Appendix G. Water Quality Assessment Methods

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INTRODUCTION

This appendix describes the assessment methods used to characterize existing water quality conditions and to analyze the potential effects of Delta Wetlands Project operations on water quality. The appendix is organized into three major sections:

- "Estimating Existing Levels of Dissolved Organic Carbon and Salinity in Agricultural Drainage": Presents an analysis of available data on Delta agricultural drainage, which is used to estimate contributions of dissolved organic carbon (DOC) and salinity from existing agricultural operations to Delta waters.

- "Estimating Project Effects on Salinity and Dissolved Organic Carbon": Describes the Delta Standards, Operations, and Quality model (DeltaSOQ), which is used to analyze the effects of Delta Wetlands Project discharges on monthly Delta export water quality. Presents information on Delta source contributions of salinity and DOC and on the salinity and DOC calculations used in the model. Also describes the range of estimates of DOC loading under reservoir operations that has been incorporated into the analysis.

- "Estimating Project Effects on Trihalomethane and Bromate Concentrations in Treated Water": Presents a review of disinfection byproduct (DBP) prediction equations and identifies the trihalomethane (THM) prediction equation used in the DeltaSOQ model.

ESTIMATING EXISTING LEVELS OF DISSOLVED ORGANIC CARBON AND SALINITY IN DELTA AGRICULTURAL DRAINAGE

The purpose of the agricultural drainage data analysis is to estimate annual loading of DOC and salinity from existing agricultural operations. The following analysis updates information on drainage water quality presented in the 1995 Delta Wetlands Project Draft Environmental Impact Report and Environmental Impact Statement (1995 DEIR/EIS). This section presents the data collected from the Delta Wetlands Project island locations through 1994, with the exception of Bacon Island, where sampling was continued through August 1999, and Twitchell Island, the location of several studies by the California Department of Water Resources (DWR) and U.S. Geological Survey (USGS) that began in 1994.

Bacon Island

Figure G-1 shows drainage measurements for chloride (Cl^-) and DOC as a function of the drainage electrical conductivity (EC) value in Bacon Island samples collected during January 1990–August 1999. Sampling of water quality at Bacon Island pumping plant (PP) 1 has been continued as part of DWR's Municipal Water Quality Investigations (MWQI) agricultural drainage sampling program (Bacon PP 2 sampling was discontinued). The range of drainage EC values varied from 200 to 1,280 microsiemens per centimeter (μS/cm). The mean EC value of these samples was 589 μS/cm, which is similar to the mean value of 650 μS/cm shown in the 1995 DEIR/EIS.

The Cl^-:EC ratio is used as an indicator of the source of irrigation water and of the amount of bromide (Br^-) expected in the agricultural drainage water (see Chapter 4, "Water Quality"). The 1986-1998 data show an average Cl^- concentration of 102 mg/l and a Cl^-:EC ratio of 0.17 in the drainage water, similar to the ratio of 0.18 for the data presented in the 1995 DEIR/EIS. These results suggest that San Joaquin River water and seawater were mixed with Sacramento River water in Bacon Island irrigation water.

DOC concentrations are plotted as a function of EC to investigate the possible relationship between drainage EC and DOC. If DOC behaves as a conservative dissolved substance (i.e., its concentration increases with evaporation, decreases with rainfall, and is not removed by biological or other physical and chemical processes), it is reasonable to suppose that DOC accumulates in soil moisture in the same manner that salt does. For example, if the drainage EC is twice the applied-water EC, the drainage DOC should be twice the applied-water DOC. The same leaching and drainage processes that eventually return salt to Delta channels in agricultural drainage should also return accumulated DOC material. A range of DOC values should be observed, just as a range of EC values is measured. Whereas no significant long-term source or sink for salt exists on Delta islands, a significant source or sink for DOC material may exist. If an island source of DOC exists, DOC concentrations in drainage water would exceed DOC values expected based on typical DOC concentrations in applied irrigation water.

Figure G-1 indicates that DOC concentrations in Bacon Island drainage vary, ranging from less than 5 milligrams per liter (mg/l) to more than 25 mg/l, and increase slightly with drainage-sample EC values. The mean Bacon Island drainage DOC concentration is 11.4 mg/l (compared to 9.4 mg/l shown in the 1995 DEIR/EIS from the 1986-1991 data set). The average of the drainage-sample DOC concentrations may only roughly approximate the actual average DOC concentration from Bacon Island drainage because the volume of drainage associated with each sample is not known.

The mean EC value in drainage water can be used to estimate the expected average increase from applied-water EC values to drainage EC values. For example, if the average EC value in water used for irrigation of Bacon Island (i.e., applied water) was assumed to be 300 μS/cm, which is higher than the Sacramento River EC value but lower than the export EC value (see Table 4-1), and the average drainage EC value is 589 μS/cm, the ratio of drainage EC to applied-water EC would be 1.96 or approximately 2. If the average ratio of drainage EC to applied-water EC is used with the typical measured channel DOC concentrations, the expected average increase from applied-water

DOC to drainage DOC concentrations would also be a factor of 2. If the average applied-water DOC concentration were assumed to be 3 mg/l, which is higher than the mean Sacramento River DOC concentration but lower than the mean export DOC (Figure 4-7), an average of 6 mg/l (3 • 2) of DOC would be expected in drainage water if a source of DOC did not exist on the island.

The difference between the measured DOC (11.4 mg/l) and the expected DOC (6 mg/l) is 5.4 mg/l (grams per cubic meter [g/m^3]) and can be used as an estimate of the contribution of DOC from agricultural practices. Thus, the DOC concentrations being discharged in drainage water can be partitioned into estimates of the contributions of DOC from agricultural sources and from applied channel water. Multiplying the source concentration by the average drainage water depth (69 inches, as shown in Table C2-2 in the 1995 DEIR/EIS) gives a DOC loading estimate for Bacon Island of about 9.3 grams per square meter per year ($g/m^2/yr$) (5.4 g/m^3 • 69 inches • 0.025 meter per inch [m/inch] = 9.3 g/m^2). The estimated DOC contribution from Bacon Island presented in the 1995 DEIR/EIS was about the same at 9 $g/m^2/yr$.

Bouldin Island

Figure G-1 also shows drainage measurements of DOC, Cl^-, and EC for Bouldin Island. Sampling at the Bouldin Island drainage pumps began in March 1987 and was discontinued in July 1994, so fewer samples have been collected and analyzed for the three constituents. The average EC value was 426 μS/cm. The pattern shown in Figure G-1 is the same as that shown in the 1995 DEIR/EIS.

As shown in the 1995 DEIR/EIS, the average Cl^- concentration was 32 mg/l and the Cl^-:EC value for Bouldin Island drainage samples was less than 0.1, indicating that Sacramento River was the primary source of irrigation water (Mokelumne River flows were below 200 cubic feet per second [cfs]). Therefore, a much lower Br^- concentration is expected in Bouldin Island drainage than in Bacon Island drainage.

Figure G-1 indicates that the drainage DOC concentrations generally increased with drainage EC values; the average of 33.7 mg/l is much greater than the average DOC for Bacon Island. Because Sacramento River DOC concentrations are relatively constant at about 2.5 mg/l (with an EC value of 160 μS/cm), the expected DOC concentration in drainage water having an average EC value of 426 μS/cm would be 6.6 mg/l ([426/160] • 2.5). DOC concentrations in all the Bouldin Island drainage samples are greater than expected, suggesting a major agricultural source of DOC.

The additional 27.1 mg/l (33.7 – 6.6) represents the average DOC concentration contributed by sources on Bouldin Island. Multiplying the source concentration by the average drainage depth (33 inches, as shown in Table C2-2 of the 1995 DEIR/EIS) gives a DOC loading estimate for Bouldin Island of 22.4 $g/m^2/yr$ (27.1 g/m^3 • 33 inches • 0.025 m/inch = 22.4 g/m^2). This estimated value for Bouldin Island is similar to the 23 $g/m^2/yr$ presented in the 1995 DEIR/EIS.

Holland Tract

DWR collected drainage water quality data at Holland Tract between January 1990 and July 1994. The average drainage EC value was 1,177 μS/cm, similar to the average of 1,090 μS/cm shown in the 1995 DEIR/EIS (Figure G-2). Holland Tract is located across the Old River channel from Bacon Island, so the quality of applied irrigation water is assumed to be similar to that assumed for Bacon Island (EC of 300 μS/cm, DOC of 3 mg/l). The higher EC values in Holland Tract drainage are consistent with the lower average measured volume of Holland Tract drainage water (16 inches, as shown in Table C2-2 of the 1995 DEIR/EIS). These data indicate a ratio of 3.9 or approximately 4 for drainage EC to applied-water EC.

The average Cl^- concentration in Holland Tract drainage water for the Holland Tract samples was 211 mg/l, similar to the average of 199 mg/l shown in the 1995 DEIR/EIS. The Cl^-:EC value for Holland Tract drainage samples was 0.18, similar to the value of 0.17 for Bacon Island. This Cl^-:EC value indicates that seawater intrusion or San Joaquin River water was a significant source of salt in Holland Tract irrigation water. Relatively high Br^- concentrations are expected in Holland Tract drainage water.

Figure G-2 indicates that the drainage DOC concentrations averaged 18.2 mg/l. Given an assumed DOC in applied water of 3 mg/l and drainage-to-applied-water EC ratio of 4, the expected average drainage DOC would be 12 mg/l. The estimated source loading of DOC would be only about 2.5 g/m^2/yr (6.2 g/m^3 • 16 inches • 0.025 m/inch). The value is lower than that of the other Delta Wetlands islands and lower than the value (6 g/m^2/yr) presented in the 1995 DEIR/EIS.

Webb Tract

DWR collected drainage water quality data at Webb Tract between January 1990 and April 1993. Most drainage EC values for Webb Tract from 1990 through 1993 ranged between about 500 and 2,000 μS/cm (Figure G-2). The Webb Tract drainage concentrations were similar to those in the Holland Tract samples. The similarity in concentrations is generally consistent with the fact that the source for irrigation water for both islands is similar and that both islands' measured drainage volumes are less than 20 inches (as shown in Table C2-2 of the 1995 DEIR/EIS).

For Webb Tract drainage samples, the average Cl^- concentration was 183 mg/l, similar to the average of 160 mg/l shown in the 1995 DEIR/EIS. The Cl^-:EC value was 0.16, similar to the values for Holland Tract and Bacon Island. Thus, seawater intrusion or San Joaquin River water was also a significant source of salt in Webb Tract irrigation water.

Figure G-2 indicates that Webb Tract drainage DOC concentrations averaged 29.7 mg/l. Given an assumed DOC in applied water of 3 mg/l and drainage-to-applied-water EC ratio of 3, the expected drainage DOC concentration in Webb Tract drainage would be 9 mg/l. The estimated source loading of DOC would be 10.4 g/m^2/yr (20.7 g/m^3 • 20 inches • 0.025 m/inch). The estimated DOC contribution is the same as the estimate of 10 g/m^2/yr presented in the 1995 DEIR/EIS (because few additional drainage samples were collected).

Twitchell Island

DWR began monitoring drainage at Twitchell Island in 1994 and has conducted special agricultural drainage water quality studies on the island in cooperation with USGS and California Urban Water Agencies (CUWA). Figure G-3a shows that during the January 1994 to January 1998 monitoring period, the drainage EC values for Twitchell Island ranged between 337 and 1,980 μS/cm, with an average of 937 μS/cm. The drainage DOC values ranged from 1.1 to 58.9 mg/l, with an average of 20.1 mg/l. Some of the siphons supplying irrigation water to Twitchell Island draw from backwater (closed-off) areas of Sevenmile Slough, which received the drainage from Brannon Island. The applied-water EC values and DOC concentrations may therefore be higher than for other Delta islands.

Drainage and siphon measurements for 1995 indicated that seepage must be a major source of drainage water for Twitchell Island. Drainage for 1995 was about 11,000 acre-feet (af), which represents an average drainage depth of 37 inches from the 3,600 acres. This is similar to the drainage measured from Bouldin Island. Rainfall was higher than average, with 25 inches recorded in 1995. The average evapotranspiration (ET) for the Delta lowlands is assumed to be 32 inches. The measured siphon flows during 1995 from 12 of the 21 siphons on Twitchell Island totaled 1,800 af. Because only half the siphons were monitored, the total applied water might have been as much as 3,600 af (i.e., twice the measured amount), which is equivalent to 12 inches. The remaining water needed to balance the water budget would be about 32 inches of seepage, which is derived as follows:

Rain (25 inches) + Applied water (12 inches) + Seepage (32 inches) =
ET (32 inches) + Drainage (37 inches)

This is similar to the estimates from the DWR Delta island consumptive use simulation results (California Department of Water Resources 1995). The DOC concentration for the seepage water is assumed to be the same as channel (i.e., applied-water) DOC concentration.

For Twitchell Island drainage samples, the average Cl^- concentration was 174 mg/l; the Cl^-:EC value was 0.18, similar to the values for Webb Tract, Holland Tract, and Bacon Island. Thus, seawater intrusion or San Joaquin River water was also a significant source of salt in Twitchell Island irrigation water.

Figure G-3a indicates that the Twitchell Island drainage DOC concentrations had an average of 20.1 mg/l. Given an assumed DOC in applied water of 3 mg/l and an assumed ratio of drainage EC to applied-water EC of 3, the expected drainage DOC concentration in Twitchell Island drainage would be 9 mg/l. The estimated source loading of DOC would therefore be 10.4 g/m^2/yr (11.1 g/m^3 • 37.5 inches • 0.025 m/inch).

The Twitchell Island special studies conducted by MWQI and USGS in 1995 provide the most accurate estimate of DOC loading from a Delta agricultural island because direct measurements of drainage flow were taken and DOC concentrations were sampled frequently. Table G-1 shows weekly data from these studies.

USGS (U.S. Geological Survey 1997) reported weekly pumping records that have been combined with daily DOC samples for 1995 to provide weekly flow-weighted DOC drainage loads from Twitchell Island. The results are shown in Table G-1 and Figure G-3b. The flow-weighted annual DOC load was about 28 g/m^2, which includes the assumed DOC load from the applied water of about 9 g/m^2. This DOC drainage load is higher than the load estimated from the average DOC because the highest concentrations were sampled during periods with the highest drainage flow. The highest drainage in the winter of 1995 corresponded with the highest EC values and the highest DOC concentrations. The DOC loading based on these weekly flow and concentration patterns was about 19 g/m^2, which is about twice the DOC load of 10.4 g/m^2 estimated from the average drainage concentration. This suggests that the DOC loads estimated from average-drainage concentrations and total annual drainage depth may be substantially less than the actual flow-weighted DOC loads that would be obtained from more frequent drainage flow and concentration estimates.

Summary of Dissolved Organic Carbon Loading Estimates for Agricultural Operations

The available drainage data from Bacon Island, Bouldin Island, Holland Tract, Webb Tract, and Twitchell Island suggest that agricultural land use increases DOC in applied water by 3 to 23 g/m^2/yr, giving an average DOC loading rate of 12 g/m^2/yr. This is consistent with the average agricultural-use DOC loading presented in the 1995 DEIR/EIS.

ESTIMATING PROJECT EFFECTS ON SALINITY AND DISSOLVED ORGANIC CARBON

Water quality at Delta export locations is a function of the quality of water coming into the Delta, the way in which that quality may change as a result of in-Delta activities, the volume of Delta inflows and exports, and the proportion of the export water coming from each source. Export water is a mixture of water from the central Delta (which is assumed to be a mixture of water from the Sacramento, Mokelumne, and Cosumnes Rivers; seawater intrusion from the western Delta; and some portion of the San Joaquin River that does not flow directly to the export locations), San Joaquin River water, and Delta agricultural drainage. Under Delta Wetlands Project operations, Delta Wetlands discharges would be another source of export water and would therefore affect Delta export water quality. Quantitative modeling is used to estimate the contribution of the Delta Wetlands islands to levels of water quality constituents at Delta channel locations and in Delta diversions and exports.

This section describes DeltaSOQ, which is used to analyze the effects of Delta Wetlands Project discharges on monthly Delta export water quality. Information on Delta source contributions of salinity and DOC is first presented, then salinity and DOC calculations used in DeltaSOQ are described. To confirm the accuracy of the DeltaSOQ calculations, simulated results are compared to historical measured results for salinity and DOC and presented in a series of figures for the 1972-1994 time period. Data on all variables for all years are not available. However, the graphs show all available data plotted against the 1972-1994 time period to provide for easy comparison of water quality conditions for each year.

Delta Source Contributions of Salinity and Dissolved Organic Carbon

Data on inflow and export water quality constituents, as reported by the DWR MWQI program and described earlier in this appendix, are used to describe existing conditions and to determine how the concentrations of constituents change as water flows through the Delta. The difference between Delta inflow and Delta export concentrations for a selected water quality constituent (e.g., DOC) is used to estimate the net contribution from Delta sources, including agricultural drains.

The net contribution of a water quality constituent from Delta sources can be estimated from:

- the observed increase in concentration in the exports (above the assumed baseline concentration),
- the Delta export pumping volume, and
- the assumed fraction of the Delta-source contribution transported to the Delta export locations.

For example, if the water quality constituent amount increased by 1 mg/l above the Sacramento River concentration in a monthly average export flow of 5,000 cfs, the net contribution from Delta sources would be calculated as follows:

$$\text{Delta source contribution rate (kilograms [kg]/month)} = 73.5 \bullet 5{,}000 \text{ cfs} \bullet 1 \text{ mg/l} = 367{,}500 \text{ kg/month}$$

where 73.5 is the conversion from cfs and mg/l to kg/month.

If some known area of the Delta uniformly contributed this amount of the water quality constituent, the average uniform contribution per unit area (grams per square meter per month [g/m^2/month]), or "areal contribution rate", could be estimated. For the example given above, with an assumed source area equal to the Delta lowlands (396,000 acres), the average areal contribution rate would be calculated as follows:

$$\text{Areal contribution rate} = \frac{0.25 \bullet 367{,}500 \text{ kg/month}}{396{,}000 \text{ acres}} = 0.23 \text{g/m}^2\text{/month}$$

where 0.25 is the conversion from kg/acre to g/m^2 (4,047 m^2 per acre).

Therefore, a monthly load of about 1 g/m^2/month from an area of about 400,000 acres (about 4 times the loading in the example) would cause an increase of about 4 mg/l in exports of about 5,000 cfs. (Refer to Appendix C1 of the 1995 DEIR/EIS for a complete description of these calculations.) This is larger than the average increase in DOC concentration observed at the export locations compared with the Sacramento River concentration.

A systematic framework for estimating these net contributions from Delta sources was developed for the 1995 DEIR/EIS (refer to Appendix C4) based on observed concentration changes, Delta inflows, and export pumping rates. A version of these calculations that considers Delta lowlands only has been included in Delta Wetlands Project simulations conducted with the DeltaSOQ model for this revised draft environmental impact report/environmental impact statement (REIR/EIS). These calculations are described in the following sections.

Salinity Calculations in the Delta Standards, Operations, and Quality Model

As mentioned previously, export water is a mixture of water from the central Delta, the San Joaquin River, and agricultural drainage. Under Delta Wetlands Project operations, export water would include Delta Wetlands discharges in addition to water from these sources. The salinity (EC and Cl^-) of water from the central Delta, the San Joaquin River, agricultural drainage, and the Delta Wetlands Project islands and the proportions in which they are present in the exports determine export salinity. The export EC is estimated in DeltaSOQ based on the fraction of water from the four assumed sources as follows:

Export EC =
(central Delta fraction • central Delta EC) + (San Joaquin River fraction • San Joaquin River EC)
+ (drainage fraction • drainage EC) + (Delta Wetlands fraction • Delta Wetlands EC)

Delta Export Source Fractions

The export fractions are estimated with simple equations that depend on the volume of Delta flows and exports. The fraction of exports not contributed by the other sources is assumed to come from the central Delta.

A constant fraction (75%) of the San Joaquin River water is assumed to be exported:

$$\text{San Joaquin River fraction} = \frac{0.75 \bullet \text{San Joaquin River flow}}{\text{Total exports}}$$

If the total San Joaquin River flow is greater than the exports, then the San Joaquin River fraction can be 1 and the export EC and Cl^- is equal to the San Joaquin River EC and Cl^-.

The central Delta diversions and drainage flow are assumed to represent 40% of the Delta acreage and 40% of all Delta diversions and drainage flow. The remainder of Delta drainage is assumed to flow out of the Delta at Chipps Island. Because net drainage exists only if the rainfall is greater than the assumed ET value, drainage is highest in the winter months. Substantial seepage occurs from the channels to the drainage canals in the Delta lowlands, so a minimum drainage flow of 1 inch per month is assumed. In addition, 1 inch of drainage from salt leaching is assumed to occur in December, January, and February. The assumed drainage is therefore 15 inches in addition to the net drainage from rainfall. The 1 inch of drainage per month is equivalent to about 410 cfs from the assumed central Delta drainage acreage of 295,000 acres (i.e., 0.4 • 738,000 acres).

Table G-2 shows the calculated monthly central Delta drainage flows that are assumed to influence the export salinity and DOC concentrations in the DeltaSOQ model. For exports shown in Table 3-4 in Chapter 3, "Water Supply and Operations", drainage fractions are generally less than 5% of export pumping during the summer but increase to as much as 20% in some months with high rainfall.

Drainage water can be diverted by Delta diversions, Delta Wetlands diversions, or export pumping or can leave the central Delta as QWEST flow past Jersey Point. (QWEST is a calculated flow parameter that represents net flow between the central and western Delta.) The drainage fraction is calculated as:

$$\frac{\text{central Delta drainage flow}}{\text{Delta Wetlands diversion} + \text{central Delta diversions} + \max(\text{QWEST},0) + \text{exports} - 0.75\ \text{San Joaquin River flow}}$$

To establish the maximum potential effects from Delta Wetlands Project operations, 100% of the project discharges are assumed to reach the exports. The Delta Wetlands Project fraction is therefore:

$$\text{Delta Wetlands fraction} = \frac{\text{Delta Wetlands discharge}}{\text{Total exports}}$$

Salinity Intrusion

Salinity intrusion from Suisun Bay is an important factor in calculations of Delta salinity. Effects are simulated in DeltaSOQ using the Contra Costa Water District (CCWD) methodology, which is based on effective outflow and negative exponential relationships between effective outflow and salinity at Delta channel locations (see Appendix B2 in the 1995 DEIR/EIS). The effective outflow is similar to a weighted running average of outflow, with a weighting function that depends on outflow. For a monthly time step, the effective outflow is calculated as:

$$\text{New effective outflow (cfs)} = \frac{\text{Outflow (cfs)}}{1 + \left(\frac{\text{outflow}}{\text{old effective outflow}} - 1\right) \bullet \exp\left(\frac{-\text{outflow}}{6{,}600}\right)}$$

The EC values for the end of each month depend on the effective outflow for the month. For Chipps Island, Emmaton, and Jersey Point, the EC was calculated as follows, with a constant of 150 μS/cm representing the assumed EC value for the Sacramento River:

Chipps Island EC (μS/cm) = 150 + 30,000 • exp(-0.00025 • effective outflow)
Emmaton EC (μS/cm) = 150 + 12,500 • exp(-0.00040 • effective outflow)
Jersey Point EC (μS/cm) = 150 + 10,000 • exp(-0.00040 • effective outflow)

To confirm the accuracy of this component of the DeltaSOQ calculations, simulated EC (for historical Delta outflows) was compared with the monthly average measured EC at Chipps Island, Emmaton, and Jersey Point. This comparison is shown in Figure G-4. The model generally reproduces the seasonal effects of reduced outflow on increased EC. The Emmaton and Jersey Point EC values are similar, with Emmaton EC values higher than Jersey Point values when outflow is very low. The model represents the basic relationship between Delta outflow and measured EC values, although the historical monthly data are not always simulated exactly.

Central-Delta Salinity

The EC and Cl^- concentrations from the central Delta are calculated in DeltaSOQ as a function of the effective outflow, as shown in the following equation. One-third of the central Delta EC value is assumed to be derived from Jersey Point EC and two-thirds from Sacramento River EC. The constant of 7.5 mg/l is the assumed Cl^- concentration for the Sacramento River:

Central Delta EC (μS/cm) = 150 + 3,333 • exp(-0.00040 • effective outflow)
Central Delta Cl^- (mg/l) = 7.5 + 1,000 • exp(-0.00040 • effective outflow)

San Joaquin River Salinity

The San Joaquin River EC is assumed to be related to Vernalis flow as follows. The San Joaquin River Cl^-:EC ratio is assumed to be 0.15.

San Joaquin River EC (μS/cm) = 25,000 • flow (cfs) $^{-0.5}$
San Joaquin River Cl^- (mg/l) = 3,750 • flow (cfs) $^{-0.5}$

Agricultural Drainage and Delta Wetlands Salinity

Agricultural drainage salinity is calculated from a mass balance that tracks soil (i.e., pore-water) salinity. It is assumed, therefore, that there are no long-term changes in soil salinity. Agricultural drainage discharge from Delta islands originates from a complex drainage network. DeltaSOQ uses a very basic conceptual model of the soil pore-water budget. During the irrigation season, water is applied to the fields and generally evaporates, but some small fraction enters the drainage network. The drainage salinity is only slightly higher than that of the applied water because most of the applied salt remains in the soil. During winter, when rainfall and applied salt-leaching water are drained from the fields, some fraction of the accumulated soil salt is transported to the drainage network. The DeltaSOQ model can only approximate this seasonal accumulation of salt.

In DeltaSOQ, the soil pore-water depth is assumed to be 12 inches (peat-soil porosity is about 50%, and the soil depth is about 2 feet) based on DWR's Delta depletion analysis. Applied-water EC is assumed to be equal to the previous month's export EC. Drainage-water salinity is assumed to be equal to soil pore-water salinity. Pore-water salt increases as water evaporates and channel water is applied. Only drainage water removes salt from the soil pore-water volume. The soil pore-water salinity increases during the spring and summer months and decreases during the winter months when there is rain and applied leaching water.

Figure G-5 compares the simulated drainage EC values with MWQI drainage EC measurements from ten of the Delta lowland islands. Winter drainage EC values were typically higher than summer values. These EC measurements have a wide range and can only generally confirm the simulated drainage EC patterns. The drainage EC values are quite variable; the simulated range of drainage EC is between approximately 300 and 1,800 μS/cm. The measured range of EC values is also broad and is generally between 200 and 2,000 μS/cm. Therefore, although the simulated range of EC values does not always capture the extreme ends of the measured range, it represents most measured values. Simulated drainage EC is generally 2 or 3 times the applied EC.

Comparison of Simulated and Measured Export Concentrations

Figure G-6 compares the simulated export Cl^- concentrations with historical monthly Cl^- measurements from the CCWD pumping plant at Rock Slough. The seasonal variation of Cl^- concentrations generally matches the simulation results. The simulated results include the effects of the San Joaquin River, seawater intrusion, and central Delta agricultural drainage under historical flow and export conditions on export Cl^-. Some of the measured Cl^- concentrations are higher than the simulated values, suggesting that local drainage may affect Rock Slough more than it affects average south-Delta exports.

Figure G-7 compares simulated export EC concentrations with historical EC measurements from the Central Valley Project (CVP) and State Water Project (SWP) export locations. CVP measurements are made at the Delta-Mendota Canal (DMC). The seasonal patterns of measured EC generally match the simulation results.

Dissolved Organic Carbon Calculations in the Delta Standards, Operations, and Quality Model

DeltaSOQ establishes baseline DOC levels at Delta exports, determines DOC loading under agricultural conditions (i.e., the No-Project Alternative), and estimates DOC loading under flooded reservoir conditions (i.e., the proposed project). Project effects on DOC concentrations in Delta exports are a function of the following:

- the DOC concentrations in water diverted onto the Delta Wetlands islands;
- evaporative losses;
- DOC loading from peat soils and plant growth;
- residence time (i.e., the length of time water is stored on the islands before being discharged);
- DOC concentrations in Delta receiving waters at the time of Delta Wetlands discharges; and
- the relative amount of Delta Wetlands water in exports.

DeltaSOQ incorporates these factors into the calculation of DOC effects in a manner similar to that described above for EC and Cl^- calculations.

Dissolved Organic Carbon in Delta Inflows

Estimated DOC concentrations in Delta inflows and from agricultural drainage are used in DeltaSOQ to determine the DOC of Delta exports under no-project conditions and at times of Delta Wetlands Project diversions and discharges. The Sacramento River is assumed to have a constant DOC concentration of 2 mg/l. The San Joaquin River DOC concentration is assumed to be a constant of 4 mg/l. Central-Delta DOC is also assumed to be 2 mg/l, with no increase in DOC concentration from seawater intrusion.

Dissolved Organic Carbon in Agricultural Drainage

The DeltaSOQ model provides a logical mass-balance framework for estimating agricultural drainage DOC loads that parallels the salt balance estimates for EC and Cl^- drainage loads. The agricultural drainage DOC is estimated from a mass balance that tracks the soil pore-water DOC concentration.

As described under "Estimating Existing Levels of Dissolved Organic Carbon in Delta Agricultural Drainage" above, the DOC loading rates calculated from MWQI measurements of DOC concentrations in Delta island drainage range from 2.5 to 22.4 $g/m^2/yr$. Based on these results, DeltaSOQ simulated two estimates of DOC loading under agricultural operations to determine which more closely represents the measured drainage and export DOC concentrations and, therefore, should be used in the impact analysis. An estimate of approximately 12 $g/m^2/yr$, or 1 $g/m^2/month$, for DOC loading was simulated to represent most of the MWQI estimates; a second estimate of 24 $g/m^2/yr$, or 2 $g/m^2/month$, was simulated to encompass the higher rate measured in Bouldin Island drainage. The simulated Delta drainage and export DOC concentrations under each assumption were compared with measured data presented in Figures G-8 and G-9, respectively, and are discussed below. The results indicate that an assumed average agricultural DOC loading of 1 $g/m^2/month$ (i.e., 12 $g/m^2/yr$)

more closely matches measured data for the central Delta region than an assumption of 24 g/m^2/yr. Therefore, this value is used in the impact analysis.

Figure G-8 shows the simulated agricultural drainage DOC and the MWQI drainage DOC measurements from ten of the Delta lowland islands. For the assumed seepage and leaching volumes and the rainfall drainage that occurs in the winter months, the simulated soil pore-water DOC concentrations fluctuate seasonally between about 20 and 40 mg/l when an assumed loading factor of 1 g/m^2/month is used. The measured drainage DOC concentrations are generally within this range, although the flow-weighted average DOC in the drainage water cannot be determined because there are no drainage flow records. Only the basic seasonal DOC patterns and DOC increases during dry years can be confirmed with these data. As shown in Figure G-8, simulated results using an assumed loading factor of 2 g/m^2/month are considerably higher than the MWQI drainage DOC measurements. The 23-year period is shown to illustrate the simulated variations between wet and dry years.

Figure G-9 shows the simulated export DOC and the MWQI measurements of export DOC concentrations from the CVP and SWP facilities. In the simulation, 40% of total Delta agricultural drainage is assumed to originate from the Delta lowlands and be transported toward the export pumps. The seasonal fluctuations in the measured DOC concentrations generally match the DeltaSOQ results with an assumed load of 1 g/m^2/month. As shown in Figure G-9, the larger assumed monthly load of 2 g/m^2/month from agricultural islands results in simulated export DOC concentrations that are almost always higher than measured values. With the higher assumed load, the simulated export DOC concentrations of between 5 and 15 mg/l are much greater than the measured DOC values. This indicates that an assumed average agricultural DOC loading of about 1 g/m^2/month (i.e., 12 g/m^2/yr) is a reasonable estimate for the central Delta. The model mixes this drainage with the water from the river sources to calculate the export DOC.

Dissolved Organic Carbon Loading under Reservoir Operations

An additional load of DOC could result from inundation of the peat soils during reservoir operations under the proposed project. Reservoir operations would likely cause more DOC to be mixed from the pore water into the water column than when the peat soils are drained under agricultural practices. DOC loading is a function of many variables, including peat-soil depth, pore-water concentration, pore-water and water column mixing, plant material growth and degradation, resuspension of peat because of wind, and the length of time water is held. The storage DOC concentrations will also increase with evaporation and seepage control (i.e., interceptor well) pumping and discharge. Measured data on DOC loading under flooded peat-soil conditions similar to conditions proposed by Delta Wetlands are not available; therefore, estimates of DOC loading from reservoir operations are based on experimental results.

In the long term, repeated filling and emptying of the Delta Wetlands reservoir islands might leach out most of the soluble organic material; therefore, DOC loading from peat soils might decline over time. At least the first few fillings, however, would likely result in high DOC loading. Therefore, the analysis presents three simulations of potential project effects on DOC in Delta exports: an assumption for long-term DOC loading, an assumption for initial-filling DOC loading, and an assumption for high initial-filling DOC loading.

The DeltaSOQ model was used to determine how an increased DOC load resulting from Delta Wetlands Project operations would affect export DOC concentrations. The largest DOC increases would occur in months with Delta Wetlands discharges. As discussed in Chapter 4 under "Environmental Consequences", the simulated increases in DOC concentrations with Delta Wetlands operations are a function of the fraction of the exports coming from the Delta Wetlands discharge, which is almost always less than 20% (see Tables 3-4 and 3-15), and the estimated Delta Wetlands discharge DOC concentrations.

Additionally, this REIR/EIS method accounts differently for cessation of agricultural activities on the Delta Wetlands islands than does the method used in the 1995 DEIR/EIS. Because project impacts change water quality conditions relative to conditions under the No-Project Alternative, the 1995 DEIR/EIS reported that the cessation of agricultural activities on the Delta Wetlands islands and the subsequent reduction in agricultural drainage DOC loading would benefit water quality. Commenters on the 1995 DEIR/EIS argued that this assumption may not be valid and that DOC loading under reservoir operations should be considered in addition to the agricultural loading estimates. Therefore, the agricultural drainage DOC loading estimate of 1 g/m^2/month (or 12 g/m^2/yr) is assumed under both the no-project and proposed project conditions. In other words, the contribution of Delta Wetlands islands to agricultural drainage DOC is not considered to change in this REIR/EIS analysis under simulated no-project and proposed project conditions.

Initial-Filling DOC Loading Estimate. For purposes of this analysis, DOC loading for the initial reservoir filling is assumed to be 5 times greater than DOC loading under agricultural conditions. This assumption results in a DOC loading estimate of 4 g/m^2/month during storage periods (in addition to the constant agricultural contribution of 1 g/m^2/month described above). This estimate is based on Special Multipurpose Applied Research Technology Station (SMARTS) 1 results for static tanks, for which a DOC load of 24 to 54 g/m^2/yr was estimated; it is also compatible with the SMARTS 2 results for static tanks filled with peat soil that produced pore-water DOC concentrations of 46.8 and 57.8 mg/l (i.e., tanks 5 and 7, respectively), for which a DOC load of 23 to 42 g/m^2/yr was estimated (see Tables 4-3, 4-4, and 4-5 in Chapter 4). This assumed initial-fill DOC load is also consistent with results from the flooded wetland demonstration project on Holland Tract and the Tyler Island flooding study (Table 4-5).

As discussed in Chapter 4, experts disagree regarding potential DOC loading under reservoir operations. The ranges of data from experiments (e.g., SMARTS) and theoretical estimates of DOC loading vary widely. The DOC loading estimate of 5 g/m^2/month of storage (4 g/m^2/month for reservoir operations plus 1 g/m^2/month for agricultural contributions) is 5 times greater than the estimate used in the 1995 DEIR/EIS, and is presented along with the long-term loading estimate described below to provide a range of DOC loading estimates for impact analysis. As described above, the 4 g/m^2/month value is based on the results of measured data from the SMARTS reports, the Holland Tract flooded wetland demonstration, and the Tyler Island flooding experiment. For all these estimates, the measured loading was assumed to represent total annual loading because, in most cases, results indicated that peat-soil pore-water samples would approach loading limits in less than 6 months. However, in recognition of the debate regarding worst-case initial-fill DOC loading, results for a high initial-fill loading estimate of 9 g/m^2/month are also presented. Combined with loading of 1 g/m^2/month for agricultural contributions, this represents a DOC loading rate that is 10 times higher than the estimated agricultural drainage loading under no-project conditions.

Long-Term DOC Loading Estimates. For long-term (versus initial-filling) DOC loading estimates, additional loading is specified in the DeltaSOQ model as an additional 1 g/m^2/month during the storage period (i.e., 1 g/m^2/month in addition to the assumed constant agricultural load of 1 g/m^2/month in the Delta). This estimate doubles the agricultural loading estimate assumed under no-project conditions.

Dissolved Organic Carbon Loads from Interceptor Wells. Commenters on the 1995 DEIR/EIS and parties testifying at the State Water Resources Control Board (SWRCB) water right hearing also contended that DOC-loading effects of interceptor wells used to control seepage from the Delta Wetlands reservoir islands (see Chapter 6, "Levee Stability and Seepage") would be a potentially significant source of DOC from the reservoir islands. When the reservoir islands are full, water seeping from the reservoirs would be captured by interceptor wells located in the perimeter levees and returned to the reservoirs.

Based on results of the levee stability and seepage technical report (see Section 2.3, "Seepage Analysis", in Appendix H of this REIR/EIS), it was assumed that the pumping rates in the interceptor well system under full storage conditions would be 0.033 to 0.238 gallon per minute (gpm) per foot of levee. Under the proposed seepage control system (see Chapter 6), interceptor wells would be installed along the entire perimeter of Bacon Island (approximately 14.5 miles) and less than half the perimeter of Webb Tract (estimated as approximately 6.5 miles). Using these estimates, the amount of water pumped when both islands are at full storage is calculated to be approximately 3,700 to 26,400 gpm, which corresponds to approximately 500 to 3,500 af/month (1,000 gpm = 4.4 af/day). This is equivalent to pumping 0.6 to 4.2 inches of water onto the reservoir islands (surface area of Bacon Island and Webb Tract is approximately 10,000 acres). Assuming a 6-month full-storage period for both islands and a DOC concentration in the seepage water that is 10 mg/l higher than reservoir DOC concentration, the additional DOC load is calculated to be 1 to 6 g/m^2/yr:

$$\text{DOC loading (g/m}^2\text{/yr)} = \text{change in DOC concentration (mg/l per year)} \bullet \text{depth (m)}$$

If it is assumed that the water will be stored for a longer period or that the DOC concentrations will change more as a result of interceptor well pumping, the resulting change in annual DOC load from the reservoir islands would be greater. For example, using the equations outlined above, a 9-month storage period with an assumed DOC concentration of 20 mg/l in pumped water results in an increased DOC loading estimate of 3 to 19 g/m^2/yr. This DOC loading rate is relatively high compared to estimates of DOC loading under existing agricultural practices, which include a considerable amount of drainage pumping to balance seepage from adjacent channels and maintain acceptable water levels for crop production.

Although seepage prevention operations could increase DOC loading on the reservoir islands, an increase of this magnitude is more likely to occur during initial storage operations. The peat soils underlying the reservoir islands may be flushed over time, and the difference in DOC concentrations between reservoir island water and pumped water is not likely to remain as high as in the estimates presented above. The assumed initial-filling DOC loads for reservoir islands (i.e., 4 and 9 g/m^2 per month of storage) include the estimated load from the interceptor well pumping.

ESTIMATING PROJECT EFFECTS ON TRIHALOMETHANE AND BROMATE CONCENTRATIONS IN TREATED WATER

SWRCB staff determined that the potential effects of Delta Wetlands Project operations on treated-drinking-water DBPs (THM and bromate) would be evaluated as an additional level of water quality impact assessment. Because DBP concentrations are determined by both the raw water quality parameters (DOC and Br^-) and the treatment process parameters (chlorination dose, pH, temperature, holding time), only representative estimates of the incremental effects of increased DOC and Br^- concentrations on these DBP concentrations can be calculated. Potential effects of Delta Wetlands operations on THM concentrations are calculated and reported; the effects on bromate concentrations are not calculated because no reliable relationship with DOC or Br^- could be identified. The effects of Delta Wetlands Project operations on THM concentrations are calculated using an approximate relationship between export water DOC and Br^- concentrations and treated water THM concentrations. This relationship is described in the following section.

Calculations Using the Malcolm Pirnie Equation

In the 1995 DEIR/EIS, the U.S. Environmental Protection Agency's (EPA's) Water Treatment Plant (WTP) model was used to estimate THM concentrations at a typical water treatment plant that may use Delta exports containing water released from the Delta Wetlands Project islands. The model consists of a series of subroutines that simulate THM formation and removal of organic THM precursor compounds. A more detailed description of the operation of the WTP model is provided in Appendix C5 of the 1995 DEIR/EIS. Estimates of THM in treated Delta exports were evaluated in the 1995 DEIR/EIS with simulated Delta conditions for 1968-1991. Export concentrations of water quality variables were estimated from the Delta Drainage Water Quality model (DeltaDWQ) results for Cl^- and DOC.

The WTP model predicts total THM concentration, then determines the concentrations of different types of THM molecules by estimating relative concentrations from separate regression equations for each of the four types of THM molecules (chloroform [$CHCl_3$], dichlorobromomethane [$CHCl_2Br$], dibromochloromethane [$CHClBr_2$], and bromoform [$CHBr_3$]). All of the multiple-logarithmic regressions are similar, but the coefficient values for the independent variables differ. The original equation for total THM concentration is:

$$\text{THM } (\mu g/l) = 0.3254 \bullet \text{DOC}^{0.44} \bullet \text{UVA}^{0.351} \bullet \text{Cl}_2^{0.409} \bullet \text{Hours}^{0.265} \bullet \text{Temp}^{1.06} \bullet (\text{pH} - 2.6)^{0.715} \bullet (\text{Br}^- + 1)^{0.516}$$

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DOC units are mg/l. Ultraviolet absorbance (UVA) is estimated as 0.0375 • DOC in the model. Chlorine (Cl_2) dose is assumed to be a fraction (i.e., 1.0) of the DOC concentration (California Urban Water Agencies 1996). Temperature is measured in Celsius. Br^- units are mg/l. The ratio of Br^- to Cl^- is assumed to be 0.0035, and the maximum allowable Cl^- concentration in Delta exports is 250 mg/l, so the maximum allowable Br^- concentration is about 0.875 mg/l, and the (Br^- + 1) term varies from about 1.05 to 1.875.

The THM equation was modified by Malcolm Pirnie (Malcolm Pirnie 1993), using experimental data measured by the Metropolitan Water District of Southern California (MWD), to specifically address differences in THM formation with high Br^- concentration in Delta source waters. The revised equation developed with MWD data is:

$$\text{THM } (\mu g/l) = 7.21 \bullet DOC^{0.004} \bullet UVA^{0.534} \bullet (Cl_2 - 7.6 \bullet NH_3 - N)^{0.224} \bullet Hours^{0.255} \bullet Temp^{0.48} \bullet (pH - 2.6)^{0.719} \bullet (Br^- + 1)^{2.01}$$

The magnitude of the coefficient for each independent variable indicates the degree to which THM concentrations will respond to a change in that variable when other conditions remain the same. Because UVA is a linear function of DOC, and Cl_2 dose generally increases as a linear function of DOC (Cl_2 dose is approximately 1.0 • DOC), an increase in DOC will generally cause all three variables to increase. The effective DOC exponent of the original equation is 1.2 (0.44 + 0.351 + 0.409), whereas for the revised equation it is only 0.762 (0.004 + 0.534 + 0.224). If source-water DOC increased by 20%, THM formation would increase by about 25% with the original equation and only by about 15% with the revised equation. However, both equations suggest that THM increases almost linearly with DOC. A linear relationship between THM and DOC was also assumed in the DeltaSOQ model, which is used to evaluate Delta Wetlands Project impacts on THM concentrations.

The modification in the equation for Br^-, however, may not accurately represent the effect of Br^- concentrations on THM formation. Basic THM chemistry dictates that the number of THM molecules formed from a given concentration of DOC depends on the chlorination dose; the only effect of the Br^- concentration will be to influence which species of THM molecules will form (see Appendix C5 of the 1995 DEIR/EIS). If all the THM formed during treatment were $CHBr_3$, the THM concentration would be about twice (2.12 x) as high as if no Br^- were present and $CHCl_3$ were formed instead (because a mole of $CHBr_3$ weighs 252 g and a mole of $CHCl_3$ weighs 119 g). Therefore, the maximum effect of Br^- should be to double the concentration (weight) of THM. However, with the original equation, THM increases by only 42% (a factor of less than 0.5) as Br^- increases from 0.05 mg/l to 1 mg/l. With the revised equation, as Br^- increases from 0.05 mg/l to 1 mg/l, the predicted THM concentration would increase by a factor of 4. Both of these results are inconsistent with the basic THM chemistry described above. Therefore, the exponent in the original equation of 0.516 is considered too low, and the exponent of 2.01 in the revised equation is considered too high.

For the approximate relationship used in the DeltaSOQ model, the exponent of the (1 + Br^-) term has been set to 1 to calculate a doubling of THM concentration as Br^- increases from 0.05 mg/l to 1 mg/l. A constant Br^-:Cl^- ratio of 0.0035 is used to estimate export Br^- concentrations. The coefficient of the equation used in DeltaSOQ (10.0) was set to simulate the ability of the water treatment plants to adjust their operating conditions to provide treated water with THM concentrations that are generally less than the current MCL concentration of 80 μg/l. The actual slope of this relationship between DOC and THM depends on specific water treatment plant operations. The simplified equation used in DeltaSOQ is:

$$THM\ (\mu g/l) = 10.0 \bullet DOC \bullet [1 + 0.0035 \bullet Export\ Cl^- (mg/l)]^{1.0}$$

Figures G-10a and G-10b show the treated-water THM concentrations actually measured at Penitencia WTP compared with the raw DOC and Br^- concentrations. A linear regression between DOC and THM concentrations from the Penitencia WTP data indicates a very small effect of DOC on THM (i.e., THM = 65 + 2.0 • DOC, $r^2 = 0.01$). The predicted THM concentrations for the original and revised Malcolm Pirnie equations as well as the simplified equation used for impact assessment purposes are also shown in the figures.

Although SWRCB staff asked CUWA to provide additional treatment plant DOC, Br^-, and THM data to help confirm the revised THM equation, CUWA was unable to provide any other data and instead resubmitted data from the MWD testing used by Malcolm Pirnie to revise the THM equation. The treatment conditions (i.e., temperature, pH, coagulant dose, and Cl_2 dose) vary too widely for relationships between THM and DOC or Br^- to be evident. Because CUWA provided no additional data to identify this relationship between DOC and THM, the DeltaSOQ model used the approximate value of 10.0 to evaluate the likely effects on THM concentrations of Delta Wetlands' discharge of water with higher DOC concentrations.

The simplified equation preserves the predicted effect of DOC on THM concentration identified in the Malcolm Pirnie equations (exponent of about 1.0) and simulates that an increase of Br^- from 0 to 1 mg/l will double the THM concentration. Using the simplified equation, an increase of 0.8 mg/l DOC will result in an expected increase in THM concentration of 8 μg/l if Br^- is 0.0 mg/l and of 16 μg/l if Br^- is 1.0 mg/l.

Estimating Bromate Concentrations in the Delta Standards, Operations, and Quality Model

Federal regulations for bromate (BrO_3) were first proposed in 1994, revised in 1997, and finally promulgated in December 1998 (63 FR 63 69389; December 16, 1998). The MCL for bromate was established at 10 μg/l. This chemical is formed during disinfection of raw water with ozone (O_3). Disinfection with O_3 is preferable to chlorination in certain situations in which DOC is elevated, because it generally produces fewer THMs than chlorination and provides greater disinfection against viruses and other microorganisms.

The predictive equation for bromate formation in treated drinking water developed by Ozekin (Ozekin 1994) was assessed for use in this REIR/EIS analysis. As described below, however, this equation does not match the measured relationship between bromate and Br^- and DOC concentration in source water. Absence of a reliable predictor of a relationship between bromate and Br^- or DOC limits the ability to evaluate Delta Wetlands Project effects on bromate.

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The equation developed by Ozekin has the following form:

$$BrO_3\ (\mu g/l) =$$
$$(1.63 \bullet 10^{-6}) \bullet DOC^{0.004} \bullet pH^{5.82} \bullet (O_3\ dose)^{1.57} \bullet Br^{-\ 0.73} \bullet Time^{0.28}$$

The O_3 dose is assumed to be some fraction (e.g., 0.5) of the DOC concentration, the Br^- units are μg/l, and the time units are minutes. The exponents in this equation indicate that bromate is not sensitive to DOC concentration; a 20% increase in DOC will increase bromate by less than 0.1%. A 20% increase in Br^- concentration will increase the predicted bromate concentration by 14%.

CUWA funded a study (California Urban Water Agencies 1996) to investigate the water treatment strategies and improvements that would be needed to comply with the revised Stage 1 rules for total THMs and other DBPs, including bromate and haloacetic acids. The study included DBP formation potential experiments using waters with high Br^- concentrations; it assessed the effectiveness of disinfection by chlorination and ozonation and the ability of enhanced coagulation processes to reduce DBPs. Measured data were also collected from CUWA member agency treatment plants for evaluation of potential compliance performance. The CUWA-funded ozonation experiments used variable ratios of O_3 to DOC, variable pH levels, and a constant O_3 contact time of 12 minutes (Malcolm Pirnie 1993).

Figures G-11a and G-11b compare data from member agency treatment plants to results predicted with the Ozekin model. Most of the data are from MWD laboratory pilot scale tests. The results of the bromate equation exceed the MCL for bromate (10 μg/l) when total organic carbon (TOC) is greater than 2 mg/l and when Br^- concentrations are higher than about 250 μg/l, with the other parameters specified as suggested by the CUWA study. This means that existing Delta water quality conditions will produce bromate concentrations that are higher than allowable if ozonation is used with the pH and O_3 doses suggested by the MWD study. However, this finding is not consistent with full-scale treatment plant measurements: the bromate prediction equation produces values that are generally higher than measured values. There appears to be no direct correlation between treatment plant measurements of bromate and measurements of either Br^- or DOC in the source water.

Based on the lack of any observed relationship between bromate formation and Br^- or DOC concentrations in the source water, it was determined that the impact analysis should address the effects of Delta Wetlands Project operations effects on Br^- and DOC, but not try to predict changes in bromate concentrations expected in drinking water treated by O_3. The impact analysis for the Delta Wetlands Project identifies the changes in DOC and Br^- that are likely to be observed at Delta diversion and export locations. Therefore, the basic proposed mitigation for water quality impacts (see "Recommended Mitigation and Delta Wetlands Project Operations" in Chapter 4) can be used to limit the allowable increase in DOC and Br^-, thus limiting the expected effect on bromate. If a predictable relationship between Br^- and bromate is identified in the future, it can be used to regulate Delta Wetlands operations to maintain acceptable changes in DOC and Br^- at the export and diversion locations, relative to the MCL value of bromate.

Table G-1. Weekly Drainage and Average DOC Concentrations for Agricultural Drainage from Twitchell Island in 1995

Date	Drainage (AF)	EC (µS/cm)	DOC mg/l	DOC Load (g/m²)	Drainage (inches)
01/04	373.4	1300	29.1	0.9	1.3
01/11	500.4	1330	31.5	1.4	1.7
01/18	564.3	1560	37.1	1.8	1.9
01/25	559.5	1860	43.2	2.1	1.9
02/01	552.9	1780	46.6	2.2	1.9
02/08	372.6	1780	41.9	1.4	1.3
02/15	295.5	1600	37.4	1.0	1.0
02/22	288.2	1570	37.0	0.9	1.0
03/01	214.2	1600	34.5	0.6	0.7
03/08	340.8	1740	51.4	1.5	1.2
03/15	534.8	1630	49.8	2.3	1.8
03/22	425.2	1780	44.8	1.7	1.5
03/29	557.1	1670	45.5	2.2	1.9
04/05	207.3	1460	30.1	0.5	0.7
04/12	178.0	1320	28.4	0.4	0.6
04/19	168.8	1120	23.8	0.3	0.6
04/26	164.0	1060	22.6	0.3	0.6
05/01	112.5	1020	21.9	0.2	0.4
05/08	164.0	1000	20.9	0.3	0.6
05/15	154.3	860	17.3	0.2	0.5
05/22	146.0	970	20.2	0.3	0.5
05/29	157.3	840	15.8	0.2	0.5
06/05	118.5	830	17.3	0.2	0.4
06/12	121.4	770	13.9	0.1	0.4
06/19	127.5	760	11.2	0.1	0.4
06/26	138.8	780	14.2	0.2	0.5
07/03	144.2	680	11.3	0.1	0.5
07/10	114.2	630	8.4	0.1	0.4
07/17	145.0	510	7.7	0.1	0.5
07/24	157.3	590	9.1	0.1	0.5
07/31	225.9	450	12.7	0.2	0.8
08/07	206.6	540	15.3	0.3	0.7
08/14	210.0	440	10.7	0.2	0.7
08/21	205.9	440	10.5	0.2	0.7
08/28	173.6	530	13.6	0.2	0.6
09/05	135.7	590	15.3	0.2	0.5
09/11	69.0	640	8.4	0.1	0.2
09/18	72.0	640	11.5	0.1	0.2
09/25	68.6	680	7.1	0.0	0.2
10/02	72.6	640	7.4	0.0	0.2
10/10	72.6	700	6.6	0.0	0.2
10/16	65.9	700	6.8	0.0	0.2
10/23	60.2	720	6.0	0.0	0.2
10/30				0.0	0.0
11/06	148.9	550	7.5	0.1	0.5
11/14				0.0	0.0
11/20	153.0	740	7.4	0.1	0.5
11/27	74.7	710	7.2	0.0	0.3
12/04	80.6	600	8.6	0.1	0.3
12/11				0.0	0.0
12/18	311.3	1070	16.9	0.5	1.1
12/31	481.7	1030	29.1	1.2	1.6
Annual Average		1000	21.1		
Annual Total	10986			27.5	37.5

Sources: U.S. Geological Survey 1997 and California Department of Water Resources 1999a.

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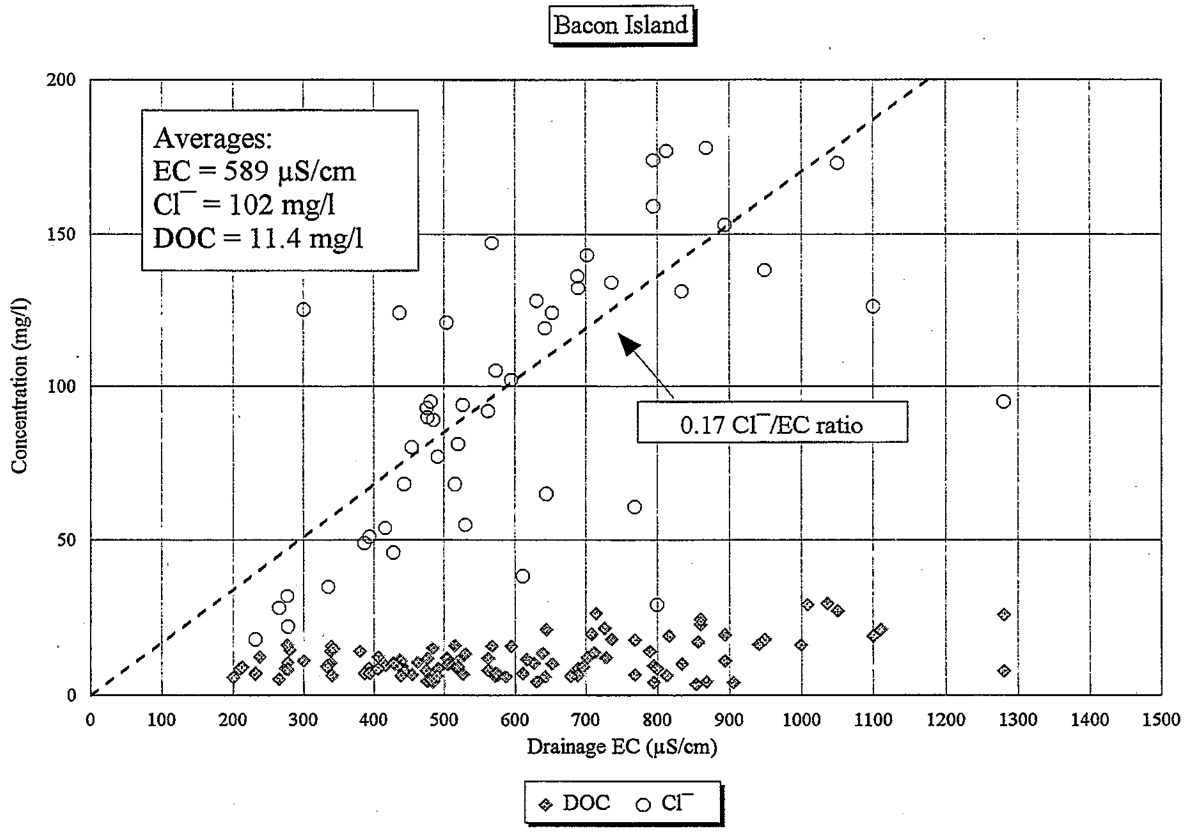
Table G-2. Calculated Central Delta Drainage Flows (cfs)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1922	410	410	410	1477	2044	820	410	410	410	410	410	410
1923	410	410	1379	1516	820	820	410	410	410	410	410	410
1924	410	410	410	872	820	820	410	410	410	410	410	410
1925	410	410	482	1087	1886	820	410	410	410	410	410	410
1926	410	410	410	1015	1605	820	410	410	410	410	410	410
1927	410	410	410	1210	2080	820	410	410	410	410	410	410
1928	410	410	410	1074	820	1035	410	410	410	410	410	410
1929	410	410	410	989	820	820	410	410	410	410	410	410
1930	410	410	410	1275	1101	833	410	410	410	410	410	410
1931	410	410	410	1067	842	820	410	410	410	410	410	410
1932	410	410	1178	1243	1522	820	410	410	410	410	410	410
1933	410	410	410	1262	820	820	410	410	410	410	410	410
1934	410	410	410	931	1360	820	410	410	410	410	410	410
1935	410	410	410	1672	820	1145	524	410	410	410	410	410
1936	410	410	410	1340	2447	820	410	410	410	410	410	410
1937	410	410	410	1243	1951	1932	410	410	410	410	410	410
1938	410	410	410	1288	3038	1601	410	410	410	410	410	410
1939	410	410	410	879	820	820	410	410	410	410	410	410
1940	410	410	410	1874	2579	1139	410	410	410	410	410	410
1941	410	410	898	2245	2023	853	410	410	410	410	410	410
1942	410	410	417	2030	1108	820	497	410	410	410	410	410
1943	410	410	410	1815	921	1009	410	410	410	410	410	410
1944	410	410	410	911	1446	820	410	410	410	410	410	410
1945	410	410	410	944	1317	1028	410	410	410	410	410	410
1946	410	410	683	911	820	820	410	410	410	410	410	410
1947	410	410	410	859	878	820	410	410	410	410	410	410
1948	410	410	410	820	820	820	410	410	410	410	410	410
1949	410	410	410	937	863	1080	410	410	410	410	410	410
1950	410	410	410	1269	935	820	410	410	410	410	410	410
1951	410	410	1126	1594	1029	820	410	410	410	410	410	410
1952	410	410	833	2726	855	1171	410	410	410	410	410	410
1953	410	410	696	1327	820	820	410	410	410	410	410	410
1954	410	410	410	885	820	820	410	410	410	410	410	410
1955	410	410	410	1588	820	820	410	410	410	410	410	410
1956	410	410	1555	2596	820	820	410	410	410	410	410	410
1957	410	410	410	866	935	820	410	410	410	410	410	410
1958	410	410	410	1776	2815	1607	652	410	410	410	410	410
1959	410	410	410	970	1295	820	410	410	410	410	410	410
1960	410	410	410	1028	1154	820	410	410	410	410	410	410
1961	410	410	410	1366	820	820	410	410	410	410	410	410
1962	410	410	410	885	2513	820	410	410	410	410	410	410
1963	410	410	410	1562	1252	1022	773	410	410	410	410	410
1964	410	410	410	1282	820	820	410	410	410	410	410	410
1965	410	410	768	1588	820	820	410	410	410	410	410	410
1966	410	410	469	1217	906	820	410	410	410	410	410	410
1967	410	410	631	2941	820	1100	686	410	410	410	410	410
1968	410	410	410	1165	917	820	410	410	410	410	410	410
1969	410	410	410	2752	2347	820	410	410	410	410	410	410
1970	410	410	410	2524	827	820	410	410	410	410	410	410
1971	410	410	1139	1035	820	820	410	410	410	410	410	410
1972	410	410	410	898	820	820	410	410	410	410	410	410
1973	410	679	514	2993	2016	898	410	410	410	410	410	410
1974	410	410	781	1412	820	918	410	410	410	410	410	410
1975	410	410	410	833	1346	1236	410	410	410	410	410	410
1976	410	410	410	820	820	820	410	410	410	410	410	410
1977	410	410	410	853	820	820	410	410	410	410	410	410
1978	410	410	410	2798	1562	1425	410	410	410	410	410	410
1979	410	410	410	1633	1814	820	410	410	410	410	410	410
1980	410	410	410	1848	2190	820	410	410	410	410	410	410
1981	410	410	410	1061	820	898	410	410	410	410	410	410
1982	410	410	566	2550	1036	1958	410	410	410	410	410	410
1983	410	780	703	2687	2217	2648	410	410	410	410	410	410
1984	410	410	1178	846	862	820	410	410	410	410	410	410
1985	410	518	410	989	820	944	410	410	410	410	410	410
1986	410	410	410	1386	3161	1295	410	410	410	410	410	410
1987	410	410	410	866	928	833	410	410	410	410	410	410
1988	410	410	410	1373	820	820	410	410	410	410	410	410
1989	410	410	410	853	820	820	410	410	410	410	410	410
1990	410	410	410	976	899	820	410	410	410	410	410	410
1991	410	410	410	820	820	983	410	410	410	410	410	410
1992	410	410	410	879	1578	846	410	410	410	410	410	410
1993	410	410	527	3364	2232	859	410	410	410	410	410	410
1994	410	410	410	989	1231	820	410	410	410	410	410	410
Average	410	420	524	1417	1288	959	425	410	410	410	410	410



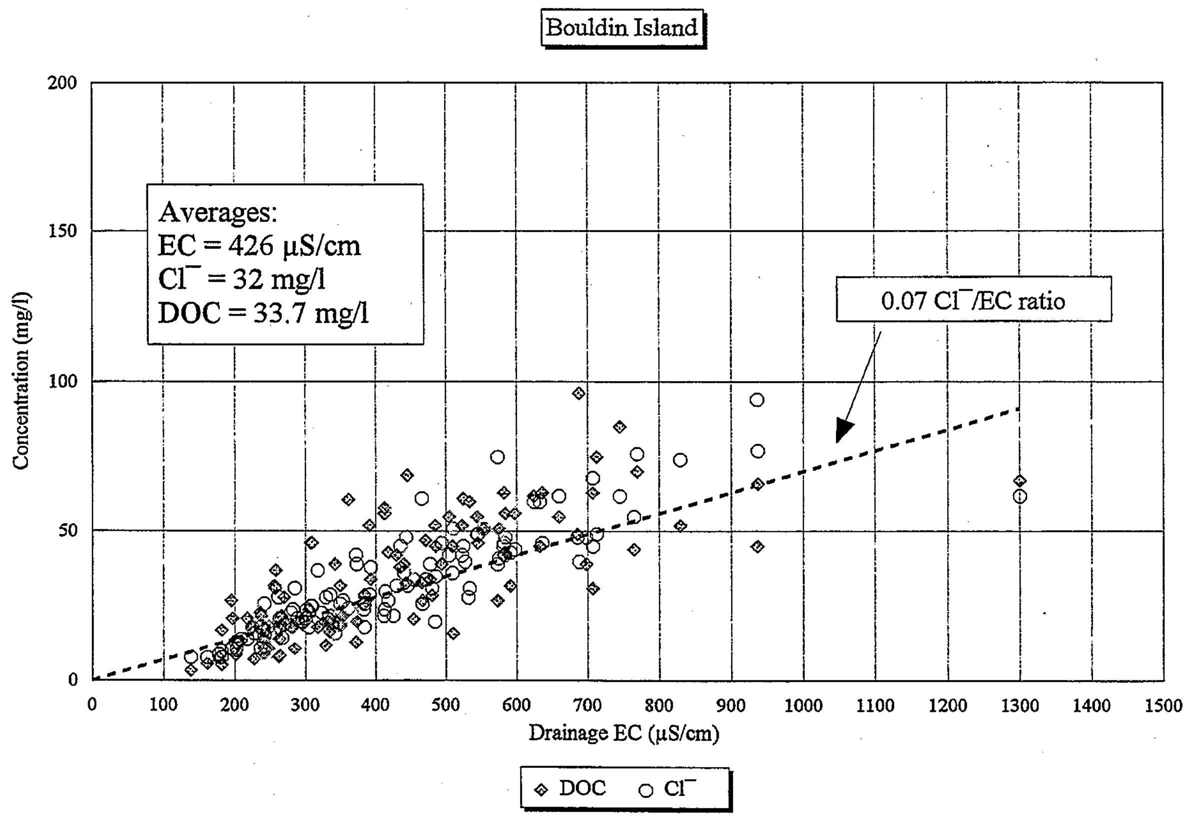


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Figure G-1
DOC and Cl^- Compared to EC Values in Monthly Bacon and Bouldin Island Drainage Samples

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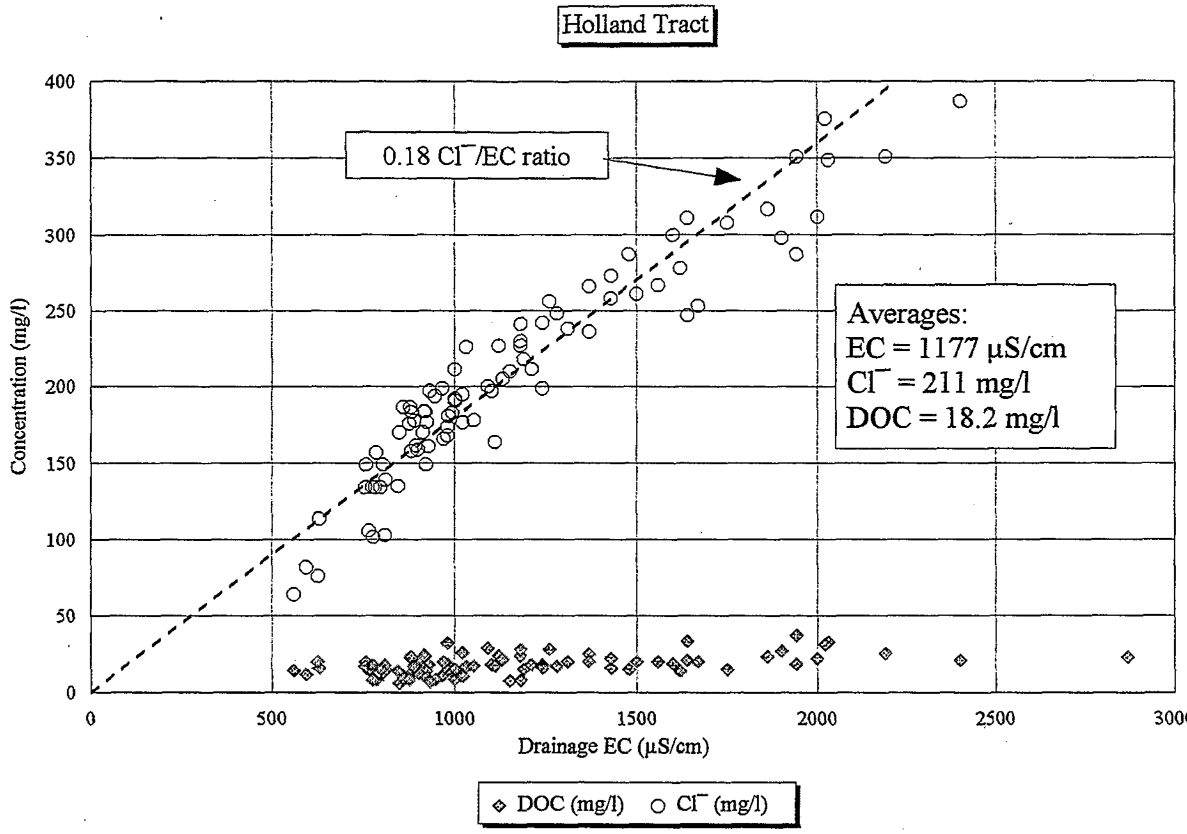

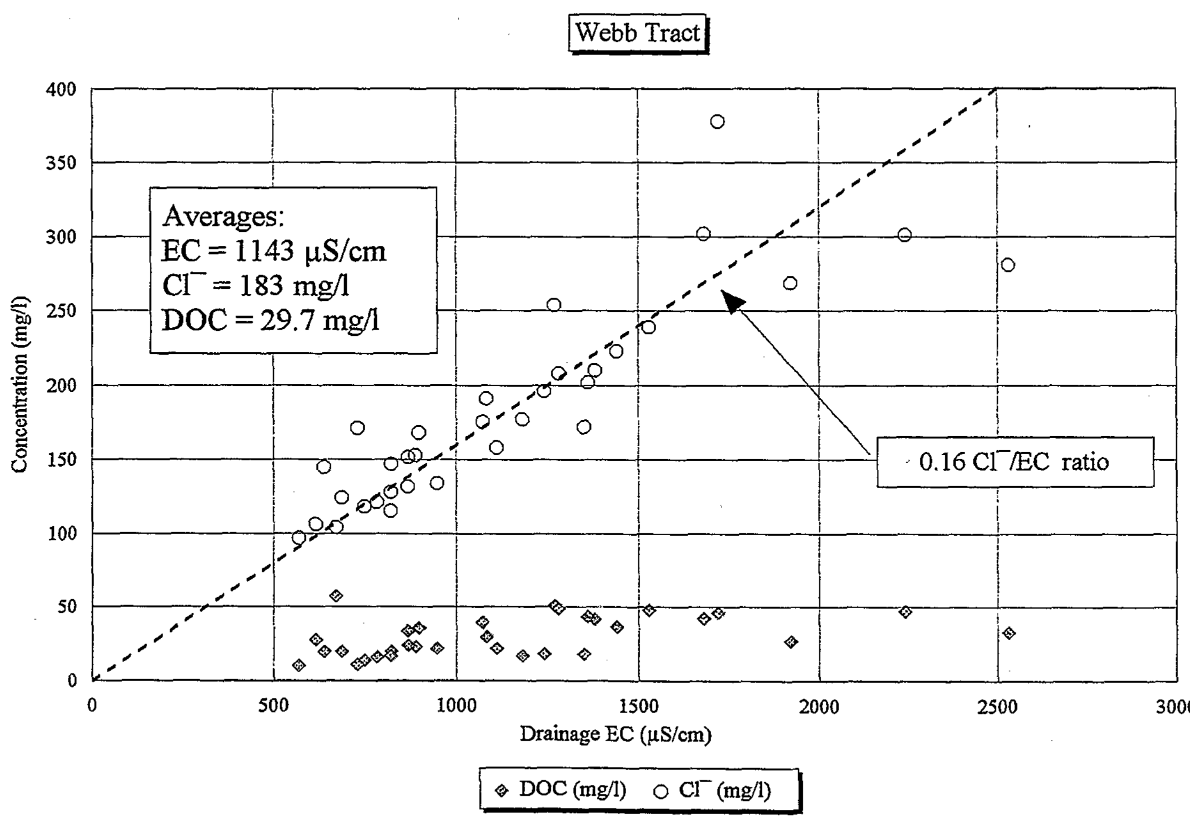

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Figure G-2
DOC and Cl⁻ Compared to EC Values in Monthly Holland Tract and Webb Tract Drainage Samples

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Figure G-3a
DOC and Cl⁻ Compared to EC Values in 1994-1998 Twitchell Island Drainage Samples

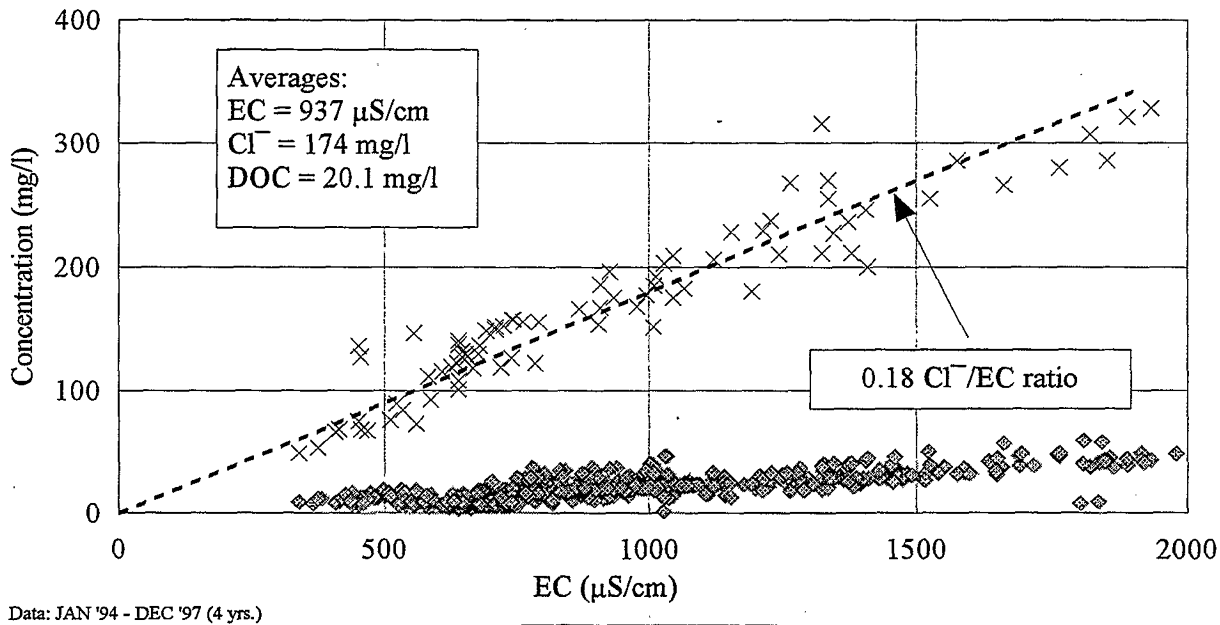
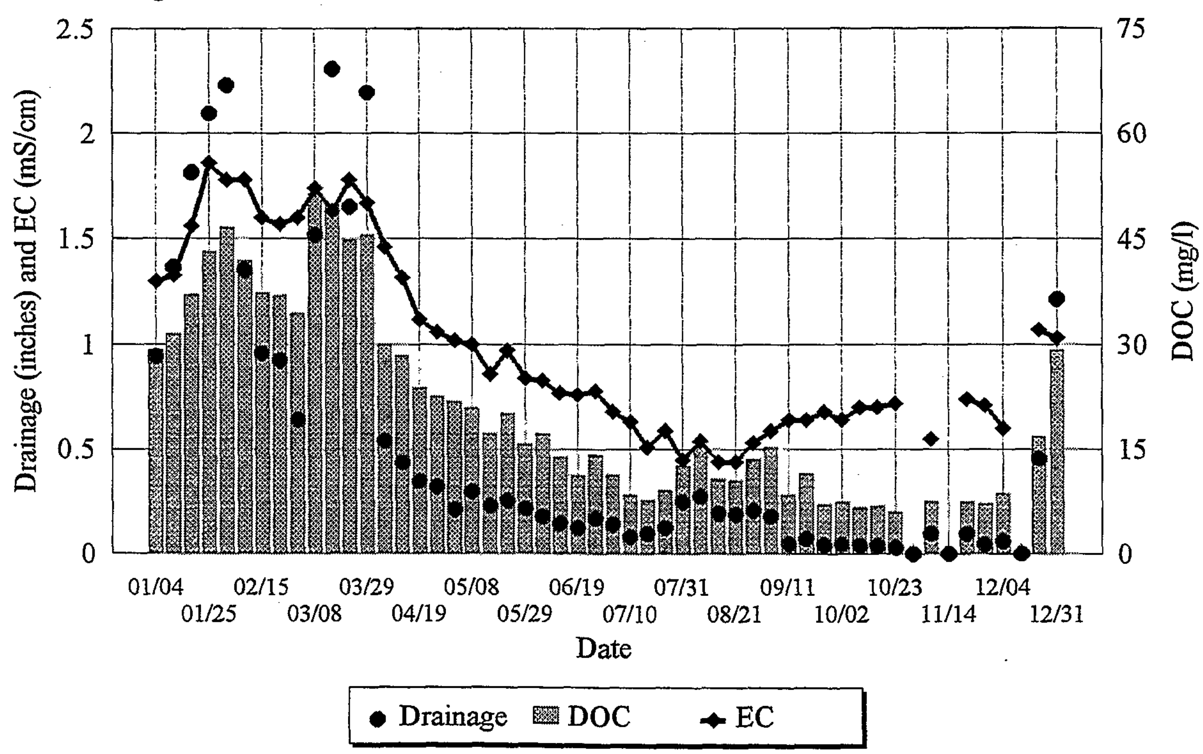


Figure G-3b
Measured Twitchell Island Drainage and DOC Loading in 1995



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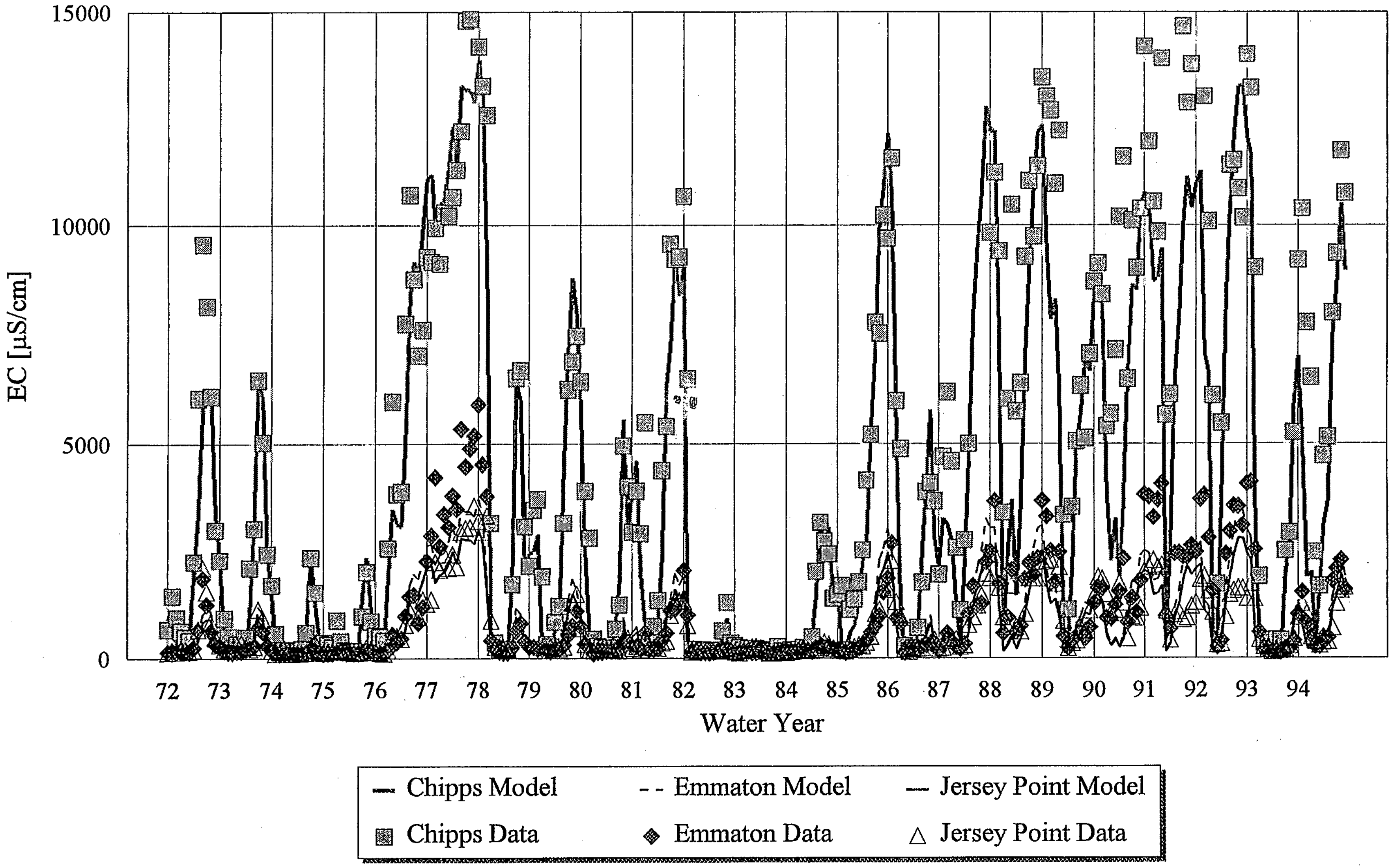

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Figure G-4
Comparison of Simulated EC and Historical EC Measurements at Chipps Island, Emmaton, and Jersey Point

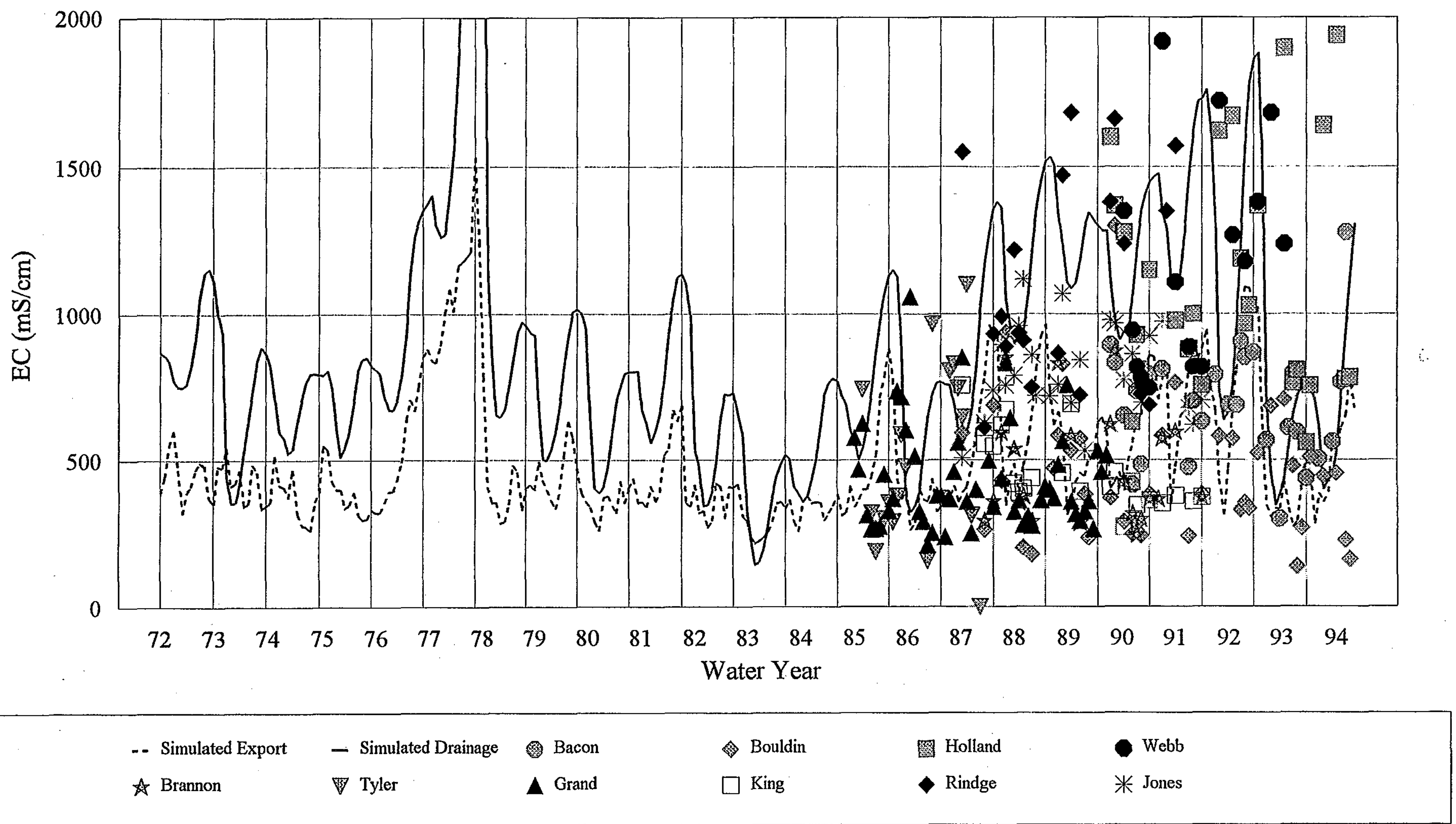

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Figure G-5
Comparison of Simulated Delta Drainage EC Values with MWQI Drainage EC Measurements

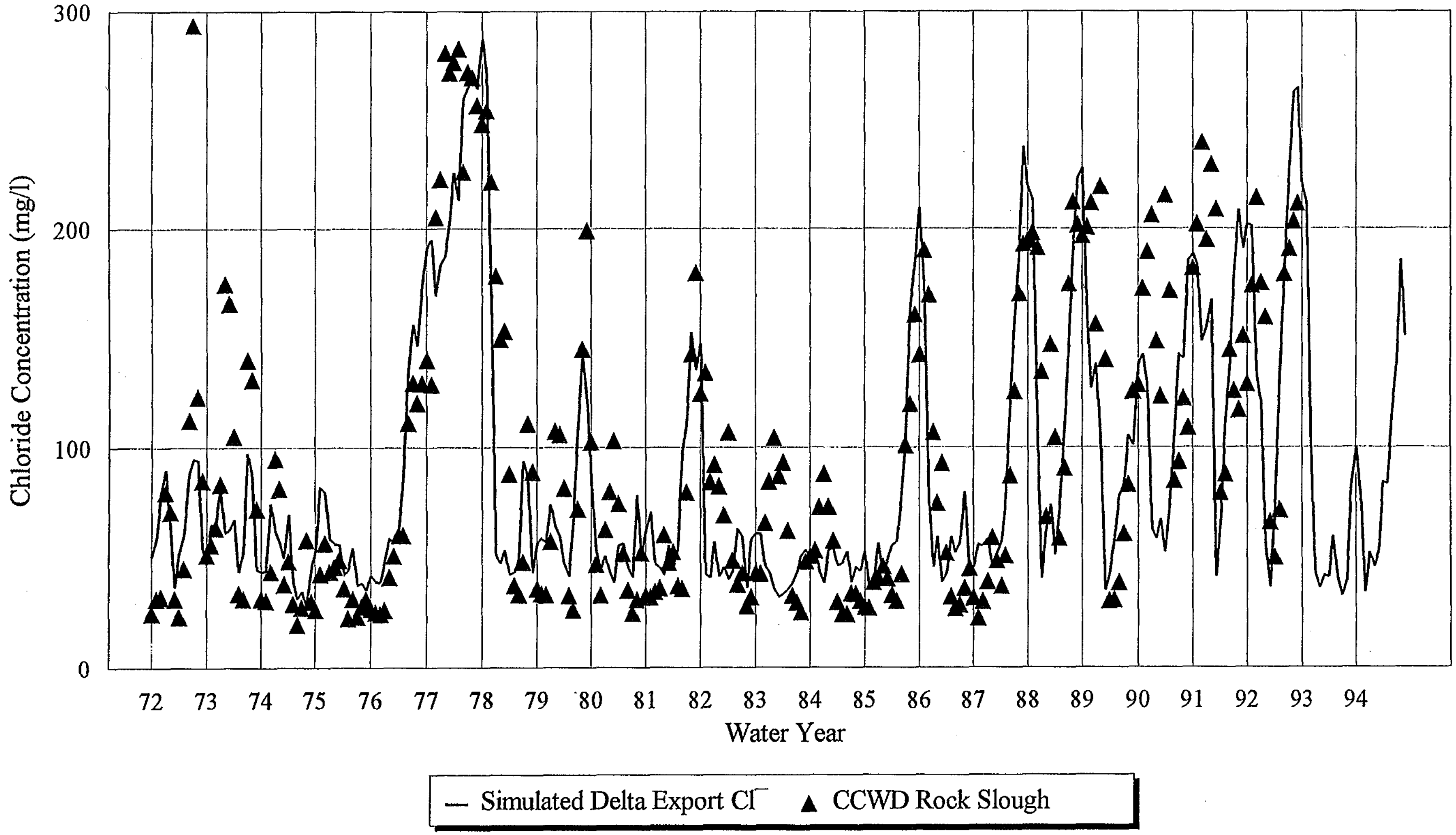

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Figure G-6
Comparison of Simulated Export Cl⁻ Concentration with Historical CCWD Rock Slough Cl⁻ Values

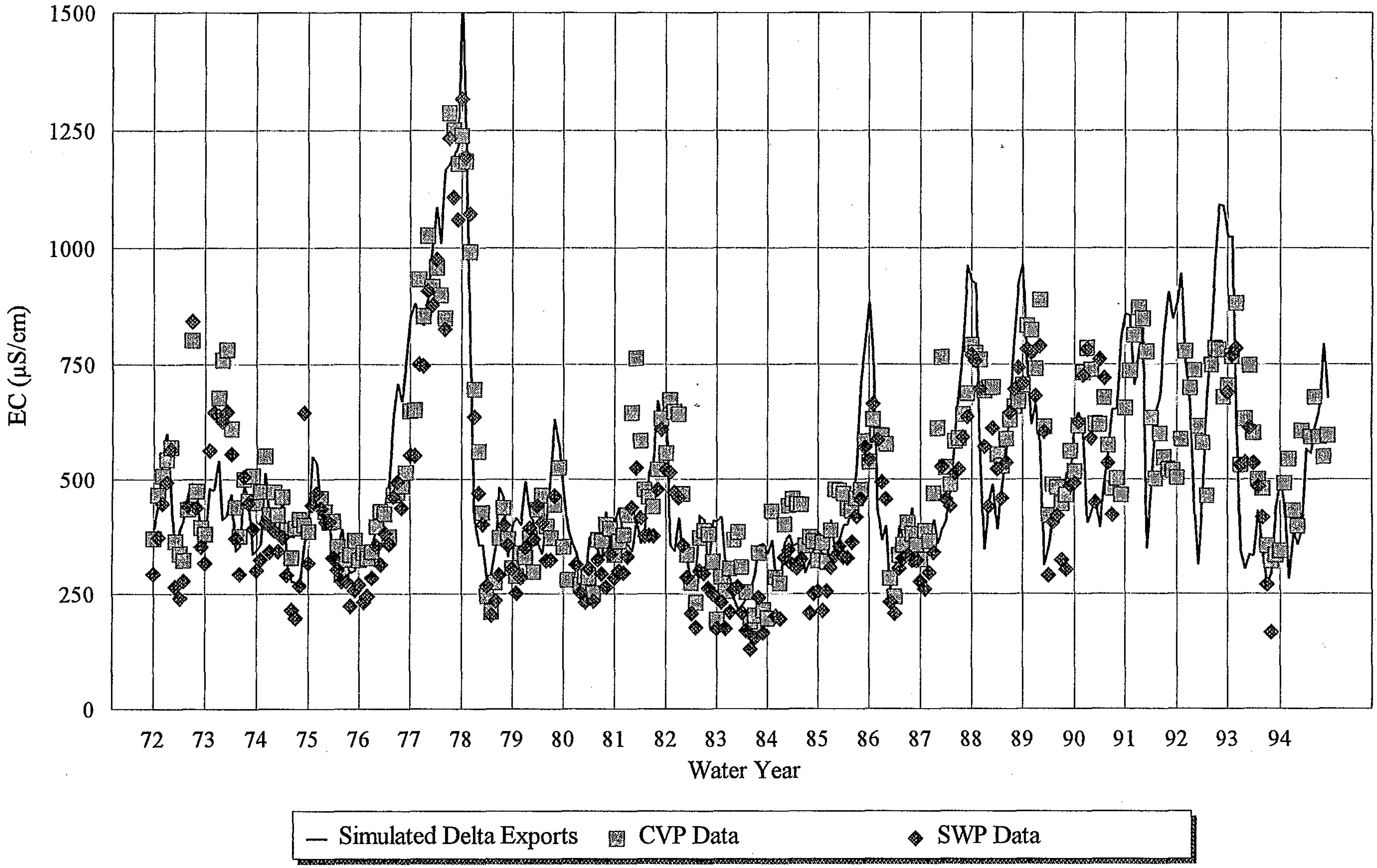

Figure G-7
Comparison of Simulated Export EC Values with Historical MWQI Export EC Values

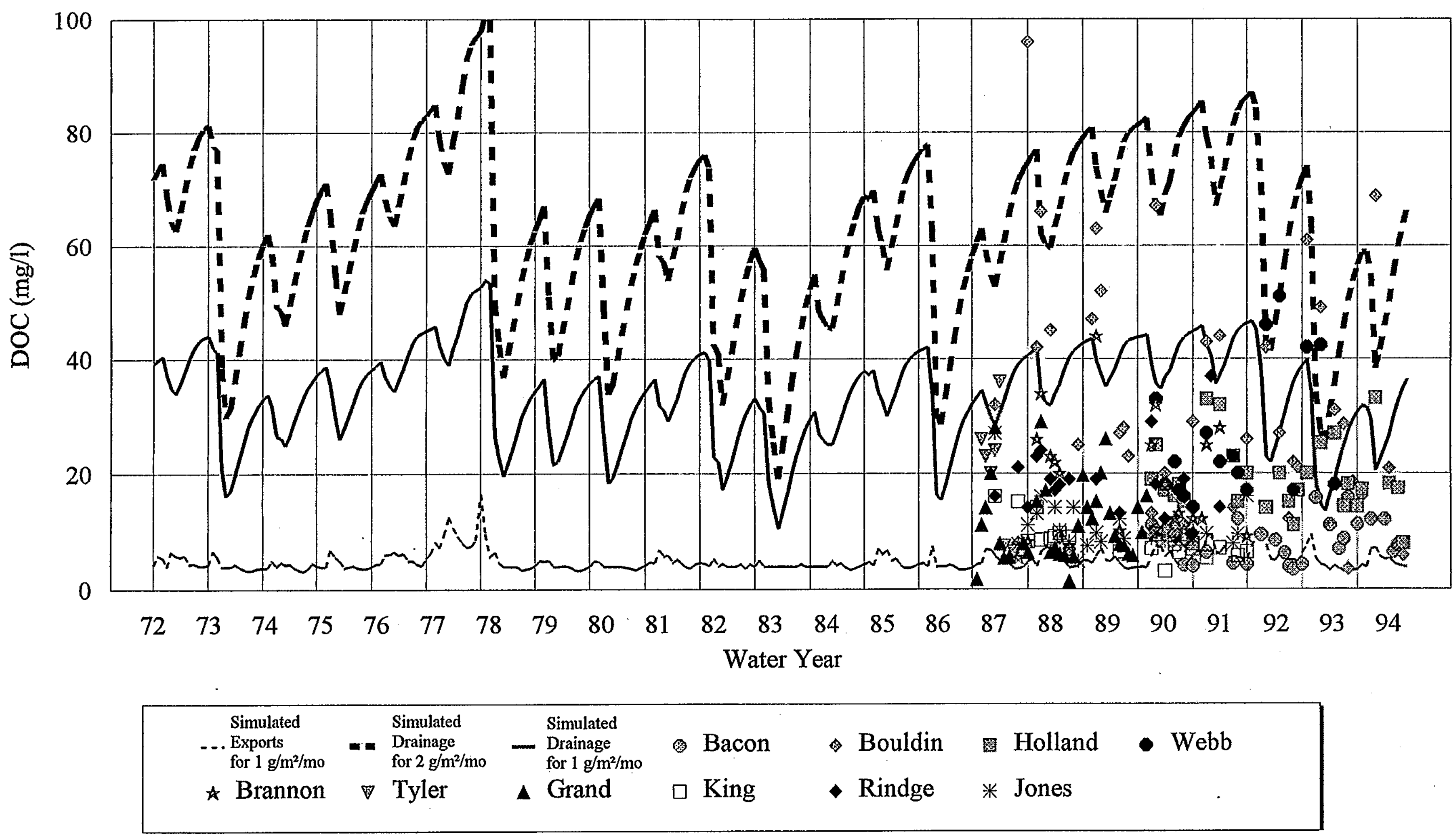

Figure G-8
Comparison of Simulated Delta Drainage DOC Concentration with MWQI Drainage DOC Measurements

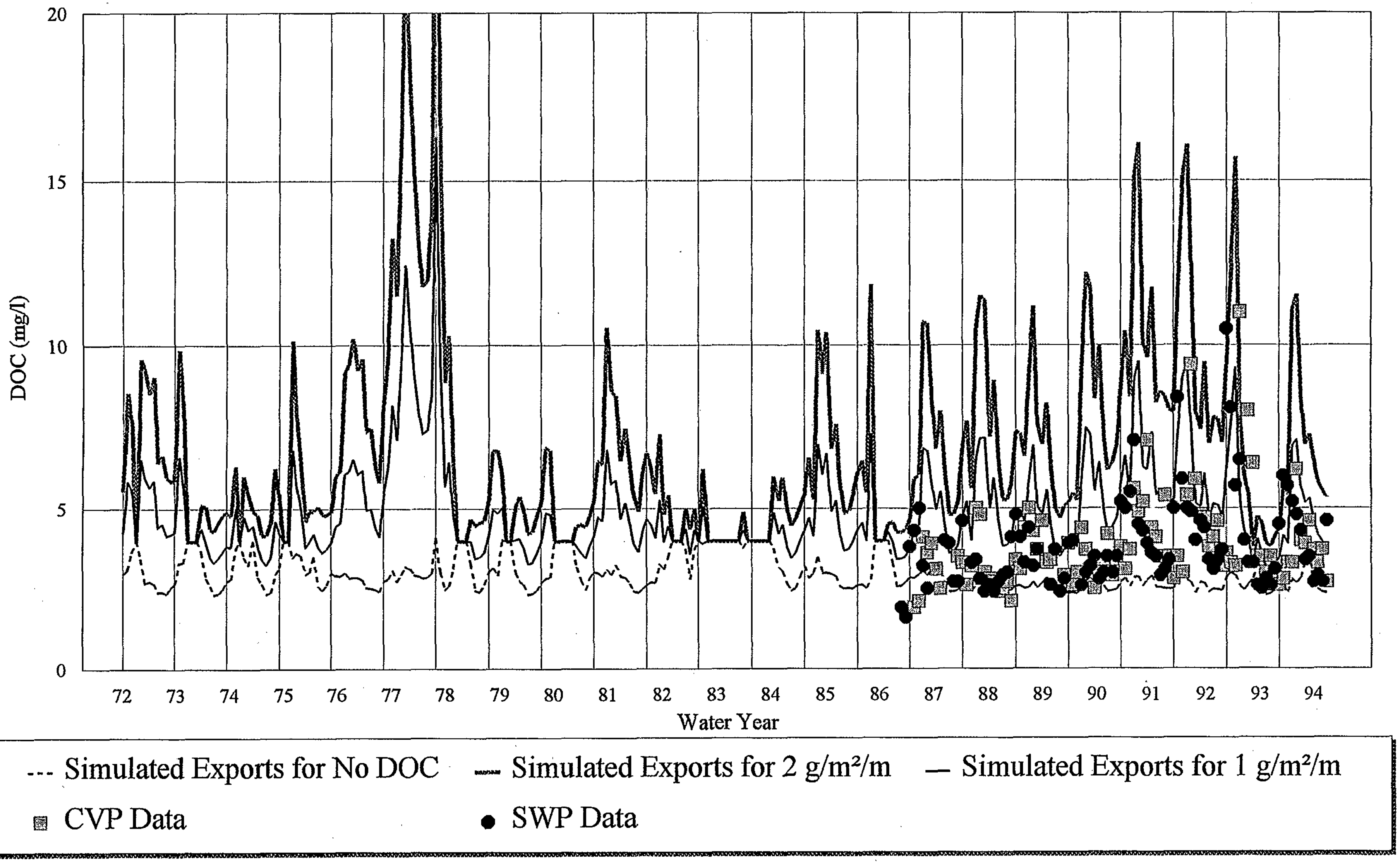

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Figure G-9
Comparison of Simulated Export DOC Concentration with Historical MWQI Export DOC Values

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Figure G-10a
Measured Source Water DOC and Treated Water THM Concentration, Penitencia Water Treatment Plant (SCVWD)

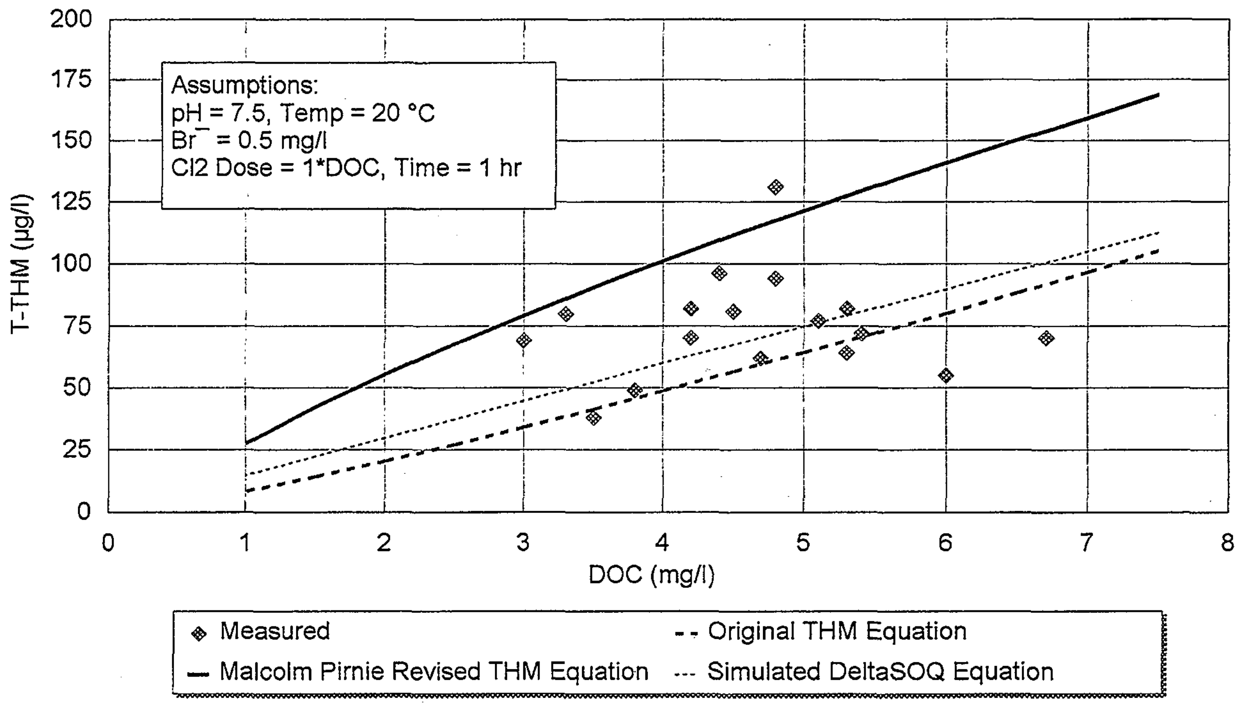

Figure G-10b
Measured Source Water Br- and Treated Water THM Concentration, Penitencia Water Treatment Plant (SCVWD)

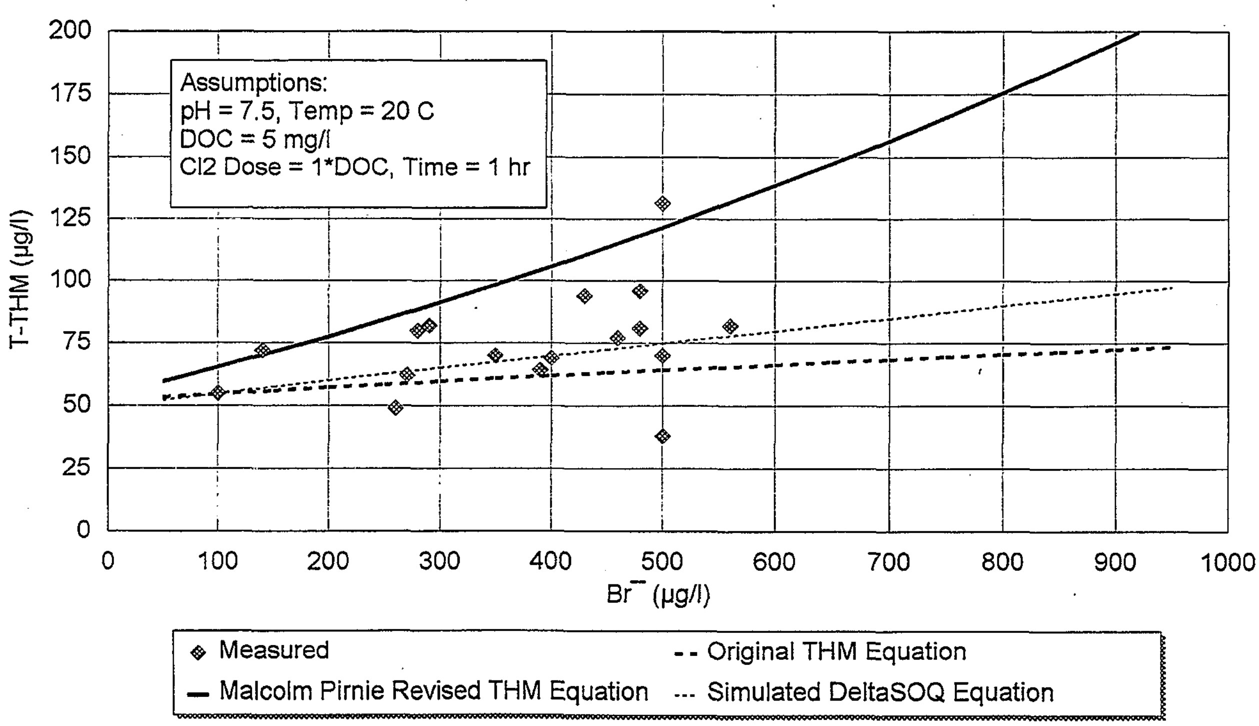

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Figure G-11a
Measured Source Water TOC and Treated Water Bromate Concentration

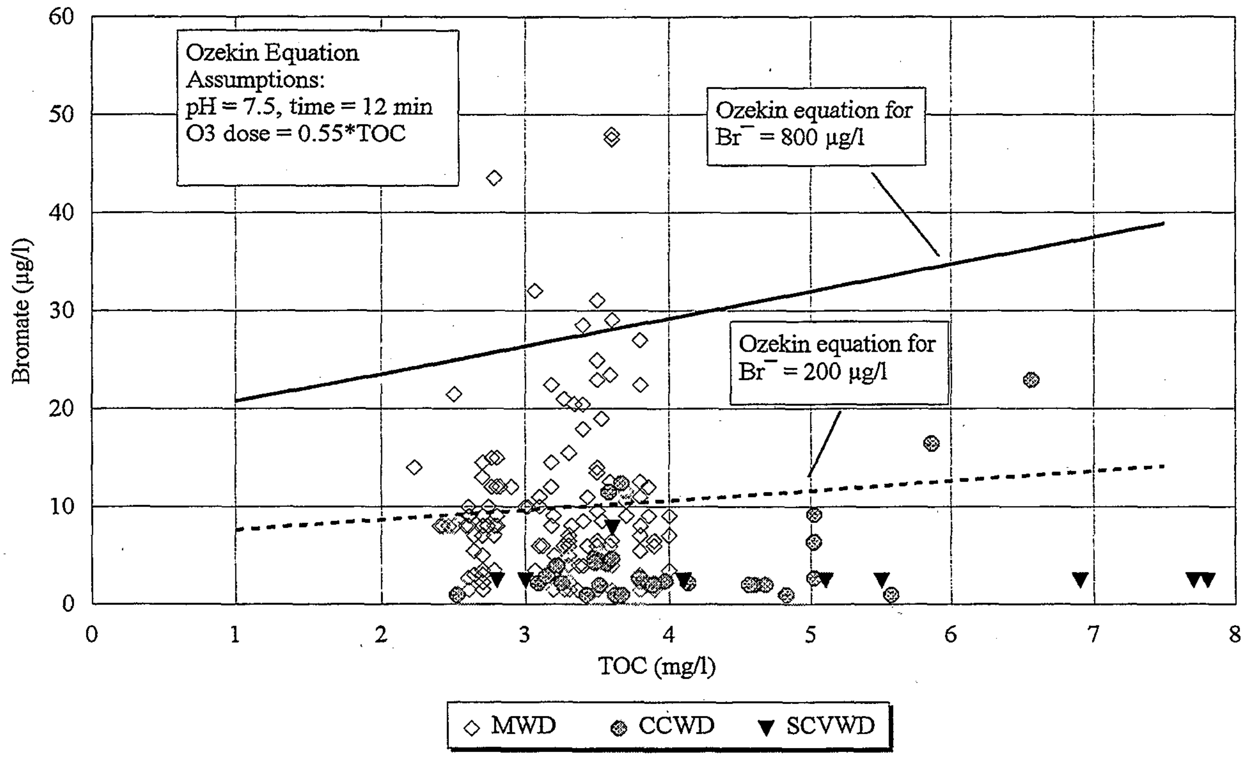

Figure G-11b
Measured Source Water Br⁻ and Treated Water Bromate Concentration