

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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Prepared for:

Leslie Palencia
Palencia Consulting Engineers
Consultant to State Water Contractors
1121 L Street, Suite 1050
Sacramento, CA 95814

Chandra Chilmakuri
State Water Contractors
1121 L Street, Suite 1050
Sacramento, CA 95814

Prepared by:

Paul Hutton, Arushi Sinha, and Sujoy Roy
Tetra Tech Inc.
3697 Mt. Diablo Blvd, Suite 150
Lafayette, CA 94549

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 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 importance to urban water users and its relationship to practical salinity, a common metric for reporting seawater salinity. The Practical Salinity Scale 1978 (i.e. practical salinity) is widely used as a conductivity-based measure of salinity in oceans and estuaries and is often used in salinity transport modeling studies. Therefore, this user guide also provides guidance on computing practical salinity in the study area.

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

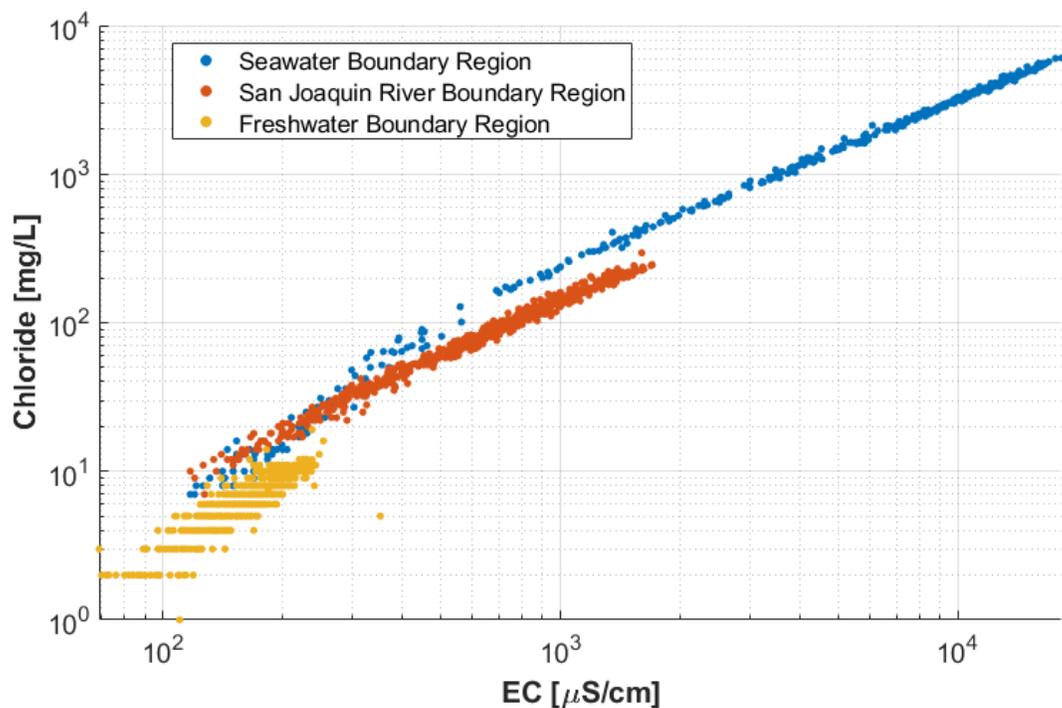


Figure 1. Distinction between the study area’s three primary sources of salinity, as measured by relationships between EC and chloride.

To predict salinity constituent concentrations more accurately 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).

Table of Contents

Purpose of this User Guide	i
1 Key Assumptions	1
1.1 Geographic Boundaries.....	1
1.2 Concentration Units.....	1
1.3 Data Screening.....	2
1.4 Statistical Methods	2
1.5 Use of Proxy Inputs for the Interior Delta	2
1.6 Previous Work.....	3
2 Geographic Overview	4
3 Methodology	6
3.1 Data, Data Screening & Statistical Approach.....	6
3.2 Practical Salinity Scale 1978.....	7
3.3 Decision Tree	8
4 Boundary Regions.....	11
4.1 Seawater Boundary Region.....	11
4.2 Freshwater Boundary Region	15
4.3 San Joaquin River Boundary Region	19
5 Interior Delta Region	23
5.1 Indeterminate Influence	24
5.2 Statistical Fits for Interior Delta Subregions	24
6 Location-Specific Urban Diversions	34
6.1 Urban Diversions Located in the Old-Middle River Export Corridor Subregion	35
6.1.1 Statistical Fits.....	35
6.1.2 Enhancements to Generalized Approach.....	35
6.2 Urban Diversions Located in the Seawater Boundary Region (Antioch)	36
6.3 Barker Slough.....	46
APPENDIX A: Data	
APPENDIX B: Regression Equation Parameter Uncertainties	
APPENDIX C: Scatter Plots	
APPENDIX D: Validation Analysis	
APPENDIX E: Alternate Least Squares Regression Fit to Seawater Boundary and Location-Specific Urban Diversion Data	
APPENDIX F: Delta Salinity Constituent Analysis (Denton, 2015)	

List of Tables

Table 1. Practical Salinity Scale Model Constants 8

Table 2. These 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 model constants (K1 thru K6) in the polynomial equation $Y = K1 + K2 [EC]^{0.5} + K3 [EC] + K4 [EC]^{1.5} + K5 [EC]^2 + K6 [EC]^{2.5}$, 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 fitting statistics (R^2 and Standard Error). The Seawater Boundary Region is divided into two salinity ranges: low and high. Each salinity range is defined by an upper and lower bound; model 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 CaCO₃. 12

Table 3. These 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 model constants (K1 thru K6) in the polynomial equation $Y = K1 + K2 [TDS]^{0.5} + K3 [TDS] + K4 [TDS]^{1.5} + K5 [TDS]^2 + K6 [TDS]^{2.5}$, 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 fitting statistics (R^2 and Standard Error). The Seawater Boundary Region is divided into two salinity ranges: low and high. Each salinity range is defined by an upper and lower bound; model 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 CaCO₃. 13

Table 4. This look-up table can be used to estimate salinity constituents of interest in the Seawater Boundary Region given a general range of EC..... 14

Table 5. 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 μ S/cm. Units are mg/L for all constituents. For alkalinity, units are expressed as mg/L as CaCO₃..... 16

Table 6. 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 CaCO₃..... 17

Table 7. This look-up table can be used to estimate salinity constituents of interest in the Freshwater Boundary Region given a general range of EC. 18

- 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 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 $CaCO_3$ 20
- Table 9.** 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 $CaCO_3$ 21
- Table 10.** 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. 22
- Table 11.** 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). Model constants and statistics corresponding to the dominant boundary influence can be used to estimate the salinity constituents. Unique equations are provided for Jones Pumping Plant under SEA dominance (see Section 6). 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. 26
- Table 12.** 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). Model constants and statistics corresponding to the dominant boundary influence can be used to estimate the salinity constituents. Unique equations are provided for Jones Pumping Plant under SEA dominance (see Section 6). 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. 27
- Table 13.** This table can be used to estimate salinity constituents of interest within the Interior Delta Region during periods of indeterminate source influence (see Tables 11 and 12) 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 28

Table 14. 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 11 and 12) given a known value of TDS. Each row represents one relationship and contains regression constants (A, B, C) in the quadratic equation $Y = A [\text{TDS}]^2 + B [\text{TDS}] + C$, 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 29

Table 15. 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 30

Table 16. 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 11 and 12) 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 31

Table 17. 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 11 and 12) 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 32

Table 18. 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 11 and 12) 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 33

Table 19. 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 11 and 12) 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 CaCO₃. 37

Table 20. These tables can be used to estimate salinity constituents of interest at the Jones Pumping Plant location given a known value of EC, during periods of seawater dominance (based on Table 11 or Table 12). 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 (R² 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 CaCO₃. During periods of seawater dominance when EC < 250 μS/cm, the use of the “low” salinity Seawater Boundary regression relationships (Table 2) is recommended. 38

Table 21. This table can be used to estimate salinity constituents of interest at the Jones Pumping Plant location given a known value of TDS, during periods of seawater dominance (based on Table 11 or Table 12). 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 (R² 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 CaCO₃. During periods of seawater dominance when TDS < 145 mg/L, the use of the “low” salinity Seawater Boundary regression relationships (Table 3) is recommended. 39

Table 22. This table presents the overall fitting statistics (R² 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 11 and 12) 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 CaCO₃. 40

Table 23. This table presents fitting statistics (R² 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 11 and 12) 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 CaCO₃. 41

- Table 24.** 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 11 and 12) 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 42
- Table 25.** 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 11 and 12) 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 43
- Table 26.** 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. 44
- Table 27.** 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 44
- Table 28.** 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 11 and 12) 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. 45
- Table 29.** 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 $Y = A [\text{EC}]^2 + B [\text{EC}] + C$, 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 CaCO₃..... 47

Table 30. 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 $Y = A [\text{TDS}]^2 + B [\text{TDS}] + C$, 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 (R² 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 CaCO₃..... 47

Table 31. This look-up table can be used to estimate salinity constituents of interest at Barker Slough given a general range of EC. 48

List of Figures

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

Figure 2. Delineation of Boundary Regions, Interior Delta Region, and Location-Specific Urban Diversions. Urban Diversion locations are identified in the map with stars. 5

Figure 3. Decision tree to select appropriate equations to estimate salinity constituents given location, time of sample, and X2 (if available). 10

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. 11

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. 15

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. 19

Figure 7. Interior Delta Region with associated subregions and monitoring station 25

Figure 8. Banks Pumping Plant monitoring location. 34

1 Key Assumptions

This work presents a simplified, “user friendly” modeling approach for estimating ionic concentrations from specific electrical conductance (EC) and total dissolved solids (TDS) 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 along the Sacramento River upstream of Emmaton, depending on hydrologic conditions. Similarly, the interface between seawater and freshwater characteristics can extend along the San Joaquin River 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 for the Interior Delta

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.

We also note that the methodology presented in this user guide generally assumes that the salinity characteristics of the interior Delta are adequately represented by either the Seawater Boundary Region or the San Joaquin River Boundary Region (see Section 5 for deviations from this general assumption). However, we note that the interior Delta is influenced by other source waters, including local agricultural drainage, local groundwater accretions, and inflows from the Freshwater Boundary Region. Quantification of this highly complex mixing regime is beyond the scope of this user guide and can be more accurately predicted through Delta hydrodynamic modeling.

1.6 Previous Work

This user guide does not provide a quantitative comparison between the proposed methodology and earlier work such as Guivetchi (1986) and Denton (2015). We believe this omission is consistent with our goal of minimizing user guide page length for ease of use. With respect to the 1986 work, we note that it i) was limited to three salinity measures (EC, TDS and Cl⁻), ii) provided a less parsimonious approach to estimating salinity constituents, and iii) is superseded by the considerably larger and longer-term database used in the user guide. With respect to the 2015 work, we note that i) the user guide is considered to be an extension of this earlier work, ii) a limited comparison of boundary region estimates (not included in this document) revealed similar predictive power between this earlier work and the user guide, and iii) for the interior Delta, while this earlier work outlines several potential methods to estimate salinity constituents (see Appendix F), it does not provide a single recommended approach that could be used for direct comparison.

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.

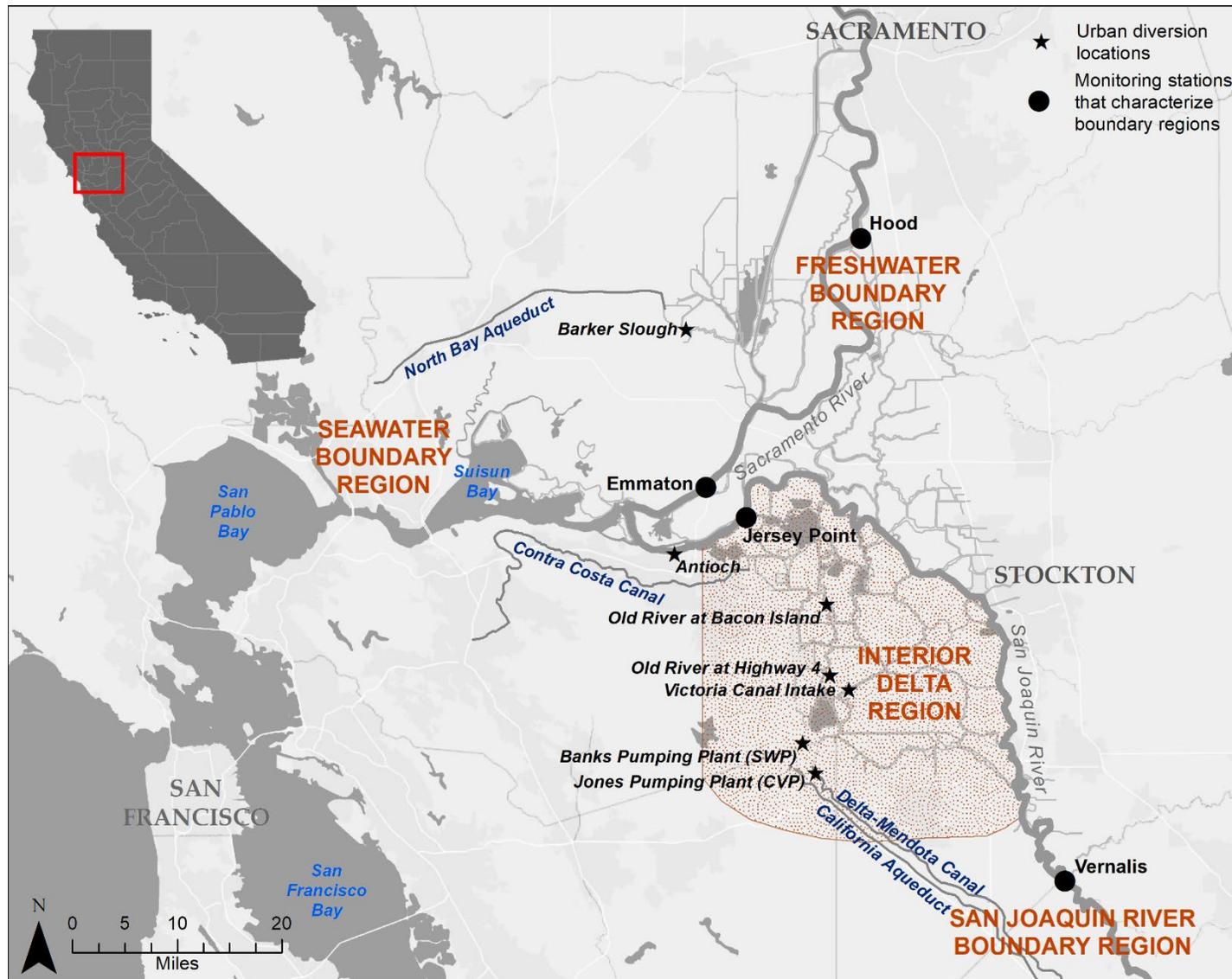
Monitoring the electrical conductivity (EC) of water in the study area through electrodes is simple and inexpensive. As a result, large amounts of continuous EC observations are available to estimate salinity concentrations and, by extension, seawater intrusion. However, there is also a need to estimate 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 (SO₄²⁻), and bicarbonate (reported as alkalinity), and cations such as sodium (Na⁺), calcium (Ca²⁺), magnesium (Mg²⁺), 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.



Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

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 calculating practical salinity and 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⁻, SO₄²⁻, Alkalinity), and major cations (Na⁺, Ca²⁺, Mg²⁺, 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:

- R², 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).

Relationships between major ions, TDS and EC for the Seawater Boundary Region were developed through an extension of the Practical Salinity Scale 1978. Details on this approach, which is not based on least squares regression, are provided elsewhere⁷. An alternate regression-based approach for this region is documented in Appendix E.

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 (see Appendix D). 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 R² 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 Practical Salinity Scale 1978

The Practical Salinity Scale 1978 is widely used as a conductivity-based measure of salinity in oceans and estuaries and is often used in salinity transport modeling studies. The scale (i.e. practical salinity) can be expressed by the following equation assuming atmospheric pressure and a standard temperature of 25° C:

⁷ Hutton, P.H. and Roy, S.B. (in preparation). Extension of the Practical Salinity Scale to Estimate Major Ion Concentrations: Application to the San Francisco Estuary.

$$S = K_0 + K_1 * R^{0.5} + K_2 * R + K_3 * R^{1.5} + K_4 * R^2 + K_5 * R^{2.5}$$

where values of K_0 through K_5 are presented in Table 1, $\Sigma K = 35$, and R is the conductivity ratio (sample conductivity divided by seawater conductivity). As reported elsewhere, the scale was found to be valid for the Seawater and Freshwater Boundary Regions; furthermore, the scale was found to be valid well below its recommended lower bound value of 2.0⁸. However, the scale under-estimates salinity in the San Joaquin River Boundary Region. A correction to the scale is presented in Table 1. This same correction is valid for i) the Barker Slough urban diversion location and ii) the interior Delta when influenced by “indeterminate” source water mixtures.

Table 1. Practical Salinity Scale Model Constants

	PSS-78 Constants	Corrected PSS-78 Constants for the San Joaquin River
K_0	0.0120	0.0083
K_1	-0.2174	-0.2174
K_2	25.3283	27.1883
K_3	13.7714	13.7714
K_4	-6.4788	66.9212
K_5	2.5842	2.5842

3.3 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 changes in the relative contributions to water quality from different sources through proxy inputs⁹. 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

⁸ Hutton, P.H. and Roy, S.B. (in preparation). A Note on the Practical Salinity Scale and its Application to the San Francisco Estuary.

⁹ 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.

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.

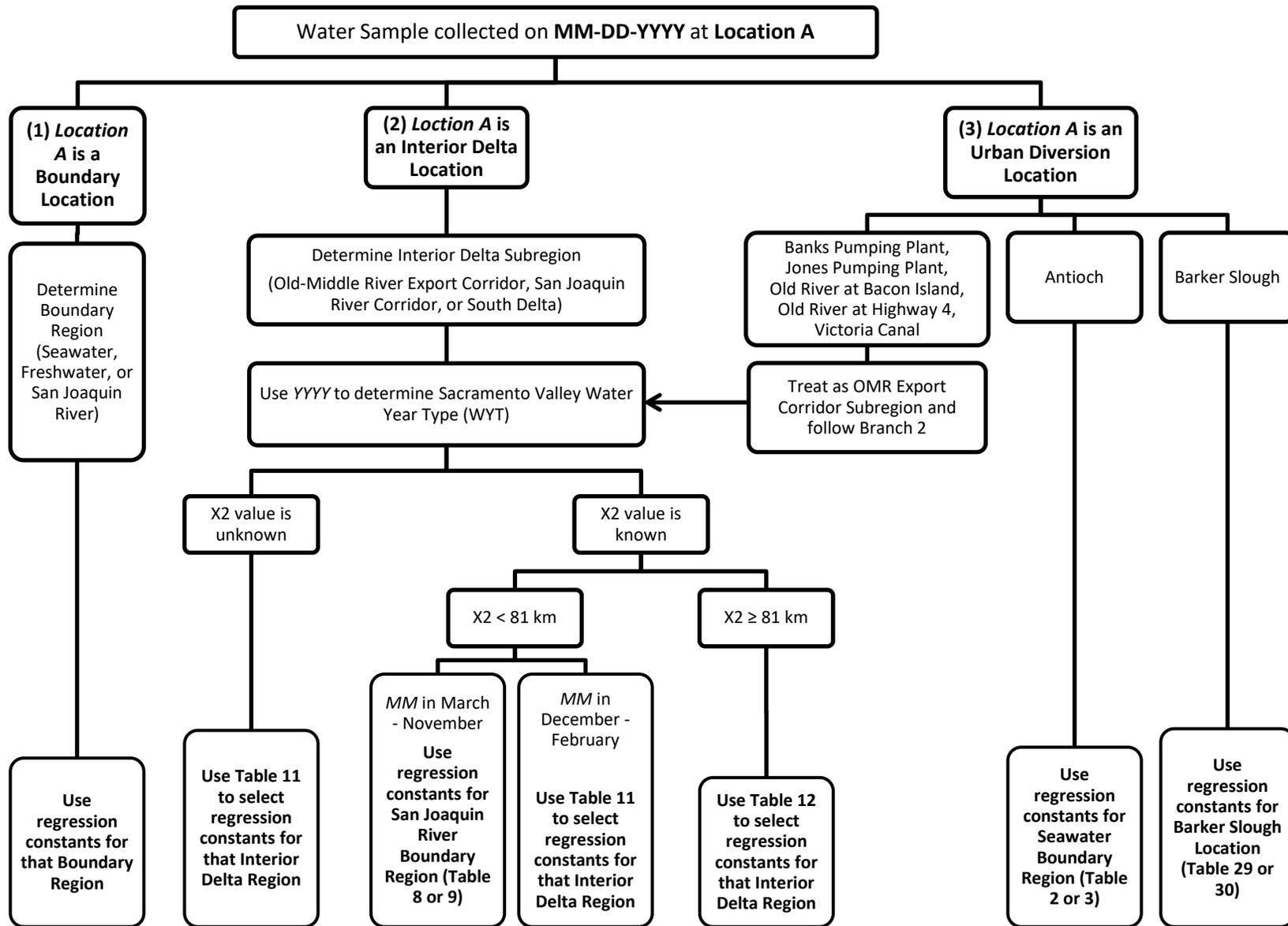


Figure 3. Decision tree to select appropriate equations to estimate salinity constituents given location, time of sample, and X2 (if available).

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). Two salinity ranges (“low” and “high” salinity) 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. The Seawater Boundary Region dataset was divided in such a manner because the constituent relationships were found to have unique trends which were not adequately captured by a single model fit¹⁰. The relationships between constituents in each of the salinity ranges are captured by the constants and statistics in Tables 2 and 3 below. Table 4 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; relationships associated with the Seawater Boundary Region overlay the measured data. Appendix D provides a validation analysis of the relationships. An alternate approach, based on least squares regression fit, is summarized in Appendix E.

¹⁰ Hutton, P.H. and Roy, S.B. (in preparation). Extension of the Practical Salinity Scale to Estimate Major Ion Concentrations: Application to the San Francisco Estuary.

Boundary Regions

Table 2. These 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 model constants (K1 thru K6) in the polynomial equation $Y = K1 + K2 [EC]^{0.5} + K3 [EC] + K4 [EC]^{1.5} + K5 [EC]^2 + K6 [EC]^{2.5}$, 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 fitting statistics (R^2 and Standard Error). The Seawater Boundary Region is divided into two salinity ranges: low and high. Each salinity range is defined by an upper and lower bound; model 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	K1	K2	K3	K4	K5	K6	R ²	SE	Data Range
“Low” Salinity 100 ≤ [EC] < 250 μS/cm	TDS	60	-1.29E+01	-9.85E-01	8.68E-01	1.19E-03	-7.73E-04	4.28E-09	0.953	4.6	67 – 151
	Br ⁻ ⁽¹⁾	59	1.47E-01	-1.82E-03	-1.48E-03	2.21E-06	5.28E-06	7.93E-12	0.666	0.01	0.01 – 0.1
	Cl ⁻	61	1.87E+01	-5.34E-01	-1.32E-01	6.47E-04	7.28E-04	2.32E-09	0.834	2.2	7 – 31
	SO ₄ ²⁻	61	-7.88E+00	-7.20E-02	1.46E-01	8.72E-05	-1.67E-04	3.13E-10	0.547	2.3	6 – 22
	Alkalinity	61	3.46E+00	-1.42E-03	3.20E-01	1.72E-06	-2.62E-04	6.18E-12	0.708	4.6	37 – 72
	Na ⁺	61	1.08E+01	-2.88E-01	-4.57E-02	3.49E-04	4.12E-04	1.25E-09	0.911	1.1	7 – 22
	Ca ²⁺	61	-6.95E+00	-1.11E-02	1.66E-01	1.34E-05	-3.32E-04	4.81E-11	0.731	0.9	8 – 16
	Mg ²⁺	61	-3.03E+00	-3.51E-02	7.26E-02	4.25E-05	-9.44E-05	1.52E-10	0.840	0.5	4 – 9
	K ⁺	61	6.79E-01	-1.10E-02	5.60E-03	1.33E-05	-2.74E-08	4.77E-11	0.161	0.3	0.9 – 2.5
X = EC	Y	Data Points	K1	K2	K3	K4	K5	K6	R ²	SE	Data Range
“High” Salinity [EC] ≥ 250 μS/cm	TDS	344	3.05E+01	-9.85E-01	5.02E-01	1.19E-03	-2.46E-06	4.28E-09	0.997	173	151 – 11,630
	Br ⁻	299	-1.25E-01	-1.82E-03	9.29E-04	2.21E-06	-4.54E-09	7.93E-12	0.986	0.7	0.07 – 20
	Cl ⁻	343	-3.67E+01	-5.34E-01	2.72E-01	6.47E-04	-1.33E-06	2.32E-09	0.998	83	23 – 6,044
	SO ₄ ²⁻	339	9.08E+00	-7.20E-02	3.67E-02	8.72E-05	-1.79E-07	3.13E-10	0.994	18	14 – 853
	Alkalinity	338	6.68E+01	-1.42E-03	7.25E-04	1.72E-06	-3.54E-09	6.18E-12	0.381	8.6	41 – 96
	Na ⁺	340	-1.15E+01	-2.88E-01	1.47E-01	3.49E-04	-7.18E-07	1.25E-09	0.997	46	21 – 3,298
	Ca ²⁺	341	1.23E+01	-1.11E-02	5.64E-03	1.34E-05	-2.76E-08	4.81E-11	0.989	3.7	9 – 143
	Mg ²⁺	336	4.76E+00	-3.51E-02	1.79E-02	4.25E-05	-8.73E-08	1.52E-10	0.993	9.2	8.94 – 424
K ⁺	339	6.79E-01	-1.10E-02	5.60E-03	1.33E-05	-2.74E-08	4.77E-11	0.984	4.4	1.90 – 134	

⁽¹⁾ When EC < 105 μS/cm, set Br to 0.03 mg/L

Table 3. These 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 model constants (K1 thru K6) in the polynomial equation $Y = K1 + K2 [TDS]^{0.5} + K3 [TDS] + K4 [TDS]^{1.5} + K5 [TDS]^2 + K6 [TDS]^{2.5}$, 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 fitting statistics (R^2 and Standard Error). The Seawater Boundary Region is divided into two salinity ranges: low and high. Each salinity range is defined by an upper and lower bound; model 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 CaCO₃.

X = TDS	Y	Data Points	K1	K2	K3	K4	K5	K6	R ²	SE	Data Range
“Low” Salinity 60 ≤ [TDS] < 145 mg/L	EC	58	-41.5	6.15	1.52	-0.00355	9.94E-06	-1.63E-08	0.965	6.2	117 – 248
	Br ⁻ ⁽¹⁾	56	-0.0792	0	0.00115	0	0	0	-0.162	0.02	0.01 – 0.08
	Cl ⁻	58	-15.8	0	0.284	0	0	0	0.578	3.2	7 – 27
	SO ₄ ²⁻	58	-3.08	0	0.142	0	0	0	0.580	2.3	6 – 22
	Alkalinity	58	11.1	0	0.385	0	0	0	0.686	4.8	37 – 72
	Na ⁺	58	-9.00	0	0.214	0	0	0	0.717	1.9	7 – 22
	Ca ²⁺	58	5.31	0	0.0574	0	0	0	0.684	1.0	8 – 16
	Mg ²⁺	58	-0.0844	0	0.0615	0	0	0	0.854	0.5	4 – 9
	K ⁺	58	0.339	0	0.0112	0	0	0	0.0724	0.3	0.9 – 2.4
X = TDS	Y	Data Points	K1	K2	K3	K4	K5	K6	R ²	SE	Data Range
“High” Salinity [TDS] ≥ 145 mg/L	EC	346	-87.7	6.15	1.84	-0.00355	9.94E-06	-1.63E-08	0.999	148	160 – 18,232
	Br ⁻	301	-0.181	0	0.00185	0	0	0	0.985	0.71	0.03 – 20
	Cl ⁻	345	-53.3	0	0.542	0	0	0	0.997	90	13 – 6,044
	SO ₄ ²⁻	341	6.85	0	0.0731	0	0	0	0.993	18	11 – 853
	Alkalinity	340	66.8	0	0.00144	0	0	0	0.387	9	41 – 96
	Na ⁺	342	-20.4	0	0.293	0	0	0	0.996	54	12 – 3,298
	Ca ²⁺	343	12.0	0	0.0112	0	0	0	0.988	3.8	9 – 143
	Mg ²⁺	338	3.67	0	0.0356	0	0	0	0.991	10	5 – 424
	K ⁺	341	0.339	0	0.0112	0	0	0	0.983	4.5	1.20 – 134

⁽¹⁾ When Br⁻ is estimated as < 0.03 mg/L, set Br⁻ to 0.03 mg/L

Boundary Regions

Table 4. 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 [μ S/cm]	Practical Salinity (¹)	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	0.052	58	0.03	8	4	33	8	6	3	1.1
150	0.075	90	0.03	10	10	46	10	10	5	1.4
200	0.099	119	0.04	16	14	57	15	13	7	1.7
250	0.122	145	0.09	25	17	67	22	14	9	2.0
...
500	0.245	272	0.32	94	27	67	59	15	13	3.4
750	0.372	403	0.57	165	36	67	98	17	18	4.8
1,000	0.500	538	0.81	238	46	68	137	18	23	6.3
...
2,000	1.032	1,088	1.8	537	86	68	298	24	42	12
3,000	1.583	1,659	2.9	846	128	69	465	31	63	19
4,000	2.147	2,243	4.0	1,163	171	70	636	37	83	25
5,000	2.721	2,839	5.1	1,486	214	71	810	44	105	32
...
10,000	5.716	5,943	11	3,169	441	75	1,718	79	215	67
15,000	8.856	9,199	17	4,935	679	80	2,671	115	330	103
20,000	12.106	12,568	23	6,761	925	85	3,657	153	451	140
25,000	15.448	16,032	29	8,640	1,179	90	4,670	192	574	179
30,000	18.871	19,581	36	10,564	1,438	95	5,708	232	700	219
35,000	22.369	23,206	43	12,530	1,703	100	6,769	273	830	259
40,000	25.937	26,905	50	14,536	1,973	106	7,851	314	961	300
45,000	29.573	30,674	57	16,579	2,249	111	8,954	357	1,095	342
50,000	33.275	34,512	64	18,660	2,529	117	10,077	400	1,231	385
52,300	35.000	36,300	68	19,630	2,660	119	10,600	420	1,295	405

(¹) Values based on standard model constants presented in Table 1.

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 5 and 6 below. Table 7 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.

Boundary Regions

Table 5. 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 $\mu\text{S}/\text{cm}$. 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 $\mu\text{S}/\text{cm}$	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 6. 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 7. 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 [$\mu\text{S}/\text{cm}$]	Practical Salinity (¹)	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	0.030	39	0.00	1.3	1.7	21	2.3	4.4	2.0	0.50
60	0.034	44	0.00	1.6	2.1	25	2.9	5.3	2.4	0.59
70	0.039	49	0.01	2.0	2.5	29	3.5	6.0	2.8	0.68
80	0.043	54	0.01	2.4	3.0	33	4.0	6.8	3.2	0.76
90	0.048	59	0.01	2.8	3.5	37	4.7	7.5	3.6	0.85
100	0.052	65	0.01	3.2	4.0	41	5.3	8.2	4.0	0.93
110	0.057	70	0.01	3.7	4.5	44	6.0	8.9	4.4	1.01
120	0.061	75	0.01	4.1	5.1	48	6.7	9.6	4.9	1.08
130	0.066	81	0.01	4.6	5.6	51	7.4	10.2	5.3	1.16
140	0.070	86	0.01	5.2	6.2	55	8.1	10.8	5.7	1.23
150	0.075	91	0.01	5.7	6.9	58	8.9	11.4	6.1	1.30
160	0.080	97	0.01	6.3	7.5	61	9.6	12.0	6.5	1.36
170	0.084	102	0.02	6.9	8.2	65	10.5	12.5	6.9	1.43
180	0.089	108	0.02	7.6	8.9	68	11.3	13.0	7.4	1.49
190	0.094	113	0.02	8.2	9.6	71	12.1	13.5	7.8	1.54
200	0.099	119	0.02	8.9	10.3	74	13.0	13.9	8.2	1.60
210	0.103	124	0.02	9.6	11.1	77	13.9	14.3	8.6	1.65
220	0.108	130	0.02	10.3	11.9	80	14.9	14.8	9.0	1.71
230	0.113	135	0.02	11.1	12.7	82	15.8	15.1	9.5	1.75
240	0.118	141	0.02	11.9	13.6	85	16.8	15.5	9.9	1.80

(¹) Values based on standard model constants presented in Table 1.

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 8 and 9 below. Table 10 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 8. 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 μ 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 9. 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 10. 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]	Practical Salinity (¹)	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	0.052	64	0.00	2	13	25	7	8	3	1.2
200	0.103	119	0.05	17	24	40	19	12	5	1.5
300	0.156	174	0.09	32	36	54	30	16	8	1.7
400	0.210	231	0.14	47	48	68	42	21	10	2.0
500	0.266	289	0.19	62	62	80	54	25	13	2.2
600	0.323	347	0.24	78	76	92	66	30	15	2.5
700	0.380	408	0.29	93	91	103	79	34	18	2.8
800	0.439	469	0.34	109	108	113	92	39	21	3.1
900	0.499	531	0.39	125	125	123	105	43	23	3.4
1,000	0.559	595	0.44	141	143	131	118	48	26	3.7
1,100	0.620	659	0.49	157	162	139	132	53	29	4.0
1,200	0.682	725	0.54	173	182	146	146	57	32	4.3
1,300	0.745	792	0.59	189	203	152	160	62	35	4.6
1,400	0.809	860	0.65	205	225	158	174	67	38	5.0
1,500	0.874	929	0.70	222	248	162	189	72	41	5.3
1,600	0.939	1,000	0.76	239	272	166	203	77	44	5.7

(¹) Values based on corrected model constants presented in Table 1.

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, local agricultural drainage and seawater intrusion¹¹. 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 11). When used in conjunction with the Decision Tree (Figure 3), this table provides guidance on the appropriate equation to use for a given subregion, month and water year type. Selection of appropriate practical salinity model constants should be informed by the dominant source water influence (see Table 1).

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 12) can be used to provide enhanced guidance on the appropriate regression equation to use for a given subregion, month and water year type.

¹¹ 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, local agricultural drainage and seawater intrusion.

As indicated in Tables 11 and 12, 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 13 and 14 summarize the regression constants and statistics that were computed for this “indeterminate” category. Table 15 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 11 and 12 – in selecting appropriate equations. Fitting statistics were computed by comparing the resultant 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 16 to 18. 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; relationships associated with the Seawater and San Joaquin River Boundary Regions overlay the measured data.

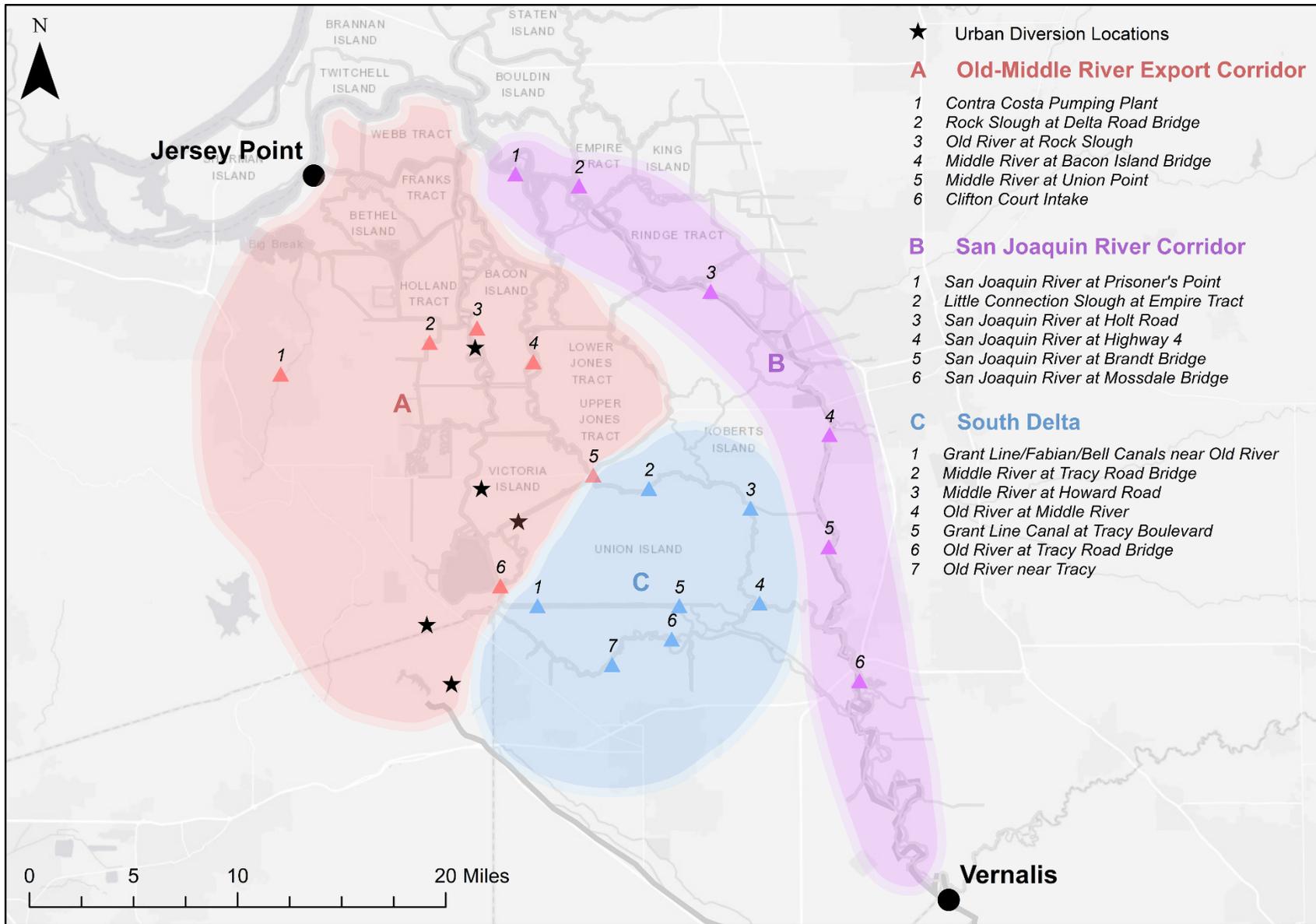


Figure 7. Interior Delta Region with associated subregions and monitoring station

Table 11. 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). Model constants and statistics corresponding to the dominant boundary influence can be used to estimate the salinity constituents. Unique equations are provided for Jones Pumping Plant under SEA dominance (see Section 6). 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	SEA	SEA	SEA	SEA						
AN	SEA	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						
San Joaquin River Corridor Subregion												
W	SJR											
AN	SJR											
BN	SJR											
D	SJR	IND	IND	IND	IND	SJR						
C	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	IND	IND	SJR
South Delta Subregion												
W	SJR											
AN	IND	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						

⁽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 12. 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). Model constants and statistics corresponding to the dominant boundary influence can be used to estimate the salinity constituents. Unique equations are provided for Jones Pumping Plant under SEA dominance (see Section 6). 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	SEA	SEA	SEA	SEA						
AN	SEA	SJR	SEA	SEA	SEA	SEA						
BN	SEA											
D	SEA											
C	SEA											
San Joaquin River Corridor Subregion												
W	SJR											
AN	SJR											
BN	SJR											
D	SJR											
C	SJR											
South Delta Subregion												
W	SJR											
AN	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						

Interior Delta Region

Table 13. This table can be used to estimate salinity constituents of interest within the Interior Delta Region during periods of indeterminate source influence (see Tables 11 and 12) 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 μS/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 14. 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 11 and 12) 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 15. 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]	Practical Salinity (¹)	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	0.077	90	0.01	7	8	50	10	11	6	1.4
250	0.129	143	0.10	30	13	57	23	13	8	2.0
300	0.156	169	0.14	42	16	60	29	14	9	2.2
350	0.183	196	0.17	52	20	64	36	15	10	2.5
400	0.210	224	0.21	63	24	68	42	17	11	2.7
450	0.238	251	0.24	73	29	72	49	19	12	2.9
500	0.266	279	0.28	83	35	76	55	20	14	3.2
550	0.294	308	0.31	93	41	80	61	22	15	3.4
600	0.323	336	0.34	102	48	84	68	24	16	3.5
650	0.351	365	0.36	111	55	89	74	27	17	3.7
700	0.380	394	0.39	119	63	94	80	29	19	3.9
750	0.410	424	0.41	127	71	98	86	31	20	4.0
800	0.439	454	0.44	135	80	103	92	34	21	4.1
850	0.469	484	0.46	143	90	108	99	37	23	4.2
900	0.499	515	0.48	150	100	114	105	40	24	4.3
950	0.529	545	0.49	157	111	119	111	43	25	4.4
1,000	0.559	577	0.51	164	122	125	117	46	27	4.4
...
1,100	0.620	640	0.54	176	146	136	128	52	29	4.5
1,200	0.682	704	0.56	187	173	148	140	59	32	4.5
1,300	0.745	770	0.57	196	202	161	151	67	35	4.5

(¹) Values based on corrected model constants presented in Table 1.

Table 16. 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 11 and 12) 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 CaCO₃.

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 μ S/cm	TDS	753	0.992	15.3	73 – 900	Generally ranged from 70 to 900 mg/L	EC	753	0.992	28.0	120 – 1,740
	Br ⁻	594	0.453	0.2	0.03 – 5.35		Br ⁻	474	0.337	0.2	0.03 – 5.35
	Cl ⁻	1057	0.958	16.7	5.9 – 511		Cl ⁻	885	0.891	26.7	5.9 – 511
	SO ₄ ²⁻	507	0.644	13.6	8 – 195		SO ₄ ²⁻	493	0.671	13.1	8 – 195
	Alkalinity	510	0.353	12.3	27 – 153		Alkalinity	514	0.328	12.7	27 – 153
	Na ⁺	957	0.986	5.0	8.5 – 250		Na ⁺	781	0.901	13.0	8.5 – 250
	Ca ²⁺	769	0.410	3.9	8 – 45.2		Ca ²⁺	629	0.504	3.8	8 – 45.2
	Mg ²⁺	770	0.896	1.8	3 – 40		Mg ²⁺	629	0.887	1.9	3 – 40
K ⁺	624	0.758	0.7	0.9 – 10	K ⁺	566	0.691	0.7	0.9 – 10		

Interior Delta Region

Table 17. 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 11 and 12) 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 $\mu\text{S/cm}$	TDS	274	0.978	23.3	49 – 852	Generally ranged from 50 to 850 mg/L	EC	273	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^-	285	0.862	18.3	4 – 260
	SO_4^{2-}	98	0.932	14.6	5 – 235		SO_4^{2-}	104	0.928	14.6	5 – 235
	Alkalinity	224	0.772	14.2	30 – 198		Alkalinity	209	0.774	14.3	30 – 198
	Na^+	149	0.982	5.6	7 – 167		Na^+	104	0.987	5.3	7 – 167
	Ca^{2+}	97	0.964	3.0	8 – 69		Ca^{2+}	103	0.975	2.4	8 – 69
	Mg^{2+}	97	0.948	1.9	4 – 38		Mg^{2+}	103	0.942	2.0	4 – 38
K^+	96	0.363	0.9	1 – 7	K^+	103	0.295	1.0	1 – 7		

Table 18. 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 11 and 12) 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 2,000 $\mu\text{S}/\text{cm}$	TDS	231	0.997	11.3	73 – 906	Generally ranged from 70 to 900 mg/L	EC	232	0.997	18.0	97 – 2,056
	Br^-	256	0.887	0.06	0.03 – 0.78		Br^-	218	0.877	0.06	0.03 – 0.78
	Cl^-	270	0.951	11.7	11 – 255		Cl^-	234	0.918	16.1	11 – 255
	SO_4^{2-}	231	0.921	15.3	9 – 254		SO_4^{2-}	232	0.938	13.8	9 – 254
	Alkalinity	231	0.915	9.3	27 – 173		Alkalinity	232	0.916	9.4	27 – 173
	Na^+	270	0.984	4.9	9 – 179		Na^+	232	0.986	4.9	9 – 179
	Ca^{2+}	270	0.908	4.7	8 – 76		Ca^{2+}	232	0.922	4.5	8 – 76
	Mg^{2+}	270	0.962	1.6	3 – 42		Mg^{2+}	232	0.956	1.8	3 – 42
K^+	229	0.624	0.7	1 – 7.2	K^+	220	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 distributed across the Delta. Most of these locations can be represented by the existing 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 Pumping Plant (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. Furthermore, this user guide presents a unique set of regression equations to estimate salinity constituent concentrations at Jones Pumping Plant when Tables 11 or 12 classify conditions as seawater dominant, as the Seawater Boundary relationships generally provide poor fits to the observed data.

Appendix C provides scatter plots of salinity constituents measured at urban diversion locations as functions of EC and TDS. 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

and Jones Pumping Plant locations. 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 11 and 12 – in selecting appropriate equations. Fitting statistics were computed by comparing the resultant estimates to the reported observations; statistics for Banks and Jones Pumping Plants, Old River at Bacon Island, Old River at Highway 4, and Victoria Canal are provided in Tables 19 to 25 (note unique treatment of Jones Pumping Plant as discussed above). No testability or data screening criteria were imposed on the datasets. We note that fits to SO_4 , alkalinity and Ca^{2+} are poor. As shown in Appendix C, these poor fits are generally associated with seawater dominant conditions in the subregion. For applications when more accurate estimates of these constituent concentrations are needed, see Appendix E for regression-based relationships; these relationships are applicable for conditions classified as seawater dominant in Tables 11 and 12.

6.1.2 Enhancements to Generalized Approach

The Decision Tree methodology and associated regression equations assume that available salinity data are 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:

$$\text{Br}^- = 0.00341 \times \text{Cl}^-$$

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 26). These statistical fits show higher R^2 and lower standard error when compared with the results expressed in Tables 19 to 25.

¹² Hutton, P.H. and Roy, S.B. (in preparation). Extension of the Practical Salinity Scale to Estimate Major Ion Concentrations: Application to the San Francisco Estuary.

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 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 27). These statistical fits show higher R² and lower standard error when compared with the results expressed in Tables 19 to 25.

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 28.

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 19. 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 11 and 12) 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 $\mu\text{S/cm}$	TDS	809	0.983	17.3	64 – 763	Generally ranged from 60 to 760 mg/L	EC	809	0.982	32.2	8.3 – 1,340
	Br^-	702	0.800	0.07	0.02 – 0.64		Br^-	448	0.783	0.07	0.02 – 0.64
	Cl^-	1172	0.931	15.0	9 – 334		Cl^-	806	0.887	20.6	9 – 334
	SO_4^{2-}	1022	0.294	14.5	7.6 – 138		SO_4^{2-}	806	0.362	14.0	7.6 – 138
	Alkalinity	757	0.375	10.9	0 – 104		Alkalinity	755	0.371	10.9	0 – 104
	Na^+	978	0.978	4.9	8 – 192		Na^+	805	0.947	7.9	8 – 192
	Ca^{2+}	799	0.174	4.5	2 – 45		Ca^{2+}	759	0.244	4.4	2 – 45
	Mg^{2+}	800	0.883	1.6	3 – 32		Mg^{2+}	759	0.885	1.5	3 – 32
	K^+	198	0.672	0.6	0.1 – 5.2		K^+	180	0.635	0.6	0.1 – 5.2

Location-Specific Urban Diversions

Table 20. These tables can be used to estimate salinity constituents of interest at the Jones Pumping Plant location given a known value of EC, during periods of seawater dominance (based on Table 11 or Table 12). 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 $CaCO_3$. During periods of seawater dominance when $EC < 250 \mu S/cm$, the use of the “low” salinity Seawater Boundary regression relationships (Table 2) is recommended.

X = EC	Y	Data Points	A	B	C	R ²	SE	Data Range
250 ≤ [EC] < 1,440 μS/cm	TDS	167	8.95E-05	0.465	28.9	0.990	14.9	149 – 829
	Br ⁻	225	-4.55E-07	0.00114	-0.19	0.759	0.06	0.08 – 0.62
	Cl ⁻	457	-6.38E-05	0.279	-40.4	0.882	15.8	25 – 258
	SO ₄ ²⁻	307	8.11E-05	-0.000240	14.1	0.699	16.9	11.5 – 159
	Alkalinity	216	5.13E-05	0.0172	56.1	0.734	14.5	47 – 179
	Na ⁺	318	-4.57E-06	0.136	-11.1	0.963	6.1	21 – 175
	Ca ²⁺	209	2.51E-05	0.00897	10.4	0.800	5.4	13 – 65
	Mg ²⁺	209	4.98E-06	0.0160	4.2	0.918	1.7	6 – 34
	K ⁺	189	-2.66E-06	0.00691	0.2	0.546	0.7	1.4 – 7

Table 21. This table can be used to estimate salinity constituents of interest at the Jones Pumping Plant location given a known value of TDS, during periods of seawater dominance (based on Table 11 or Table 12). 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 $CaCO_3$. During periods of seawater dominance when $TDS < 145$ mg/L, the use of the “low” salinity Seawater Boundary regression relationships (Table 3) is recommended.

X = TDS	Y	Data Points	A	B	C	R^2	SE	Data Range
145 ≤ [TDS] < 830 mg/L	EC	170	-4.11E-04	2.02	-39.3	0.990	24.9	237 – 1,360
	Br ⁻	53	-1.95E-06	0.00245	-0.25	0.737	0.07	0.08 – 0.62
	Cl ⁻	167	-2.90E-04	0.573	-53.9	0.894	17.4	24 – 258
	SO ₄ ²⁻	168	1.95E-04	0.0142	13.6	0.797	14.0	15 – 159
	Alkalinity	169	1.26E-04	0.0474	53.1	0.726	14.5	47 – 179
	Na ⁺	169	-6.61E-05	0.269	-14.7	0.941	8.1	21 – 172
	Ca ²⁺	169	5.18E-05	0.0307	8.3	0.831	5.1	13 – 65
	Mg ²⁺	169	4.16E-06	0.0352	3.0	0.918	1.7	6 – 34
	K ⁺	167	-9.19E-06	0.0130	0.0212	0.558	0.7	1.2 – 7

Location-Specific Urban Diversions

Table 22. This table presents the overall 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 11 and 12) 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 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 1,440 $\mu\text{S}/\text{cm}$	TDS	394	0.990	14.4	56 – 829	Generally ranged from 60 to 830 mg/L	EC	393	0.991	23.6	106 – 1,440
	Br^-	320	0.866	0.05	0.02 – 0.62		Br^-	98	0.859	0.06	0.02 – 0.62
	Cl^-	835	0.906	14.7	9 – 258		Cl^-	385	0.909	15.2	9 – 258
	SO_4^{2-}	578	0.594	17.9	3.2 – 159		SO_4^{2-}	388	0.553	18.2	3.2 – 159
	Alkalinity	515	0.804	12.2	31 - 179		Alkalinity	392	0.798	12.3	31 - 179
	Na^+	653	0.916	9.3	12 – 229		Na^+	392	0.958	6.5	12 – 229
	Ca^{2+}	469	0.860	4.2	8 – 65		Ca^{2+}	392	0.881	3.8	8 – 65
	Mg^{2+}	469	0.705	3.6	2.9 – 78		Mg^{2+}	392	0.673	3.9	2.9 – 78
	K^+	443	0.576	0.7	1 – 8.4		K^+	386	0.573	0.7	1 – 8.4

Table 23. 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 11 and 12) 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 CaCO₃.

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 μ S/cm	TDS	281	0.989	12.0	65 – 551	Generally ranged from 65 to 550 mg/L	EC	281	0.989	22.5	109 – 1,040
	Br ⁻	337	0.965	0.04	0.01 – 0.86		Br ⁻	279	0.948	0.04	0.01 – 0.86
	Cl ⁻	281	0.983	7.4	4 – 246		Cl ⁻	281	0.971	9.7	4 – 246
	SO ₄ ²⁻ (1)	280	-0.014	10.3	6 – 67		SO ₄ ²⁻	280	0.038	10.0	6 – 67
	Alkalinity (1)	339	-0.141	12.6	29 – 102		Alkalinity	281	0.135	11.5	29 – 102
	Na ⁺	281	0.985	3.7	8 – 147		Na ⁺	281	0.969	5.4	8 – 147
	Ca ²⁺	281	0.481	2.4	7 – 24		Ca ²⁺	281	0.522	2.3	7 – 24
	Mg ²⁺	281	0.880	1.5	2 – 23		Mg ²⁺	281	0.870	1.6	2 – 23
	K ⁺	280	0.865	0.5	0.8 – 6.3		K ⁺	280	0.853	0.5	0.8 – 6.3

(1) The negative R² associated with SO₄²⁻ and with alkalinity reflect extremely high scatter that is present in the dataset and suggest that a mean value generalization, regardless of the estimations of the other constituents, may be used. The observed mean SO₄²⁻ at Old River at Bacon Island was 23.3 mg/L. The observed mean alkalinity at Old River at Bacon Island was 63.0 mg/L as CaCO₃.

Location-Specific Urban Diversions

Table 24. 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 11 and 12) 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	0.979	15.5	1 – 711	Generally ranged from 70 to 750 mg/L	EC	351	0.979	28.0	120 – 1,230
	Br^-	425	0.927	0.05	0.02 – 0.77		Br^-	323	0.871	0.06	0.02 – 0.77
	Cl^-	413	0.963	10.6	6 – 293		Cl^-	351	0.921	14.3	6 – 293
	SO_4^{2-}	363	0.361	11.3	7 – 142		SO_4^{2-}	346	0.422	10.8	7 – 142
	Alkalinity	421	0.206	11.0	27 – 92		Alkalinity	345	0.371	10.2	27 – 92
	Na^+	408	0.979	4.3	10 – 168		Na^+	347	0.941	6.5	10 – 168
	Ca^{2+}	406	0.367	3.5	7 – 49		Ca^{2+}	346	0.495	3.2	7 – 49
	Mg^{2+}	406	0.875	1.6	3 – 28		Mg^{2+}	346	0.853	1.7	3 – 28
	K^+	373	0.777	0.5	1.1 – 5.7		K^+	342	0.755	0.6	1.1 – 5.7

Table 25. 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 11 and 12) 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 775 $\mu\text{S/cm}$	TDS	0	N/A	N/A	N/A	N/A	EC	0	N/A	N/A	
	Br^-	85	0.880	0.05	0.01 – 0.74		Br^-	0			
	Cl^-	82	0.969	10.1	8 – 165		Cl^-	0			
	SO_4^{2-}	85	0.066	10.1	8 – 52		SO_4^{2-}	0			
	Alkalinity	86	0.413	10.9	28 – 89		Alkalinity	0			
	Na^+	60	0.963	4.5	8 – 93		Na^+	0			
	Ca^{2+}	0	N/A	N/A	N/A		Ca^{2+}	0			
	Mg^{2+}	0	N/A	N/A	N/A		Mg^{2+}	0			
	K^+	0	N/A	N/A	N/A		K^+	0			
	Hardness ⁽¹⁾	86	0.802	12.2	32 – 146		Hardness	0			

⁽¹⁾ At this location, total hardness was 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.

Location-Specific Urban Diversions

Table 26. 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	0.949	0.03	mg/L
	Jones Pumping Plant	347	0.909	0.04	mg/L
	Old River at Bacon Island	280	0.979	0.03	mg/L
	Old River at Highway 4	367	0.967	0.03	mg/L
	Victoria Canal	82	0.859	0.05	mg/L

Table 27. 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	757	0.657	8.0	mg/L as CaCO_3
	Jones Pumping Plant	388	0.871	9.8	mg/L as CaCO_3
	Old River at Bacon Island	281	0.527	8.5	mg/L as CaCO_3
	Old River at Highway 4	361	0.622	7.9	mg/L as CaCO_3
	Victoria Canal	82	0.618	8.8	mg/L as CaCO_3

Table 28. 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 11 and 12) 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	70.8	82 – 4,460	Generally ranged from 80 to 4,500 mg/L	EC	50	0.995	124	101 – 10,700
	Br ⁻	0	N/A	N/A	N/A		Br ⁻	0	N/A	N/A	N/A
	Cl ⁻	246	0.989	50.0	2 – 3,390		Cl ⁻	46	0.985	61.5	2 – 3,390
	SO ₄ ²⁻	63	0.923	13.7	7 – 294		SO ₄ ²⁻	17	0.964	5.1	7 – 294
	Alkalinity	212	0.389	11.0	29 – 112		Alkalinity	19	0.469	12.5	29 – 112
	Na ⁺	201	0.986	26.5	2.3 – 1,050		Na ⁺	20	0.991	20.1	2.3 – 1,050
	Ca ²⁺	88	0.817	4.4	8 – 61		Ca ²⁺	17	0.728	3.8	8 – 61
	Mg ²⁺	83	0.961	4.8	3.2 – 138		Mg ²⁺	17	0.905	4.5	3.2 – 138
	K ⁺	77	0.903	2.4	1 – 42		K ⁺	17	0.819	1.6	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 29 and 30. Table 31 can be used to quickly estimate the salinity constituents of interest when the general EC range is known.

Table 29. 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 ≤ [EC] < 800 μ 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 30. 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 ≤ [TDS] < 450 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 31. 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 [μ S/cm]	Practical Salinity (¹)	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	0.052	67	0.00	1	0	47	4	10	4	1.3
150	0.077	94	0.01	5	4	59	9	11	6	1.6
200	0.103	120	0.02	10	10	72	14	12	9	1.8
250	0.129	147	0.03	15	16	84	20	14	11	2.0
300	0.156	175	0.04	21	22	96	25	15	13	2.2
350	0.183	203	0.05	26	28	107	31	17	15	2.4
400	0.210	232	0.06	31	35	119	36	19	17	2.6
450	0.238	261	0.07	37	41	129	41	21	20	2.8
500	0.266	291	0.07	42	48	140	46	23	22	3.0
550	0.294	321	0.08	48	54	151	52	25	24	3.2
600	0.323	352	0.08	54	61	161	57	28	25	3.4
650	0.351	383	0.09	59	68	171	62	30	27	3.5
700	0.380	414	0.09	65	75	180	67	33	29	3.7
750	0.410	446	0.09	72	82	189	72	36	31	3.9
800	0.439	479	0.09	78	89	198	77	38	33	4.0

(¹) Values based on corrected model constants presented in Table 1.