Enhancing Chloride Plume Resolution Through Incorporation of Soils Data – Could it Shrink Your Plume?

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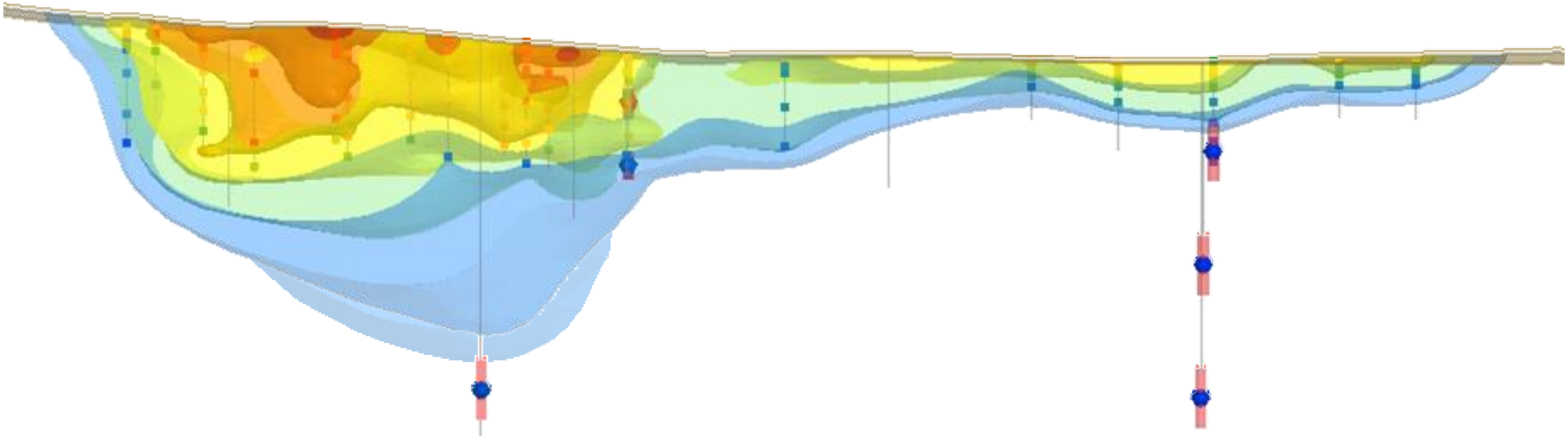
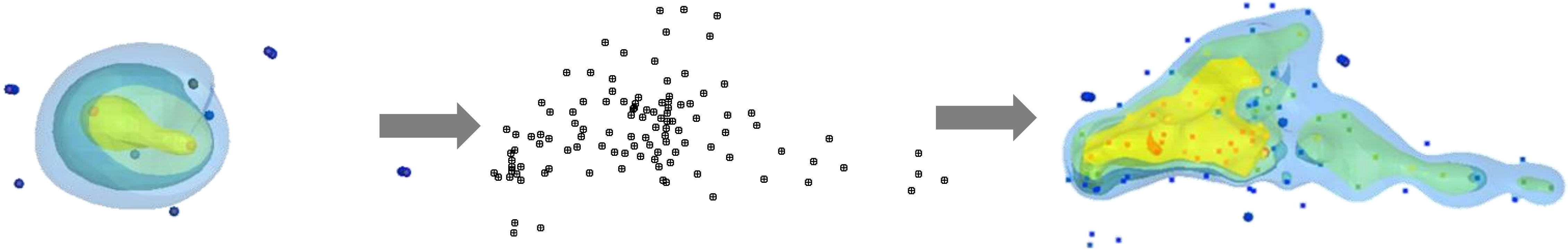
The Value of Extra Data





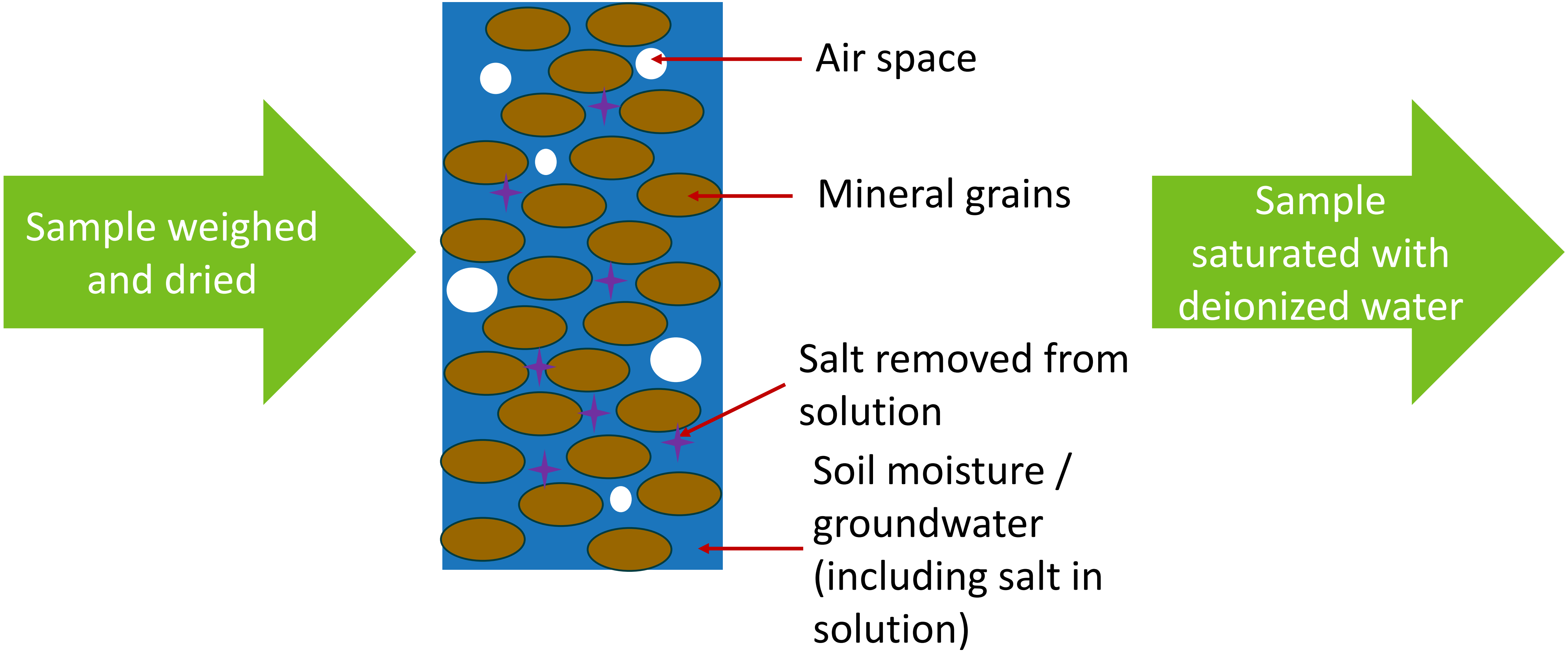
Understanding Chloride in Soil: What Are We Really Measuring?

How does this relate to chloride in groundwater?

"When delineating chloride-based soil salinity for comparison to Tier 1 soil salinity guidelines (Table 4), delineation must include the lateral and vertical extent of ***chloride concentrations in saturated paste extracts (expressed as mg/L)*** *that exceed the* ***Tier 1 groundwater guideline****. The area and depth defined by soil chloride delineation requirements may extend beyond the area and depth of soil that exceeds Tier 1 soil salinity guidelines. In that case, soil remediation may be based on the Tier 1 soil salinity guidelines, but consideration must be given to the potential for chloride contamination in groundwater."*

What Are Saturated Paste Extract Concentrations?

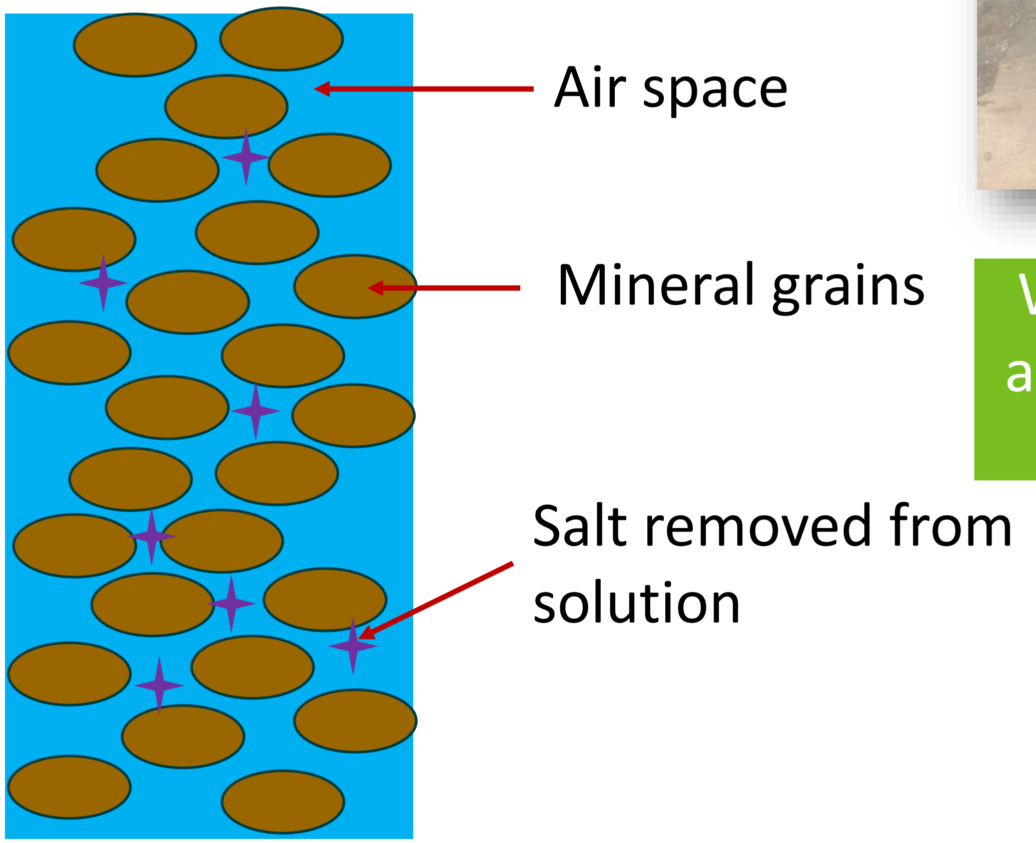
Step 1: Sample arrives and is weighed and dried

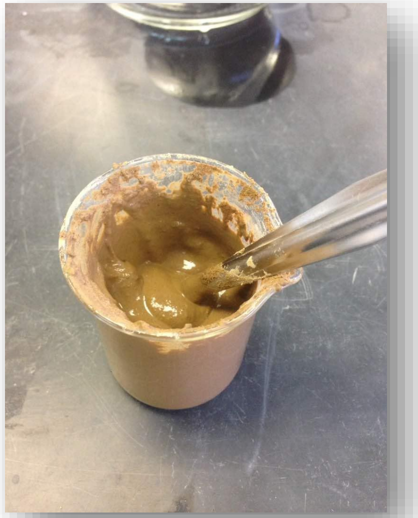


What Are Saturated Paste Extract Concentrations?

Step 2: Deionized water is added to sample to create a paste

Sample saturated with deionized water



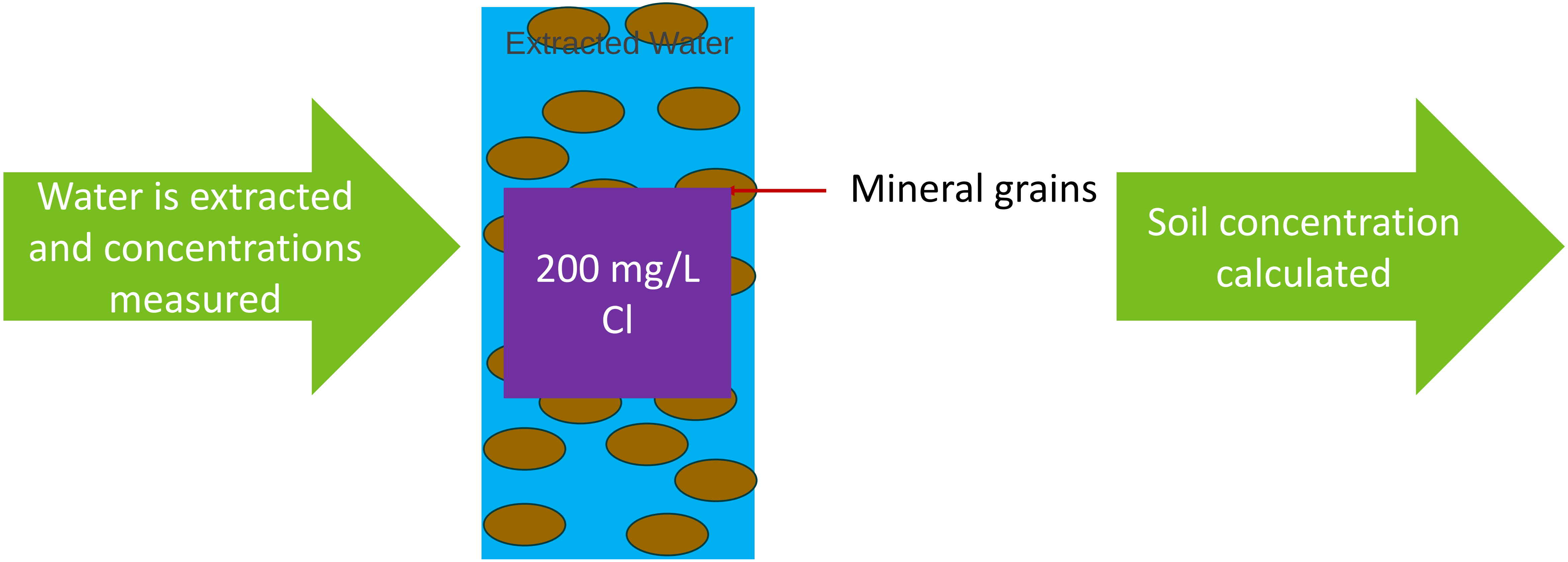


Water is extracted and concentrations measured

$$\text{Sat. \%} = \frac{\text{Wt of Water Added at Saturation}}{\text{Dry Wt of Soil}} \text{X } 100\%$$

What Are Saturated Paste Extract Concentrations?

Step 3: Water is extracted from the paste and the concentration measured

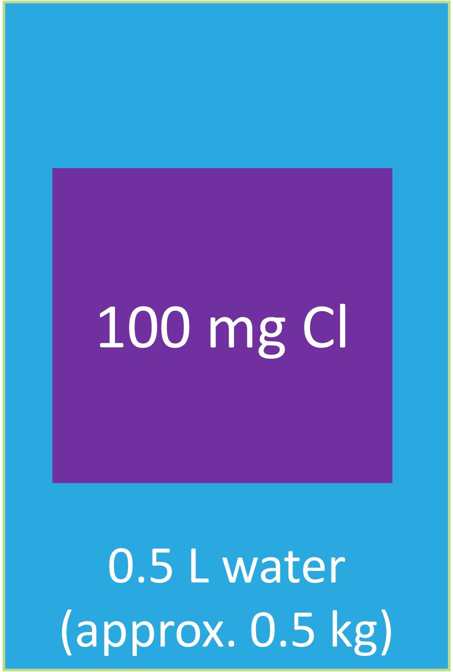


What Are Saturated Paste Extract Concentrations?

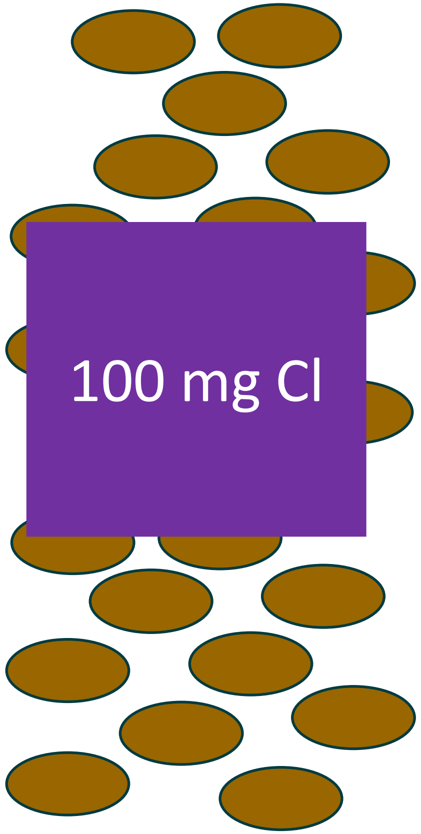
Step 4: Calculate the concentration in the soil

$$[\mathrm{Cl}_s\ (^{\mathrm{mg}}/_{\mathrm{kg}})] = [\mathrm{Cl}_{SPE}\ (^{\mathrm{mg}}/_{\mathrm{L}})] \times \frac{Sat.\%}{100\%}$$

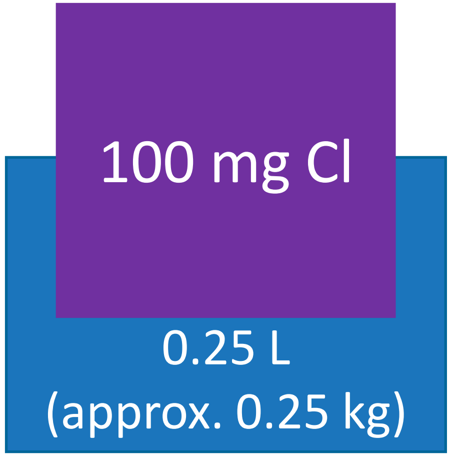
$$[\mathrm{Cl}_w\ (^{\mathrm{mg}}/_{\mathrm{L}})] = [\mathrm{Cl}_S\ (^{\mathrm{mg}}/_{\mathrm{kg}})] \div \frac{Moist.\%}{100\%}$$



If 0.5 kg of water was added to 1 kg of soil (soil saturation is 50%)



If 1 kg of soil originally contained 0.25 kg of soil moisture



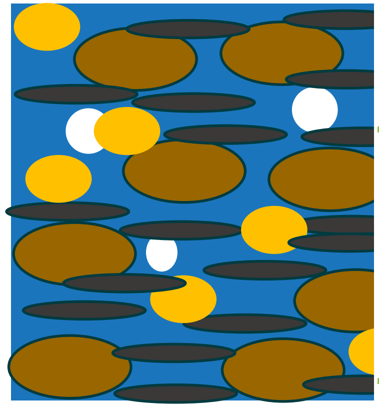
200 mg/L Cl in sat paste extract

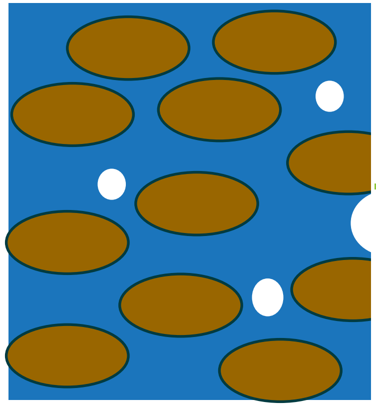
100 mg/kg Cl in soil

400 mg/L Cl in soil moisture

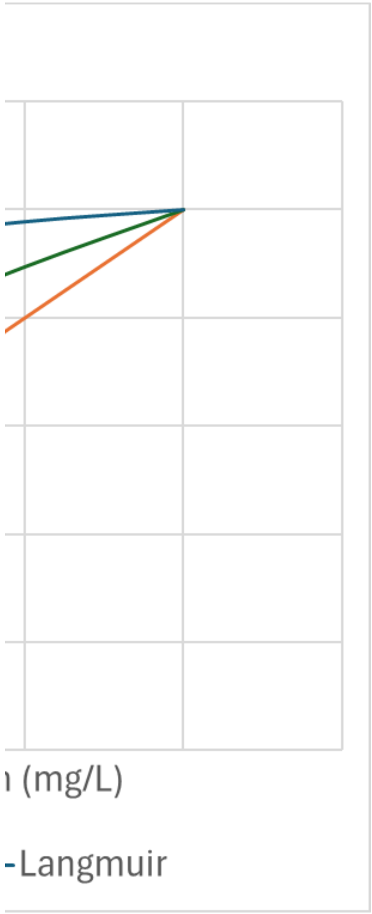
Factors and Processes Affecting Distribution

K^{+} Ca^{+2}





- Soil Physical Properties
  - Porosity, bulk density, particle type
- Adsorption
  - CEC, AEC, pH
- Anion Exclusion
  - Clay content (net negative), pH, CEC
- Ionic Strength
  - Ion concentration, clay content, porosity
- Contaminant & Site History



Existing Approaches To Relate Soil to Groundwater Concentrations

- Soil groundwater *partitioning* coefficient

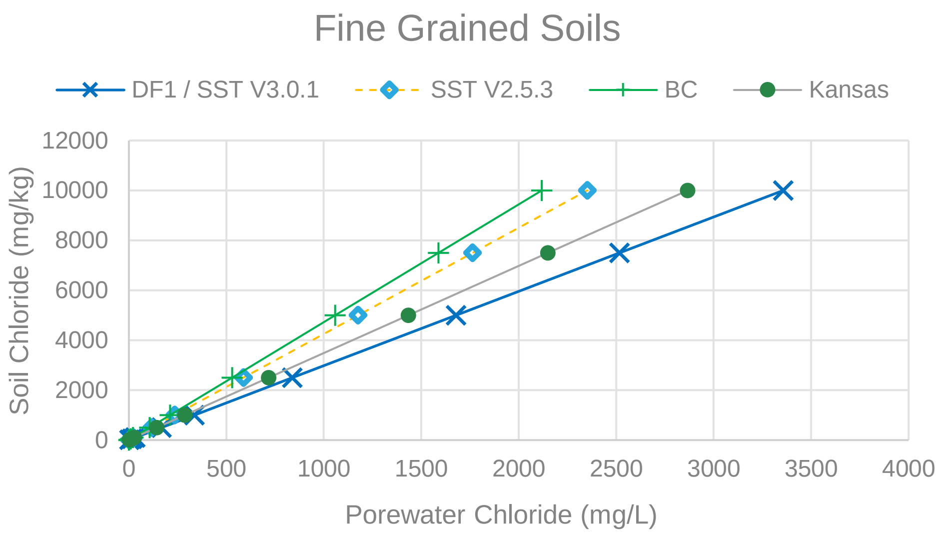
$$K_d\left(\frac{L}{kg}\right) = \frac{mg\ chemical\ per\ kg\ of\ soil}{mg\ chemical\ per\ L\ solution}$$

- Common Empirical Models for Estimating Ion Adsorption
  - Linear, Freundlich, Langmuir

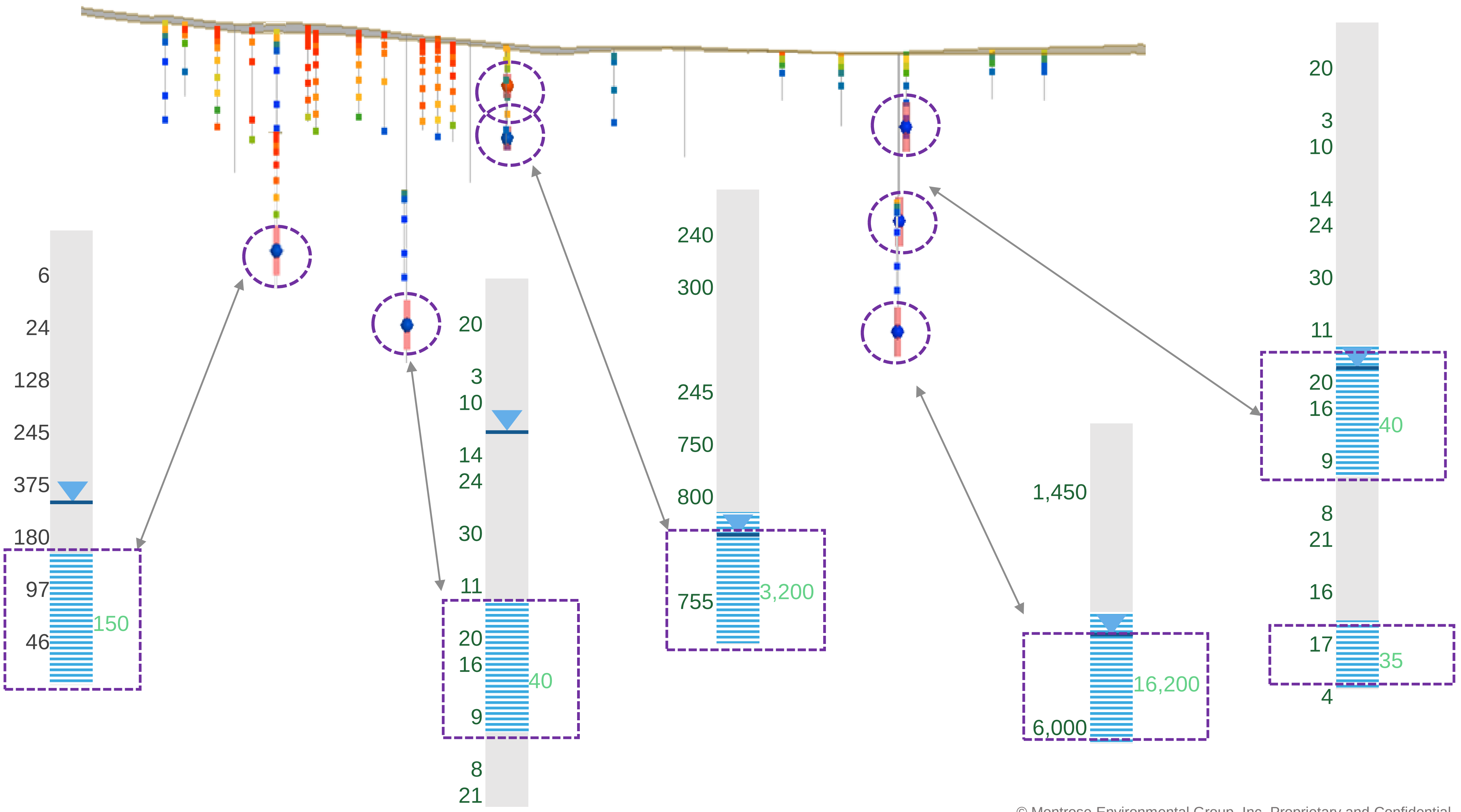
$$DF1 = K_{oc} \times f_{oc} + \frac{(\theta_w + H' \times \theta_a)}{\rho_b}$$

$$K_{oc} = \frac{K_d \times 100}{Organic\ Carbon\ (\%)}$$

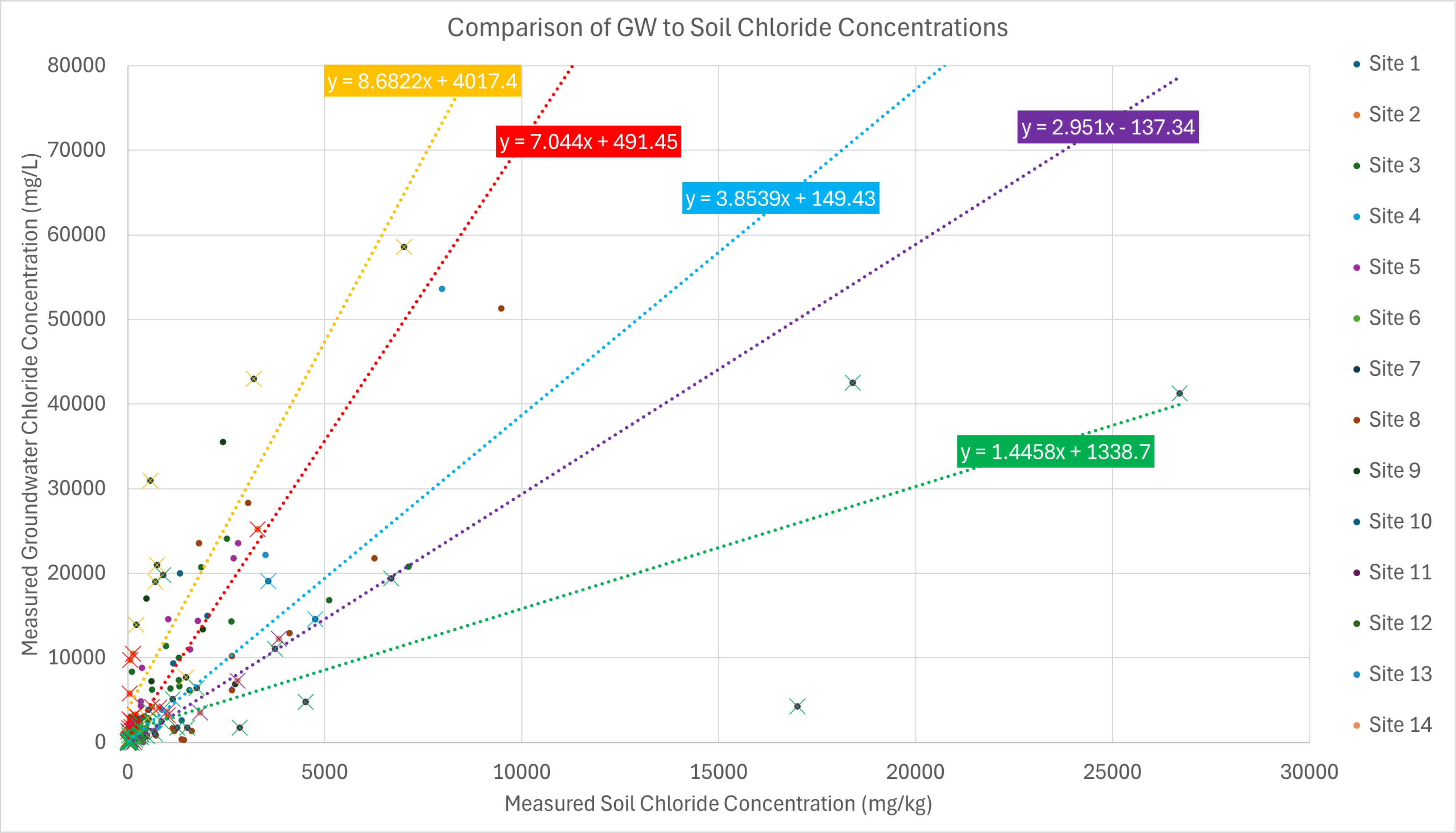
- Approaches for Chloride:
  - Alberta Tier 1 Soil and Groundwater Remediation Guidelines (DF1) & SST V3.0
  - SST V2.5
  - British Columbia Contaminated Sites Regulation (Protocol 28 and Protocol 13)
  - United States Environmental Protection Agency & Kansas Department of Health and Environment



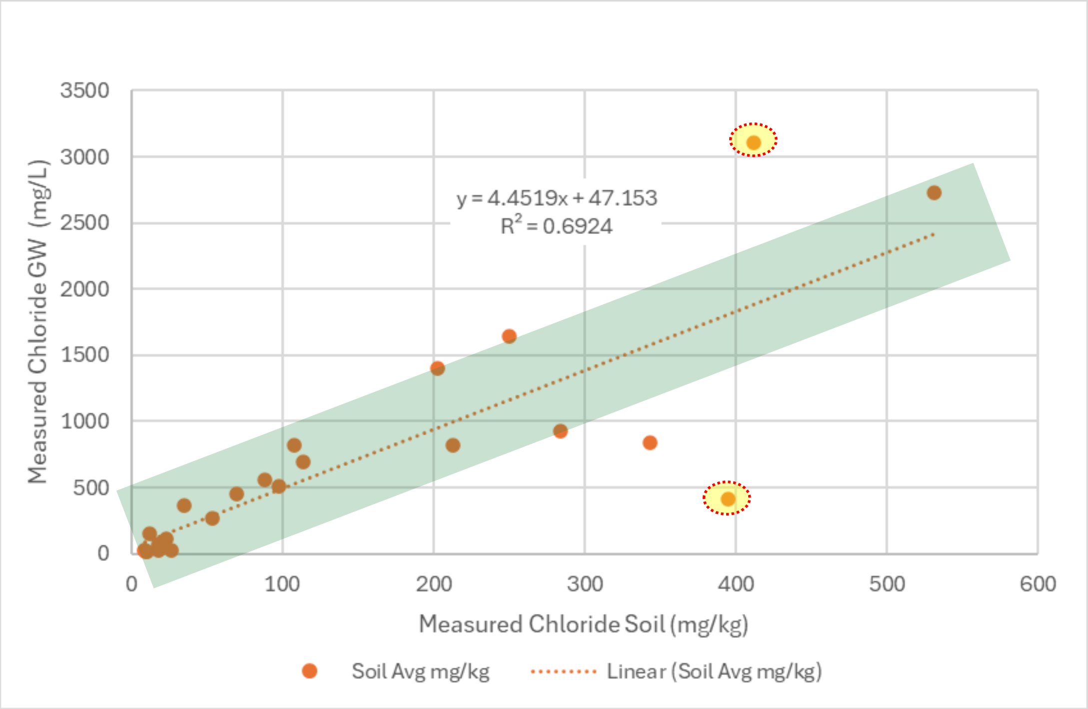
Testing the Relationship Between Soil and Groundwater Concentrations

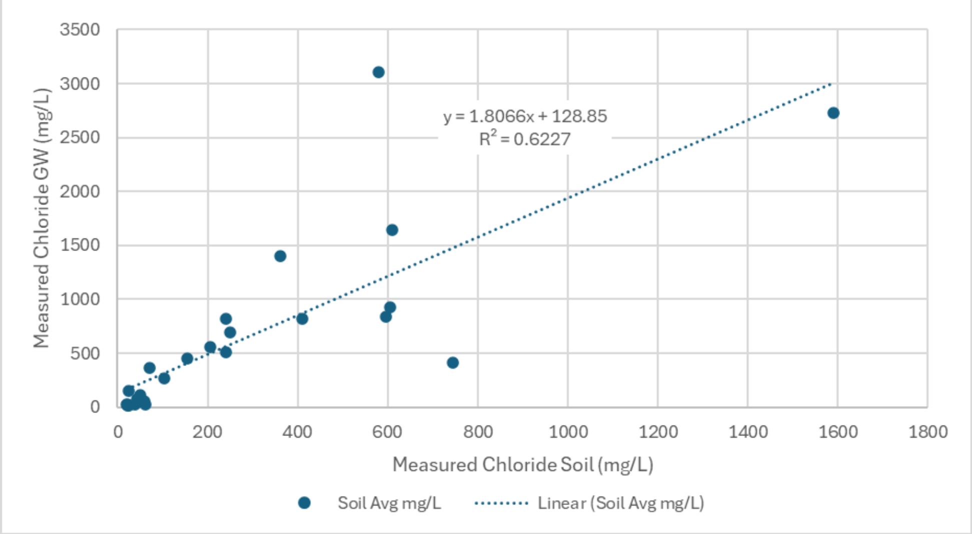


Individual Site Correlation Comparison



How Does Soil Chloride Concentrations Relate to Groundwater Chloride Concentrations?

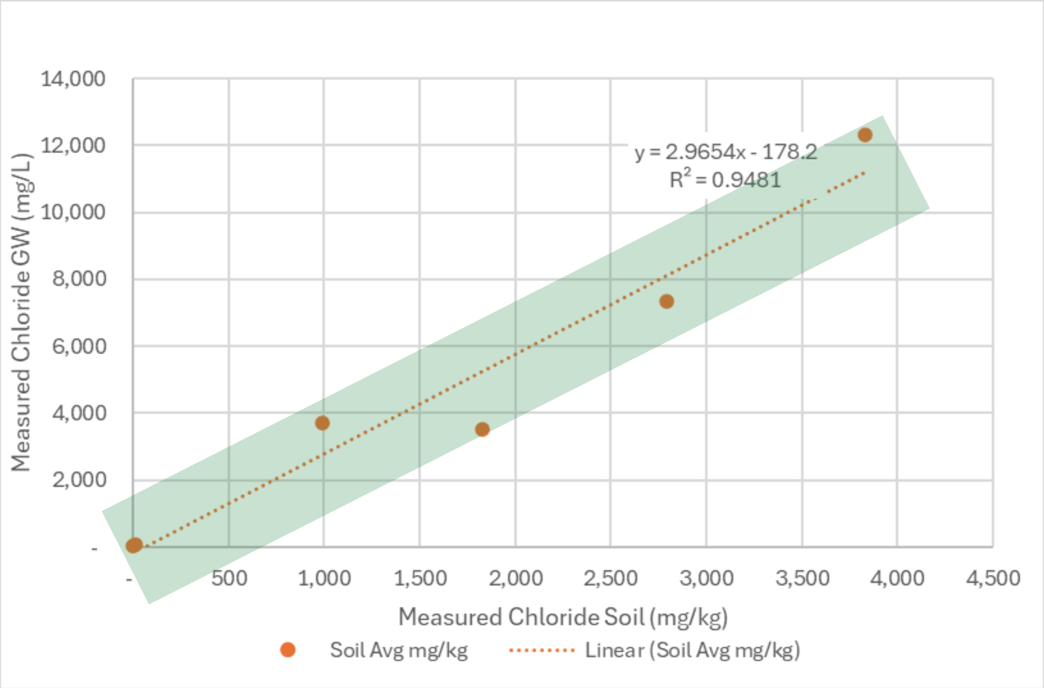


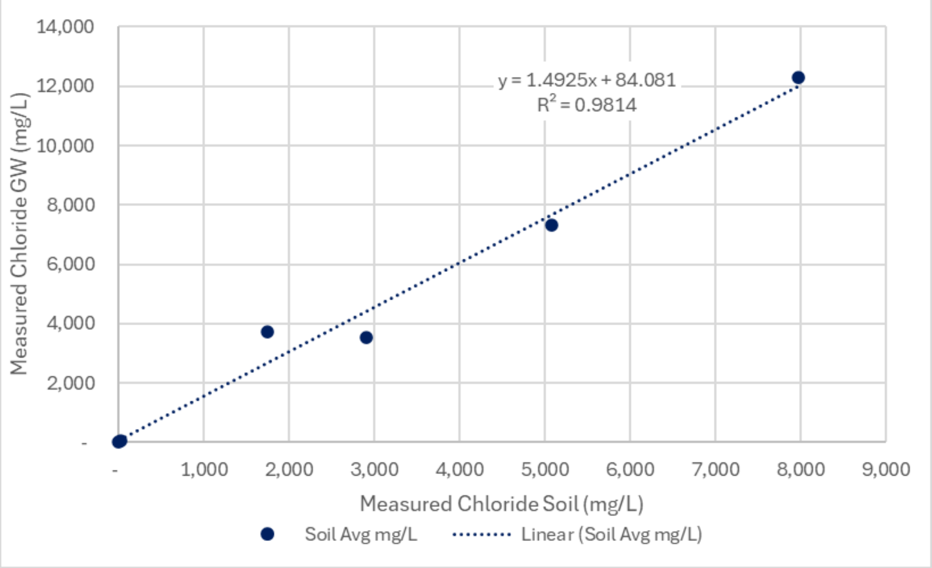


	Measured Chloride			Ratio	
Location	GW (mg/L)	Soil (mg/kg)	Soil (mg/L)	GW : Soil (mg/kg)	GW : Soil (mg/L)
1	17	10	22	1.58	0.76
2	23	27	61	0.86	0.38
3	29	9	23	3.18	1.24
4	29	9	21	3.27	1.43
5	53	18	58	2.87	0.90
6	76	19	43	4.11	1.76
7	824	108	240	7.63	3.43
8	825	213	410	3.87	2.01

	Groundwater (mg/L): Soil Ratio	
	Soil (mg/kg)	Soil (mg/L)
Count (n)	25	25
Minimum	0.86	0.38
Maximum	12.33	6.17
Average	**4.84**	2.29

How Does Soil Chloride Concentrations Relate to Groundwater Chloride Concentrations?





	Measured Chloride			Ratio	
Location	GW (mg/L)	Soil (mg/kg)	Soil (mg/L)	GW : Soil (mg/kg)	GW : Soil (mg/L)
1	61	13	22	4.70	2.78
2	3540	1830	2909	1.93	1.22
3	3710	992	1740	3.74	2.13
4	7340	2790	5080	2.63	1.44
5	12300	3830	7980	3.21	1.54

FIELD SITE

	Groundwater (mg/L): Soil Ratio	
	Soil (mg/kg)	Soil (mg/L)
Count (n)	5	5
Minimum	1.93	1.22
Maximum	4.70	2.78
Average	**3.24**	1.82

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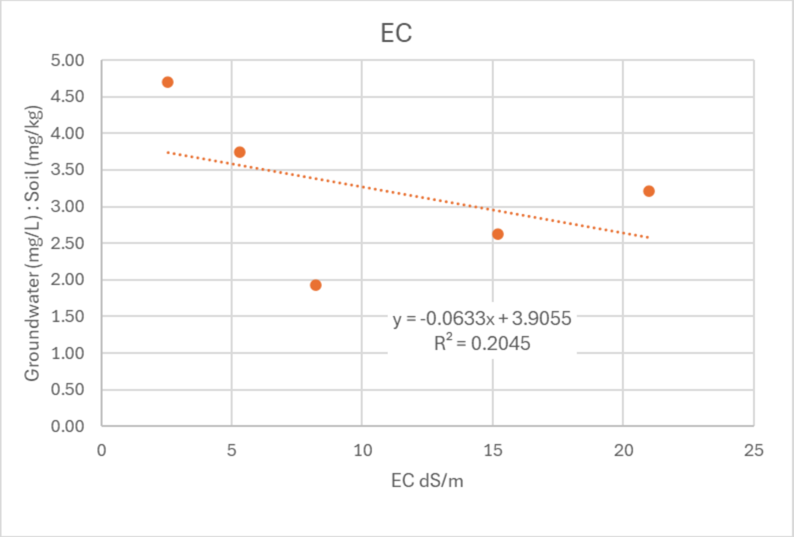
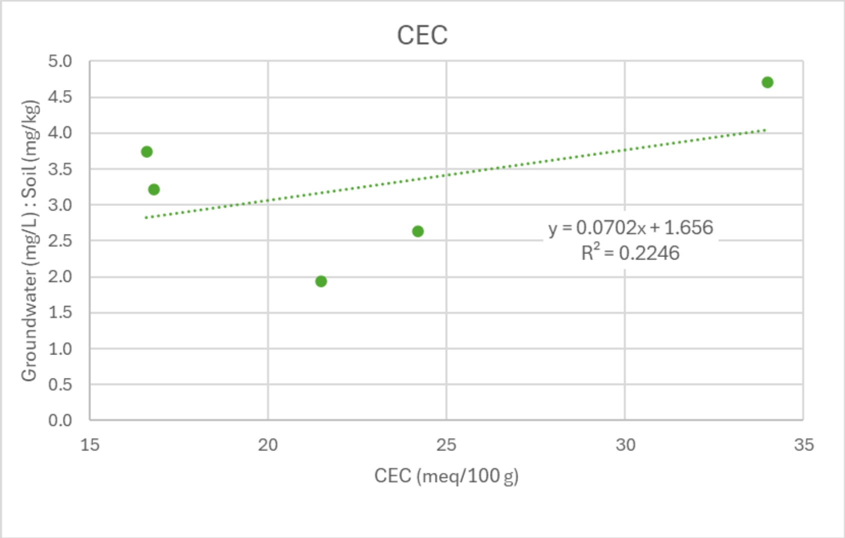
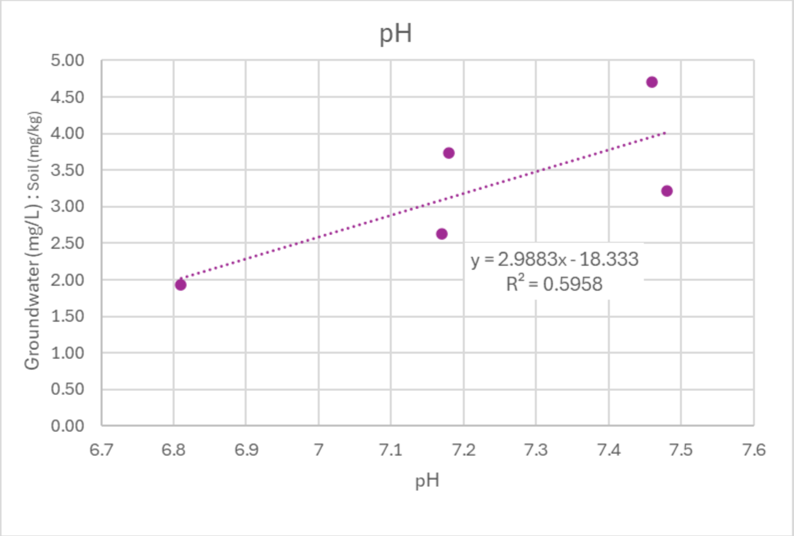
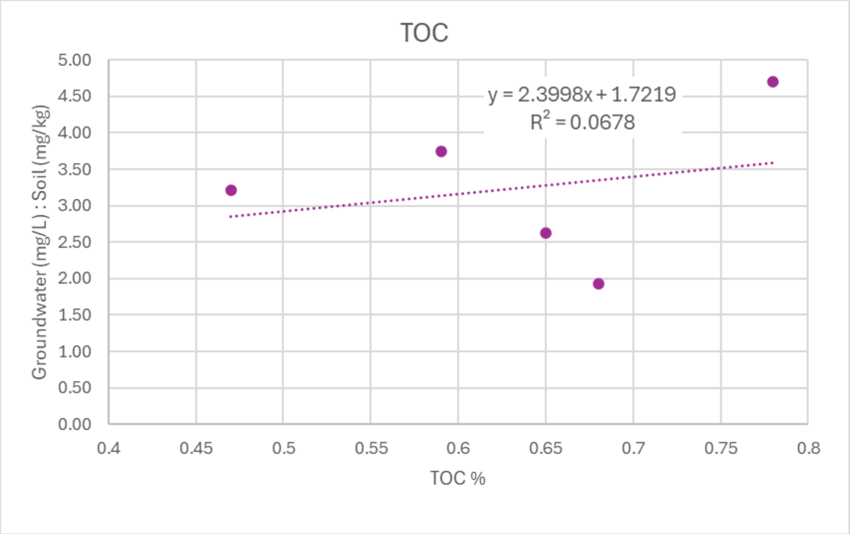
Factors Affecting Chloride Distribution









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DF1 to Enhance Groundwater Chloride Plumes???

Dilution Factor 1

assume gw in contact

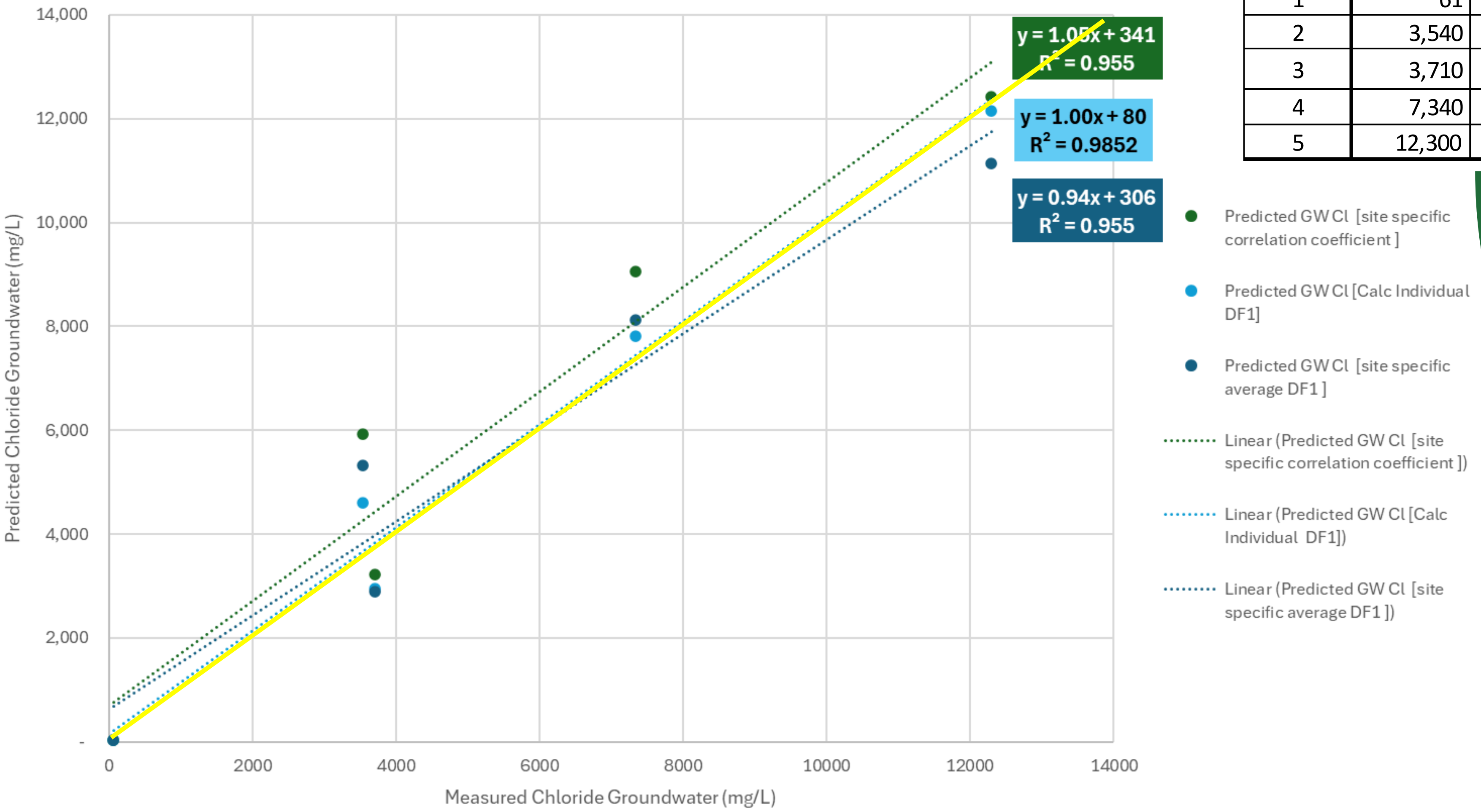
Dilution factor 1 (DF1) is the ratio of the concentration of a contaminant in soil to the concentration in leachate that is in contact with the soil. This "dilution factor" represents the three phase partitioning between contaminant sorbed to soil, contaminant dissolved in pore water (*e.g.*, as leachate), and contaminant present as soil vapour. DF1 is calculated using the following equation:

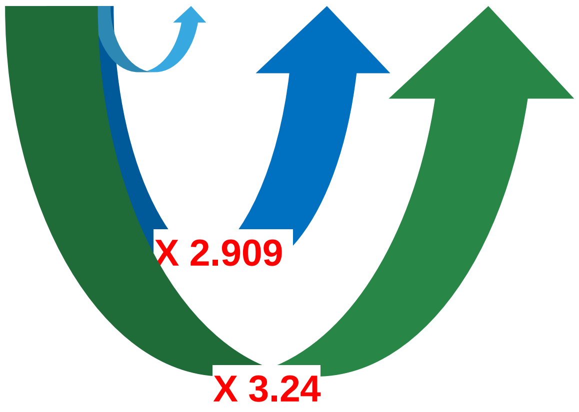
$$\boxed{DF1} = \cancel{K_{oc} \times f_{oc}} + \frac{(\theta_w + \cancel{H'} \times \cancel{\theta_a})}{\rho_b}$$

Where:	DF1	=	dilution factor 1 (L/kg);	
	~~K_{oc}~~	~~=~~	~~organic carbon-water partition coefficient (L/kg);~~	Assume no sorption
	~~f_{oc}~~	~~=~~	~~fraction organic carbon (g/g);~~	
	θ_w	=	water filled porosity (dimensionless);	Measured for test site
	~~H'~~	~~=~~	~~dimensionless Henry's Law constant (dimensionless);~~	Assume no volatilization
	~~θ_a~~	~~=~~	~~air filled porosity (dimensionless); and;~~	Assume fully saturated
	ρ_b	=	dry soil bulk density (g/cm^3).	Measured for test site

How Does This Relate to Chloride in Groundwater?

	Measured Chloride		Predicted Groundwater Chloride		
			DF1		Site Specific Correlation Coefficient (3.24)
Location	GW (mg/L)	Soil (mg/kg)	Individual	Site Specific Avg (2.909)	
1	61	13	36	38	42
2	3,540	1,830	4,605	5,323	5,935
3	3,710	992	2,942	2,886	3,217
4	7,340	2,790	7,816	8,116	9,049
5	12,300	3,830	12,157	11,141	12,422

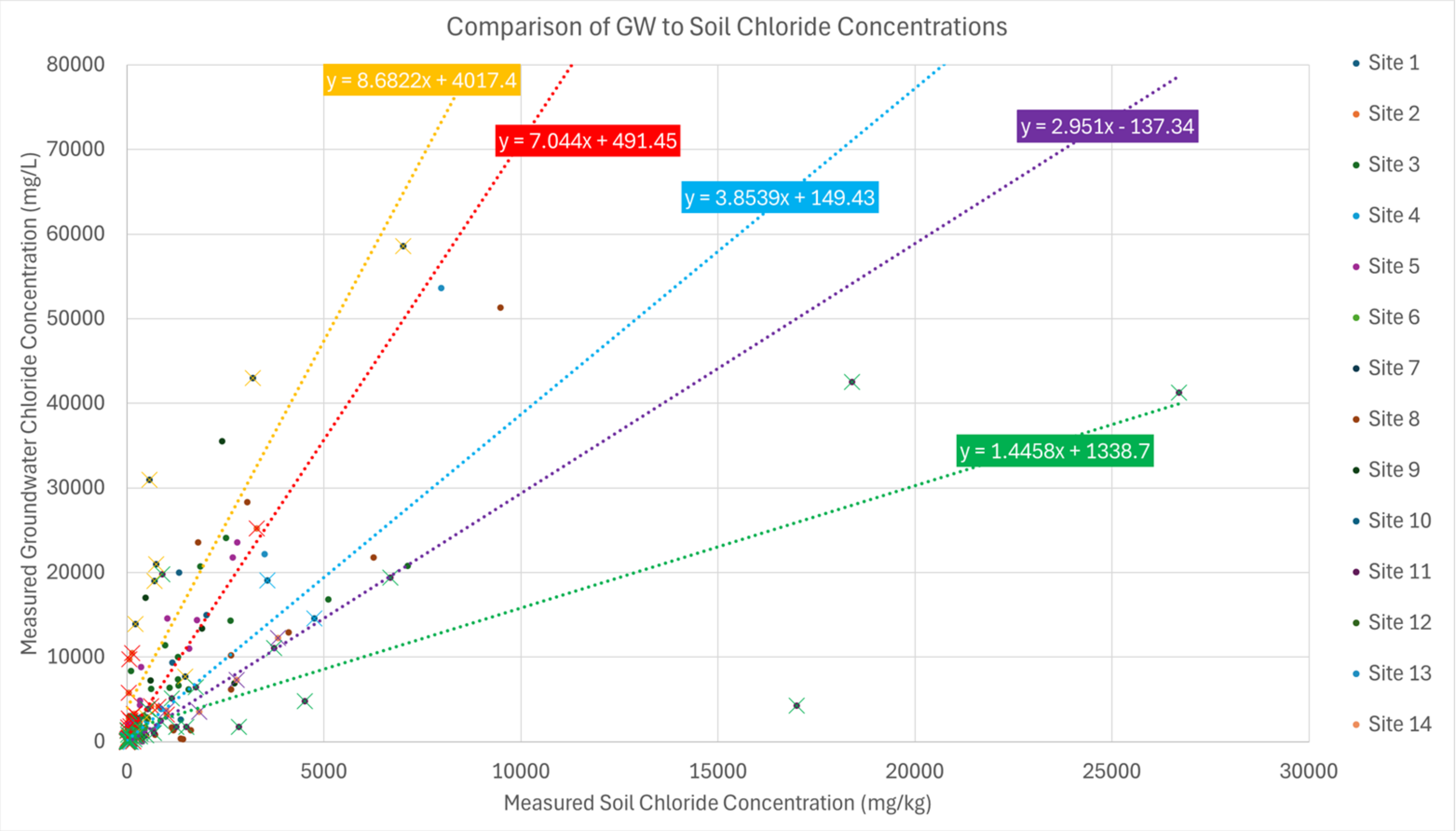




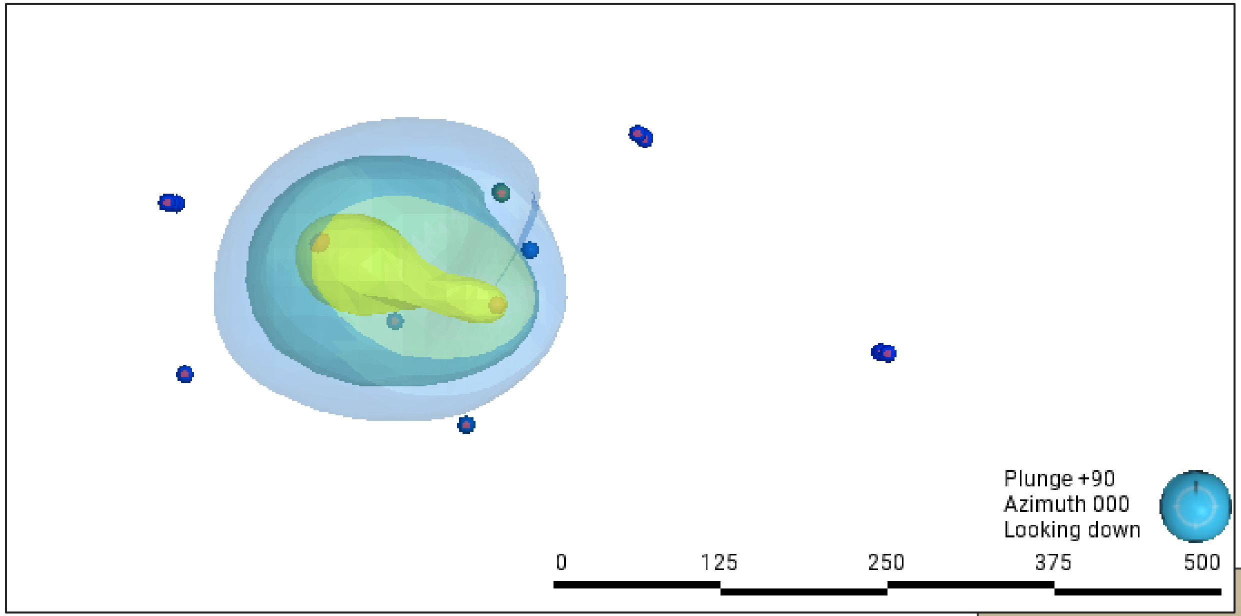
Variability in Correlation Coefficients

Site	Count (n)	Correlation Coefficient
14	58	8.41
2	13	4.57
4	8	4.51
6	32	3.04
5	6	4.68
All	299	5.71
	Minimum	3.04
	Maximum	8.41
	Average	5.23

Correlation Coefficient	100 mg/kg Soil - Predicted Groundwater Concentration (mg/L)
3.04 (min)	304
8.41 (max)	841
5.23 (avg)	523



Variability of Correlation Coefficient on Chloride Plumes



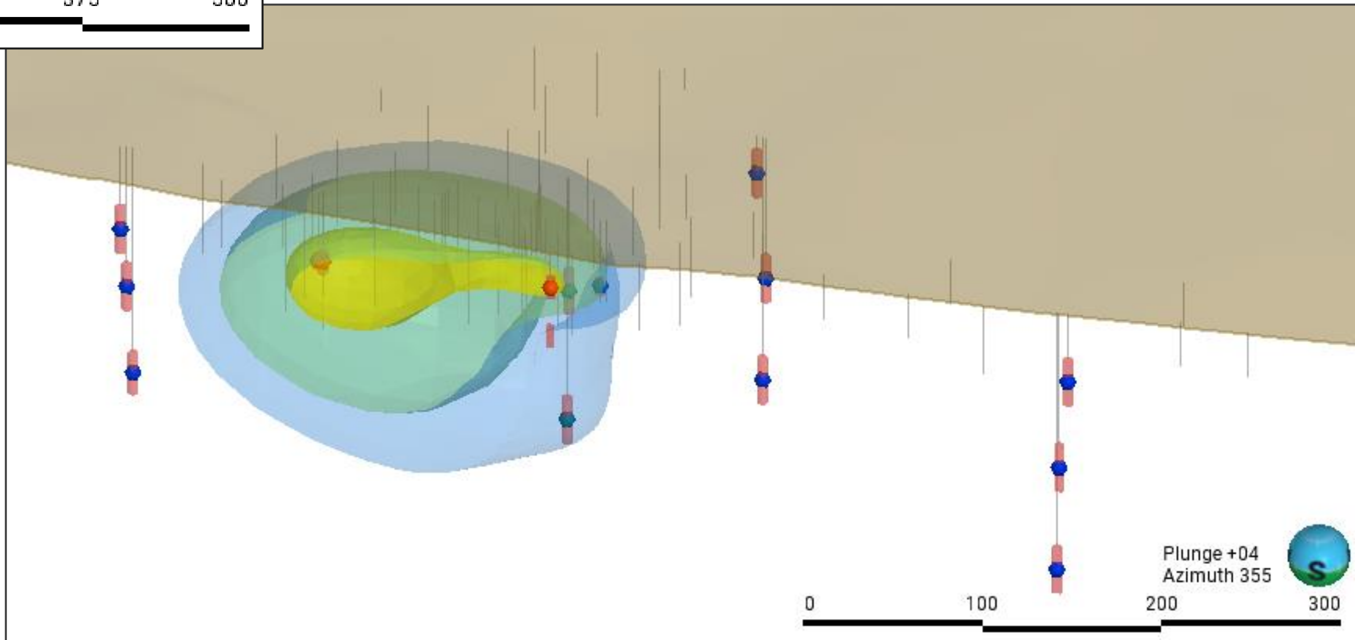
Dissolved Chloride Plume
Groundwater Data Only

Cl mass > 100 mg/L: 28 t

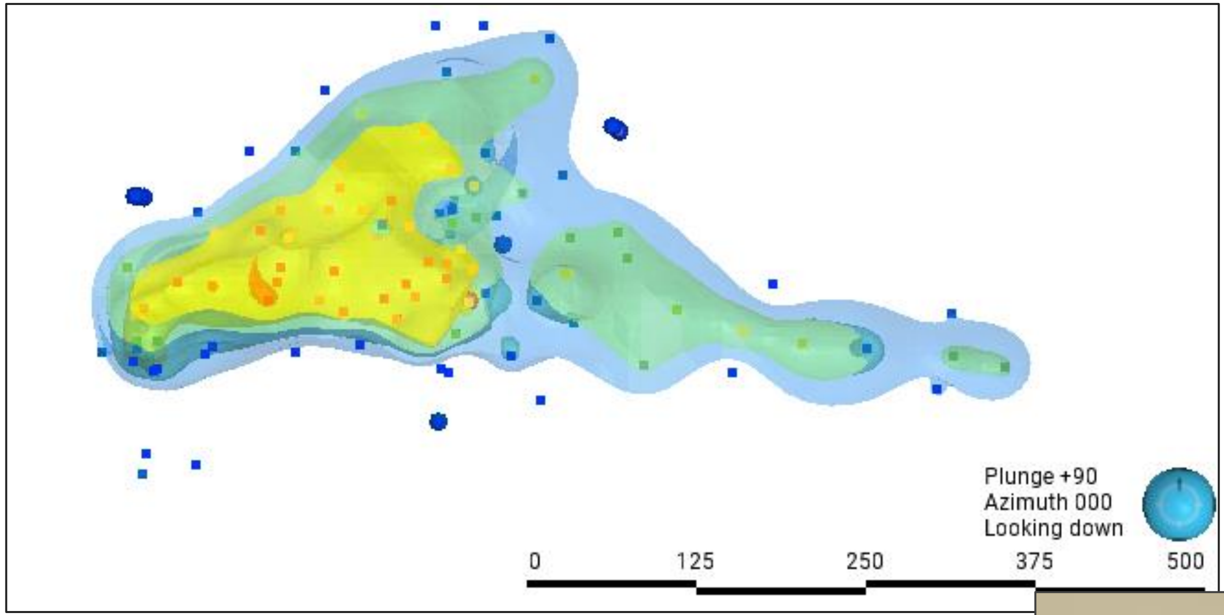
Well screen with GW sample

Scaled soil sample

Cl (mg/L)	
	100.0 – 250.0
	250.0 – 1000.0
	1000.0 – 5000.0
	5000.0 – 10000.0
	> 10000.0



Variability of Correlation Coefficient on Chloride Plumes



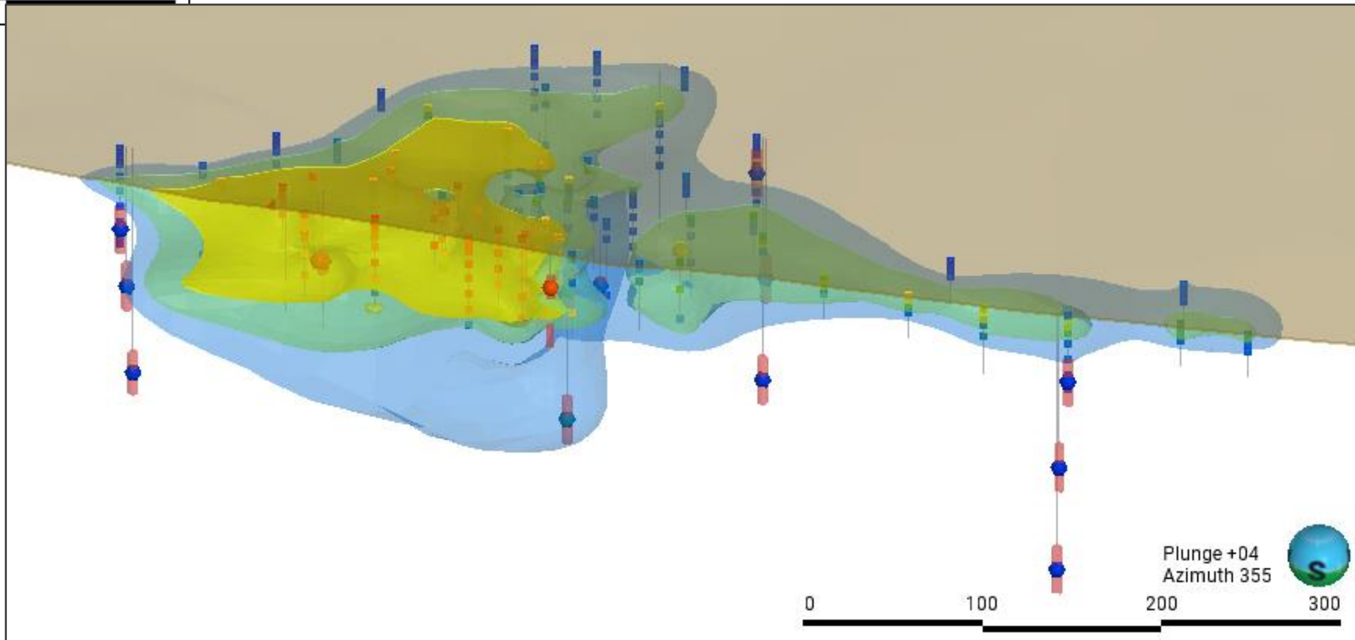
Dissolved Chloride Plume
Groundwater + Soil (sat. paste - mg/L)

Volume > 100 mg/L: 484,000 m3
Cl mass > 100 mg/L: 42 t

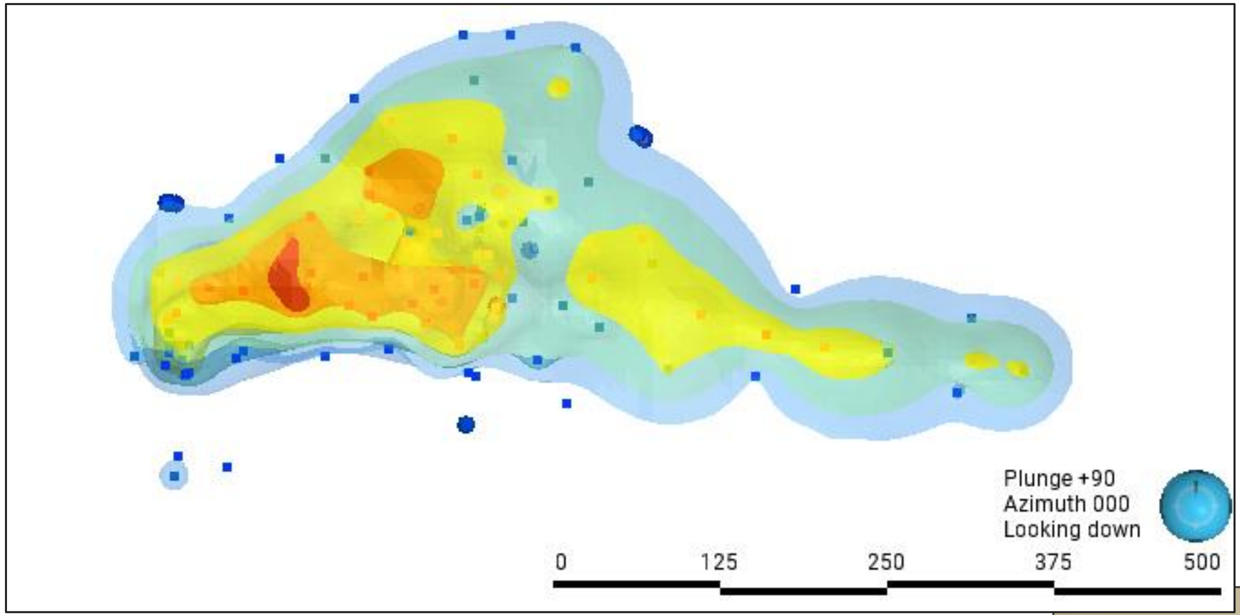
Well screen with GW sample

Scaled soil sample

Cl (mg/L)
100.0 – 250.0
250.0 – 1000.0
1000.0 – 5000.0
5000.0 – 10000.0
> 10000.0



Variability of Correlation Coefficient on Chloride Plumes



Dissolved Chloride Plume Groundwater + Soil (mg/kg x 2.69)

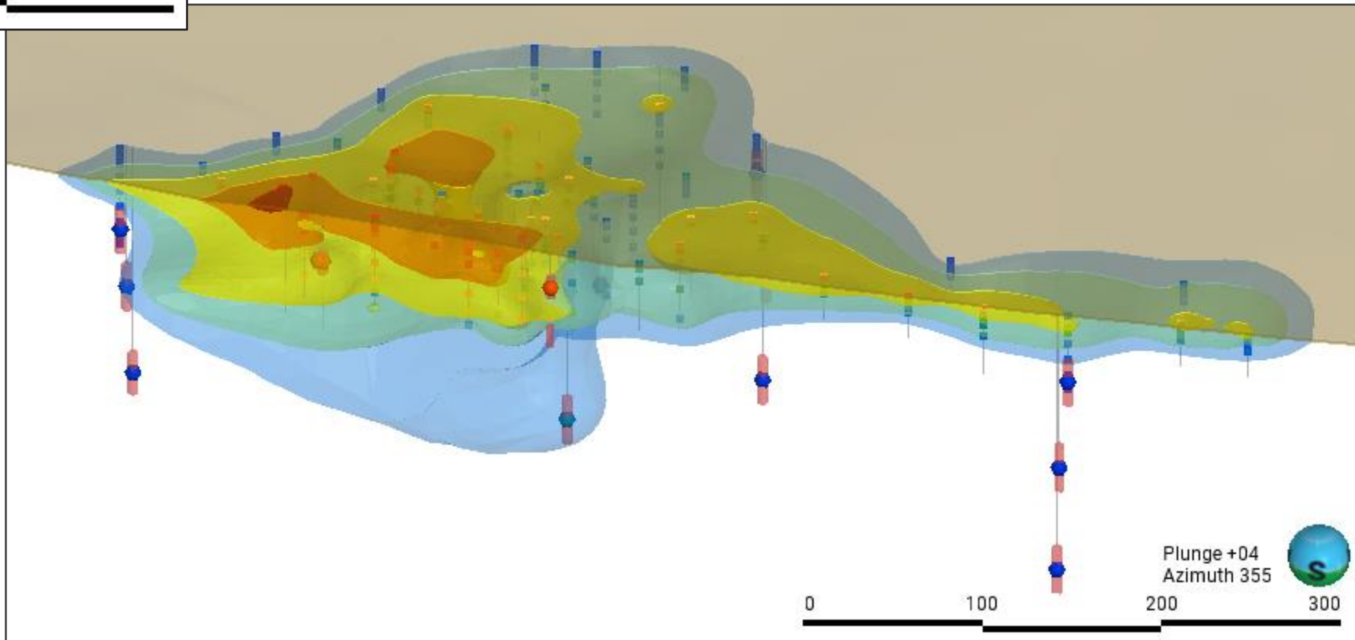
Volume > 100 mg/L: 526,000 m3
Cl mass > 100 mg/L: 66 t

Well screen with GW sample

Scaled soil sample

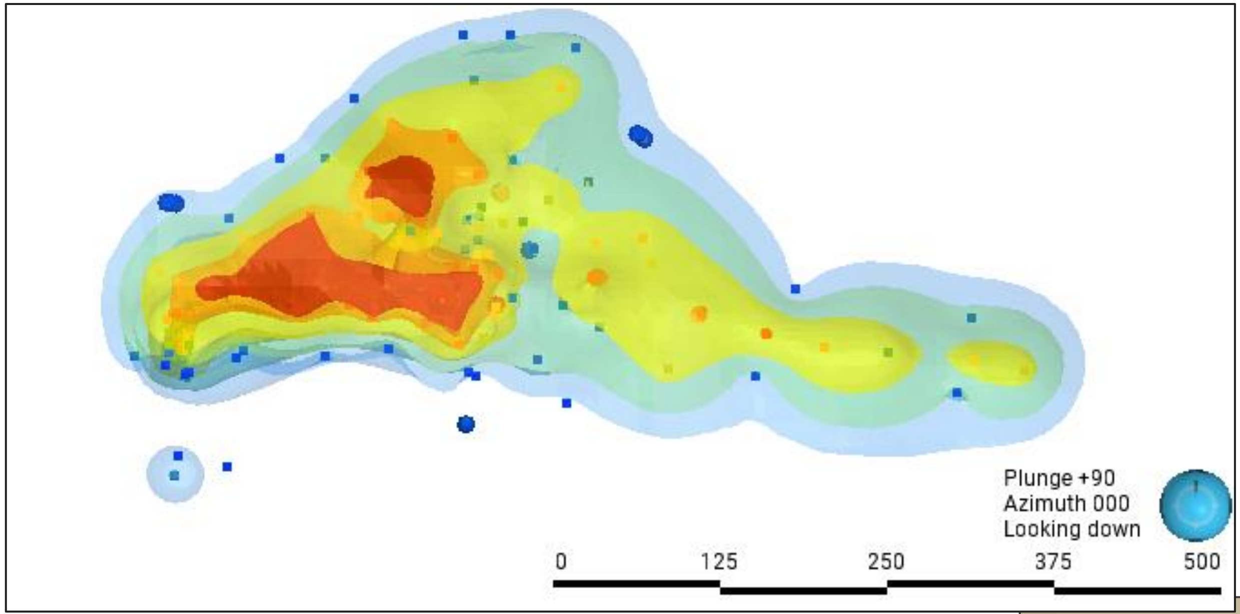
Cl (mg/L)

100.0 – 250.0
250.0 – 1000.0
1000.0 – 5000.0
5000.0 – 10000.0
> 10000.0



Variability of Correlation Coefficient on Chloride Plumes

Site Specific



Dissolved Chloride Plume Groundwater + Soil (mg/kg x 4.61)

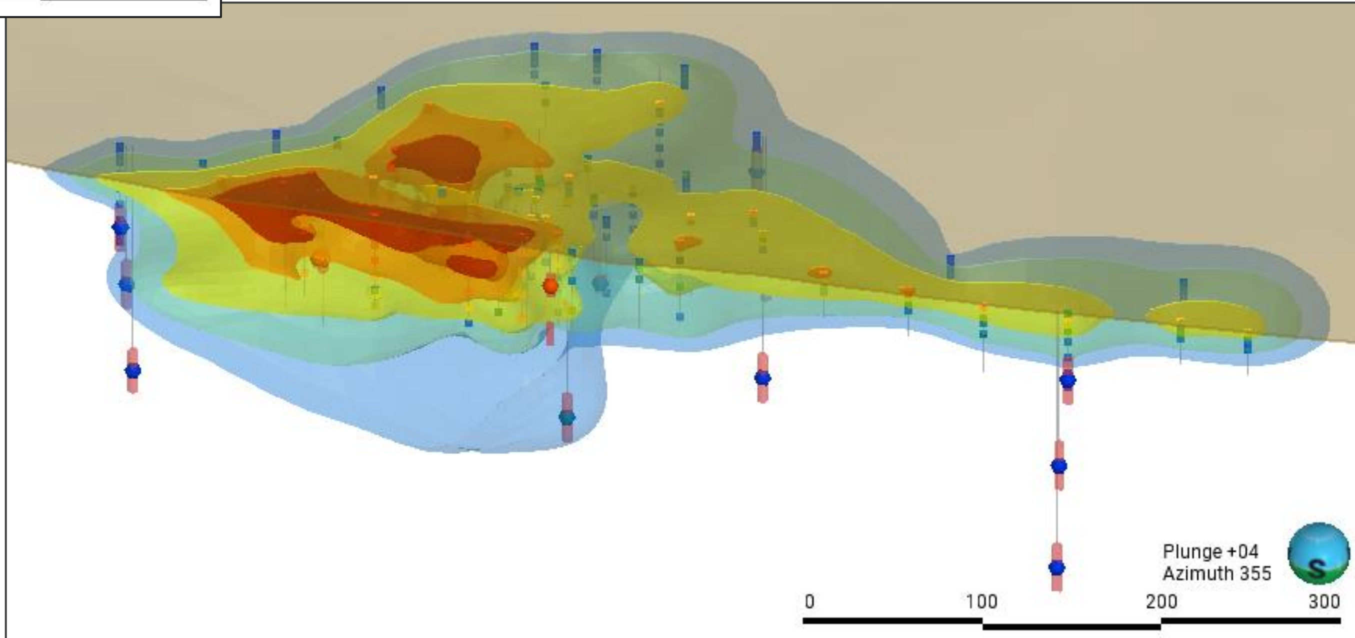
Volume > 100 mg/L: 679,000 m3
Cl mass > 100 mg/L: 115 t

Well screen with GW sample

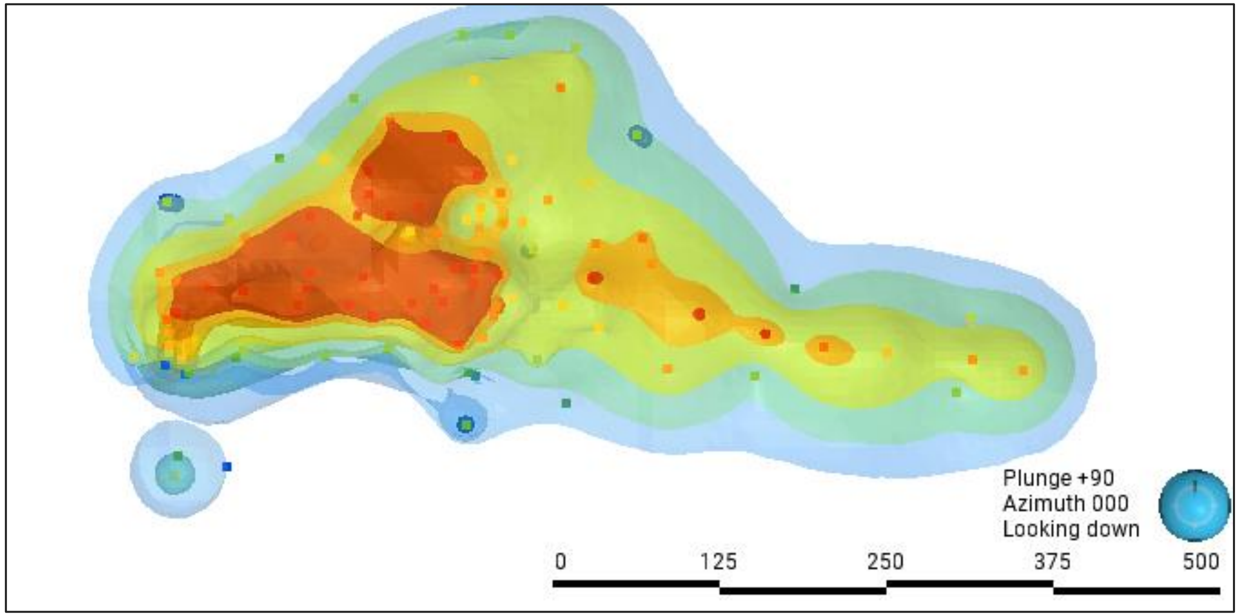
Scaled soil sample

Cl (mg/L)

	100.0 – 250.0
	250.0 – 1000.0
	1000.0 – 5000.0
	5000.0 – 10000.0
	> 10000.0



Variability of Correlation Coefficient on Chloride Plumes



Dissolved Chloride Plume
Groundwater + Soil (mg/kg x 8.64)

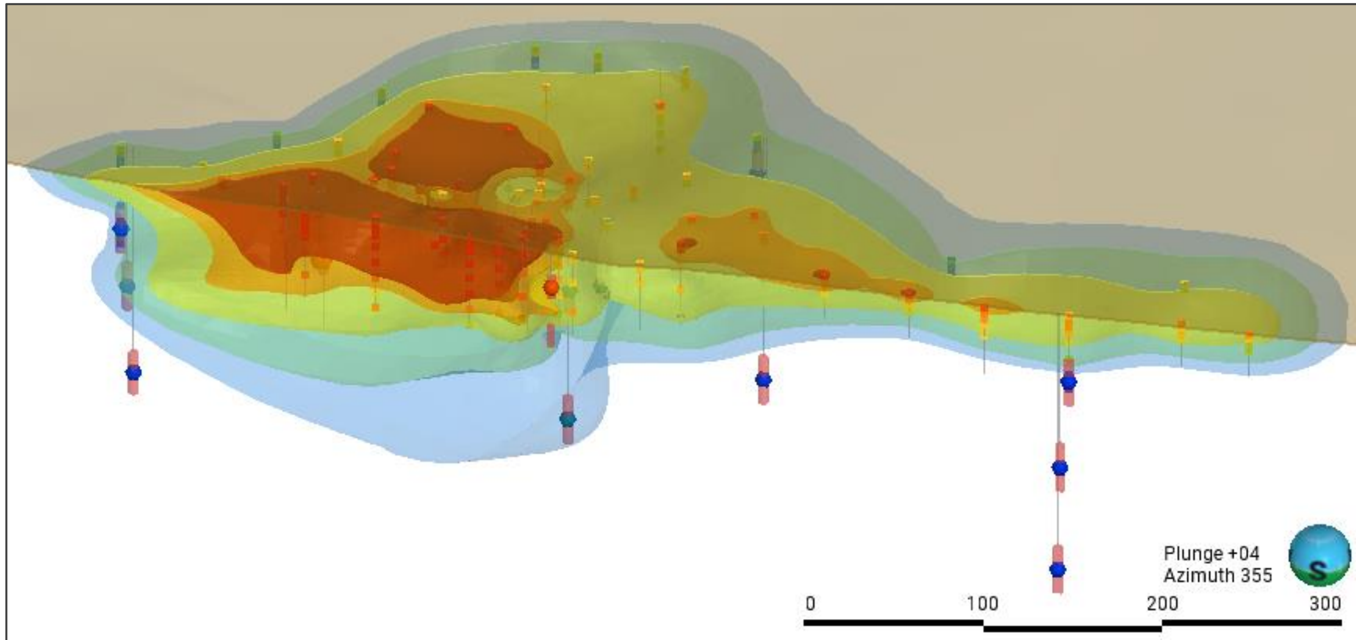
Volume > 100 mg/L: 900,000 m3
Cl mass > 100 mg/L: 217 t

Well screen with GW sample

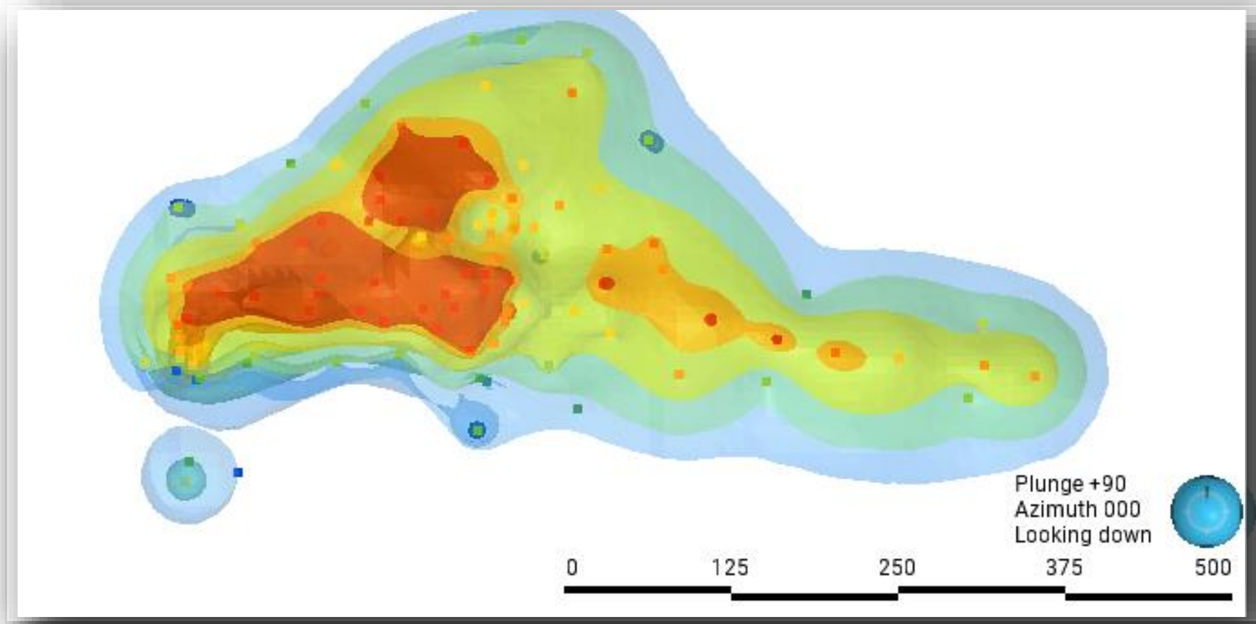
Scaled soil sample

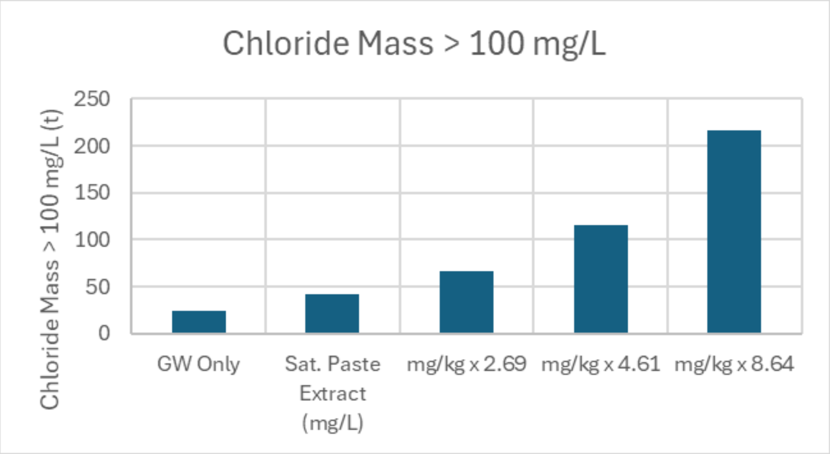
Cl (mg/L)

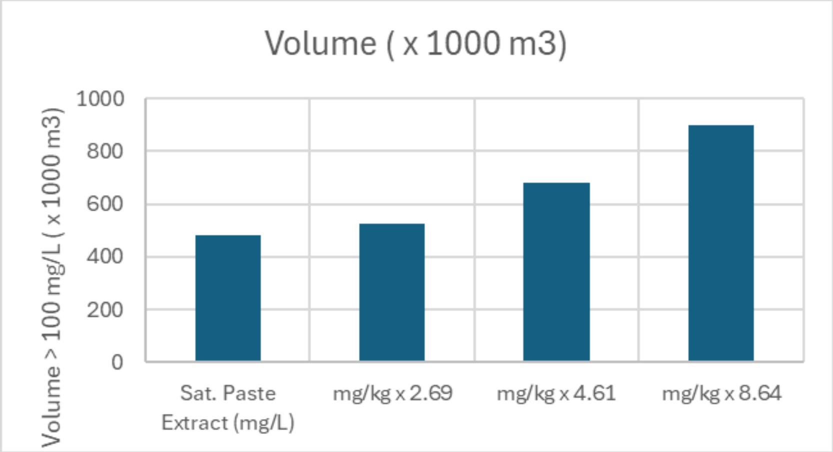
	100.0 – 250.0
	250.0 – 1000.0
	1000.0 – 5000.0
	5000.0 – 10000.0
	> 10000.0



Variability of Correlation Coefficient on Chloride Plumes

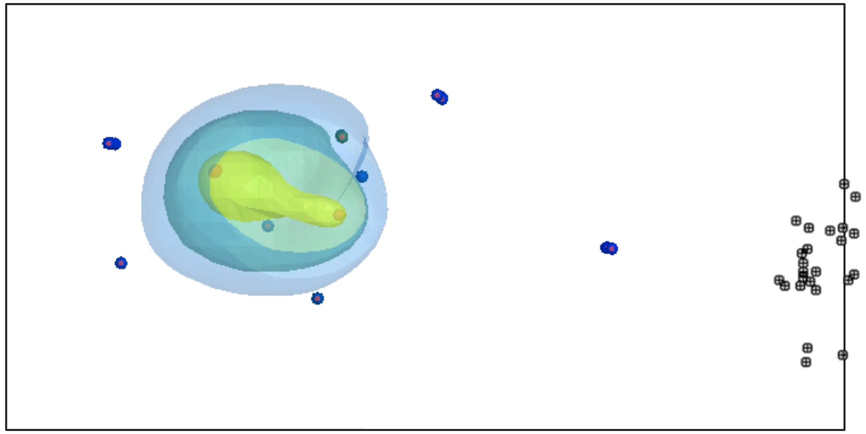


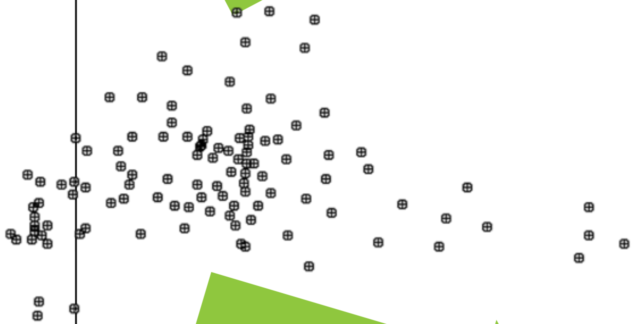


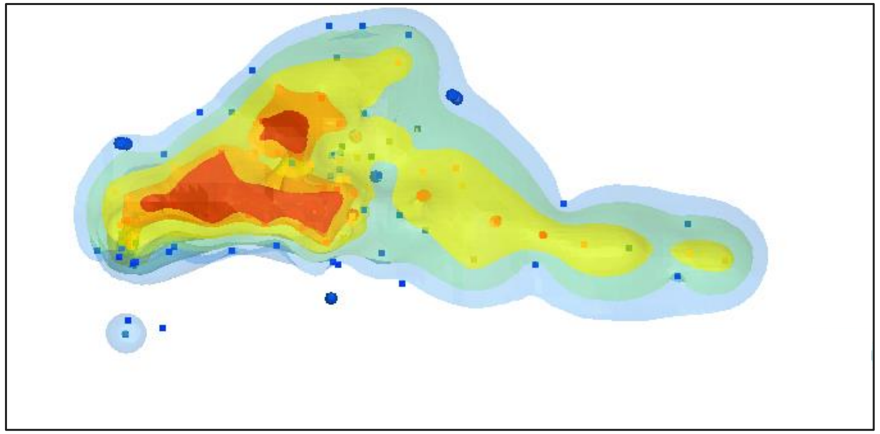


Enhancing Groundwater Chloride Plumes With Soil

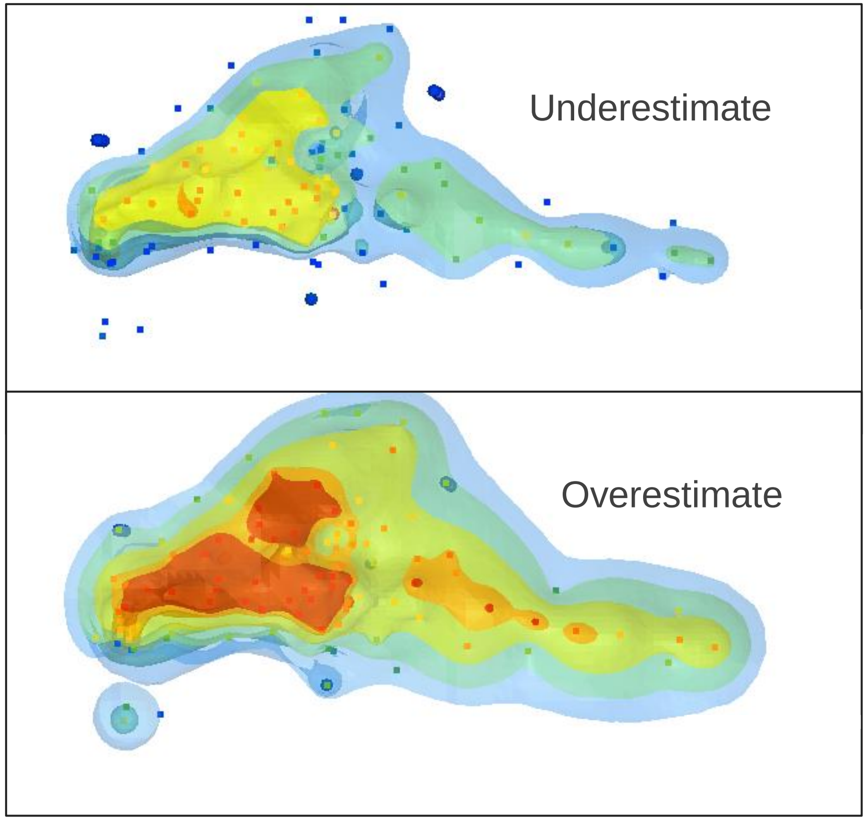
By optimizing the data we routinely collect we can enhance our groundwater plumes.







An incorrect correlation coefficient can over or underestimate your plume.



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- Anna Best, Carl Ayer, Gabrielle Marchand –Montrose Environmental Company

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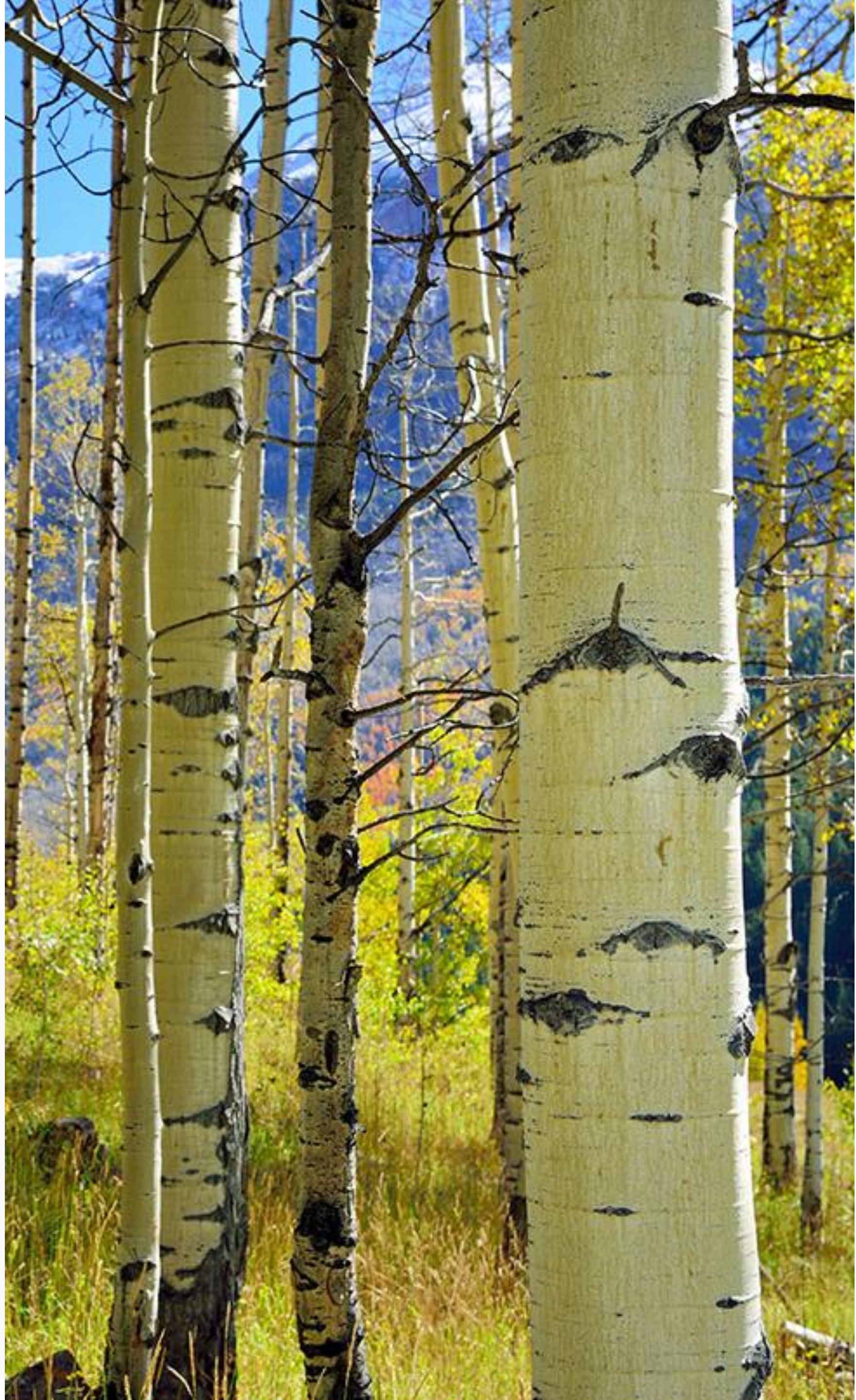

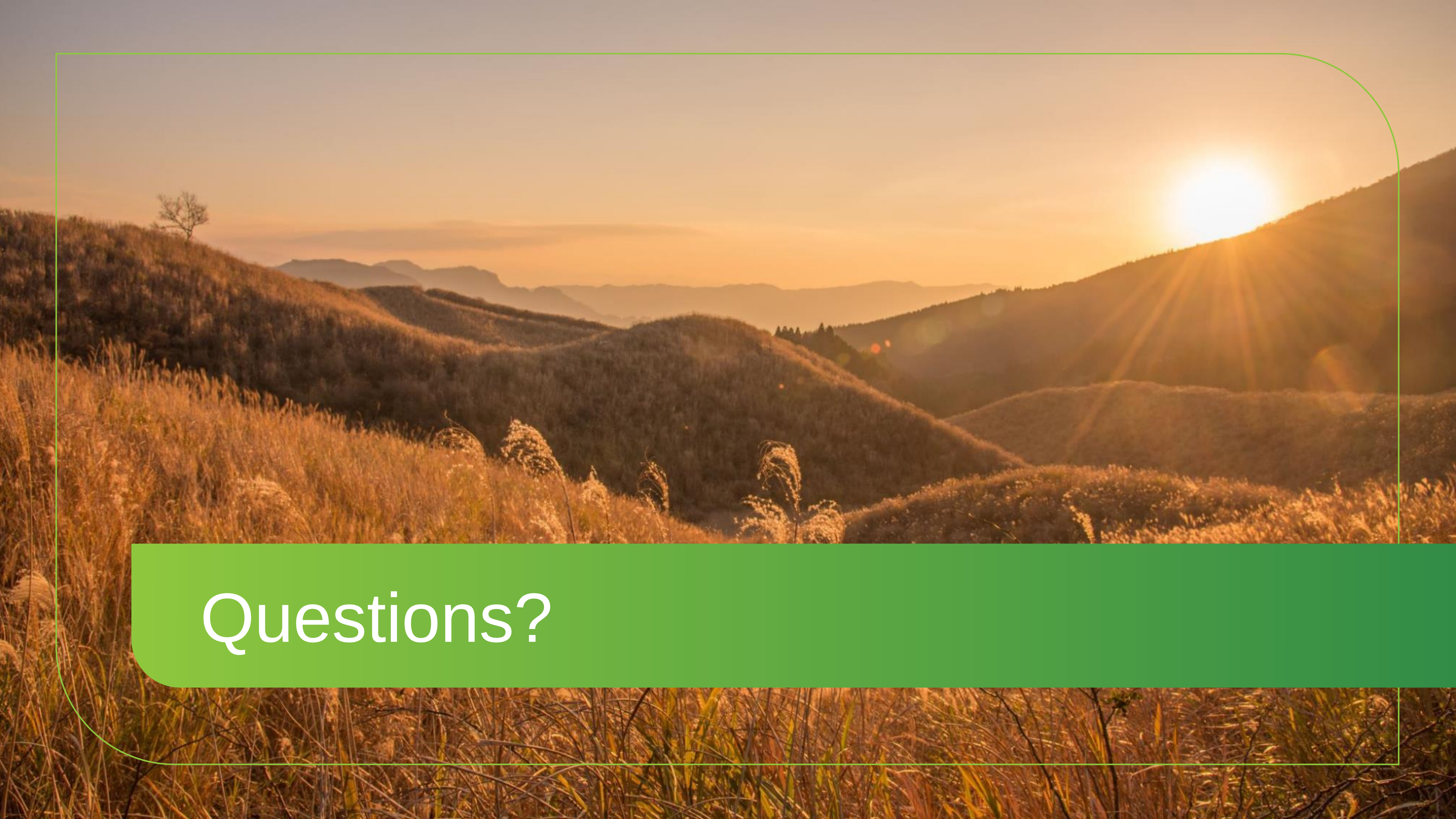

Questions?

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Montrose At A Glance

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We implement environmental solutions that scale.

- ~3,200 employees
- ~100 locations worldwide
- ~5,600 clients from the private and public sectors
- 6 patents issued in 2022, for a total of 18 patents

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- Conclusions based on sites that were reviewed as part of this project and can not necessarily be applied to all sites.

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