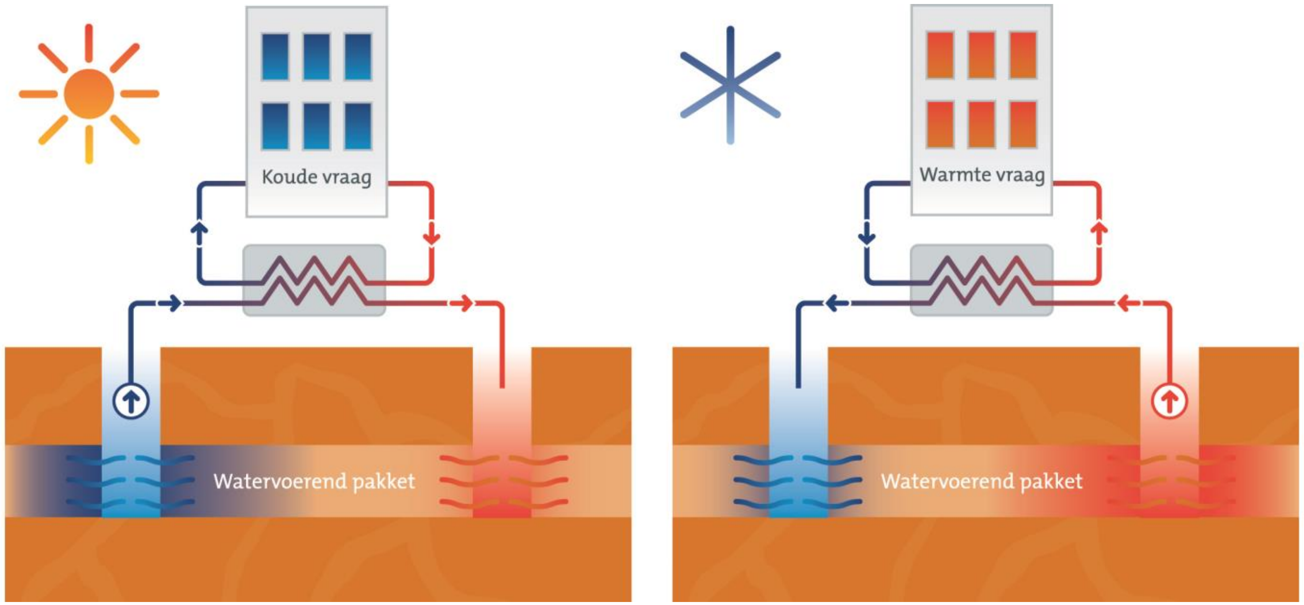
COMBINATION OF ENHANCED REDUCTIVE DECHLORINATION AND AQUIFER THERMAL ENERGY STORAGE – PILOT TEST



Mette Christophersen

ATV meeting November 28^{th} 2019

RAMBOLL Bright ideas. Sustainable change.

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

- Lars Bennedsen and Britt Boye Thrane, Rambøll
- Line Mørkebjerg Fischer, 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

MAIN POINTS IN THIS PROJECT

1. It is possible to combine Aquifer Thermal Energy Storage with remediation of chlorinated solvents
2. Increasing the groundwater temperature really increase the degradation rate and the degradation can be fulfilled
3. Could ERD+ (enhanced reductive dechlorination at elevated temperature) be a new remediation method?

BACKGROUND

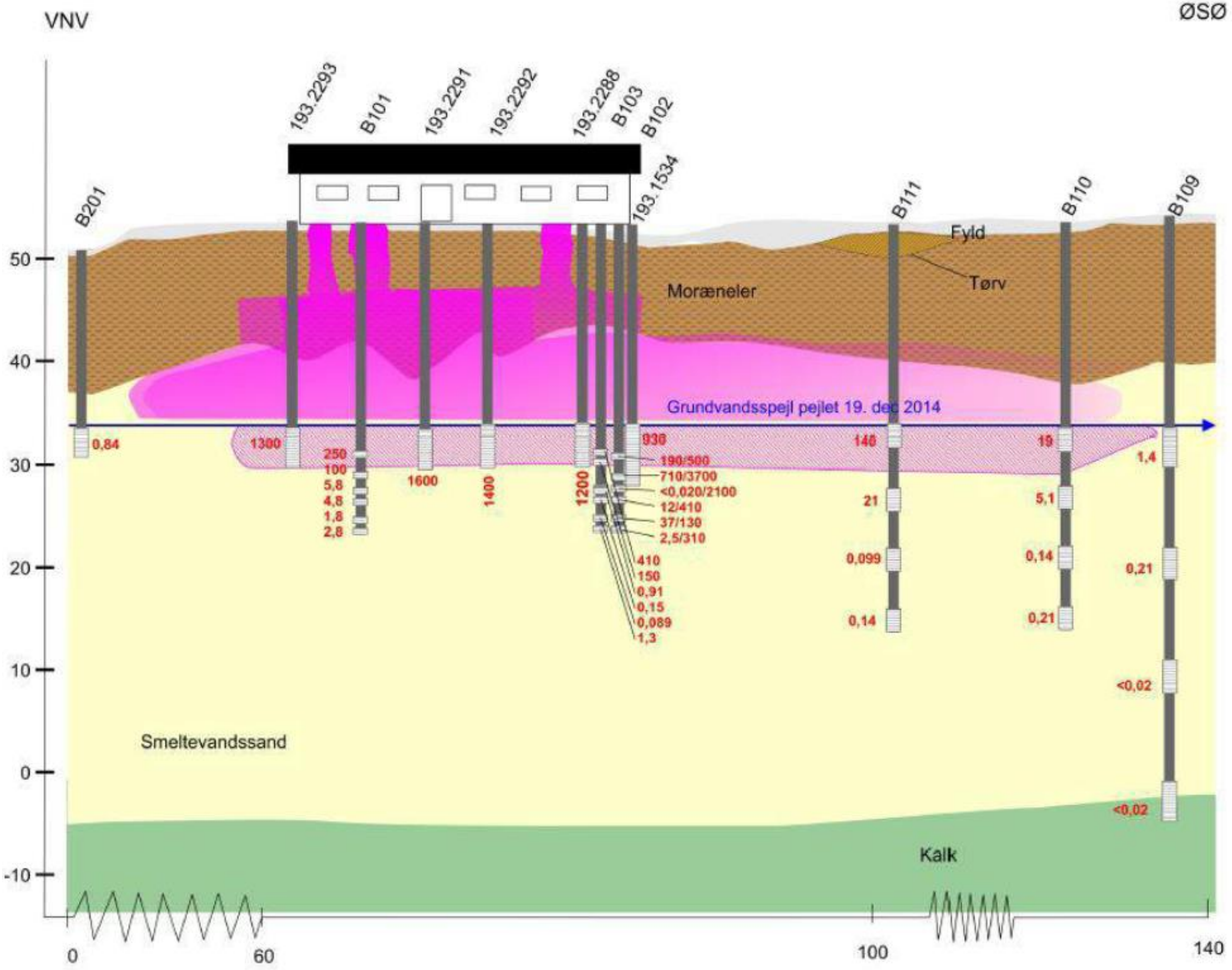
- Aquifer Thermal Energy Storage (ATES)-systems are highly effective energy-storage systems - provide energy with low CO_2-emmisions
- Increasing interest in ATES systems - the potential in Denmark is at least 400 ATES plants
- Large need for cooling and heating in urban and industrial areas
- Contaminated 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

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

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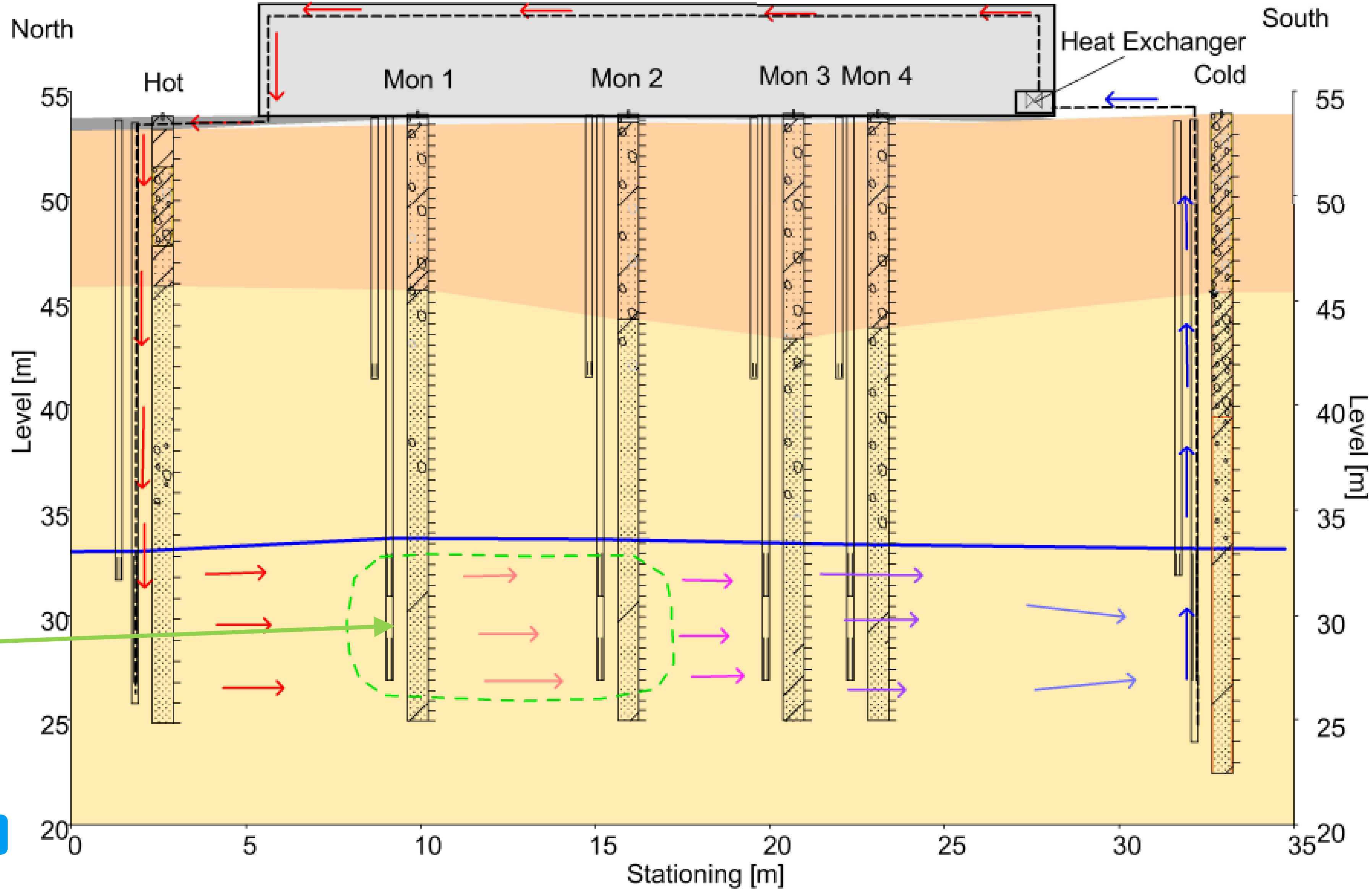
CONCEPTUEL MODEL



Ares with bacteria

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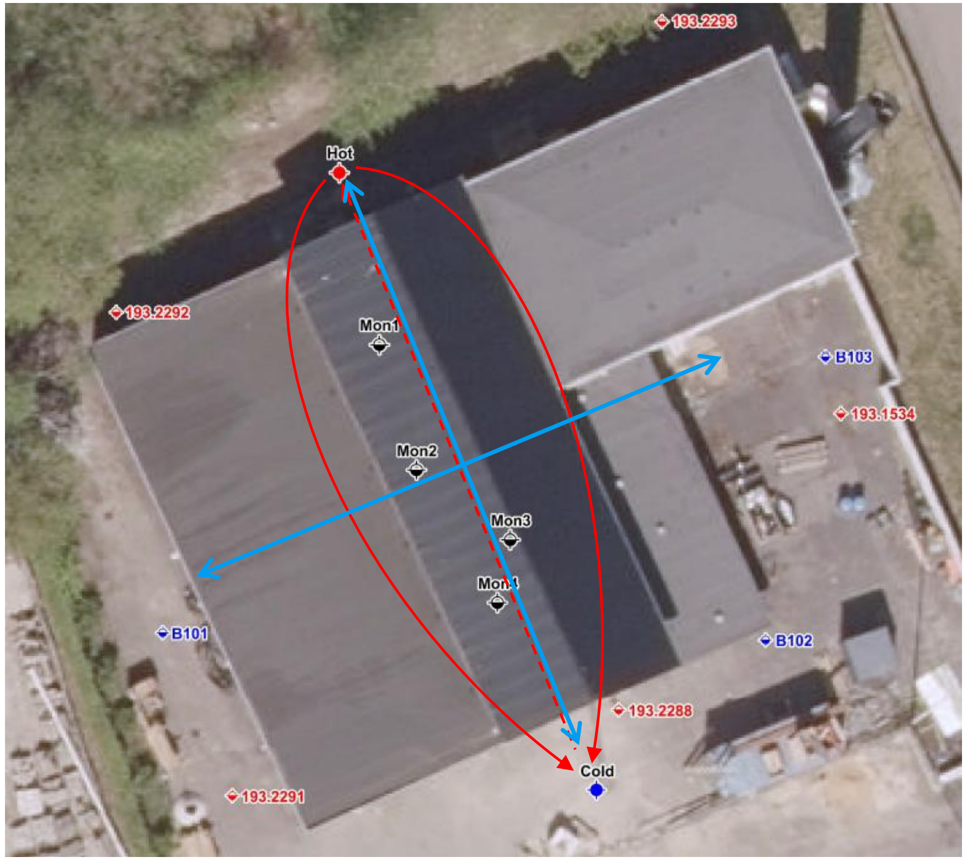
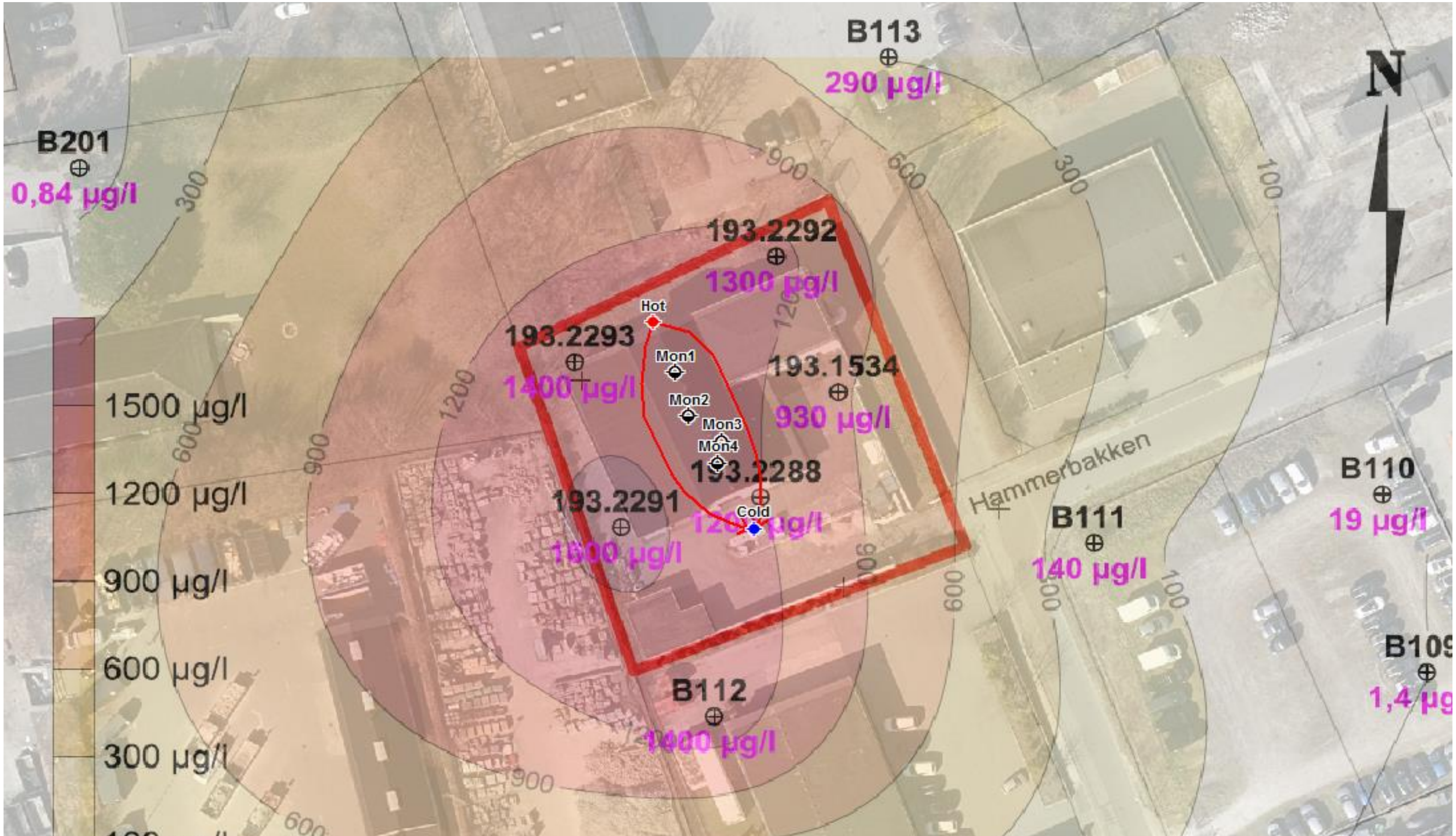
SYSTEM DESIGN AND IMPLEMENTATION

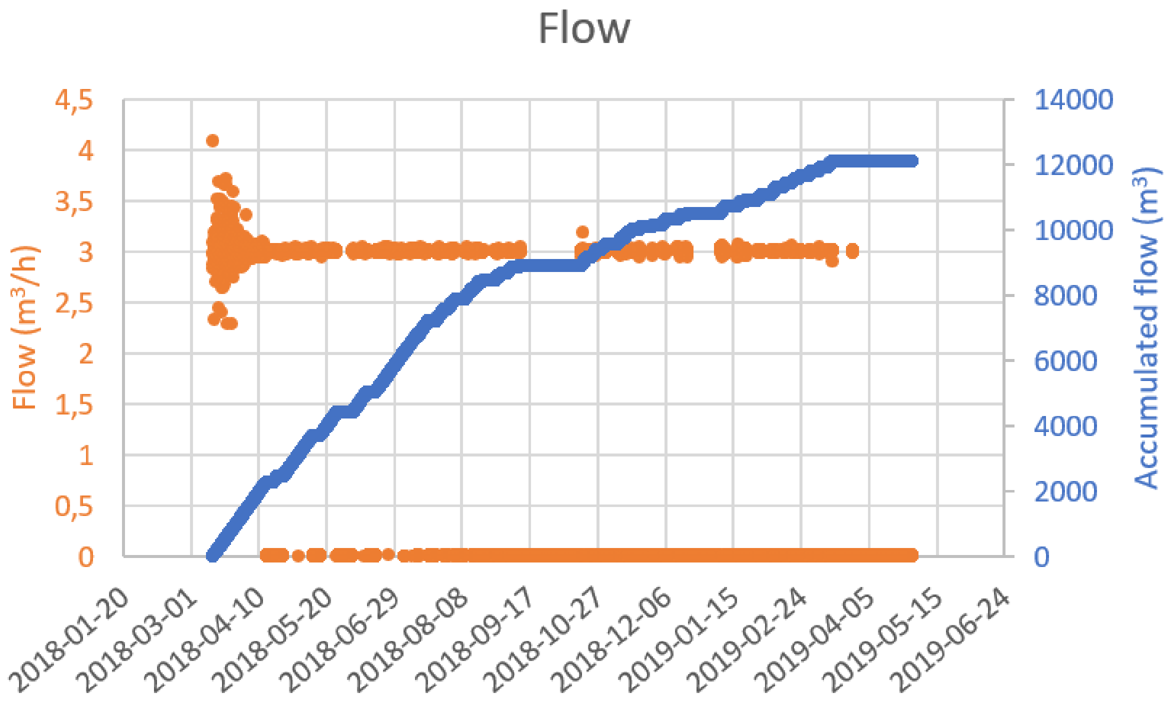


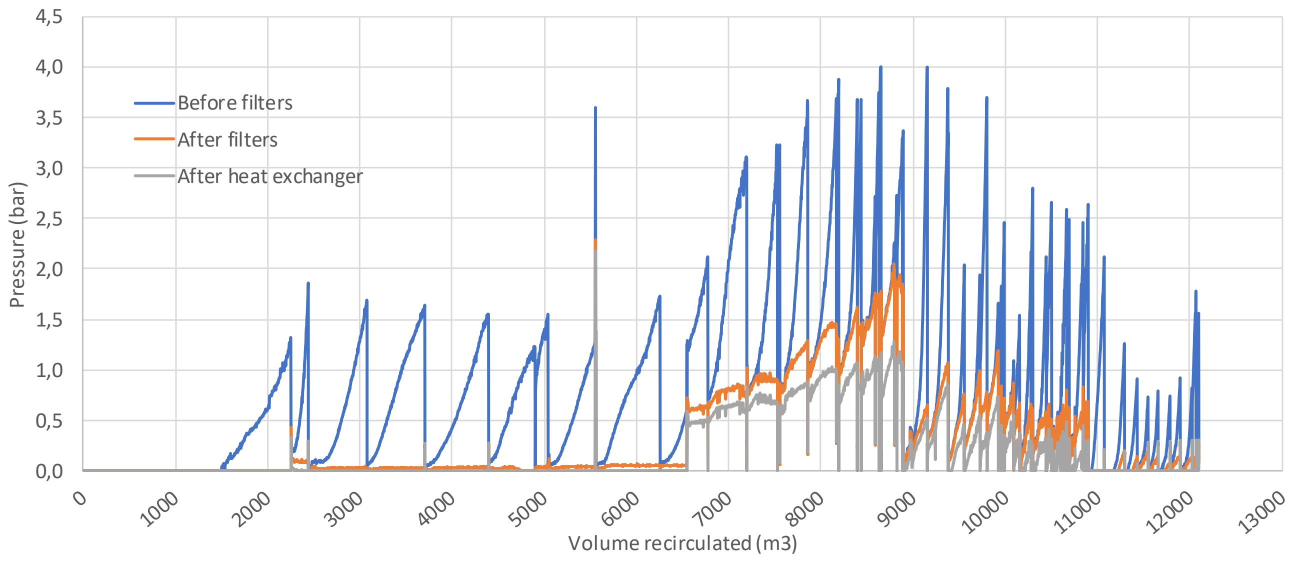
- Influenced area:
  - L x W x D: 30 x 25 x 8 m
  - 6,000 m^3 soil => 2,100 m^3 groundwater (porosity 0,35)
  - 3 m^3/h recirculation (2,200 m^3/month)
    => 1 pore volume flushed in 1 month
    => flow 1 m/day
  - (natural groundwater flow app. 5 m/year)

TEST AREA IN THE PLUME



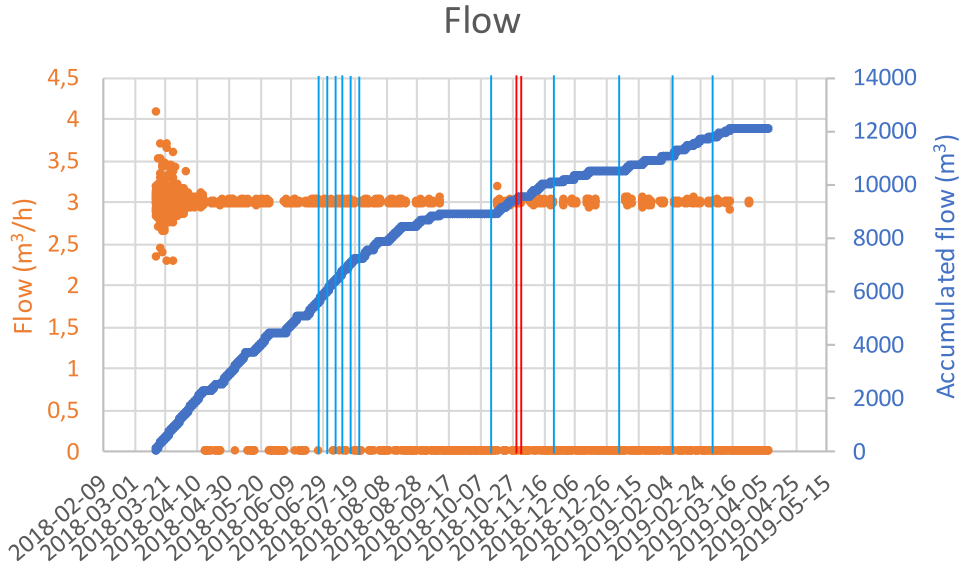
RECIRCULATION





DONOR ADDITION AND BIOAUGMENTATION

- Initial recirculation/mixing of water types did not results in reduced conditions.
- Lab test: Donor and bacteria are needed
- June/July: Donor/nutrients (warm well)
- October-Februar: Donor/nutrients (warm well)
- November: Bioaugmentation (Mon1 og Mon2)



Donor (carbon source): lactic acid and natrium acetate

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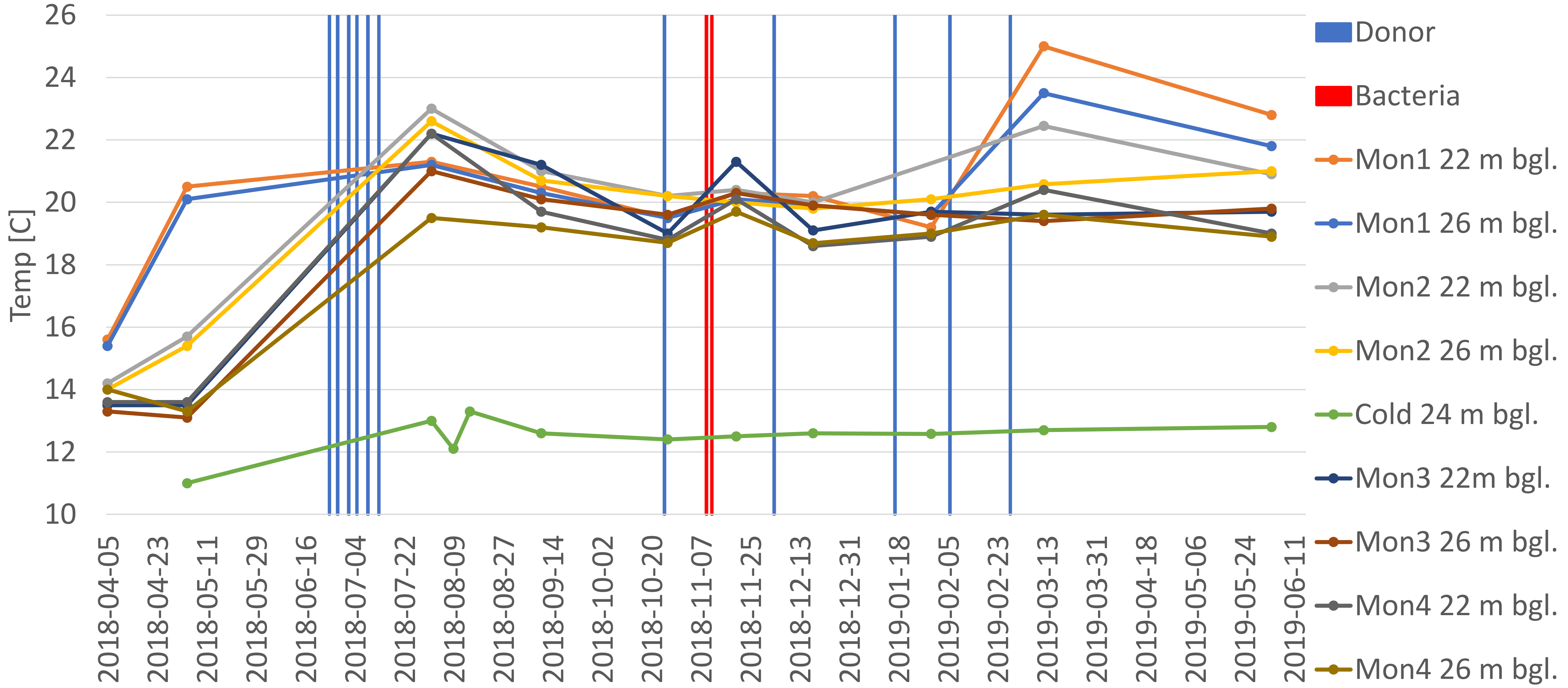
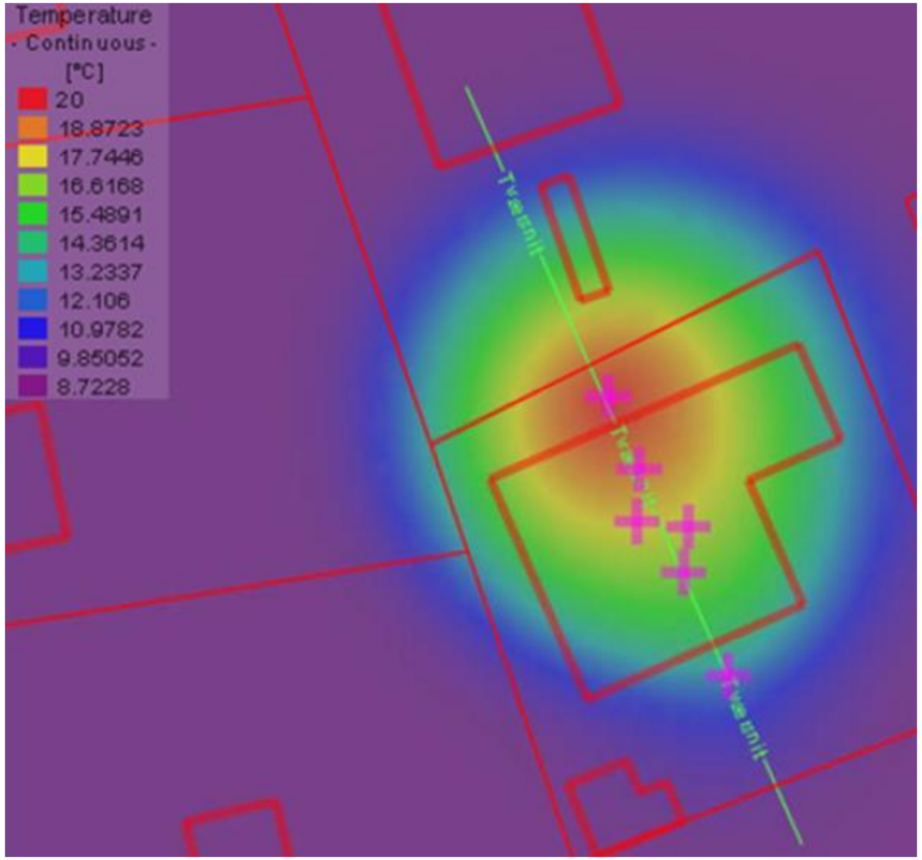
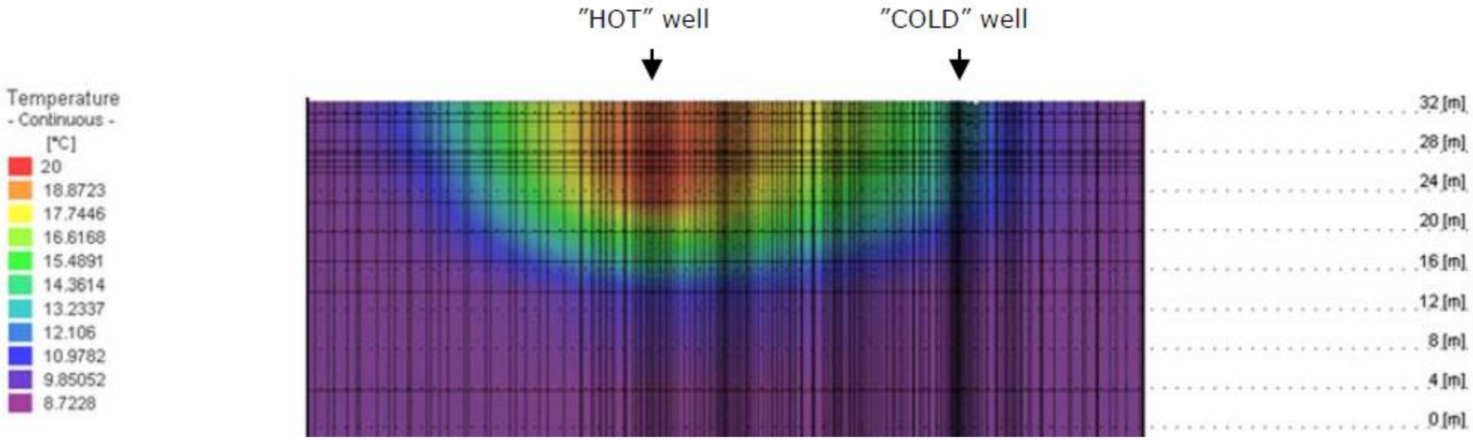
TEMPERATURE



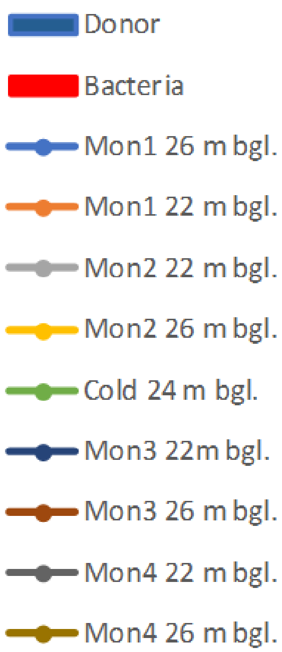
MODEL (6 MONTH ~ 14000 M³)

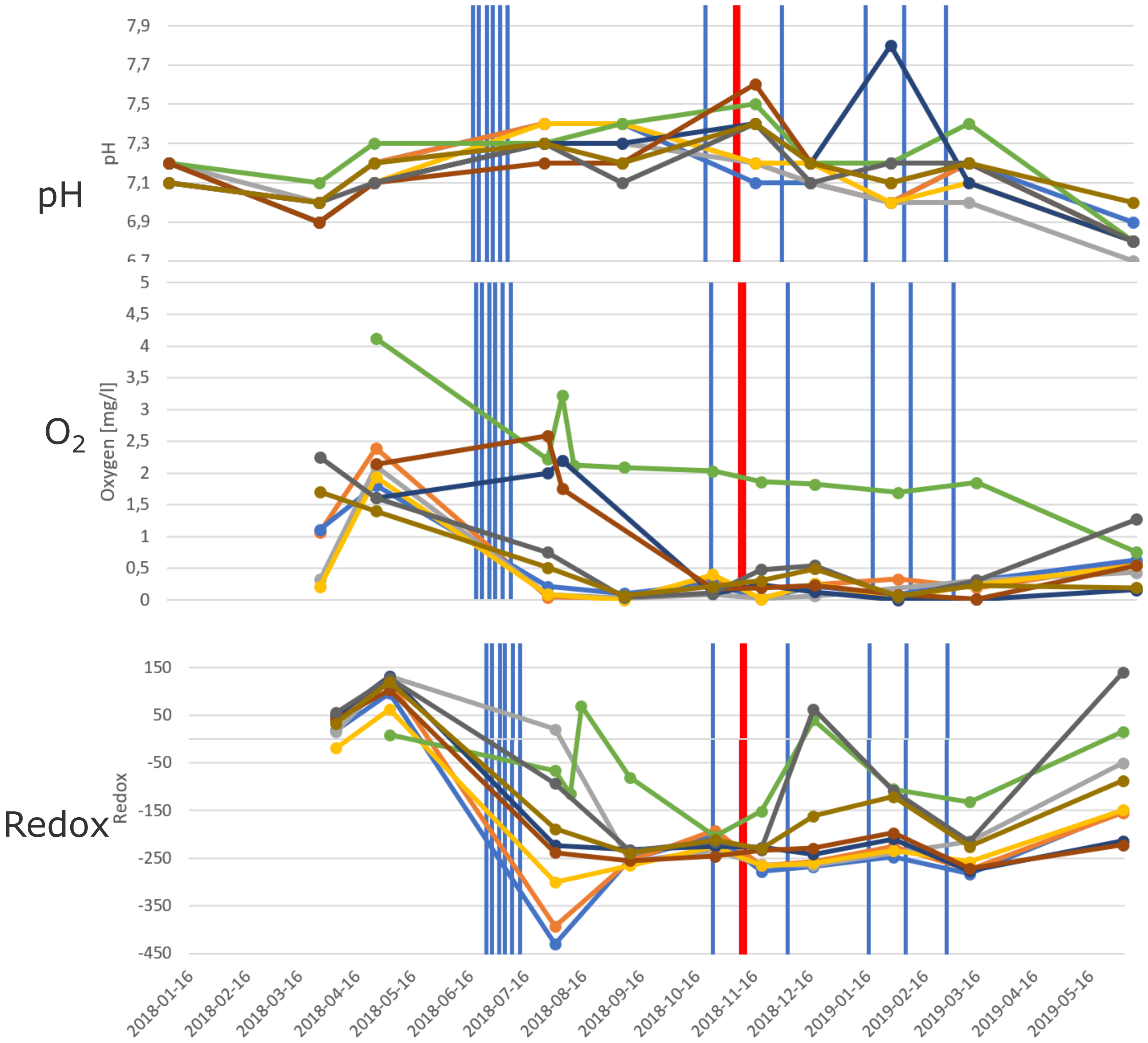




FIELD PARAMETERS

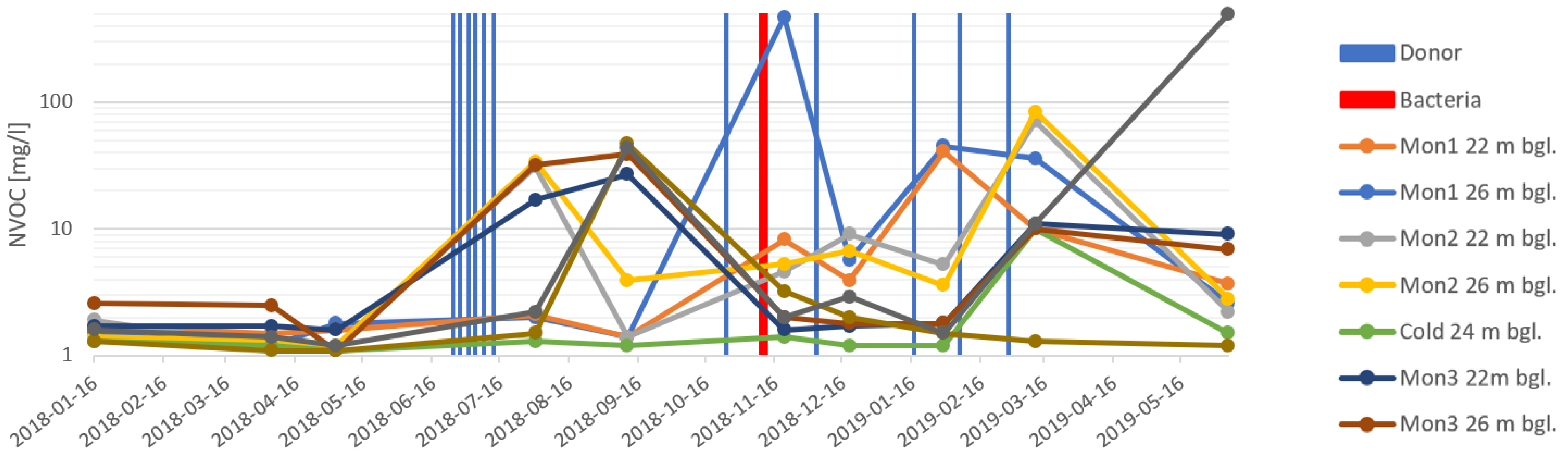
- pH: stable and optimal
- Oxygen: depleted after donor addition, except in the cold well
- Redox: reduced after donor addition





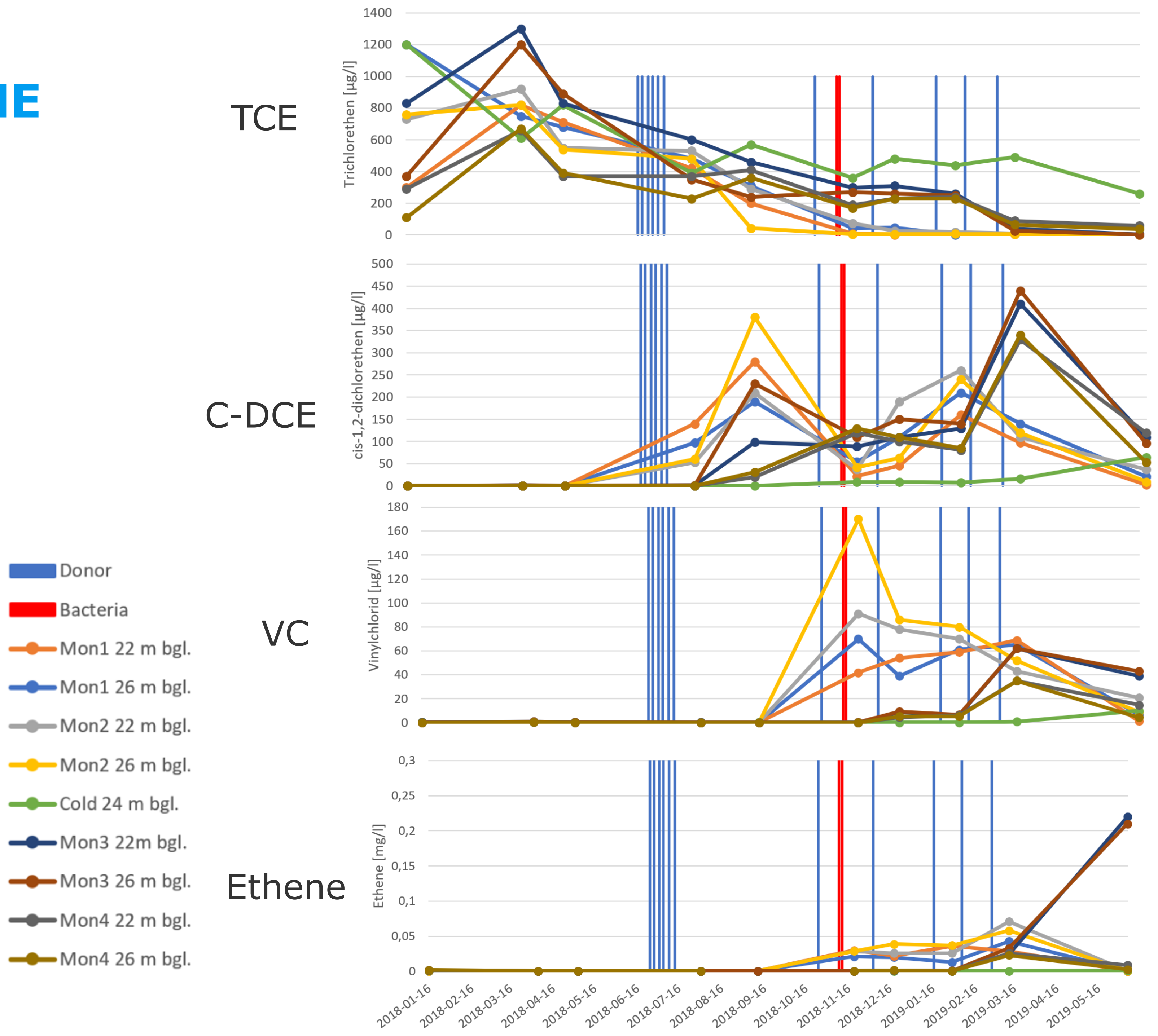
NVOC

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



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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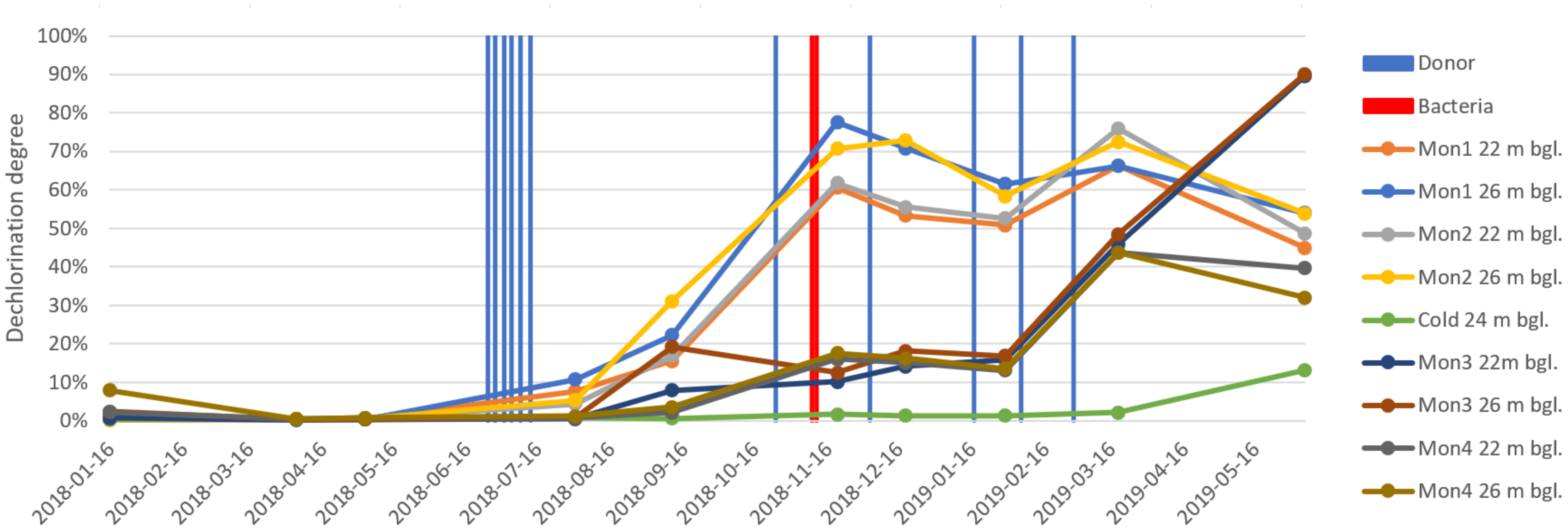
DECHLORINATION DEGREE



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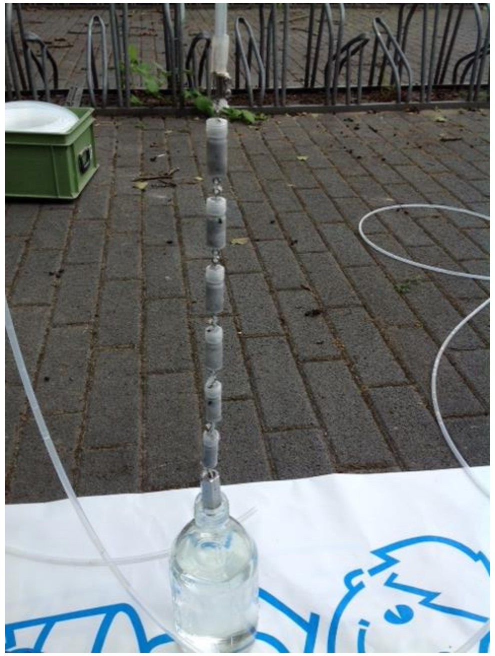
BACTERIAL ANALYSIS

- Groundwater: increase from background level of 1E+06 gene copies/ml total bacteria and no DHC to almost 1E+08 gene copies/ml total bacteria and 1E+05 DHC/ml
  - Clearly increasing levels in groundwater downgradient the bioaugmented area
- Soil: increase from background level of 1E+03 cells/g DHC to almost 1E+09 cells/g DHC
  - Clearly increasing levels in soil downgradient the bioaugmented area



DEGRADATION RATES

- Kind of column flow through reactor - not a batch system
- Ideally the sequential degradation should be modelled (incl. retardation

- TCE half life (only donor): 40 days = 1. order 0.02 days^{-1}
- After bioaugmentation: significant VC and ethene produced within days

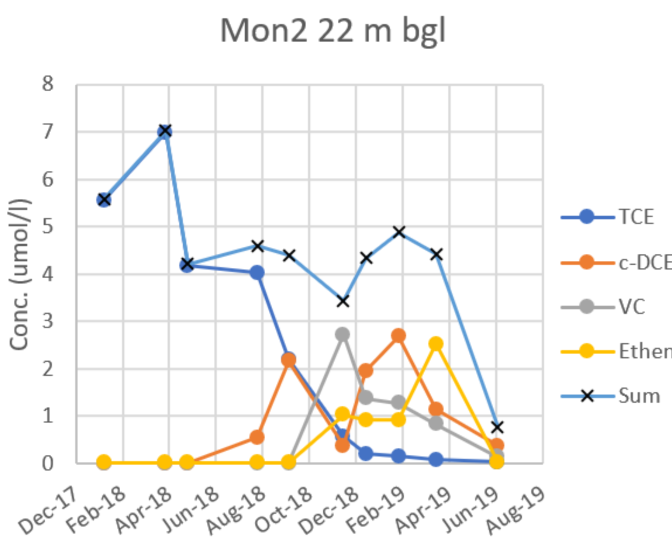


Table 7. Recommended aerobic and anaerobic degradation rates to be used in GrundRisk /8/. In addition to the recommended degradation rates, minimum rates, average rates, and maximum rates based on the literature study is shown /8/.

	Aerobic degradation rates (d^{-1})				Anaerobic degradation rates (d^{-1})			
Conta-minant	Recom-mended	Min.	Average	Max.	Recom-mended	Min.	Average	Max.
PCE	-	-	-	-	0.0007	0.00066	0.0037	0.017
TCE	-	-	-	-	0.0006	0.0003	0.0019	0.007
cis-1,2-DCE	0.3	0,28	1	2	0.0007	0.0007	0.0024	0.009
VC	0.0003	0.00031	0.0032	0.006	0.0007	0,0004	0,0018	0,007

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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

CONCLUSIONS

- Microbial analyses
  - No natural DHC
  - Good distribution of DHC obtained with bioaugmentation
  - DHC increases several m downgradient injection points and DHC are active (alive)
  - Very significant attachment of injected DHC to soil particles
- Degradation
  - Donor caused dechlorination to c-DCE with natural present bacteria
  - Bioaugmentation caused fast dechlorination of c-DCE to ethene - within days
  - Dechlorination score for TCE about 70% within a few weeks after bioaugmentation
  - 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.
- Area based approach versus case based approach
- Challenge with:
  - Mixing of water types
  - Contact time for degradation

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THANK YOU FOR YOUR ATTENTION!

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