

Simplified Approach for Estimating Salinity Constituent Concentrations in the San Francisco Estuary & Sacramento-San Joaquin River Delta

A User Guide



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Final

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Purpose of this User Guide

Salinity in the San Francisco Estuary and Sacramento-San Joaquin River Delta (Delta) is generally measured indirectly as electrical conductivity (EC) and reported as specific conductance¹. However, the ability to directly measure and/or estimate the concentration of salinity constituents such as bromide, chloride and total dissolved solids (TDS) is also important for managing water operations and municipal and agricultural source water quality. Across the Delta, these salinity constituents are typically measured using discrete (i.e. grab) samples and are reported less frequently than EC. Analysts are frequently confronted with the need to estimate the spatial and temporal distribution of salinity constituent concentrations from measured or model-simulated EC values. This document provides a simple “user friendly” statistical approach to estimate salinity constituent concentrations from an observed value for either EC or TDS. EC was used as an independent master variable because it is the most commonly reported measure of salinity and real-time sensors for its measurement have been available for many decades. TDS was also used as an alternative master variable because of its relationship to practical salinity, a common metric for reporting seawater salinity.

Distinction between the study area’s three primary sources of salinity is illustrated in Figure 1. This figure, which shows unique relationships between discrete EC and chloride measurements within domains dominated by seawater intrusion, freshwater inflows, and the drainage-influenced San Joaquin River, also shows significant differences in salinity ranges associated with each domain.

In spite of a wealth of data available to support the conversion between EC, TDS and other salinity constituents², at the time this user guide was prepared, the primary authoritative guidance on this issue was provided by a California Department of Water Resources interoffice memorandum prepared nearly four decades ago³; this memo tabulated location-specific regression constants and statistics for estimating salinity concentrations assuming polynomial (quadratic) relationships between EC, chloride and TDS. The tabulated regression constants varied by water year type to account for hydrologic variability. Over time, it became increasingly clear that the memo’s underlying conceptual model and statistical rigor was unable to account for seasonal changes in the relative contributions to salinity from different sources in much of the interior Delta. During summer and fall months, seawater intrusion can dominate as the source of salinity in some parts of the interior Delta. In winter and spring months, seawater intrusion is typically repelled by high Delta outflows and non-marine sources of salinity typically dominate the interior Delta.

¹ Electrical conductivity (EC) converted to a standard temperature of 25°C is referred to as specific conductance. Sometimes, the terms EC and specific conductance are used interchangeably in the Delta literature.

² The California Department of Water Resources (DWR) (and its predecessors), the U.S. Bureau of Reclamation, and other agencies have been systematically collecting detailed grab sample measurements of salinity constituents from the Delta from as early as the 1950s, including total dissolved solids (TDS), bromide, chloride, sulfate, alkalinity, sodium, calcium, magnesium, and potassium. DWR’s Municipal Water Quality Investigations Program has been instrumental in collecting such data since the 1980s.

³ Guivetchi, K. (1986). Salinity Unit Conversion Equations, California Department of Water Resources Interoffice Memo, www.rtdf.info

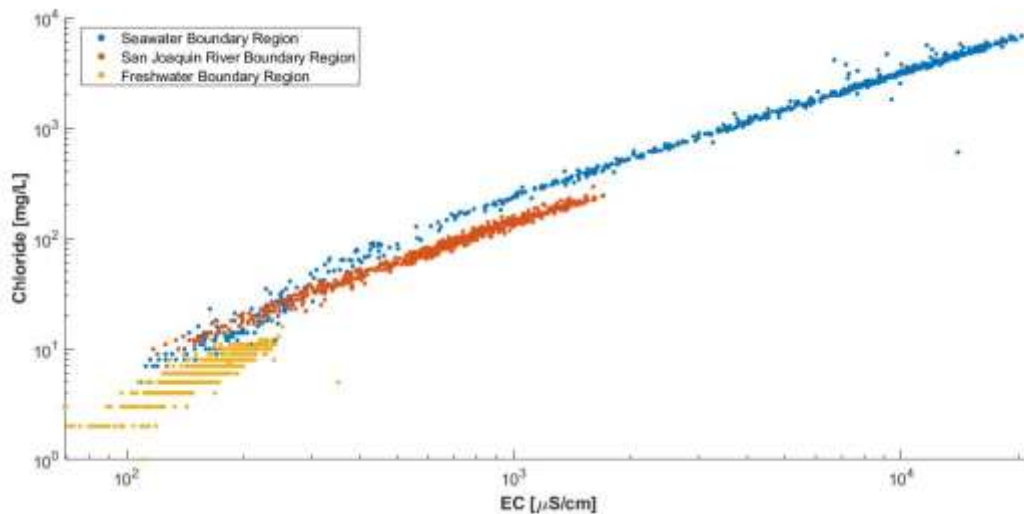


Figure 1. Distinction between the study area’s three primary sources of salinity, as measured by relationships between EC and chloride.

To more accurately predict salinity constituent concentrations from measurements or simulations of EC, informed guidance is needed to account for seasonal changes in sources of water and salinity at a given Delta location. The State Water Project Contractors Authority funded an effort to provide such guidance, providing a comprehensive background on the issue and an extensive data analysis summary⁴. Building upon that work, this user guide presents a simplified, “user friendly” methodology to estimate salinity constituent concentrations from a given EC or TDS value within various regions and at select urban diversion locations in the San Francisco Estuary and Delta. Required user inputs include region or location of interest, water year type, month, measured (or simulated) value of EC or TDS, and (optionally) X2 position⁵ to estimate major anion and cation concentrations, including bromide (Br^-), chloride (Cl^-), sulfate (SO_4^{2-}), bicarbonate (HCO_3^- , reported as alkalinity), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+). The guide is targeted toward a broad stakeholder community and does not require specialized modeling background. To assist potential users of this guide in determining the appropriateness of this approach for their unique application, key assumptions are provided in Section 1.

⁴ Denton, R.A. (2015). Delta Salinity Constituent Analysis, prepared for the State Water Project Contractors Authority, February, www.rtdf.info

⁵ X2 refers to the position of the 2 parts per thousand bottom salinity isohaline, reported as kilometers from the Golden Gate Bridge. This nomenclature, which is common in the San Francisco Estuary literature, should not be confused with scattered references in this user guide to X when talking about the x-axis (abscissa).

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1 Key Assumptions

This work presents a simplified, “user friendly” modeling approach for estimating ionic concentrations from specific electrical conductance (EC) data in the Sacramento-San Joaquin River Delta (Delta) and San Francisco Estuary. This approach, while not a substitute for more sophisticated Delta hydrodynamic modeling, can provide useful information under constrained schedules and budgets. Here we outline key assumptions associated with the approach. As with any model, potential users should carefully consider these in determining its appropriateness for their unique application.

1.1 Geographic Boundaries

Strictly speaking, the interface between marine and land sources of salinity within an estuary varies with hydrologic conditions and is not fixed in space. However, the simplified modeling approach presented here requires assignment of unique salinity constituent relationships to geographic regions and subregions with fixed boundaries. Model users should consider these boundaries to be somewhat “fuzzy”. For example, as discussed in greater detail in subsequent sections of this user guide, we have nominally defined the Seawater Boundary Region to extend along the Sacramento River to Emmaton and along the San Joaquin River to Jersey Point. Although the salinity gradient along the Sacramento River sharply trends from saline to fresh between Emmaton and Rio Vista (an upstream location) under typical low outflow conditions, the interface between seawater and freshwater characteristics can extend upstream of Emmaton, depending on hydrologic conditions. Similarly, the interface between seawater and freshwater characteristics can extend upstream of Jersey Point.

1.2 Concentration Units

This user guide reports salinity amounts in concentration units of milligrams per liter (mg/L). We note that the oceanography literature often reports salinity amounts in units such as parts per thousand (ppt) or parts per million (ppm). While both are indicators of an “amount of substance”, the main difference between the two measures is that mg/L is a mass-to-volume relationship and ppm is a mass-to-mass ratio. Numerically, concentrations reported in mg/L and ppm are roughly equivalent in dilute solutions with approximately unit density. But as salinity concentrations increase, these measures deviate due to higher seawater density. Salinity concentrations can be converted from mg/L to ppm by dividing by sample density:

$$\rho_{sample} = 1 + \frac{X_{sample}}{X_{seawater}} (\rho_{seawater} - 1)$$

where ρ_{sample} is the density of the water sample, $\rho_{seawater}$ is the density of seawater (1.024), and X_{sample} and $X_{seawater}$ are the respective ionic concentrations of the water sample and seawater in mg/L.

1.3 Data Screening

A data screening protocol, described in Section 3, was applied to raw datasets that were used to calibrate regression equations between ionic concentrations, EC and TDS. Denton (2015) notes that the robustness of salinity correlations at many locations within the study area allows for easy identification of data outliers and errors. We assumed that extreme data outliers were erroneous data; this assumption is supported by the fact that ionic relationships are highly constrained by mass and charge balance considerations. Although salinity concentrations may change under extreme hydrologic conditions, the relationships between constituent concentrations are still expected to hold. We also applied a “testability” criterion to screen samples used for calibration, including only those where the main ions were measured (Section 3). However, the data screened by this protocol were not discarded; they were used to validate the resulting mathematical relationships (see Appendix D).

1.4 Statistical Methods

Various goodness-of-fit measures are reported here to allow the user to judge the confidence and accuracy of individual regression equation predictions. In some limited cases, even though the goodness-of-fit measures indicate a lack of significant correlation, model constants are still reported. For a subset of these cases, the user guide indicates that a mean value generalization may be an appropriate prediction. However, we note that when viewed as a system of eight independent equations for cations and anions for a given TDS or EC value, the equations reasonably preserve mass and charge balance. Thus, the overall estimation methodology is of use even when an individual constituent is not predicted as well as the others. We therefore present equations for all anions/cations for individual geographical groupings; our assumption is that the determination of model appropriateness should be left to the individual users, as they must confront specific tradeoffs associated with their given analysis.

As discussed in Section 3, the regression approach assumed a quadratic model structure and in some cases the intercept term was set to zero to avoid negative predictions. Appendix B reports parameter uncertainties associated with the models; however, the statistical significance associated with individual coefficients was not evaluated. We assumed that providing a consistent equation form outweighed strict statistical considerations. Residuals associated with the boundary regression equations were largely random over the data range and suggested that the regression approach was suitable for these data.

1.5 Use of Proxy Inputs

Regression equations developed in support of this user guide seek to account for variations in source water mixtures associated with various subregions within the interior Delta. The proxies used to represent complex hydrodynamics within the interior Delta include water year type, month, and X2 position and are necessarily simplified (see Section 5); as a result, accuracy may be limited. Furthermore, we note that this proxy approach assumes the level of development broadly representative of the past five decades for which data were used – including channel geometry, upstream reservoir facilities, in-Delta facilities, and environmental regulations. From the standpoint of salinity intrusion and source water mixing in the interior Delta, this level of development has been relatively stationary since the 1980s. However, more significant future modifications to facilities and regulations could impact the proxy approach used here.

We note that water year type is a coarse measure of interannual hydrologic variability and says little about intra-annual hydrologic variability. In theory, this proxy measure has limited real-time application since the water year classification is not finalized until May. In spite of these limitations, we assume that its use within our simplified framework is valid because i) water year type is an easily understandable metric, ii) it is a

readily available piece of data for planning applications, iii) in response to concerns about real-time application, distinctions between water year types in the approach are greatest in late spring and summer when water year types are firmly established and iv) the approach allows the user to employ a salinity threshold (through the X2 proxy) to more finely address intra-annual hydrologic variability.

2 Geographic Overview

The Delta supplies drinking water to over 25 million people in California. Salinity concentrations at different points within the San Francisco Estuary and Delta result from complex source water mixing that varies by location, hydrology and season. The primary sources of salinity entering the Delta are seawater intrusion from the San Francisco Bay, freshwater inflows primarily from the Sacramento River, and inflows from the San Joaquin River that often includes a significant proportion of agricultural drainage.

Monitoring the electrical conductivity (EC) of water in the study area through electrodes is simple and inexpensive. As a result, large amounts of continuous EC observations are available to estimate salinity concentrations and, by extension, seawater intrusion. However, there is also a need to estimate other salinity constituents for beneficial use concerns, regulatory needs, modeling efforts, and tracking source water dominance.

In addition to EC, salinity constituents of interest include total dissolved solids (TDS), anions such as bromide (Br^-), chloride (Cl^-), sulfate (SO_4^{2-}), and bicarbonate (reported as alkalinity), and cations such as sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+). The relationships between these constituents vary by location, hydrology, and season.

This user guide classifies the San Francisco Estuary and Delta into three types of geographic groupings for purposes of characterizing salinity constituent relationships:

1. **Boundary Regions** – these locations are dominated year-round by either seawater (Seawater Boundary Region), freshwater (Freshwater Boundary Region), or San Joaquin River (San Joaquin River Boundary Region) influences.
2. **Interior Delta Region** – this location exhibits composite characteristics of the boundary regions that vary by hydrology and season.
3. **Location-Specific Urban Diversions** – these locations are of particular interest from the standpoint of drinking water quality management.

The map on the next page (**Figure 2**) visually delineates these geographic groupings.

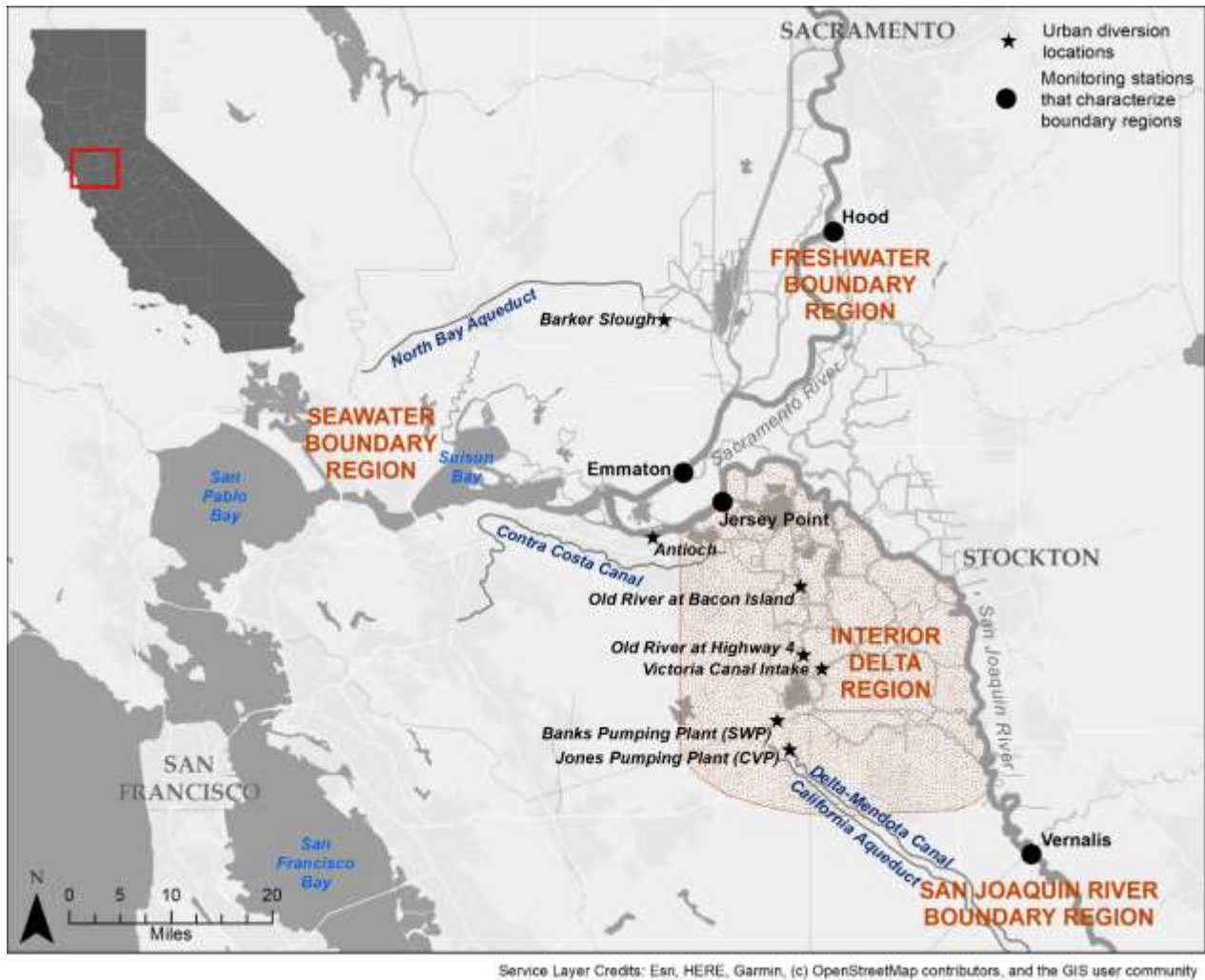


Figure 2. Delineation of Boundary Regions, Interior Delta Region, and Location-Specific Urban Diversions. Urban Diversion locations are identified in the map with stars.

3 Methodology

This section summarizes the data, data screening and statistical approach employed in this user guide to develop mathematical relationships between salinity constituents in the San Francisco Estuary and Delta. This section also provides user guidance for selecting appropriate mathematical relationships.

3.1 Data, Data Screening & Statistical Approach

A subset of grab sample data was compiled from the California Department of Water Resources Water Data Library (WDL) and other sources to characterize the relationships between salinity constituents in each geographic grouping and to test the accuracy of the proposed estimation method. See Appendix A.

Denton (2015) notes that i) the quality of salinity grab sample data in the study area is generally very good and ii) the robustness of correlations between various salinity constituents, EC and TDS at many locations within the study area allows for easy identification of data outliers and errors. Here we describe a protocol that was followed to screen data that were used to calibrate mathematical relationships between ionic concentrations, EC and TDS.

Grab sample data selected to represent the Boundary Regions⁶ were checked for “testability”. A testable data sample was defined as one that had a measured value for each of the following constituents: EC, TDS, Cl⁻, SO₄²⁻, Na⁺, and Mg²⁺. Testability was enforced to ensure that samples were generally mass- and charge-balanced. Following the check for “testability”, two additional screening criteria for outliers were imposed on the datasets that were compiled for each Boundary Region:

- A data point associated with a single constituent was removed if, when plotted against EC or TDS, fell outside the 99% prediction band (three standard errors) for the testable set of observations for that constituent.
- An entire sample, including all data points associated with it, was removed if three or more constituents in that sample fell outside the 95% prediction band (two standard errors) for the testable set of observations for the constituents.

The above screening is based on the assumptions that, while total salinity can exhibit unusual behavior under extreme hydrologic conditions, i) relationships between individual constituents and total salinity exhibit consistent behavior and ii) major departures from these relationships are indicative of outlier behavior.

This data screening protocol was also applied to datasets that were used to calibrate salinity constituent relationships for i) the Barker Slough urban diversion location and ii) a subset of data from the Interior Delta Region with “indeterminate” source influence. However, for the remaining data associated with the Interior

⁶ Grab sample data from Mallard Island, Chipps Island, and Jersey Point were used to represent the Seawater Boundary Region; Hood and Greene’s Landing offered data to represent the Freshwater Boundary Region; Vernalis and Maze were the stations chosen to represent the San Joaquin River Boundary Region. See Appendix A.

Delta Region (for which salinity constituent relationships were not calibrated), no testability or data screening criteria were imposed to preserve inherent seasonal and hydrodynamic nuances.

These screened salinity constituent data were used to develop unique regression equations (with associated regression constants) reported in this user guide. Some of these regression equations use EC as the independent variable and predict TDS, major anions (Br^- , Cl^- , SO_4^{2-} , Alkalinity), and major cations (Na^+ , Ca^{2+} , Mg^{2+} , K^+). Other regression equations use TDS as the independent variable and predict EC and major anions and cations. An Ordinary Least Squares approach was generally used to determine the regression constants A, B, and C in the quadratic equation $Y = AX^2 + BX + C$, where X is the independent variable (either EC or TDS). In limited cases, the intercept term C was set to zero. Appendix B reports parameter uncertainties associated with the regression constants. The following goodness-of-fit statistics were computed for each regression equation:

- R^2 , a dimensionless measure of the proportion of the variance in the dependent variable (Y), that is explained by the independent variable (X).
- SE, Standard Error, the statistical accuracy of the estimate, expressed in units of the dependent variable (Y).

The following additional tests were performed once the best-fit equations were obtained:

- Residuals associated with the boundary regression equations (as a function of EC and TDS) were evaluated; this analysis did not show patterns that would indicate that the regression approach was inappropriate.
- Mass and charge balance analyses were performed on estimated anion and cation concentrations. These analyses showed that the independently obtained concentration estimates (in units of mass or equivalents) were well constrained, i.e. total ion mass reasonably matched TDS and anion charge approximately equaled the cation charge.
- A validation analysis of the regression equations was performed with independent data. This analysis included boundary data that were screened out by the “testability” criterion (the screening for outliers was retained) as well as additional data associated with urban diversion locations. In this analysis, mean bias was reported in addition to R^2 and SE. The mean bias statistic indicates the difference between data the regression estimates; the fits are favorable when the bias is lower than the Standard Error.

3.2 Decision Tree

Given a location-specific value of EC or TDS and knowledge of the sampling period and region, a *Decision Tree* (Figure 3) can be used to find the most appropriate set of regression constants which estimate the salinity constituents of interest. The *Decision Tree* was developed based on extensive assessment of grab sample data across the regions.

In the simplest case, an EC or TDS value associated with one of the Boundary Regions (i.e. Seawater, Freshwater, or San Joaquin River) can be converted to various salinity constituent concentrations using the corresponding boundary regression relationships (see Branch 1 of the *Decision Tree*). An EC or TDS value associated with the Interior Delta Region can be converted to a salinity concentration by applying the logic shown in Branch 2 of the *Decision Tree*; this more complicated logic attempts to account for seasonal

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changes in the relative contributions to water quality from different sources through proxy inputs⁷. For this branch, required user inputs include location (i.e. Interior Delta subregion), month and water year type, with X2 position being an optional user input. Finally, an EC or TDS value associated with a location-specific Urban Diversion can be converted to a salinity constituent concentration by applying the logic shown in Branch 3 of the *Decision Tree*.

Regression equations developed in support of this user guide seek to account for variations in source water mixtures associated with various subregions within the interior Delta. The proxies used to represent complex hydrodynamics within the interior Delta are necessarily simplified; as a result, accuracy may be limited. Various regression statistics are reported here to allow the user to judge the confidence and accuracy of the regression equation predictions. The resulting predictions, while not a substitute for Delta hydrodynamic modeling, can provide the user with useful information under constrained schedules and budgets.

The methodology employed in this user guide, including the *Decision Tree*, varies somewhat by geographic grouping (i.e. Boundary Regions, Interior Delta Region, Urban Diversion) and is summarized accordingly in the remainder of this guide. For each geographic grouping, the appropriate *Decision Tree* branch is traversed to illustrate the steps that should be taken to estimate salinity constituent concentrations for a given water sample.

⁷ As previously noted, seawater intrusion can dominate as the source of salinity in some parts of the interior Delta during summer and fall months. In winter and spring months, seawater intrusion is typically repelled by high Delta outflows and non-marine sources of salinity typically dominate the interior Delta.

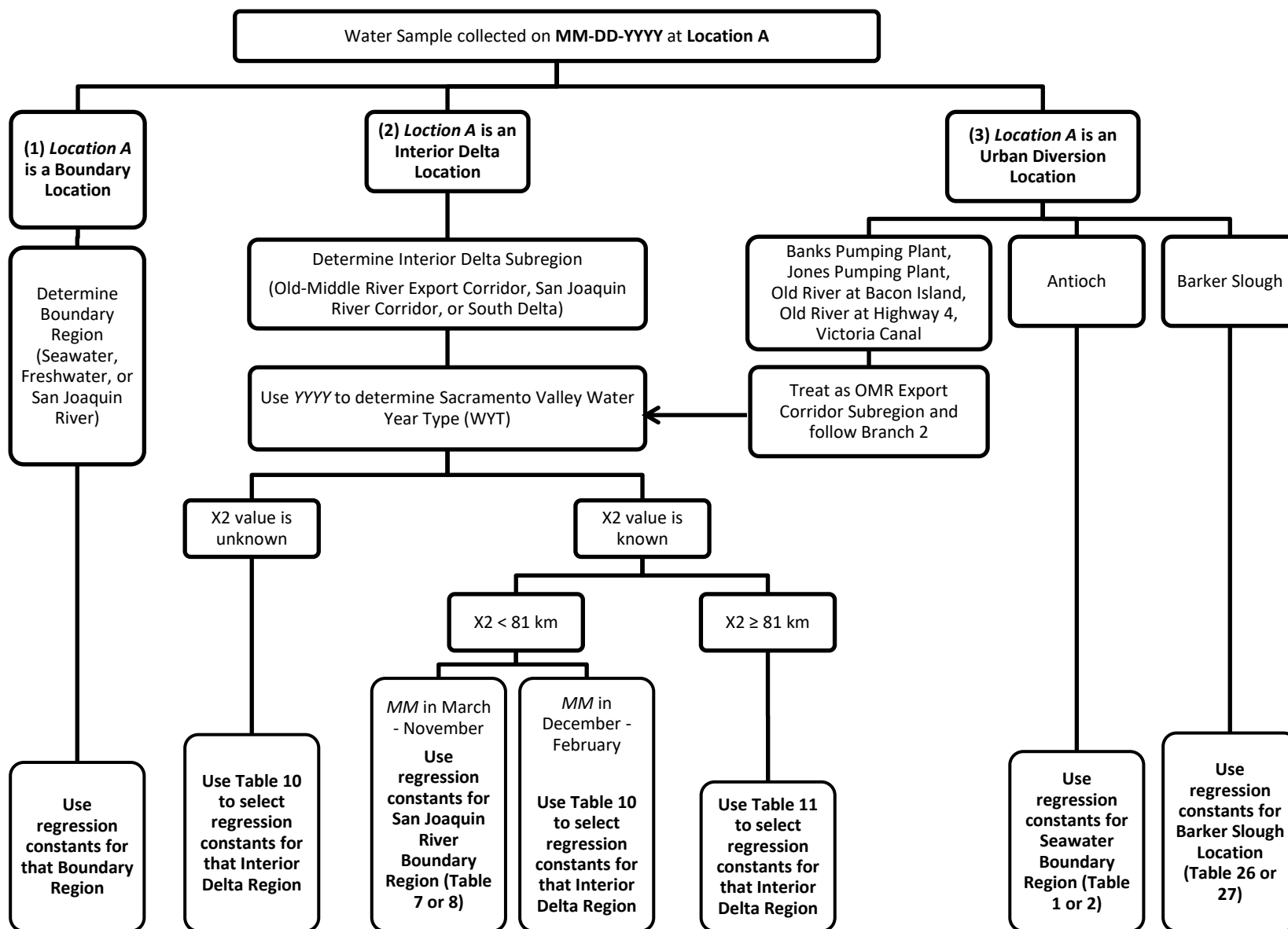


Figure 3. Decision tree to select appropriate equations to estimate salinity constituents given location, time of sample, and X2 (if available).

4 Boundary Regions

Boundary Regions include the Seawater Boundary, the Freshwater Boundary, and the San Joaquin River Boundary

4.1 Seawater Boundary Region



Figure 4. Seawater enters San Francisco Estuary at Golden Gate. Grab sample data from Mallard Island, Chipps Island, and Jersey Point were used to characterize the Seawater Boundary Region.

Seawater enters the San Francisco Estuary through tidal action at Golden Gate (see Figure 4). Four salinity ranges were defined to divide the spectrum of observed and expected values of the independent variables (i.e. EC and TDS) within the Seawater Boundary Region: (i) “Low”, (ii) “Low-Medium”, (iii) “Medium”, and (iv) “High” salinity. The Seawater Boundary Region dataset was divided in such a manner because the constituent relationships were found to have unique trends in certain salinity ranges which were not adequately captured by a single regression fit. The relationships between constituents in each of the salinity ranges are captured by the constants and statistics in Tables 1 and 2 below. Table 3 can be used to quickly estimate the salinity constituents of interest when the general EC range is known. Appendix C provides scatter plots of measured salinity constituents as functions of EC and TDS; regression relationships associated with the Seawater Boundary Region overlay the measured data. Appendix D provides a validation analysis of the regression relationships.

Because data were generally unavailable to characterize the “High” salinity range, constants associated with this range were derived assuming a linear combination (“mix”) of low salinity water and ambient seawater.⁸ As the data used to derive these constants were not measured, regression statistics and parameter uncertainties were not generally calculated.⁹

⁸ Ambient seawater was assumed to have the following properties: EC = 53,097 $\mu\text{S}/\text{cm}$, TDS = 35,000 mg/L TDS, Br^- = 65 mg/L, Cl^- = 19,284 mg/L, SO_4^{2-} = 2,710 mg/L, Alkalinity = 116 mg/L as CaCO_3 , Na^+ = 10,693 mg/L, Ca^{2+} = 403 mg/L, Mg^{2+} = 1,298 mg/L, and K^+ = 387 mg/L. See Voutchkov (2010). Introduction to Reverse Osmosis Desalination – A SunCam Online Continuing Education Course, Technical Report, January. DOI: 10.13140/RG.2.2.13908.60801. Also see Schemel, L. and Park, M. (2001). Simplified Conversions Between Specific Conductance and Salinity Units for Use with data from Monitoring Stations, Interagency Ecological Program Newsletter, 14(1).

⁹ Regression statistics (R^2 and Standard Error) were calculated and reported for EC, TDS and Cl^- in the high salinity range, as limited data were available for these constituents. Other constituents were either not observed or were not reported in the high salinity range.

Table 1. This series of tables can be used to estimate salinity constituents of interest within the Seawater Boundary Region given a known value of EC. Each row represents one relationship and contains the regression constants (A, B, C) in the quadratic equation $Y = A [EC]^2 + B [EC] + C$, that are used to estimate Y, the concentration of the salinity constituent of interest. Also listed in each row are the number of data points that were used to generate the associated regression constants and statistics (R^2 and Standard Error). The Seawater Boundary Region is divided into four salinity ranges: low, low-medium, medium, and high. Each salinity range is defined by an upper and lower bound; regression constants are valid for the listed range of EC values. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as $CaCO_3$.

X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
“Low” Salinity $100 \leq [EC] < 250$ $\mu S/cm$	TDS	68	0	0.593	0.8	0.957	4.5	67 – 151
	Br ⁻	64	0	0.000401	-0.03	0.604	0.01	0.01 – 0.1
	Cl ⁻	68	0	0.139	-10.9	0.781	2.6	7 – 31
	SO ₄ ²⁻	68	0	0.0716	-1.0	0.544	2.3	6 – 22
	Alkalinity	68	0	0.205	15.0	0.706	4.7	37 – 72
	Na ⁺	68	0	0.102	-4.9	0.892	1.3	7 – 22
	Ca ²⁺	68	0	0.0422	4.0	0.665	1.1	8 – 16
	Mg ²⁺	68	0	0.0355	0.1	0.836	0.6	4 – 9
	K ⁺	68	0	0.00484	0.6	0.221	0.3	0.9 – 2.5

X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
“Low-Medium” Salinity $250 \leq [EC] < 1,000$ $\mu S/cm$	TDS	51	0	0.527	13.3	0.996	8.3	151 – 541
	Br ⁻	50	0	0.000869	-0.13	0.786	0.11	0.07 – 0.83
	Cl ⁻	51	0	0.282	-45.1	0.984	8.6	23 – 235
	SO ₄ ²⁻	51	0	0.0342	8.9	0.755	4.7	14 – 47
	Alkalinity	51	0	0.00280	61.9	0.004	10.2	41 – 85
	Na ⁺	51	0	0.155	-16.8	0.988	4.2	21 – 137
	Ca ²⁺	51	0	0.00482	12.4	0.202	2.3	9 – 21
	Mg ²⁺	51	0	0.0188	4.1	0.900	1.5	8.9 – 26
	K ⁺	51	0	0.00583	0.5	0.924	0.4	1.9 – 6.8

Table 1 (contd.)

X = EC	Y	Data Points	A	B	C	R ²	SE	Data Range
“Medium” Salinity $1,000 \leq [\text{EC}] < 17,500 \text{ } \mu\text{S/cm}$	TDS	308	4.84E-06	0.544	-20.9	0.996	185	532 – 10,800
	Br⁻	266	3.21E-10	0.00114	-0.46	0.982	0.7	0.08 – 19.65
	Cl⁻	308	2.42E-06	0.299	-72.5	0.997	89	238 – 5,704
	SO₄²⁻	308	3.60E-07	0.0400	1.3	0.992	19	40 – 793
	Alkalinity	308	-1.13E-08	0.00168	61.5	0.449	8	46 – 96
	Na⁺	308	1.16E-06	0.163	-35.0	0.997	50	138 – 3130
	Ca²⁺	308	5.06E-08	0.00619	10.9	0.987	4	15 – 135
	Mg²⁺	308	9.13E-08	0.0207	-0.4	0.991	10	22 – 376
	K⁺	308	5.01E-08	0.0062	-0.6	0.979	5	2.6 – 132

X = EC	Y	Data Points	A	B	C	R ²	SE	Data Range
“High” Salinity $[\text{EC}] \geq 17,500 \text{ } \mu\text{S/cm}$	TDS	103	0	0.659	-15.8	0.936	2,460	10,200 – 36,200
	Br⁻	0	0	0.00123	-0.24	N/A	N/A	N/A
	Cl⁻	228	0	0.364	-67.3	0.947	910	5,400 – 18,800
	SO₄²⁻	0	0	0.0510	4.2	N/A	N/A	N/A
	Alkalinity	70	0	0.000950	66.0	0.509	9	47 – 108
	Na⁺	0	0	0.202	-22.9	N/A	N/A	N/A
	Ca²⁺	0	0	0.00735	12.7	N/A	N/A	N/A
	Mg²⁺	0	0	0.0244	2.9	N/A	N/A	N/A
	K⁺	0	0	0.00729	0.0	N/A	N/A	N/A

Table 2. This series of tables can be used to estimate salinity constituents of interest within the Seawater Boundary Region given a known value of TDS. Each row represents one relationship and contains the regression constants (A, B, C) in the quadratic equation $Y = A [TDS]^2 + B [TDS] + C$, that are used to estimate Y, the concentration of the salinity constituent of interest. Also listed in each row are the number of data points that were used to generate the associated regression constants and statistics (R^2 and Standard Error). The Seawater Boundary Region is divided into four salinity ranges: low, low-medium, medium, and high. Each salinity range is defined by an upper and lower bound; regression constants are valid for the listed range of TDS values. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as $CaCO_3$.

X = TDS	Y	Data Points	A	B	C	R^2	SE	Data Range
“Low” Salinity $60 \leq [TDS] < 150$ mg/L	EC	68	0	1.62	6.3	0.954	7.4	117 – 248
	Br ⁻	64	0	0.000592	-0.03	0.559	0.01	0.01 – 0.08
	Cl ⁻	68	0	0.213	-9.0	0.745	2.6	7 – 27
	SO ₄ ²⁻	68	0	0.128	-1.8	0.589	2.2	6 – 22
	Alkalinity	68	0	0.334	16.1	0.651	5.1	37 – 72
	Na ⁺	68	0	0.163	-4.1	0.849	1.4	7 – 22
	Ca ²⁺	68	0	0.0741	3.7	0.725	1.0	8 – 16
	Mg ²⁺	68	0	0.0595	0.1	0.808	0.6	4 – 9
	K ⁺	68	0	0.00894	0.5	0.259	0.3	0.9 – 2.5

X = TDS	Y	Data Points	A	B	C	R^2	SE	Data Range
“Low-Medium” Salinity $150 \leq [TDS] < 700$ mg/L	EC	59	0	1.92	-30.3	0.996	21.5	249 – 1,299
	Br ⁻	58	0	0.00184	-0.20	0.884	0.11	0.07 – 1.21
	Cl ⁻	59	0	0.547	-54.6	0.984	11.7	23 – 321
	SO ₄ ²⁻	59	0	0.0674	7.2	0.864	4.5	12 – 57
	Alkalinity	59	0	0.00603	61.3	0.011	9.7	41 – 85
	Na ⁺	59	0	0.295	-20.8	0.986	5.9	21 – 179
	Ca ²⁺	59	0	0.00998	12.0	0.359	2.2	9 – 21
	Mg ²⁺	59	0	0.0362	3.5	0.946	1.5	7 – 29
	K ⁺	59	0	0.0113	0.3	0.952	0.4	1.5 – 8.4

Table 2 (contd.)

X = TDS	Y	Data Points	A	B	C	R ²	SE	Data Range
“Medium” Salinity $700 \leq [\text{TDS}] < 12,000 \text{ mg/L}$	EC	304	-2.34E-05	1.83	34.9	0.996	281	1,180 – 18,232
	Br ⁻	263	-2.60E-08	0.00209	-0.42	0.979	0.8	1.15 – 20
	Cl ⁻	304	-1.83E-06	0.560	-77.5	0.994	116	301 – 6,044
	SO ₄ ²⁻	304	-1.07E-07	0.0745	1.7	0.992	19	51 – 853
	Alkalinity	304	-6.26E-08	0.00303	61.5	0.442	8	46 – 96
	Na ⁺	304	-1.01E-06	0.302	-32.3	0.995	59	178 – 3,298
	Ca ²⁺	304	-1.83E-08	0.0114	11.1	0.987	4	16 – 143
	Mg ²⁺	304	-2.78E-07	0.0382	-0.4	0.989	11	25 – 424
	K ⁺	304	-3.47E-08	0.0116	-0.7	0.978	5	2.6 – 134

X = TDS	Y	Data Points	A	B	C	R ²	SE	Data Range
“High” Salinity $[\text{TDS}] \geq 12,000 \text{ mg/L}$	EC	97	0	1.52	23.9	0.947	3,200	14,600 – 50,100
	Br ⁻	0	0	0.00186	-0.21	N/A	N/A	N/A
	Cl ⁻	241	0	0.553	-58.6	0.956	941	5,680 – 18,800
	SO ₄ ²⁻	0	0	0.0773	5.4	N/A	N/A	N/A
	Alkalinity	129	0	0.00144	66.0	0.579	9	62 – 123
	Na ⁺	0	0	0.306	-25.1	N/A	N/A	N/A
	Ca ²⁺	0	0	0.0111	12.9	N/A	N/A	N/A
	Mg ²⁺	0	0	0.0370	3.5	N/A	N/A	N/A
	K ⁺	0	0	0.0111	0.2	N/A	N/A	N/A

Table 3. This look-up table can be used to estimate salinity constituents of interest in the Seawater Boundary Region given a general range of EC.

SEAWATER BOUNDARY REGION									
EC [μS/cm]	TDS [mg/L]	Br ⁻ [mg/L]	Cl ⁻ [mg/L]	SO ₄ ²⁻ [mg/L]	Alkalinity [mg/L as CaCO ₃]	Na ⁺ [mg/L]	Ca ²⁺ [mg/L]	Mg ²⁺ [mg/L]	K ⁺ [mg/L]
100	60	0.01	3	6	35	5	8	4	1.1
150	90	0.03	10	10	46	10	10	5	1.3
200	119	0.05	17	13	56	15	12	7	1.6
250	149	0.07	24	17	66	21	15	9	1.8
...
500	277	0.30	96	26	63	61	15	14	3.4
750	409	0.52	167	35	64	99	16	18	4.9
1,000	541	0.74	237	43	65	138	17	23	6.3
...
2,000	1,087	1.8	534	83	65	296	24	41	12
3,000	1,655	3.0	845	125	66	465	30	62	18
4,000	2,233	4.1	1,161	167	68	636	36	84	25
5,000	2,821	5.2	1,481	211	70	810	43	105	32
...
10,000	5,905	11	3,156	438	77	1,712	78	215	66
15,000	9,230	17	4,951	683	84	2,674	115	330	104
20,000	13,164	24	7,213	1,024	85	4,017	160	491	146
25,000	16,459	31	9,033	1,279	90	5,027	196	613	182
30,000	19,754	37	10,853	1,534	95	6,037	233	735	219
35,000	23,049	43	12,673	1,789	99	7,047	270	857	255
40,000	26,344	49	14,493	2,044	104	8,057	307	979	292
45,000	29,639	55	16,313	2,299	109	9,067	343	1,101	328
50,000	32,934	61	18,133	2,554	114	10,077	380	1,223	365
53,097	35,000	65	19,284	2,710	116	10,693	403	1,298	387

4.2 Freshwater Boundary Region



Figure 5. Sampling station on the Sacramento River at Hood, a key real-time monitoring station located within the Freshwater Boundary Region. Grab sample data at Hood and Greene's Landing (also on the Sacramento River) were used to characterize the Freshwater Boundary Region.

Freshwater inflows from the Sacramento, Cosumnes and Mokelumne Rivers dominate the salinity characteristics of the Freshwater Boundary Region, a significant area of the Delta above (i.e. north of) the San Joaquin River. The relationships between salinity constituents measured along the Sacramento River (see Figure 5) are used to characterize the Freshwater Boundary Region and are captured by the constants and statistics in Tables 4 and 5 below. Table 6 can be used to quickly estimate the salinity constituents of interest when the general EC range is known. Appendix C provides scatter plots of measured salinity constituents as functions of EC and TDS; regression relationships associated with the Freshwater Boundary Region overlay the measured data. Appendix D provides a validation analysis of the regression relationships.

Table 4. This table can be used to estimate salinity constituents of interest within the Freshwater Boundary Region given a known value of EC. Each row represents one relationship and contains the regression constants (A, B, C) in the quadratic equation $Y = A [EC]^2 + B [EC] + C$, that are used to estimate Y, the concentration of the salinity constituent of interest. Also listed in each row are the number of data points that were used to generate the associated regression constants and statistics (R^2 and Standard Error). Constants are valid for the listed range of EC values; the bromide equation range is 100-240 $\mu S/cm$. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as $CaCO_3$.

X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
50 ≤ [EC] < 250 $\mu S/cm$	TDS	643	1.21E-04	0.503	13.2	0.923	5.2	44 – 151
	Br ⁻	417	8.51E-08	7.61E-05	0	0.236	0.01	0 – 0.03
	Cl ⁻	643	1.26E-04	0.0194	0	0.816	0.9	2 – 13
	SO ₄ ²⁻	643	1.20E-04	0.0277	0	0.727	1.3	2 – 17
	Alkalinity	643	-3.67E-04	0.442	0	0.916	3.3	24 – 88
	Na ⁺	643	1.22E-04	0.0408	0	0.902	0.9	3 – 17
	Ca ²⁺	643	-1.28E-04	0.0952	0	0.828	0.8	6 – 17
	Mg ²⁺	643	5.77E-06	0.0398	0	0.892	0.5	3 – 10
	K ⁺	639	-1.27E-05	0.0105	0	0.422	0.2	0.6 – 2.2

Table 5. This table can be used to estimate salinity constituents of interest within the Freshwater Boundary Region given a known value of TDS. Each row represents one relationship and contains the regression constants (A, B, C) in the quadratic equation $Y = A [TDS]^2 + B [TDS] + C$, that are used to estimate Y, the concentration of the salinity constituent of interest. Also listed in each row are the number of data points that were used to generate the associated regression constants and statistics (R^2 and Standard Error). Constants are valid for the listed range of TDS values; the bromide equation range is 70-140 mg/L. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as $CaCO_3$.

X = TDS	Y	Data Points	A	B	C	R^2	SE	Data Range
45 ≤ [TDS] < 150 mg/L	EC	643	-4.76E-04	1.80	-9.7	0.923	9.2	70 – 237
	Br ⁻	417	2.62E-07	0.000124	0	0.219	0.01	0.01 – 0.03
	Cl ⁻	643	3.76E-04	0.0287	0	0.759	1.1	2 – 12
	SO ₄ ²⁻	643	4.00E-04	0.0385	0	0.710	1.4	2 – 15
	Alkalinity	643	-8.33E-04	0.713	0	0.838	4.6	29 – 88
	Na ⁺	643	3.80E-04	0.0625	0	0.837	1.1	3 – 16
	Ca ²⁺	643	-3.18E-04	0.154	0	0.760	0.9	6 – 17
	Mg ²⁺	643	4.37E-05	0.0628	0	0.837	0.6	3 – 10
	K ⁺	639	-2.79E-05	0.0167	0	0.416	0.2	0.6 – 2.21

Table 6. This look-up table can be used to estimate salinity constituents of interest in the Freshwater Boundary Region given a general range of EC.

FRESHWATER BOUNDARY REGION									
EC [μS/cm]	TDS [mg/L]	Br ⁻ [mg/L]	Cl ⁻ [mg/L]	SO ₄ ²⁻ [mg/L]	Alkalinity [mg/L as CaCO ₃]	Na ⁺ [mg/L]	Ca ²⁺ [mg/L]	Mg ²⁺ [mg/L]	K ⁺ [mg/L]
50	39	0.00	1.3	1.7	21	2.3	4.4	2.0	0.50
60	44	0.00	1.6	2.1	25	2.9	5.3	2.4	0.59
70	49	0.01	2.0	2.5	29	3.5	6.0	2.8	0.68
80	54	0.01	2.4	3.0	33	4.0	6.8	3.2	0.76
90	59	0.01	2.8	3.5	37	4.7	7.5	3.6	0.85
100	65	0.01	3.2	4.0	41	5.3	8.2	4.0	0.93
110	70	0.01	3.7	4.5	44	6.0	8.9	4.4	1.01
120	75	0.01	4.1	5.1	48	6.7	9.6	4.9	1.08
130	81	0.01	4.6	5.6	51	7.4	10.2	5.3	1.16
140	86	0.01	5.2	6.2	55	8.1	10.8	5.7	1.23
150	91	0.01	5.7	6.9	58	8.9	11.4	6.1	1.30
160	97	0.01	6.3	7.5	61	9.6	12.0	6.5	1.36
170	102	0.02	6.9	8.2	65	10.5	12.5	6.9	1.43
180	108	0.02	7.6	8.9	68	11.3	13.0	7.4	1.49
190	113	0.02	8.2	9.6	71	12.1	13.5	7.8	1.54
200	119	0.02	8.9	10.3	74	13.0	13.9	8.2	1.60
210	124	0.02	9.6	11.1	77	13.9	14.3	8.6	1.65
220	130	0.02	10.3	11.9	80	14.9	14.8	9.0	1.71
230	135	0.02	11.1	12.7	82	15.8	15.1	9.5	1.75
240	141	0.02	11.9	13.6	85	16.8	15.5	9.9	1.80

4.3 San Joaquin River Boundary Region



Figure 6. Sampling station at Vernalis on the San Joaquin River, a key real-time monitoring station representative of the San Joaquin River Boundary Region. Grab sample data at Vernalis and Maze Road Bridge (upstream of Vernalis) are used to characterize this boundary region.

San Joaquin River inflow to the Delta at Vernalis (see Figure 6), which is a mixture of freshwater runoff from the Sierra Nevada mountain range and high-salinity agricultural drainage from the west side of the San Joaquin Valley, greatly influences salinity in the subregions of the Interior Delta. The relationships between salinity constituents are captured by the constants and statistics in Tables 7 and 8 below. Table 9 can be used to quickly estimate the salinity constituents of interest when the general EC range is known. Appendix C provides scatter plots of measured salinity constituents as functions of EC and TDS; regression relationships associated with the San Joaquin River Boundary Region overlay the measured data. Appendix D provides a validation analysis of the regression relationships.

Boundary Regions

Table 7. This table can be used to estimate salinity constituents of interest within the San Joaquin River Boundary Region given a known value of EC. Each row represents one relationship and contains the regression constants (A, B, C) in the quadratic equation $Y = A [EC]^2 + B [EC] + C$, that are used to estimate Y, the concentration of the salinity constituent of interest. Also listed in each row are the number of data points that were used to generate the associated regression constants and statistics (R^2 and Standard Error). Constants are valid for the listed range of EC values. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as $CaCO_3$.

X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
100 ≤ [EC] < 1,600 $\mu S/cm$	TDS	611	5.73E-05	0.526	11.3	0.997	10.7	75 – 1070
	Br ⁻	511	2.70E-08	0.000458	-0.05	0.941	0.03	0.02 – 0.74
	Cl ⁻	611	6.50E-06	0.147	-12.5	0.989	5.2	7 – 242
	SO ₄ ²⁻	611	4.76E-05	0.0917	3.8	0.968	9.3	10 – 304
	Alkalinity	609	-4.01E-05	0.162	9.5	0.946	7.8	29 – 181
	Na ⁺	611	1.24E-05	0.110	-3.9	0.992	3.5	10 – 217
	Ca ²⁺	611	2.41E-06	0.0420	3.4	0.979	2.1	8 – 82
	Mg ²⁺	611	2.44E-06	0.0232	0.5	0.985	1.0	3 – 46
	K ⁺	611	3.78E-07	0.00232	1.0	0.803	0.4	0.5 – 6.2

Table 8. This table can be used to estimate salinity constituents of interest within the San Joaquin River Boundary Region given a known value of TDS. Each row represents one relationship and contains the regression constants (A, B, C) in the quadratic equation $Y = A [TDS]^2 + B [TDS] + C$, that are used to estimate Y, the concentration of the salinity constituent of interest. Also listed in each row are the number of data points that were used to generate the associated regression constants and statistics (R^2 and Standard Error). Constants are valid for the listed range of TDS values. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as $CaCO_3$.

X = TDS	Y	Data Points	A	B	C	R^2	SE	Data Range
60 ≤ [TDS] < 1,000 mg/L	EC	611	-2.39E-04	1.85	-13.2	0.997	17.6	120 – 1,530
	Br ⁻	511	-5.73E-08	0.000865	-0.05	0.934	0.04	0.02 – 0.7
	Cl ⁻	611	-2.30E-05	0.275	-15.1	0.985	6.1	7 – 231
	SO ₄ ²⁻	611	8.62E-05	0.188	0.2	0.972	8.7	10 – 255
	Alkalinity	609	-1.29E-04	0.282	9.4	0.941	8.1	29 – 181
	Na ⁺	611	8.77E-07	0.208	-6.0	0.991	3.8	10 – 190
	Ca ²⁺	611	-3.52E-06	0.0778	2.9	0.980	2.0	7 – 78
	Mg ²⁺	611	-1.82E-08	0.0438	0.1	0.984	1.1	3 – 43
	K ⁺	611	2.46E-07	0.00450	0.9	0.810	0.4	0.5 – 6.2

Table 9. This look-up table can be used to estimate salinity constituents of interest in the San Joaquin River Boundary Region given a general range of EC.

SAN JOAQUIN RIVER BOUNDARY REGION									
EC [μS/cm]	TDS [mg/L]	Br ⁻ [mg/L]	Cl ⁻ [mg/L]	SO ₄ ²⁻ [mg/L]	Alkalinity [mg/L as CaCO ₃]	Na ⁺ [mg/L]	Ca ²⁺ [mg/L]	Mg ²⁺ [mg/L]	K ⁺ [mg/L]
100	64	0.00	2	13	25	7	8	3	1.2
200	119	0.05	17	24	40	19	12	5	1.5
300	174	0.09	32	36	54	30	16	8	1.7
400	231	0.14	47	48	68	42	21	10	2.0
500	289	0.19	62	62	80	54	25	13	2.2
600	347	0.24	78	76	92	66	30	15	2.5
700	408	0.29	93	91	103	79	34	18	2.8
800	469	0.34	109	108	113	92	39	21	3.1
900	531	0.39	125	125	123	105	43	23	3.4
1,000	595	0.44	141	143	131	118	48	26	3.7
1,100	659	0.49	157	162	139	132	53	29	4.0
1,200	725	0.54	173	182	146	146	57	32	4.3
1,300	792	0.59	189	203	152	160	62	35	4.6
1,400	860	0.65	205	225	158	174	67	38	5.0
1,500	929	0.70	222	248	162	189	72	41	5.3
1,600	1,000	0.76	239	272	166	203	77	44	5.7

5 Interior Delta Region

The Interior Delta Region is characterized by the following subregions: Old-Middle River Export Corridor, San Joaquin River Corridor, and South Delta

The Interior Delta Region is nominally bounded by the San Joaquin River to the north and east, Jersey Point to the west, and Vernalis to the south. The region is divided into three subregions to reflect unique source water influences that vary by hydrology and season: Old-Middle River Export Corridor, San Joaquin River Corridor, and South Delta. Subregion boundaries and grab sample locations used to represent each subregion are identified in Figure 7.

The salinity characteristics of this region are influenced by Delta boundary inflows primarily from the San Joaquin River and seawater intrusion¹⁰. The Old-Middle River Export Corridor subregion is uniquely influenced by hydrodynamic patterns driven by the export operations at Banks and Jones Pumping Plants. The San Joaquin River Corridor subregion is uniquely influenced by salinity conditions at Vernalis. Finally, the South Delta subregion is uniquely influenced by the placement of seasonal rock barriers, in addition to salinity inflows from Vernalis and local sources of salinity (including agricultural drainage and groundwater). As a result of these salinity conditions, characteristics, and competing inflows, the grab sample dataset that was used to represent each Interior Delta subregion demonstrated greater scatter when compared to the grab sample dataset that was used to represent each of the Boundary Regions. To preserve the seasonal and hydrodynamic nuances, no testability or data screening criteria were imposed on the Interior Delta Region datasets. The findings in this section instead present a characterization of this inherent scatter.

The dominant source water influence in each Interior Delta subregion tends to vary by water year type and month, as shown in Water Year Type and Season Matrix #1 (Table 10). When used in conjunction with the Decision Tree (Figure 3), this table provides guidance on the appropriate regression equation to use for a given subregion, month and water year type.

When X2 position is known (in addition to sampling month and water year type), seawater intrusion into the Interior Delta can be more confidently quantified. Following the Decision Tree (see Figure 3), when X2 is known and is greater than 81 km, Water Year Type and Season Matrix #2 (Table 11) can be used to provide enhanced guidance on the appropriate regression equation to use for a given subregion, month and water year type.

¹⁰ Volumetrically, the region is also influenced by Delta inflows from the Freshwater Boundary Region (particularly the Sacramento River). However, because these inflows contain relatively little salinity, their influence on salinity characteristics tends to be masked by the influence of San Joaquin River inflows and seawater intrusion.

As indicated in Tables 10 and 11, under certain conditions, salinity in the San Joaquin River Corridor and South Delta subregions is influenced by an indeterminate mixture of source water influences that is not adequately characterized by a single boundary region. Regression equations associated with this indeterminate (IND) source influence are presented in Section 5.1. Section 5.2 reports statistical fits associated with the methodology for the three Interior Delta subregions.

5.1 Indeterminate Influence

An exploration of the datasets compiled for each of the Interior Delta subregions showed that their salinity characteristics were either akin to the Seawater Boundary, the San Joaquin River Boundary, or an indeterminate mixture of source waters. In most instances, hydrologic proxies (i.e. sampling month, water year type, and X2 position) provided sufficient information to discriminate between data samples with stronger Seawater characteristics and data samples with stronger San Joaquin River characteristics. However, a subset of samples associated with the San Joaquin River Corridor and the South Delta subregions exhibited indeterminate source characteristics. Unique regression relationships were developed to characterize this data subset. Tables 12 and 13 summarize the regression constants and statistics that were computed for this “indeterminate” category. Table 14 can be used to quickly estimate the salinity constituents of interest when the general EC range is known.

5.2 Statistical Fits for Interior Delta Subregions

The *Decision Tree* methodology presented in Figure 3 was used to estimate salinity constituent concentrations in the Interior Delta given reported EC or TDS values. We used available estimates of X2 position – along with Tables 10 and 11 – in selecting appropriate regression equations. Fitting statistics were computed by comparing the resultant regression estimates to the reported observations; statistics for the Old-Middle River Export Corridor, San Joaquin River Corridor, and South Delta subregions are provided in Tables 15 to 17. We acknowledge that some older data associated with the Rock Slough stations reflect influences of agricultural discharges that were relocated in more recent years. Appendix C provides scatter plots of measured salinity constituents as functions of EC and TDS; regression relationships associated with the Seawater and San Joaquin River Boundary Regions overlay the measured data.



Table 10. This matrix can be used to select the appropriate Interior Delta salinity relationship when X2 position is unknown ⁽¹⁾. The rows denote the water year types and the columns denote months of the year. For each Interior Delta Subregion, the cell that represents a particular month and water year type combination shows the dominant boundary influence: San Joaquin River (SJR), Seawater (SEA), or indeterminate (IND). The regression constants and statistics corresponding to the dominant boundary influence can be used to estimate the salinity constituents. Water year types can be Wet (W), Above Normal (AN), Below Normal (BN), Dry (D), or Critical (C). The California Department of Water Resources maintains an updated database of Sacramento Valley water year types from 1906 to the most recent water year.

WATER YEAR TYPE AND SEASON MATRIX #1												
	J	F	M	A	M	J	J	A	S	O	N	D
Old-Middle River Export Corridor Subregion												
W	SEA	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SEA	SEA	SEA	SEA
AN	SEA	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SEA	SEA	SEA	SEA
BN	SEA	SEA	SJR	SJR	SJR	SJR	SJR	SEA	SEA	SEA	SEA	SEA
D	SEA	SEA	SJR	SJR	SJR	SJR	SJR	SEA	SEA	SEA	SEA	SEA
C	SEA	SEA	SJR	SJR	SJR	SEA	SEA	SEA	SEA	SEA	SEA	SEA
San Joaquin River Corridor Subregion												
W	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
AN	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
BN	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
D	SJR	SJR	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	SJR
C	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	IND	IND	SJR
South Delta Subregion												
W	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
AN	IND	SJR	SJR	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND
BN	IND	IND	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	IND
D	IND	IND	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	IND
C	IND	IND	SJR	SJR	SJR	IND	IND	IND	IND	IND	IND	IND

⁽¹⁾ As indicated in Figure 3, this matrix can also be used to select the appropriate Interior Delta salinity relationship when X2 position is known and < 81 km during the months of December through February.

Table 11. This matrix can be used to select the appropriate Interior Delta salinity relationship when X2 position is known and is ≥ 81 km. The rows denote the water year types and the columns denote months of the year. For each Interior Delta Subregion, the cell that represents a particular month and water year type combination shows the dominant boundary influence: San Joaquin River (SJR), Seawater (SEA), or indeterminate (IND). The regression constants and statistics corresponding to the dominant boundary influence can be used to estimate the salinity constituents. Water year types can be Wet (W), Above Normal (AN), Below Normal (BN), Dry (D), or Critical (C). The California Department of Water Resources maintains an updated database of Sacramento Valley water year types from 1906 to the most recent water year.

WATER YEAR TYPE AND SEASON MATRIX #2												
	J	F	M	A	M	J	J	A	S	O	N	D
Old-Middle River Export Corridor Subregion												
W	SEA	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SEA	SEA	SEA	SEA
AN	SEA	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SEA	SEA	SEA	SEA
BN	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA
D	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA
C	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA	SEA
San Joaquin River Corridor Subregion												
W	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
AN	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
BN	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
D	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
C	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
South Delta Subregion												
W	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
AN	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
BN	IND	IND	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	IND
D	IND	IND	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	IND
C	IND	IND	SJR	SJR	SJR	IND	IND	IND	IND	IND	IND	IND

Interior Delta Region

Table 12. This table can be used to estimate salinity constituents of interest within the Interior Delta Region during periods of indeterminate source influence (see Tables 10 and 11) given a known value of EC. Each row represents one relationship and contains regression constants (A, B, C) in the quadratic equation $Y = A [EC]^2 + B [EC] + C$, that are used to estimate Y, the concentration of the salinity constituent of interest. Also listed in each row are the number of data points that were used to generate the associated regression constants and statistics (R^2 and Standard Error). Constants are valid for the listed range of EC values. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as $CaCO_3$.

X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
150 ≤ [EC] < 1,300 $\mu S/cm$	TDS	188	6.32E-05	0.500	13.8	0.991	16.9	110 – 752
	Br ⁻	192	-3.31E-07	0.000963	-0.12	0.860	0.06	0.05 – 0.69
	Cl ⁻	242	-6.56E-05	0.259	-30.3	0.937	13.6	21 – 217
	SO ₄ ²⁻	155	1.15E-04	0.00158	5.1	0.915	16.2	9 – 199
	Alkalinity	174	2.91E-05	0.0545	41.1	0.893	10.5	46 – 173
	Na ⁺	198	-8.52E-06	0.136	-10.5	0.989	4.1	18 – 150
	Ca ²⁺	188	2.66E-05	0.0107	8.3	0.931	4.0	11 – 64
	Mg ²⁺	188	3.73E-06	0.0203	2.6	0.975	1.3	6 – 35
	K ⁺	157	-3.01E-06	0.00708	0.4	0.645	0.7	1.4 – 7.2

Table 13. This table can be used to estimate the salinity constituents of interest within the Interior Delta Region during periods of indeterminate source influence (see Tables 10 and 11) given a known value of TDS. Each row represents one relationship and contains regression constants (A, B, C) in the quadratic equation $Y = A [TDS]^2 + B [TDS] + C$, that are used to estimate Y, the concentration of the salinity constituent of interest. Also listed in each row are the number of data points that were used to generate the associated regression constants and statistics (R^2 and Standard Error). Constants are valid for the listed range of TDS values. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as $CaCO_3$.

X = TDS	Y	Data Points	A	B	C	R^2	SE	Data Range
100 ≤ [TDS] < 800 mg/L	EC	188	-3.91E-04	2.01	-27.6	0.992	27.4	197 – 1,320
	Br ⁻	150	-8.54E-07	0.00153	-0.10	0.844	0.07	0.05 – 0.69
	Cl ⁻	189	-2.51E-04	0.483	-31.5	0.905	16.6	21 – 217
	SO ₄ ²⁻	155	2.64E-04	0.0578	-1.6	0.933	14.4	9 – 199
	Alkalinity	173	2.43E-05	0.141	34.9	0.886	10.8	46 – 173
	Na ⁺	155	-5.61E-05	0.252	-11.0	0.985	5.0	18 – 153
	Ca ²⁺	155	4.50E-05	0.0432	5.4	0.948	3.6	11 – 65
	Mg ²⁺	155	-1.70E-06	0.0442	1.5	0.968	1.5	6 – 37
	K ⁺	150	-8.90E-06	0.0121	0.4	0.633	0.7	1.4 – 7.2

Table 14. This look-up table can be used to estimate salinity constituents of interest during periods of indeterminate source influence given a general range of EC.

INTERIOR DELTA REGION: INDETERMINATE SOURCE INFLUENCE									
EC [μS/cm]	TDS [mg/L]	Br ⁻ [mg/L]	Cl ⁻ [mg/L]	SO ₄ ²⁻ [mg/L]	Alkalinity [mg/L as CaCO ₃]	Na ⁺ [mg/L]	Ca ²⁺ [mg/L]	Mg ²⁺ [mg/L]	K ⁺ [mg/L]
150	90	0.01	7	8	50	10	11	6	1.4
250	143	0.10	30	13	57	23	13	8	2.0
300	169	0.14	42	16	60	29	14	9	2.2
350	196	0.17	52	20	64	36	15	10	2.5
400	224	0.21	63	24	68	42	17	11	2.7
450	251	0.24	73	29	72	49	19	12	2.9
500	279	0.28	83	35	76	55	20	14	3.2
550	308	0.31	93	41	80	61	22	15	3.4
600	336	0.34	102	48	84	68	24	16	3.5
650	365	0.36	111	55	89	74	27	17	3.7
700	394	0.39	119	63	94	80	29	19	3.9
750	424	0.41	127	71	98	86	31	20	4.0
800	454	0.44	135	80	103	92	34	21	4.1
850	484	0.46	143	90	108	99	37	23	4.2
900	515	0.48	150	100	114	105	40	24	4.3
950	545	0.49	157	111	119	111	43	25	4.4
1,000	577	0.51	164	122	125	117	46	27	4.4
...
1,100	640	0.54	176	146	136	128	52	29	4.5
1,200	704	0.56	187	173	148	140	59	32	4.5
1,300	770	0.57	196	202	161	151	67	35	4.5

Table 15. This table presents fitting statistics (R^2 and Standard Error) for the Old-Middle River Export Corridor subregion. As demonstrated in Figure 3 (Branch 2), given EC or TDS observations, sampling month, water year type, and (optionally) X2 position, the appropriate Water Year Type and Season Matrix (see Tables 10 and 11) can be consulted to determine the dominant boundary influence. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of EC and TDS that were observed in the Old-Middle River Export Corridor subregion. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as CaCO_3 .

X = EC	Y	Data Points	R^2	SE	Data Range	X = TDS	Y	Data Points	R^2	SE	Data Range
Generally ranged from 100 to 1,750 $\mu\text{S}/\text{cm}$	TDS	753	0.992	15.3	73 – 900	Generally ranged from 70 to 900 mg/L	EC	753	0.992	27.6	120 – 1,740
	Br^-	594	0.465	0.2	0.03 – 5.35		Br^-	474	0.347	0.7	0.03 – 5.35
	Cl^-	1057	0.959	16.5	5.9 – 511		Cl^-	885	0.892	26.5	5.9 – 511
	SO_4^{2-}	507	0.618	14.1	8 – 195		SO_4^{2-}	493	0.644	13.6	8 – 195
	Alkalinity	510	0.225	13.5	27 – 153		Alkalinity	514	0.208	13.8	27 – 153
	Na^+	957	0.984	5.3	8.5 – 250		Na^+	781	0.901	13.0	8.5 – 250
	Ca^{2+}	769	0.361	4.0	8 – 45.2		Ca^{2+}	629	0.449	4.0	8 – 45.2
	Mg^{2+}	770	0.890	1.9	3 – 40		Mg^{2+}	629	0.887	1.9	3 – 40
	K^+	624	0.776	0.6	0.9 – 10		K^+	566	0.700	0.7	0.9 – 10

Table 16. This table presents fitting statistics (R^2 and Standard Error) for the San Joaquin River Corridor subregion. As demonstrated in Figure 3 (Branch 2), given EC or TDS observations, sampling month, water year type, and (optionally) X2 position, the appropriate Water Year Type and Season Matrix (see Tables 10 and 11) can be consulted to determine the dominant boundary influence. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of EC and TDS that were observed in the San Joaquin River Corridor subregion. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as CaCO_3 .

X = EC	Y	Data Points	R^2	SE	Data Range	X = TDS	Y	Data Points	R^2	SE	Data Range
Generally ranged from 100 to 1,400 $\mu\text{S}/\text{cm}$	TDS	274	0.978	23.3	49 – 852	Generally ranged from 50 to 850 mg/L	EC	274	0.982	37.9	100 – 1,410
	Br^-	99	0.922	0.04	0.02 – 0.6		Br^-	75	0.933	0.04	0.02 – 0.6
	Cl^-	352	0.913	14.3	4 – 260		Cl^-	286	0.862	18.3	4 – 260
	SO_4^{2-}	98	0.932	14.6	5 – 235		SO_4^{2-}	105	0.928	14.6	5 – 235
	Alkalinity	224	0.772	14.2	30 – 198		Alkalinity	210	0.774	14.3	30 – 198
	Na^+	149	0.982	5.6	7 – 167		Na^+	105	0.987	5.3	7 – 167
	Ca^{2+}	97	0.964	3.0	8 – 69		Ca^{2+}	104	0.975	2.4	8 – 69
	Mg^{2+}	97	0.948	1.9	4 – 38		Mg^{2+}	104	0.942	2.0	4 – 38
	K^+	96	0.363	0.9	1 – 7		K^+	103	0.295	1.0	1 – 7

Table 17. This table presents fitting statistics (R^2 and Standard Error) for the South Delta subregion. As demonstrated in Figure 3 (Branch 2), given EC or TDS observations, sampling month, water year type, and (optionally) X2 position, the appropriate Water Year Type and Season Matrix (see Tables 10 and 11) can be consulted to determine the dominant boundary influence. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of EC and TDS that were observed in the South Delta subregion. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as CaCO_3 .

X = EC	Y	Data Points	R^2	SE	Data Range	X = TDS	Y	Data Points	R^2	SE	Data Range
Generally ranged from 100 to 1,500 $\mu\text{S}/\text{cm}$	TDS	233	0.997	11.3	73 – 906	Generally ranged from 70 to 900 mg/L	EC	233	0.997	18.0	97 – 2,056
	Br^-	257	0.887	0.06	0.03 – 5.35		Br^-	218	0.876	0.06	0.03 – 5.35
	Cl^-	272	0.951	11.7	11 – 255		Cl^-	235	0.918	16.1	11 – 255
	SO_4^{2-}	233	0.921	15.3	9 – 254		SO_4^{2-}	233	0.938	13.8	9 – 254
	Alkalinity	233	0.915	9.3	27 – 173		Alkalinity	233	0.916	9.4	27 – 173
	Na^+	272	0.984	4.9	9 – 179		Na^+	233	0.986	4.9	9 – 179
	Ca^{2+}	272	0.908	4.7	8 – 76		Ca^{2+}	233	0.922	4.5	8 – 76
	Mg^{2+}	272	0.962	1.6	3 – 42		Mg^{2+}	233	0.956	1.8	3 – 42
	K^+	231	0.624	0.7	1 – 7.2		K^+	221	0.624	0.7	1 – 7.2

6 Location-Specific Urban Diversions



Figure 8. Banks Pumping Plant monitoring location

This user guide characterizes seven location-specific Urban Diversions that are distributed across the Delta. Most of these locations can be represented by the existing regression relationships developed for the Boundary Regions as applied through the *Decision Tree* methodology. For example, the approach developed for the Old-Middle River Export Corridor subregion can be accurately applied to estimate salinity constituent concentrations at Banks and Jones Pumping Plants (see Figure 8), Old River at Bacon Island (near the CCWD Rock Slough intake), Old River at Highway 4 (near the CCWD Los Vaqueros intake), and the CCWD Victoria Canal intake. Similarly, the approach developed for the Seawater Boundary Region can be accurately applied to estimate salinity constituent concentrations at Antioch. This user guide presents a unique set of regression equations to estimate salinity constituent concentrations in the Barker Slough area (near the State Water Project North Bay Aqueduct intake), as this location is not adequately characterized by the Freshwater Boundary Region.

Appendix C provides scatter plots of salinity constituents measured at urban diversion locations as functions of EC and TDS. Regression relationships associated with the Seawater and San Joaquin River Boundary Regions overlay the measured data for locations within the Old-Middle River Export Corridor subregion. Regression relationships associated with the Seawater Boundary Region overlay the measured data for the Antioch location. Finally, unique regression relationships overlay the measured data for the Barker Slough location. Appendix D provides a validation analysis of the regression relationships.

6.1 Urban Diversions Located in the Old-Middle River Export Corridor Subregion

6.1.1 Statistical Fits

The *Decision Tree* methodology presented in Figure 3 was used to estimate salinity constituent concentrations at urban diversions located in the Old-Middle River Export Corridor Subregion given reported EC or TDS values. We used available estimates of X2 position – along with Tables 10 and 11 – in selecting appropriate regression equations. Fitting statistics were computed by comparing the resultant regression estimates to the reported observations; statistics for Banks Pumping Plant, Jones Pumping Plant¹¹, Old River at Bacon Island, Old River at Highway 4, and Victoria Canal are provided in Tables 18 to 22. No testability or data screening criteria were imposed on the datasets.

6.1.2 Enhancements to Generalized Approach

The Decision Tree methodology and associated regression equations assume that available salinity data is limited to EC or TDS. However, additional salinity data are collected at some of the urban diversion locations. For example, Contra Costa Water District typically collect Cl^- data at their Rock Slough, Old River and Victoria Canal intakes. As another example, the MWQI program collects a suite of salinity constituent data through grab samples at Banks and Jones Pumping Plants; the program also collects continuous EC and anion data (Br^- , Cl^- and SO_4^{2-}) at these locations. As discussed below, access to additional salinity constituent data allows for some unique enhancements to the generalized approach.

6.1.2.1 Estimating Bromide from Known Chloride Concentration

Estimating the bromide concentration at urban diversion locations is of particular interest, given the ion's relationship to the formation of disinfection by-products in drinking water. If chloride concentration is known at the urban diversions located in the Old-Middle River Export Corridor, the generalized approach presented in this user guide (estimating ion concentrations as functions of EC or TDS) can be improved upon by estimating bromide concentration as a function of chloride concentration¹²:

$$\text{Br}^- = 0.00333 \times \text{Cl}^- - 0.015$$

where Br^- and Cl^- are reported in units of mg/L. Using this linear relationship, statistical fits were determined for each of the four urban diversions located in the Old-Middle River Export Corridor (see Table 23). These statistical fits show higher R^2 and lower standard error when compared with the results expressed in Tables 18 to 22.

6.1.2.2 Estimating Alkalinity from EC and Known Chloride & Sulfate Concentrations

Estimating the alkalinity at urban diversion locations is of particular interest, given its influence on finished drinking water quality. While moderately low alkalinity levels can improve the effectiveness of the coagulation process in water treatment plants, especially when aluminum sulfate is used as a coagulant, extremely low alkalinity levels can depress pH levels and can result in re-stabilization of organic carbon. If EC and concentrations of chloride and sulfate are known at the urban diversions located in the Old-Middle River Export Corridor, the generalized approach presented in this user guide (estimating ion concentrations

¹¹ Statistical fits at Jones Pumping Plant are notably poorer than the other urban diversion locations. It is hypothesized that, while all locations are tidally influenced sub-daily (except Banks Pumping Plant), the proximity of Jones Pumping Plant to Vernalis may result in greater swings between San Joaquin River dominance and seawater dominance.

¹² $n = 1730$, $R^2 = 0.972$, $SE = 0.03 \text{ mg/L}$

as functions of EC or TDS) can be improved upon by estimating alkalinity concentration according to the following multivariate function where alkalinity is in units of mg/L as CaCO₃, EC is in units of µS/cm, and Cl⁻ and SO₄²⁻ are in units of mg/L¹³:

$$\text{Alkalinity} = 1.45\text{E-}5 \times \text{EC}^2 + 0.440 \times \text{EC} - 1.41 \times \text{Cl}^- - 1.04 \times \text{SO}_4^{2-} + 4.69$$

Using this relationship, statistical fits were determined for each of the four urban diversions located in the Old-Middle River Export Corridor (see Table 24). These statistical fits show higher R² and lower standard error when compared with the results expressed in Tables 18 to 22.

6.2 Urban Diversions Located in the Seawater Boundary Region (Antioch)

Antioch is an urban diversion located within the Seawater Boundary Region. The salinity characteristics expressed in the data are the same as those present within the Seawater Boundary Region. Thus, according to the *Decision Tree* methodology presented in Figure 3, regression equations associated with the Seawater Boundary Region were used to compute the fitting statistics for Antioch. The results are presented in Table 25.

¹³ This multivariate equation was derived through ordinary least square regression between EC and the sum of major anions (chloride, sulfate and bicarbonate) reported in units of milliequivalents per liter (meq/L). The regression is based on grab samples from the urban diversions located in the Old-Middle River Export Corridor Subregion (n = 1786, R² = 0.993, SE = 0.165 meq/L)

Table 18. This table presents fitting statistics (R^2 and Standard Error) for the Banks Pumping Plant location. As demonstrated in Figure 3 (Branch 3), given EC or TDS observations, sampling month, water year type, and (optionally) X2 position, the appropriate Water Year Type and Season Matrix (see Tables 10 and 11) can be consulted to determine the dominant boundary influence. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of EC and TDS. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as CaCO_3 .

X = EC	Y	Data Points	R^2	SE	Data Range	X = TDS	Y	Data Points	R^2	SE	Data Range
Generally ranged from 80 to 1,350 $\mu\text{S}/\text{cm}$	TDS	810	0.984	16.4	64 – 763	Generally ranged from 60 to 760 mg/L	EC	810	0.983	31.2	8.3 – 1,340
	Br^-	705	0.869	0.05	0.02 – 0.64		Br^-	449	0.838	0.06	0.02 – 0.64
	Cl^-	1175	0.937	14.4	9 – 334		Cl^-	807	0.903	19.2	9 – 334
	SO_4^{2-}	1025	0.403	13.3	7.6 – 138		SO_4^{2-}	807	0.463	12.9	7.6 – 138
	Alkalinity	757	0.321	11.2	0 – 104		Alkalinity	755	0.304	11.3	0 – 104
	Na^+	979	0.975	5.3	8 – 192		Na^+	806	0.948	7.9	8 – 192
	Ca^{2+}	800	0.224	4.4	2 – 45		Ca^{2+}	760	0.270	4.3	2 – 45
	Mg^{2+}	801	0.882	1.6	3 – 32		Mg^{2+}	760	0.884	1.5	3 – 32
	K^+	198	0.665	0.6	0.1 – 5.2		K^+	180	0.636	0.6	0.1 – 5.2

Table 19. This table presents fitting statistics (R^2 and Standard Error) for the Jones Pumping Plant location. As demonstrated in Figure 3 (Branch 3), given EC or TDS observations, sampling month, water year type, and (optionally) X2 position, the appropriate Water Year Type and Season Matrix (see Tables 10 and 11) can be consulted to determine the dominant boundary influence. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of EC and TDS. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as CaCO_3 .

X = EC	Y	Data Points	R^2	SE	Data Range	X = TDS	Y	Data Points	R^2	SE	Data Range
Generally ranged from 100 to 1,450 $\mu\text{S}/\text{cm}$	TDS	394	0.975	22.5	56 - 829	Generally ranged from 50 to 825 mg/L	EC	515	0.972	40.9	106 – 1,440
	Br^-	322	0.532	0.10	0.02 – 0.62		Br^-	98	0.434	0.11	0.02 – 0.62
	Cl^-	837	0.661	28.1	9 – 258		Cl^-	386	0.537	34.2	9 – 258
	SO_4^{2-}	580	0.125	26.3	3.2 – 159		SO_4^{2-}	389	0.202	24.3	3.2 – 159
	Alkalinity	515	0.054	26.8	31 – 179		Alkalinity	393	0.095	26.0	31 – 179
	Na^+	653	0.873	11.4	12 – 229		Na^+	393	0.821	13.3	12 – 229
	$\text{Ca}^{2+ (1)}$	469	-0.021	11.2	8 – 65		Ca^{2+}	393	0.064	10.8	8 – 65
	Mg^{2+}	469	0.671	3.8	2.9 – 78		Mg^{2+}	393	0.668	3.9	2.9 – 78
	K^+	443	0.234	1.0	1 – 8.4		$\text{K}^{+ (1)}$	387	-0.057	1.1	1 – 8.4

⁽¹⁾ The negative R^2 associated with Ca^{2+} and K^+ reflect extremely high scatter that is present in the datasets and suggest that mean value generalizations, regardless of the estimations of the other constituents, may also be used. The observed mean Ca^{2+} and K^+ concentrations at Jones Pumping Plant were 25.9 mg/L and 2.8 mg/L, respectively.

Table 20. This table presents fitting statistics (R^2 and Standard Error) for the Old River at Bacon Island location. As demonstrated in Figure 3 (Branch 3), given EC or TDS observations, sampling month, water year type, and (optionally) X2 position, the appropriate Water Year Type and Season Matrix (see Tables 10 and 11) can be consulted to determine the dominant boundary influence. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of EC and TDS. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as CaCO_3 .

X = EC	Y	Data Points	R^2	SE	Data Range	X = TDS	Y	Data Points	R^2	SE	Data Range
Generally ranged from 100 to 1,040 $\mu\text{S}/\text{cm}$	TDS	282	0.992	10.6	65 – 551	Generally ranged from 65 to 550 mg/L	EC	282	0.991	20.6	109 – 1,040
	Br^-	338	0.968	0.03	0.01 – 0.86		Br^-	280	0.960	0.04	0.01 – 0.86
	Cl^-	282	0.983	7.5	4 – 246		Cl^-	282	0.970	9.9	4 – 246
	SO_4^{2-}	281	0.014	10.1	6 – 67		SO_4^{2-}	281	0.080	9.8	6 – 67
	Alkalinity ⁽¹⁾	340	-0.220	13.0	29 – 102		Alkalinity	282	0.079	11.8	29 – 102
	Na^+	282	0.982	4.1	8 – 147		Na^+	282	0.968	5.5	8 – 147
	Ca^{2+}	282	0.455	2.5	7 – 24		Ca^{2+}	282	0.492	2.4	7 – 24
	Mg^{2+}	282	0.878	1.6	2 – 23		Mg^{2+}	282	0.870	1.6	2 – 23
	K^+	281	0.863	0.5	0.8 – 6.3		K^+	281	0.854	0.5	0.8 – 6.3

⁽¹⁾ The negative R^2 associated with alkalinity reflects extremely high scatter that is present in the dataset and suggests that a mean value generalization, regardless of the estimations of the other constituents, may be used. The observed mean alkalinity at Old River at Bacon Island was 63.0 mg/L as CaCO_3 .

Table 21. This table presents fitting statistics (R^2 and Standard Error) for the Old River at Highway 4 location. As demonstrated in Figure 3 (Branch 3), given EC or TDS observations, sampling month, water year type, and (optionally) X2 position, the appropriate Water Year Type and Season Matrix (see Tables 10 and 11) can be consulted to determine the dominant boundary influence. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of EC and TDS. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as CaCO_3 .

X = EC	Y	Data Points	R^2	SE	Data Range	X = TDS	Y	Data Points	R^2	SE	Data Range
Generally ranged from 100 to 1,250 $\mu\text{S}/\text{cm}$	TDS	352	0.981	14.7	1 – 711	Generally ranged from 70 to 750 mg/L	EC	352	0.981	26.6	120 – 1,230
	Br^-	425	0.943	0.04	0.02 – 0.77		Br^-	324	0.901	0.05	0.02 – 0.77
	Cl^-	413	0.959	11.0	6 – 293		Cl^-	352	0.921	14.3	6 – 293
	SO_4^{2-}	363	0.347	11.5	7 – 142		SO_4^{2-}	347	0.410	11.0	7 – 142
	Alkalinity	421	0.093	11.8	27 – 92		Alkalinity	346	0.284	10.9	27 – 92
	Na^+	408	0.974	4.7	10 – 168		Na^+	348	0.940	6.6	10 – 168
	Ca^{2+}	406	0.312	3.7	7 – 49		Ca^{2+}	347	0.441	3.4	7 – 49
	Mg^{2+}	406	0.876	1.6	3 – 28		Mg^{2+}	347	0.856	1.7	3 – 28
	K^+	373	0.789	0.5	1.1 – 5.7		K^+	343	0.772	0.5	1.1 – 5.7

Table 22. This table presents fitting statistics (R^2 and Standard Error) for the Victoria Canal location. As demonstrated in Figure 3 (Branch 3), given EC or TDS observations, sampling month, water year type, and (optionally) X2 position, the appropriate Water Year Type and Season Matrix (see Tables 10 and 11) can be consulted to determine the dominant boundary influence. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of EC and TDS. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as CaCO_3 .

X = EC	Y	Data Points	R^2	SE	Data Range	X = TDS	Y	Data Points	R^2	SE	Data Range
Generally ranged from 100 to 800 $\mu\text{S}/\text{cm}$	TDS	0	N/A	N/A	N/A	N/A	EC	0	N/A		
	Br^-	70	0.890	0.05	0 – 0.75		Br^-	0			
	Cl^-	1893	0.957	11.1	8 – 165		Cl^-	0			
	SO_4^{2-}	83	-0.022	10.0	8 – 52		SO_4^{2-}	0			
	Alkalinity	86	0.291	12.0	28 – 89		Alkalinity	0			
	Na^+	60	0.958	4.8	8 – 93		Na^+	0			
	Ca^{2+}	0	N/A	N/A			Ca^{2+}	0			
	Mg^{2+}	0	N/A	N/A			Mg^{2+}	0			
	K^+	0	N/A	N/A			K^+	0			
	Hardness ⁽¹⁾	86	0.804	12.1	32 – 146		Hardness	0			

⁽¹⁾ At this location, total hardness was also reported in lieu of individual Ca^{2+} and Mg^{2+} ions. To compare the reported hardness data with our methodology, we substituted the appropriate Ca^{2+} and Mg^{2+} regression equations into the following equation to estimate total hardness: Total Hardness [mg/L] = $2.5 \times [\text{Ca}^{2+}] + 4.1 \times [\text{Mg}^{2+}]$. Hardness is often underpredicted as this estimating equation does not incorporate concentrations of additional cationic constituents that may contribute to the total hardness of a sample.

Table 23. This table presents fitting statistics (R^2 and Standard Error) for the urban diversions located within the Old-Middle River Export Subregion: Banks Pumping Plant, Jones Pumping Plant, Old River at Bacon Island, Old River at Highway 4, and Victoria Canal when using the method in Section 6.1.2.1 above to estimate bromide using known concentration of chloride. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of chloride that were observed at these locations. For bromide, units are mg/L.

X = Chloride	Y = Bromide	Data Points	R^2	SE	Units
Generally ranged from 5 to 340 mg/L	Banks Pumping Plant	736	0.971	0.03	mg/L
	Jones Pumping Plant	347	0.953	0.03	mg/L
	Old River at Bacon Island	280	0.986	0.02	mg/L
	Old River at Highway 4	367	0.974	0.03	mg/L
	Victoria Canal	67	0.904	0.04	mg/L

Table 24. This table presents fitting statistics (R^2 and Standard Error) for the urban diversions located within the Old-Middle River Export Subregion: Banks Pumping Plant, Jones Pumping Plant, Old River at Bacon Island, Old River at Highway 4, and Victoria Canal when using the method in Section 6.1.2.2 above to estimate alkalinity using known values for EC, chloride, and sulfate. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of EC, chloride and sulfate that were observed at these locations. For alkalinity, units are expressed as mg/L as CaCO_3 .

X = EC, Chloride & Sulfate	Y = Alkalinity	Data Points	R^2	SE	Units
EC generally ranged from 80 to 1,450 $\mu\text{S}/\text{cm}$ Chloride generally ranged from 15 to 340 mg/L Sulfate generally ranged from 10 to 160 mg/L	Banks Pumping Plant	749	0.729	7.3	mg/L as CaCO_3
	Jones Pumping Plant	385	0.882	10.1	mg/L as CaCO_3
	Old River at Bacon Island	281	0.668	8.4	mg/L as CaCO_3
	Old River at Highway 4	353	0.675	7.8	mg/L as CaCO_3
	Victoria Canal	80	0.700	8.2	mg/L as CaCO_3

Table 25. This table presents fitting statistics (R^2 and Standard Error) for the Antioch location. As demonstrated in Figure 3 (Branch 3), given EC or TDS observations, sampling month, water year type, and (optionally) X2 position, the appropriate Water Year Type and Season Matrix (see Tables 10 and 11) can be consulted to determine the dominant boundary influence. The following statistics were computed by comparing the resultant estimations to the reported observations. Also listed in each row are the number of data points that were used to compute these statistics and the general ranges of EC and TDS.

X = EC	Y	Data Points	R^2	SE	Data Range	X = TDS	Y	Data Points	R^2	SE	Data Range
Generally ranged from 100 to 10,700 $\mu\text{S}/\text{cm}$	TDS	50	0.995	77.1	82 – 4,460	Generally ranged from 80 to 4,500 mg/L	EC	50	0.994	134	101 – 10,700
	Br^-	0	N/A	N/A	N/A		Br^-	0	N/A	N/A	N/A
	Cl^-	246	0.989	49.7	2 – 3,390		Cl^-	46	0.984	64.0	2 – 3,390
	SO_4^{2-}	63	0.918	14.1	7 – 294		SO_4^{2-}	17	0.969	4.4	7 – 294
	Alkalinity	212	0.319	11.6	29 – 112		Alkalinity	19	0.409	12.1	29 – 112
	Na^+	201	0.986	26.5	2.3 – 1,050		Na^+	20	0.990	21.9	2.3 – 1,050
	Ca^{2+}	88	0.790	4.7	8 – 61		Ca^{2+}	17	0.659	4.2	8 – 61
	Mg^{2+}	83	0.960	4.9	3.2 – 138		Mg^{2+}	17	0.881	4.9	3.2 – 138
	K^+	77	0.906	2.4	1 – 42		K^+	17	0.821	1.5	1 – 42

6.3 Barker Slough

Barker Slough is the only urban diversion reported in this user guide that is located within the Freshwater Boundary Region. A small number of stations contributed to the grab sample data used to represent this diversion, including stations along the North Bay Aqueduct, Lindsey Slough, and Cache Slough. The salinity characteristics of these data showed little agreement with the Freshwater Boundary Region, presumably due to local watershed influences. Thus, a unique set of regression constants was developed to characterize the salinity constituent relationships for Barker Slough.

The same data processing steps imposed on the Boundary Region datasets were used for the Barker Slough dataset. First, grab sample data were checked for “testability”. A testable data sample was defined as one that had a measured value for each of the following constituents: EC, TDS, Cl^- , SO_4^{2-} , Na^+ , and Mg^{2+} . Testability was enforced to ensure that samples were generally mass- and charge-balanced. Following the check for “testability”, two additional screening criteria were imposed on the datasets that were compiled for the Barker Slough Urban Diversion Location:

1. A data point associated with a single constituent was removed if, when plotted against EC or TDS, fell outside the 99% prediction band (three standard errors) for the testable set of observations for that constituent.
2. An entire sample, including all data points associated with it, was removed if three or more constituents in that sample fell outside the 95% prediction band (two standard errors) for the testable set of observations for the constituents.

The number of data points that remained following the testability and screening criteria are listed in Appendix B. This appendix also reports parameter uncertainties associated with the regression constants.

The relationships between constituents are captured by the constants and statistics in Tables 26 and 27. Table 28 can be used to quickly estimate the salinity constituents of interest when the general EC range is known.

Table 26. This table can be used to estimate the salinity constituents of interest at Barker Slough given a known value of EC. Each row represents one relationship and contains regression constants (A, B, C) in the quadratic equation $Y = A [EC]^2 + B [EC] + C$, that are used to estimate Y, the concentration of the salinity constituent of interest. Also listed in each row are the number of data points that were used to compute the associated regression constants and statistics (R^2 and Standard Error). Constants are valid for the listed range of EC values. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as $CaCO_3$.

X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
$100 \leq [EC] < 800 \mu S/cm$	TDS	462	9.69E-05	0.501	16.2	0.982	8.0	68 – 466
	Br ⁻	400	-1.68E-07	0.000284	-0.03	0.695	0.01	0.01 – 0.27
	Cl ⁻	461	2.19E-05	0.0904	-8.6	0.903	3.6	4 – 98
	SO ₄ ²⁻	453	2.06E-05	0.111	-13.0	0.949	3.0	1 – 87
	Alkalinity	462	-5.64E-05	0.267	20.5	0.877	8.6	35 – 210
	Na ⁺	456	-5.73E-06	0.111	-7.4	0.929	3.0	9 – 80
	Ca ²⁺	459	2.37E-05	0.0197	7.4	0.841	1.7	6 – 54
	Mg ²⁺	460	-1.00E-05	0.0497	-0.8	0.934	1.1	4 – 45
	K ⁺	204	-1.09E-06	0.00484	0.8	0.531	0.4	0.9 – 16

Table 27. This table can be used to estimate the salinity constituents of interest at Barker Slough given a known value of TDS. Each row represents one relationship and contains regression constants (A, B, C) in the quadratic equation $Y = A [TDS]^2 + B [TDS] + C$, that are used to estimate Y, the concentration of the salinity constituent of interest. Also listed in each row are the number of data points that were used to compute the associated regression constants and statistics (R^2 and Standard Error). Constants are valid for the listed range of EC values. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as $CaCO_3$.

X = TDS	Y	Data Points	A	B	C	R^2	SE	Data Range
$50 \leq [TDS] < 450 \text{ mg/L}$	EC	462	-2.89E-04	1.84	-13.1	0.981	14.1	84 – 696
	Br ⁻	400	-4.55E-07	0.000471	-0.03	0.678	0.01	0.01 – 0.27
	Cl ⁻	461	1.74E-05	0.176	-10.8	0.895	3.8	4 – 98
	SO ₄ ²⁻	453	6.75E-05	0.214	-15.6	0.937	3.3	1 – 71
	Alkalinity	462	-1.88E-04	0.467	19.5	0.856	9.3	20 – 210
	Na ⁺	456	-6.54E-05	0.213	-10.1	0.933	2.9	2.9 – 68
	Ca ²⁺	459	6.17E-05	0.0356	7.3	0.811	1.9	3 – 54
	Mg ²⁺	460	-3.69E-05	0.0884	-1.2	0.921	1.3	3 – 45
	K ⁺	204	-4.94E-06	0.00929	0.7	0.526	0.4	0.9 – 17.3

Table 28. This look-up table can be used to estimate salinity constituents of interest at Barker Slough given a general range of EC.

BARKER SLOUGH URBAN DIVERSION LOCATION									
EC [μS/cm]	TDS [mg/L]	Br ⁻ [mg/L]	Cl ⁻ [mg/L]	SO ₄ ²⁻ [mg/L]	Alkalinity [mg/L as CaCO ₃]	Na ⁺ [mg/L]	Ca ²⁺ [mg/L]	Mg ²⁺ [mg/L]	K ⁺ [mg/L]
100	67	0.00	1	0	47	4	10	4	1.3
150	94	0.01	5	4	59	9	11	6	1.6
200	120	0.02	10	10	72	14	12	9	1.8
250	147	0.03	15	16	84	20	14	11	2.0
300	175	0.04	21	22	96	25	15	13	2.2
350	203	0.05	26	28	107	31	17	15	2.4
400	232	0.06	31	35	119	36	19	17	2.6
450	261	0.07	37	41	129	41	21	20	2.8
500	291	0.07	42	48	140	46	23	22	3.0
550	321	0.08	48	54	151	52	25	24	3.2
600	352	0.08	54	61	161	57	28	25	3.4
650	383	0.09	59	68	171	62	30	27	3.5
700	414	0.09	65	75	180	67	33	29	3.7
750	446	0.09	72	82	189	72	36	31	3.9
800	479	0.09	78	89	198	77	38	33	4.0