Safeguarding Drinking Water by Modelling the Fate of Contaminant in Groundwater An Example from Amines in Carbon Capture

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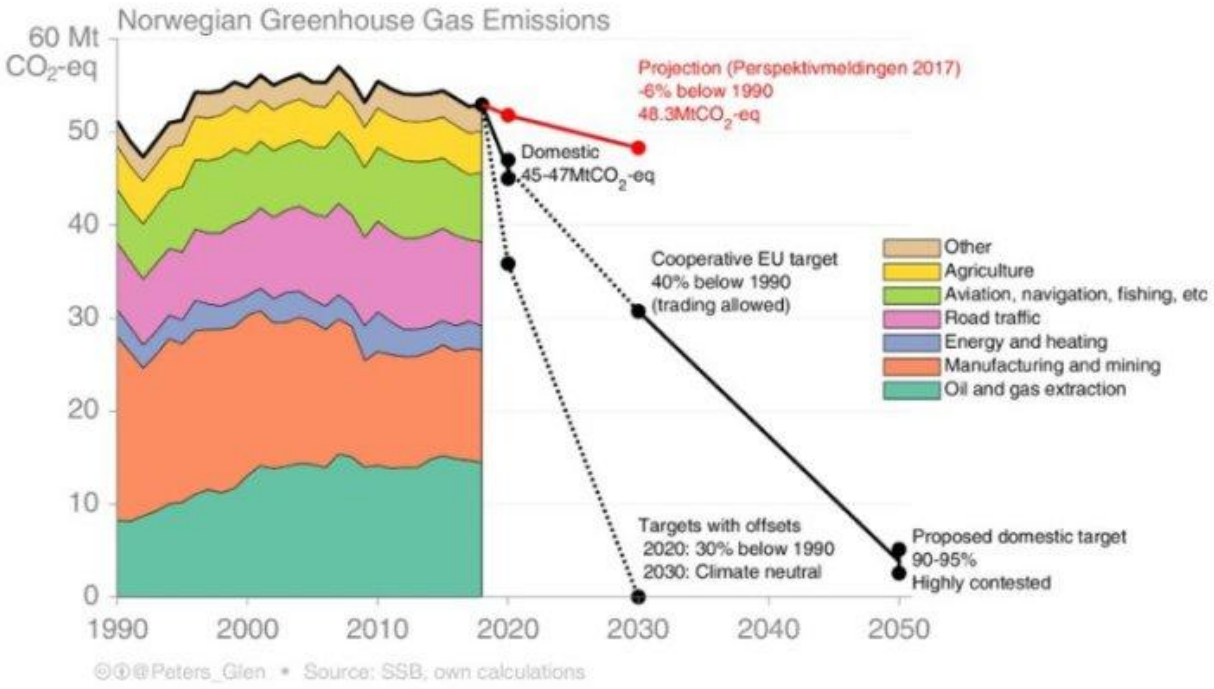
IAHs Høstmøtet 2026 – Drikkevann - Trondheim

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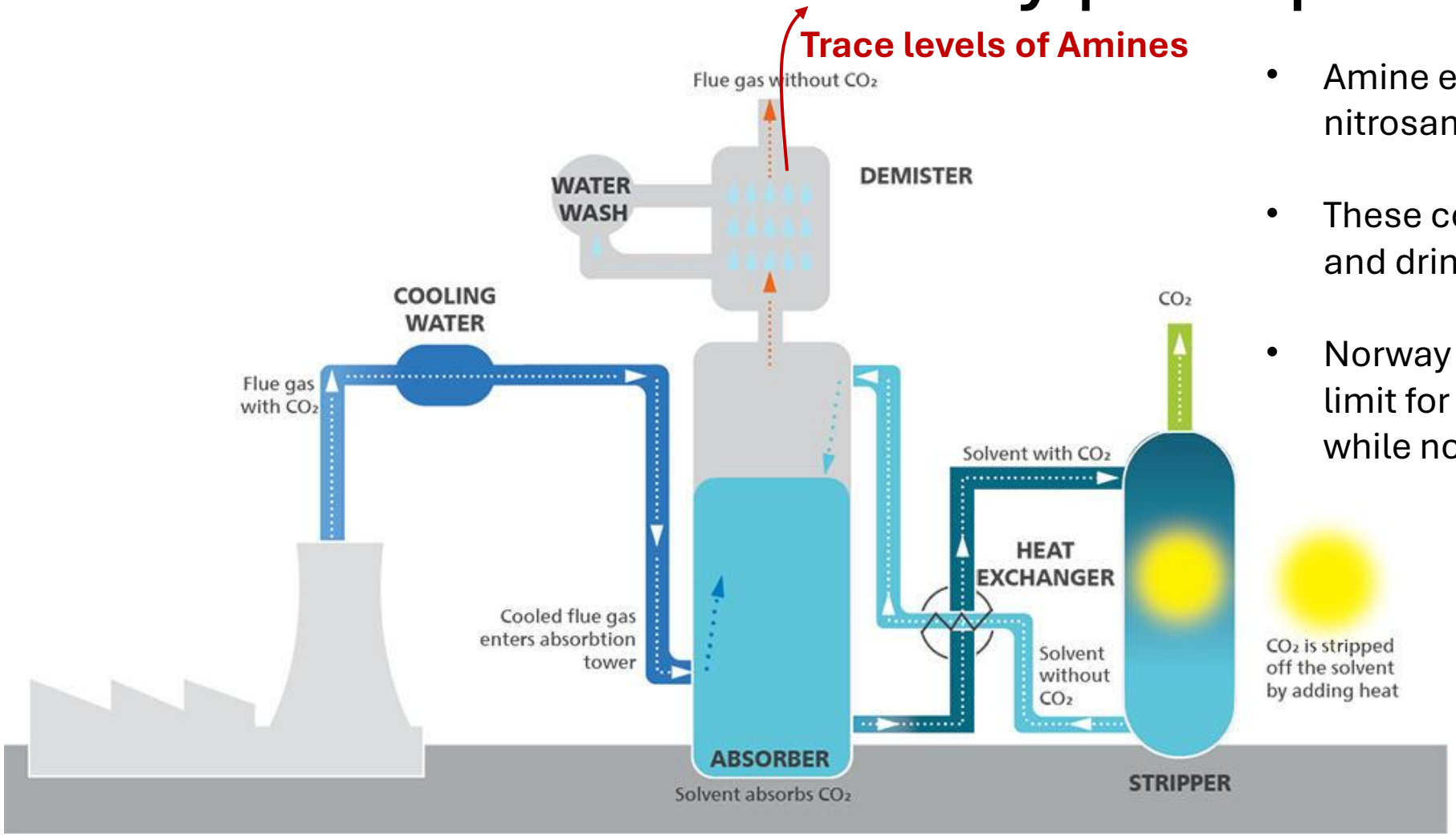
Policy context – Carbon Capture

- The EU aims to reduce greenhouse gas (GHG) emissions by 55% by 2030 and achieve carbon neutrality by 2050
- Carbon capture (CC) will play an important part and will have to increase drastically at a global level and in the EU.
- Current CCS estimations:
    - By 2030: at least 50 Mt CO_2 per yr will have to be captured, transported and stored
    - By 2050: at least 250 Mt CO_2 per yr

Tumara et al., (2024): JRC, 2024



Amine-based CC – key principles



- Amine emissions can form carcinogenic nitrosamines (NSAs) and nitramines (NAs)
- These compounds may reach groundwater and drinking water resources
- Norway applies a 4 ng/L drinking-water limit for total NAs + NSAs in permitting, while no EU-wide limit exists.

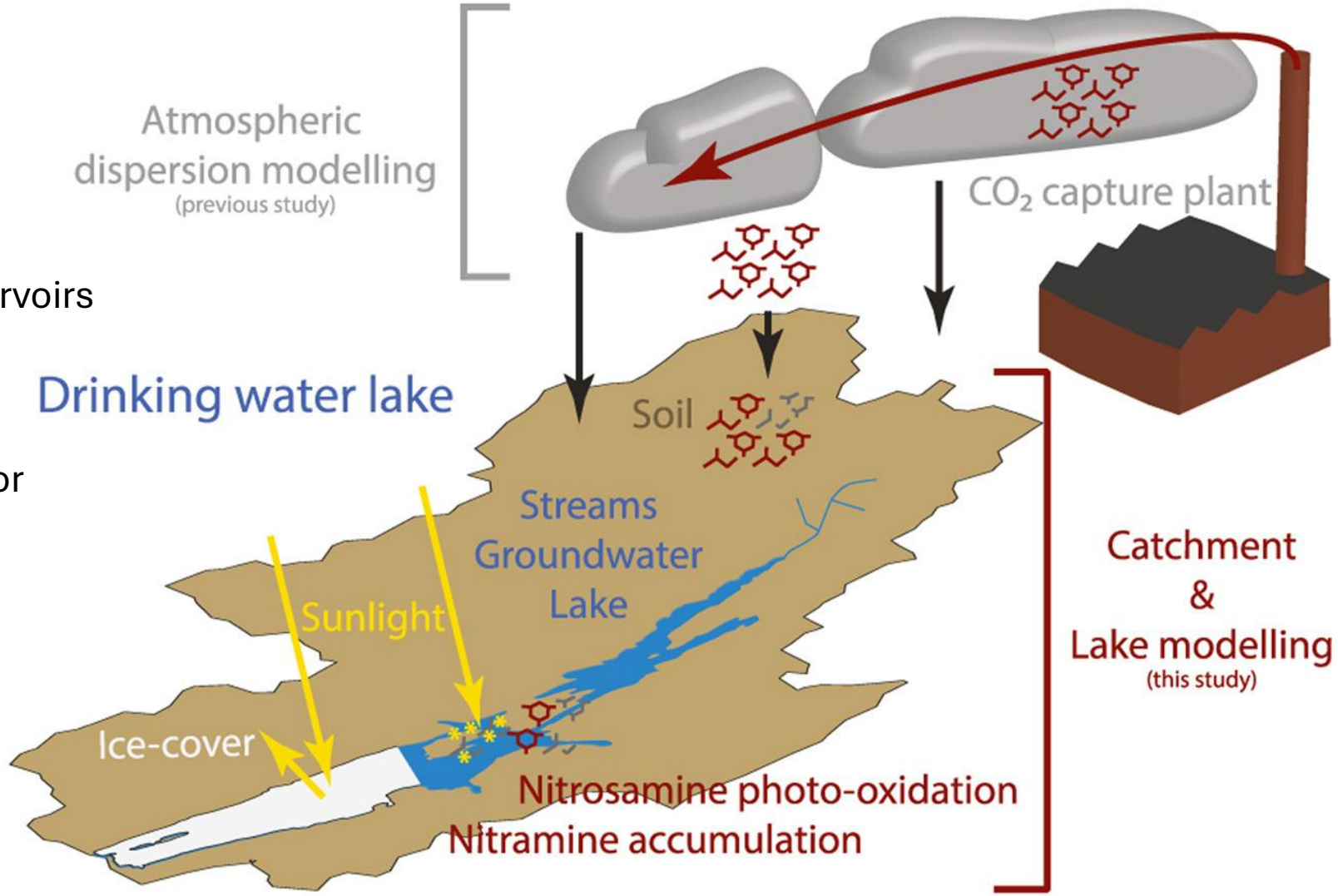
Metrohm

Catchment model to simulate the fate of contaminant in groundwater

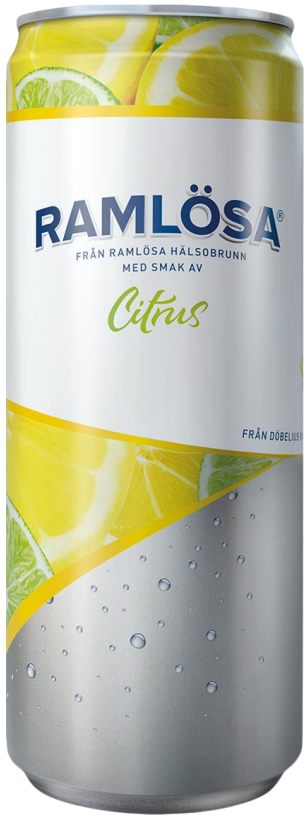
We need models to estimate how much amines can be released to safely stay below

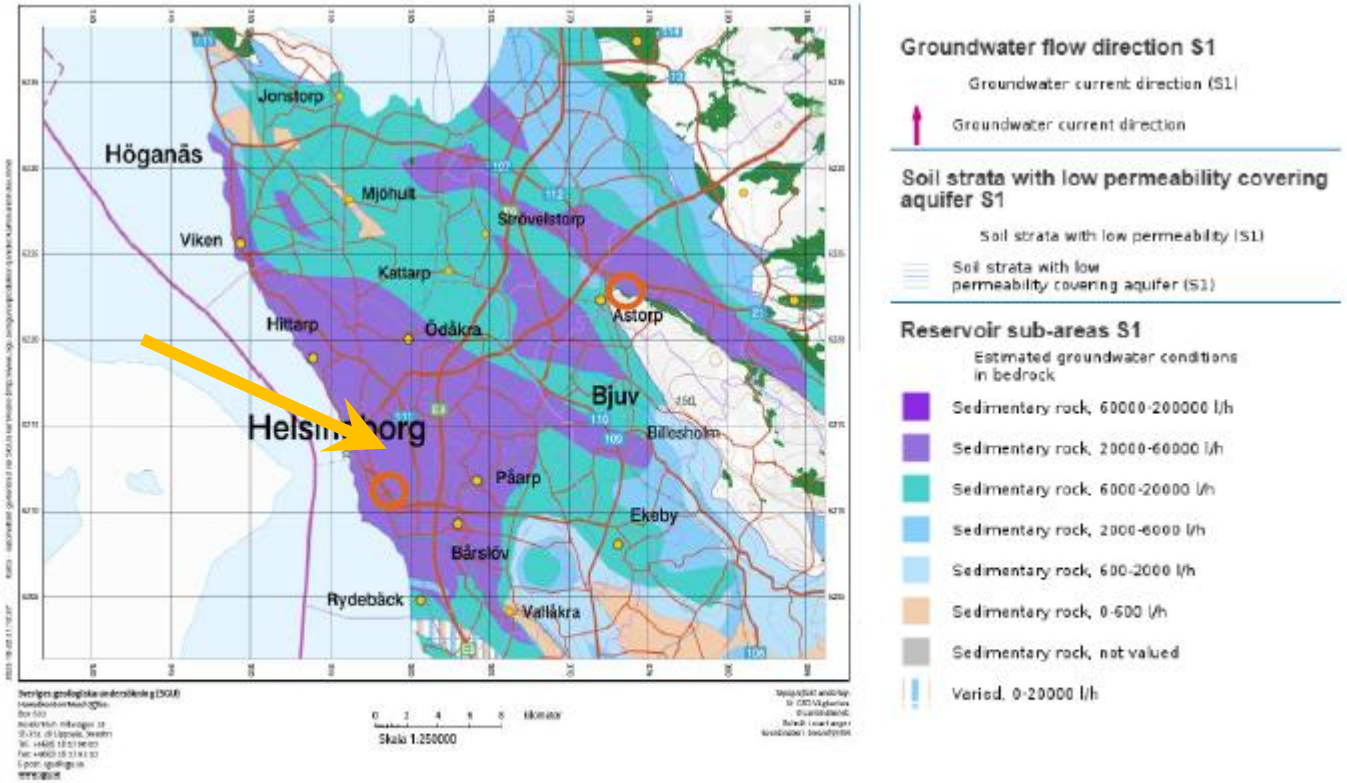
4 ng/L
in drinking water reservoirs

To date, no analytical procedure exists for for concentration < 100 ng/L



Case studies: Ramlösa Hälsobrunn and Åstorp groundwater reservoirs







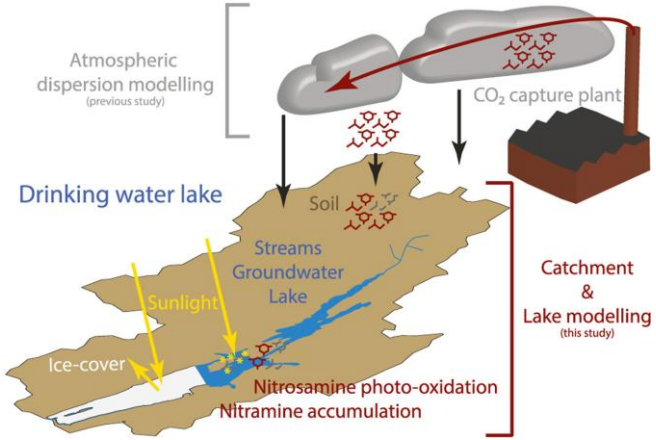


Figure 2: Overview of the sedimentary aquifers in the study area showing Ramlösa Hälsobrunn (close to Helsingborg) to be located in the purple region, indicating sedimentary rock, and Åstorp to be located in the green and white areas. Source: (Gustafsson, 1999).

Case studies: Ramlösa Hälsobrunn and Åstorp groundwater reservoirs

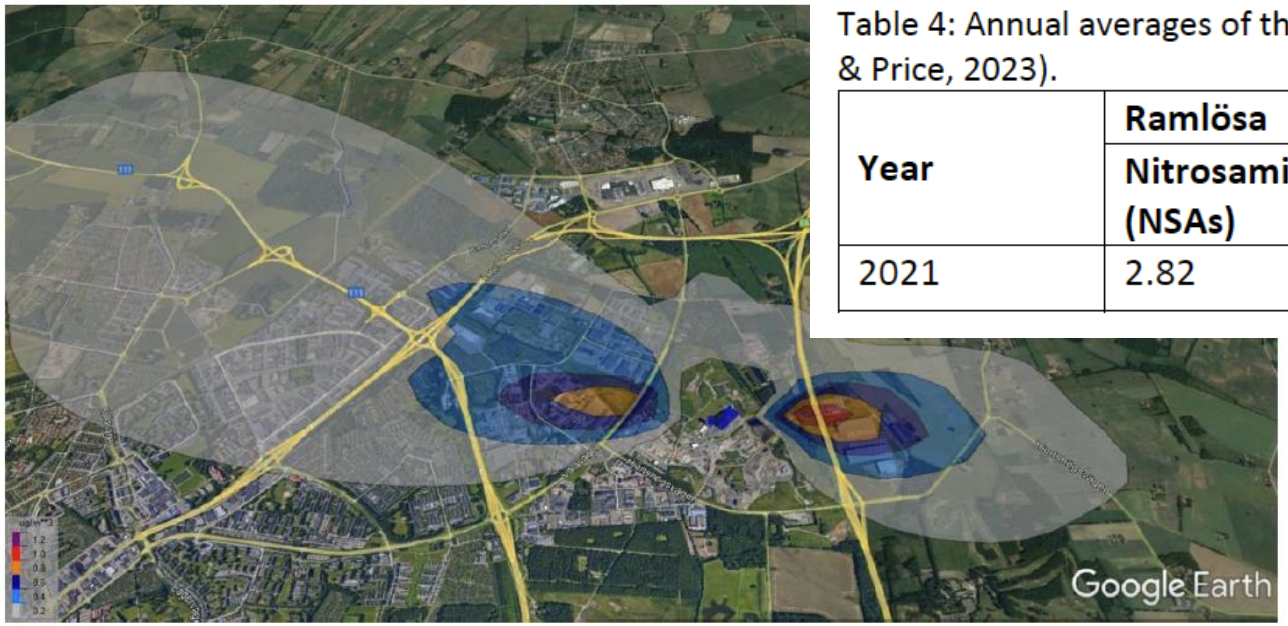


Table 4: Annual averages of the daily dry and wet deposition rates ($ng\ m^{-2}\ day^{-1}$) of NSAs and NAs (Borgnes & Price, 2023).

Year	Ramlösa		Åstorp	
	Nitrosamines (NSAs)	Nitramines (NAs)	Nitrosamines (NSAs)	Nitramines (NAs)
2021	2.82	11.52	0.54	4.64

Table 1: General descriptive parameters of the two studied groundwater basins.

Parameter	Ramlösa hälsobrunn	Åstorp
ID	NVR-ID 2012279	NVR-ID 2012368
Residence time	> 65 years	Unknown*
Bedrock	Jurassic sandstone	Siltstones, sandstones, claystones, and clay
Hydraulic conductivity	5.08 – 5.71 m/s	4.40 – 7.74 m/s

*based on the limited available knowledge, set to 5-20 years as a worst-case scenario.

Validation of the water budget

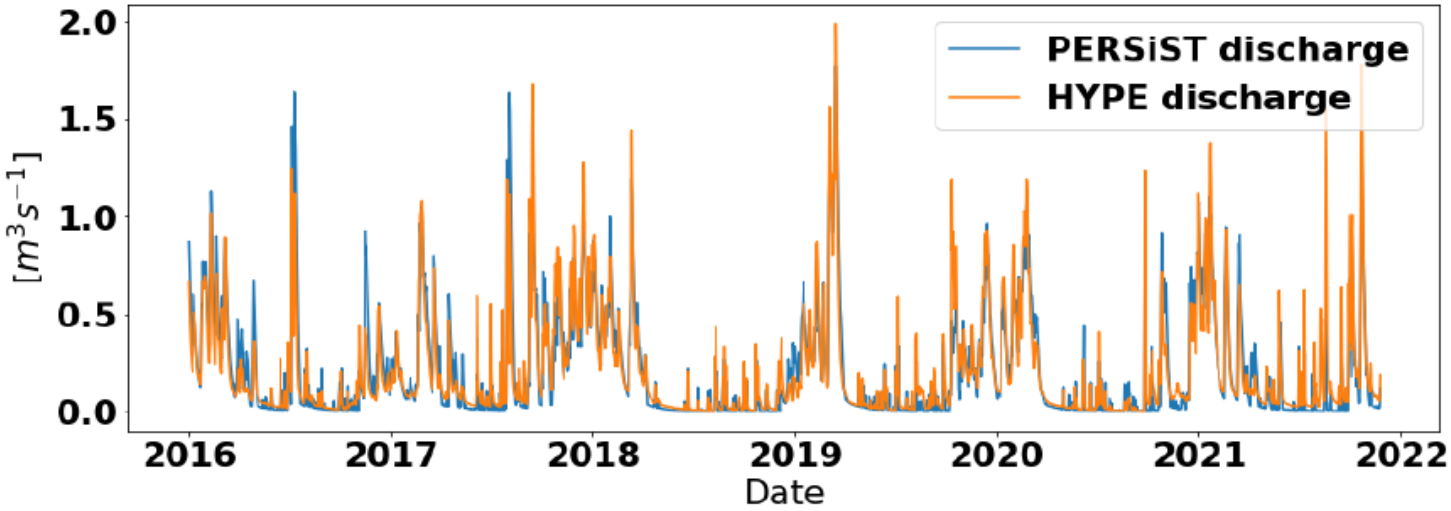


Figure 4: Comparison of the discharge ($m^3 s^{-1}$) over time using our model (blue) and the HYPE model (orange), for the sub catchment of Råån.

Against surface runoff

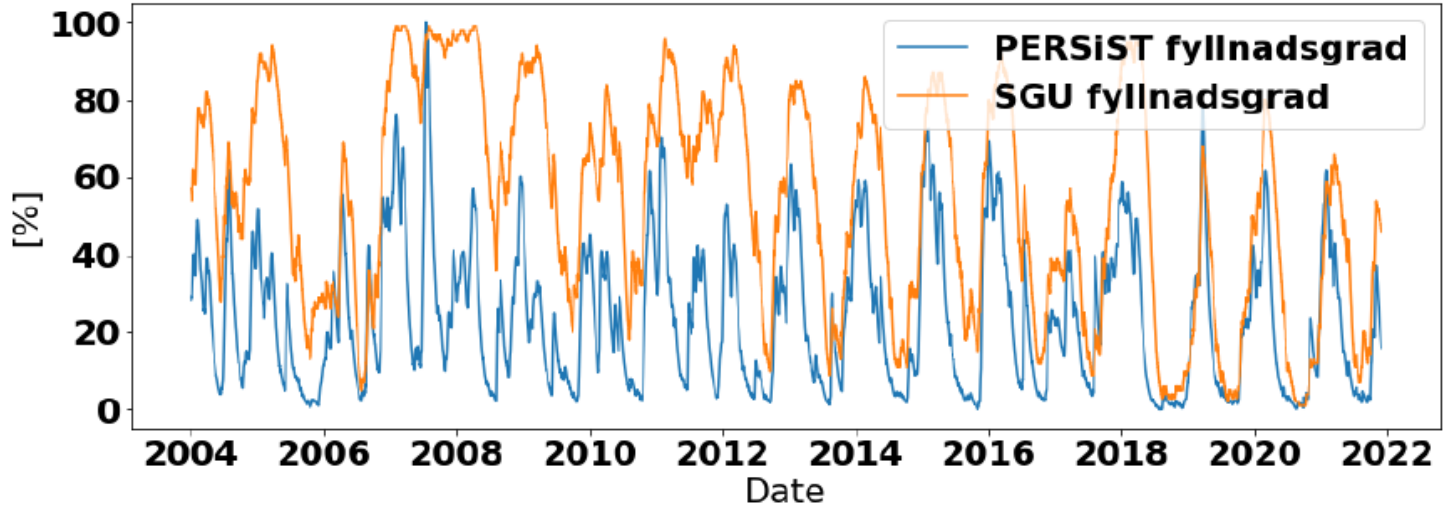


Figure 5: Comparison of the water fullness (%, sv: fyllningsgrad) our model (blue) and SGU model (orange) for the groundwater basin at Ramlösa. The SGU modeled data is for "fyllnadsgrad stora magasin" at site 52054, which covers southern Helsingborg and Ramlösa.

Against groundwater level

Will groundwater likely be safe for consumption?

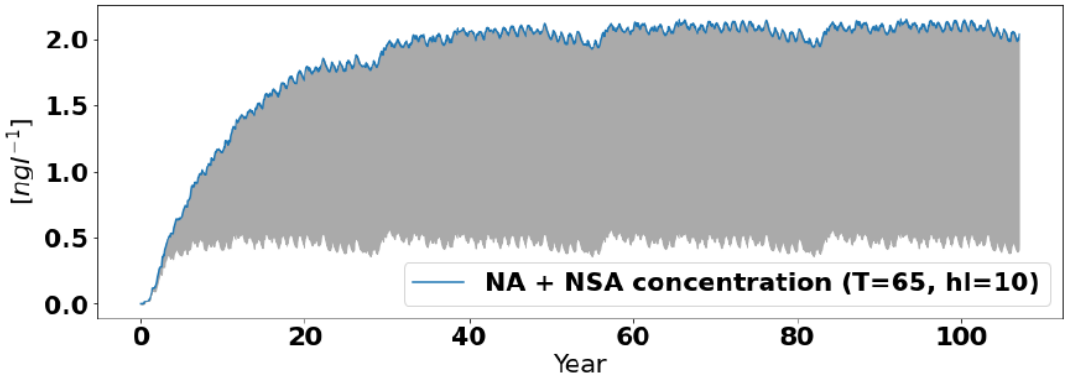


Figure 6: Modelled concentrations for the sum of NSAs and Nas in the Ramlösa groundwater basin over time. The blue line signifies the concentration with the configuration of groundwater residence time (T) at 65 years and with a groundwater half-life (hl) of 10 years. The grey area shows the range of concentrations within the configurations T = 65 years, and with hl = 2 to 10 years.

Safe in Ramlösa,
because of the long residence time

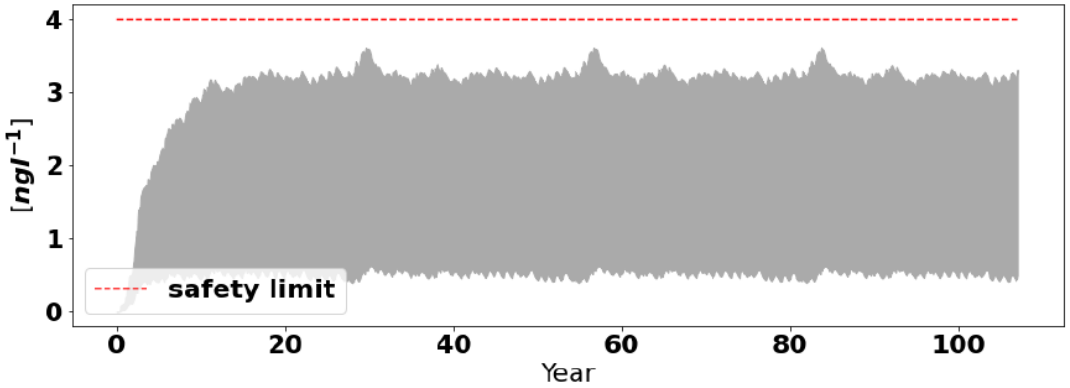


Figure 7: Modelled concentrations for the sum of NSAs and Nas in the Åstorp groundwater basin over time. The grey area shows the range of concentrations within the configurations T = 5 to 20 years, and with hl = 2 to 10 years. The red dotted line indicates the NIPH recommended drinking water safety limit.

Safe in Åstorp,
because of lower deposition
But close to the limit and
Still uncertainty in residence time

NGI

The important role of biodegradation

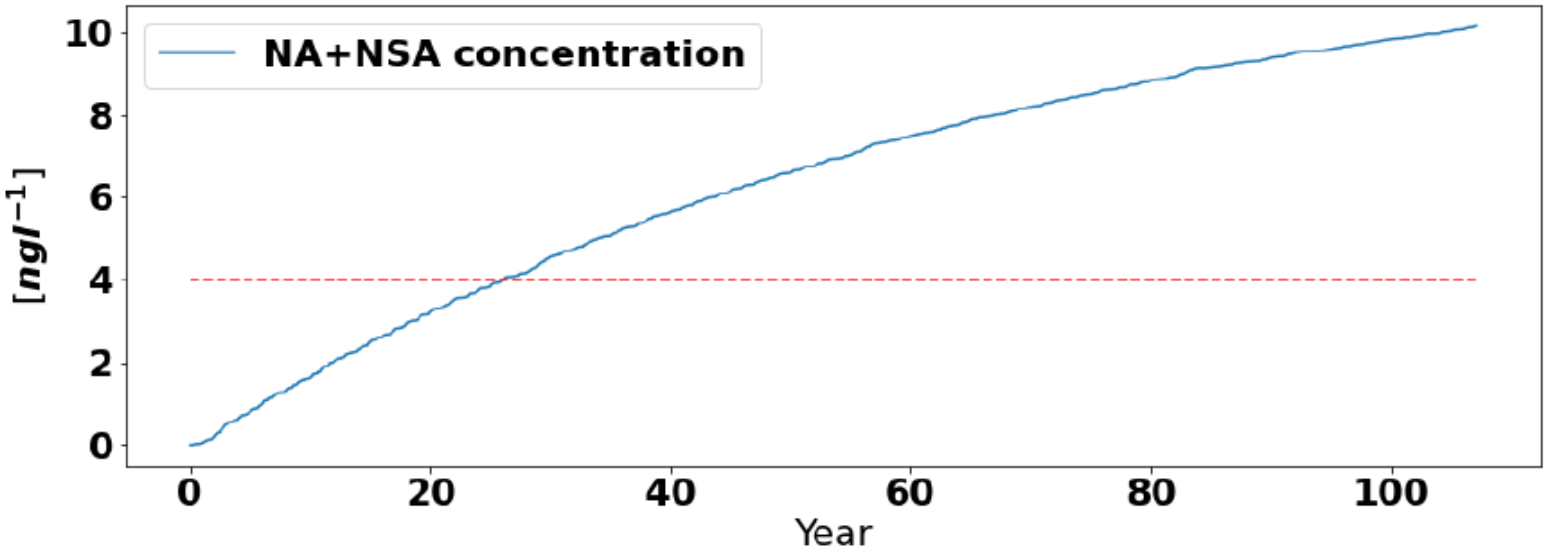


Figure 8: Modelled concentrations for the sum of NSAs and NAs in the Ramlösa groundwater basin over time with no biodegradation in the groundwater. The blue line signifies the concentration with the configuration of residence time (T) at 65 years and with no biodegradation taking place. This is considered a highly unlikely scenario. The red dotted line shows the NIPH recommended drinking water safety limit.

Without biodegradation, drinking water safety limit is passed in 25 years

Still large uncertainty in biodegradation rates

But…

Impacts of residence time and biodegradation rates on concentrations

Table 7: Analytical (control calculation) and simulated concentrations of NAs+NSAs in extracted water (ng^{-1}) after a long time (depending on computation type) of steady deposition. (T=residence time (years), hl = half-life (years)). The INCA-Tox concentration is not necessarily the equilibrium but is the average concentration in 118 years. Scenarios we consider more likely are highlighted.

T	hl	Ramlösa Control 1 (Vollen.)	Control 2 (Parcel)	INCA-Tox
5	2	7.1	3.4	4.0
5	5	11.4	9.7	6.9
5	10	14.4	13.7	9.1
5	∞	19.4	19.4	13.0
10	2	4.3	0.6	2.3
10	5	8.1	4.8	4.7
10	10	11.4	9.7	7.0
10	∞	19.4	19.4	12.9
20	2	2.4	0.0	1.3
20	5	5.1	1.2	2.9
20	10	8.1	4.8	4.8
20	∞	19.3	19.3	12.7
65	2	0.8	0.0	0.4
65	5	1.9	0.0	1.1
65	10	3.5	0.2	2.0
65	∞	19.3	19.3	10.1

$$\frac{dm}{dt} = Qc_0 - Q\frac{m}{V} - K_{bio}m,$$

Another source of uncertainty is the total water volume

Large point sources of CO_2 and high potential for CC

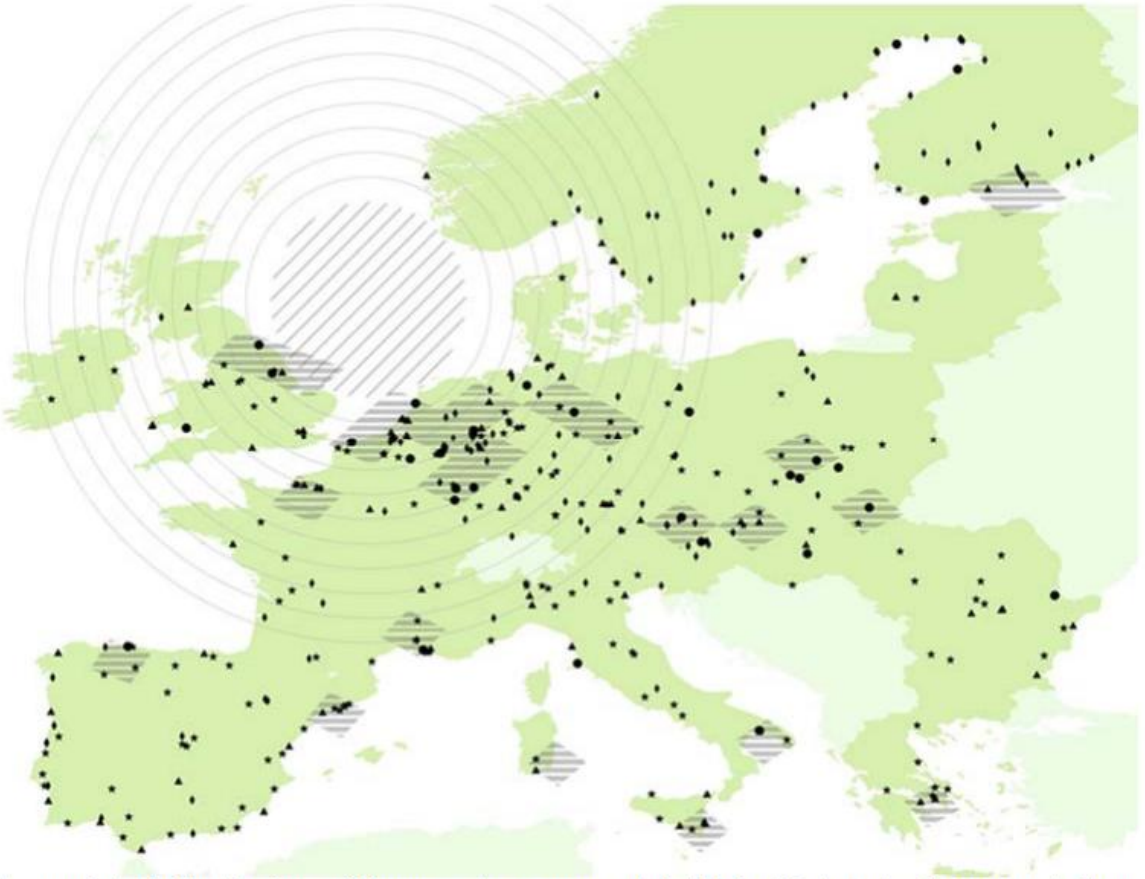


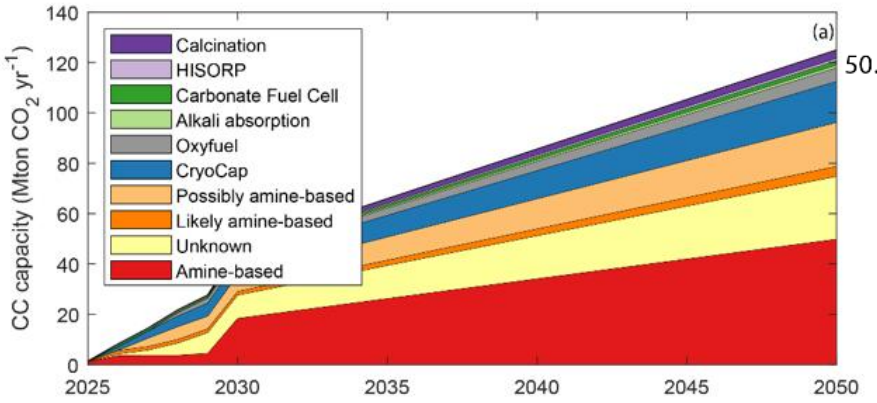
Figure 7. Geographical distribution of large point sources (>0.5 Mt CO_2/yr) in European industry (EU27 + Norway). The dashed circles marks approximate location of potential storage sites. The triangles denote refineries, circles indicate integrated steel plants, stars indicate cement plants, and diamonds designate pulp and paper plants. Regions where emissions from large industry point sources exceed 5 $MtCO_2$ annually are highlighted in grey.

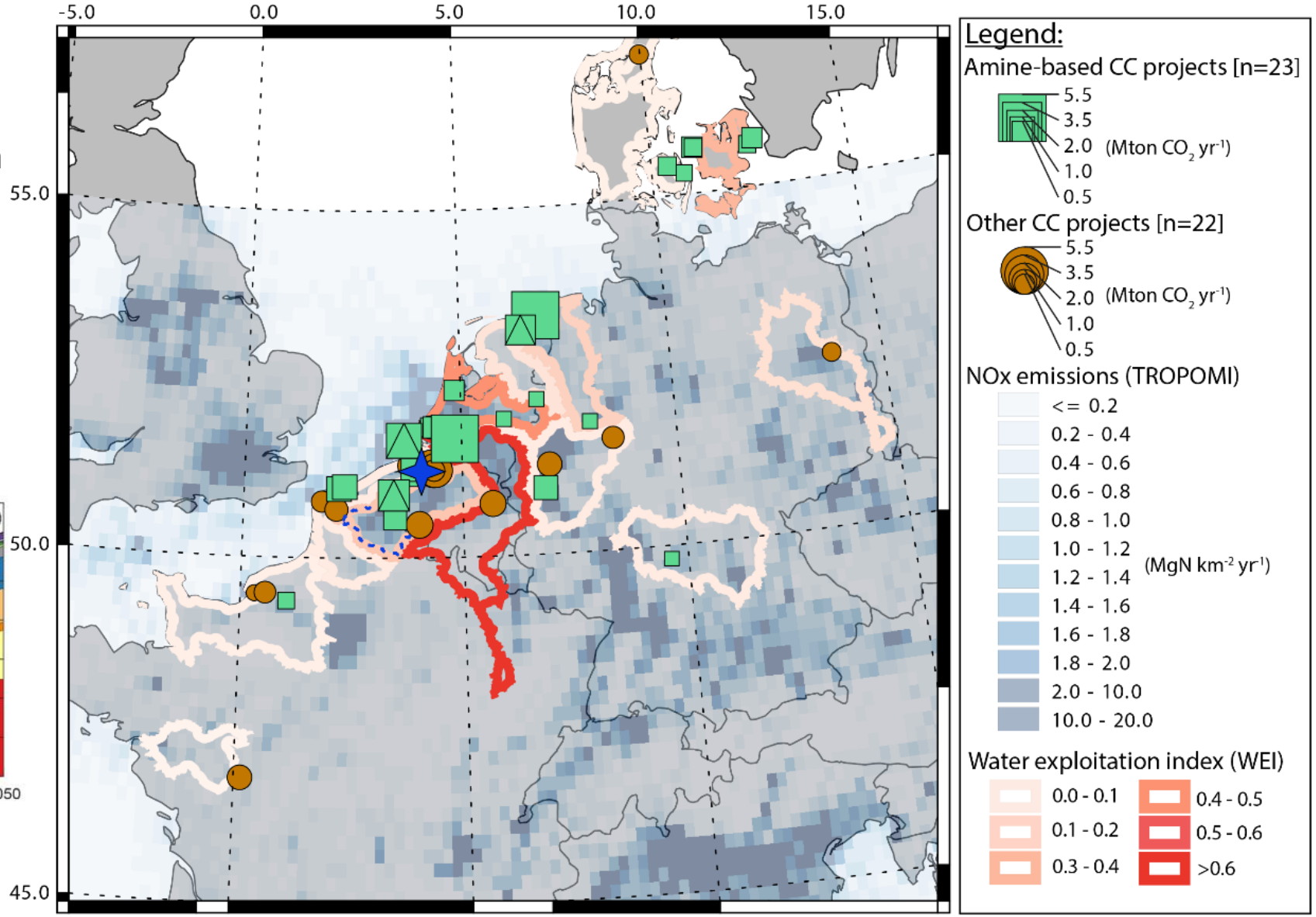
- The potential for CC is not evenly distributed throughout EU
- Highest potential concentrated from North-Eastern France through Northern Germany

Rootzén PhD Thesis (2015)

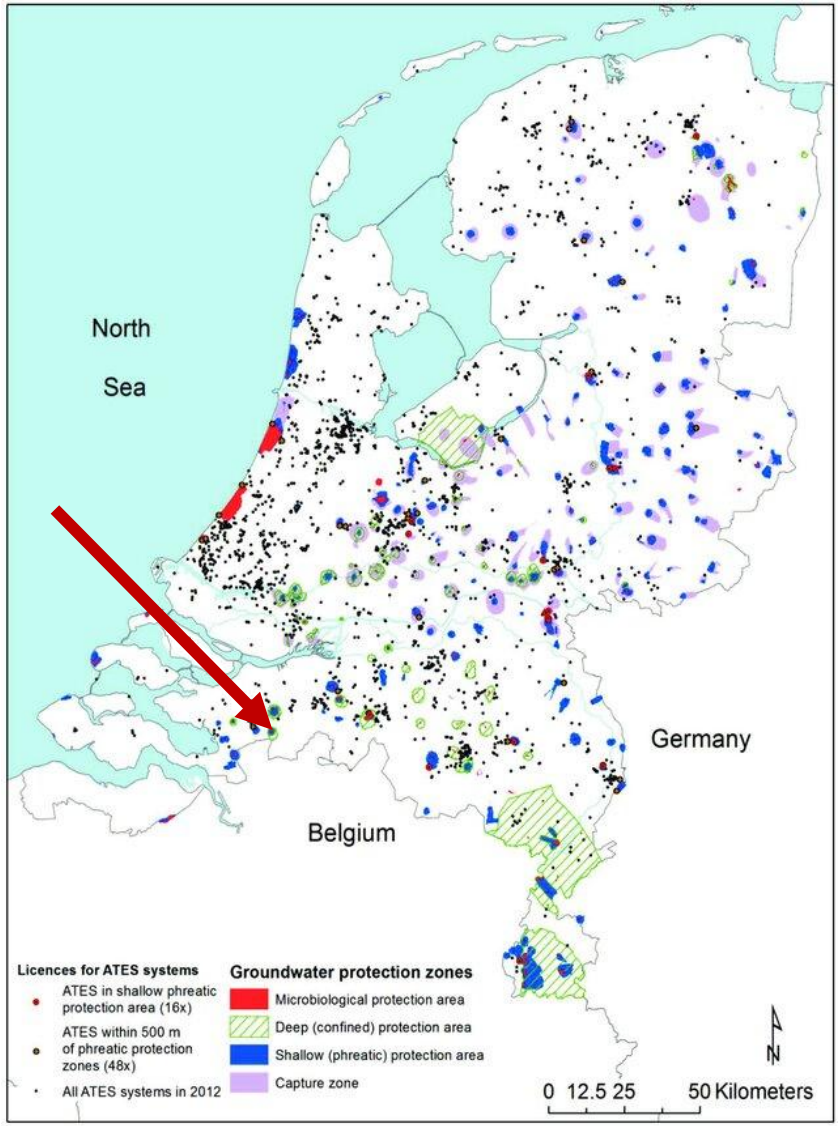
Planned CC projects in the Franco-Danish corridor

- Most CC capacity will be in Belgium and Netherlands
- >43% of the CC capacity will be amine-based





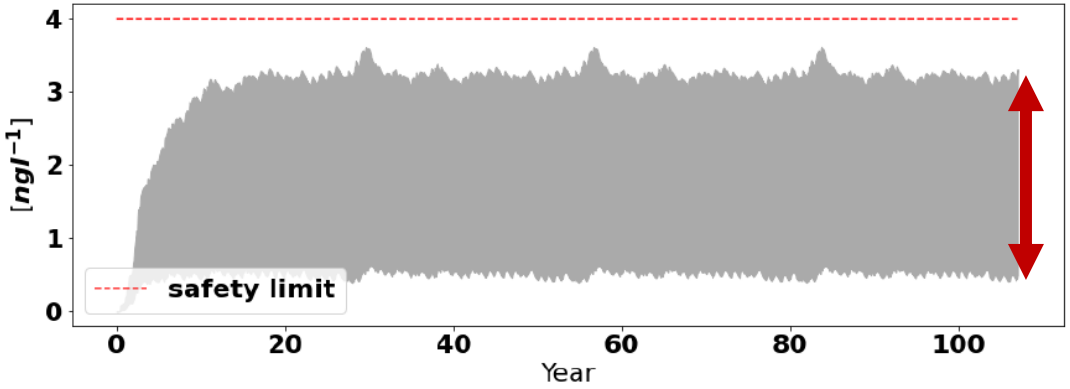
Shallow unconfined (sandy) aquifers

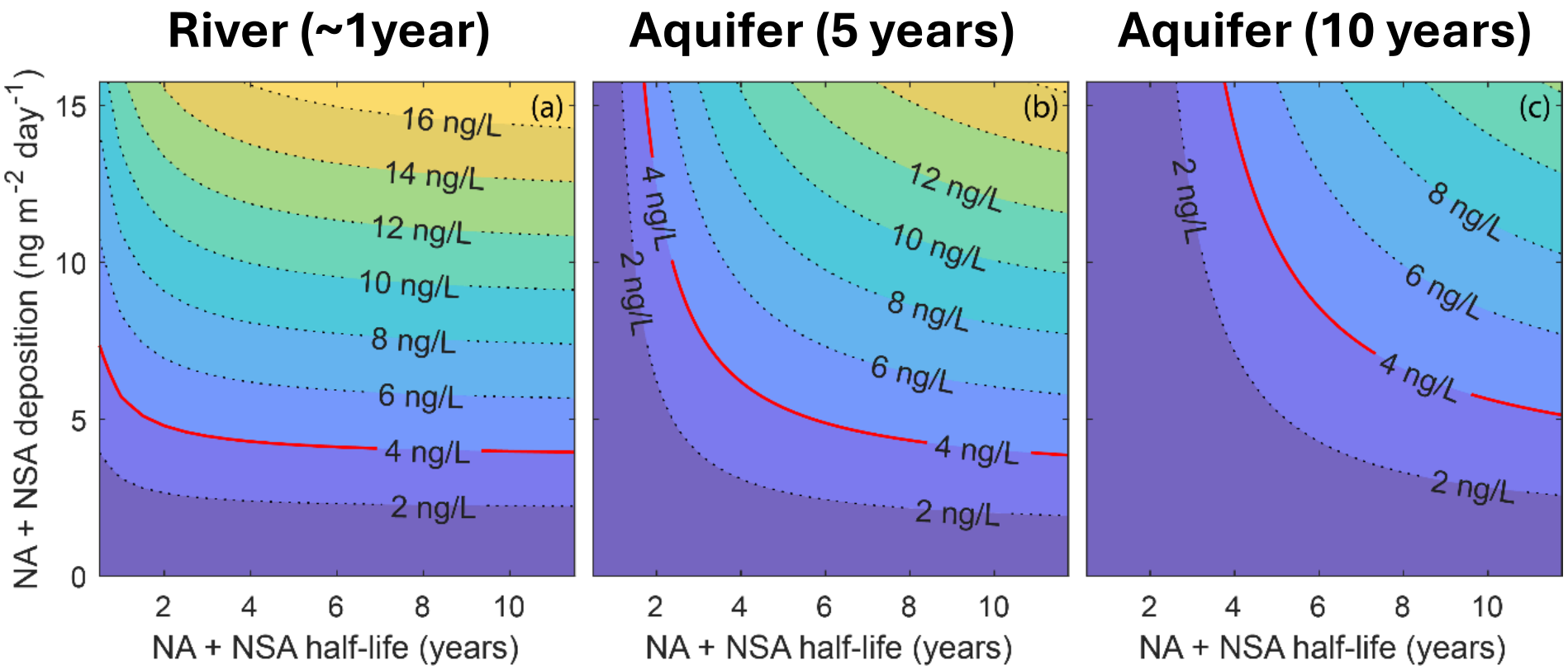


- Groundwater supplies ~65% of urban drinking water in the EU.
- Sint Jansteen is representative of small unconfined sandy aquifers across the Belgian-Dutch-German region
  - 5–10-year water residence time
  - 10-15m thick
  - Production of up to 3 Mm^3 / year
- The aquifer supports significant industrial and backup drinking water extraction.
- Its hydrogeological characteristics make it a useful model for contaminant transport studies in northwestern Europe.

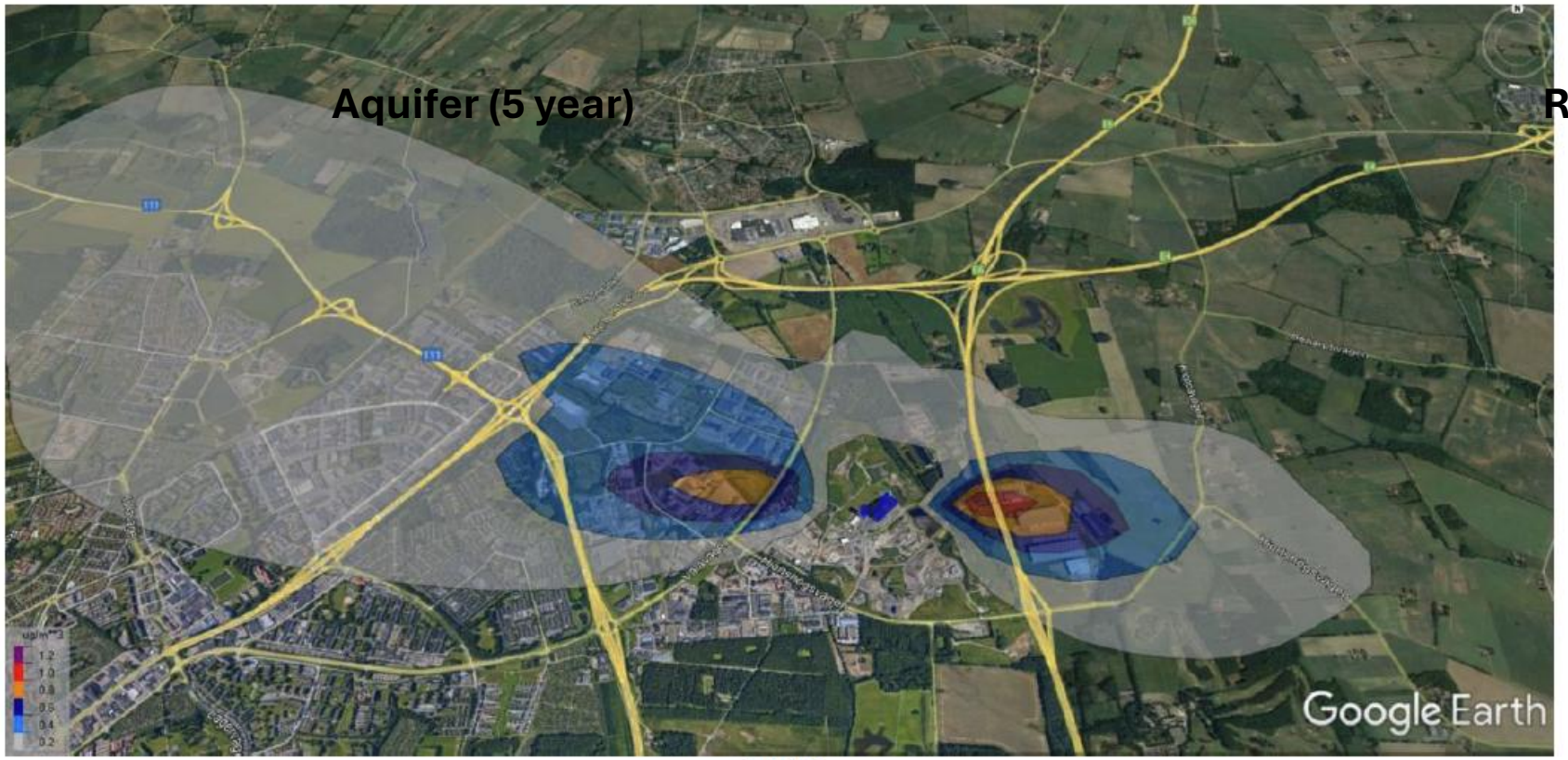
Impact of deposition and biodegradation on concentrations

- River concentrations are mainly driven by NA + NSA deposition.
- Groundwater concentrations are driven by both NA + NSA persistence and travel time.



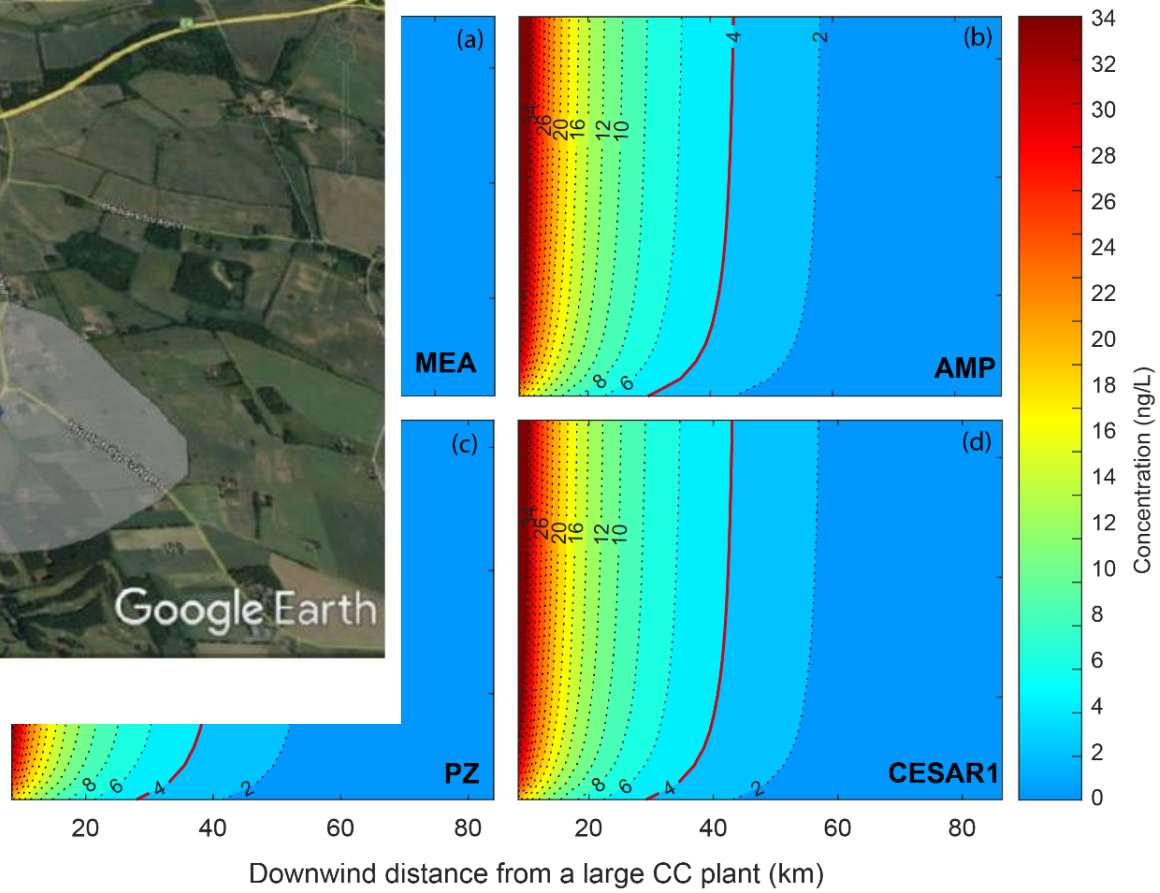


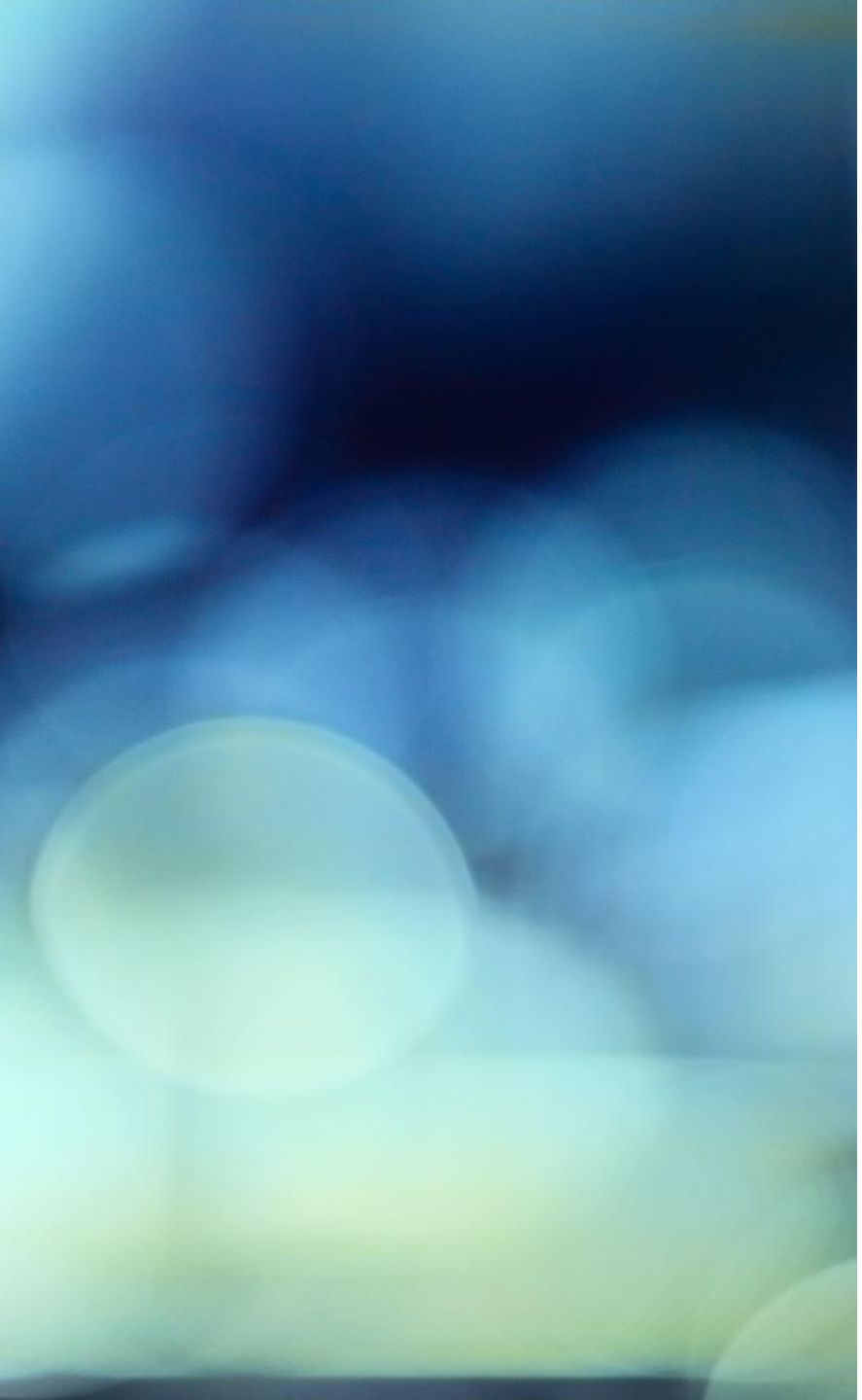
Impact of distance and biodegradation on concentrations



2018

River (1 year)





Some take home messages

- Small unconfined aquifers are particularly vulnerable to amine-derived contaminants.
- Groundwater risk depends on contaminant persistence relative to aquifer travel times.
- Limited dilution makes small aquifers more sensitive to contamination.
- MEA showed the lowest groundwater risk among the solvents evaluated.
- Regional assessment is needed to protect groundwater as CC deployment increases.



På sikker grunn

Thank you!