Steam-Air Injection in fractured Bedrock: Results and Lessons Learned of a CHC-Remediation at the Site Biswurm (Villingen-Schwenningen, Germany)

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Short History of the "Biswurm" Site

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

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

- 2004: excavation of top soil (4 m bgs): 1600 kg CHC and 600 kg mineral oils etc. were removed
- 2006 – 2007: detailed site investigation → hydraulic containment P&T and SVE
- 2009 looking for alternative remediation options

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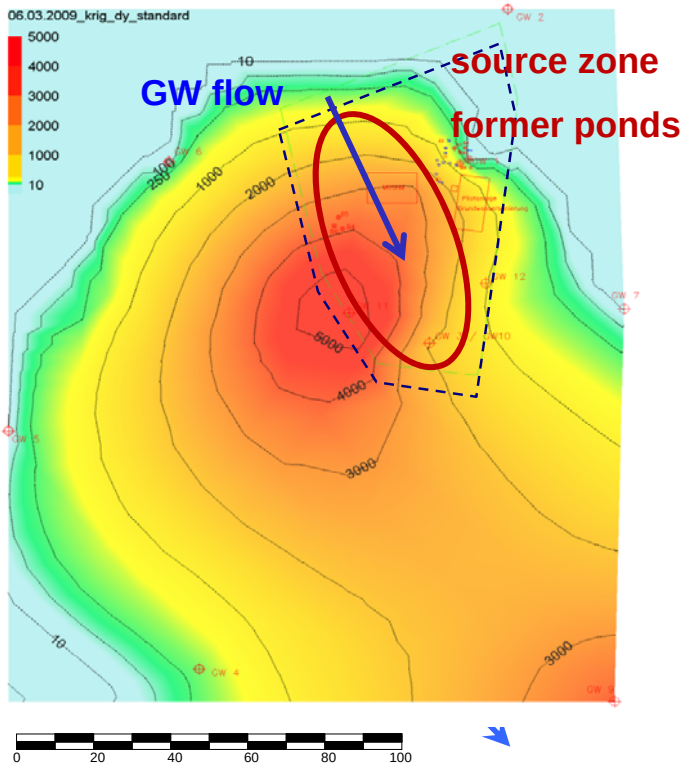
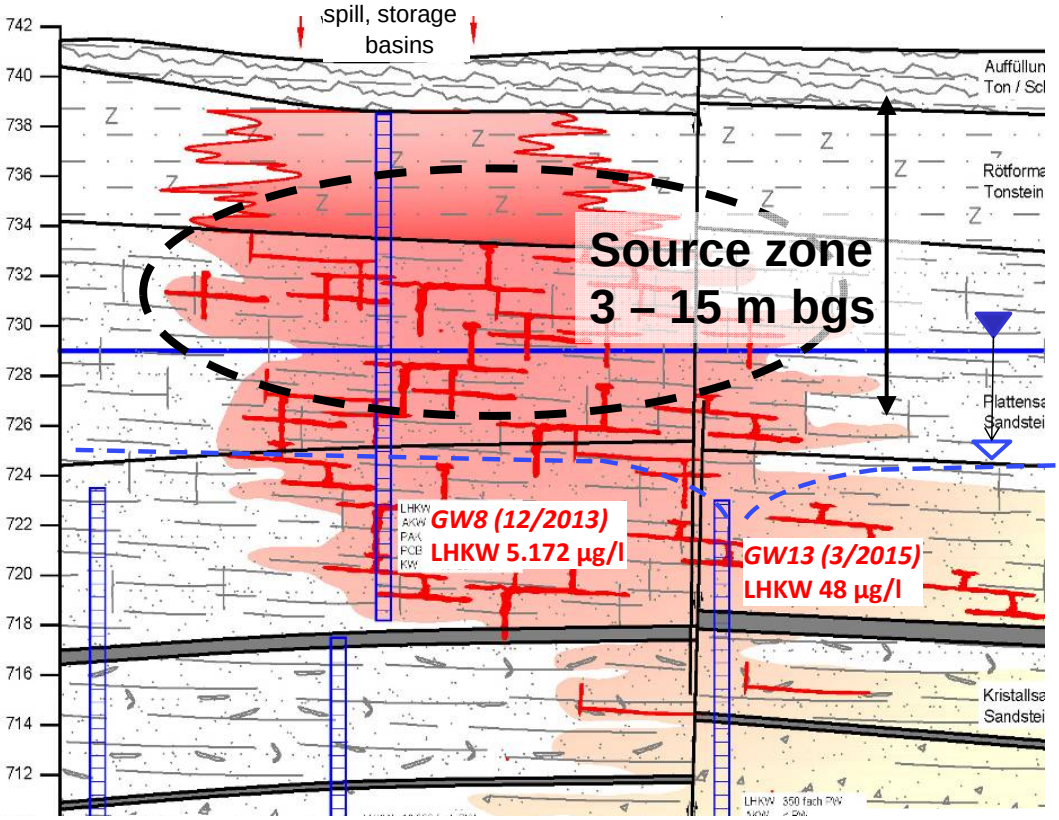
Extent of Contamination at Biswurm

- ➔ 2.900 m² surface area (source zone)
  35 m thick sandstone formation affected
- ➔ CHC up to 40 mg/L in surface water,
  1 mg/L in groundwater,
  up to 4 g/m³ in soil vapor
- ➔ high contaminant potential in unsaturate
  zone, smaller potential in saturated zone
- ➔ estimated contaminant mass: 50 – 100 tons of CHC, 5 - 50 tons BTEX and mineral oils
- ➔ **pilot application** to investigate applicability of steam-air driven remediation



CHC (groundwater, µg/l): 06.03.2009

Geology and Contamination

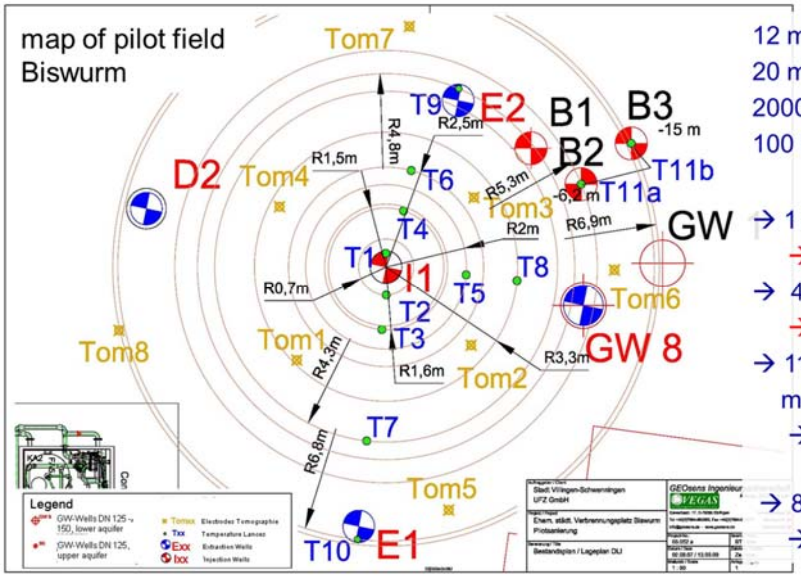


complex fractured bedrock aquifer

- ➢ unsaturated zone „Röt“ formation = claystone
- ➢ upper platy sandstone aquifer mudstone basis (21 m bgs.)
- ➢ lower siliceous sandstone aquifer
- ➢ granite basis (37 m bgs.)

Pilot Field Biswurm in 2009

- Applicability of steam-air injection to remediate the claystone and upper platy sandstone
- Increase of mass extraction by a factor of 2 to 5 as compared to „cold“ soil vapour extraction

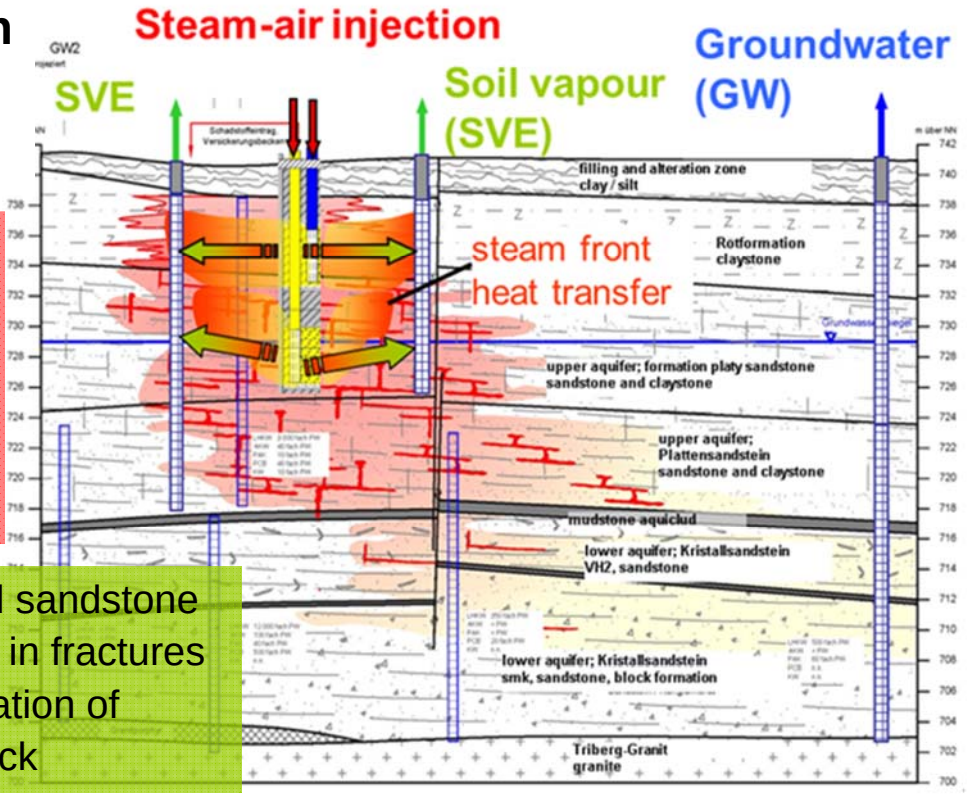


- For the upper aquifer and for the unsaturated zone a steam expansion of more than 10 m in diameter was confirmed
- Total mass removal of 500 kg CHC during 3 months from 1,500 m³ of bedrock

Remediation Concept (I)

Design of remediation based on pilot application

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



- **Heating** of claystone and sandstone by steam-air propagation in fractures
- **Desorption** and evaporation of contaminants from bedrock

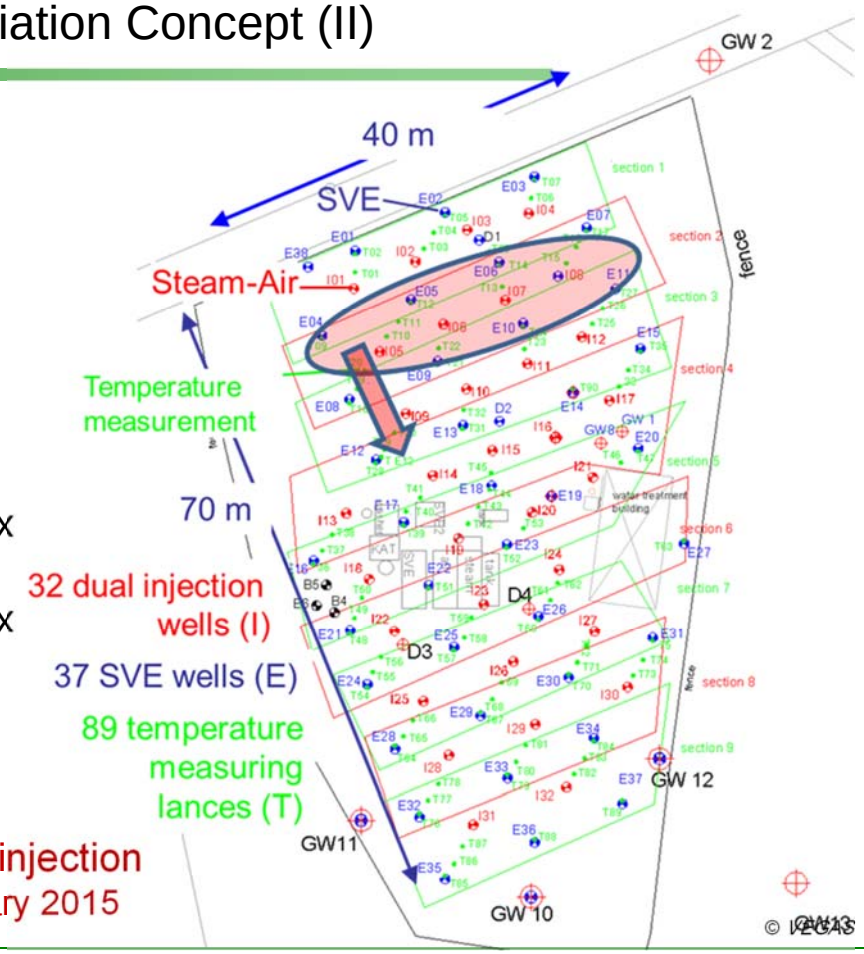
Remediation Concept (II)

- **9 treatment sections**
  each 4 or 5 injection wells
  to treat 4000 m³ of bedrock

- **Steam-air injection** with
  350 – 450 kW heating power
  ➔ *steam expansion phase*
  6 weeks at 550 kg/h steam-air flux
  ➔ *CHC desorption phase*
  8 weeks at 450 kg/h steam-air flux

- Groundwater containment at southern border

- 36 months of plant operation
  including 33 months of steam-air injection
  ➔ planned end of remediation January 2015



Impressions of Current Remediation

Design and Reality of the Remediation

Remediation design based on pilot application

➔ thermally enhanced remediation section by section

- **Steam-air injection**
  3 - 4 months each section (33 month)
  ➔ **6 weeks** steam-air expansion (heating)
  ➔ **+ 8 weeks** removal time (evaporation & desorption)
- **Cooling phase**
  one week each section (2,5 months)
- **January 2015**
  end and remediation control

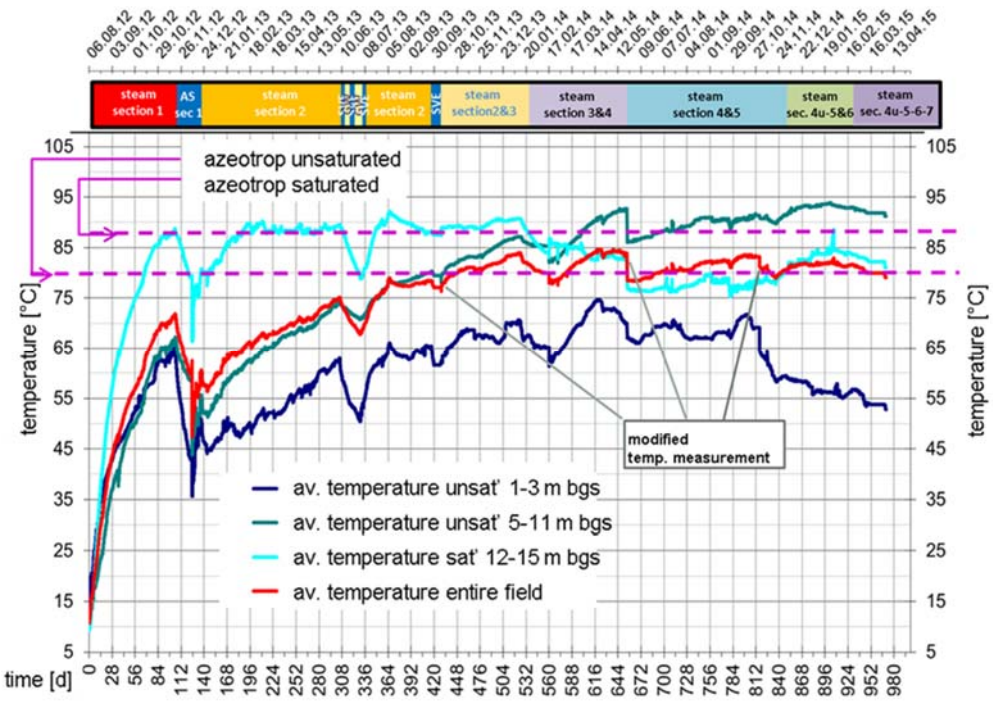
.. but real life is different

➔ time of desorption is significantly longer
➔ simultaneous remediation of two sections each

- **Steam-air injection**
  4 - 6 months each section (> 45 month)
  ➔ **5 weeks** heating time of claystone (200 kW)
  ➔ **+ 11 – 13 weeks** evaporation time of claystone and sandstone (300 kW)
  ➔ **9 weeks** desorption phase of platy sandstone (150 kW)
- **Cooling phase** ➔ in total 6 months
- **June 2016** (estimated)
  end and remediation control

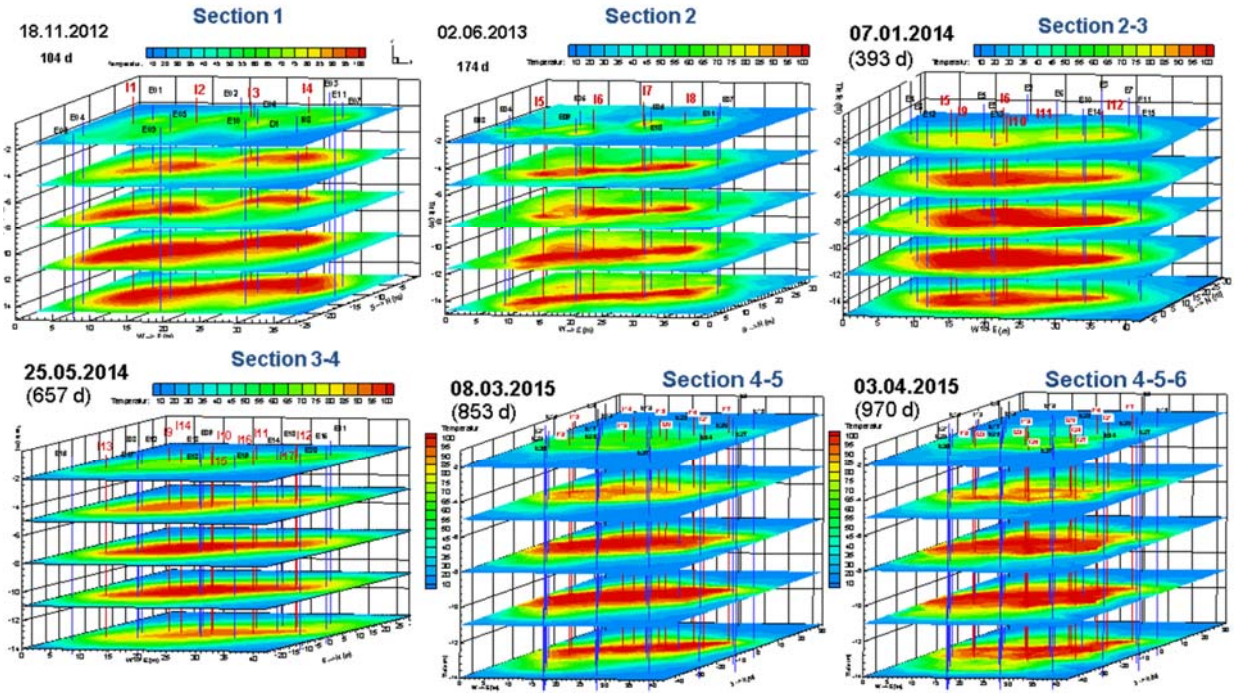
Temperature Development

Target temperature in the unsaturated zone > 80°C
Target temperature in the saturated zone > 88°C



- Dewatering leads to a target temperature of 80°C
- Until end of dewatering process (section 3) temperature in saturated zone > 88°C
- Pre-heating of claystone results in temperatures > 90°C,
  ➔ increase of evaporation process

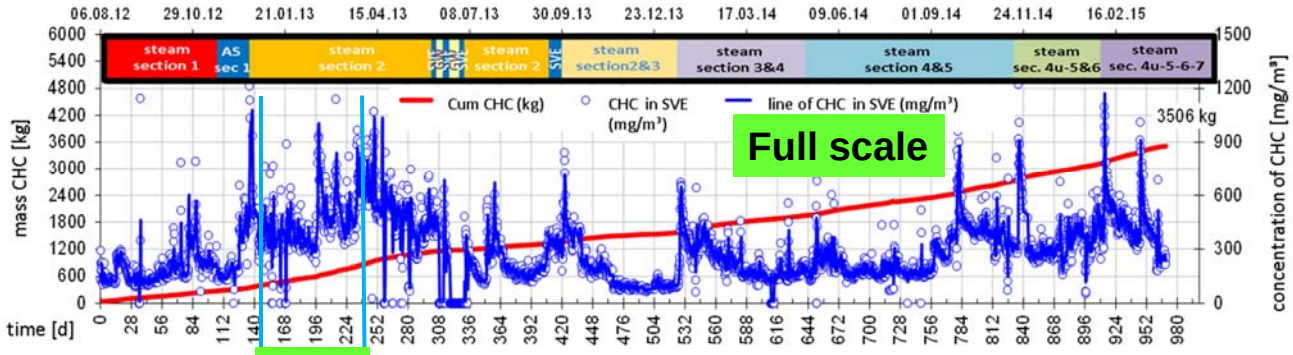
Heat propagation and consequences

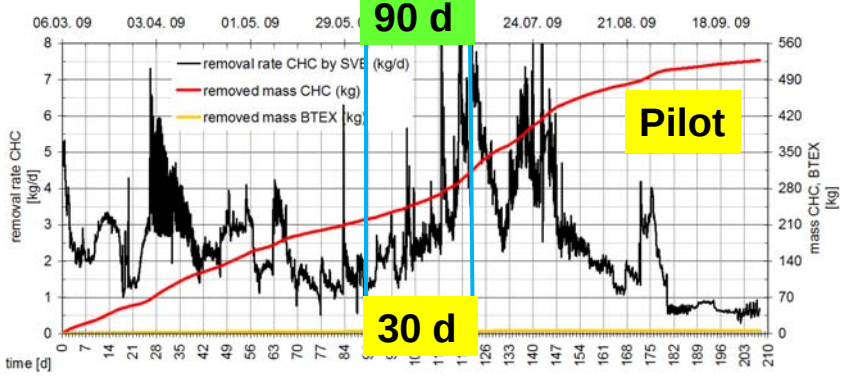


- Heat propagation 5 - 15 m radius
- Heated volume 13,000 m³ of bedrock (3 sections)
- Instead of 4,000 m³ (1 section)

➔ **Extension of SVE from 1 section to 5 sections**
Meaning 50% of additional capacity needed

Contaminant Mass Removal



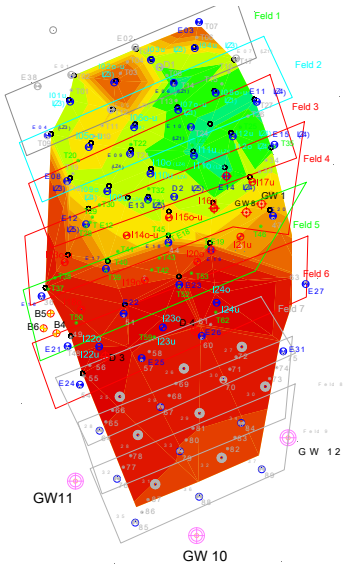


- Specific mass removal behaviour: heating phase: increasing mass flux, desorption phase: fading mass flux
- Target value of 20 mg CHC per m³
- Removal time increased by factors in comparison to pilot

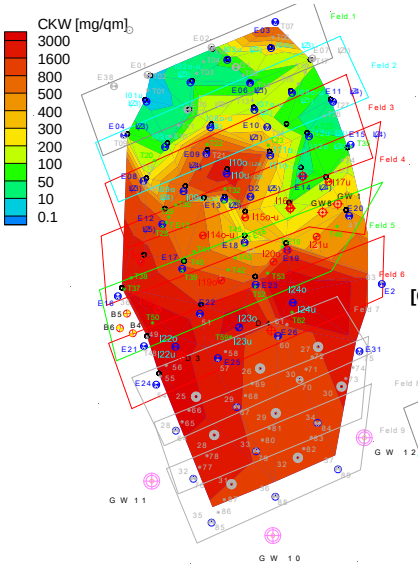
- **Mass removal up to 20 kg CHC per day, average 3.5 kg CHC per day**
- **after 960 days of steam-air injection ➔ removal of 3,500 kg CHC**

Spatial Contaminant Distribution (I)

[CHC] in sos Mar2014



[CHC] in sot Mar2014



CHC in soil vapour
platy sandstone (sos)

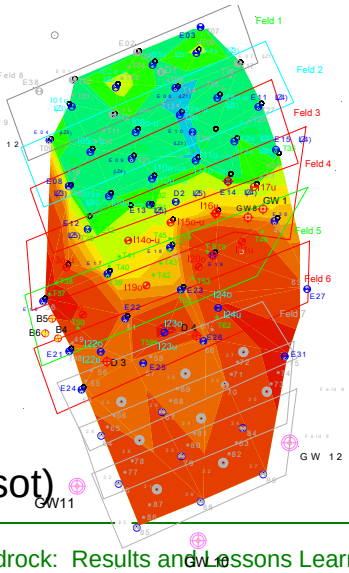
CHC in soil vapour
claystone-sandstone (sot)

Water and heat storage in fractures and bedrock increased duration of mass removal and desorption

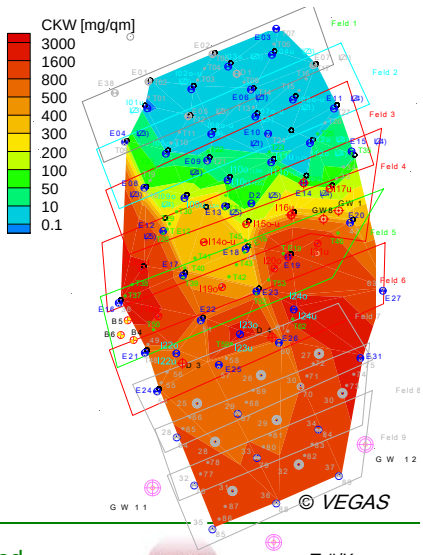
➔ mass removal during time without heating

➔ extension of SVE capacities

[CHC] in sos Sept 2014

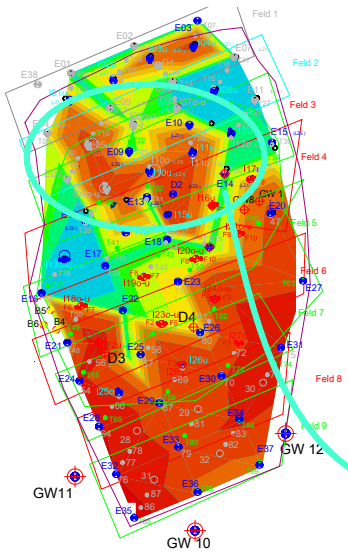


[CHC] in sot Sept 2014

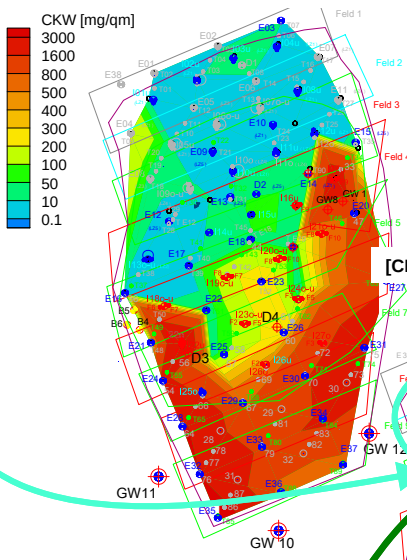


Spatial Contaminant Distribution (II)

[CHC] in sos Mar2015



[CHC] in sot Mar 2015



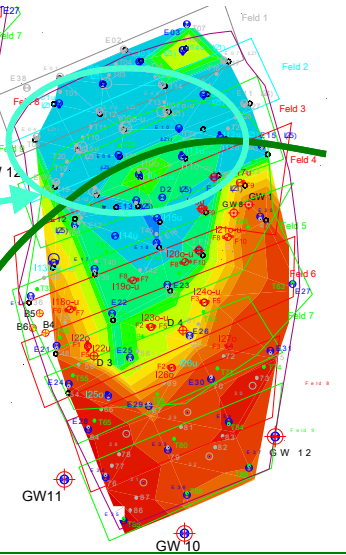
Underpressure belt and steam-air off during sampling in April 2015

➔ **contaminant spreading in fractures**

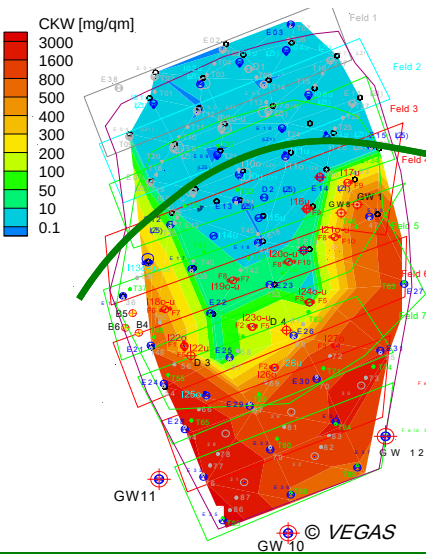
Rebound effects in sandstone bedrock (sos)

➔ Investigation of overlapping effects

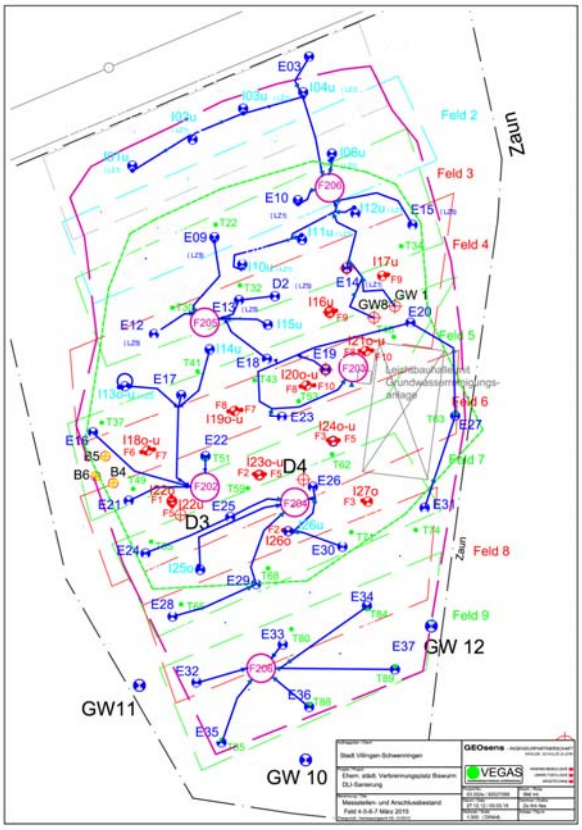
[CHC] in sos Apr 2015



[CHC] in sot Apr 2015



Limits of Application - Lessons Learned -



Conductive heating of bedrock takes 40% more time as estimated

➔ remediation time will be 20 – 25% longer

- **simultaneous injection in 2 sections**
- **SVE from 5 sections**

➔ energy consumption optimized

Steam-air propagation in fractures is hard to control

- **SVE from 40 SVE-wells instead of 10 wells**

➔ mass flux of SVE at least 1.5 x injection rate

Heat storage capacity results in long-term desorption capacity

➔ extending cooling phase

Summary after 30 months

- Fractured bedrock is challenging in flux and control
  ➔ spreading of evaporated contaminants in fractures
- Heat transport and contaminant removal differs from pilot trial
  ➔ uncertainty requires additional resources (+ 30%)
- Target temperatures exceeded
- CHC removal by SVE is dominant: 4,000 kg CHC
  120 kg CHC by groundwater containment
- Remediation procedure requires adaption to mass removal (SVE system)
- Additional time required 45 months instead of 33 months

➔ the efficient remediation of fractured bedrock by steam-air injection requires additional control and financial resources

Acknowledgements

Thank you

The work presented would not have been possible without

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- the decision of the public construction authority to support an innovative technology in a novel field of application

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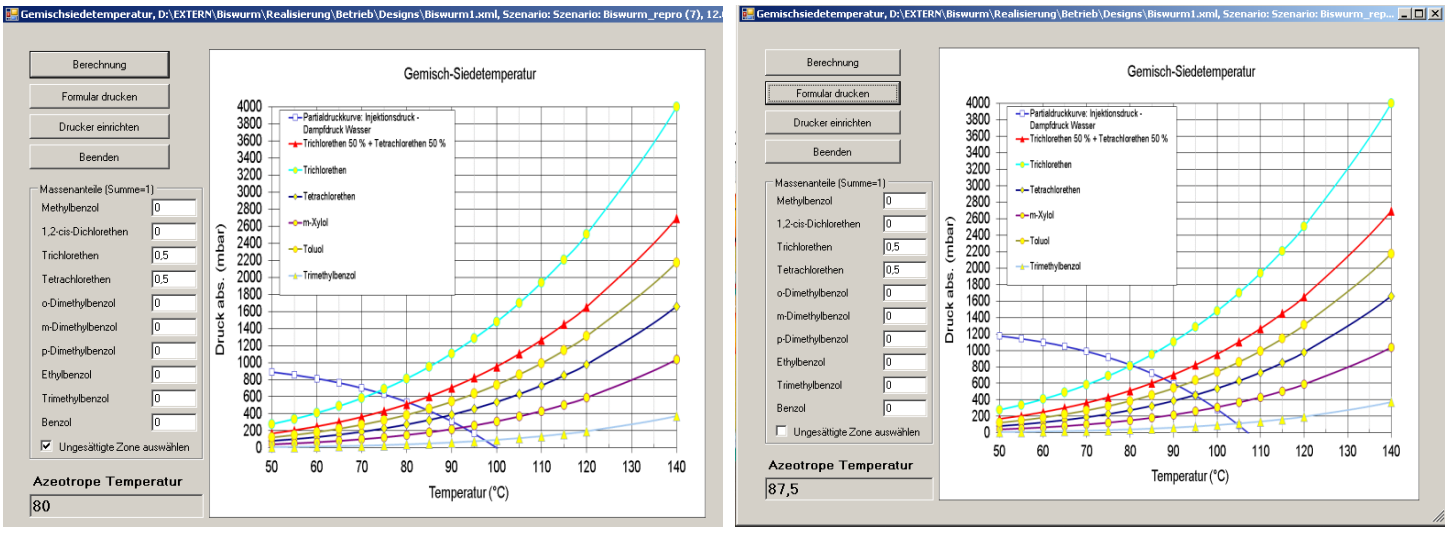
Azeotropic Temperatures at Biswurm



Azeotropic temperature = co-boiling of steam and CHC depends on pressure

→ **target temperature unsaturated zone (claystone and sandstone) down to 12 m bgs.: 80°C**

→ **target temperature saturated zone (sandstone) down to 15 m bgs.: 88°C**