less than 20 micrograms per liter ($\mu g/L$) of bromide (California Department of Water Resources, 1998b).

A report prepared by the Department of Water Resources (California Department of Water Resources, 1998b) articulated the following points regarding the sources of bromide in Delta waters. The Delta has one major source of bromide, sea water that enters the western Delta from tidal excursions and mixes with Sacramento River water flowing through the Delta to the export facilities in the southern Delta. Bromide levels at Clifton Court Forebay and at the Contra Costa Canal intake are attributed to sea water intrusion. Another source of bromide may be the San Joaquin River; however, the primary source of bromide in the San Joaquin River is probably from agricultural return water which contains bromide and is exported from the Delta, so this may simply be a "recycling" of bromide from sea water intrusion. Another source of bromide is connate water beneath some Delta islands (e.g., Empire Tract) (California Department of Water Resources, 1994). Overall, the primary source of bromide in Delta waters is the result of sea water intrusion (Krasner et al., 1994).

Figure 9 (Metropolitan Water District of Southern California, 1998) show average bromide concentrations in ug/L and percentage of total respectively for (1) CCC (Contra Costa Canal) Intake, (2) H.O. Banks Intake, and (3) DMC (Delta Mendota Canal) Intake for baseline 1922-92, with sources of bromide from sea water, agricultural drainage, east sources, San Joaquin River and Sacramento River.

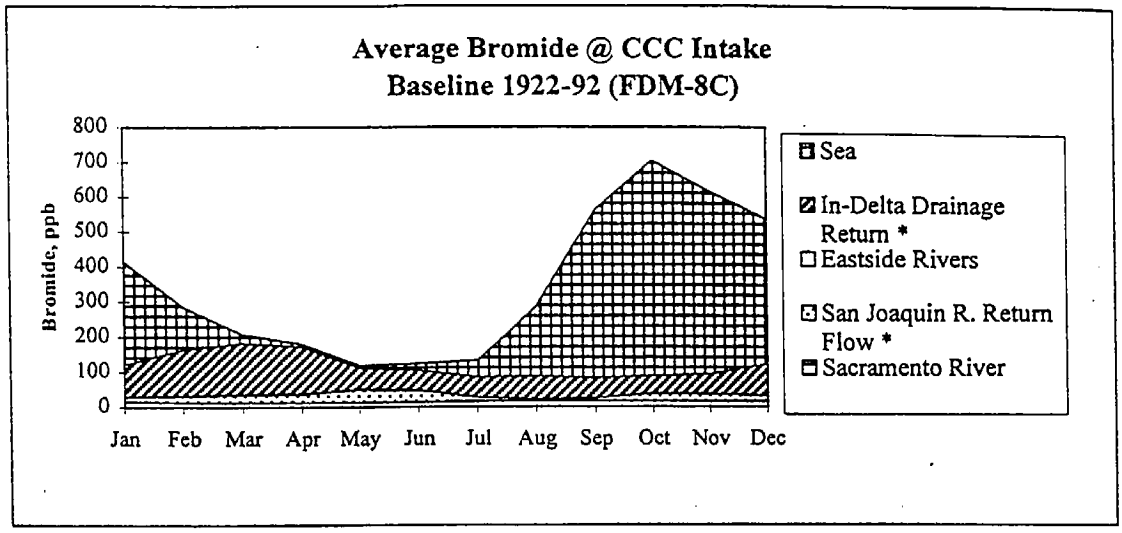
Figures 6 through 9 contain information on the magnitude of sources of bromide at points of diversion for drinking water supply and at other locations in the Delta. The magnitude of bromide in the Delta is near the upper 90th to 95th percentile, based on the nationwide bromide survey by Amy et al. (1994), suggesting that the bromide problem facing CalFed is more of a regional than national one.

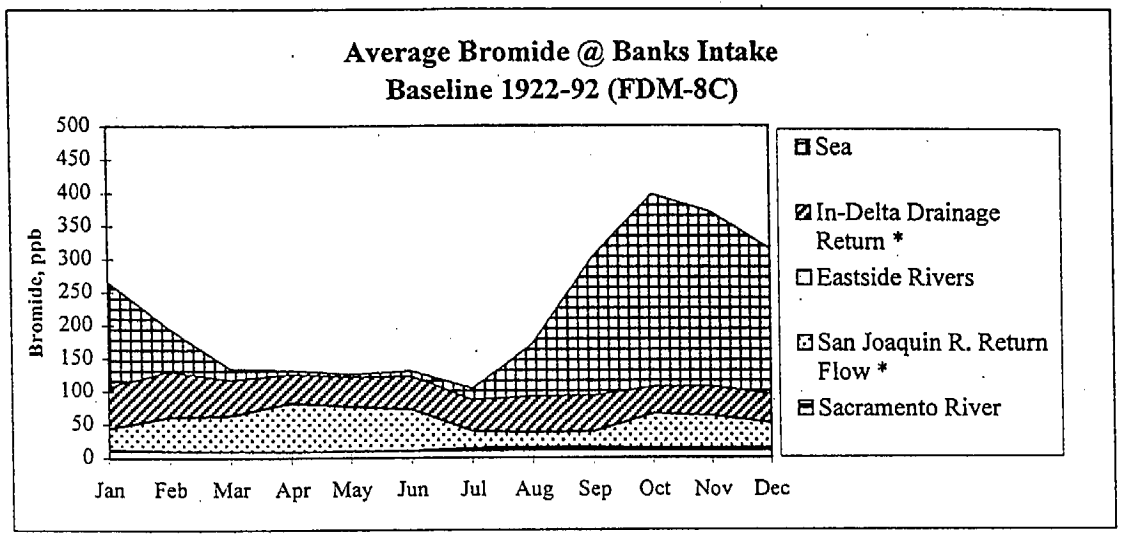
A concern was expressed during the Bromide Panel meetings in Sacramento held on September 8 and 9, 1998, that some of the "recycled" bromide in the San Joaquin agricultural drain waters could come from agricultural applications of methyl bromide.

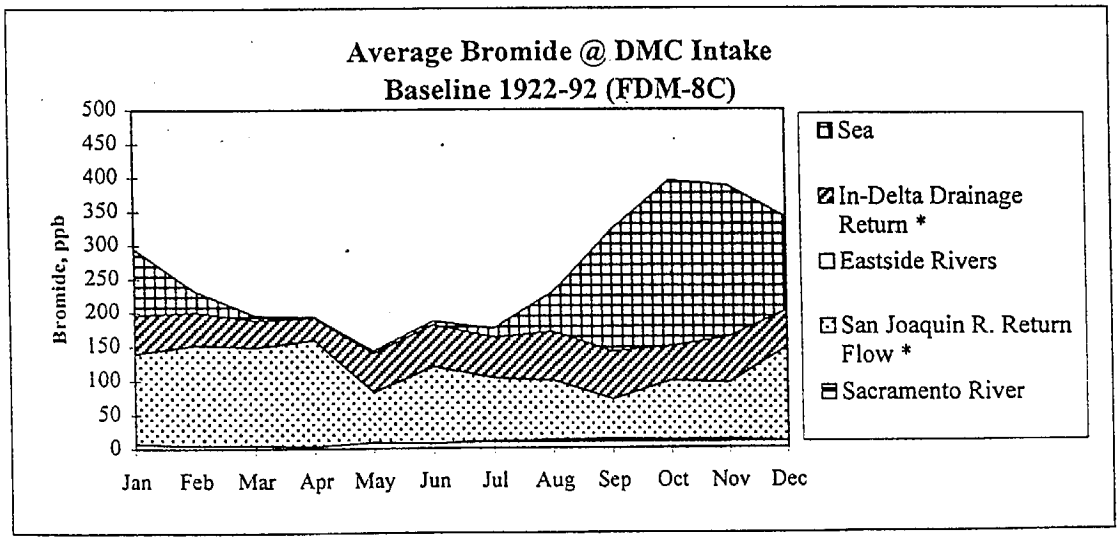
2.3 Management Options for Bromide Sources

Identification of sources of bromide from: (i) methyl bromide fumigation applications, (ii) olive processing facilities, (iii) municipal wastewater treatment plants, and (iv) disinfectants

FIGURE 9







* Past studies indicated that seawater intrusion is the primary source of bromide in the Delta, hence bromide in San Joaquin River return flows and in-Delta drainage returns primarily originated from the ocean.

Source: Metropolitan Water District of Southern California

used in spas; will allow for management and control of these sources. Information on methyl bromide fumigation applications could be obtained from the Department of Pesticide Regulation. Regional water quality control boards could provide information on potential bromide discharges from municipal wastewater treatment plants and olive processing facilities. Merchants selling disinfectants for spas could indicate whether or not bromine is used as a disinfectant, how much is used, and its ultimate fate (as bromide) in the environment.

Considerable modeling has been performed by various agencies to forecast the effectiveness of various combinations of storage and conveyance features for Alternatives 1, 2 and 3.

The predicted effectiveness of these three alternatives for changing water quality concentrations of bromide are shown in Figure 10 (Clifton Court) and Figure 11 (Rock Slough) (California Department of Water Resources, 1998a). The figures show average predicted bromide concentrations as well as the upper and lower 95 percent bromide confidence limits. Projected TOC levels at the H. O. Banks Pumping Plant are 3.2, 3.1, 3.1, and 2.5 mg/L for no action, Alternative 1, Alternative 2, and Alternative 3, respectively.

Figures 12 and 13 (California Department of Water Resources, 1998a) illustrate the predicted monthly average bromide concentrations in ug/L at Clifton Court and the Contra Costa intake for Alternatives 1, 2 and 3 for the water year. It is evident that Alternative 3 has the most impact on Br^- levels at Clifton Court, whereas Alternative 2 provides lower Br^- levels at the Contra Costa intake; thus, there is no single alternative that provides lowest Br^- levels for all drinking-water export points.

2.4 Additional Information Needed

CalFed should assemble information on the monthly variations of bromide concentrations for key locations (Clifton Court, Contra Costa Intake) for each alternative (1, 2, 3). CalFed should perform a sensitivity analysis by estimating how much effort, cost, benefit and environmental impact would result if each alternative (1, 2, 3) were modified for both an incremental increase and decrease of bromide at key locations (Clifton Court, Contra Costa Intake). CalFed should assemble and analyze additional TOC occurrence data, particularly co-occurrence of TOC with Br^-.

FIGURE 10

Bromide Water Quality
Predicted Bromide at Clifton Court

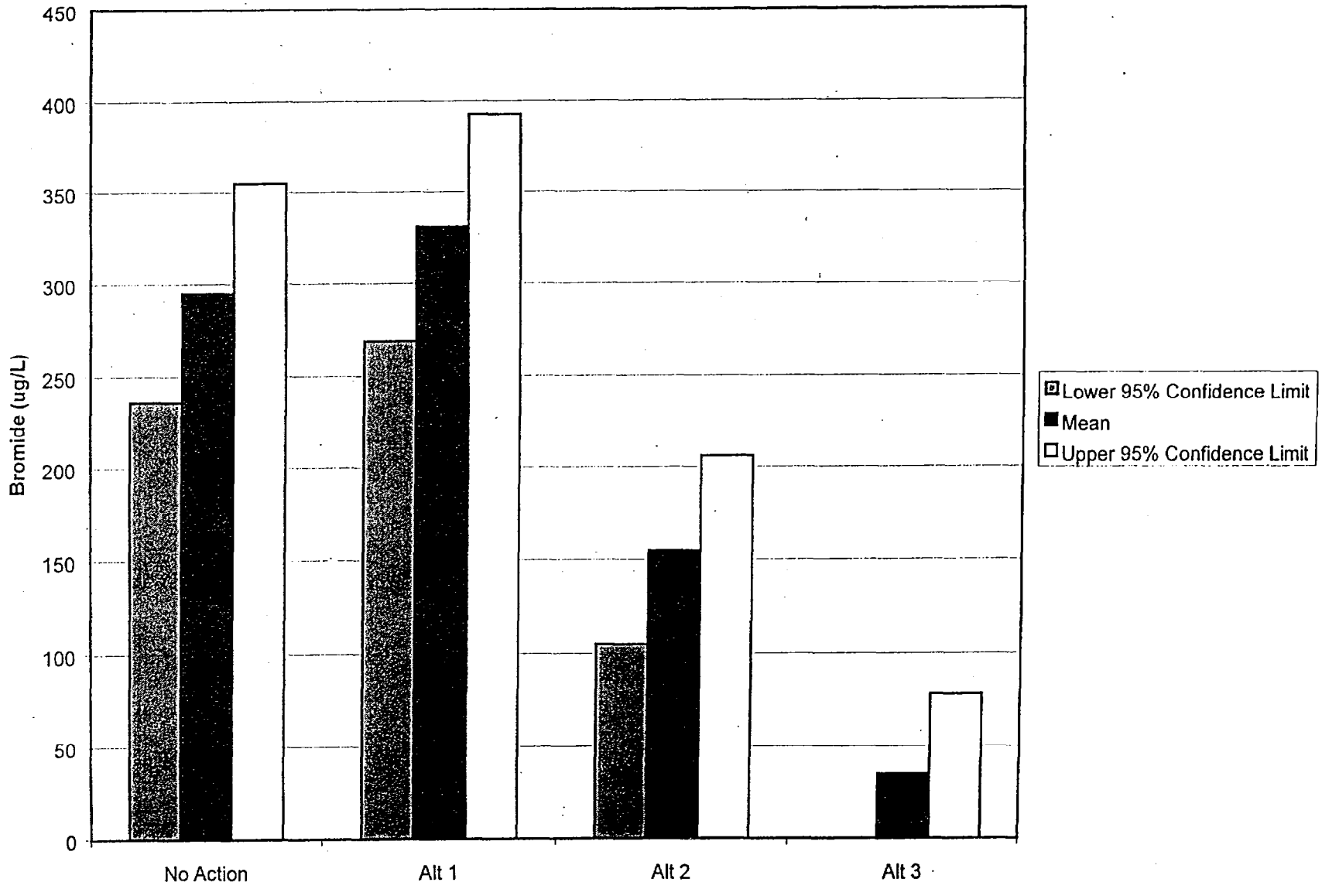


FIGURE 11

Bromide Water Quality
Predicted Bromide – Contra Costa Canal Intake at Rock Slough

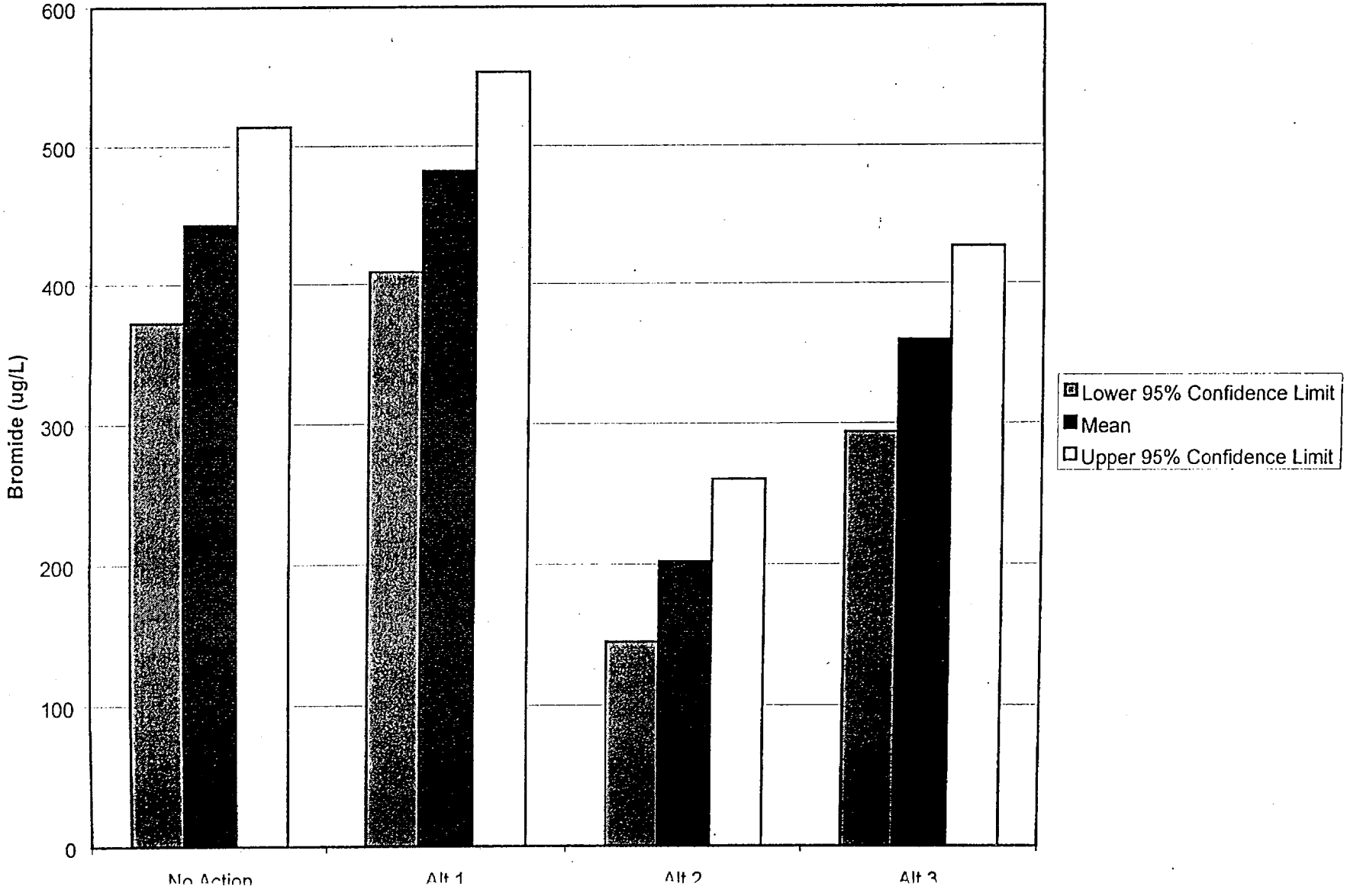
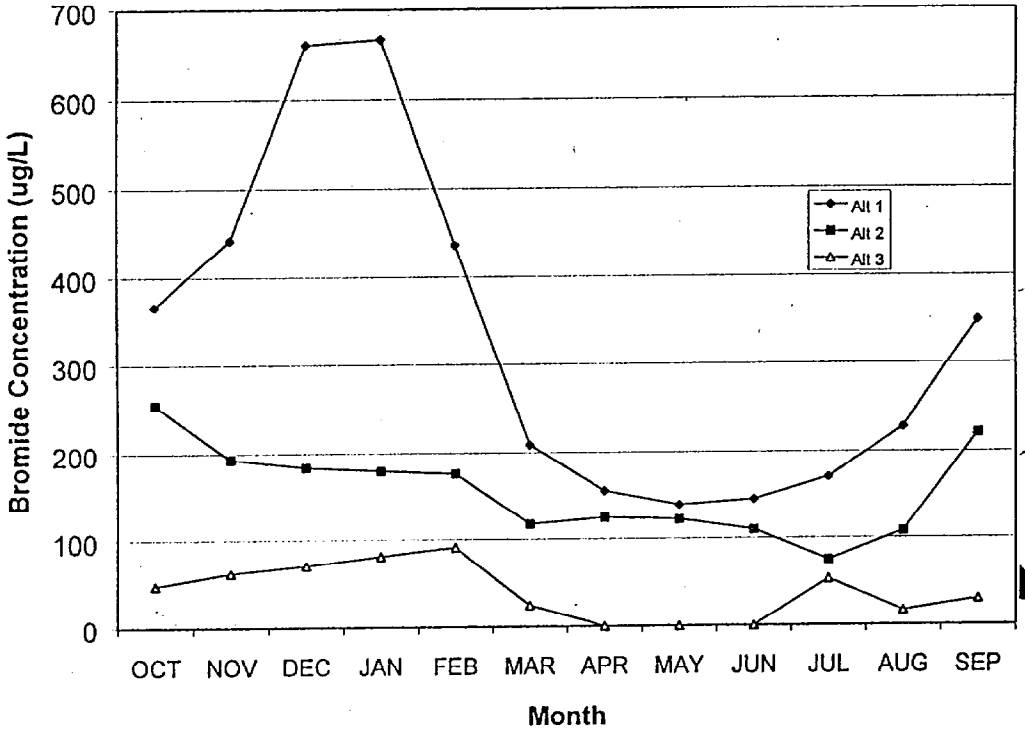
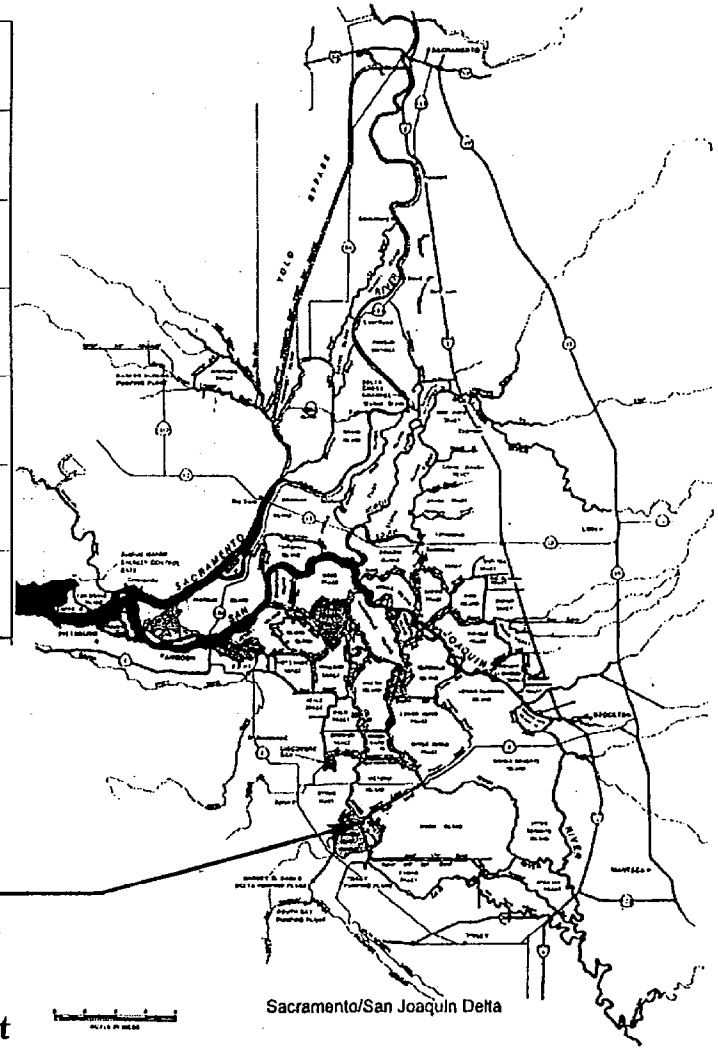


FIGURE 12

Predicted Average Monthly Bromide at Clifton Court Forebay

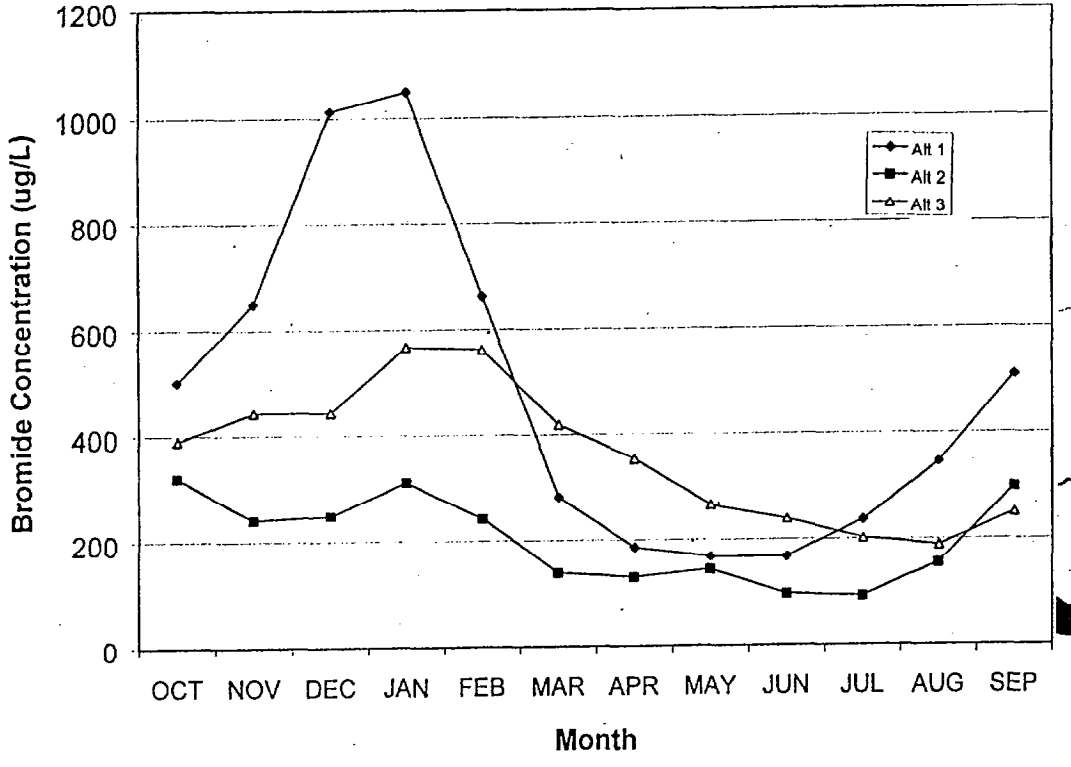


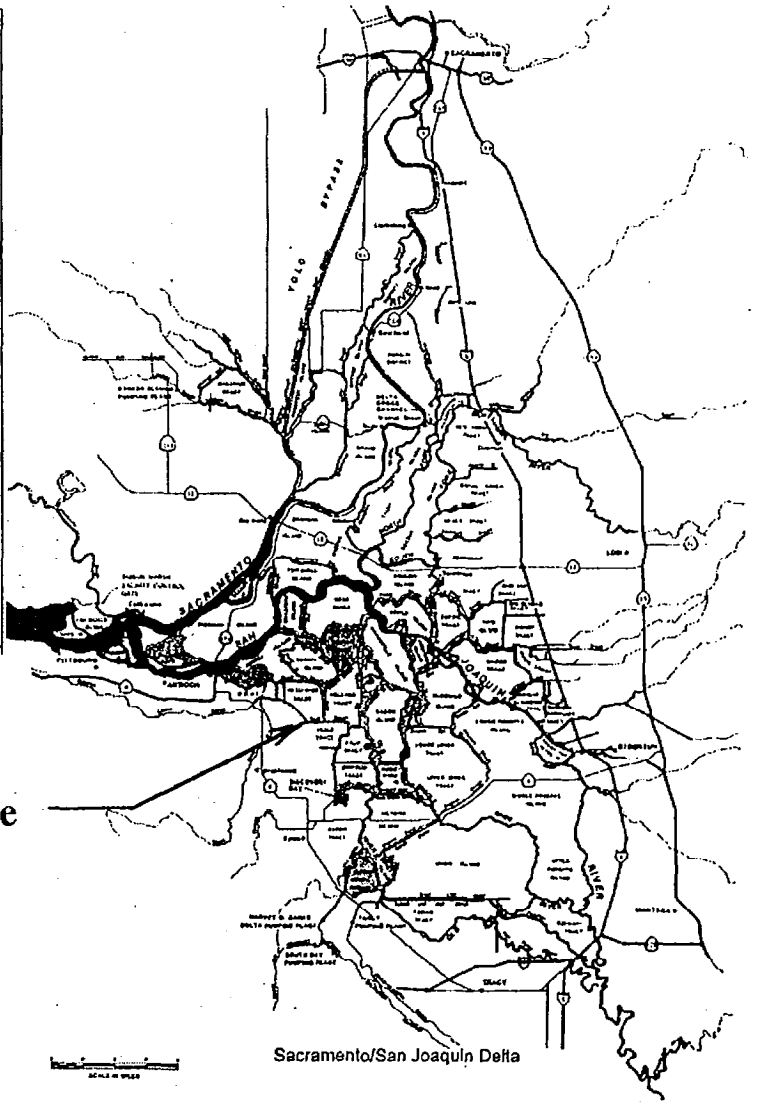


Clifton Court Forebay
Combined Point of Diversion
For State Water Project
And Federal Central Valley Project

FIGURE 13

Predicted Average Monthly Bromide at Contra Cost Canal Intake





Contra Costa Canal Intake
at Rock Slough
Point of Diversion for
Contra Costa Water District

2.5 Recommendations

CalFed should resolve concern regarding whether or not (or how much) of "recycled" bromide from agricultural return drains is actually "recycled" or is from agricultural fumigation activities using methyl bromide. CalFed should investigate options for immediate opportunities to enhance source controls of bromide. These options could include identification and control of all possible sources of bromide. Another option could be alternative means of managing storage and flows through the Delta. Potential short-term solutions/options should be implemented as soon as possible. CalFed should study the potential for using alternative sources of high quality water for drinking purposes and using lower quality waters to meet agricultural water supply demand.

3.0 Health Concerns Posed by Bromide in Source Waters Used for Drinking Water

High concentrations of bromide in source water are of little direct health concern. However, bromide serves as a precursor for the formation of a wide variety of organic by-products when chlorine or chloramines are used in disinfection. With the use of ozone, bromate becomes a major concern. A number of these by-products are carcinogenic, produce reproductive and developmental toxicities, and have other toxicological properties that would be of concern if produced at sufficient concentrations. The major focus of this section is to provide some basis for appreciating the reasons one might be more concerned about brominated by-products than their chlorinated analogs.

3.1 Epidemiology Suggests Different and Greater Hazards than Available Toxicological Data.

It is difficult to gauge the actual magnitude of risks from disinfection by-products in drinking water. Epidemiological data has associated increases in bladder and colorectal cancer with the use of chlorine as a disinfectant. Meta analyses have been applied to these data that suggest that the attributable risk could be thousands of cases of cancer in the U.S. annually (Morris et al., 1992). It must be noted that the utilization of meta analyses in this case has been seriously questioned (Poole, 1997). However, *if the epidemiological results are actually valid, these are the levels of risk that would be derived from the positive studies*. If these estimates are real, risks of this magnitude may warrant significantly more stringent control of chlorinated

DBPs than anticipated under the Stage 1 DBP rule. However, proof of causality has been elusive (Poole et al., 1997; USEPA, 1998a). Many scientists in the area believe it to be premature for precipitous action based on available epidemiological data.

Toxicological studies have identified chemicals that can produce cancer in rodents, but the target organs most frequently identified are the liver and kidney. Two by-products have been shown capable of producing colon cancer in rats (bromodichloromethane and bromoform), but their activities are much too weak to account for the incidence seen in the epidemiology studies. To date, no bladder carcinogen has been identified. There are a number of reasons to explain both the quantitative and qualitative discrepancies between the epidemiological and toxicological data. The possible risks suggested by epidemiology studies may simply not be correct. On the other hand, the experimental animals used may simply be poor models for human susceptibilities to these disinfection by-products. The fact is that a very large fraction of disinfectant by-products have not actually been subjected to cancer bioassays. Brominated by-products are very underrepresented in the tested compounds. Moreover, the National Toxicology Program (NTP) noted that induction of colon cancer was a rare event in bioassays. However, this site was targeted by three other brominated compounds in the experience of NTP (Melnick et al., 1994). Therefore, one must consider the problem that is stated in Table 1.

The same type of problem of interpreting possible cancer risks from chlorinated DBPs pertains to understanding possible reproductive and developmental risks from chlorinated DBPs. There has been a single, well conducted epidemiology study associating disinfection by-products as a potential cause of spontaneous abortion (Waller et al., 1998); it is noteworthy that this study was performed in California, involved brominated THMs, and possibly some Delta water. Toxicological studies have identified a number of chemicals that have effects on male reproduction and new experiments are exploring other reproductive hazards. The most potent DBP found to affect male reproductive function is dibromoacetic acid (Linder et al., 1995) suggesting that brominated species may be the most likely group of chemicals to produce these effects. Still the potency of dibromoacetic acid is too low to account for the epidemiological results and the studies focused on different endpoints. However, if other short-chained chlorinated hydrocarbons are examined, the substitution of bromine for chlorine significantly increases the probability of adversely affecting male reproductive function (Lag et al., 1991).

Therefore, the issues identified in Table 1 are even more important for developmental and reproductive toxicities that might be associated with DBPs.

Table 1. Potential explanations for the discrepancy between epidemiological studies of chlorinated water and toxicological studies of disinfection by-products.

1. Chlorinated by-products have been the most thoroughly studied.
2. Concerns about major chlorinated by-products (chloroform, dichloroacetate and trichloroacetate) are fading at the low levels produced in drinking water based upon new toxicodynamic data. These by-products are the major liver and kidney carcinogens.
3. The majority of by-products produced from chlorination have not been subjected to toxicological testing.
4. Brominated by-products comprise a major portion of the untested compounds.

3.2 Brominated By-products – Reasons for Concern.

As should be appreciated from the above discussion, the data available at this time are too sparse to raise alarms about brominated DBPs. However, relatively large investments are being considered to improve environmental conditions in the Bay-Delta system. These improvements are being viewed to an end point that is 25-30 years in the future. As some of the alternatives could potentially change bromide levels present in drinking water sources, it is necessary to consider the potential impacts of the resulting by-products on human health. Aside from the limited data on brominated by-products referenced above, there are several theoretical reasons why bromine containing disinfection by-products could become a serious problem over this time horizon. Anticipation of these potential problems should help avoid commitment to alternatives that could be untenable in the long-term.

3.2.1 Direct and Indirect Effects of DBPs

Chemicals may exert their toxic effects as the parent compound or they may require metabolism to become active. Examples of both types are found with disinfection by-products. Dichloroacetic acid and trichloroacetic acid appear to act directly (i.e. do not require metabolism