Application of the Practical Salinity Scale to the Waters of San Francisco Estuary

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PSS-78 Equation [1,2]

transforms EC measurements into salinity estimates assuming T=25°C and atmospheric pressure

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

where:

S = practical salinity (2 < S < 42) and seawater ≈ 35

R = conductivity ratio (sample EC ÷ seawater EC)

K_i = fitting constants, $\sum K_i = 35$ (for uncorrected scale)

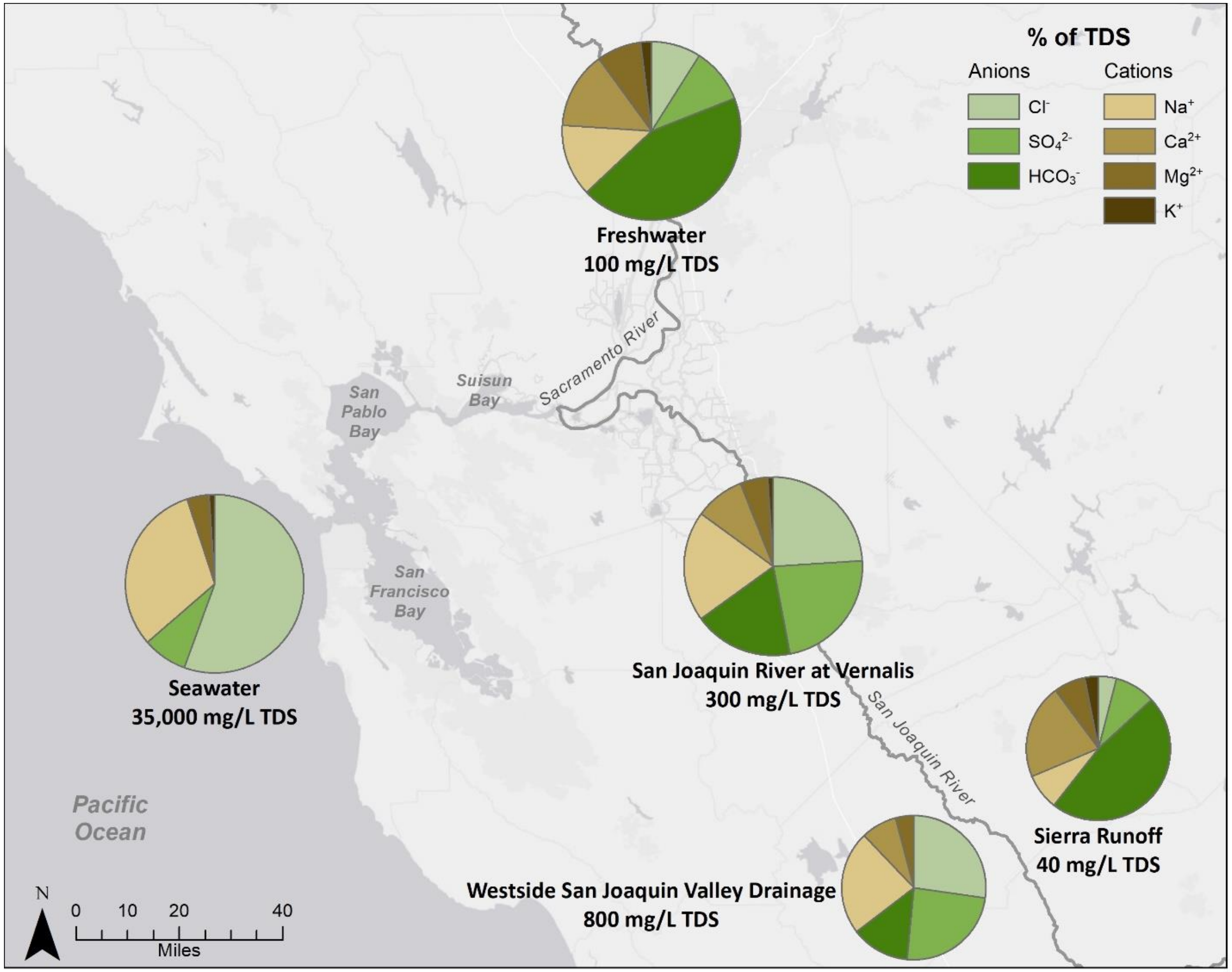
- S, a dimensionless term, is linearly related to the mixing ratio of freshwater and seawater (unlike EC).
- We assume seawater EC = 52.3 mS/cm

PSS-78 Equation (cont'd)

- Widely used as an EC-based measure of salinity in oceans and estuaries
- Equation "…should be used with caution in waters that have a chemical composition different from standard seawater" (UNESCO, 1981)
- Hill et al. (1986) presents a standard correction to extend the applicability of PSS-78 below a value of 2.
  - Based on dilutions of standard seawater with deionized water
  - Strictly applicable to waters that have the same proportional ionic makeup as seawater

Mineralogy of Primary Water Sources

source compositions different from seawater



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Findings

- PSS-78 is valid in waters dominated by seawater intrusion as well as in waters dominated by the Sacramento River
- PSS-78 is valid well below the recommended lower-bound value of 2.0
- PSS-78 under-estimates salinity in waters dominated by the San Joaquin River or agricultural drainage

Number of EC and Ion Data Points

by Monitoring Location

EC/Ion	Western Delta & Downstream Bays				Sacramento River			San Joaquin River (SJR)				Agricultural Drainage
	Sac. R. @ Mallard	Sac. R. @ Chipps	SJR @ Jersey	∑	Sac. R. @ Hood	Sac. R. @ Greene's	∑	SJR near Vernalis	SJR @ Maze	SJR near Vernalis	∑	Various Locations
	1986 - 2019	2019 - 2019	1990 - 1995		1982 - 2020	1983 - 1998		1982 - 2005	1988 - 1994	2005 - 2020		1990 - 2001
EC	382	3	20	405	445	156	601	341	62	140	543	781
Br^-	335	3	20	358	297	80	377	280	38	140	458	781
Cl^-	381	3	20	404	444	154	598	339	62	140	541	781
SO_4^{2-}	377	3	20	400	444	151	595	340	62	140	542	781
Alkalinity	376	3	20	399	438	153	591	340	61	140	541	781
Na^+	378	3	20	401	442	152	594	338	59	140	537	781
Ca^{2+}	379	3	20	402	441	155	596	338	56	140	534	781
Mg^{2+}	374	3	20	397	442	154	596	338	60	140	538	781
K^+	377	3	20	400	436	155	591	330	61	139	530	781

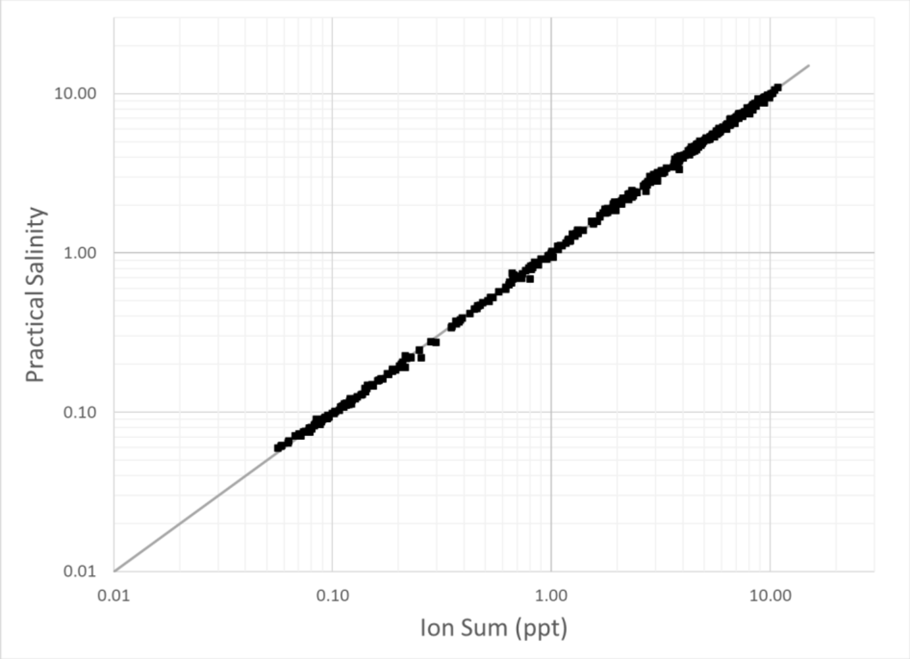
Methods

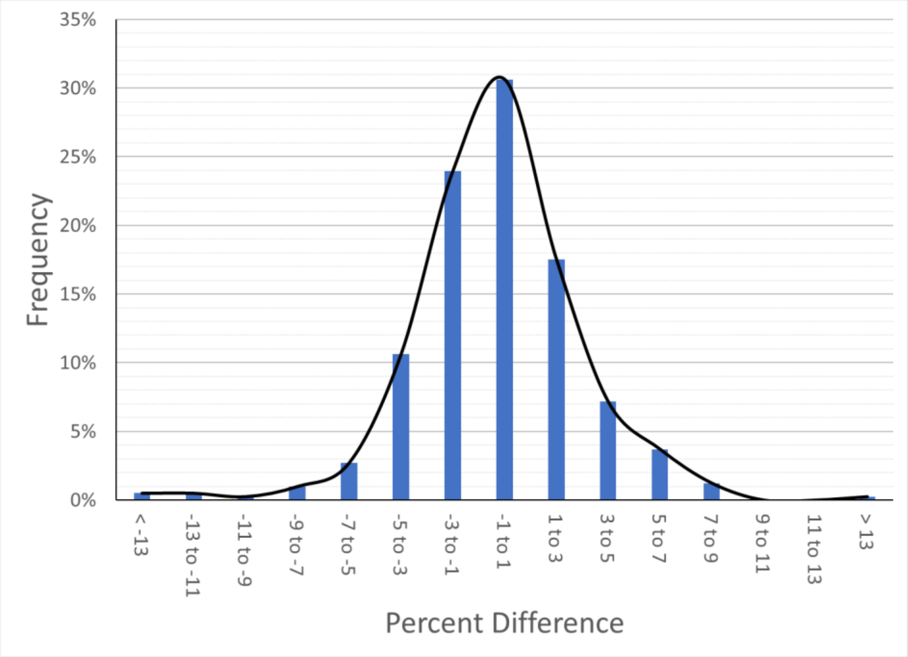
Calculation of Mass-Based Salinity (Ion Concentration Sum)

- Salinity calculated as the sum of 8 major ions
  - Anions: bromide (Br^-), chloride (Cl^-), sulfate (SO_4^{2-}) and alkalinity
  - Cations: sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+).
  - Missing ion data filled using EC-based regression equations
  - Samples reasonably charge-balanced
  - Alkalinity converted to equivalent bicarbonate (HCO_3^-)
- Ion sum converted from mg/L to ppt by accounting for sample density
- Ion sum compared with EC-based salinity estimates to evaluate fidelity of PSS-78 to measured data
  - Ion Sum (units of ppt) ≈ Practical Salinity

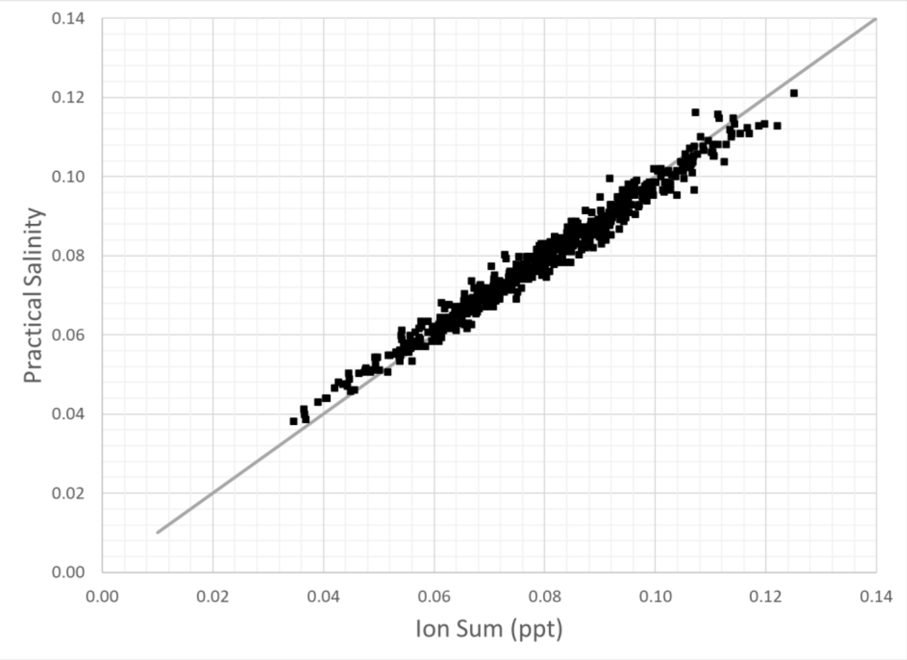
Fidelity of Ion Concentration Sum to PSS-78:

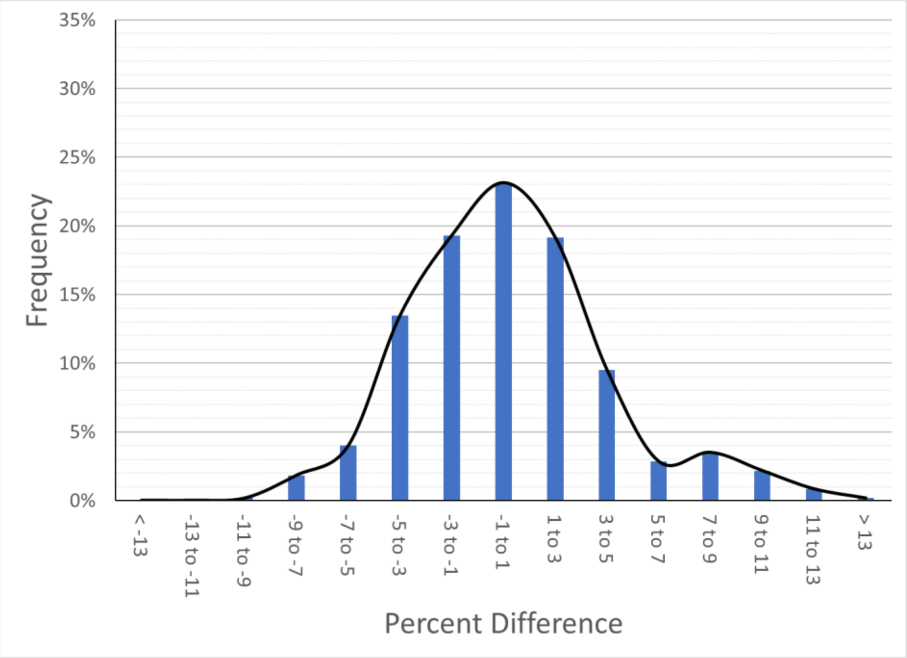
Western Delta & Downstream Bay Data





Fidelity of Ion Concentration Sum to PSS-78:
Sacramento River Data





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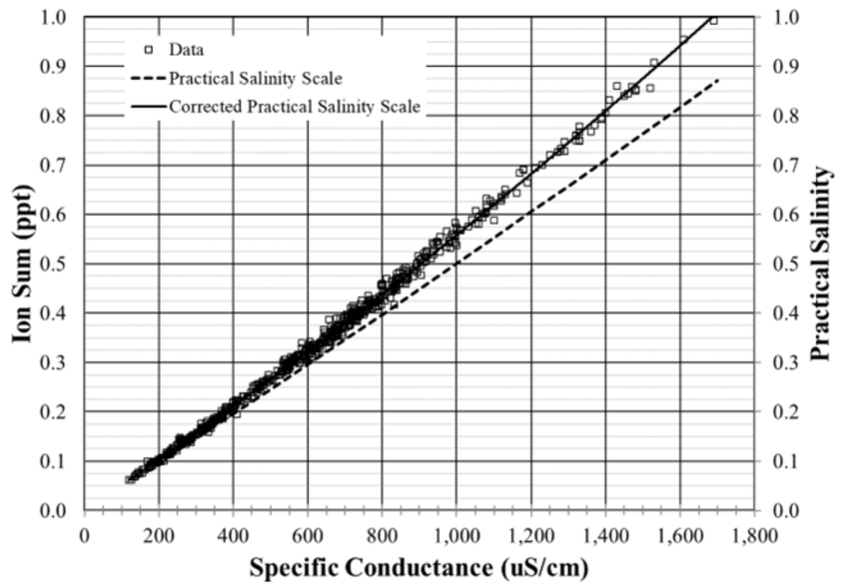
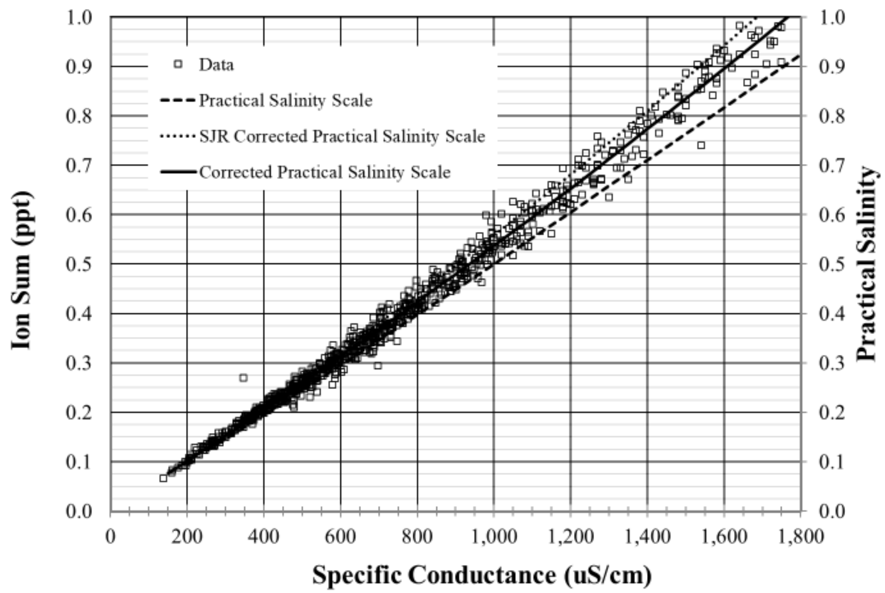
Ion Concentration Sum vs. EC

for San Joaquin River (left) & Agricultural Drainage (right) Data

PSS-78 under-estimates salinity





Corrected Relationships Between Ion Sum & EC San Joaquin River & Agricultural Drainage

$$S = \omega_1 * EC + \omega_2 * EC^2$$

where:

S = corrected practical salinity

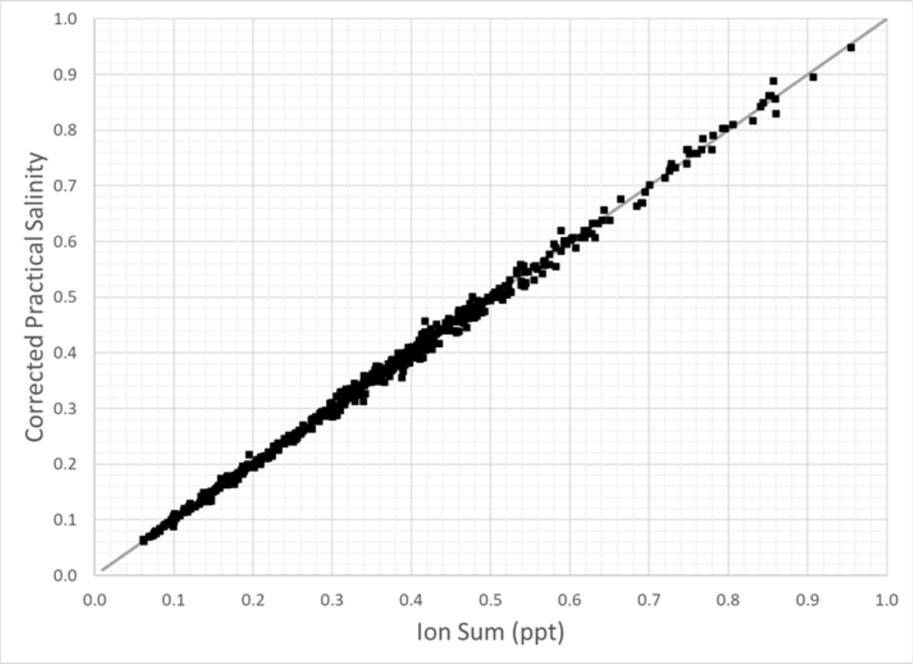
ω_i = fitting constants

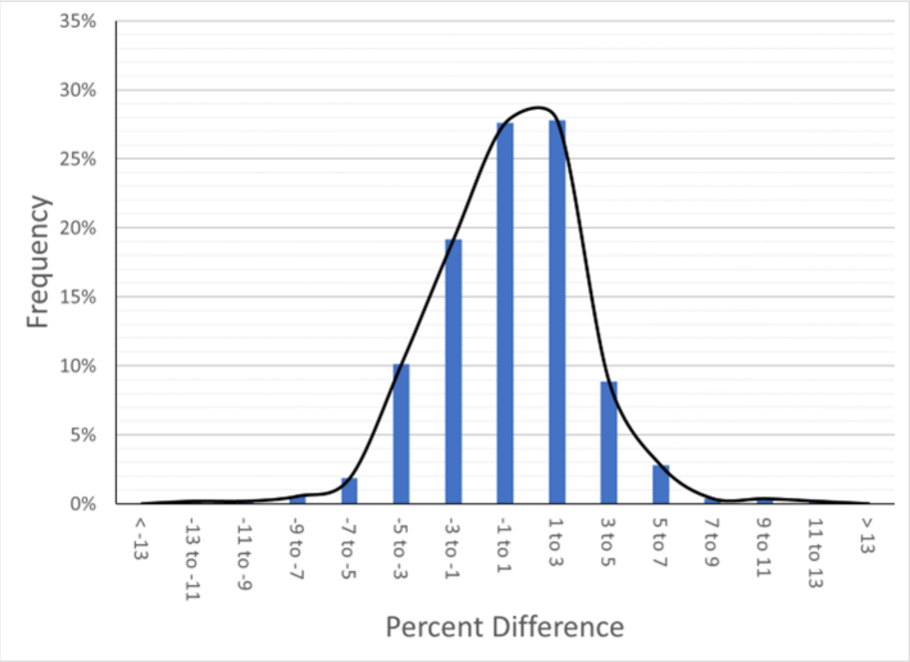
Approximate applicable range is 130 µS/cm – 1700 µS/cm

Constant	San Joaquin River	Agricultural Drainage
ω_1	5.08E-4	4.99E-4
ω_2	5.07E-8	3.81E-8

Fidelity of Ion Concentration Sum to Corrected PSS-78:

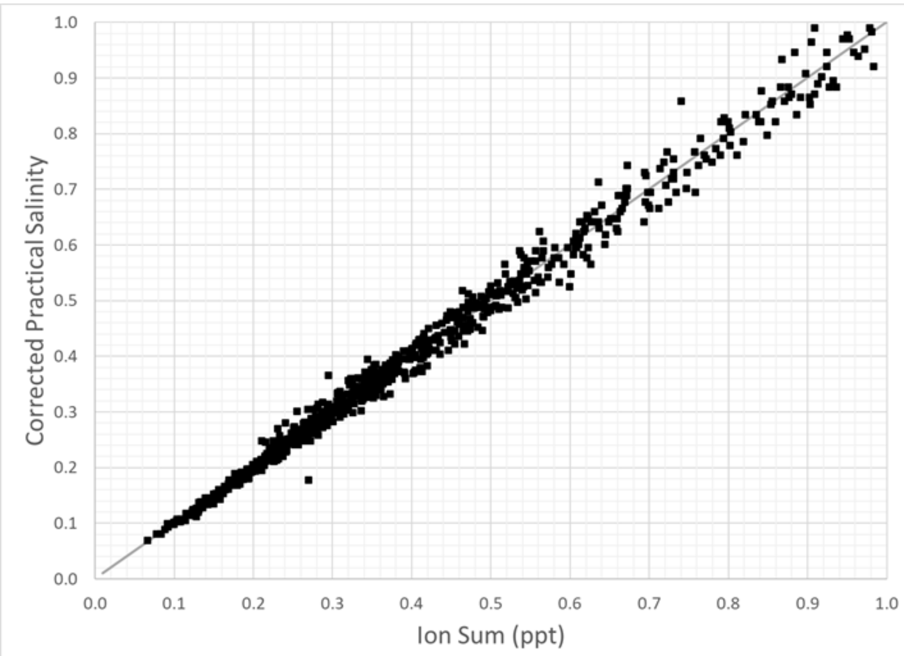
San Joaquin River Data

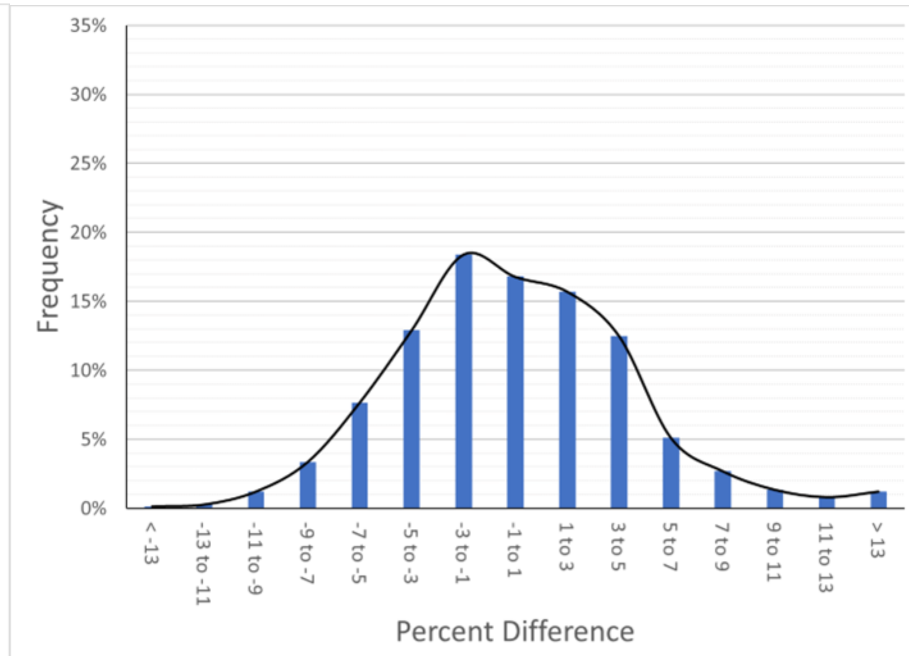




Fidelity of Ion Concentration Sum to Corrected PSS-78:

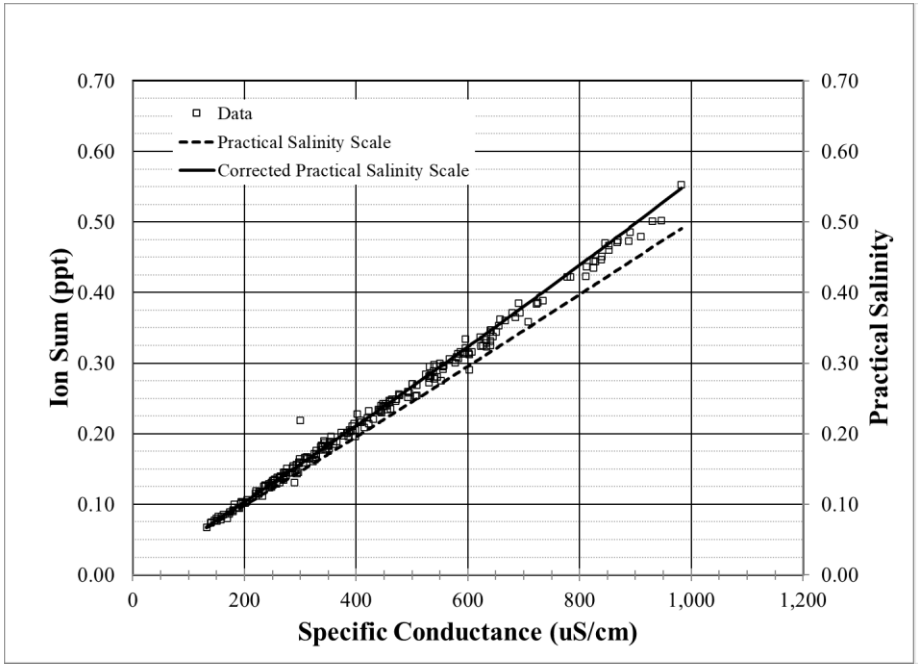
Agricultural Drainage Data

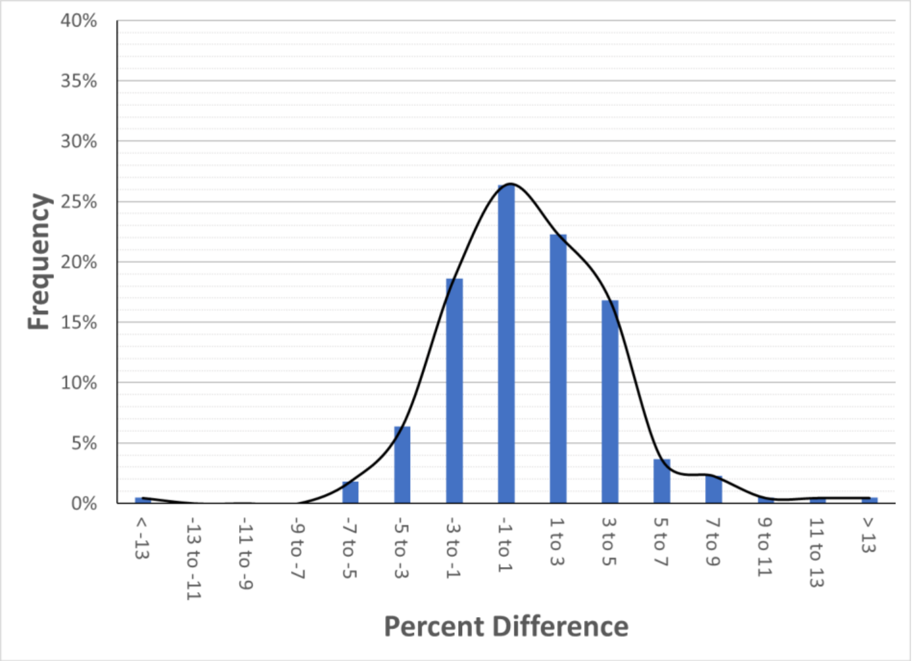




Fidelity of Ion Concentration Sum to Corrected PSS-78

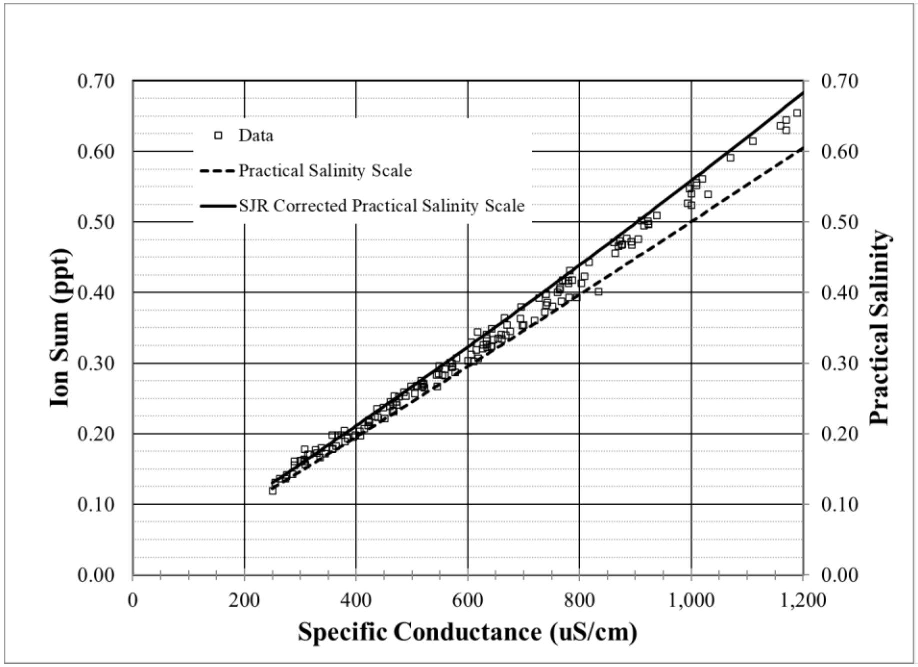
Jones Pumping Plant (SJR Dominant)

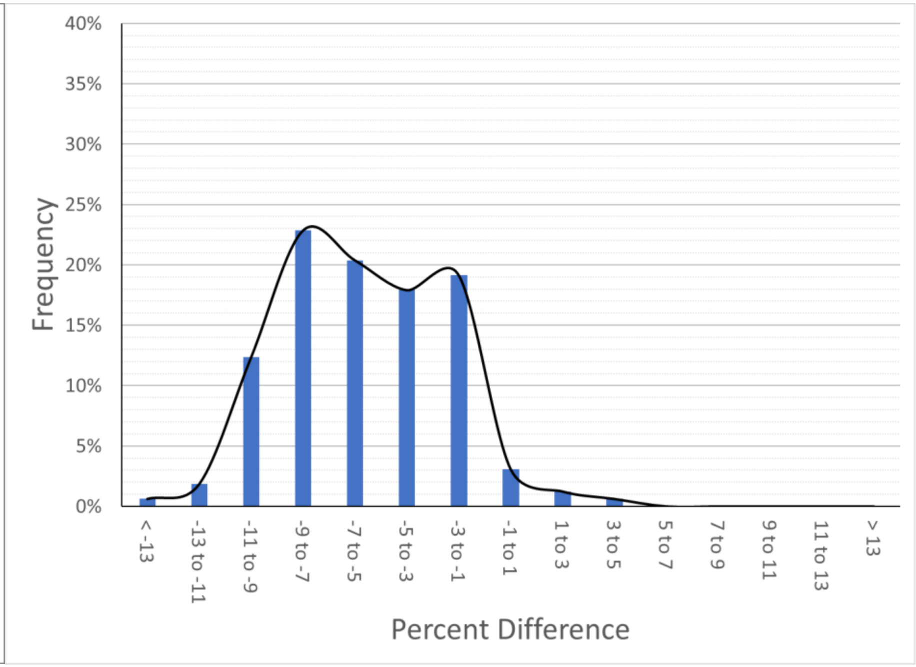




Fidelity of Ion Concentration Sum to PSS-78

Jones Pumping Plant (Seawater Dominant)





Inverse PSS-78 Equation

$$R = K'_0 + K'_1 * I^{0.5} + K'_2 * I + K'_3 * I^{1.5} + K'_4 * I^2 + K'_5 * I^{2.5}$$

where:

R = conductivity ratio (sample EC ÷ seawater EC)

I = practical salinity ratio (sample salinity ÷ seawater salinity)

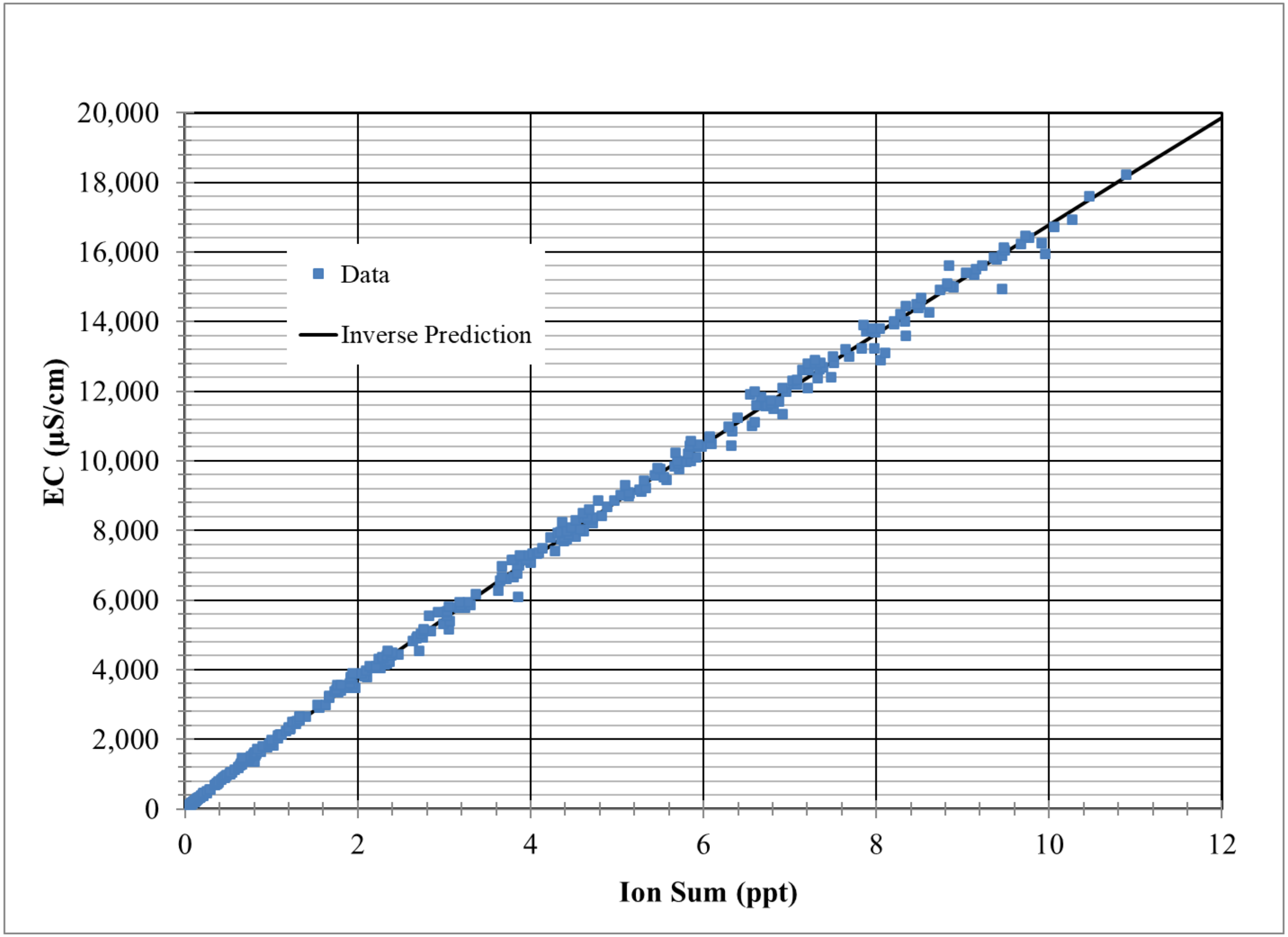
K'_i = fitting constants, $\sum K'_i$ = 1.0 (for uncorrected scale)

Inverse PSS-78 Model Constants Seawater Relationship

	Inverse PSS-78 Constants	Standard Errors
K_0'	-0.0008	1.81E-5
K_1'	0.0190	3.29E-4
K_2'	1.2893	1.79E-3
K_3'	-0.4932	4.15E-3
K_4'	0.2706	4.27E-3
K_5'	-0.0850	1.62E-3

Inverse Model

Compared with Ion Concentration Sum Data



Summary & Conclusions

- PSS-78 is well-aligned with mass-based measurements of salinity in the western Delta and downstream bays as well as the Sacramento River.
- PSS-78 underestimates salinity in the San Joaquin River at Vernalis as well as in-Delta agricultural return flows. We propose modified relationships between ion concentration sum and EC to address these deviations.
- Lewis (1980) cautions against using PSS-78 below practical salinity values of 2. However, we found the PSS-78 relationships (both uncorrected and corrected) to be valid over this range of salinity.

Summary & Conclusions (cont'd)

- Relationships between measured ion concentration sum and EC in the interior Delta are bounded by the PSS-78 and corrected San Joaquin River relationships.
- Inverse relationships were developed to estimate EC as a function of practical salinity.
- The relationship between PSS-78 and EC is not universal within the study area and assuming a singular relationship may introduce considerable error in monitoring and modeling applications.
- Given dynamic & complex source mixing in the interior Delta, using PSS-78 introduces significant challenges for interpreting transport model results.

TETRA TECH

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