evident between GLCTB and SJRV. The ORTB and GLCTB databases are to a certain extent incongruous and likely introduced some bias in the previous

Table 5-1. Statistics of monthly average conductivity differences between the San Joaquin River at Vernalis (SJRV) and Old River at Tracy (Boulevard) Bridge (ORTB) and, late 1989 to mid-2006

					Percentiles	
Month	Median	Minimum	Maximum	N	20th	80th
Jan	76	-60	171	16	-24	117
Feb	69	-153	190	15	-49	116
Mar	61	-167	232	16	-13	122
Apr	130	14	522	14	69	283
May	129	66	352	13	82	217
Jun	100	-73	323	14	46	207
Jul	136	7	300	14	69	206
Aug	128	-13	223	14	90	196
Sep	123	56	265	14	65	206
Oct	185	31	336	17	140	293
Nov	129	-124	364	16	26	198
Dec	59	-178	157	16	-4	129

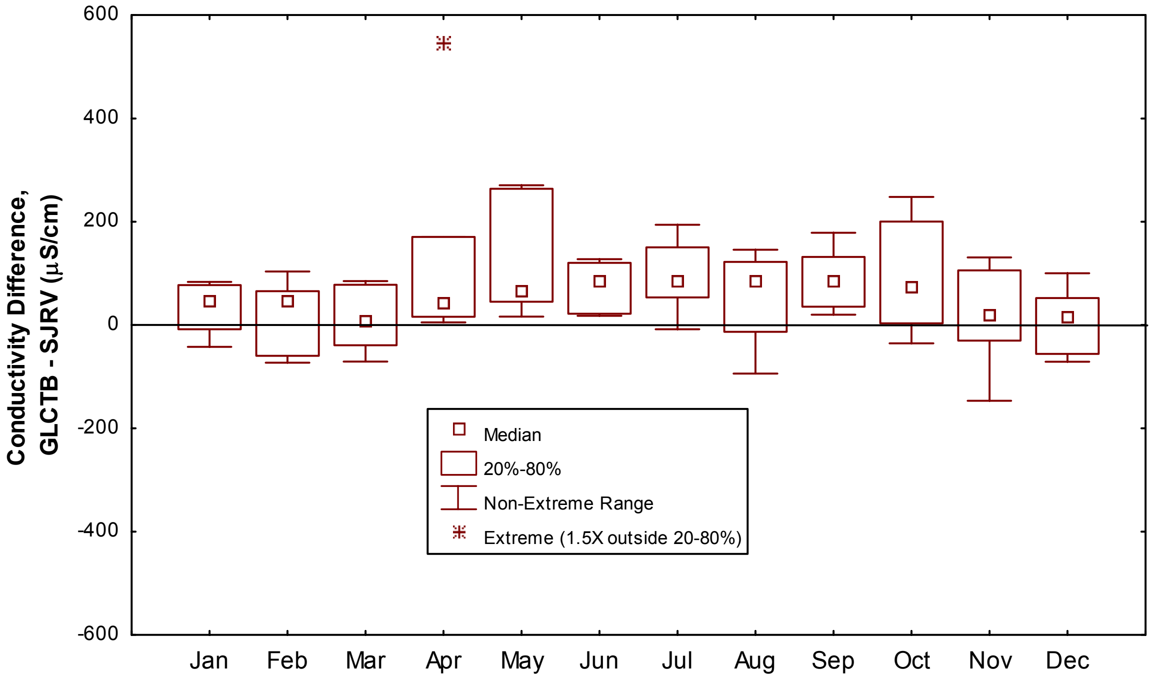


Figure 5-5. Monthly trends in conductivity differences between the San Joaquin River at Vernalis (SJRV) and Grant Line Canal at Tracy (Boulevard) Bridge (GLCTB), late 1991 to mid-2006 (data sources: HEC-DSS and CDEC)

Table 5-2. Statistics of monthly average differences in conductivity between the San Joaquin River at Vernalis and Grant Line Canal at Tracy Bridge, late 1991 to mid-2006

					Percentiles	
Month	Median	Minimum	Maximum	N	20th	80th
Jan	46	-42	84	10	-8	77
Feb	45	-73	104	8	-60	65
Mar	6	-71	85	9	-39	78
Apr	43	5	544	8	16	171
May	68	16	271	7	45	264
Jun	87	18	127	8	22	120
Jul	87	-8	194	7	53	150
Aug	87	-94	146	8	-13	122
Sep	84	20	178	8	35	132
Oct	76	-35	248	10	3	200
Nov	20	-147	131	11	-30	106
Dec	17	-71	100	10	-56	52

analyses with SJRV. First, the temporary barrier on Grant Line Canal was installed for the first time in 1996, reducing the number of years of potential influence (available data extends back to 1991). This was not the case for Old River in which the barrier had been installed in all but one year since 1991. Second, more conductivity data from the GLCTB station had been deleted over the years. For some months, the number of monthly averages available for GLCTB was half that of ORTB (compare N in Tables 5-1 and 5-2). Despite the stated incongruities between the GLCTB and ORTB datasets, both stations consistently exhibited higher conductivities than SJRV.

Old River versus Grant Line Canal

One final comparison shows conductivity was highest at ORTB than GLCTB during most months of the year (Figure 5-6). To eliminate any bias from the aforementioned database incongruities, only data available for both stations on the same day were included in Figure 5-6. Further, data prior to 1996 was excluded from both datasets to remove any potential water quality influence from barrier installation on one waterway and not the other. Conductivity at ORTB was statistically higher than at GLCTB for all months except February and June ($p<0.05$, Mann-Whitney U-Test).

Several explanations can be provided to account for the higher conductivity at ORTB. One involves the flow differential between Old River and Grant Line Canal. Old River bifurcates with Grant Line Canal about 8 miles downstream from the head of Old River (Figure 5-7). Models estimate that a majority of flow dissociates down Grant Line Canal with the remainder continuing down Old River (DWR 2007). Less water in Old River downstream from the bifurcation translates into less dilution capacity for the numerous saline inputs located on that stretch of river.

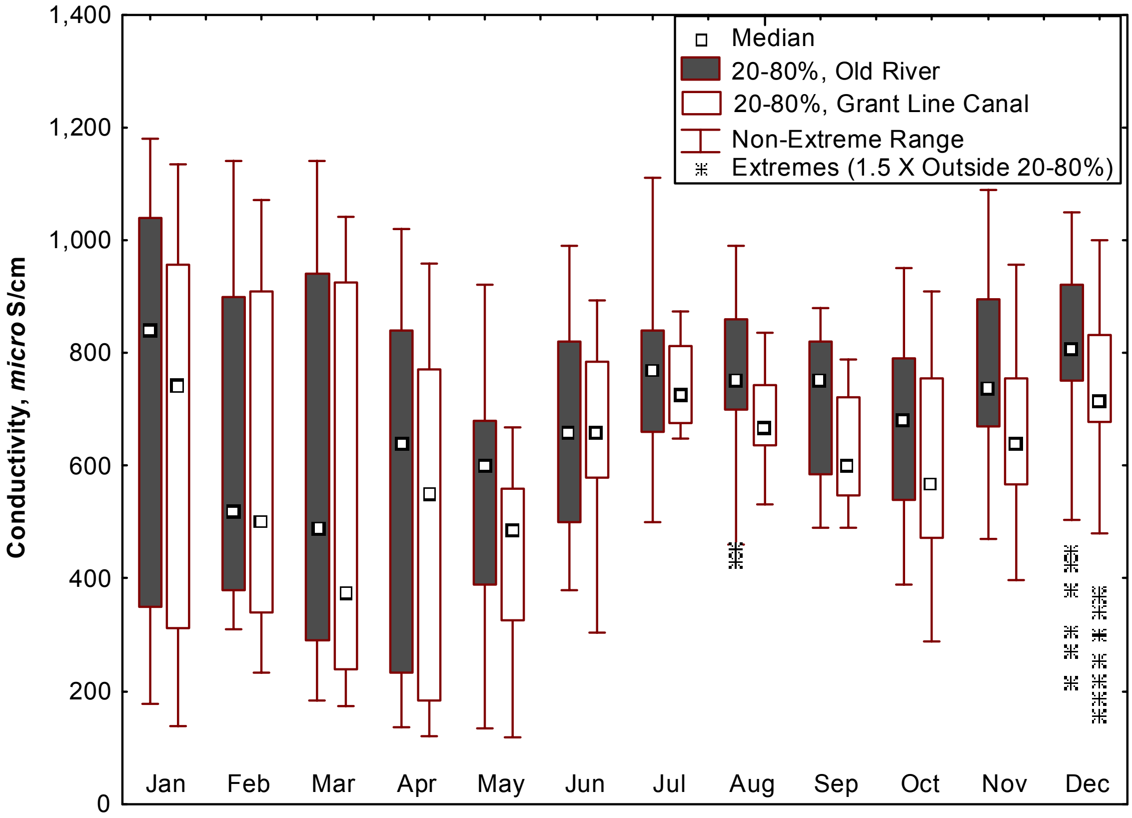


Figure 5-6. Conductivity in Old River at Tracy (Boulevard) Bridge (ORTB) and Grant Line Canal at Tracy (Boulevard) Bridge (GLCTB), 1996 to mid 2006. Only data available at both stations on the same day were used. Conductivity was statistically higher ($p<0.05$) at ORTB than at GLCTB for all months except February and June (Mann-Whitney U-Test).

Tom Paine Slough, Paradise Cut, and Sugar Cut are three tributaries of Old River. All connect with Old River downstream from the bifurcation with Grant Line Canal (Figure 5-7). A number of saline discharges are situated along these waterways and their outflows are likely contributing to the higher conductivities observed at ORTB.

Discharges to Paradise Cut include seven agricultural drains and one wastewater treatment plant. Data presented earlier show the agricultural drains are often saline with conductivities ranging from 450 to 3,160 µS/cm. The Deuel Vocational Institution also discharges treated sewage to the headwaters of Paradise Cut with conductivities ranging from 1,600 to 2,400 µS/cm. This NPDES facility was recently issued a Cease and Desist Order by the CVRWQCB for exceeding the permit limit for conductivity of 700 µS/cm. Dry season conductivity in Paradise Cut was 2,200 µS/cm (measurement made for this study in April 2007), revealing the influence of the contributory discharges.

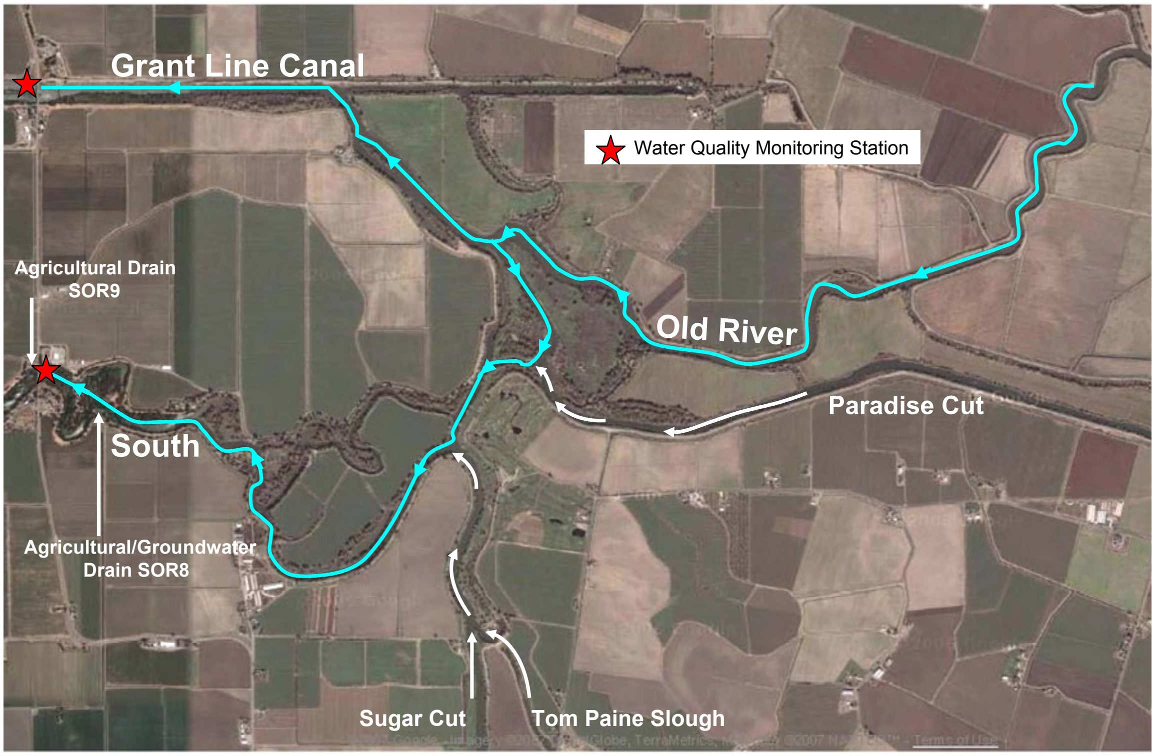


Figure 5-7. Sources of saline water to Old River downstream of the bifurcation with Grant Line Canal

Another tributary of Old River is Tom Paine Slough. The confluence of Tom Paine Slough with Old River is located south-west of the Paradise Cut confluence (Figure 5-7). Water in Tom Paine Slough can be relatively saline from a number of contributory agricultural drains.

Data presented earlier show agricultural drains along Tom Paine Slough were especially salty with conductivities ranging between 1,100 and 4,500 µS/cm. The extra-saline nature of these drains is attributable to the heavily mineralized soils (and associated groundwater) in the southernmost portion of the south Delta. These soils originated from erosion of salt-rich marine sedimentary rocks in the Diablo Range. Soils farther north of the south Delta originated from a variety of sources including floodwaters from the Sierra Nevada. One sample collected from Tom Paine Slough for this study in December 2006 exhibited a conductivity of 2,500 µS/cm, revealing the water quality impact of the drains discharging to this slough.

A siphon on Tom Paine Slough seasonally restricts outflow to Old River. Just upstream from the Old River confluence, four siphons with single-direction flap-gates are situated on a dike across Tom Paine Slough at Sugar Cut (DWR 2004B). The flap-gates allow water to enter the slough on high tide then close with ebb tide as water begins to leave. The siphon helps maintain water levels and is operated during the growing season when stage can be seasonally lowest. During periods when water levels in the south Delta are not at certain low levels (e.g., under high flow conditions in the San Joaquin River), another gate can be opened to allow water to move freely in and out of Tom Paine Slough. Therefore, water in Tom Paine Slough can only flow to Old River when the unidirectional siphons are not in operation.

Another source with the potential to affect conductivity at ORTB is groundwater effluence to an urban/agricultural drain flowing to Sugar Cut (SC1). The mouth of Sugar Cut merges with Tom Paine Slough just upstream from the confluence with Old River (Figure 5-7). Dry season flow in SC1 is between 1 and 2 cfs with a conductivity of 2,100 µS/cm (measurements made for this study in December 2006 before any appreciable rainfall had fallen during water year 2007). Other sources of saline water to Sugar Cut include several drainage pumping stations and, possibly, groundwater accretion from wastewater ponds situated directly adjacent Sugar Cut.

One fairly large discharge to the aforementioned urban/agricultural drain, and hence Sugar Cut, is agricultural drainage from Westside Irrigation District. This district has an agreement with the City of Tracy to pump as much as 35 cfs (22.6 mgd) to the drain about a mile upstream from the confluence with Sugar Cut (Reyna e-mail communication 2007).

Lastly, two agricultural discharges on Old River are particularly close to the ORTB water quality station. One pumping station is near Tracy Boulevard Bridge immediately downstream from the ORTB station (SOR9 in Figure 5-7). The other is a short distance upstream from the bridge (SOR8). This latter drain collects drainage from a relatively large parcel of agricultural land south of Old River (from USGS quadrangle maps and aerial photographs at CaliforniaMaps.org). The SOR8 drain may also be intercepting and conveying groundwater to Old River. The conductivity of both SOR8 and SOR9 ranges from 920 to 3,880 µS/cm (Table 5-3). Conductivity at ORTB may be inordinately influenced by one or both of these drains due to their proximity and saline nature. This was supported by assessing short-term conductivity trends.

Figure 5-8 shows quarter-hour conductivity measurements at ORTB and GLCTB during June 2006. Not only was conductivity higher at ORTB, it also exhibited a daily bimodal oscillation trend that was absent at GLCTB. The oscillations roughly mimicked the same sinusoidal periodicity as tidal stage but at an apparent 11 to 12 hour offset (Figure 5-8).

The conductivity oscillations observed at ORTB reveal that a plume of high-salinity water is cyclically moving past the station's intake with tide. Conductivity temporarily increases as the plume moves into the station's intake zone, then declines as tidal flow reverses. If the nearest agricultural drain (SOR9) is in fact the source of the plume, the rise in conductivity would occur immediately on the incoming or rising tide (the SOR9 agricultural pumping station is on the other side of Tracy Boulevard Bridge from ORTB). This does not appear to be the case in Figure 5-8, which shows that the highest tidal and conductivity crests are separated by 11 to 12 hours.

Table 5-3. Conductivity, chloride, and sulfate in two agricultural drains located on Old River near Tracy Boulevard Bridge (source: Belden et al. 1989)

Drain 1/	Sample Date	Conductivity, µS/cm	Chloride, mg/L	Sulfate, mg/L
SOR8	4/29/1986	2,100	400	300
	7/28/1986	1,100	140	160
	9/9/1986	2,300	400	320
	3/19/1987	3,880	750	
	5/8/1987	1,210	180	
	7/22/1987	1,600	190	200
	9/23/1987	2,250	380	340
SOR9	1/22/1986	920	180	120
	4/29/1986	1,400	270	160
	7/28/1986	940	91	120
	9/9/1986	1,000	190	47
	3/19/1987	1,140	280	
	5/8/1987	1,020	170	
	7/22/1987	990	120	120
	9/23/1987	1,200	210	86

1/ Drain locations in Figure 2-1

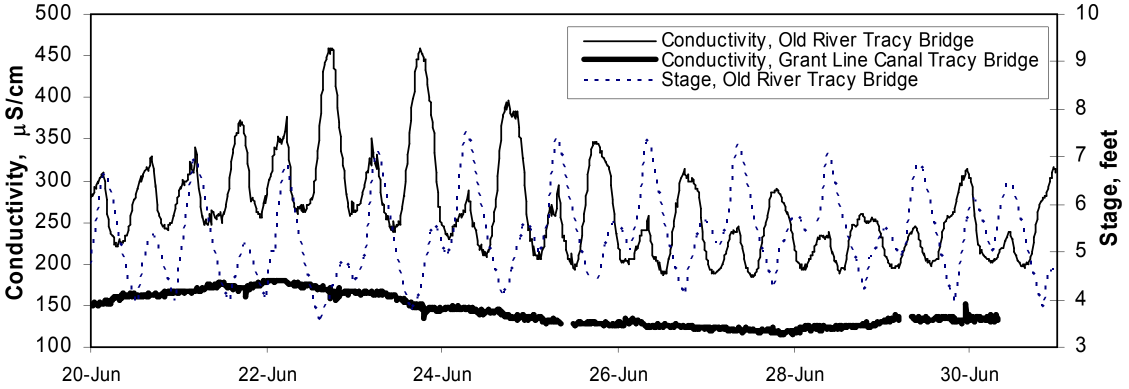


Figure 5-8. Conductivity and stage in Old River at Tracy (Boulevard) Bridge (ORTB) and conductivity in Grant Line Canal at Tracy (Boulevard) Bridge (GLCTB), June 2006 (sources: Swift, email communication 2006 and CDEC)

Another agricultural drain is roughly 1,500 feet upstream from ORTB (SOR8 in Figure 5-7). Drainage from this source is particularly salty with conductivity measurements ranging exclusively above 1,000 µS/cm (Table 5-3). This drain may also be intercepting and conveying groundwater to Old River year-round. Discharges could build up in Old River during slack tide before moving downstream as a slug of extra-saline water on the outgoing tide. Under this scenario, it may take several tidal cycles before the slug reaches ORTB. Regardless of the source or sources and associated hydrodynamics, evidence of these slugs of extra-saline water were sometimes absent in the database, inferring that the discharge (or discharges) periodically abates.

Figure 5-9 shows conductivity at ORTB during a portion of March-April 2006. First, the conductivity crests were somewhat synchronized with high tide (not necessarily relevant if the source is the upstream discharge). More importantly, oscillation amplitude rose and shrank dramatically within a relatively short period of time.

The fact that the highest conductivity excursions lasted only a few days suggests that the inferred slug of water was only present over the same duration, as if the pumping station was turned on and off. This would make sense if the presumed discharge pump(s) was float-activated as many are in the Delta (DWR 1956). Further, pumping stations can be equipped with multiple pumps that, individually or combined, could also theoretically control the amplitude of the conductivity oscillations at ORTB.

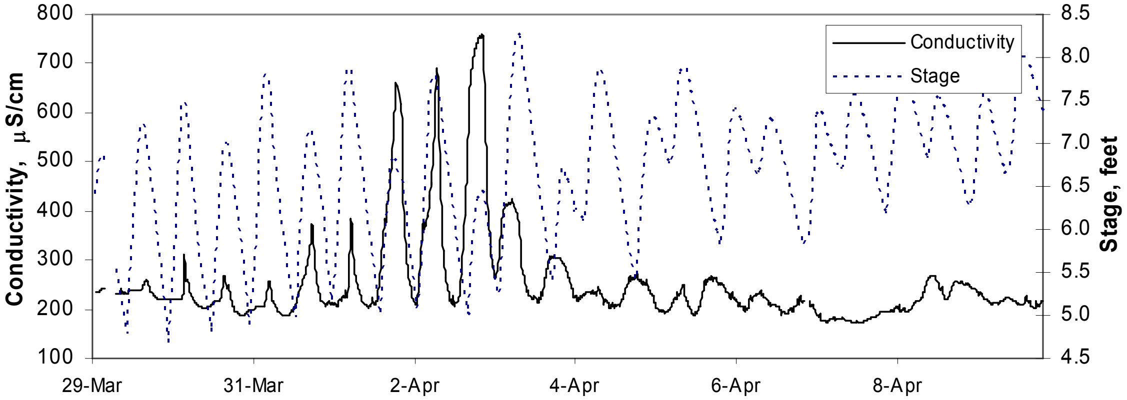


Figure 5-9. Conductivity and stage in Old River at Tracy (Boulevard) Bridge (ORTB), late March to early April 2006 (source: CDEC)

The ORTB water quality station appears to be inappropriately located to make representative water quality measurements of Old River. Based on the above salinity trends, the ORTB station is inordinately influenced by one or more nearby saline discharges. Discharges from the presumed source or sources do not become fully mixed with channel water before reaching ORTB.

VI. Other Water Quality Parameters

Agricultural Drainage

Four agricultural drains along Paradise Cut were sampled for water quality parameters besides salinity (stations PC4 and PC6-8 in Table 2-1). As expected, salt-related parameters such as chloride, sulfate, and bromide were elevated in the drains (Table 6-1). The median chloride concentration of 306 mg/L was above the Secondary Maximum Contaminant Level of 250 mg/L while the median sulfate concentration of 215 mg/L was below it. Bromide ranged from 0.24 to 1.74 mg/L with a median of 0.82 mg/L.

The variability of most minerals in the Paradise Cut drains was moderately high with CVs ranging from 24 to 42 percent and one extreme value of 219 percent for nitrate (Table 6-1). Similar to conductivity, the variability of individual minerals in Delta agricultural drainage is associated with seasonal irrigation practices and the buildup of salt in the soil during the growing season. Salts are leached from the soil during winter from rainfall and water applications, increasing the concentration of minerals in the drainage ditches. The CV of 219 percent for nitrate was biased by 1 extreme concentration of 105 mg/L. The median nitrate concentration was 3.8 mg/L and well below the Primary Maximum Contaminant Level of 45 mg/L (Table 6-1).

Table 6-1. Summary of water quality results from four agricultural drains discharging to Paradise Cut (stations PC4 and PC6-8 in Table 2-1) from periodic sampling between 1987 and 1997 (sources: DWR 1990, 1994, and 1999 MWQI data query)

Parameter, Units	Minimum	Maximum	Median	Average	Std. Dev.	CV 1/	N	MCL 2/
Boron, mg/L	0.2	1.7	0.8	0.8	0.3	38	75	
Bromide, mg/L	0.24	1.74	0.82	0.86	0.36	42	68	
Calcium, mg/L	43	174	98	105	31	29	75	
Chloride, mg/L	117	680	306	341	124	36	78	250**
Dissolved Organic Carbon, mg/L as C	2.2	14	5.1	5.7	2.3	40	102	
Hardness, mg/L as CaCO3	194	805	464	499	154	31	75	
Magnesium, mg/L	21	110	51	58	20	34	75	
Nitrate, mg/L as NO3	0.5	105	3.8	15	32	219	10	45*
pH	6.9	7.8	7.3				8	
Potassium, mg/L	1.1	10	4.2	4.6	1.8	39	75	
Sodium, mg/L	71	372	177	183	54	30	78	
Sulfate, mg/L	81	482	215	226	73	32	75	250**
Total Alkalinity, mg/L as CaCO3	78	326	175	181	43	24	75	
Total Dissolved Solids, mg/L	444	2,120	1,050	1,094	324	30	74	500**
Trihalomethane Formation Potential, µg/L	250	1,400	750	743	262	35	64	
Turbidity, NTU	5	124	28	36	24	67	64	
UV Absorbance @254nm, absorbance/cm	0.059	0.600	0.144	0.156	0.074	47	74	

1/ Coefficient of Variation

2/ * Primary Maximum Contaminant Level

** Recommended Secondary Maximum Contaminant Level

Dissolved organic carbon in the drains along Paradise Cut ranged from 2.2 to 14 mg/L and was moderately correlated with trihalomethane formation potential (THMFP) (Table 6-1 and Figure 6-1). These relatively low concentrations contrast with those from agricultural drains in the central Delta which exhibit much higher levels of DOC due to their peat soils. Some of the highest levels have been reported for drainage from Empire Tract (central-eastern Delta): DOC range = 15 to 119 mg/L, median = 42 mg/L (DWR 1994). The disparity in DOC concentrations between drains in the central and southern Delta illustrates the contrast in water quality between agricultural drainage from islands composed of peat soils versus drainage from islands with more mineralized soils in the south Delta.

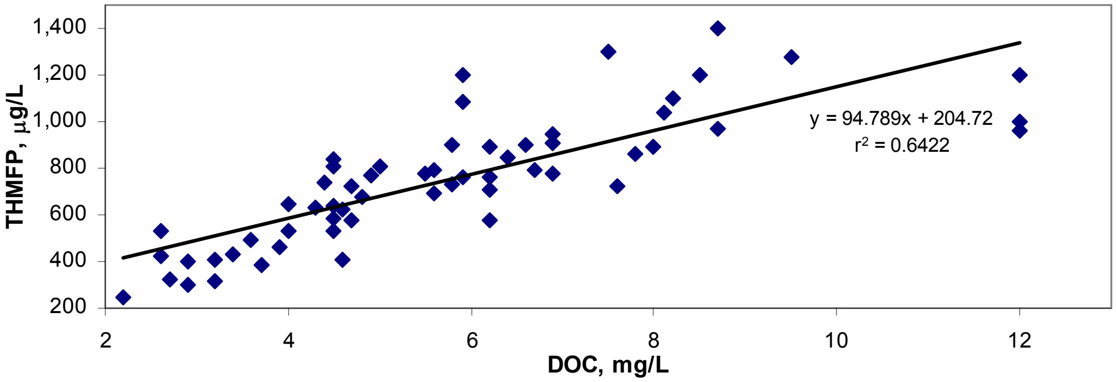


Figure 6-1. Correlation between dissolved organic carbon and trihalomethane formation potential (DWR modified 510.1) in four agricultural drains in the south Delta (PC4 and PC6-8) (data from DWR 1990, 1994, and 1999 MWQI data query)

Dissolved organic carbon in all four south Delta drains was seasonally highest from June to October (Figure 6-2A). These seasonal trends were dissimilar to those from a drain on Twitchell Island in which DOC was highest during the winter and, to a lesser extent, fall (Figure 6-2B). The two distinct DOC trends reveal differing mechanisms controlling seasonal organic carbon concentrations between Delta island drains.

Monthly DOC trends on Twitchell Island generally mimicked those of salinity whereby the highest levels were observed during winter and, to a lesser extent, late fall. Salts accumulate in the soil during the growing season from evaporation and the osmotic exclusion of salts at the root zone of crops consuming irrigation water. The salt residuals left behind at the root zone are dissolved and transported to collector drains during winter rainfall events and water applications. Similar residuals of DOC from Twitchell Island also appear to co-elute with the salts. The seasonal DOC trends observed on Twitchell Island were the opposite of those observed in the south Delta drains along Paradise Cut.

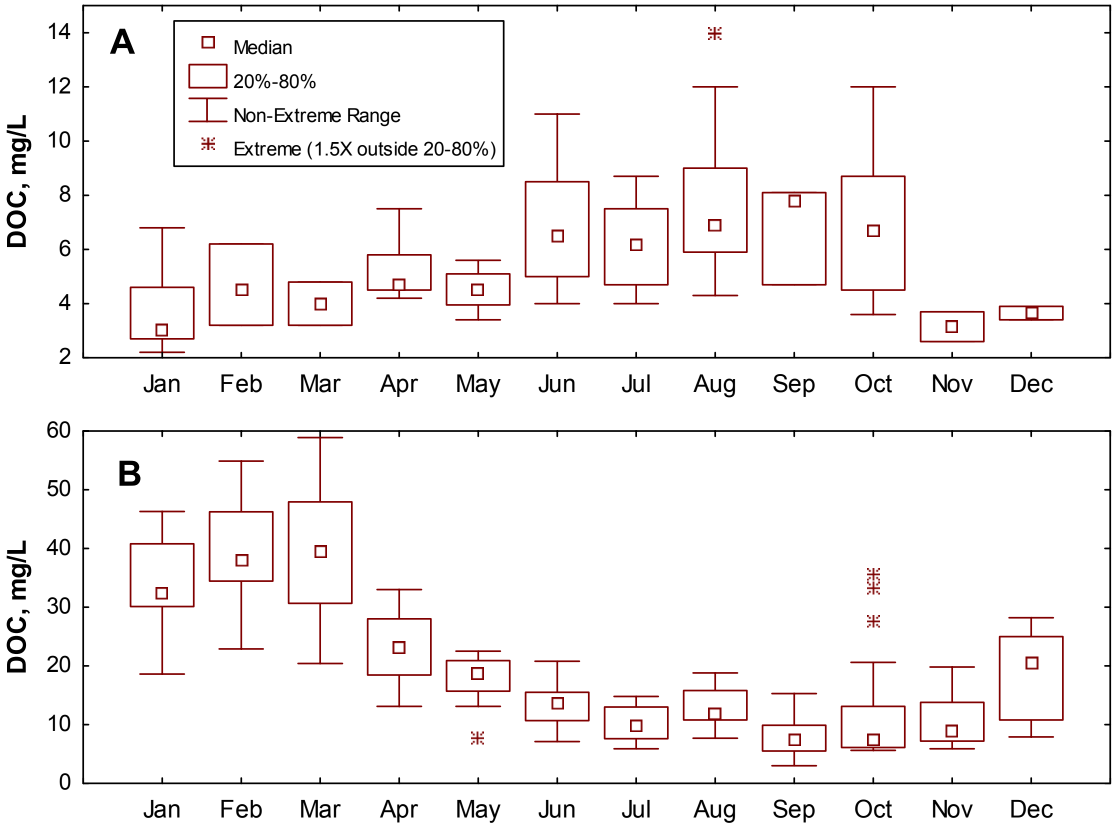


Figure 6-2. Monthly dissolved organic carbon in four drains discharging to Paradise Cut (stations PC4 and PC6-8 in Table 2-1) (A) and a drain on Twitchell Island (B) from periodic sampling between 1987 and 1999 (sources: DWR 1990, 1994, and 1999 MWQI data query)

Unlike Twitchell Island, drains along Paradise Cut exhibited DOC concentrations that were generally highest during June to October and lowest during winter and late fall. Higher levels during the growing season imply that irrigation applications were associated with the higher DOC concentrations – similar to the way irrigation applications coincide with salinity reductions in Delta island drainage. Unlike salinity, DOC in the Paradise Cut drains did not exhibit the same increase in drainage concentrations due to soil leaching from rainfall and winter water applications.

Point Sources

Organic carbon data for point-source discharges in the south Delta were almost non-existent (CVRWQCB 2003, 2004A, 2004B, 2005, and 2006A). Brown Sand listed a TOC concentration of 6.7 mg/L in its permit application. The NPDES permit for the City of Manteca reported a TOC of 13 mg/L. Permits for the other two dischargers (City of Tracy and Deuel Vocational Institution) made no mention of organic carbon levels.

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Attachment A. Composition and distribution of soils in the Sacramento-San Joaquin Delta lowlands (reproduced from DWR 1967)