Evaluation of High Resolution Methods for VOC Contaminant and Flux Distribution in Igneous Rock

An example from the site ”Malmen” in Hovmantorp, Sweden

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Evaluation of High Resolution Methods for VOC Contaminant and Flux Distribution in Igneous Rock

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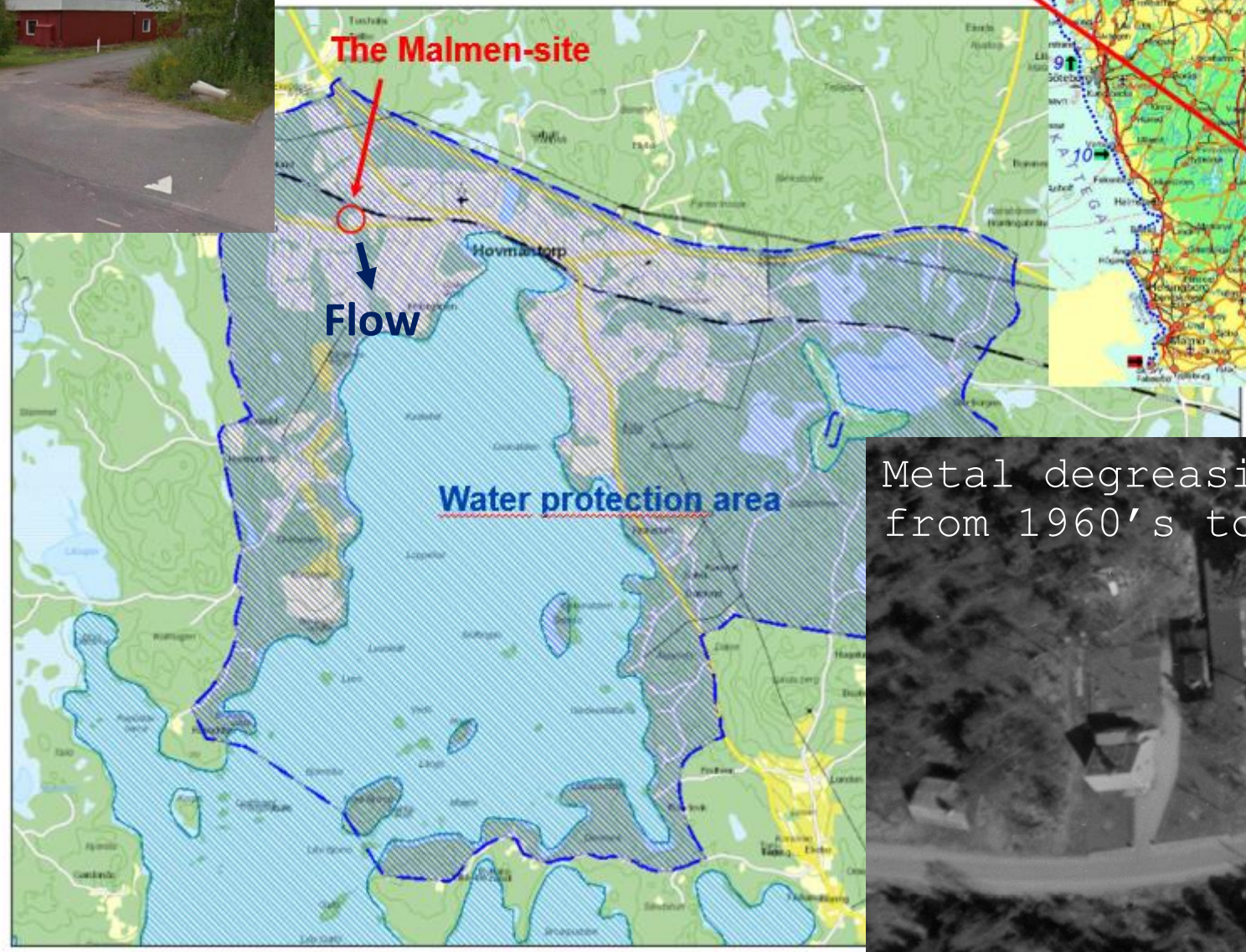
ATV JORD OG GRUNDVAND - *Evaluation of High Resolution Methods for VOC Contaminant and Flux Distributions in Igneous Rock*

March 9, 2022

Agenda

- Site info / History – Malmen, Hovmantorp
- Previous investigations / CSM
- DFN-M approach
- Methods
- Results and evaluations
- Key findings

Site info / History – Malmen, Hovmantorp



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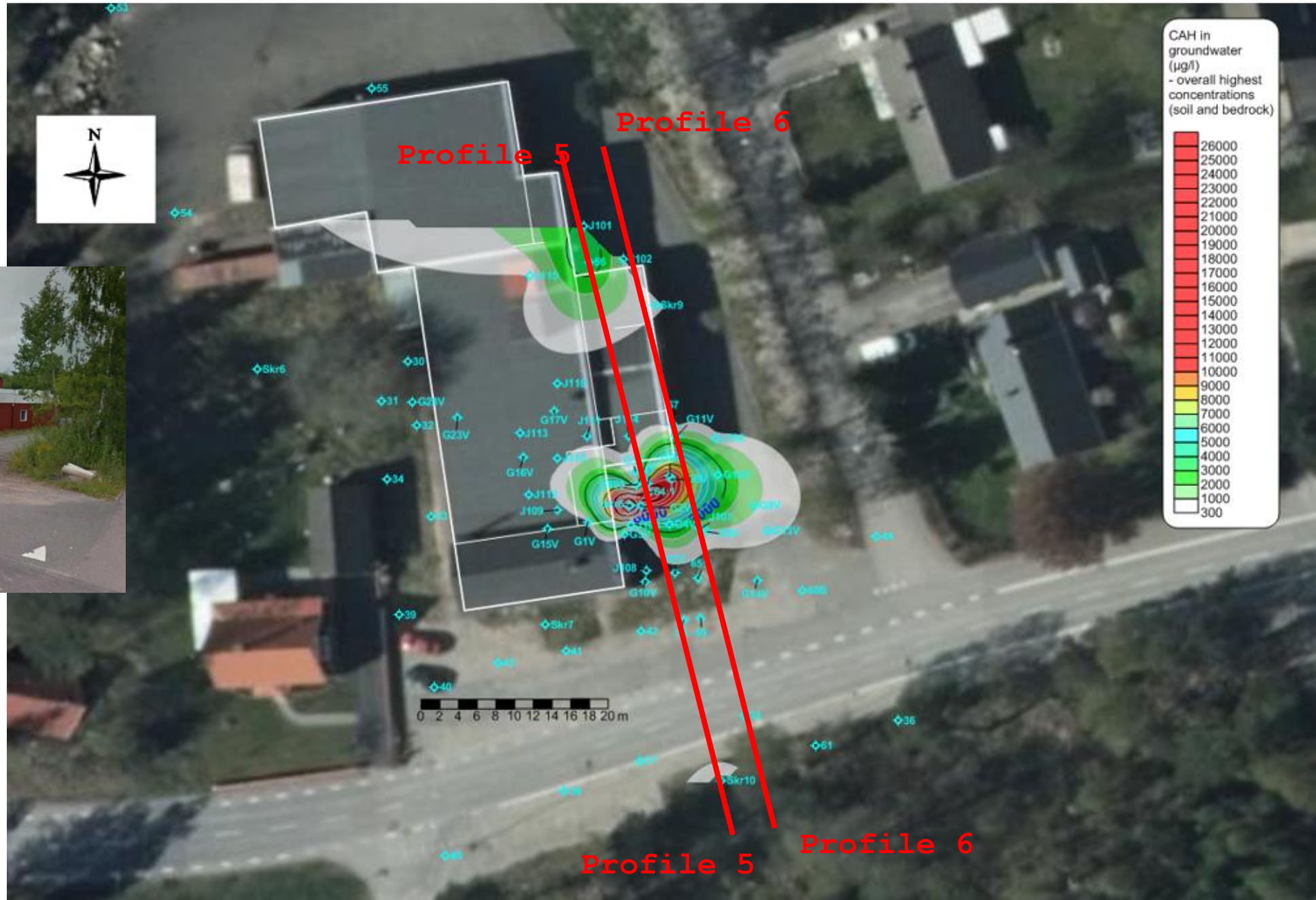
Previous investigations / CSM

CAH in groundwater (sampling points and contamination in soil and bedrock)



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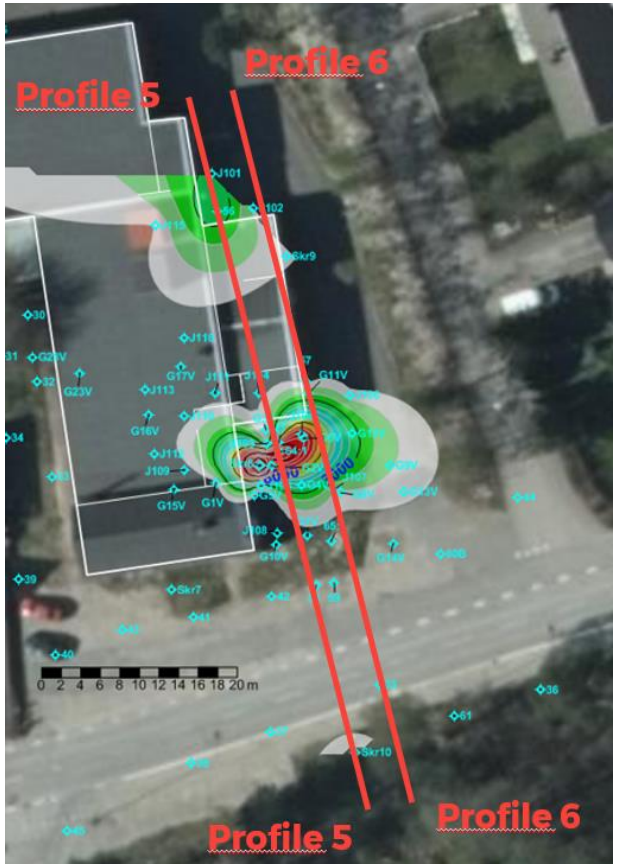
Previous investigations / CSM



Contamination in groundwater – overall results

Profile 5 – Industry building (Malmen)

south — north

164 masl — 160 — 156 — 152 — 148 — 140

road

Skr 10 | 58 | 59 | 65 | G7V | G4V | G2V | Skr 8 | J103 | 64 | 47 | G3V | J114 | 56 | J101

Fill

Groundwater table

Till

Bedrock

13 | 11 | 8,3

25 378 | 5 080 | 665 | 1 385

0 10 20 30 m

CAH: 5 µg/l
TCE: 0,1 µg/l
cDCE: 2,2 µg/l
VC: 1,3 µg/l
DCA: 1,4 µg/l

CAH: <0,1 µg/l
TCE: <0,2 µg/l
cDCE: <0,1 µg/l
VC: < 1 µg/l
TCA: <0,1 µg/l

CAH: 424 (<0,1) µg/l
TCE: 340 (<0,2) µg/l
cDCE: 83 (<0,1) µg/l
VC: < 1 (< 1) µg/l
TCA: 0,85 (<0,1) µg/l

CAH: 9 528 µg/l
TCE: 9 200 µg/l
cDCE: 270 µg/l
VC: 1,8 µg/l
TCA: 48 µg/l

CAH: 6 152 µg/l
TCE: 5 600 µg/l
cDCE: 470 µg/l
VC: 45 µg/l
TCA: 30 µg/l

CAH: 18,4 µg/l
TCE: 4,2 µg/l
cDCE: 0,6 µg/l
VC: < 0,1 µg/l
TCA: 12,9 µg/l

CAH: 28 231 (6 545)[1] µg/l
TCE: 28 000 (6 100)[1] µg/l
cDCE: 74 (420)[1] µg/l
VC: 10 (3,8)[1] µg/l
TCA: 120 (16)[1] µg/l

CAH: 3 171 µg/l
TCE: 1 170 µg/l
cDCE: 1 040 µg/l
VC: 65 µg/l
ethene: 26 µg/l
TCA: 448 µg/l

CAH: 4 170 µg/l
TCE: 562 µg/l
cDCE: 1 980 µg/l
VC: 624 µg/l
ethene: 13,5 µg/l
TCA: 343 µg/l

CAH: 1 821 µg/l
TCE: 1 740 µg/l
cDCE: 56 µg/l
VC: <0,1 µg/l
TCA: 23 µg/l

CAH: 17 863 µg/l
TCE: 17 200 µg/l
cDCE: 281 µg/l
VC: 130 µg/l
TCA: 252 µg/l

CAH: 567 µg/l
TCE: 356 µg/l
cDCE: 117 µg/l
VC: 88 µg/l
ethene: 59 µg/l
TCA: 1,2 µg/l

CAH: 269 µg/l
TCE: 150 µg/l
cDCE: 110 µg/l
VC: 5,5 µg/l
TCA: 0,7 µg/l

CAH: 89 µg/l
TCE: 23 µg/l
cDCE: 50 µg/l
VC: 15 µg/l
TCA: 0,9 µg/l

CAH: 39 µg/l
TCE: 12 µg/l
cDCE: 1,7 µg/l
VC: < 1 µg/l
ethene: < 1 µg/l
TCA: 22,2 µg/l

Groundwater in soil

Groundwater in bedrock

Excisting monitoring wells / sampling points

Old monitoring wells / sampling points

HVOC (old results)

Old results

Results – fall 2016

1/ Sampling a second time, 1 mounth later

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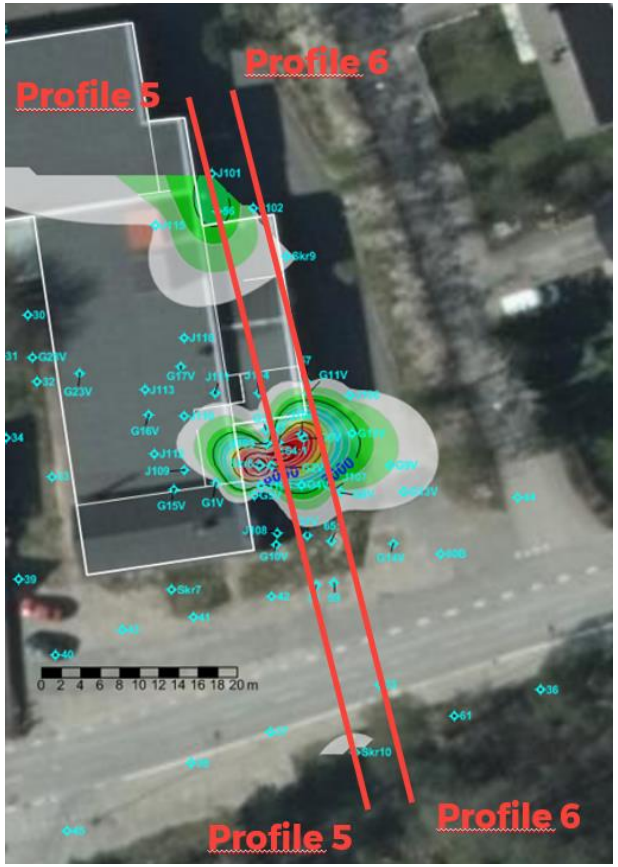
Previous investigations / CSM



Groundwater in soil

Contamination in groundwater – overall results

Profile 6

south — north

Industry building (Malmen)

road

Fill

Till

Bedrock

Groundwater table

Existing monitoring wells / sampling points

Old monitoring wells / sampling points

35	G8V	J107	G6V	J104	G11V	57	Skr9	J102
CAH: 1,1 µg/l TCE: 0,2 µg/l cDCE: < 1 µg/l VC: < 1 µg/l TCA: 0,6 µg/l	CAH: 996 µg/l TCE: 904 µg/l cDCE: 45 µg/l VC: 23 µg/l ethene: 7,5 µg/l TCA: 18,9 µg/l	CAH: 12 041 µg/l TCE: 10 500 µg/l cDCE: 936 µg/l VC: 411 µg/l ethene: 97 µg/l TCA: 160 µg/l	CAH: < 0,1 µg/l TCE: <0,1 µg/l cDCE: <0,1 µg/l VC: < 1 µg/l ethene: <0,1 µg/l TCA: < 0,1 µg/l	CAH: 53 µg/l TCE: 4,0 µg/l cDCE: 15,7 µg/l VC: 1,1 µg/l ethene: < 1 µg/l TCA: 20,5 µg/l	CAH: 453 µg/l TCE: 450 µg/l cDCE: 1,3 µg/l VC: < 1 µg/l TCA: 1,4 µg/l	CAH: 742 µg/l TCE: 193 µg/l cDCE: 339 µg/l VC: 37 µg/l ethene: 2,7 µg/l TCA: 32 µg/l

164 masl
160
156
152
148
144
140

0 10 20 30 m

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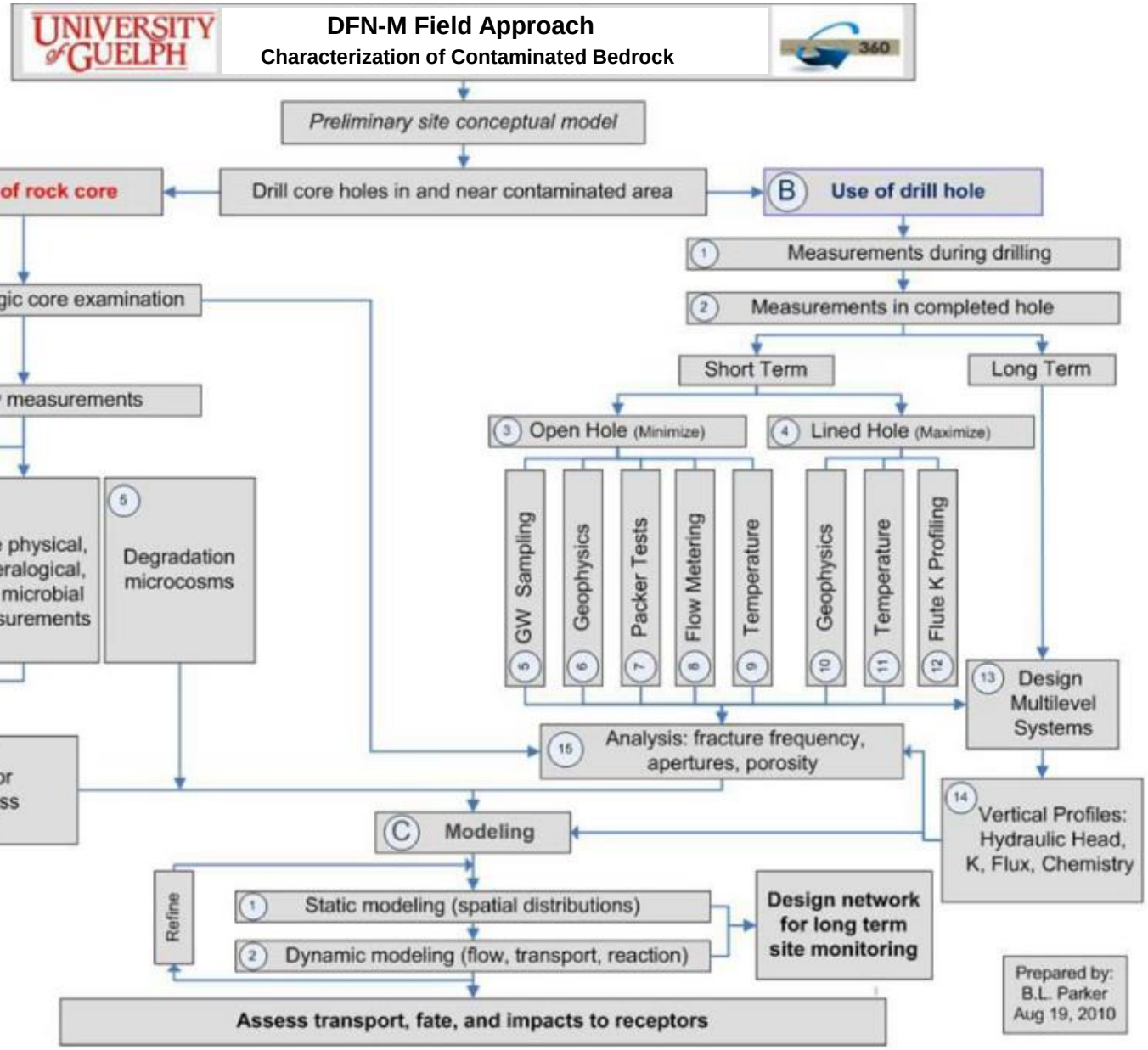
DFN-M approach



Summary of the components of the Discrete Fracture Network Matrix Field Approach for contaminated bedrock site characterization.

Methods: DFN-M Field Approach Activities

- Bedrock coring - HQ3 (triple tube), DFN-1 (8,9 m), DFN-2 (29,2 m) and DFN-3 (25,5 m)
- Rock core sampling (206 rock core VOC samples)
- Rock core processing (samples crushed and directly placed into a 40 ml vial with methanol)
- Laboratory rock core sample analysis (VOC, moisture)

- FLUTe-liner (NAPL/FACT) installation)
- Liner removal and NAPL-cover evaluation
- FACT subsampling and analysis
- Blank liner installed

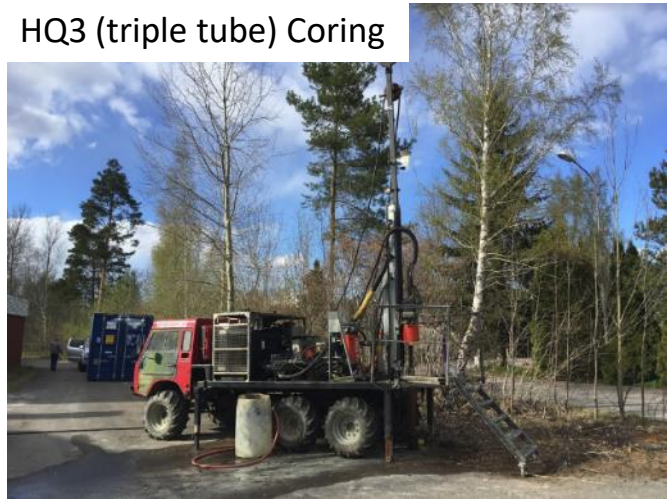
- Active line source (ALS) Testing - lined hole
- Open Hole Geophysical Logging (ATV, OTV, FWS, gamma, temp)
- Temporary Transducer Deployments (outside blank liner)

- FLUTe-liner (NAPL/FACT) installation)
- Liner removal and NAPL-cover evaluation
- FACT subsampling and analysis
- Blank liner installed

- Active distributed temperature sensing (A-DTS) testing
- FLUTe CHS (Cased Hole Sampler) installation
- CHS sampling and analysis (of groundwater) – (Nov 2019, Dec 2019 and March 2020)

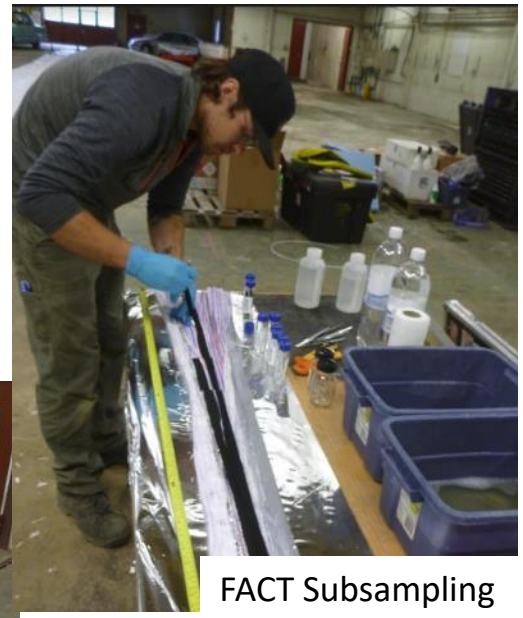
Methods: DFN-M Field Approach Activities

HQ3 (triple tube) Coring



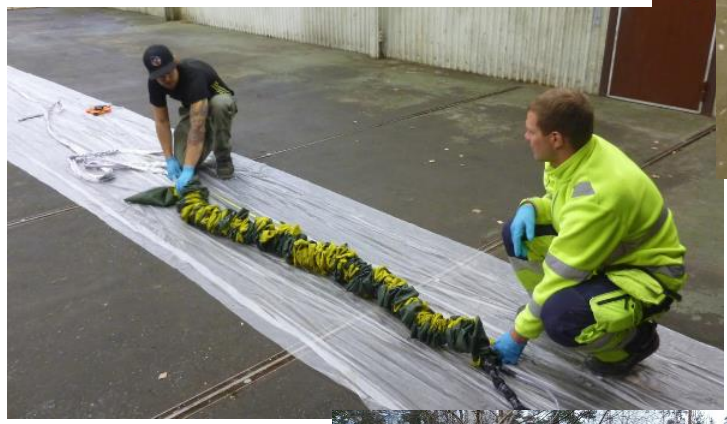
FLUTE Liner Removals

Geophysical Logging



FACT Subsampling

NAPL cover / FACT separation from liner



Rock core crushing / processing

Rock core sampling

FLUTe CHS MLS Installation

Results and evaluations.

Moisture content

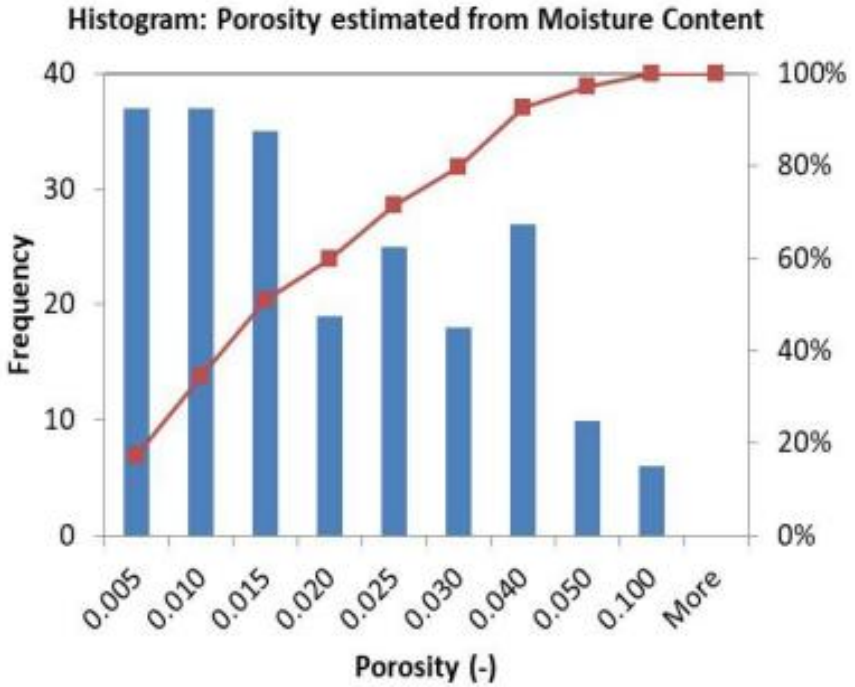
- The granitic bedrock was very competent.
- High RQD
- Little evidence of weathering and/or micro-fracturing.

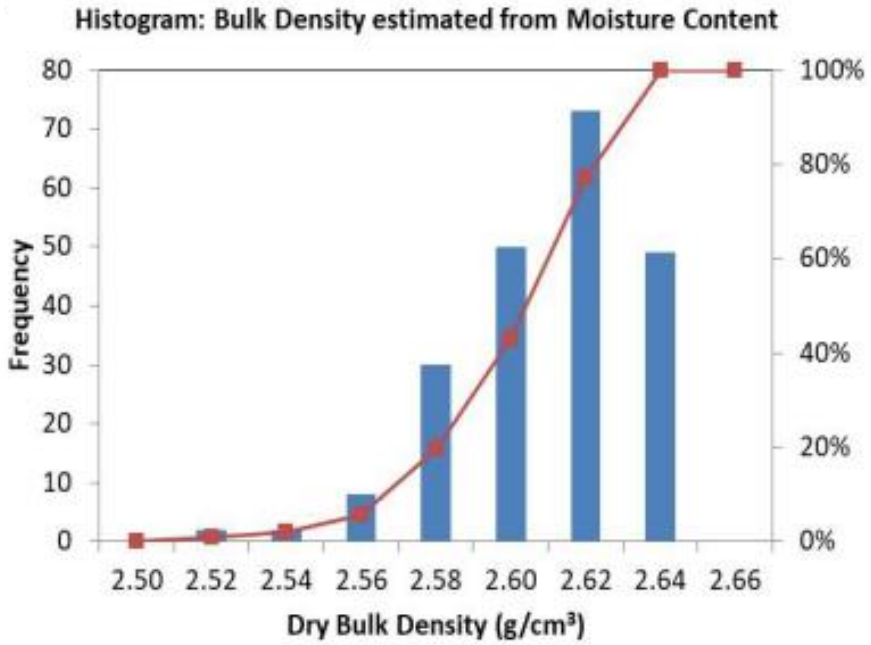
Moisture content used for estimating matrix porosity and density:

Matrix porosity: geometric mean of 1.3%
Bulk density: 2,62 g/cm3

Possible these estimates are biased high:
1/ slow drilling process (small rig) and a lot of water used
2/ incomplete drying of crushed rock samples

More important in dry granite than in sedimentary rocks.





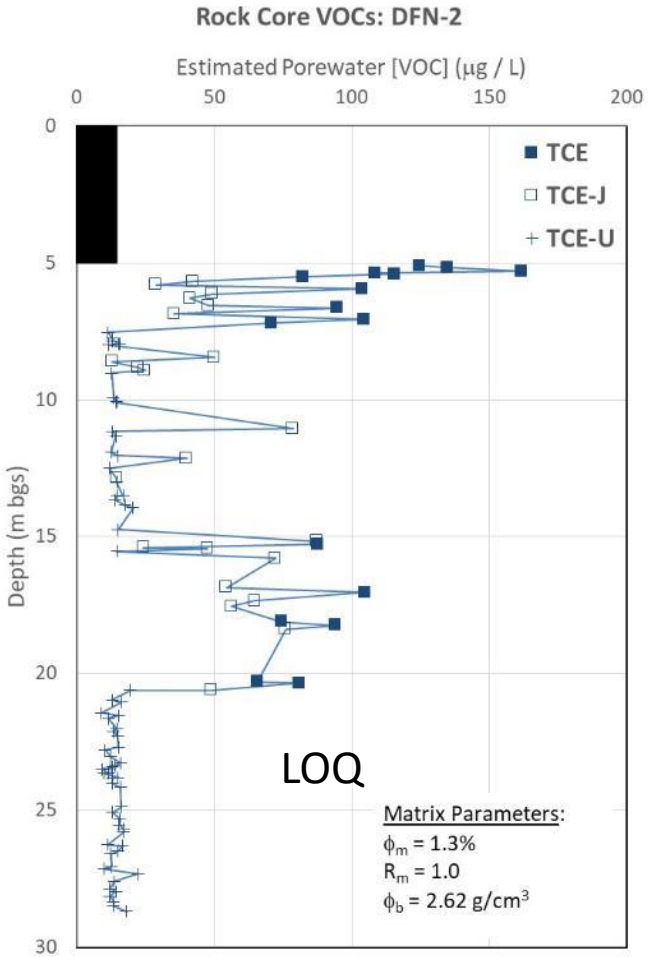
Results and evaluations.

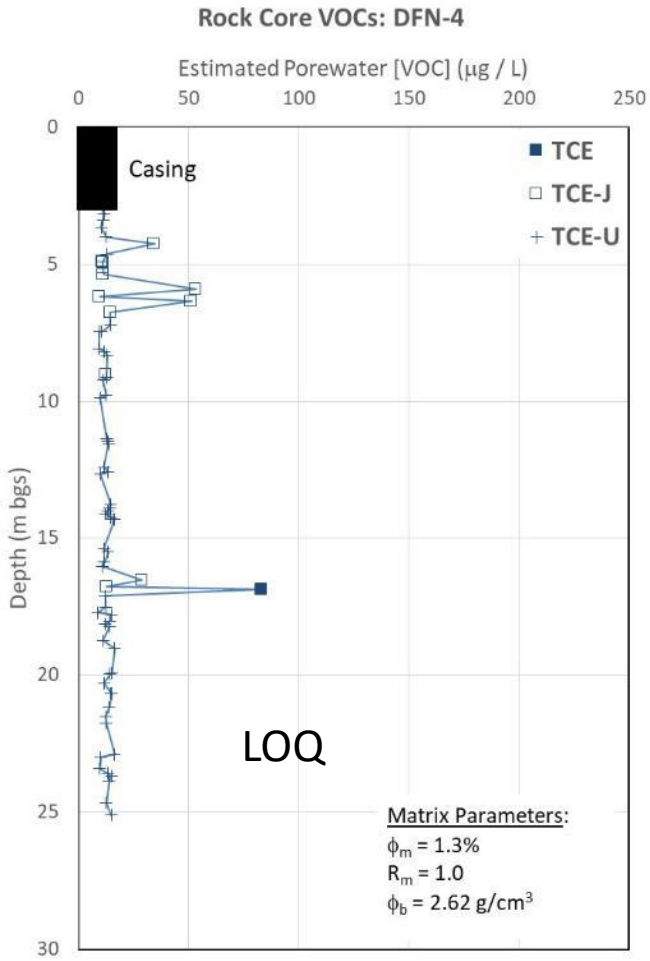
Estimated Matrix Porewater [TCE]

$$C_t = \frac{C_{MeOH}\ V_{MeOH}}{M_{rock}}$$

$$C_w = \frac{C_t\ \rho_{bwet}}{R_m\ \phi_m}$$

C_w = 13 µg/L (MDL)
C_w = 65 µg/L (LOQ)





Results and evaluations.

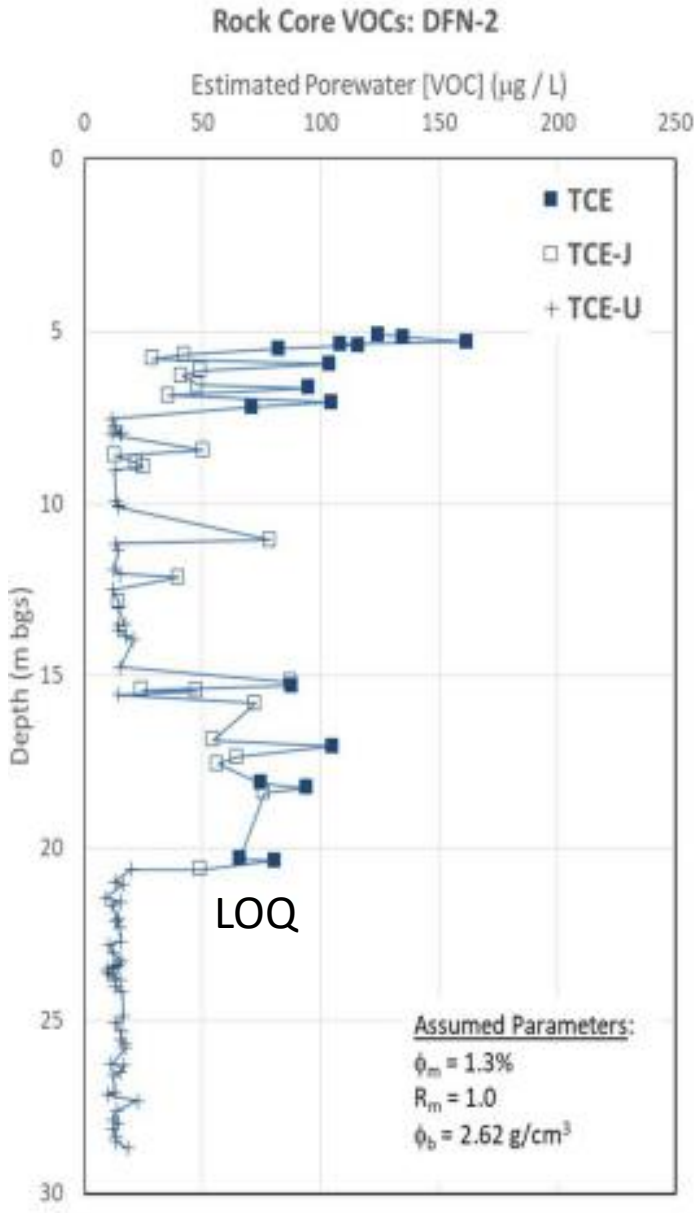
Overall, Very low TCE contamination levels in the bedrock matrix, compared to previous investigations estimated higher contamination levels. A few possibilities exist:

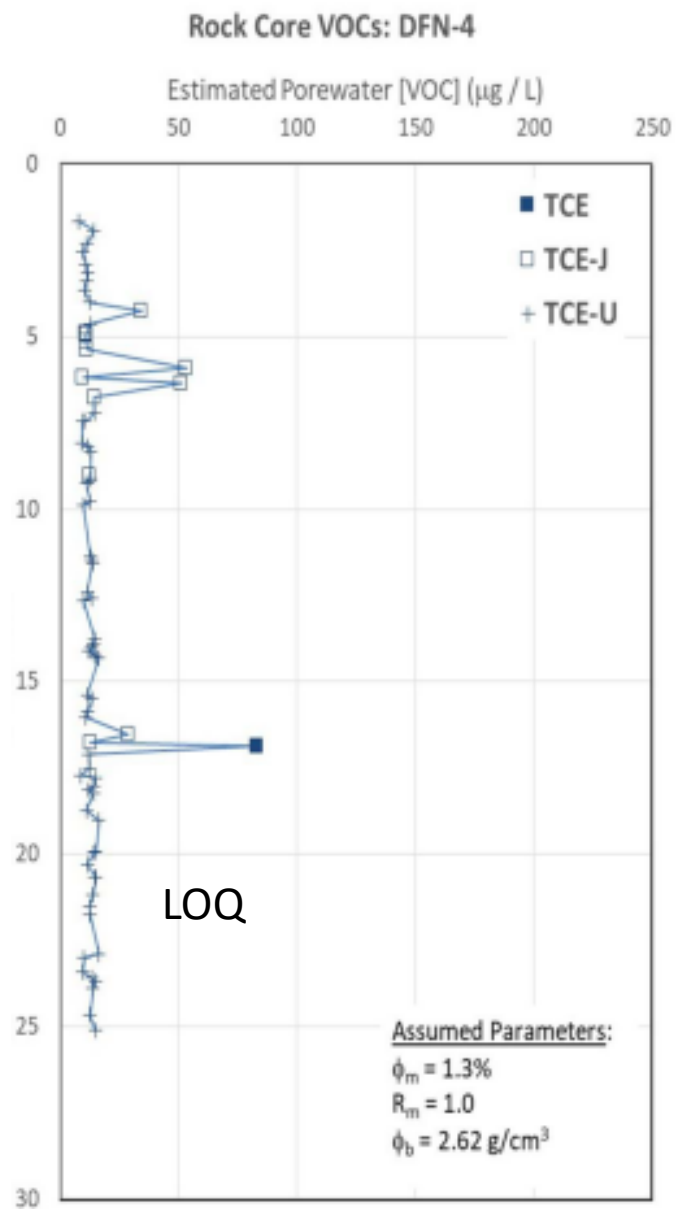
1) prior deeper bedrock results is a result of cross-connection during drilling;

2) the high contamination zone in bedrock was missed by DFN-2 and DFN-4; or

3) diffusion into the granite matrix may be very low due to low bedrock effective diffusion coefficients / matrix tortuosity and lack of sorption

Rock core VOC results are very low and quite close to or lower than the LOQ, making the results suspect or questionable.





Results and evaluations.

FACT VOC Results

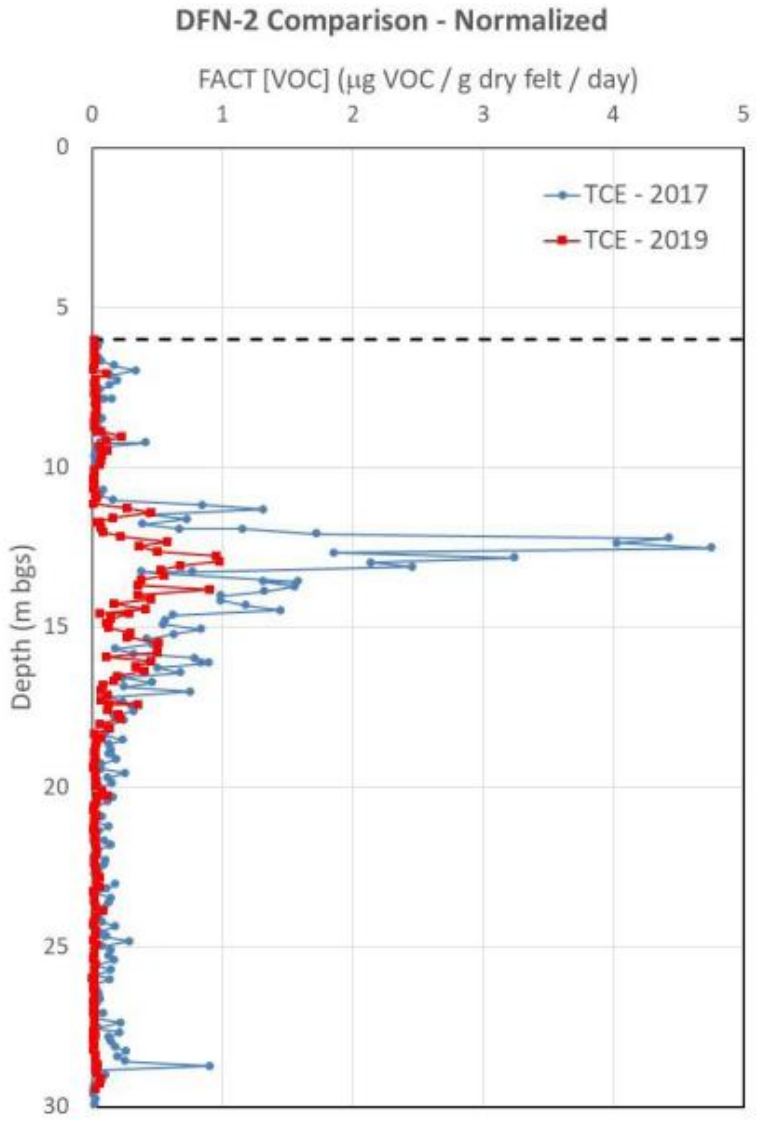
The results of FACT- investigation are quite different than the rock core VOC results.

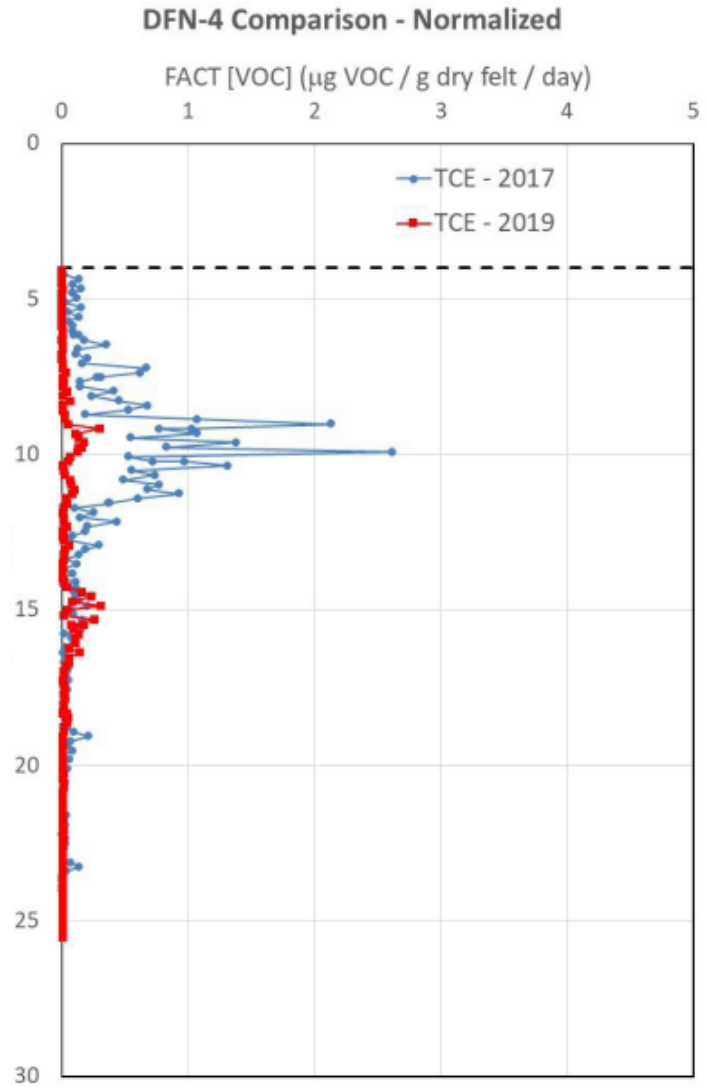
Hardly no contaminants near the bedrock surface in DFN-2.

The FACT suggests a well-defined plume in bedrock groundwater.

Concentrations much lower in 2019.

Declining flux from 2017 to 2019.





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Results and evaluations.

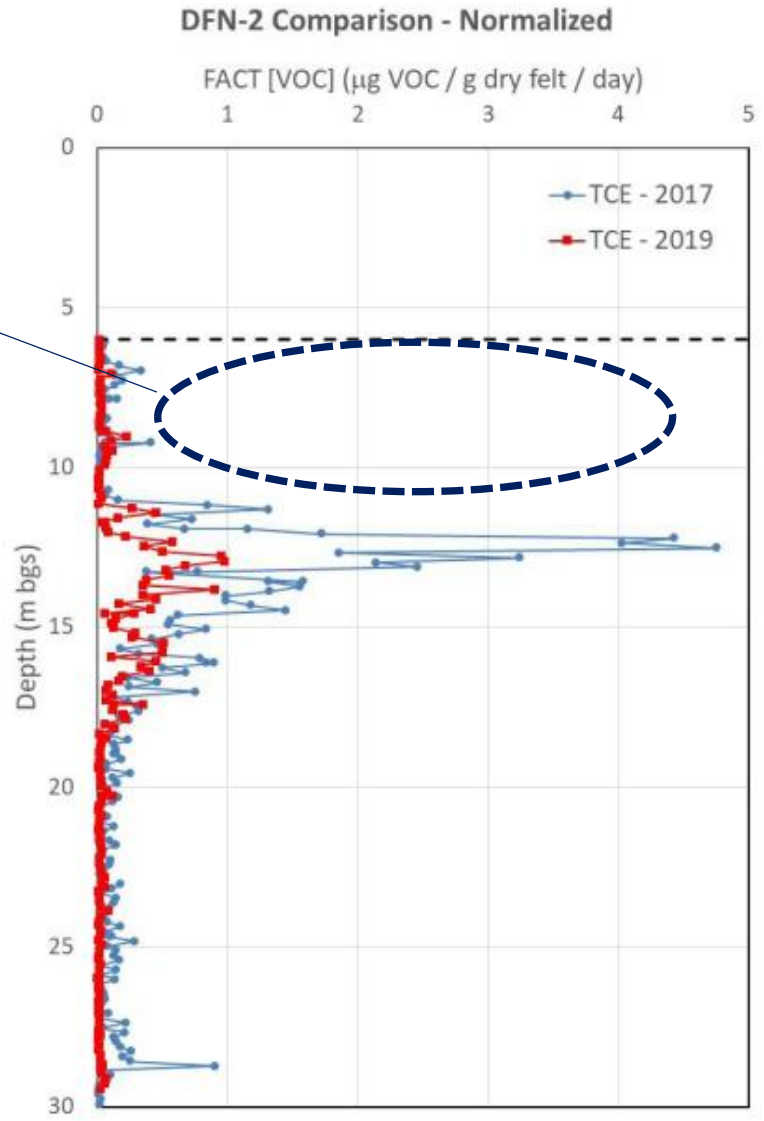
FACT VOC Results

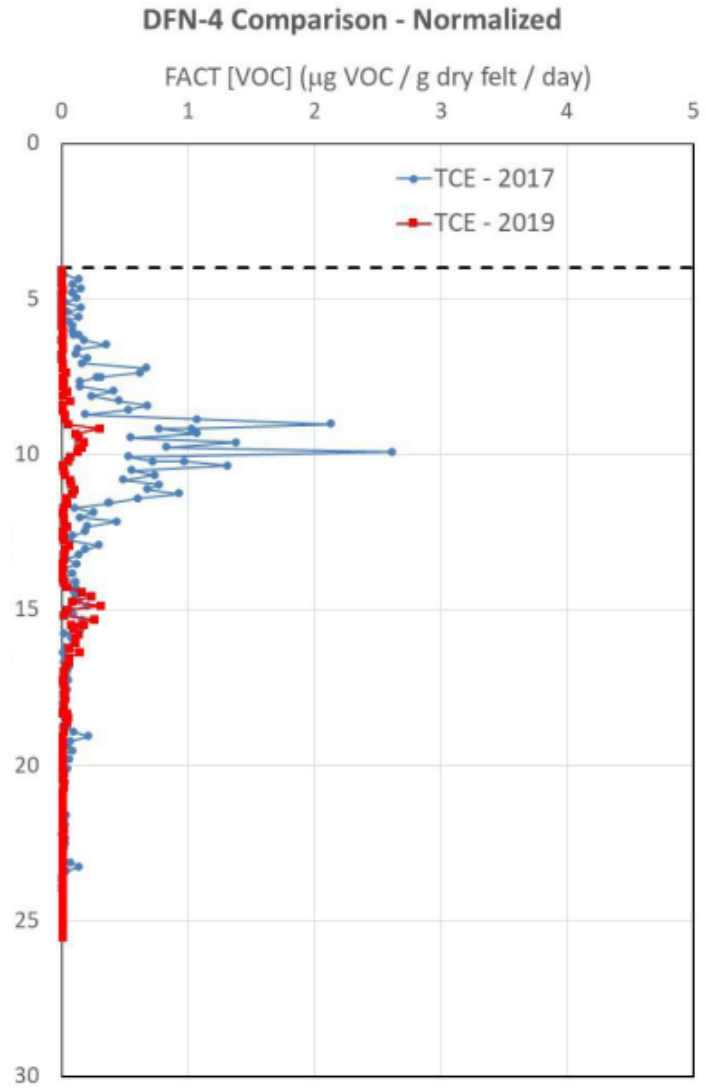
1/ Large water usage – flushing fractures, particulary in shallower zones

2/ Difference between FACT 2017 and FACT 2019 could be even higher

3/ Slow rates of drilling - cross-connection in open hole

4/ FACT/NAPL-cover a pathway for minor flow - smears the contamination





Results and evaluations.

Groundwater VOC Results

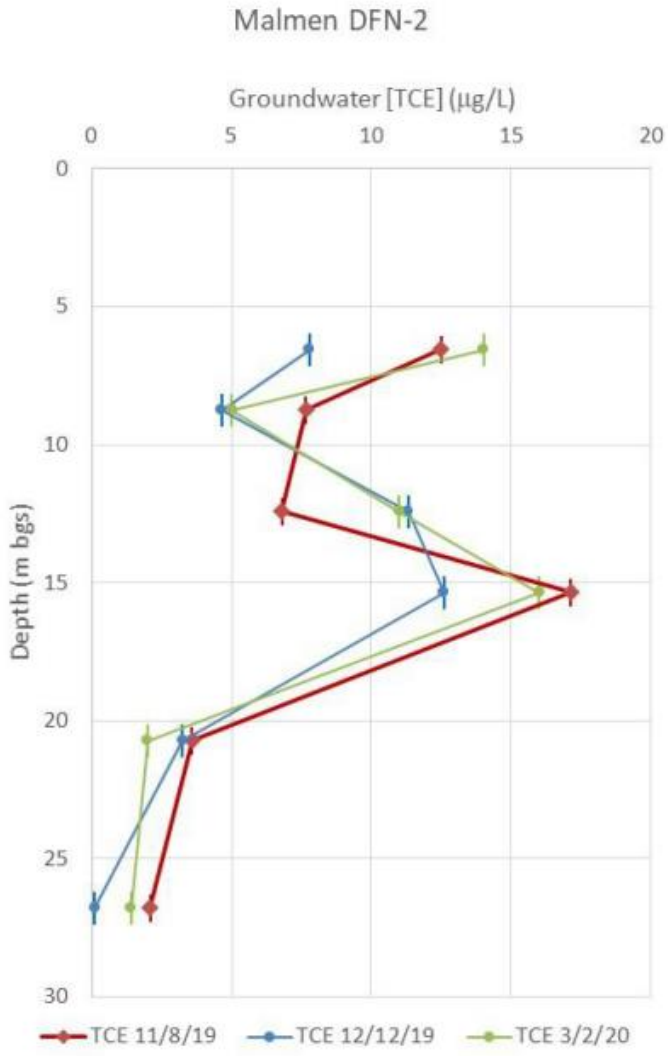
Groundwater sampling
(November 2019-March 2020)

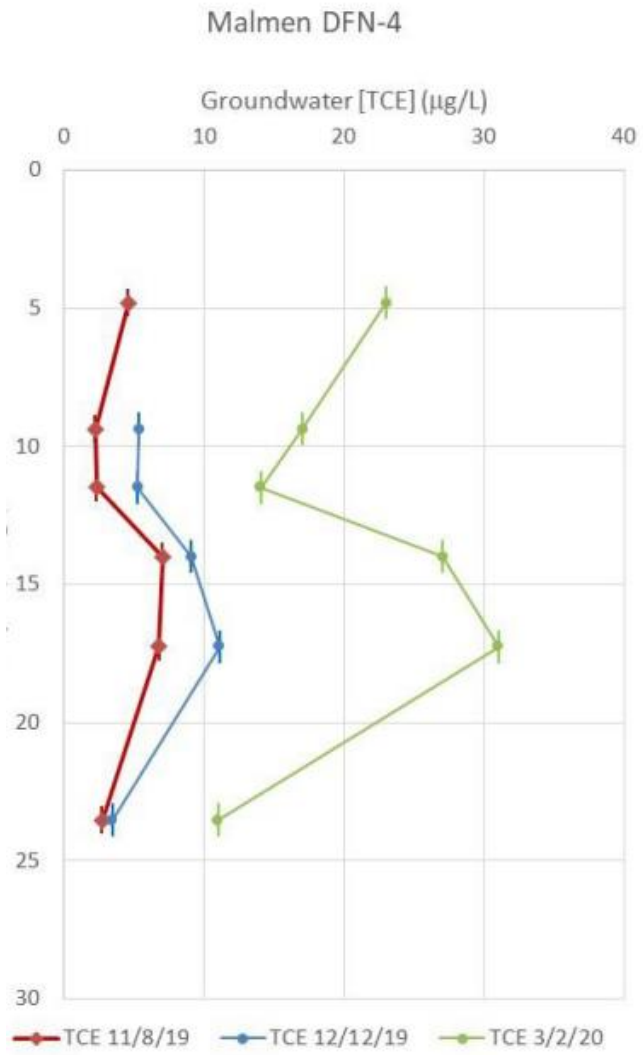
Low concentrations. < 20 µg TCE/L

3 OoM lower concentrations than previous results from 2013 (17 000 µg TCE/L)

Higher concentrations at DFN-4 in March 2020, difficult to explain. Bad sealed CHS liner?

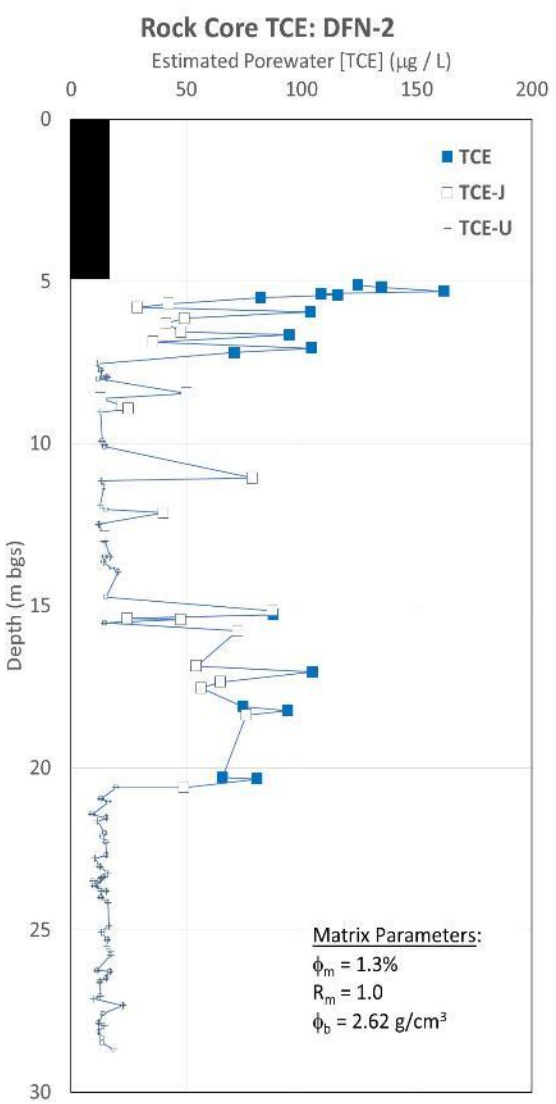
A longer period of monitoring would be required to confirm trends.

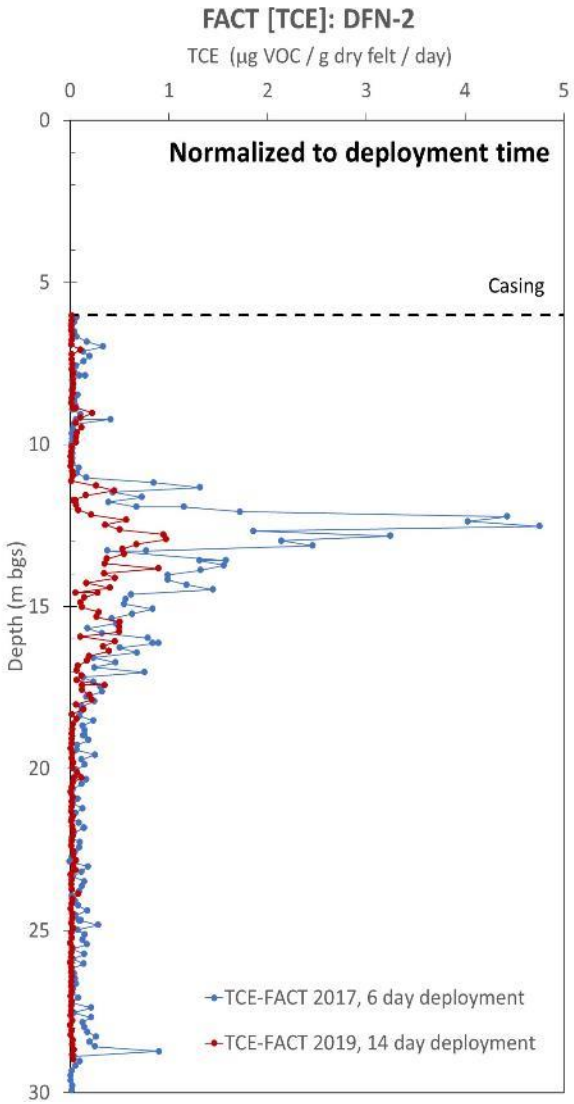


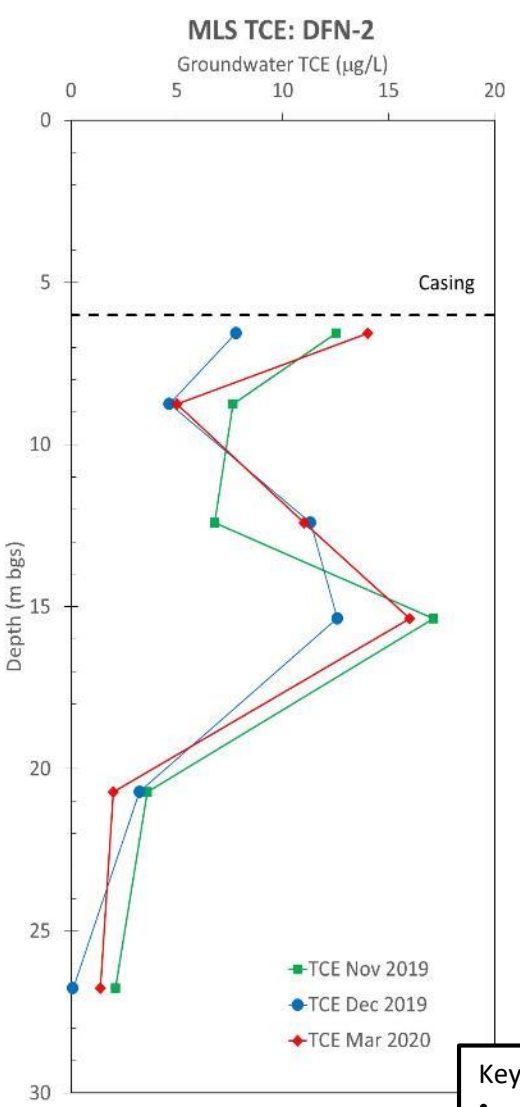


Results and evaluations.

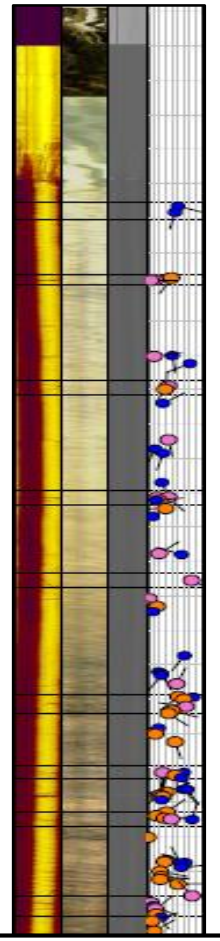
Composite Data Interpretation: DFN-2



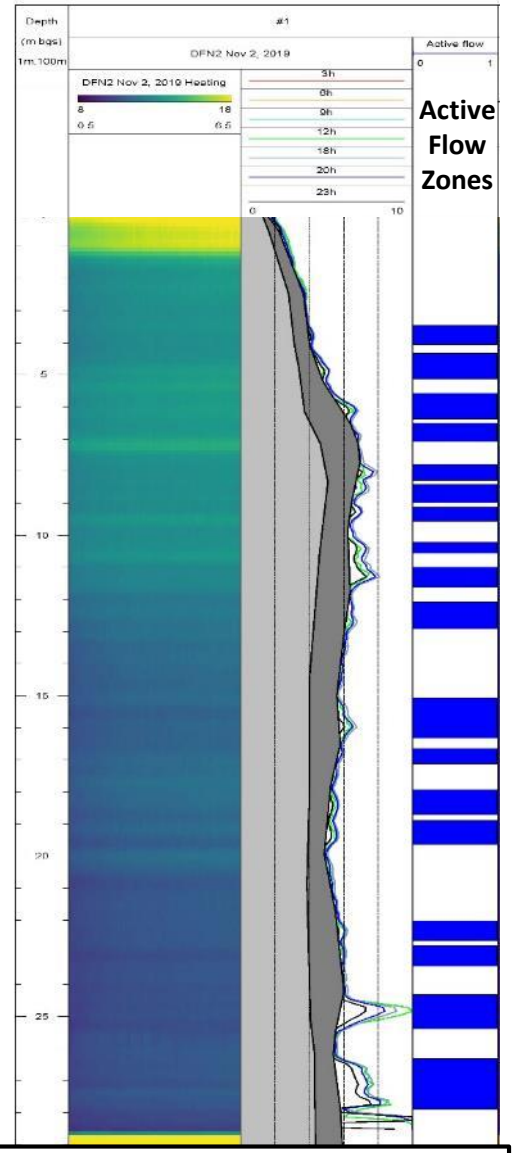




ATV



A-DTS

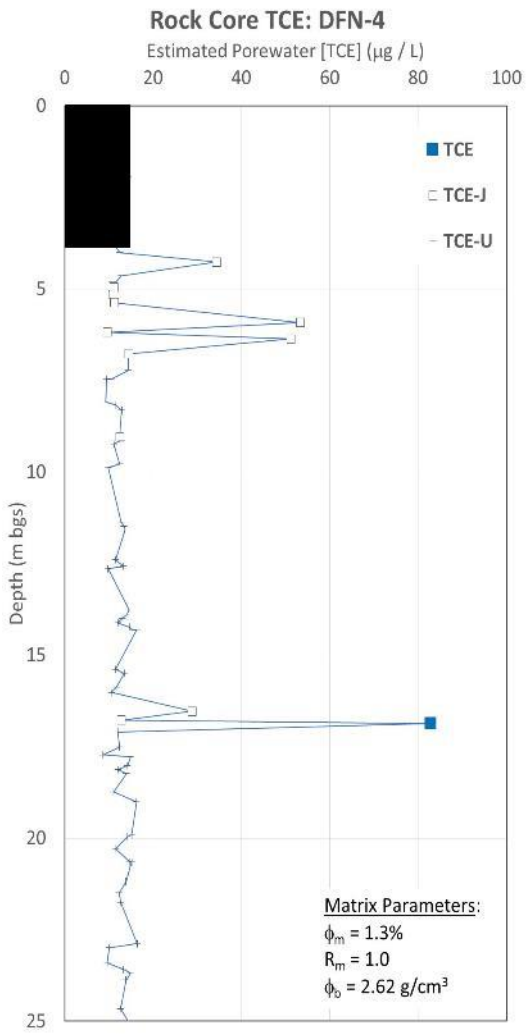


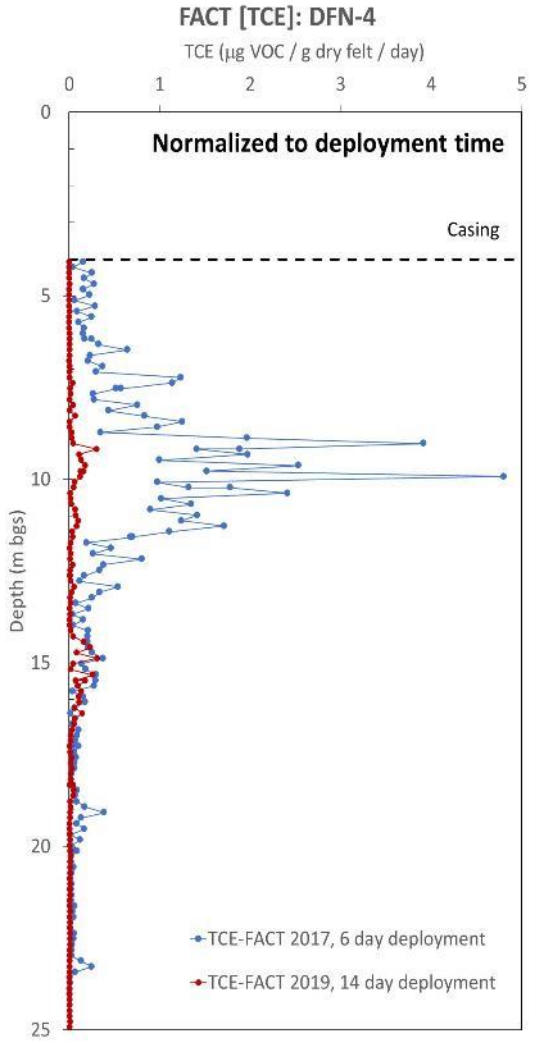
Key Points →

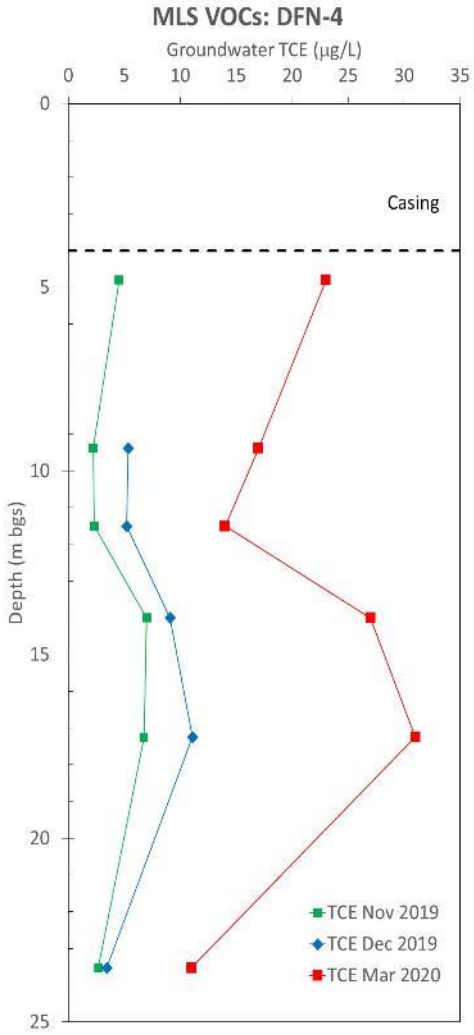
- rock core not diagnostic
- FACT tracking higher mass discharge interval
  - Decline in mass discharge over 2.5 year period
- Reasonable correlation between FACT and GW [TCE]
  - GW blended over port intervals (~1.0-1.5m)

Results and evaluations.

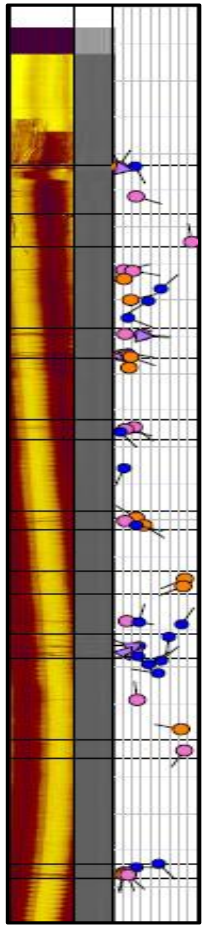
Composite Data Interpretation: DFN-4



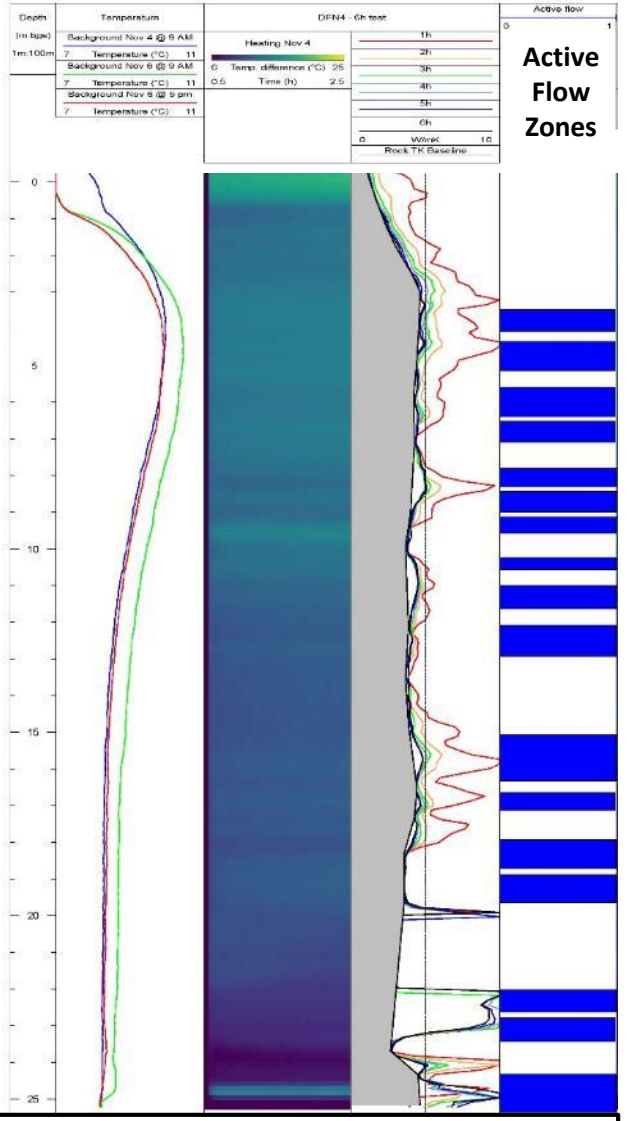




ATV



A-DTS



Key Points →

- FACT tracking higher mass discharge interval
  - Decline in mass discharge over 2.5 year period
- More temporal variability in GW [TCE] downgradient

Results and evaluations. ALS and A-DTS

Assessments of hydraulically active fractures, based on the ALS and A-DTS datasets, telling us something about potential ways for transport of contaminant, can be compared with other measurements of fracture spacing to identify bias between the methods.

- Fractures observed in core are biased due to mechanical breaks during drilling and core retrieval.
- Fractures observed in core at surface do not indicate they are transmissive in-situ.
- Fractures indicated by ATV or OTV are subject to influence from drilling and borehole wall quality, turbid water in the borehole , instrument sensitivity, and operator interpretation of fractures and also do not indicate whether the fractures are open and connected beyond the borehole.

Key findings.

The most likely hypothesis regarding the bedrock contamination identified in 2013 is open-hole cross-connection. Remnants of this cross-connected contamination have been observed at DFN-2 and DFN-4.

- In general, downward hydraulic gradients in bedrock at DFN-2.
- Interval of bedrock groundwater contamination from 2013 is coincident with the interval of highest contamination on the FACT at DFN-2. And the contamination is also traceable downgradient at DFN-4.
- There is a lack of contaminant flux in shallower bedrock that would result from longer-term inputs from an ongoing vadose zone or shallow bedrock source.
- Low contamination in rock cores, the bedrock matrix, and a contamination that seems to be quite rapidly flushed out of the system, consistent with this being a recent occurrence.

- **Improving conditions within the bedrock groundwater on-site and down-gradient of the site.**
- **Contamination in the bedrock appears fairly minor without a major ongoing source.**

Last slide

Thank you!

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