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Effect of Soil Transfer on Groundwater Quality

Statistical Analysis and Numerical Modeling

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EcoNomics

Soil Transfer Alternatives

A

Stack 1

Dig & Dump

Soil Loss $1.6 m

Landfill

Elevated salinity

Reuse

ESRD Beneficial Use Policy $290 K

B

Stack 2

Includes

- Above-grade production **waste** (licensed)
- An engineered clay liner
- Undergoing capping

Question

Will transferring from stack 1 to stack 2 affect soil and GW quality?

Method

1. Define parameters that characterise soil quality
2. Compare the parameters between Stack 1 and Stack 2
3. If soil quality parameters of the two stacks are statistically different, then the effect on GW should be assessed

Method

Step 1

Define parameters that characterise soil quality:

- 16 salinity and metal parameters were identified as representative for soil quality. For example: EC, pH, sodium, sulfate, cadmium, arsenic, etc.

Method

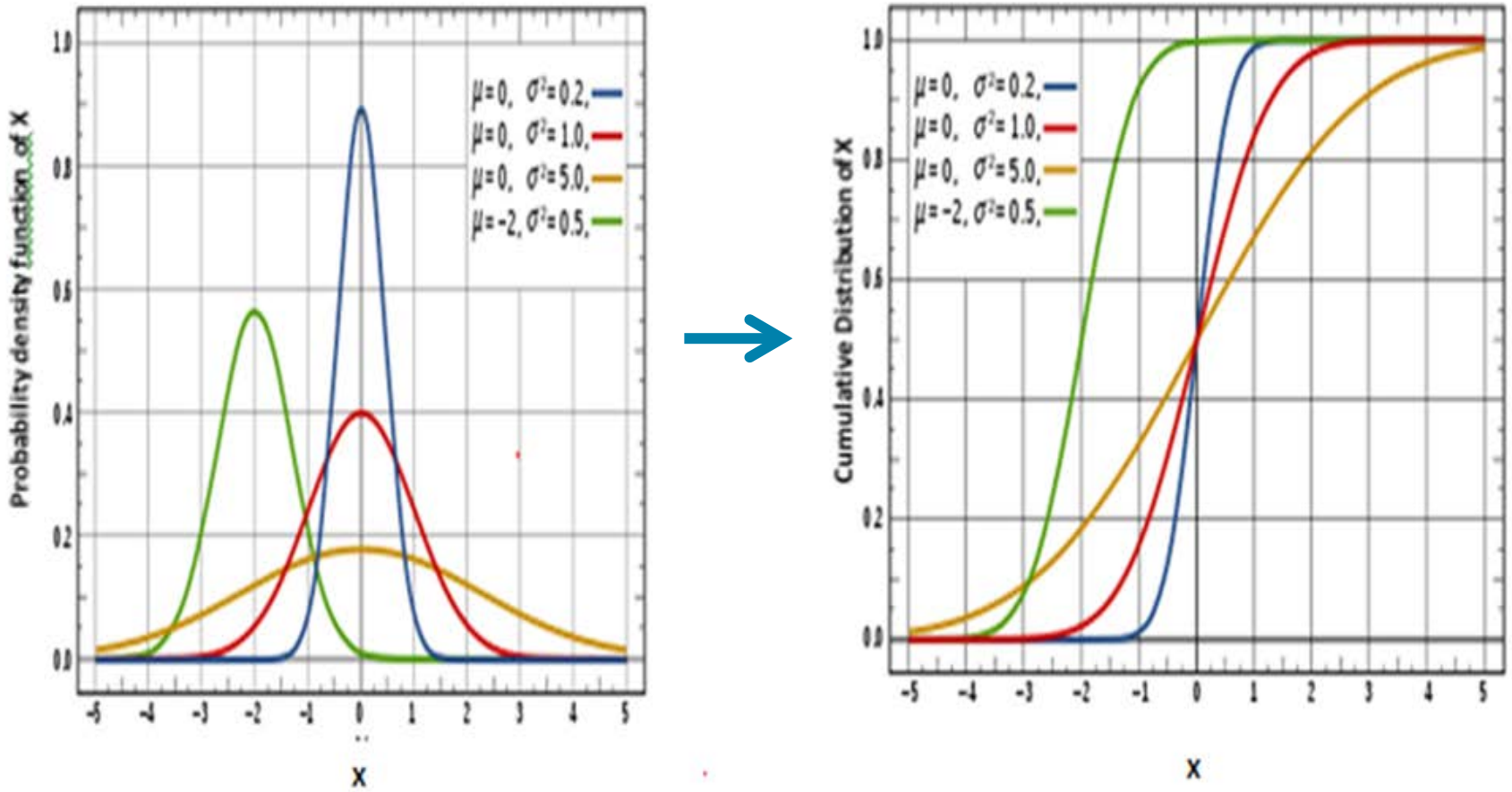
Step 2

Compare parameters between Stack 1 and Stack 2:

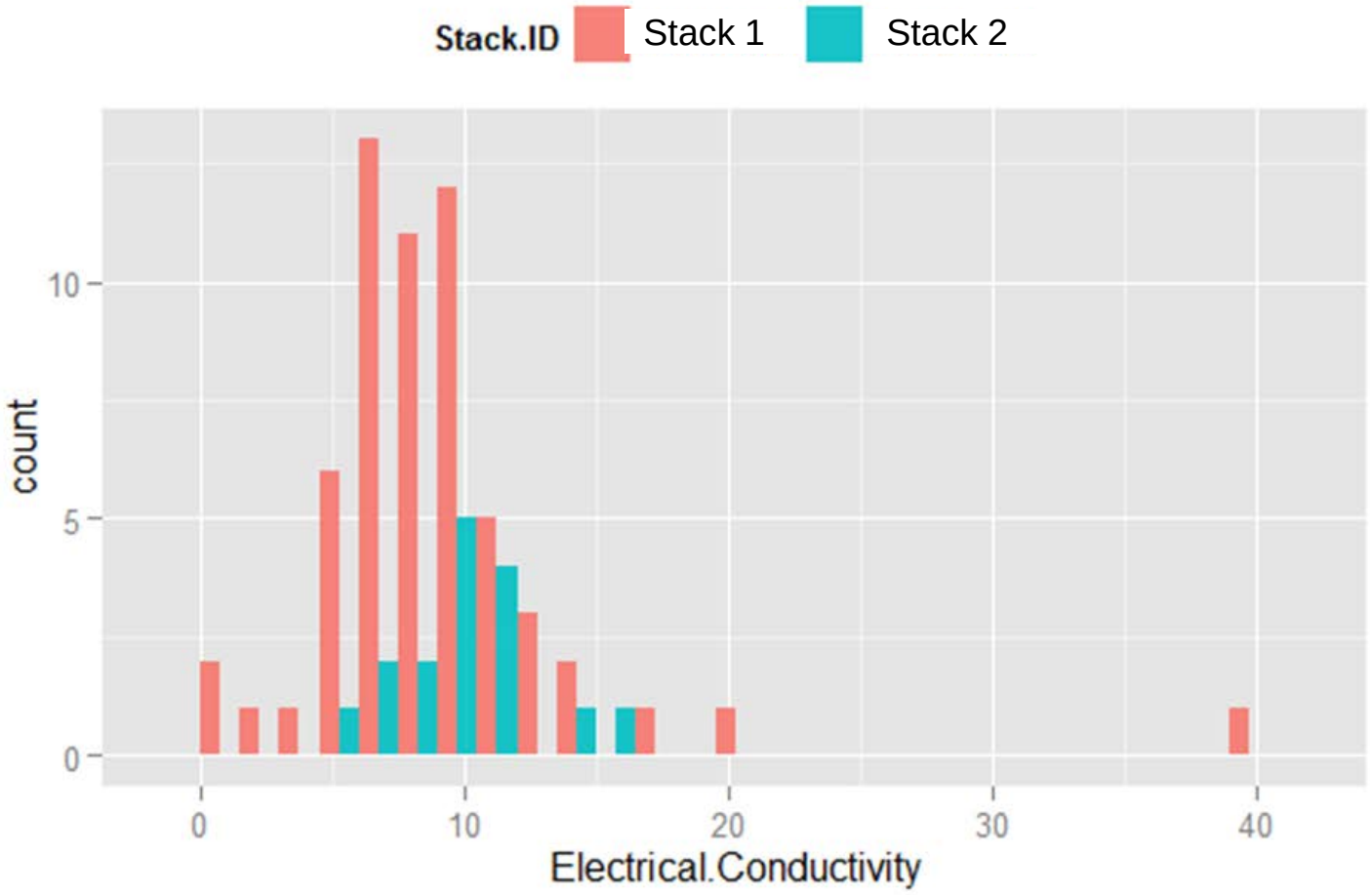
- Each of the 16 parameters were compared statistically using:
  1. Visual comparison of probability distributions
  2. Statistical test (Kolmogorov- Smirnoff test)

Statistical analyses -Backround

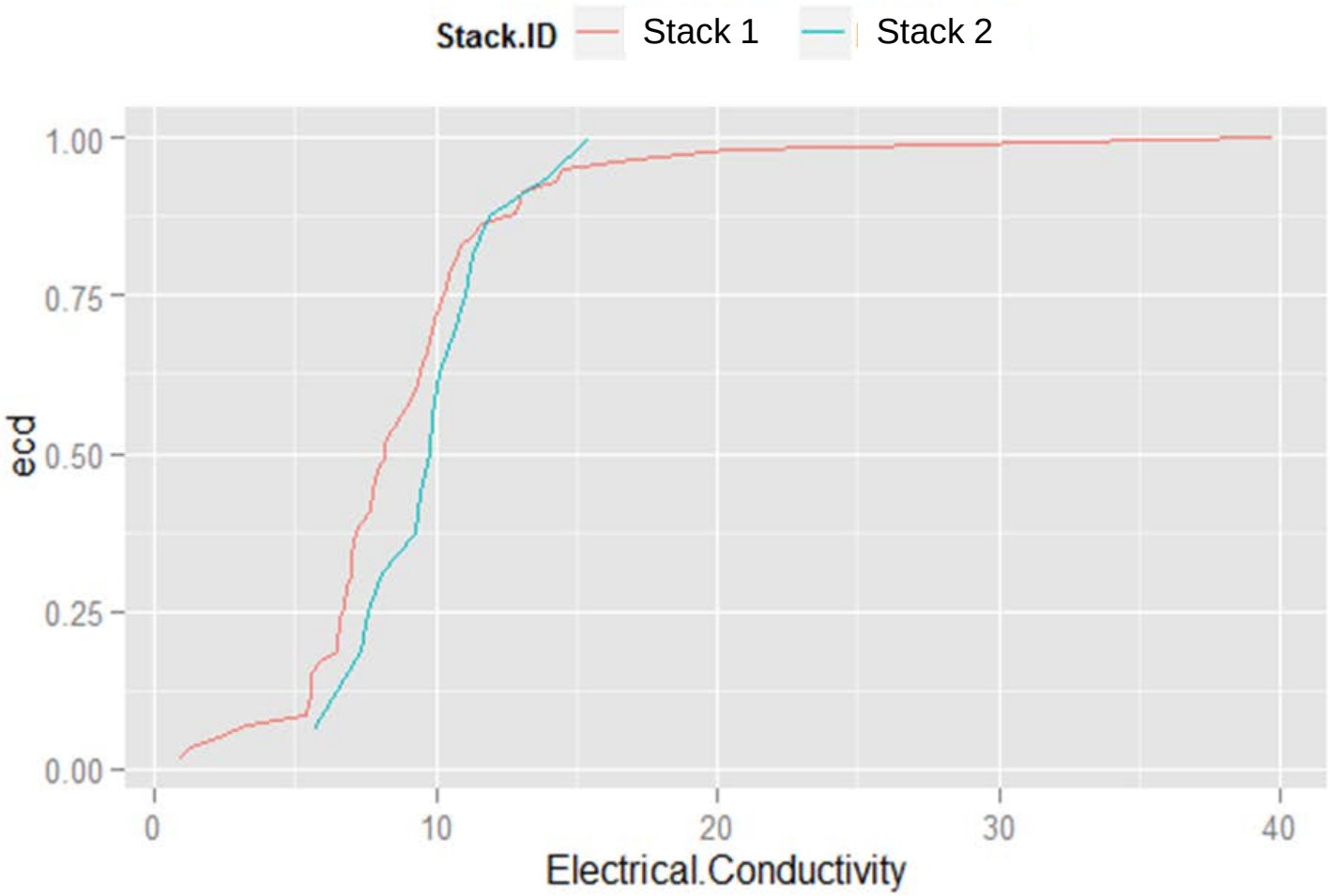
Schematic Plots of Normal Probability Distributions and their Corresponding Cumulative Distribution Functions with Means, μ, and Variances, $\tilde{A}^2$



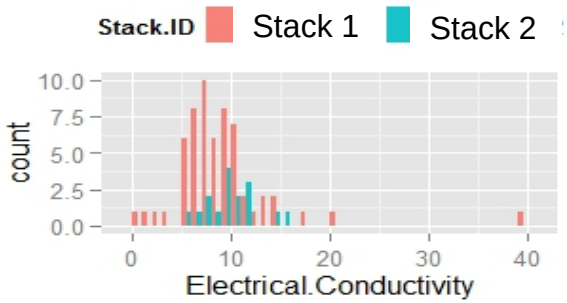
Results

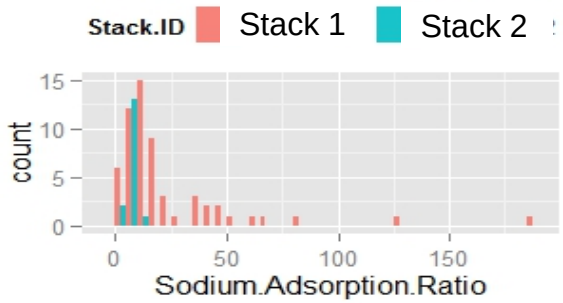

Stack.ID
Stack 1
Stack 2
count
10
5
0
0
10
20
30
40
Electrical.Conductivity

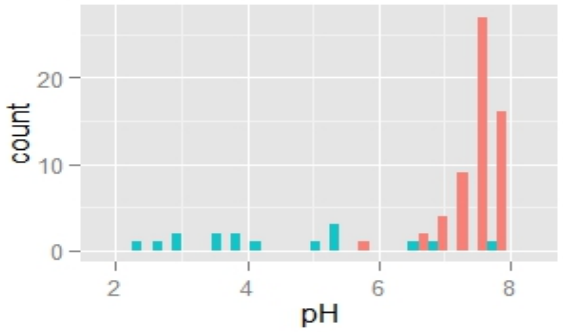
Results

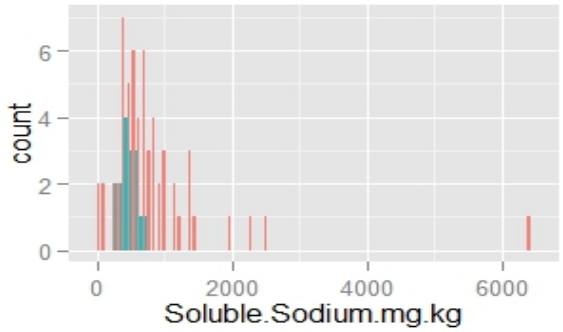

Stack.ID
Stack 1
Stack 2
1.00
0.75
0.50
0.25
0.00
ecd
0
10
20
30
40
Electrical.Conductivity

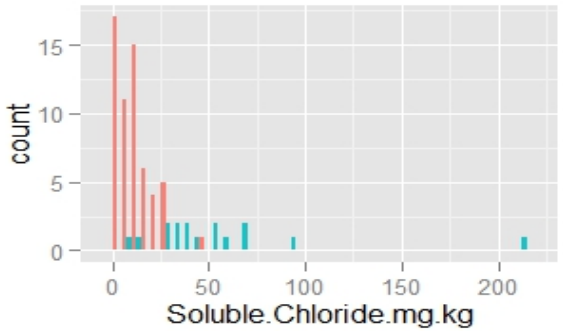
Results

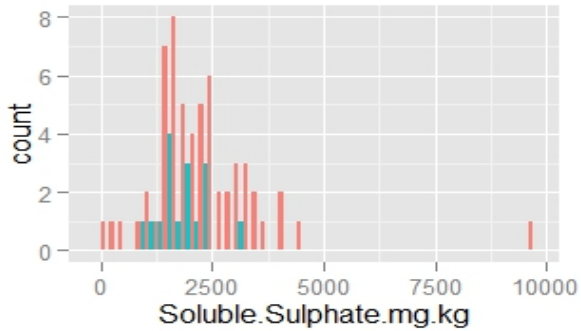






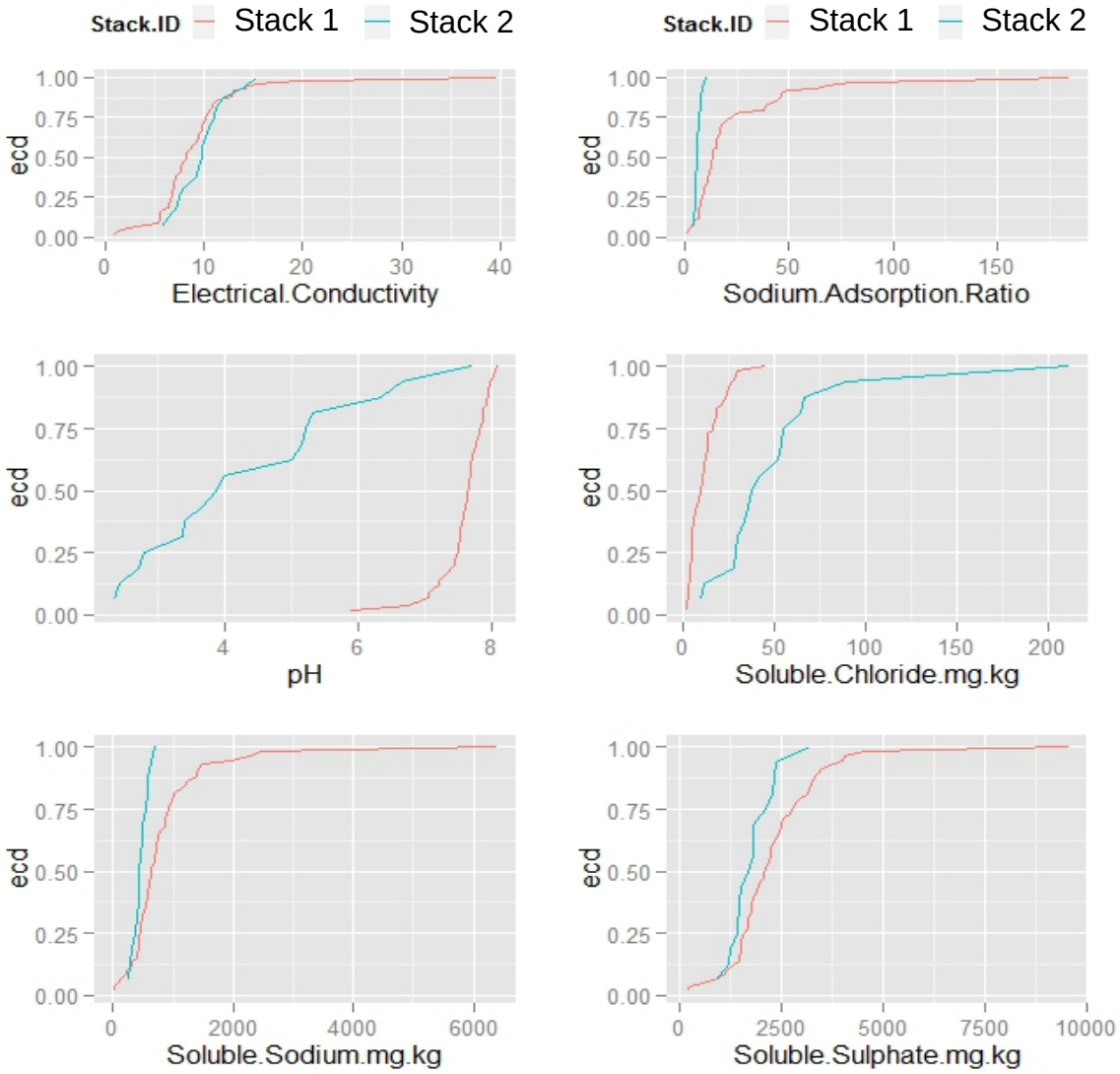






Comparing histograms based on multiple samples >12

Results



Comparing cumulative probability distributions based on multiple samples

ecd = empirical cumulative distribution (in R)

Kolmogorov-Smirnoff Test

K–S Test Comparing Salinity Parameters in Stack 1 and Stack 2

Parameter	P-Value	Is there statistical evidence that parameter values in Stack 1 and Stack 2 are <u>different</u>?
EC	.274 >.05	No (they are similar)
Sodium adsorption ratio	7.4×10^{-6} <.05	Yes (Stack 1 parameter value is higher)
pH	1.2×10^{-9} <.05	Yes (Stack 1 parameter value is higher)
Soluble chloride (mg/kg)	1.5×10^{-7} <.05	Yes (Stack 1 soil parameter is higher)
Soluble sodium (mg/kg)	.006 <.05	Yes (Stack 1 soil parameter is higher)
Soluble sulfate (mg/kg)	7.1×10^{-7} <.05	Yes (Stack 1 soil parameter is higher)

Solute Transport Modeling

Objective:

Predict changes in groundwater chemistry beneath Stack 2. Focus on soluble Sodium and Sulfate

Methodology:

Use a numerical flow and transport model, HYDRUS1D, to predict the effect of added stack on groundwater quality

Information

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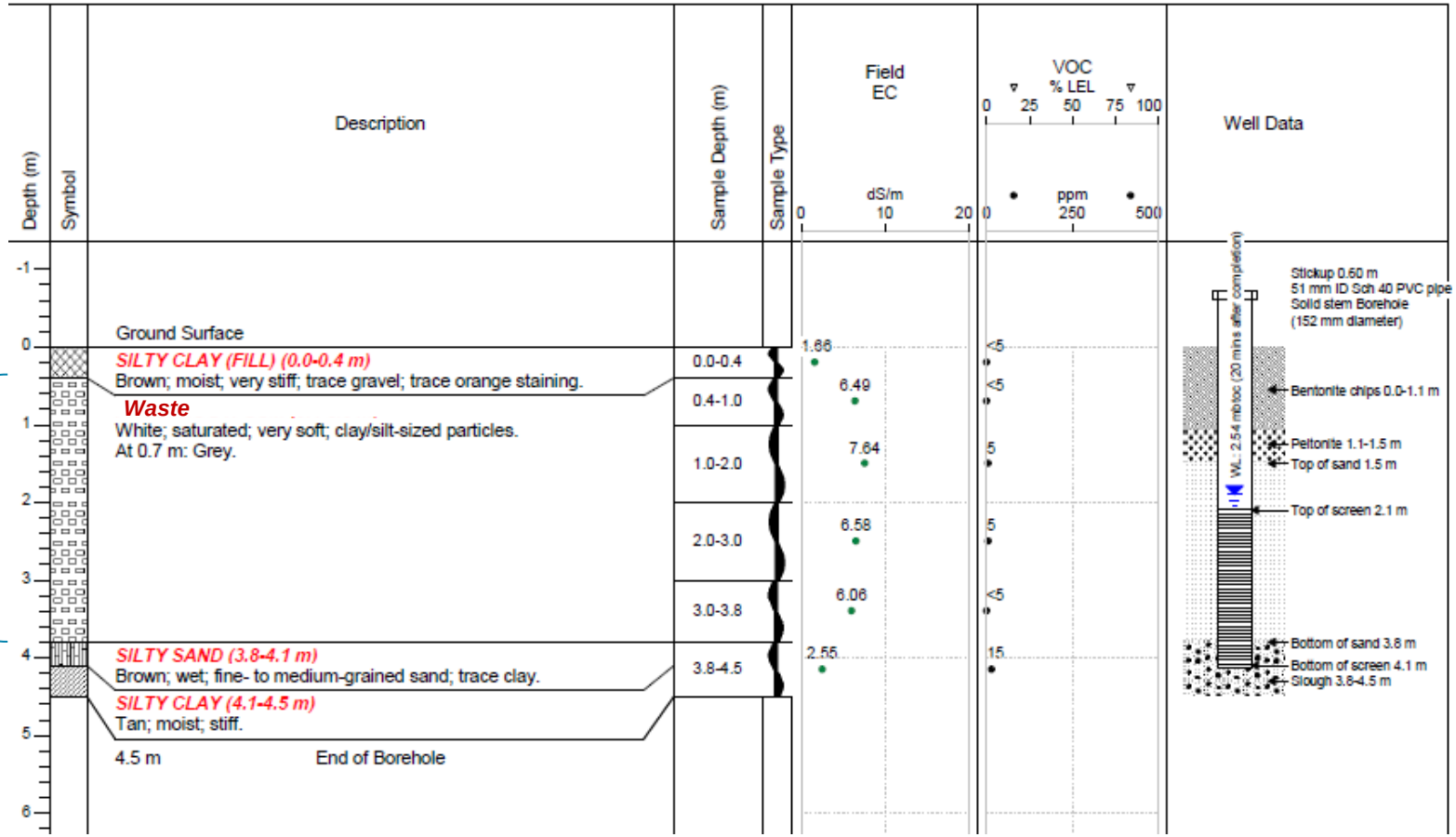
Borehole # S12-18/12-8-4
PROJECT # 307074-01460.101

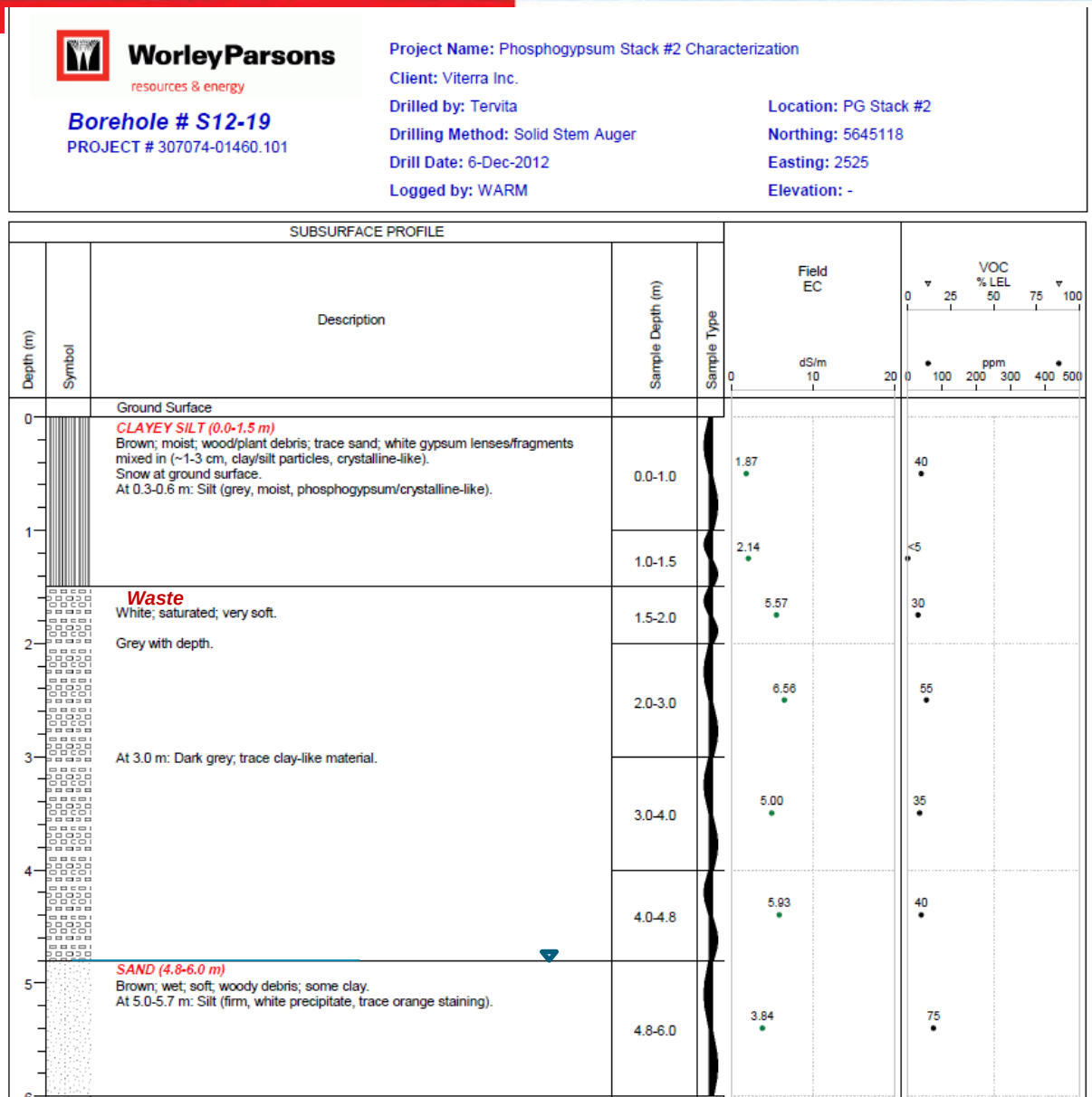
Project Name: Phosphogypsum Stack #2 Characterization
Client: Viterra Inc.
Drilled by: Tervita
Drilling Method: Solid Stem Auger
Drill Date: 6-Dec-2012
Logged by: VANR
Location: PG Stack #2
Northing: 5644828
Easting: 2564
Elevation: -



Production waste

Information

Production waste



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Borehole # S12-19
PROJECT # 307074-01460.101

Project Name: Phosphogypsum Stack #2 Characterization
Client: Viterra Inc.
Drilled by: Tervita
Drilling Method: Solid Stem Auger
Drill Date: 6-Dec-2012
Logged by: WARM
Location: PG Stack #2
Northing: 5645118
Easting: 2525
Elevation: -

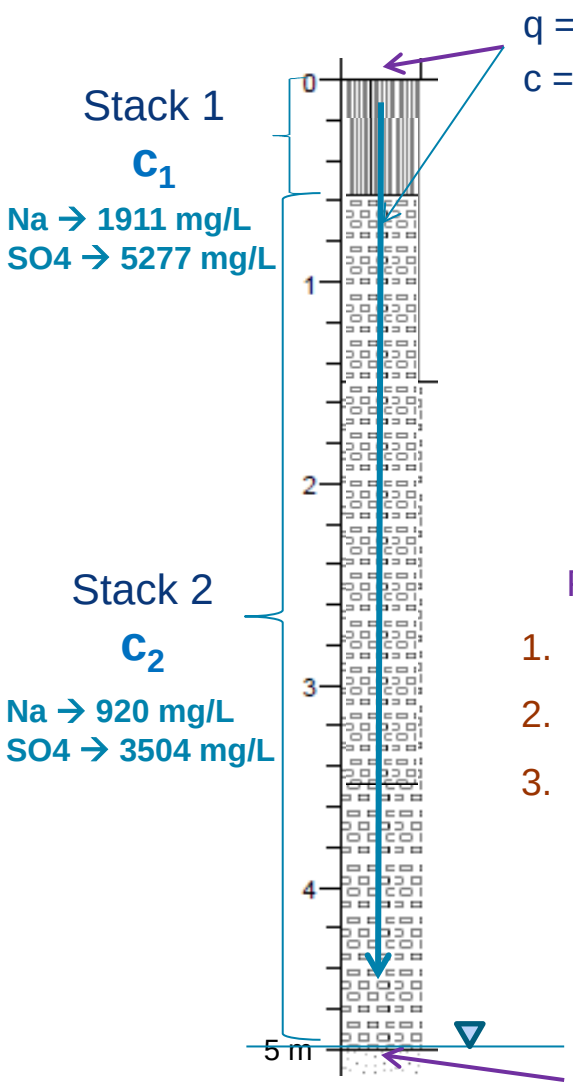
SUBSURFACE PROFILE

Depth (m)	Description	Sample Depth (m)	Field EC (dS/m)	VOC % LEL
0	Ground Surface			
0	***CLAYEY SILT (0.0-1.5 m)*** Brown; moist; wood/plant debris; trace sand; white gypsum lenses/fragments mixed in (~1-3 cm, clay/silt particles, crystalline-like). Snow at ground surface. At 0.3-0.6 m: Silt (grey, moist, phosphogypsum/crystalline-like).	0.0-1.0	1.87	40
1		1.0-1.5	2.14	<5
1	***Waste*** White; saturated; very soft.	1.5-2.0	5.57	30
2	Grey with depth.	2.0-3.0	6.56	55
3	At 3.0 m: Dark grey; trace clay-like material.	3.0-4.0	5.00	35
4		4.0-4.8	5.93	40
5	***SAND (4.8-6.0 m)*** Brown; wet; soft; woody debris; some clay. At 5.0-5.7 m: Silt (firm, white precipitate, trace orange staining).	4.8-6.0	3.84	75
6				

Conceptual Model

c_1 H 2 c_2 for Na

c_1 H 1.5 c_2 for SO_4



Production Waste Material Representation:

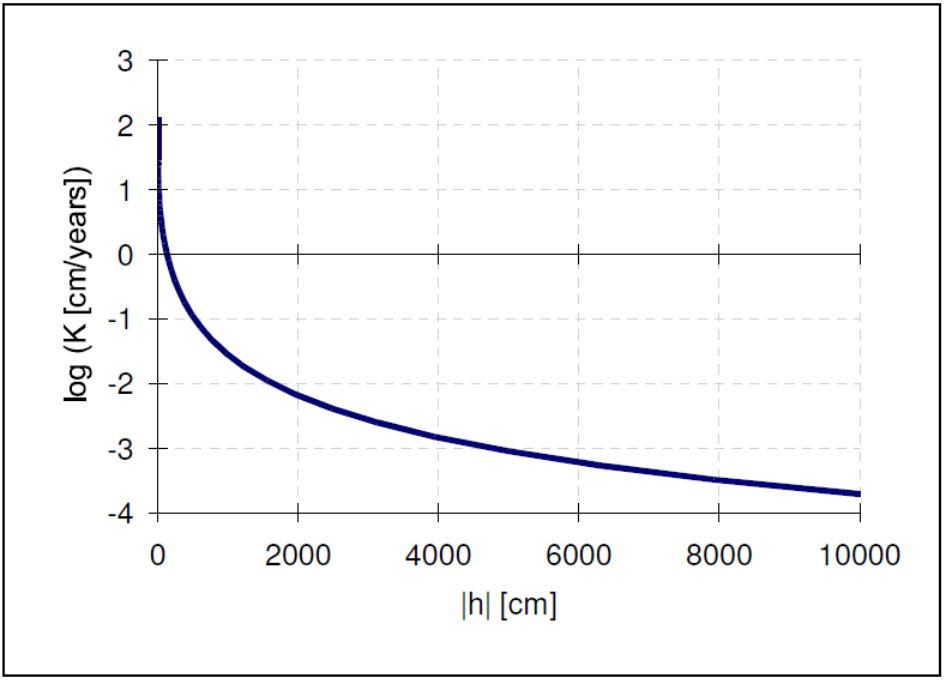
1. Silty Clay (low K_{s1} = 5.55 x 10^{-8} m/s)
2. Sandy Clay (K_{s2} = 3.33 x 10^{-7} m/s = 6 K_{s1})
3. Actual Waste Material (K_{s3} = 1.23 x 10^{-5} m/s > 200 K_{s1}) (Sandy Loam)

Conceptual Model

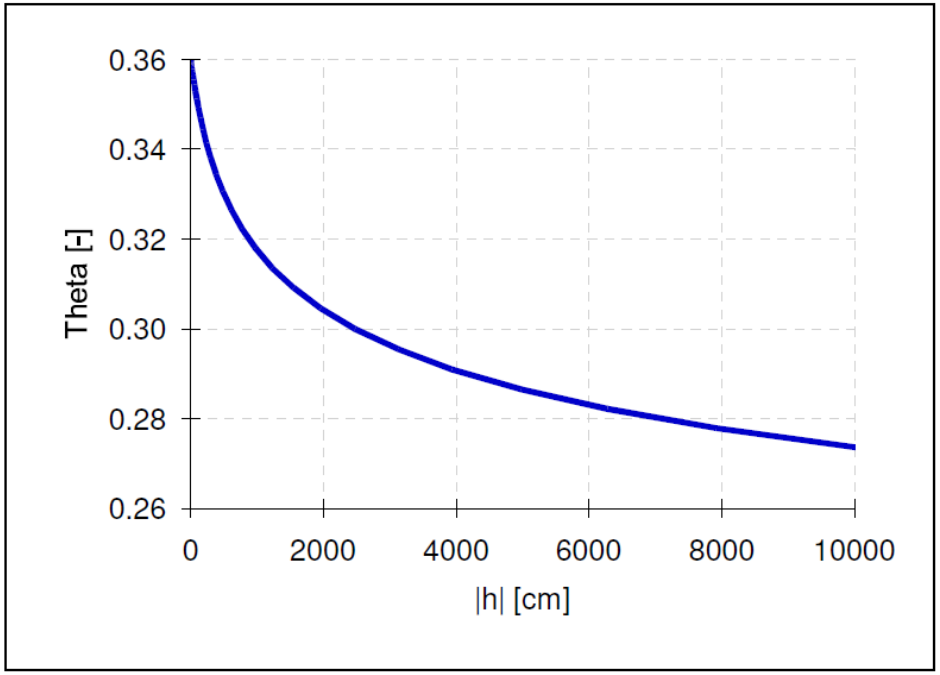
Hydraulic Properties (one of the production waste materials)

1. Silty Clay (low K) $K_s = 5.55 \times 10^{-8}$ m/s

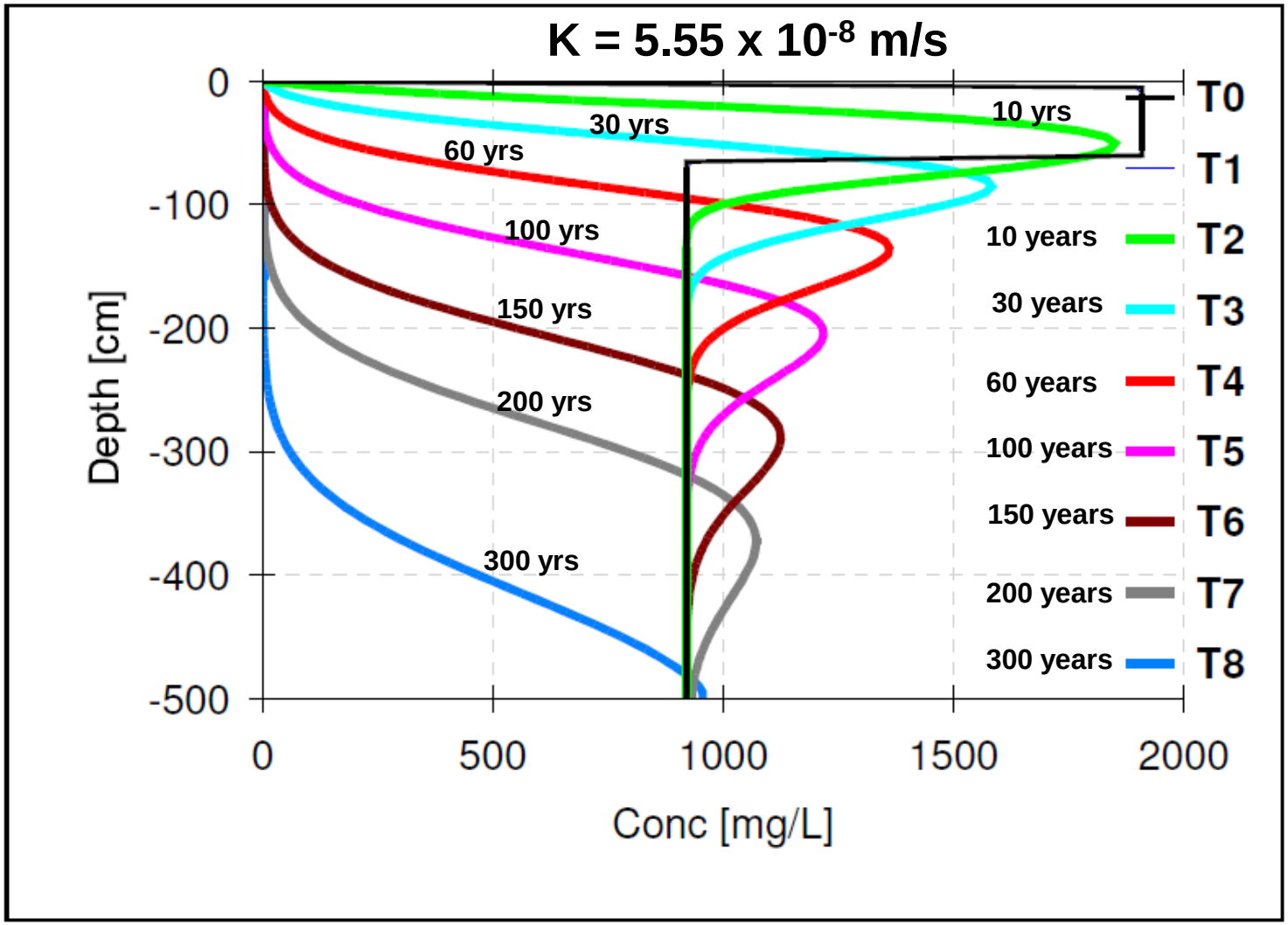
Hydraulic Properties: log K vs. h



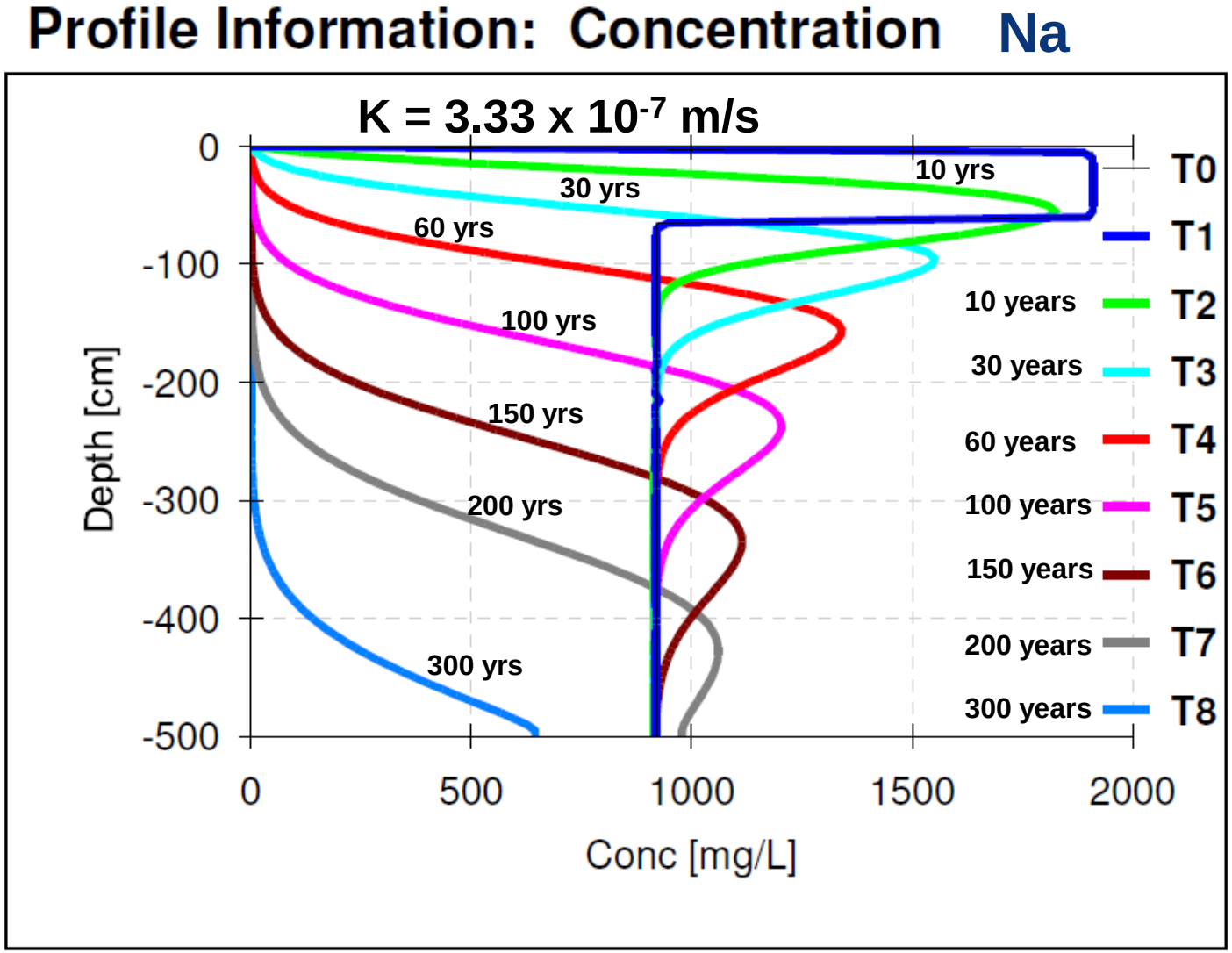
Hydraulic Properties: Theta vs. h



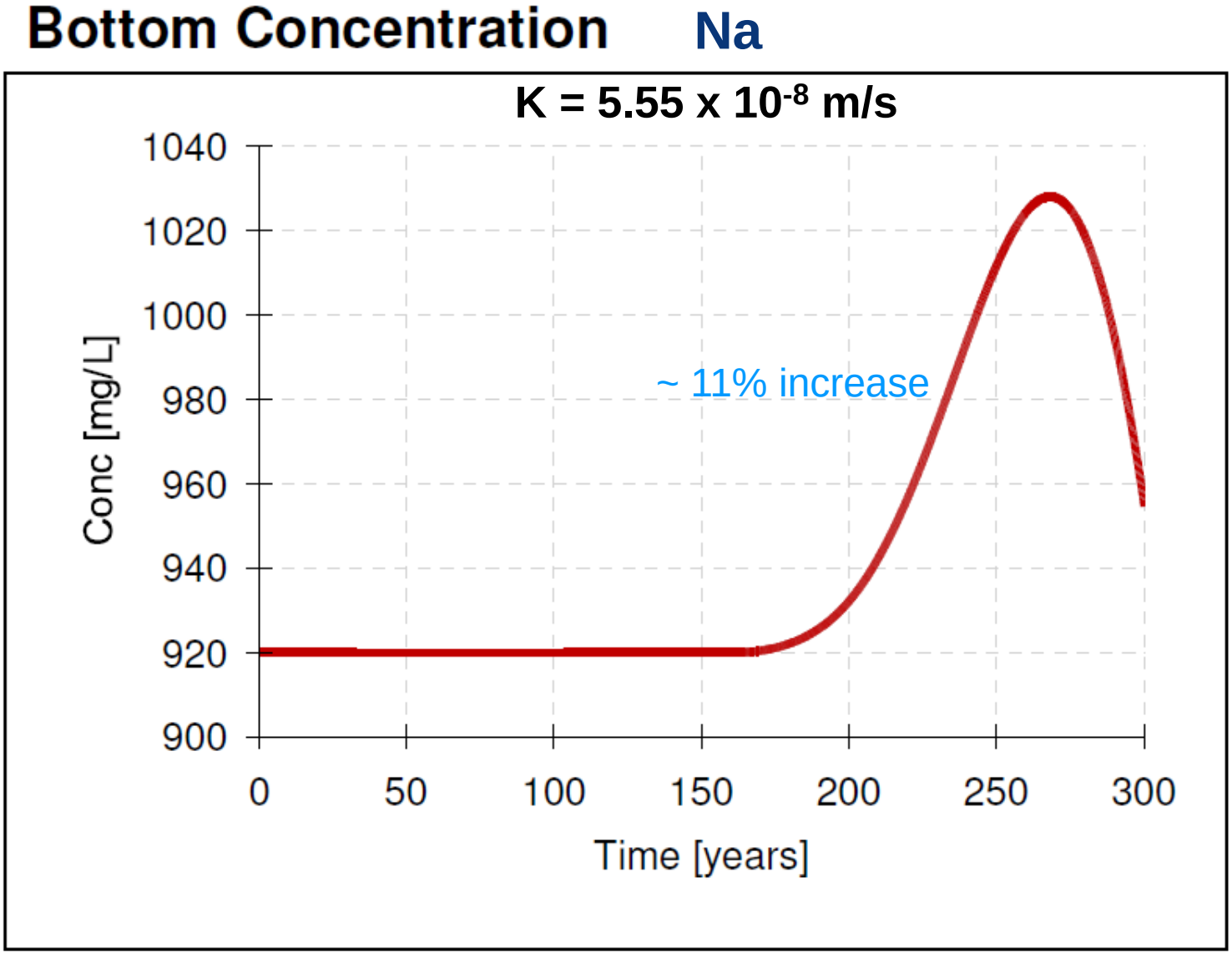
Results: Vertical Concentration Profiles – Sodium, Low K



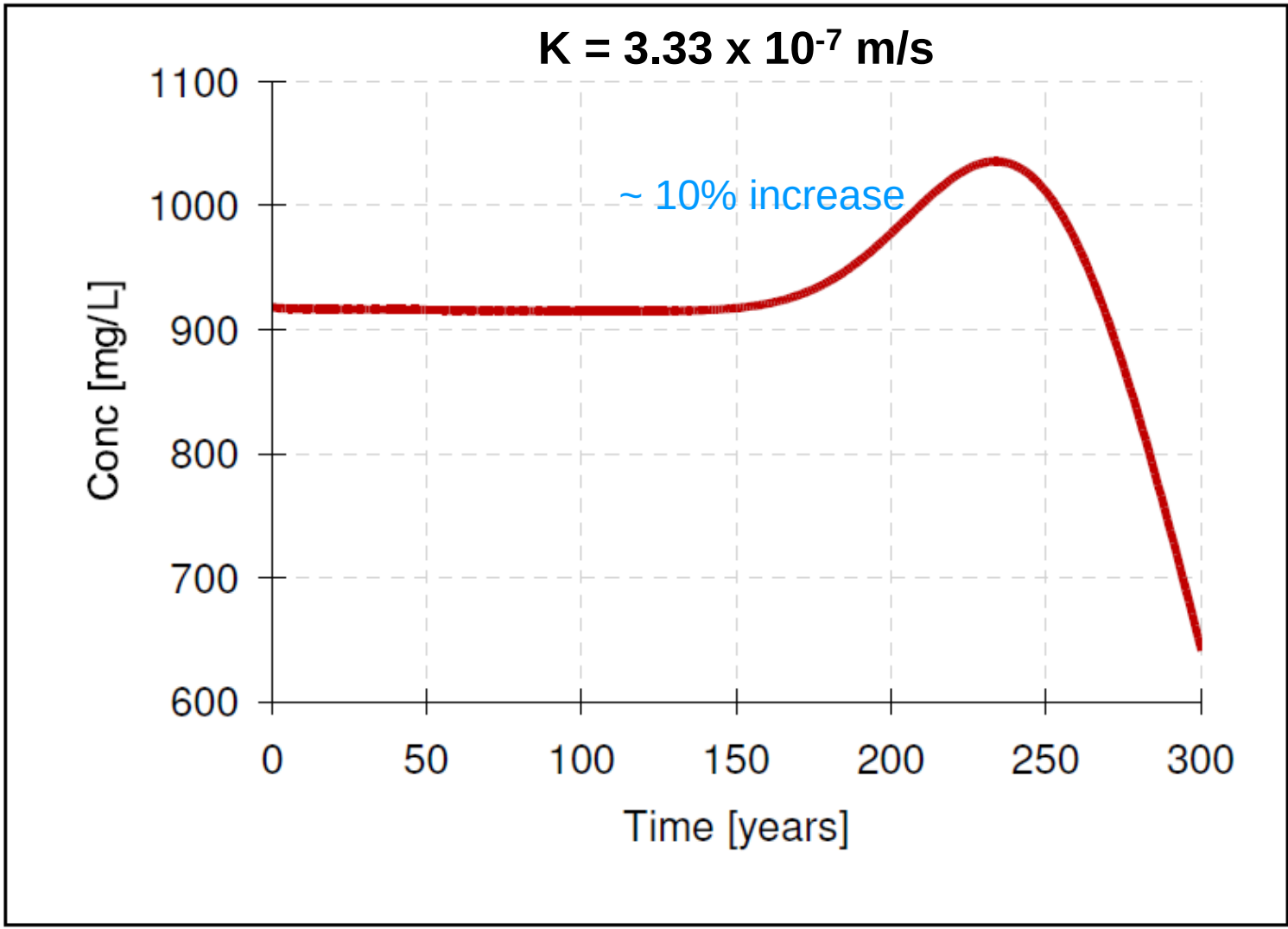
Results: Vertical Concentration Profiles – Sodium, K x 10



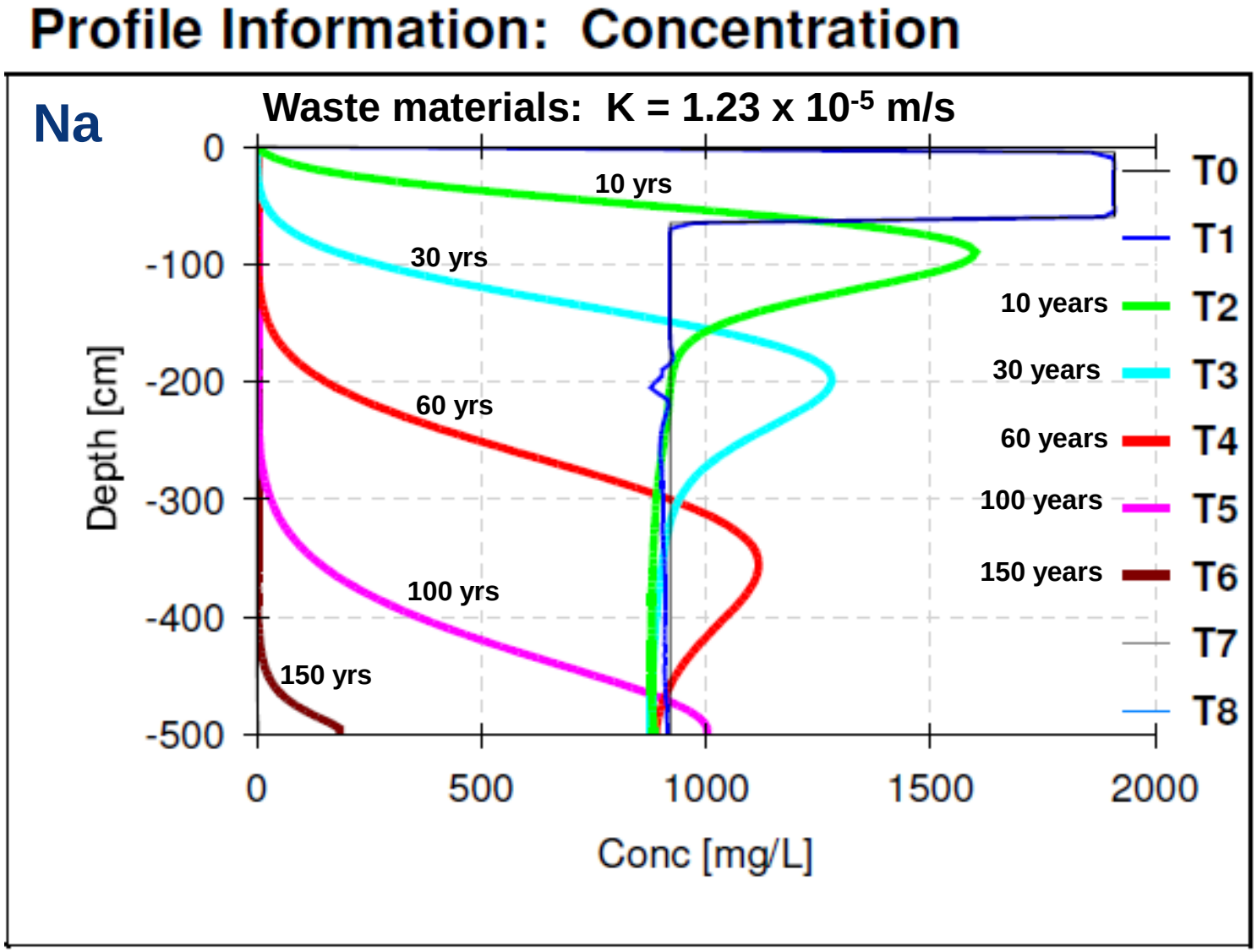
Simulated Sodium Concentrations at Bottom – Low K



Simulated Sodium Concentrations at Bottom – K x 10

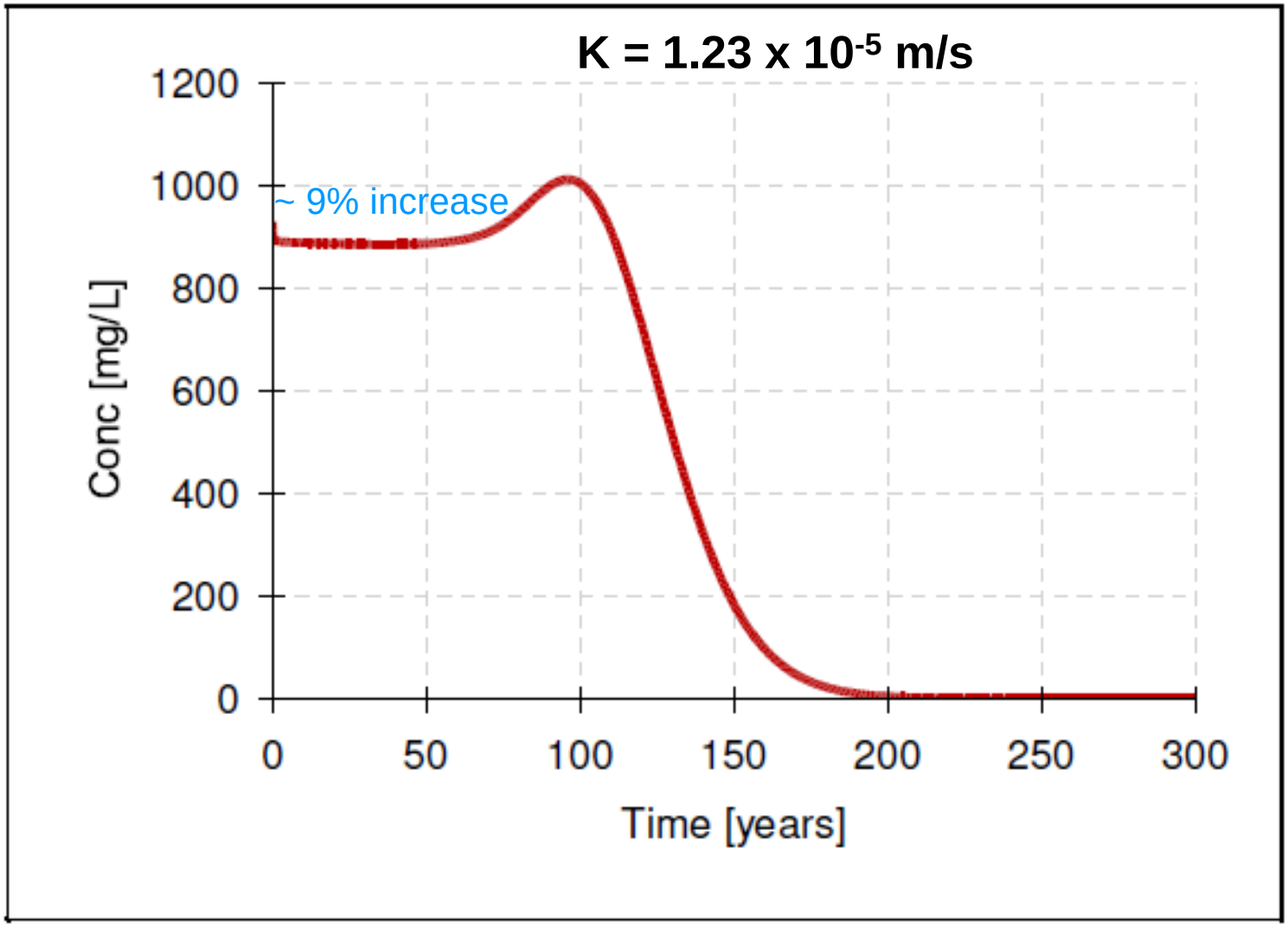


Simulated Sodium Concentration Profiles – Very High K



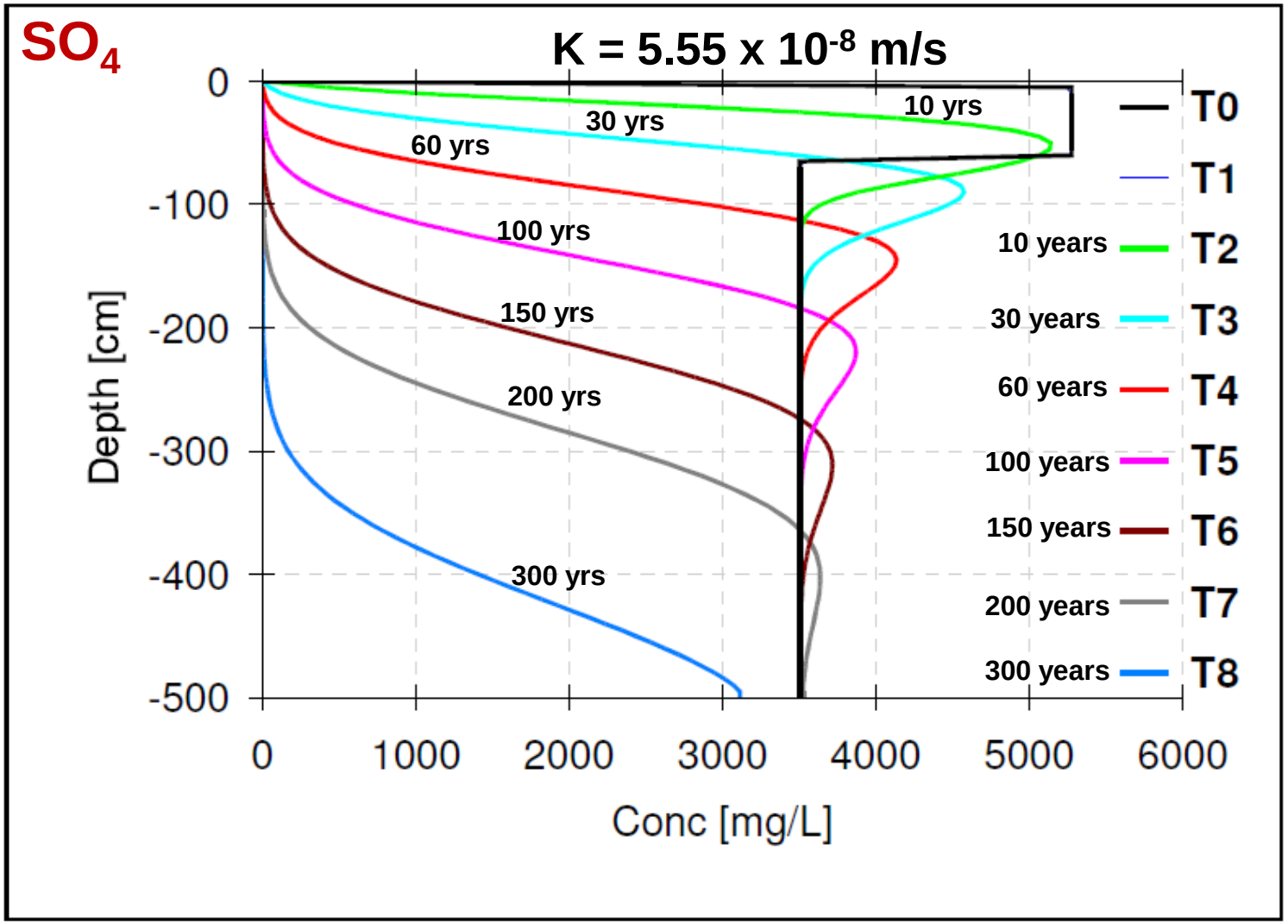
Simulated Sodium Concentrations at Bottom – Very High K

Na Bottom Concentration waste materials

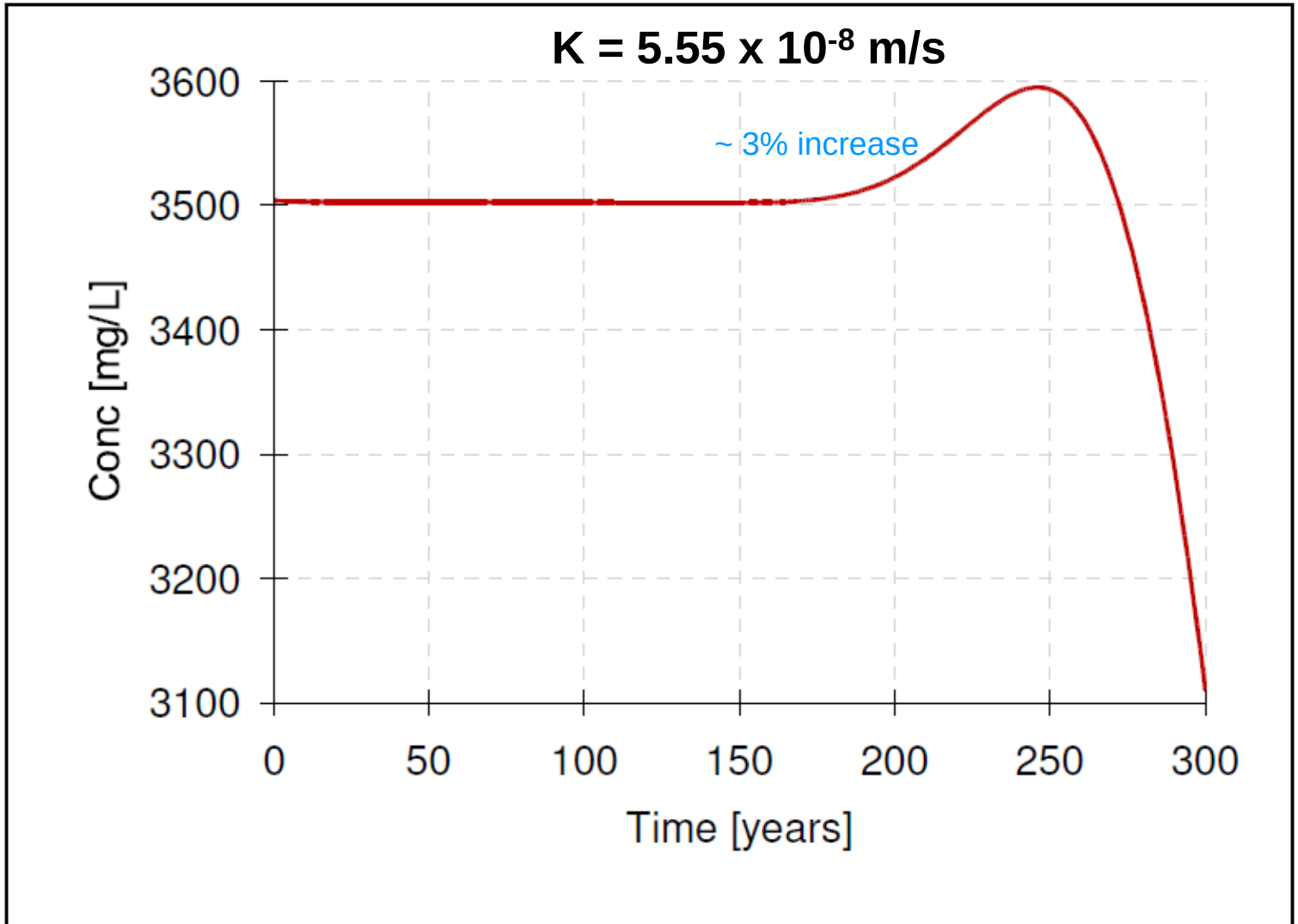


Simulated Sulfate Concentration Profiles – Low K

Profile Information: Concentration



Simulated Sulfate Concentrations at Bottom – Low K



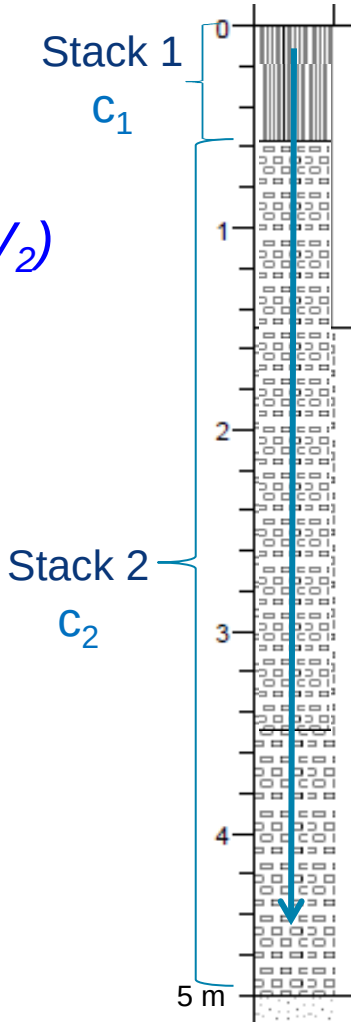
Conceptual Model

Simple mixing-cell:

$c_{mix} = (c_1V_1 + c_2V_2)/(V_1 + V_2)$

= 1019 mg/L of Na

→ 11% increase
(from 922 mg/L)



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c_1 H 1.5 c_2 for SO_4

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Conclusions

- Statistical analyses revealed that out of 16 soil parameters in the two stacks, five parameters are significantly different
- A 1D model of the two stacks was built to simulate the combined effect on concentrations within and beneath the soil column over time
- Simulations show that the addition of Stack1 materials to Stack 2 does not cause significant increase in concentrations
- Increasing Ks from 5.55×10^{-8} m/s to 1.23×10^{-5} m/s shortens transport time from 280 years to 80 years, but reduces the effect on groundwater quality

Thank you

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