DRAFT TECHNICAL MEMORANDUM NO. 2B - IMPACT OF AGRICULTURAL DRAINAGE ON SACRAMENTO-SAN JOAQUIN DELTA WATER QUALITY CALIFORNIA URBAN WATER AGENCIES STUDY OF DRINKING WATER QUALITY IN DELTA TRIBUTARIES

November 5, 1993

Introduction

With the exception of extreme high river flow conditions such as during winter storms, the water quality at the intakes of the State Water Project (SWP) and Central Valley Project (CVP) is quite different from that of upstream inflows to the Sacramento-San Joaquin Delta (Delta). Water quality at the Tracy Pumping Plant and Clifton Court Forebay gates is affected by daily tidal excursions and upstream flows that control the extent of saltwater intrusion. Seawater can contaminate drinking water supplies with increased total dissolved solids (including sodium and bromide) rendering it less palatable and healthful, and more corrosive to water systems. Waters with bromide, when oxidized for disinfection purposes, will react with naturally occurring organic matter to form various toxic disinfection byproducts.

Agriculture also impacts Delta water quality. There are 260 pump stations dispersed among 60 islands and tracts that discharge a combination of seepage, runoff, and irrigation return water into the adjacent channels, as shown on Figure 1. Drainage water is high in mineral salts and organic matter. The salts come from the evaporation of irrigation water. However, in some areas such as Empire Tract, connate water also contributes mineral salts to the drainage. Organic matter comes from the natural peat material in the soil and decaying crops in the fields. The Delta was once a vast tule marsh prior to being reclaimed about one hundred years ago. The depth of peat soil in some areas is over thirty feet.

Drain water quality varies with the seasonal farming activities and the soil type of the area being drained. Drainage dissolved organic carbon (DOC) concentrations are highest during the winter when farmers deliberately pond and flood the fields to leach out salt accumulations in the

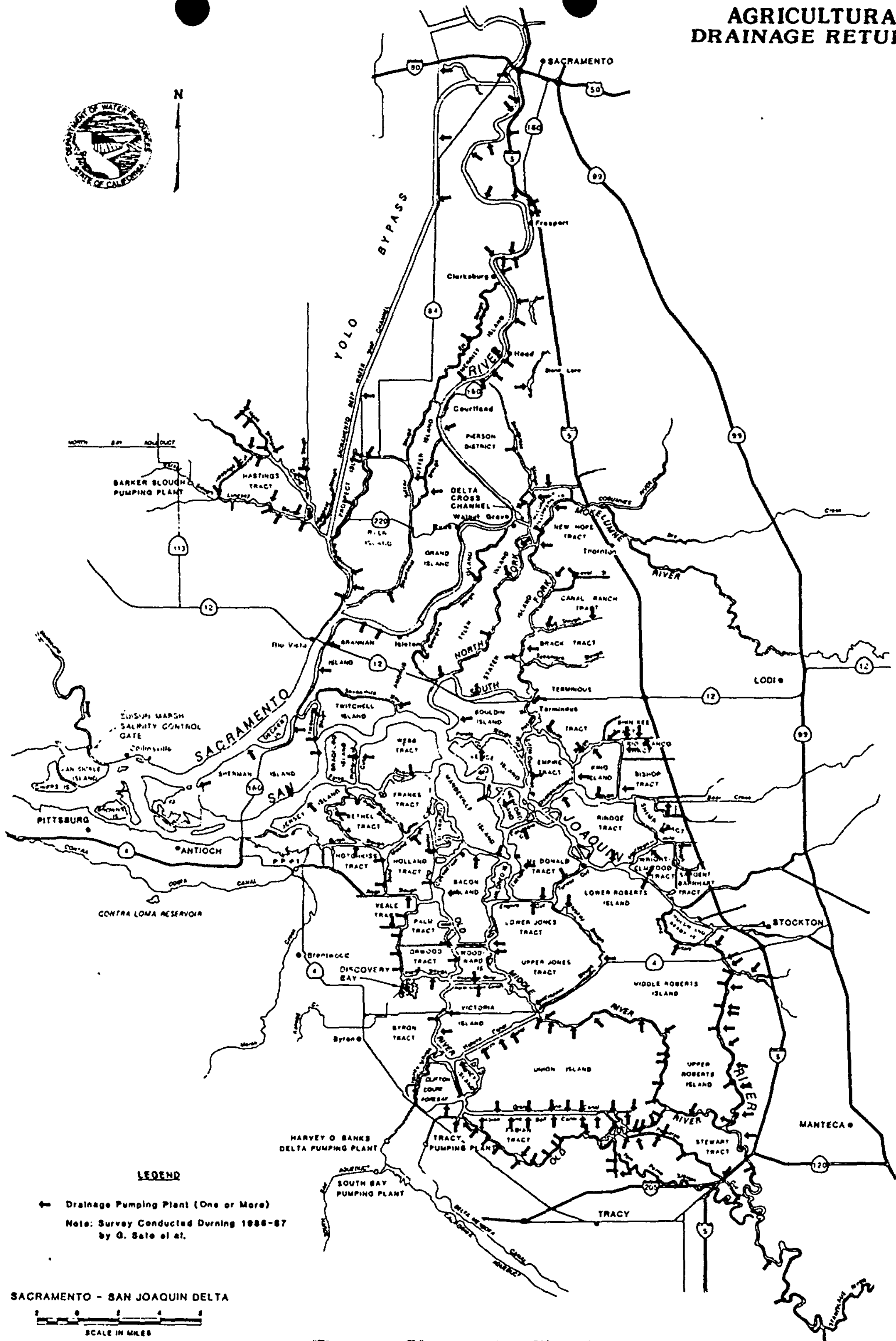


Figure 1. Agricultural Drains in the Delta

soil. High DOC and trihalomethane formation potential (THMFP) levels are also associated with the organic content of the drained soils. The highest concentrations are typically found in drains overlying peat organic soils and the lowest overlying mineral type soils. U.S. Geological Survey (USGS) studies attribute the variability in DOC at a given site to soil-water contact time, water table height, soil moisture, and temperature (Deverel, et. al., 1993).

Drain water has a greater propensity to form trihalomethanes (THMs) and other disinfection byproducts when chlorinated than non-drain water samples (Amy et. al., 1990; DWR, 1990). This is attributed to the high humic nature of the peat organic soils of the region. The ease of humic substances in forming trihalomethanes when chlorinated has been well studied.

Based on past drainage volume estimates (1954-55) and more recent monitoring data assessments (1983-93), the increases in DOC and THM precursor concentrations in the Delta channel waters are mostly from drainage discharges. There may be some increases due to within channel events such as dredging, sediment leaching, and biological productivity but they are relatively small compared to drainage discharges. The California Department of Water Resources (DWR) published early rough estimates on the contribution of THMFP for Delta island drainage in the Delta Island Drainage Investigation Report (DWR, 1990). The significance of these increases is that most water agencies that use the Delta as a drinking water supply must now enhance treatment operations to meet new drinking water quality standards for total organic carbon (TOC) and disinfection by-products (DBPs).

Although pesticides are heavily used in the Delta, the residue levels in channel and drain water samples have been near or below laboratory detection limits (DWR, 1986; DWR, 1990). Recent studies by the USGS and California Regional Water Quality Control Board, Central Valley Region (Regional Board) further confirm that these pesticide levels are far below drinking water maximum contaminant levels (MCLs).

This technical memorandum presents an overview of the major differences in water quality in the Delta. The latest results of DWR estimates on the impact of Delta drainage discharges on DOC and THM precursors concentrations on Delta water quality are also summarized. This information will later be used to assess how much improvement in water quality would result at the SWP and CVP intakes from each proposed alternative at the upstream locations in this Study of Drinking Water Quality in Delta Tributaries.

Delta Water Quality (1987-91)

Drinking water quality data for the Delta is limited to the long-term studies of DWR under the Municipal Water Quality Investigations (MWQI) Program (1982 - present). Currently, over 70 drain and channel stations are monitored. Data collected after 1986 are more comprehensive as the program expanded by monitoring more stations (both channel and drains), sampled more frequently, and conducted more tests (e.g., ultra-violet absorbance (UVA-254nm), DOC, bromide). An analysis of the 1987-91 data was therefore made. This period of record, however, covered a five year drought, in which water quality observations represent an extreme water year condition.

During this five year period, almost all of the low San Joaquin River flows were diverted back into the CVP intake. Monitoring in the southern Delta and DWR flow calculations for Stockton substantiated this condition. Sacramento River flows (at Greene's Landing) were generally about ten times greater than San Joaquin inflows (near Vernalis). During 1987-91, the overall source of fresh water in the Delta was the Sacramento River.

Nonparametric statistics were used to compare and summarize the sample data set. For comparison, notched box and whisker plots of electrical conductivity (EC), sodium, DOC, alkalinity, bromide, and THMFP data at key Delta stations were made. These figures show the maximum, upper quartile, median, 95 percent confidence interval for the median, low quartile, minimum values, and outlier data points, as shown on Figure 2.

The median EC was less than 100 micro Siemens per centimeter (μS/cm) at the American River Water Treatment Plant (WTP) intake station and under 200 μS/cm at Greene's Landing, as shown on Figure 3. Increases in EC values were evident downstream at the other Delta stations. The high EC (median 850 μS/cm) at Vernalis reflected the upstream agricultural drainage discharges into the San Joaquin River. The 700 μS/cm EC median at Rock Slough near Old River is attributed to seawater mixing with Sacramento River water. The median EC values

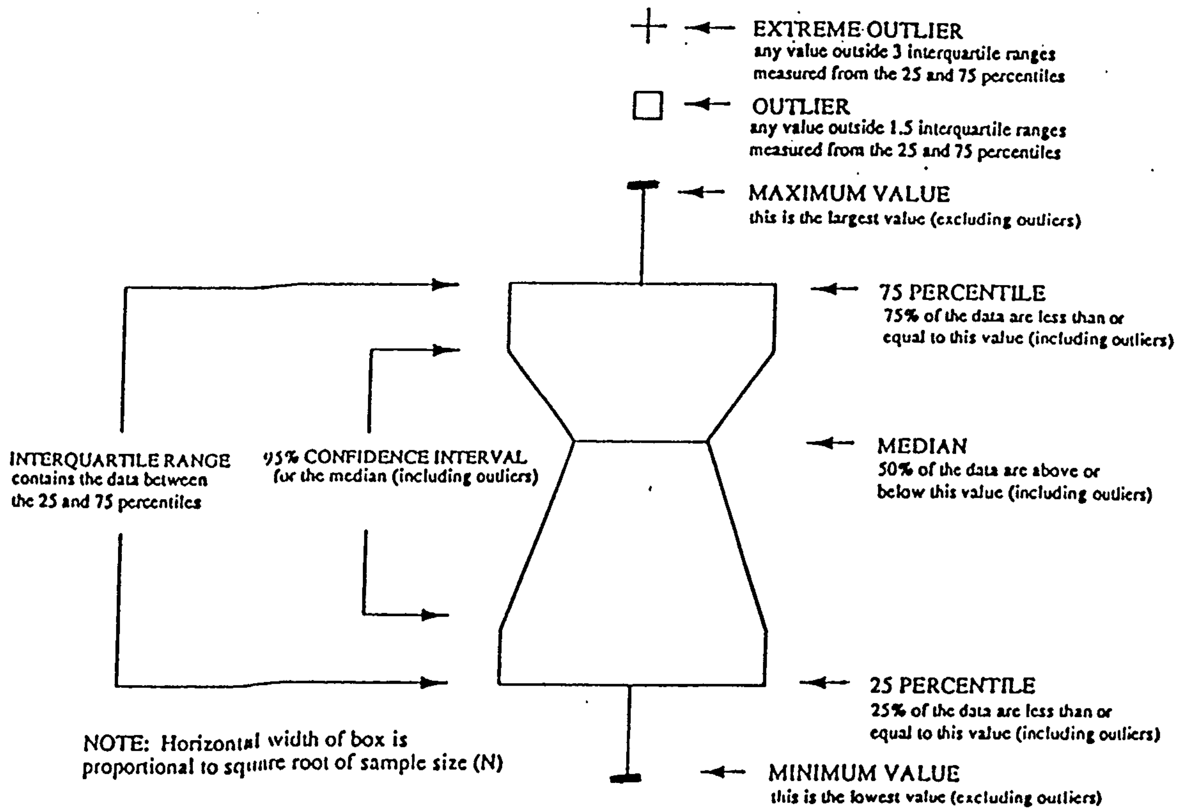


Figure 2. Guide to Notched Box-and-Whisker Plots

Figure 3.
Delta E.C. Ranges (1987-91)

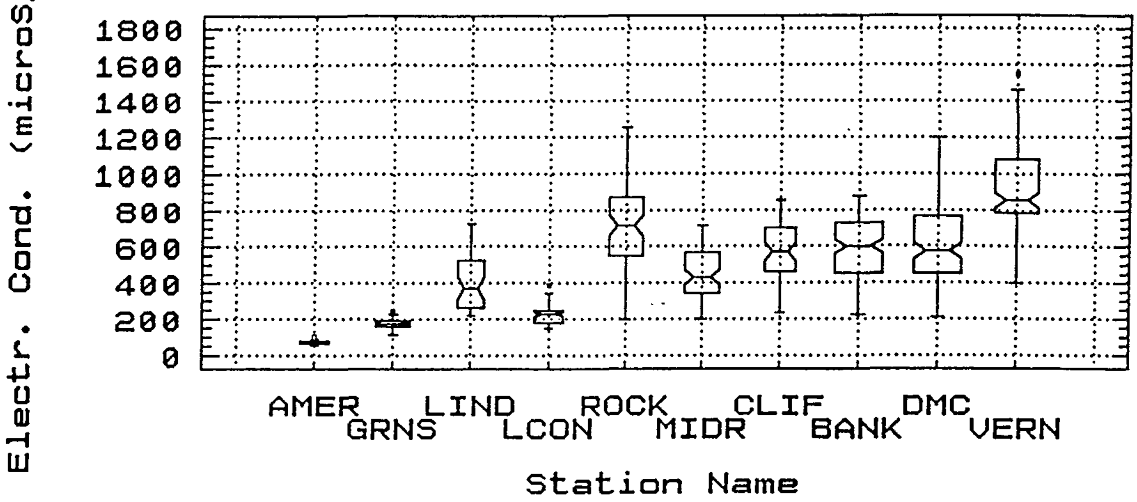
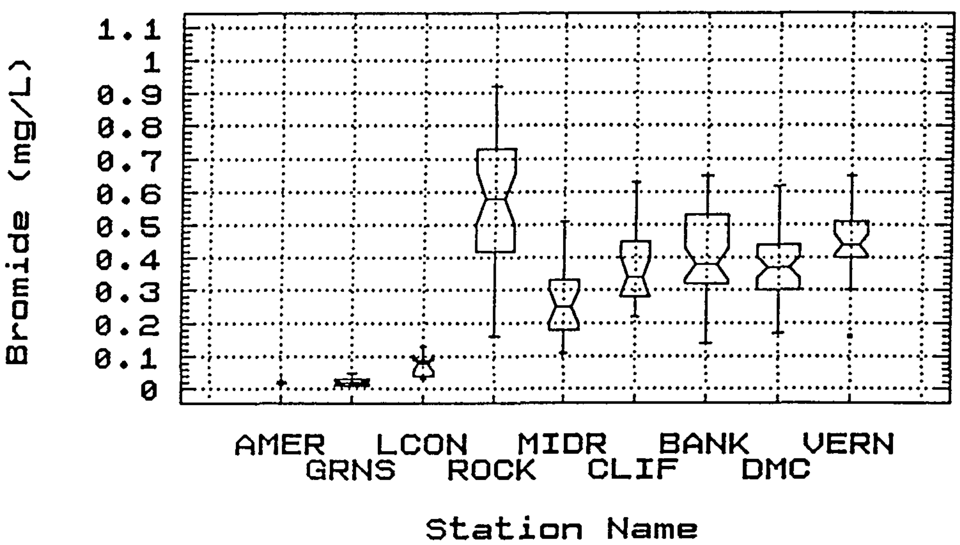


Figure 4.
Delta Bromide Ranges (1990-91)



Besides seawater bromide could be coming from ag drainage flows or from marine from geologic formations at the Banks Pumping Plant, Clifton Court Forebay intake gates, and Tracy Pumping Plant intake stations were about 550 to 600 µS/cm and are attributed to mixing with lower EC water from Middle River (median 450 µS/cm) that joins Old River at three canals between Bacon Island and Union Island.

Seawater intrusion has been traced by common ocean water ions such as sodium, bromide, and chloride. Water taken from the southern Delta is higher in bromide than in the northern Delta region, as shown on Figure 4. Water treatment concerns for bromide related disinfection byproducts are therefore greater for the southern region raw water supplies.

New TOC limits (2 milligrams per liter (mg/L)) will require enhanced coagulation in treatment of Delta water. Delta TOC data are limited but DOC data are available for comparison. In general, Delta DOC concentrations are over 90 percent of the TOC levels. The median DOC concentrations at Greene's Landing and the American River stations were about 2 mg/L, as shown on Figure 5. Downstream median DOC was generally over 3 mg/L and had a wider range of concentrations. DOC usually doubles during the wet rainy season from heavy surface runoff and drainage.

As shown on Figure 6, the American River has the lowest alkalinity (median 25 mg/L as $CaCO_3$). Median alkalinities at the other stations were over 60 mg/L. Vernalis had a median of 110 mg/L. This is attributed to the mineral type drainage of the San Joaquin Valley. Alkalinity control is important to control the formation of DBPs during ozone treatment (Siddiqui and Amy, 1993).

As shown on Figure 7, THMFP based on the DWR THMFP assay for raw water was two to three times higher in the southern Delta than at Greene's Landing and the American River. Since the THMFP results are proportional to bromide concentration, the higher THMFP in the southern Delta is in part due to seawater intrusion. To distinguish THMFP concentrations caused by bromide from that caused by reactive organic material, the amount of organic carbon from the THMFP concentrations was computed to yield the trihalomethane formation potential carbon (TFPC) concentration. The distribution pattern of Delta TFPC data was identical to the THMFP data, as shown on Figure 8. This suggests that Delta THMFP was more closely related to the

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Figure 5.
Delta DOC Ranges (1987-91)

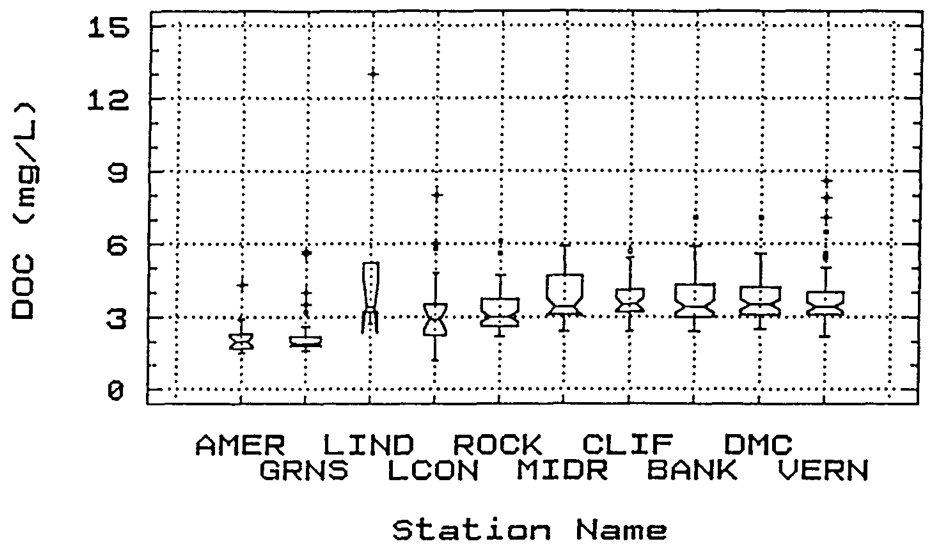


Figure 6.
Delta Alkalinity Ranges (1987-91)

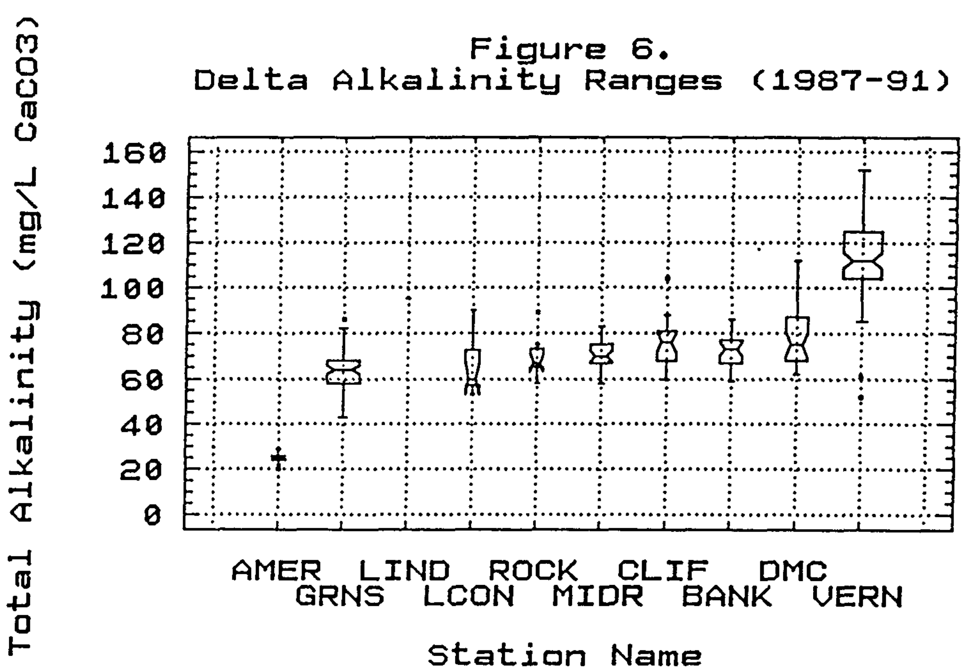


Figure 7.
Delta THMFP Ranges (1987-91)

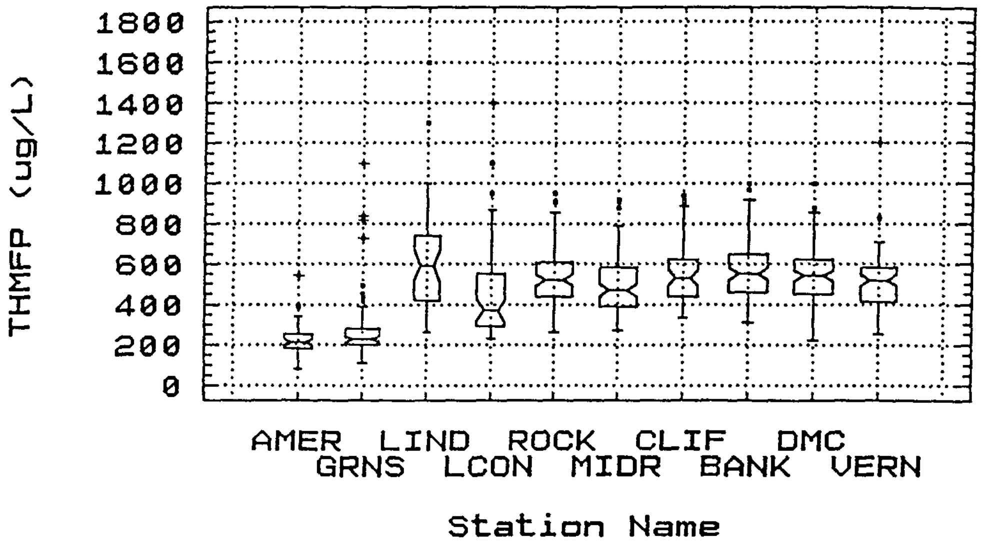
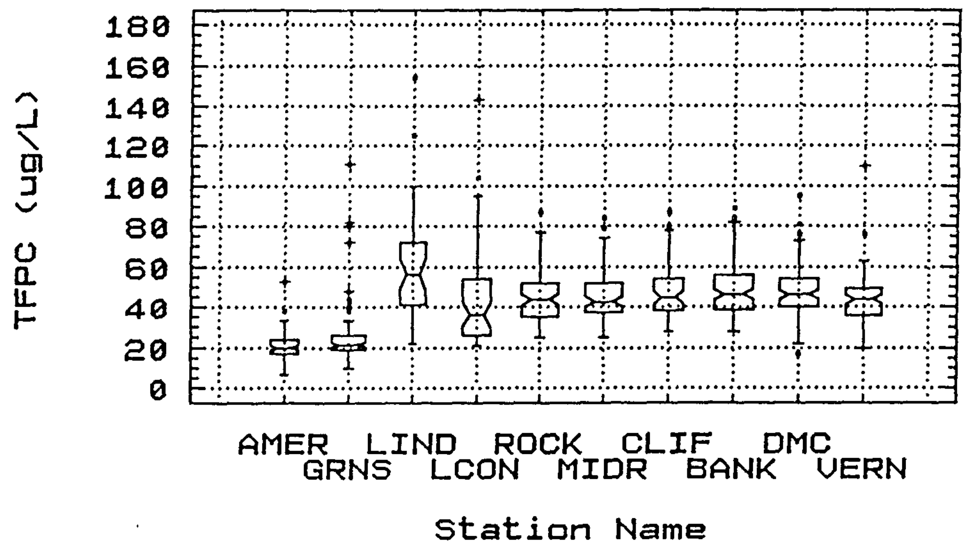


Figure 8.
Delta TFPC Ranges (1987-91)



organic carbon (TFPC) than bromide concentrations. However, disinfection byproducts other than trihalomethanes are now of major concern, especially those related to the presence of bromide in raw water supplies (Krasner, et. al., 1993; Pourmoghaddas, et. al., 1993; Glaze, et. al., 1993).

Impacts of Drainage on Delta DOC and TFPC

DWR has recently revised their estimates of the impact of Delta island drainage on channel water DOC and TFPC concentrations (DWR, 1993). A summary of this work is presented.

The combined effects of the drought and drainage on channel water DOC and TFPC were assessed for calendar years 1987-1991. Several assumptions were made to adjust for the lack of data from unsampled areas and on current drainage volumes.

An earlier estimate of the drainage portion of TFPC in the channels for Water Year 1988 was presented in the Delta Island Drainage Investigation Report (DWR, 1990). With some exceptions, the new revised method for deriving annual TFPC and DOC levels during 1987 through 1991 is similar to the earlier method. The new approach has the benefit of using more data in the analysis.

A simple model was used to generalize the input of organic matter in the Delta. The Delta was treated as a well-mixed basin with water quality data represented by data averaged from four stations: Old River at Rock Slough, Clifton Court Forebay intake, Middle River at Borden Highway, and the Tracy Pumping Plant intake. River input was represented by data from the Sacramento River at Greene's Landing, San Joaquin River near Vernalis, the Cosumnes River near Sloughhouse and the Mokelumne River near Woodbridge. Drainage input was computed by dividing the drainage monitoring data into two groups of islands based on soil type and 1954-55 drainage volume (DWR, 1956).

The main assumptions of this model were:

1. Present monthly drainage volumes are nearly the same as those reported in the 1954-55 study.

2. Drainage DOC and TFPC data at sampled sites can be extrapolated to unsampled drain sites based on soil type and region within the Delta.

3. Monthly flow-weighted DOC and TFPC data from various island drains can be used to represent total Delta island drainage loads.

4. For simplification "Delta channel water quality" is represented by averaging the monthly data from the four selected channel stations in the southwestern Delta.

5. TFPC concentrations in the Cosumnes and Mokelumne rivers have not significantly changed since 1984.

6. Flow-weighted monthly DOC and TFPC data collected from the Sacramento, San Joaquin, Mokelumne and Cosumnes rivers represent that which would exist in the Delta channels in the absence of island drainage or other factors that impact water quality. In this model, these data represent "river inflow or input" to the Delta.

7. The difference between the concentrations of TFPC and DOC in the Delta channels and river inflow water are from agricultural drainage. Simply stated, drainage contribution is equal to the river inflow levels subtracted from the higher Delta channel concentrations. The contribution from within the channels (e.g., leaching, riparian, algae) and the estuary are assumed to be relatively small enough to be ignored.

DOC and TFPC concentrations in the channels were predicted from drainage data. These predicted values were then compared against the observed data of the four Delta stations, which represented the channels. Inflow loadings of DOC and TFPC were also compared against observed values. Details on how the assumptions and computations were made are described in detail in the Draft Municipal Water Quality Investigations Program Five Year Summary Report, 1987-91 (DWR, 1993).

Predicted and observed DOC and TFPC concentrations were calculated as a percentage of the respective inflow concentrations for each month of the study period. The percentages are derived by subtracting the average river inflow concentration from the predicted channel concentration and dividing the result by the inflow concentration.

The DOC data were better than TFPC data for studying the release of organic material from agriculture drainage. This is because the DWR THMFP Assay Method tended to underestimate THMFP in drainage water samples with DOC above 20 mg/L. DWR began modifying the testing procedure in July 1992.

A progressive increase of DOC and TFPC concentrations in the Delta channels was not evident during the five consecutive dry years. The highest carbon concentrations occurred either in drainage or in the rivers and channels during heavy precipitation. During the summer, carbon concentrations were lower in all waters.

Predicted and observed DOC and TFPC concentrations did not compare well on a month-to-month basis for each year. There was closer agreement between predicted and observed data when the monthly carbon concentrations were averaged either for a calendar year (i.e., average of all 12 months) or for the same calendar months averaged for the total five year period.

The predicted and observed DOC monthly concentrations averaged 3.55 and 3.52 mg/L, respectively. The averaged monthly concentrations for inflow DOC was 2.45 mg/L. The predicted DOC shows that agricultural drainage increased channel water concentration by 1.1 mg/L which was near the observed DOC. Table 1 shows the five year monthly averaged DOC concentrations. The predicted concentrations were calculated using 100 percent of the estimated island drainage flow.

Table 1. Comparison of Inflow, Observed, and Predicted DOC Five Year Monthly Averages, 1987-91

Month	Inflow DOC, mg/L	Predicted DOC, mg/L	Observed DOC, mg/L
January	2.71	4.61	4.58
February	2.57	3.98	4.31
March	3.78	4.30	4.06
April	2.55	3.10	3.82
May	2.06	3.13	3.06
June	2.16	3.12	3.16
July	1.93	2.98	3.04
August	1.96	2.87	3.02
September	2.81	3.84	2.97
October	2.03	3.01	3.24
November	2.23	3.17	3.14
December	2.63	4.45	3.85
Average	2.45	3.55	3.52
Minimum	1.93	2.87	2.97
Maximum	3.78	4.61	4.58

Table 2 is based on relative concentrations and shows the predicted monthly and observed DOC in terms of percent increase above inflow concentrations. There are three predicted values based on 90, 100 and 110 percent of the 1954-55 drainage volumes. The averages show the predicted drainage impact nearest to the observed DOC for the four Delta stations was calculated using 110 percent of the island drainage flow. This prediction shows a 55 percent increase above inflow concentrations, whereas the observed increase was 54 percent. If these calculations accurately represent the Delta condition then the current drainage volume may be 10 percent higher than the 1954-55 estimates.

Table 2. Predicted and Observed DOC Increases from Drainage

Month	Five year monthly averages, 1987-91, predicted percent increase in DOC: 1954-55 drainage volume	90 percent of 1954-55 drainage volume	110 percent of 1954-55 drainage volume	Observed percent increase in DOC
January	83	75	90	85
February	59	53	64	77
March	20	18	22	22
April	24	22	26	65
May	61	55	67	57
June	45	41	49	48
July	55	50	60	58
August	47	42	51	55
September	41	37	45	17
October	50	45	54	69
November	43	39	47	40
December	73	67	80	52
Average	50	45	55	54
Minimum	20	18	22	17
Maximum	83	75	90	85

The predicted and observed TFPC monthly concentrations for the four Delta stations averaged 3.50 and 3.86 µmoles/L, respectively. A µmole/L of TFPC multiplied by 12 yields the concentration in µg/L. The inflow TFPC was 2.42 µmoles/L. The predicted TFPC was 1.08 µmoles/L higher than the inflow TFPC. The observed TFPC was 1.44 µmoles/L greater than the inflow TFPC. The predicted TFPC underestimated the observed TFPC by 0.36 µmoles/L. Table 3 shows the five year averaged TFPC concentrations. These predicted concentrations were calculated using 100 percent of the estimated island drainage flow.

Table 3. Comparison of Inflow, Observed, and Predicted TFPC Five Year Monthly Averages, 1987-91

Month	Inflow TFPC, µmoles/L	Predicted TFPC, µmoles/L	Observed TFPC, µmoles/L
January	2.69	4.59	4.66
February	2.64	3.83	4.85
March	5.07	5.55	4.09
April	2.12	2.71	3.93
May	1.94	3.09	3.79
June	2.02	3.09	3.57
July	1.97	3.02	3.49
August	2.03	2.94	3.45
September	2.43	3.42	3.71
October	1.79	2.64	3.27
November	2.13	3.04	3.26
December	2.22	4.03	4.26
Average	2.42	3.50	3.86
Minimum	1.79	2.64	3.26
Maximum	5.07	5.55	4.85

Table 4 is based on relative concentrations and shows the predicted monthly and observed TFPC in terms of percent increase above inflow concentrations. There are three predicted values based on 90, 100 and 110 percent of the island drainage flow. Averages for the study period, show the predicted drainage impact nearest to the observed TFPC was calculated using 110 percent of the 1954-55 drainage volume. Results of the calculations show that agricultural drainage from the Delta islands, theoretically increased the concentration of TFPC in Delta channels by 56 percent during the five year period. The observed average percent increase above the inflow concentration was 79 percent. For the five year period of study, the averaged monthly TFPC predicted was 23 percent less than the average observed TFPC concentration.

A possible explanation for the 23 percent difference is that TFPC values are calculated from analyses of THMs. Recently, it was discovered that the methods used for analyzing THMs reported lower THM values than the water actually contained for water samples with over 20 mg/L DOC. Drainage water is the only water involved in these calculations that would be significantly affected by this problem. Although a correction factor was developed and applied to the THM data before the TPFC was calculated, there is the possibility that TFPC in drainage water is still underestimated because of data scatter. The resulting low TFPC would certainly cause the predicted impacts of drainage water to be lower than the observed concentrations. Table 4 shows the five year averaged TFPC concentrations.

Table 4. Predicted and Observed THMFP Carbon (TFPC) Increases from Drainage

Month	Five year monthly averages, 1987-91, predicted percent increase in TFPC			Observed percent increase in TFPC
	1954-55 drainage volume	90 percent of 1954-55 drainage volume	110 percent of 1954-55 drainage volume	
January	84	77	92	93
February	56	50	61	101
March	16	15	18	3
April	28	25	31	84
May	60	55	66	97
June	56	51	61	81
July	56	51	61	81
August	48	44	53	87
September	39	35	42	65
October	49	44	54	100
November	44	40	48	56
December	83	75	90	105
Average	52	47	56	79
Minimum	16	15	18	3
Maximum	84	77	92	105

On several occasions, monthly concentrations of DOC and TFPC in the Sacramento River were higher than the measured channel concentrations. It is highly probable that these data do not represent the quality of the river for the total month, as these were grab samples. These occurred during rainy periods north of Sacramento, except in September 1987 and 1988. The source of the high river carbon concentrations during September 1987 and 1988 is likely upstream rice field drainage.

Summary

During the five year drought period of 1987-91, the Sacramento River water was virtually the sole fresh water source for the SWP. San Joaquin River contributed about 10 percent of river input to the Delta and most of this was rediverted back into the CVP by pumping at the Tracy Pumping Plant.

Waters taken from the southern Delta will require additional treatment to meet new drinking water standards for disinfection byproducts. Southern Delta waters are consistently higher in EC, DOC, bromide, alkalinity, THMFP, and TFPC than upstream Sacramento River water at Greene's Landing and American River water.

Seawater was the major source of bromide to the water intakes of the Contra Costa Water District at Rock Slough and the SWP at Clifton Court Forebay. Based on the flow conditions the CVP received bromides both from seawater and inflow from the San Joaquin River.

A simple basin model was used to generalize the contribution of DOC and TFPC from Delta island drainage. Drainage volume data were limited to a DWR study in 1954-55 (DWR, 1956). DWR data on DOC and TFPC for 1987-91 were used for concentration data. The model results were compared to observed data and DOC predictions were in good agreement with observed averages. The model estimated an average increase of DOC by 1.1 mg/L from drainage over the average river input concentration (2.45 mg/L). The model's results for DOC were best when the drainage volume estimate was 10 percent higher than the 1954-55 estimates.

The observed average Delta TFPC was 79 percent higher than the inflow average. The model's results were lower at 56 percent. The difference is in part attributed to underestimated THMFP or TFPC results in the DWR test method for drainage water samples with DOC concentrations above 20 mg/L and in part due to the data set consisting of monthly grab samples.

Diversion of agricultural drainage from the Delta to the San Francisco Bay was examined in the Delta Drinking Water Quality Study (Brown and Caldwell, 1989). In this study of Delta Tributary Drinking Water Quality, the effect of removing agricultural drainage from the Delta will be examined in conjunction with the alternatives for improving drinking water quality upstream of the Delta. Each of the alternatives identified in Task 7 of this study will be evaluated with and without the removal of Delta agricultural drainage. The information contained in this technical memorandum will be used to estimate the effect on drinking water quality of removing Delta Agricultural drainage from the Delta channels.

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