

PFAS transport i den umættede zone under Korsør Brandskole Resultater fra 2 års kontinuerlig monitoring og perspektiv for modellering

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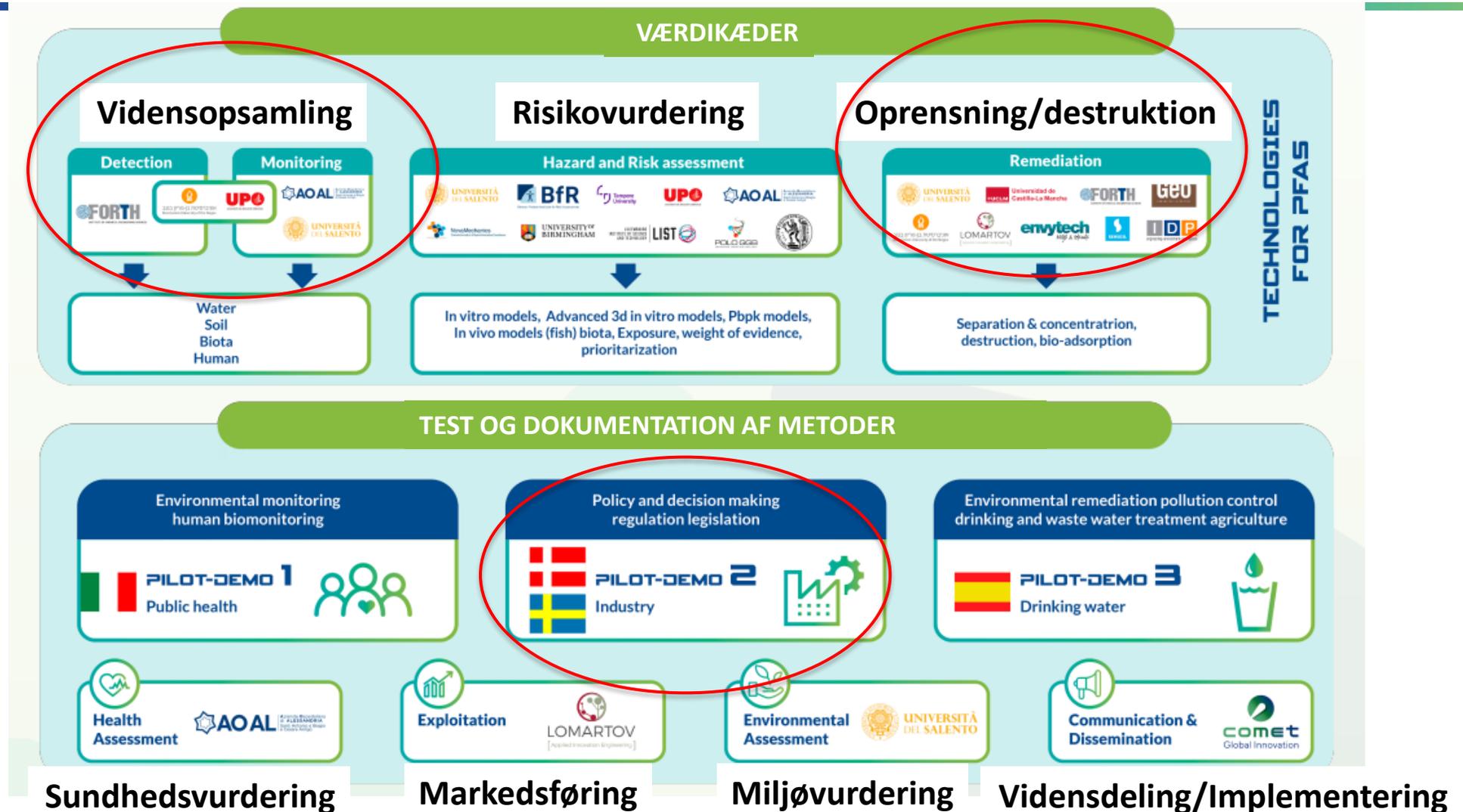
³Foundation for Research and Technology Hellas, Institute of Chemical Engineering Sciences, 26504 Patras, Greece

ATV Jord og Grundvand, Vingsted 4-5 marts 2025



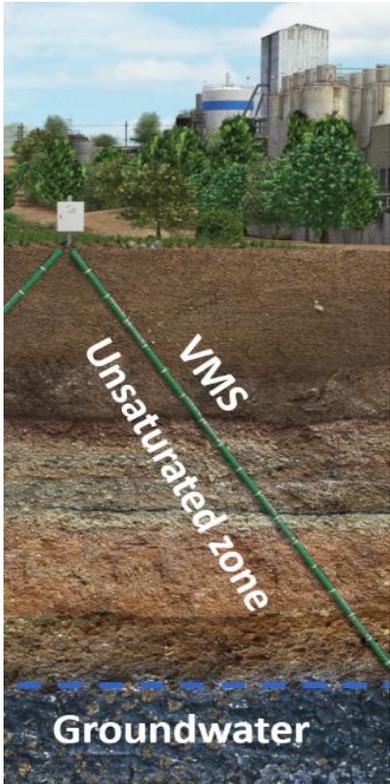
This project has received funding from the H2020 programme under Grant Agreement No. 101037509



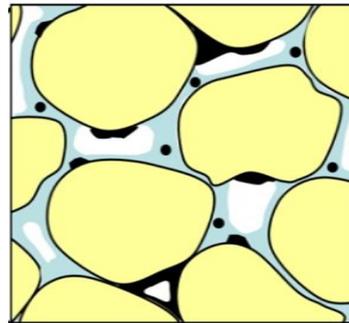


Pilot område:

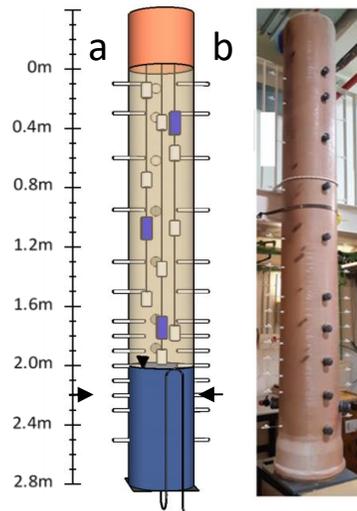
Prøvetagning og Monitoring
Tidsserier nedbør, vand og jord data



Pore scale study

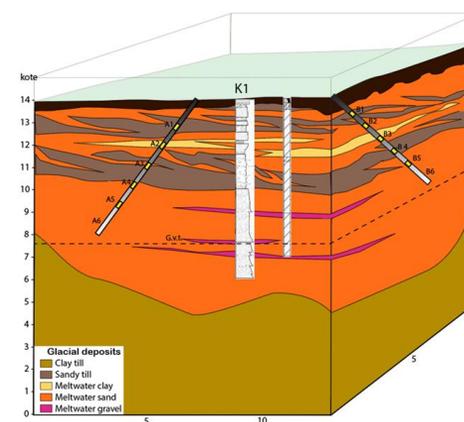


Lab scale study

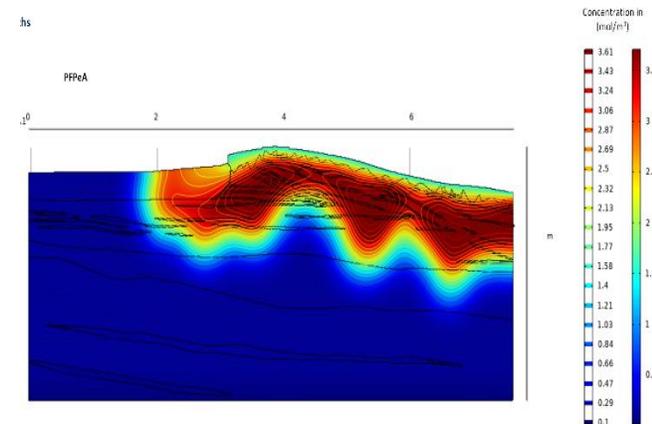
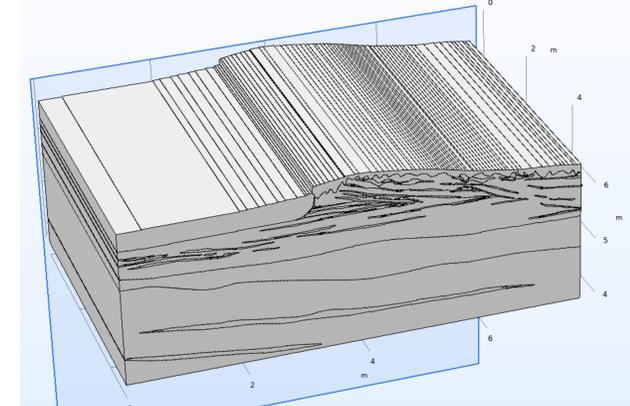


Parameterestimering

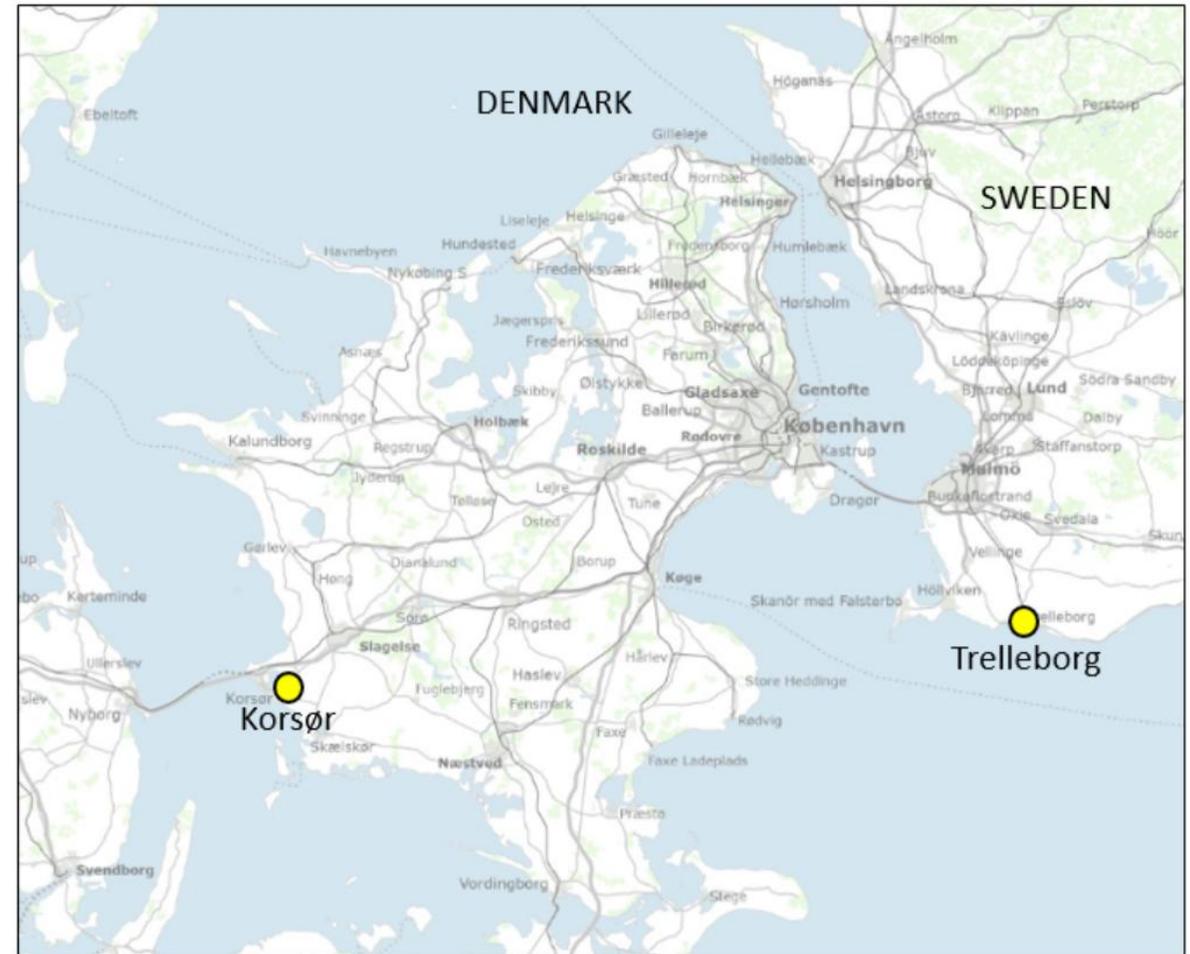
Konceptuel model
Nedbør
Infiltration
Udvaskning/binding
Transport i matrix og makropore
Flux beregning



Modellering/Risikovurdering



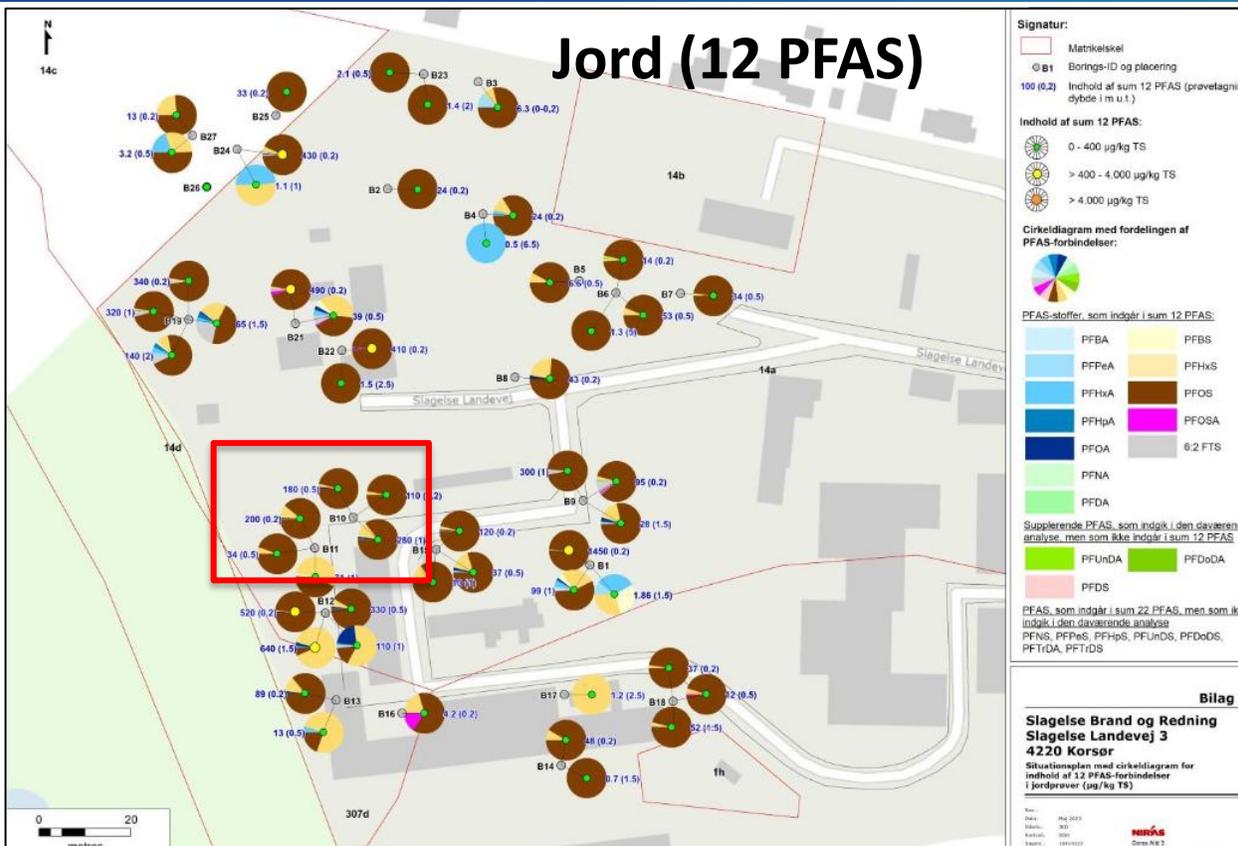
- **Korsør Rescue center (Danmark)**
smeltevandssand/silt/ler
morænesand, i issøbakke
- **Trelleborg brandøvelses plads (Sverige)**
Losseplads på moræneler og
smeltevandssand i ådal



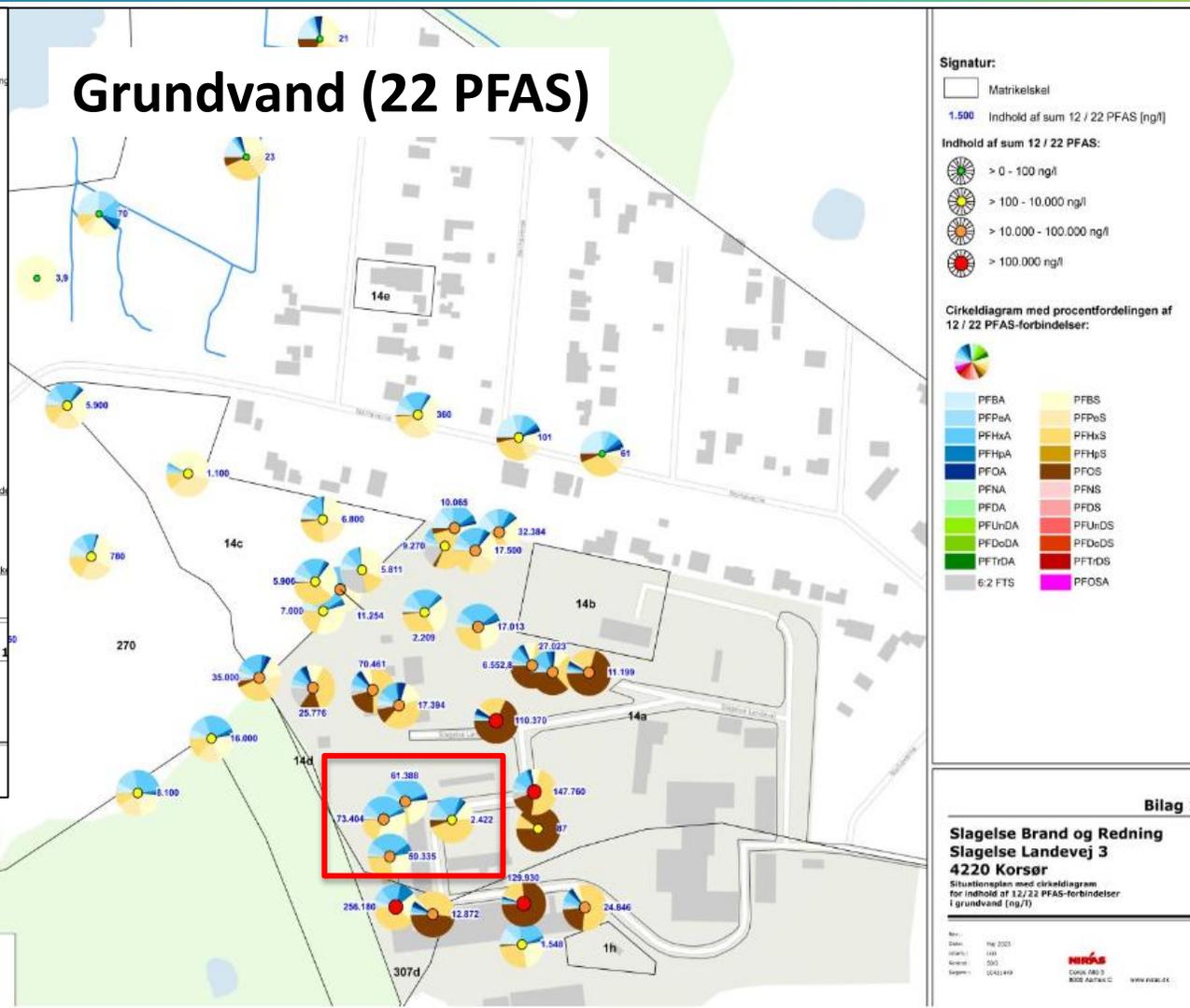
Multi skala 3-D geologisk modellering og monitoring



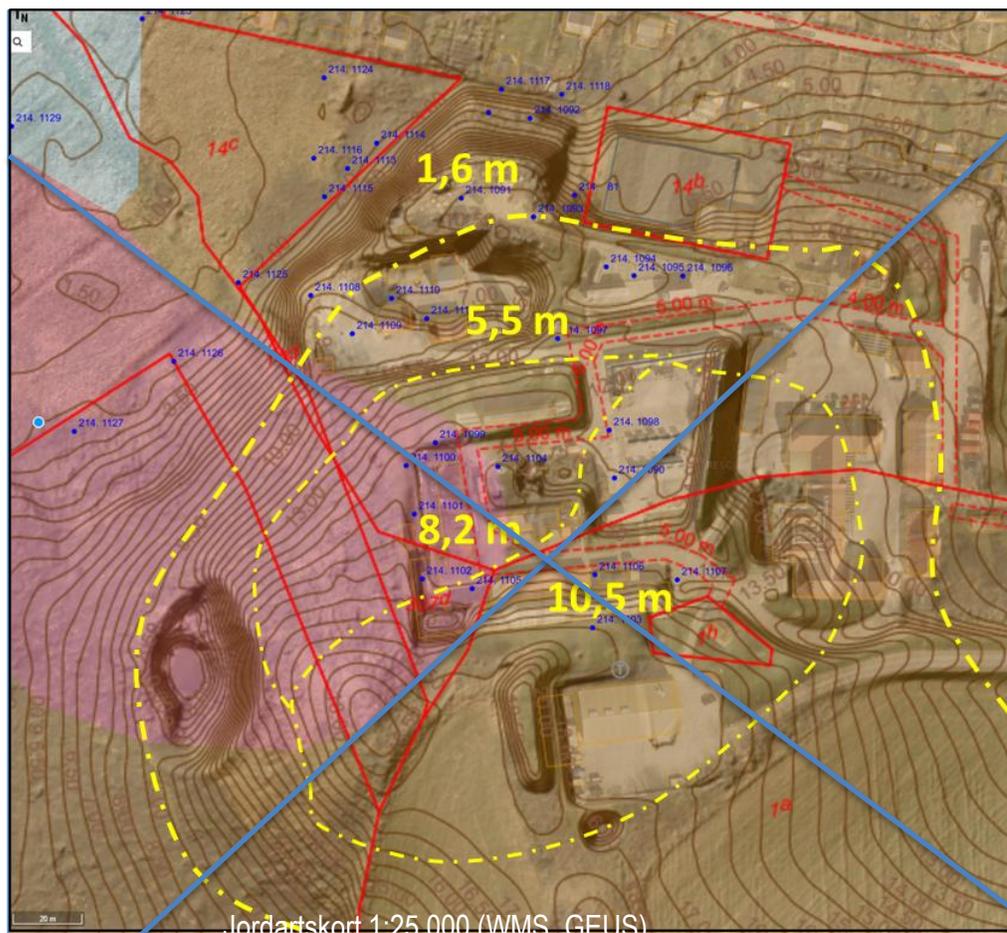
Jord (12 PFAS)



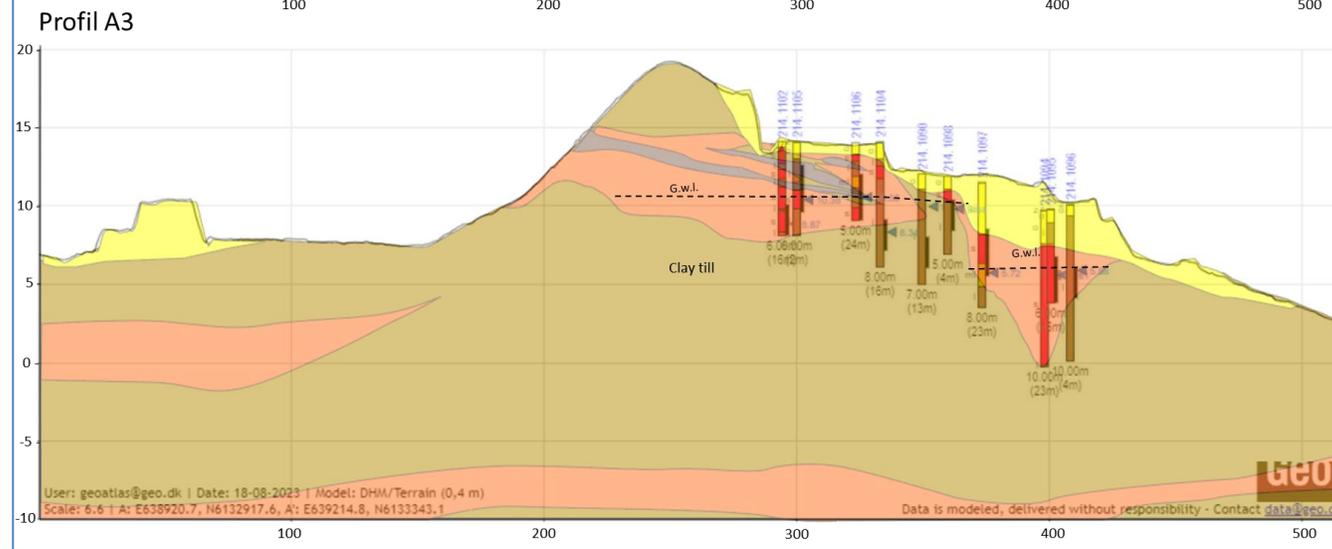
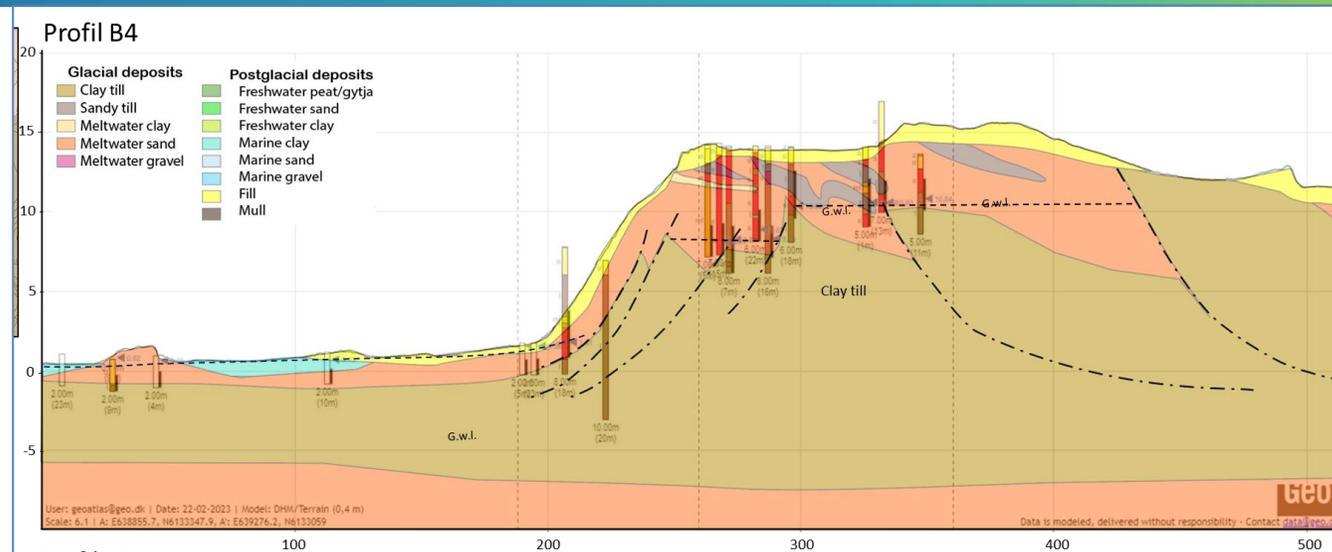
Grundvand (22 PFAS)

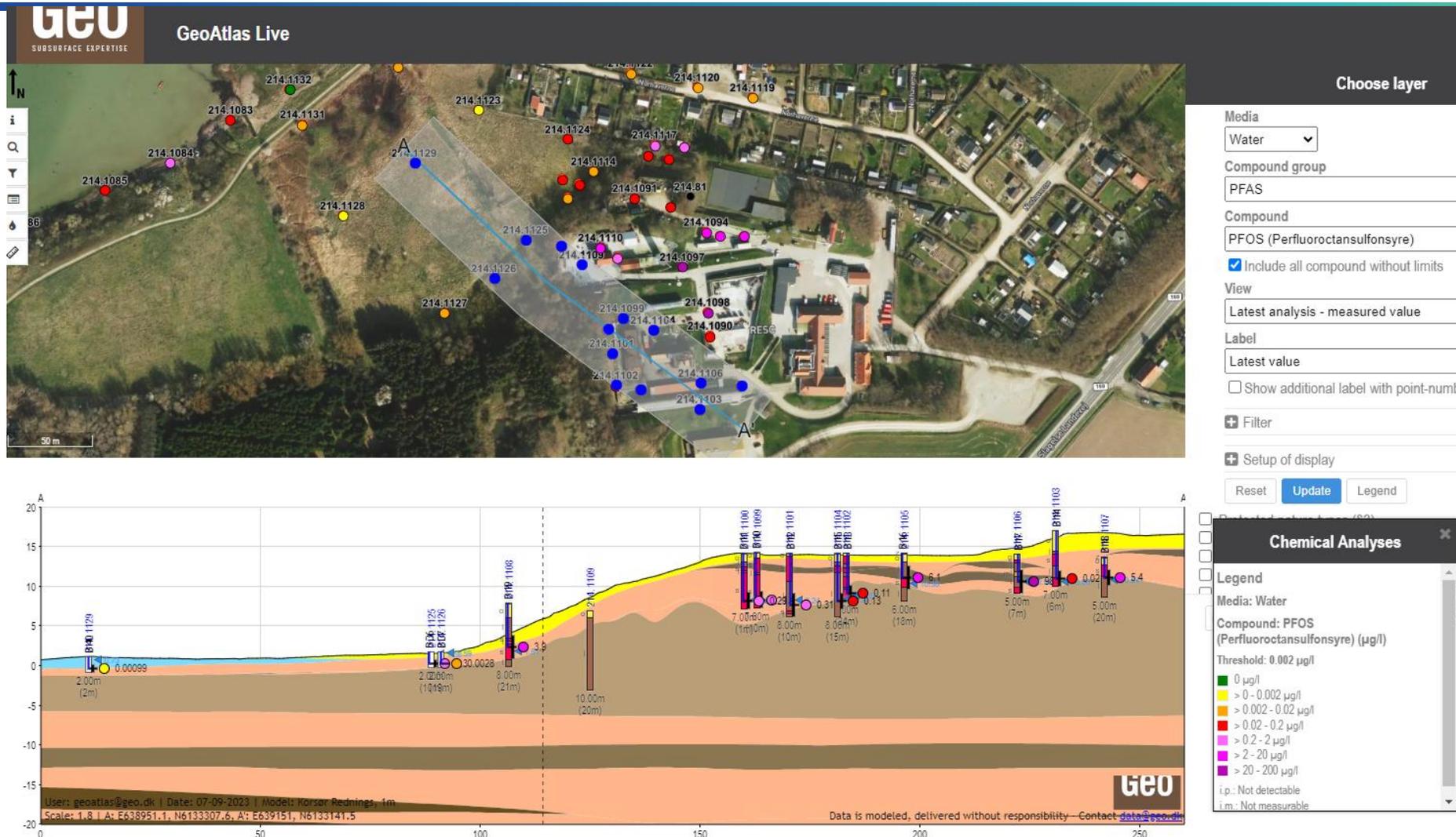


Flere separate grundvandsmagasiner med individuel gv.sp.



Jordartskort 1:25.000 (WMS, GEUS)

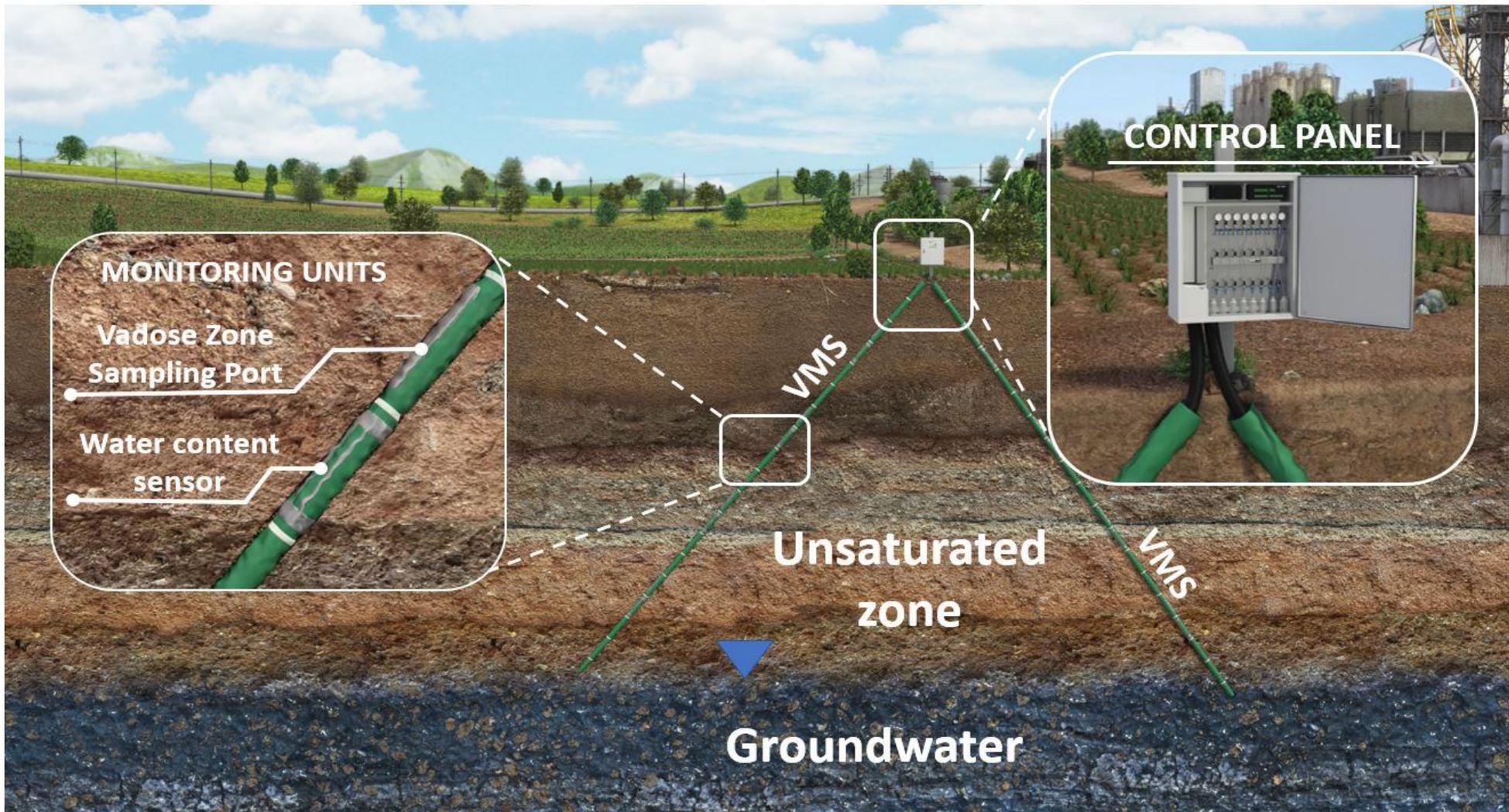






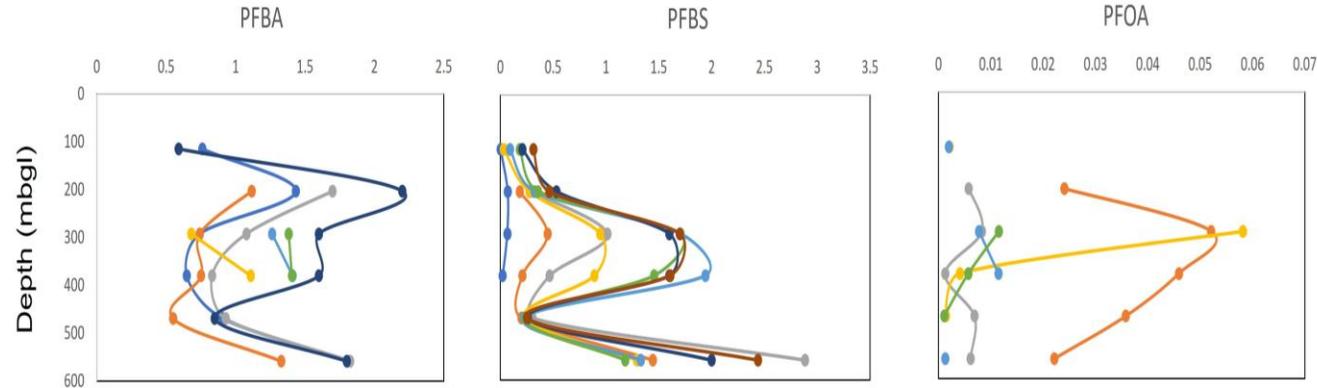
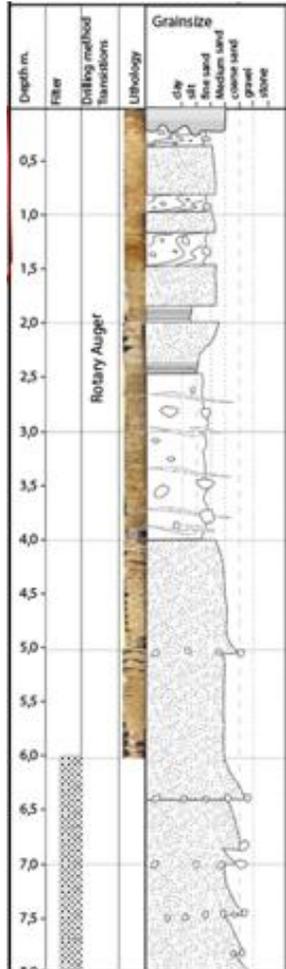
Drill log		page 1/1		Borehole no: K1		PI: KEK			
Project 205579		Driller id: Mats		Coordinat:		Gw. table m b.g.s.:			
Borehole: Korsoer		Start date:		End date:		kote, terrain: ROK:			
Depth m.	Filter	Drilling method Transitions	Lithology	Grainsize clay silt fine sand Medium sand coarse sand gravel stone	Description and geological setting	soil sample	Watersample		
0,5					Mull, sandy topsoil brown CaCO ₃ poor Sandy till, clayey, silty, few stones, yellowish brown CaCO ₃ poor Sand, medium, light yellowish brown CaCO ₃ poor "meltwatersand"	242			
1,0					Sandy till, w. clayey, silty, some gravel, brown CaCO ₃ poor Sand, medium, light reddish brown CaCO ₃ poor "meltwatersand" Sandy till, w. clayey, silty, some gravel, reddish brown CaCO ₃ poor	245			
1,5					Sand, medium, light yellowish brown CaCO ₃ rich "meltwatersand"				
2,0					Clay silty, massive, brown, CaCO ₃ rich "meltwater-clay"	244			
2,5					Sand, fine, medium, coarse, laminated, light yellowish brown CaCO ₃ rich "meltwatersand"	243			
3,0					Sandy till, w. clayey, silty, some gravel, few stones, sandstringer, brown, CaCO ₃ rich, "flowtill"				
3,5					Sandy till, w. clayey, silty, some gravel, few stones, sandstringer, brown, CaCO ₃ rich, "flowtill"	227			
4,0									
4,5					Sand, medium, coarse, gravely, light yellowish brown, CaCO ₃ rich "meltwatersand"				
5,0					Sand, medium, coarse, light yellowish brown CaCO ₃ rich "meltwatersand"	223			
5,5					Sand, medium, coarse, gravely, light yellowish brown, CaCO ₃ rich "meltwatersand"				
6,0									
6,5					Sand, medium, coarse, gravely, few stones, light yellowish brown, CaCO ₃ rich "meltwatersand"				
7,0						224			
7,5					Sand, medium, coarse, gravely, few stones, light yellowish brown, CaCO ₃ rich "meltwatersand"				
8,0						222			

Installering af VMS-anlæg til monitoring transport af vand og PFAS i den umættede zone.

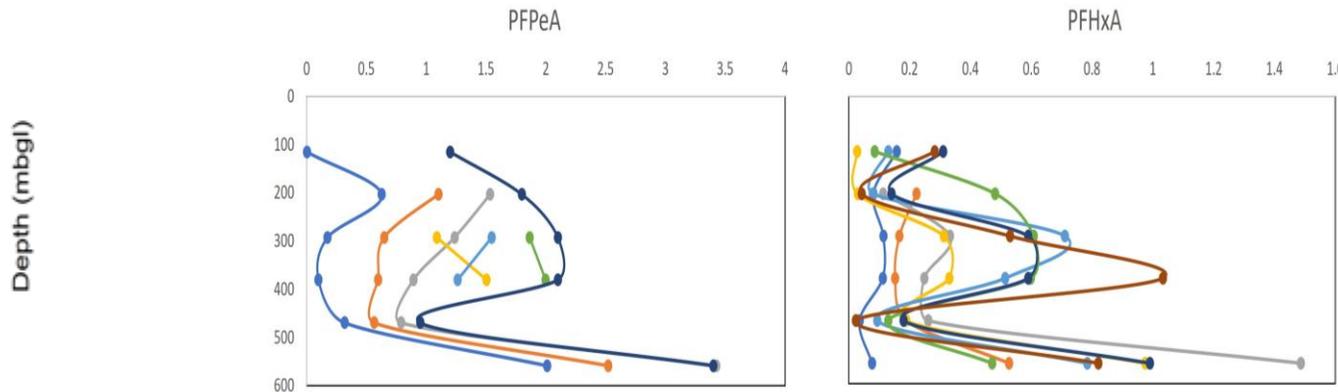


- Systematisk indsamling og analyse af vandprøver én gang pr måned siden forsøgets start i sep. 2022.
- Kontinuert måling af vandmætning i 6 forskellige dybder i 24 måneder
- I maj 2023 er der udført kontrollerede nedsivningsforsøg der skal simulere skybrud med en kendt nedbørsmængde, samt tracerforsøg med bromid til vurdering af infiltrationshastighed
- I juni 2023 er der indsamlet en lang række jordprøver fra overfladen og ned til 3,5 m u.t. for at sammenligne PFAS indhold i jord og vand
- Nedbørsdata indsamlet elektronisk i lokal vejstation
- Yderligere målrettet indsamling af vand og jordprøver planlagt marts 2025

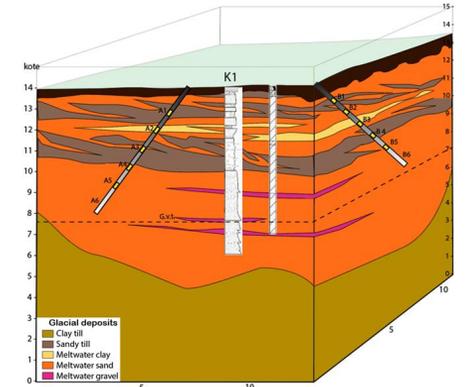
De første resultater efter 6 mdr. monitoring



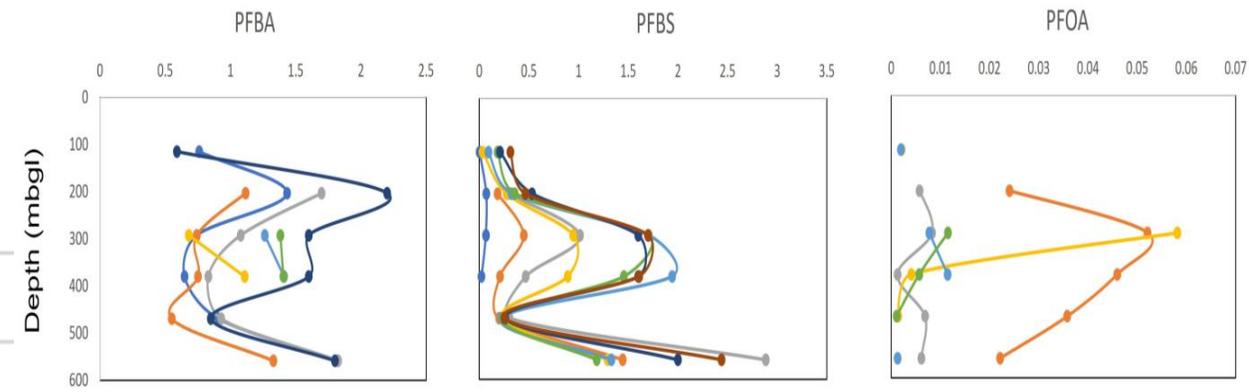
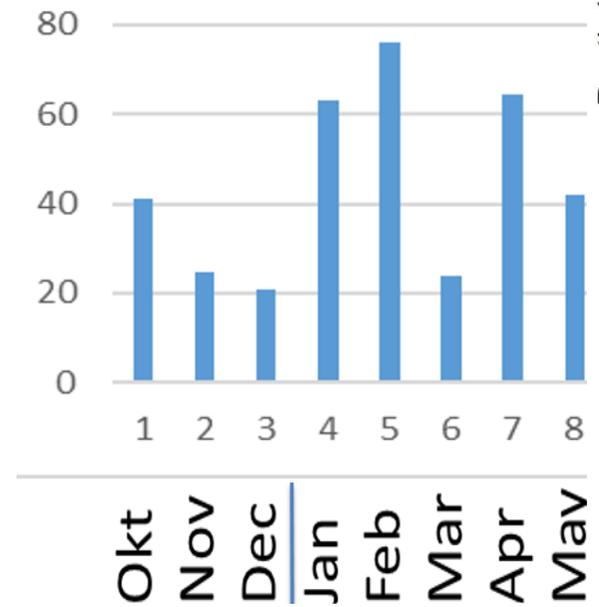
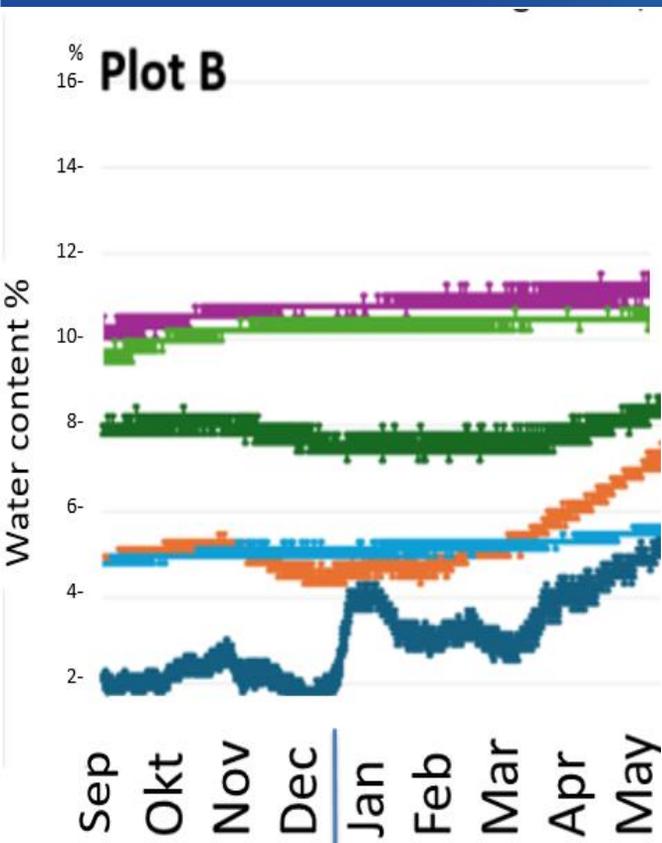
PFAS Concentration(µg/L)



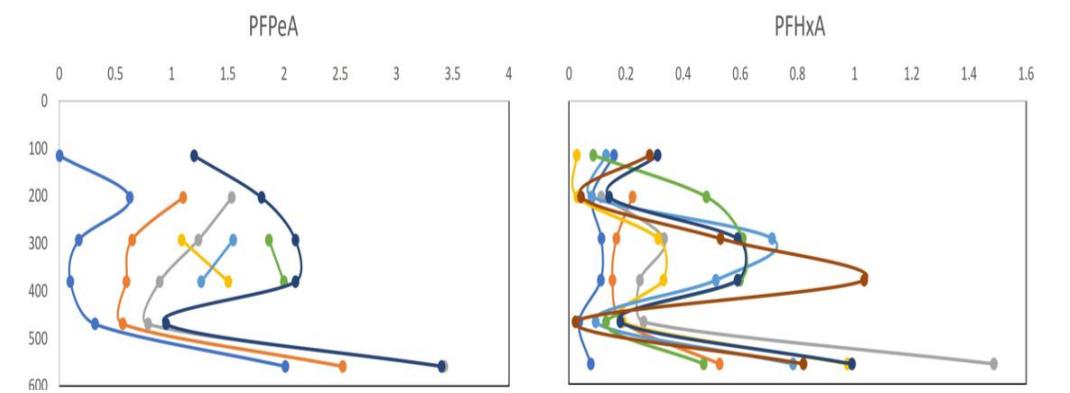
— 27.10.2022 — 25.11.2022 — 04.01.2023 — 02.02.2023 — 02.03.2023 — 30.03.2023 — 27.04.2023



Vandindhold/nedbør/PFAS konc i porevand



PFAS Concentration(µg/L)



Water content in soil m b.g. ◆ 0,7 ◆ 1,58 ◆ 2,47 ◆ 3,35 ◆ 4,25 ◆ 5,15

◆ 27.10.2022 ◆ 25.11.2022 ◆ 04.01.2023 ◆ 02.02.2023 ◆ 02.03.2023 ◆ 30.03.2023 ◆ 27.04.2023

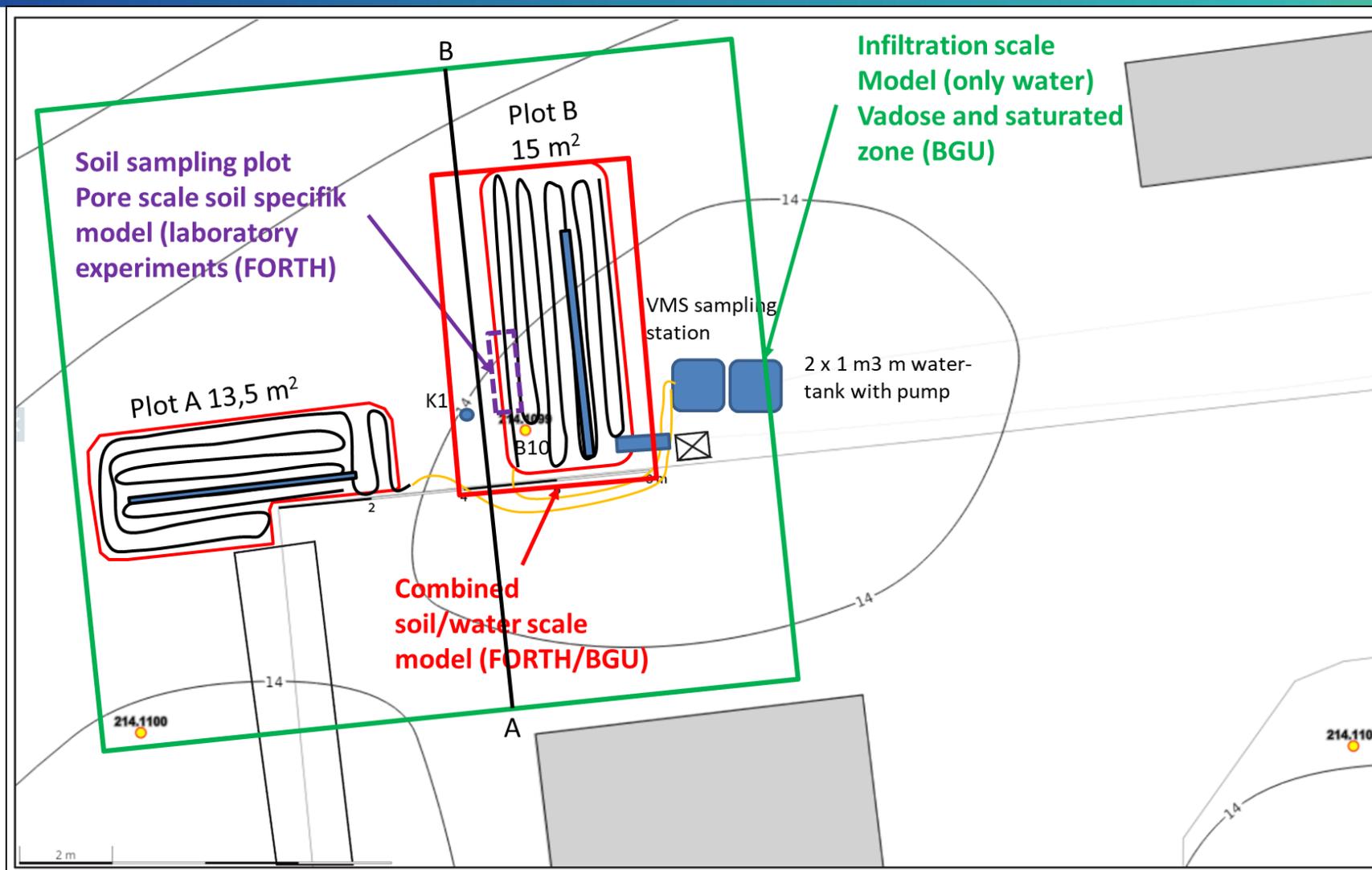
- Vandindholdet stiger generelt nedadtil, men varierer med nedbør
- Koncentrationen af PFAS stiger med stigende vandindhold

Spørgsmål

Hvor hurtigt infiltrere regnvand igennem matrix?

Hvad er PFAS-indholdet i jord og porevand?

Hvor meget udvaskes og hvornår?

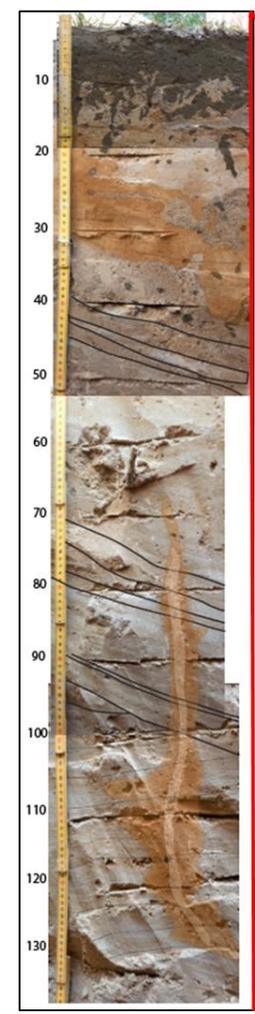
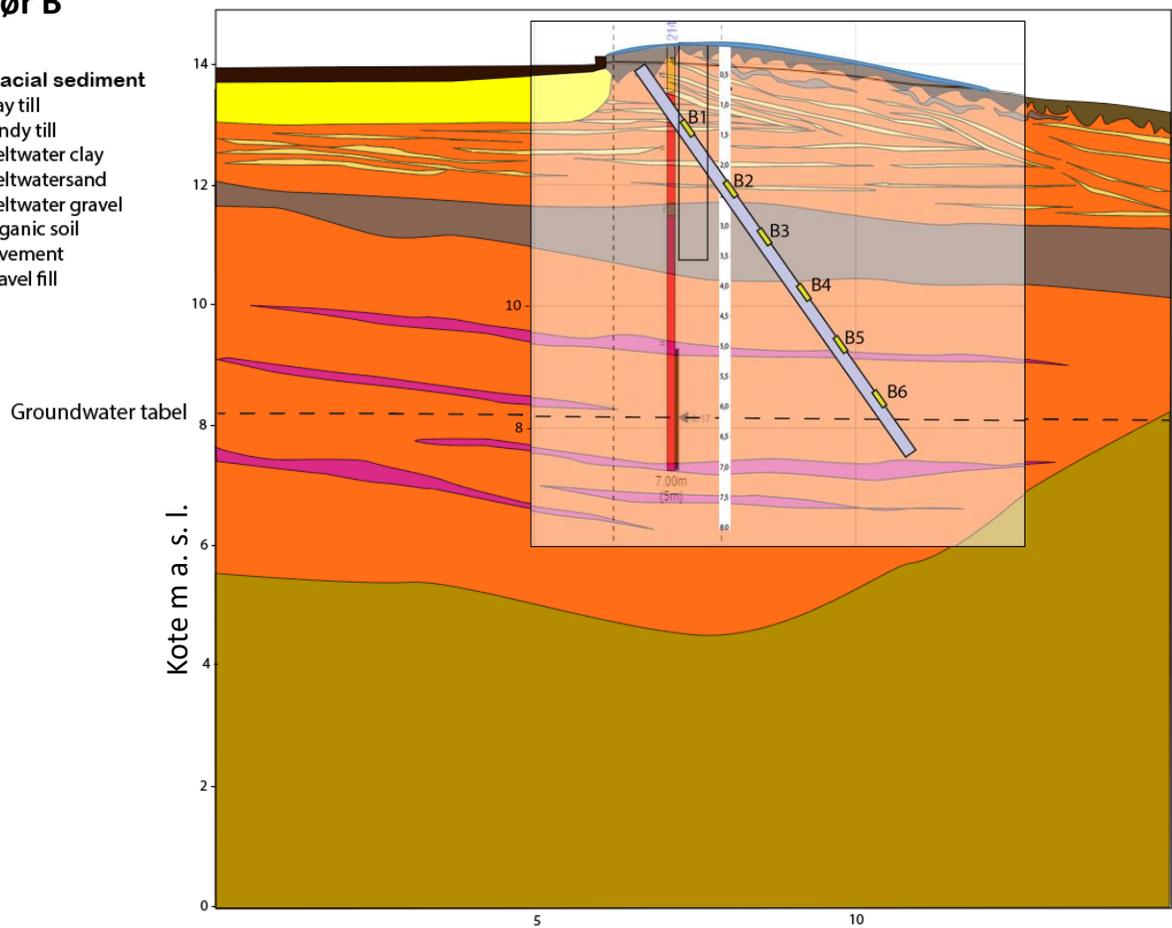


Opstilling af optimeret 2-D konceptuel geologisk model

Korsør B

- Glacial sediment**
- Clay till
 - Sandy till
 - Meltwater clay
 - Meltwatersand
 - Meltwater gravel
 - Organic soil
 - Pavement
 - Gravel fill

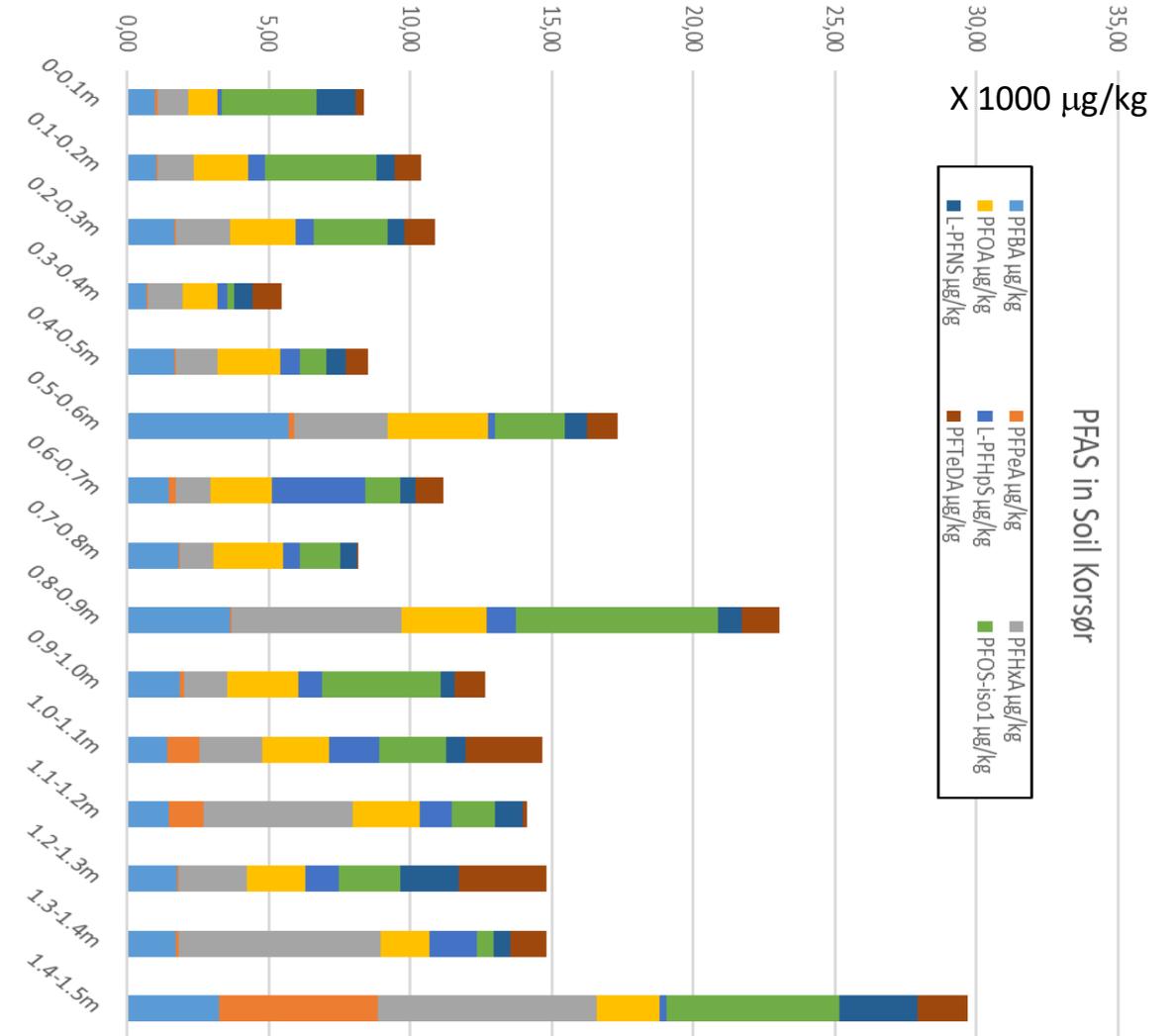
south A north B



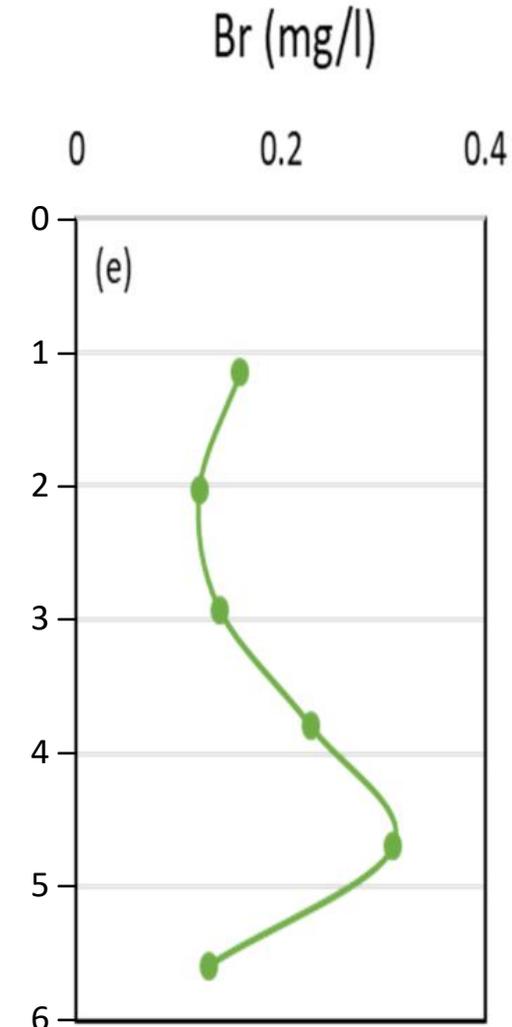
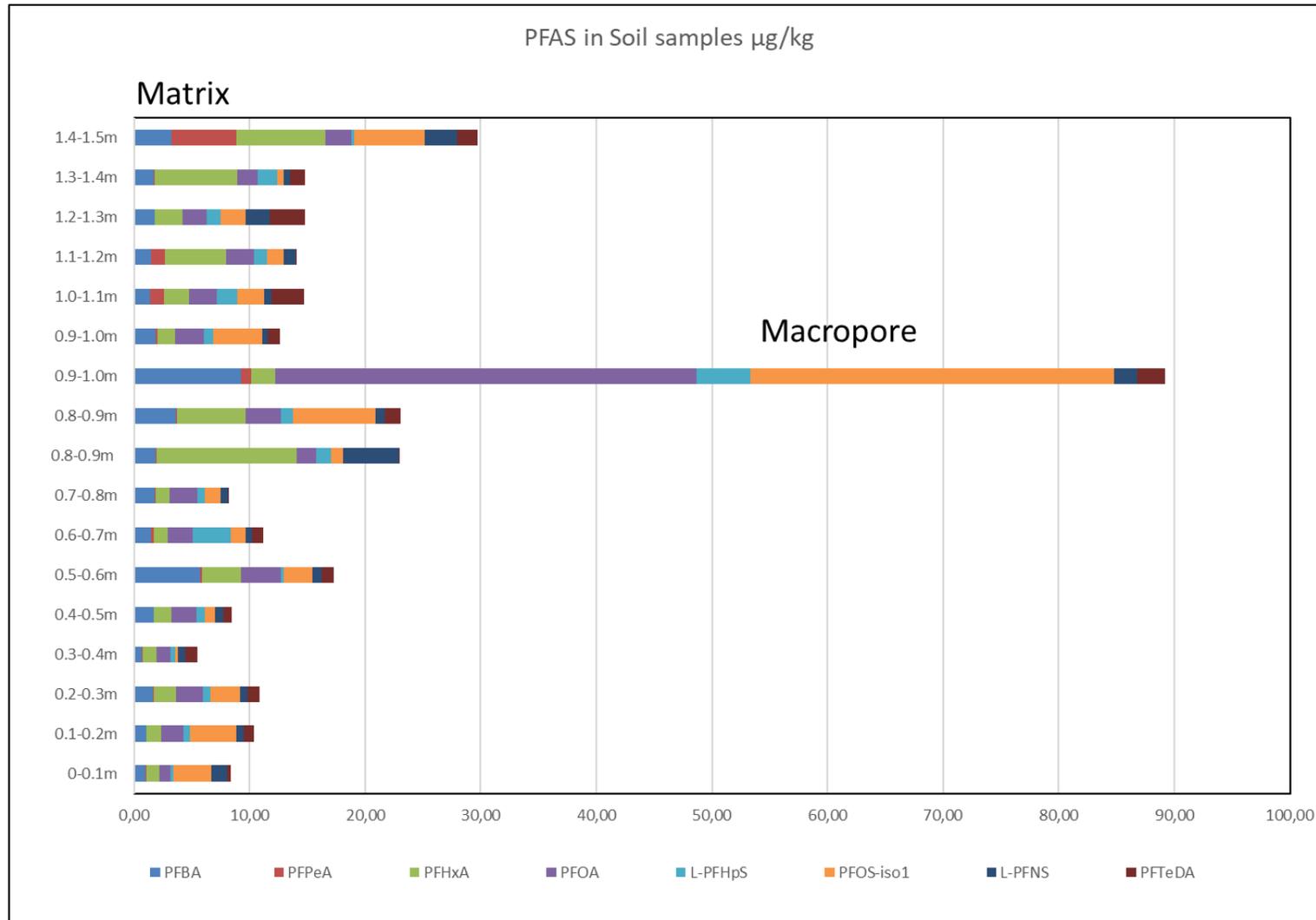
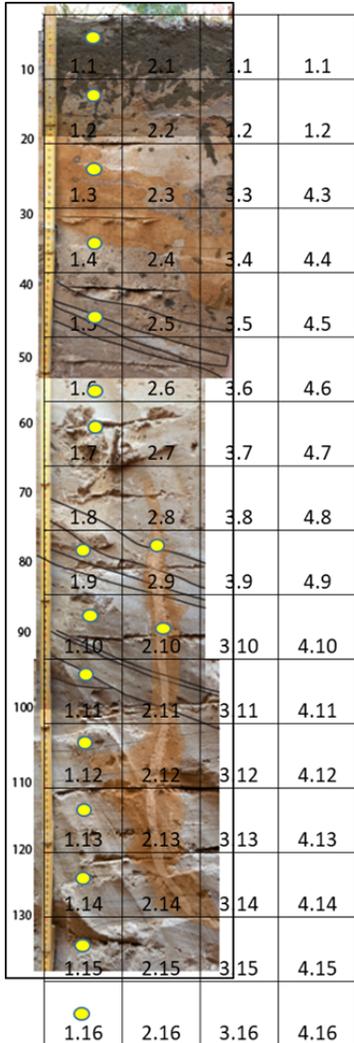
Drill log		page 1/1		Borehole no: K1	Pl: KEK	GEO
Project 205579		Driller id: Mats		Start date:	Coordinat:	
Borehole: Korsoer		End date:		Gw. table m b.g.s.:		soil sample
				kote, terrain: ROK:		
Depth m.	Filter	Drilling method	Transitions	Lithology	Description and geological setting	
0,5				Rotary Auger	Mull, sandy topsoil brown CaCO ₃ poor	242
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1,5					Sand, medium, light yellowish brown CaCO ₃ poor "meltwatersand"	
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8,0					Sand, medium, coarse, gravely, few stones, light yellowish brown, CaCO ₃ rich "meltwatersand"	222



10	1.1	2.1	3.1	4.1
15	1.2	2.2	3.2	4.2
20	1.3	2.3	3.3	4.3
25	1.4	2.4	3.4	4.4
30	1.5	2.5	3.5	4.5
35	1.6	2.6	3.6	4.6
40	1.7	2.7	3.7	4.7
45	1.8	2.8	3.8	4.8
50	1.9	2.9	3.9	4.9
55	1.10	2.10	3.10	4.10
60	1.11	2.11	3.11	4.11
65	1.12	2.12	3.12	4.12
70	1.13	2.13	3.13	4.13
75	1.14	2.14	3.14	4.14
80	1.15	2.15	3.15	4.15
85	1.16	2.16	3.16	4.16

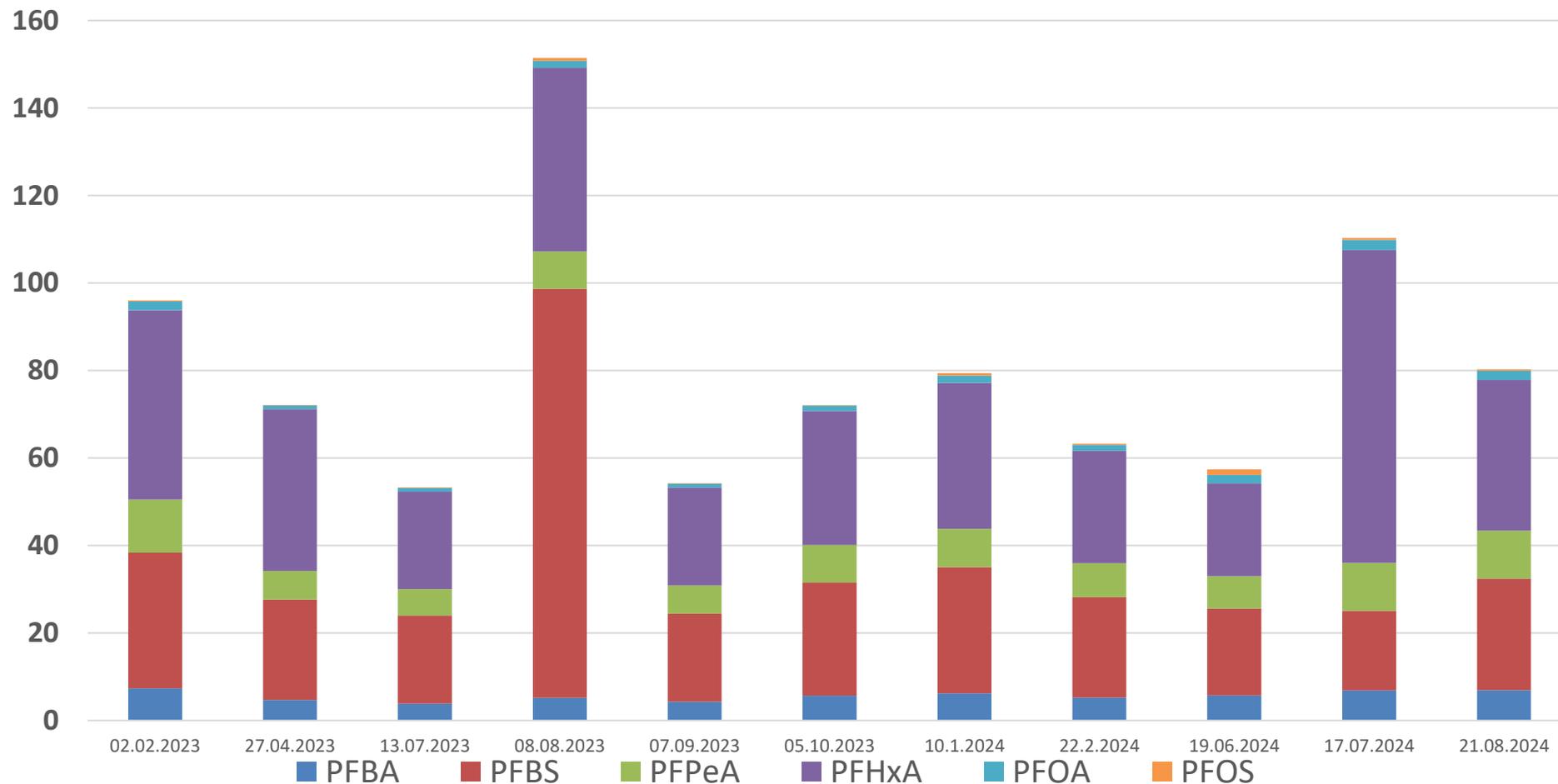


Preferentiel flow i makropore?

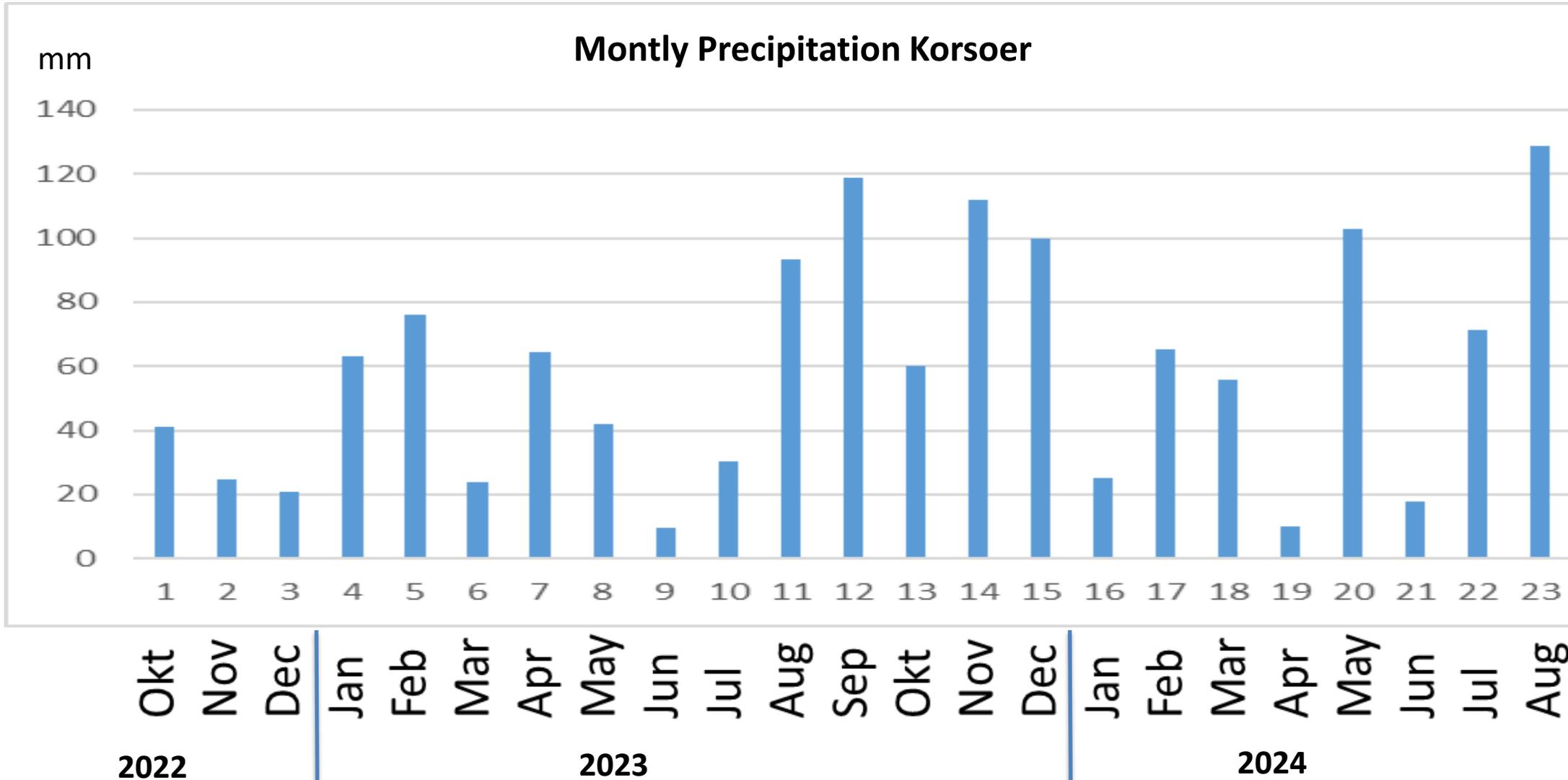


m.b.g.s.

PFAS Grundvand K1

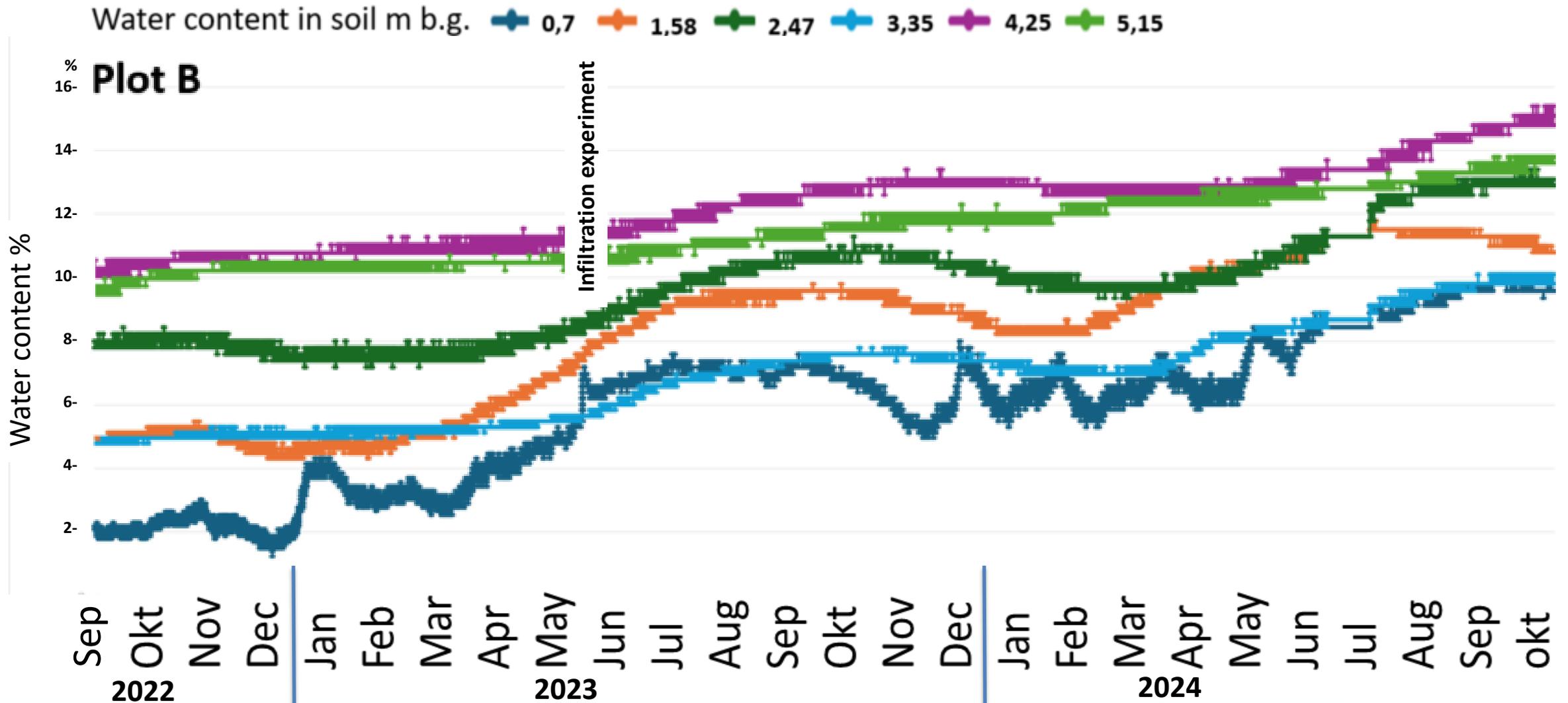


Montly Precipitation Korsoer

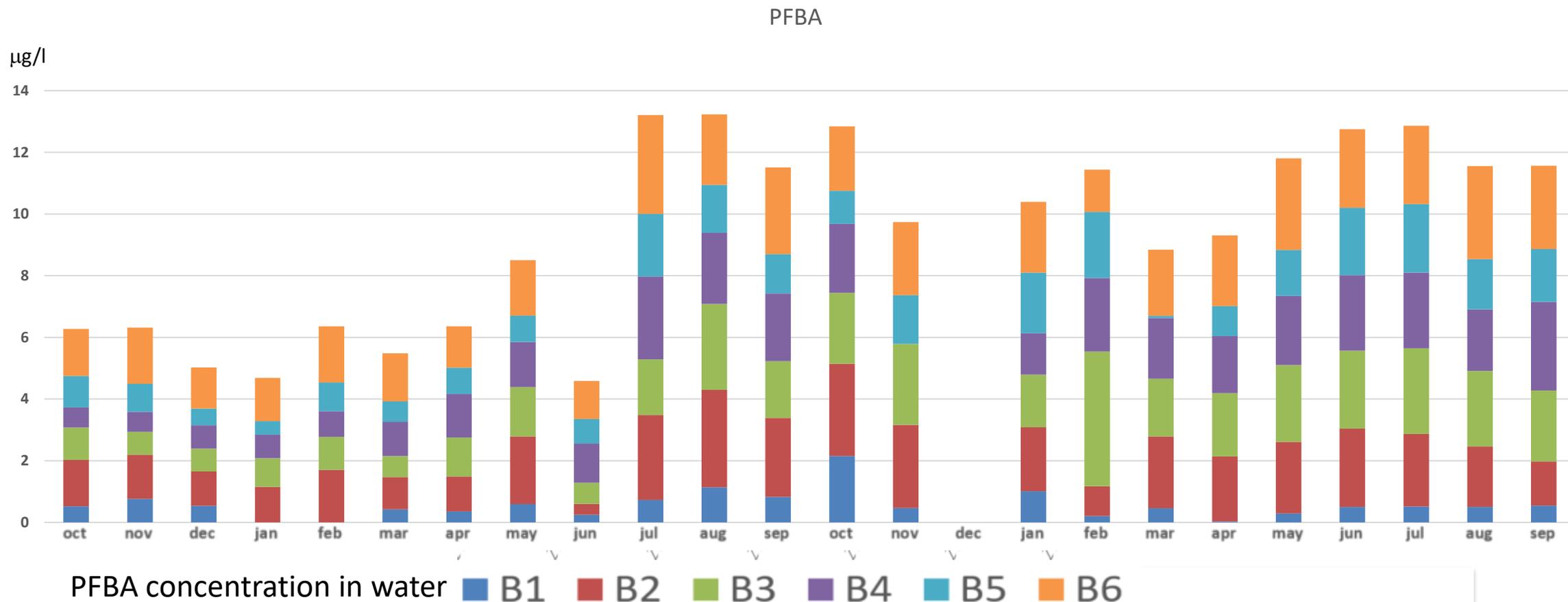


	Precipitation mm
	mm/month
10	41
11	25
12	21
1	63
2	76
3	24
4	65
5	42
6	10
7	31
8	93
9	119
10	60
11	112
12	100
1	25
2	65
3	56
4	10
5	103
6	18
7	71
8	129
9	141

Vandindhold i 6 dybder i den umætte zone i 24 mdr

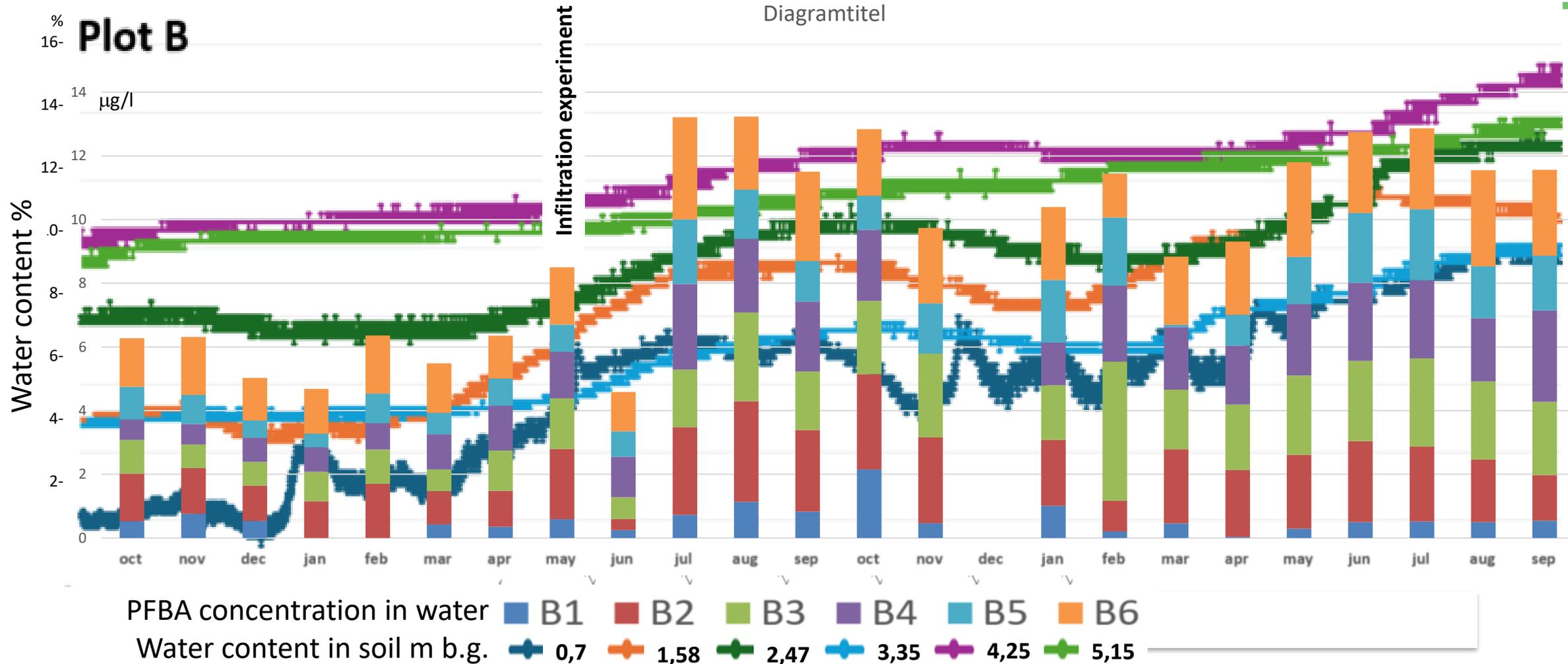


PFBA koncentrationer i 6 dybder i vandprøver igennem 2 år

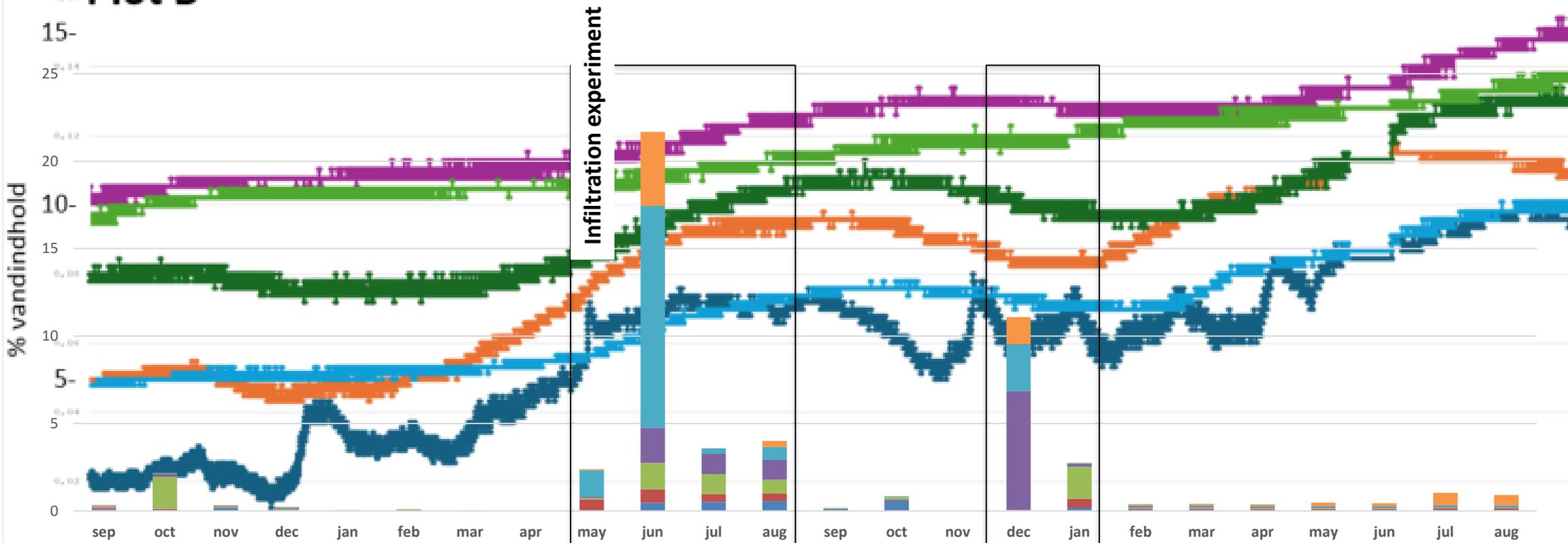


PFBA koncentration som funktion af vandindhold i jorden.

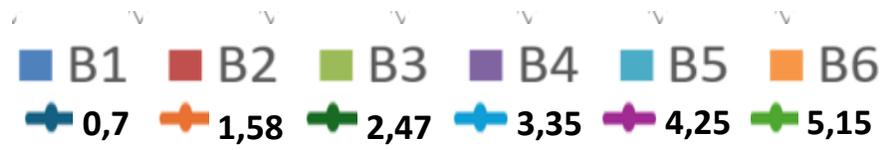
Diagramtitel



Plot B

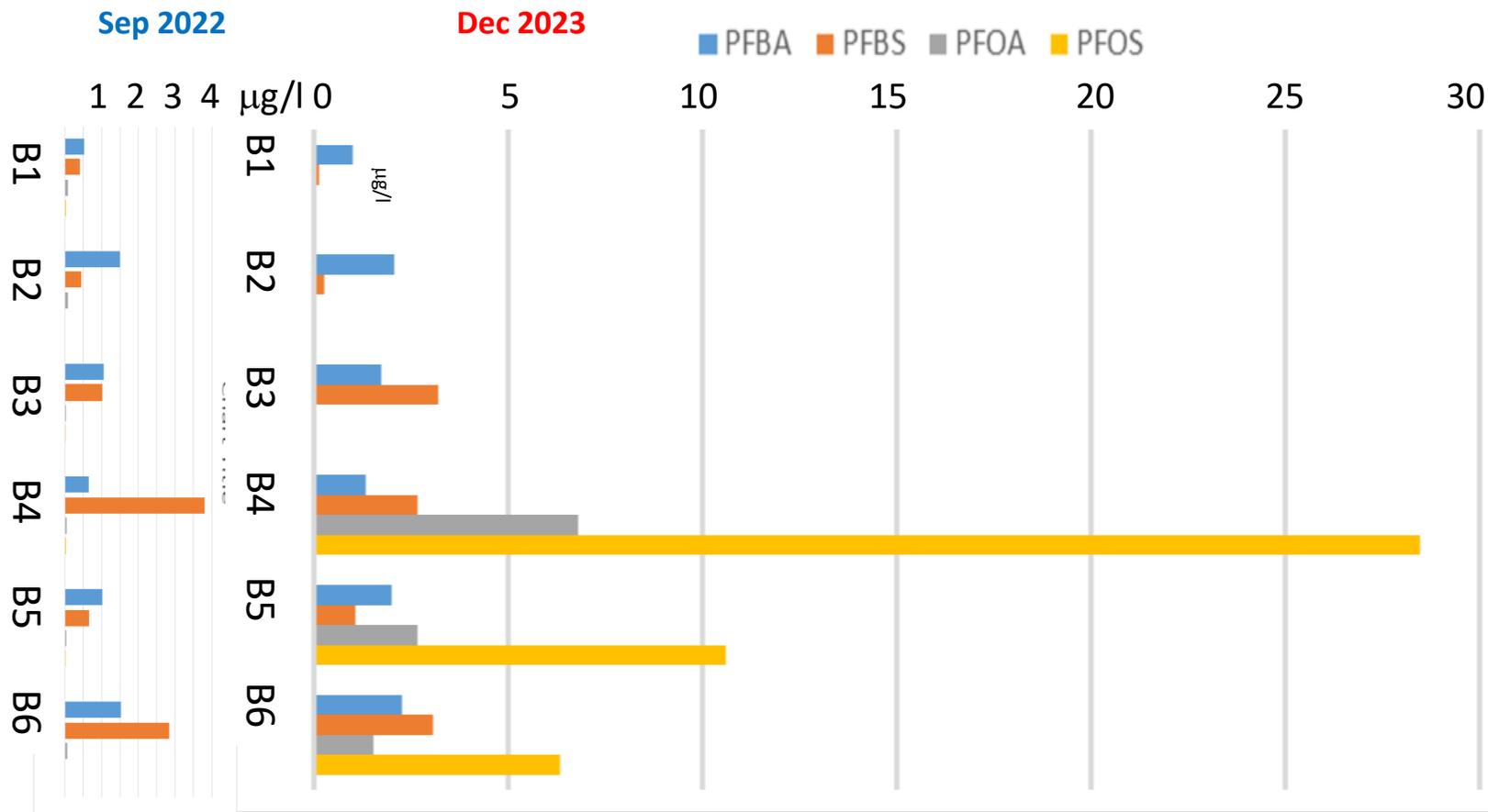


PFOA concentration in water
Water content in soil

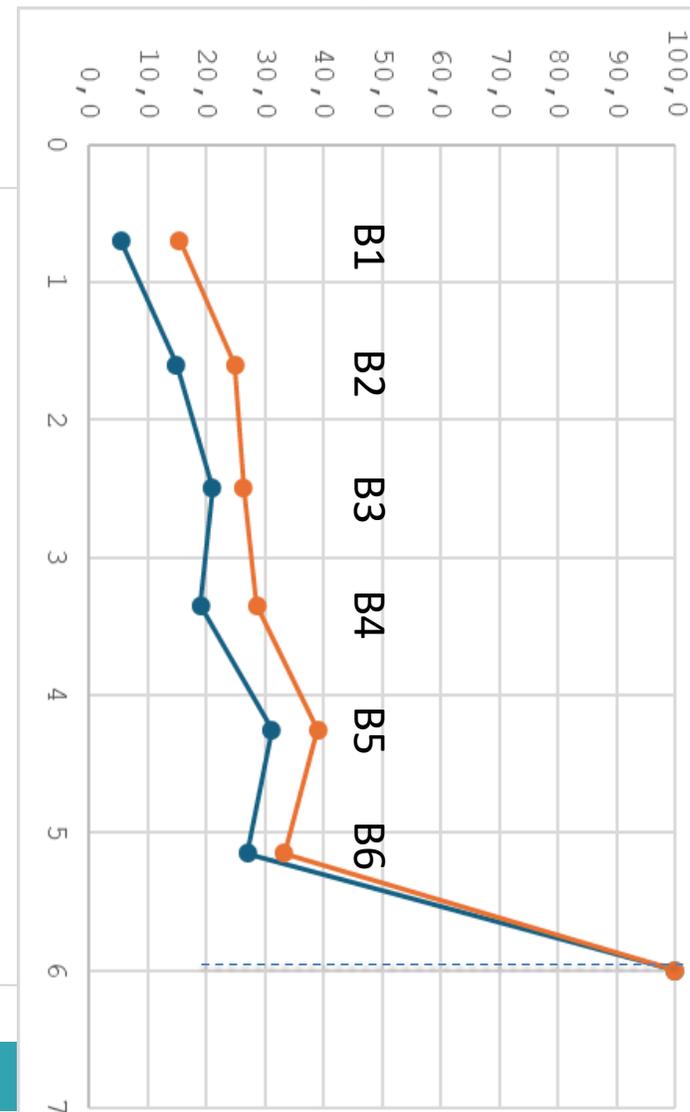


Hvad betyder vandindholdet for udvaskning af PFAS?

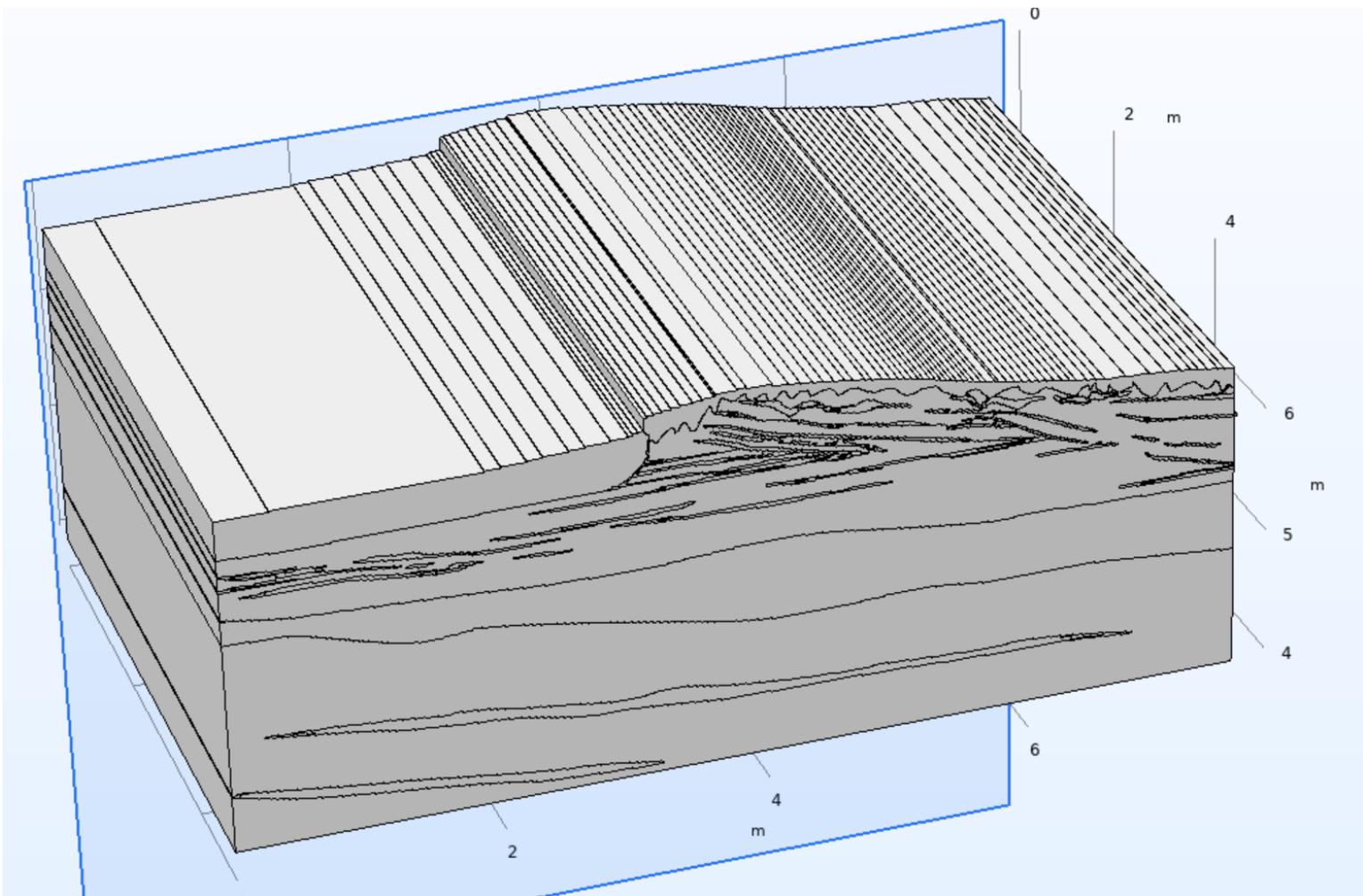
PFAS koncentration/ composition in water samples with two different water content



Water saturation 22 sep 2022 and 15 dec 2023

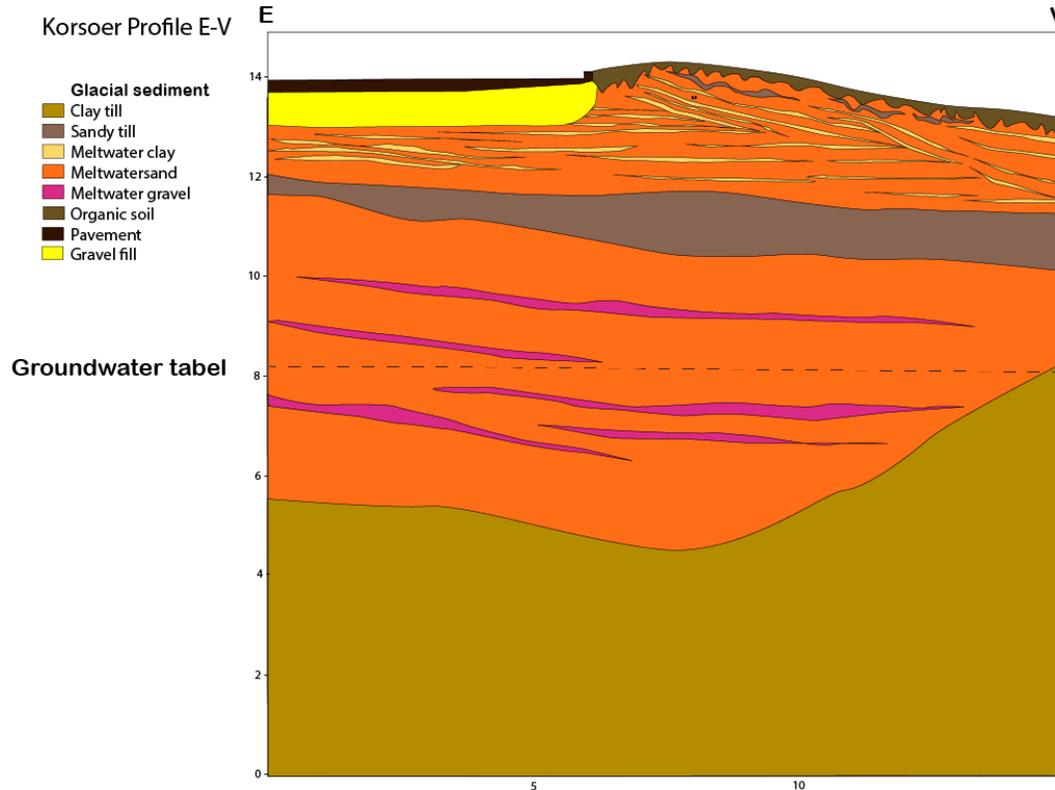


Perspektiv for modellering og Parameter estimering

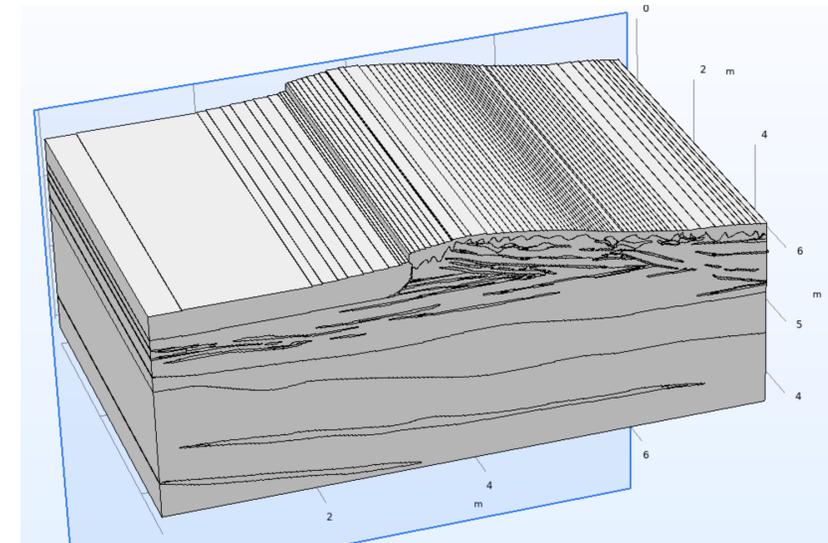


Soil type	Parameter	Value	Description
Clayey sandy till	ϵ	0.22	Porosity
	K	$4.8 \cdot 10^{-13} \text{ m}^2$	Absolute permeability
	α	0.5 m^{-1}	Van Genuchten parameter
	n	1.09	Van Genuchten parameter
	θ_s	0.22	Water saturation = porosity
	θ_r	0.015	Water residual
Apply to all layers	aL	200 μm	Dispersivity (the default)
	D_{pfos}	$0.5 \cdot 10^{-9} \text{ m}^2/\text{s}$	Diffusion coefficient of PFOS
	D_{pfoa}	$3.5 \cdot 10^{-9} \text{ m}^2/\text{s}$	Diffusion coefficient of PFOA
	D_{pfda}	$2 \cdot 10^{-9} \text{ m}^2/\text{s}$	Diffusion coefficient of PFDA
	D_{pfba}	$8 \cdot 10^{-9} \text{ m}^2/\text{s}$	Diffusion coefficient of PFBA
	K_{dpfos}	$302.5 \cdot 10^{-9} \text{ mol/kg}$	Freundlich constant PFOS
	K_{dpfoa}	$31.3 \cdot 10^{-9} \text{ mol/kg}$	Freundlich constant PFOA
	K_{dpfda}	$386 \cdot 10^{-9} \text{ mol/kg}$	Freundlich constant PFDA
	K_{dpfba}	$38.7 \cdot 10^{-9} \text{ mol/kg}$	Freundlich constant PFBA
	n_{pfos}	0.63	Freundlich exponent PFOS
	n_{pfoa}	0.63	Freundlich exponent PFOA
	n_{pfda}	0.42	Freundlich exponent PFDA
n_{pfba}	0.35	Freundlich exponent PFBA	
Melt-water clay/silt	ϵ	0.28	Porosity
	K	$2.4 \cdot 10^{-13} \text{ m}^2$	Absolute permeability
	α	0.8 m^{-1}	Van Genuchten parameter
	n	1.09	Van Genuchten parameter
	θ_s	0.28	Water saturation = porosity
	θ_r	0.015	Water residual
Melt-water Sand	ϵ	0.38	Porosity
	K	$7.2 \cdot 10^{-12} \text{ m}^2$	Absolute permeability
	α	7.45 m^{-1}	Van Genuchten parameter
	n	1.89	Van Genuchten parameter
	θ_s	0.38	Water saturation = porosity
	θ_r	0.025	Water residual
Melt-water gravel/sand	ϵ	0.45	Porosity
	K	$3.6 \cdot 10^{-11} \text{ m}^2$	Absolute permeability
	α	14.5 m^{-1}	Van Genuchten parameter
	θ_s	0.45	Water saturation = porosity

Geological conceptual model

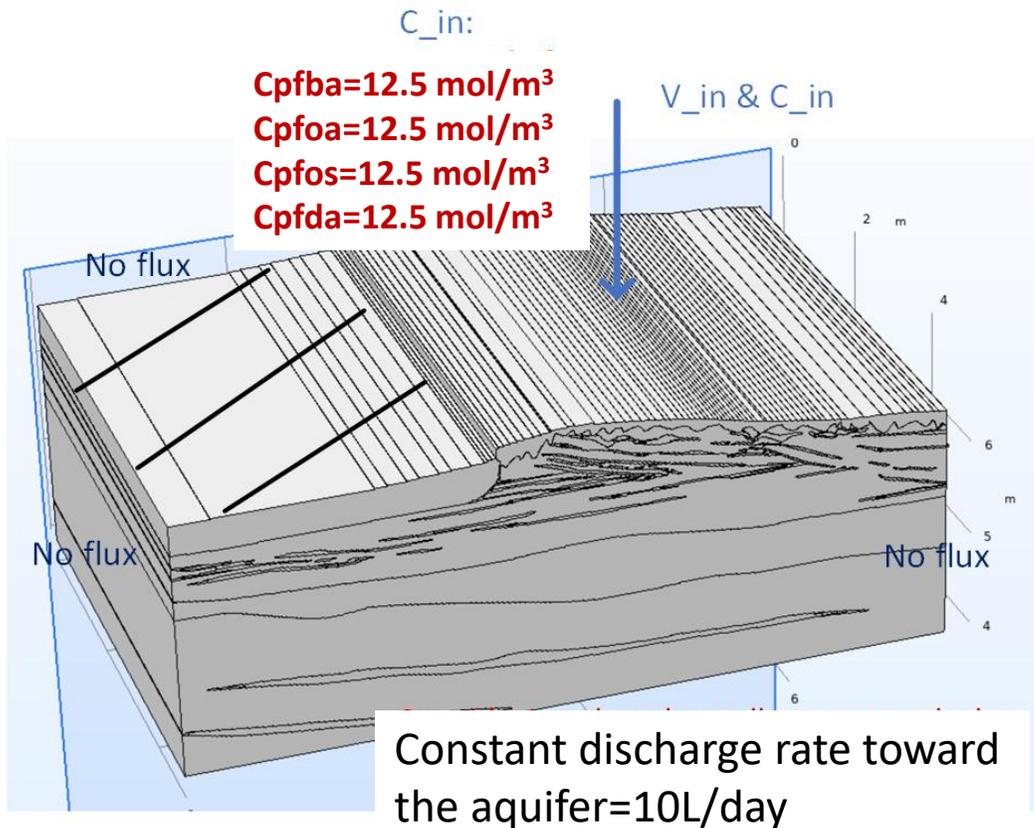


Reconstructed –simulation domain

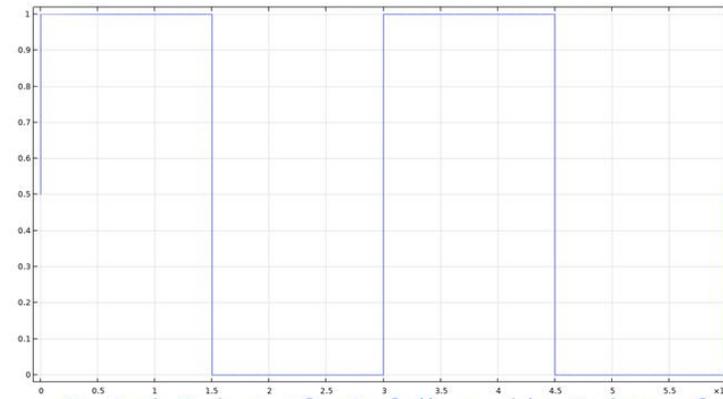


- Using Adobe Illustrator and an algorithm in python that transforms images to CAD geometry for further exploitation
- Different soil layers take into account

Scenario-based boundary conditions



Precipitation rate: $V_{in}=0.2 \times 10^{-5} \text{ m/s}$



Periodic precipitation rate:
 $0.2 \times 10^{-5} \text{ m/s}$ for 1.74 days followed
by 5.78 days of drought
Initial concentration of 4 PFAS
(PFBA, PFOA, PFOS, PFDA) on the
ground: $C_{in}=12.5 \text{ mol/m}^3$

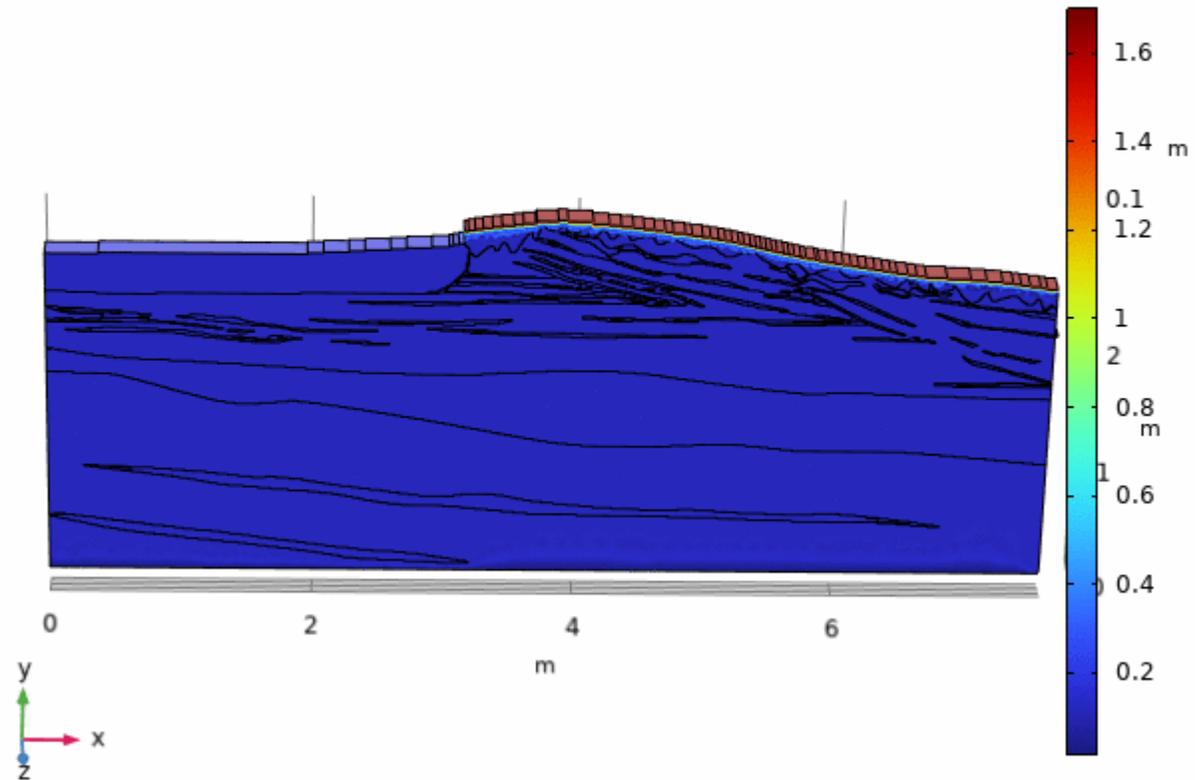
- Simulation during a couple of years

- Computational cost (COMSOL): 4.75M elements, and 3 days simulation time, depending on initial saturation conditions

PFBA transport in the unsaturated zone

Time=1096.5 s

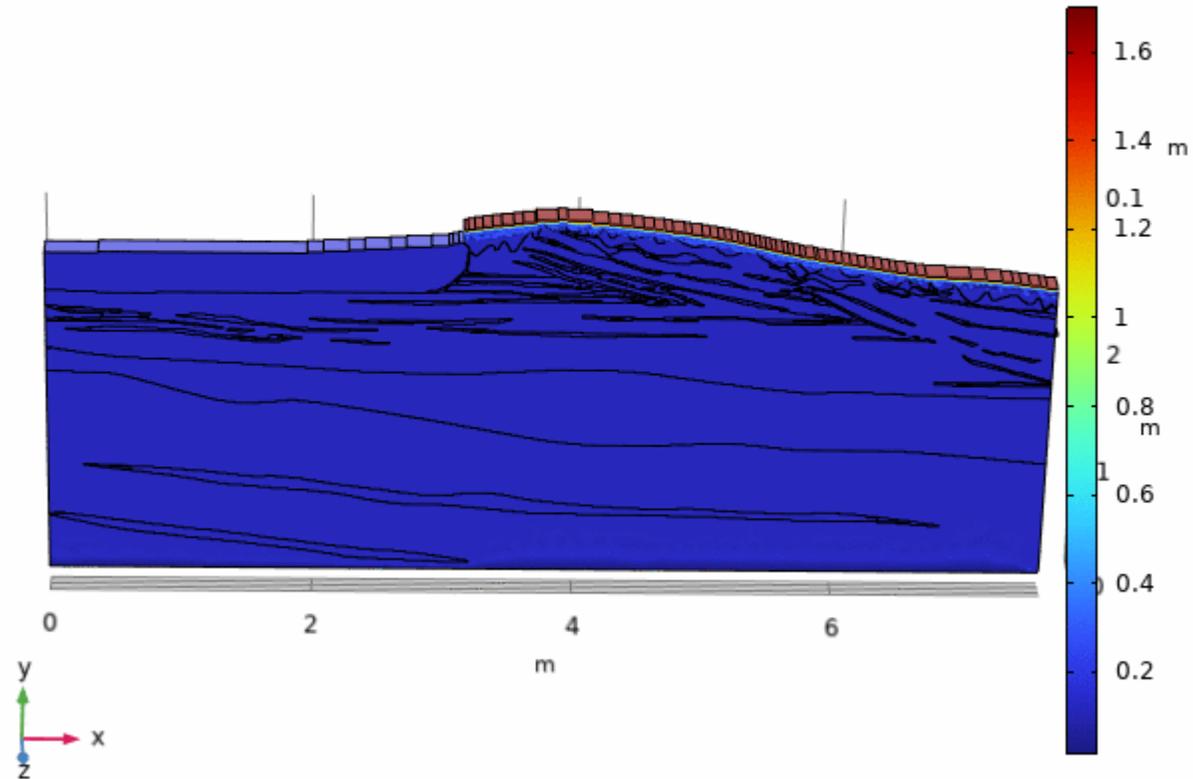
Species c: concentration of PFBA (mol/m³)



PFOA transport in the unsaturated zone

Time=1096.5 s

Species c: concentration of PFOA (mol/m^3)



- Forståelse for den dynamiske udvaskning af PFAS til grundvandet fra den umættede zone kræver mulighed for løbende monitorering af PFAS indholdet i porevand sammenholdt med vandmætning og nedbørsdata.
- Lange tidsserier (år) er afgørende for at opnå den fulde forståelse.
- Vandindholdet/vandmætningen i jorden er afgørende for mobilisering af langkædede PFAS typer.
- Vandmætningen er dynamisk og følger nedbørshændelser/nettoinfiltration
- Makropore spiller en vigtig rolle for forståelsen af flowmønstre i den umættede zone
- Modellering af PFAS transport bør tage hensyn til heterogen transport i sprækker og makropore

Thank you for
your attention



SCENARIOS

Vil du vide mere så kontakt kek@geo.dk

Eller besøg Scenarios hjemmeside <https://scenarios-project.eu/>