PESTICIDER I LANDBRUGSJORD OG DERES PÅVIRKNING AF GRUNDVAND OG VANDMILJØER.

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ATV vintermøde | 3. marts 2026

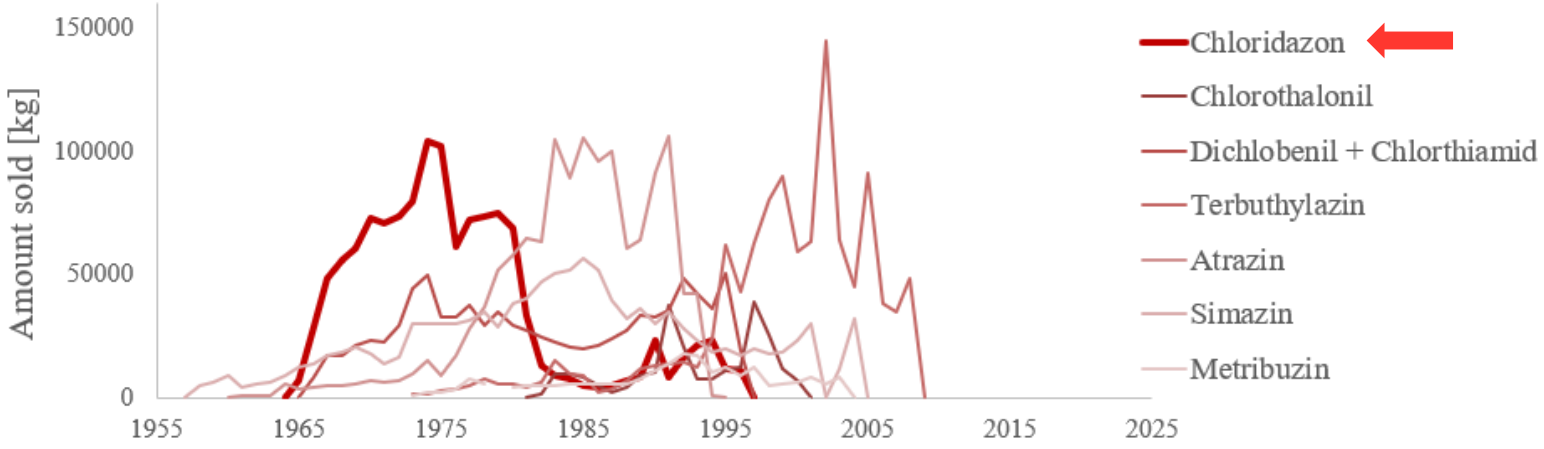
Grundvandets nuværende tilstand

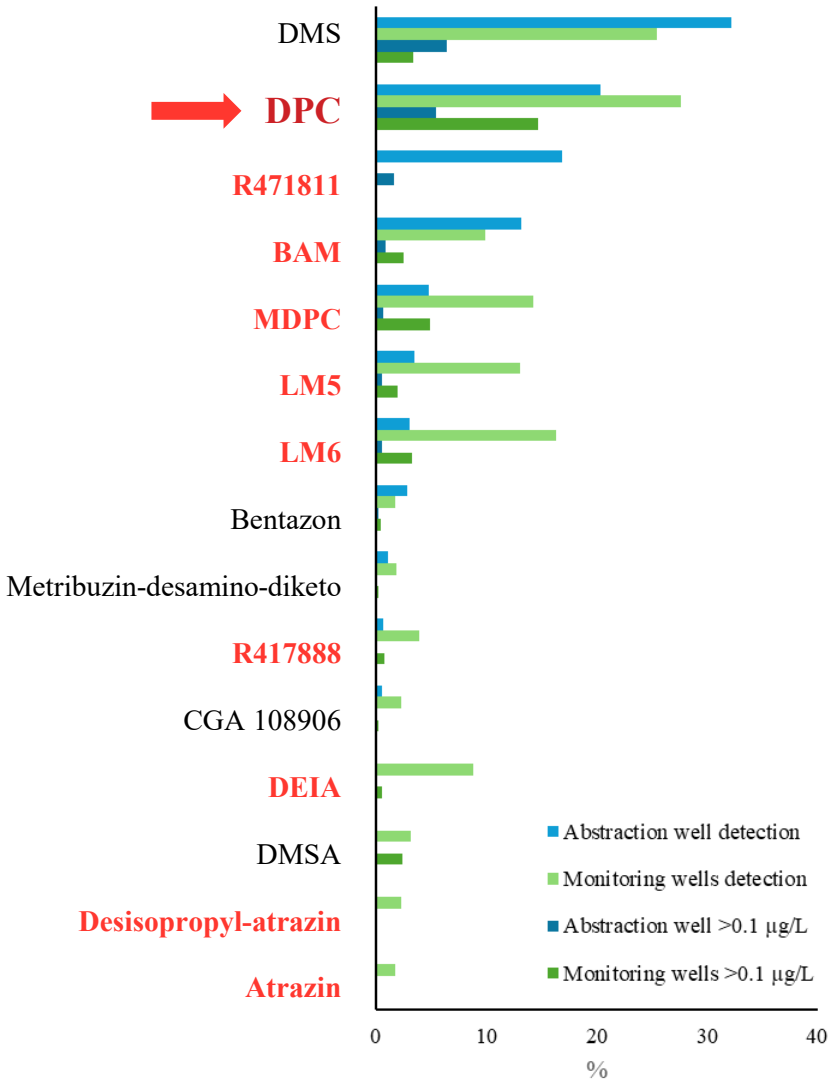
50% danske vandforsyningsboringer med pesticidforurening.

14% med overskridelser af grænseværdien (0,1 µg/L)

Størstedelen er nedbrydningsprodukter fra pesticidstoffer

Landbrugspesticider forbudt i mere end 15 år.



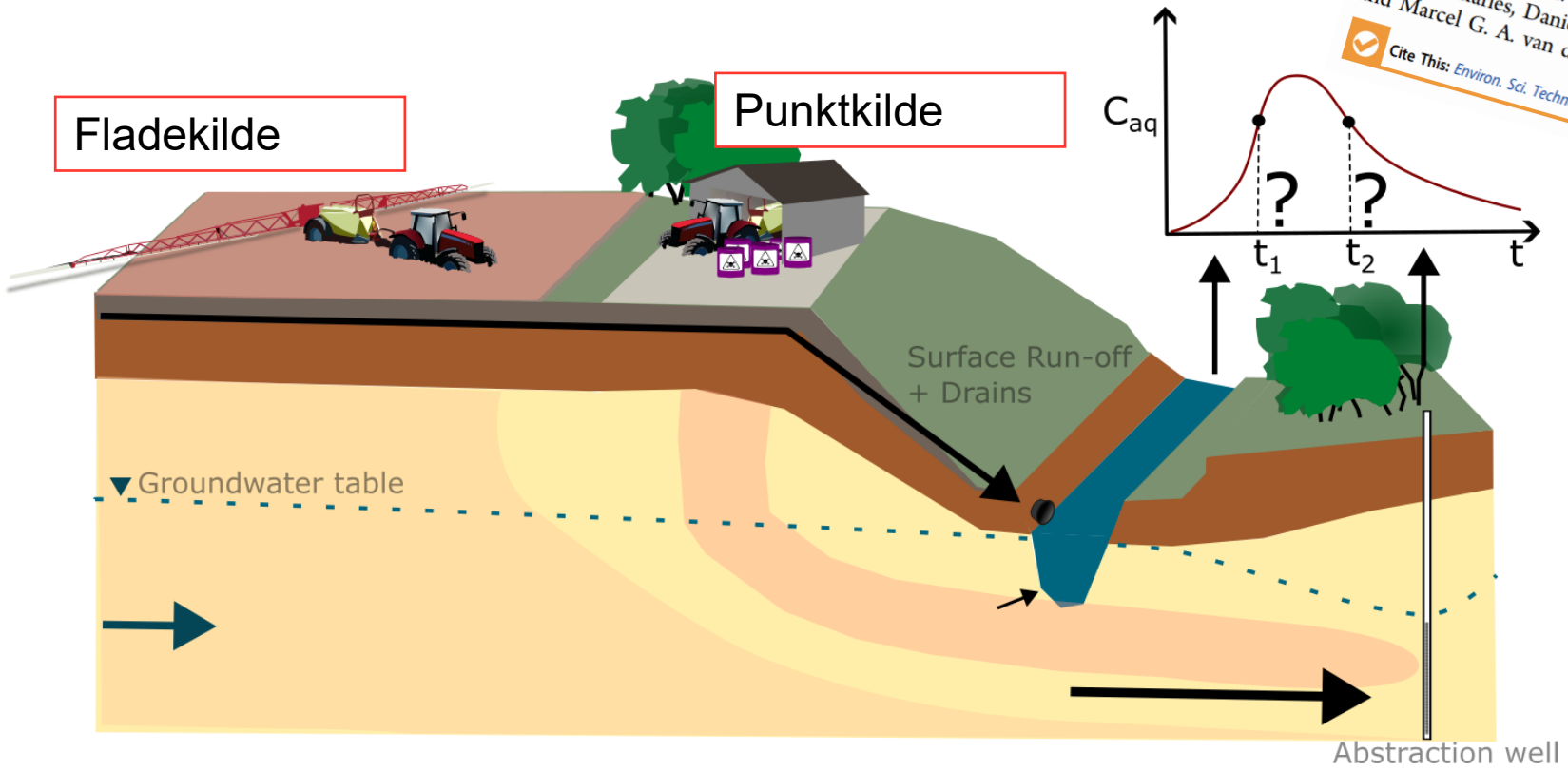


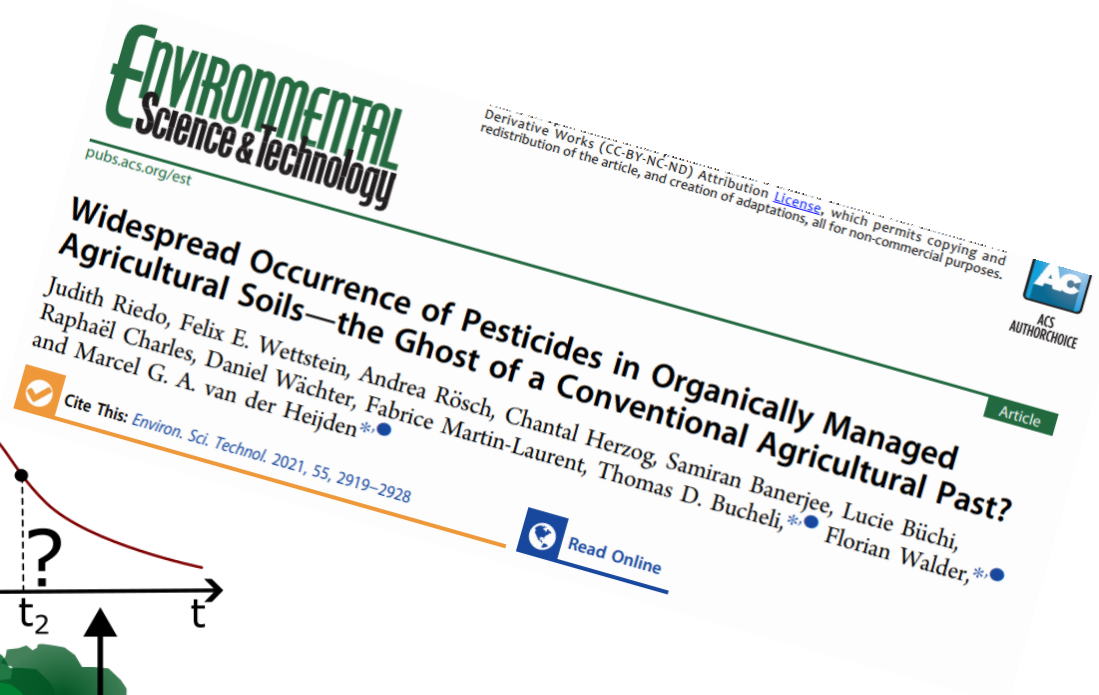
Fladekilde/punktkilde

Administrativt ansvar for håndtering

Muligheder for indgre og afværge

Vurdering af varighed og tidshorisonter





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Article

Widespread Occurrence of Pesticides in Organically Managed Agricultural Soils—the Ghost of a Conventional Agricultural Past?

Judith Riedo, Felix E. Wettstein, Andrea Rösch, Chantal Herzog, Samiran Banerjee, Lucie Büchi, Raphaël Charles, Daniel Wächter, Fabrice Martin-Laurent, Thomas D. Bucheli,* Florian Walder,* and Marcel G. A. van der Heijden*

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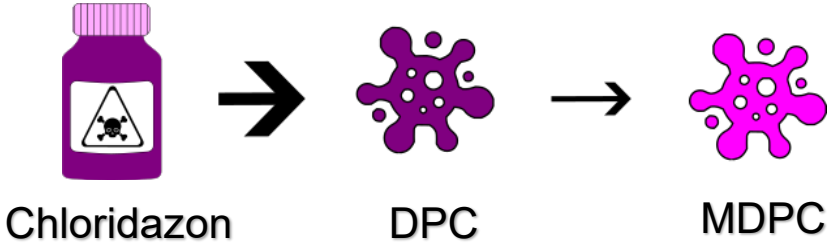
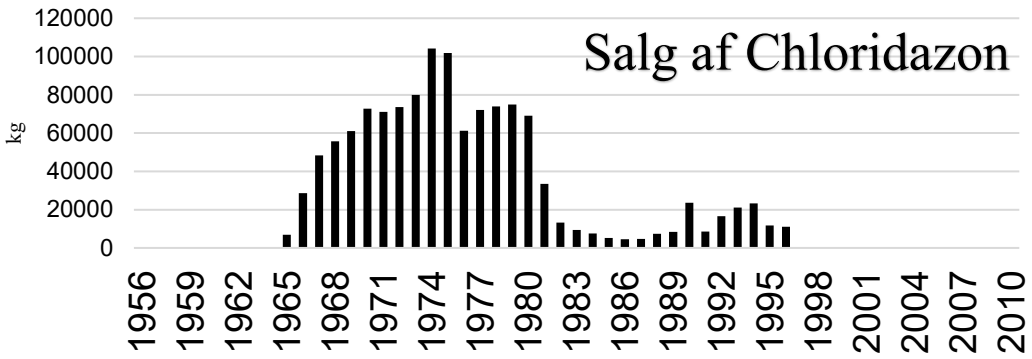
Pesticidrester tilbageholdt i overjorden på konventionelle og økologiske markarealer

Desphenyl chloridazon, DPC





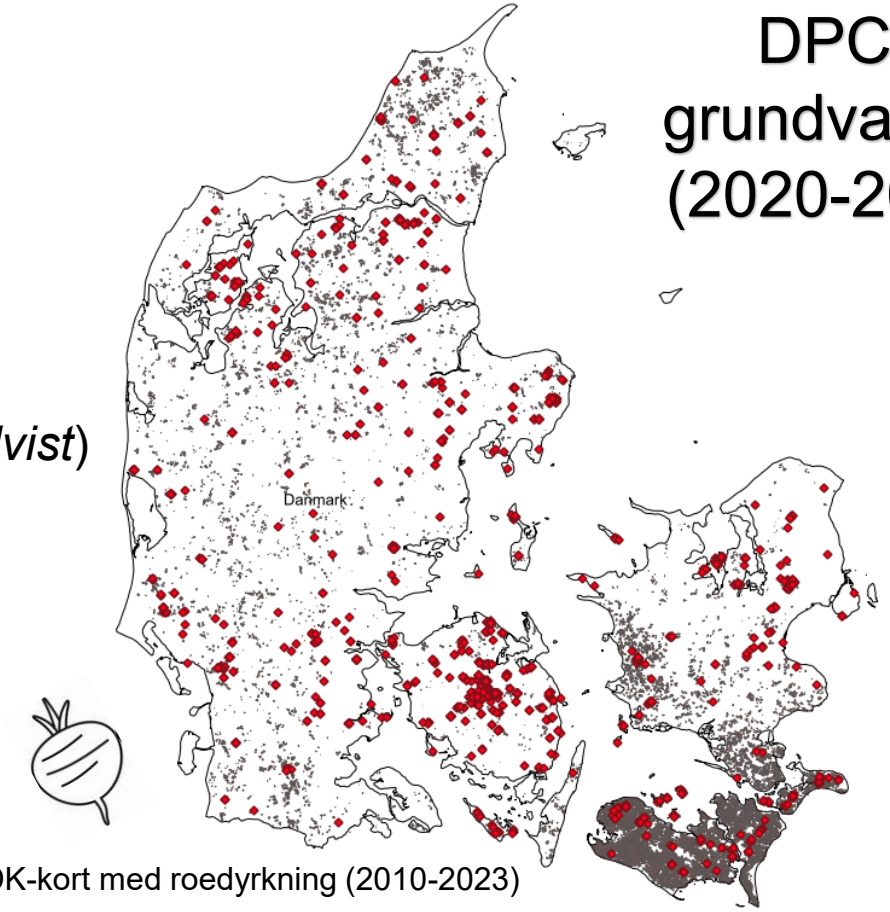
Chloridazon (1964 – 1996)

- Herbicid (ukrudtsmiddel)
- Anvendes til dyrkning af roer, løg og rødbeder.
- Behandlingshyppighed: hvert 4. år

DPC

- Nedbrydes fra chloridazon i aerob grundvand (*helt*) og jord (*delvist*)
- **Stabilt** (*nedbrydes aerobt til MDPC i grundvand og jord*)
- Klassificeres normalt som **meget mobilt stof**
- Påvist i overfladevand og grundvand i hele landet
- Særligt nær tidl. sukkerfabrikker

DPC i grundvandet (2020-2025)



DK-kort med roedyrkning (2010-2023)

DPC i jorden under punktkildeforurening, C_{total}

$$C_{total} = \frac{C_{aq}\theta_w + C_s\rho_b}{\rho_b}$$

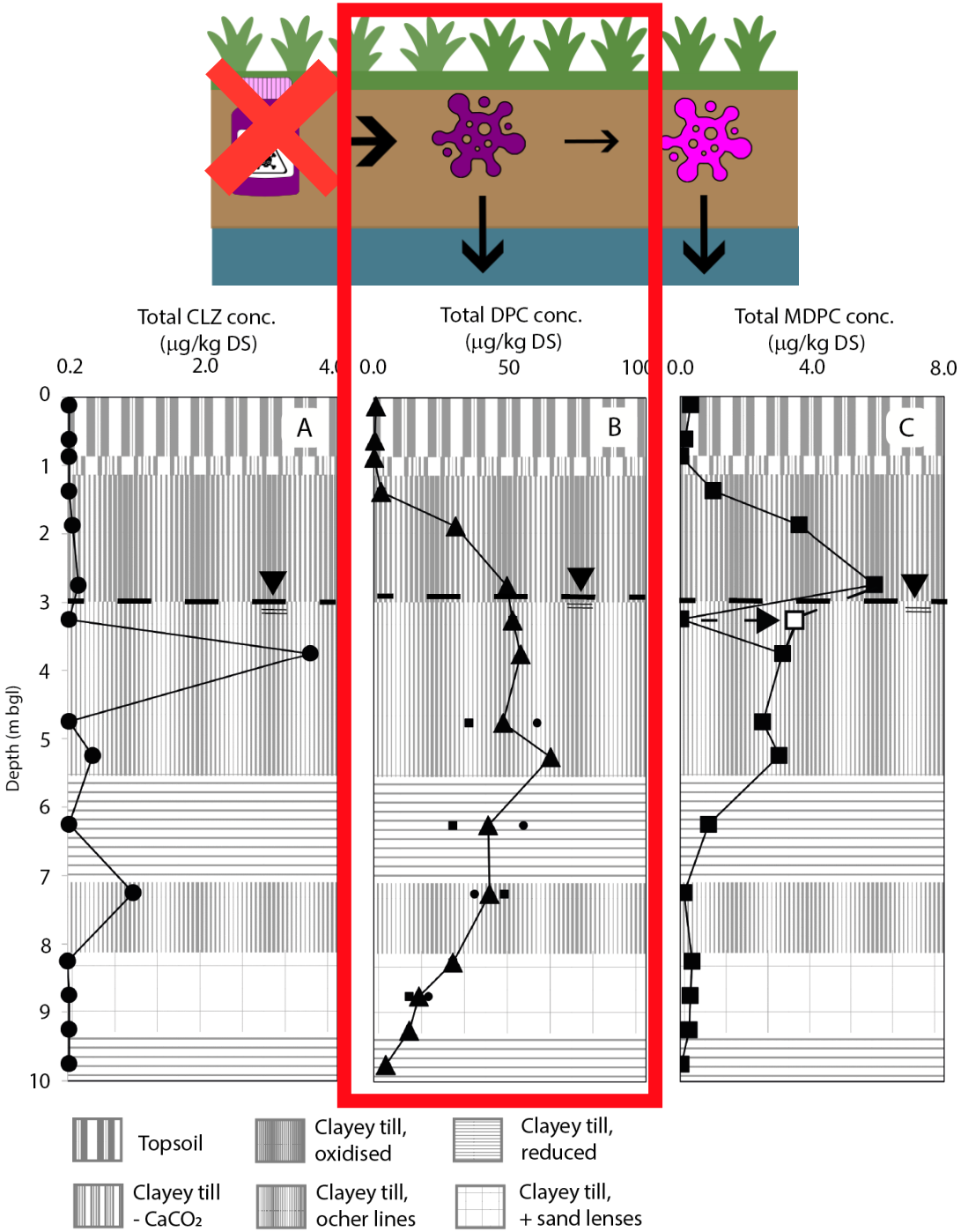
Punktkilde = møddingsplads

Chloridazon ikke anvendt siden 1996

Akkumulerede koncentrationer med DPC ned til 10 meters dybde (DPC >> CLZ (op til 1500x)

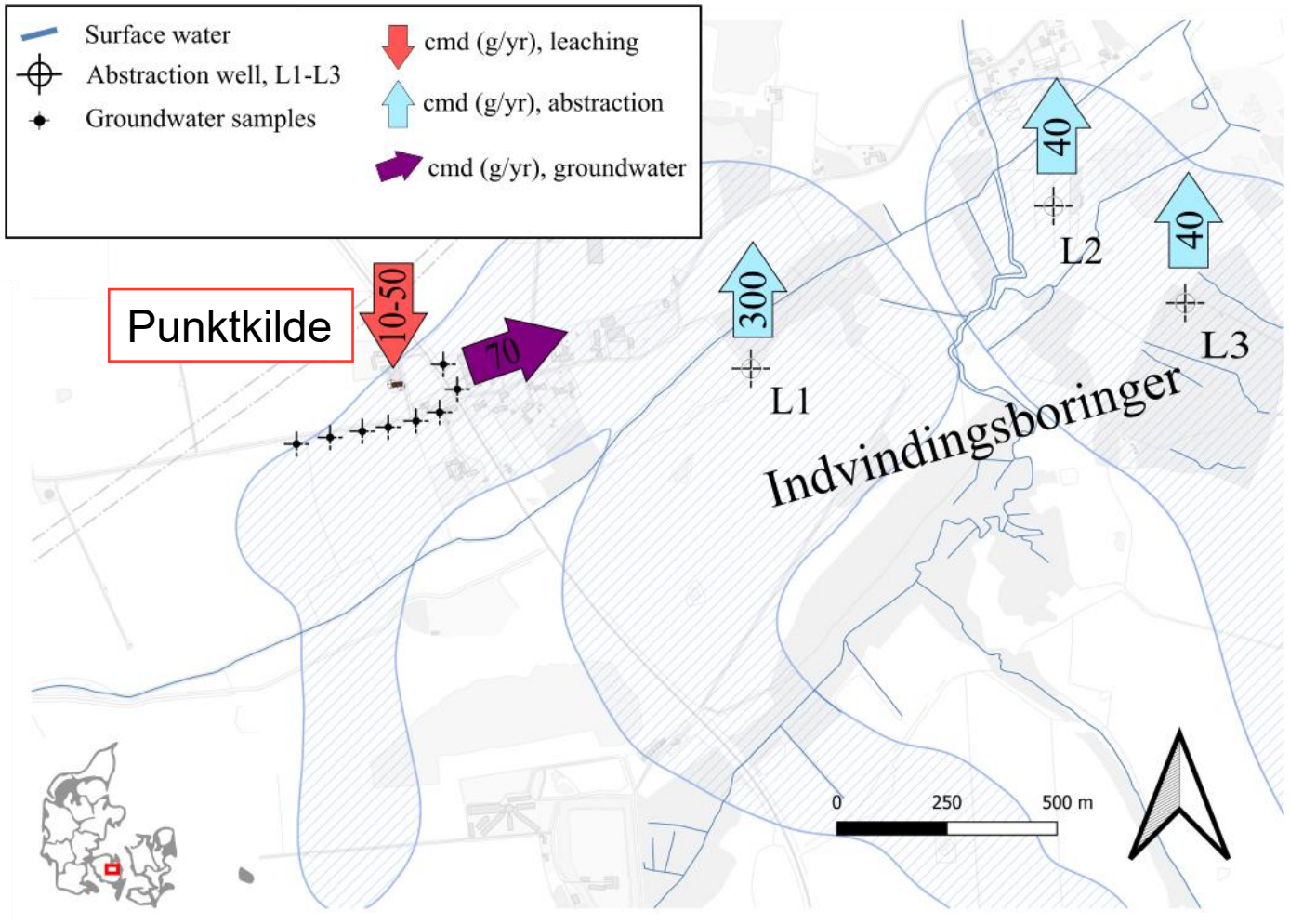
Sekundære kilder med DPC forurening under punktkilder

Langsom nedsivning og længerevarende forurening af grundvand.



Læs mere: VMR 2021 nr. 4, s. 18-23

Kendte forureningsfluxe i oplandet



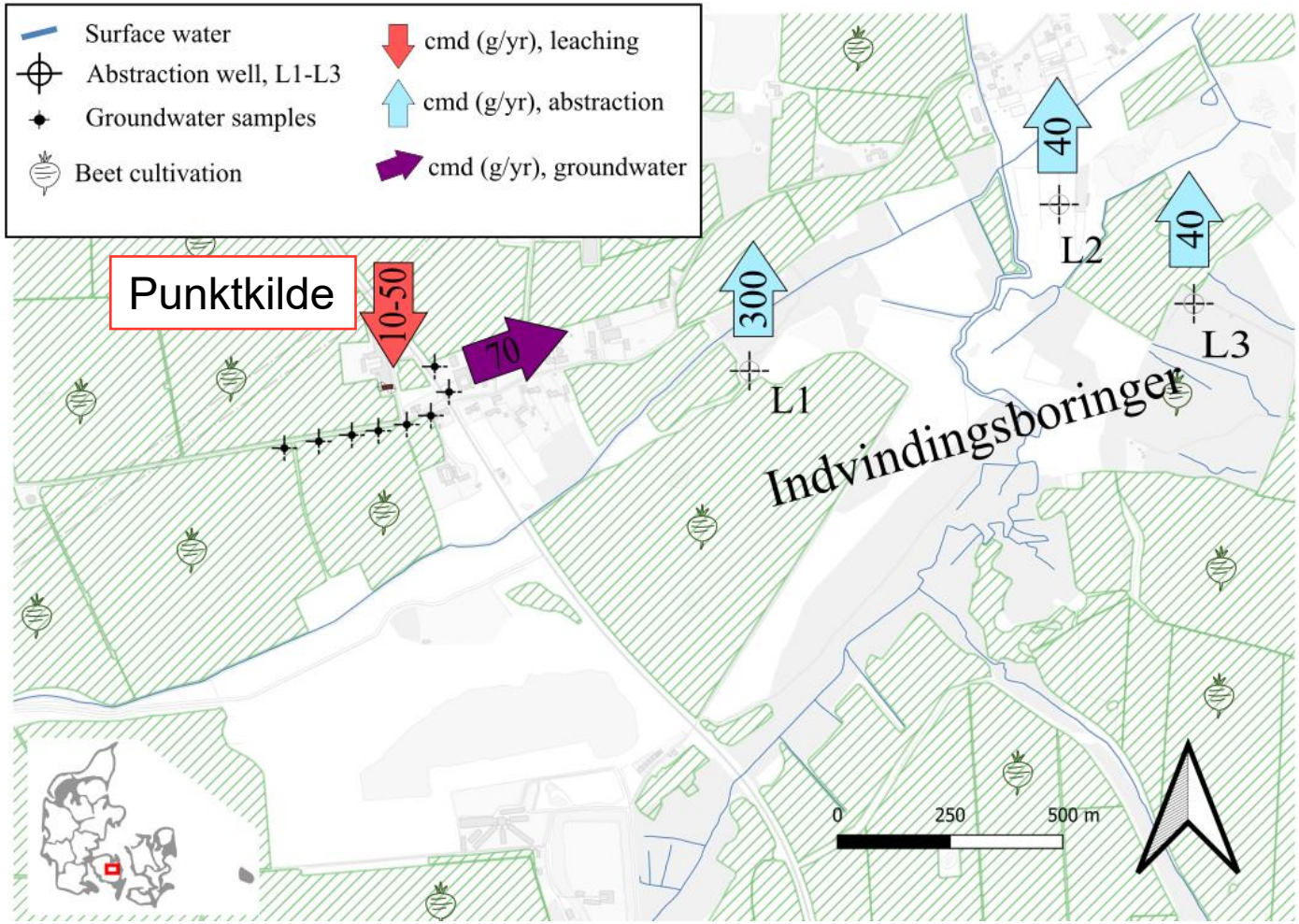
Indvinding fra sandmagasin (400.000 m^3/år)
Filtre 20-40 m u.t.

Forureningsflux (g/år) fra L1:
$J_{L1} = Q_{L1} C_{L1}$ **~ 300 g DPC/år**

Forureningsflux (g/år) fra punktkilde:
$J_{punktkilde} = Inf \cdot A \cdot C_{porevand}$ **~ 10-50 g DPC/år**

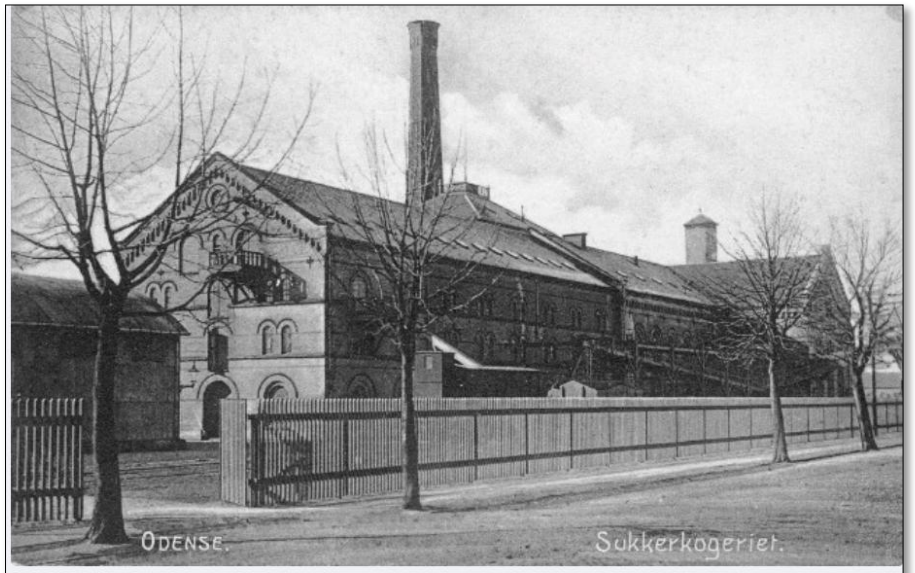
Massebalance stemmer ikke overens

Lokalisering af forureningskilder



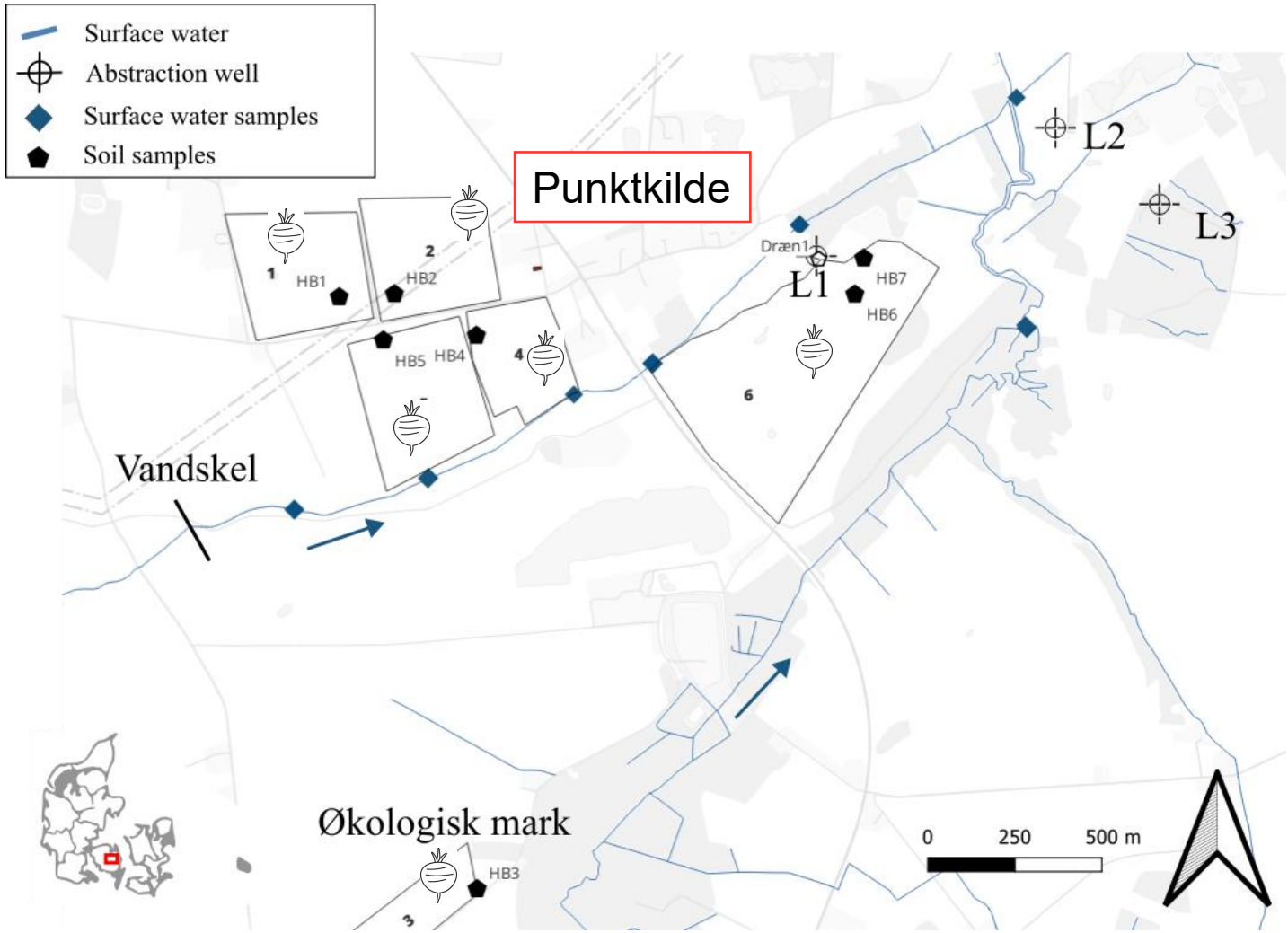
Lokalhistorik: chloridazon frem til 1994

- Overfladevandprøver
- Overfladejordprøver



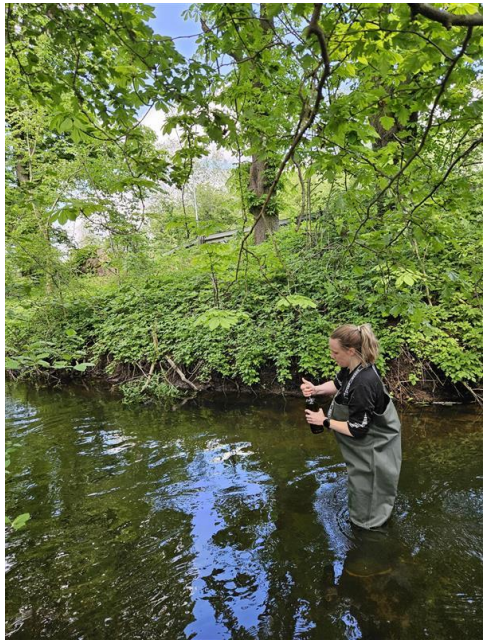
Danmarks største sukkerkogeri bygget i Odense i 1873

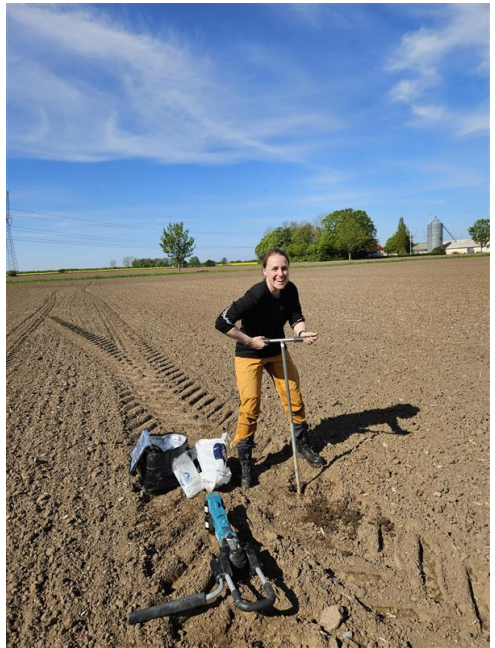
Lokalisering af forureningskilder



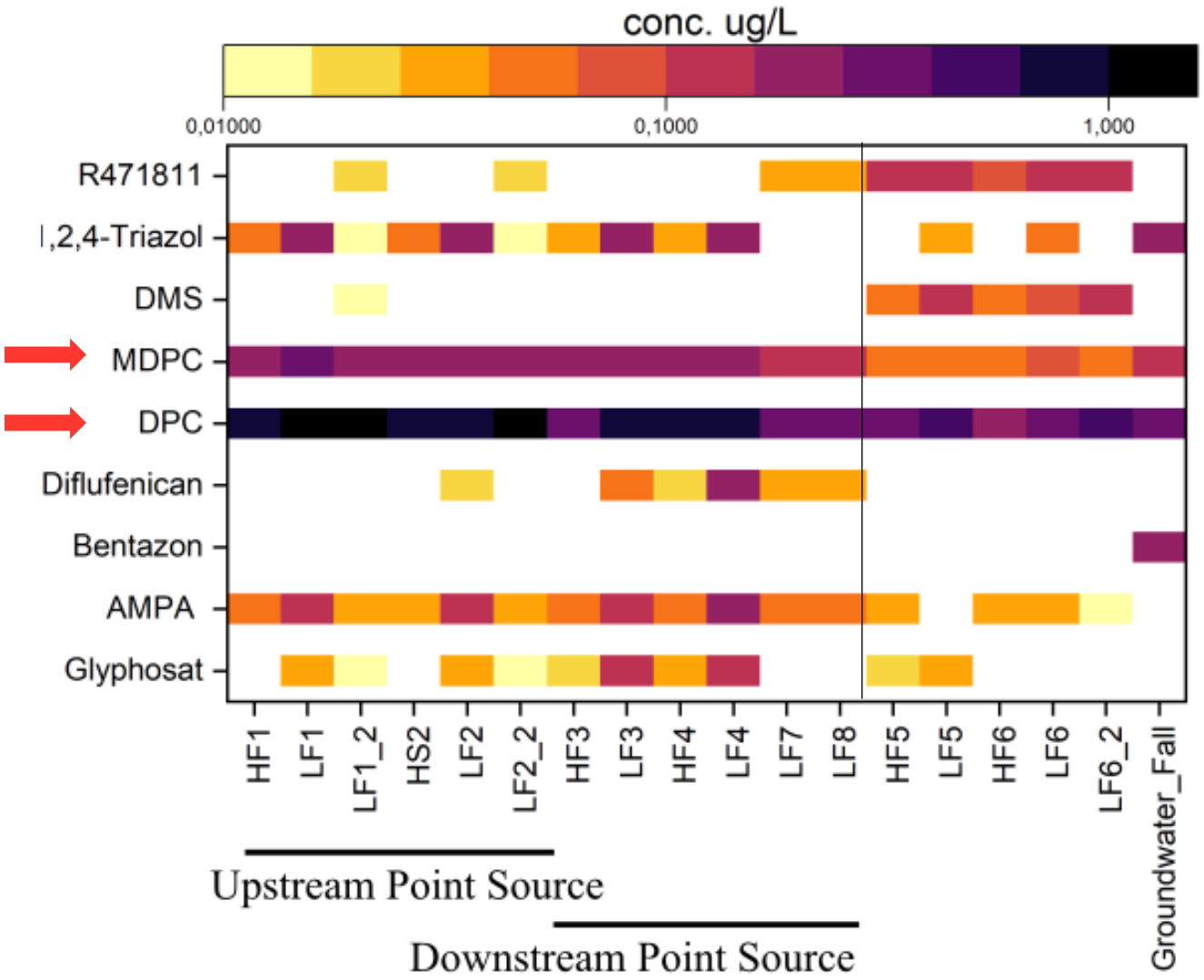
Lokalhistorik: chloridazon frem til 1994

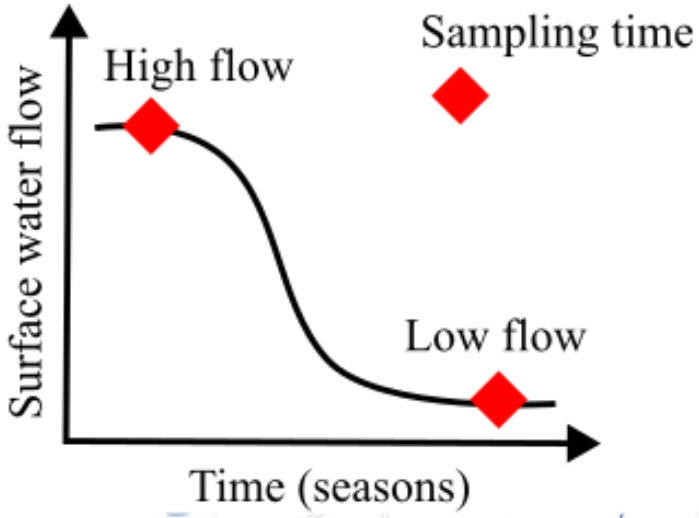
- **Overfladevandprøver, forår/efterår**
- **Overfladejordprøver**

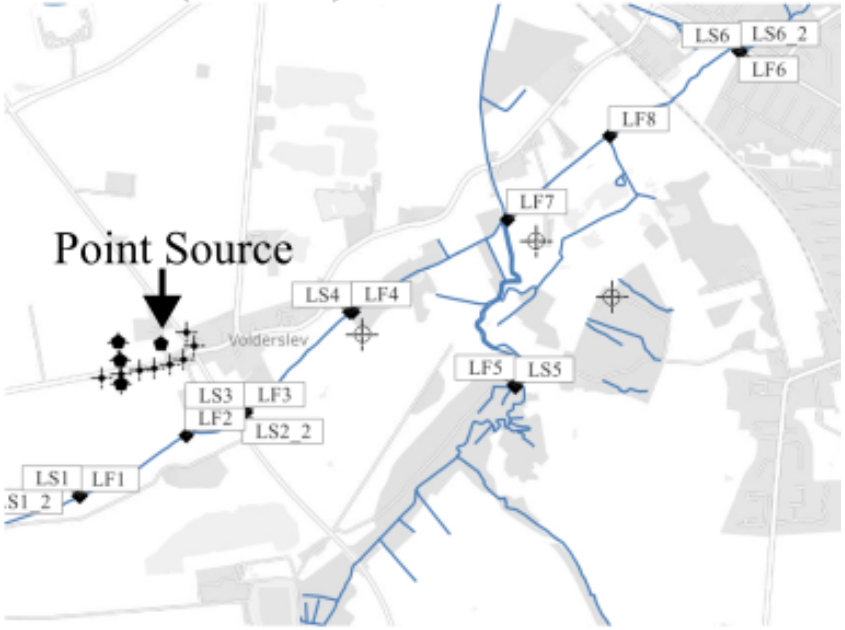




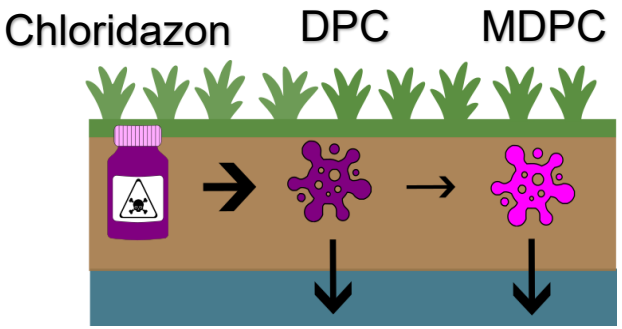
Vedvarende input med DPC og MDPC i overfladevand

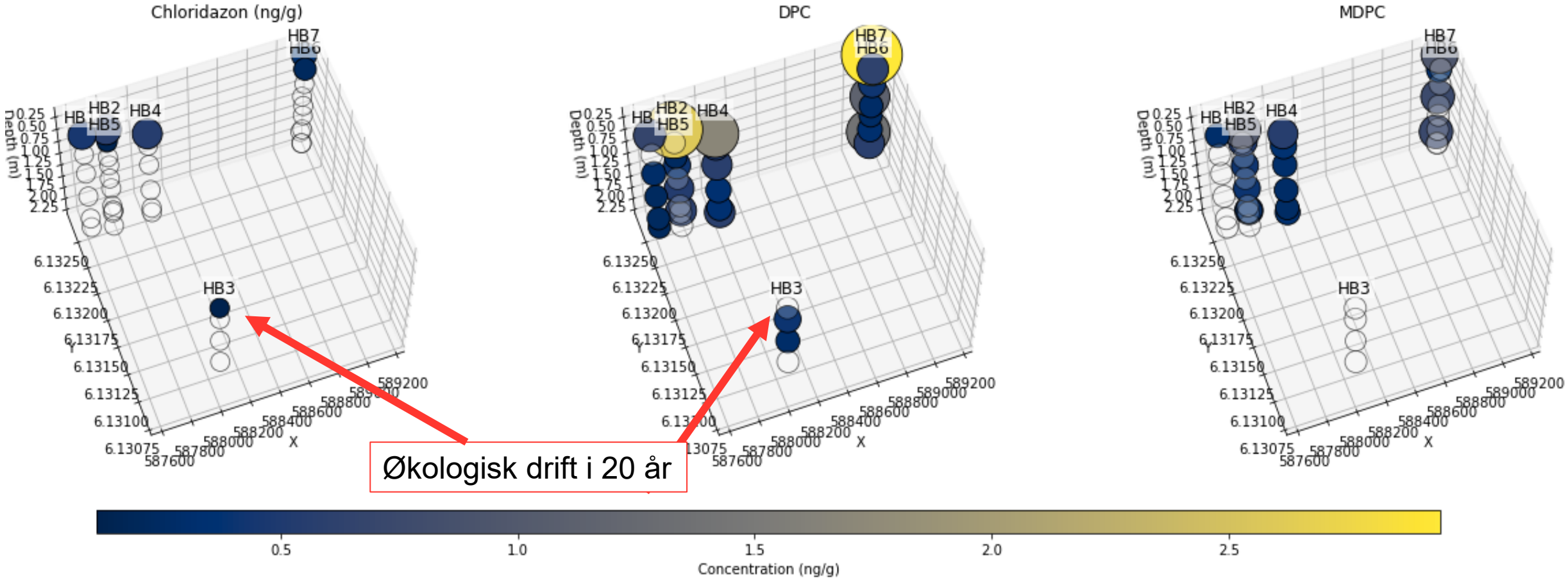






Jordkoncentrationer, C_{total}, under markarealer





Økologisk drift i 20 år

$$C_{total} = \frac{C_{aq}\theta_w + C_s\rho_b}{\rho_b}$$

Pesticidrester under markarealer vs. punktkilde

Jordprøver til 5 m u.t.

3 boringer i markareal

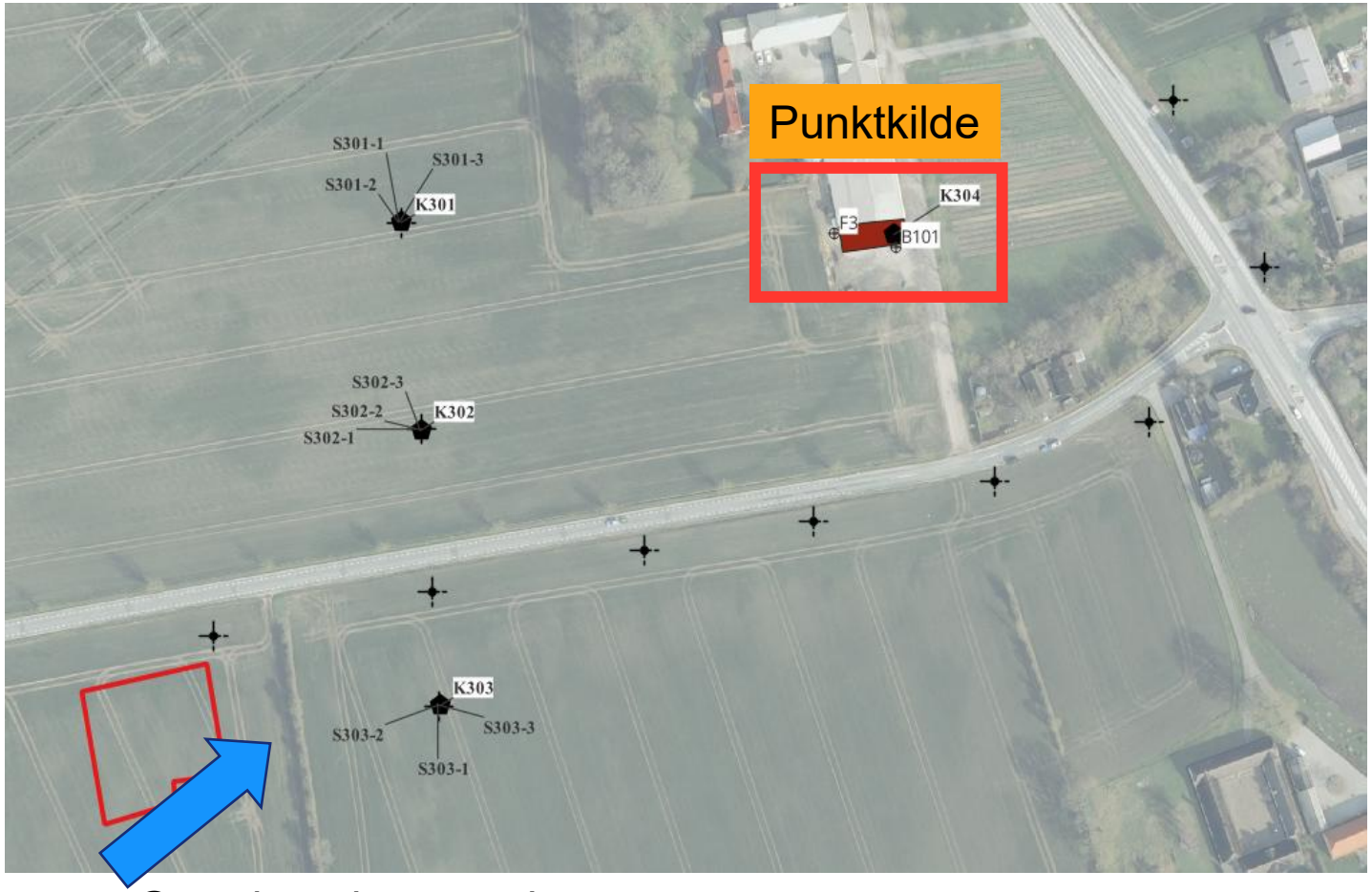
1 boring i punktkildeområde

Vandprøver:

9 porevandsprøver

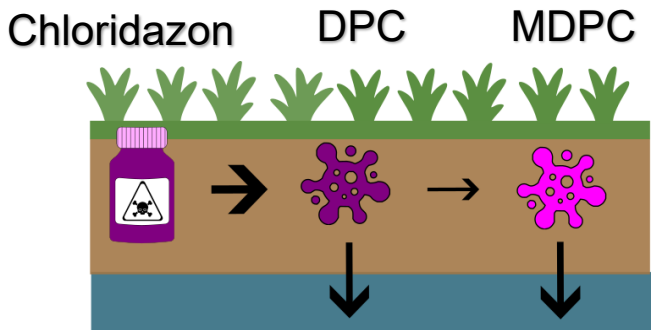
9 niveauspecifikke grundvandsprøver

2 grundvandsprøver ved punktkilde

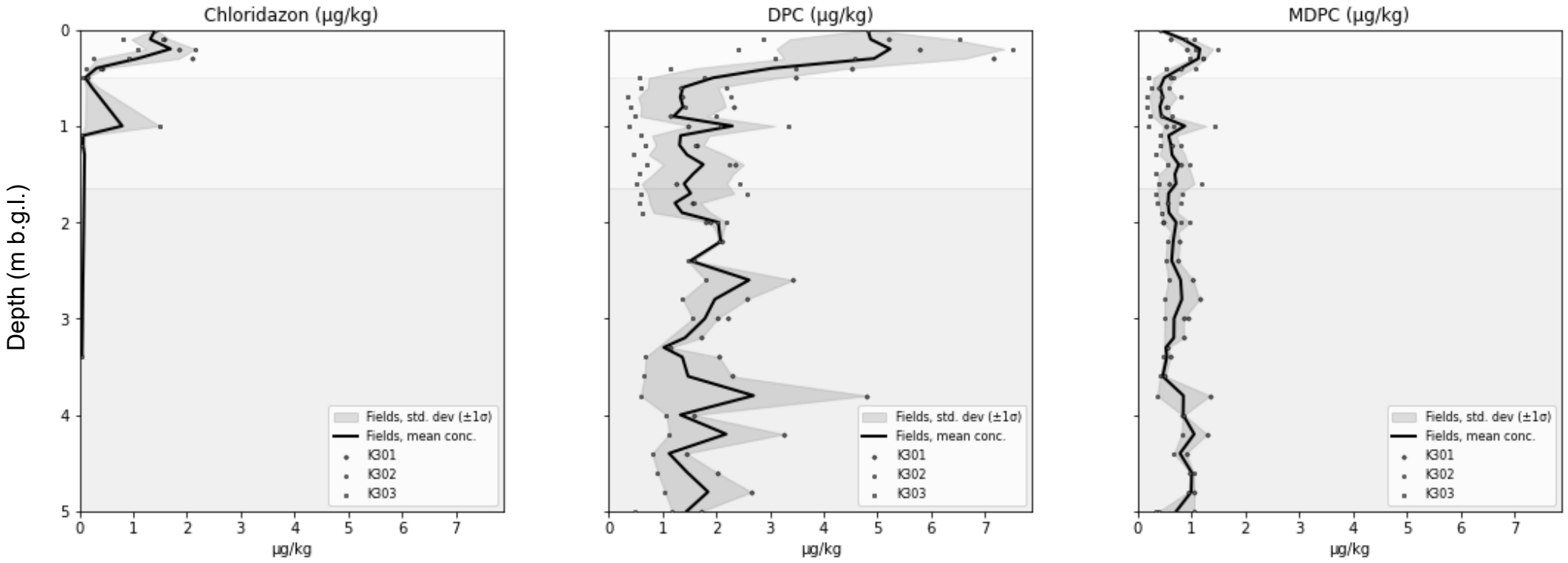


Grundvandsstrømning

C_{total} under **markarealer**



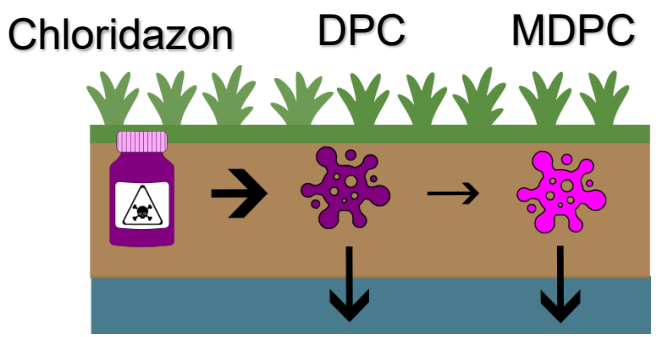
- Chloridazon blev sidst anvendt i 1994.

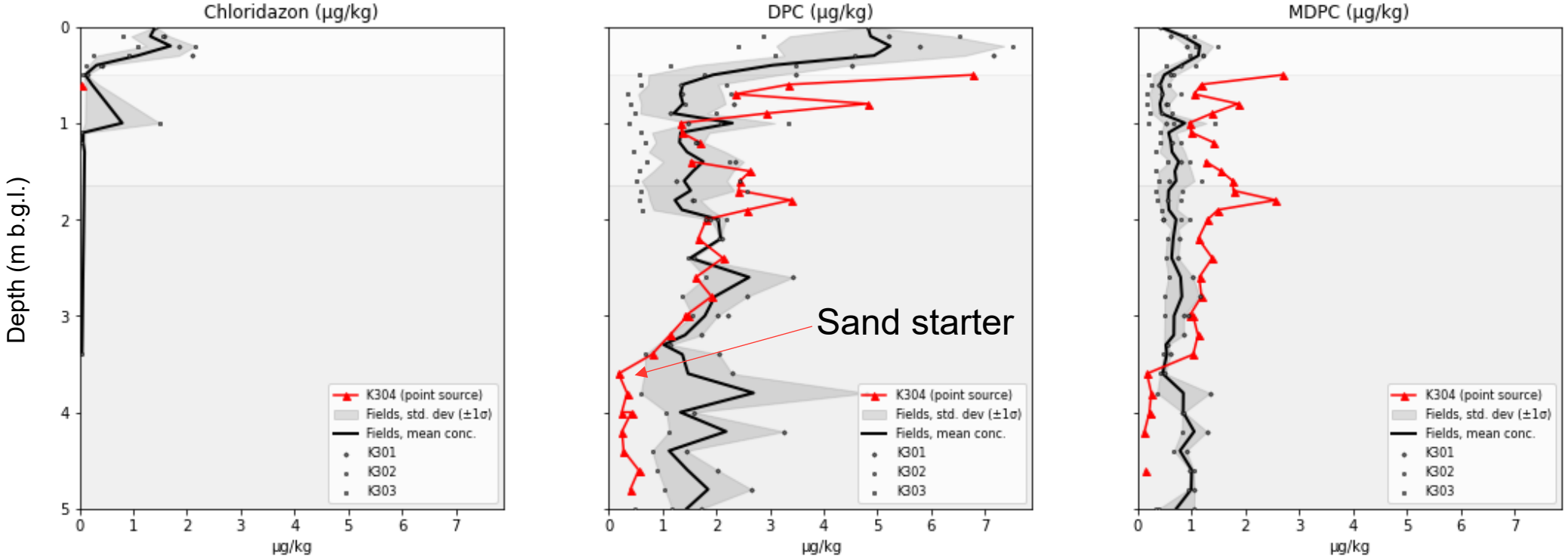


- Chloridazon er påvist i muldjorden
- DPC påvist op til 7,5 µg/kg i muldjord samt i alle jordprøver ned til 5 m u.t.!

C_{total} under **punktkilde**

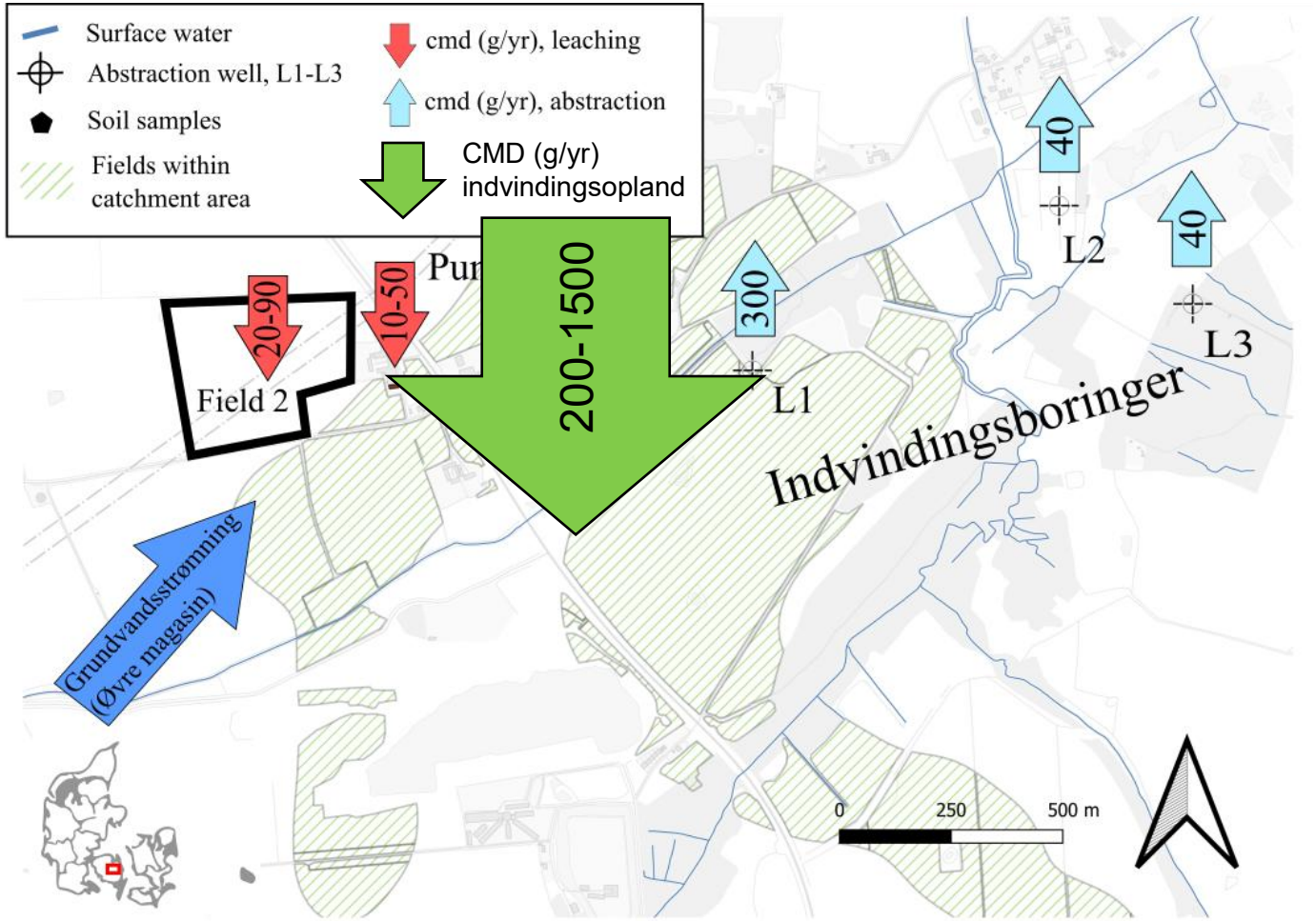
- Chloridazon blev sidst anvendt i 1994.





- DPC er påvist under punktkilden
  – men i koncentrationer, der kun ligger lidt over dem under fladekilderne

Beregnet forureningsflux fra fladekilder (ud fra C_{total})



Forureningsflux (g/år) fra punktkilde:

$J_{punkt} = Inf \cdot A_{punkt} \cdot C_{porevand}$ **~ 10-50 g DPC/år**

Forureningsflux (g/år) fra mark 2:

$J_{mark} = Inf \cdot A_{mark} \cdot C_{porevand}$ **~ 20-90 g/år**

Forureningsflux (g/år) fra indvindingsopland:

$J_{opland} = Inf \cdot A_{opland} \cdot C_{porevand}$ **~ 200-1500 g/år**

- *Inf: 50 mm/år – 200 mm/år*
- *Kd-værdier: 0.2 – 0.8 L/kg*

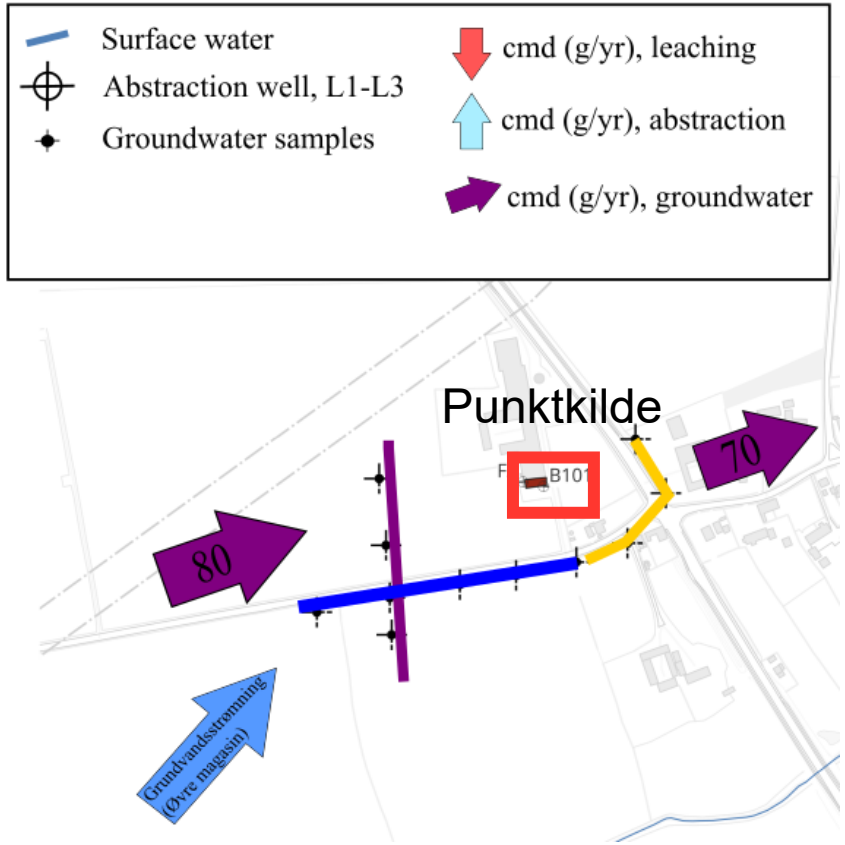
DPC koncentrationer i vand under markarealer

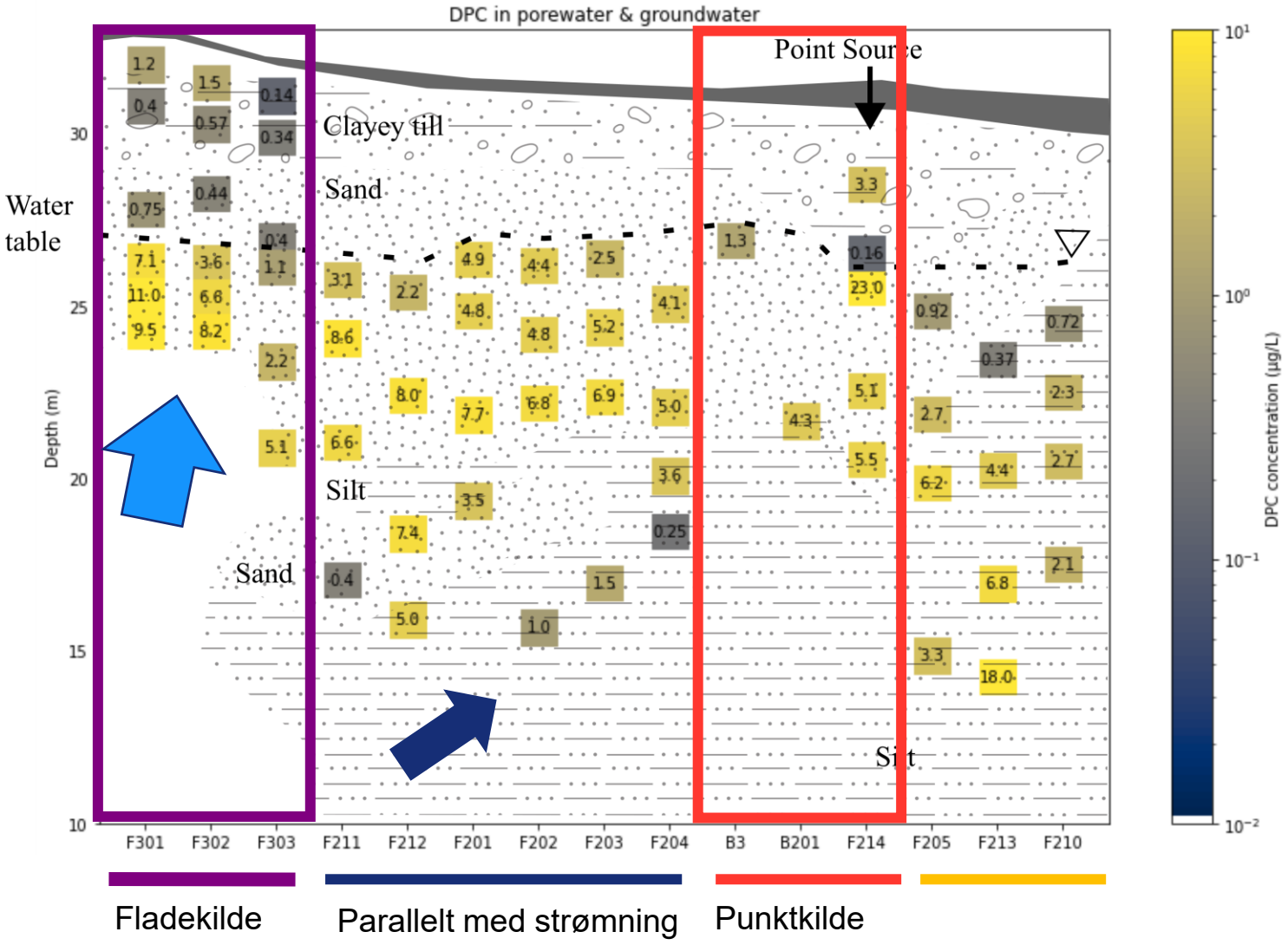
Chloridazon sidst anvendt i 1994

DPC koncentrationer **i alle** vandprøver

DPC under fladekildearealer

Punktkilden er ikke hovedkilden til DPC-forurening



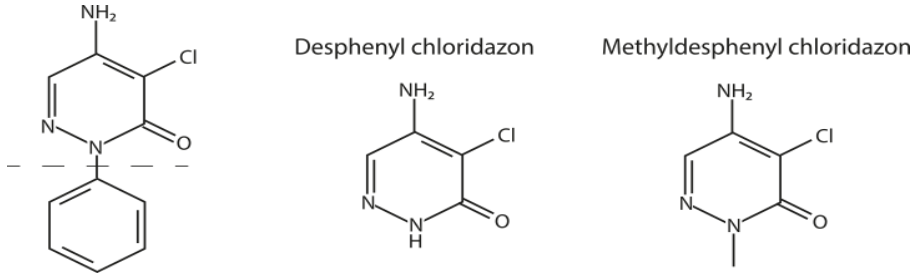


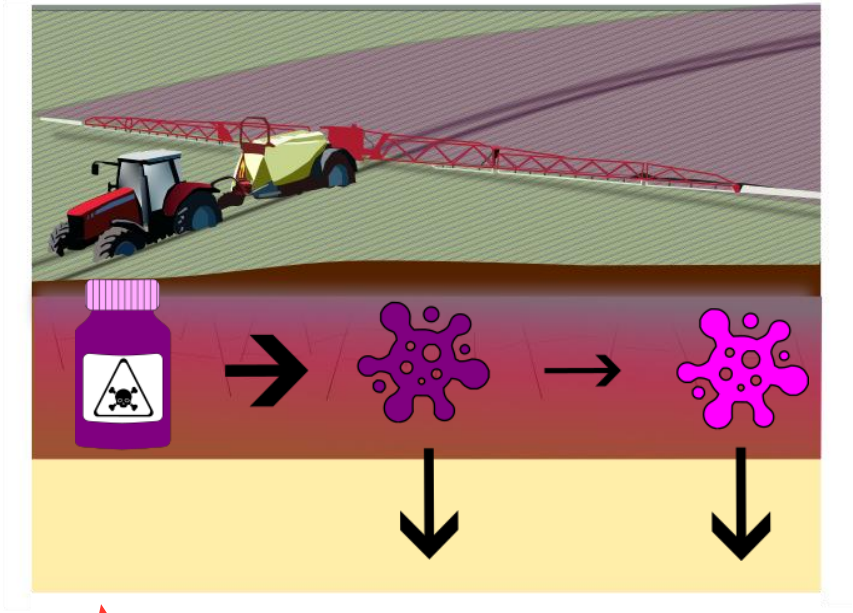
Konklusioner

- Chloridazon (>30 år forbud) → rester findes stadig under markarealer.
- DPC og MDPC påvises i både overfladejord og dybere ler-sedimenter.
- DPC frigives langsomt fra jord med højt organisk indhold → er mere mobilt i lerjord.
- Udbredt forurening med DPC og MDPC i grundvand under landbrugsarealer
- **DPC-forureningen stammer primært fra fladekilder**
- **Bidraget fra fladekilder vurderes som væsentligt større end fra punktkilder.**

Landbrugsjord fungerer som langsigtede reservoirer, der langsomt frigiver DPC (og andre???), hvilket udgør en vedvarende risiko for kvaliteten af overfladevand og grundvand.

Chloridazon





Det videre arbejde:

- Modellering af tilbageholdelse, forureningsflux og varighed af DPC-forurening.

Referencer (og anden interessant læsning ☺)

Krog, A., Tsitonaki, K., Sadowski, K., Pedersen, S. R., Jannerup, H., & Bjerg, P. L. (2021). *Den umættede zone som en sekundær kilde til forurening af grundvandet med desphenyl-chloridazon (DPC)*. Miljø og Ressourcer, 4, 18–23.

Miljøstyrelsen**.** (2022). *Skelnen mellem pesticidkilder* (red. Sandra Roost, Katerina Tsitonaki & Anna Krog Nielsen; med bidrag af Poul L. Bjerg, Klaus Mosthaf, Annika S. Fjordbøge, Anders Risbjerg Johnsen & Lærke Thorling). Miljøstyrelsen.

Hintze, S., Cochand, F., Glauser, G., & Hunkeler, D. (2024). *Soil and unsaturated zone as a long-term source for pesticide metabolites in groundwater*. Water Research, 261, 121901. https://doi.org/10.1016/j.watres.2024.121901

Branco, R. H. R., Meulepas, R. J. W., Kadlecová, K., Cardoso, M. F. S., Rijnaarts, H. H. M., & Sutton, N. B. (2024). *Effect of dissolved organic carbon on micropollutant biodegradation by aquifer and soil microbial communities*. Chemosphere, 347, 140644. https://doi.org/10.1016/j.chemosphere.2023.140644

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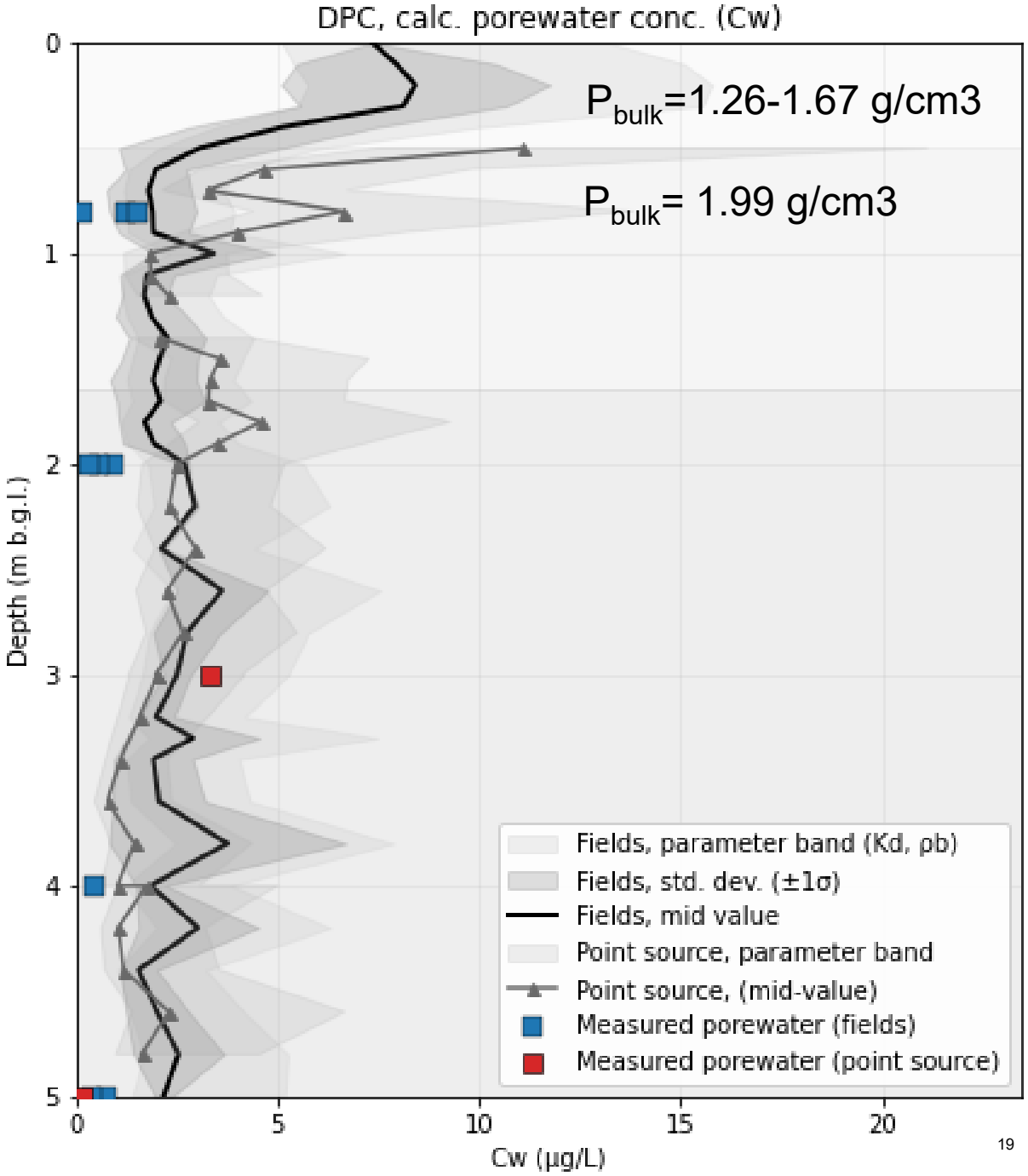
https://sustain.dtu.dk/en/

Porevandskoncentrationer under markarealer

$$C_w = C_T \cdot \frac{\rho_b}{K_d \rho_b + \theta_w}$$

Kd- værdier (egne batchforsøg)

Compound	Topsoil	Clayey till	Sand
DPC	**0,22-0,8**	**0,29-1.04**	**0,06-0,37**



Fraktion af DPC i porevand contra jordprøver

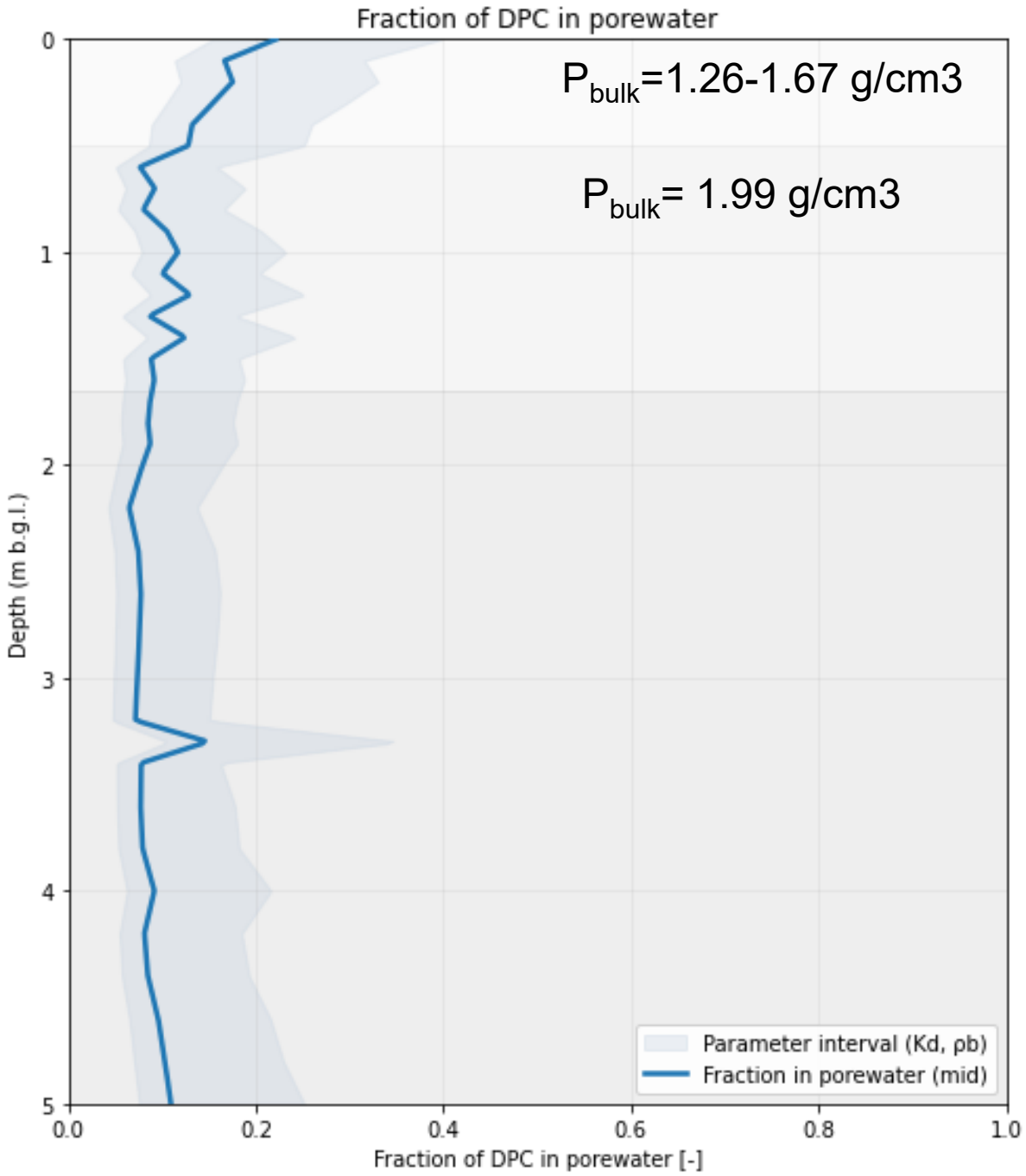
$$C_w = C_T \cdot \frac{\rho_b}{K_d \rho_b + \theta_w}$$

Kd- værdier (egne batchforsøg)

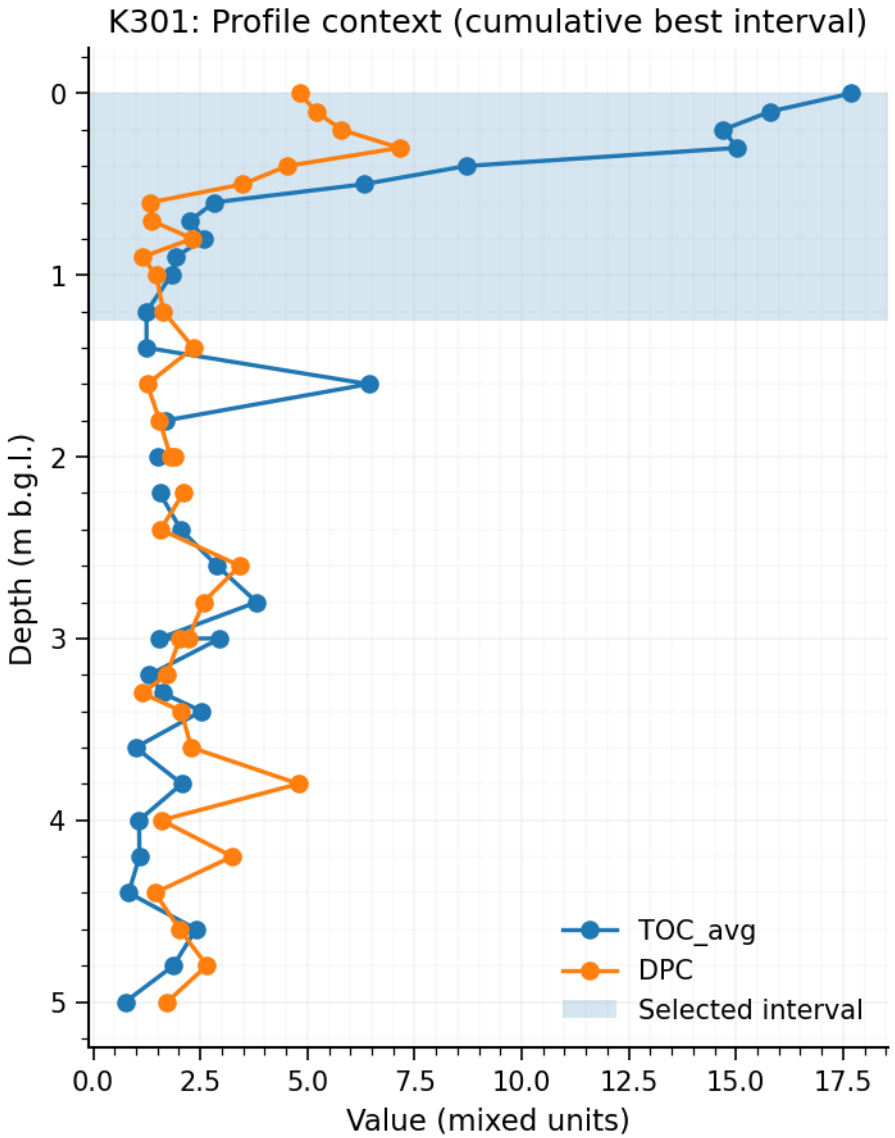
Compound	Topsoil	Clayey till	Sand
DPC	**0,22-0,8**	**0,29-1.04**	**0,06-0,37**

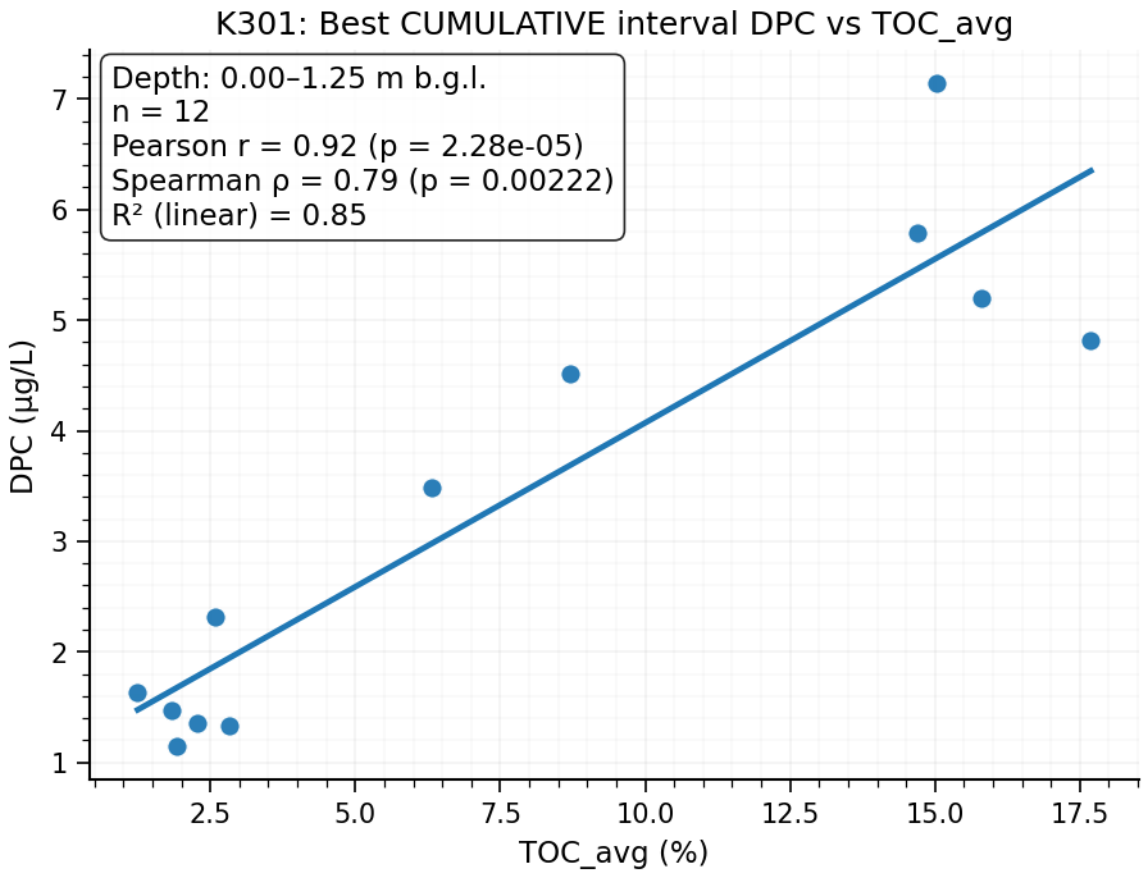
$$f_{porewater} = \frac{C_w}{C_{total}} \cdot \frac{\theta_w}{\rho_b}$$

Mindre end 20% af DPC er i porevandet
– resten findes i jorden



DPC og TOC korrelation

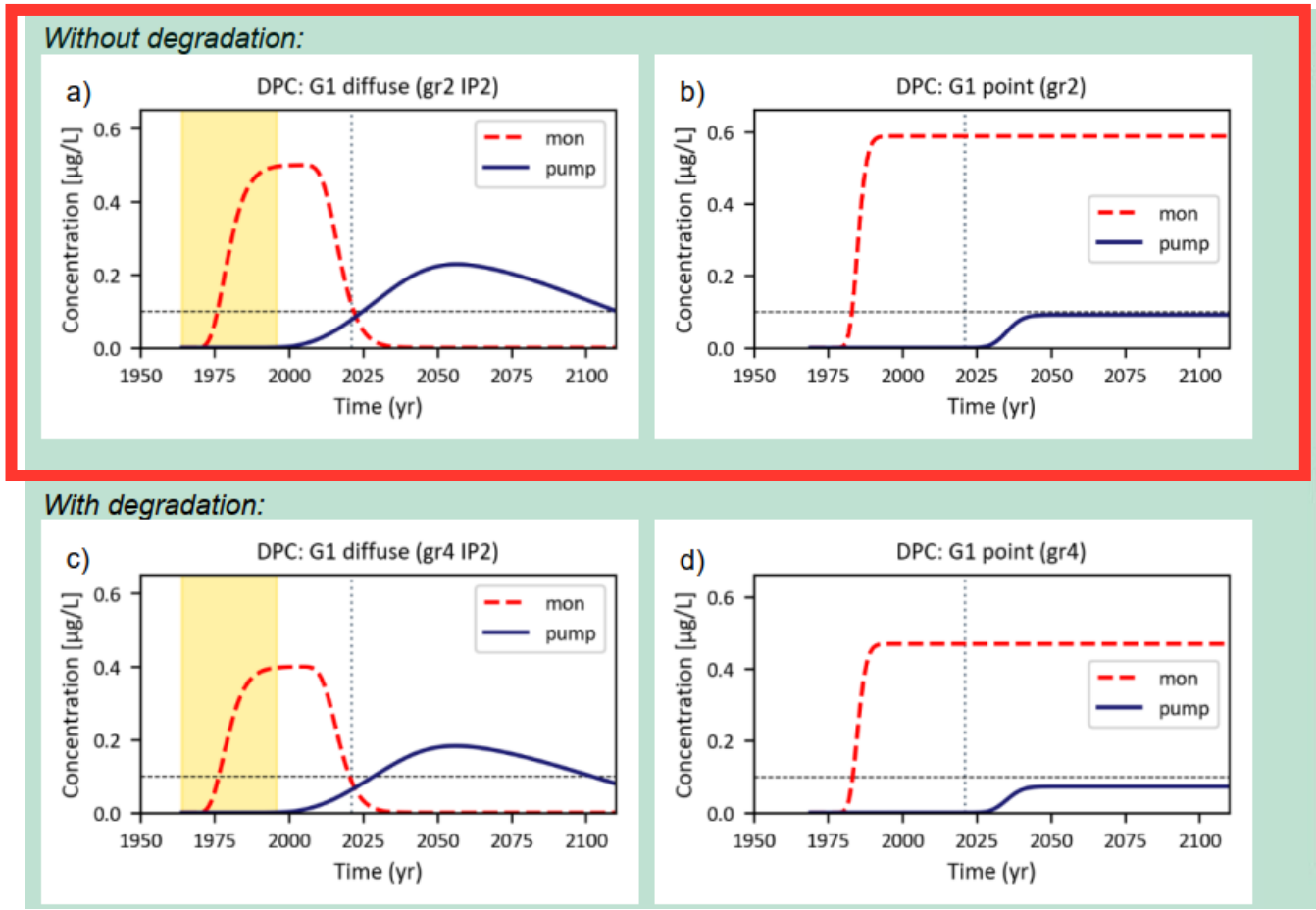


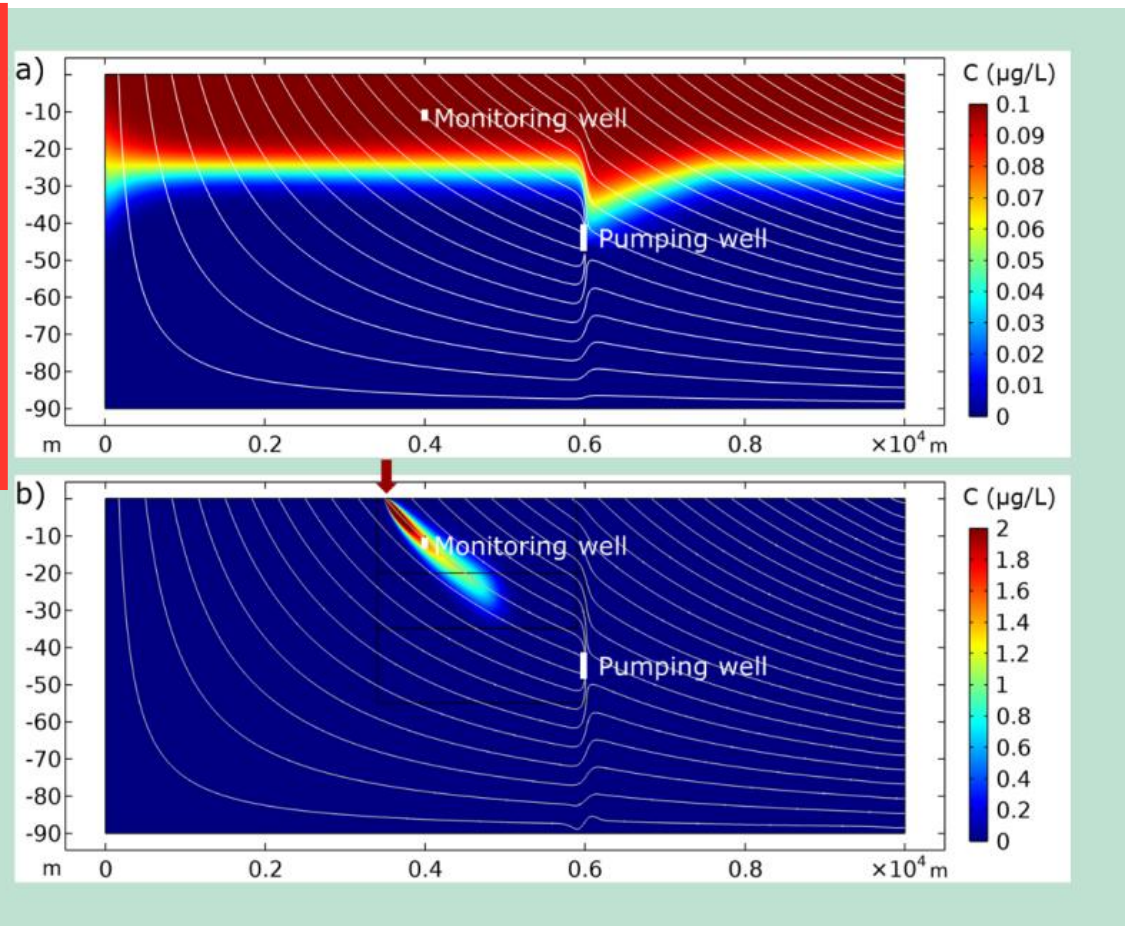


Varighedsprognoser

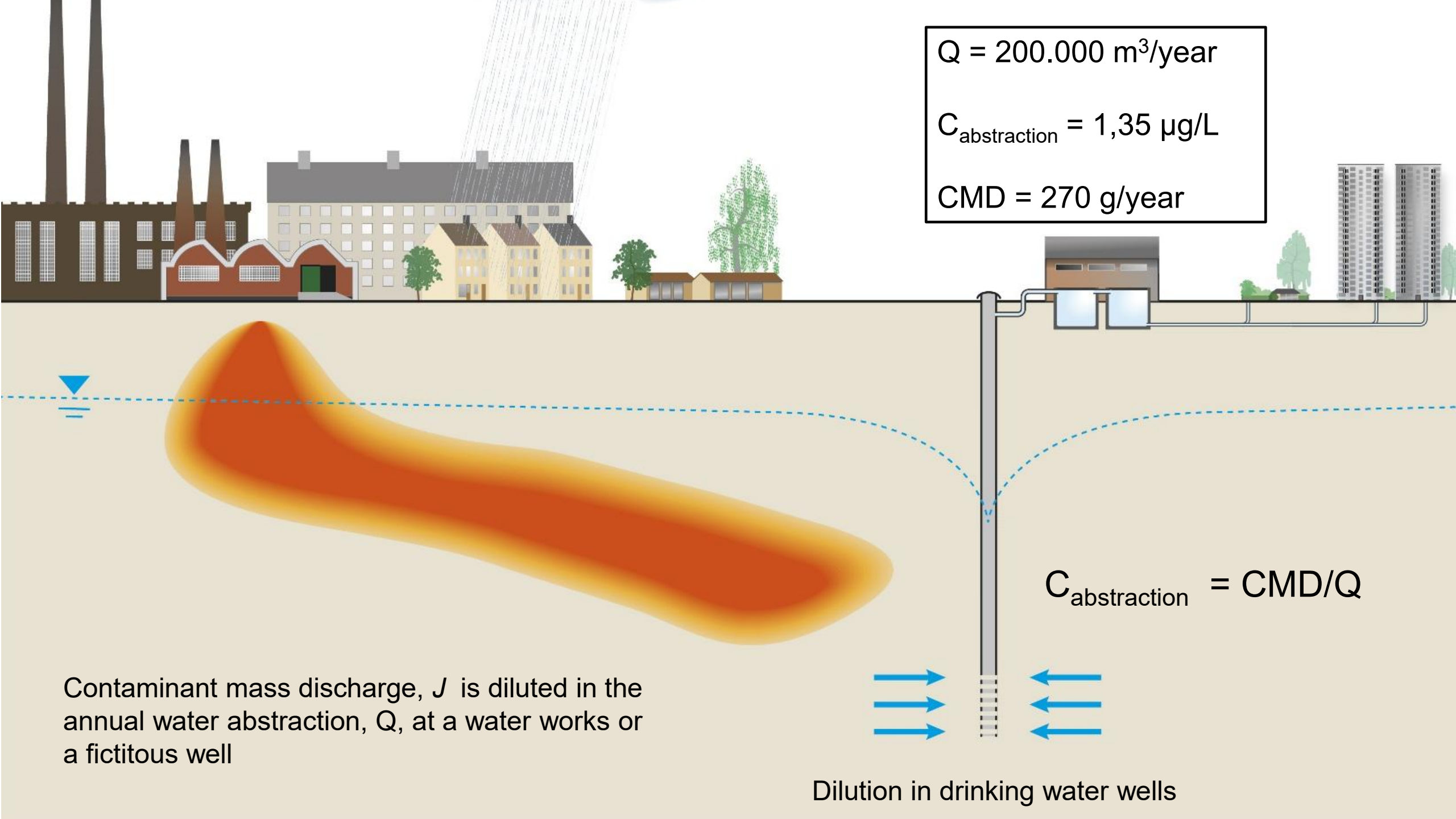
Fladekilde

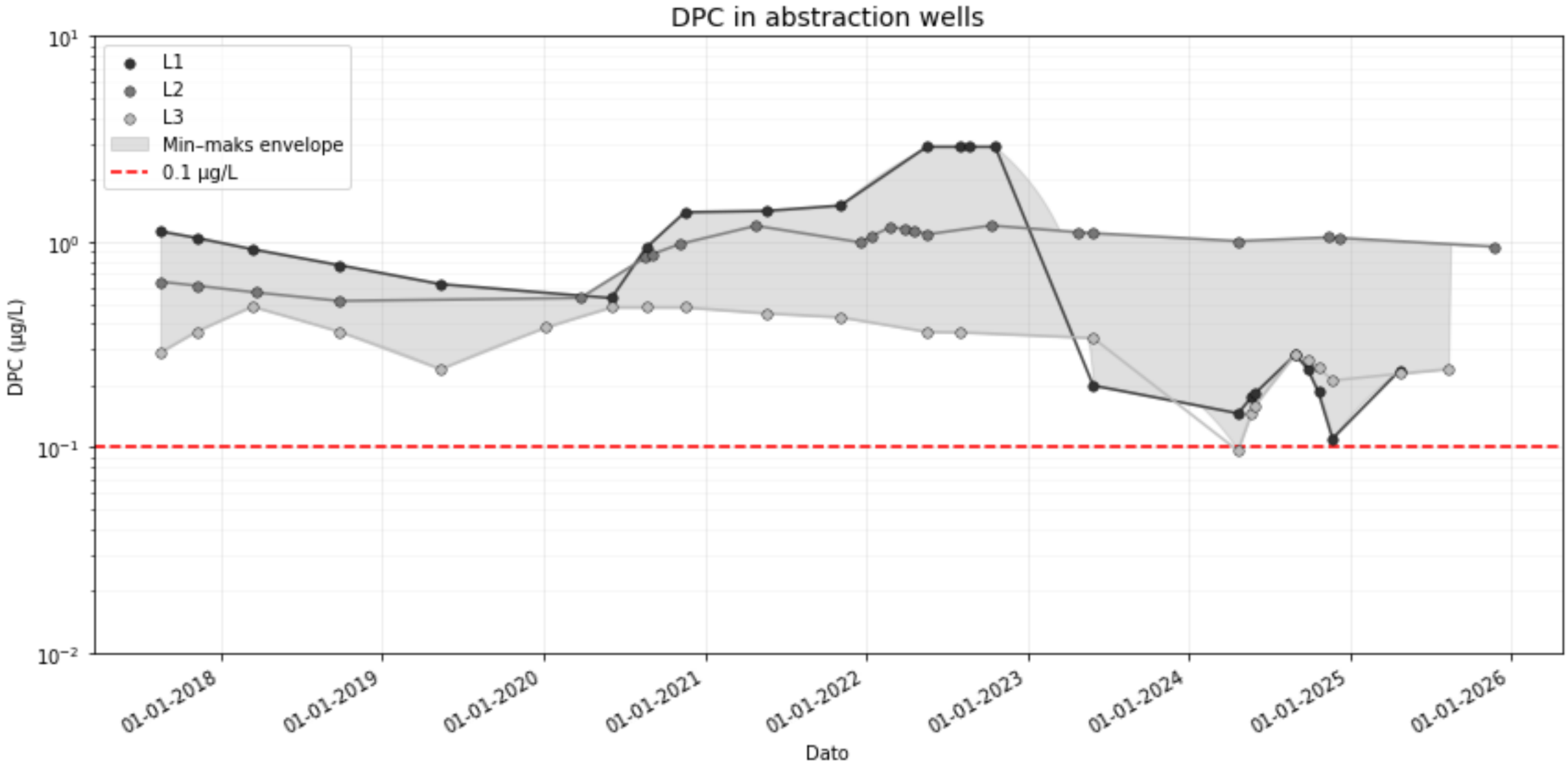
Punktkilde



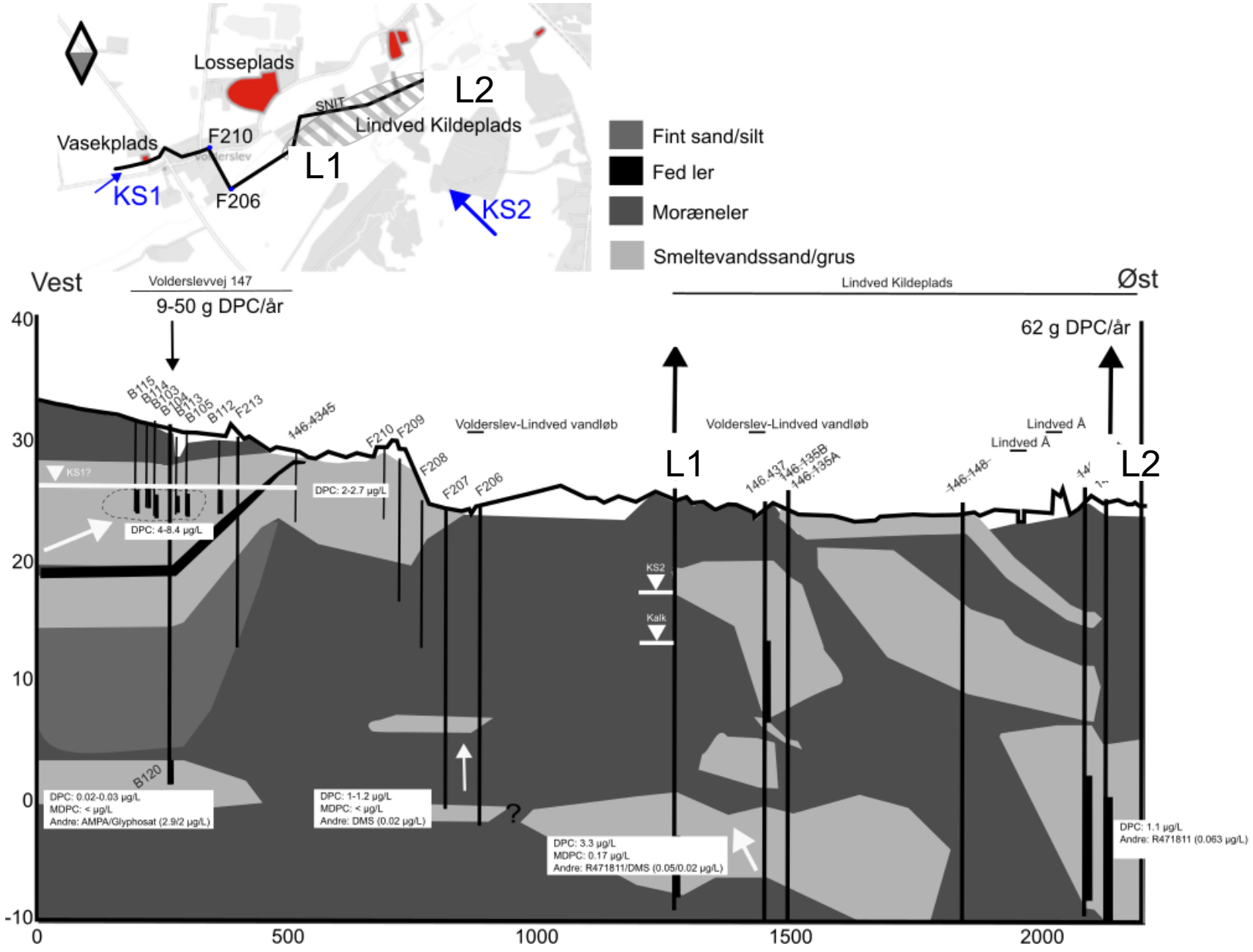


Miljøstyrelsen. (2022). Skelnen mellem pesticidkilder

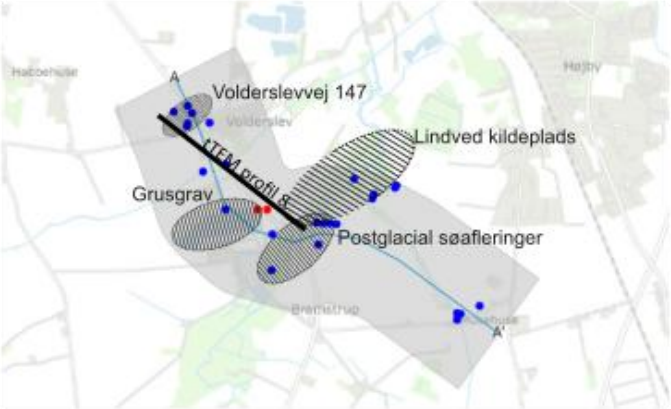

Q = 200.000 m³/year
C abstraction = 1,35 µg/L
CMD = 270 g/year
C abstraction = CMD/Q
Contaminant mass discharge, J is diluted in the annual water abstraction, Q, at a water works or a fictitous well
Dilution in drinking water wells

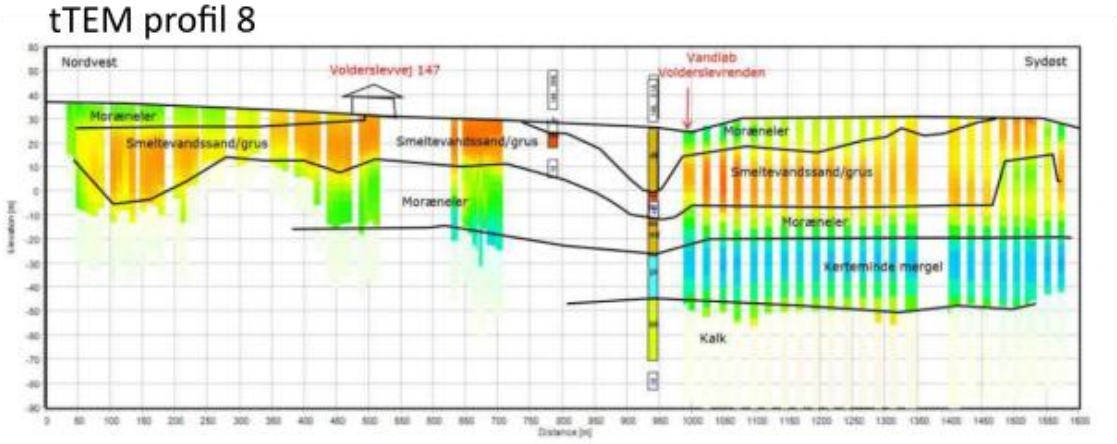

DPC in abstraction wells
L1
L2
L3
Min–maks envelope
0.1 µg/L
DPC (µg/L)
10^1
10^0
10^{-1}
10^{-2}
01-01-2018
01-01-2019
01-01-2020
01-01-2021
01-01-2022
01-01-2023
01-01-2024
01-01-2025
01-01-2026
Dato

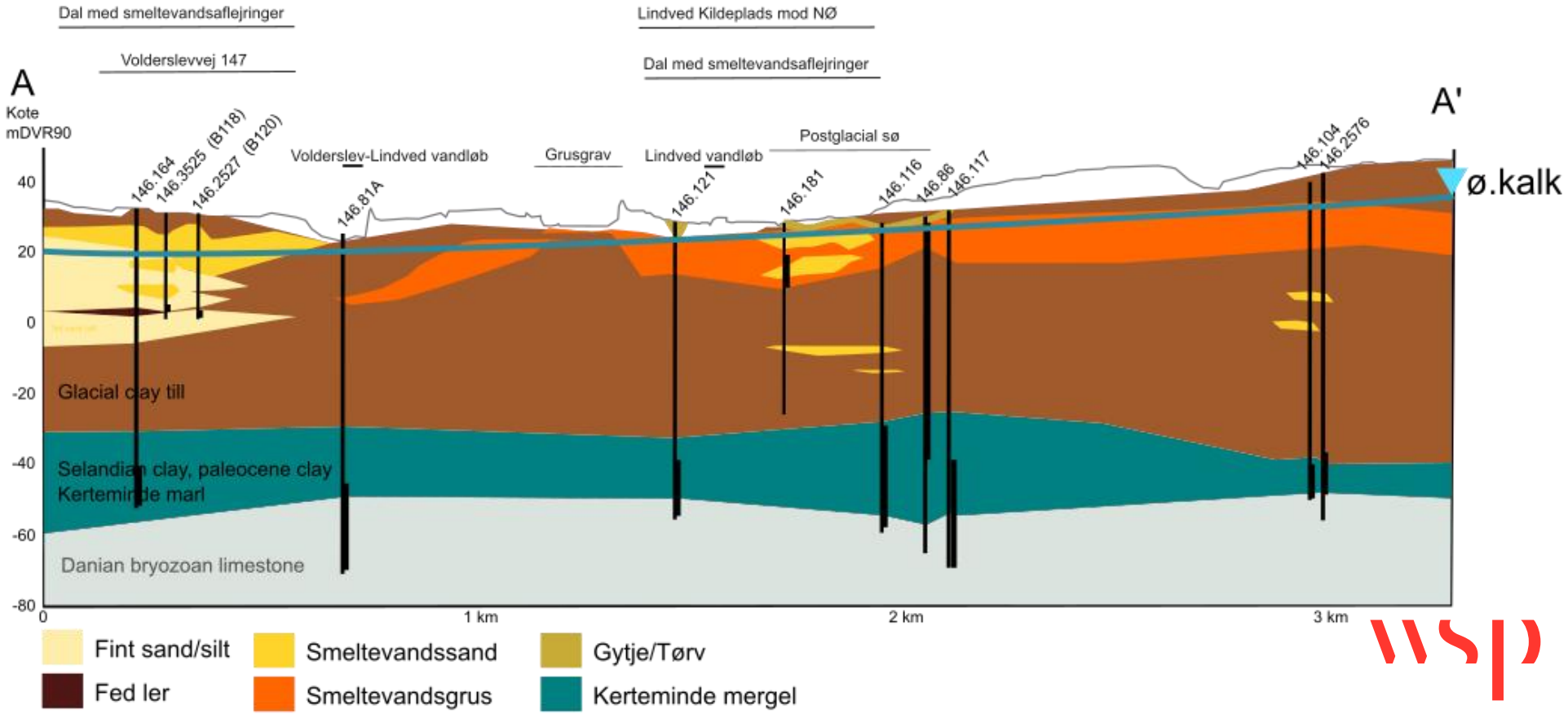
Indl. konceptual geologisk model

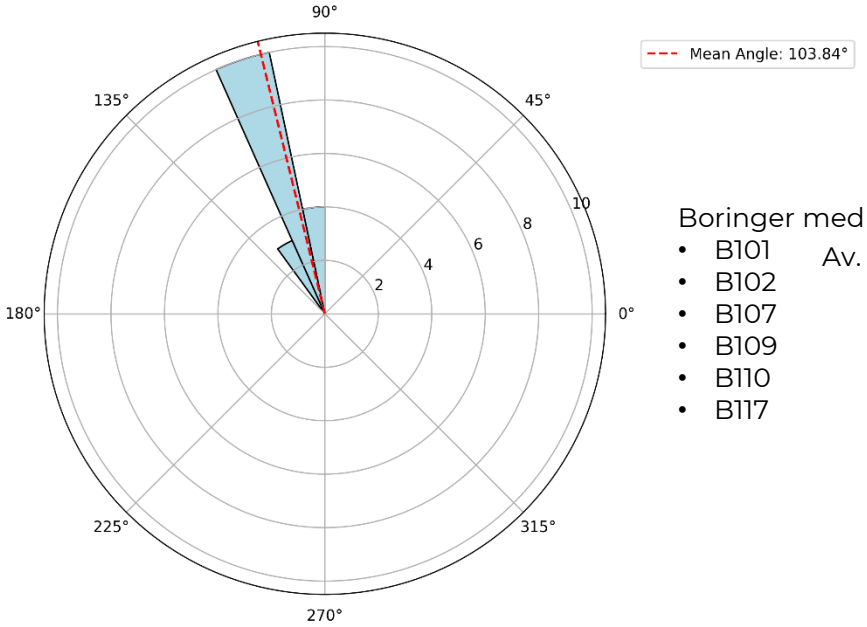


Indl. konceptual geologisk model





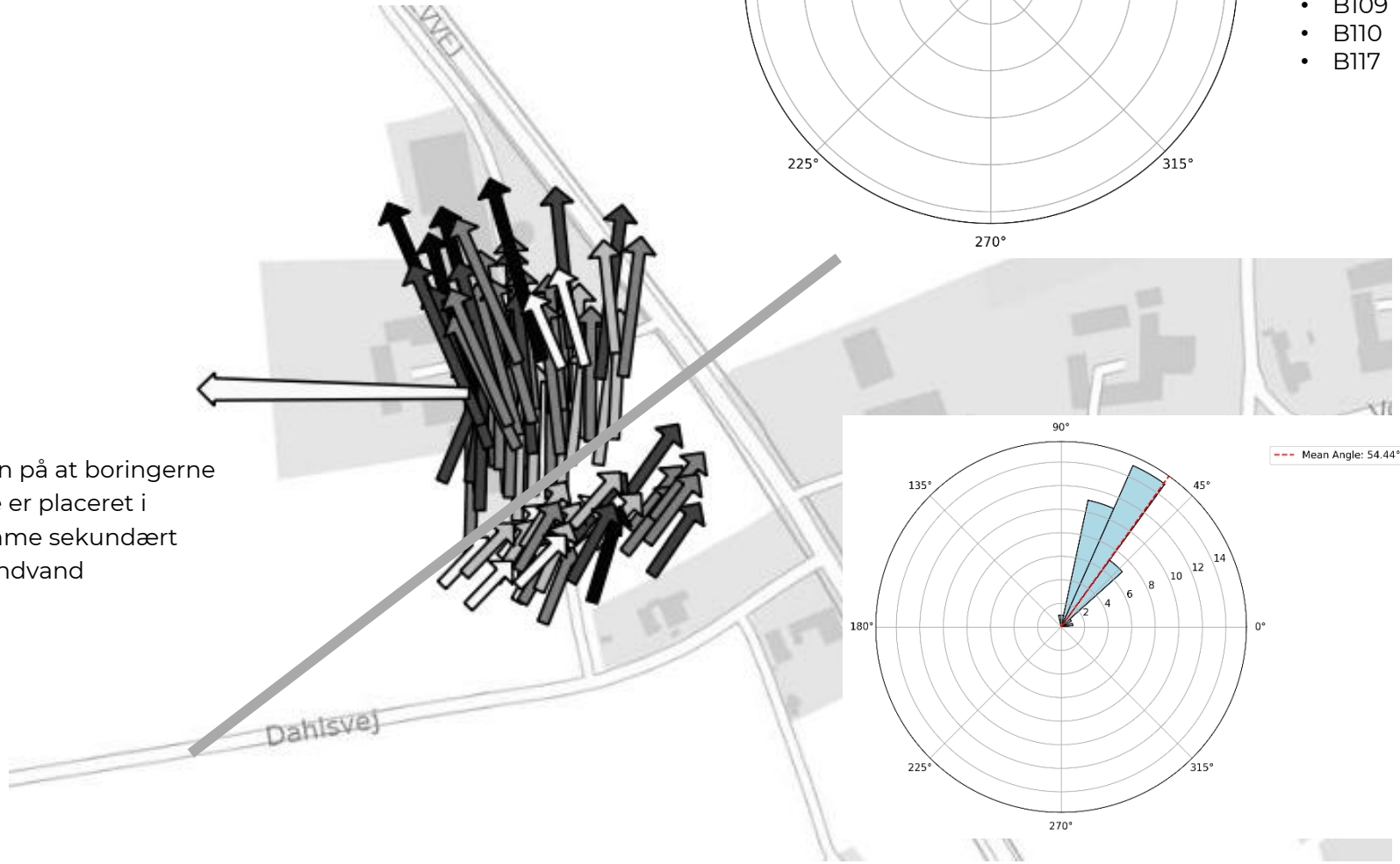




Boringer med N strømning:

- B101
- B102
- B107
- B109
- B110
- B117

Av. Gradient, i: 7,3e-4



Tegn på at boringerne ikke er placeret i samme sekundært grundvand

Boringer med NE strømning:

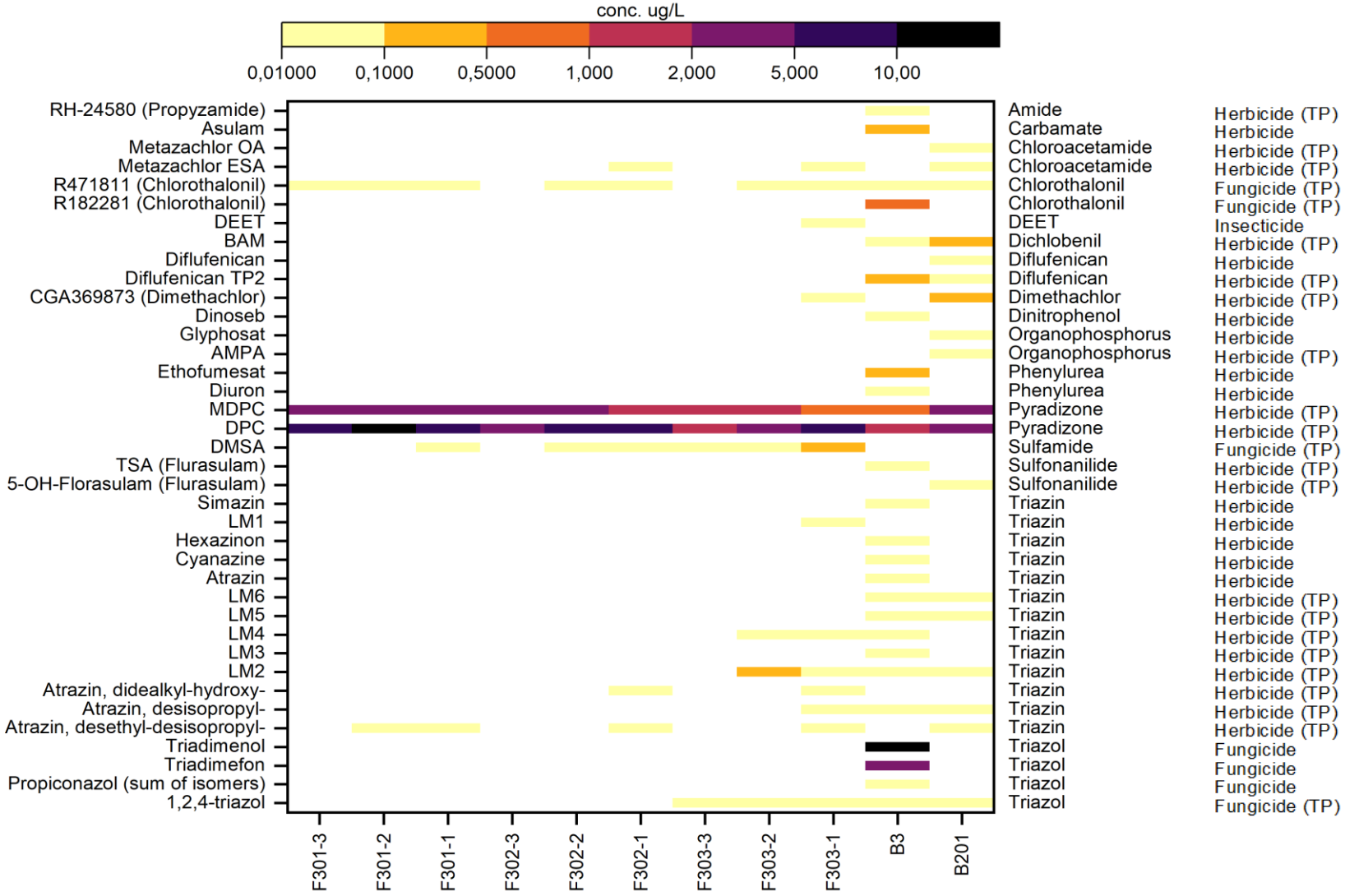
- B103
- B104
- B105
- B106
- B112
- B113
- B114
- B115

Av. Gradient, i: 3,12-4

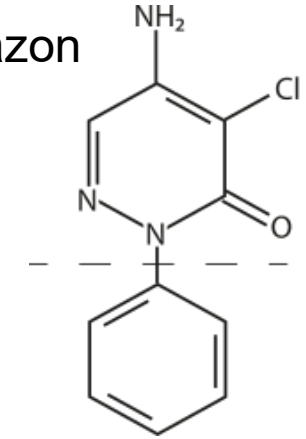
Porevand

Well screen	S301-1	S301-2	S301-3	S302-1	S302-2	S302-3	S303-1	S303-2	S303-3
Depth	5	2	0,8	4	2	0,8	5	2	0,8
Pesticides	S301-1	S301-2	S301-3	S302-1	S302-2	S302-3	S303-1	S303-2	S303-3
xutm	588040,9	588040,6	588041	588048,5	588048,4	588048,2	588054,5	588054,5	588054,2
yutm	6132626	6132626	6132626	6132556	6132556	6132556	6132463	6132463	6132463
Melamin	< 0,1	< 0,1	< 0,1	< 0,1		0,14	< 0,1	< 0,1	< 0,1
2,6-dichlorbenzosyre	< 0,01	< 0,01	0,031	0,084	< 0,01	0,016	0,02	< 0,01	< 0,02
R471811	< 0,01	< 0,05	< 0,01	0,014	< 0,01	0,012	0,026	0,023	0,059
AE-0542291	< 0,01	< 0,01	< 0,01	0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
AMPA	< 0,05	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	0,031
Asulam	< 0,01	< 0,01	< 0,05	0,09		< 0,01	< 0,01	< 0,05	< 0,05
Atrazin, didealkyl-hydroxy-	< 0,01	< 0,01	< 0,01	< 0,04	< 0,01	< 0,03	< 0,01	0,022	0,017
DPC	0,75	0,91	1,2	0,44	0,57	1,5	0,4	0,34	0,14
MDPC	0,36	0,49	1,2	0,19	0,3	0,84	0,14	0,2	0,069
DEET (Diethyltoluamid)	0,013	< 0,01	0,026	0,036	< 0,01	0,068	0,028	< 0,01	0,036
N,N-dimethylsulfamidsyre, DMSA	0,02	0,02	< 0,01	< 0,01	< 0,01	0,06	< 0,01	< 0,01	< 0,01
Fluopyram			< 0,025	0,059				< 0,025	< 0,025
Metazachlor ESA	0,02	< 0,01	< 0,01	0,02	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
Metsulfuron methyl	< 0,01	< 0,01	< 0,025	0,026		< 0,01	< 0,01	< 0,025	< 0,025
Tebuconazol	< 0,01	0,016	< 0,01	0,61	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
4-nitrophenol	< 0,01	< 0,01	0,15	0,027	< 0,01	0,22	< 0,01	0,11	0,031
1,2,4-triazol	< 0,01	0,019	0,054	0,088	0,042	0,047	< 0,01	0,053	< 0,02
Sum pesticider	1,2	1,5	2,7	1,8	0,9	2,9	0,6	0,7	0,4

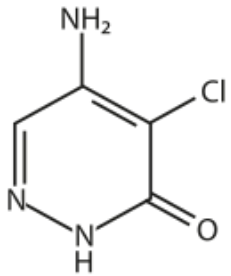
Grundvand


conc. ug/L
0,01000
0,1000
0,5000
1,000
2,000
5,000
10,00
RH-24580 (Propyzamide)
Asulam
Metazachlor OA
Metazachlor ESA
R471811 (Chlorothalonil)
R182281 (Chlorothalonil)
DEET
BAM
Diflufenican
Diflufenican TP2
CGA369873 (Dimethachlor)
Dinoseb
Glyphosat
AMPA
Ethofumesat
Diuron
MDPC
DPC
DMSA
TSA (Flurasulam)
5-OH-Florasulam (Flurasulam)
Simazin
LM1
Hexazinon
Cyanazine
Atrazin
LM6
LM5
LM4
LM3
LM2
Atrazin, didealkyl-hydroxy-
Atrazin, desisopropyl-
Atrazin, desethyl-desisopropyl-
Triadimenol
Triadimefon
Propiconazol (sum of isomers)
1,2,4-triazol
Amide
Carbamate
Chloroacetamide
Chloroacetamide
Chlorothalonil
Chlorothalonil
DEET
Dichlobenil
Diflufenican
Diflufenican
Dimethachlor
Dinitrophenol
Organophosphorus
Organophosphorus
Phenylurea
Phenylurea
Pyradizone
Pyradizone
Sulfamide
Sulfonanilide
Sulfonanilide
Triazin
Triazol
Herbicide (TP)
Herbicide
Fungicide (TP)
Insecticide
F301-3
F301-2
F301-1
F302-3
F302-2
F302-1
F303-3
F303-2
F303-1
B3
B201

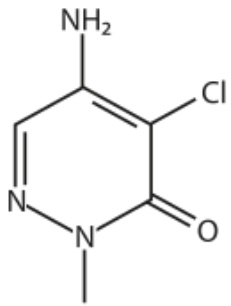
Chloridazon



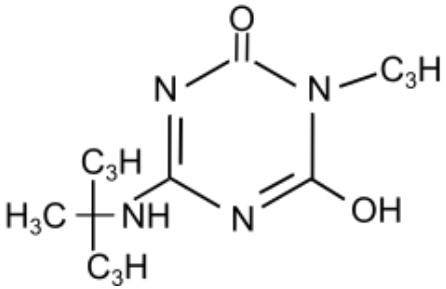
Desphenyl chloridazon



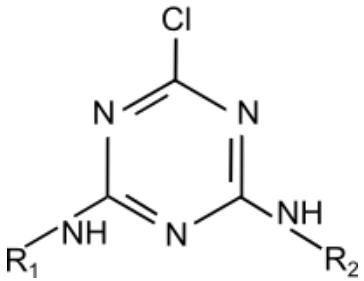
Methyldesphenyl chloridazon

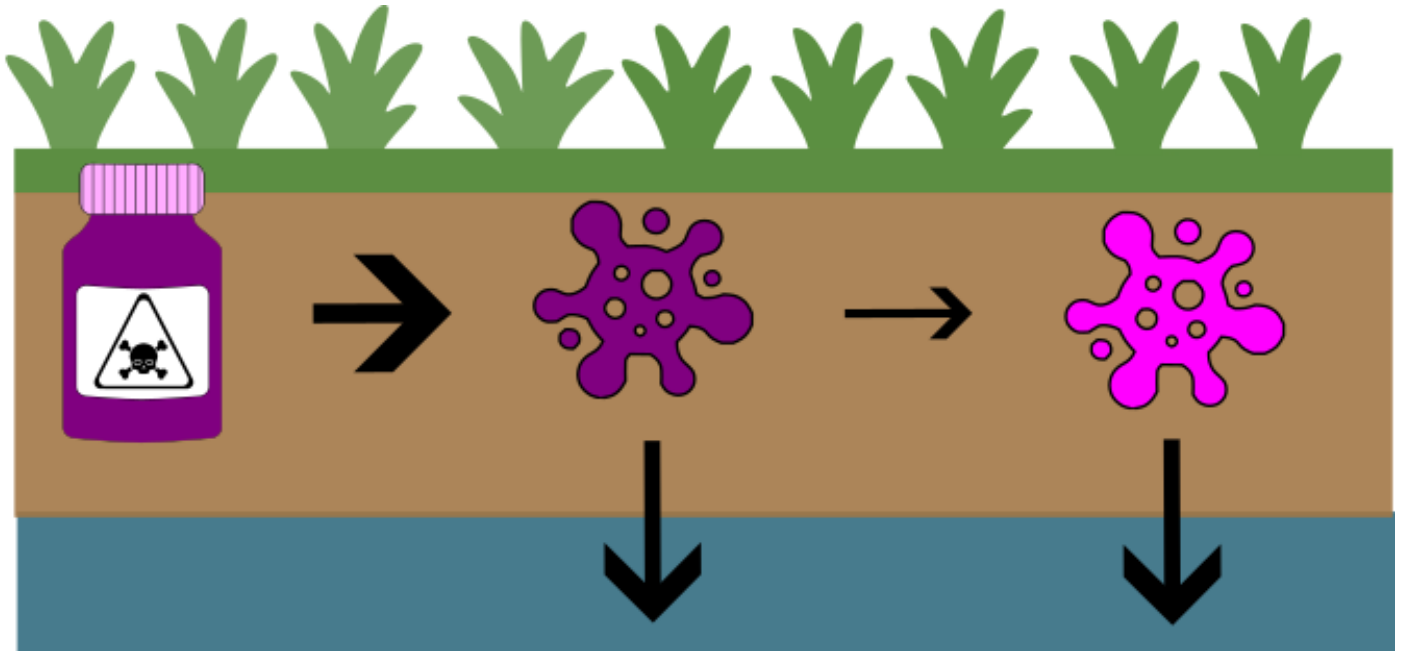


LM6

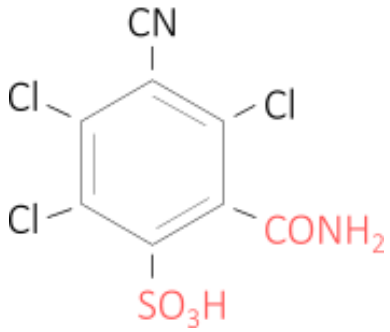


Terbutylazine

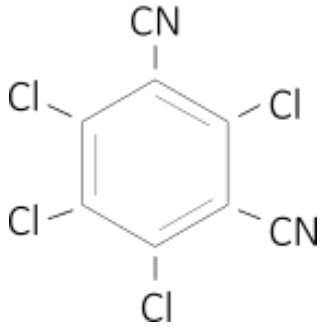




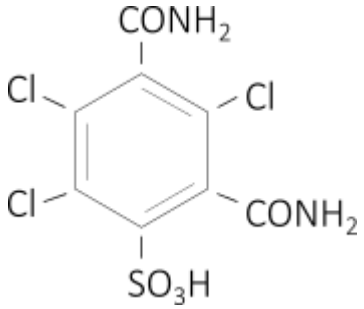
R417888



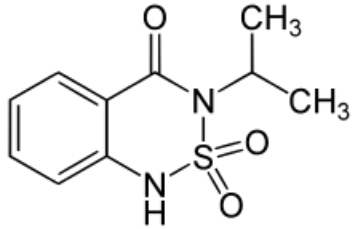
Chlorothalonil



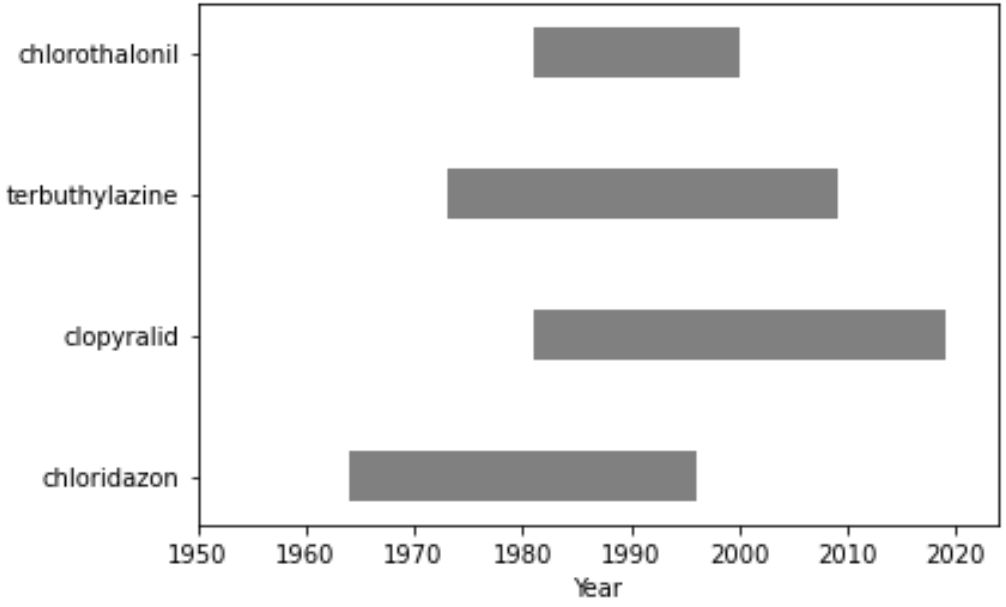
R471811

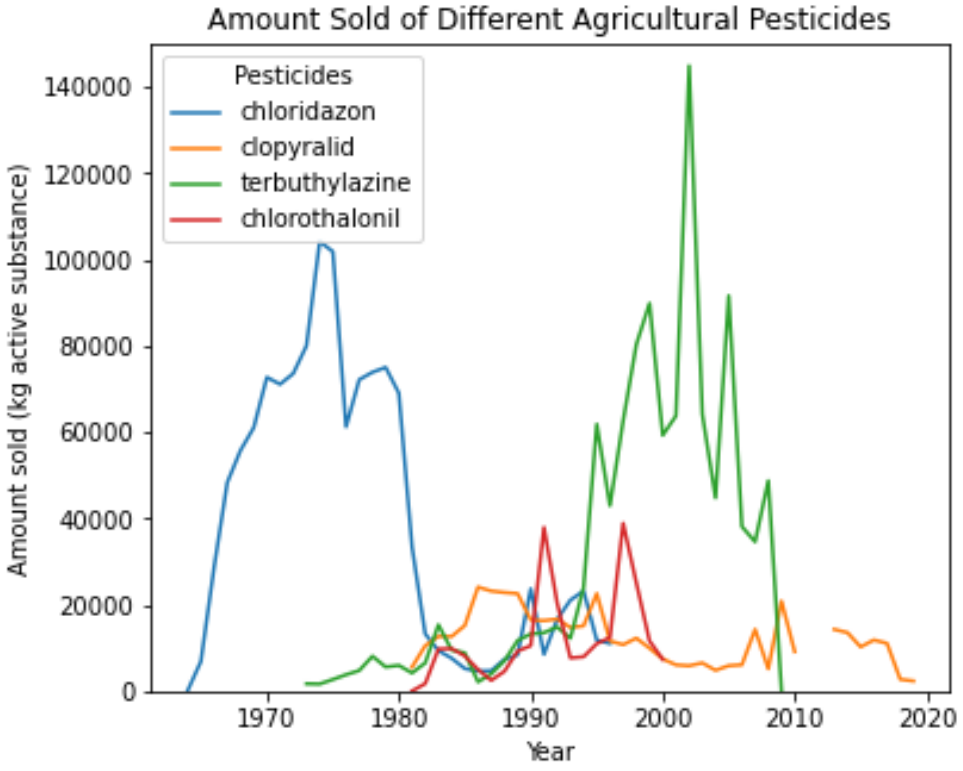


Bentazone



Application periods for pesticides
Amount sold





Stof	Koc / Kfoc	DT50 (jord)	Mobilitet	Binding	Persistens	Sandsynlighed for grundvandsfund	Anvendelse / udfasning i DK
Glyphosat	stærk sorption; angives som “does not normally leach”	not persistent in soil	Meget lav	Meget stærk	Lav	Meget lav	Fortsat godkendt i EU/DK
AMPA	kendt som stærkt adsorberende	omtales som mere	Meget lav	Stærk	Moderat	Meget lav	-
Chloridazon	Kfoc = 199 L/kg (EFSA, 2007)	DT50 (lab) = 43,1 d, DT50 (felt) = 19 d (EFSA, 2007)	Moderat	Svagere	Moderat	Lav	Anvendt i DK ca. 1964–1996; efterfølgende forbud/ikke godkendt
DPC	klassificeret som “mobile / high leachability”	PPDB: “persistent”	Høj	Meget	Høj	Meget høj	-
1,2,4-triazol	“moderately mobile”	DT50 hurtig 1,68 d, langsom 60,5 d	Høj (som polær metabolit)	Svag	Moderat → høj	Høj	Ikke et aktivstof; dannes fra triazol-fungicider, der fortsat anvendes i EU/DK

Desphenyl-chloridazon, DPC

Forureningsrådet, nr. 17, Pesticider, 1971

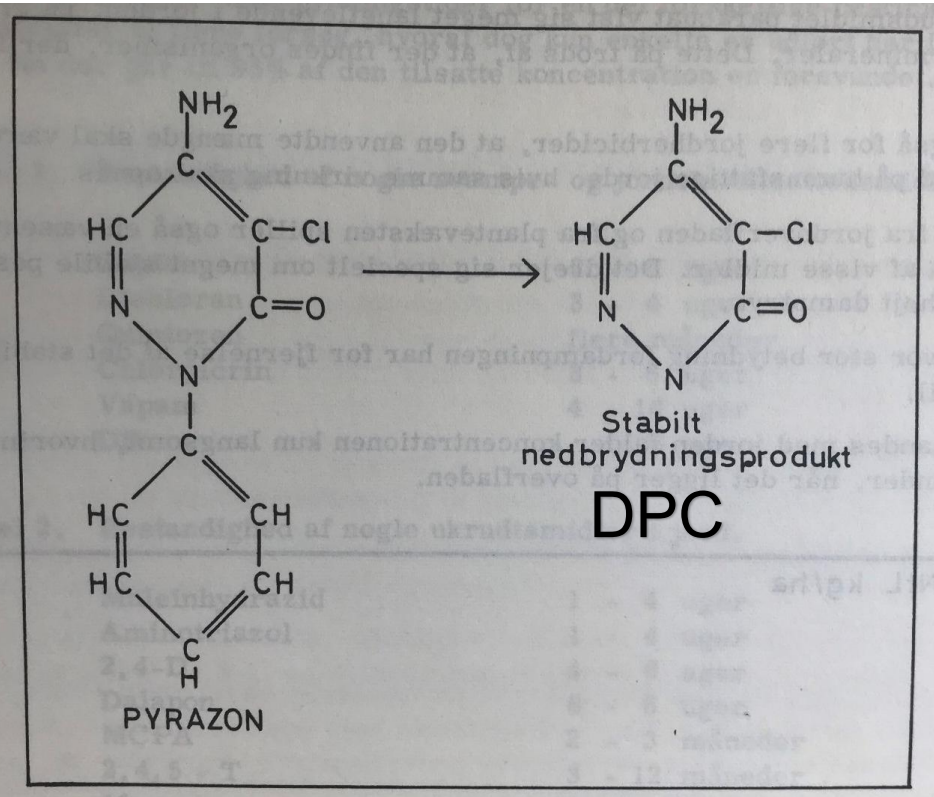


Fig. 5. Ukrudtsmidlet pyrazon og pyridazinringen, som bliver tilbage efter stoffets biologiske nedbrydning. (Efter Engvild og Jensen 1969).

”There is a reason to keep a close watch on this compound as it is apparently quite stable in soil. Continued use of pyrazon might in course of time lead to accumulation of the breakdown product, with possible undesired consequences”

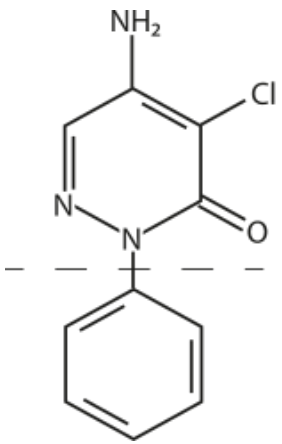
Soil Biol. Biochem. Vol. 1, pp. 295–300.

MICROBIOLOGICAL DECOMPOSITION OF THE HERBICIDE PYRAZON

K. C. ENGVILD and H. L. JENSEN

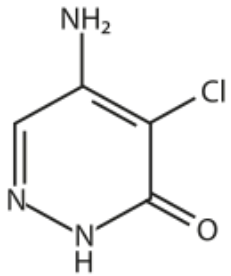
Government Laboratory for Soil and Crop Research, Lyngby, Denmark

Chloridazon



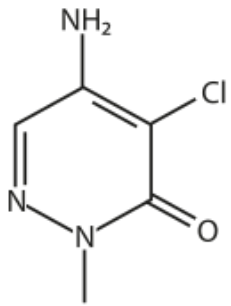
DPC

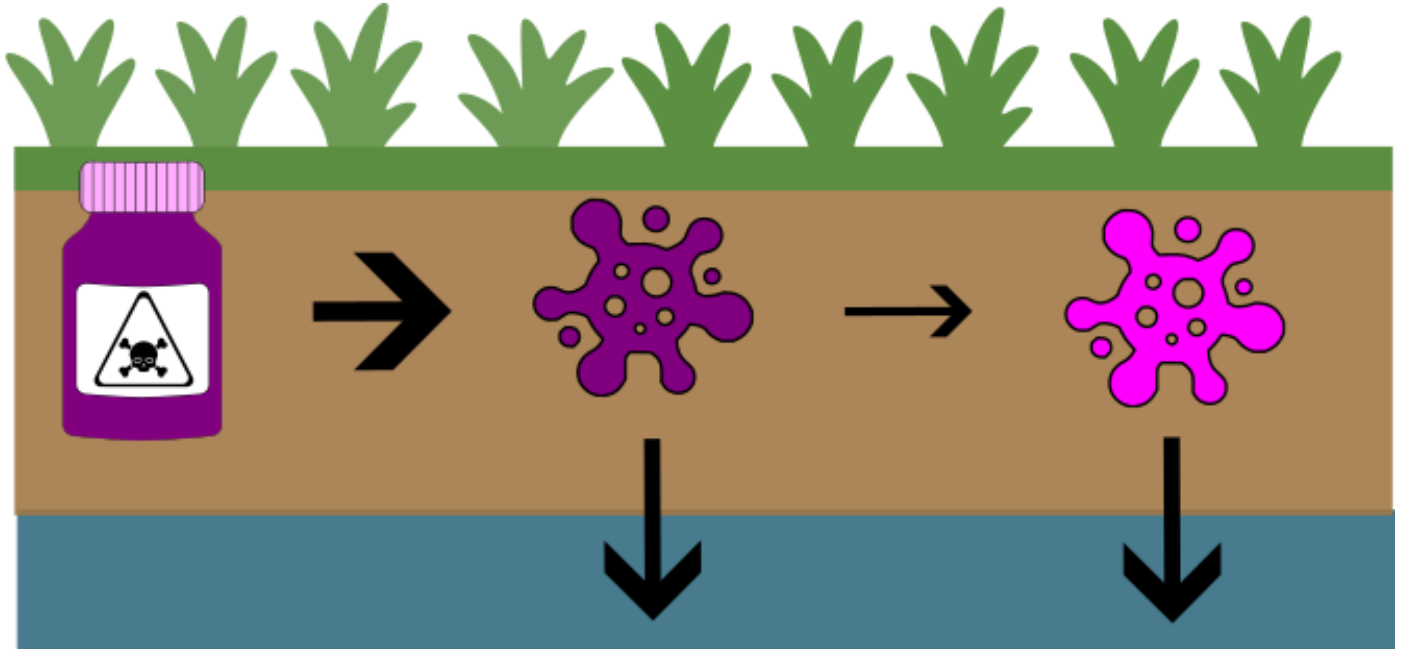
Desphenyl chloridazon



MDPC

Methyldesphenyl chloridazon

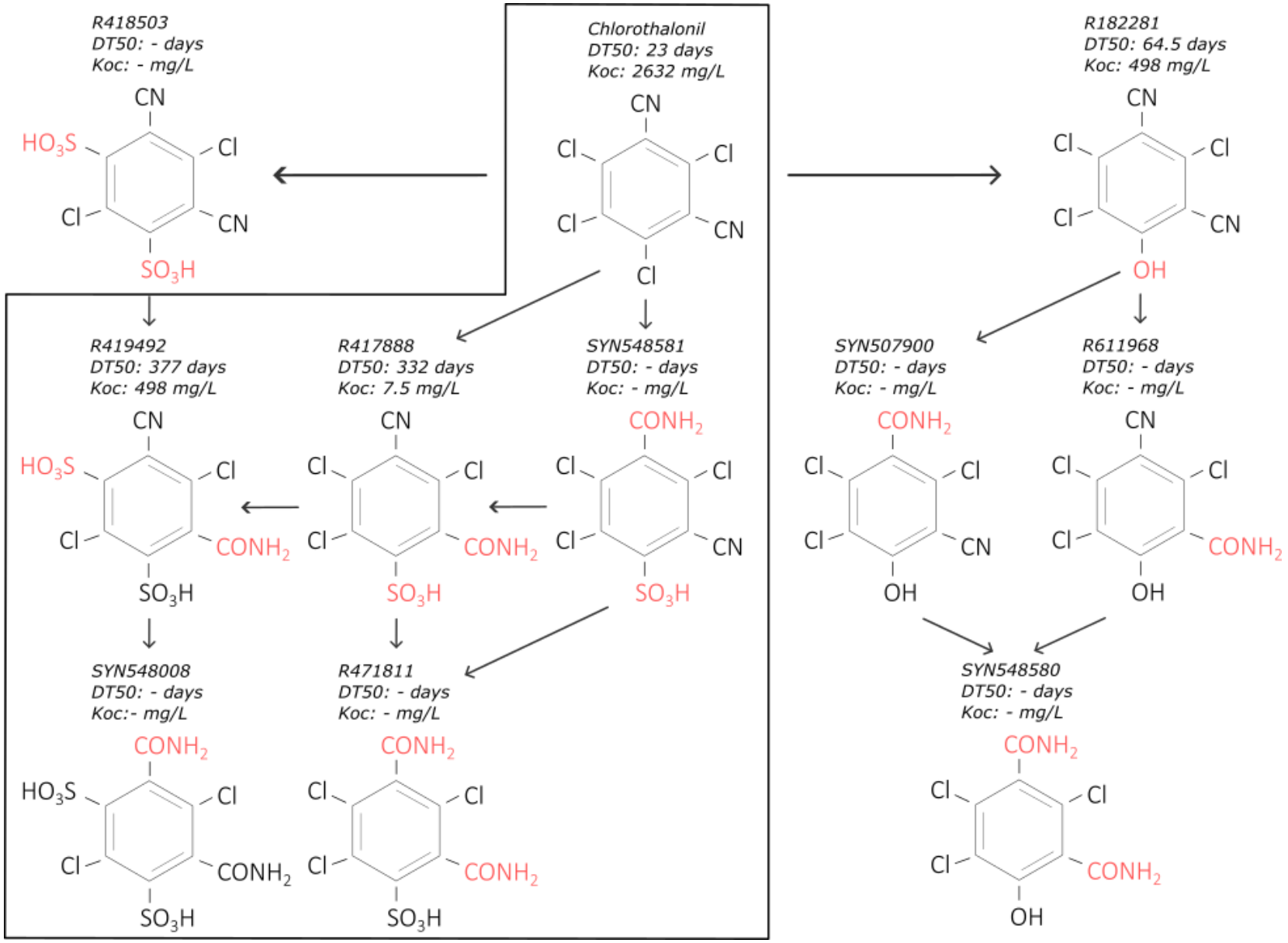


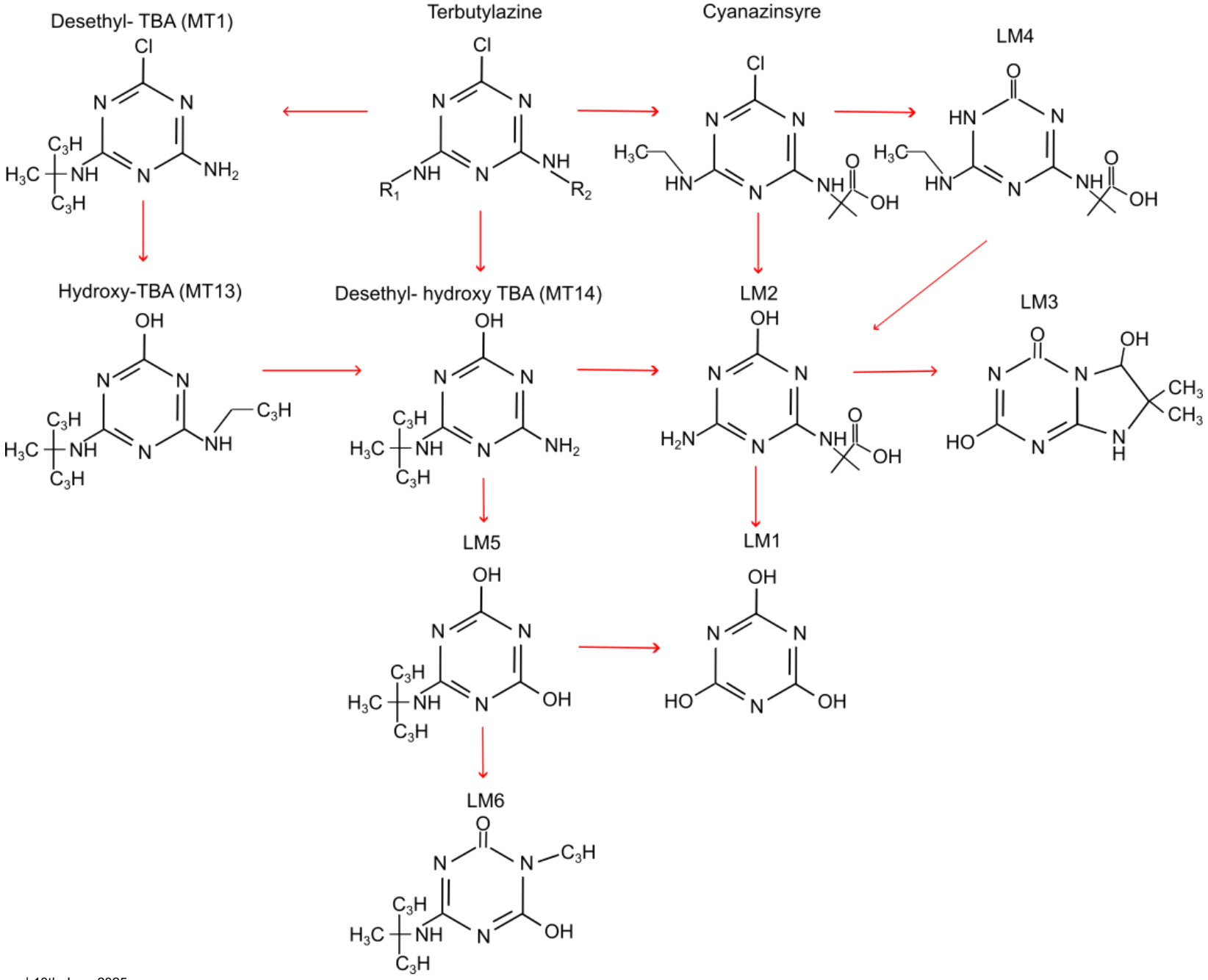


Chloridazon
DT50: 31 days
Koc: 89-340 mg/L

DPC
DT50: 108 days
Koc: 29-74 mg/L

MDPC
DT50: 145 days
Koc: 92 mg/L


R418503
DT50: - days
Koc: - mg/L
Chlorothalonil
DT50: 23 days
Koc: 2632 mg/L
R182281
DT50: 64.5 days
Koc: 498 mg/L
R419492
DT50: 377 days
Koc: 498 mg/L
R417888
DT50: 332 days
Koc: 7.5 mg/L
SYN548581
DT50: - days
Koc: - mg/L
SYN507900
DT50: - days
Koc: - mg/L
R611968
DT50: - days
Koc: - mg/L
SYN548008
DT50: - days
Koc:- mg/L
R471811
DT50: - days
Koc: - mg/L
SYN548580
DT50: - days
Koc: - mg/L


Desethyl- TBA (MT1)
Terbutylazine
Cyanazinsyre
LM4
Hydroxy-TBA (MT13)
Desethyl- hydroxy TBA (MT14)
LM2
LM3
LM5
LM1
LM6