Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

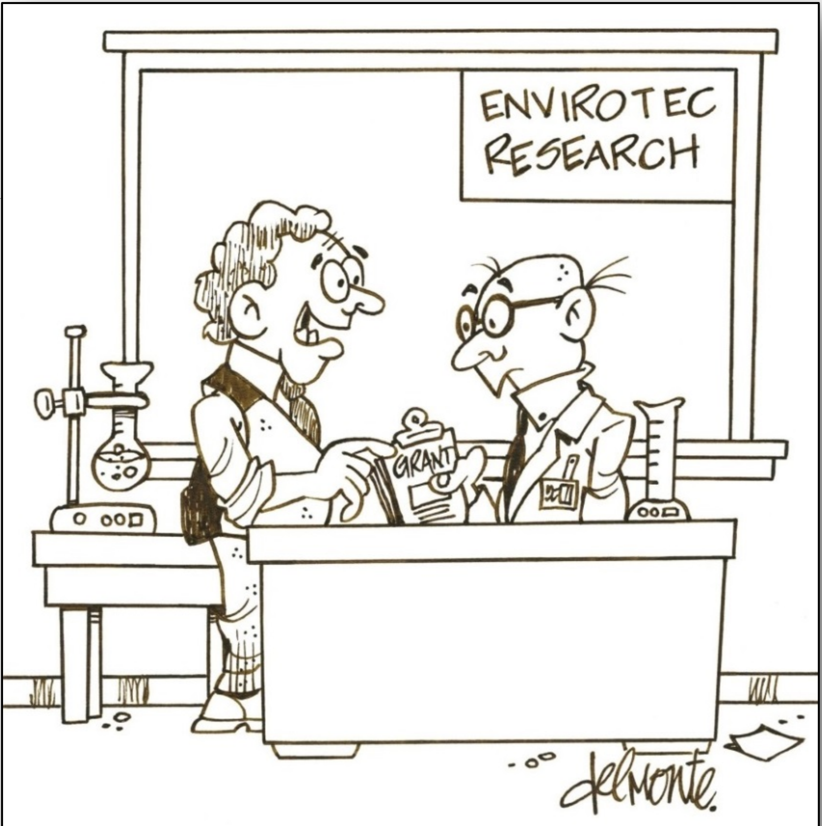
Practical Closure Approaches for Salinity Impacted Wellsites

EnviroTech - Virtual

June 3, 2021

Outline

- Linear Regression Analysis
  - The Dataset
  - The Regression
  - Variability of the Regression
  - Regression Application
- Approaches for Site Closure
  - Background Soil Quality
  - Quantifying EC Exceedances
  - Background TDS



"Never mind that it's silly, we've got a four year grant to find out what Sodium Chloride is."

Linear Regression Analysis

Linear Regression Analysis

- *Diagnosis and Improvement of Saline & Alkali Soils* (Richards 1954)

- Strong correlation between solute concentrations & EC
  - *meq/L*

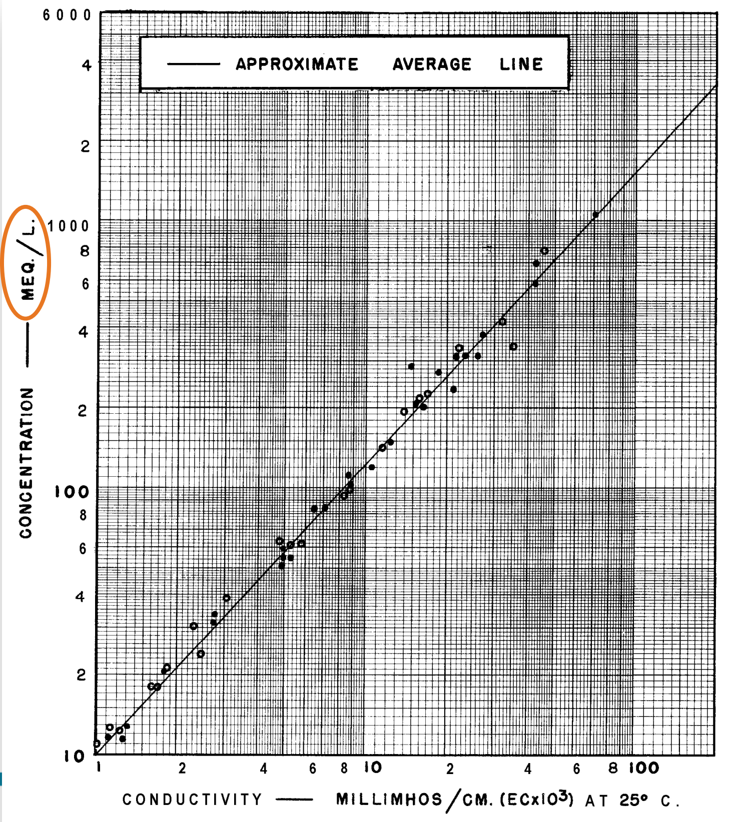
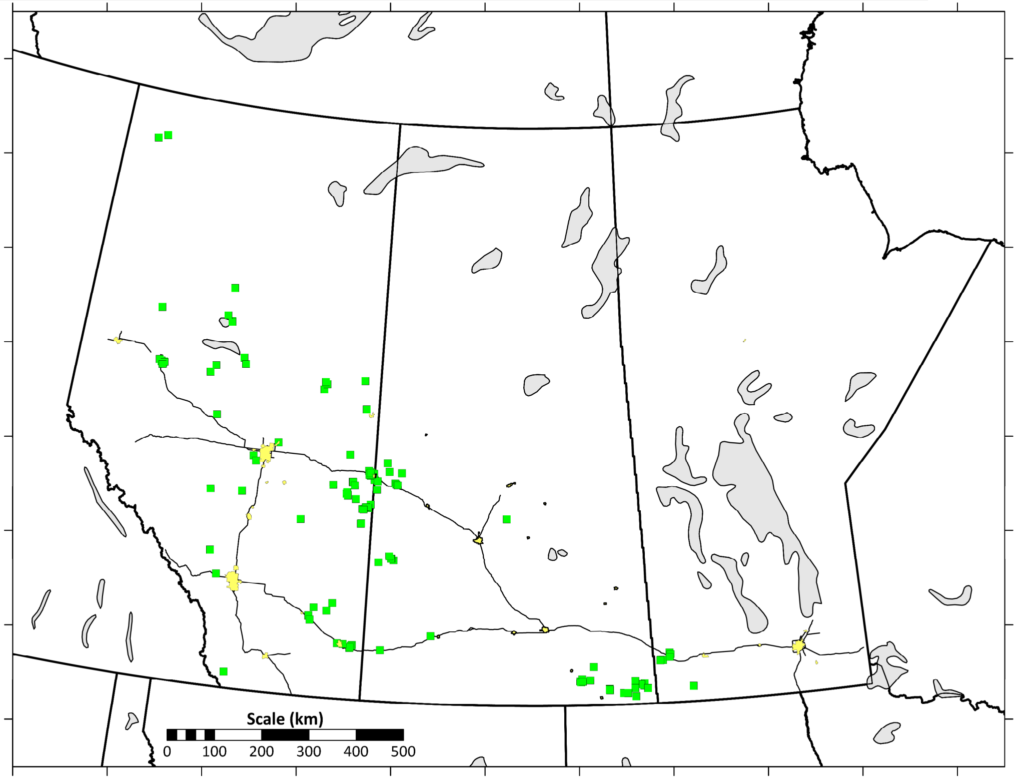


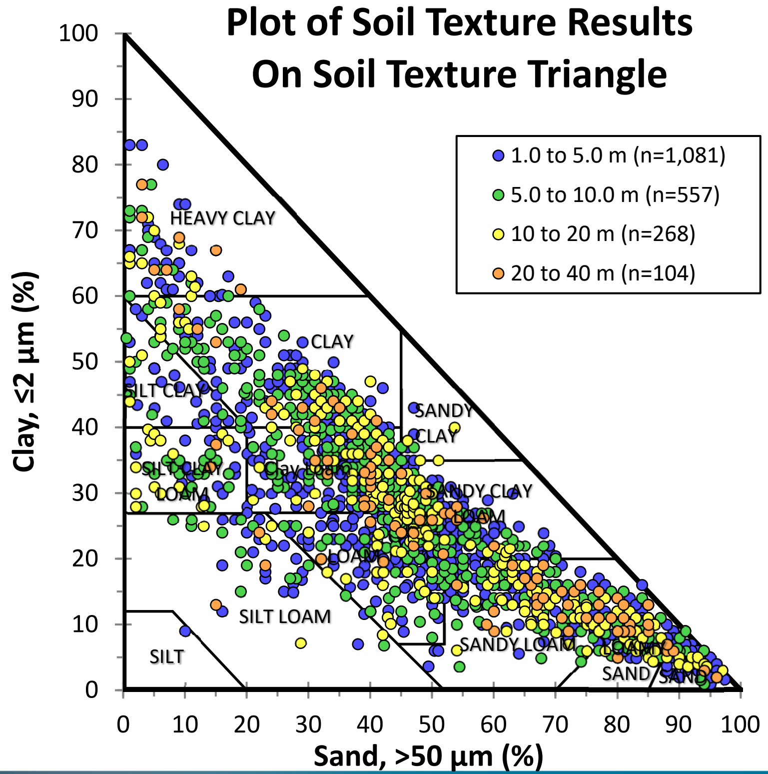
FIGURE 4.-Concentration of saturation extracts of soils in milliequivalents per liter as related to electrical conductivity.

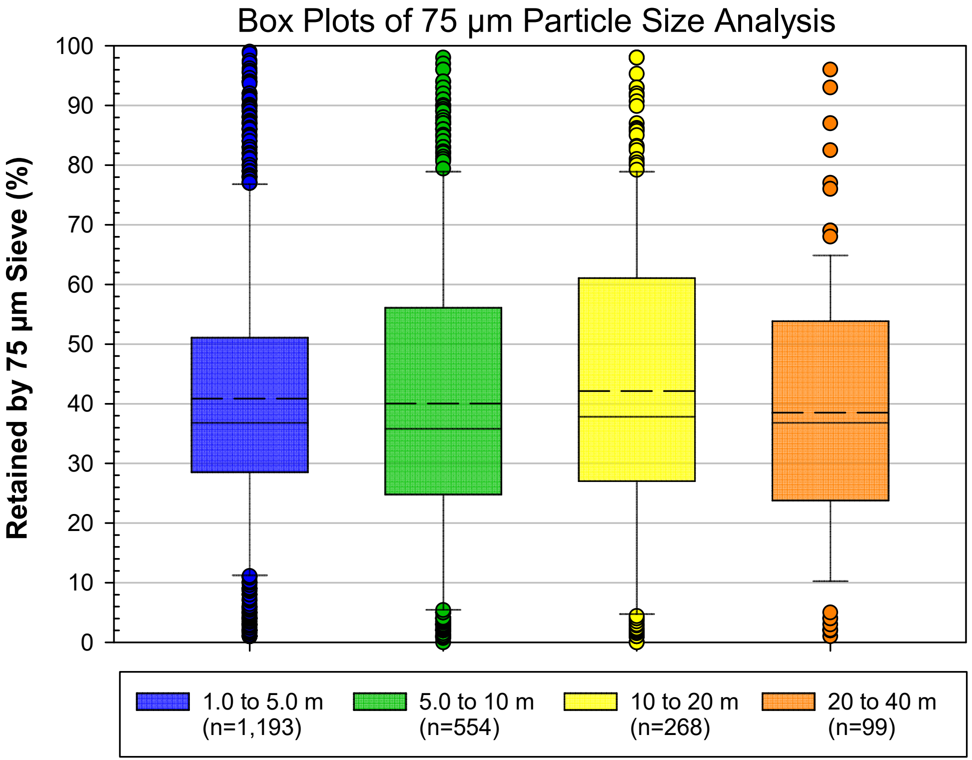
The Dataset

- 126 unique sites
- 2014 to 2019
- 20,510 soil samples
  - 163 samples/site
- Saturated paste
- Sample depths between 1.0 and 40 m
- Mineral soil

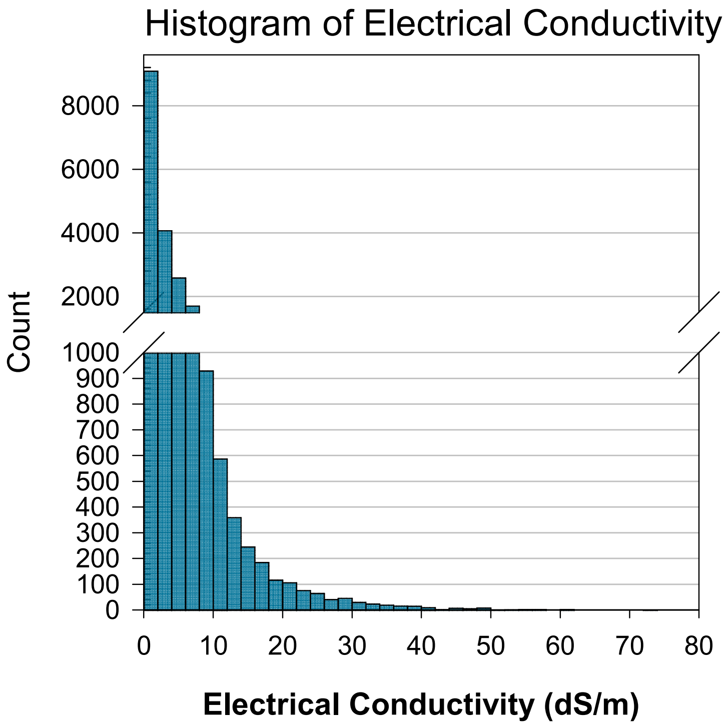


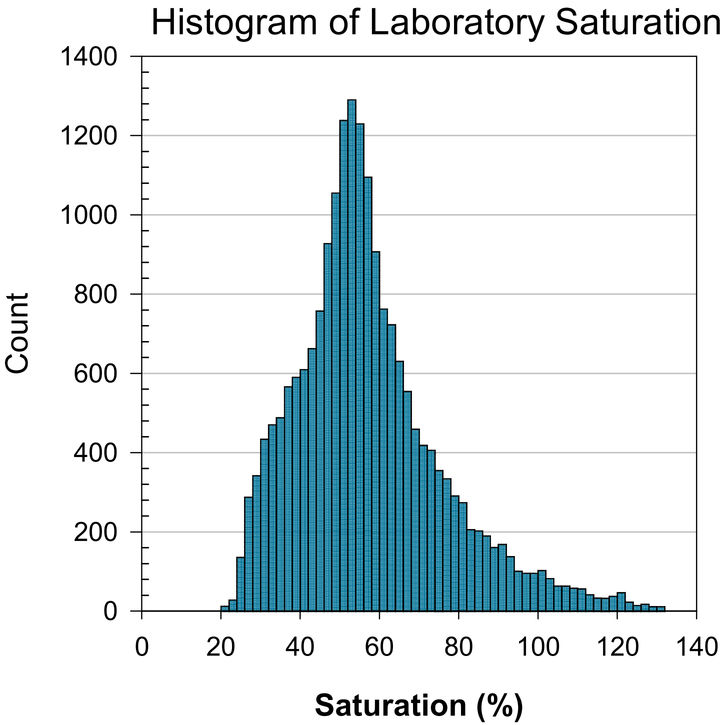
Soil Textures



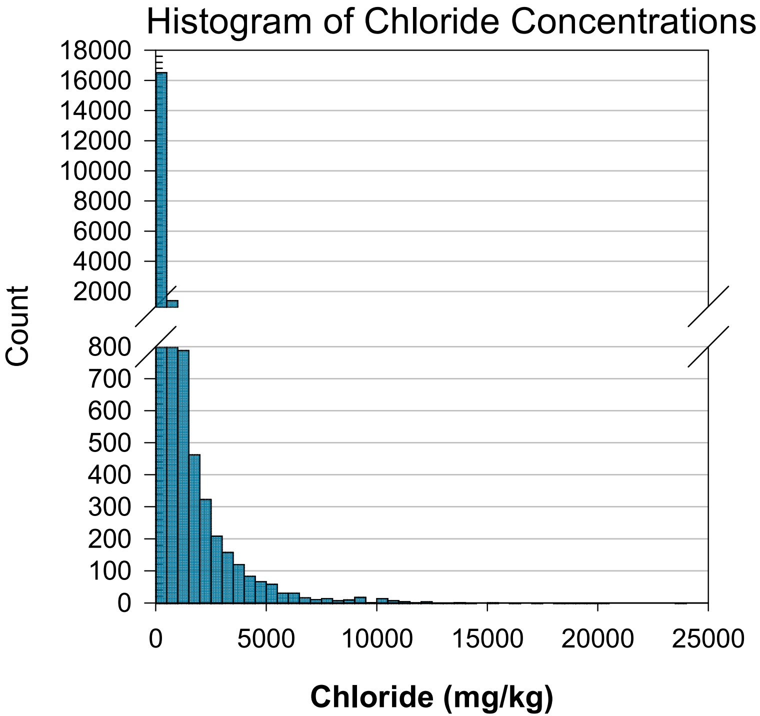


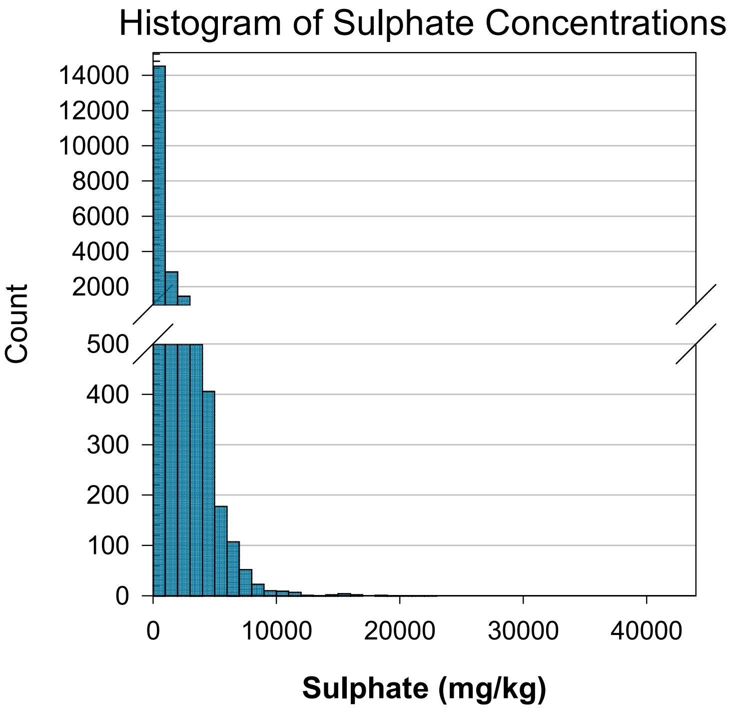
Dataset Chemistry





Dataset Chemistry (con't)

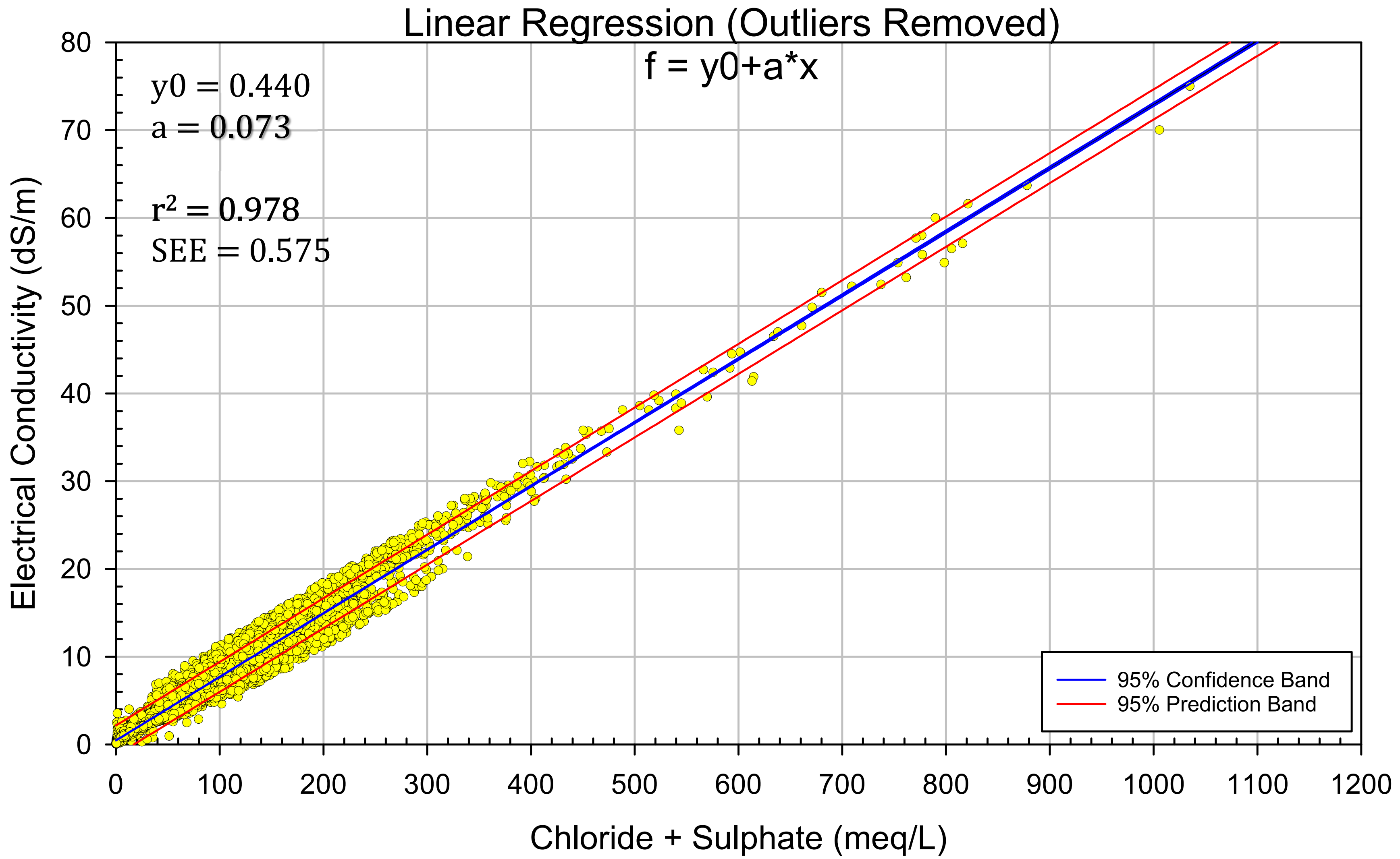




Outlier Analysis

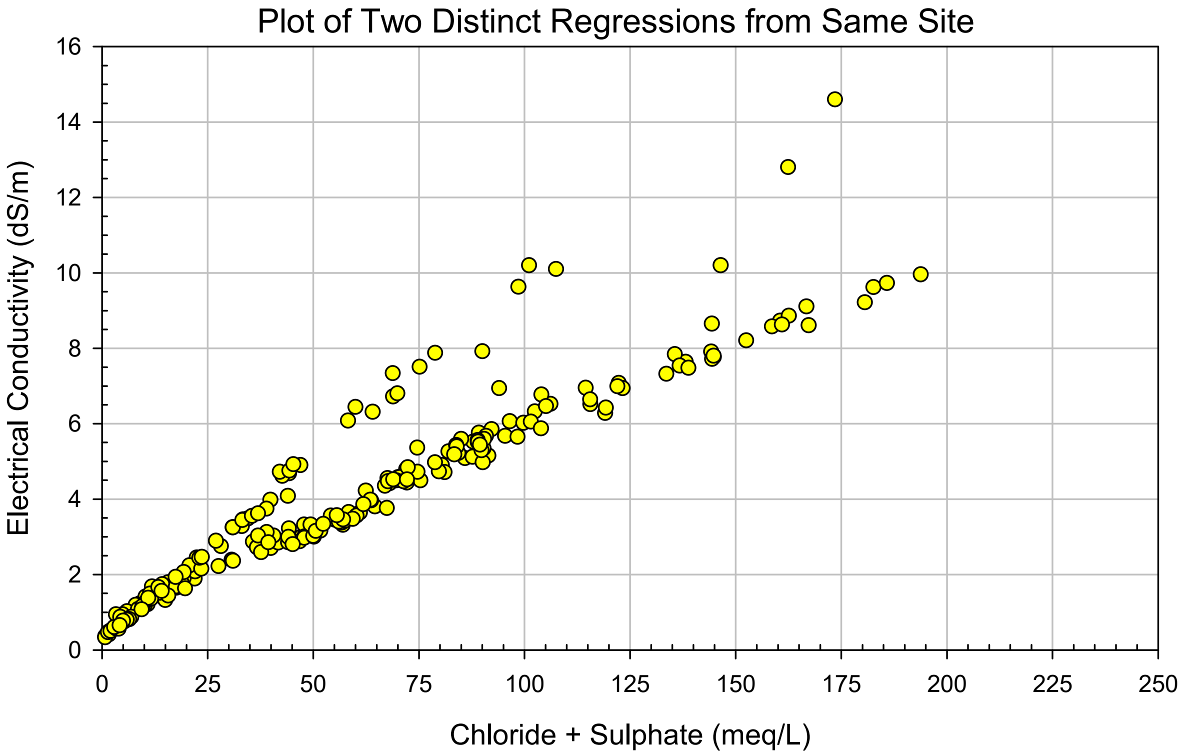
- Removal of standard residuals >2, <-2
- Two iterations

Parameter	Original Data	Outlier 1	Outlier 2
n	20,510	19,937	18,486
r^2	0.916	0.965	0.978
SEE	1.855	0.872	0.575
slope	0.071	0.072	0.073
y-intercept	0.603	0.457	0.440



Linear Regression (Outliers Removed)
f = y0+a*x
y0 = 0.440
a = 0.073
r² = 0.978
SEE = 0.575
Electrical Conductivity (dS/m)
Chloride + Sulphate (meq/L)
95% Confidence Band
95% Prediction Band
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
1100
1200

Site-Specific Regression Variability



Slope Variability

- Slope variability correlates to sulphate versus chloride-dominant soils
  - $Cl^{-1} = 35.453/1$
  - $SO_4^{-2} = 96.06/2\ \ (48.03)$

Site-Specific Regression Variability

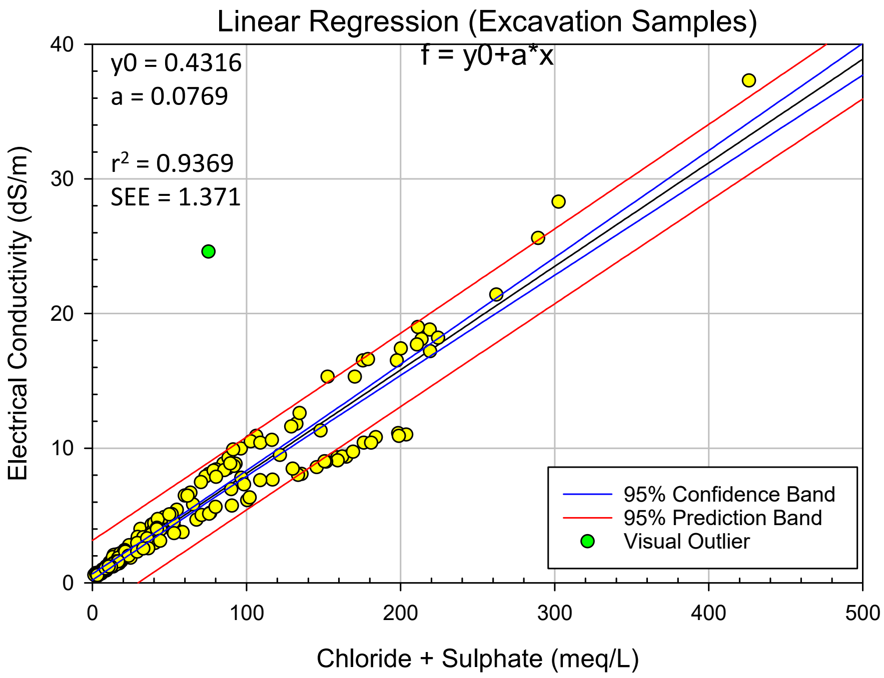
Descriptive Statistics of 126 Linear Regressions

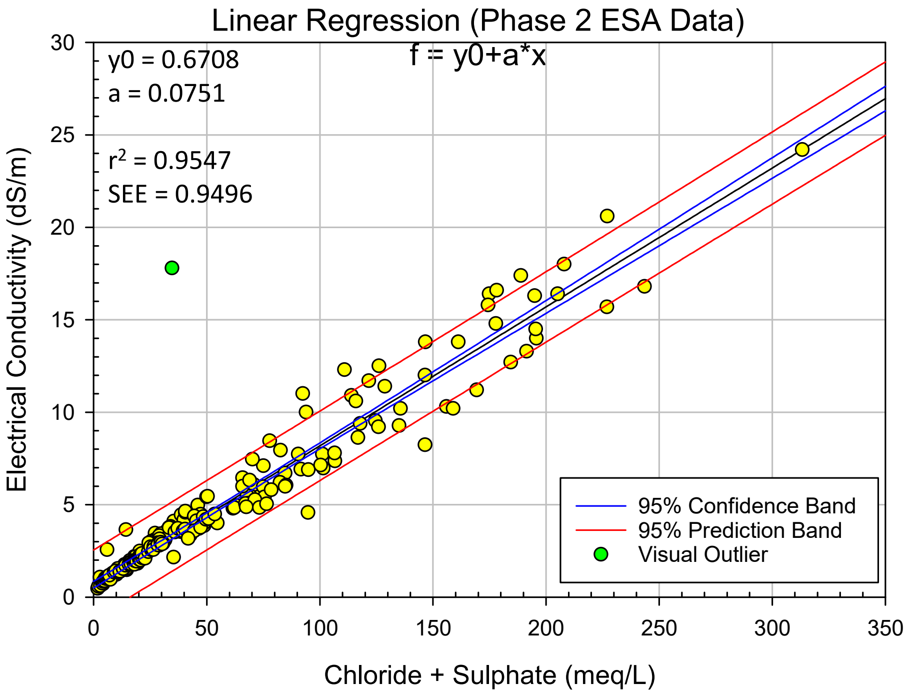
Parameter	Slope (a)	Y-Intercept (y0)	Regression Coefficient (r^2)
Minimum	0.0452	-1.018	0.801
Maximum	1.103	2.202	0.998
Mean	0.0953	0.513	0.948
Median	0.073	0.495	0.958
Standard Error	0.0129	0.0381	0.0039

***** No outlier analyses***

Regression Application

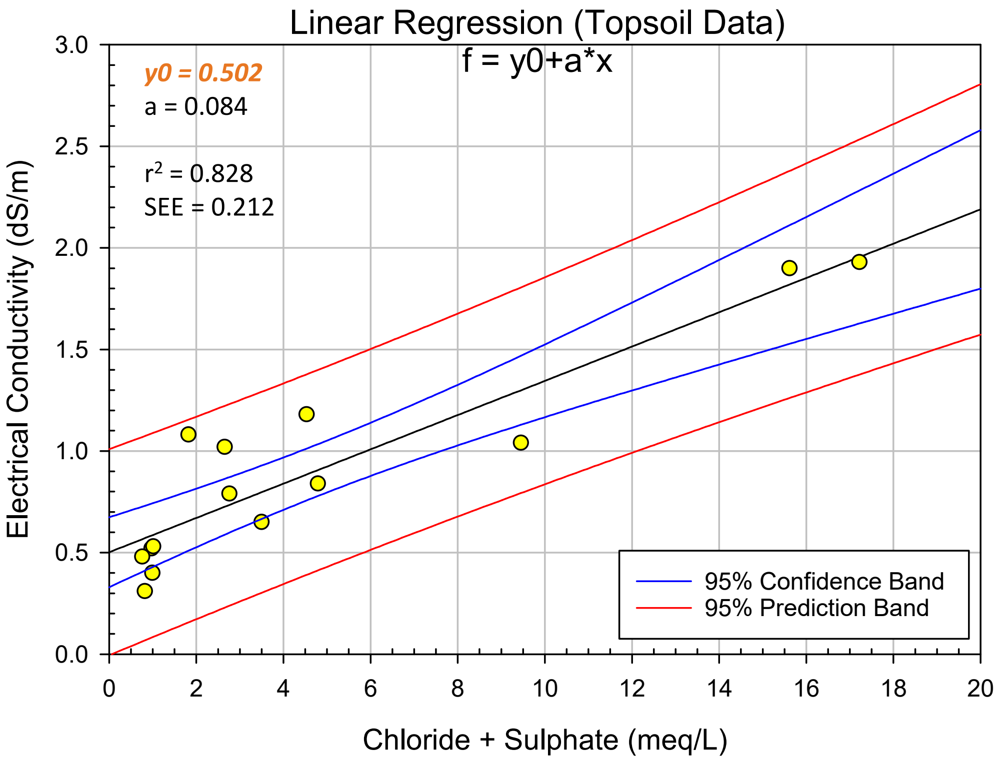
Visual Outliers: Site-Specific Data





Identification of other Anions

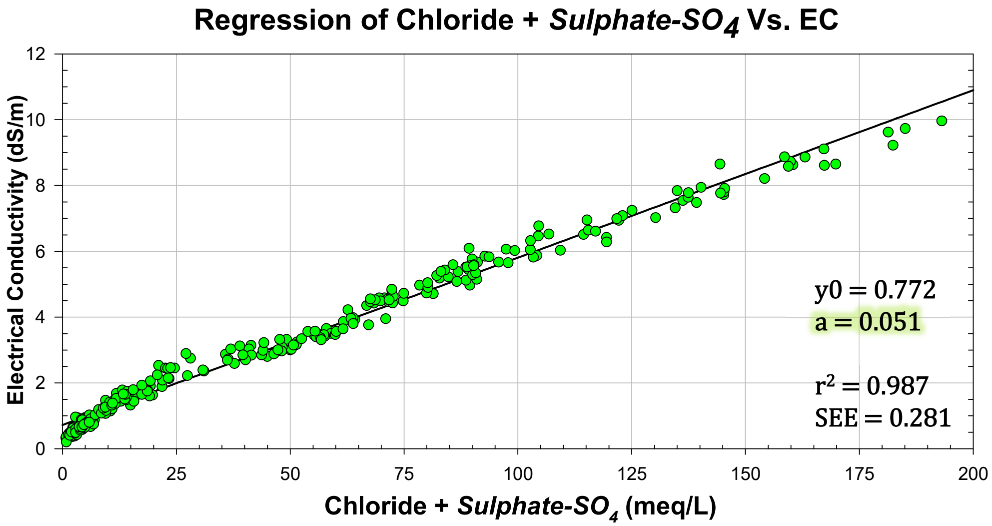
- Topsoil samples
- Adverse vegetation effects
- Relatively high y-intercept with relatively low EC values
- Another anion?
  - Nitrate

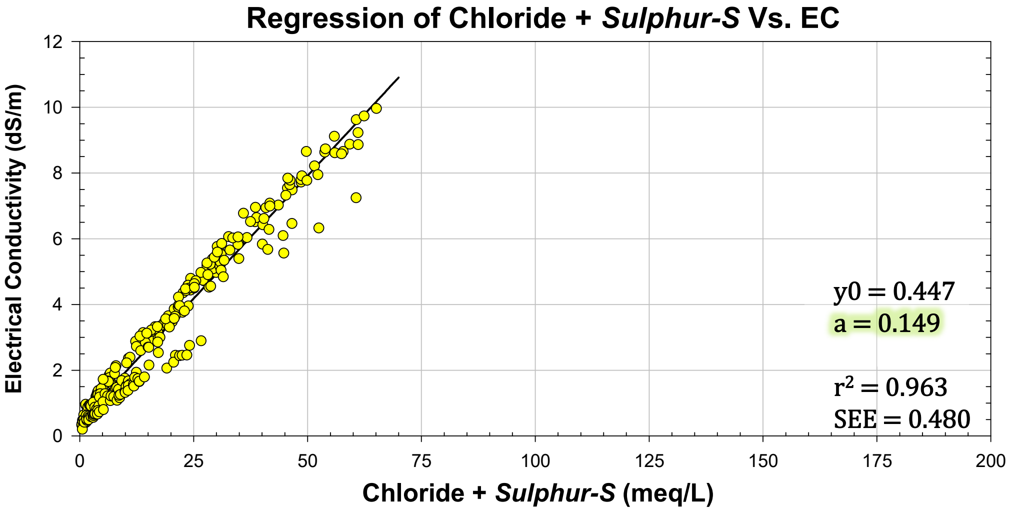


Understanding Sulphate – Sulphur

- Historical variability in how labs report soil sulphate concentrations
  - Sulphate (SO_4)
  - Sulphate (SO_4-S)
  - Sulphur as Sulphate
- Some historical concentrations are as the molecular weight of sulphate and some are sulphur…

Sulphate – Sulphur (con't)





$$SO_4 = S \times \frac{96.06\ (sulphate)}{32.06\ (sulphur)}$$

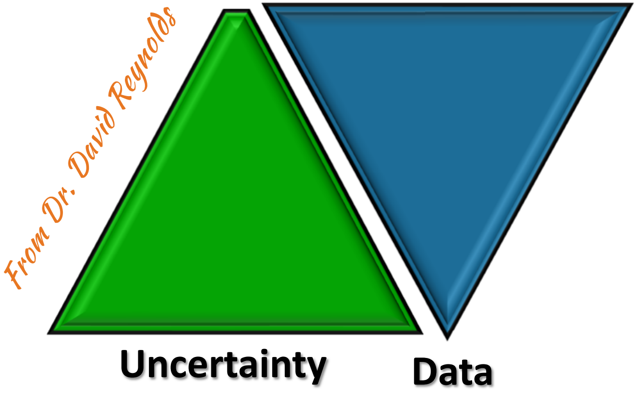
Application of the Linear Regression

- Quick, no special software required
- Insight into data
- *QA/QC*
  - outliers
  - other anions
  - sulphate

Approaches for Site Closure

Background Soil Quality

- <u>Sufficient dataset</u> *is critically important* for determining Tier 1 guidelines
- *DUCI model*



Parameter		Rating Categories			
		Good	Fair	Poor	Unsuitable
Topsoil[c]	EC dS/m (salinity)	<2[a]	2 to 4	4 to 8	>8
	SAR (sodicity)	<4	4 to 8	8 to 12	>12[b]
Subsoil[c]	EC dS/m (salinity)	<3	3 to 5	5 to 10	>10
	SAR (sodicity)	<4	4 to 8	8 to 12	>12

a Some plants are sensitive to salts at EC < 2 dS/m (e.g., flax, clover, beans, wheat, peas, some garden crops).

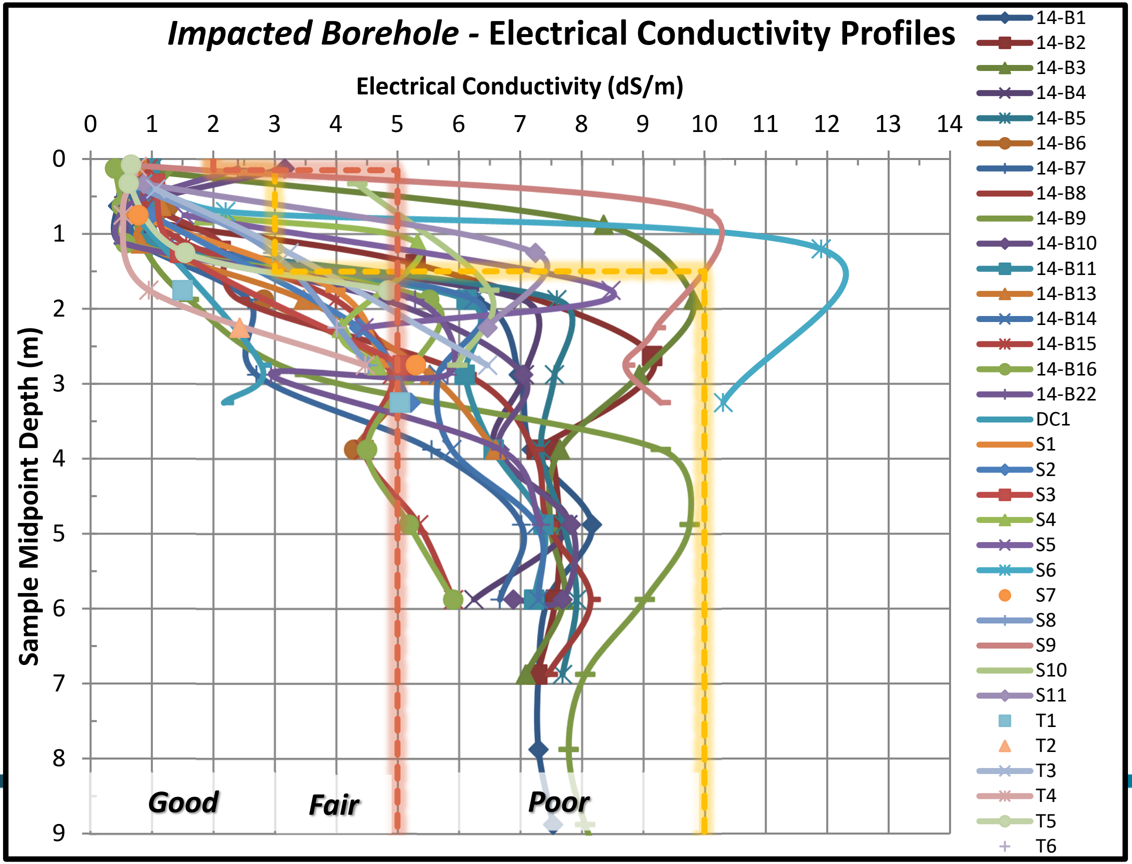
b Material characterized by SAR of 12 to 20 may be rated as poor if texture is sandy loam or coarser and saturation % is less than 100.

c Topsoil: surface A horizons on the control area, or the equivalent surface soil on the reclaimed site. Subsoil: B and C horizons and the upper portion of the parent material.

Depth-Specific EC & SAR Guidelines

- Natural variability of EC & SAR with depth
  - Recharge Vs. Discharge
- With sufficient background data, can develop depth-specific EC & SAR guidelines
  - Considered within the framework of Tier 1
  - Easy solution (win) for many sites
  - Salinity analysis is less expensive compared to PHCs, etc.
- Representative background dataset is key
  - Sufficient spatial representation
  - Sufficient amount of data (samples)
- Generally, use the 95th percentile for each depth interval
  - Professional judgement required

Case Example – Depth Specific EC



- Elevated chloride throughout (>100 mg/kg)
- 4 additional background boreholes
- Increased EC guidelines from 5 dS/m (fair) to 10 dS/m (poor) at depth
- *~15,000 m³ reduction in remediation volume*

Case Example

Background Depth-Specific Descriptive Statistics – EC

Statistical Parameter	Sample Depth (m)							
	0.00 - 0.25	0.26 - 1.00	1.01 - 1.50	1.51 - 2.00	2.01 - 3.00	3.01 - 4.00	4.01 - 5.00	>5.01
	Topsoil	*Upper RZ*	*Deep RZ*	*Deep Subsoil*				
n (count)	7	7	6	6	6	6	6	5
Minimum	0.58	0.22	0.48	0.58	0.66	1.24	2.42	5.34
Maximum	1.05	0.85	1.00	5.93	5.63	6.78	7.51	7.50
Standard Deviation	0.17	0.21	0.21	1.99	1.97	2.24	1.96	0.95
Median	0.77	0.61	0.85	4.05	4.67	6.03	6.77	7.04
Arithmetic Mean	0.77	0.59	0.79	3.94	3.84	4.97	5.97	6.53
95th Percentile	1.01	0.82	0.99	5.91	5.53	6.72	7.45	7.42
Tier 1 Category*	*Good*	*Good*	*Good*	*Poor*	*Poor*	*Poor*	*Poor*	*Poor*
Tier 1 Guideline**	***2***	***3***	***3***	***10***	***10***	***10***	***10***	***10***

Notes:

- values are expressed as dS/m

* - *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AEP 2019) for soils with an unrestricted land use

** - Tier 1 Category Guideline is based on the 95th percentile value

RZ - rooting zone (0.0 - 1.5 m)

Estimating Background EC With Elevated Chloride

- Situations with marginally elevated chloride:
  - Because of the linear EC & anion relationship, a simple analytical model can be used to estimate background EC

$$\text{Calcuated EC}\left(\frac{\text{dS}}{\text{m}}\right)=\frac{\text{Sample EC}\left(\frac{\text{dS}}{\text{m}}\right)}{\left[\left(\frac{\text{sample Sulphate}\left(\frac{\text{mg}}{\text{kg}}\right)}{\frac{\text{saturation (\%)}}{100}}\div\frac{96.064\left(\frac{\text{g}}{\text{mol}}\right)}{2}\right)+\left(\frac{\text{sample chloride}\left(\frac{\text{mg}}{\text{kg}}\right)}{\frac{\text{saturation (\%)}}{100}}\div\frac{35.453\left(\frac{\text{g}}{\text{mol}}\right)}{1}\right)\right]}\times\left[\left(\frac{\text{Sample Sulphate}\left(\frac{\text{mg}}{\text{kg}}\right)}{\frac{\text{saturation (\%)}}{100}}\div\frac{96.064\left(\frac{\text{g}}{\text{mol}}\right)}{2}\right)+\left(\frac{x\left(\frac{\text{mg}}{\text{kg}}\right)\text{chloride}}{\frac{\text{saturation (\%)}}{100}}\div\frac{35.453\left(\frac{\text{g}}{\text{mol}}\right)}{1}\right)\right]$$

$$Calcuated\ EC\left(\frac{dS}{m}\right)=\frac{Sample\ EC\left(\frac{dS}{m}\right)}{\left(Sulphate\left(\frac{meq}{L}\right)+chloride\left(\frac{meq}{L}\right)\right)}\times\left(Sulphate\left(\frac{meq}{L}\right)+x\left(\frac{meq}{L}\right)\right)$$

$Where\ x = assumed\ background\ chloride$

EC Exceedances & Slightly Elevated Chloride

- Many situations with naturally elevated EC but also some marginally elevated chloride
  - Associated with elevated sulphate
- Simple justification approach: calculate the chloride contribution towards EC
  - *Quantified as opposed to qualified*

$$Est.\,Chloride\ contribution\ to\ EC\ (\%) = \frac{Chloride\ \left(\frac{meq}{L}\right)}{Chloride\ \left(\frac{meq}{L}\right) + Sulphate\ \left(\frac{meq}{L}\right)} \times 100$$

Background Total Dissolved Solids

- Many situations with salinity impacts in waterbodies and dugouts
  - And groundwater
- Often concern for livestock watering
- Was the water suitable to begin with?
  - Based on TDS

Background TDS (con't)

$$TDS_{Cal} = 0.6 \times \left(\frac{HCO_3}{1.22} + \frac{CO_3}{0.6}\right) + \mathbf{Cl} + Mg + K + \mathbf{Na} + (0.17 \times OH) + NO_3 + NO_2 + SO_4$$

$$Na_{BG}\left(\frac{mg}{L}\right) = \frac{Na_{meas}\left(\frac{mg}{L}\right)}{\frac{AW_{Na}}{Val}} - \left(\frac{Cl_{meas}\left(\frac{mg}{L}\right)}{\frac{AW_{Cl}}{Val}} - \frac{Cl_{BG}\left(\frac{mg}{L}\right)}{\frac{AW_{Cl}}{Val}}\right) \times \frac{\frac{AW_{Na}}{Val}}{\frac{AW_{Na}}{Val} + \frac{AW_{Cl}}{Val}}$$

Where:

BG = background

meas = measured concentration

AW = atomic weight

Val = molecular valence

Acknowledgements

- Many anonymous clients
- Ashley Morgan – Matrix
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- Equilibrium Environmental
  - Tony and Greg

Questions?

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Unfortunately, not all salinity questions can be answered by Google