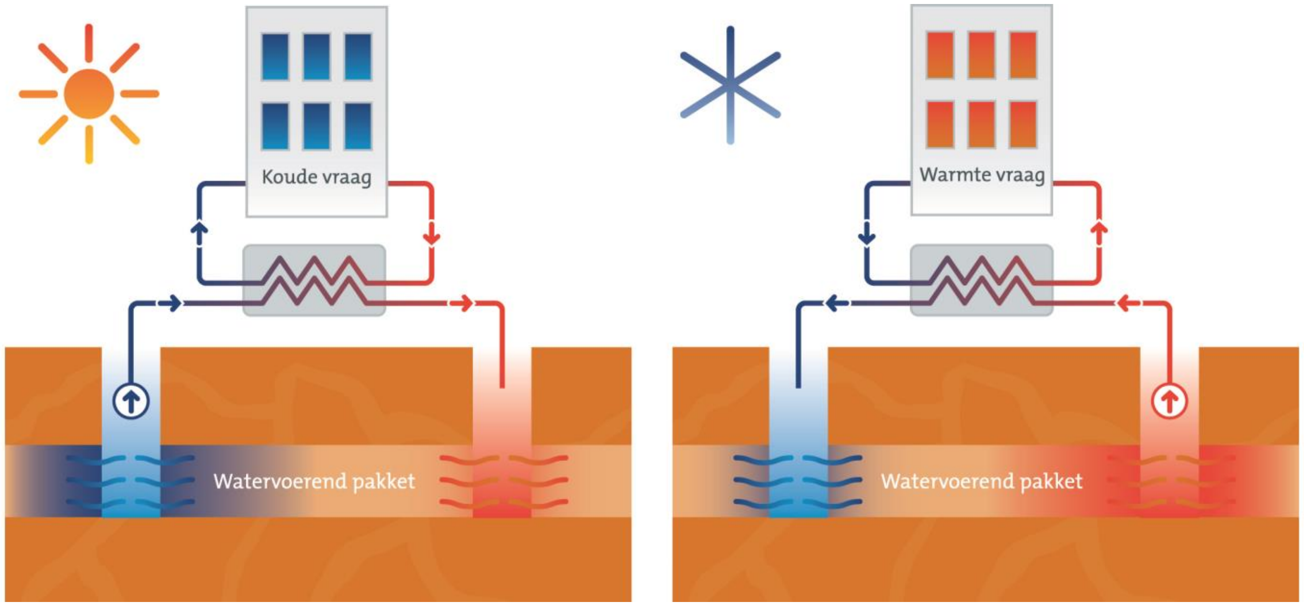
PERSPEKTIVER I KOMBINATION AF STIMULERET REDUKTIV DEKLORERING OG ATES I FORURENEDE INDUSTRIOMRÅDE



Mette Christophersen

ATV møde 25. maj 2021

RAMBØLL Bright ideas. Sustainable change.

MANY AUTHORS...........

- Lars Bennedsen and Britt Boye Thrane, Rambøll
- Nina Tuxen and John Flyvbjerg, Capital Region of Denmark
- Bas Godschalk, IF Technology
- Maurice Henssen, Bioclear Earth
- Nanne Hoekstra, Deltares and
- Tim Grotenhuis, Wageningen University

BACKGROUND

- Aquifer Thermal Energy Storage (ATES)-systems are highly effective energy-storage systems - provide energy with low CO_2-emmisions
- Increasing interest in ATES systems - the potential in Denmark is at least 400 ATES plants
- Large need for cooling and heating in urban and industrial areas
- Contaminated sites can hamper urban development – often contaminated with chlorinated solvents
- New approach: view the combination of ATES and remediation as an opportunity, as synergies and benefits are expected:
  - Elevated groundwater temperature and
  - Elevated flow will increase the degradation rate

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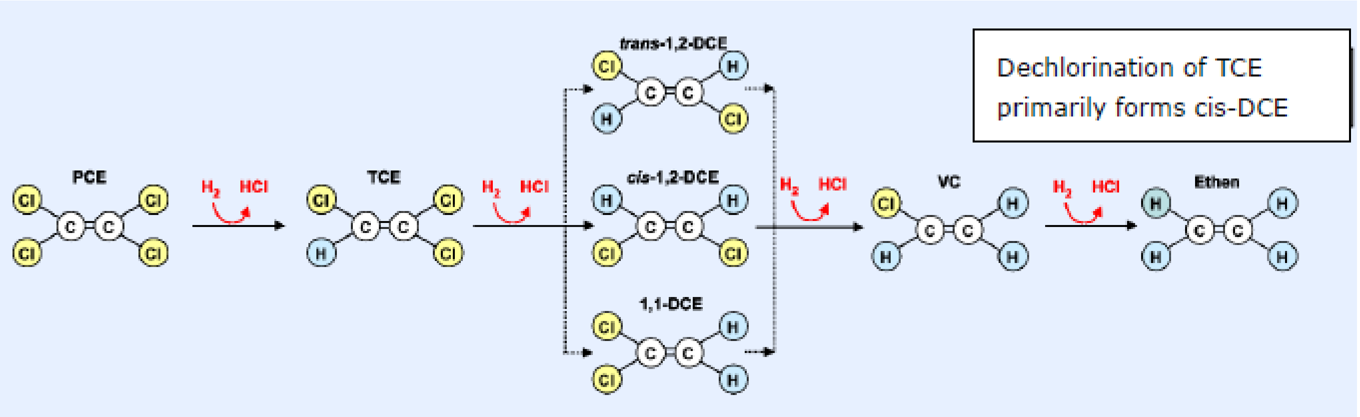
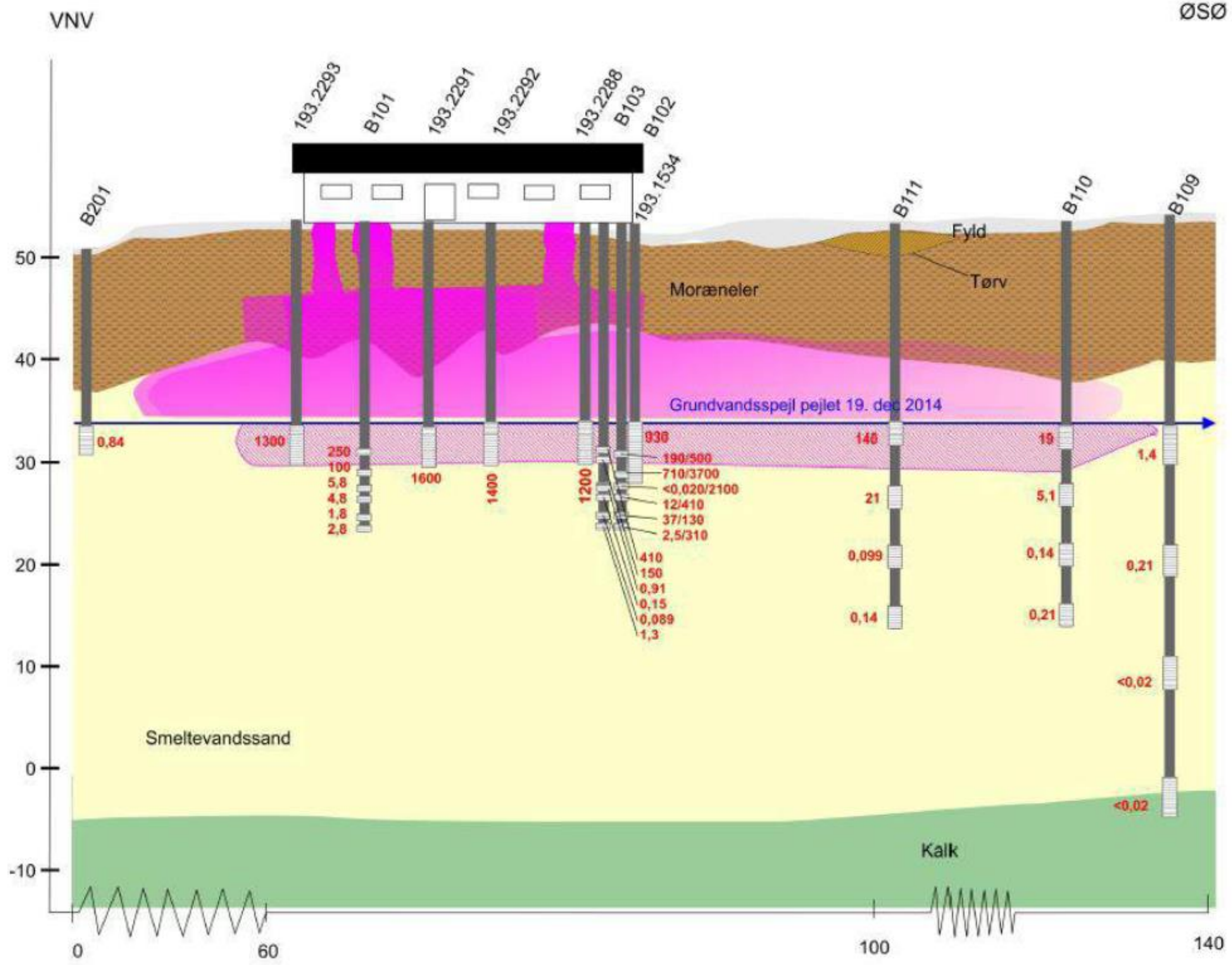
PURPOSES WITH THE PILOT TEST

To investigate the synergy effects of combining ATES and ERD and whether the effects improve the efficiency of ERD as well as gaining energy for heating/cooling of e.g. buildings at the same time?

1. Is it possible to design a functional and effective combination of ATES and ERD?
2. Can we enhance remediation at the site? Heated water and higher flowrate should enhance the degradation and the removal of the contamination
3. Can we deliver energy (heat and/or cold)? Are we using a flowrate high enough for a potential energy production?
4. Make sure that the contamination is not getting worse or spreading in the groundwater or to neighboring locations thereby increasing the risk towards the groundwater

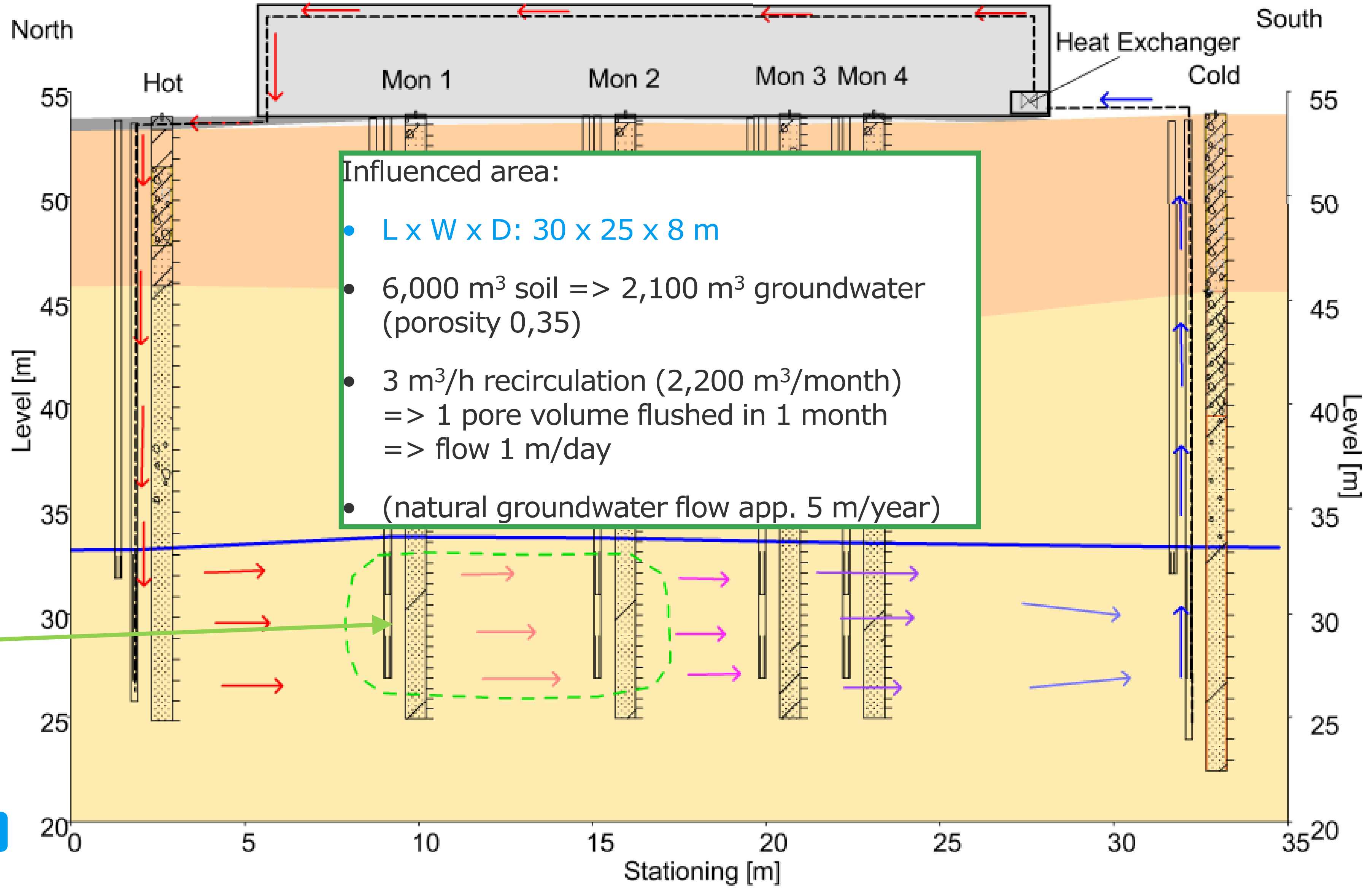


THE SITE - HAMMERBAKKEN



From Orbicon, 2017

CONCEPTUEL MODEL

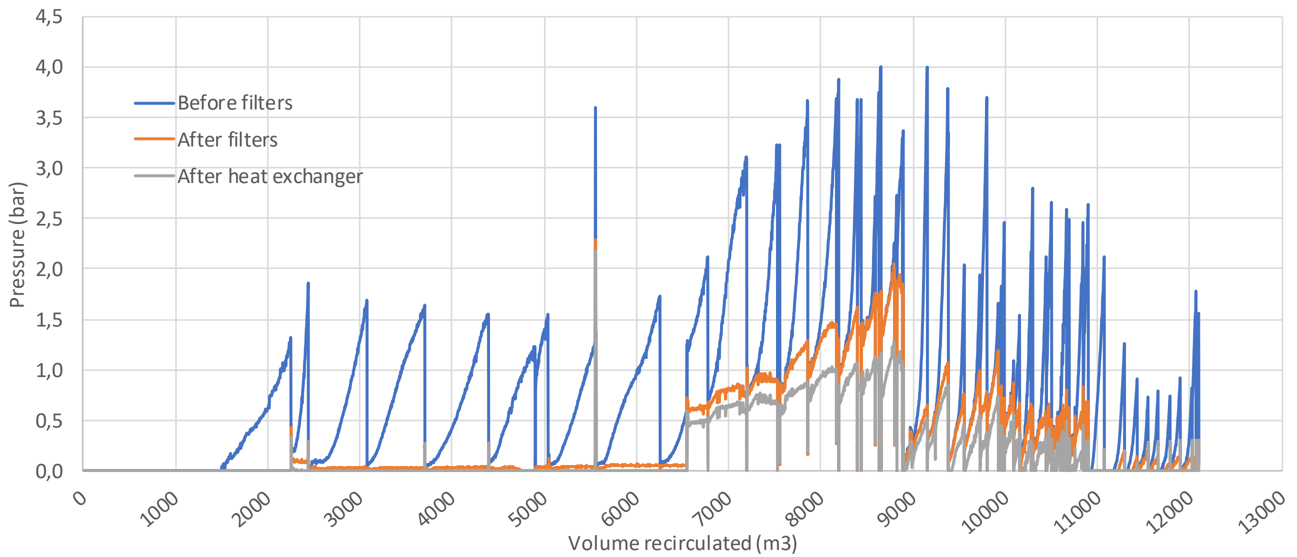


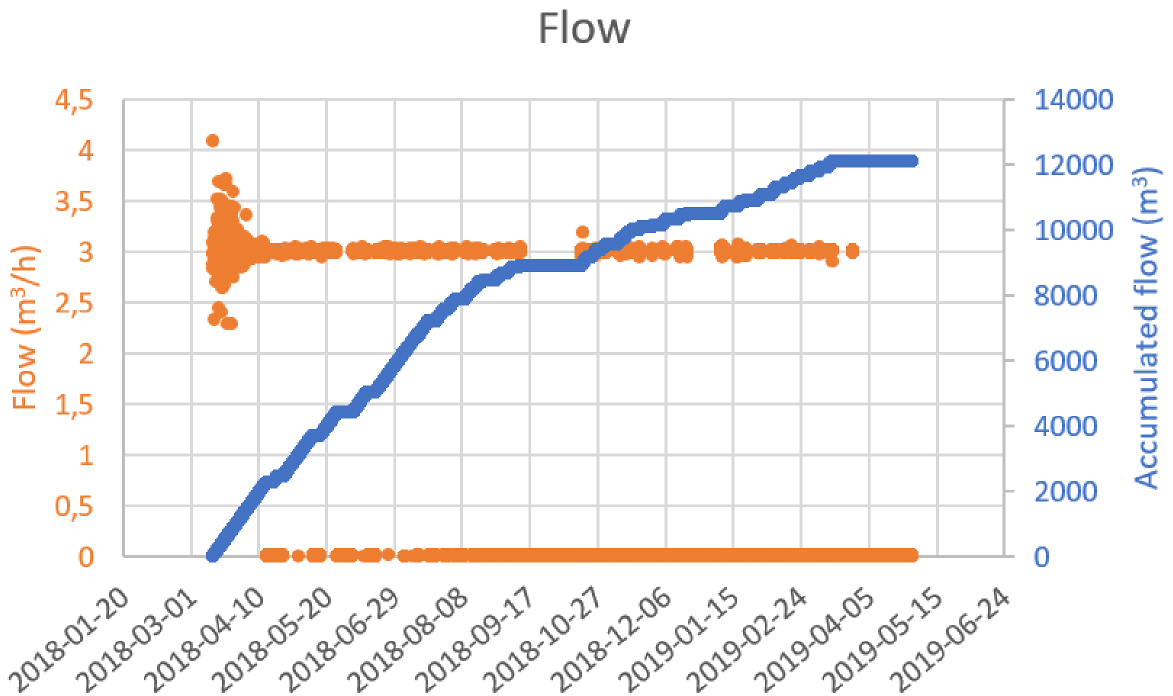
Influenced area:

- L x W x D: 30 x 25 x 8 m
- 6,000 m^3 soil => 2,100 m^3 groundwater (porosity 0,35)
- 3 m^3/h recirculation (2,200 m^3/month)
=> 1 pore volume flushed in 1 month
=> flow 1 m/day
- (natural groundwater flow app. 5 m/year)

Ares with bacteria

RECIRCULATION





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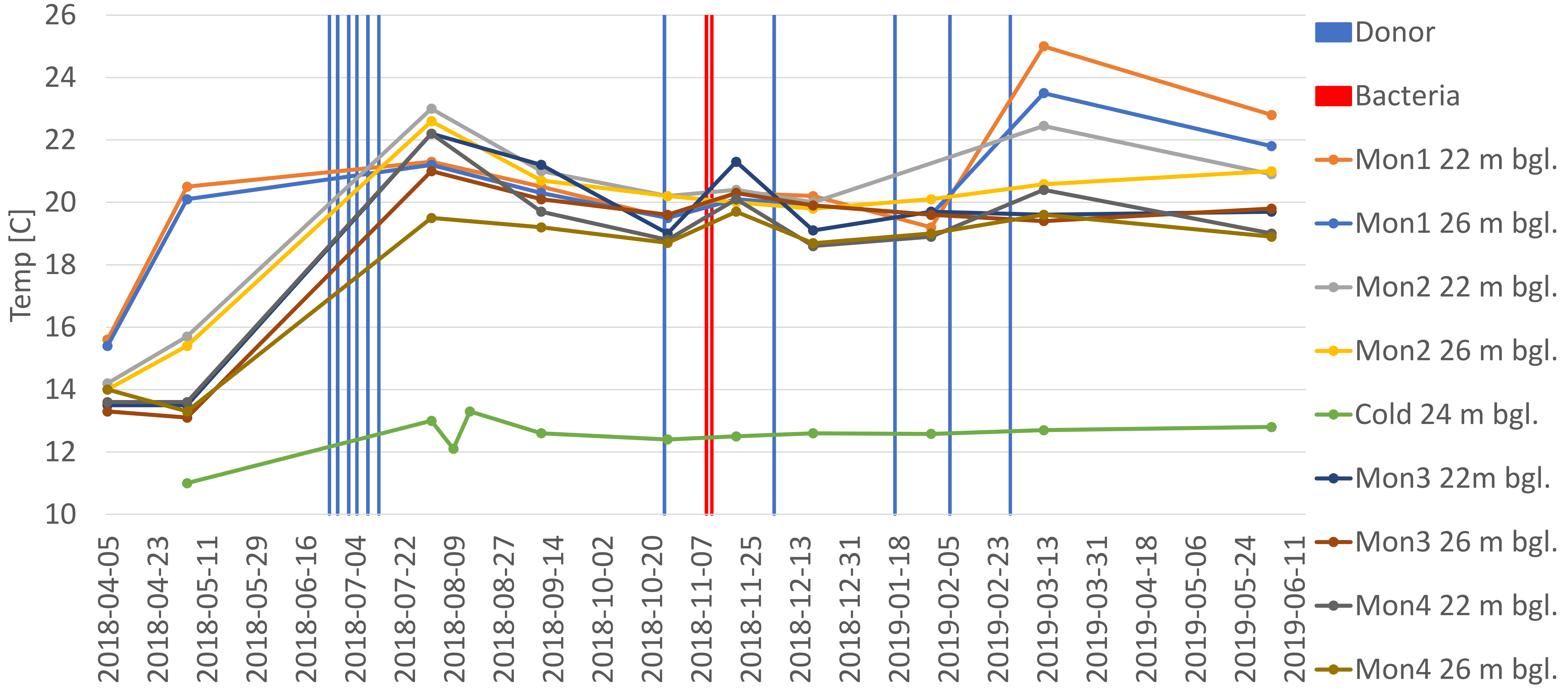
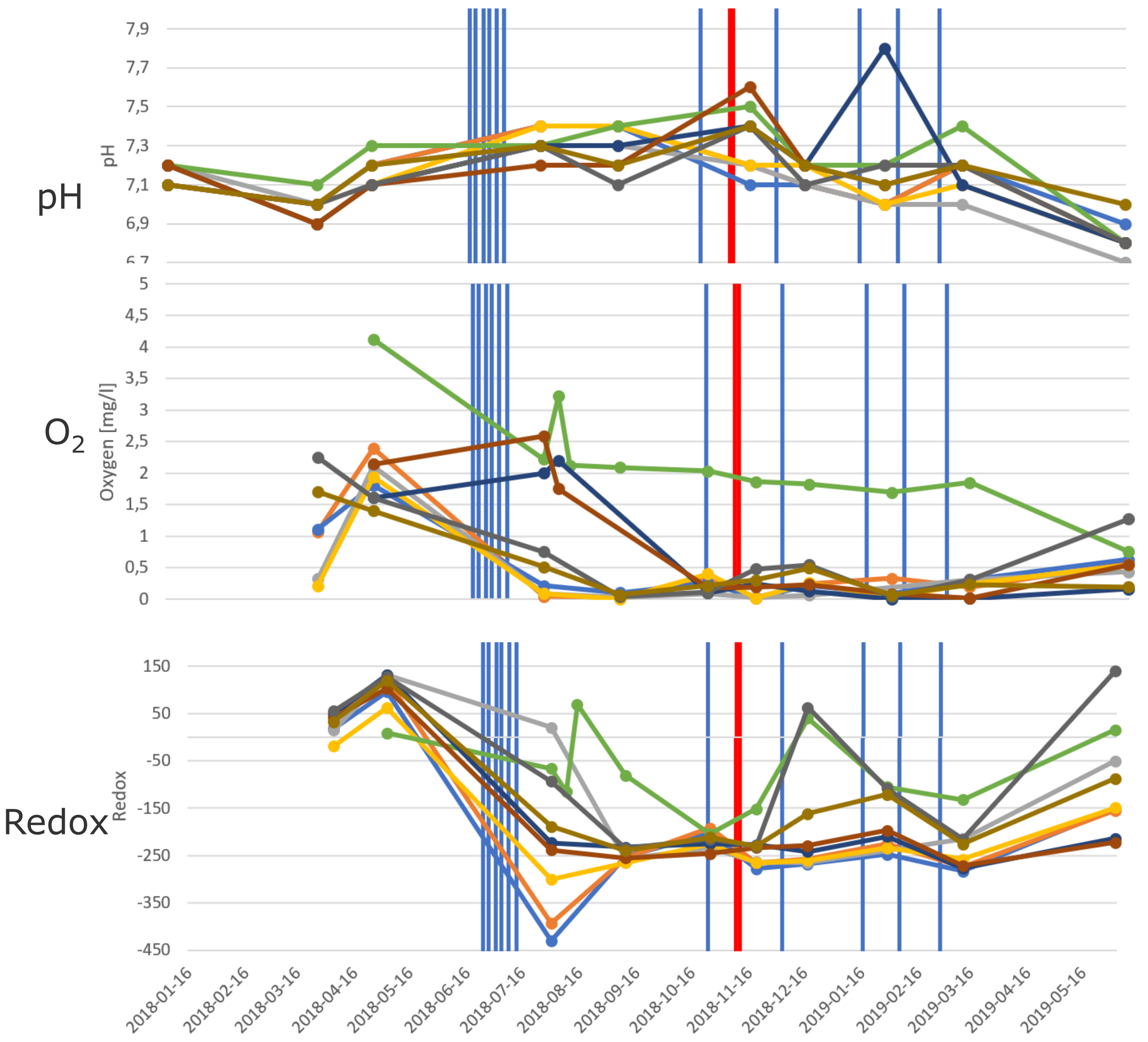
TEMPERATURE



FIELD PARAMETERS

- pH: stable and optimal
- Oxygen: depleted after donor addition, except in the cold well
- Redox: reduced after donor addition



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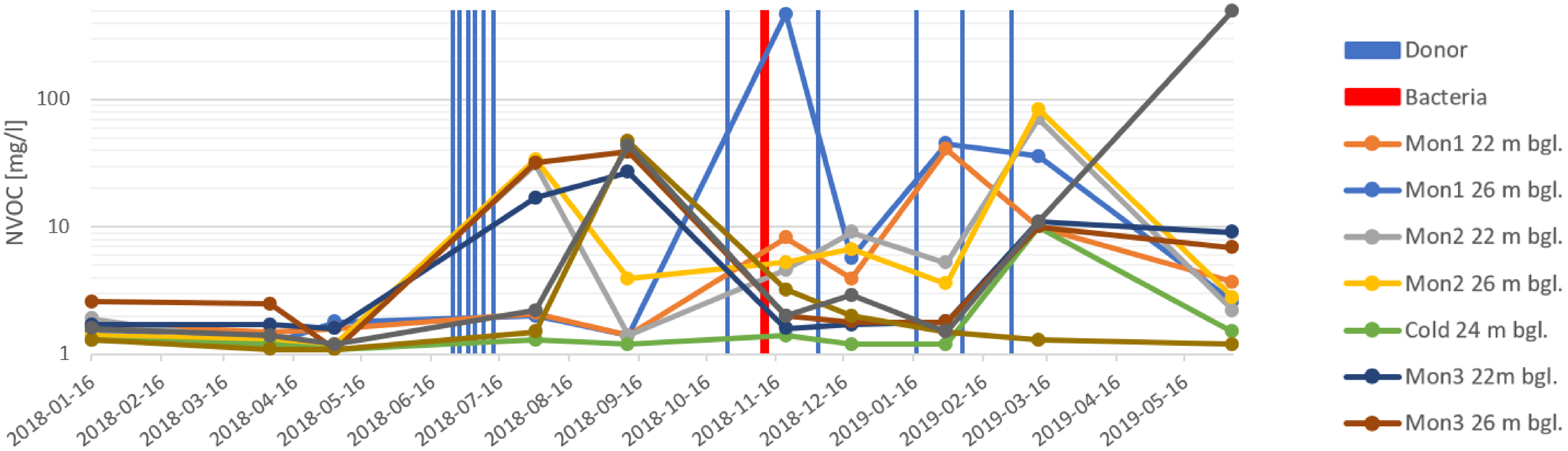
NVOC

NVOC (donor): Design 110-175 mg C/l



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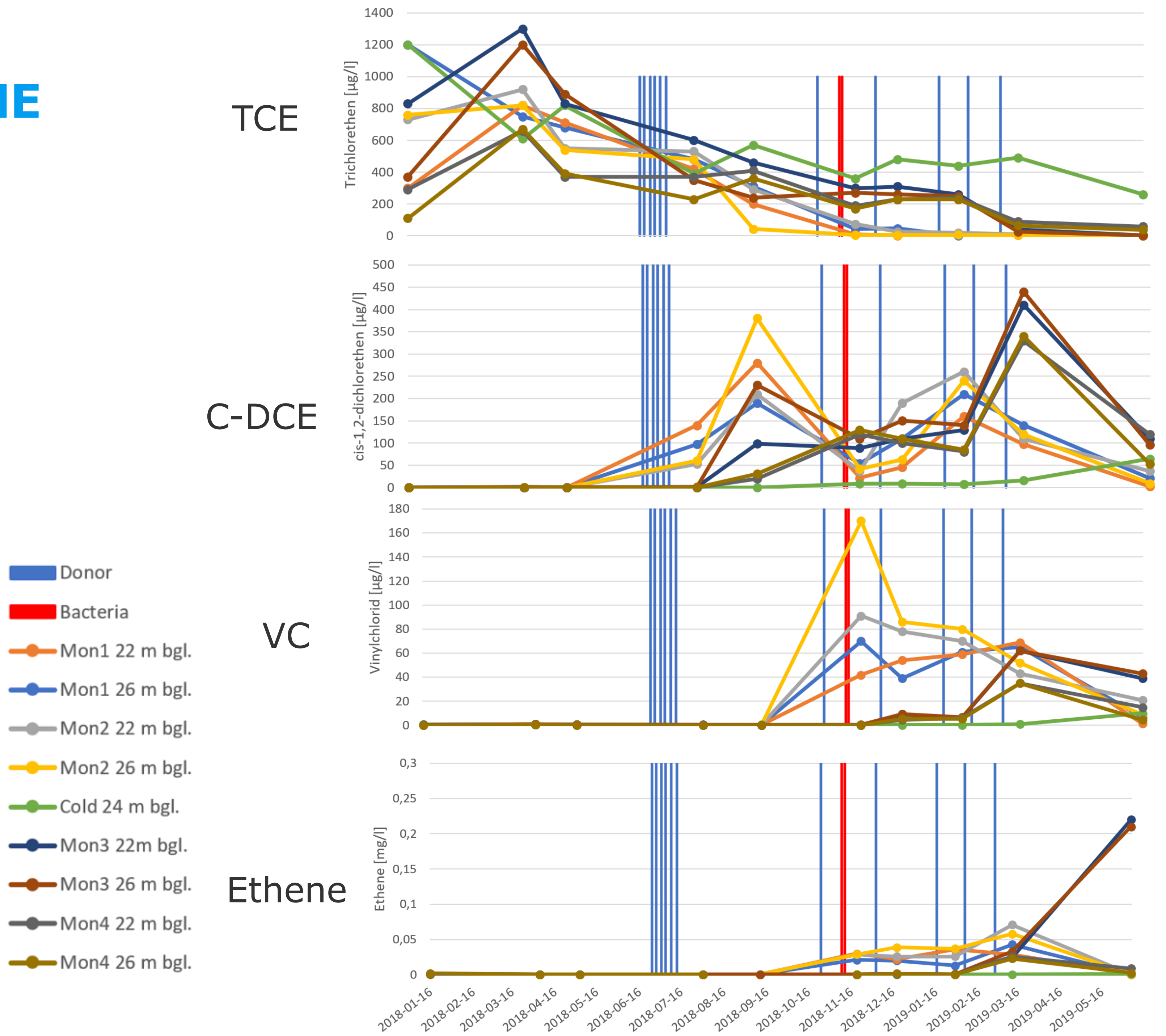
TCE, C-DCE, VC, ETHENE

- TCE: decreasing and disappearing
- DCE: increasing and decreasing in pulses
- VC: high conc. after bioaugmentation - later decreasing
- Ethen: increasing – very much at the end at Mon4…..



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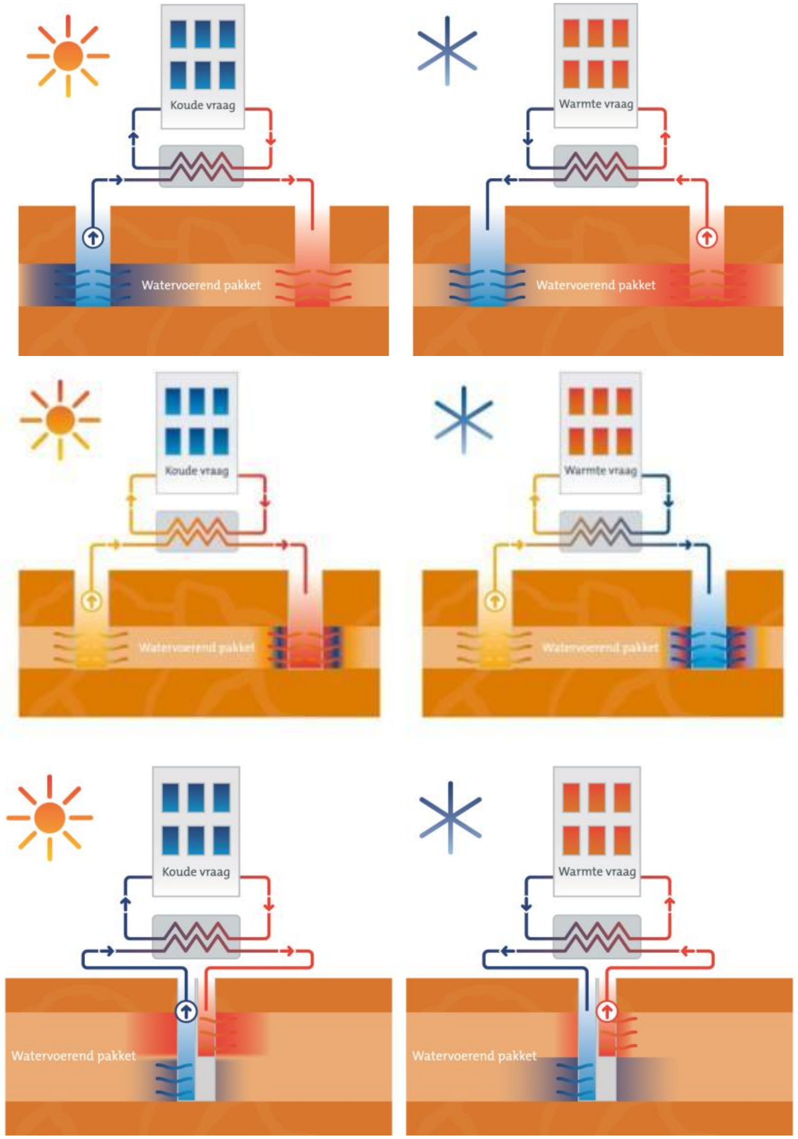
CONCLUSIONS

- Temperature
  - Quick breakthrough in the monitoring wells, with stable temp. close to 20 C°
  - Breakthrough of heat in cold well a little lower than calculated (more water from surroundings were extracted)
- Redox
  - Mixing not enough to obtain reduced conditions
  - Donor effectively reduced redox to optimal conditions – Monthly additions enough
  - Extracted water remained oxic
- Degradation
  - Donor caused dechlorination to c-DCE with natural present bacteria
  - Bioaugmentation caused fast dechlorination of c-DCE to ethene - within days
  - The capacity for degradation in the active zone was estimated to be 4-8 kg VOC removal/year for a relatively small treatment zone
  - Rates significant faster than traditional ERD

PERSPECTIVES FOR THE METHOD

- Many chlorinated solvent plumes - focus so far has been on source remediation
- Combining ATES and ERD could make the remediation much more cost effective and sustainable due to the low CO_2 emission and the recirculation and heating could increase degradation of contamination
- It is kind of a Funnel & Gate - recirculation is Funnel and bioreactive zone Gate
- Degradation of the chlorinated solvents was so effective and complete that future ERD-projects should consider recirculating and heating groundwater (could be called ERD+)
  - For the project at Hammerbakken less than 100,000 DKK was used for district heating
- Challenge with:
  - Mixing of water types
  - Contact time for degradation

ATES MULIGHEDER



Ref: Meer met Bodemenergie, 2012

Dipol system

- Dobbelt med separat kold og varm boring
- I NL op til 300 m^3/t pr boring
- To retninger (sæsonvis)
- Storskala projekter - alle formål

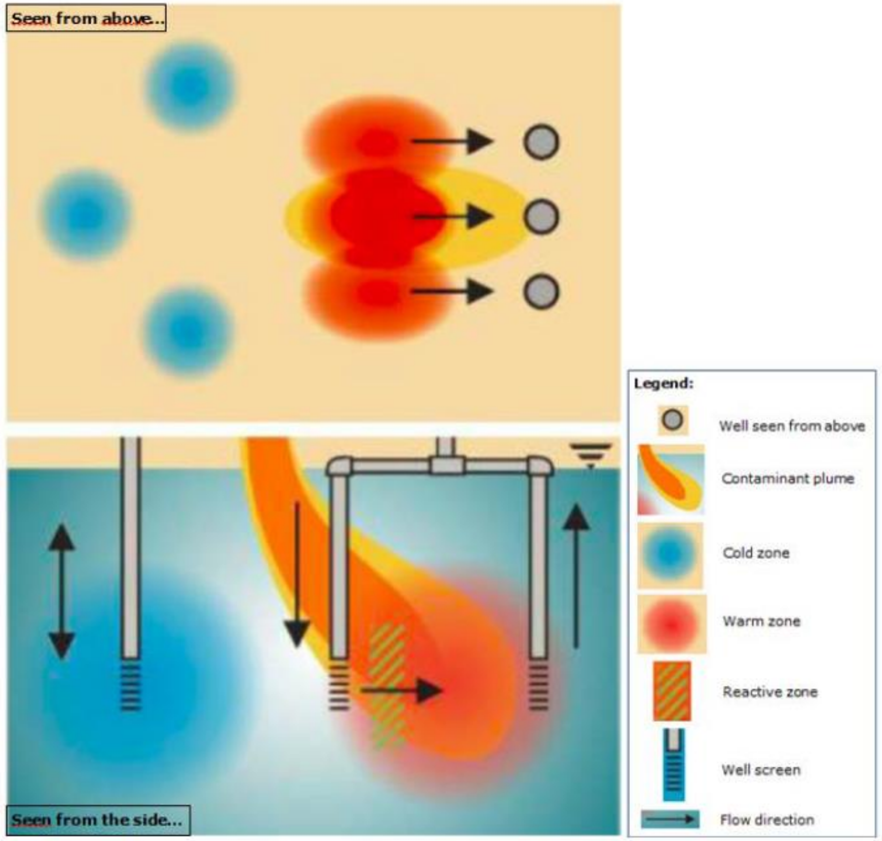
Recirkulationssystem

- Recirkulation med ekstraktions- og injektionsboring
- Samme retning hele året
- I NL op til 300 m^3/t pr boring
- Storskala projekter - hovesageligt industrielt formål

Enkeltboringssystem

- En boring med koldt og varmt filter i forskellig dybde
- I NL op til 80 m^3/t pr boring
- Mindre skala – alle formål

TRIPLET ATES SYSTEM



- A kind of combination between the mono- and bi-directional systems
- Not typical for common ATES systems - probably only relevant for combinations of ATES and remediation
- One pair of wells (doublet), in which a mono-directional flow regime is applied, as well as a third well, which is a combined extraction- and injection well (located in the cold zone), whereas the doublet with mono-directional flow regime will be located in the warm zone
- Cooling: water is abstracted from the combined extraction- and injection well and injected into the warm zone via the dipole’s injection well
- Heating: water is extracted from the dipole’s extraction well (located downstream), passes the heat pump and is cooled off, and is subsequently injected into the cold zone via the combined extraction- and injection well
- A Triplet ATES-system has the advantage that it generally provides better plume control than bi-directional ATES, due to the relative uniform flow pattern

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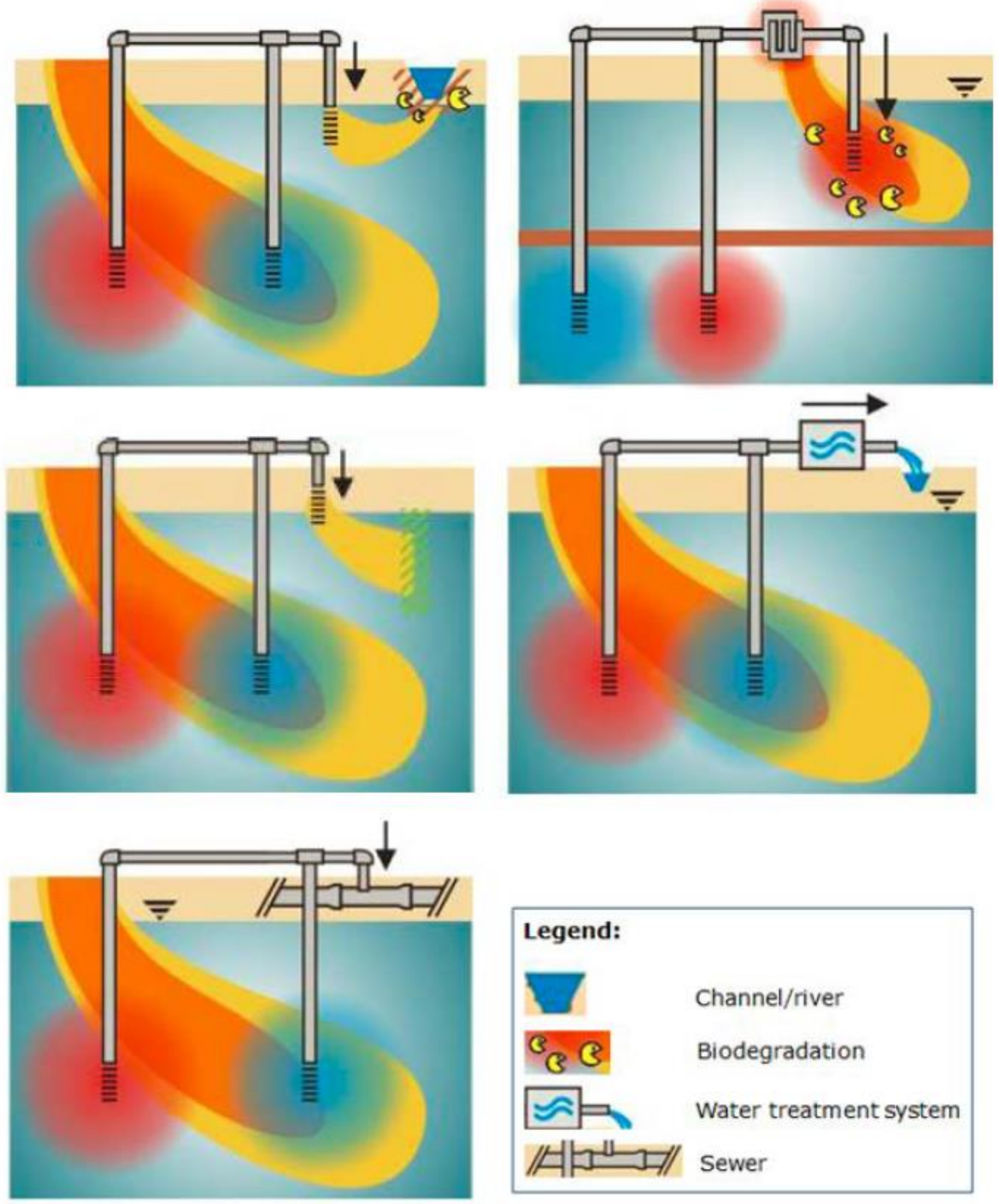
ATES-SYSTEM WITH REMOVAL OF A FRACTION OF THE EXTRACTED WATER

- Examples of ATES-systems where a fraction of the extracted water is not returned to thermal storage part of the aquifer, but is instead e.g. treated before reinjection, or returned to another recipient (sewer or otherwise) – in a remediation context
- Only relevant when both thermally and hydraulically balance is not required



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MULIGE KOMBINATIONER AF GEOENERGI OG AFVÆRGE

Type of combination concept	ATES-efficiency	Remediation efficiency
ATES and control/containment (without natural degradation)	High	Very low, the pollution is controlled thus reducing the spreading risks
ATES and natural degradation	High	Low, natural degradation is often a slow process. Without management, possible risk of spreading.
BTES and natural degradation	High, however, energy yield is small	Low, natural degradation is often a slow process. Without management, possible risk of spreading.
ATES combined with heat transport	High	Low, natural degradation is often a slow process. Without management, possible risk of spreading.
ATES with transport to a zone with natural degradation	High	Low, natural degradation is often a slow process.
ATES with transport to a zone with stimulated degradation	High	Moderate, with abstraction there is almost always a residual contamination left behind.
ATES with a reactive zone around the infiltration screens	High	High (only chlorinated solvents)
ATES with a reactive zone at a large distance from the well screens	High	High (only chlorinated solvents)
ATES and aerobic zone	High	High (only for BTEX, cis-dichloroethene (cis-DCE) and vinyl chloride (VC), not for tetrachloroethene (PCE) or for trichloroethene (TCE)
ATES and above-ground purification and re-infiltration	High	Moderate, with abstraction there is almost always a residual contamination left behind.
ATES and above-ground purification and discharge of a fraction of the pumped water	High	Moderate, with abstraction there is almost always a residual contamination left behind
ATES and discharge (of a fraction of the pumped water) to sewer	High	Moderate, with abstraction there is almost always a residual contamination left behind

Ref: Meer met Bodemenergie, 2012

FAKTORER DER PÅVIRKER ATES OG SRD

- Geologi og hydrogeologi:
  - ATES kan installeres i både konsoliderede og løse aflejringer
  - Kræver en tilstrækkelig transmissivitet og porøsitet men ikke for høj GV-hastighed (ca. 50 m/år for at kunne holde på varme/kulde)
  - Kræver et magasin med en mægtighed på min 5 m og placeret min 5 m u.t. (gerne 10-20 m u.t.)
  - Helst spændt magasin (for at undgå ilt – klogning)
- Temperatur:
  - Kan påvirke både nedbrydningshastighed, sorption/desorption, udfældning, opløsning osv.
- Temperaturer i ATES:
  - Kuldelager, typisk: 5 – 12 ^{o}C (Bek.: Min. 2 ^{o}C gnsn. pr. md.)
  - Varmelager, typisk: 14 – 20 ^{o}C (Bek.: Max afløb 25 ^{o}C, max. 20 ^{o}C gnsn. pr. md.)

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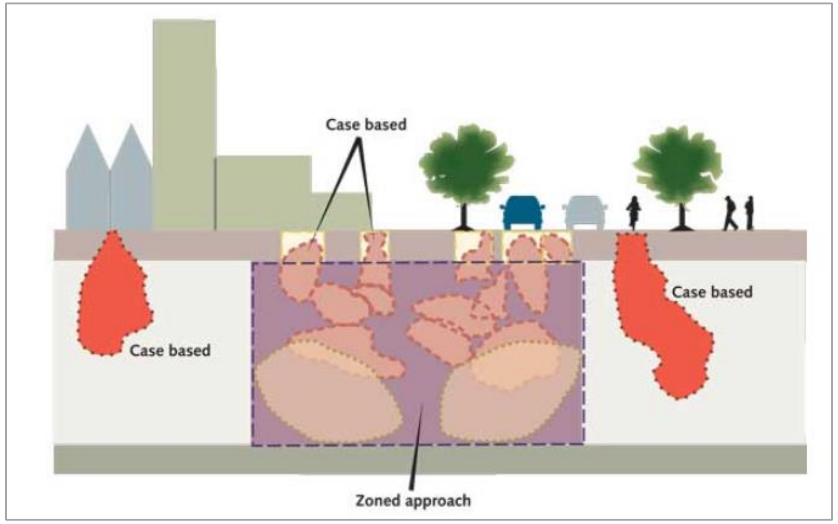
KOMBINATION AF ATES OG SRD - UDFORDRINGER

- Formål med ATES og SRD (energi ⟷ afværge)
- Abstraktionsdybde (dyb ⟷ terrænnært)
- Flowhastighed (høj ⟷ lav)
- Interesser (ejer/projektudvikler ⟷ grundejer)
- Varighed (så lang som muligt ⟷ så kort som mulig)
- Økonomi (tilbagebetalingsperiode ⟷ udgifter)
- Reducere risiko for grundvand ⟷ introducere risiko for ATES

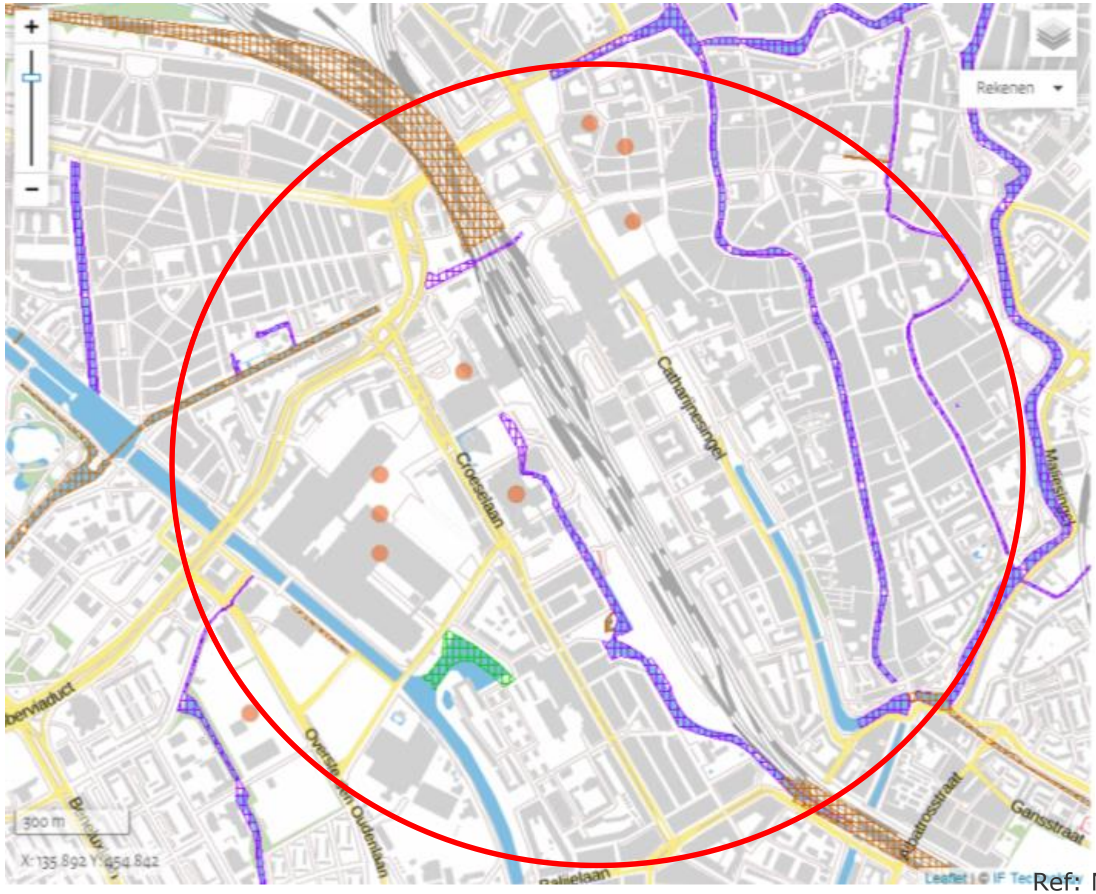
AREA BASERET TILGANG

The area-based/zoned approach is based on three pillars:

- Protect. I.e. to contain the contaminated groundwater within the defined zone to pre-vent further spreading and protect the environment
- Use. I.e. to use the groundwater for beneficial purposes e.g. ATES-systems to obtain sustainable energy
- Improve. I.e. to improve groundwater quality over time, e.g. by improving conditions for natural degradation over time, or by active measures to stimulate degradation



Ref: Slenders, 2013



Ref: Meer met Bodemenergie, 2012

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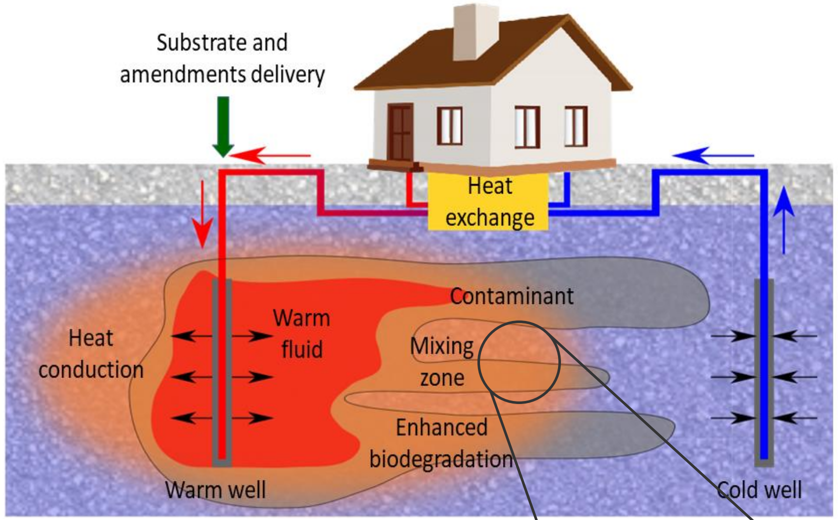
BiodegrATES – In situ contaminant biodegradation meets Aquifer Thermal Energy Storage

New project!

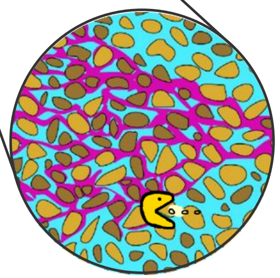
Concept



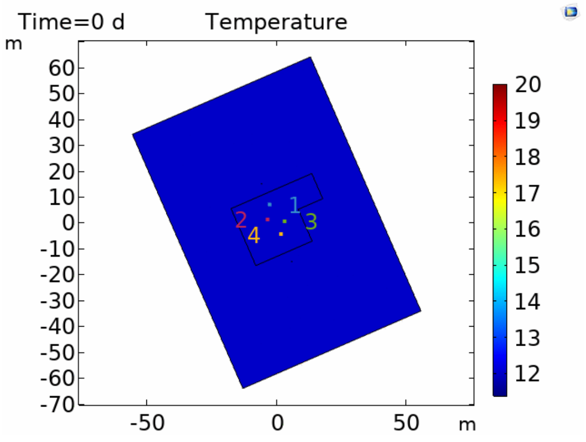
Advection

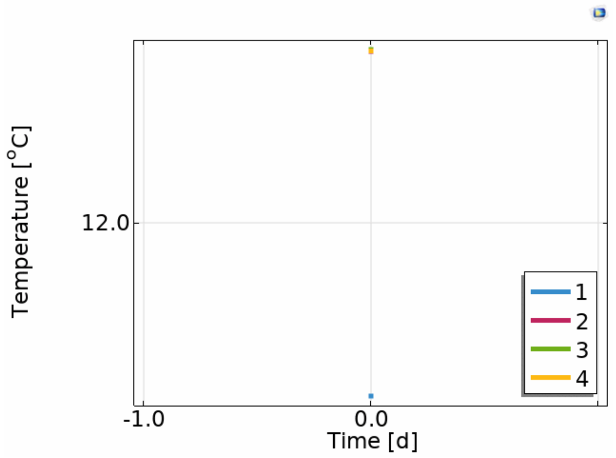
Non-isothermal reactive transport

Heat transport



Process-based modelling







H. Wienkenjohann, K. Mosthaf, M. Rolle (DTU Miljø)

BiodegrATES

This project is funded by
DANMARKS FRIE FORSKNINGSFOND
INDEPENDENT RESEARCH FUND DENMARK

Aim

Synergically couple shallow aquifer thermal energy storage systems (ATES) with in situ biodegradation of xenobiotic organic pollutants (e.g. chlorinated solvents)

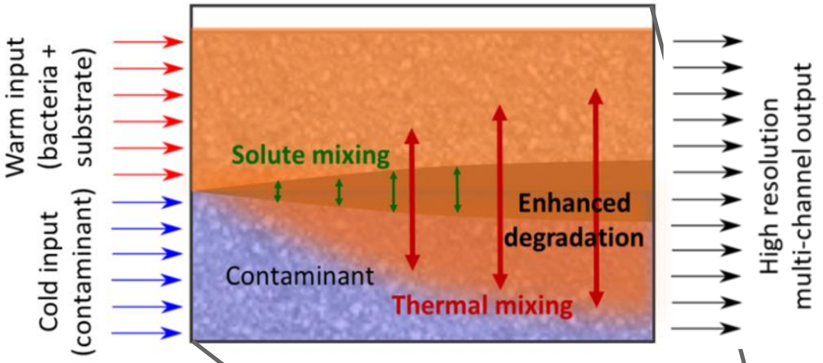
BiodegrATES – In situ contaminant biodegradation meets Aquifer Thermal Energy Storage

BiodegrATES

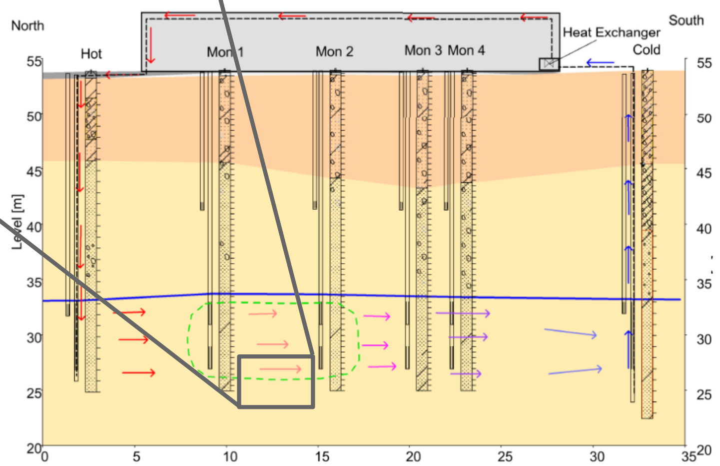
This project is funded by
DANMARKS FRIE FORSKNINGSFOND
INDEPENDENT RESEARCH FUND DENMARK

Experiments ⟷ *Strongly interconnected* ⟷ Modelling

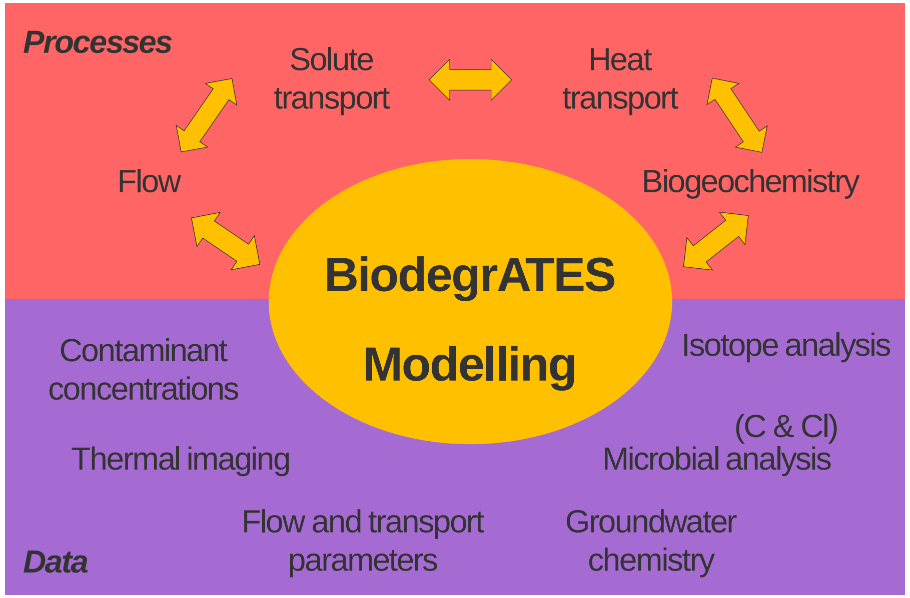
Lab-scale tank setup



Field-scale ATES-ERD setup



Simulation of lab- and field-scale setups



COMSOL-PhreeqC coupling

Rolle et al. (2018) WRR
Sprocati et al. (2019) AdWR

THANK YOU FOR YOUR ATTENTION!

Mette Christophersen

METC@Ramboll.dk