

STEAM-AIR INJECTION IN FRACTURED BEDROCK: COMPLETION OF A CHC-REMEDIATION AT THE SITE BISWURM (Villingen-Schwenningen, Germany)

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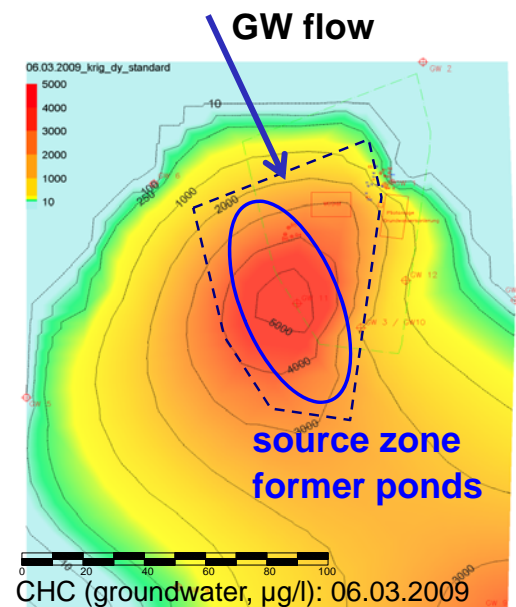


Extent and Investigation of the Contamination at Biswurm

Former communal incineration plant for liquid organic waste (1960-1974)

- ➔ leaking storage and incineration ponds
 - ➔ chlorinated and aromatic hydrocarbons (CHC, BTEX), mineral oils

- ➔ 2,900 m² source zone area and 43,000 m³ of fractured bedrock
- ➔ 5 m claystone layer (unsaturated) and 16 m sandstone formation (saturated) affected CHC up to 40 mg/L in surface water, 4,000 µg/L in groundwater, 4 g/m³ in soil vapor
- ➔ Contaminant mass: several tons of CHC and BTEX
- ➔ **Pilot application in 2009** to verify and design ISTR
 - ➔ steam propagation > 5 m radius
 - ➔ 500 kg CHC, 2,000 m³, 3 months of operation
 - ➔ major contaminant mass 4 – 15 m bgs.



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Remediation Concept based on Pilot Test (I)

Steam-air injection

- two injection levels:
 - sandstone and claystone (4 – 8 m bgs.)
 - sandstone, upper aquifer (11 – 15 m bgs.)

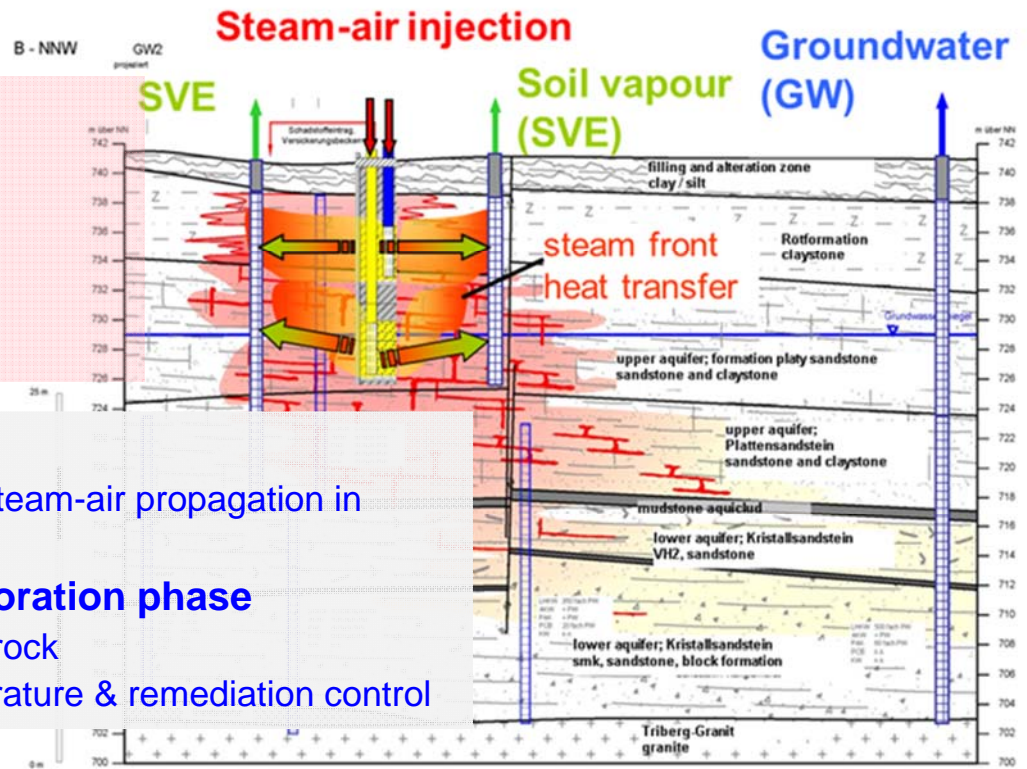
→ Heating phase

conductive heating by steam-air propagation in fractures

→ Desorption and evaporation phase

of contaminants from bedrock

→ mass removal, temperature & remediation control



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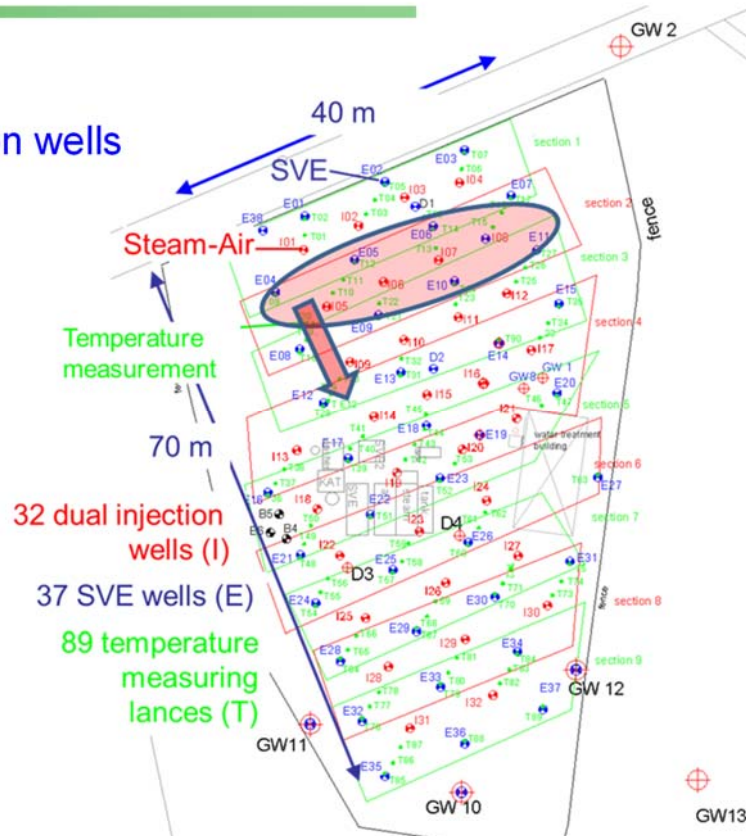
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Remediation Concept (II)

- 9 treatment sections each 4 or 5 injection wells surrounded by SVE wells to treat 4,000 m³ of bedrock
- Section-wise treatment in direction of groundwater flow from north to south
 - 350 – 450 kW heating power
 - 1) steam expansion phase
 - 2) CHC desorption phase
- Groundwater containment at southern border (GW10 –GW12)
- 3.5 years of total remediation time including 3 years of steam-air injection



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Impressions of Biswurm In-situ Thermal Remediation



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Design and Reality of the Remediation

Remediation design due to pilot application

.. but real life is different

→ desorption of contaminant lasts longer

ISTR section by section

simultaneous remediation of 2 and 3 sections

Steam-air injection

3 months each section

using 2 filter level sections

→ 6 weeks of steam-air expansion (heating) +

→ 8 weeks removal time (evaporation & desorption)

Steam-air injection

4 - 6 months each section

pre-heating of claystone

→ 5 weeks heating time of claystone

→ 11 – 13 weeks of evaporation time of claystone and sandstone

→ 9 weeks desorption phase of platy sandstone

Cooling phase,
one week each section

Cooling phase, in total 7 months

Closure in September 2015

Closure in March 2017

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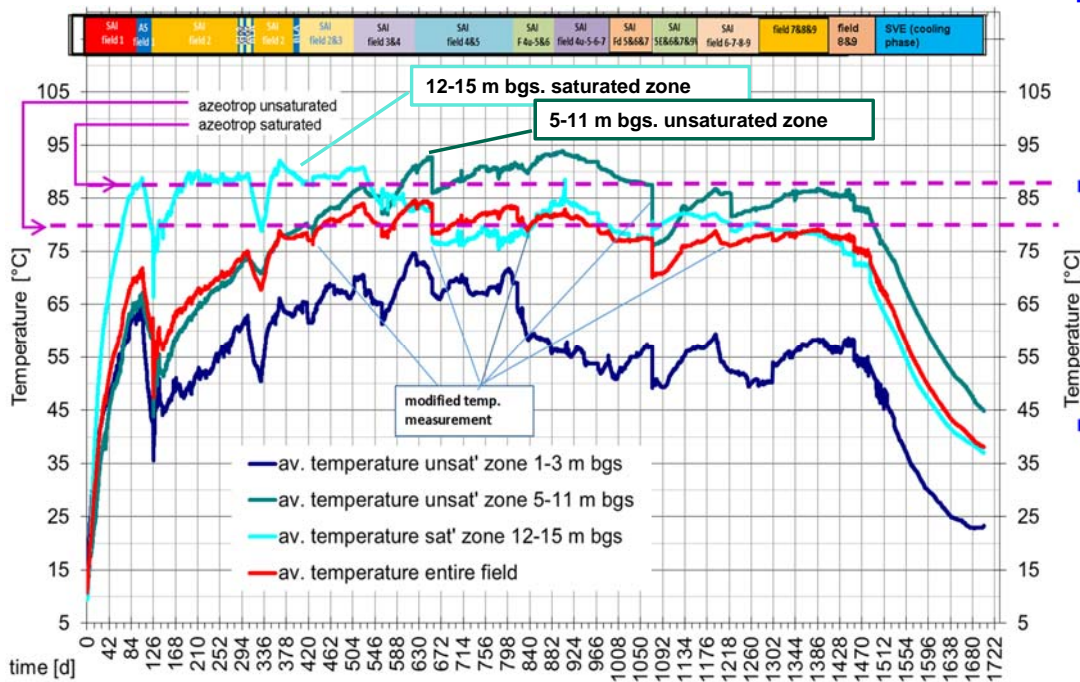
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Temperature Development

- Target temperature = co-boiling temperature in the unsaturated zone > 80°C
- Target temperature in the saturated zone > 88°C



- Dewatering provides a reduced target temperature of 80°C
- Until completion of dewatering (section 3) temperature in saturated zone > 88°C
- Pre-heating of claystone results in temperatures > 90°C, → increase of evaporation process

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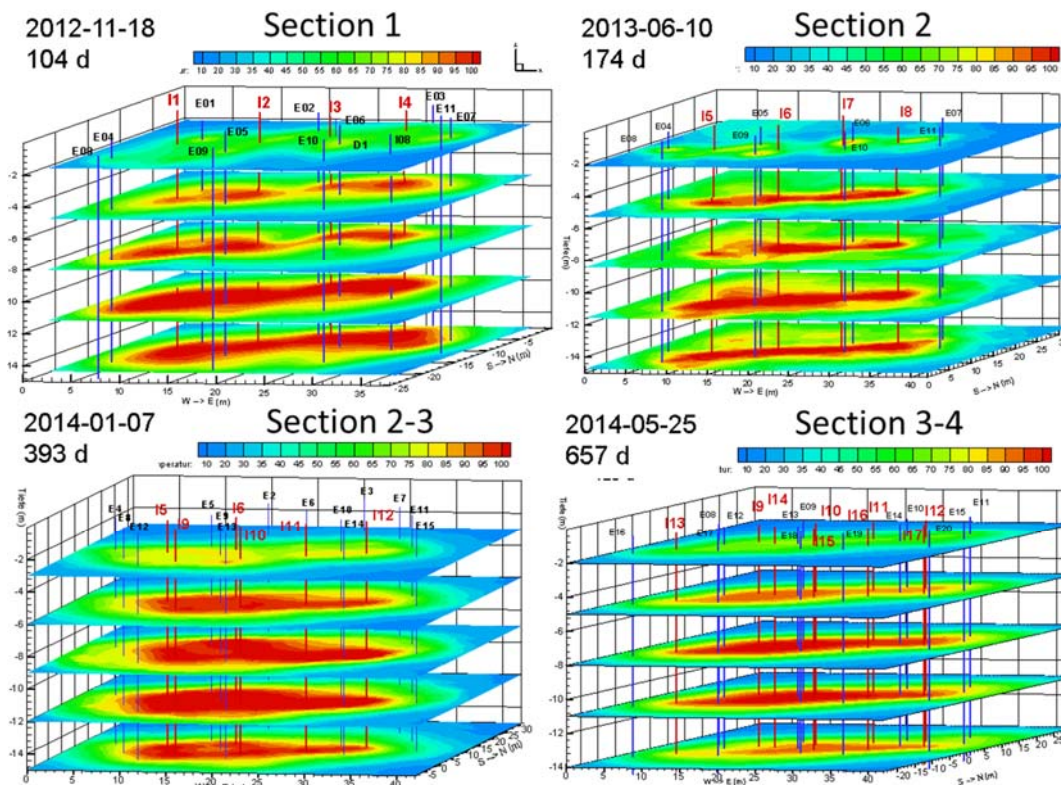
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Heat propagation and ..



- Heat propagation expanded 5 → 15 m radius

- Heated volume

4000 m³ → 8,000 m³ of bedrock (2 sections)

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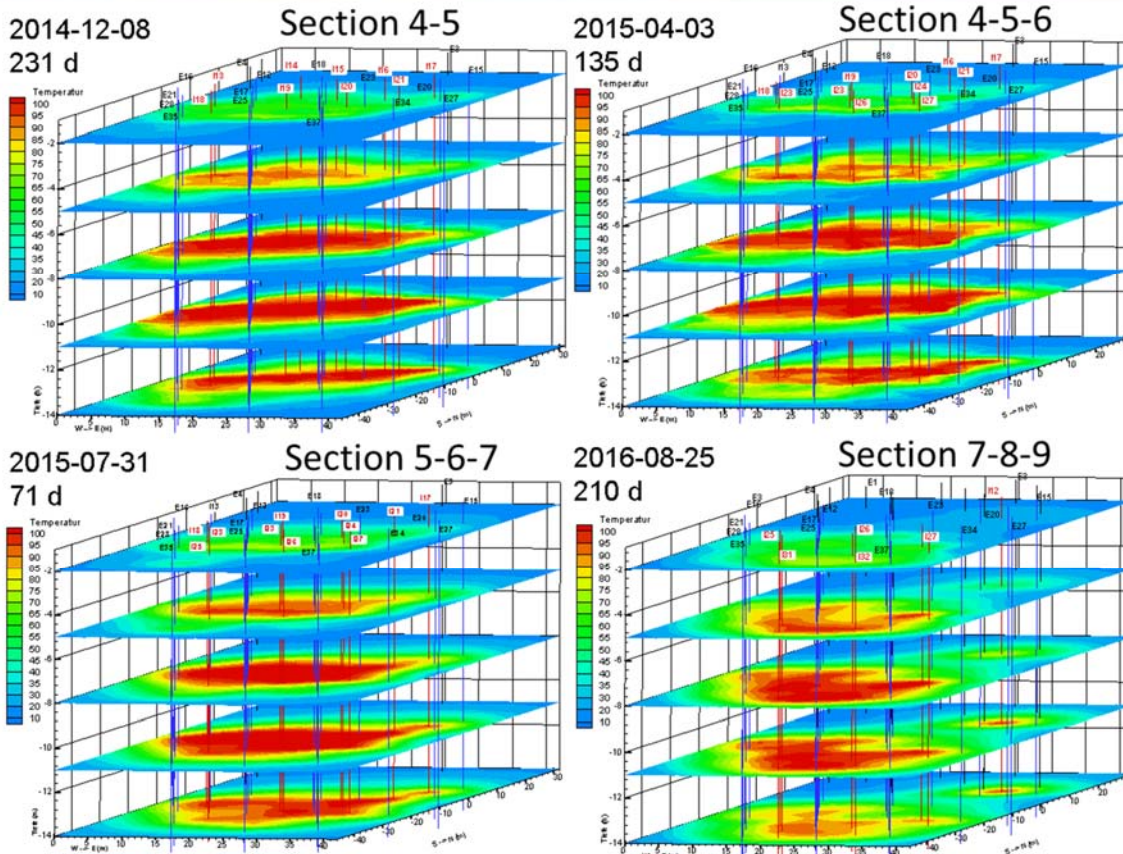
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.. its Expansive and the Consequences



- Heat propagation
15 m radius
- Heated volume
8,000 m³ →
13,000 m³ of
bedrock

→ SVE extended
from one to five
sections:
50% of additional
capacity

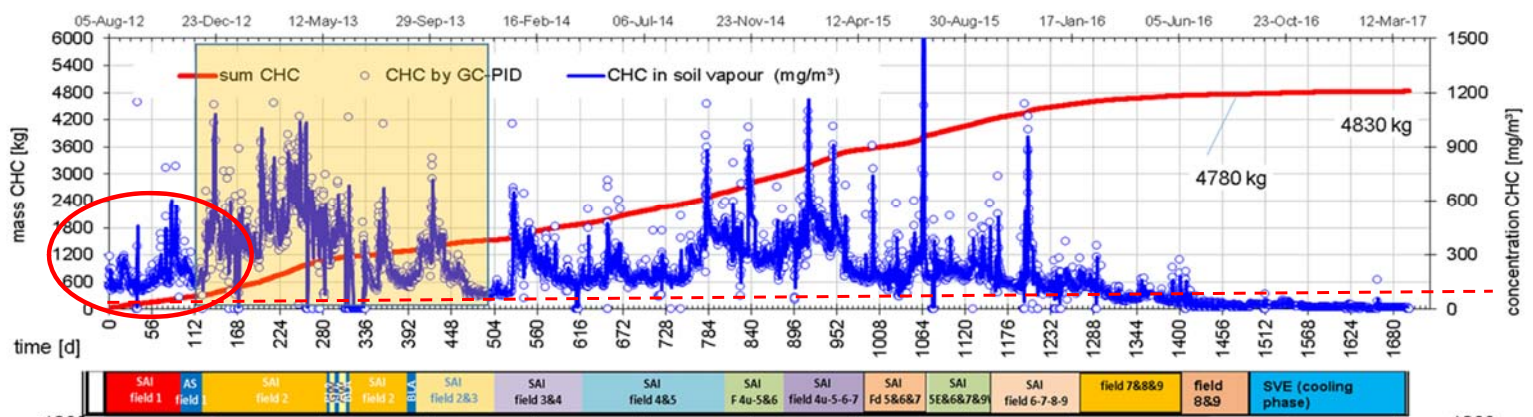
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Contaminant Mass Removal and Operation



- Typical mass removal in section 1, but zones 2 – 6 were different
- Cleanup target value of each section: **20 mg/m³ CHC** in soil vapour
- Removal time increased by a **factor 3** in comparison to pilot test
- Mass removal up to 20 kg CHC daily; in average **3.5 kg CHC daily**
- **4,780 kg CHC** removed at stop of steam-air injection (1,480 days, **13 mg/m³ CHC**)
- After 7 months cooling phase **4,830 kg CHC** removed

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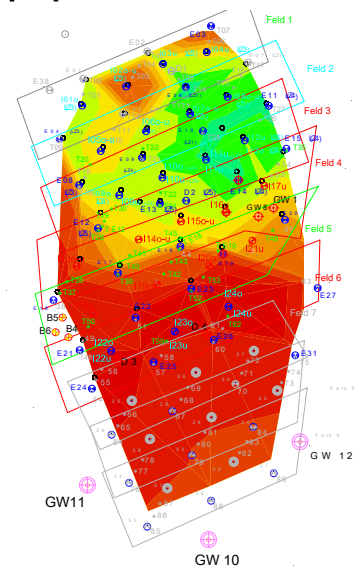


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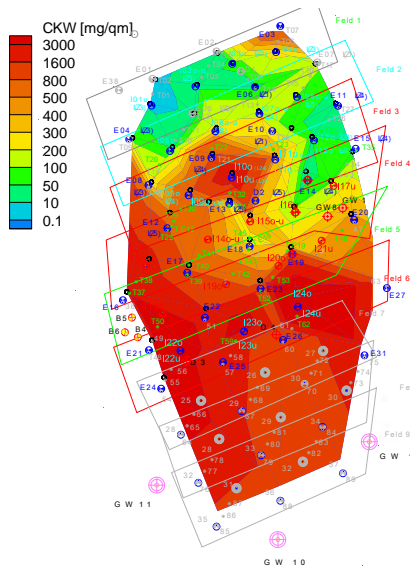
Spatial Contaminant Distribution (I)

[CHC] in sos Mar2014



CHC in soil vapour
platy sandstone (sos)

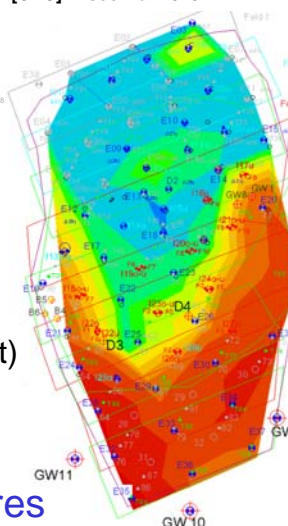
[CHC] in sot Mar2014



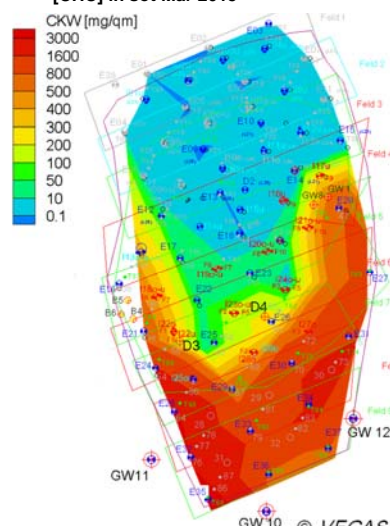
CHC in soil vapour
claystone-sandstone (sot)

Monitoring of SVE wells monthly
to control remediation progress

[CHC] in sos Mar 2015



[CHC] in sot Mar 2015



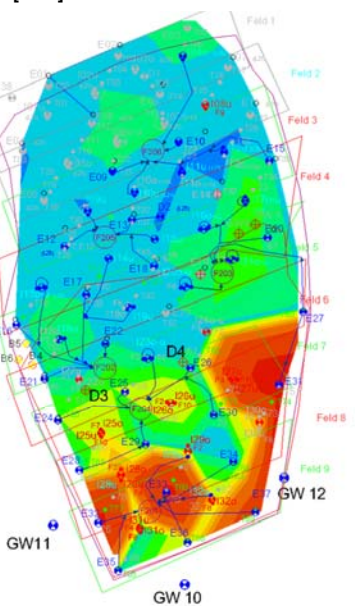
- slow desorption from bedrock
- gaseous contaminant transport in fractures



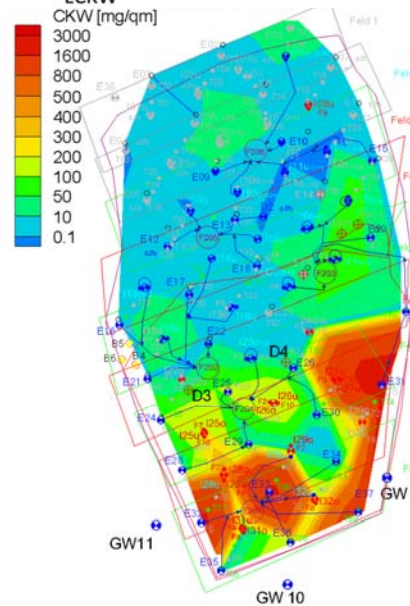
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Spatial Contaminant Distribution (II)

[CHC] in sos Mar 2016

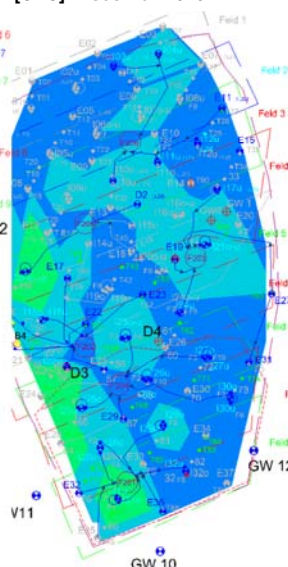


[CHC] in sot Mar 2016

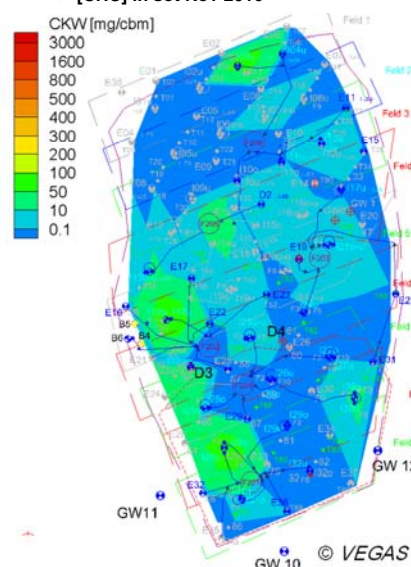


- Steam-air injection finished
for 13 mg/m³ CHC in hot soil vapour
- 81 of 95 wells were < 10 mg/m³ CHC

[CHC] in sos Nov 2016



[CHC] in sot Nov 2016



- Logarithmic-shaped CHC reduction
in downstream groundwater
from 4,000 µg/L → 16 µg/l



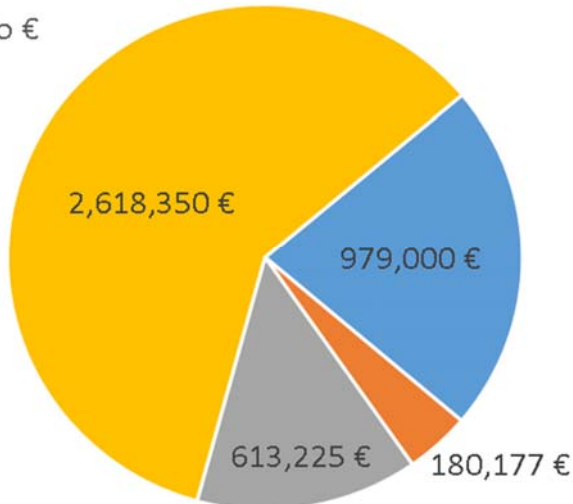
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Adoption of Remediation And Resulting Costs

- Conductive heating of bedrock and CHC desorption takes 40% more time
- Steam-air propagation in fractures required extended SVE
- Cubature of heated soil enlongered cooling phase

total costs: 4.4 Mio €

■ infrastructure
■ monitoring phase
■ engineering
■ operating



- plus of 1 year of steam-air (33% longer)
- 26% additional costs for consumables, operation and (energy)

Budget: 2010: 3.5 Mio €

→ 4.4 Mio € (2017)

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Remediation Costs in Comparision

- Removal of approx. 5,000 kg CHC from fractured bedrock
- CHC emission from 1,100 g/d → < 10 g/d; April 2017: 6.5 g/d

		Steam-air injection	Groundwater remediation
Discharge [m³/h]	Groundwater	15	15
	Soil vapour	500 - 800	-
CHC removal [kg/d]	Groundwater	0.1	0.2
	Soil vapour	ca. 3 - 4	-
Yearly mass removal [tons p. year]		ca. 1 - 1.5	<0.1
Remediation costs [EUR] brutto		4.4 Mio (5 years duration)	7.6 Mio (80 years duration)

→ Costs of the groundwater remediation: 7.6 Mio € vs. 4.4 Mio €

→ Remediation duration: 80 years vs. 5 years

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Summary

- Fractured bedrock is challenging in flux and contaminant control
→ spreading of evaporated contaminants in fractures
- Heat transport and contaminant removal differed from pilot trial
→ uncertainty requires additional resources (+ 30%)
- CHC removal by SVE is dominant: 4,900 kg CHC
125 kg CHC by groundwater containment
- Remediation procedure requires adaption to mass removal
- Regulatory remediation goal achieved
< 10 g/d CHC emission and < 20 µg/L CHC in groundwater

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15

Acknowledgements

Thank you

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16