Factors Affecting Total Organic Carbon and Trihalomethane Formation Potential in Exports from the South Sacramento-San Joaquin Delta and Down the California Aqueduct

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

Cover Photo: State and federal export sites in the South Sacramento-San Joaquin Delta. Facilities include the Clifton Court Forebay (upper right), Bethany Reservoir (lower left) and the channels of the State Water Project's California Aqueduct (left channel) and the Central Valley Project's Delta-Mendota Canal (left-middle channel). The photograph was taken with false color imaging film by a U-2 surveillance and reconnaissance aircraft in 1991. The film picks up reflective radiation from foliage such as agricultural crops and images the color red (source: Dale Kolke, DWR Photography Section).

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Acronyms and Abbreviations

af	acre-feet
cfs	cubic feet per second
CALFED	California Bay-Delta Authority
CV	coefficient of variation
CVC	Cross Valley Canal
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
DBP	disinfection by-product
Delta (the)	Sacramento-San Joaquin Delta
DFG	Department of Fish and Game
DHS	Department of Health Services
DMC	Delta-Mendota Canal
DOC	dissolved organic carbon
DWR	Department of Water Resources
EPA	Environmental Protection Agency
IEP	Interagency Ecological Program
KRI	Kern River Intertie
maf	million acre-feet
mgd	million gallons per day
mg/L	milligrams per liter
MCL	maximum contaminant level
MWQI	Municipal Water Quality Investigations
NOAA Fisheries	National Marine Fisheries Service
NTU	nephelometric turbidity unit
O&M	Division of Operations and Maintenance
pH	negative log of the hydrogen ion activity
Reclamation	Bureau of Reclamation
RPD	relative percent difference
SLC	San Luis Canal
SRI	Sacramento River Index
SWP	State Water Project
SWRCB	State Water Resources Control Board
t	metric tons
taf	thousand acre-feet
tcfs	thousand cubic feet per second
TDS	total dissolved solids
THMFP	trihalomethane formation potential
TOC	total organic carbon
TSS	total suspended solids
μg/L	micrograms per liter
μS/cm	microseimens per centimeter
USFWS	Fish and Wildlife Service
USGS	Geological Survey
WQCP	Water Quality Control Plant for the Bay-Delta

1. Executive Summary

Total organic carbon (TOC) and trihalomethane formation potential (THMFP) were assessed in water exports from the south Sacramento-San Joaquin Delta (Delta) at Banks Pumping Plant, the Delta-Mendota Canal (DMC), and further down the State Water Project's California Aqueduct. Focus was placed on defining seasonal and long-term trends with respect to operations and hydrology during 1990 to 2003. Operations and hydrology were major factors affecting concentration trends in the California Aqueduct.

Banks Pumping Plant and the Delta-Mendota Canal

Pumping

Monthly pumping at Banks Pumping Plant was consistently variable due to the complex array of hydrological, operational, and regulatory factors that govern south Delta exports. Pumping was generally highest in winter, summer, and fall and lowest during April to June.

The relative amount of water pumped from the DMC into the California Aqueduct at O'Neill Forebay was highest between November and April. During this 6-month period, DMC inflows, on average, made up a little less than half of the water entering O'Neill Forebay from south Delta sources (DMC + California Aqueduct). The contributions were rather variable from year-to-year.

Concentrations

Total organic carbon and THMFP were correlated at Banks Pumping Plant and in the DMC with r^2 values of 0.77 and 0.89, respectively. Monthly concentrations were not statistically different ($p>0.05$) between stations.

Dry Season: Dry season (August to November) TOC averages at Banks Pumping Plant were modestly correlated with total Delta exports ($r^2 = 0.70$). The correlation makes sense from the standpoint that the Delta Cross Channel gates are typically open during most of the 4-month period from August to November. More Sacramento River flow from upstream reservoir releases (tied to Delta exports) would be conveyed directly to the south Delta via the Delta Cross Channel, providing greater dilution of TOC sources such as point and non-point discharges. Based on this, increasing exports from 1990 to 2003 (concurrent with more available water) contributed to a statistically significant ($p<0.001$) decline in TOC observed at Banks Pumping Plant over the 14-year period.

Dry season TOC averages in the DMC were most often higher than – and not well correlated with – those at Banks Pumping Plant. Certain South Delta Temporary Barriers are usually in place for at least a portion of the period between August and November, impeding direct flow from the San Joaquin River towards Banks Pumping Plant via south Old River and Grant Line Canal (DWR 2004a). However, water can still flow to the DMC export site via this route. Based on this, TOC is usually higher in flow from Grant

Canal and south Old River versus cross Delta flow during the dry season. The TOC-reducing benefits from export-related reservoir releases observed at Banks Pumping Plant were not apparent in the DMC.

Wet Season: Wet season (December to April) TOC averages at Banks Pumping Plant and in the DMC were well correlated ($r^2 = 0.95$), inferring greater influence from the San Joaquin River at both stations during this period. This makes sense since the south Delta Temporary Barriers are not in place, allowing more water from the San Joaquin River to flow to both export sites via south Old River and Grant Line Canal. Further, the Delta Cross Channel gates are oftentimes closed during much of the wet season, reducing the amount of Sacramento River flow entering the central Delta from the north, potentially lessoning the dilution of San Joaquin River flow entering the central Delta from the south and increasing its proportion in cross Delta flow.

Wet season averages from these two stations were correlated with similar averages in the San Joaquin River – substantiating that river's predominance in south Delta exports during a period when exports can be relatively high. Mud and Salt Sloughs were shown to be major potential sources of organic carbon to the San Joaquin River.

Loads

On average, 40 percent of the annual TOC load was pumped at Banks Pumping Plant during a 3-month period from January to March. This increased to nearly 50 percent with the inclusion of December. Monthly loading was rather variable from year-to-year.

Inflow to O'Neill Forebay from the DMC contributed nearly half the average TOC load from south Delta sources (DMC + California Aqueduct) during November to April. Outside of this 6-month period, monthly average DMC load contributions ranged from 9 to 31 percent. Monthly load contributions from the DMC were rather variable from year-to-year.

Joint-Use Facilities

San Luis Reservoir is filled during the low demand seasons of fall and winter – periods when bromide and TOC, respectively, have been highest at Banks Pumping Plant. The bromide and TOC loads banked in San Luis Reservoir during fall and winter are released the following spring and summer when demand is greatest. Reservoir releases (and, to a lesser extent, inflow to O'Neill Forebay from the DMC) during June to September coincided with THMFP levels at O'Neill Forebay Outlet that were, on average, 7 to 11 percent higher than those at Banks Pumping Plant. These higher levels continued down the California Aqueduct to Check 41.

Check 41

Check 41 is located at milepost 303 near the bifurcation of the East and West Branches of the California Aqueduct. Total organic carbon and THMFP were not well correlated at this station.

Pumping at Edmonston Pumping Plant influenced THMFP trends at Check 41. Pumping rates essentially determined how quickly water quality conditions at O'Neill Forebay Outlet reached Check 41. Higher pumping rates translated into quicker travel times. Travel times over this 232.5-mile stretch of California Aqueduct ranged from days to over a month.

Reduced pumping often resulted in a delay in wet season THMFP spikes between O'Neill Forebay Outlet and Check 41. In one case, pumping at Edmonston Pumping Plant virtually ceased in January and February 1999. During these months, THMFP at O'Neill Forebay Outlet reached a season peak. By the time pumping resumed the next month, THMFP at O'Neill Forebay Outlet had declined, resulting in the absence of a major THMFP spike at Check 41 that year. A delay or decrease in THMFP levels between O'Neill Forebay Outlet and Check 41 due to reduced pumping at Edmonston Pumping Plant was observed in most years. Trihalomethane formation potential at Check 41 was further reduced by groundwater turn-ins – usually when their volumes were highest relative to pumping rates.

Devil Canyon Headworks

Devil Canyon Headworks is located at milepost 411, just downstream from Silverwood Lake. Total organic carbon and THMFP were modestly correlated at this station.

Natural inflows to Silverwood Lake from the upstream watershed reduced THMFP in Project water. Natural inflows were correlated with a decline in monthly average THMFP between Check 41 and Devil Canyon Headworks. The declines ranged from 4 to 17 percent: resulting in a benefit to drinking water quality during 9 months of the year. For the other 3 months, monthly average THMFP was 3 to 13 percent higher at Devil Canyon Headworks than Check 41. Natural inflows to Silverwood Lake were highly variable from year-to-year.

2. Introduction

Total organic carbon and THMFP were assessed in water exports from the Delta at Banks Pumping Plant, the DMC, and further down the State Water Project's (SWP's) California Aqueduct. Focus was placed on defining seasonal and long-term trends with respect to operations and hydrology during 1990 to 2003.

The objectives were to assess:

1. pumping trends at Banks Pumping Plant and O'Neill Forebay (inflow from the DMC);
2. concentration and loading trends at Banks Pumping Plant and O'Neill Forebay;
3. concentration trends down the California Aqueduct to Devil Canyon Headworks.

This study relied mostly on water quality data from the Division of Operations and Maintenance's (O&M's) Environmental Assessment Branch and the Delta, San Luis, San Joaquin, and Southern Field Divisions.

Problem Description

Water is pumped into the California Aqueduct and delivered to SWP contractors for the primary purpose of furnishing drinking water. Many municipal water treatment plants use chemical disinfectants to inactivate potentially harmful pathogens (USEPA 2003). While effective, disinfectants can react with organic matter (e.g., TOC) to form disinfection by-products (DBPs) such as trihalomethanes. Studies have shown that exposure to DBPs may cause health problems. As a result, the U.S. Environmental Protection Agency adopted DBP drinking water standards for water treatment plant compliance.

One of the Program Elements of the California Bay-Delta Authority is the Drinking Water Quality Program. Objectives of this program include providing municipal water suppliers with water that will meet or exceed applicable drinking water standards (CALFED 2000). Proposed strategies to reduce unwanted water quality parameters such as TOC range from source control to altering water operations.

To that end, existing water quality data from the California Aqueduct was assessed for trends relative to factors such as water operations and hydrology. The water quality parameters TOC, a DBP precursor, and THMFP (trihalomethane concentration after sample chlorination and incubation) have been routinely monitored in the California Aqueduct as far back as 1990. The focus was on Banks Pumping Plant, the start of the California Aqueduct, and to a lesser extent, inflow from the DMC at O'Neill Forebay. A better understanding of the interplay between operations, hydrology, and water quality at those locations and further down the California Aqueduct may provide insight into what actions may or may not be feasible to achieve the goal of improving drinking water quality.

Total organic carbon and THMFP can be relatively high in south Delta exports. General sources include rainfall runoff from around the Central Valley and point and non-point sources. Two specific sources include Delta agricultural drainage and municipal wastewater treatment plants (DWR 1990, 1994, 1995d, 2001, and 2003, and CUWA 1995). Total organic carbon in south Delta exports typically spike upward in winter – not unlike that observed in the much smaller, largely undeveloped, and well studied watershed upstream of the SWP's Barker Slough Pumping Plant (DWR 1996a, 1997b and 1999). No single source was identified and the TOC spikes were explained simply as offsite movement of organic carbon in rainfall runoff from around the watershed along with sediment (DiGiorgio and Pimental 2002). A similar mechanism is also likely behind the rainy season spikes observed in south Delta exports, but on a much larger scale.

Operations around the Delta can affect export water quality. The Bureau of Reclamation's (Reclamation's) Delta Cross Channel was built to combat salt water intrusion, dilute local pollution, and prevent "...low water flows of the San Joaquin River from getting into the Tracy Pumping Plant" (http://www.usbr.gov/dataweb/html/delta.html#development, 7/2005). The South Delta Temporary Barriers are periodically installed, in part, to help with circulation, water level, and fishery issues (http://sdelta.water.ca.gov/index.htm). Some of the barriers have been shown to reduce direct influence from the San Joaquin River at Banks Pumping Plant and Tracy Pumping Plant – with an accompanying shift in water quality (DWR 2004a). Seasonal operation of these structures (cross channel and barriers) was assessed in this report with respect to TOC and THMFP in south Delta exports.

Description of Study Area

Water in the south Delta is admitted to the SWP at the Clifton Court Forebay intake gates and pumped into the California Aqueduct at Banks Pumping Plant (Figure 2-1). A major freshwater source to the Delta is the Sacramento River. Water released to the Sacramento River from the SWP's Lake Oroville originates from the north, south, and middle forks of the Feather River (Figure 2-2). The Delta Cross Channel is located in the north Delta and was designed to convey more Sacramento River flow into the central Delta (Figure 2-1). The South Delta Temporary Barriers are periodically installed on channels that convey water from the San Joaquin River to the two export sites (Figure 2-1).

Water quality stations on the California Aqueduct include Banks Pumping Plant, O'Neill Forebay Outlet, Check 41, and Devil Canyon Headworks. This last station is located at the termination of the East Branch of the California Aqueduct – over 400 aqueduct miles south of Banks Pumping Plant (Figure 2-2). Routine water quality samples are collected on the third Wednesday of each month and analyzed for a variety of parameters (see DWR 2004b for details).

Water is also exported from the south Delta at the federal Central Valley Project's (CVP's) Tracy Pumping Plant and conveyed down the DMC (Figure 2-1). Water from the DMC can be pumped into the California Aqueduct at O'Neill Forebay via O'Neill Pumping-Generating Plant (see inset in Figure 2-2). O'Neill Forebay is part of the Joint-Use Facilities that are operated jointly by State and federal agencies to convey water to municipal and agricultural contractors, respectively. Other Joint-Use Facilities include

San Luis Reservoir, Gianelli Pumping-Generating Plant, and a 101-mile stretch of the California Aqueduct starting at O'Neill Forebay Outlet (San Luis Canal).

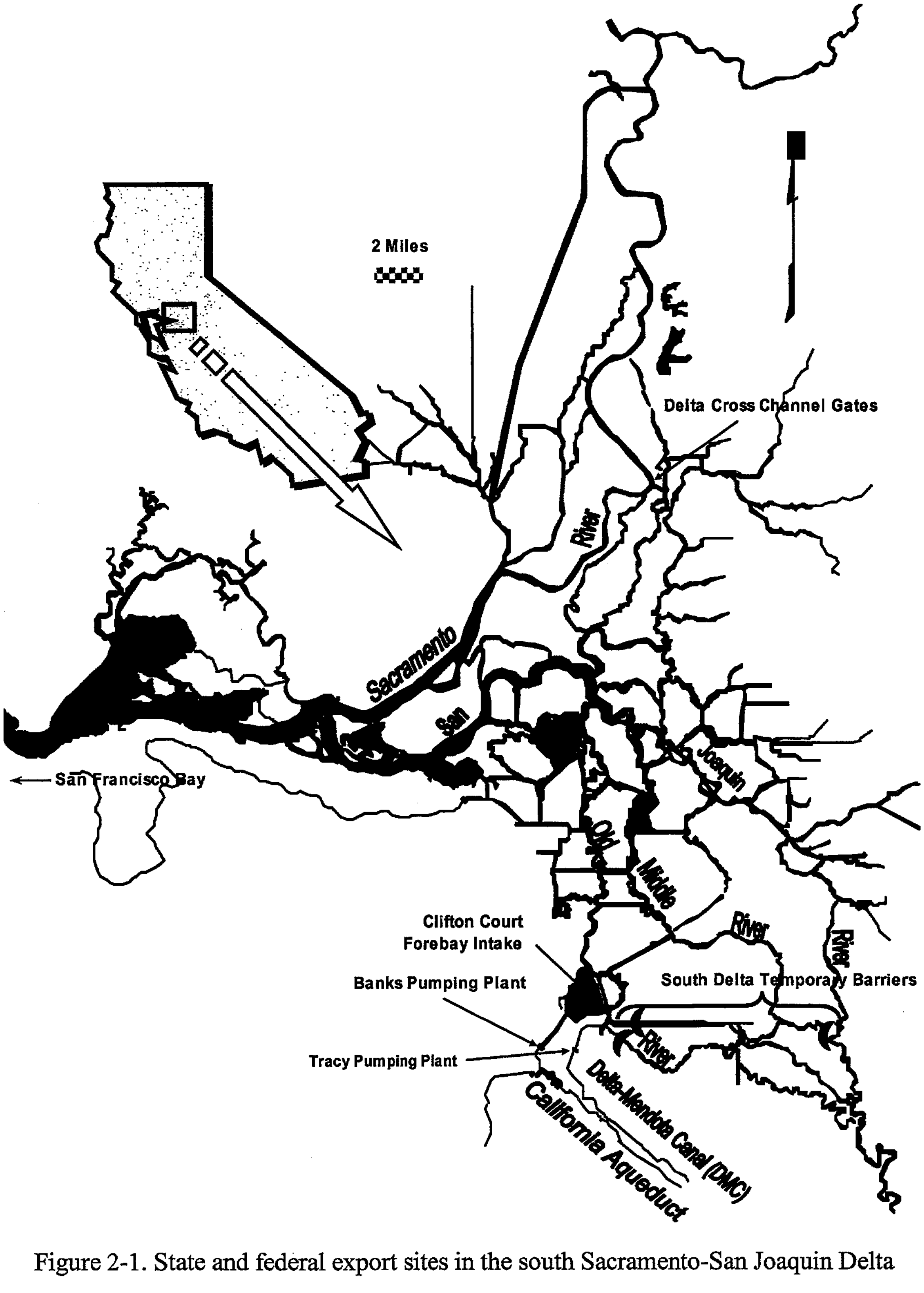

Figure 2-1. State and federal export sites in the south Sacramento-San Joaquin Delta

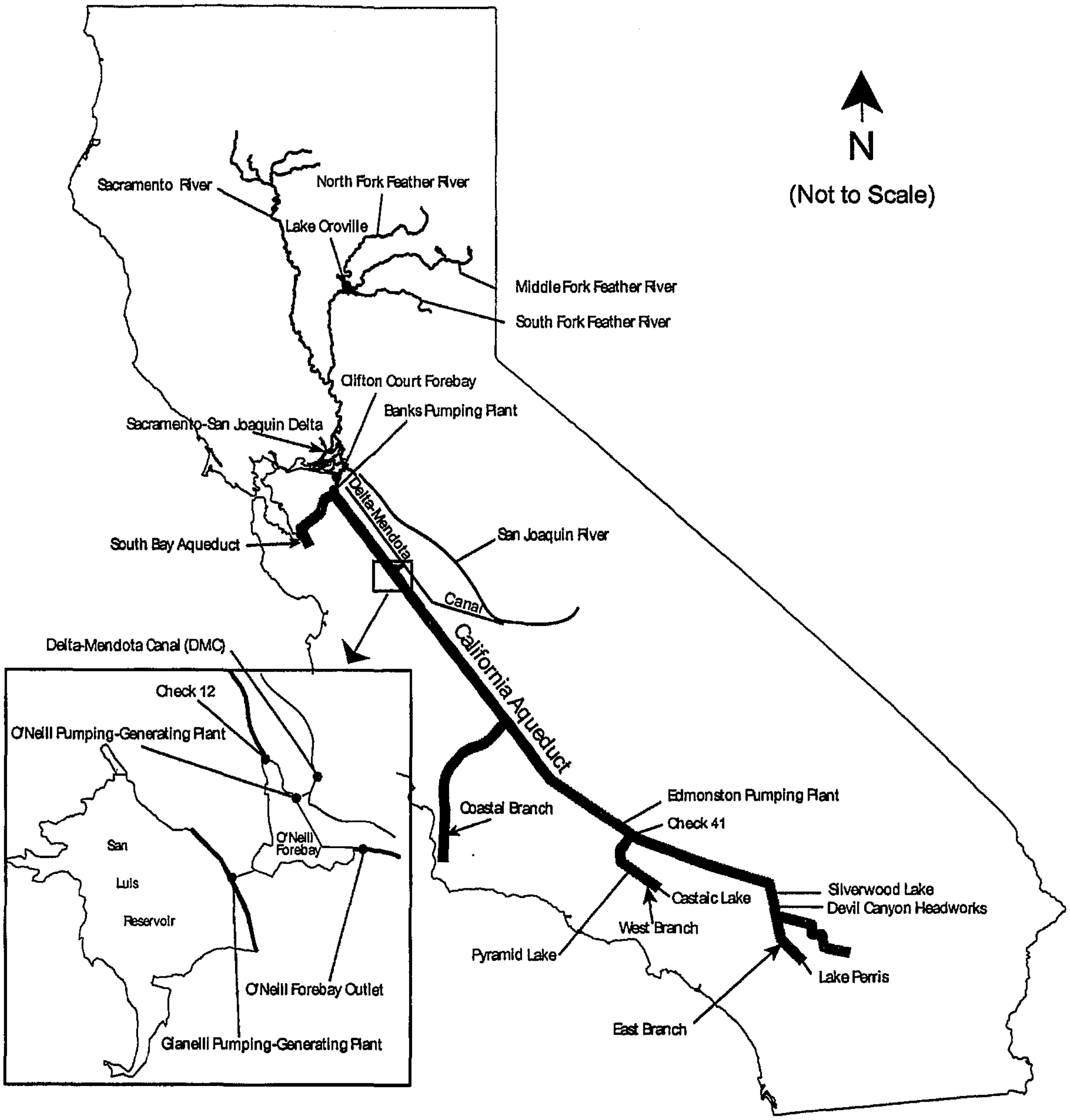

Figure 2-2. The California Aqueduct with it's associated branches and the Delta-Mendota Canal

State Water Project Operations

Pumping at Banks Pumping Plant is currently operated in accordance with the State Water Resources Control Board's Decision 1641 (SWRCB D-1641) (see Appendix A). Adopted in 1999, D-1641 contains water quality, flow, and operational criteria for Delta exports. Criteria contained within D-1641 are conditioned by water year classification and generally become less stringent during water years with less water supply availability. State pumping 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.

Pumping operations of the SWP and CVP are also directed by various objectives of the 1995 Bay-Delta Water Quality Control 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, Department of Fish and Game (DFG), U.S. Fish and Wildlife Service (USFWS), and Reclamation. 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.

3. Banks Pumping Plant

Pumping

Much of the pumping data and information was obtained from DWR's monthly and annual Reports of Operations. The reports can be viewed at the following web sites:

http://swpoco.water.ca.gov/annual/annual.menu.html
http://swpoco.water.ca.gov/monthly/monthly.menu.html

Information regarding water operations in the Delta was obtained from the annually published Appendix E reports of DWR's Bulletin 132, "Water Operations in the Sacramento-San Joaquin Delta." These reports are listed in the reference section by year but will not be individually cited for brevity.

Historic, 1967 to 2003

Pumping at Banks Pumping Plant for the 37-year period from 1967 to 2003 is shown in Figure 3-1. Monthly pumping ranged from 1.87 thousand acre-feet (taf) in April 1998 to 465 taf in January 1993. The high variability indirectly portrays the array of hydrological, operational, and regulatory factors that govern pumping.

April 1998 was one of 3 consecutive months with low export rates. Pumping was severely curtailed during February to April 1998 due to emergency repairs and an abundance of water south of the Delta. Pumps were idle at Banks Pumping Plant for a total of 77 days during this 3-month period.

The maximum of 465 taf in January 1993 was related to several factors. High freshwater inflow to the Delta that month permitted elevated pumping to increase storage in San Luis Reservoir that had been depleted after 6 years of drought. The high inflow also provided an opportunity to test whether the California Aqueduct channel could handle the full output of pumps newly installed the previous year (the test was successful).

Smoothed line analysis depicts an increasing trend in monthly pumping from 1967 to around 1987, the first year of a 6-year drought (Figure 3-1). The Sacramento Valley experienced 6 consecutive critical or dry water years during 1987 to 1992 (Figure 3-2). Pumping volumes began declining midway through the drought as water deliveries down the California Aqueduct were dramatically reduced. More favorable water supply after 1992 was accompanied by resumption in the upward pumping trend through 2003 (Figure 3-1).

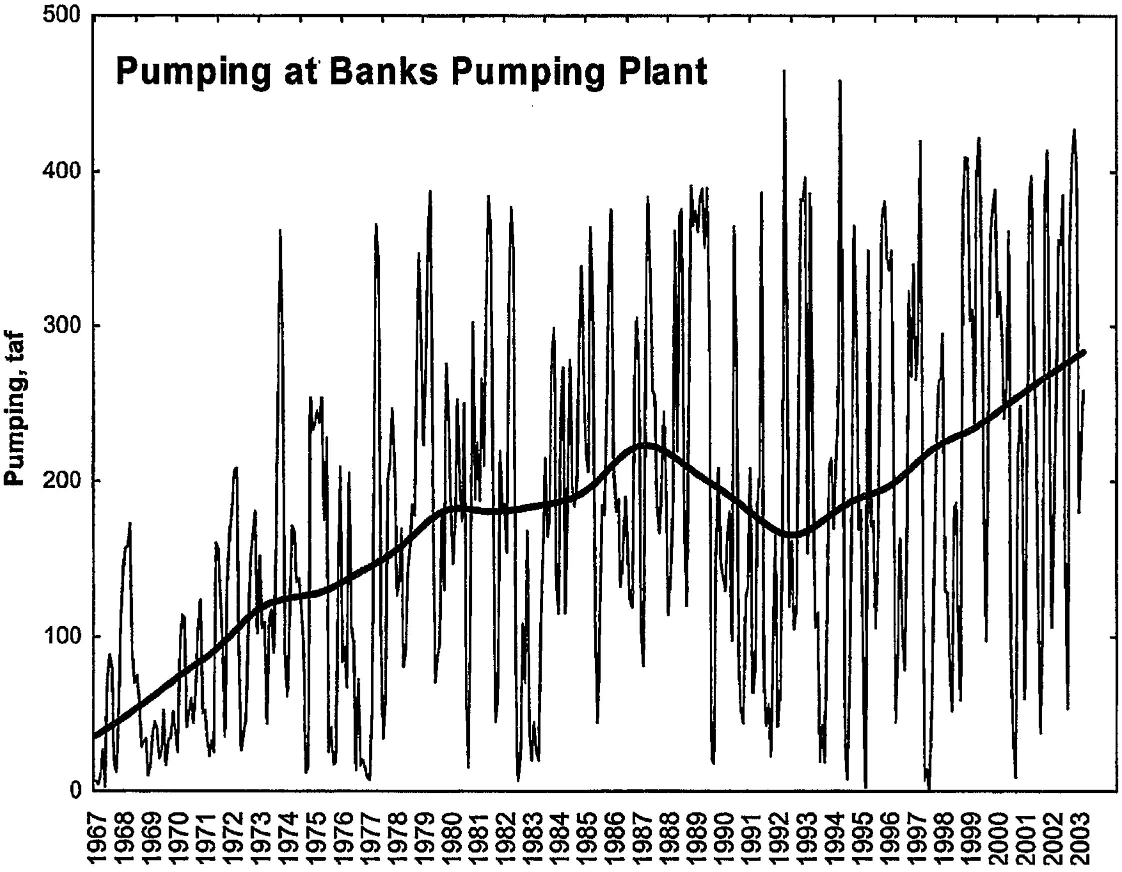

Figure 3-1. Long-term pumping at Banks Pumping Plant, 1967 to 2003. The central data-smoothing line (LOWESS) de-emphasizes more distant surrounding data both vertically and horizontally.

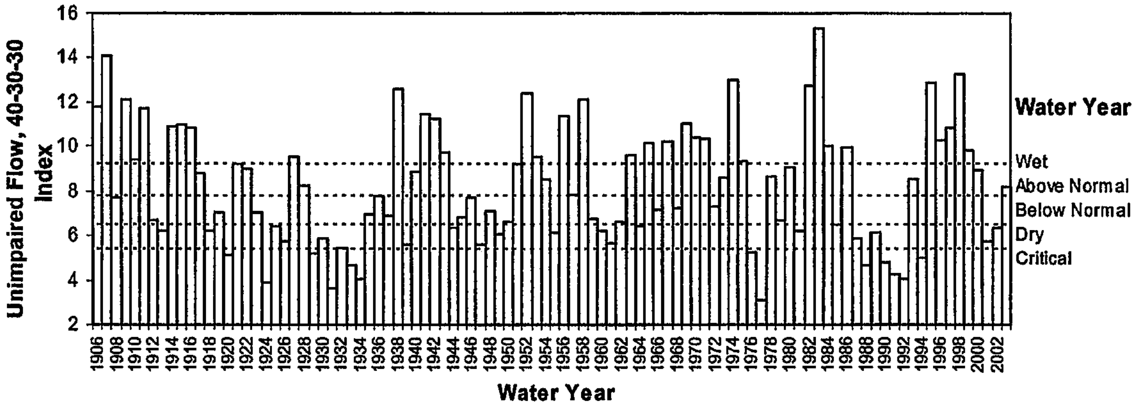

Figure 3-2. Sacramento Valley water year hydrologic classification indices (million acre-feet), 1906 to 2003 (Index = 0.4 x current year April to July unimpaired runoff + 0.3 x current year October to March unimpaired runoff + 0.3 x previous years index up to 10.0 MAF)

Contemporary, 1990 to 2003

Pumping at Banks Pumping Plant from 1990 to 2003 was generally highest during the winter, summer, and fall months with medians near 200 taf or more (Figure 3-3 and Table 3-1). Higher pumping in summer denotes greater demand from downstream water service areas. Pumping is usually needed in fall and winter to replenish storage in San Luis Reservoir when downstream demand is lowest. During all months, pumping variability was relatively high from year-to-year with coefficients of variation (CVs) ranging from 37 to 83 percent (Table 3-1). For example, pumping in April ranged from a period minimum of 1.87 taf to a relatively high rate of 309 taf.

Some of the highest volumes were pumped in January with a median of 295 taf and a period maximum of 465 taf. January is one of several low-demand months when much of the pumpage goes to storage in San Luis Reservoir. January also overlaps a period when exporters are allowed to take a greater proportion of Delta inflows. The Bay-Delta Water Quality Control Plan (WQCP) conditionally allows 65 percent of Delta inflow to be exported during July to January (SWRCB 1995). This percentage drops to 35-45 percent

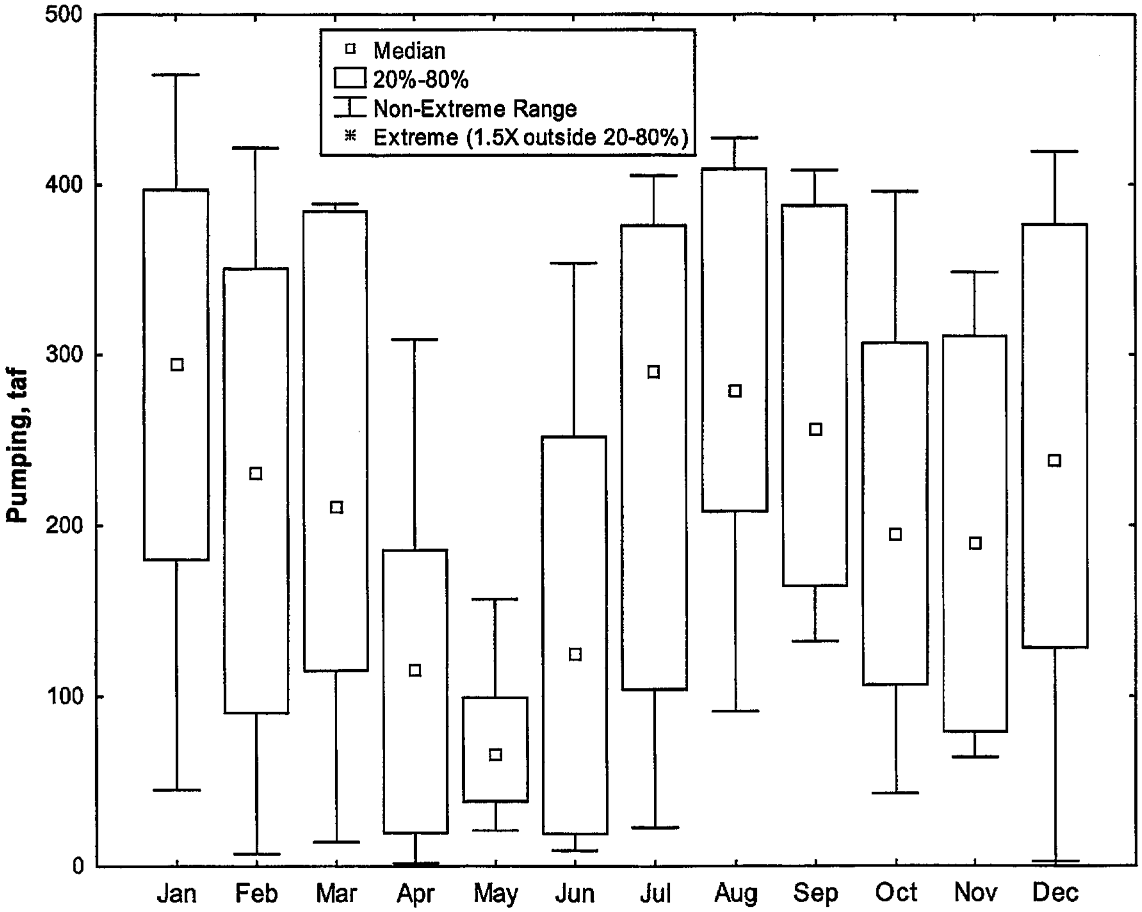

Figure 3-3. Monthly pumping trends at Banks Pumping Plant, 1990 to 2003

Table 3-1. Statistics of monthly pumping (taf) at Banks Pumping Plant, 1990 to 2003

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	282	295	45	465	136	48
Feb	209	230	7.3	422	125	60
Mar	233	211	14	389	137	59
Apr	128	115	1.9	309	91	71
May	69	66	21	157	37	54
Jun	132	124	9.2	354	109	83
Jul	256	290	23	405	133	52
Aug	293	279	91	428	109	37
Sep	272	256	132	409	102	38
Oct	214	195	43	396	107	50
Nov	194	190	64	349	97	50
Dec	230	237	2.6	420	118	51

1/ Coefficient of Variation

the following month (February to June). The 65 percent allowance for January provides an elevated ceiling on exports during a month when Delta inflow is seasonally high.

Figure 3-4 and Table 3-2 show monthly average total Delta inflow from 1990 to 2003 (from DWR's Dayflow database). Total Delta inflow was highest during January to March with medians ranging from 36 to 51 thousand cubic feet per second (tcfs). Therefore, January is a month when Delta inflow is seasonally elevated and allowable exports are conditionally high. The term "conditionally" is included because there are other regulatory restrictions not necessarily related to Delta inflow. In 1992, pumping reductions were mandated by biological opinions from the National Marine Fisheries Service (NOAA Fisheries) for the protection of winter run-sized salmon when their salvage at the SWP's Skinner Fish Facility becomes an issue – usually January and February.

Pumping has been lowest during April to June with medians ranging between 66 and 124 taf (Figure 3-3 and Table 3-1). The lower pumping rates for May, and secondarily April and June, can be attributed to export restrictions required for the protection and enhancement of Delta fisheries.

Exports during April to June have been historically limited under D-1485 to reduce entrainment of juvenile anadromous fishes at Skinner Fish Facility. In 1993, export restrictions were mandated by biological opinions from the USFWS for the protection of Delta smelt when their salvage at the fish facility is an issue – usually May and June. Further, pumping had been voluntarily reduced in April and May to help with salmon out-migration in the San Joaquin River. These reductions were codified in the 1995 WQCP and again in 2000 with a preferred alternative plan (Vernalis Adaptive Management Plan). Both require, in part, specifically lowered pumping rates during a sometimes flexible period around April 15 to May 15.

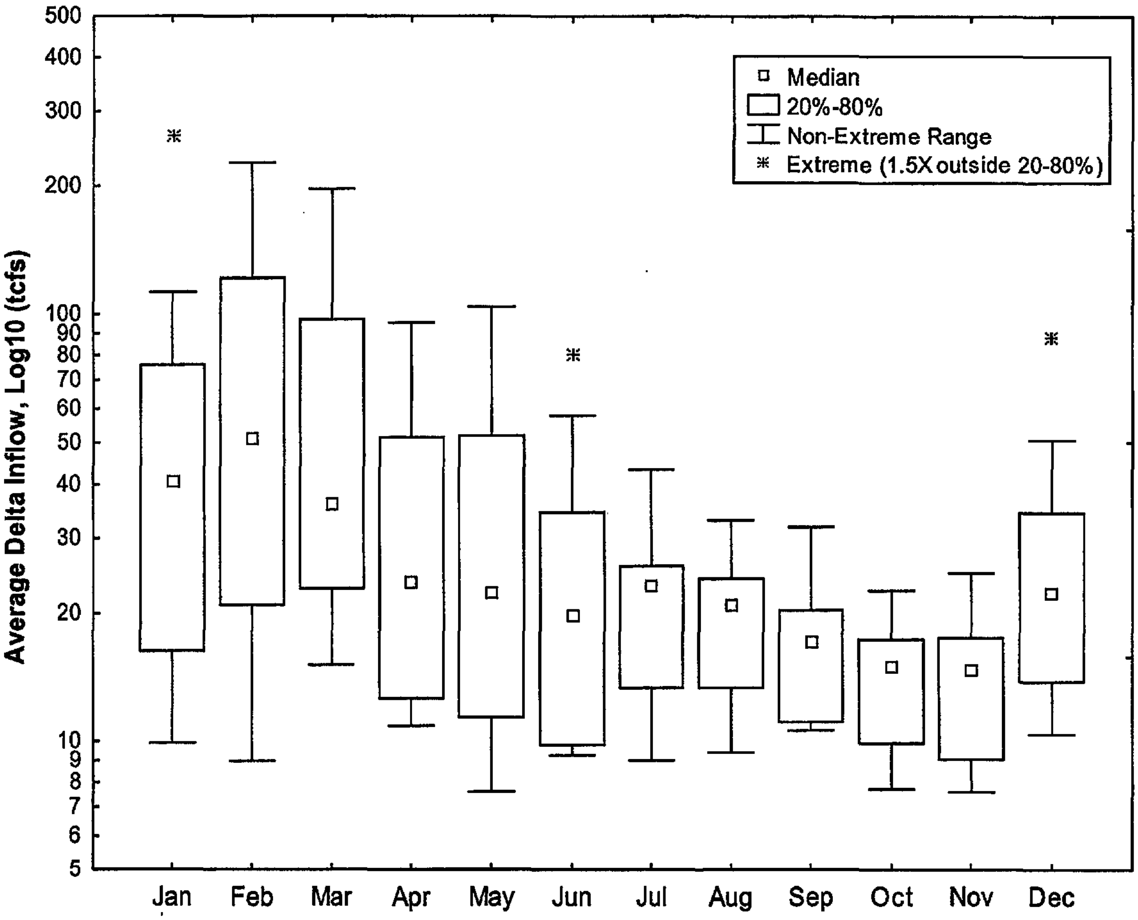

Figure 3-4. Monthly average total Delta inflow trends, 1990 to 2003 (source: Dayflow database)

Table 3-2. Statistics of monthly average total Delta inflow (tcfs), 1990 to 2003 (source: Dayflow database)

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	58	41	10	263	66	113
Feb	71	51	9	227	61	87
Mar	60	36	15	197	51	84
Apr	35	24	11	95	28	79
May	32	22	8	104	28	87
Jun	26	20	9	81	20	79
Jul	23	23	9	43	10	45
Aug	20	21	9	33	6	33
Sep	18	17	11	32	6	35
Oct	14	15	8	23	5	33
Nov	14	15	8	25	5	33
Dec	29	22	10	88	21	74

1/ Coefficient of Variation

Median monthly pumping at Banks Pumping Plant increased to 290 taf in July with a CV of 52 percent (Figure 3-3 and Table 3-1). Median pumping was also relatively high in August (279 taf) and September (256 taf) with lower CVs that together averaged

37.5 percent. Elevated pumping during summer denotes increased demand from downstream service areas. Median monthly pumping declined to 190-195 taf in October and November before increasing to 237 taf in December. The general decline in pumping from summer to mid fall coincides with a similar decline in Delta inflow. Median total Delta inflow steadily declined from 23 tcfs in July to 15 tcfs in October and November (Figure 3-4 and Table 3-2). Lower freshwater inflow to the Delta can translate into mandated pumping reductions at Banks Pumping Plant.

As Delta inflow declines from summer to fall, less water is available for balancing exports with regulatory objectives. Pumping reductions are often needed during these seasons to maintain Delta salinity objectives. Lowering the pumping rate at Banks Pumping Plant is one of the operational tools used to limit seawater intrusion from San Francisco Bay. Other operational actions employed to repel seawater intrusion include increasing reservoir releases upstream of the Delta and/or opening the Delta Cross Channel gates. Maintaining flow objectives in the west Delta may also require pumping reductions. Other factors that can affect pumping include reduced demand and scheduled/unscheduled outages for repair work.

One major factor that influences pumping at Banks Pumping Plant is the amount of water approved for delivery to SWP contractors. A principal goal of the SWP is to deliver water requested by contractors while assuring sufficient carryover storage to meet Delta protection and emergency deliveries the following year. The amount of water approved for delivery each year is based on environmental/operational constraints and water supply availability from storage and projected runoff. Delivery approval for each calendar year is finalized in early May with the potential for revision later in the year if actual water supply conditions differ from the May forecast. Generally, less water is approved for delivery in years of limited runoff and reservoir storage.

Annual pumpage at Banks Pumping Plant during 1990 to 2003 ranged from 1.5 to 3.7 million acre-feet (maf) (Figure 3-5). The low volumes for 1991, 1992, and 1994 (1.5 to 1.7 maf) were largely related to limited precipitation. During these years, only 30 to

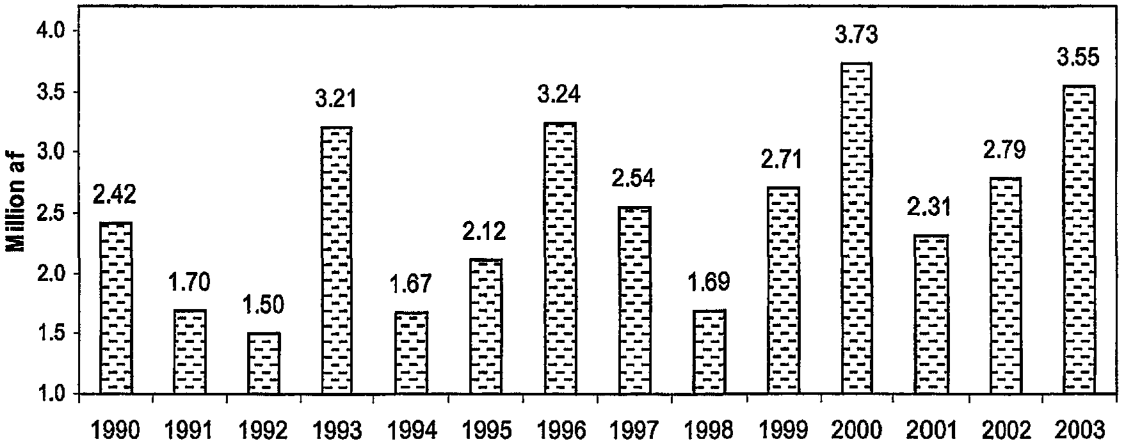

Figure 3-5. Total annual pumpage at Banks Pumping Plant, 1990 to 2003

50 percent of the water requested by SWP contractors was approved for delivery. All 3 water years in the Sacramento and San Joaquin Valleys were classified as critical and the low approval percentages were due to reduced water supply availability. The 1991 approval percentage of 30 percent was lower than in 1977 (40 percent) and remains the most severe curtailment of water deliveries to SWP contractors.

Annual pumpage at Banks Pumping Plant was also relatively low in 1998 (1.69 maf), but not because of reduced water availability. That year was the fourth consecutive wet water year in the Sacramento Valley, and 100 percent of the water requested for delivery was approved (>3 maf). However, a little more than half that volume was pumped due to heavy precipitation around much of the state.

Starting in January 1998, pumping at Banks Pumping Plant was lower than usual because the desired storage goal for San Luis Reservoir had been reached the previous month. In early February, pumping virtually ceased due to flooding and reduced water demand. Extensive rainfall around the State necessitated emergency releases from several SWP reservoirs including Del Valle, Los Banos, Little Panoche, Pyramid, Castaic, and Silverwood. Further, the California Aqueduct was augmented with inflows from the Kern River Intertie, Cross Valley Canal, and drain inlets on the San Luis Canal between February and July 1998. DWR took advantage of the reduced demand to dewater several sections of the California Aqueduct between February and April to make needed repairs on unstable embankment liners and other structures.

Because annual pumpage at Banks Pumping Plant can vary from year-to-year, the amount of water pumped per month relative to the total for the year was calculated (monthly percent-of-annual pumpage). This value is the relative amount of water pumped per month regardless of the total volume approved for delivery in any given year.

Monthly percent-of-annual pumpage trends at Banks Pumping Plant from 1990 to 2003 were not unlike those of pumping volumes with the highest percentages outside the months of April to June (Figure 3-6 and Table 3-3). Percentages were consistently highest in August and September with medians (and averages) of around 11 percent and moderately low CVs of around 25.5 percent. Therefore, these 2 months, on average, have somewhat consistently accounted for 22.4 percent of the water pumped at Banks Pumping Plant during any given year regardless of the volume approved for delivery.

Percent-of-annual pumpage was also consistently high in January with the exception of 2 years – 1997 and 1999 (see low extremes in Figure 3-6). The two low extremes occurred during an unprecedented period of high water availability. Water years 1997 and 1999 were the third and fifth years of a 5-year period from 1995 to 1999 when the Sacramento Valley experienced back-to-back wet water years (see previous Figure 3-2). No other such period exists in the record, making it a rare period of extensive water supply availability in the Delta (the second longest series of consecutive wet water years in the Sacramento Valley on record was three). In January 1997 and 1999, the storage goal for San Luis Reservoir had been reached during the preceding month(s). Without these 2 months (January 1997 and 1999), the median percent-of-annual pumpage for January increased to 13 percent with a CV of 25 percent.

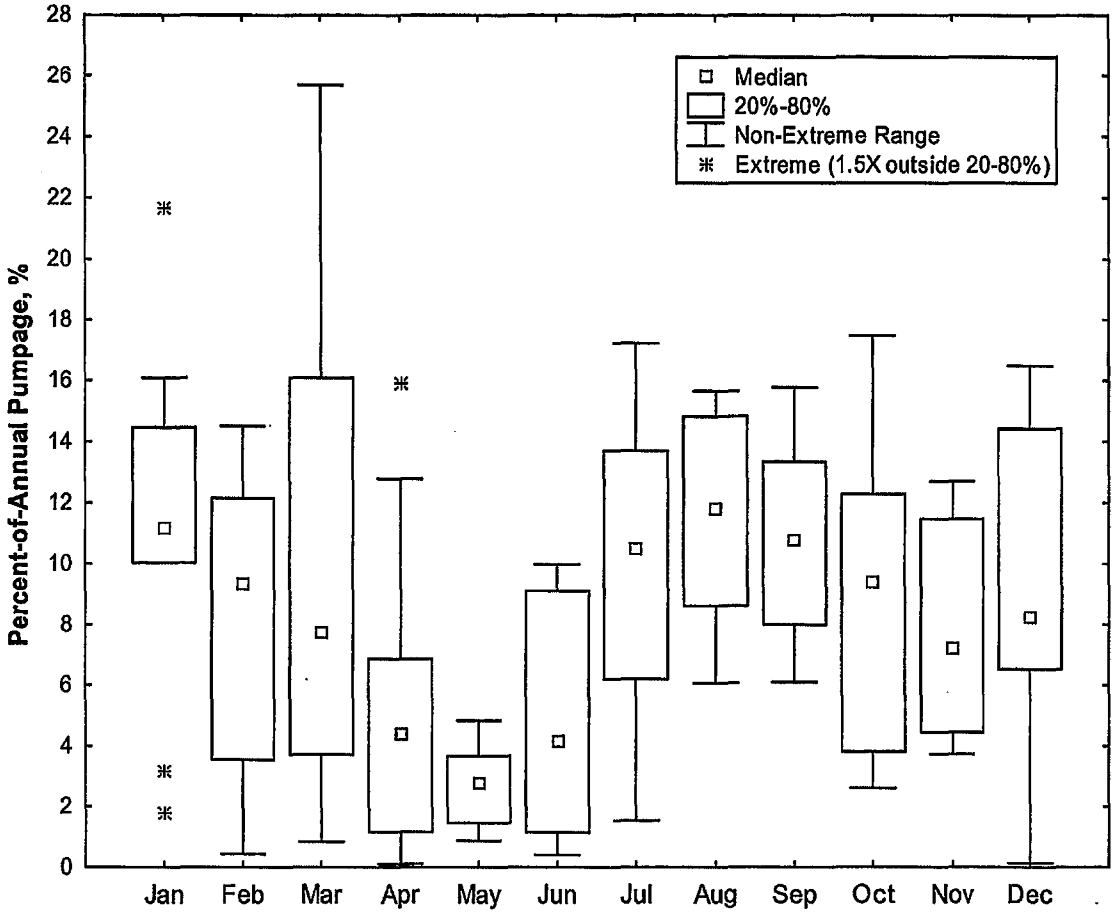

Figure 3-6. Monthly percent-of-annual pumpage trends at Banks Pumping Plant, 1990 to 2003

Table 3-3. Statistics of monthly percent-of-annual pumpage (percent) at Banks Pumping Plant, 1990 to 2003

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	11.5	11.2	1.8	21.7	4.9	43
Feb	8.2	9.3	0.4	14.5	4.4	53
Mar	9.9	7.7	0.8	25.7	7.3	74
Apr	5.2	4.4	0.1	15.9	4.4	85
May	2.8	2.7	0.9	4.8	1.2	43
Jun	4.9	4.2	0.4	10.0	3.3	67
Jul	9.8	10.5	1.5	17.2	4.4	46
Aug	11.5	11.8	6.1	15.6	2.9	25
Sep	10.9	10.8	6.1	15.8	2.8	26
Oct	8.7	9.4	2.6	17.5	4.2	49
Nov	7.6	7.2	3.7	12.7	3.1	41
Dec	9.2	8.2	0.1	16.5	4.5	49

1/ Coefficient of Variation

Therefore, January was usually one of the months (along with August and September) of somewhat consistently higher pumping relative to the amount of water delivered in a given year between 1990 and 2003. January was also a month when TOC at Banks Pumping Plant was often highest.

Total Organic Carbon

Total organic carbon samples were collected at Banks Pumping Plant and down the California Aqueduct by staff of the Delta, San Luis (sampling in the DMC), San Joaquin, and Southern Field Divisions. Samples were analyzed at DWR's Bryte Laboratory using the "wet oxidation" method (EPA 415.1). The relationship between TOC and dissolved organic carbon (DOC) is discussed in Appendix B, "Concentration Characteristics in the California Aqueduct." Results from the "combustion" method were also assessed in Appendix B. Methods and monitoring strategies in the California Aqueduct are detailed in DWR 2004b.

Seasonal and long-term TOC trends were assessed at Banks Pumping Plant for the 14-year period from 1990 to 2003. Values were averaged when more than one sample per month was collected. Months with missing TOC results were assigned DOC values from samples collected by the Delta Field Division (two substitutions) or DWR's Municipal Water Quality Investigations (MWQI) Program (five substitutions). Three of the MWQI substitutions represent the start of 1990, before O&M sampling for TOC began. All DOC samples were analyzed at Bryte Laboratory using the same analytical methodology as for TOC.

The influence of these substitutions (DOC for TOC) on the conclusions of this report is considered to be nominal because turbidity in all substitution samples was 10 nephelometric turbidity units (NTUs) or less, inferring a relatively small difference between the 2 values (see Appendix B for a discussion of the relationship between TOC, DOC, and turbidity in the California Aqueduct).

Total organic carbon at Banks Pumping Plant during 1990 to 2003 was generally highest in winter and lowest during late summer to mid fall. Median monthly TOC was around 5 mg/L in January and February then declined through the year to seasonal minimums near 3 mg/L between September and November before increasing to 3.7 mg/L in December (Figure 3-7 and Table 3-4). Variability during September to November was relatively low with CVs ranging from 11 to 16 percent (Table 3-4), contributing to a narrow 95 percent confidence interval of 2.7 to 3.0 mg/L.

Total organic carbon at Banks Pumping Plant exhibited a statistically significant declining trend over the 14-year period ($p<0.001$, seasonal Kendall) (Figure 3-8). Total organic carbon generally fell below 3 mg/L less frequently earlier in the period compared to later (see horizontal dotted line in Figure 3-8). This was especially the case for the 3-year period from 1990 to 1992 when TOC declined below 3 mg/L in only 1 monthly sample and in 1992, did not drop below 3.4 mg/L – the highest individual dry season concentration over the 14-year period.

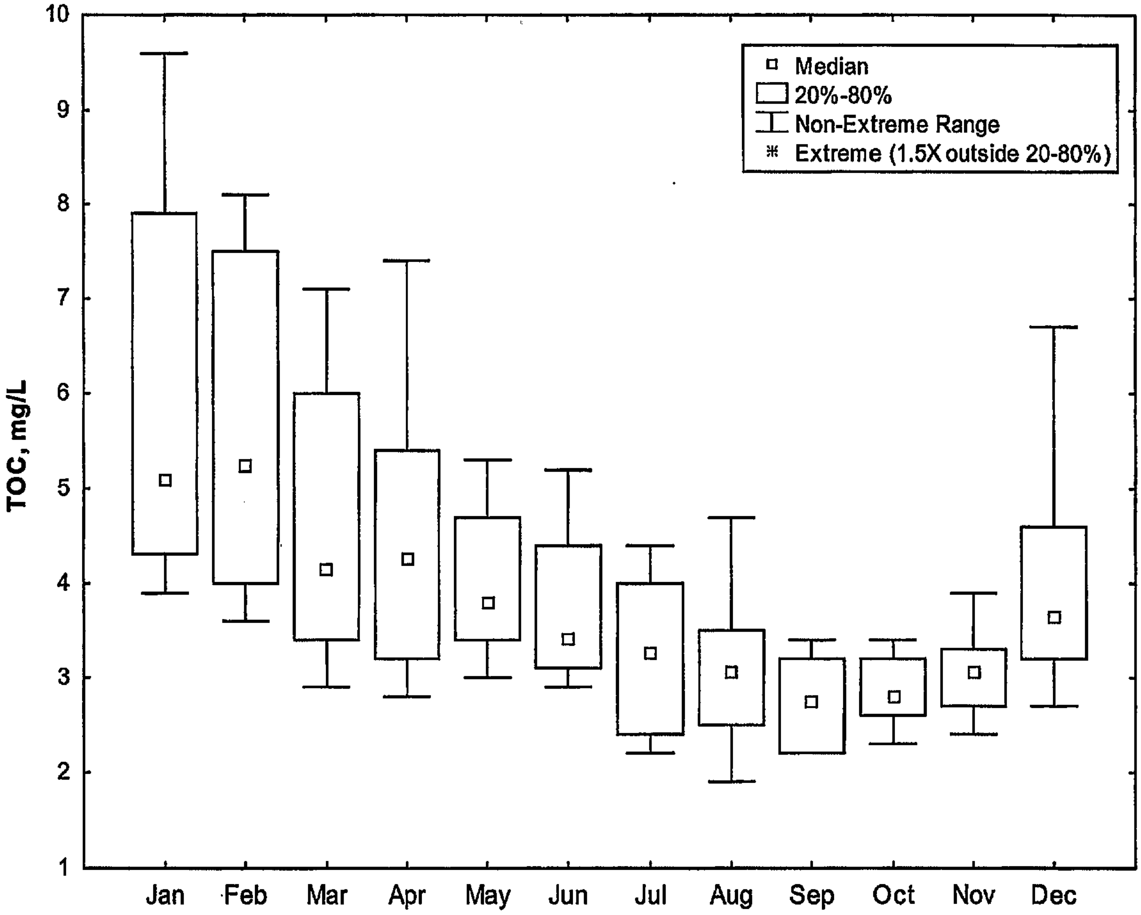

Figure 3-7. Monthly total organic carbon trends at Banks Pumping Plant, 1990 to 2003

Table 3-4. Statistics of monthly total organic carbon (mg/L) at Banks Pumping Plant, 1990 to 2003

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	5.6	5.1	3.9	9.6	1.74	31
Feb	5.4	5.2	3.6	8.1	1.53	28
Mar	4.6	4.2	2.9	7.1	1.38	30
Apr	4.4	4.3	2.8	7.4	1.33	30
May	4.0	3.8	3.0	5.3	0.73	18
Jun	3.6	3.4	2.9	5.2	0.69	19
Jul	3.3	3.3	2.2	4.4	0.72	22
Aug	3.0	3.1	1.9	4.7	0.71	23
Sep	2.7	2.8	2.2	3.4	0.43	16
Oct	2.9	2.8	2.3	3.4	0.32	11
Nov	3.1	3.1	2.4	3.9	0.40	13
Dec	3.9	3.7	2.7	6.7	1.05	27

1/ Coefficient of Variation

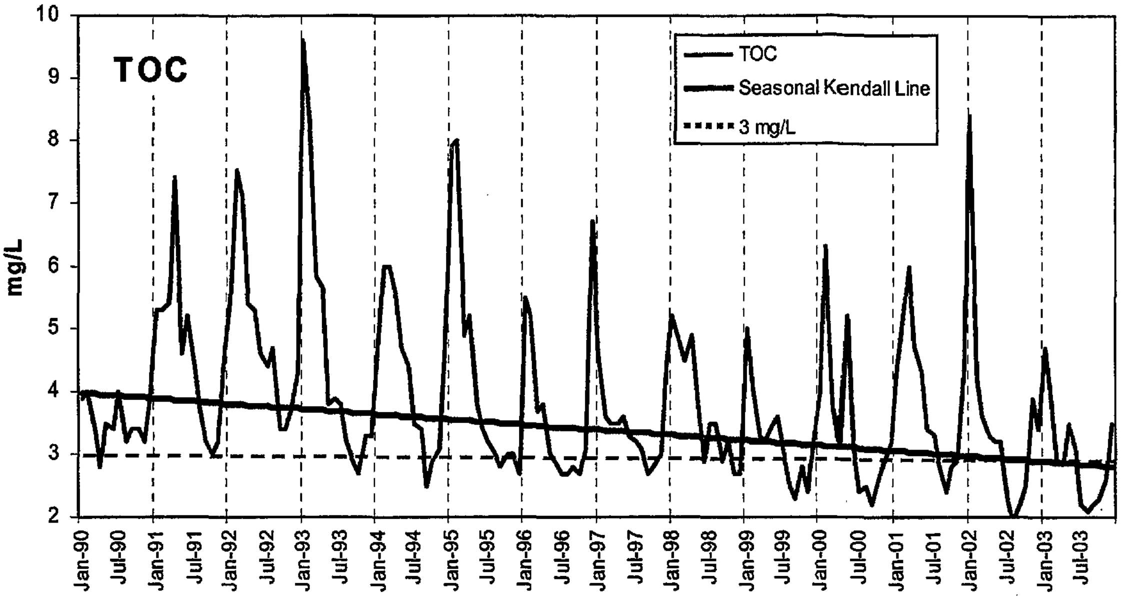

Figure 3-8. Long-term total organic carbon at Banks Pumping Plant, 1990 to 2003. The nonparametric seasonal Kendall line exhibited a statistically significant ($p<0.001$) declining trend.

The declining TOC trend at Banks Pumping Plant between 1990 and 2003 was not associated with any change in analytical methodology. The method for TOC analysis – EPA 415.1 (wet oxidation) – used by Bryte Laboratory was implemented in 1973 (a chronology of Bryte Lab methods can be found in Appendix B of DWR 1995a). The decline was more apparent, and to a certain extent explainable, by assessing wet and dry season concentration trends.

Dry Season

Total organic carbon at Banks Pumping Plant during the dry season months of August to November were averaged and plotted in Figure 3-9. The dry season averages went from 3.3 mg/L in 1990, dropped to 2.5 mg/L in 1999, then reached a period low of 2.3 mg/L in 2003.

The elevated dry season averages early in the 14-year period coincided with a period of extremely low Delta inflow. Organic carbon sampling during 1990 to 1992 overlapped the second half of a 6-year drought. The 1987 to 1992 drought was only the second time in recorded history (back to 1906) that the Sacramento Valley exhibited six consecutive dry or critical water years (see previous Figure 3-2). The last time this occurred was during 1929 to 1934.

Total Delta inflow was extremely low during 1990 to 1992 with a minimum monthly average inflow of 7.6 tcfs in May and November 1992, lower than any other month in the 14-year period (see horizontal dotted line in Figure 3-10). Although 2001 and 2002 were classified as dry, monthly average Delta inflow never fell below 11 tcfs (Figure 3-11).

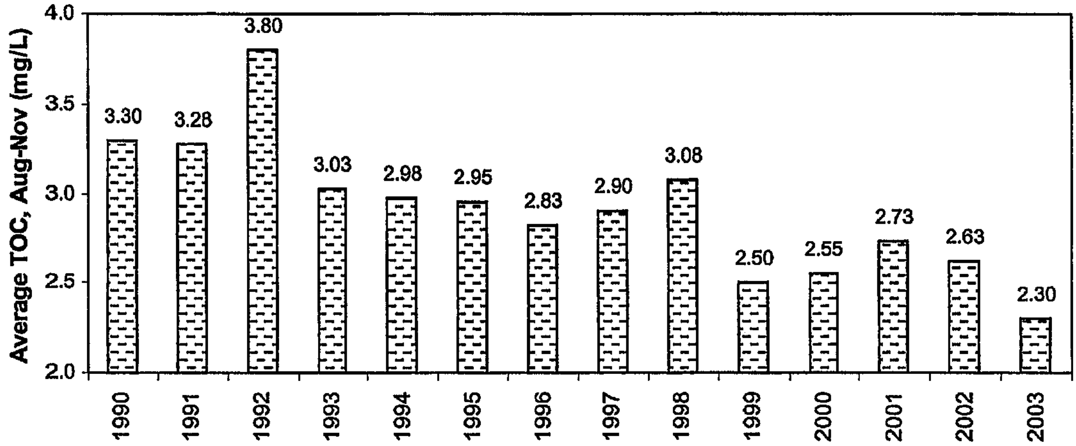

Figure 3-9. Average dry season (August to November) total organic carbon at Banks Pumping Plant, 1990 to 2003

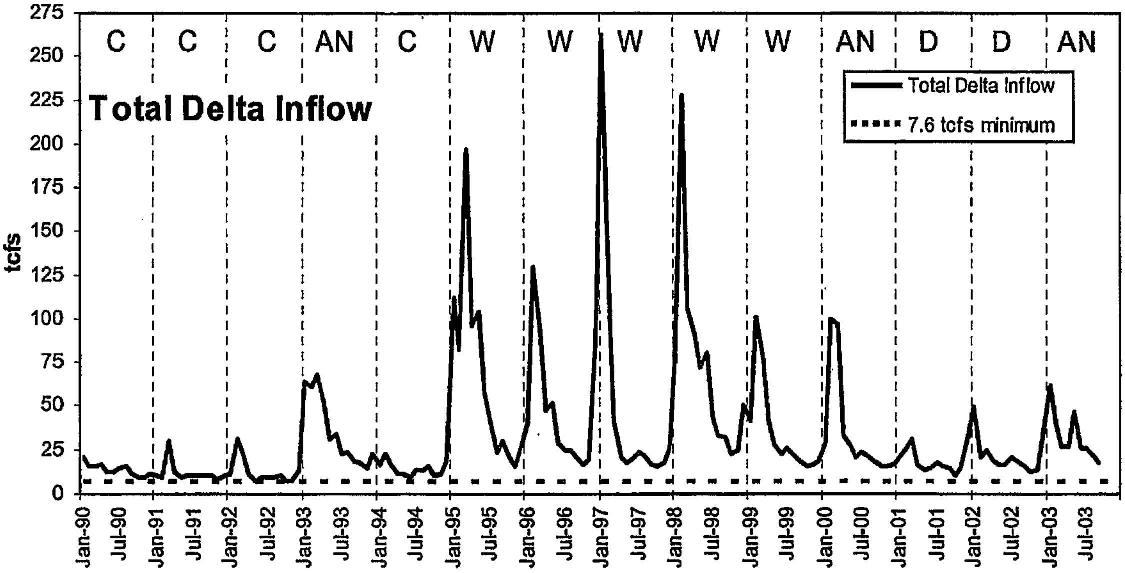

Figure 3-10. Long-term monthly average total Delta inflow (source: Dayflow database) and water year classification in the Sacramento Valley (C=critical, D=dry, AN=above normal, W=wet), 1990 to late 2003

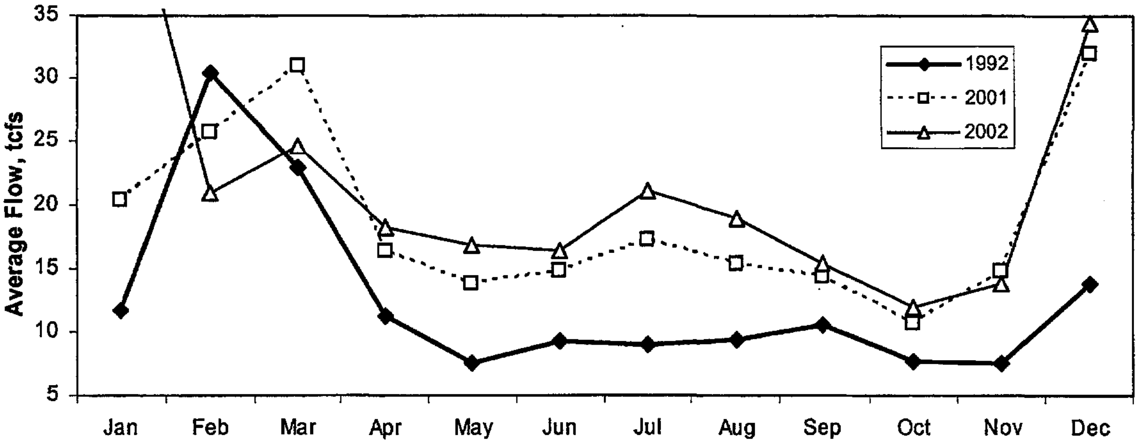

Figure 3-11. Monthly average total Delta inflow for 1992, 2001, and 2002 (source: Dayflow database)

One manifestation of low freshwater inflow to the Delta during the dry season would be less dilution of point and non-point discharges. Organic carbon can be relatively high in Delta island agricultural drains (DOC: range = 4.8 to 85 mg/L, DWR 1990) and wastewater treatment plants for cities such as Sacramento (TOC: range = 7 to 27 mg/L, average = 15.7 mg/L, DWR 2001). This latter municipal facility (Sacramento Regional Wastewater Treatment Plant) alone was estimated to make up from 3.1 to 11.8 percent of the organic carbon concentration downstream in the Sacramento River during certain months in 1991 and 1992 (ibid). With less freshwater inflow during the dry season, point and non-point discharges would exert a greater influence on organic carbon concentrations in the Delta and at Banks Pumping Plant. Based on this, extended periods of drought in the future would not only result in increased salinity and bromide at Banks Pumping Plant, but also higher levels of TOC during the dry season.

Total Delta exports (from DWR's Dayflow database) and dry season TOC at Banks Pumping Plant were modestly correlated with an r^2 of 0.7 (Figure 3-12). During 1992, an average dry season export rate of around 2.9 tcfs corresponded with a TOC average of 3.8 mg/L. Alternately, the average export rate during the same 4-month period in 2003 was more than 3 times higher (9.6 tcfs) while TOC was lower (2.3 mg/L).

Two possible interpretations can be provided for Figure 3-12. The first is that the relationship was skewed by a few data points. Although the correlation in Figure 3-12 was statistically significant ($p<0.005$, Spearman rank), the three points on the far left of the graph heavily influenced the correlation. These data were from the drought years of 1990 to 1992. Without these points, the relationship appears negligible. It may be that during those drought years, reduced exports – concurrent with low Delta inflows – did affect TOC levels at Banks Pumping Plant (possibly from less dilution of point and non-point sources), but in later years, export volumes did not play a major role in controlling dry season TOC at Banks Pumping Plant.

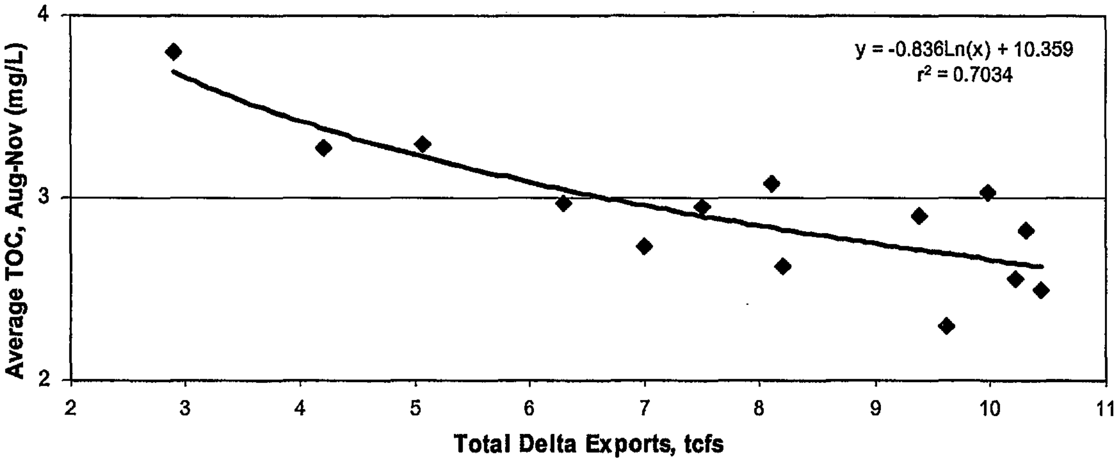

Figure 3-12. Correlation between total Delta exports (source: Dayflow database) and total organic carbon at Banks Pumping Plant averaged over the dry season months of August to November, 1990 to 2003. Total exports include all State and federal exports in the north, west, and south Sacramento-San Joaquin Delta (http://www.iep.ca.gov/dayflow/documentation/index.html).

Another interpretation of Figure 3-12 is that dry season TOC co varies with export volumes and the association can be explained by operations. Higher export rates would be tied to greater releases from upstream reservoirs. With the Delta Cross Channel gates usually open from mid-June to October (see Appendix A), a greater proportion of releases to the Sacramento River from Shasta, Oroville, and Folsom dams would be permitted to flow directly to the south Delta where SWP and CVP exports make up a majority of the total. Higher reservoir releases traveling to the Delta – and through it via the Delta Cross Channel – would dilute point and non-point discharges along the way (and other potential sources of higher TOC such as the San Joaquin River), resulting in lower TOC levels at Banks Pumping Plant. This was supported by performing a similar regression with certain dry season months.

Regressing individual TOC data points with pumping at Banks Pumping Plant for July and August produced an r^2 of 0.78 (Figure 3-13). It is unclear why this relationship is stronger during these particular months. There is nothing operationally unique to July and August other than they were 2 of several months when pumping at Banks Pumping Plant was usually highest. The inference being that a higher range of pumping is needed for this relationship to manifest, but pumping is overshadowed by other factors outside the months of July and August.

These last graphs indicate that total Delta exports and/or pumping at Banks Pumping Plant were, to a certain extent, inversely correlated with dry season TOC at Banks Pumping Plant, more in some months, less in others. The simple explanation provided was that greater reservoir releases to the Sacramento River furnished more freshwater to dilute TOC as flows made their way to the Delta – and through it via the Delta Cross Channel. This theory was supported by a much lower correlation between total

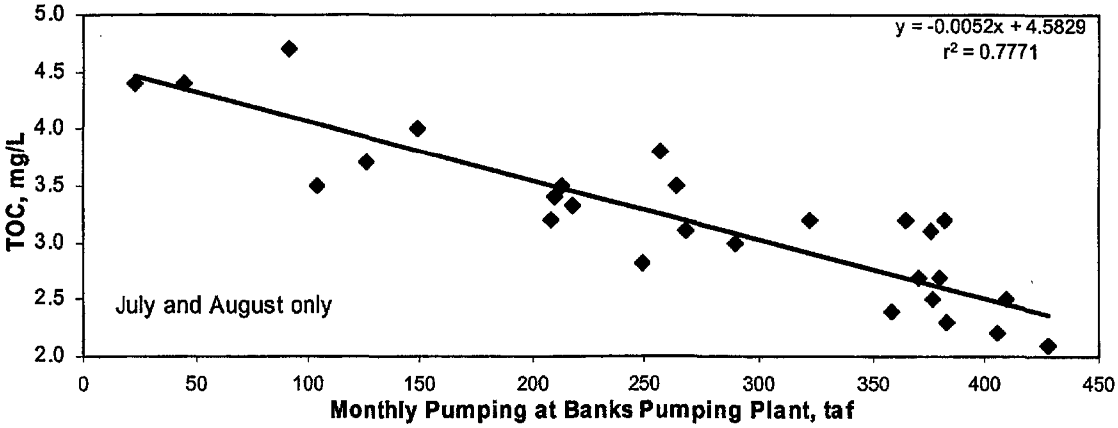

Figure 3-13. Correlation between pumping and total organic carbon at Banks Pumping Plant for the months of July and August, 1990 to 2003

Delta exports and dry season TOC in the DMC (discussed later). Based on this, exports that are similar in magnitude to those in the latter portion of the 14-year period from 1990 to 2003 (which are contingent upon a parallel level of water supply availability) will result in dry season TOC averages at Banks Pumping Plant that are on the lower end of those in Figure 3-9.

Wet Season

Total organic carbon at Banks Pumping Plant typically spiked upward during the wet season months of December to April, generally coinciding with seasonal increases in total Delta inflow (see previous Figures 3-8 and 3-10). Maximum concentrations were not necessarily related to the magnitude of Delta inflow. Average monthly Delta inflow peaked at around 100 tcfs during 1999 and TOC at Banks Pumping Plant reached a season maximum of 5 mg/L (Figures 3-8 and 3-10). Conversely, during the wet seasons of 1991 and 1992, average monthly Delta inflow peaked at around 30 tcfs, corresponding with TOC spikes of over 7 mg/L. Despite peak seasonal inflows in 1991 and 1992 that were a third of that in 1999, TOC at Banks Pumping Plant was higher. This behavior can be explained if TOC in inflows to the Delta during the wet season exhibits a behavior analogous to a first flush effect parameter.

Certain water quality parameters exhibit a first flush effect where levels in rainfall runoff are highest in the initial runoff of a storm event and decline thereafter despite continued rain (CVRWQCB 1988). Concentrations also decline in subsequent storm events as the availability of the parameters on the surface of a watershed are depleted over the duration of a wet season (ibid). During the dry season, deposits build up due to the lack of flushing from rainfall. An analogous trend was exhibited in the lower Sacramento River in 2000 when organic carbon peaked with the first and second flow increases of the wet season, then declined despite similarly high flow (DWR 2004b). In terms of a first flush effect, less organic carbon was available to be flushed into the river later in the wet season. The timing of TOC maximums would be influenced more by the characteristics of the first major runoff event or events of the year (e.g., timing, duration, volume, etc.) than the magnitude of the season's inflow. Thereafter, dilution of flushed parameters would likely be dependent on sustained or increased inflows.

Wet season TOC concentrations at Banks Pumping Plant usually peaked at 5 mg/L or more. One possible exception was in 1990 when DOC (one of the substitutions) peaked at 4 mg/L in February (see previous Figure 3-8). Although this was one of the DOC substitutions, it is thought that the actual TOC concentration would be comparable due to the accompanying turbidity. Turbidity in the February 1990 sample was 10 NTU, and as discussed in Appendix B, TOC averaged about 0.1 mg/L higher than the corresponding DOC value when turbidity was at or below 15 NTU. If this DOC value was a close approximation of TOC, the low value could be explained by unusually depressed Delta inflow that wet season.

Total Delta inflow was extremely low during winter 1990, averaging 20 tcfs in January before declining through the rest of the year. During the next 13 years (1991 to 2003), monthly average Delta inflow was never below 30 tcfs during the months of January through March. Months when winter inflow averaged as low as 30 tcfs (1991, 1992, and 2001), the corresponding TOC at Banks Pumping Plant reached from 6 to 7.5 mg/L. An average monthly inflow of 30 tcfs corresponded with some of the highest TOC levels measured at Banks Pumping Plant while a maximum of 20 tcfs during winter 1990 coincided with only a moderate organic carbon peak of 4 mg/L. If DOC in the February 1990 sample was a close approximation of TOC, the monthly average inflow of 20 tcfs observed during winter 1990 may indicate a threshold by which TOC at Banks Pumping Plant does not reach relatively high levels.

Wet season (December to April) TOC averages at Banks Pumping Plant were generally lower after 1995 (Figure 3-14). One possible explanation relates to the flushing action of wetter versus drier water years.

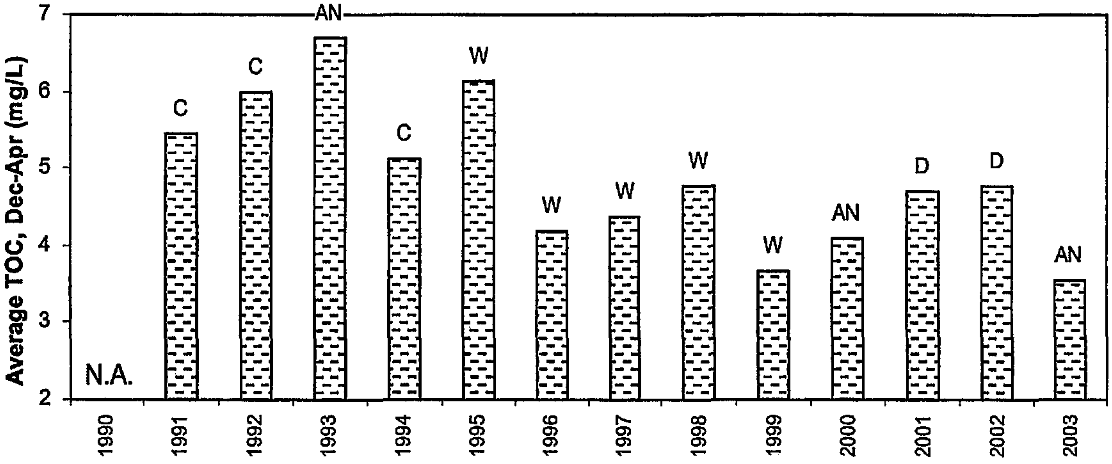

Figure 3-14. Average wet season (December to April) total organic carbon at Banks Pumping Plant and water year classification in the Sacramento Valley, 1991 to 2003 (C = critical, AN = above normal, W = wet, D = dry)

The paucity of rainfall during the 6-year drought from 1987 to 1992 may have resulted in a greater accumulation of TOC around the Central Valley. Less rainfall would translate into less off-site movement of TOC. The higher rainfall runoff in 1993 (above normal) and 1995 (wet) may have removed a good portion of that "standing crop" of TOC, making less available for future runoff seasons. If this is in fact the case, maximum TOC levels at Banks Pumping Plant during any given wet season would be influenced by hydrological conditions during the preceding year or years (along with factors such as the characteristics of the first major runoff event or events of the year).

Loads

Similar to TOC concentrations, monthly TOC loads at Banks Pumping Plant usually spiked around winter of each year between 1990 and 2003 (Figure 3-15). Conversely, there was no apparent long-term decreasing (or increasing) trend in TOC loading over the 14-year period (linear slope = 0.0078). Elevated TOC concentrations observed early in the period were countered by relatively low to moderate export rates. The lower TOC concentrations measured later in 14-year period were countered by higher export rates.

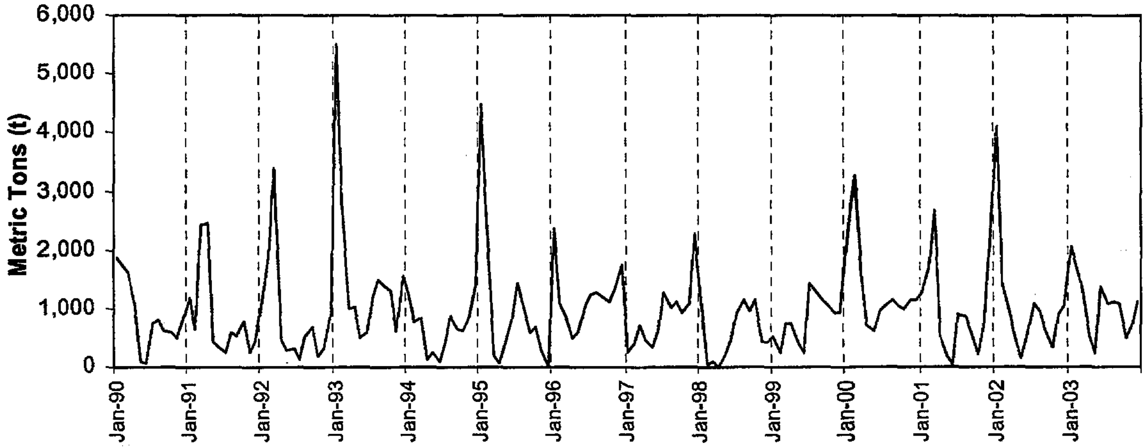

Figure 3-15. Long-term total organic carbon loading at Banks Pumping Plant, 1990 to 2003

Total organic carbon loads at Banks Pumping Plant were generally highest during the winter months of January and February with medians near 1,600 metric tons (t) (Figure 3-16 and Table 3-5). Loading variability was rather elevated during these months with CVs of 74 and 68 percent, respectively. Median monthly TOC loads declined to 316 t in May before increasing to summer peaks of over 1,000 t in July and August. Median loads then declined to between 701 and 822 t during September to November before increasing to 1,091 t in December.

The highest monthly TOC load at Banks Pumping Plant of 5,504 t was calculated for January 1993. As discussed before, this was the first month of increased water supply availability after 6 years of drought. Increased pumping in January 1993 (largely to fill San Luis Reservoir) coincided with increased TOC concentrations following the first wet season Delta inflow event(s) of the year.

Table 3-6. Statistics of percent-of-annual total organic carbon loading (percent) at Banks Pumping Plant, 1990 to 2003

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	17	16	2.4	36	9.6	57
Feb	11	12	0.6	21	6.6	57
Mar	12	9.3	1.1	33	9.1	79
Apr	5.7	4.4	0.2	24	5.9	103
May	2.8	2.9	0.9	4.3	1.1	40
Jun	4.4	3.6	0.3	10	2.9	66
Jul	8.1	8.1	1.2	15	3.8	47
Aug	8.9	8.2	5.1	16	2.9	32
Sep	7.7	6.9	4.7	13	2.7	35
Oct	6.6	6.6	1.7	16	3.9	58
Nov	6.2	6.0	2.3	10	2.8	46
Dec	9.8	8.5	0.1	22	5.6	58

1/ Coefficient of Variation

Trihalomethane Formation Potential

Trihalomethane formation potential samples were collected in the California Aqueduct between mid 1990 and January 2000. DWR's Bryte Laboratory used a modified version of EPA method 510.1. Samples were dosed with around 120 mg/L chlorine and incubated for seven days (a similar unmodified method requires dosing based on sample demand and an endpoint chlorine residual of 3 to 5 mg/L (Anonymous 1995)). The samples were then analyzed for bromoform, dibromochloromethane, bromodichloromethane, and chloroform by EPA method 502.2. The sum of these trihalomethanes is THMFP. This method was developed by Bryte Laboratory in conjunction with Clayton Environmental Consultants (DWR undated and Clayton Environmental Consultants, Inc. 1993). See Appendix B for an assessment of this method in the California Aqueduct.

Total organic carbon and THMFP at Banks Pumping Plant were correlated with an r^2 of 0.77 (Figure 3-18). The highest THMFP level of 1,300 µg/L was associated with a less extreme TOC concentration of 7.4 mg/L. The second highest THMFP level of 1,053 µg/L was associated with the highest TOC concentration measured at Banks Pumping Plant (9.6 mg/L).

Trihalomethane formation potential exhibited seasonal peaks around winter of each year and declined over the period of sampling (Figure 3-19). The decline was statistically significant ($p<0.001$, seasonal Kendall) like that of TOC over the last decade or so. As discussed before, the long-term decline in TOC (and hence THMFP) at Banks Pumping Plant was thought to be associated, in part, with a combination of increased Delta inflows/exports over the period of sampling.

Trihalomethane formation potential at Banks Pumping Plant was consistently highest during January to March with medians ranging from 650 to 807 µg/L and CVs of 20 to 28 percent (Figure 3-20 and Table 3-7). After March, median levels declined to between 364 and 411 µg/L in August to November with relatively low CVs of 14 to 19 percent.

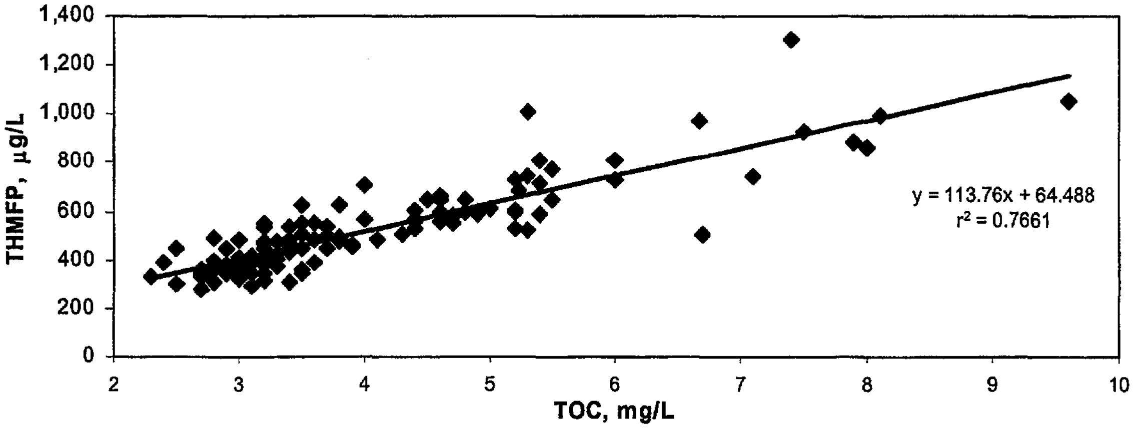

Figure 3-18. Correlation between total organic carbon and trihalomethane formation potential at Banks Pumping Plant

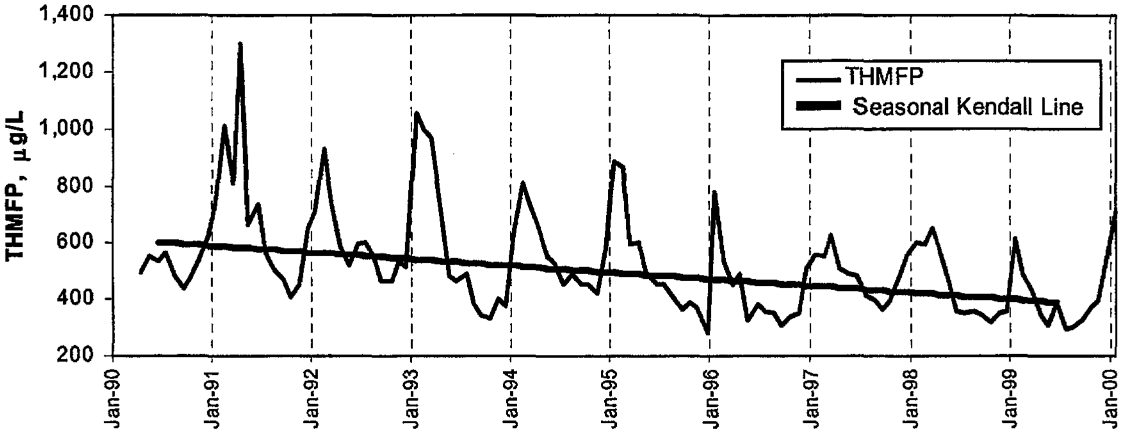

Figure 3-19. Long-term trihalomethane formation potential at Banks Pumping Plant, mid 1990 to January 2000. The nonparametric seasonal Kendall line exhibited a statistically significant ($p<0.001$) declining trend.

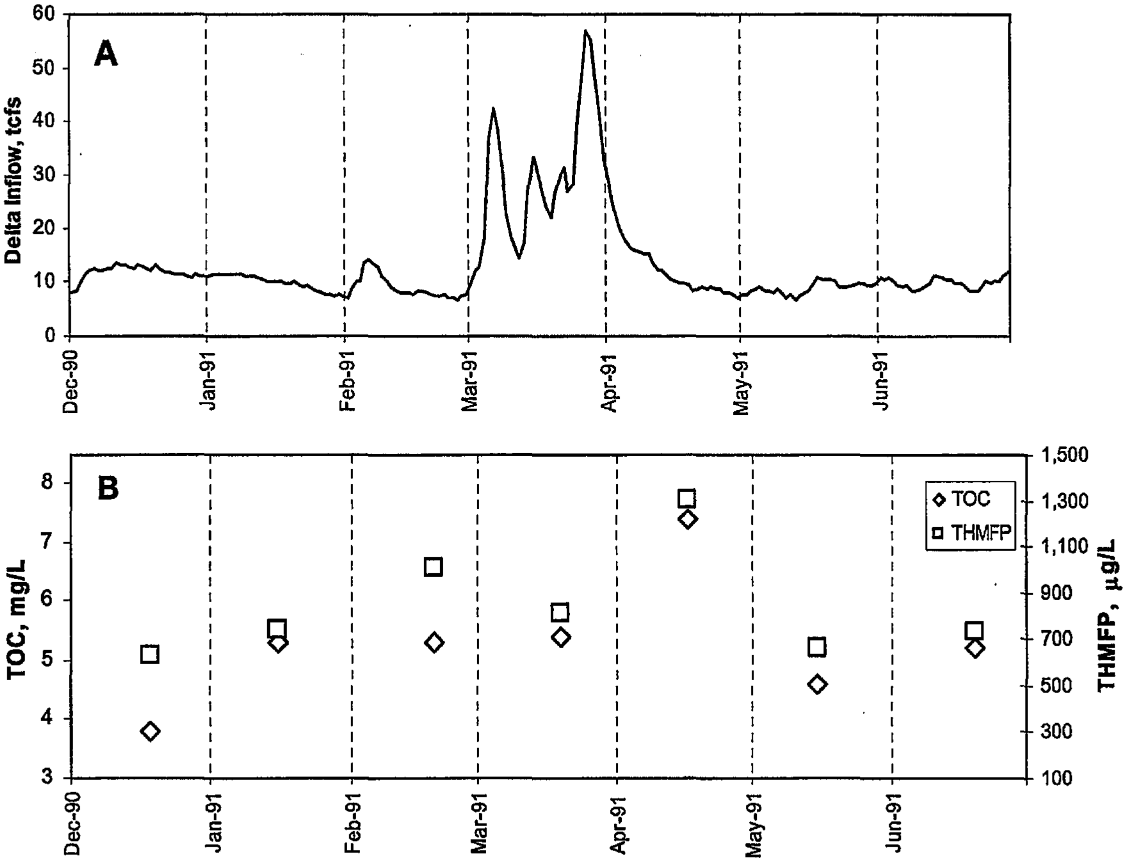

Figure 3-21. Total Delta inflow (A), total organic carbon, and trihalomethane formation potential at Banks Pumping Plant (B), December 1990 to June 1991 (inflow source: Dayflow database)

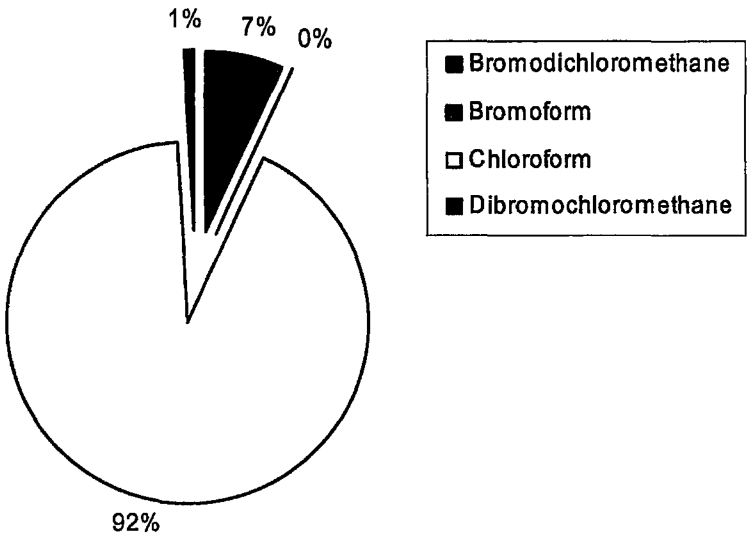

Figure 3-22. Composition (in percent) of trihalomethane formation potential in the sample collected at Banks Pumping Plant on April 16, 1991

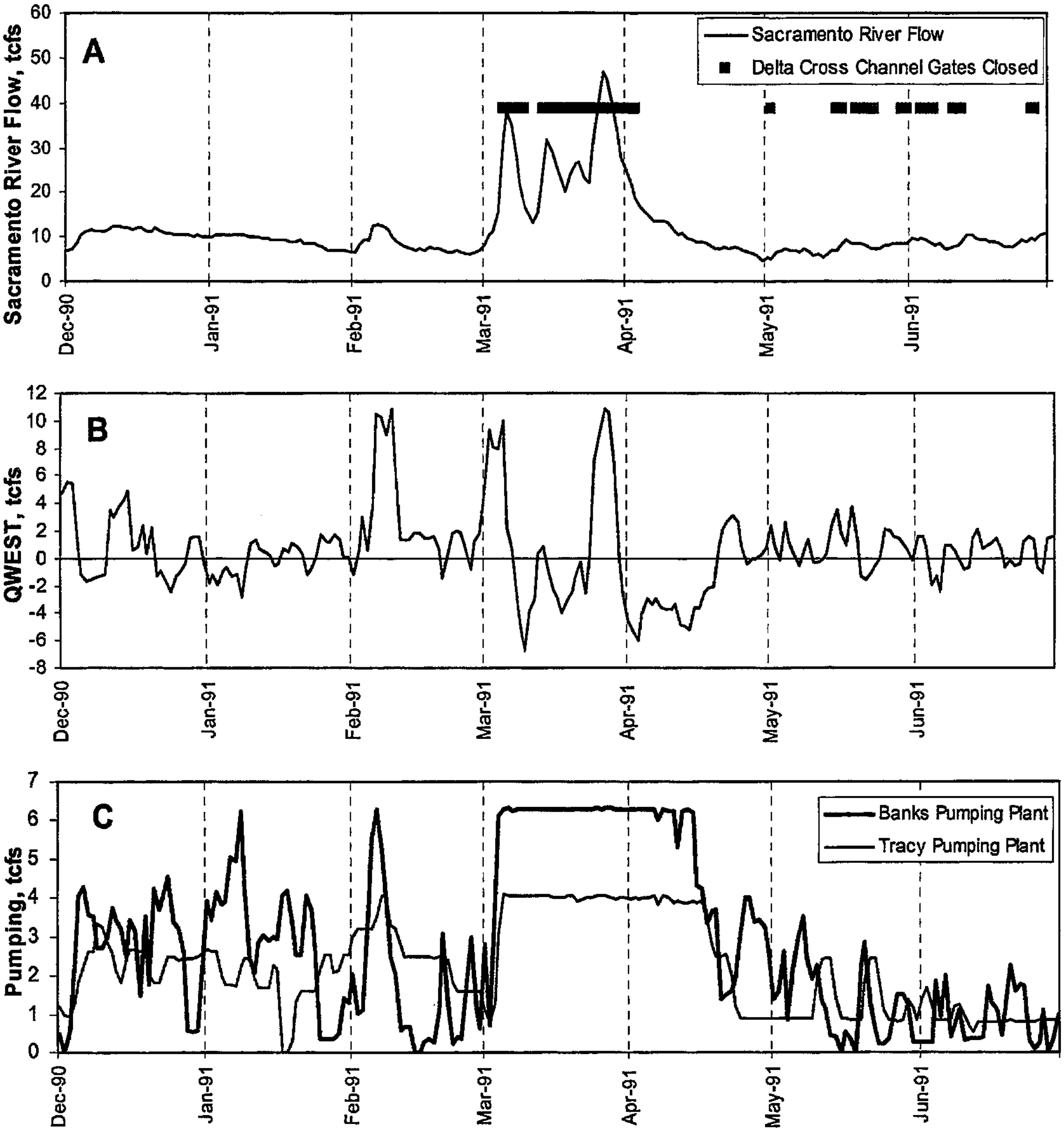

Figure 3-23. Sacramento River flow at Freeport, status of the Delta Cross Channel gates (A), QWEST (B), and south Delta pumping at Banks Pumping Plant and Tracy Pumping Plant (C), December 1990 to June 1991. QWEST is estimated flow in the San Joaquin River past Jersey Island and reflects water flowing into, and out of, the Delta (negative and positive values, respectively) (sources: Dayflow and I.E.P. HEC-DSS Time-Series Databases).

South Delta pumping continued into April 1991 at the increased rate as flow in the Sacramento River was declining (Figure 3-23A and C). More water began moving into the Delta from the west as exhibited by decreasing QWEST that reached a monthly minimum of -6 tcfs on April 4 (Figure 3-23B). Extensive sampling by DWR's MWQI Program during this period provided a snapshot of THMFP levels around the Delta.

Sampling around Delta by the MWQI Program during March and April 1991 revealed elevated THMFP levels in key channels that convey water to the export sites (source: DWR 1994b). Levels in Old and Middle Rivers north of the export sites ranged from 790 to 800 µg/L on March 26, 1991 and from 910 to 1,200 µg/L the following month on the ninth (Figure 3-24). These channels can convey water from the western and central Delta to the export sites. Water can also flow to the export sites from the east via south Old River and Grant Line Canal. Levels of THMFP were 1,200 µg/L or more in these channels on the same March/April dates and in the San Joaquin River on March 26. Levels of THMFP at Banks Pumping Plant on the same dates ranged from 740 to 890 µg/L, increasing to 1,300 µg/L on April 16 (Figure 3-24).

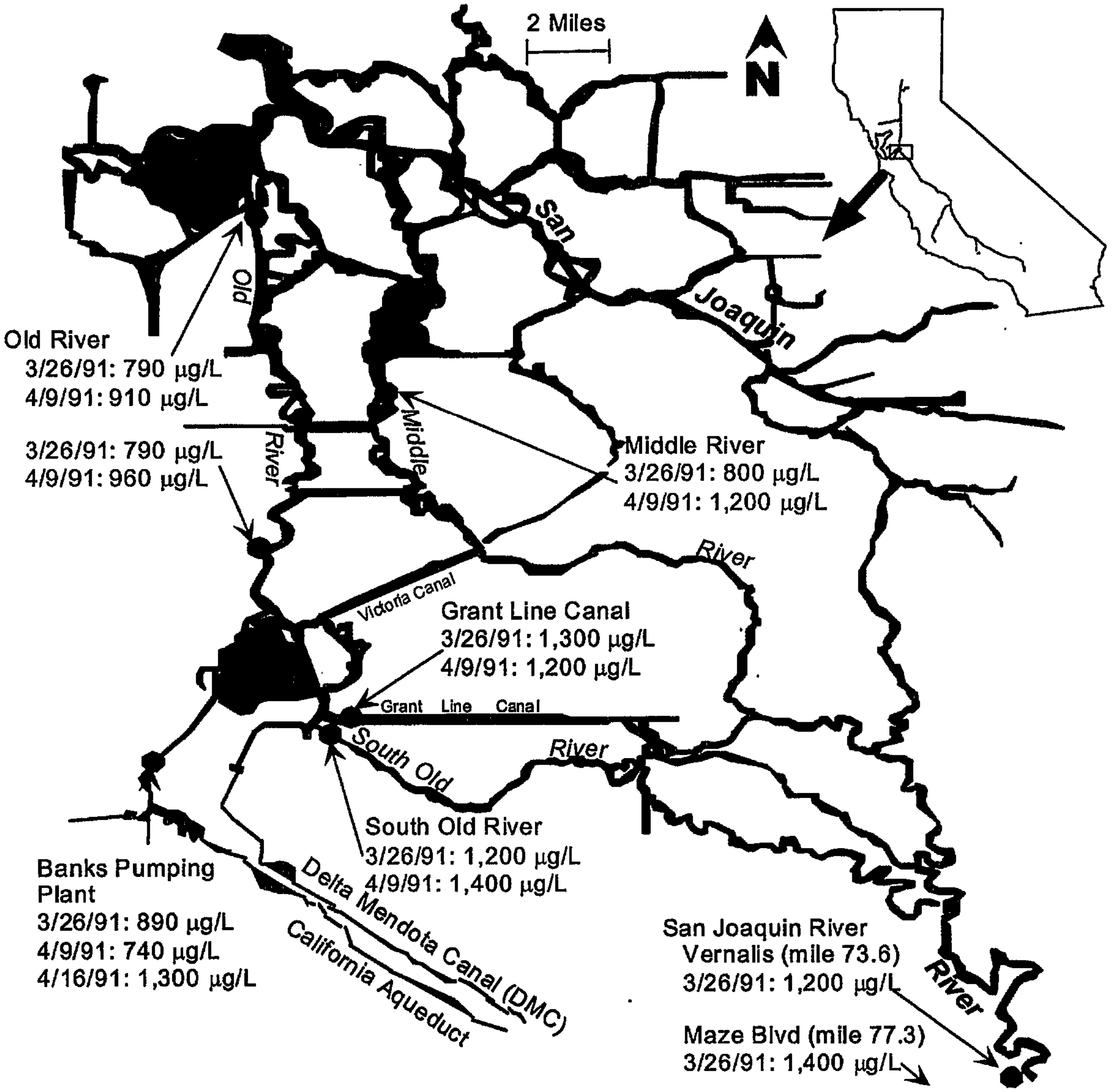

Figure 3-24. Trihalomethane formation potential around the Sacramento-San Joaquin Delta, March and April 1991(most data from DWR 1994b)

Inflow to the Delta from the San Joaquin River was the probable source of elevated THMFP (> = 1,200 µg/L) in south Old River and Grant Line Canal during late March to early April 1991 (no barriers were in place). This inflow also likely contributed to the period maximum THMFP measured at Banks Pumping Plant on April 16, 1991 (1,300 µg/L). The San Joaquin River was the conveyance source of water with elevated THMFP that pervaded much of the south Delta during a period of high pumping.

On March 26, 1991 THMFP in the San Joaquin River was 1,200 µg/L at Vernalis and 1,400 µg/L further upstream at Maze Boulevard (no THMFP data was available for April 9, 1991 at these stations) (Figure 3-24) (DWR 1994b). Since the Vernalis station is below the Stanislaus River and the Maze Boulevard station is above it, this tributary was eliminated as the source of the March 26 level at Vernalis. Two potentially major sources were Mud and Salt Sloughs.

Mud and Salt Sloughs reached their lowest outflow on record (back to October 1985) during late 1990 to early 1991 before surging to 0.5 tcfs in March (Figure 3-25A). This outflow increase may have been related to pre-irrigation of farmland in the western San Joaquin Valley that usually starts peaking between January and March – earlier during wetter water years and later during drier ones (DWR 2001). Pre-irrigation of agricultural fields is performed to remove salt accumulated in the soil during the previous growing season in preparation for planting (DWR 1974b). Pre-irrigation during winter takes advantage of higher San Joaquin River flow for dilution purposes (DWR 1960).

Flow in the San Joaquin River (at Vernalis) also increased in March 1991, reaching a maximum of 4 tcfs by the end of the month, followed by two smaller peaks in May (Figure 3-25B). Combined outflow from Mud and Salt Sloughs composed 12 and 21 percent of the San Joaquin River during March and April, respectively.

Dry conditions leading up to March 1991 may have resulted in a buildup of organic carbon (and hence THMFP) in the western San Joaquin Valley. Combined outflow in Mud and Salt Sloughs fell below 100 cfs for almost 95 consecutive days between November 1990 and February 1991, and reached a period low of 54 cfs on February 1st (Figure 3-26). Prior to this, the lowest measured flow was less than 100 cfs for 1 day in December 1987. The low outflow infers extremely dry conditions in the upstream watersheds for several months prior to the rise in outflow during March 1991. The first pre-irrigation event of the season would have provided a potential vehicle for the off-site movement of any organic carbon amassed – physically or otherwise (e.g., soil oxidation) – in the watersheds.

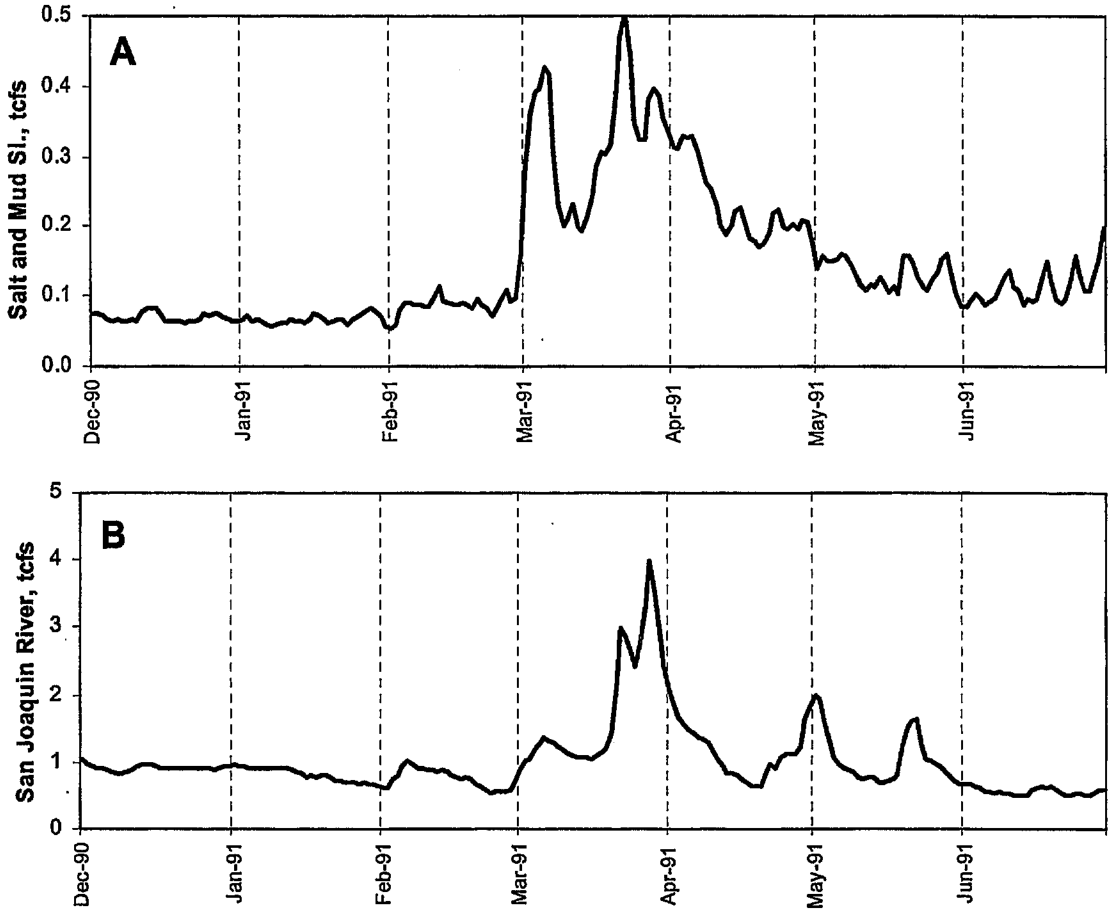

Figure 3-25. Combined flow in Mud and Salt Sloughs (A) and in the San Joaquin River at Vernalis (B), December 1990 to June 1991 (sources: Dayflow database and http://waterdata.usgs.gov/ca/nwis/discharge (flow in Mud and Salt Sloughs))

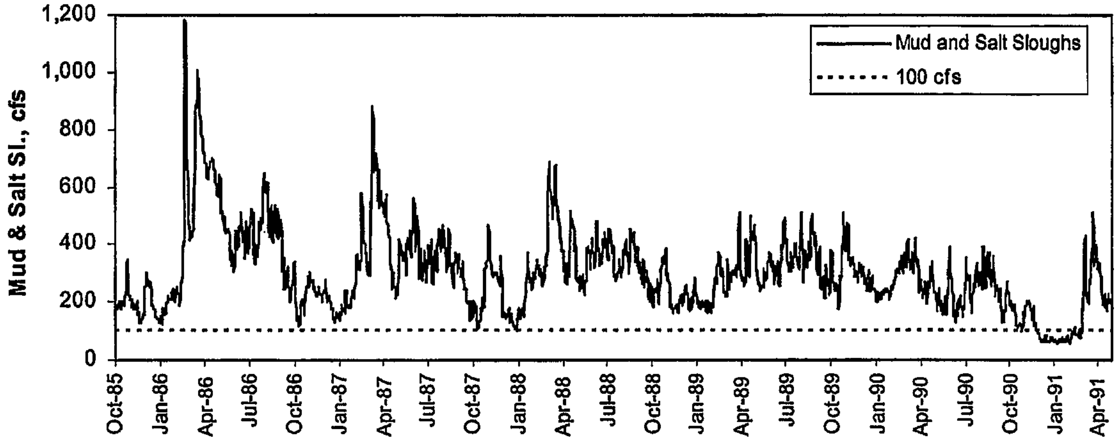

Figure 3-26. Combined flow in Mud and Salt Sloughs, October 1985 to April 1991 (existing data up to April 1991). Combined flow dropped below 100 cfs (dotted line) for almost 95 consecutive days between November 1990 and February 1991 (source: http://waterdata.usgs.gov/ca/nwis/discharge).

Total organic carbon in Mud and Salt Sloughs can be relatively high. In samples collected by USGS (largely in the 1980s), TOC was generally highest and most variable during several fall and winter months (Figure 3-27 and Table 3-8). During the pre-irrigation months of January to March, median TOC ranged from 9.6 to 12 mg/L with minimums of 7.5 or 7.6 mg/L. These three months overlap a period when combined flow in Mud and Salt Sloughs has been highest.

Monthly combined flow in Mud and Salt Sloughs during 1990 to 2003 was distinctly highest in February and March with medians of 451 and 531 cfs, respectively (Figure 3-28 and Table 3-9). Flows were rather variable during these months with CVs of 71 and 39 percent, respectively. Combined flow was secondarily highest in January, November, and December with monthly medians around 300 cfs. Therefore, flows in Mud and Salt Sloughs were generally highest during winter and, to a lesser extent, fall.

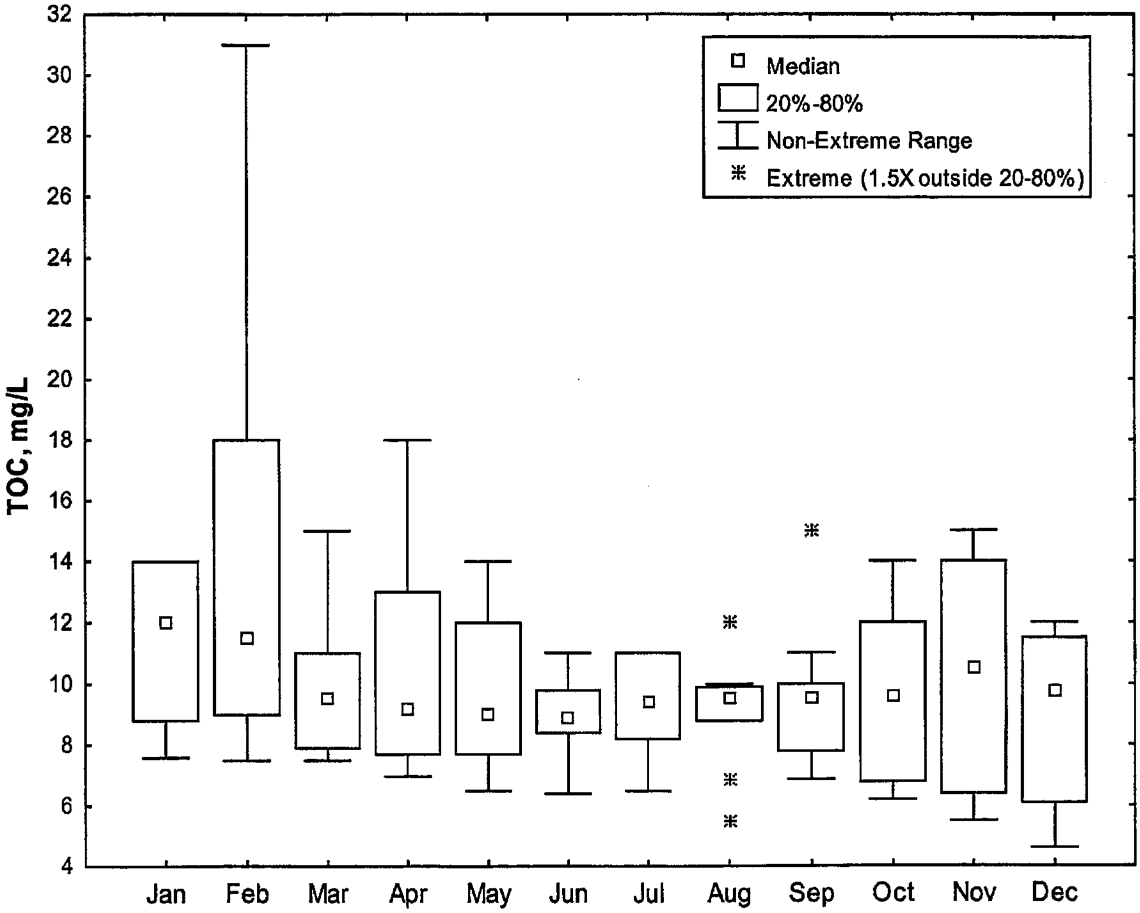

Figure 3-27. Monthly total organic carbon trends in Mud and Salt Sloughs. Samples were collected largely in the 1980s by USGS (source: http://waterdata.usgs.gov/ca/nwis/qw, 5/2005).

Table 3-8. Statistics of monthly total organic carbon (mg/L) in Mud and Salt Sloughs. Samples were collected largely in the 1980s by USGS (source: http://waterdata.usgs.gov/ca/nwis/qw, 5/2005).

Month	Average	Median	Minimum	Maximum	Valid N	Std.Dev.	COV 1/
Jan	11.4	12.0	7.6	14.0	12	2.4	21
Feb	13.7	11.5	7.5	31.0	14	6.3	46
Mar	9.8	9.6	7.5	15.0	12	2.1	22
Apr	10.6	9.2	7.0	18.0	13	3.6	34
May	9.5	9.0	6.5	14.0	12	2.3	25
Jun	8.9	8.9	6.4	11.0	12	1.2	14
Jul	9.2	9.4	6.5	11.0	12	1.4	15
Aug	9.2	9.6	5.5	12.0	12	1.6	18
Sep	9.5	9.6	6.9	15.0	12	2.2	23
Oct	9.6	9.6	6.2	14.0	8	2.8	29
Nov	10.3	10.5	5.5	15.0	8	3.6	35
Dec	9.1	9.8	4.6	12.0	10	2.7	30

1/ Coefficient of Variation

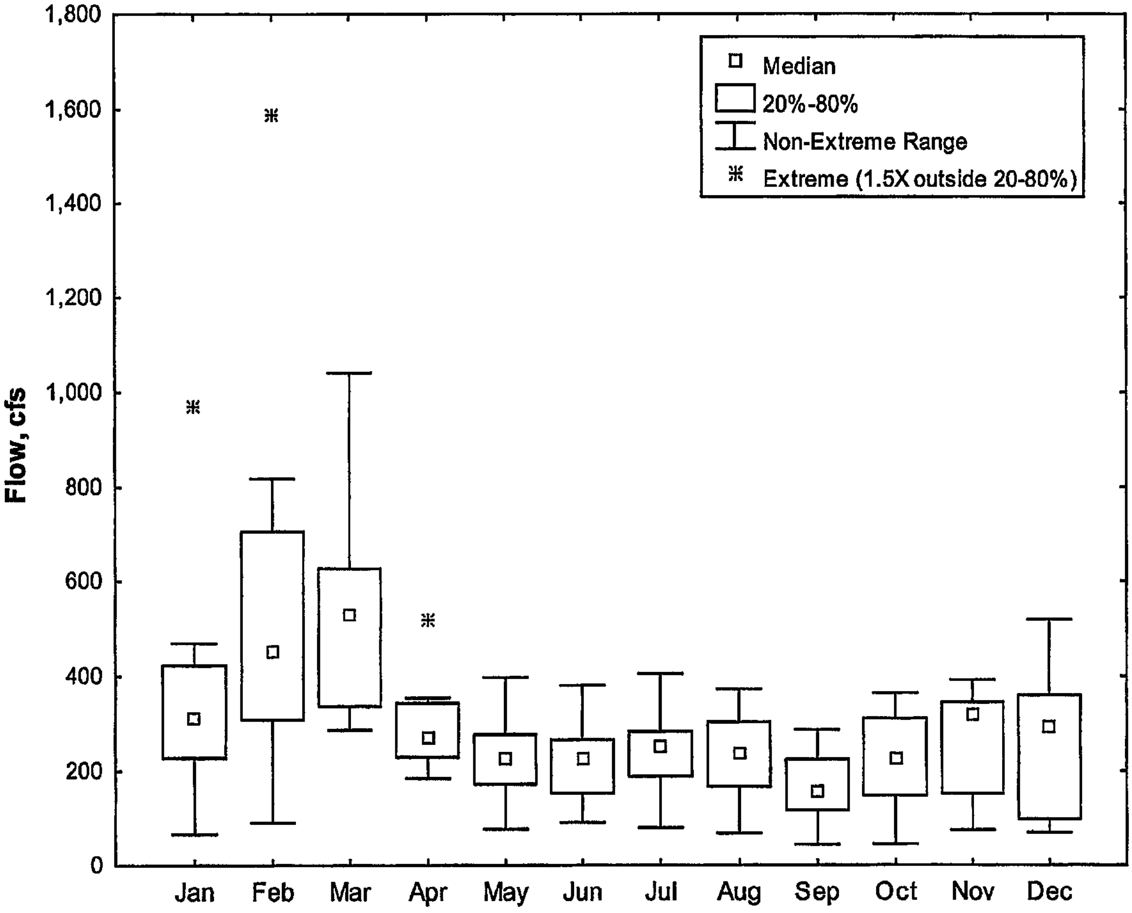

Figure 3-28. Monthly average combined flow trends in Mud and Salt Sloughs, 1990 to 2003 (source: http://waterdata.usgs.gov/ca/nwis/discharge) (water year 1995 was missing at the time of download)

Table 3-9. Statistics of monthly average combined flow (cfs) in Mud and Salt Sloughs, 1990 to 2003 (source: http://waterdata.usgs.gov/ca/nwis/discharge) (water year 1995 was missing at the time of download)

Month	Average	Median	Minimum	Maximum	Std.Dev.	COV 1/
Jan	348	310	67	971	219	63
Feb	530	451	90	1,588	375	71
Mar	519	531	286	1,041	205	39
Apr	290	269	184	519	87	30
May	224	226	77	397	78	35
Jun	220	226	91	380	76	34
Jul	240	251	80	405	79	33
Aug	239	238	68	371	83	35
Sep	158	155	44	286	67	42
Oct	220	225	45	363	97	44
Nov	278	320	75	392	100	36
Dec	279	295	69	519	140	50

1/ Coefficient of Variation

Combined flow in Mud and Salt Sloughs was compared to San Joaquin River flow at Vernalis. The ratio of combined slough drainage to river flow (slough:river ratio) ranged from 2 to 29 percent with medians between 7 and 19 percent (Figure 3-29 and Table 3-10). Slough:river ratios were generally highest during several winter, summer, and fall months and were often variable with CVs ranging from 27 to 55 percent.

The variability of slough:river ratios is likely related to flow in San Joaquin River that has ranged from less than 100 cfs to almost 40,000 cfs (DWR 2004a). In fact, water year classification was a major factor affecting the slough:river ratios. The San Joaquin Valley 60-20-20 water year hydrologic index was inversely correlated with the average annual slough:river ratio (Figure 3-30). This index is used to determine water year classification in the San Joaquin Valley (Index = 0.6 x current year April to July unimpaired runoff + 0.2 x current year October to March unimpaired runoff + 0.2 x previous years index up to 4.5 MAF). Combined flow from Mud and Salt Sloughs, on average, composed less of the San Joaquin River at Vernalis during wetter water years and more during drier water years. Therefore, these sloughs would influence water quality in the San Joaquin River more during drier water years with the presumed manifestation of higher average TOC concentrations.

The sough:river ratios from the above analysis were used to estimate how much Mud and Salt Sloughs contributed to the concentration of organic carbon in the San Joaquin River. Nine different scenarios are presented revolving around the 20th, 50th (median), and 80th percentiles of both DOC in the San Joaquin River and TOC in Mud and Salt sloughs. The estimates are the maximum possible contributions because of the underlying assumption in this analysis that DOC = TOC.

Figure 3-31 shows all nine different contribution scenarios. The x-axis represents the range of potential volumetric contributions (sough:river ratio in percent) presented in Figure 3-29. The three y-axes show the estimated percent contribution that Mud and Salt Sloughs made to the organic carbon concentration in the San Joaquin River.

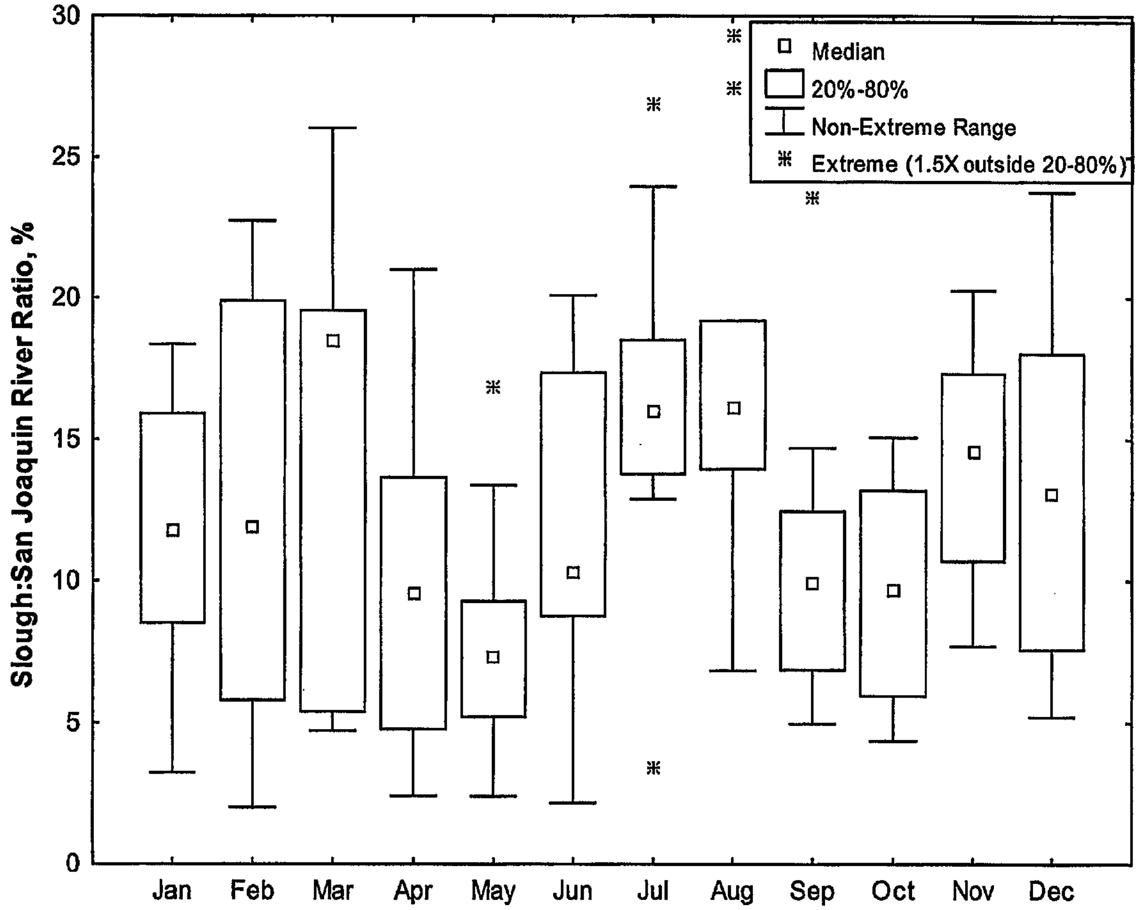

Figure 3-29. Monthly average Mud+Salt Slough:San Joaquin River flow ratio trends (slough:river ratio), 1990 to 2003 (water year 1995 was missing) (sources: http://waterdata.usgs.gov/ca/nwis/discharge and Dayflow database)

Table 3-10. Statistics of the monthly average Mud+Salt Slough:San Joaquin River flow ratio (slough:river ratio in percent), 1990 to 2003 (water year 1995 was missing) (sources: http://waterdata.usgs.gov/ca/nwis/discharge and Dayflow database)

Month	Average	Median	Minimum	Maximum	Std.Dev.	COV 1/
Jan	12.0	11.8	3.2	18.4	4.4	36
Feb	12.8	11.9	2.0	22.7	6.6	52
Mar	14.1	18.5	4.7	26.0	7.6	54
Apr	10.2	9.6	2.4	21.0	5.6	55
May	7.7	7.3	2.4	16.9	3.9	50
Jun	12.3	10.3	2.2	20.1	5.1	41
Jul	16.4	16.0	3.4	26.9	5.6	34
Aug	16.9	16.1	6.8	29.3	6.0	36
Sep	10.4	9.9	5.0	23.5	4.9	47
Oct	9.6	9.6	4.4	15.1	3.4	36
Nov	14.2	14.6	7.7	20.3	3.8	27
Dec	13.2	13.1	5.2	23.7	5.5	41

1/ Coefficient of Variation

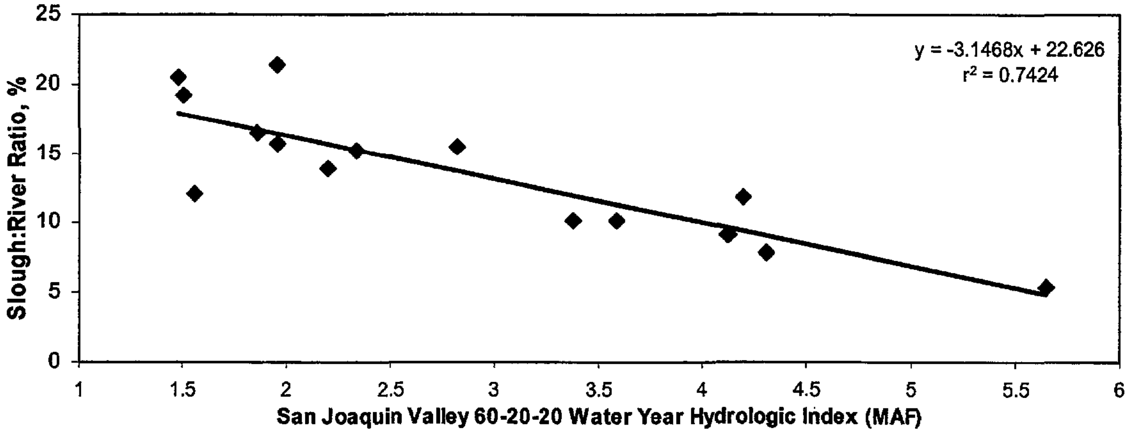

Figure 3-30. Correlation between the San Joaquin Valley water year hydrologic index (million acre-feet) and the annual average Mud+Salt Slough:San Joaquin River flow ratio

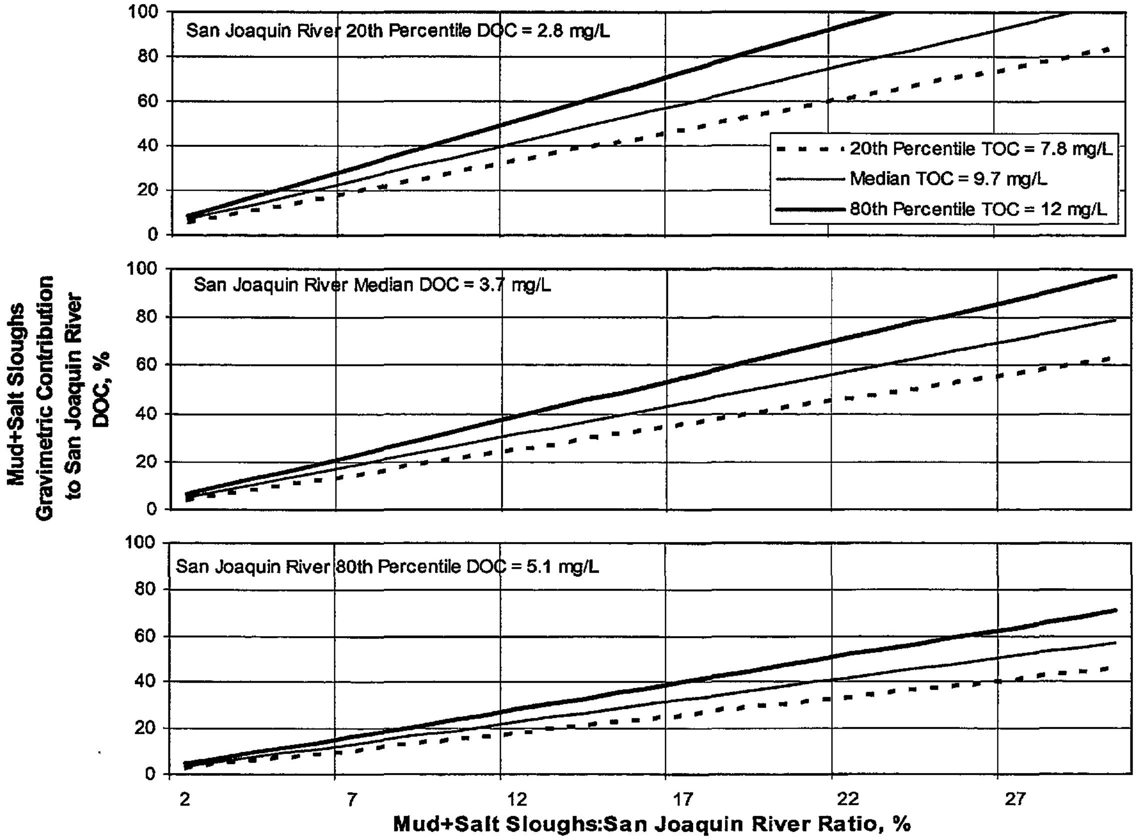

Figure 3-31. The Mud+Salt Sloughs:San Joaquin River flow ratio versus the gravimetric contribution from Mud+Salt Sloughs to dissolved organic carbon in the San Joaquin River at Vernalis. Nine different scenarios are presented involving the 20th, 50th (median), and 80th percentiles of dissolved organic carbon in the San Joaquin River and total organic carbon in Mud and Salt Sloughs (assumption: DOC = TOC) (source of San Joaquin River DOC data: DWR's MWQI program and accessed by the Water Data Library (http://dpladev5.water.ca.gov/wdl/index.cfm)).

The lowest contributions were estimated with the 80th percentile DOC in the San Joaquin River (5.1 mg/L) and the 20th percentile TOC in Mud+Salt Sloughs (7.8 mg/L). Under this scenario, Mud+Salt Sloughs contributed 3 to 46 percent of the San Joaquin River organic carbon concentration with volumetric percentages ranging from 2 to 30 percent. The highest contributions were estimated with the 20th percentile DOC in the San Joaquin River (2.8 mg/L) and the 80th percentile TOC in Mud+Salt Sloughs (12 mg/L). Mud+ Salt Sloughs contributed 7 to 99 percent of the San Joaquin River concentration with volumetric percentages ranging from 2 to 23 percent. Using the medians for both sources, the gravimetric percentages ranged from 5 to 79 percent with volumetric percentages of 2 to 30 percent.

These gravimetric percentages may be slight overestimates because DOC is likely to be less than TOC. However, the probable slight difference does not overshadow the relative magnitude of the gravimetric contributions from Mud and Salt Sloughs. For the last example (all median concentrations) the gravimetric contributions were at least 2.5 times higher than the volumetric contributions. Based on this, Mud and Salt Sloughs are major contributors of organic carbon to the San Joaquin River during most months of the year, and in particular, late fall and winter when south Delta exports can be relatively high and no barriers are in place to impede San Joaquin River flow to the export sites via south Old River and Grant Line Canal.

Although Mud and Salt Sloughs are major sources of TOC, rainfall runoff also likely contributed to the elevated THMFP levels detected in the San Joaquin River in March 1991. General rainfall runoff from around the San Joaquin Valley may have mobilized a considerable amount of TOC built up after 4 consecutive drought years. Less rainfall during any given year may result in a greater accumulation of organic carbon (and hence THMFP) around the watershed, making more available for the next major runoff event. Another extreme THMFP event that appeared to be associated with inflow to the Delta from the San Joaquin River was observed in the DMC during 1993.

After 6 consecutive dry or critical water years in the Sacramento Valley (and 6 critical ones in the San Joaquin Valley), 1993 was an above normal water year that officially ended the drought. Total organic carbon in the DMC near O'Neill Forebay (DMC milepost ~68) increased from 3.8 mg/L in December 1992 to 11.7 mg/L in January 1993 (Figure 3-32A). A considerable increase in THMFP was also observed in the same samples (529 to 1,261 µg/L). Total organic carbon and THMFP in the DMC remained elevated the following month (February) and were greater than levels at Banks Pumping Plant (Figure 3-32A).

The Sacramento River exhibited several flow crests between December 1992 and March 1993 (Figure 3-32B). Although the Delta Cross Channel gates had been closed during most of the 5-month period, QWEST values were largely positive indicating net flow out of the Delta (Figure 3-32B). Maximum pumping at Tracy Pumping Plant was continuous for more than 3 consecutive months and pumping at Banks Pumping Plant reached a record rate of 10.6 tcfs in January (Figure 3-32C). Both plants increased pumping, in part,

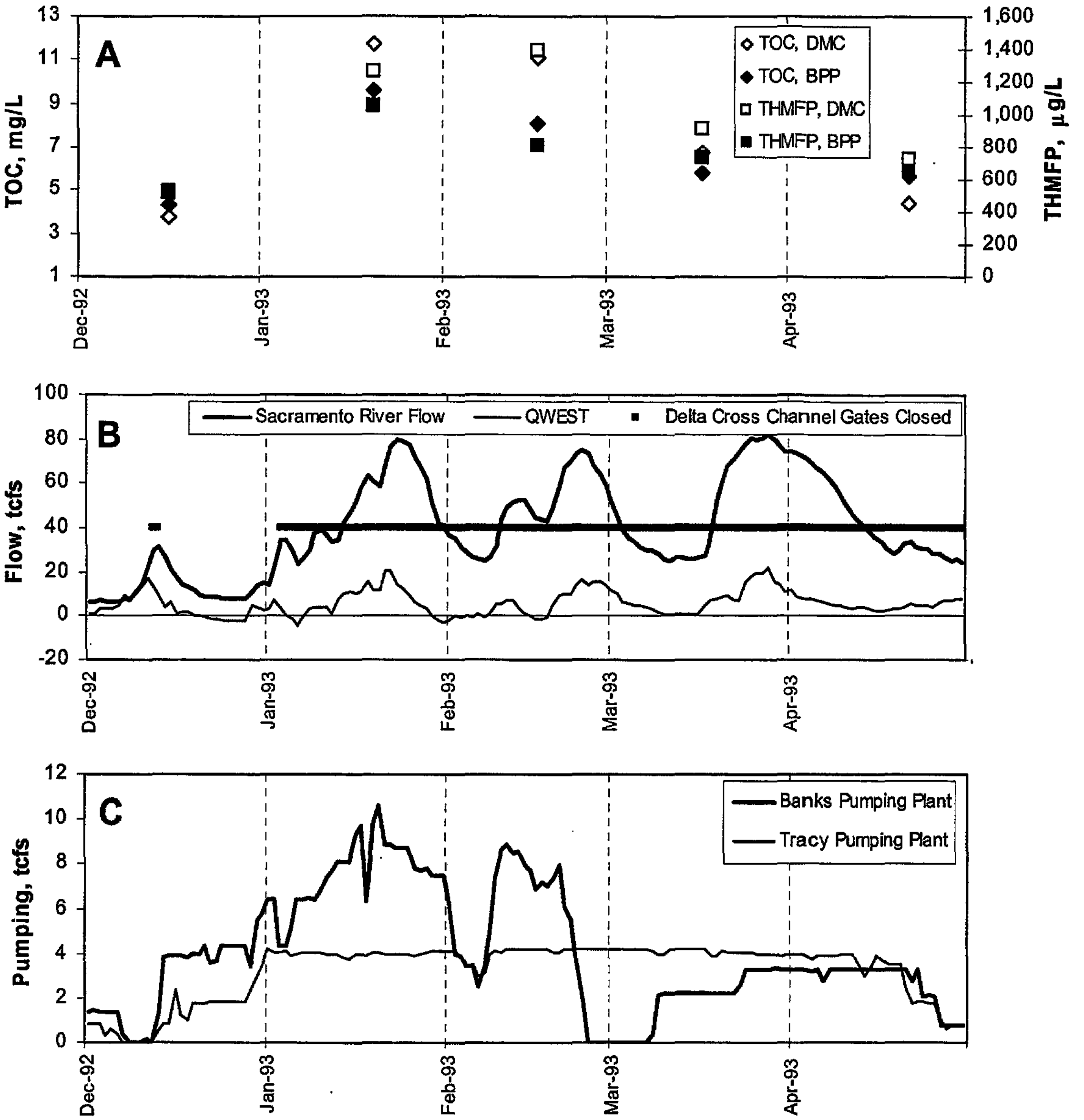

Figure 3-32. Total organic carbon and trihalomethane formation potential at Banks Pumping Plant and the Delta-Mendota Canal, December 1992 to April 1993 (A). Also shown is flow in the Sacramento River (Freeport), QWEST, Delta Cross Channel gate status (B), and pumping at Banks Pumping Plant and Tracy Pumping Plant (C) (sources for B and C: Dayflow and I.E.P. HEC-DSS Time-Series databases).

to fill downstream reservoir storage that had been depleted after 6 years of drought. Figure 32B and C reveal that reverse flow was nominal and water quality conditions in the south Delta were quickly conveyed into the California Aqueduct and DMC during most of that period.

Flow in the San Joaquin River also increased in January 1993, exceeding 9 tcfs for a short period of time (Figure 3-33). When flow in that river is sustained at around 3.4 tcfs or more, and certain barriers are not in place, most to all of the water at Tracy Pumping

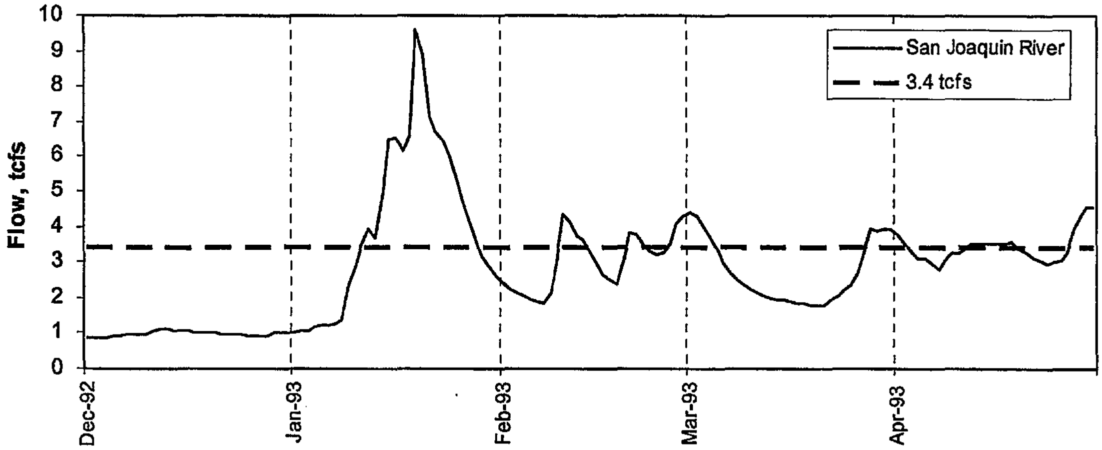

Figure 3-33. Flow in the San Joaquin River at Vernalis, December 1992 to April 1993 (source: Dayflow database). The 3.4 tcfs horizontal dashed line represents flow in the San Joaquin River at Vernalis when that river, under certain conditions, can dominate the composition of water at Tracy Pumping Plant (DWR 2004a).

Plant is from that river flowing directly to the export site via south Old River and Grant Line Canal (DWR 2004a). During January 1993, no barriers were in place and flow exceeded 3.4 tcfs for 18 consecutive days (see dashed line in Figure 3-33). Based on this, water in the DMC was largely from the San Joaquin River when the January 1993 sample was collected (TOC: 11.7 mg/L; THMFP: 1,261 µg/L). The following month (February), TOC and THMFP in the DMC remained elevated at 11.1 mg/L and 1,387 µg/L, respectively. Because flow in the San Joaquin River fluctuated both above and below 3.4 tcfs during February, water pumped at Tracy Pumping Plant was still probably heavily influenced by direct flow from that river (via south Old River and Grant Line Canal).

Other potential contributing sources include a number of drains and discharges between the DMC sampling station and the San Joaquin River. There are approximately 40 agricultural sump pumps along south Old River and Grant Line Canal (DWR 1995b). Some of these drains have exhibited THMFP levels ranging between 250 and 2,600 µg/L (DWR 1994b). The City of Tracy operates a wastewater treatment plant that discharges an average 5.9 million gallons per day to south Old River (DWR 2001).

Lastly, there are 187 small drains (6 to 30 inches) and 77 large drains (>30 inches to 5 x 2.6 feet) on the DMC between Tracy Pumping Plant and O'Neill Forebay (USBR 1986). These drains convey rainfall runoff and excess irrigation water from agricultural land and, to a lesser extent, roadways into the DMC. Monthly rainfall totals at Tracy Pumping Plant during December 1992 to February 1993 ranged from 2.9 to 5.9 inches, so rainfall runoff to the DMC was likely from these drains.

Therefore, there were myriad sources that could have contributed to the high TOC and THMFP levels in the DMC during January and February 1993, the likely principal being inflow to the Delta from the San Joaquin River. Since water from the DMC can be pumped into O'Neill Forebay at O'Neill Pumping-Generating Plant, these sources can also influence water quality in the California Aqueduct, downstream of Banks Pumping Plant.

During January and February 1993, inflow to O'Neill Forebay from the DMC accounted for 38 percent of the total water volume from south Delta sources (DMC + California Aqueduct) (Figure 3-34) and 43 percent of the TOC load. As discussed before, the increase in freshwater inflow to the Delta during early 1993 spurred increased pumping to replenish depleted storage in San Luis Reservoir – the endpoint for most (94 percent) of the water pumped into O'Neill Forebay during January and February 1993 (Figure 3-34). Since water from the DMC routinely enters the California Aqueduct at O'Neill Forebay, TOC and THMFP in the DMC were assessed relative to levels at Banks Pumping Plant.

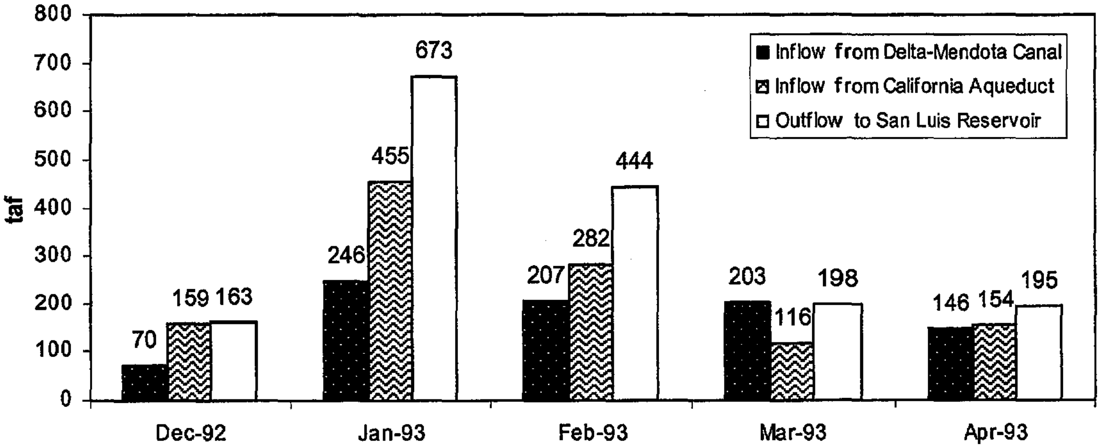

Figure 3-34. Monthly inflow to O'Neill Forebay from the Delta-Mendota Canal and California Aqueduct, December 1992 to April 1993. Also shown is pumping into San Luis Reservoir (outflow from O'Neill Forebay) at Gianelli Pumping-Generating Plant.

4. Delta-Mendota Canal

Total Organic Carbon

Monthly TOC trends in the DMC near O'Neill Forebay (DMC milepost ~68) were somewhat similar to those at Banks Pumping Plant with the highest levels detected in winter. Median TOC was around 5 mg/L in January and February, declined through October then increased in November and December (Figure 4-1 and Table 4-1). Monthly TOC concentrations between this station and Banks Pumping Plant were not statistically different ($p>0.05$, Mann-Whitney U test).

Total organic carbon during winter was both lower and higher in the DMC than at Banks Pumping Plant. From January to March, the lowest TOC concentrations in the DMC ranged from 2.4 to 3.1 mg/L while at Banks Pumping Plant they were higher, ranging from 2.9 to 3.9 mg/L. Further, maximum levels were higher in the DMC (7.4 to 11.7 mg/L) than at Banks Pumping Plant (7.1 to 9.6 mg/L). The wider TOC range in the DMC contributed to greater variability during January to March with CVs ranging from 35 to 45 percent compared to 28 to 31 percent at Banks Pumping Plant.

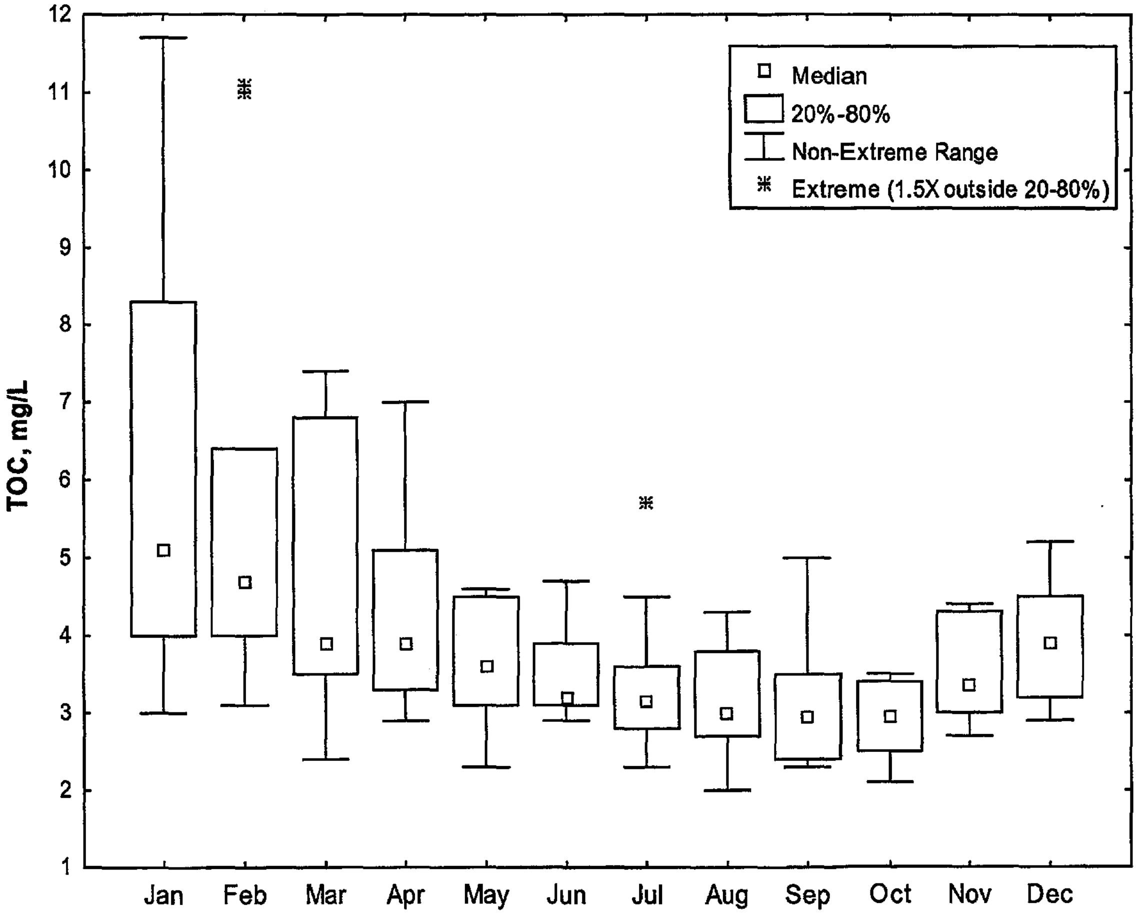

Figure 4-1. Monthly total organic carbon trends in the Delta-Mendota Canal, mid 1990 to 2003

Table 4-1. Statistics of monthly total organic carbon (mg/L) in the Delta-Mendota Canal, mid 1990 to 2003

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	5.7	5.1	3.0	11.7	2.5	43
Feb	5.7	4.7	3.1	11.1	2.5	45
Mar	4.9	3.9	2.4	7.4	1.7	35
Apr	4.2	3.9	2.9	7.0	1.1	28
May	3.6	3.6	2.3	4.6	0.7	18
Jun	3.4	3.2	2.9	4.7	0.5	15
Jul	3.4	3.2	2.3	5.7	0.9	28
Aug	3.1	3.0	2.0	4.3	0.6	20
Sep	3.1	3.0	2.3	5.0	0.8	25
Oct	2.9	3.0	2.1	3.5	0.4	15
Nov	3.5	3.4	2.7	4.4	0.6	17
Dec	3.9	3.9	2.9	5.2	0.7	17

1/ Coefficient of Variation

The higher variability in TOC is likely related to influence from the San Joaquin River, which is more predominant in the DMC than at Banks Pumping Plant (DWR 2004a). Variability of TOC in the San Joaquin River may be relatively high due to it's contrasting tributaries such as Sierra Nevada rivers and agricultural drainage.

Figure 4-2 shows long-term TOC at Banks Pumping Plant and in the Delta-Mendota Canal between 1990 and 2003. Analysis of wet and dry season TOC averages disclosed some differences and similarities between these 2 stations over the 14-year period.

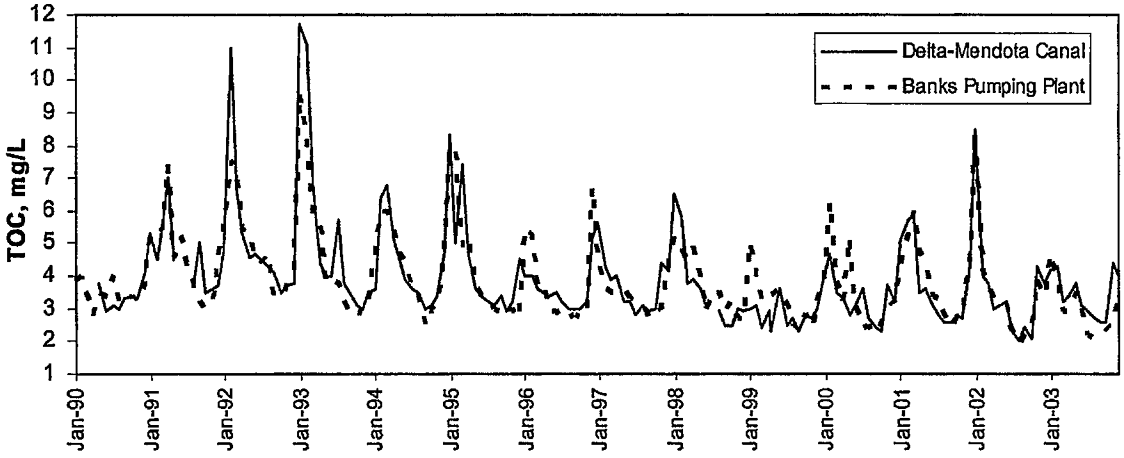

Figure 4-2. Long-term total organic carbon at Banks Pumping Plant and the Delta-Mendota Canal, 1990 to 2003

Dry Season

Average dry season (August to November) TOC was higher in the DMC than at Banks Pumping Plant in all but 3 years (Figure 4-3). The difference was widest in 2003 when the dry season average of 3.08 mg/L in the DMC contrasted with a period low of

2.3 mg/L at Banks Pumping Plant. Further, dry season averages between stations were not strongly correlated (Figure 4-4).

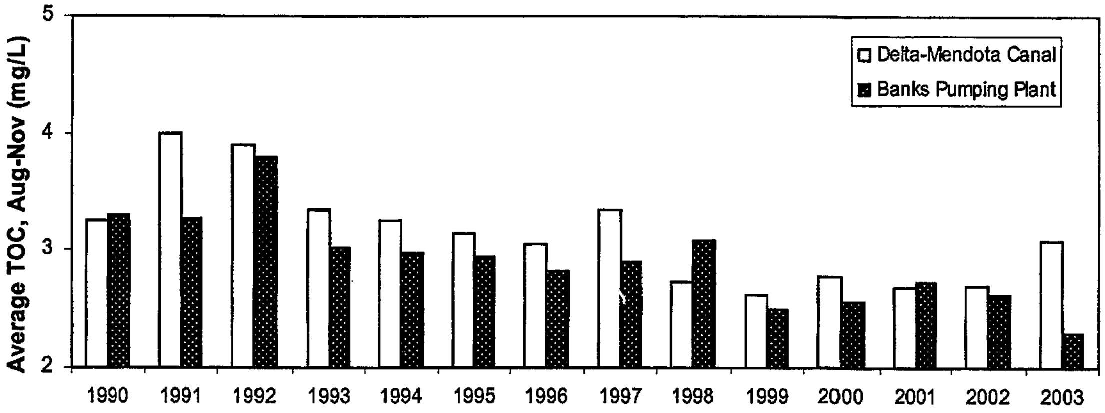

Figure 4-3. Average dry season (August to November) total organic carbon at Banks Pumping Plant and the Delta-Mendota Canal, 1990 to 2003

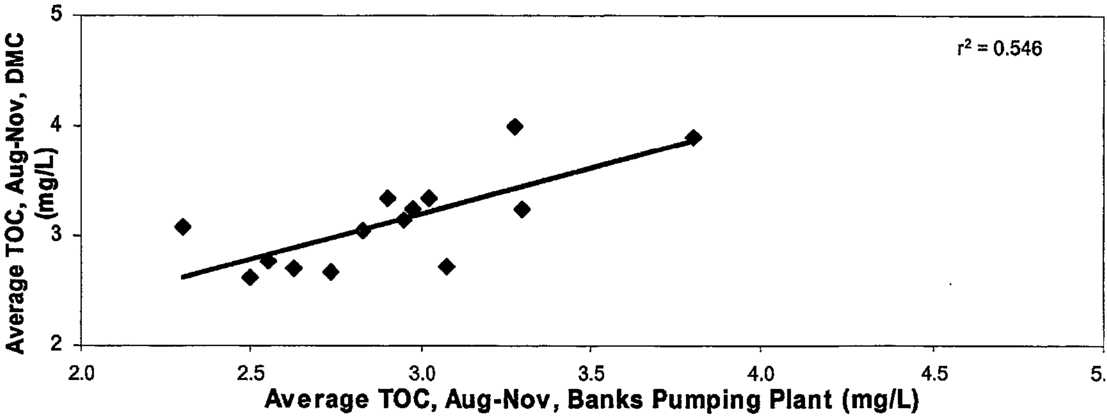

Figure 4-4. Correlation of average dry season (August to November) total organic carbon between Banks Pumping Plant and the Delta-Mendota Canal

Seasonal operations provide an explanation for the relatively low correlation in dry season TOC between Banks Pumping Plant and the DMC. Certain South Delta Temporary Barriers are usually in place for at least a portion of the period between August and November. Although these barriers can reduce or prevent San Joaquin River flow from directly approaching the Clifton Court Forebay gates via south Old River and Grant Line Canal, flow to Tracy Pumping Plant is sometimes just reduced (DWR 2004a). Water quality in the DMC can still be influenced by direct flow from the San Joaquin River with the barriers installed. Compared to Banks Pumping Plant, direct flow from the San Joaquin River would be more predominant in the DMC at the expense of influence from reservoir releases to the Sacramento River which can flow directly to the export sites via the Delta Cross Channel. This was supported by comparing dry season TOC in the DMC with total Delta exports.

Average dry season TOC in the DMC and total Delta exports were not well correlated with an r^2 of 0.51 (Figure 4-5). The same correlation at Banks Pumping Plant was stronger ($r^2 = 0.70$).

The aggregate of this information infers that TOC was, on average, usually lower in cross Delta flow than direct flow from the San Joaquin River (via south Old River and Grant Line Canal) during the collective months of August to November. As a result, TOC during this period was usually lower at Banks Pumping Plant than in the DMC. The South Delta Temporary Barriers (likely combined with pumping at Tracy Pumping Plant) prevented higher TOC water in south Old River and Grant Line Canal from reaching the Clifton Court Forebay gates.

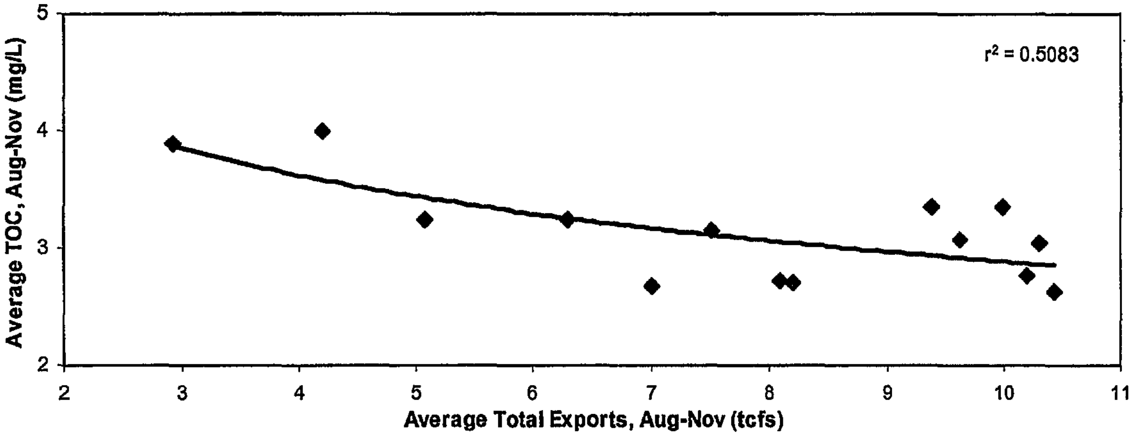

Figure 4-5. Correlation of average dry season (August to November) total organic carbon in the Delta-Mendota Canal and total Delta exports averaged over the same 4-month period. Total exports include all State and federal exports in the north, west, and south Sacramento-San Joaquin Delta (http://www.iep.ca.gov/dayflow/documentation/index.html).

Wet Season

Wet season (December to April) TOC averages at Banks Pumping Plant and in the DMC were similar (Figure 4-6) and well correlated with an r^2 of 0.95 (Figure 4-7).

Operations during the wet season (often dictated by hydrology) provide an explanation for the close correlation in wet season TOC between Banks Pumping Plant and the DMC. First, the South Delta Temporary Barriers are typically not in place during much of the period between December and April. With no barriers, the San Joaquin River can flow unimpeded to both export sites via south Old River and Grant Line Canal (DWR 2004a). This unimpeded flow increases with increasing flow in the San Joaquin River. The chance of direct flow reaching both export sites rises with flow in the San Joaquin River (ibid).

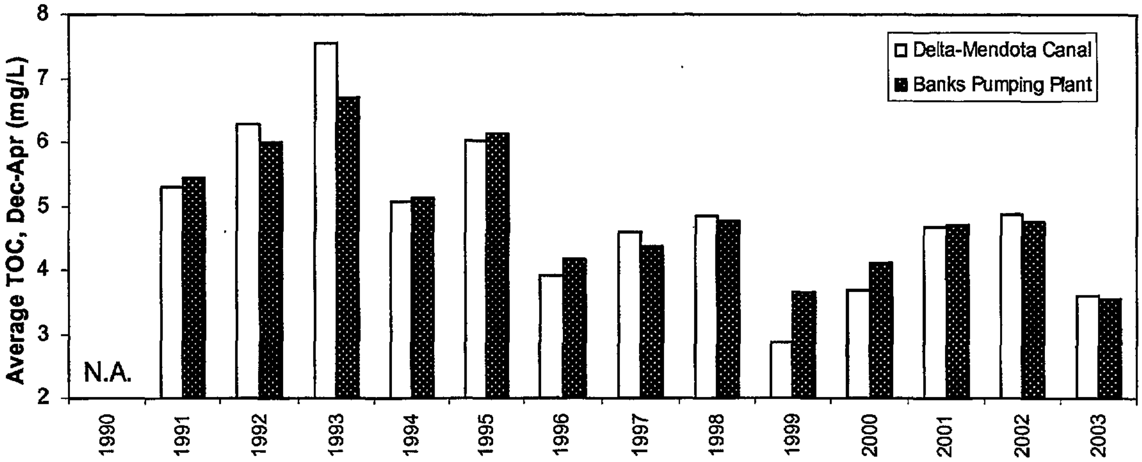

Figure 4-6. Average wet season (December to April) total organic carbon at Banks Pumping Plant and in the Delta-Mendota Canal, 1991 to 2003

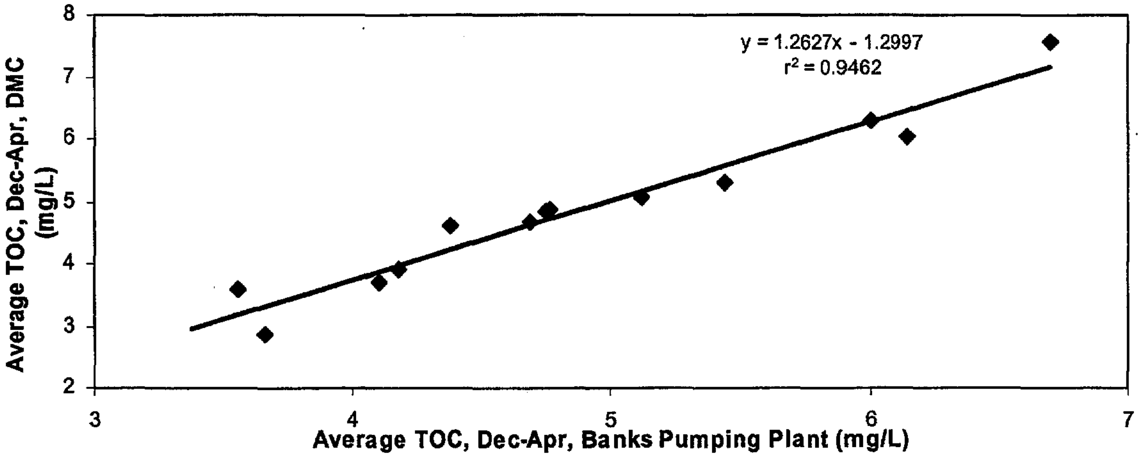

Figure 4-7. Correlation of average wet season (December to April) total organic carbon between Banks Pumping Plant and the Delta-Mendota Canal

Seasonal operation of the Delta Cross Channel may also play a role in explaining the high correlation in wet season averages between Banks Pumping Plant and the DMC. The Delta Cross Channel gates are often closed for a good portion of the period between December and April, conditionally or otherwise (see Appendix A). Gate closure reduces the amount of Sacramento River water entering the central Delta from the north. Any water entering the central Delta from the west (reverse flow) would mix with water from the San Joaquin River (during a period when flow in that river is highest) to become a component of cross Delta flow. Because of closed gates, less water from the Sacramento River would be available in the central Delta to commingle with inflow from the San Joaquin River, reducing the potential dilution of that river and increasing its proportion in cross Delta flow.

Both of these operational practices (no barriers and gate closure) are surmised to allow the export of more water from the San Joaquin River at Banks Pumping Plant and Tracy Pumping Plant during December to April. This was supported by correlating wet season averages at these stations with those in the San Joaquin River at Vernalis. Wet season DOC in the San Joaquin River was correlated with wet season TOC in the DMC ($r^2 = 0.82$) (Figure 4-8). The same correlation using wet season averages at Banks Pumping Plant was weaker, but still apparent (Figure 4-9).

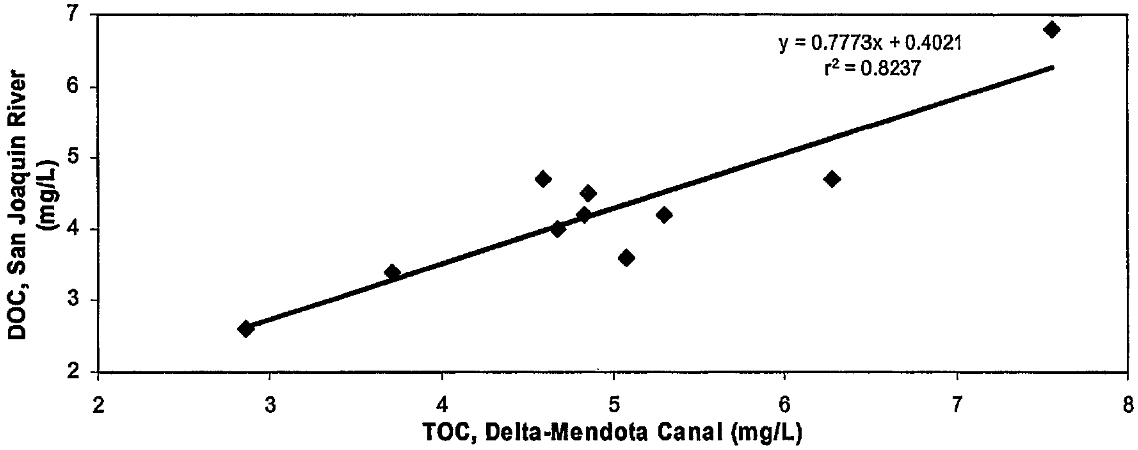

Figure 4-8. Correlation between average wet season (December to April) total organic carbon in the Delta-Mendota Canal and average wet season dissolved organic carbon in the San Joaquin River at Vernalis (San Joaquin River data from DWR's MWQI Program and accessed by the Water Data Library (http://dpladev5.water.ca.gov/wdl/index.cfm))

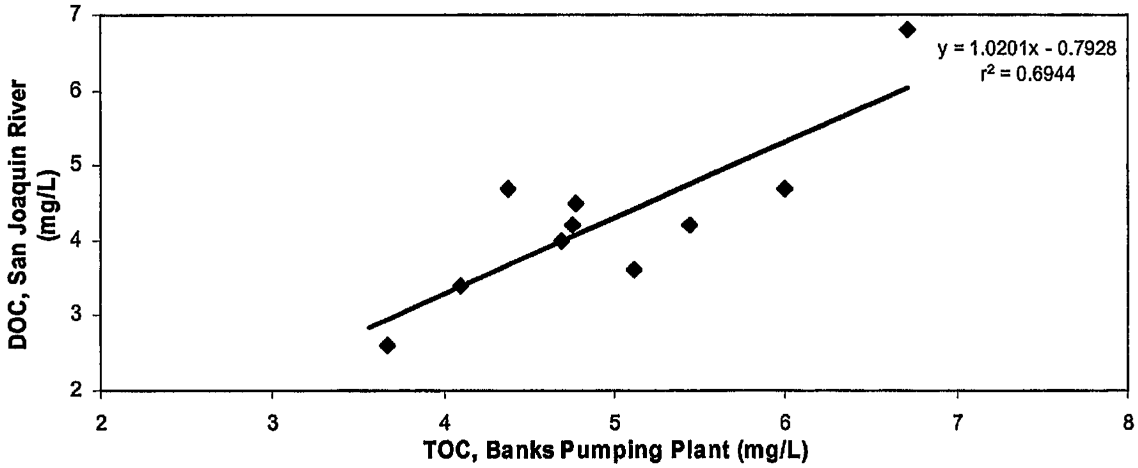

Figure 4-9. Correlation between average wet season (December to April) total organic carbon at Banks Pumping Plant and average wet season dissolved organic carbon in the San Joaquin River at Vernalis (San Joaquin River data from DWR's MWQI Program and accessed by the Water Data Library (http://dpladev5.water.ca.gov/wdl/index.cfm))

The sum of this information furnishes ample evidence that inflow to the Delta from the San Joaquin River is a major source of organic carbon to both State and federal water projects during the months of December to April. As discussed in the previous section, major sources of organic carbon in the San Joaquin Valley are Mud and Salt Sloughs. Combined outflow from these sloughs during 1990 to 2003, on average, composed 10.2 to 14 percent of San Joaquin River flow at Vernalis between December and April (see previous Figure 3-29). With TOC concentrations that averaged from 9 to 13.7 mg/L during the same 5-month period (see previous Figure 3-27), Mud and Salt Sloughs are major contributors of TOC to the San Joaquin River, and particularly, during a period when south Delta exports can be high and heavily influenced by that river.

Trihalomethane Formation Potential

Total organic carbon and THMFP were well correlated in the DMC (Figure 4-10). The r^2 of 0.89 was stronger than that at Banks Pumping Plant for the same linear association (0.77). The higher correlation infers a closer relationship between these two parameters in the San Joaquin River versus cross Delta flow. The DMC is more influenced by that river than Banks Pumping Plant (DWR 2004a). The r^2 improved to 0.93 when regressing only data collected during the wet season months of December to April – months when the San Joaquin River is more likely to make up most or all of the water in the DMC (ibid). Therefore, TOC is a better predictor of THMFP in the DMC than at Banks Pumping Plant due to a higher degree of influence from the San Joaquin River versus cross Delta flow.

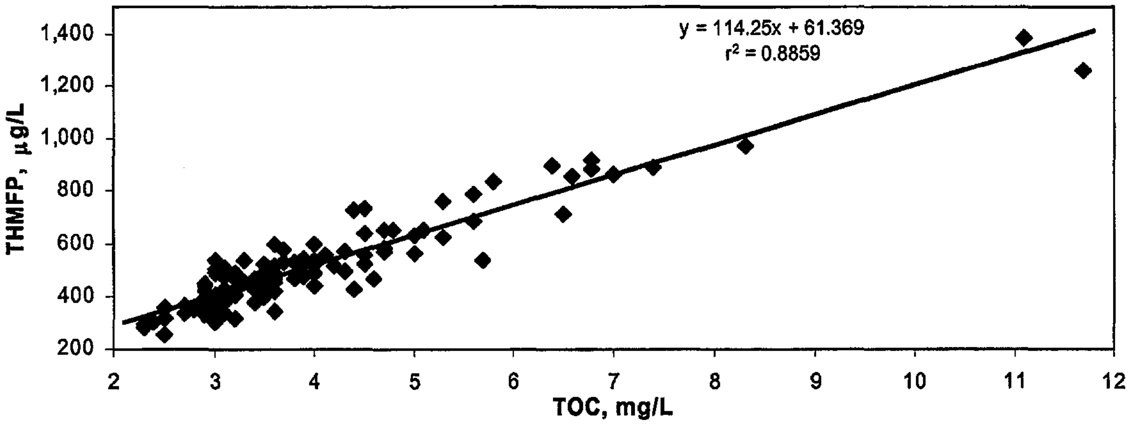

Figure 4-10. Correlation between total organic carbon and trihalomethane formation potential in the Delta-Mendota Canal

Monthly THMFP trends in the DMC were somewhat similar to those at Banks Pumping Plant. Levels were highest in winter and lowest during late summer to early fall (Figure 4-11 and Table 4-2). As with TOC, THMFP in the DMC was both higher and lower than at Banks Pumping Plant during the winter months of January to March. This was reflected in a wider CV range for the DMC (35 to 43 percent) versus Banks Pumping Plant (20 to 28 percent). Monthly levels between these stations were not statistically different (p>0.05, Mann-Whitney U test) A graph of long-term THMFP at Banks Pumping Plant and the DMC shows winter levels were not consistently highest at either station (Figure 4-12).

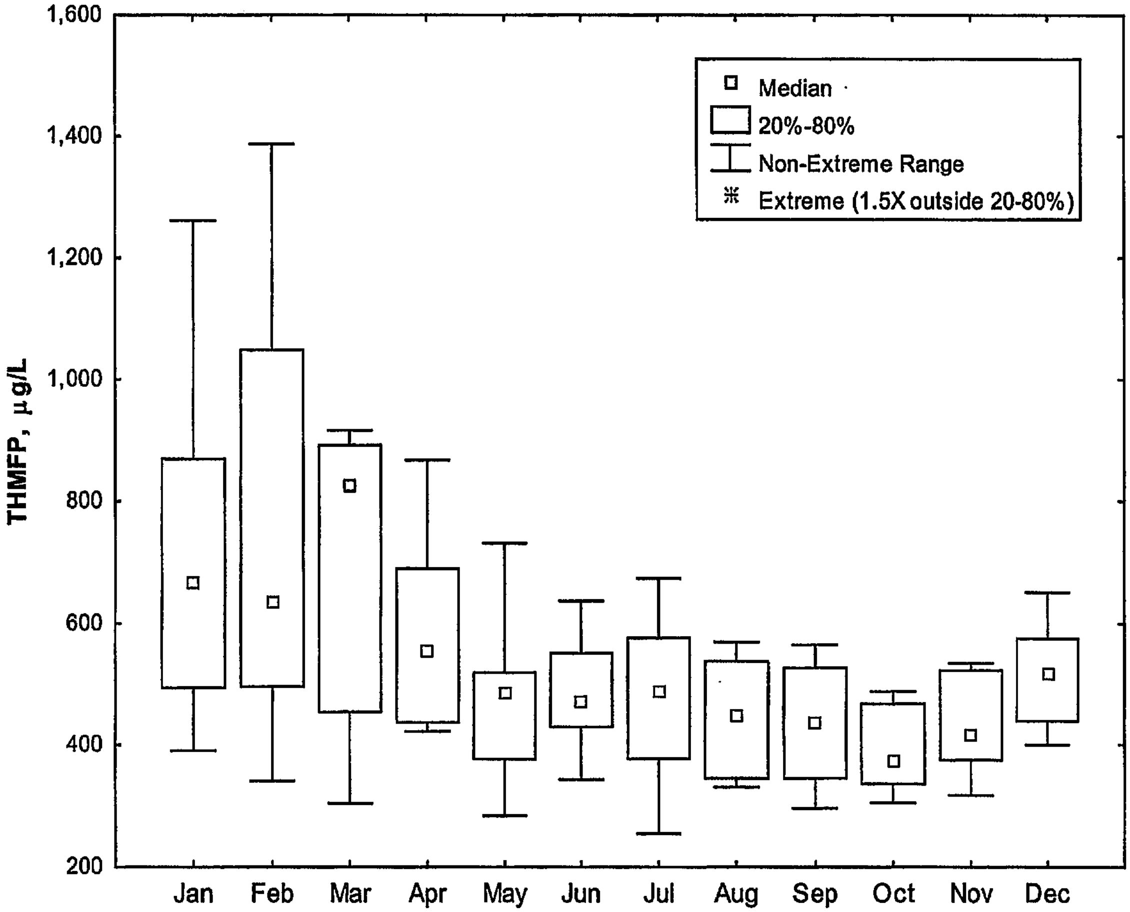

Figure 4-11. Monthly trihalomethane formation potential trends in the Delta-Mendota Canal, mid 1990 to January 2000

Table 4-2. Statistics of monthly trihalomethane formation potential (µg/L) in the Delta-Mendota Canal, mid 1990 to January 2000

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	702	668	390	1,261	256	36
Feb	756	635	340	1,387	323	43
Mar	697	825	303	916	244	35
Apr	574	554	422	867	146	25
May	473	485	283	731	121	26
Jun	487	472	342	637	83	17
Jul	477	488	254	674	123	26
Aug	448	449	330	569	91	20
Sep	432	438	295	565	91	21
Oct	396	373	304	488	67	17
Nov	433	415	317	534	74	17
Dec	510	517	400	651	78	15

1/ Coefficient of Variation

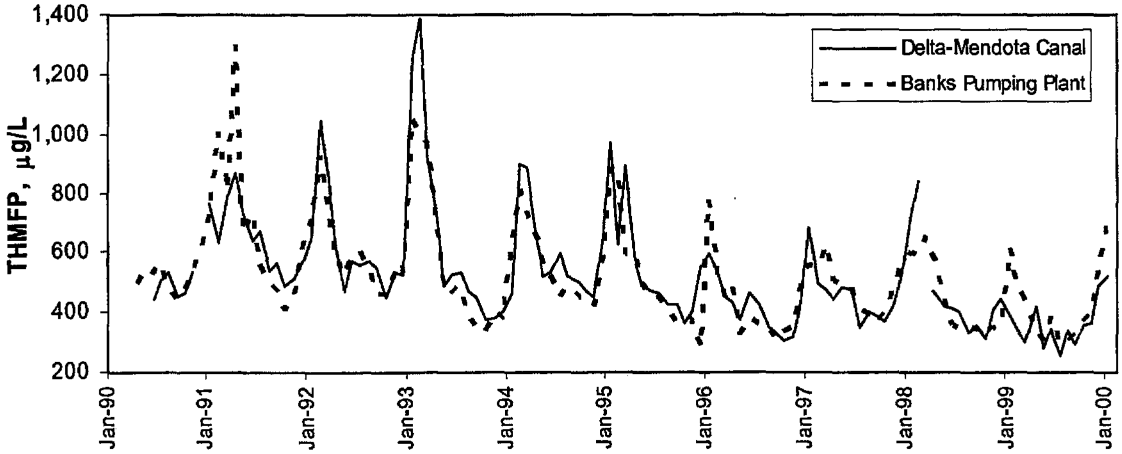

Figure 4-12. Long-term trihalomethane formation potential at Banks Pumping Plant and in the Delta-Mendota Canal, mid 1990 to January 2000

5. Joint-Use Facilities

The Joint-Use Facilities include O'Neill Forebay, San Luis Reservoir, and the California Aqueduct between mileposts 70.89 and 172.26 (the San Luis Canal). These facilities are used jointly by State and federal water agencies to deliver water to municipal and agricultural entities, respectively.

San Luis Reservoir is an off-site storage facility that provides water during spring and summer when demand is usually highest. Water is pumped into San Luis Reservoir from O'Neill Forebay largely during the fall and winter when demand is usually lowest. Inflow to O'Neill Forebay from the south Delta can originate from the California Aqueduct or the DMC.

Inflow to O'Neill Forebay

Water from the DMC is pumped into O'Neill Forebay at O'Neill Pumping-Generating Plant (see aerial location in Figure 2-2). Monthly pumping trends from 1990 to 2003 are presented in Figure 5-1 and Table 5-1. Median monthly pumping was highest in January

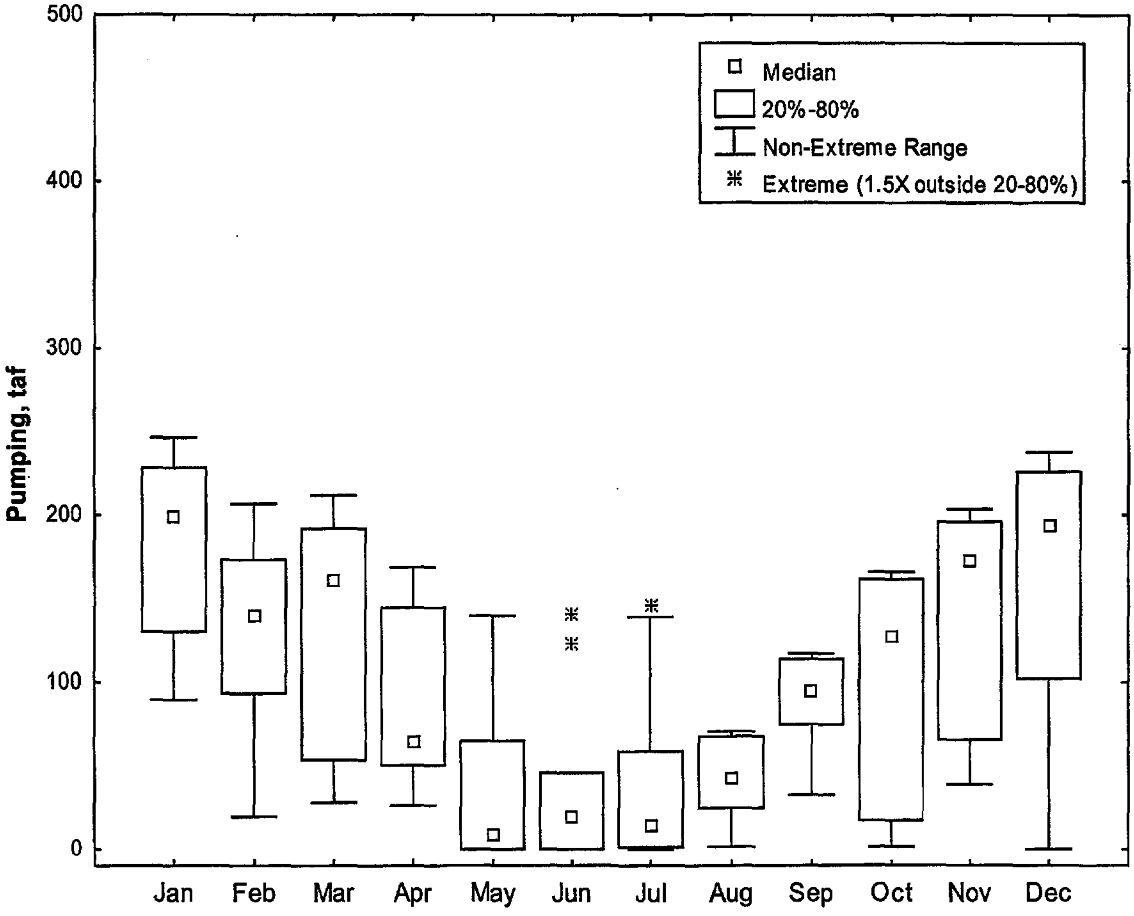

Figure 5-1. Monthly pumping trends at O'Neill Pumping-Generating Plant, 1990 to 2003. This plant pumps water from the Delta-Mendota Canal into O'Neill Forebay.

Table 5-1. Statistics of monthly pumping (taf) at O'Neill Pumping-Generating Plant, 1990 to 2003. This plant pumps water from the Delta-Mendota Canal into O'Neill Forebay.

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	182	199	90	246	54	30
Feb	133	141	20	207	48	36
Mar	141	161	28	212	61	43
Apr	83	64	26	169	45	53
May	31	9	0	140	46	149
Jun	36	20	0	141	44	125
Jul	34	14	0	146	49	142
Aug	43	43	2	71	23	54
Sep	90	95	33	118	27	30
Oct	104	127	1	166	60	58
Nov	147	172	39	203	59	40
Dec	167	194	0	238	70	42

1/ Coefficient of Variation

with 199 taf, declined to a minimum of 9 taf in May, then steadily increased to 194 taf in December. Pumping was moderately to highly variable with CVs ranging from 30 to 149 percent. The maximum monthly pumping volume of 246 taf at O'Neill Pumping-Generating Plant was a little more than half that at Banks Pumping Plant (465 taf) – both were in the month of January.

Water also enters O'Neill Forebay from the California Aqueduct at Check 12 (milepost 66.71). Although this inflow would be less than that pumped at Banks Pumping Plant because of upstream diversions for the South Bay Aqueduct, monthly trends would essentially be the same due to a strong correlation between the 2 monthly volumes (Figure 5-2). Monthly pumping at Banks Pumping Plant generally declined from January to May, increased to a peak in July and then declined into October and November before increasing again in December (see previous Figure 3-3).

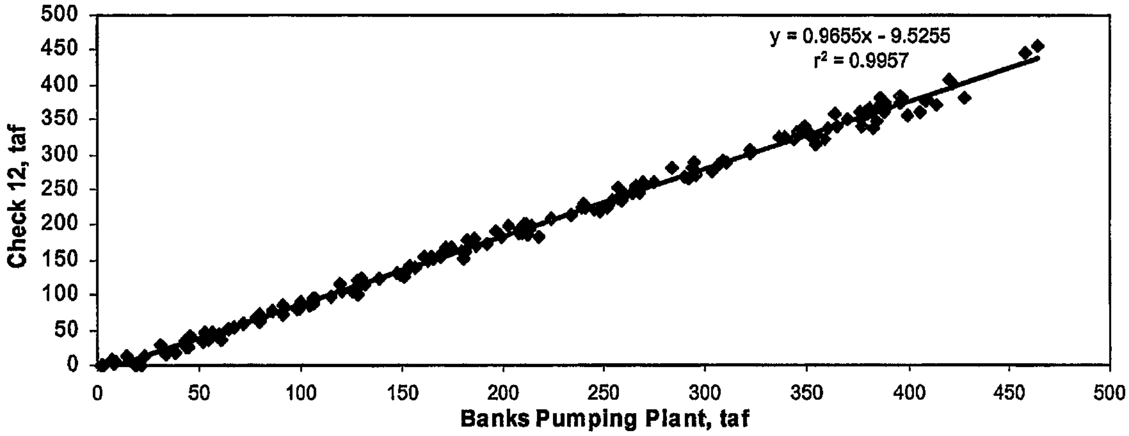

Figure 5-2. Correlation between pumping at Banks Pumping Plant and inflow to O'Neill Forebay from the California Aqueduct at Check 12, 1990 to 2003

A comparison was made between water entering O'Neill Forebay from the DMC at O'Neill Pumping-Generating Plant versus the total from south Delta sources (DMC + Check 12). Inflow from the DMC was highest relative to the total during the 6-month period between November and April. Median percent-of-totals during these months ranged from 37 to 44 percent while the averages were higher ranging from 43 to 50 percent (Figure 5-3 and Table 5-2).

Therefore, on average, a little less than half of the water entering O'Neill Forebay from south Delta sources originated from the DMC during the six-month period from November to April. The percent-of-total inflow values during these months were usually relatively variable with CVs ranging from 21 to 55 percent.

Based on this, water from the DMC would more likely have a greater influence on water quality in O'Neill Forebay during November to April. Influence from the DMC would be least during July and August when it consistently made up less than 20 percent of the total inflow originating from south Delta sources (Figure 5-3).

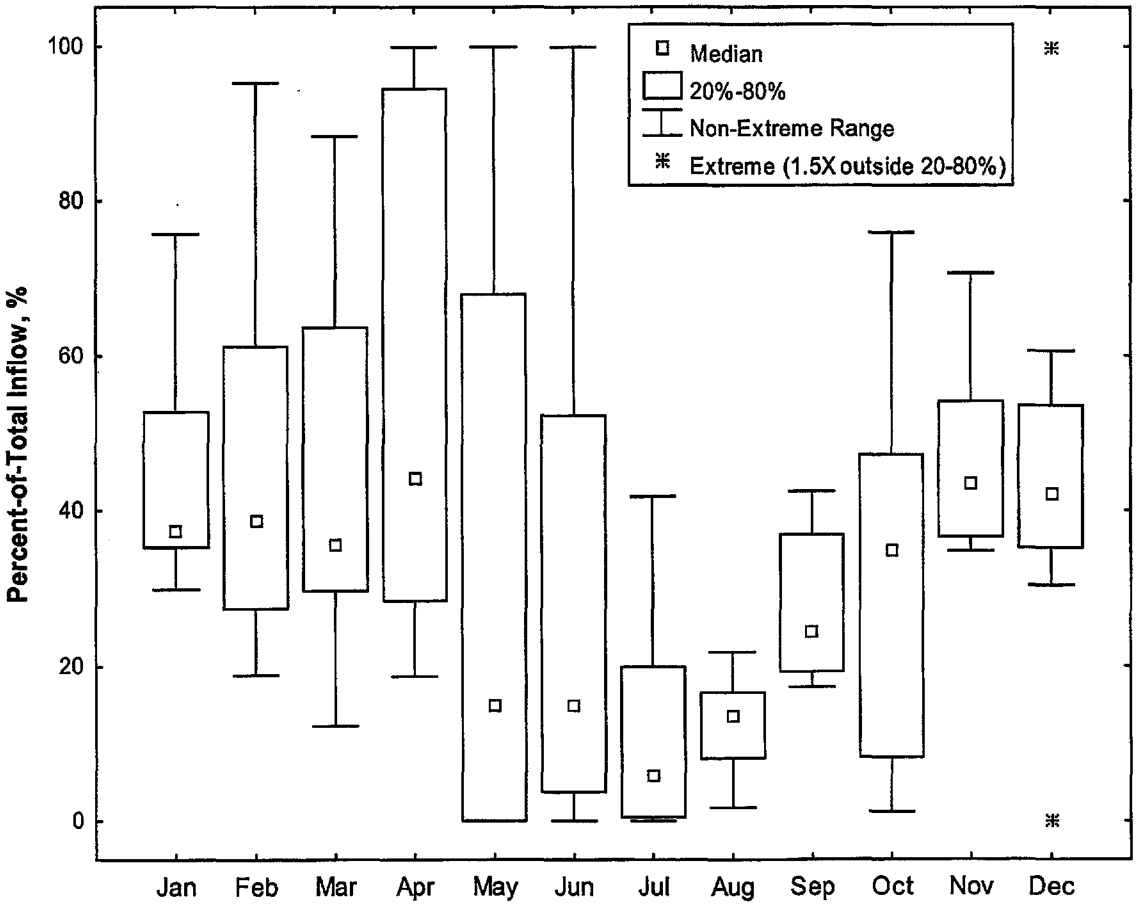

Figure 5-3. Monthly percent-of-total inflow trends at O'Neill Pumping-Generating Plant, 1990 to 2003. Total inflow to O'Neill Forebay includes the sum of Check 12 on the California Aqueduct and O'Neill Pumping-Generating Plant on the Delta-Mendota Canal.

Table 5-2. Statistics of monthly percent-of-total inflow (percent) at O'Neill Pumping-Generating Plant, 1990 to 2003. Total inflow to O'Neill Forebay includes the sum of Check 12 on the California Aqueduct and O'Neill Pumping-Generating Plant on the Delta-Mendota Canal.

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	43	37	30	76	13	30
Feb	44	39	19	95	22	49
Mar	44	36	12	88	22	51
Apr	50	44	19	100	27	55
May	26	15	0	100	32	127
Jun	27	15	0	100	29	106
Jul	10	6	0	42	12	123
Aug	13	14	2	22	6	45
Sep	27	24	17	42	9	32
Oct	33	35	1	76	20	61
Nov	46	43	35	71	10	21
Dec	44	42	0	100	21	48

1/ Coefficient of Variation

Total Organic Carbon Loading to O'Neill Forebay

Monthly trends in TOC loading to O'Neill Forebay at O'Neill Pumping-Generating Plant were similar to those of pumping volumes. From mid 1990 to 2003, the highest TOC loads were generally pumped during fall and winter. Median loads during these seasons ranged from 430 t in October to 1,098 t in January (Figure 5-4 and Table 5-3). The period maximum load of 3,553 t was pumped in January 1993 – 65 percent of the period maximum pumped at Banks Pumping Plant (5,504 t) the same month. Monthly loads were usually highly variable with CVs ranging from 31 to 156 percent (Table 5-3).

A comparison was made between TOC loading to O'Neill Forebay at O'Neill Pumping-Generating Plant versus the total from south Delta sources (DMC + Check 12 (TOC data from Banks Pumping Plant)). Median monthly percent-of-total values were greatest during November to April with a range of 38 to 48 percent; the averages were slightly higher ranging from 43 to 50 percent (Figure 5-5 and Table 5-4). The percent-of-total values were often variable during this 6-month period with CVs ranging from 21 to 56 percent. Outside of this November-to-April period, DMC load contributions averaged between 9 and 31 percent with CVs ranging from 31 to 127 percent.

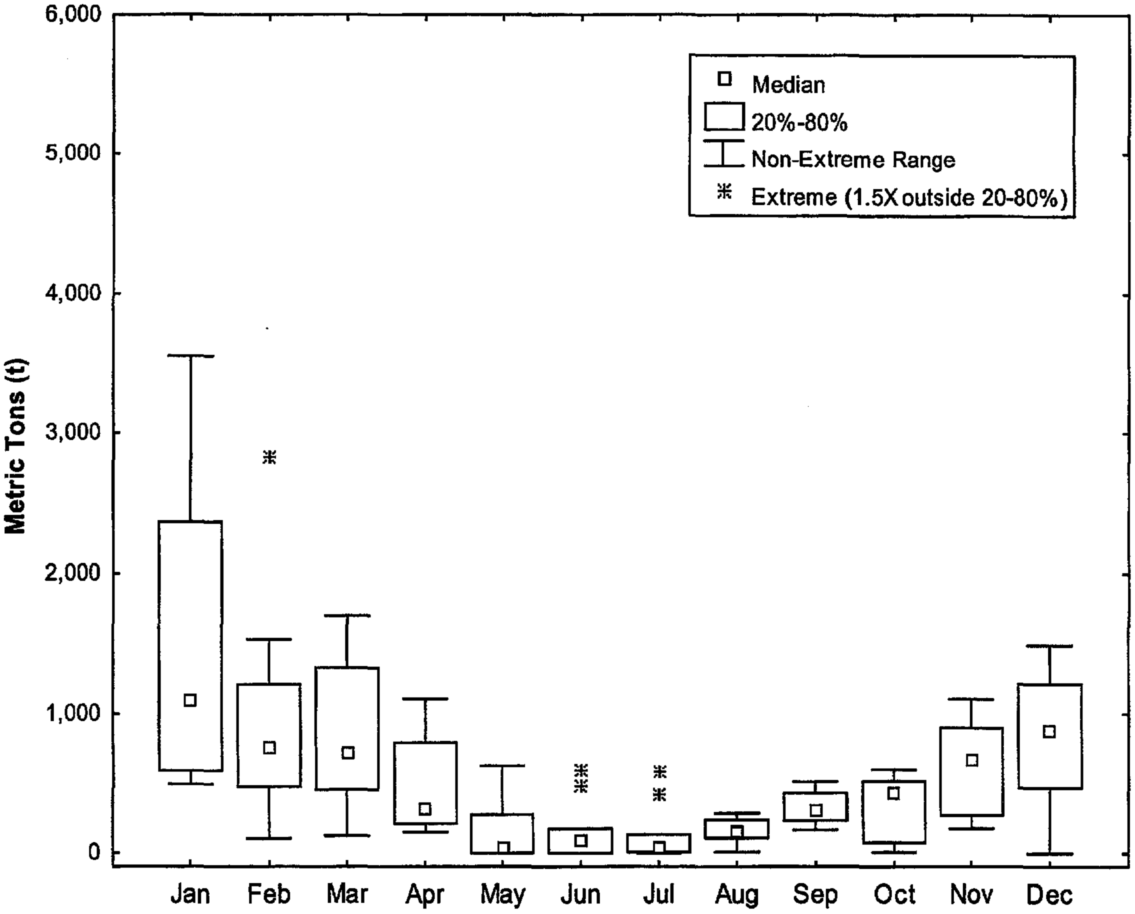

Figure 5-4. Monthly trends in total organic carbon loading to O'Neill Forebay at O'Neill Pumping-Generating Plant, mid 1990 to 2003

Table 5-3. Statistics of monthly total organic carbon loading (metric tons) to O'Neill Forebay at O'Neill Pumping-Generating Plant, mid 1990 to 2003

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	1,352	1,098	490	3,553	926	68
Feb	972	757	104	2,829	676	69
Mar	826	719	124	1,700	476	58
Apr	428	317	149	1,106	319	75
May	138	41	0	622	203	147
Jun	143	86	0	591	178	125
Jul	114	45	0	576	177	156
Aug	152	149	9	282	82	54
Sep	327	305	165	507	101	31
Oct	351	430	6	598	201	57
Nov	635	662	177	1,105	301	47
Dec	839	879	0	1,493	412	49

1/ Coefficient of Variation

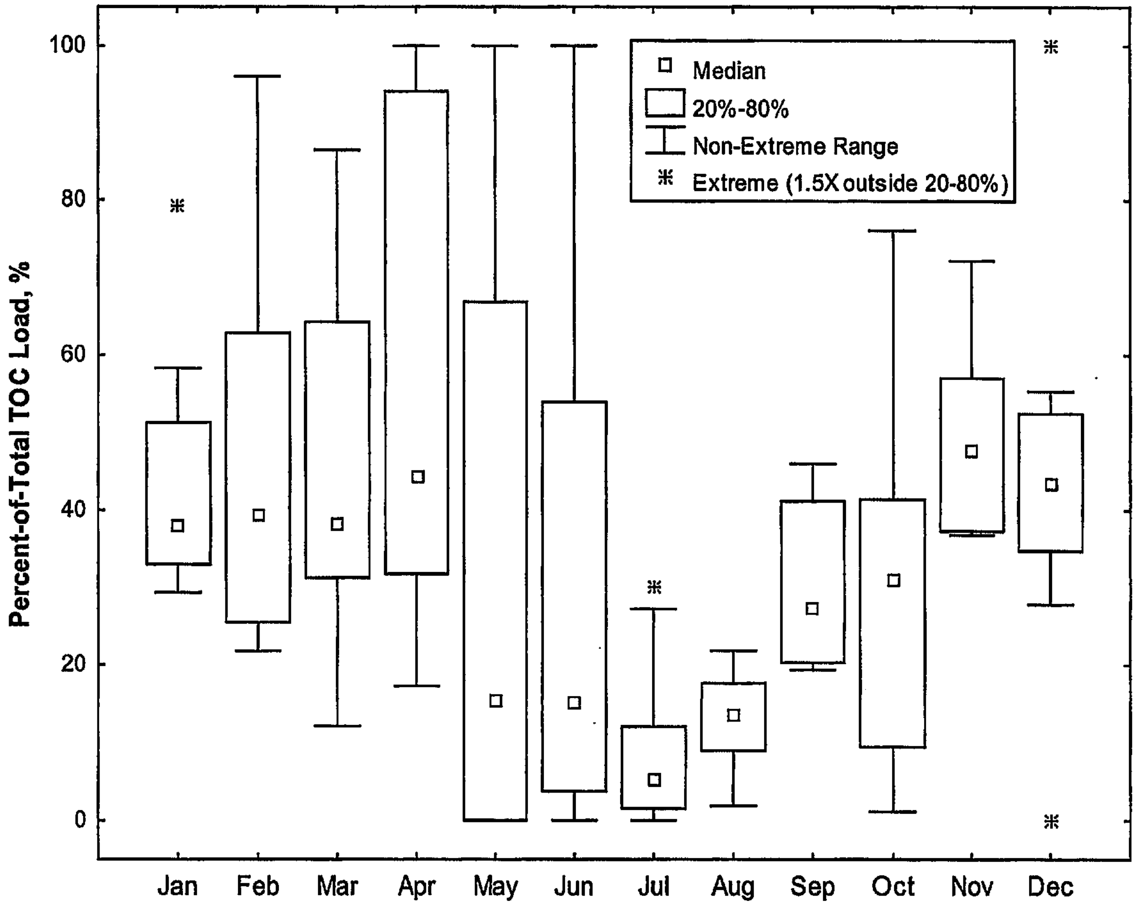

Figure 5-5. Monthly trends in percent-of-total total organic carbon loading to O'Neill Forebay contributed by O'Neill Pumping-Generating Plant, mid 1990 to 2003. Total loads included Check 12 + the Delta-Mendota Canal at O'Neill Pumping-Generating Plant.

Table 5-4. Statistics of monthly of percent-of-total total organic carbon loading (percent) to O'Neill Forebay contributed by O'Neill Pumping-Generating Plant, mid 1990 to 2003. Total loads included Check 12 + the Delta-Mendota Canal at O'Neill Pumping-Generating Plant.

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	43	38	29	79	14	32
Feb	44	39	22	96	22	49
Mar	45	38	12	87	24	53
Apr	50	44	17	100	28	56
May	25	15	0	100	32	127
Jun	28	15	0	100	29	105
Jul	9	5	0	30	10	112
Aug	13	14	2	22	6	44
Sep	30	27	19	46	9	31
Oct	31	31	1	76	19	62
Nov	49	48	37	72	10	21
Dec	44	43	0	100	21	48

1/ Coefficient of Variation

Therefore, pumping at O'Neill Pumping-Generating Plant has, on average, contributed a little less than half the TOC load from south Delta sources (DMC + Check 12) during the 6-month period from November to April. The percent-of-total averages for TOC loading and inflow and were nearly identical (Figure 5-6). This makes sense since monthly TOC concentrations were not determined to be statistically different between the DMC and Banks Pumping Plant (Check 12 loads were calculated with TOC concentration data from Banks Pumping Plant). Therefore, the percent-of-total TOC loading contributions to O'Neill Forebay from the DMC at O'Neill Pumping-Generating Plant were, on average, roughly equal to the percent-of-total inflow contributions.

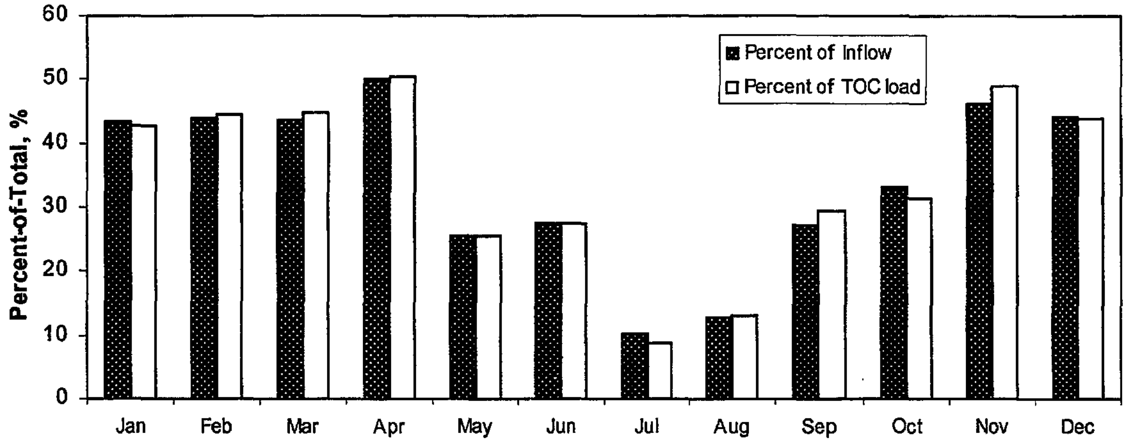

Figure 5-6. Monthly average percent-of-total inflow (DMC + Check 12) and total organic carbon loading to O'Neill Forebay contributed by O'Neill Pumping-Generating Plant, mid 1990 to 2003

San Luis Reservoir Operations

Water is pumped into San Luis Reservoir at Gianelli Pumping-Generating Plant (see aerial location in Figure 2-2). Median monthly pumping at this plant during 1990 to 2003 was highest in January with 305 taf, declined to 6 taf or less between May and July then steadily increased to 241 taf in December (Figure 5-7 and Table 5-5). Monthly pumping was often highly variable with CVs ranging from 48 to 194 percent.

Filling of San Luis Reservoir during fall and winter has significance with respect to downstream THMFP levels. Bromide and TOC at Banks Pumping Plant are highest during fall and winter, respectively. Water pumped into San Luis Reservoir during fall and winter is subsequently released down the California Aqueduct the following spring and summer, along with the accompanying DBP precursors.

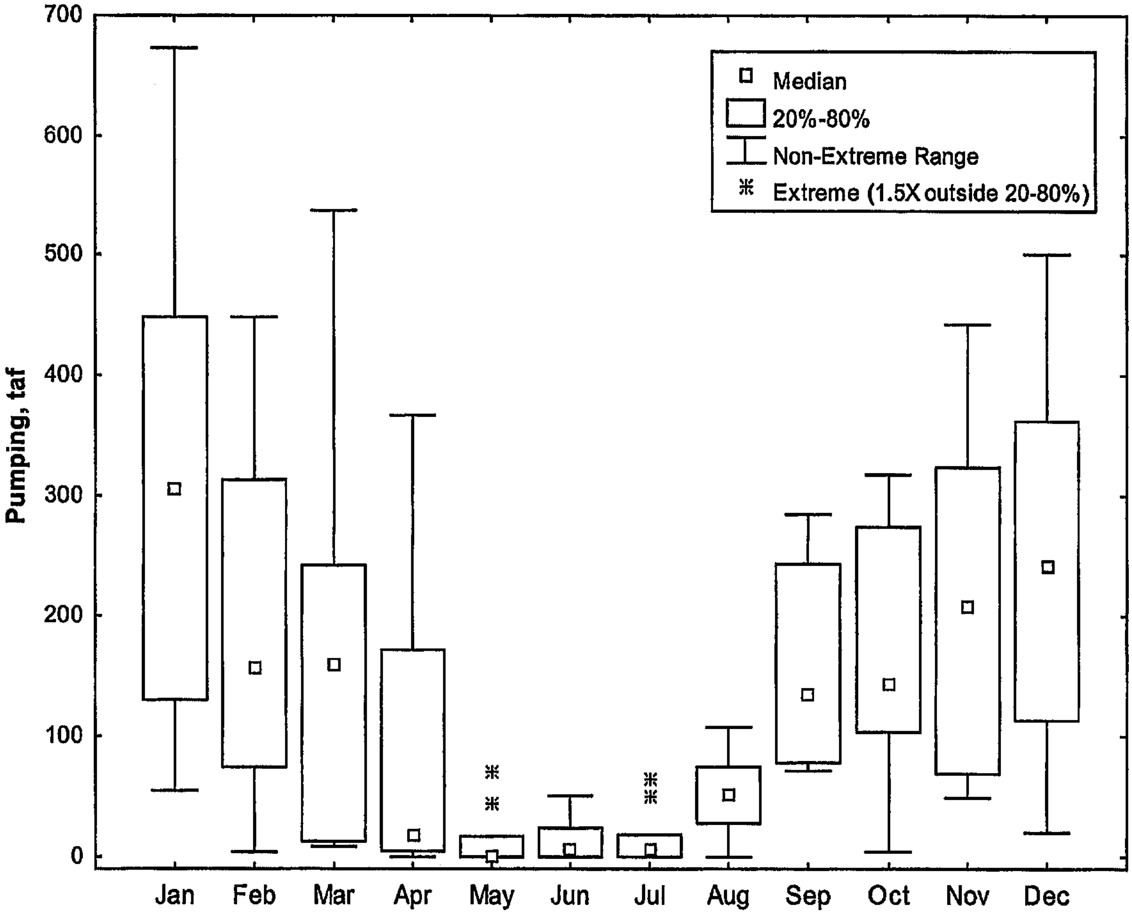

Figure 5-7. Monthly pumping trends at Gianelli Pumping-Generating Plant, 1990 to 2003

Table 5-5. Statistics of monthly pumping (taf) at Gianelli Pumping-Generating Plant, 1990 to 2003

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	311	305	55	673	183	59
Feb	188	156	4	448	128	68
Mar	178	159	9	537	173	97
Apr	71	18	0	367	106	150
May	11	0	0	71	21	194
Jun	12	6	0	51	16	131
Jul	14	6	0	64	19	139
Aug	53	51	0	107	27	51
Sep	164	135	71	285	78	48
Oct	170	143	4	318	98	58
Nov	216	208	49	442	116	54
Dec	247	241	20	501	137	55

1/ Coefficient of Variation

Releases from San Luis Reservoir at Gianelli Pumping-Generating Plant during 1990 to 2003 have generally been highest between April and August. Median releases during these months ranged from 115 to 372 taf with accompanying CVs that were rather elevated (45 to 74 percent) (Figure 5-8 and Table 5-6). Releases are conveyed down the California Aqueduct past O'Neill Forebay Outlet and, to a lesser extent, into the DMC.

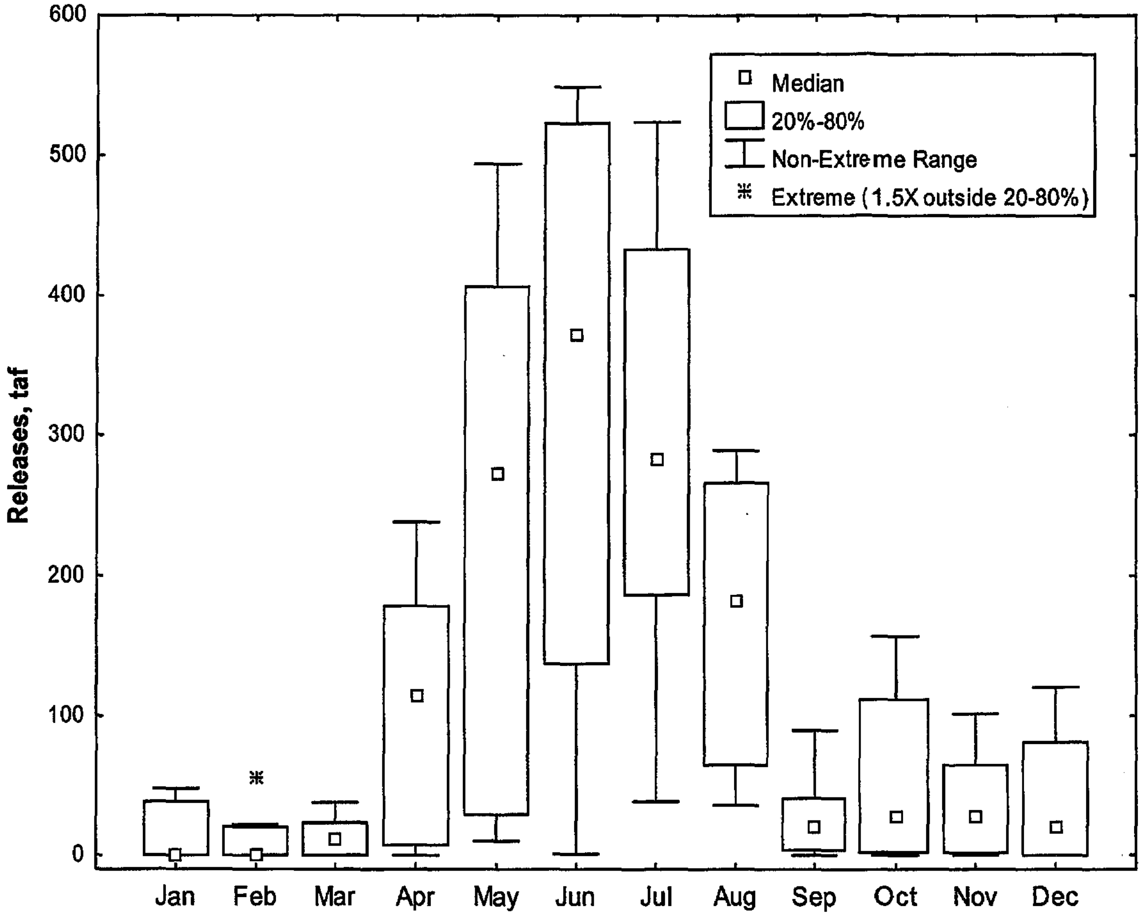

Figure 5-8. Monthly trends in releases from San Luis Reservoir at Gianelli Pumping-Generating Plant, 1990 to 2003

Table 5-6. Statistics of monthly releases (taf) from San Luis Reservoir at Gianelli Pumping-Generating Plant, 1990 to 2003

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	13	0.7	0.0	47	19	147
Feb	8	0.0	0.0	55	16	190
Mar	13	11	0.0	38	13	100
Apr	106	115	0.0	238	79	74
May	266	272	10	494	165	62
Jun	339	372	0.7	548	177	52
Jul	284	282	38	523	129	45
Aug	177	182	36	289	88	50
Sep	25	21	0.0	90	24	96
Oct	51	28	0.0	157	55	109
Nov	34	27	0.0	102	33	96
Dec	36	21	0.0	120	40	111

1/ Coefficient of Variation

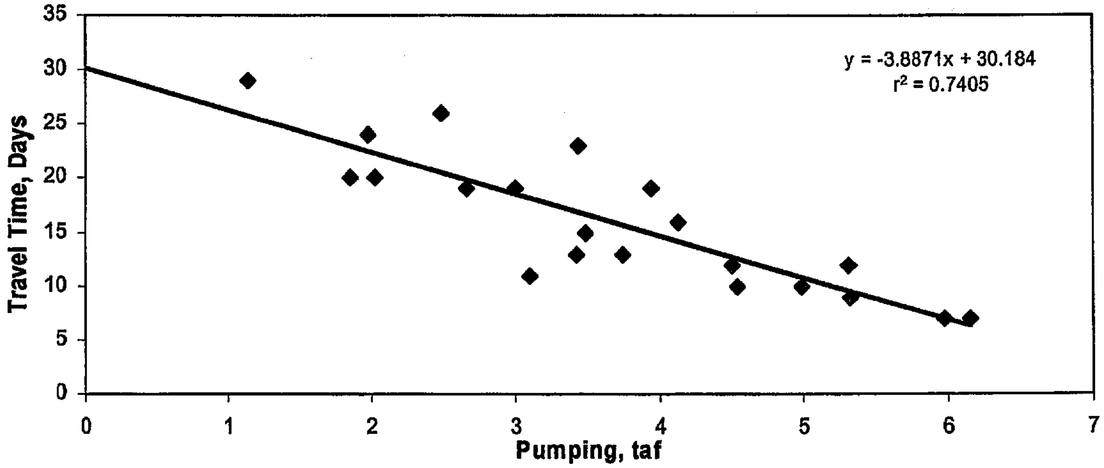

Figure 6-4. Correlation between average daily pumping at Edmonston Pumping Plant and travel time from O'Neill Forebay Outlet to Check 41. Travel times were determined using clearly related conductivity crests or troughs from daily automated station conductivity measurements (1993 to early 2005). Longer and shorter travel times exist outside of this range.

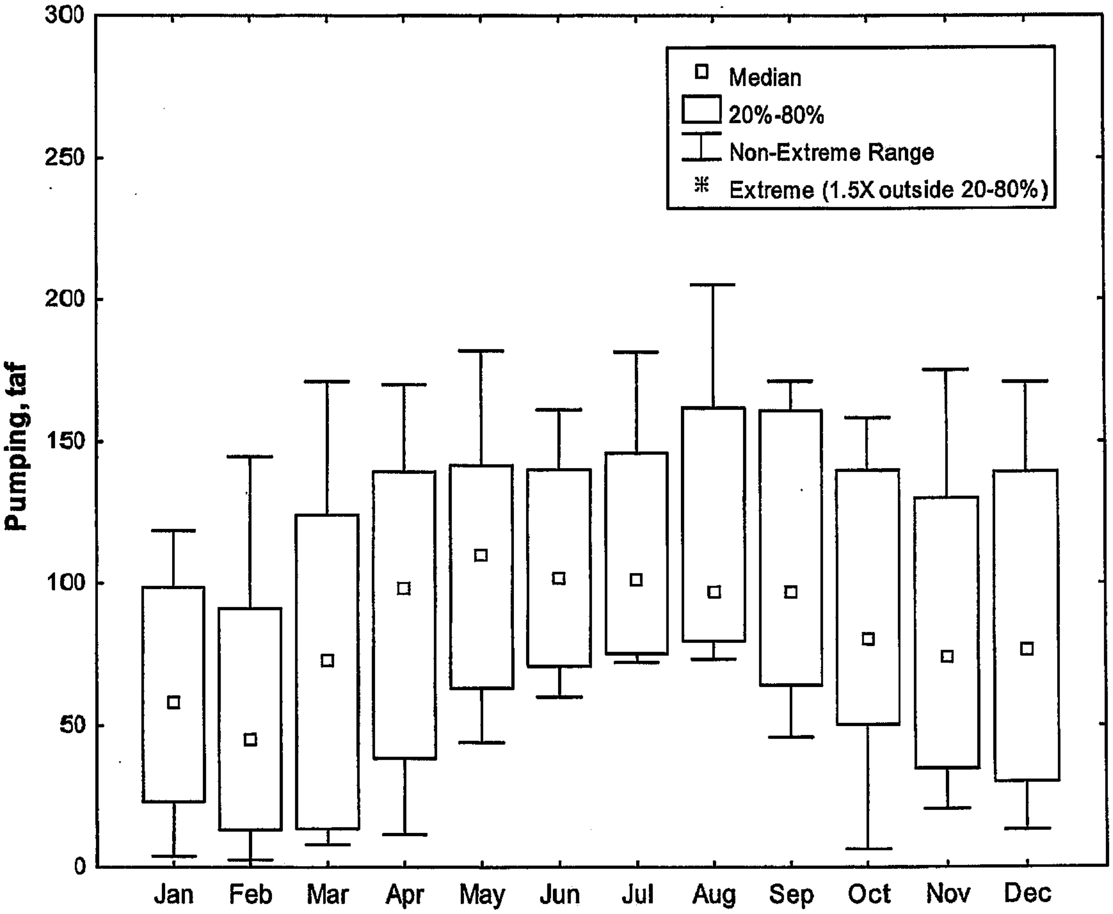

Figure 6-5. Monthly pumping trends at Edmonston Pumping Plant, 1990 to 2003

Table 6-2. Statistics of monthly pumping (taf) at Edmonston Pumping Plant, 1990 to 2003

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	62	58	4	119	36	58
Feb	48	45	3	145	40	85
Mar	77	73	8	171	55	71
Apr	93	98	11	170	51	55
May	106	110	44	182	42	40
Jun	103	102	60	161	33	32
Jul	114	101	72	181	38	34
Aug	115	97	73	205	40	35
Sep	104	97	46	171	42	41
Oct	93	80	6	158	47	50
Nov	82	74	21	175	51	63
Dec	84	76	13	171	52	62

1/ Coefficient of Variation

spikes between O'Neill Forebay Outlet and Check 41. A few examples in the database are presented to describe this.

Monthly pumping was relatively low during November 1995 to January 1996 ranging between 21 and 25 taf (Figure 6-6). Over the same 3-month period, THMFP at O'Neill Forebay Outlet went from 407 µg/L to a season peak of 678 µg/L, while at Check 41, levels remained below 450 µg/L. The following month (February), THMFP at Check 41 reached a peak of 718 µg/L. The seasonal peak observed at O'Neill Forebay Outlet in January reached Check 41 in February. The relatively low pumping rate during this period resulted in an approximate 1-month delay in the winter THMFP spike between stations. An approximate 1-month delay in THMFP trends from one station to the other was also observed at the end of the 16-month period in Figure 6-6.

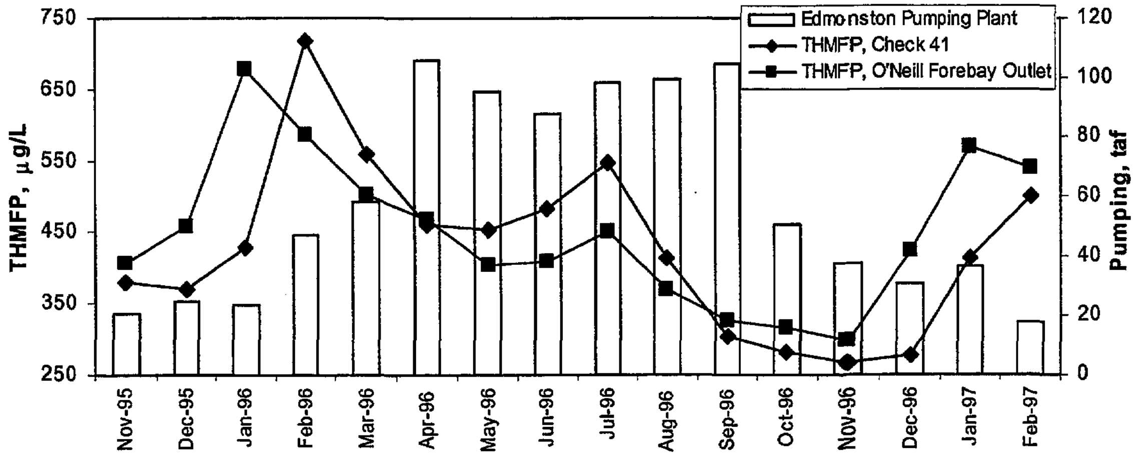

Figure 6-6. Trihalomethane formation potential at O'Neill Forebay Outlet and Check 41 along with monthly pumping at Edmonston Pumping Plant, November 1995 to February 1997

The same graph shows pumping increased to 106 taf in April 1996 and stayed relatively high through September. During this period, THMFP at O'Neill Forebay Outlet and Check 41 trended alike, rising to a peak in July before dropping to a seasonal minimum in the fall. Although levels between stations were not identical, the relative THMFP trends at O'Neill Forebay Outlet were conveyed to Check 41 more quickly due to a higher pumping rate.

The differential in THMFP between stations during the high pumping period in Figure 6-6 was not entirely explainable. Trihalomethane formation potential was higher at Check 41 during the 4-month period from May to August 1996. Although the differential was near the method recovery limits (+-20 percent, EPA 502.2), one-sided trends for multiple months ostensibly portray something other than randomness. One potential explanation involves some type of natural in-channel increase in reactive organic matter between stations due to warmer water temperatures. This was countered with data from 1997 when THMFP was lower at Check 41 than O'Neill Forebay Outlet for the entire summer (Figure 6-7). During this period (July to September 1997), pumping was greater than 90 taf, so water quality conditions at O'Neill Forebay Outlet would have been conveyed to Check 41 within about 20 days. Like the previous example, there were no known coincident inputs between stations. The data record shows numerous instances where a multi-month, one-sided differential in THMFP between stations could not be explained by pumping or other non-Project inputs.

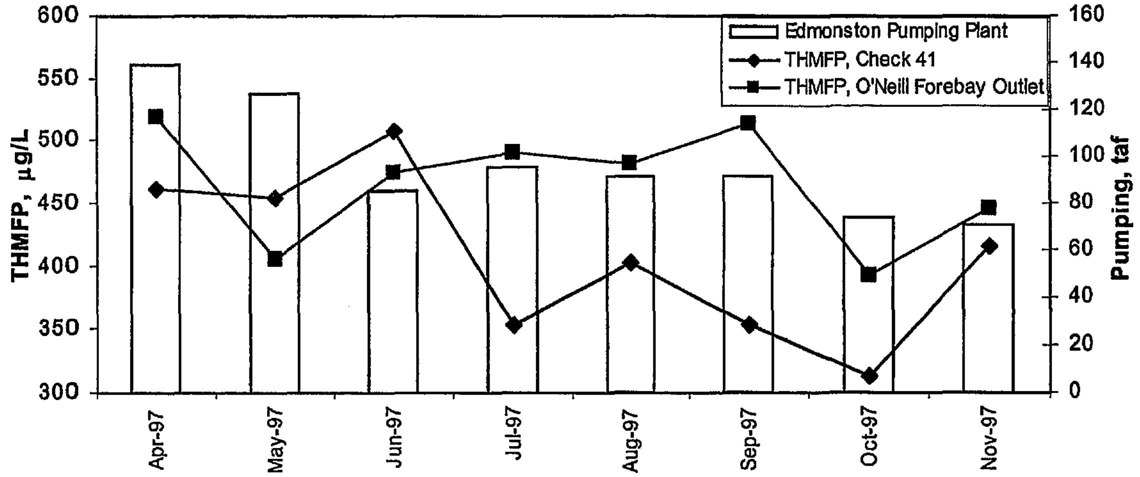

Figure 6-7. Trihalomethane formation potential at O'Neill Forebay Outlet and Check 41 along with monthly pumping at Edmonston Pumping Plant, April to November 1997

Reduced pumping at Edmonston Pumping Plant during winter often resulted in lower THMFP levels at Check 41 compared to upstream. One example is presented for the period around January-February 1999 when pumping virtually ceased.

Pumping steadily declined over the last 5 months of 1998 and reached a period minimum of 3 to 4 taf the following year in January-February (Figure 6-8). Although THMFP at Check 41 during these 2 months remained below 400 µg/L, levels at O'Neill Forebay

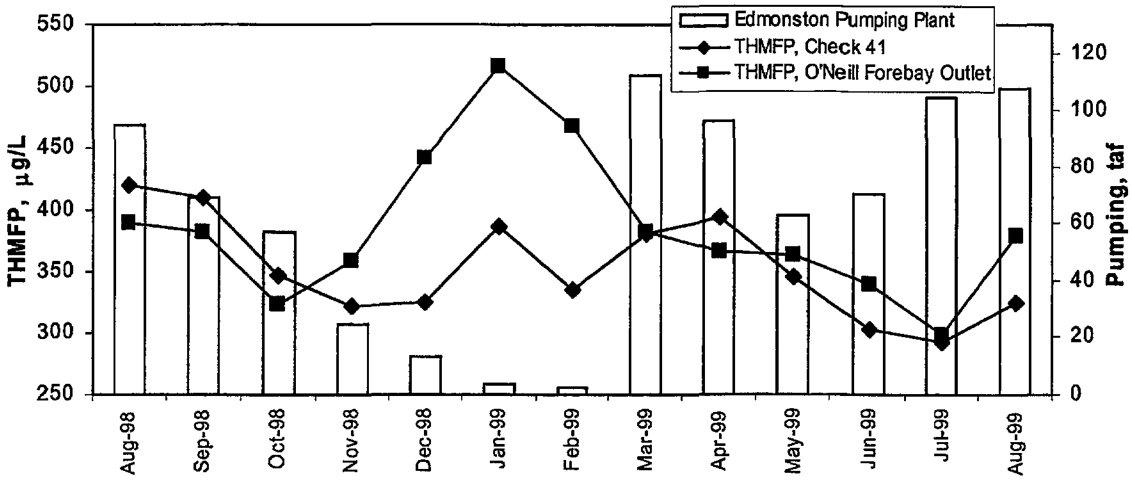

Figure 6-8. Trihalomethane formation potential at O'Neill Forebay Outlet and Check 41 along with monthly pumping at Edmonston Pumping Plant, August 1998 to August 1999

Outlet increased to a season peak of 516 µg/L in January 1999. Due to reduced pumping, the relatively high levels observed at O'Neill Forebay Outlet during December 1998 to February 1999 were not conveyed to Check 41. When pumping increased to 113 taf in March 1999, THMFP at O'Neill Forebay Outlet had declined to 381 µg/L and this level was reflected at Check 41.

Therefore, pumping at Edmonston Pumping Plant is essential to assessing water quality trends at Check 41. In the last example, the concentration data alone would suggest that THMFP had decreased between O'Neill Forebay Outlet and Check 41. The decrease would be interpreted as a benefit to drinking water quality. In reality, water was essentially stagnant at Check 41 during most of January and February 1999.

A delay in THMFP trends between O'Neill Forebay Outlet and Check 41 (or a lower winter THMFP at Check 41) due to reduced pumping at Edmonston Pumping Plant was observed in most years. Decreases in THMFP between stations were compounded by groundwater turn-ins.

Groundwater Turn-ins

Groundwater turn-ins to the California Aqueduct were active during 1990 to 1996 (DWR 1994a, 1995c, and 1997). At the time, turn-ins provided needed water to augment supplies depleted from the 1987-92 drought. Many turn-ins were essentially pipes plumbed to the aqueduct channel from nearby groundwater wellheads. Individual turn-ins were located throughout the aqueduct from Banks Pumping Plant to Devil Canyon Headworks. However, the largest contributors were concentrated in the San Luis Canal with 106 individual turn-in sites along the 101-mile stretch of California Aqueduct that starts at O'Neill Forebay Outlet (DWR 1994a).

Turn-in sampling during 1990 to 1996 focused, in part, on salinity and arsenic – two of the constituents-of-concern in many of the well fields. More recent sampling shows that certain turn-ins consistently exhibit TOC (and DOC) levels of around 1 mg/L (DWR 2002 and 2005). However, this latest data represents only a small subset of the turn-ins that were active during 1990 to 1996. Therefore, not all turn-ins during this > half-decade (1990-96) may have exhibited such low TOC (and presumably THMFP) levels.

There were several examples in the database where these earlier turn-ins were associated with a decline in THMFP between O'Neill Forebay Outlet and Check 41. In many cases, they occurred in association with reduced pumping at Edmonston Pumping Plant, increasing the proportion of turn-in water at Check 41. Conversely, there were also months when turn-ins appeared to increase – or had no influence on – THMFP between stations. Examples of these trends are described for the period between August 1991 and December 1992.

A reduction in THMFP between O'Neill Forebay Outlet and Check 41 was obvious from November 1991 to March 1992 (Figure 6-9). Pumping generally declined over this 5-month period while the turn-in composition reached a maximum of 85 percent in February 1992. Turn-in activity, in conjunction with reduced pumping, resulted in a dramatic decrease in THMFP at Check 41. A similar series of events were evident during the fall-to-winter seasons of 1992-1993 and 1994-1995.

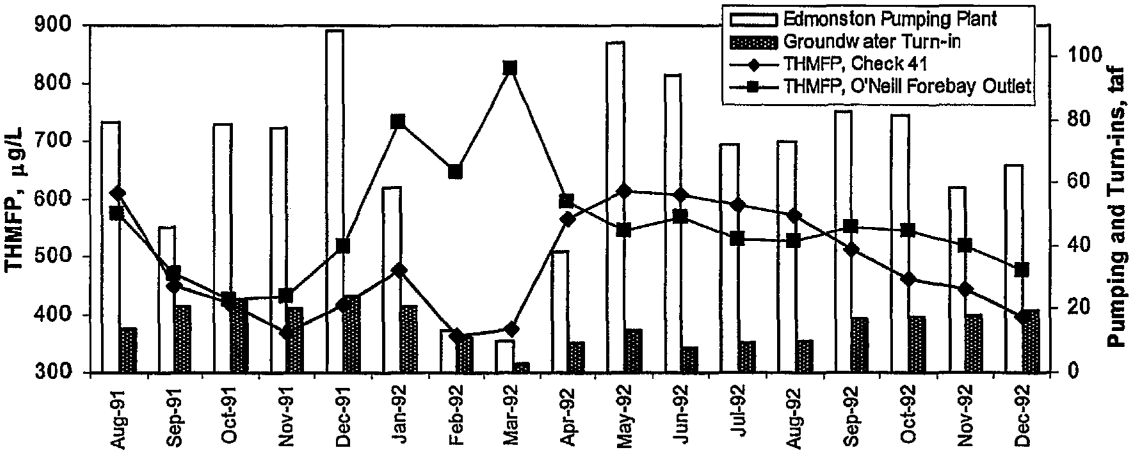

Figure 6-9. Trihalomethane formation potential at O'Neill Forebay Outlet and Check 41, monthly pumping at Edmonston Pumping Plant, and groundwater turn-ins, August 1991 to December 1992

The benefit to drinking water quality in this last example (and others like it) was offset, to a certain extent, by the relatively small amount of water pumped in February and March 1992. However, these trends reinforce the importance of pumping at Edmonston Pumping Plant and non-Project inputs like groundwater turn-ins when assessing water quality trends at Check 41.

Another, less extreme, example of the preceding trend occurred during September to December 1992 (turn-ins composed 20 to 31 percent of the pumping) (Figure 6-9). Downstream reductions at Check 41 as a result of turn-ins during periods of high pumping is consonant with current studies that conclude that turn-ins have consistently provided a benefit to drinking water quality by lowering downstream TOC (and presumably THMFP) (DWR 2002 and 2005).

The inverse of the above examples was observed during May to August 1992. Turn-ins composed 8 to 13 percent of pumping yet THMFP was higher at Check 41 than O'Neill Forebay Outlet. One explanation for the higher levels at Check 41 was a change in turn-in composition during that period. This is possible because some of the participating agencies had tapped numerous wells from large well fields. The terminal composition could be changed by shutting off some wells while turning others on – with the possibility of altering water quality in the final effluent. Another unexpected trend was observed during August to October 1991 when THMFP was nearly identical between stations despite a turn-in composition as high as 45 percent (Figure 6-9).

Although these examples describe trends associated with turn-ins in the 1990s, the likelihood of the same group of turn-ins becoming active is improbable. Newly established criteria are more critical of groundwaters with degraded quality (e.g., with respect to salinity and arsenic) that were active back then. Only groundwater turn-in programs with no substantial net degradation of water quality in the California Aqueduct have been approved in the recent past.

Other Non-Project Inputs

Other non-Project inputs to the California Aqueduct have included floodwaters from the Kern River Intertie (KRI). This structure was built with the flexibility to convey water into, and out of, the California Aqueduct at milepost 241. Floodwaters from this structure (and, to a lesser extent, the Cross Valley Canal (CVC)) were admitted to the California Aqueduct during January-February 1997 and April to July 1998. Floodwaters were conveyed into the California Aqueduct, in part, to reduce flooding of cropland in the Tulare Basin.

Chloroform was usually the only trihalomethane component detected in the KRI and CVC. Chloroform in 10 samples ranged between 390 and 625 µg/L with a mean and median of around 500 µg/L. Therefore, inflow from these two sources may, or may not, provide a benefit to drinking water quality with respect to THMFP depending on upstream levels in the California Aqueduct. A known benefit from these two inputs was a dramatic decrease in salinity and bromide (DWR 2000).

Drain inlets on the San Luis Canal have been another source of non-Project floodwaters to the California Aqueduct. These inlets convey rainfall runoff from the east side of the Diablo Range into the California Aqueduct largely between mileposts 70.89 and 172.26 (San Luis Canal). Characteristics of these floodwaters have been detailed in DWR 1995a and 2001.

Total organic carbon in all drain inlets sampled ranges from 4 to 49 mg/L with medians between 7 and 12 mg/L (no THMFP data exists). Floodwater inflows to the San Luis Canal have been limited to short duration periods when rainfall produces runoff in the ephemeral streams west of the San Luis Canal. Along with TOC, many of the drain inlets exhibit high levels of salt and suspended sediment.

7. Devil Canyon Headworks

Devil Canyon Headworks is located on the San Bernardino Tunnel (milepost 411.34) just downstream from Silverwood Lake (see aerial location in Figure 2-2). This station was originally located at Devil Canyon Afterbay, about 1 mile downstream (in pipe) from the headworks station. Natural inflow to Silverwood Lake has influenced water quality at these stations (DWR 1999 and 2000).

Silverwood Lake and its surrounding watershed were thoroughly reviewed in the latest Sanitary Survey, "Sanitary Survey Update Report 2001" (DWR 2001):

- The watershed is approximately 29 square miles and mainly within the boundary of the San Bernardino National Forest;
- At 3,355 feet elevation, the upstream watershed is generally characterized by desert chaparral (scrub oak and manzanita) and conifer stands that are inhabited by wildlife typically associated with these biomes;
- The two major intermittent streams, Cleghorn and Miller Creeks, can be muddy torrents in winter or clear brooks in summer (DWR 1996b);
- Commercial grazing has not been allowed in the watershed since 1990;
- There is some development in the Cleghorn Creek watershed and a substantial amount around Lake Gregory, a tributary of Silverwood Lake via Miller Creek; and
- Effluent from four wastewater treatment plants servicing recreation and development is piped out of the watershed.

The maximum operating storage capacity of Silverwood Lake is 73.031 taf (DWR 1974b). Residence times range from 24.3 days with an average Project inflow of 3 taf per day to 73 days with an average inflow of 1 taf per day.

Total organic carbon and THMFP at Devil Canyon Headworks were moderately correlated with an r^2 of 0.71 (Figure 7-1). Median monthly THMFP at Devil Canyon

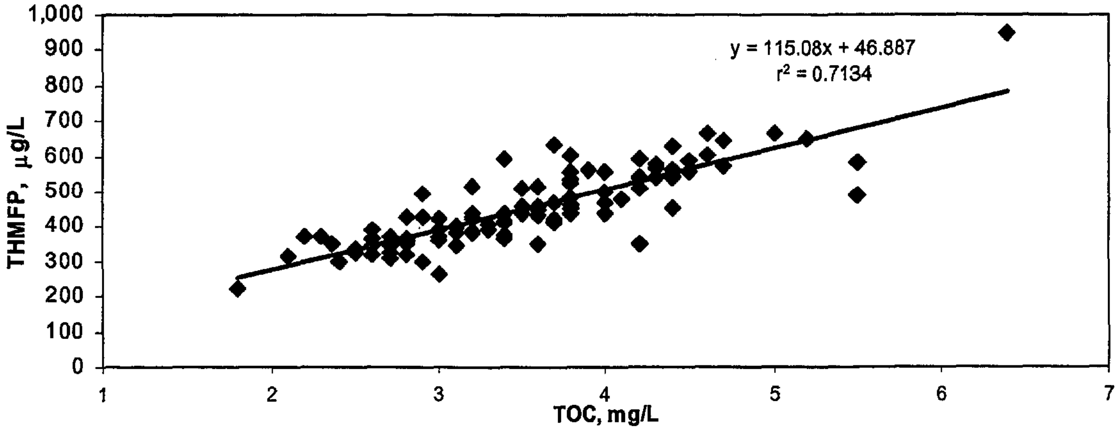

Figure 7-1. Correlation between total organic carbon and trihalomethane formation potential at Devil Canyon Headworks

Headworks was 382 µg/L in January, increased to 548 µg/L in April then declined to 369 µg/L in December (Figure 7-2 and Table 7-1). With the exception of February, variability was relatively low to moderate with CVs ranging between 12 and 25 percent. The highest and lowest THMFP levels were measured in February (949 and 220 µg/L, respectively), contributing to a greater CV of 42 percent.

Monthly average THMFP was 4 to 17.5 percent lower at Devil Canyon Headworks than Check 41 in all but 3 months (Figure 7-3). The difference was greatest during January to April – a period when natural inflows to Silverwood Lake have been highest.

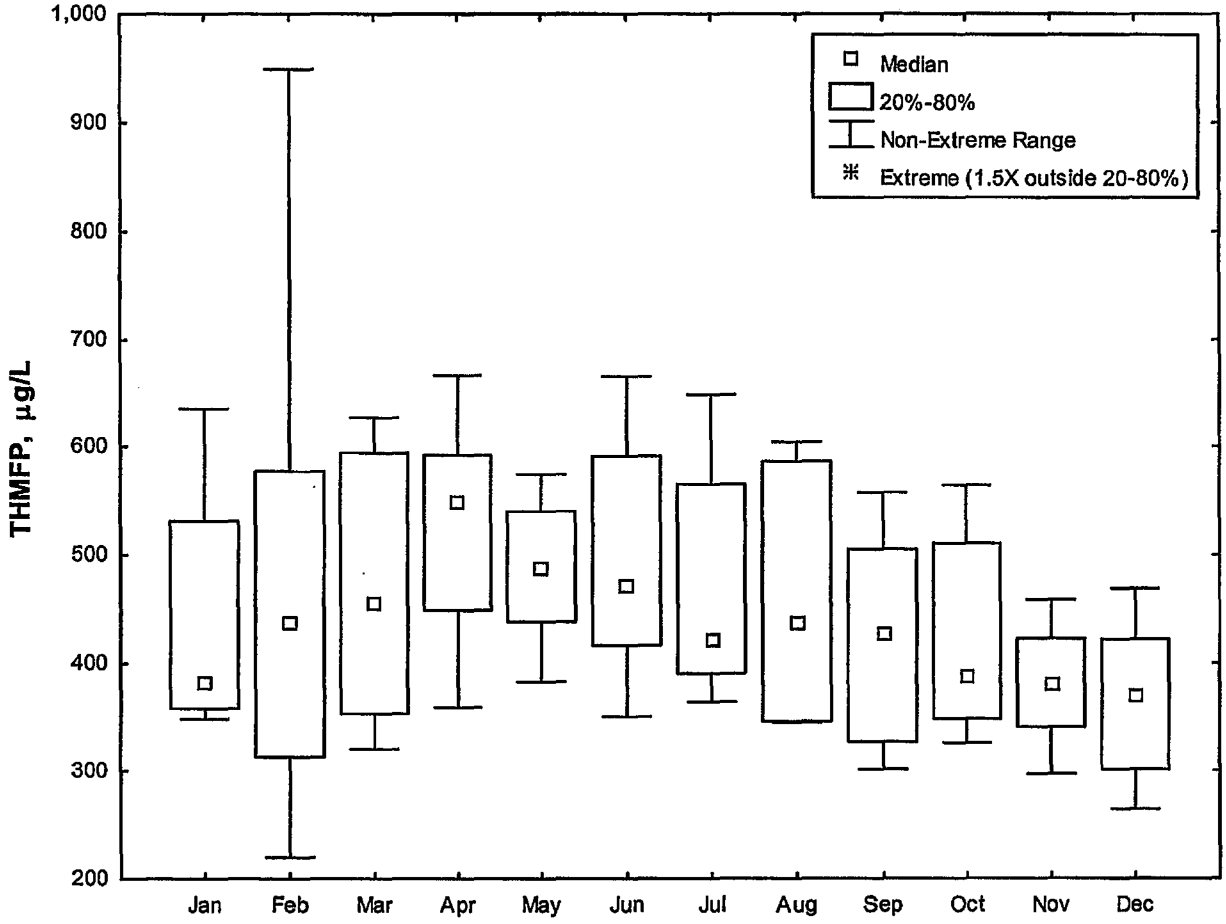

Figure 7-2. Monthly trihalomethane formation potential trends at Devil Canyon Headworks, mid 1990 to January 2000

Table 7-1. Statistics of monthly trihalomethane formation potential (μg/L) at Devil Canyon Headworks, mid 1990 to January 2000

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	429	382	348	635	105	25
Feb	485	438	220	949	205	42
Mar	477	455	320	627	105	22
Apr	529	548	359	666	87	17
May	484	488	383	574	58	12
Jun	493	472	350	665	101	21
Jul	456	422	364	648	91	20
Aug	458	437	345	604	111	24
Sep	423	428	301	557	89	21
Oct	419	387	326	564	82	20
Nov	380	381	297	459	49	13
Dec	364	369	264	469	63	17

1/ Coefficient of Variation

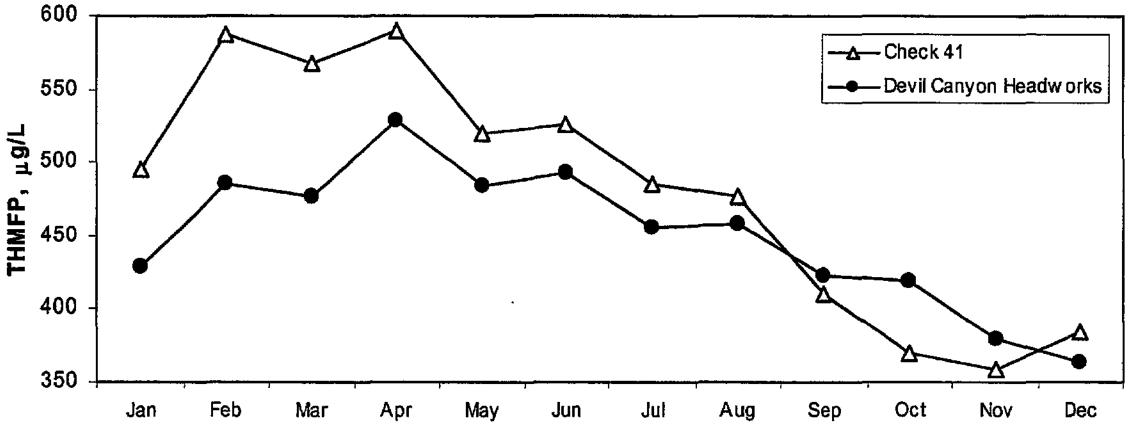

Figure 7-3. Monthly average trihalomethane formation potential at Devil Canyon Headworks and Check 41, mid 1990 to January 2000

Median monthly natural inflow to Silverwood Lake during 1990 to 2003 was 0.215 taf in January, increased to 2.121 in March before decreasing to less than 0.01 taf during July to October (Figure 7-4 and Table 7-2). Variability was high during all months with CVs ranging from 108 to 225 percent. For the month of January, inflow volumes ranged over 3 orders of magnitude from 0.028 to 27.6 taf. The high variability indicates that any influence from these inflows on water quality in Silverwood Lake (and hence Devil Canyon Headworks) will vary dramatically from year-to-year with hydrologic conditions.

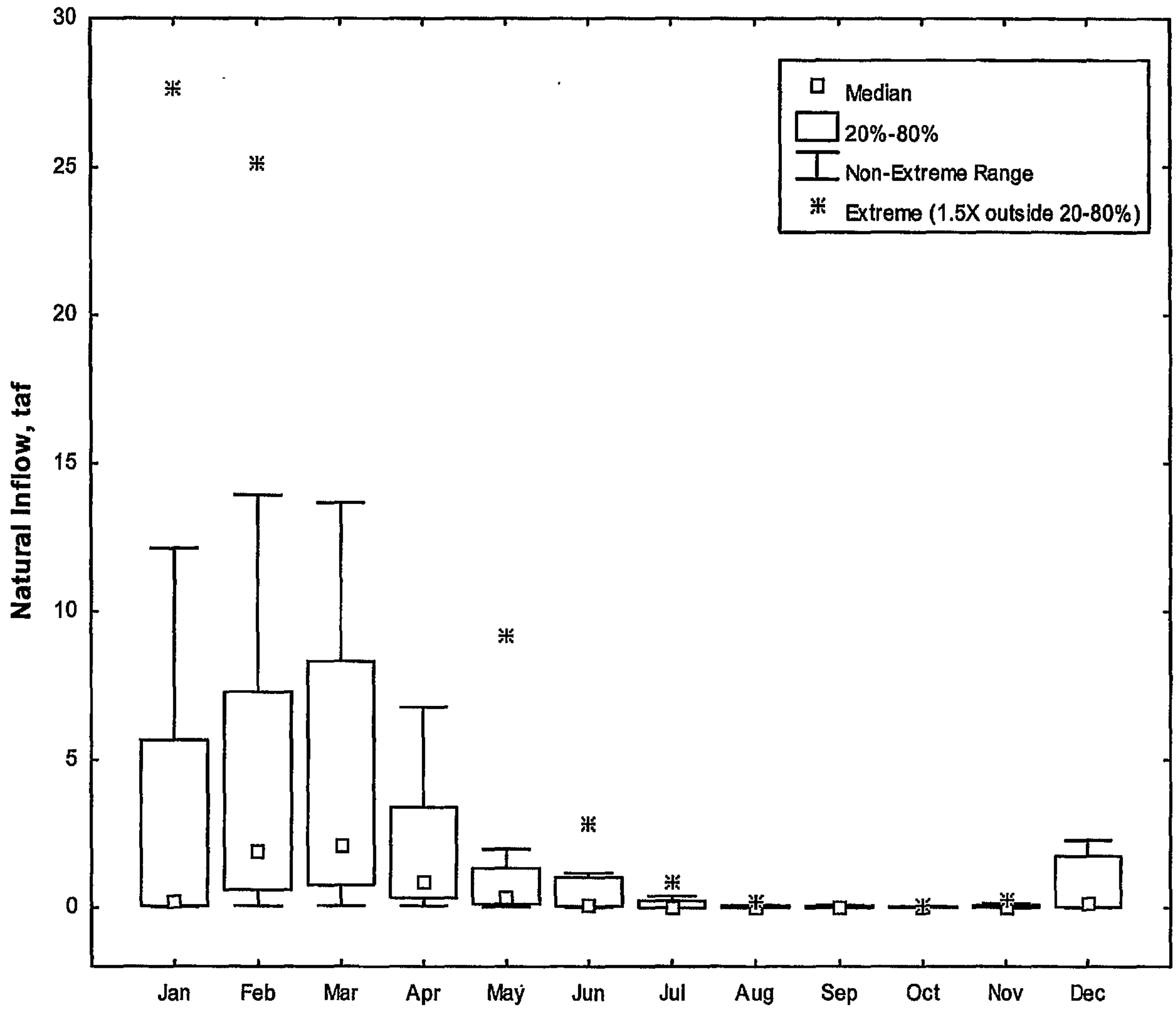

Figure 7-4. Monthly trends in natural inflow to Silverwood Lake, 1990 to 2003

Table 7-2. Statistics of monthly natural inflow (taf) to Silverwood Lake, 1990 to 2003

Month	Average	Median	Minimum	Maximum	Std.Dev.	CV 1/
Jan	3.438	0.215	0.028	27.643	7.743	225
Feb	4.875	1.917	0.057	25.126	6.956	143
Mar	3.884	2.121	0.069	13.693	4.214	108
Apr	1.633	0.867	0.054	6.781	1.832	112
May	1.170	0.319	0.027	9.177	2.370	203
Jun	0.422	0.085	0.000	2.860	0.794	188
Jul	0.113	0.004	0.000	0.839	0.238	211
Aug	0.023	0.000	0.000	0.172	0.050	222
Sep	0.018	0.000	0.000	0.081	0.031	170
Oct	0.015	0.004	0.000	0.074	0.022	148
Nov	0.049	0.020	0.000	0.269	0.076	157
Dec	0.509	0.145	0.000	2.310	0.819	161

1/ Coefficient of Variation

Natural inflows were associated with a decline in THMFP between Check 41 and Devil Canyon Afterbay. Monthly average natural inflow was correlated with the difference in average THMFP between stations with an r^2 of 0.74 (Figure 7-5). The r^2 improved to 0.94 when excluding the negative values (September to November). Therefore, natural inflows to Silverwood Lake, on average, reduced THMFP by 4 to 17.5 percent between stations during nine months of the year – presumably by diluting THMFP in Project inflows.

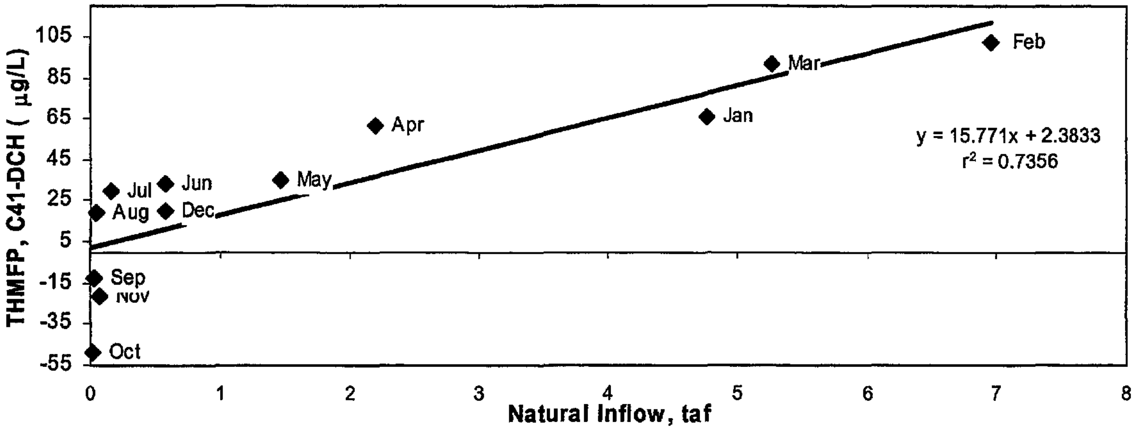

Figure 7-5. Correltation between monthly average natural inflow to Silverwood Lake and the difference in monthly average trihalomethane formation potential between Devil Canyon Headworks and Check 41 (C41 - DCH)

There was one (or possibly two) instance(s) in the database when natural inflow to Silverwood Lake was associated with an increase in THMFP between stations. Trihalomethane formation potential was higher at Devil Canyon Headworks than Check 41 (989 and 718 µg/L, respectively) in February 1996 when natural inflow was relatively high (5 taf). Therefore, on certain occasions, runoff to Silverwood Lake (possibly from a first flush event) may increase THMFP in the lake and at Devil Canyon Headworks.

Lastly, THMFP was, on average, 3 to 13 percent higher at Devil Canyon Headworks than Check 41 during September to November (see negative values in Figure 7-5). The California Aqueduct conveys water for 102.5 miles between Check 41 and the Mohave Siphon Inlet at Silverwood Lake. Potential inputs along this stretch are minor and include groundwater dewatering sumps and a relatively small turn-in discharge that has been infrequently active. The Devil Canyon Headworks station is another approximate 8 miles across the lake from the Mohave Siphon Inlet.

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Appendix A

Sacramento-San Joaquin Delta Standards

Table A-1. Draft D-1641 standards for the Sacramento-San Joaquin Delta (http://wwwoco.water.ca.gov/cmplmon/bay_deltastandards.htm, 8/05)

Bay-Delta Standards

Contained in D-1641

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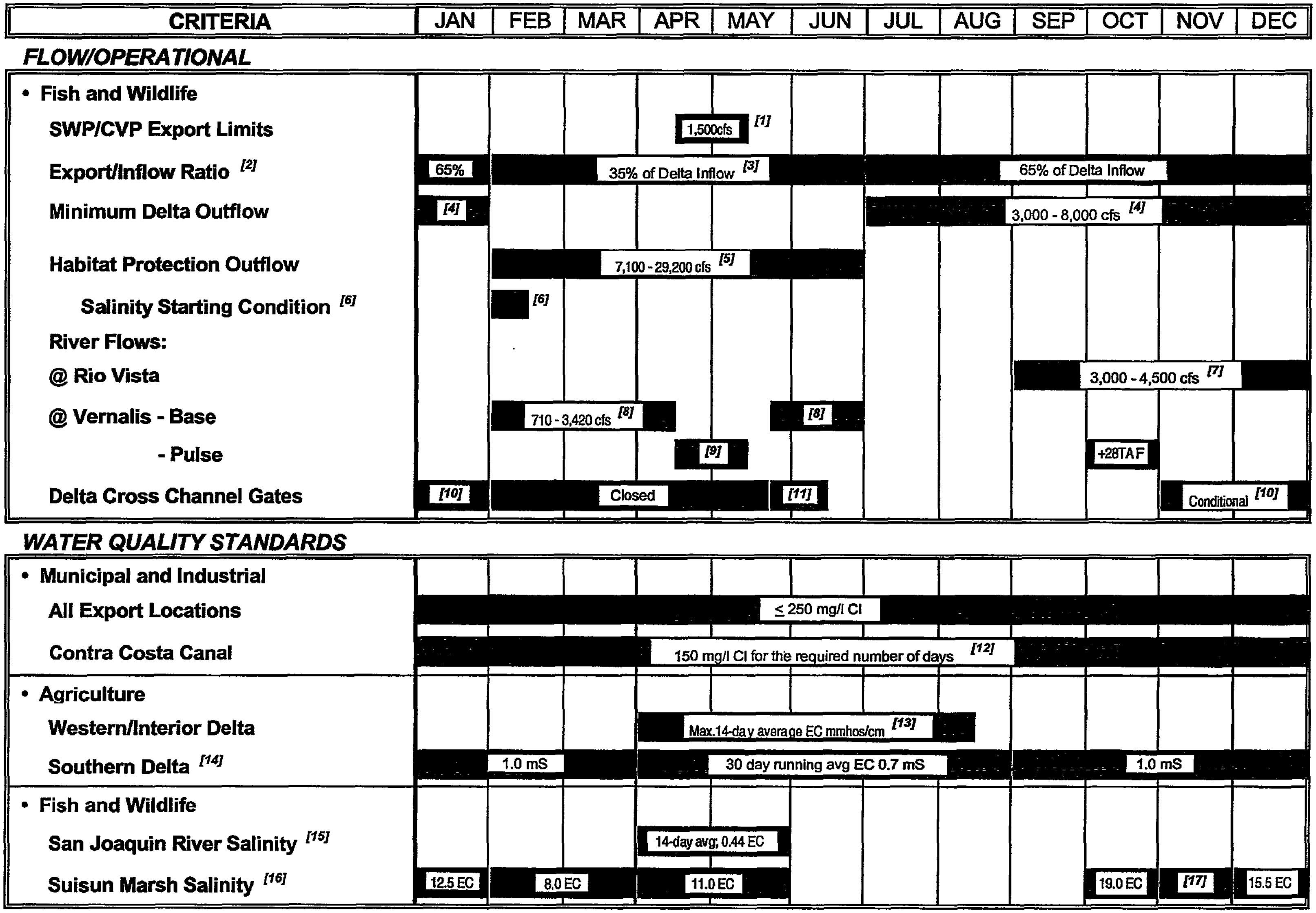

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Footnotes

[1] Maximum 3-day running average of combined export rate (cfs) which includes Tracy Pumping Plant and Clifton Court Forebay Inflow less Byron-Bethany pumping.

Year Type	All
Apr15 - May15*	The greater of 1,500 or 100% of 3-day avg. Vernalis flow

* This time period may need to be adjusted to coincide with fish migration. Maximum export rate may be varied by CalFed Op's group.

[2] The maximum percentage of average Delta inflow (use 3-day average for balanced conditions with storage withdrawal, otherwise use 14-day average) diverted at Clifton Court Forebay (excluding Byron-Bethany pumping) and Tracy Pumping Plant using a 3-day average. (These percentages may be adjusted upward or downward depending on biological conditions, providing there is no net water cost.)

[3] The maximum percent Delta Inflow diverted for Feb may vary depending on the January 8RI.

Jan 8RI	Feb exp. limit
≤ 1.0 MAF	45%
between 1.0 & 1.6 MAF	35%-45%
> 1.5 MAF	35%

DRAFT

[4] Minimum monthly average Delta outflow (cfs). If monthly standard ≤ 5,000 cfs, then the 7-day average must be within 1,000 cfs of standard; if monthly standard > 5,000 cfs, then the 7-day average must be ≥ 80% of standard.

Year Type	All	W	AN	BN	D	C
Jan	4,500*					
Jul		8,000	8,000	6,500	5,000	4,000
Aug		4,000	4,000	4,000	3,500	3,000
Sep	3,000					
Oct		4,000	4,000	4,000	4,000	3,000
Nov-Dec		4,500	4,500	4,500	4,500	3,500

* Increase to 6,000 if the Dec 8RI is greater than 800 TAF

[5] Minimum 3-day running average of daily Delta outflow of 7,100 cfs OR: either the daily average or 14-day running average EC at Collinsville is less than 2.64 mmhos/cm (This standard for March may be relaxed if the Feb 8RI is less than 500 TAF. The standard does not apply in May and June if the May estimate of the SRI IS < 8.1 MAF at the 90% exceedence level in which case a minimum 14-day running average flow of 4,000 cfs is required.) For additional Delta outflow objectives, see **TABLE A**

[6] February starting salinity: If Jan 8RI > 900 TAF, then the daily or 14-day running average EC @ Collinsville must be ≤ 2.64 mmhos/cm for at least one day between Feb 1-14. If Jan 8RI is between 650 TAF and 900 TAF, then the CalFed Op's group will detemine if this requirement must be met.

[7] Rio Vista minimum monthly average flow rate in cfs (the 7-day running average shall not be less than 1,000 below the monthly objective).

Year Type	All	W	AN	BN	D	C
Sep	3,000					
Oct		4,000	4,000	4,000	4,000	3,000
Nov-Dec		4,500	4,500	4,500	4,500	3,500

[8] BASE Vernalis minimum monthly average flow rate in cfs (the 7-day running average shall not be less than 20% below the objective). Take the higher objective if X2 is required to be at or west of Chipps Island.

Year Type	All	W	AN	BN	D	C
Feb-Apr14 and May16-Jun	·	2,130 or 3,420	2,130 or 3,420	1,420 or 2,280	1,420 or 2,280	710 or 1,140

[9] PULSE Vernalis minimum monthly average flow rate in cfs. Take the higher objective if X2 is required to be at or west of Chipps Island.

Year Type	All	W	AN	BN	D	C
Apr15 - May15		7,330 or 8,620	5,730 or 7,020	4,620 or 5,480	4,020 or 4,880	3,110 or 3,540
Oct	1,000*					

* Up to an additional 28 TAF pulse/attraction flow to bring flows up to a monthly average of 2,000 cfs except for a critical year following a critical year. Time period based on real-time monitoring and determined by CalFed Op's group.

[10] For the Nov-Jan period, Delta Cross Channel gates may be closed for up to a total of 45 days.

[11] For the May 21-June 15 period, close Delta Cross Channel gates for a total of 14 days per CALFED Op's group. During the period the Delta cross channel gates may close 4 consecutive days each week, excluding weekends.

[12] Minimum # of days that the mean daily chlorides ≤ 150 mg/l must be provided in intervals of not less than 2 weeks duration. Standard applies at Contra Costa Canal Intake or Antioch Water Works Intake.

Year Type	W	AN	BN	D	C
# Days	240	190	175	165	155

[13] The maximum 14-day running average of mean daily EC (mmhos/cm) depends on water year type

	WESTERN DELTA				INTERIOR DELTA			
	Sac River @ Emmaton		SJR @ Jersey Point		Mokelumne R @ Terminous		SJR @ San Andreas	
Year Type	0.45 EC from April 1 to date shown	EC value from date shown to Aug15 *	0.45 EC from April 1 to date shown	EC value from date shown to Aug15 *	0.45 EC from April 1 to date shown	EC value from date shown to Aug15 *	0.45 EC from April 1 to date shown	EC value from date shown to Aug15 *
W	Aug 15		Aug 15		Aug 15		Aug 15	
AN	Jul 1	0.63	Aug 15		Aug 15		Aug 15	
BN	Jun 20	1.14	Jun 20	0.74	Aug 15		Aug 15	
D	Jun 15	1.67	Jun 15	1.35	Aug 15		Jun 25	0.58
C		2.78		2.20		0.54		0.87

* When no date is shown, EC limit continues from April 1

[14] As per D-1641, for San Joaquin River at Vernalis: however, the April through August maximum 30- day running average EC for San Joaquin River at Brandt Bridge, Old River near Middle River, and Old River at Tracy Road Bridge shall be 1.0 EC until April 1, 2005 when the value will be 0.7 EC

[15] Compliance will be determined between Jersey Point & Prisoners Point.
Does not apply in critical years or in May when the May 90% forecast of SRI ≤ 8.1 MAF.

[16] During deficiency period, the maximum monthly average mhtEC at Western Suisun Marsh stations as per SMPA is:

Month	mhtEC
Oct	19.0
Nov	16.5
Dec-Mar	15.6
Apr	14.0
May	12.5

[17] In November, maximum monthly average mhtEC = 16.5 for Western Marsh stations and maximum monthly average mhtEC = 15.5 for Eastern Marsh stations in all periods types.

TABLE A

Number of Days When Max. Daily Average Electrical Conductivity of 2.64 mmhos/cm Must Be Maintained. (This can also be met with a maximum 14-day running average EC of 2.64 mmhos/cm, or 3-day running average Delta outflows of 11,400 cfs and 29,200 cfs, respectively.) Port Chicago Standard is triggered only when the 14-day average EC for the last day of the previous month is 2.64 mmhos/cm or less. PMI is previous month's 8RI. If salinity/flow objectives are met for a greater number of days than required for any month, the excess days shall be applied towards the following month's requirement. The number of day's for values of the PMI between those specified below shall be determined by linear interpolation.

PMI	Chipps Island (Chipps Island Station D10)				
(TAF)	FEB	MAR	APR	MAY	JUN
≤ 500	0	0	0	0	0
750	0	0	0	0	0
1000	28*	12	2	0	0
1250	28	31	6	0	0
1500	28	31	13	0	0
1750	28	31	20	0	0
2000	28	31	25	1	0
2250	28	31	27	3	0
2500	28	31	29	11	1
2750	28	31	29	20	2
3000	28	31	30	27	4
3250	28	31	30	29	8
3500	28	31	30	30	13
3750	28	31	30	31	18
4000	28	31	30	31	23
4250	28	31	30	31	25
4500	28	31	30	31	27
4750	28	31	30	31	28
5000	28	31	30	31	29
5250	28	31	30	31	29
≥ 5500	28	31	30	31	30

*When 800 TAF < PMI < 1000 TAF, the number of days is detemined by linear interpolation between 0 and 28 days.

PMI	Port Chicago (continuous recorder at Port Chicago)				
(TAF)	FEB	MAR	APR	MAY	JUN
0	0	0	0	0	0
250	1	0	0	0	0
500	4	1	0	0	0
750	8	2	0	0	0
1000	12	4	0	0	0
1250	15	6	1	0	0
1500	18	9	1	0	0
1750	20	12	2	0	0
2000	21	15	4	0	0
2250	22	17	5	1	0
2500	23	19	8	1	0
2750	24	21	10	2	0
3000	25	23	12	4	0
3250	25	24	14	6	0
3500	25	25	16	9	0
3750	26	26	18	12	0
4000	26	27	20	16	0
4250	26	27	21	18	1
4500	26	28	23	21	2
4750	27	28	24	23	3
5000	27	28	25	25	4
5250	27	29	25	26	6
5500	27	29	26	28	9
5750	27	29	27	28	13
6000	27	29	27	29	16
6250	27	30	27	29	19
6500	27	30	28	30	22
6750	27	30	28	30	24
7000	27	30	28	30	26
7250	27	30	28	30	27
7500	27	30	29	30	28
7750	27	30	29	31	28
8000	27	30	29	31	29
8250	28	30	29	31	29
8500	28	30	29	31	29
8750	28	30	29	31	30
9000	28	30	29	31	30
9250	28	30	29	31	30
9500	28	31	29	31	30
9750	28	31	29	31	30
10000	28	31	30	31	30
> 10000	28	31	30	31	30

Appendix B

Concentration Characteristics in the California Aqueduct

Total Organic Carbon

Organic carbon samples from the California Aqueduct were collected by the Delta, San Luis, San Joaquin, and Southern Field Divisions and analyzed at DWR's Bryte Laboratory using the "wet oxidation" method (EPA 415.1). Water quality monitoring strategies and methods in the California Aqueduct are documented in DWR 2004b.

Total versus Dissolved

Total organic carbon and DOC in the California Aqueduct were well correlated with an r^2 of 0.93 (Figure B-1). Unlike the extensive SWP database for TOC that extends back to 1990, sampling for DOC in the California Aqueduct began in 2000. The relationship was approximately one-to-one with a handful of TOC-DOC pairs largely responsible for the relative correlation degradation (data points farthest away from the regression line): the r^2 increased to 0.97 without them.

Differences between DOC and TOC appeared to be associated with turbidity. Concentrations were furthest apart when turbidity was highest (Figure B-2). Total organic carbon averaged 0.34 mg/L higher than the corresponding DOC concentration at turbidities over 15 NTU. This makes sense since water with higher turbidity-influencing suspended solids may also contain more filterable organic carbon. Therefore, TOC in the California Aqueduct is most likely to be greatest relative to DOC when turbidity is highest.

In samples exhibiting turbidities of 15 NTU or less, TOC averaged 0.09 mg/L higher than DOC (95% confidence interval = +0.07 to +0.11 mg/L). This last group of samples (turbidity <= 15 NTU) made up 80 percent of the total, and hence, TOC in most samples

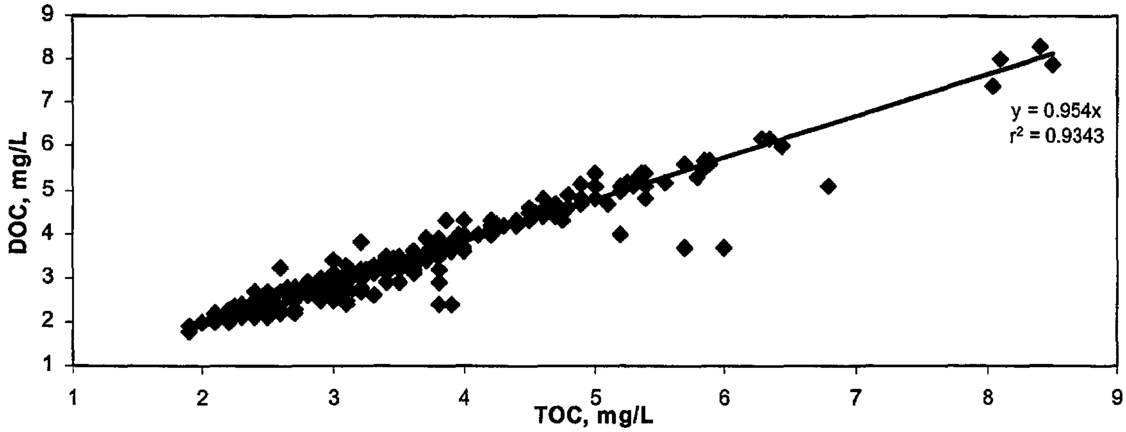

Figure B-1. Correlation between total organic carbon and dissolved organic carbon in the California Aqueduct

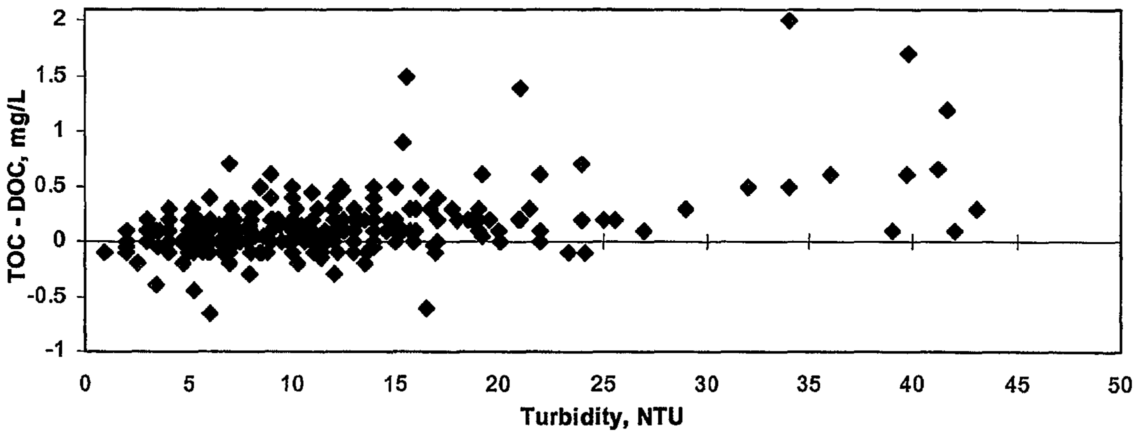

Figure B-2. Relationship between turbidity and the remainder of dissolved organic carbon from total organic carbon in the California Aqueduct

exhibited a concentration that averaged around one-tenth of 1 mg/L higher than the corresponding DOC value, a magnitude within the precision limits of California Aqueduct samples (see Appendix C).

Although turbidities are expected to be highest in winter due to rainfall runoff, elevated turbidities have been recorded in the California Aqueduct during many non-winter months (Figure B-3). These elevated levels can be explained, in part, by aqueduct conveyance operations.

Unlike a river, factors affecting turbidity in the California Aqueduct channel are not limited to natural events such as rainfall runoff. When flow increases, the change in velocity re-suspends any sediment settled-out on the channel invert (bottom) (DWR 1999). Flow can change hourly due to scheduling for water demand that is based, in part, on electricity. Pumping in the California Aqueduct is generally conducted nocturnally for off-peak energy savings (pumping also increases on weekends for the same reason). Conversely, releases from storage facilities such as San Luis Reservoir are scheduled diurnally when energy needs are greatest. At any given time, water may be flowing in some sections of the California Aqueduct and stagnant in others. Flow can range from minimum to maximum all within a 24-hour period. Therefore, flow-induced turbidity increases would also exhibit the same variability.

The link between flow and turbidity in the California Aqueduct was reflected in the rise in turbidity during summer. Median monthly turbidity increased from April to July, then declined into fall (Figure B-3). This rise and fall of median turbidity around July corresponds with the same trend in water conveyance down the California Aqueduct (e.g., see Figure 3-3, DWR 2004b). Turbidity in the California Aqueduct can also be influenced by non-Project inputs like groundwater turn-ins, floodwater inflows to the San Luis Canal, and floodwater inflows from the Kern River Intertie and Cross Valley Canal.

Another factor affecting turbidity in the California Aqueduct – in particular at Banks Pumping Plant – is wind. On windy days, bed sediments can be re-suspended in Clifton

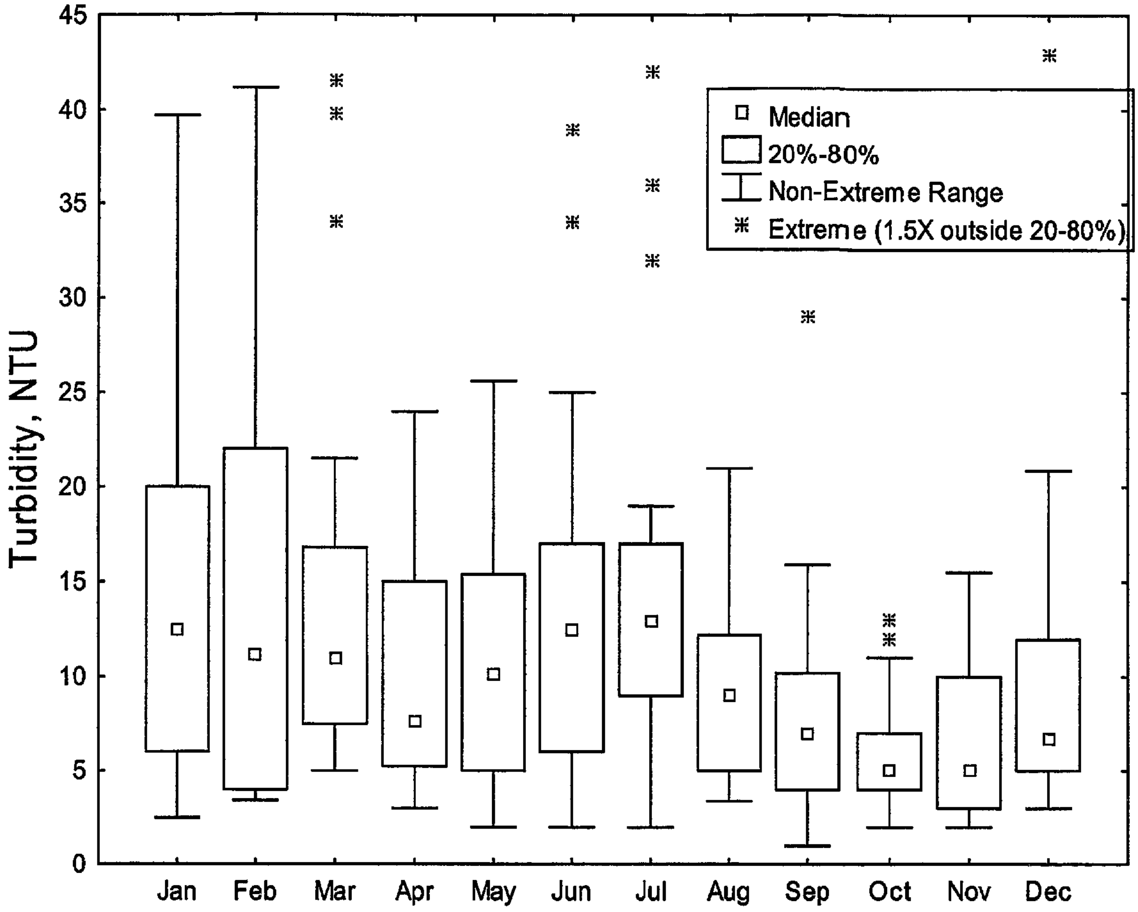

Figure B-3. Monthly turbidity trends in the California Aqueduct using data from the previous figure

Court Forebay, increasing turbidity at Banks Pumping Plant (Gage, pers. comm.). As with flow-induced turbidity increases, wind-induced turbidity increases in Clifton Court Forebay can occur any time of the year as exemplified by the wind farms just east of the forebay.

Total organic carbon was sometimes lower than the corresponding DOC measurement (see previous Figure B-2). These differences can be explained, in part, by the variability inherent in the analytical method and other possible field or lab effects related to filtration, bottles, preservatives, etc. This also applies to instances where TOC was higher than DOC at a magnitude that was within the precision limits of replicate samples.

Combustion versus Wet Oxidation

Analysis for TOC in the California Aqueduct by the combustion method began in 2001. Correlation of TOC (wet oxidation or "wo") with TOC (combustion or "cmb") was neither strong nor one-to-one (Figure B-4). The difference between these two measurements was generally greatest during the months of January, March, and April (Figure B-5).

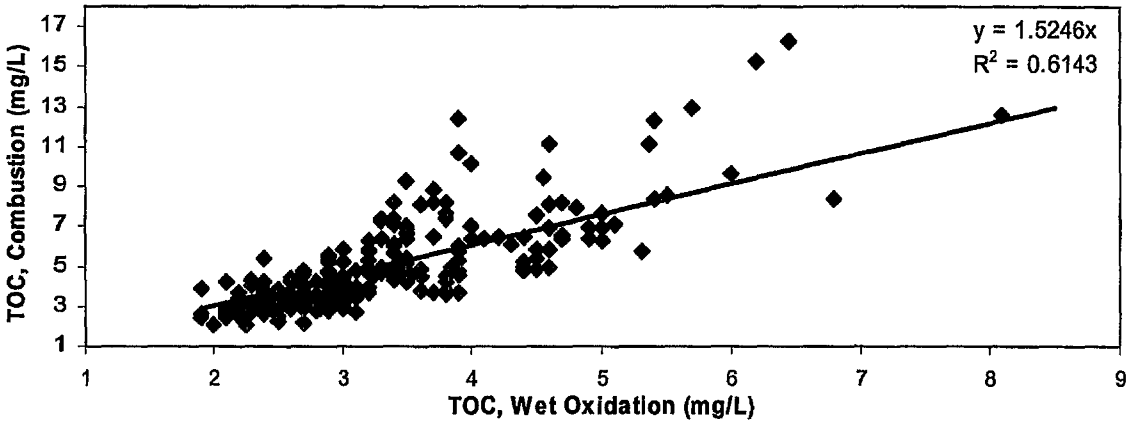

Figure B-4. Correlation between total organic carbon (wet oxidation) and total organic carbon (combustion) in the California Aqueduct (note the different axes scales)

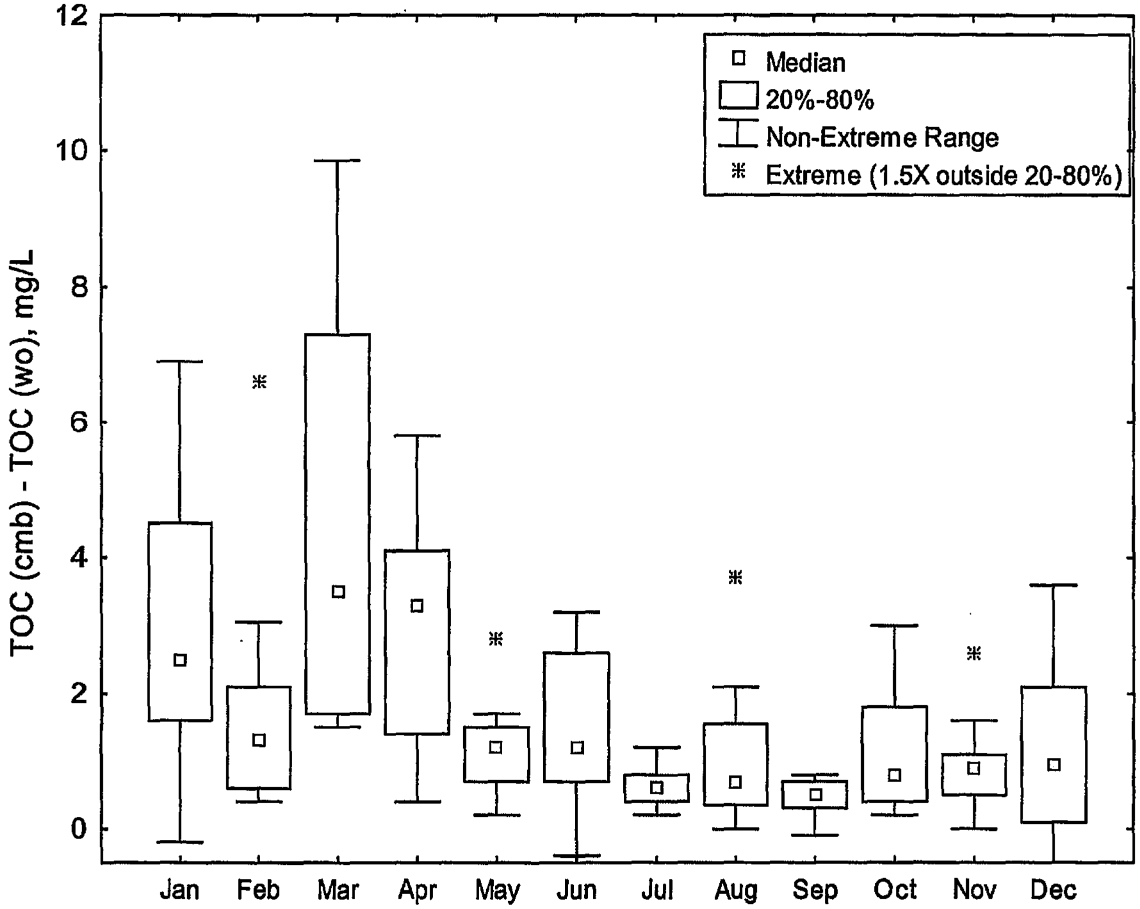

Figure B-5. Monthly trends in the remainder of total organic carbon (wet oxidation) from total organic carbon (combustion) in the California Aqueduct

Because of the relatively poor correlation between TOC (cmb) and TOC (wo), results from the combustion method are not strongly comparable to historic TOC in the California Aqueduct analyzed by wet oxidation. Based on this and the relatively good correlation between TOC (wo) and THMFP at many locations in the California Aqueduct, analysis for TOC by the combustion method would not appear to be a strong surrogate for the potential to form trihalomethanes in the California Aqueduct.

Trihalomethane Formation Potential

Trihalomethane formation potential was routinely analyzed in the California Aqueduct from mid 1990 to January 2000. DWR's Bryte Laboratory used a modified version of method EPA 510.1. Samples were dosed with around 120 mg/L chlorine and incubated for 7 days (the unmodified method requires, in part, dosing based on chlorine demand and an endpoint chlorine residual of 2 to 5 mg/L). The samples were then analyzed for bromoform, dibromochloromethane, bromodichloromethane, and chloroform by EPA method 502.2. The sum of these trihalomethanes is THMFP. This method was developed by Bryte Lab in conjunction with Clayton Environmental Consultants (DWR (undated) and Clayton Environmental Consultants 1993).

A small number of samples from Banks Pumping Plant were analyzed using both methods (modified and unmodified method EPA 510.1). The chlorine dose of the unmodified EPA 510.1 method was determined using an equation developed and recommended by Metropolitan Water District of Southern California (chlorine dose = 3 x DOC (mg/L) + 7.6 x ammonia-nitrogen (mg/L), Krasner et al., 1994). The results of this method are called "reactivity based".

Data from the two methods exhibit a modest correlation with an r^2 of 0.7 (Figure B-6). The r^2 improved to 0.8 with the removal of two results (one data pair) that were unusually equal (~350 µg/L). Without this pair, THMFP values by the reactivity method were, on average, 70 percent of the values analyzed by Bryte Lab's modified EPA 510.1 method (range = 56 to 77 percent).

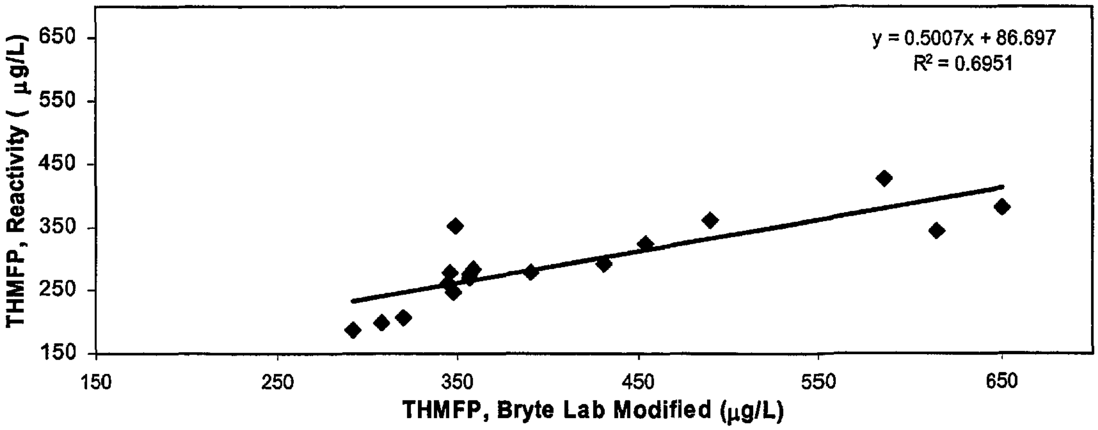

Figure B-6. Correlation between trihalomethane formation potential by Bryte Lab Modified EPA 510.1 and the reactivity method. All samples were collected at Banks Pumping Plant. Chlorine residuals for the reactivity analyses ranged from 1.9 to 3 mg/L, with 1 value of 0.1 mg/L.

Appendix C

Organic Carbon Precision Analysis

Replicate TOC sample pairs collected in the California Aqueduct were well correlated (Figure C-1). Variation of individual replicates from the regression line did not appear to be related to concentration extremes (either high or low). Relative percent differences (RPDs) of replicate pairs ranged from 0 to 12.3 percent with an average and median of 5.2 and 3.8 percent, respectively.

The dataset for DOC replicate pairs in the California Aqueduct was smaller than that for TOC but better correlated (Figure C-2). The RPDs for DOC were somewhat similar to those for TOC with a range of 0 to 20 percent and an average and median of 5.3 and 3.5 percent, respectively.

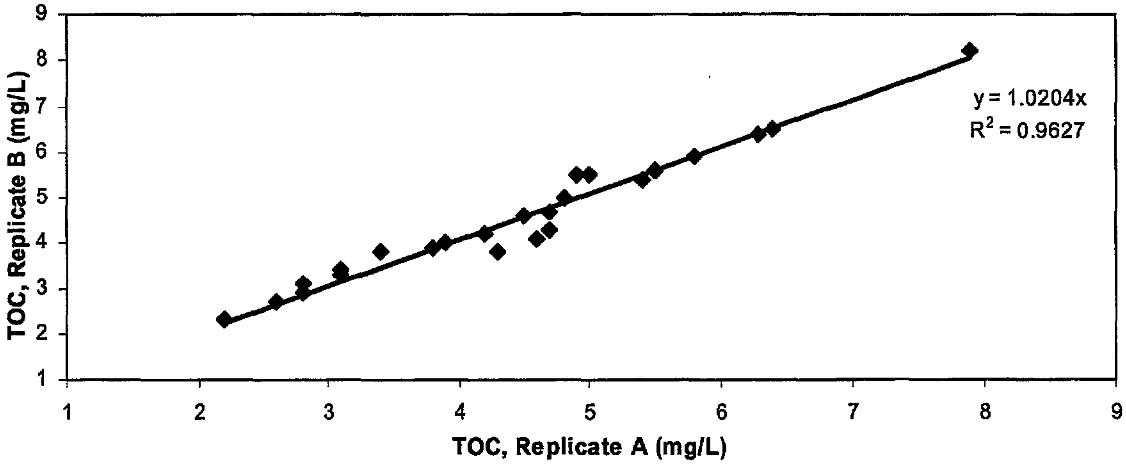

Figure C-1. Correlation between replicate TOC pairs collected in the California Aqueduct

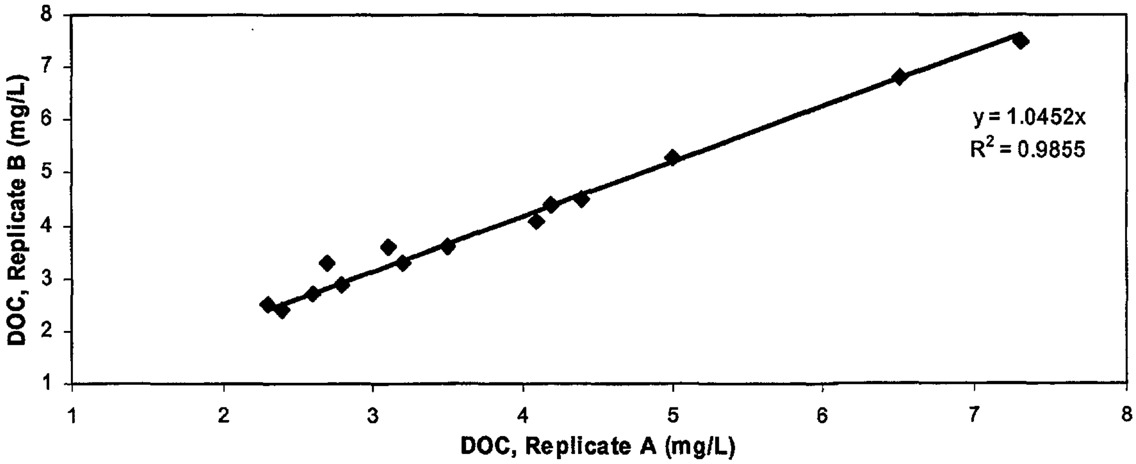

Figure C-2. Correlation between replicate DOC pairs collected in the California Aqueduct

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