PROBLEM DESCRIPTION

Salinity is generally defined as the amount of salt dissolved in a given unit volume of water. It is variously measured in units of electrical conductivity (EC), total dissolved solids (TDS), practical salinity units (psu), or other units depending on the scientific discipline of the person doing the measuring and the purpose of the study or monitoring program.

Salinity is often considered equivalent to total dissolved solids. More specifically, TDS is the fraction of solids in water that will pass through a 1.2 µm filter and that will remain on a dish when a sample of water is dried at a specified temperature. The remaining solids may include volatile and non-volatile organic and inorganic compounds. The vast majority of dissolved solids in most ambient waters are ionic inorganic substances (salts) such as calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, bromide, and nitrate.

The composition of dissolved substances varies depending on source. Freshwaters are typically high in calcium, magnesium, bicarbonate, and sulfate while seawater is higher in sodium and chloride. Bromide concentrations are typically low in freshwater and high in seawater. The average bromide concentration in U.S. drinking water sources is 62 µg/L (Amy, 1998) while the concentration in seawater is about one thousand times higher, 67 mg/L (Hem, 1989). The average bromide concentration at the State Water Project's Delta (Banks) Pumping Plant is about 230 µg/L. In contrast, the average bromide concentration in the Sacramento River at Hood is about 14 µg/L and is often less than the 10 µg/L detection limit. In the Delta, high bromide concentrations are usually associated, directly or indirectly, with seawater. Other ions are associated with specific source areas in the watershed. Runoff and drainage from irrigated lands on the west side of the San Joaquin Valley have characteristically high concentrations of sulfate. The composition of salts in water can be an important determinant of the impact on a particular beneficial use and can be an indicator of the source. At the Delta diversion points, water that has relatively high concentrations of chloride and bromide is indicative of seawater intrusion.

The ability of water containing dissolved salts to conduct electricity gives rise to a simple method for measuring the concentration of salt. Electrical conductivity (EC) is a measure of the ability of water to conduct an electric current and thus is a measure of the amount of dissolved salts. EC is often measured in units of microsiemens per centimeter (µS/cm), also called micromhos per centimeter, which is the inverse of the resistance of a sample of water between two electrodes that are one centimeter apart. It is a far simpler to measure this property of water than doing the required laboratory method to measure TDS directly. EC is therefore a quick, cost effective, and widely used surrogate measure of salinity.

Impacts of Salinity on Use of Delta Water for Domestic Supply

Bad taste is one of the most common complaints that utilities receive about tap water and salinity is often the problem. There is a secondary maximum contaminant level (MCL) for TDS of 500 mg/L set primarily to address taste but also to prevent staining and mineral deposits. Secondary MCLs regulate contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. Chloride (250 mg/L) and sulfate (250 mg/L) are also secondary MCLs established to prevent salty taste in tap water.

The State of California has established the following secondary standards for salinity and chloride.

Table 1: Secondary maximum contaminant levels and ranges.

	Maximum Contaminant Level Ranges		
Constituent, Units	*Recommended*	*Upper*	*Short Term*
Total Dissolved Solids, mg/L	500	1,000	1,500
or Specific Conductance, micromhos	900	1,600	2,200
Chloride, mg/L	250	500	600

Even though the 500 mg/L TDS and 250 mg/L chloride standards are only "recommended" levels, water suppliers rarely serve water that exceeds these concentrations and then only when there is no feasible alternative.

Another impact of salinity on municipal water use is on the "utility" of the water. Utility is the ability to recycle the water or blend it with lower quality supplies. Domestic and commercial use of water increases its salinity. Wastewater may be further treated beyond the typical secondary level to produce usable recycled water. This recycled wastewater typically used for landscape watering and other non-potable uses, makes up a significant fraction of the water supply in many parts of the state. Water can be collected and reused or recycled until the salinity increases to the point where it is too high for even landscape irrigation (usually the most salt tolerant use). Lower salinity to start with allows more cycles of water use and reuse. Higher quality water is therefore equivalent to more water in many parts of the State.

The most critical impact of salinity on drinking water, however, is the role it plays in the formation of disinfection byproducts (DBPs). Bromide is a precursor to formation of a variety of harmful byproducts when water is treated and disinfected for domestic water supply. Trihalomethanes and haloacetic acids form when water containing organic carbon is treated with chlorine. Disinfection byproduct formation is increased when the source water contains both dissolved organic compounds and bromide. Bromate forms when water containing bromide is disinfected with ozone. A study commissioned by the California Urban Water Agencies (CUWA) in 1998 concluded that, if a bromate MCL of 5 µg/L were adopted, it would be necessary to keep raw water bromide concentrations below 50 µg/L for plants that use unmodified ozone disinfection. Since bromide concentrations at Delta municipal water supply diversions are nearly always higher than 50 µg/L, the reduced bromate MCL would have been extremely problematic. Even though the connection between bromide in source water and disinfection byproducts in finished water is fairly well known, there are no applicable bromide water quality standards. The high concentrations of bromide, from seawater intrusion into the upper estuary, are unusual for a major drinking water source.

Contrary to early indications about new regulatory limits and the associated compliance problems, the MCL for bromate has remained at 10 µg/L and nearly all treatment plants using Delta water as their primary supply modify their raw water supply and treatment systems to minimize bromate formation. Acceptable bromide concentrations at Delta drinking water intakes are clearly greater than 50 µg/L however, the exact concentration that can be tolerated is not known and the evolution of drinking water regulations under the Safe Drinking Water Act continues. The recent promulgation of new disinfection byproduct and surface water treatment rules presents new challenges for municipal water suppliers using Delta water.

Impacts of Salinity on Other Uses: Agriculture, Industry, Wildlife

The standards that are most controlling of CVP and SWP operations have been established to protect the agricultural, industrial, and fish and wildlife beneficial uses. Collectively these standards require the responsible agencies to balance reservoir releases, export pumping, and the routing of water through the Delta to achieve their water delivery goals and stay in compliance. The agencies maintain a complex network of monitoring stations and computer models to give them the information necessary to manage the system.

To protect salt sensitive crops during the irrigation season, the conductivity objective in the San Joaquin River and the interior South Delta is set at 0.7 mS/cm (700 µS/cm) during the irrigation season (April – August) and at 1.0 mS/cm for the remainder of the year. These standards are based on research on a variety of crops. For the most sensitive crops grown in this area, it was determined that water exceeding these standards could reduce yields.

Excess salinity in soil water can decrease plant available water and cause plant stress. In the San Joaquin Valley, particularly on the west side, soils and shallow groundwater have become increasingly saline and groundwater levels have risen since irrigation began in these areas. These factors have required installation of tile drains in the most heavily impacted fields in order to keep them in production. The shallow groundwater drained through these systems is high in salts, nitrate, and selenium making discharge of this water problematic. Management of agricultural drainage water in the San Joaquin Valley will be discussed further in the watershed sources section.

The chloride objectives that apply at Delta export locations are intended to protect municipal and industrial uses. The most restrictive of these, the 150 mg/L chloride objective for Contra Costa Canal and the Antioch intake, was developed to prevent the adverse effects of residual salt in corrugated paper boxes. Linerboard made using water with too high a salt content can cause corrosion in canned goods. This standard was originally established to protect the water supply for a corrugated paper box plant in Contra Costa County that has since closed but the standard was retained to protect drinking water quality pending further evaluation.

A number of fish and wildlife species are dependent on the estuarine zone of the Bay-Delta system. Some of these species are highly dependent on water of a particular salinity at certain life stages to survive. The extent and location of estuarine habitat of the correct salinity is highly dependent on flow. The Delta outflow standards are intended to maintain this estuarine habitat and minimize seawater intrusion into the Delta. The outflow standards are therefore also an important factor governing water quality at the Delta water diversion points.

History of Delta Salinity

Salinity in the Delta is a function of freshwater inflow, wastestreams, tides, reservoir operations, Delta exports, diversions, and the configuration of Delta channels. Early records of Delta salinity (Jackson and Paterson, 1977) and evidence from diatoms in marsh sediments (Starratt, 2001) suggest that seawater intrusion into the Delta was relatively rare prior to the development of large scale irrigated agriculture in the Central Valley. The natural patterns of water movement in the Delta began to change with the sediment influx from hydraulic mining and the beginning of Delta levee construction in the late 1800s. Steadily increasing agricultural water diversions reduced Delta inflow in the early 1900s exacerbating seawater intrusion. The era of modern Delta water management, and with it significant changes in salinity, began with the completion of Shasta Dam in 1945 and continued with the first State Water Project deliveries in 1967. As Figure 3 shows, from 1921 to 1943, Delta salinity was much more variable than it is today. In the late fall of dry years during this period, brackish water extended far inland. Figure 4 shows the extent of seawater intrusion from 1944-1990. The storage of winter and spring runoff behind the many Federal and State Water Project dams and the subsequent release has changed the seasonal pattern of Delta inflow and has reduced the year to year variability.

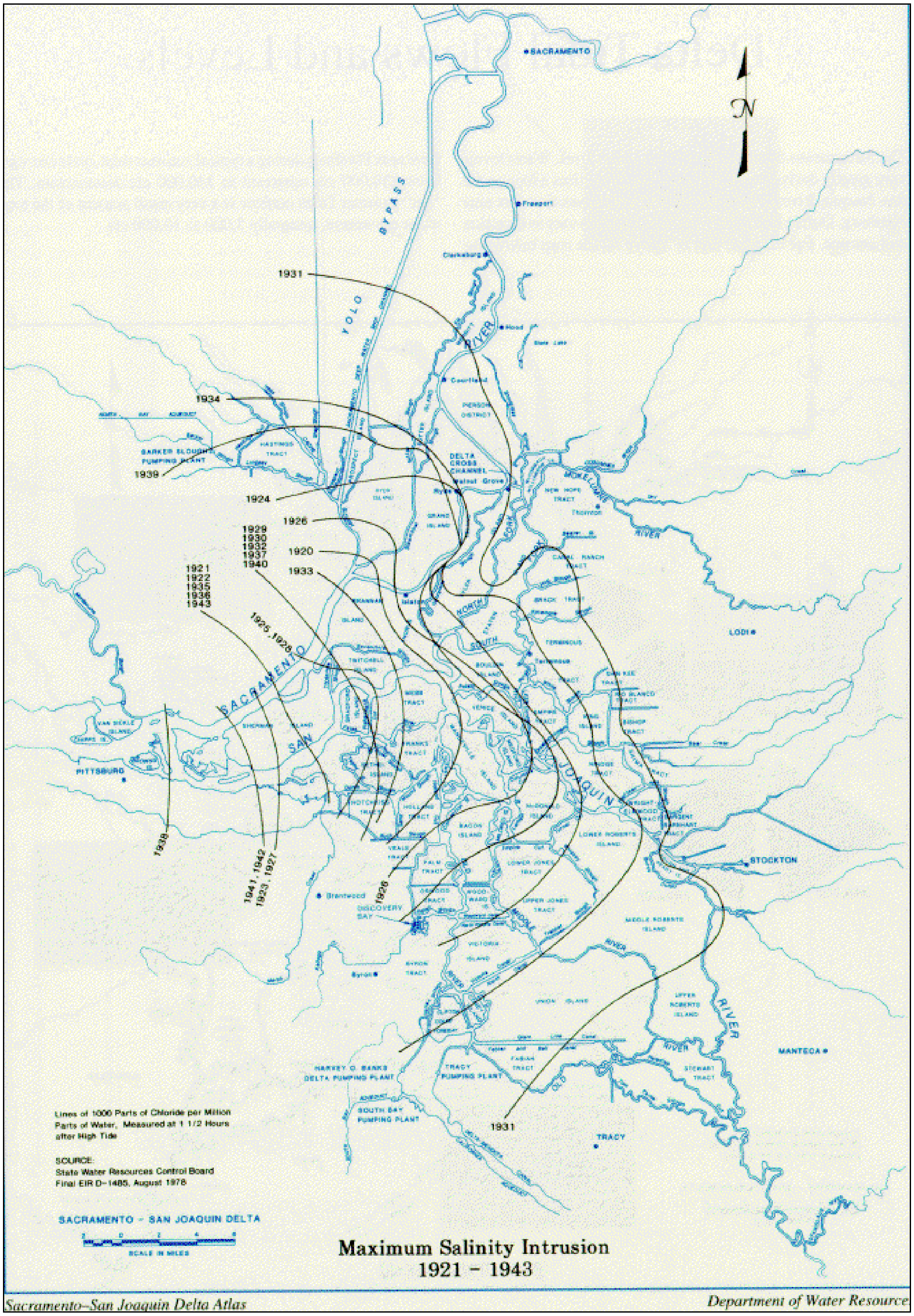

Figure 3: (DWR 1995)

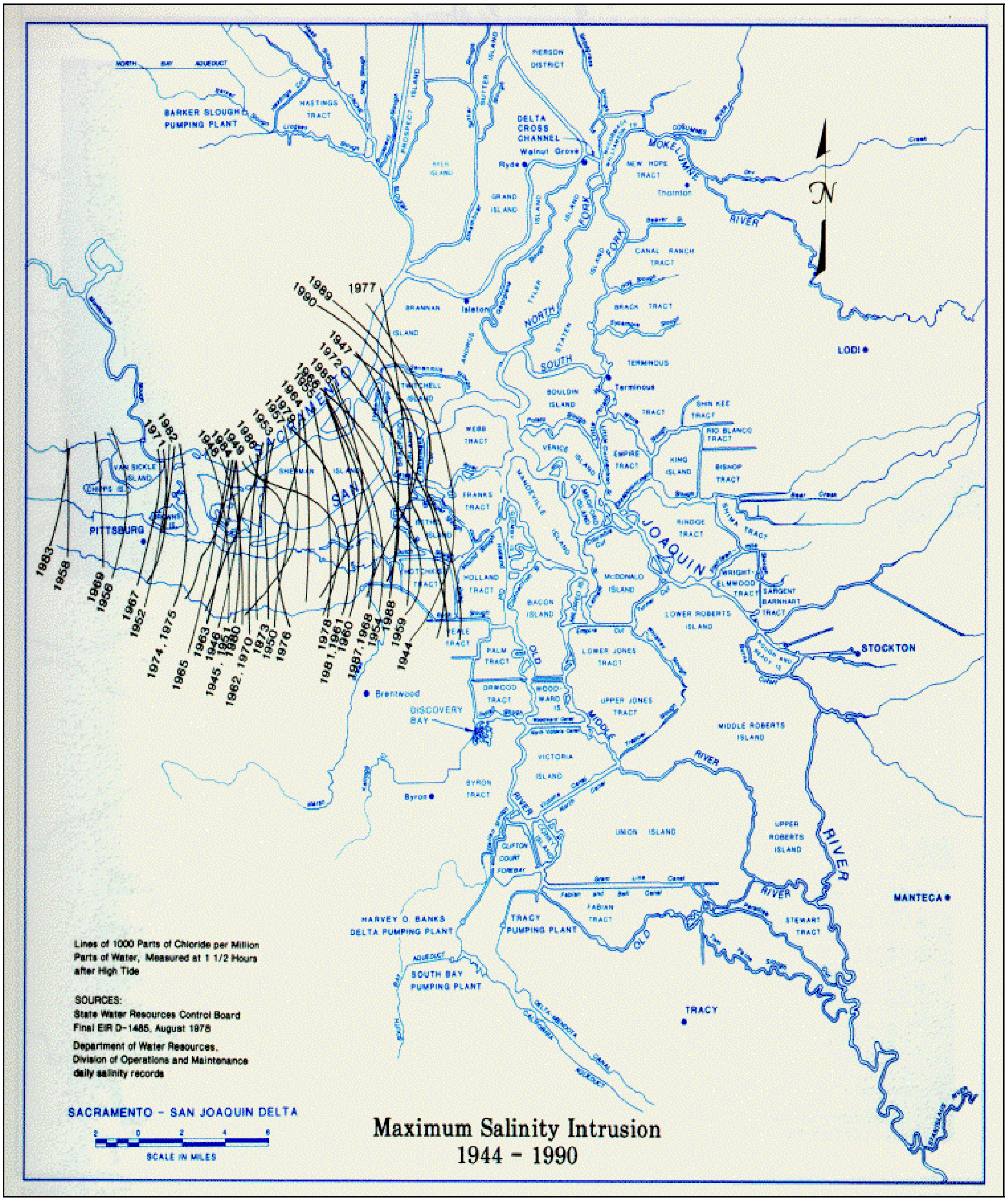

Figure 4: (DWR, 1995)

The changing patterns of Delta salinity have continued to a lesser degree with changes in water project operations in recent years and will continue with any significant shifts in the way we manage water. The continuing rise in sea level and changing runoff patterns associated with climate change are also expected to change Delta salinity.

OBSERVED SALINITY IN THE CENTRAL VALLEY AND DELTA

There is more conductivity and TDS information available in the Bay-Delta sytem than for any other constituent. This allows us to characterize salinity with a great deal more confidence, but can also be a challenge just due to the sheer volume of data that needs to be captured. This chapter presents available salinity and flow monitoring data that indicate where salinity is a problem, how salinity is changing over time, how salinity changes seasonally, and the sources of salinity. The monitoring data used in this chapter was taken from a variety of sources including agricultural, urban, and surface water discrete samples as well as conductivity measurements from continuously recording meters operated by several agencies. In some cases, computational models were used to generate continuous salinity distributions based on observed monitoring data. In essence, the models were used to fill in the gaps and graphically display the data. Information from the models is identified as such and should be viewed with appropriate caution.

Even with our level of control over Delta inflow through reservoir releases and water diversions, salinity is periodically a problem both in the Delta and in the San Joaquin River. One of the basic conflicts in the Delta is the complex relationship between water quality, water for the environment, and water supply for cities and farms. Meeting water quality objectives frequently means that the SWP and CVP must release much more water from upstream reservoirs than the amount of water to be diverted at the South Delta pumps in order to meet environmental and water supply demands. Even while meeting the applicable objectives, salinity at south and central Delta diversions has changed with recent changes in system operations.

Monitoring

The simplicity and reliability of the monitoring equipment makes EC one of the most commonly monitored characteristics in the Delta and its tributaries. A recent examination of the data available online through the California Data Exchange Center (CDEC) found 69 stations that are continuously monitoring EC. Of these 69 stations, 25 also have continuous flow monitoring. Most of these stations have several years of hourly data available and many have data at 15-minute intervals as well. If each station has an average of 6 years of data and there is hourly data for each station, then there are more than 3,600,000 EC results in the system. Although this data is labeled “preliminary” and is not considered “data of record,” when checked against laboratory analyses, it is reasonably accurate.

The system of conductivity sensors connected by the CDEC system gives the user a real-time view of salinity in the Delta and the San Joaquin River. The same is not true however for most of the Sacramento River watershed. The station at Hood has the only

CDEC conductivity sensor in the Sacramento River system. However, salinities in the Sacramento River watershed are generally very low so periodic discrete EC data captured in the CVDWPWG database is generally adequate to characterize Sacramento Valley streams. The amount of EC and TDS data is generally more than adequate, however; in a survey of existing data (CVDWPWG 2004), the authors concluded that additional TDS monitoring in some of the San Joaquin River lesser tributaries would be useful.

Salinity in the Bay-Delta and Tributaries

This section presents the spatial and temporal distribution of salinity with two basic types of graphic tools. The first are traditional time series plots of daily average salinity parameters for key monitoring locations. These plots show the seasonal, between years, and, in some cases, long-term trends in salinity at a specific location. The second way salinity data is presented is with false color EC contour maps. These maps show a snap shot of average salinity over the entire system on a given day.

Figure 5 shows EC taken from monthly grab samples taken at the H.O. Banks Pumping Plant for the period 1986-2006. The data shows a weak downward trend over this period.

Figure 6 shows fall chloride concentrations at Rock Slough from 1944 to 2004 (CCWD, 2005). As the figure shows, salinity (chloride) near the intake of the Contra Costa canal has increased since the early 1970s. This is thought to be largely the result of changed operations at the State and Federal water projects in the south Delta where, to protect threatened and endangered fish species, pumping has been shifted from spring to summer and fall.

Figures 7, 8, and 9 show more recent salinity (EC) at the southern Delta intakes. Several generalizations about Delta salinity are apparent from these figures: 1) At times Delta Mendota Canal and Contra Costa Canal salinities have exceeded the recommended secondary MCL for drinking water; 2) Banks Pumping Plant and Delta Mendota canal salinities are similar and both are much better than Contra Costa Canal; and 3) All three intakes show the typical seasonal variation in salinity. Salinity is generally lowest in late winter or spring and highest in the fall. Although there may appear to be a downward trend in salinity over the period shown, this is probably due primarily to an upward trend in precipitation and runoff over this period.

Figure 10 shows a single calendar year of EC data averaged from continuously recorded data at the Banks Pumping Plant. Although the seasonal EC variation is different each year, this pattern is typical with a seasonal minimum in early spring and a maximum in late fall. The timing and magnitude of the seasonal maximum and minimum each year depends on the amount of Delta inflow during the preceding weeks and months which in turn depends on the timing and amount of precipitation and the amount of carryover reservoir storage from the previous year.

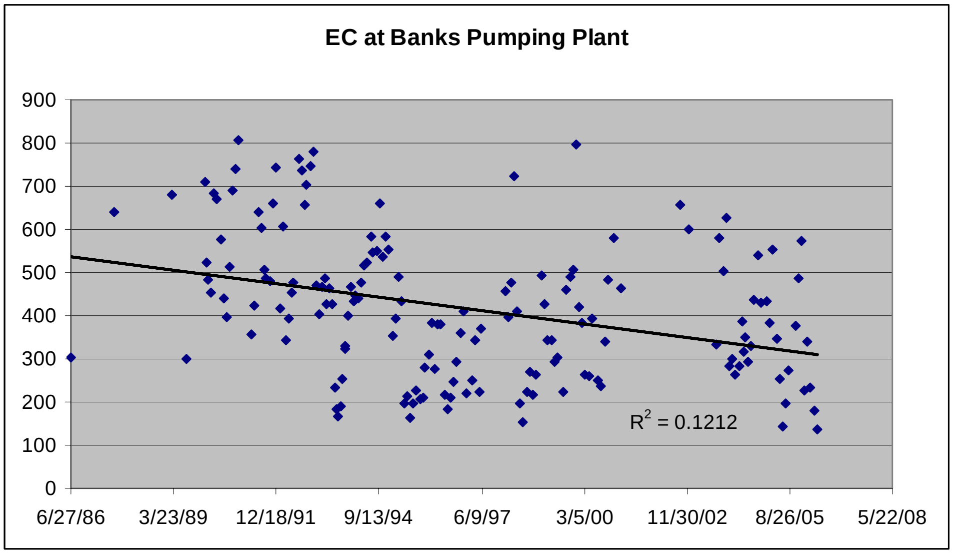

Figure 5: Electrical Conductivity at the H.O. Banks Delta Pumping Plant

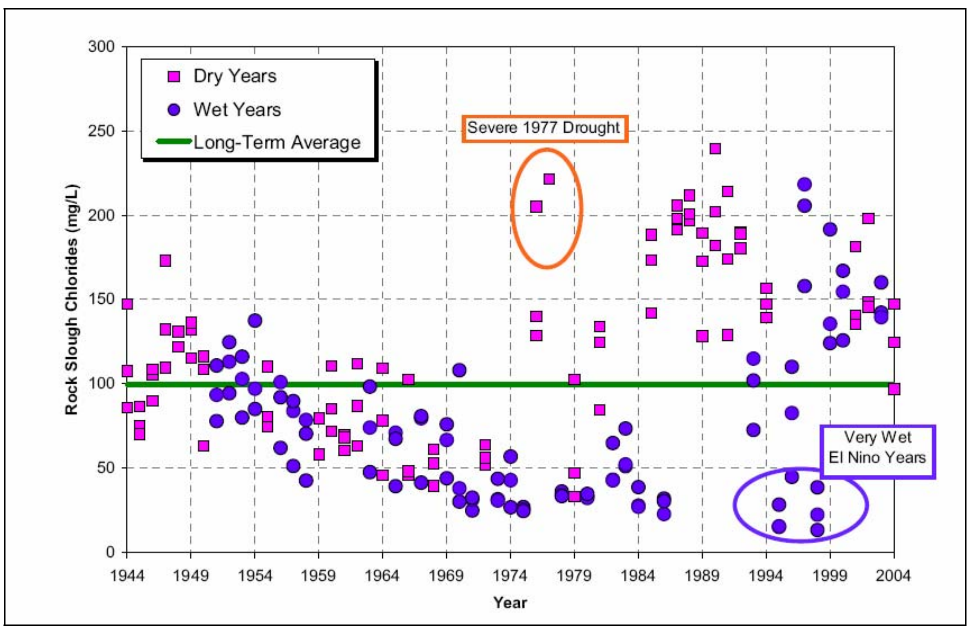

Figure 6: Fall chloride concentration in Rock Slough, 1944-2004

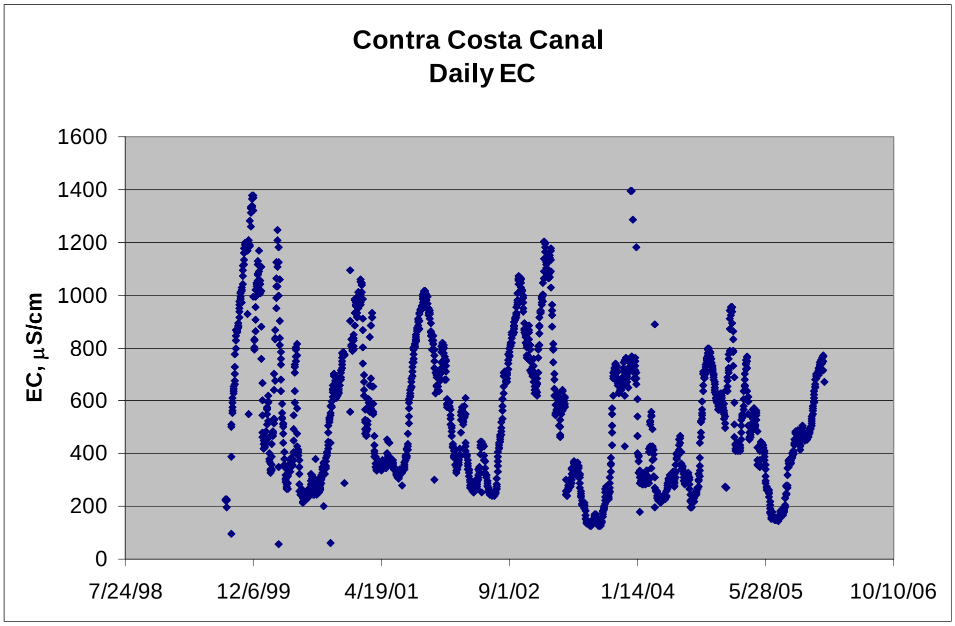

Figure 7: Daily average Electrical Conductivity (EC) in the Contra Costa Canal 1999-2006

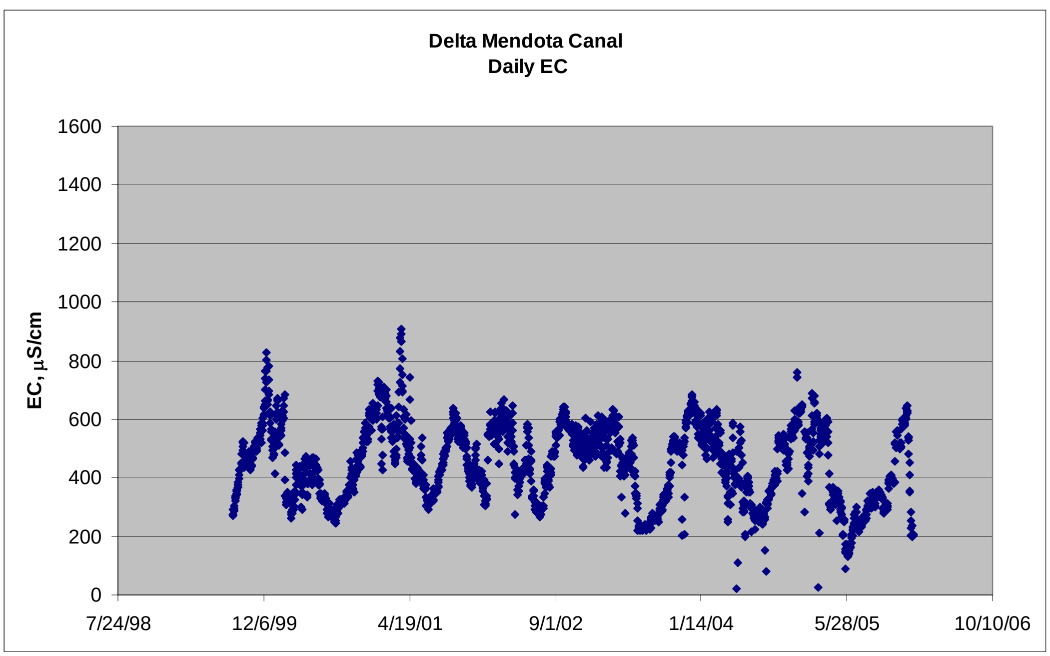

Figure 8: Daily average Electrical Conductivity (EC) in the Delta Mendota Canal near Tracy 1999-2006.

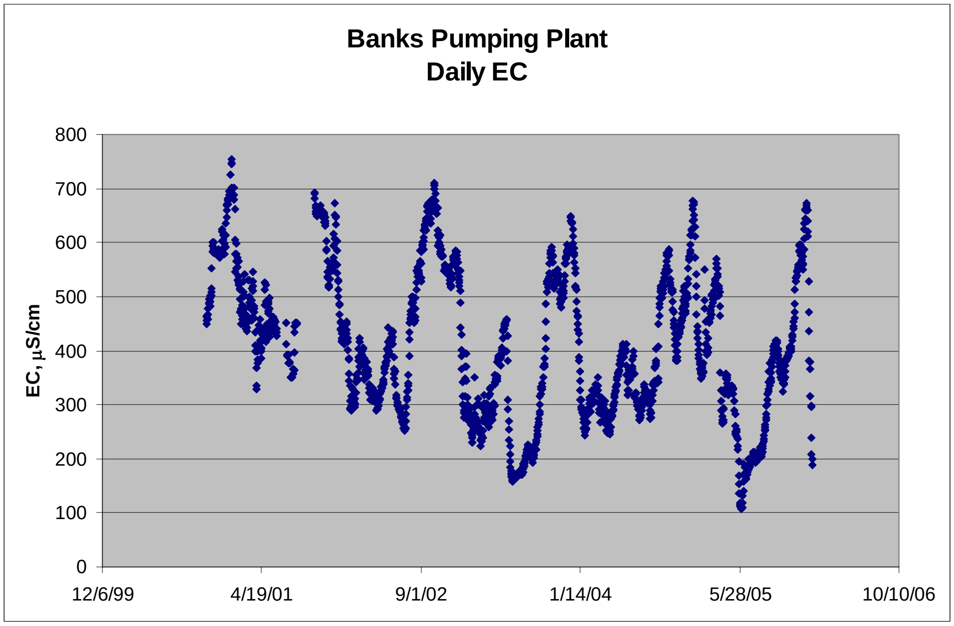

Figure 9: Daily average Electrical Conductivity (EC) at the State Water Project Banks pumping plant 2000-2005.

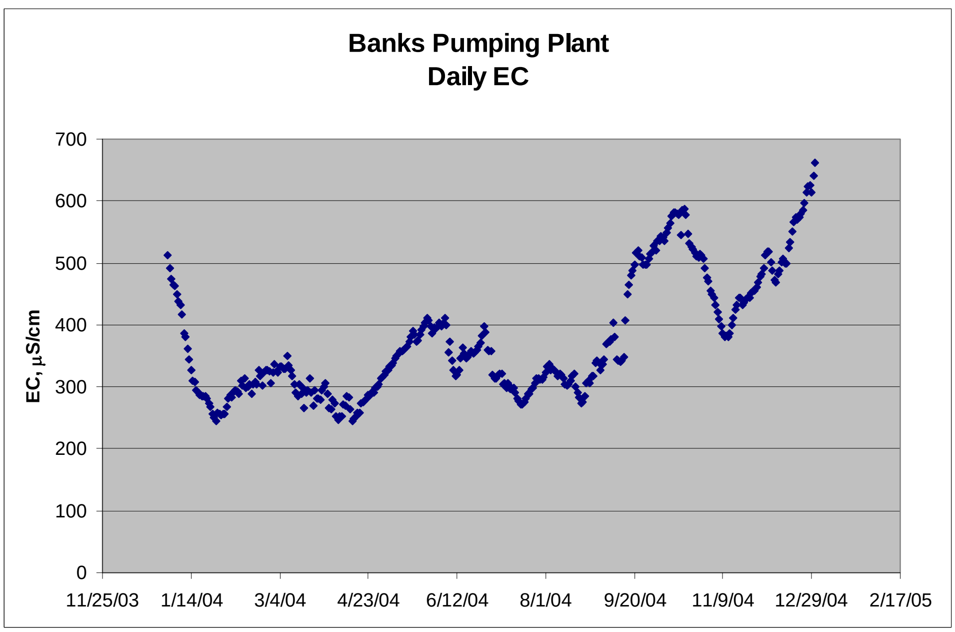

Figure 10: Daily average EC at H.O. Banks Delta Pumping Plant in 2004 (DWR data from CDEC).

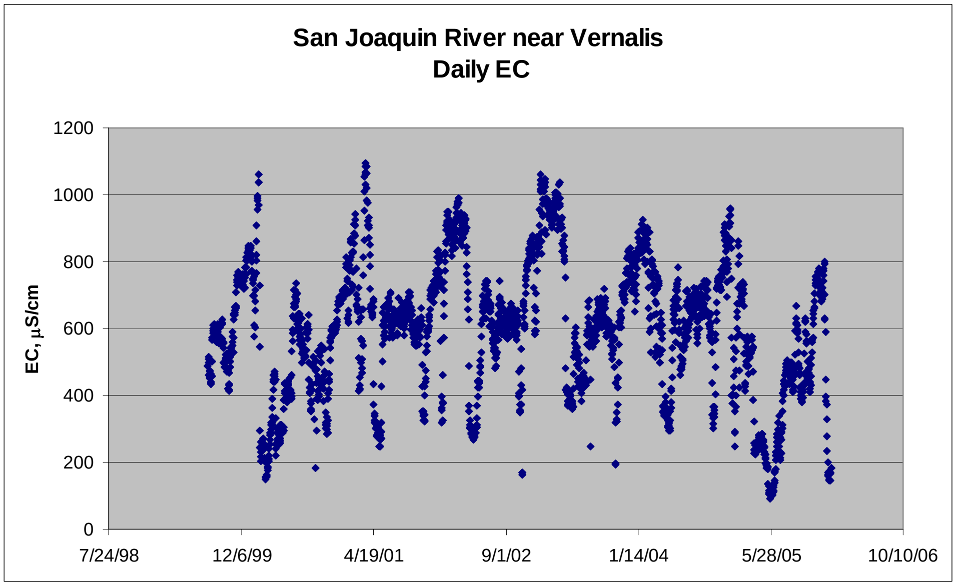

Figure 11: Daily average Electrical Conductivity (EC) for the San Joaquin River near Vernalis 1999-2005.

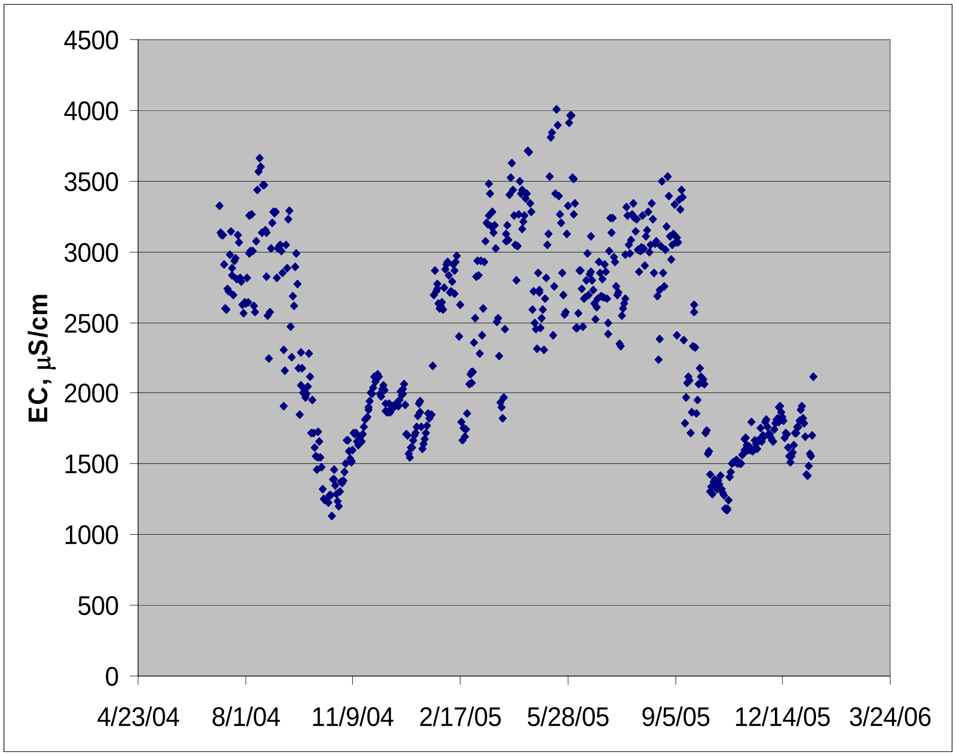

Figure 12: Daily average Electrical Conductivity (EC) for Mud Slough near Gustine, 2004-2006. (Notice that the scale is approximately 4 times the scale at the downstream Vernalis site shown in Figure 11.)

Next to seawater intrusion, the San Joaquin River is the largest source of salinity at the south Delta pumps (- this is discussed in the conceptual model section). Figure 11 shows recent salinity concentrations for the San Joaquin River near Vernalis, CA. The source of this San Joaquin River salinity is not evenly spread over the watershed but is concentrated on the west side. The largest concentrations and loads have historically come from the west side tributaries upstream of the Merced River confluence. Figure 12 shows the EC typical in Mud Slough.

Bromide and Chloride

Bromide at the Banks Pumping Plant has averaged 230 µg/L in recent years (1990-2006). The time series for bromide at the Banks Pumping Plant is shown in the Figure 13. The consistently high bromide concentration at the export pumps ranks the Delta among the drinking water sources with the highest Br concentrations in the United States (Amy et al, 1994). As Figure 14 shows, San Joaquin River bromide concentrations are also high because of the recirculation of Delta salts and bromide through the San Joaquin Valley. In contrast to the elevated concentrations of bromide seen at the Banks Pumping Plant and the San Joaquin River at Vernalis, the median concentration in the Sacramento River at Hood is at the method reporting limit of 10 µg/L with the 95th percentile at 20 µg/L.

Bromide concentration at the south Delta diversion points is closely correlated with chloride (Figure 15). This suggests that both constituents have a common origin (seawater). There is also a predictable relationship between EC and bromide (Figure 16) at the diversion points although it appears to be bimodal suggesting more than one major source of salts contributes to the observed conductivity. These plots show that bromide concentration in water diverted from the south Delta can be estimated from EC or chloride data with chloride being the most reliable indicator.

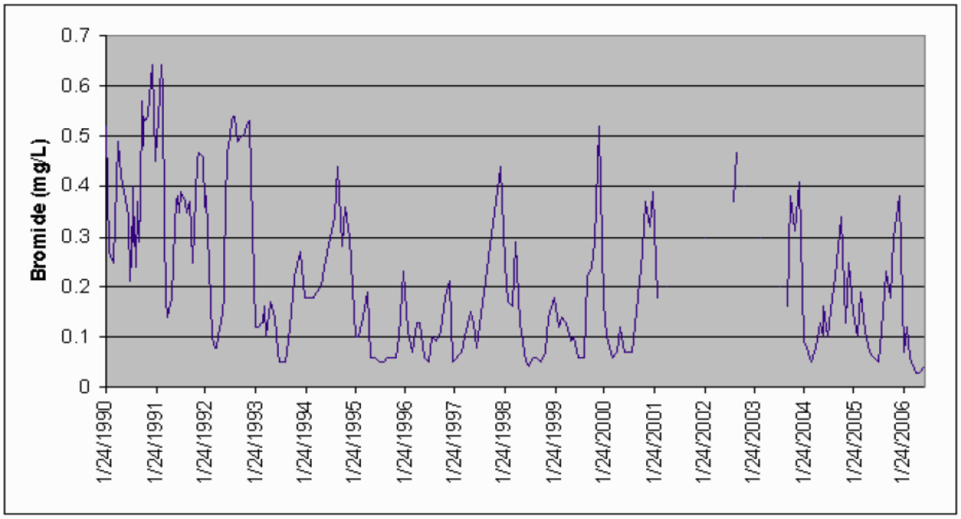

Figure 13: Bromide concentration at Banks Pumping Plant 1990-2006.

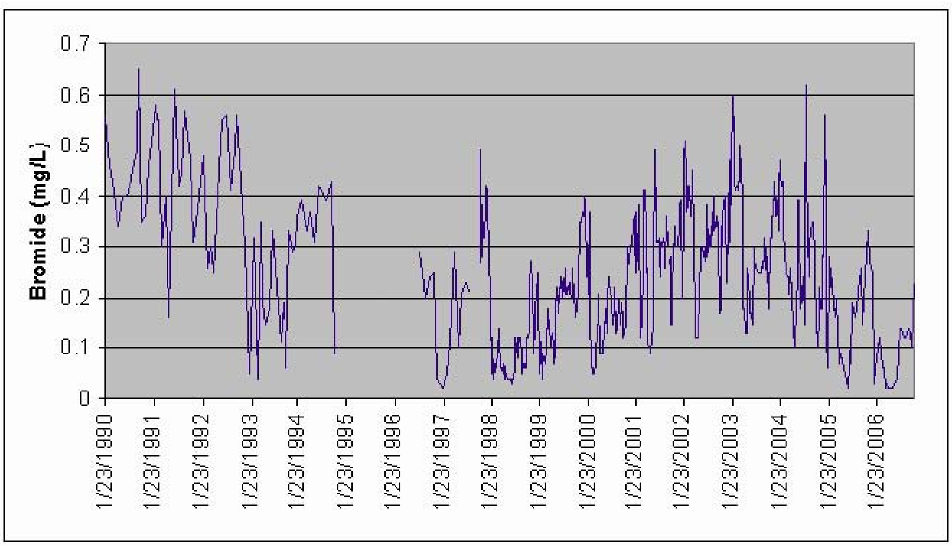

Figure 14: Bromide concentration for the San Joaquin River near Vernalis 1990-2006

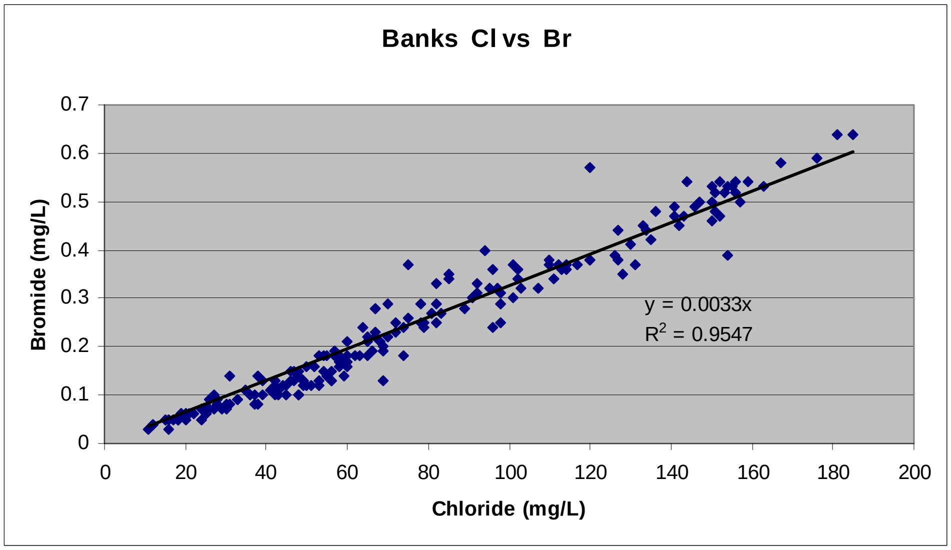

Figure 15: Chloride and bromide at the H.O. Banks Pumping Plant, 1990-2006.

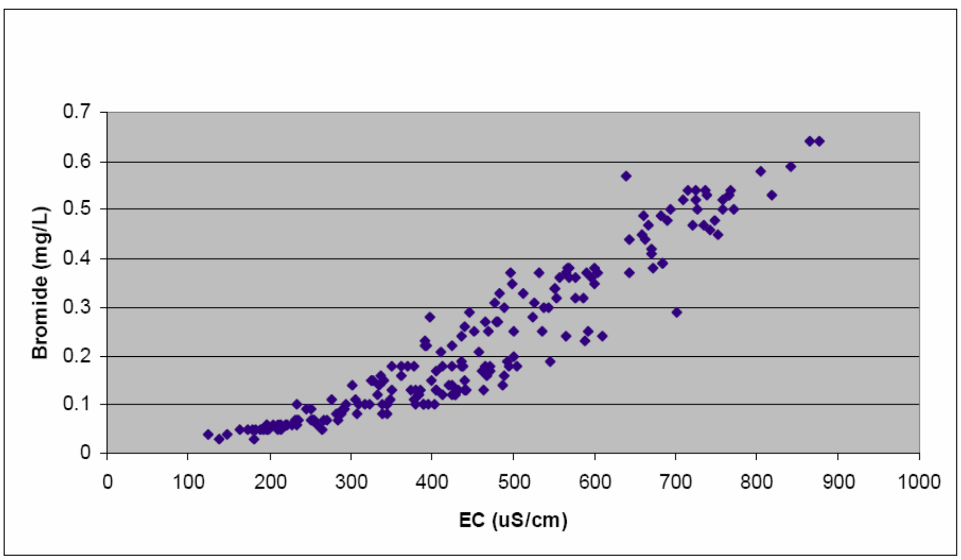

Figure 16: Bromide and EC at the H.O. Banks Pumping Plant, 1990-2006.