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

A User Guide

February 2022

Final

Simplified Approach for Estimating Salinity Constituent Concentrations

in the San Francisco Estuary & Sacramento-San Joaquin River Delta

2022 CWEMF Annual Meeting

April 6, 2022

Paul Hutton, Ph.D., P.E.

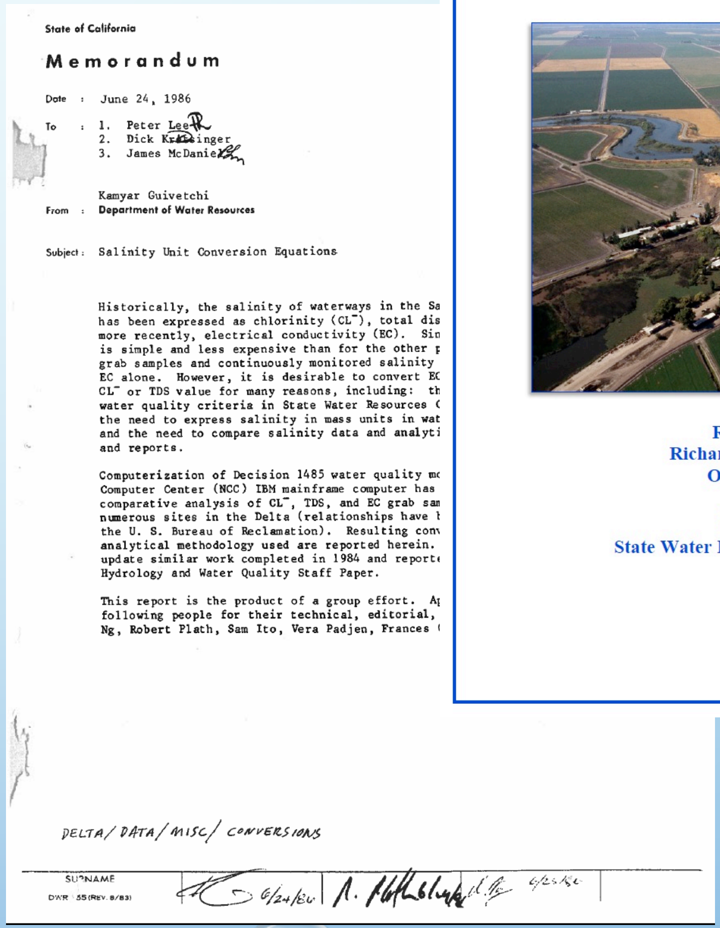
Tetra Tech, Inc.

ACKNOWLEDGEMENTS

- Tetra Tech Team
  - Arushi Sinha
  - Sujoy Roy
- Funding provided by State Water Contractors under the direction of Leslie Palencia

USER GUIDE OBJECTIVES

- Supersedes Guivetchi (1986) memo
- Builds upon Denton (2015) Report
  - Provide guidance for estimating salinity constituent concentrations from a given EC or TDS value at several key regions (and locations) in the Delta.
  - Targeted toward an inclusive audience so that it can provide guidance to a broad Delta stakeholder community.
- Not a substitute for hydrodynamic modeling


State of California

Memorandum

Date : June 24, 1986

To : 1. Peter Lee
2. Dick Kretsinger
3. James McDaniel

From : Kamyar Guivetchi
Department of Water Resources

Subject : Salinity Unit Conversion Equations

Historically, the salinity of waterways in the Sa
has been expressed as chlorinity (CL⁻), total dis
more recently, electrical conductivity (EC). Sin
is simple and less expensive than for the other p
grab samples and continuously monitored salinity
EC alone. However, it is desirable to convert EC
CL⁻ or TDS value for many reasons, including: th
water quality criteria in State Water Resources C
the need to express salinity in mass units in wat
and the need to compare salinity data and analyti
and reports.

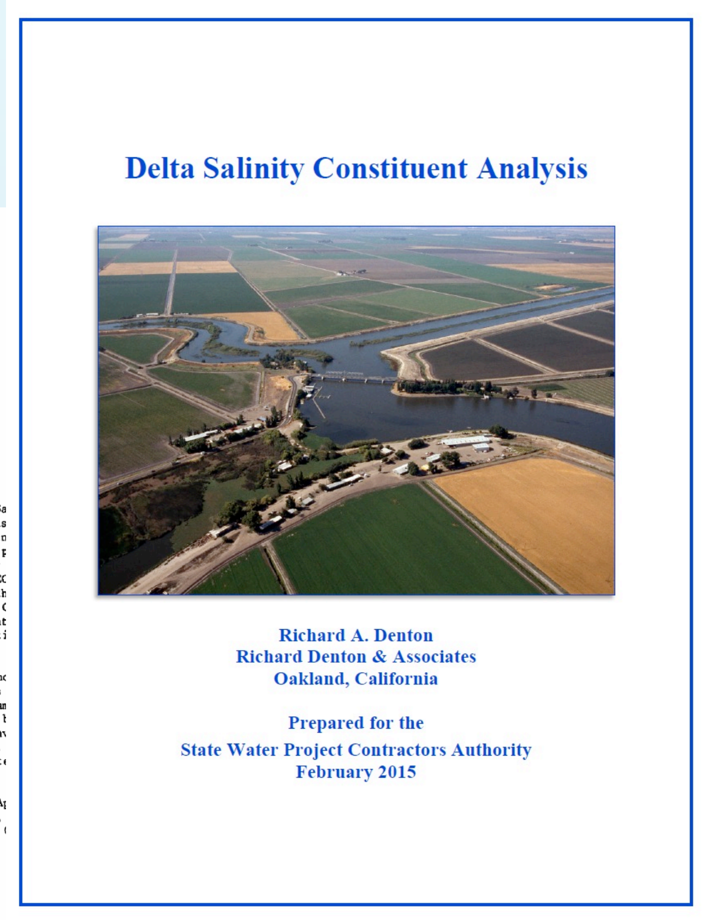
Computerization of Decision 1485 water quality mo
Computer Center (NCC) IBM mainframe computer has
comparative analysis of CL⁻, TDS, and EC grab sam
numerous sites in the Delta (relationships have b
the U. S. Bureau of Reclamation). Resulting conv
analytical methodology used are reported herein.
update similar work completed in 1984 and report
Hydrology and Water Quality Staff Paper.

This report is the product of a group effort. Ap
following people for their technical, editorial,
Ng, Robert Plath, Sam Ito, Vera Padjen, Frances

DELTA/DATA/MISC/CONVERSIONS

SURNAME

DWR 55 (REV. 8/83)


Delta Salinity Constituent Analysis

Richard A. Denton
Richard Denton & Associates
Oakland, California

Prepared for the
State Water Project Contractors Authority
February 2015

PREDICTING SALINITY CONSTITUENT CONCENTRATIONS
FROM SPECIFIC CONDUCTANCE (EC)

$$S\ (mg/L) = A * EC^2 + B * EC + C$$

where S = ionic constituents such as Br^-, Cl^-, SO_4^{2-}, HCO_3^-, Na^+, Ca^{2+}, Mg^{2+} and K^+

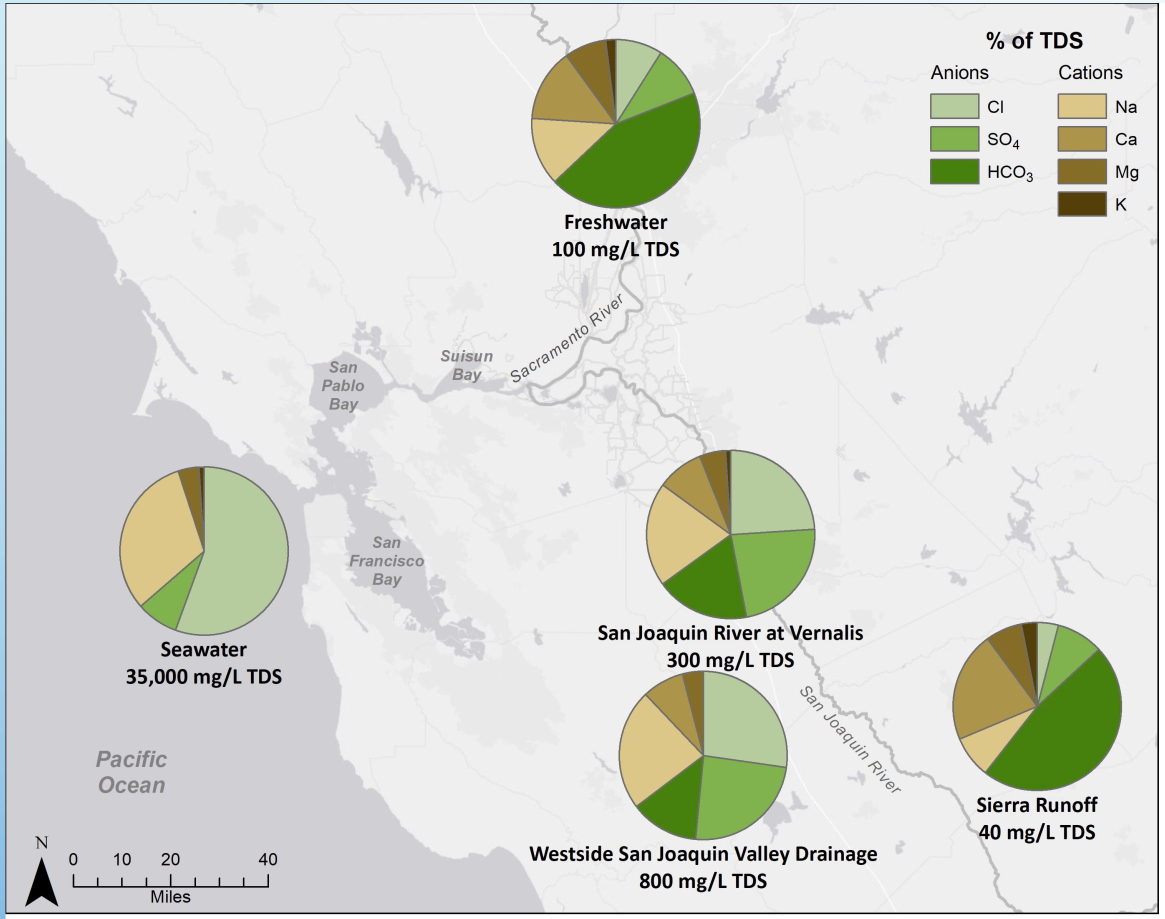
A, B, C = constants typically determined through least squares regression

USER GUIDE CONTENTS
48 PAGES; 28 TABLES; 8 FIGURES

- Purpose of User Guide
- Key Assumptions
- Geographic Overview
- Methodology
- Boundary Regions
- Interior Delta Region
- Location-Specific Urban Diversions

PRIMARY SOURCES OF SALINITY

VARY IN IONIC MAKEUP



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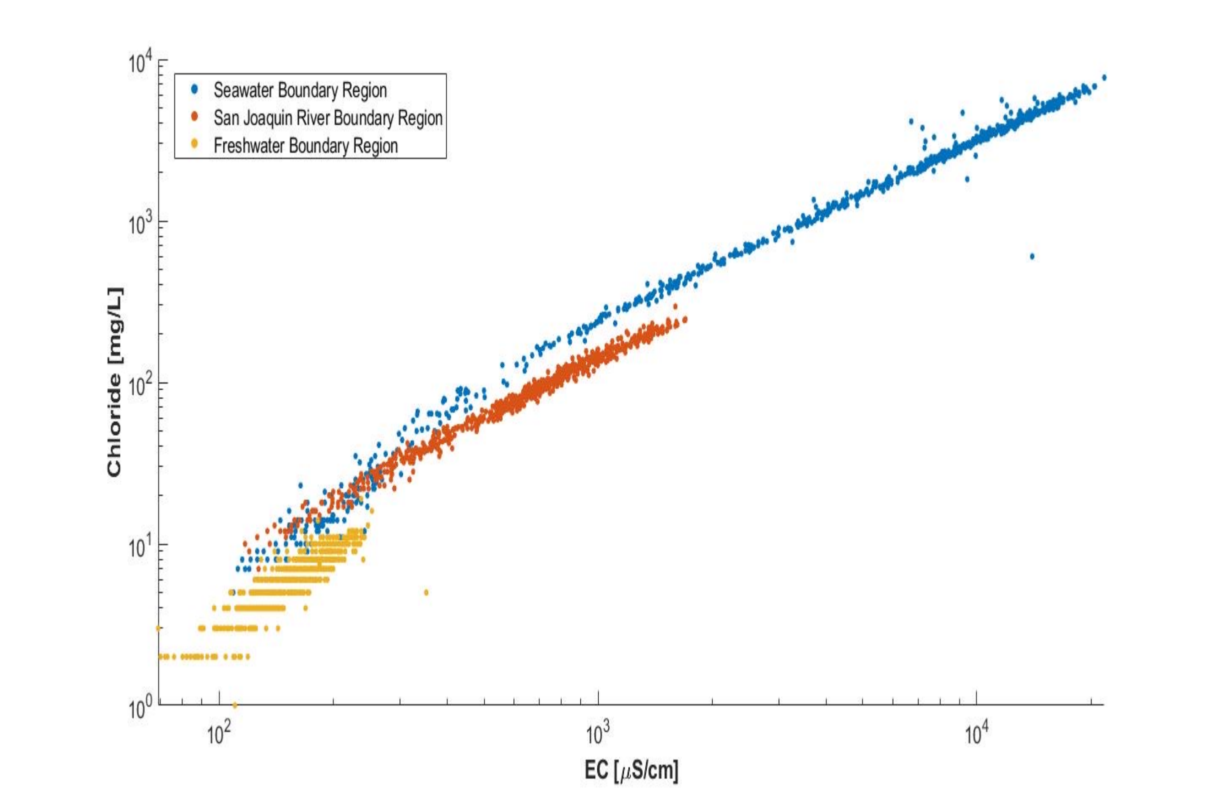
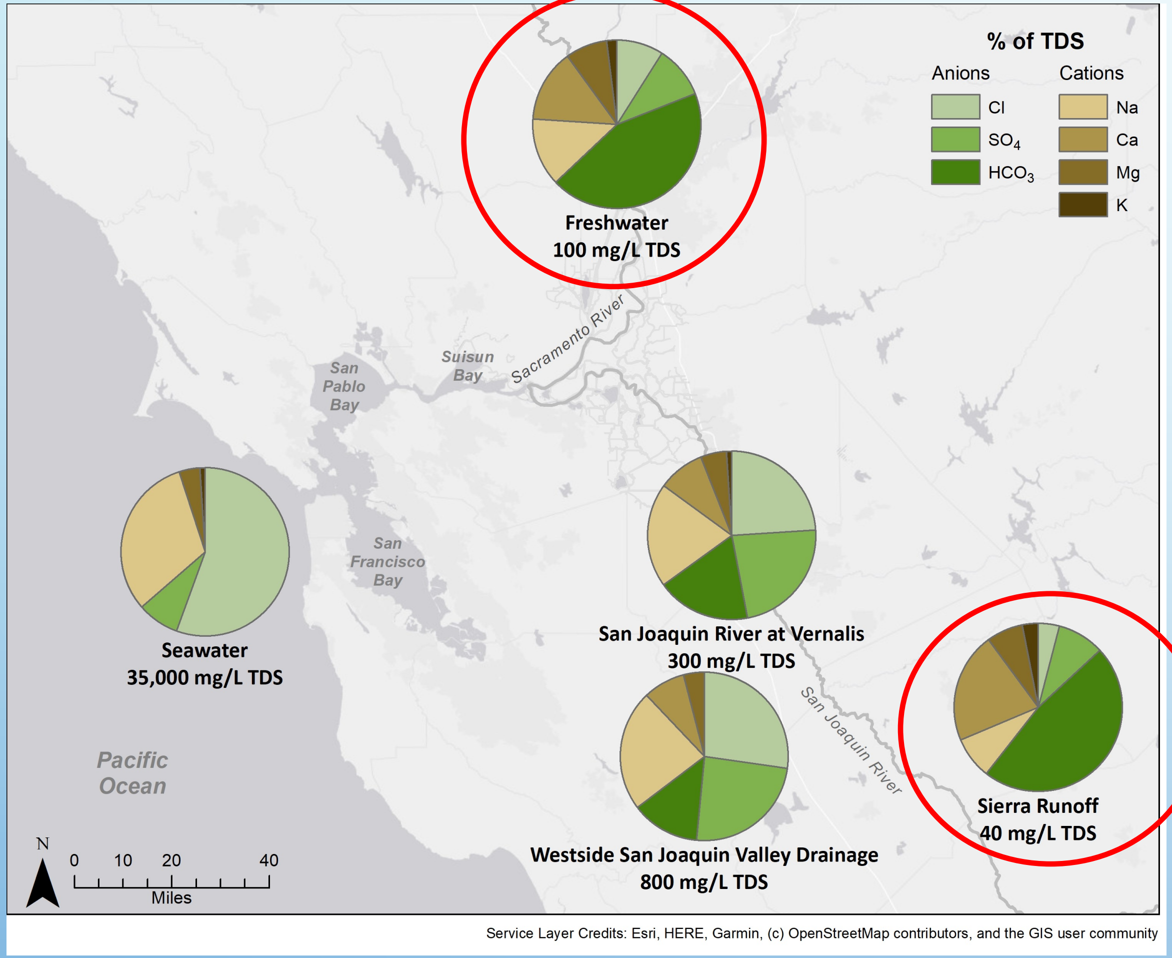
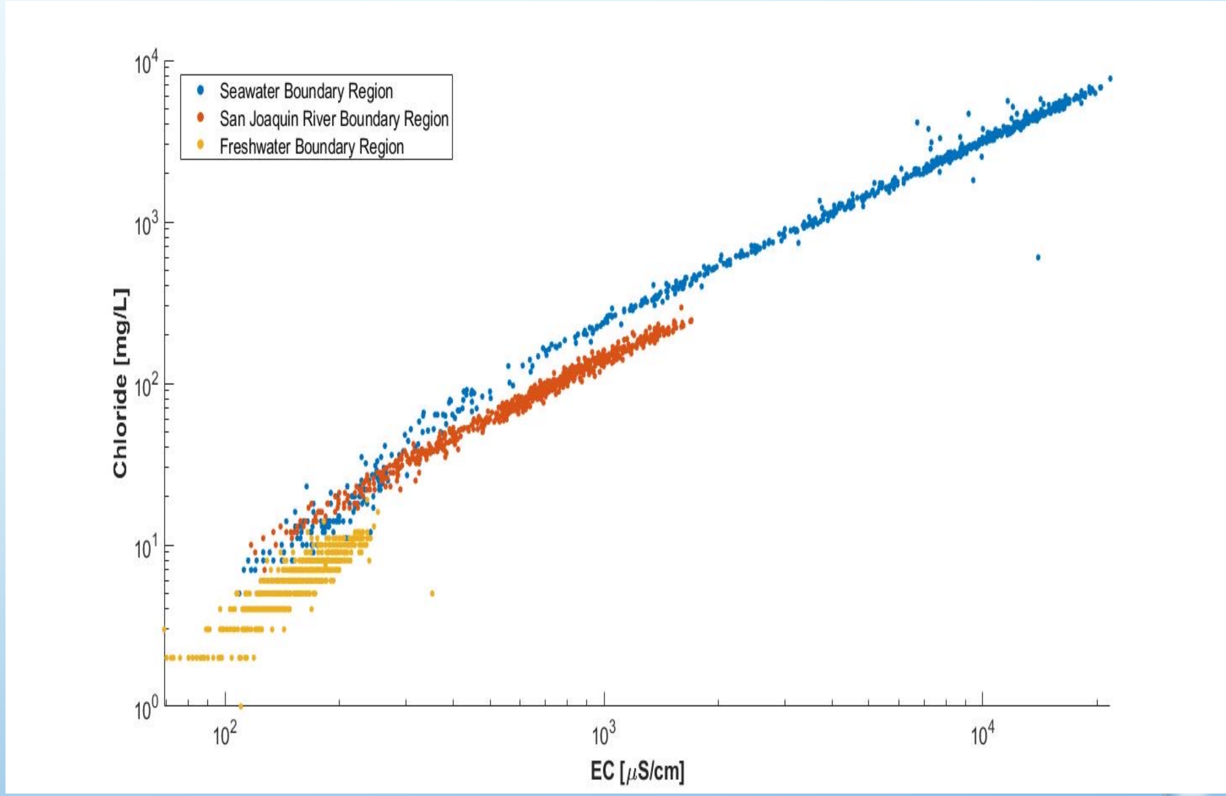


PRIMARY SOURCES OF SALINITY

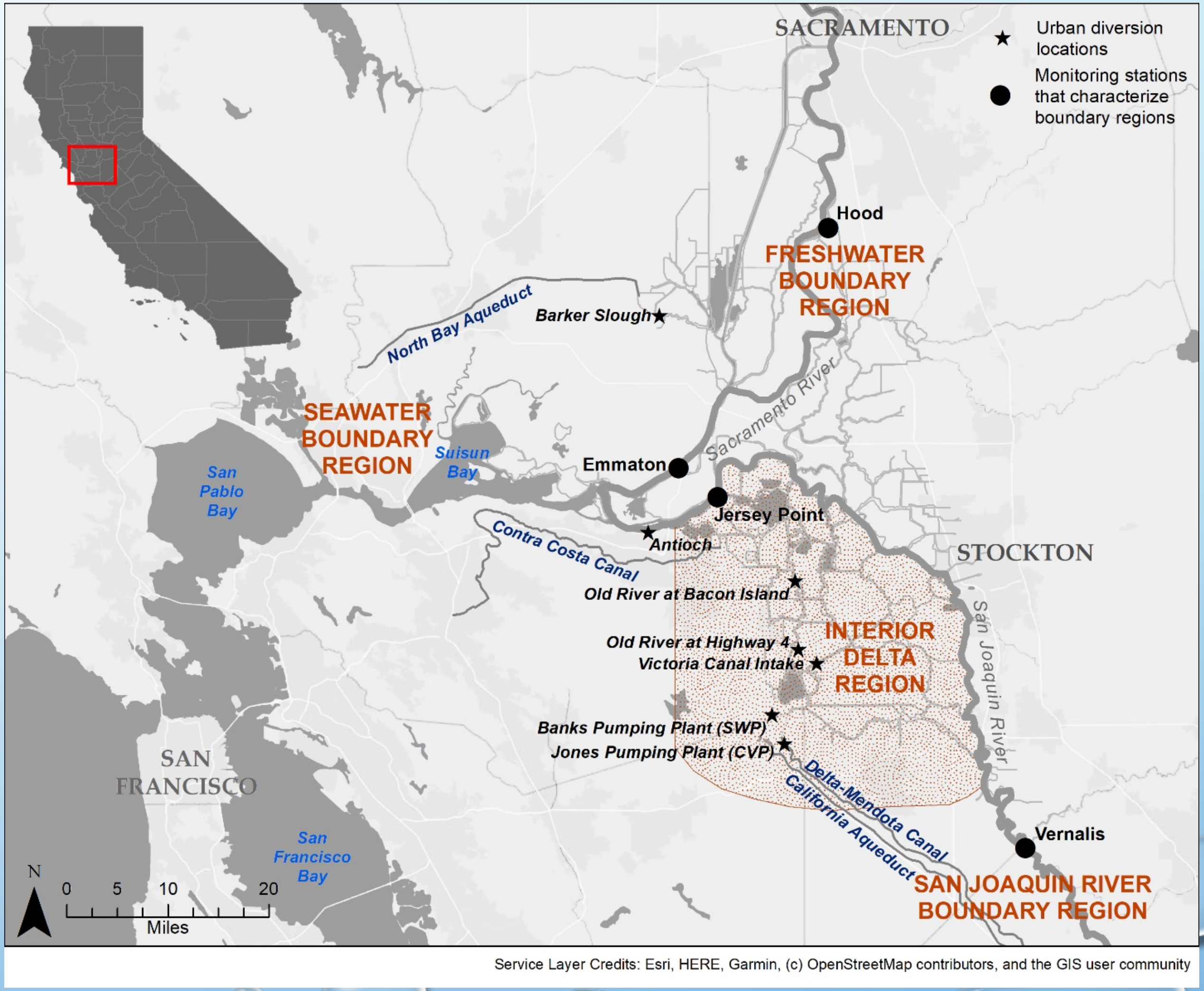
VARY IN IONIC MAKEUP





GEOGRAPHIC OVERVIEW

- Three Geographic Groupings:
  - Boundary Regions
    - Seawater Boundary Region
    - Freshwater Boundary Region
    - San Joaquin River Boundary Region
  - Interior Delta Region
  - Location-Specific Urban Diversions



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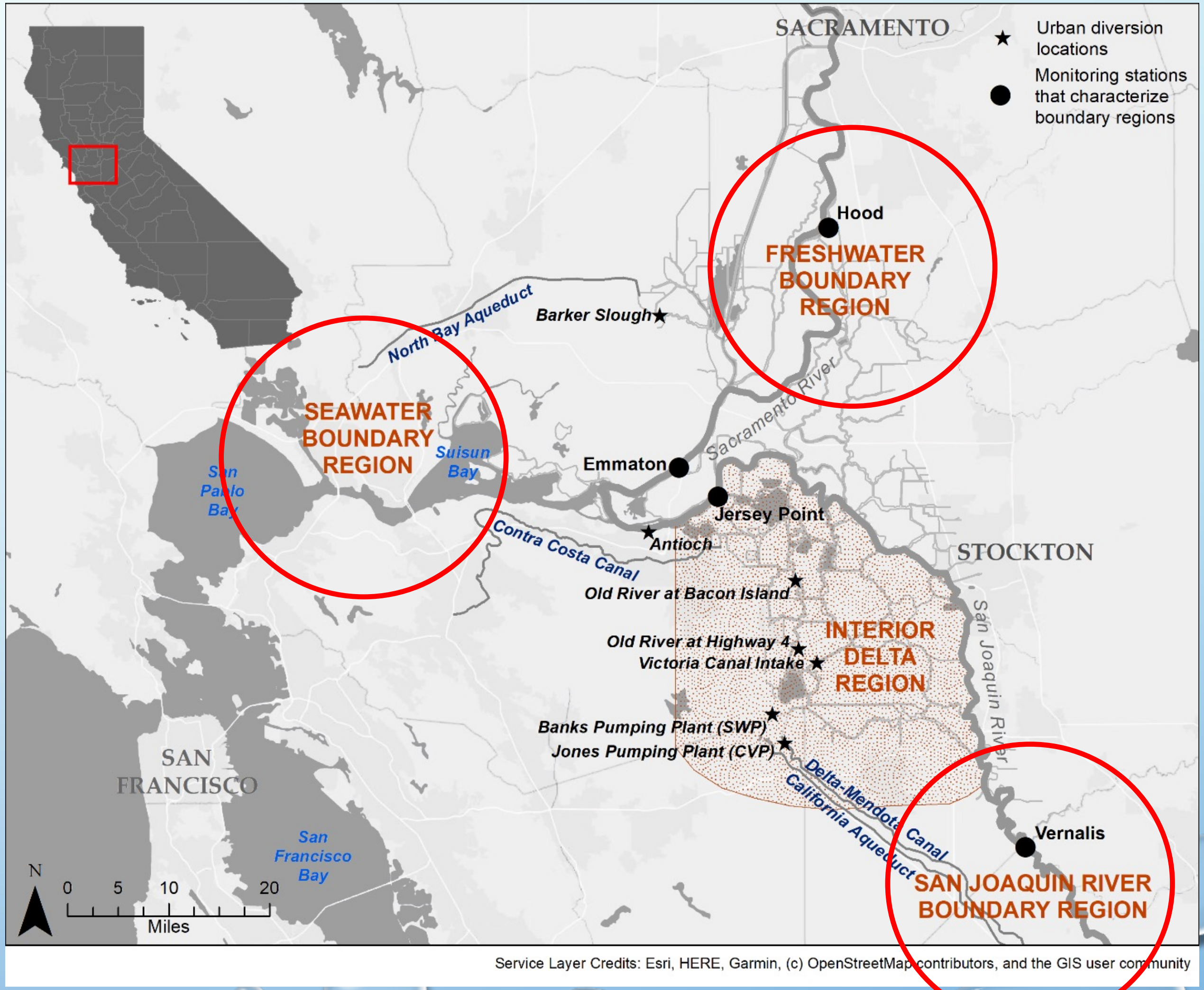

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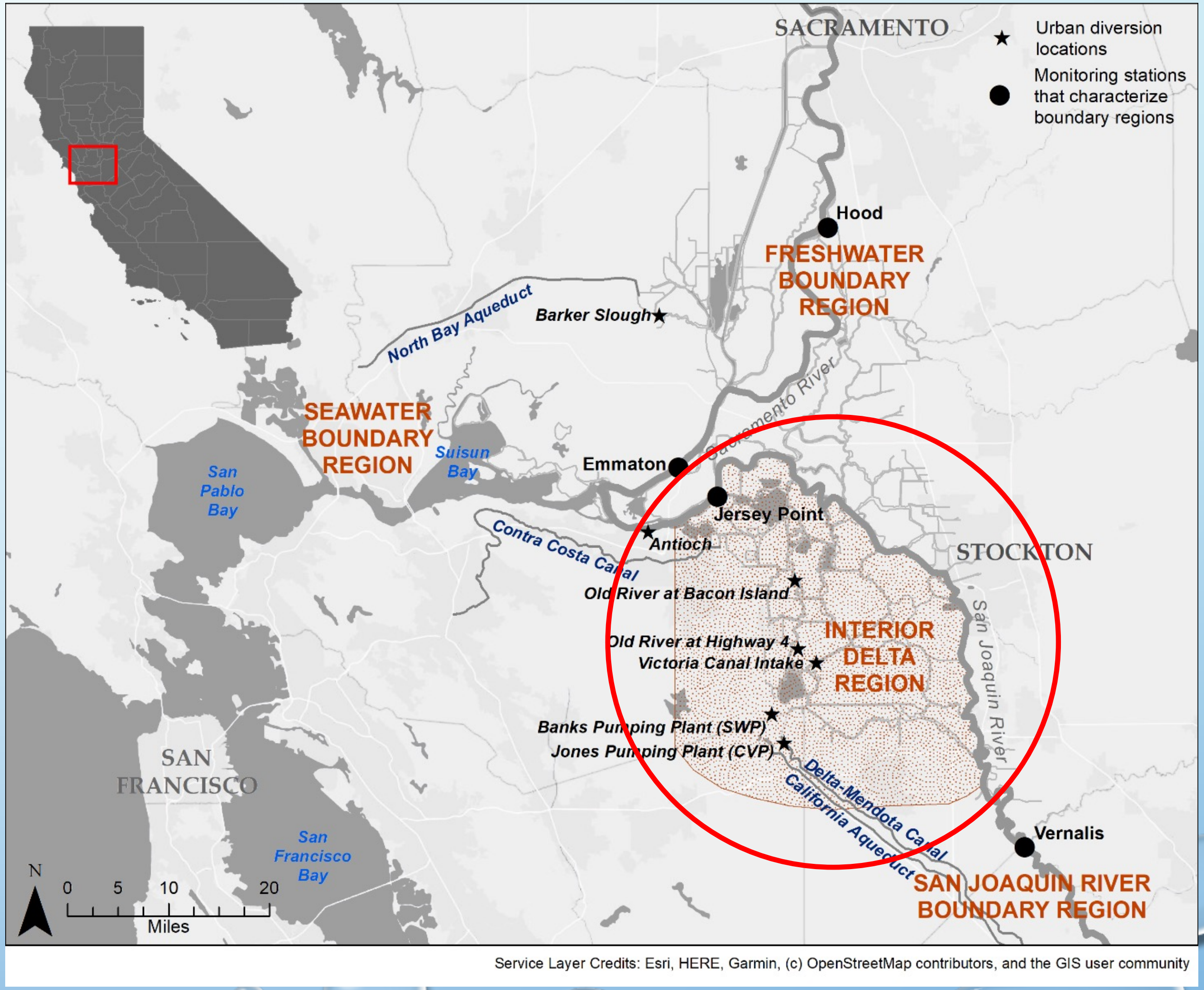

EXAMPLE USER GUIDE TABLES

San Joaquin River Boundary

X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
100 ≤ [EC] < 1,600 µS/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

SAN JOAQUIN RIVER BOUNDARY REGION									
EC [µS/cm]	TDS [mg/L]	Br^- [mg/L]	Cl^- [mg/L]	SO_4^{2-} [mg/L]	Alkalinity [mg/L as $CaCO_3$]	Na^+ [mg/L]	Ca^{2+} [mg/L]	Mg^{2+} [mg/L]	K^+ [mg/L]
100	64	0.00	2	13	25	7	8	3	1.2
200	119	0.05	17	24	40	19	12	5	1.5
300	174	0.09	32	36	54	30	16	8	1.7
400	231	0.14	47	48	68	42	21	10	2.0
500	289	0.19	62	62	80	54	25	13	2.2
600	347	0.24	78	76	92	66	30	15	2.5
700	408	0.29	93	91	103	79	34	18	2.8
800	469	0.34	109	108	113	92	39	21	3.1
900	531	0.39	125	125	123	105	43	23	3.4
1,000	595	0.44	141	143	131	118	48	26	3.7
1,100	659	0.49	157	162	139	132	53	29	4.0
1,200	725	0.54	173	182	146	146	57	32	4.3
1,300	792	0.59	189	203	152	160	62	35	4.6
1,400	860	0.65	205	225	158	174	67	38	5.0
1,500	929	0.70	222	248	162	189	72	41	5.3
1,600	1,000	0.76	239	272	166	203	77	44	5.7

EXAMPLE USER GUIDE TABLES

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100 ≤ [EC] < 1,600 µS/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
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	K^+	611	3.78E-07	0.00232	1.0	0.803	0.4	0.5 – 6.2

Regression Constants & Statistics

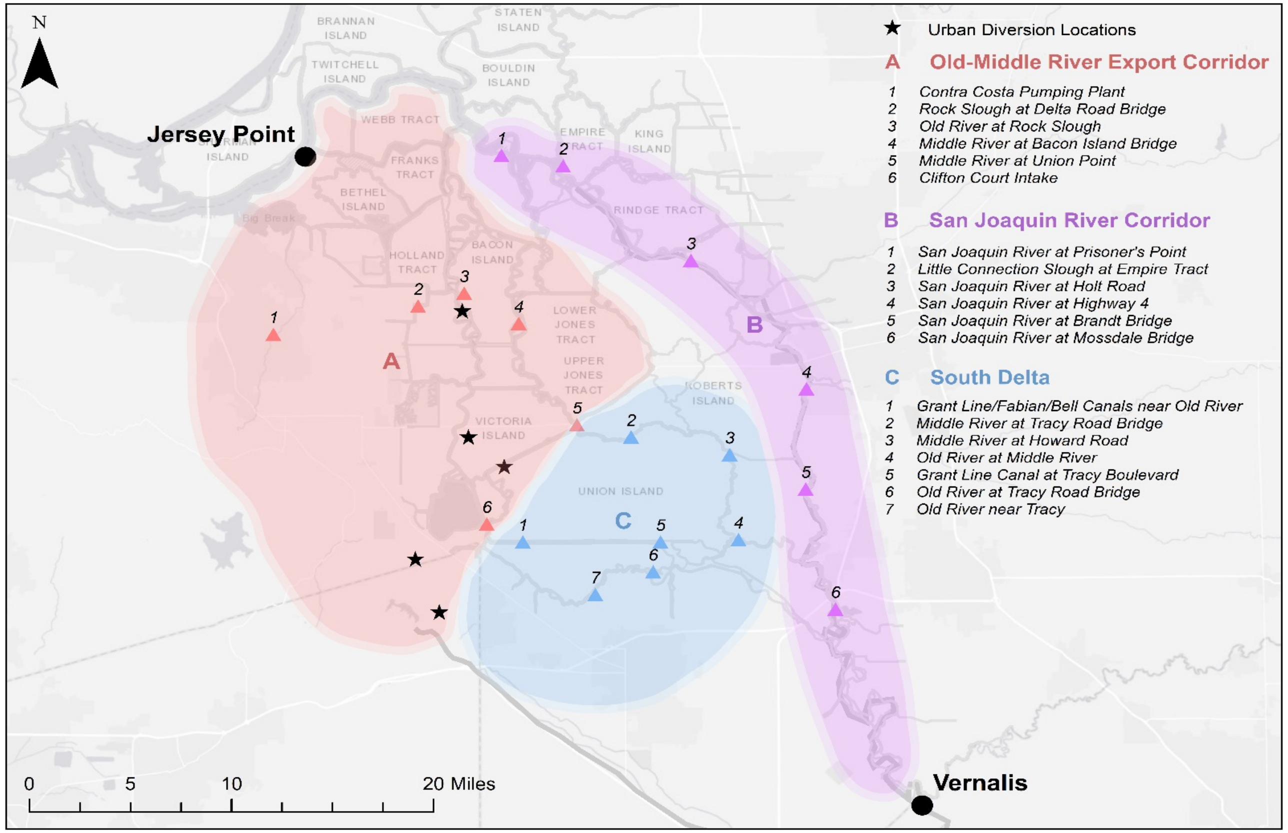
SAN JOAQUIN RIVER BOUNDARY REGION

EC [µS/cm]	TDS [mg/L]	Br^- [mg/L]	Cl^- [mg/L]	SO_4^{2-} [mg/L]	Alkalinity [mg/L as $CaCO_3$]	Na^+ [mg/L]	Ca^{2+} [mg/L]	Mg^{2+} [mg/L]	K^+ [mg/L]
100	64	0.00	2	13	25	7	8	3	1.2
200	119	0.05	17	24	40	19	12	5	1.5
300	174	0.09	32	36	54	30	16	8	1.7
400	231	0.14	47	48	68	42	21	10	2.0
500	289	0.19	62	62	80	54	25	13	2.2
600	347	0.24	78	76	92	66	30	15	2.5
700	408	0.29	93	91	103	79	34	18	2.8
800	469	0.34	109	108	113	92	39	21	3.1
900	531	0.39	125	125	123	105	43	23	3.4
1,000	595	0.44	141	143	131	118	48	26	3.7
1,100	659	0.49	157	162	139	132	53	29	4.0
1,200	725	0.54	173	182	146	146	57	32	4.3
1,300	792	0.59	189	203	152	160	62	35	4.6
1,400	860	0.65	205	225	158	174	67	38	5.0
1,500	929	0.70	222	248	162	189	72	41	5.3
1,600	1,000	0.76	239	272	166	203	77	44	5.7

Lookup Table

GEOGRAPHIC OVERVIEW (CONT'D)

- Interior Delta Region further classified into three subregions:
  - Old-Middle River Export Corridor Influenced by hydrodynamic patterns driven by exports
  - San Joaquin River Corridor Influenced by Vernalis inflow
  - South Delta Influenced by Vernalis inflow, rock barriers, and local salinity sources



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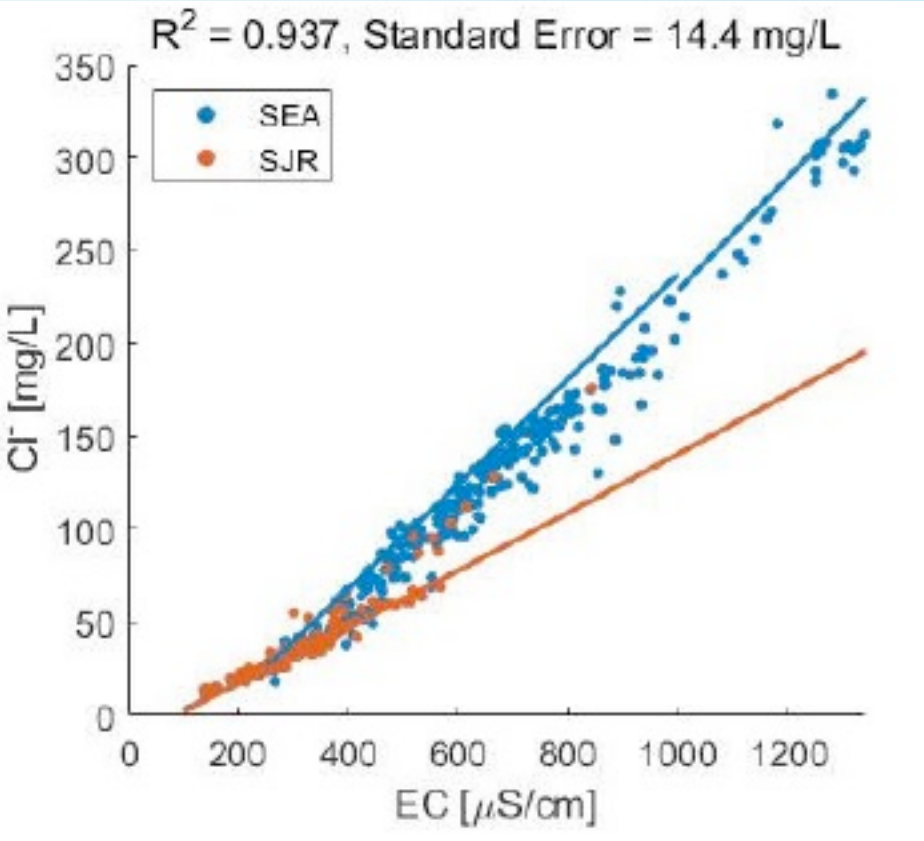
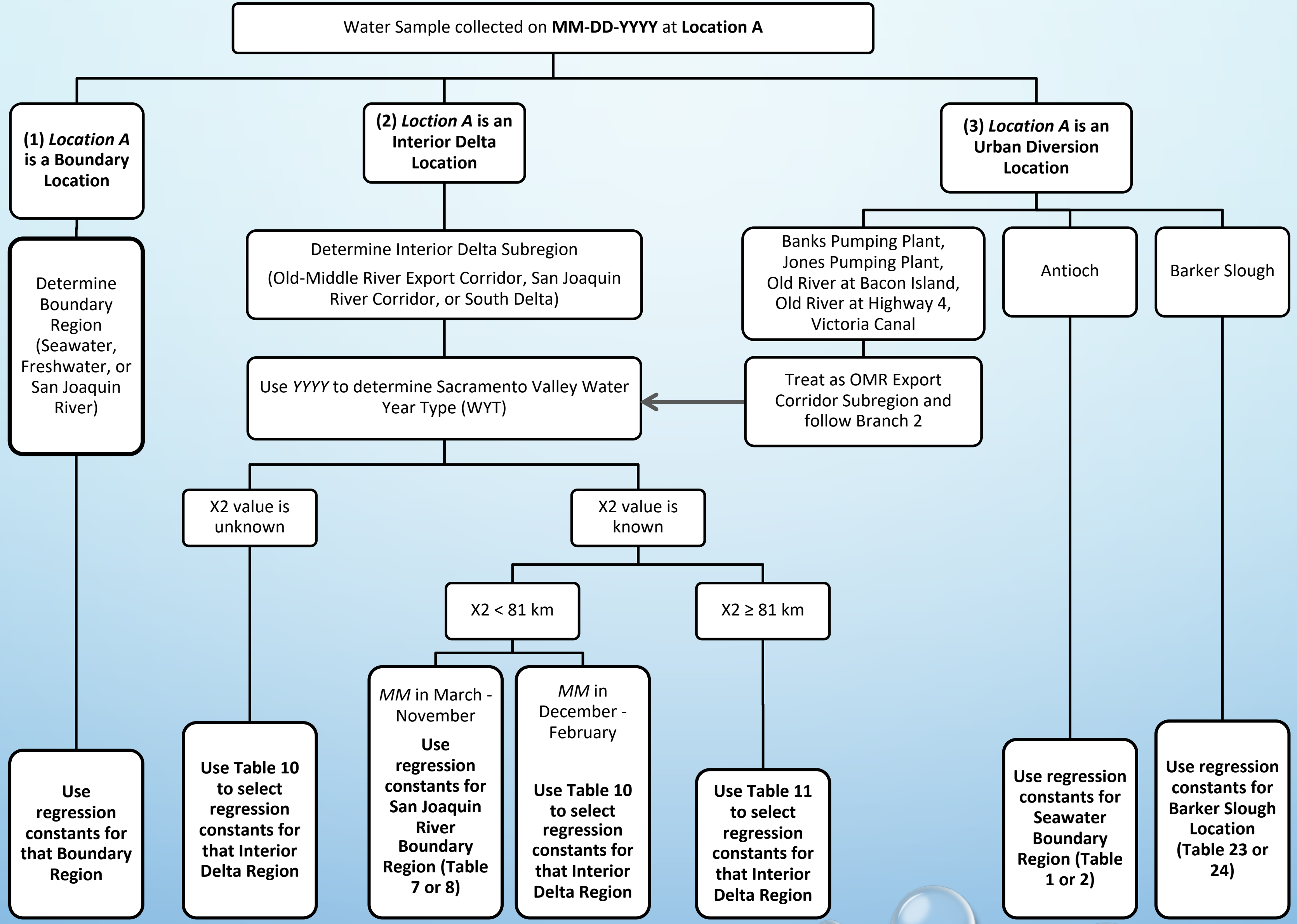
INTERIOR DELTA SALINITY SOURCES VARY WITH HYDRODYNAMIC CONDITIONS

- Salinity characteristics generally bounded by Seawater Boundary and San Joaquin River Boundary characteristics
- Regression equations NOT developed for this region
- Hydrodynamic proxies
  - Month
  - 40-30-30 Water Year Type
  - X2 Position
- User guidance provided through "Decision Tree"

Banks Pumping Plant





Water Sample collected on MM-DD-YYYY at Location A
(1) Location A is a Boundary Location
Determine Boundary Region (Seawater, Freshwater, or San Joaquin River)
Use regression constants for that Boundary Region
(2) Loction A is an Interior Delta Location
Determine Interior Delta Subregion
(Old-Middle River Export Corridor, San Joaquin River Corridor, or South Delta)
Use YYYY to determine Sacramento Valley Water Year Type (WYT)
X2 value is unknown
Use Table 10 to select regression constants for that Interior Delta Region
X2 value is known
X2 < 81 km
MM in March - November
Use regression constants for San Joaquin River Boundary Region (Table 7 or 8)
MM in December - February
Use Table 10 to select regression constants for that Interior Delta Region
X2 ≥ 81 km
Use Table 11 to select regression constants for that Interior Delta Region
(3) Location A is an Urban Diversion Location
Banks Pumping Plant, Jones Pumping Plant, Old River at Bacon Island, Old River at Highway 4, Victoria Canal
Treat as OMR Export Corridor Subregion and follow Branch 2
Antioch
Use regression constants for Seawater Boundary Region (Table 1 or 2)
Barker Slough
Use regression constants for Barker Slough Location (Table 23 or 24)

WATER YEAR TYPE AND SEASON MATRIX #1

	J	F	M	A	M	J	J	A	S	O	N	D
Old-Middle River Export Corridor Subregion												
W	SEA	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SEA	SEA	SEA	SEA
AN	SEA	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SEA	SEA	SEA	SEA
BN	SEA	SEA	SJR	SJR	SJR	SJR	SJR	SEA	SEA	SEA	SEA	SEA
D	SEA	SEA	SJR	SJR	SJR	SJR	SJR	SEA	SEA	SEA	SEA	SEA
C	SEA	SEA	SJR	SJR	SJR	SEA	SEA	SEA	SEA	SEA	SEA	SEA
San Joaquin River Corridor Subregion												
W	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
AN	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
BN	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
D	SJR	SJR	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	SJR
C	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	IND	IND	SJR
South Delta Subregion												
W	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR	SJR
AN	IND	SJR	SJR	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND
BN	IND	IND	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	IND
D	IND	IND	SJR	SJR	SJR	SJR	SJR	IND	IND	IND	IND	IND
C	IND	IND	SJR	SJR	SJR	IND	IND	IND	IND	IND	IND	IND

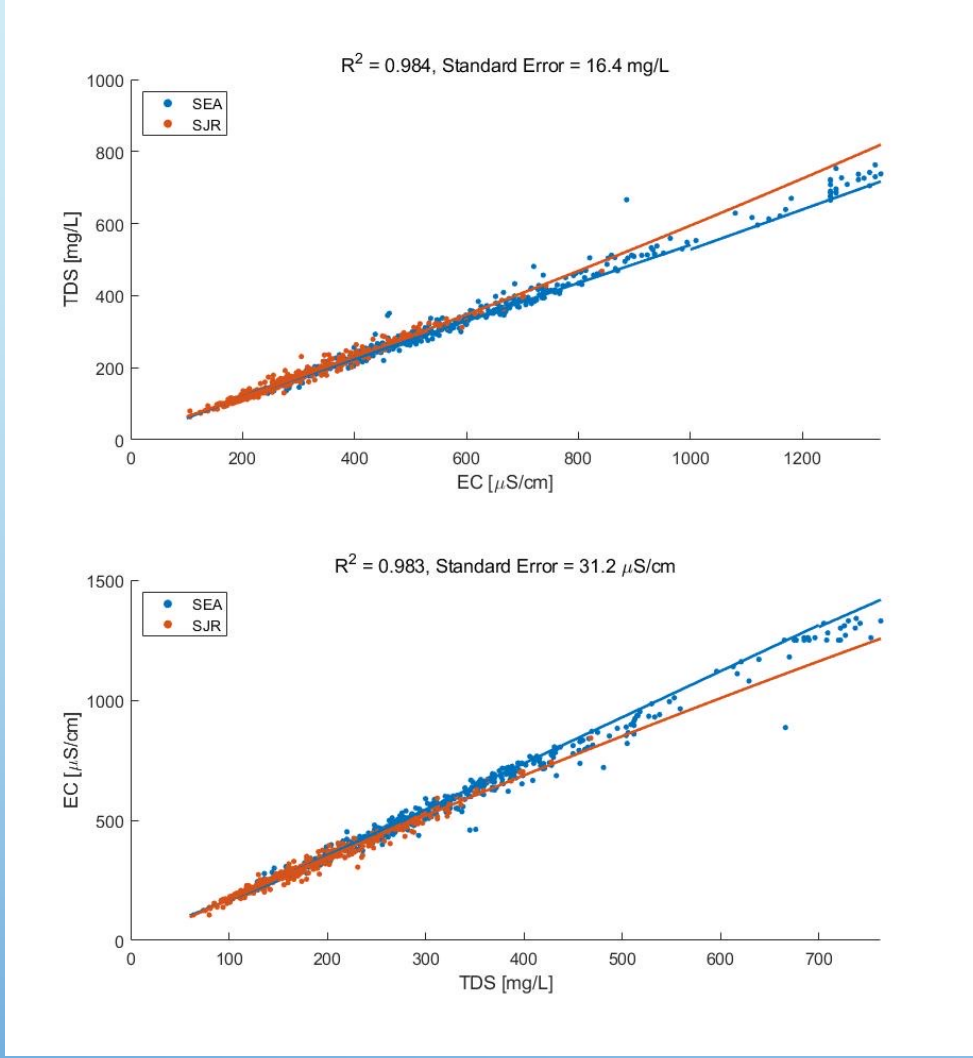
USER GUIDE APPENDICES

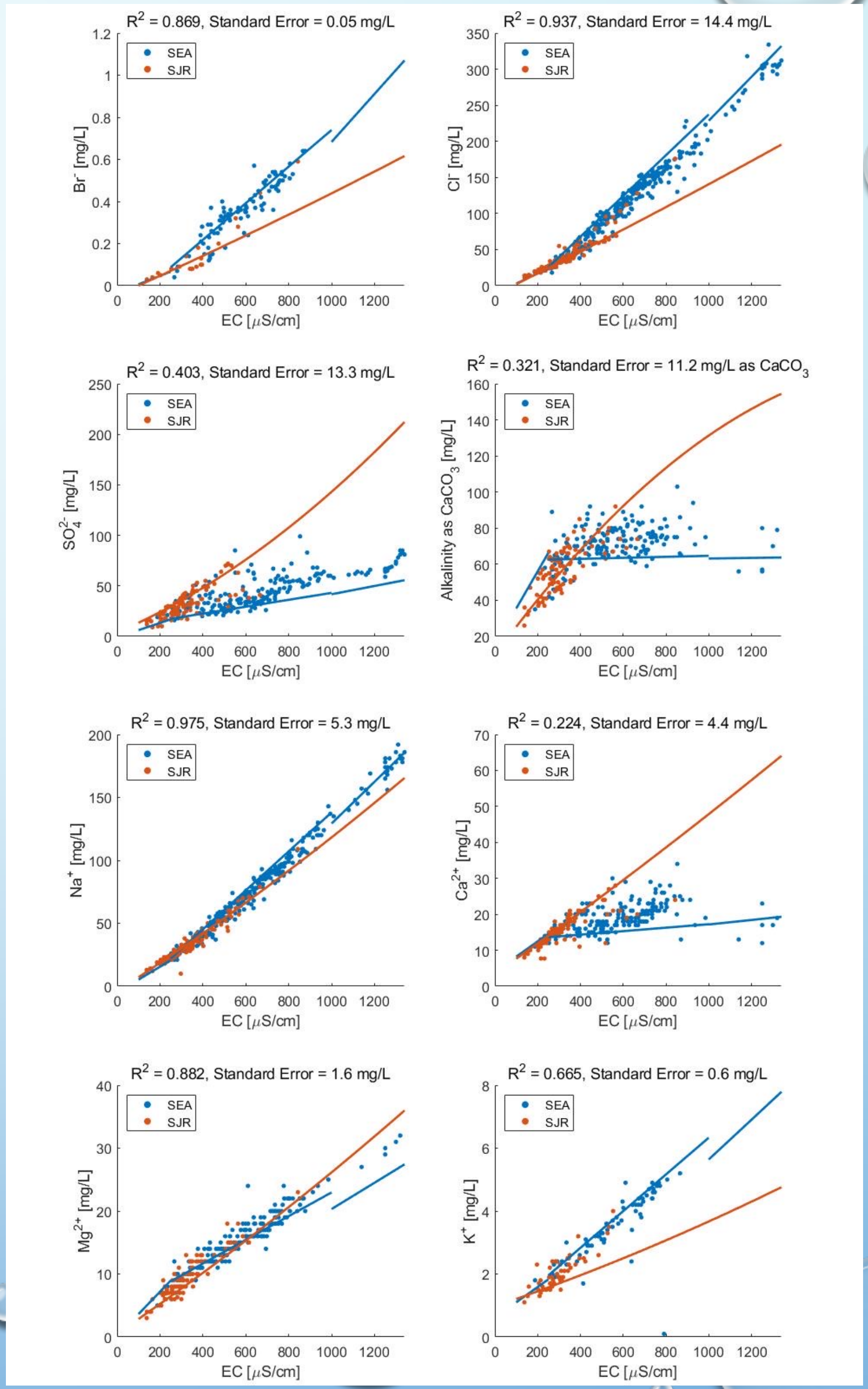
- Appendix A: Data
- Appendix B: Regression Equation Parameter Uncertainties
- Appendix C: Scatter Plots
- Appendix D: Validation Analysis
- Appendix E: Delta Salinity Constituent Analysis (Denton, 2015)

EXAMPLE APPENDIX C FIGURES

Banks Pumping Plant

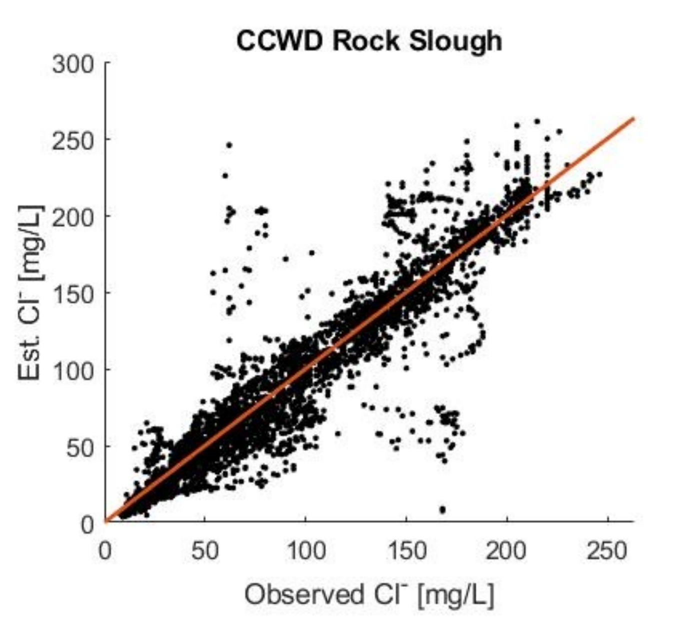
Data Points Classified through Decision Tree Compared to Boundary Equations

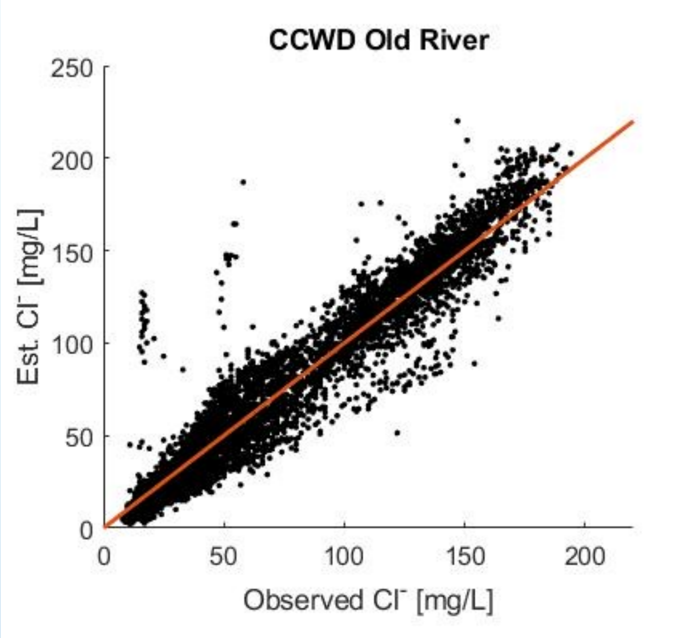


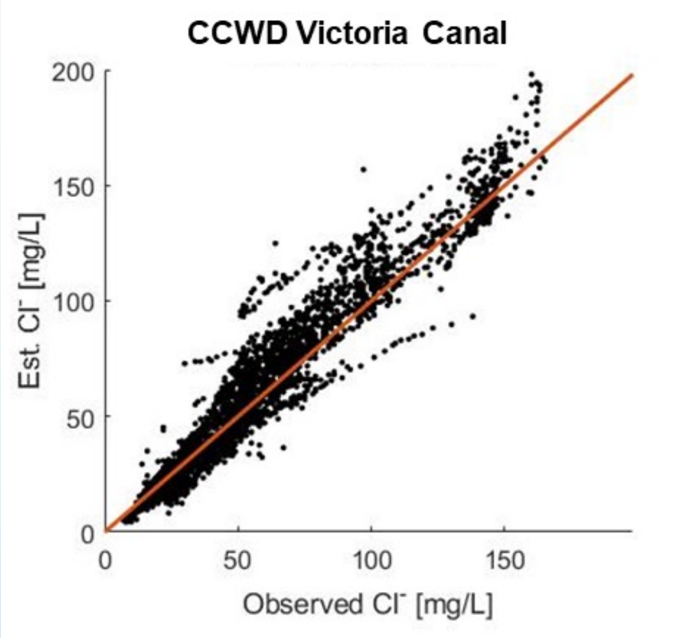


EXAMPLE APPENDIX D FIGURES

Urban Diversion Validation







CONCLUDING THOUGHTS

- Adoption of User Guide by modeling community
- Potential Future Work
  - Update User Guide to incorporate more parsimonious Seawater Boundary Formulation (presented in Tuesday's Pop-Up session)
  - Update User Guide to incorporate guidance on practical salinity conversions

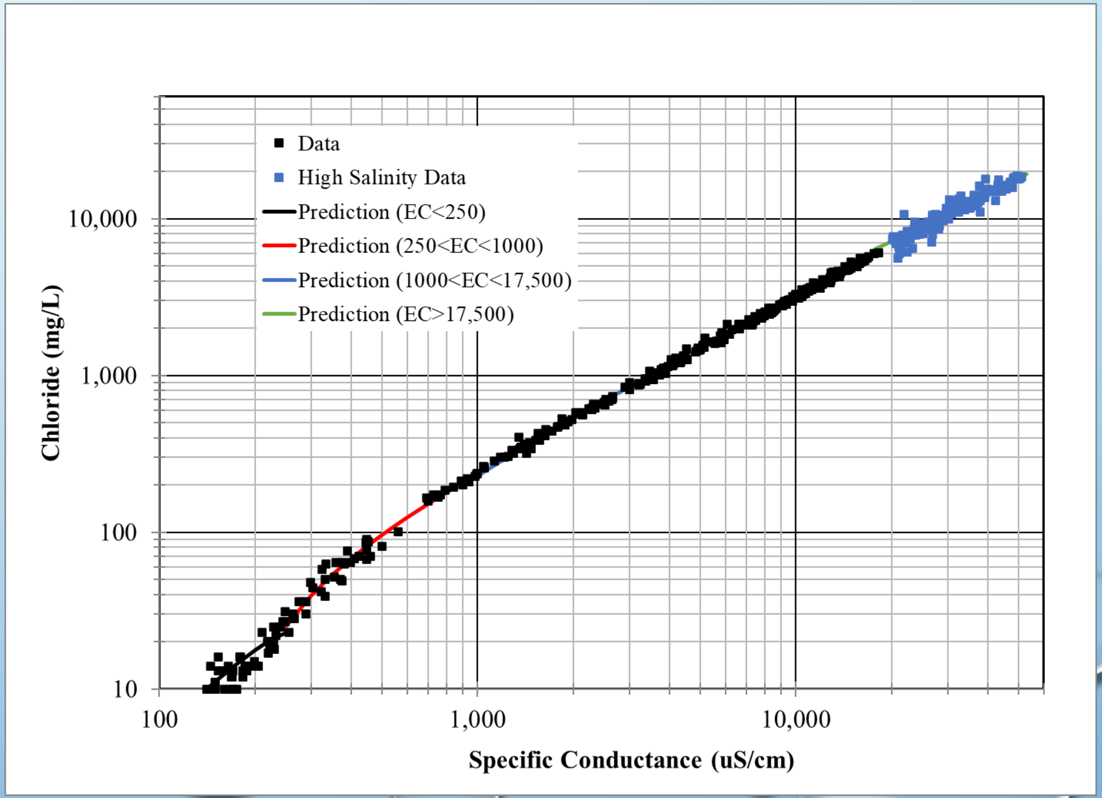
X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
“Low” Salinity 100 ≤ [EC] < 250 µS/cm	TDS	68	0	0.593	0.8	0.957	4.5	67 – 151
	Br^-	64	0	0.000401	-0.03	0.604	0.01	0.01 – 0.1
	Cl^-	68	0	0.139	-10.9	0.781	2.6	7 – 31
	SO_4^{2-}	68	0	0.0716	-1.0	0.544	2.3	6 – 22
	Alkalinity	68	0	0.205	15.0	0.706	4.7	37 – 72
	Na^+	68	0	0.102	-4.9	0.892	1.3	7 – 22
	Ca^{2+}	68	0	0.0422	4.0	0.665	1.1	8 – 16
	Mg^{2+}	68	0	0.0355	0.1	0.836	0.6	4 – 9
	K^+	68	0	0.00484	0.6	0.221	0.3	0.9 – 2.5

X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
“Low-Medium” Salinity 250 ≤ [EC] < 1,000 µS/cm	TDS	51	0	0.527	13.3	0.996	8.3	151 – 541
	Br^-	50	0	0.000869	-0.13	0.786	0.11	0.07 – 0.83
	Cl^-	51	0	0.282	-45.1	0.984	8.6	23 – 235
	SO_4^{2-}	51	0	0.0342	8.9	0.755	4.7	14 – 47
	Alkalinity	51	0	0.00280	61.9	0.004	10.2	41 – 85
	Na^+	51	0	0.155	-16.8	0.988	4.2	21 – 137
	Ca^{2+}	51	0	0.00482	12.4	0.202	2.3	9 – 21
	Mg^{2+}	51	0	0.0188	4.1	0.900	1.5	8.9 – 26
	K^+	51	0	0.00583	0.5	0.924	0.4	1.9 – 6.8

X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
“Medium” Salinity 1,000 ≤ [EC] < 17,500 µS/cm	TDS	308	4.84E-06	0.544	-20.9	0.996	185	532 – 10,800
	Br^-	266	3.21E-10	0.00114	-0.46	0.982	0.7	0.08 – 19.65
	Cl^-	308	2.42E-06	0.299	-72.5	0.997	89	238 – 5,704
	SO_4^{2-}	308	3.60E-07	0.0400	1.3	0.992	19	40 – 793
	Alkalinity	308	-1.13E-08	0.00168	61.5	0.449	8	46 – 96
	Na^+	308	1.16E-06	0.163	-35.0	0.997	50	138 – 3130
	Ca^{2+}	308	5.06E-08	0.00619	10.9	0.987	4	15 – 135
	Mg^{2+}	308	9.13E-08	0.0207	-0.4	0.991	10	22 – 376
	K^+	308	5.01E-08	0.0062	-0.6	0.979	5	2.6 – 132

X = EC	Y	Data Points	A	B	C	R^2	SE	Data Range
“High” Salinity [EC] ≥ 17,500 µS/cm	TDS	103	0	0.659	-15.8	0.936	2,460	10,200 – 36,200
	Br^-	0	0	0.00123	-0.24	N/A	N/A	N/A
	Cl^-	228	0	0.364	-67.3	0.947	910	5,400 – 18,800
	SO_4^{2-}	0	0	0.0510	4.2	N/A	N/A	N/A
	Alkalinity	70	0	0.000950	66.0	0.509	9	47 – 108
	Na^+	0	0	0.202	-22.9	N/A	N/A	N/A
	Ca^{2+}	0	0	0.00735	12.7	N/A	N/A	N/A
	Mg^{2+}	0	0	0.0244	2.9	N/A	N/A	N/A
	K^+	0	0	0.00729	0.0	N/A	N/A	N/A

Constants Generally Determined through Least Squares Regression: 4 Data Ranges



TWO-SOURCE LINEAR MIXING ASSUMPTION FITS THE DATA (EXCEPT FOR EC !)

High Salinity Seawater %	Low Salinity Seawater %	EC (uS/cm)	PSU	Na	Ca	Mg	K	Cl	SO4	Alkalinity	Br	TDS
100	0	52000	35.00	10900	423	1325	420	19817	2700	119	68.61	37000
90	10	46825	31.51	9812	382	1193	378	17838	2432	114	61.76	33315
80	20	41650	28.02	8724	341	1062	336	15859	2163	108	54.90	29629
70	30	36475	24.54	7637	300	930	295	13880	1895	102	48.05	25944
60	40	31300	21.05	6549	259	799	253	11901	1627	97	41.20	22258
50	50	26125	17.56	5461	218	667	211	9921	1359	91	34.35	18573
40	60	20950	14.07	4373	177	535	169	7942	1090	85	27.50	14887
30	70	15775	10.59	3285	136	404	127	5963	822	80	20.64	11202
20	80	10600	7.10	2198	95	272	86	3984	554	74	13.79	7516
10	90	5425	3.61	1110	55	140	44	2005	286	68	6.94	3831
9	91	4908	3.26	1001	50	127	40	1807	259	68	6.25	3462
8	92	4390	2.91	892	46	114	35	1609	232	67	5.57	3093
7	93	3873	2.56	783	42	101	31	1411	205	67	4.88	2725
6	94	3355	2.22	675	38	88	27	1213	178	66	4.20	2356
5	95	2838	1.87	566	34	75	23	1015	152	65	3.51	1988
4	96	2320	1.52	457	30	61	19	817	125	65	2.83	1619
3	97	1803	1.17	348	26	48	14	619	98	64	2.14	1251
2	98	1285	0.82	240	22	35	10	421	71	64	1.46	882
1	99	768	0.47	131	18	22	6	223	44	63	0.77	514
0.9	99.1	716	0.44	120	17	21	6	204	42	63	0.70	477
0.8	99.2	664	0.40	109	17	19	5	184	39	63	0.64	440
0.7	99.3	612	0.37	98	16	18	5	164	36	63	0.57	403
0.6	99.4	561	0.33	87	16	17	4	144	34	63	0.50	366
0.5	99.5	509	0.30	76	16	15	4	124	31	63	0.43	329
0.4	99.6	457	0.26	66	15	14	4	105	28	63	0.36	292
0.3	99.7	405	0.23	55	15	13	3	85	25	63	0.29	256
0.2	99.8	354	0.19	44	14	11	3	65	23	63	0.22	219
0.1	99.9	302	0.16	33	14	10	2	45	20	63	0.16	182
0	100	250	0.12	22	14	9	2	25	17	63	0.09	145

ALTERNATE SEAWATER BOUNDARY FORMULATION

(EC $\geq$ 250 µS/cm)

Practical Salinity Scale at standard pressure & temperature (Schemel, 2000)

S_i = practical salinity of sample i;
R = conductivity ratio of sample i (EC_i/EC_s)
EC_i = EC of sample i;
EC_s = EC of seawater;
K = fitting constants; $\sum K$ = 35 psu

$$S_i = K_0 + K_1[R]^{0.5} + K_2[R] + K_3[R]^{1.5} + K_4[R]^2 + K_5[R]^{2.5}$$

ALTERNATE SEAWATER BOUNDARY FORMULATION

(EC ≥ 250 μS/cm) (CONT'D)

Two-Source Linear Mixing Equation

S_i = *practical salinity of sample i*
S_s = *practical salinity of seawater = 35 psu*
S_f = *practical salinity of freshwater*

C_i = *ion conc. of sample i*
C_s = *ion conc. of seawater*
C_f = *ion conc. of freshwater*

A_i = *proportionality constant*
$\sum C_i \approx S_i$; $\sum A_i \approx 1$; $\sum B_i \approx 0$

$$C_i = A_i S_i + B_i$$

$$A_i = \frac{C_s - C_f}{S_s - S_f}$$

$$B_i = C_f - [A_i S_f]$$

ALTERNATE SEAWATER BOUNDARY FORMULATION

(EC ≥ 250 μS/cm) (CONT'D)

Write $C_i = f(EC_i)$ through substitution

$$C_i = K_0' + K_1' EC_i^{0.5} + K_2' EC_i + K_3' EC_i^{1.5} + K_4' EC_i^{2} + K_5' EC_i^{2.5}$$

$$K_0' = [A_i K_0] + B_i \qquad K_3' = \frac{[A_i K_3]}{EC_s^{1.5}}$$

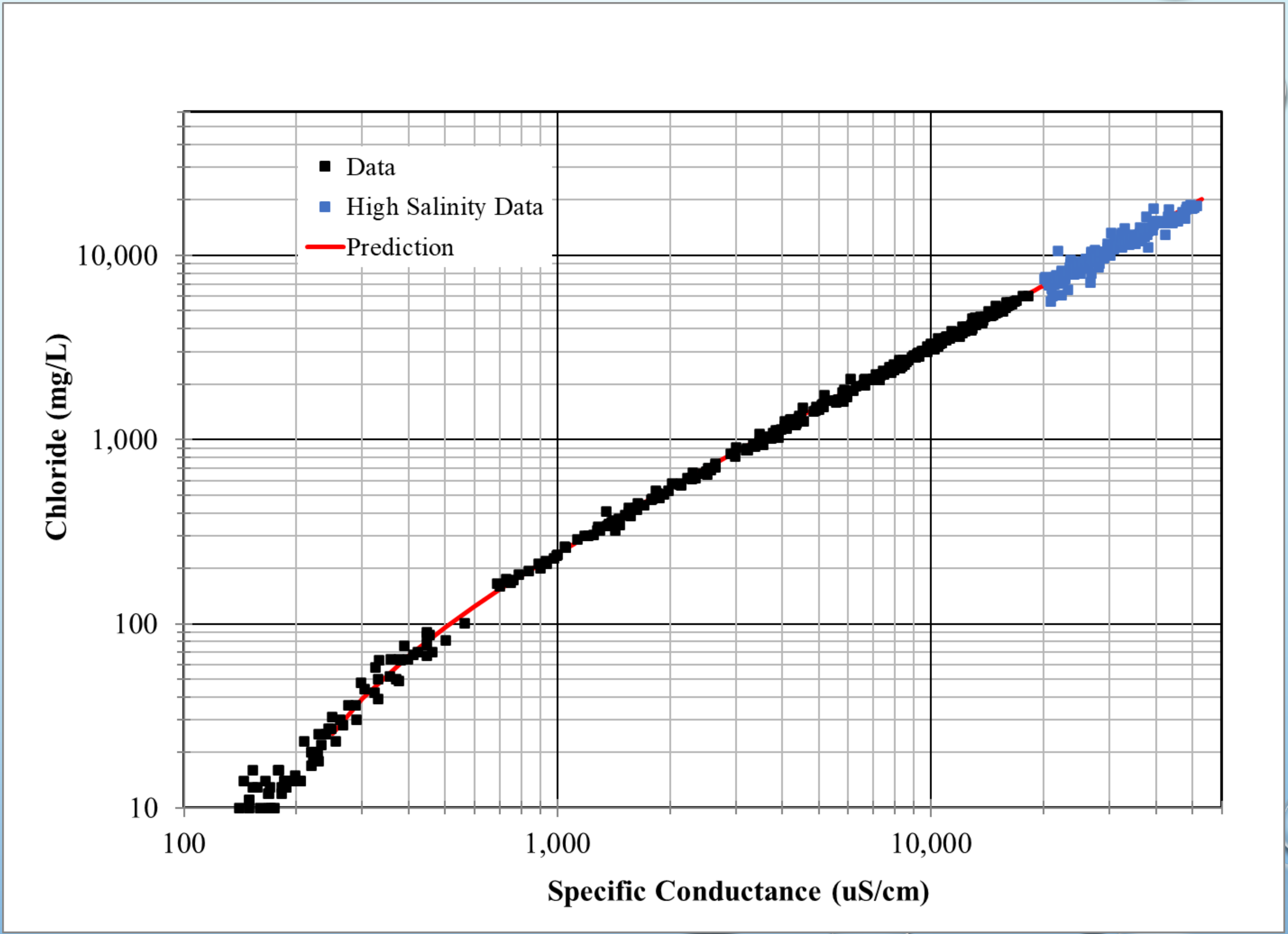
$$K_1' = \frac{[A_i K_1]}{EC_s^{0.5}} \qquad K_4' = \frac{[A_i K_4]}{EC_s^{2}}$$

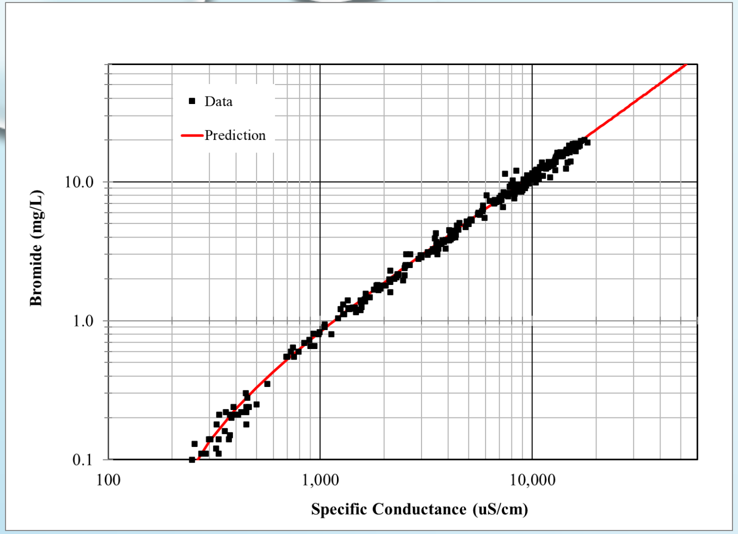
$$K_2' = \frac{[A_i K_2]}{EC_s} \qquad K_5' = \frac{[A_i K_5]}{EC_s^{2.5}}$$

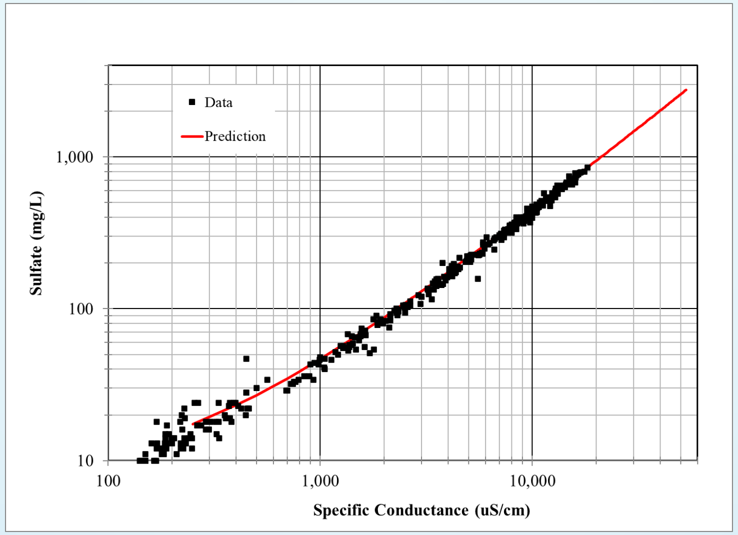
Valid for $EC_i \geq$ 250 µS/cm

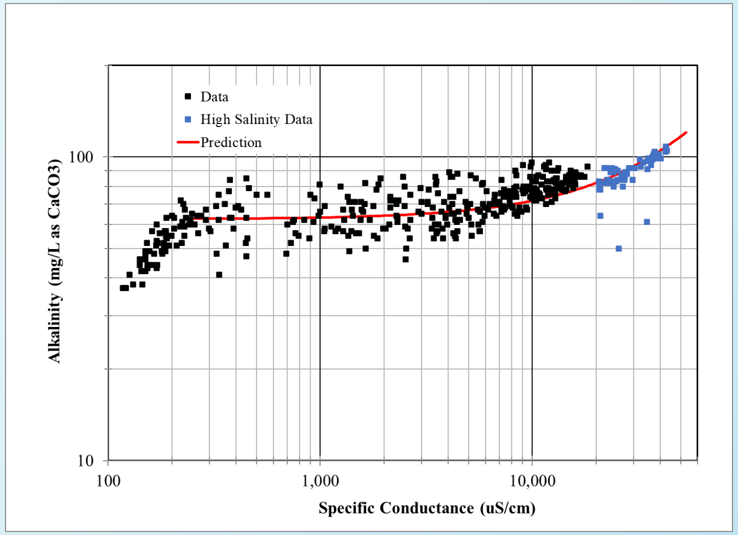
K'_0 = -3.77E+01
K'_1 = -5.41E-01
K'_2 = 2.76E-01
K'_3 = 6.59E-04
K'_4 = -1.36E-06
K'_5 = 2.38E-09

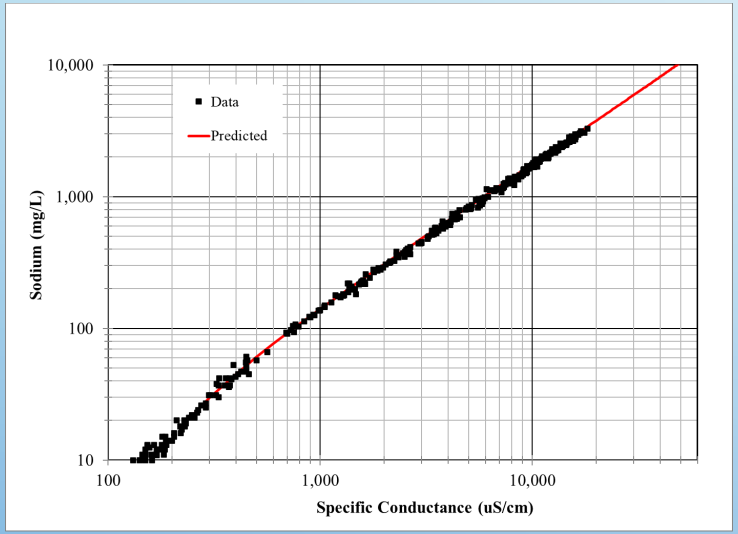
C_s = 19.35 ppt = 19.82 g/L
C_f = 0.025 ppt = 0.025 g/L
S_s = 35 psu
S_f = 0.123 psu
EC_s = 52 mS/cm

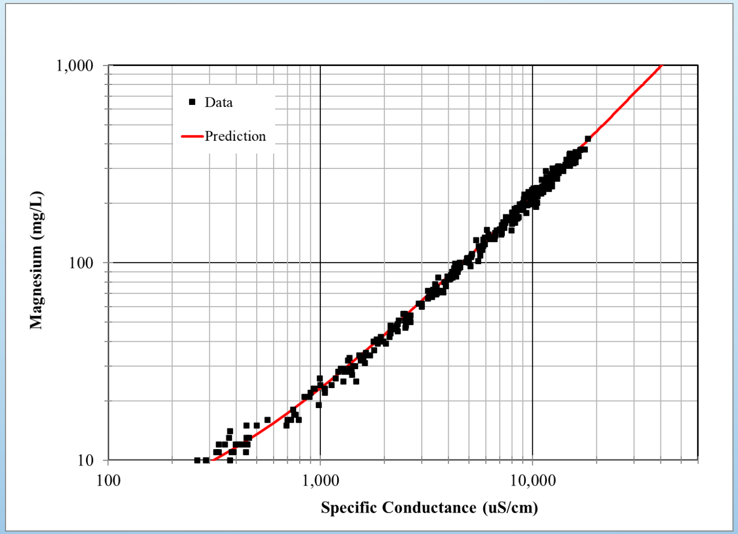


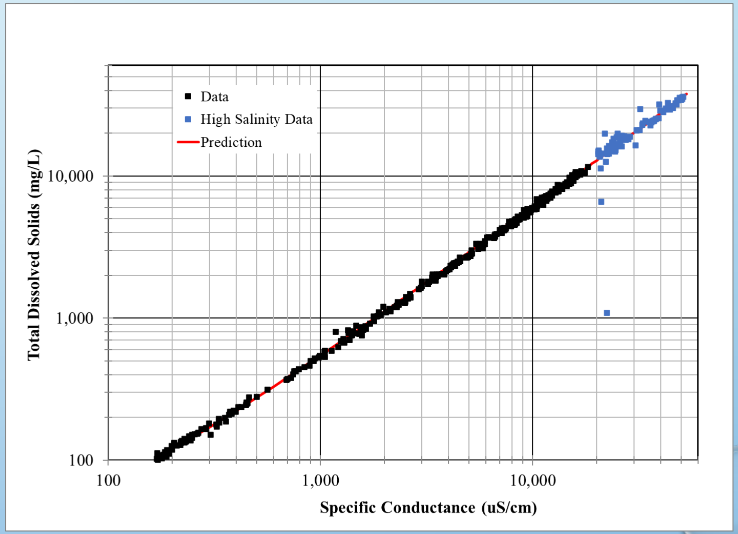

Data
Prediction
Bromide (mg/L)
10.0
1.0
0.1
100
1,000
10,000
Specific Conductance (uS/cm)


Data
Prediction
Sulfate (mg/L)
1,000
100
10
100
1,000
10,000
Specific Conductance (uS/cm)


Data
High Salinity Data
Prediction
Alkalinity (mg/L as CaCO3)
100
10
100
1,000
10,000
Specific Conductance (uS/cm)


Data
Predicted
Sodium (mg/L)
10,000
1,000
100
10
100
1,000
10,000
Specific Conductance (uS/cm)


Data
Prediction
Magnesium (mg/L)
1,000
100
10
100
1,000
10,000
Specific Conductance (uS/cm)


Data
High Salinity Data
Prediction
Total Dissolved Solids (mg/L)
10,000
1,000
100
100
1,000
10,000
Specific Conductance (uS/cm)