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Assessment of AMD Potential and Prediction of a long-term Sulfate Plume of a Tailing Storage Facility Decades after its Decommissioning

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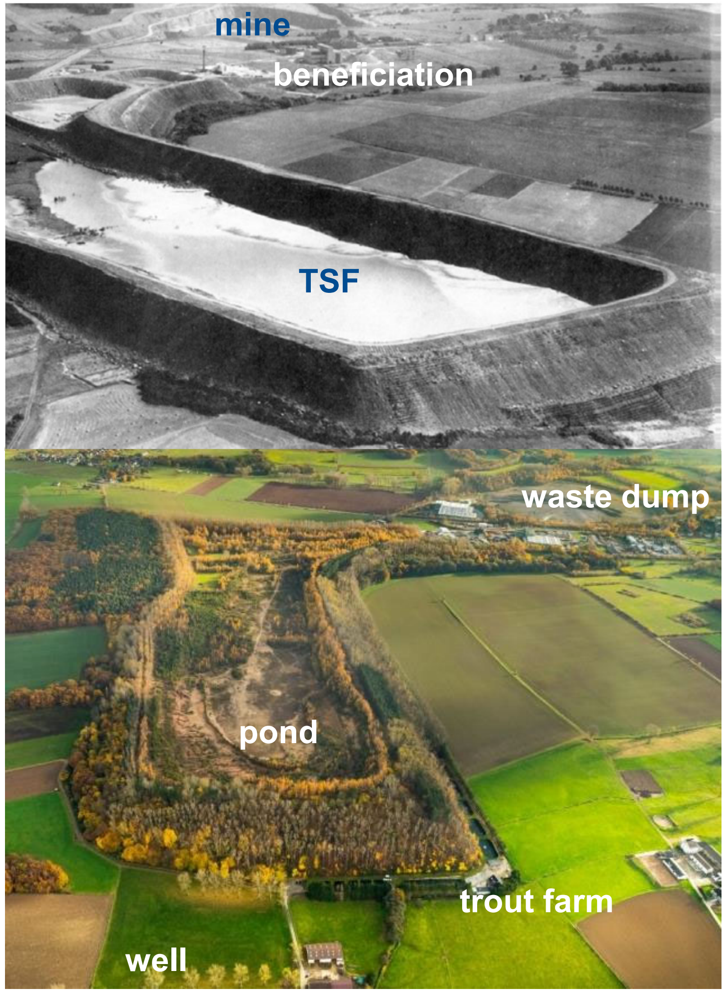
Beythal Tailings Storage Facility



1955 – 1969
TSF of lead zinc mine Maubacher Bleiberg
5.4 million m^3 of tailings

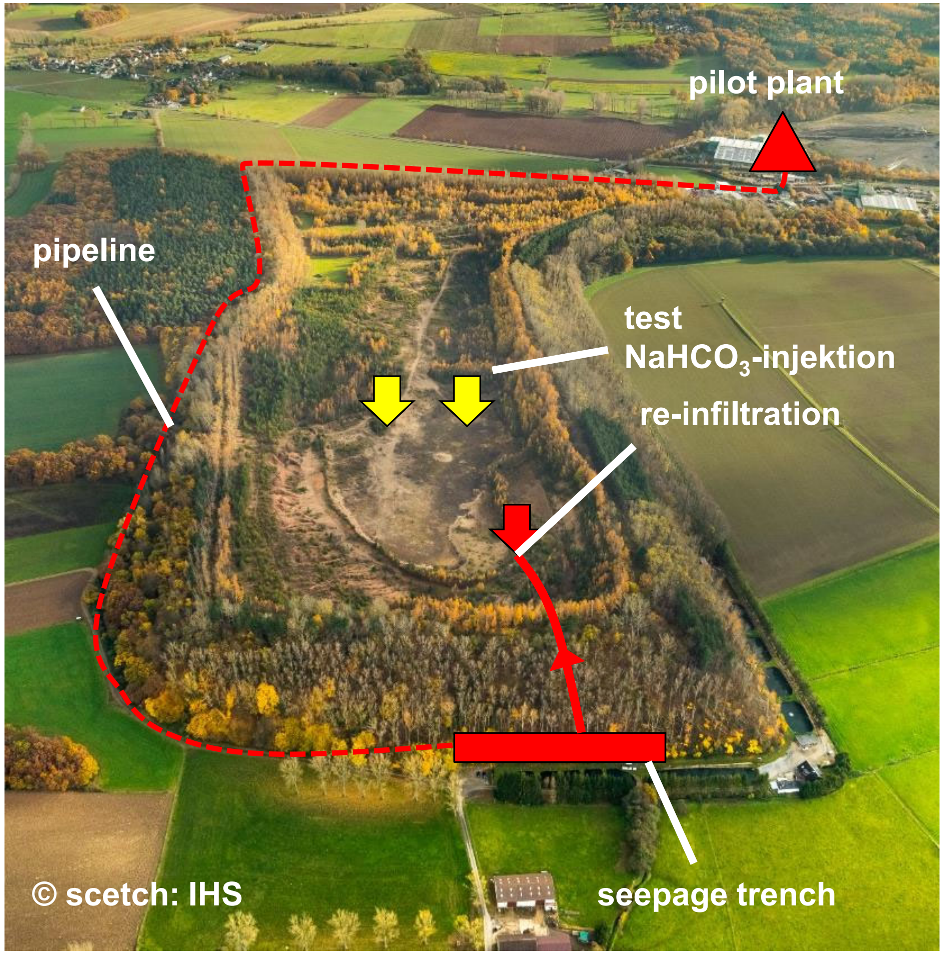
1969 – 2002
Recovery of quartz sand: 1.7 million m^3 by Stolberger Zink AG

3.7 million m^3 including ring dike left
covering 45 ha, 15 – 20 m thick
0.7 – 3.6 wt% of sulfides: arsenopyrite, bravoite, pyrite, sphalerite

2007 liquidation of assignee of Stolberger Zink AG
Since 2007 risk management by District Council of Arnsberg, State NRW
Since 2015 coordination of measures by AAV

In 1999 fish kill in the trout farm at the northwestern foot of TSF
nature reserve since 2017

Why to care about – Former Investigations and Recommendations



Statement 1

Material is on the long run potentially acid forming

Increase of buffering capacity is needed

Field test: Injection of bicarbonate fluid

not successful

Statement 2

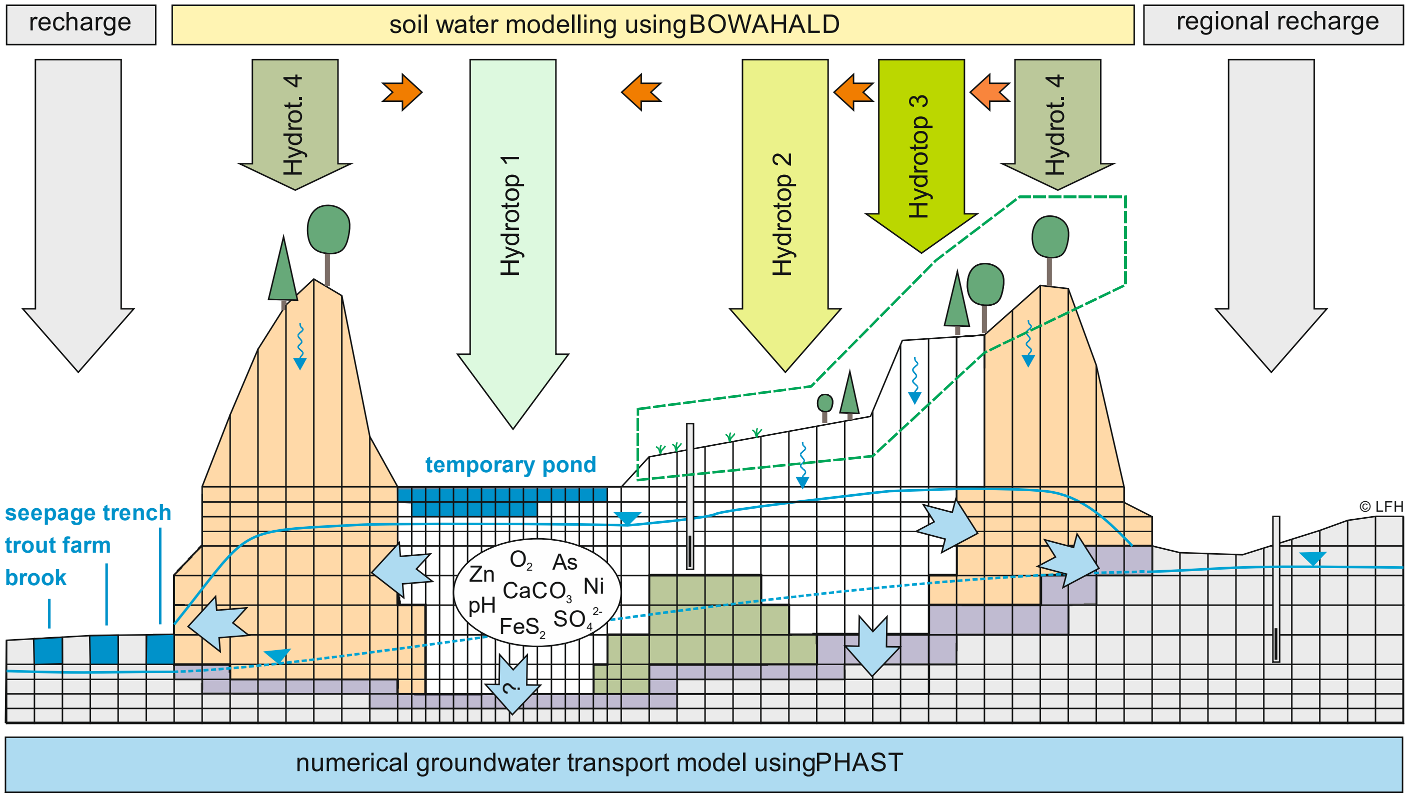
TSF will release acid mine drainage high in metals

Active Treatment is needed

Field test: Pilot plant for treatment of metals and acidity

not successful

Our Concept – starting 2017

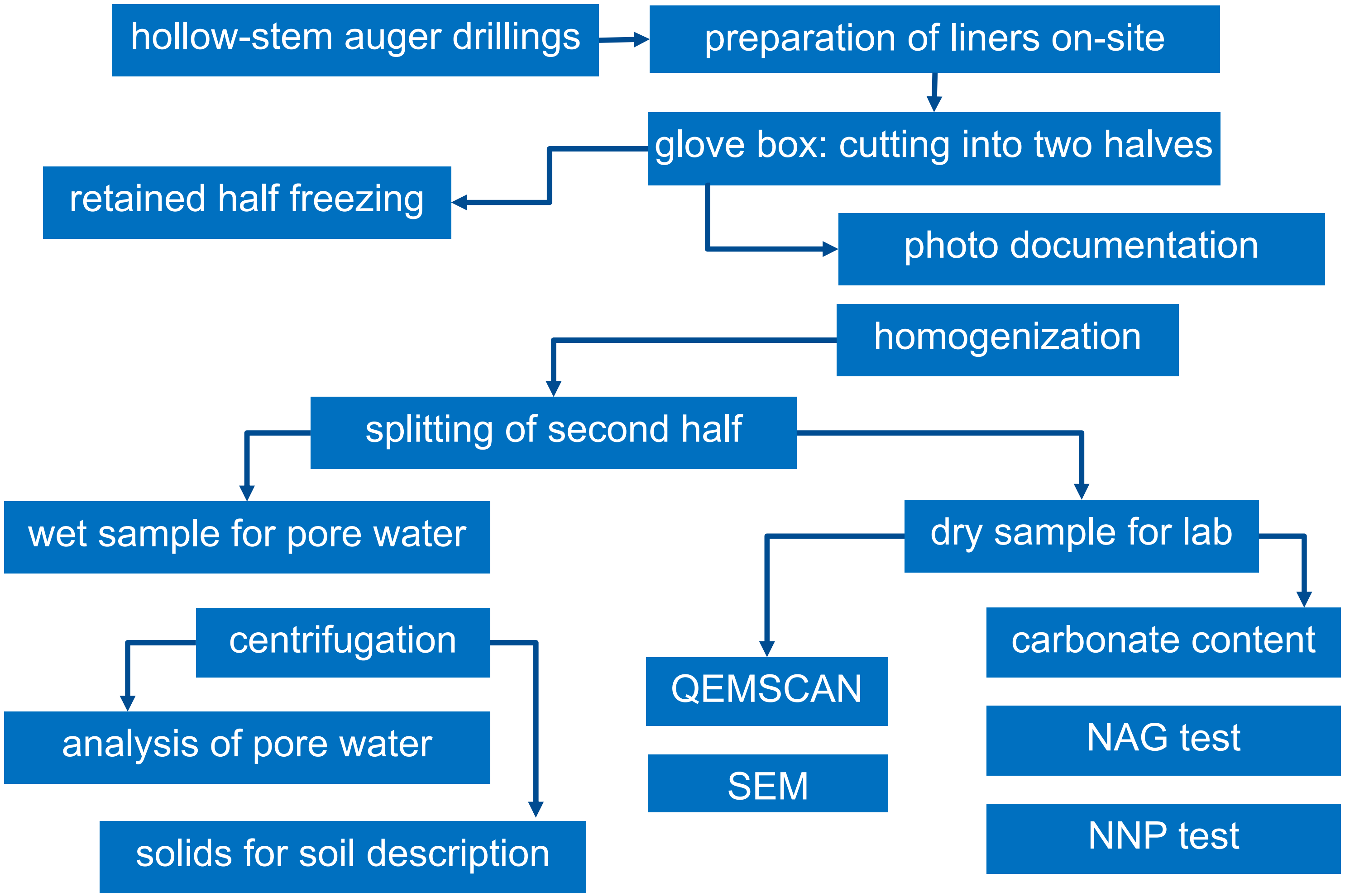


- Evaluation of existing data
- New sampling (coring)
- Tailings‘ Pore Waters
- Static Tests
- Mineralogical analyses

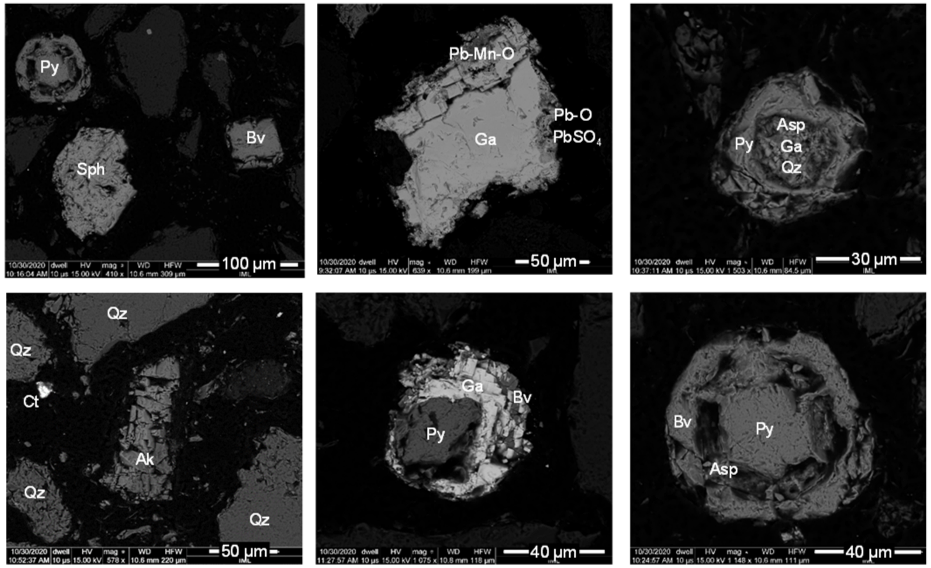
- Soil water balance
  BOWAHALD (Dunger 2007)
- Flow | Transport Modelling
  PHAST (Parkhurst et al. 2010)

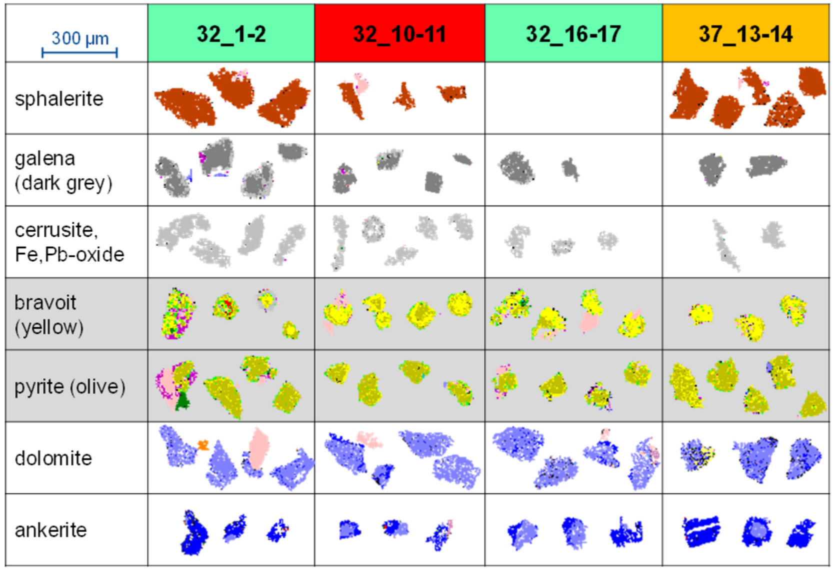
- Assessment and Recommendations

Starting from Scratch – New Samples and their Analysis



Benefits from Advanced Mineralogical Data





Scanning electron microscopy (SEM)

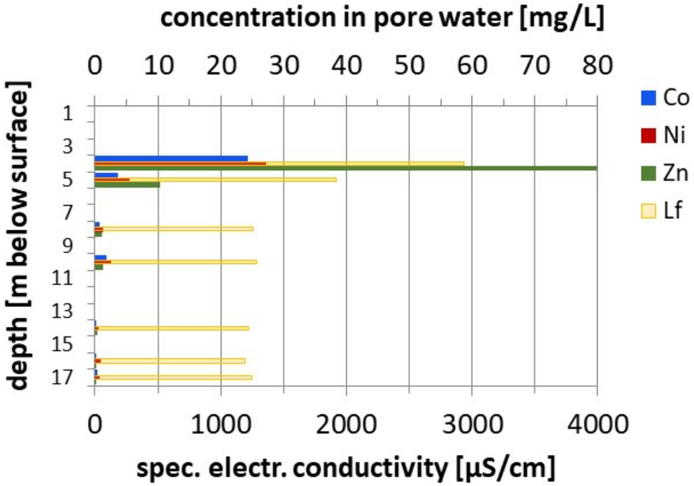
arsenopyrite as intergrowth (not in QEMSCAN)
mineral surfaces mostly unoxidized
galena with secondary minerals on the surfaces

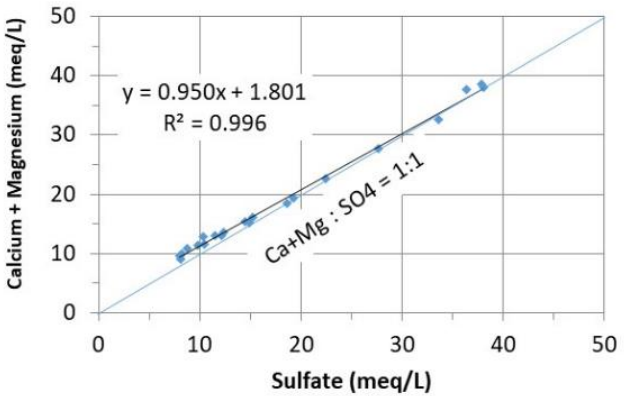
Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN)

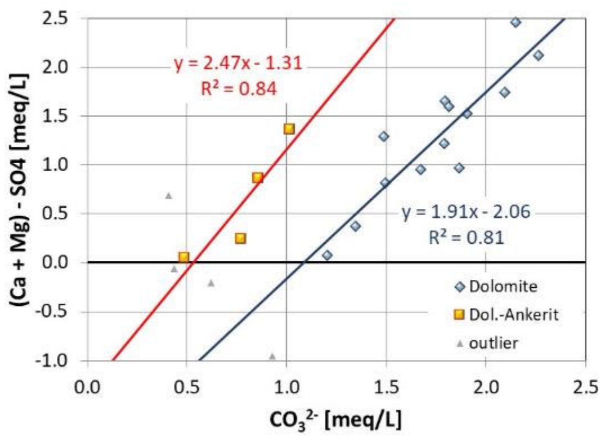
0.4 – 2.3 vol% sulfides
4.6 – 8.1 vol% dolomite, 0.6 – 1.5 vol% ankerite
0.1 – 0.5 vol% Fe-hydroxides
cerrusite as Pb sink

Pore Water Chemistry

pore water by centrifugation







Neutral pH (7 – 8),
values in capillary fringe 6.8

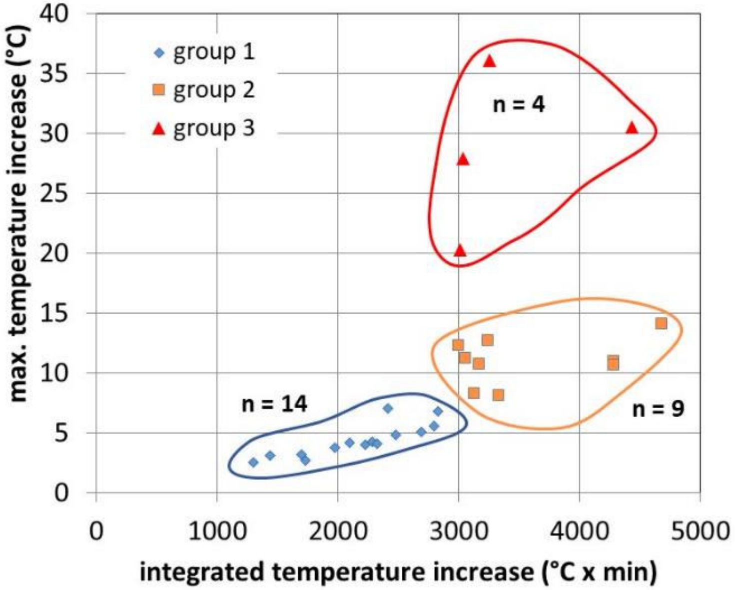
Ca, Mg correlate to SO_4^{2-} (r^2 = 0.996)
they are the major ions

Dissolution of dolomite and ankerite act as pH buffering

Zn (+/- Co, Ni) can be very high in the capillary fringe

As, Pb up to 0.4 mg/L (not shown)

Appropriate Static Testing



Net Acid Generation (NAG)

group 1 materials (not shown)
very low reactivity, neutral pH

group 2 materials
low reactivity, well buffered

group 3 materials
fast exothermic reaction, well buffered

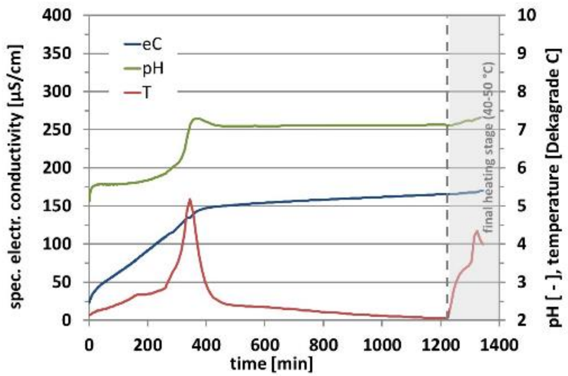
Net Neutralization Potential (NNP)

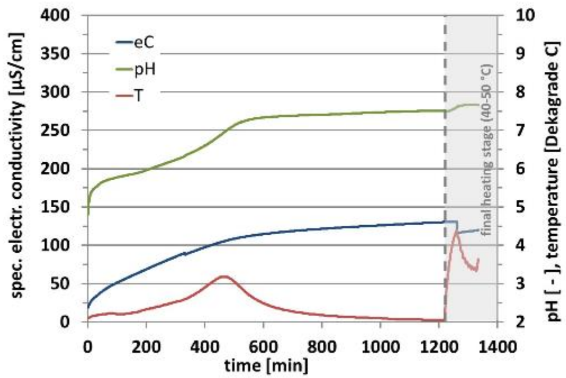
Acid producing potential (AP)

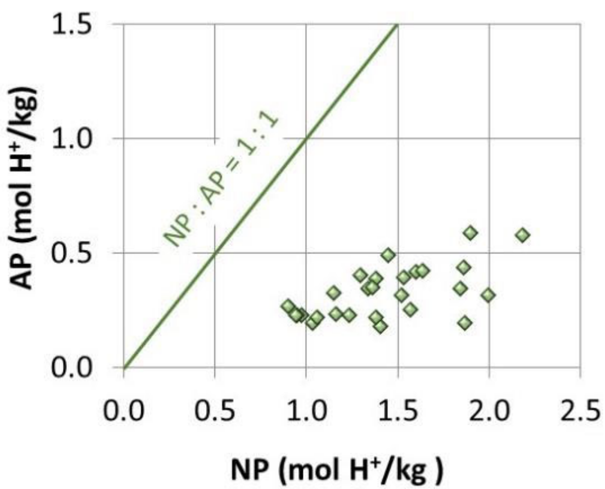
S_{tot} 0.3 – 0.9 wt.%
from S_{tot} as sulfate mean 0.04 wt.%
as pyrite, despite monosulfides
including Fe(II) oxidation

Neutralization potential (NP)

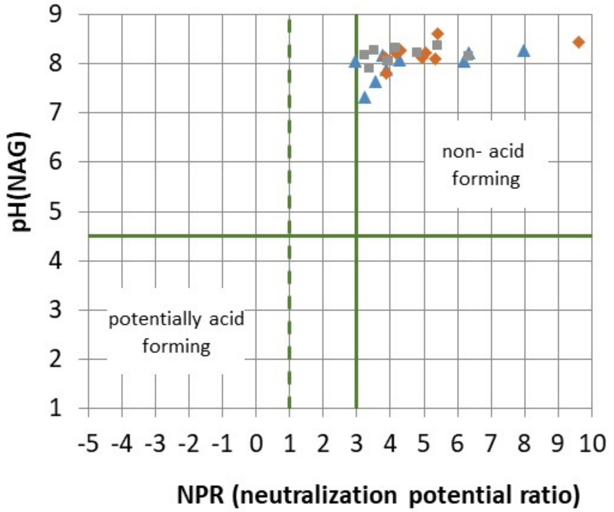
titration according to DIN EN 15875



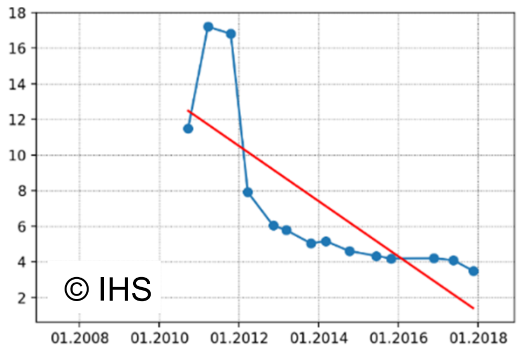


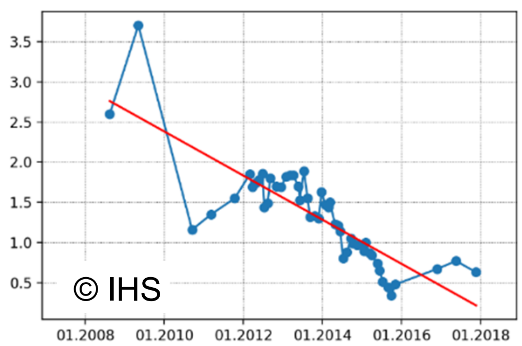


Revised Assessment



Zinc [mg/L] in an observation well (left) and the seepage trench





High NPR of 2.9 - 9.6

- Non-acid forming tailings
- Dolomite as buffering mineral
- Locally unfavored kinetics, but in bulk sufficient buffering

No indications of long-term sulfide oxidation

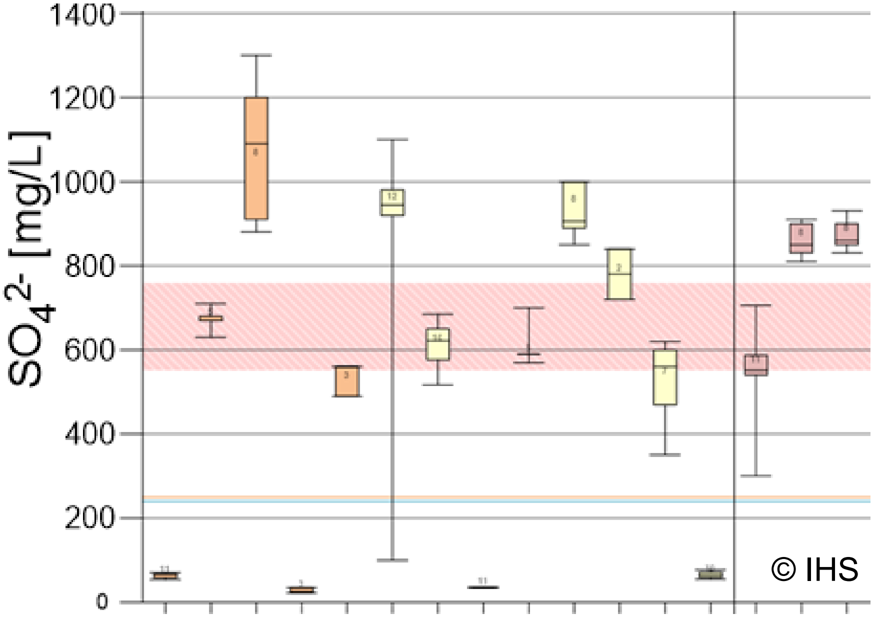
- Sulfidic minerals show fresh surfaces
- Intergrowth as described from the ore deposit
- Secondary minerals esp. on surfaces of galena

High values are a late „flush stage“

- High values of metals, esp. zinc, observed at the beginning of monitoring period
- Values have decreased since then

Recovery of quartz sand disturbed the „chemical settling“ of the TSF.
More than two decades after that period, metal concentrations are close to background.

Why still to care about and where to go?



box plots of wells and observation wells
downstream of the TSF
most of them close to the ring dike

pink bar: hinge spread in seepage trench

German Legislation and Guidelines
in the follow-up of the European Water Framework Directive

Threshold value when transported into groundwater
zinc: 0.5 mg/L

Eco-toxicologically no adverse effect threshold for groundwater
zinc 0.06 mg/L
sulfate 250 mg/L

Recommended threshold values for surface waters
sulfate 75 | 140 | 200 | 220 mg/L
depending on bicarbonate hardness and river type

Opportunities

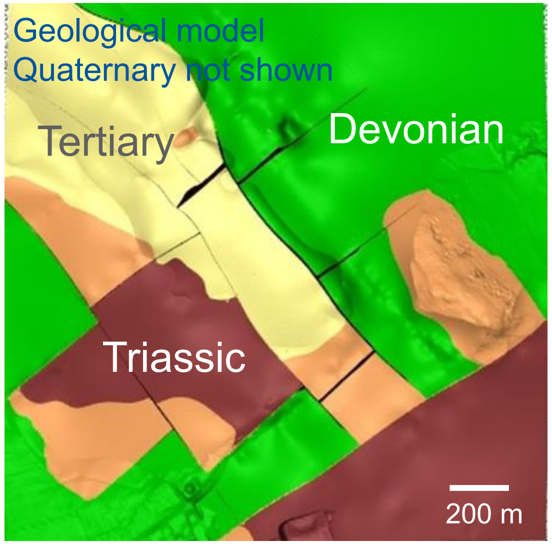
Mitigation of seepage volume

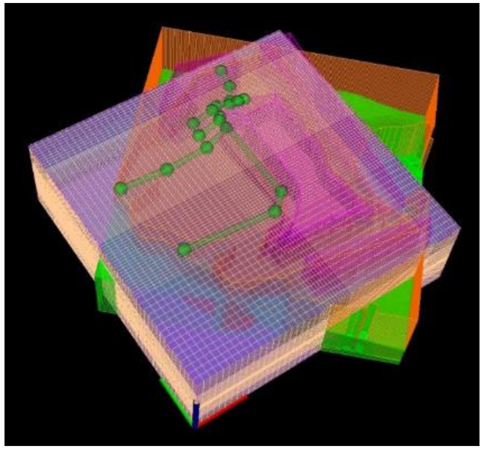
Mitigation of sulfate (and zinc) flux

Enhancement of seepage intake

Passive treatment

Few Notes about the Modelling



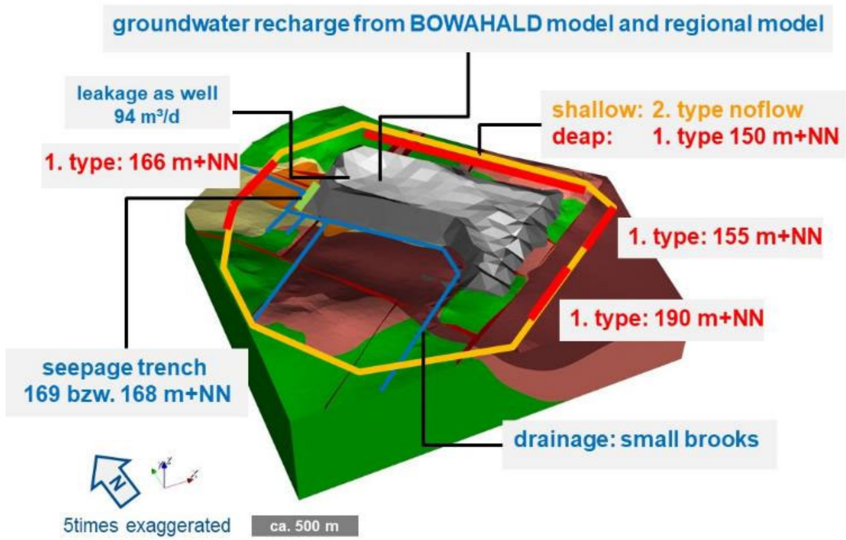


Model grid (PHAST)

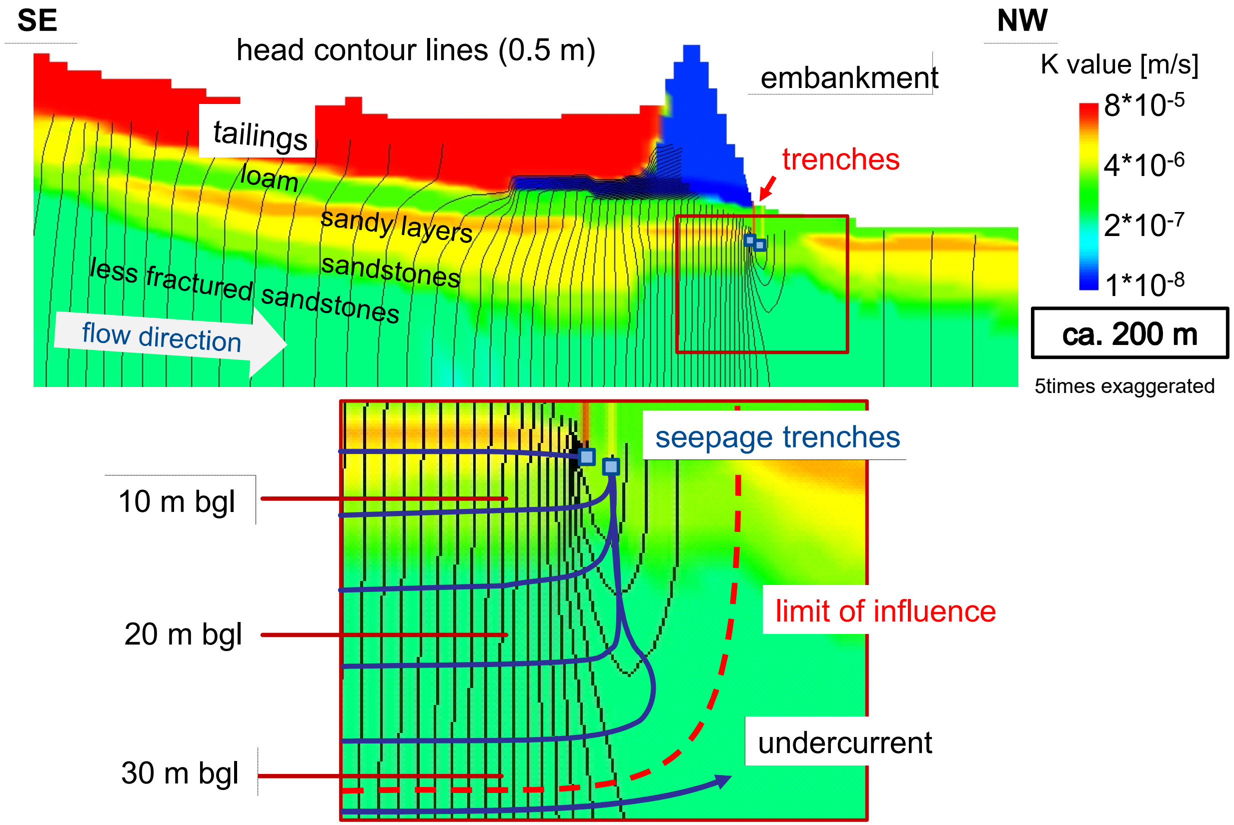
- 100 x 106 x 54 = 572.400 cells
- Width of grid 40 m, in the north 10 m
- Vertical spacing 4 m, some areas in 2 m, in the north 1 m
- Calibration by piezometric heads, leakage and regional flow

Modeled water balance of the TSF

groundwater recharge	81,000 m³ a^{-1}
infiltration	16,000 m³ a^{-1}
groundwater inflow below the TSF	31,000 m³ a^{-1}
seepage at the TSF base	- 119,000 m³ a^{-1}
seepage by the embankments	- 9,000 m³ a^{-1}



Benefits from Modelling – Appropriate Design



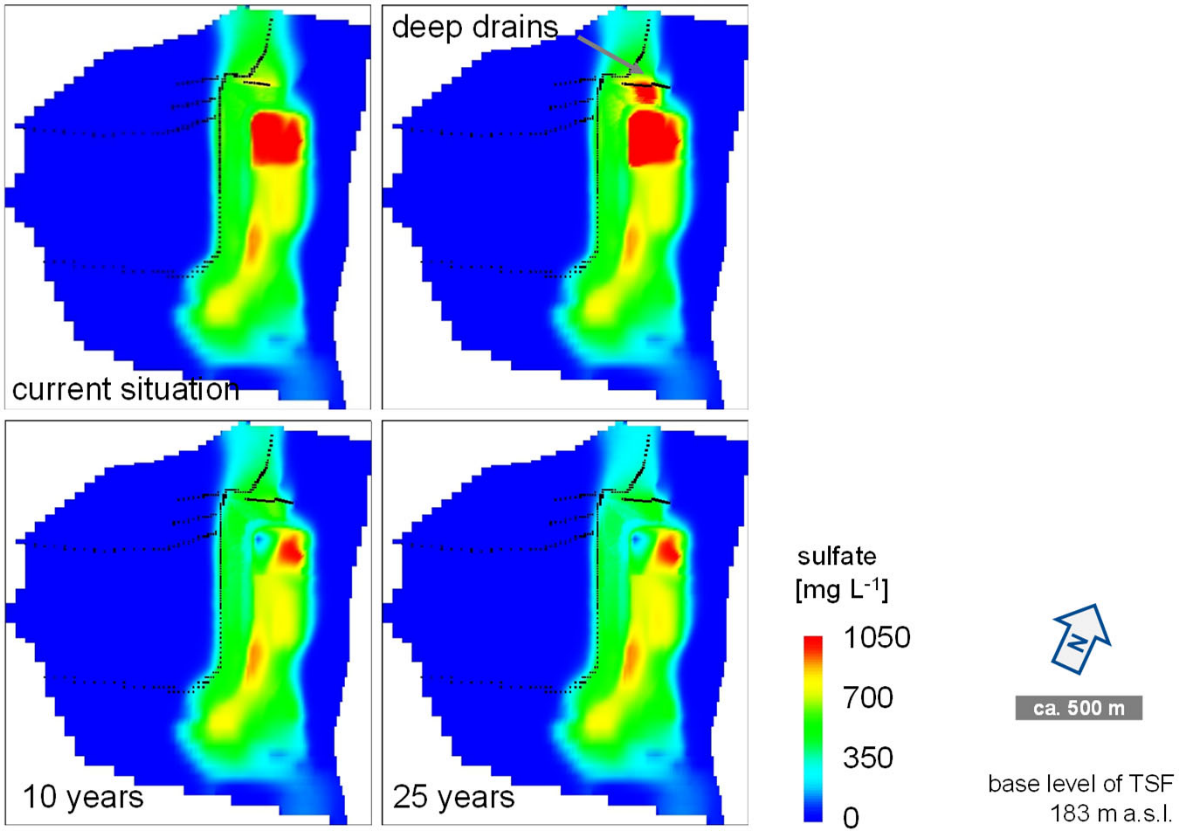
Effect of deep seepage trenches on the seepage flow beneath the TSF.

Minimum depth of trenches is 8 m.

Trench constructed in 2001:
3.5 t a^{-1} sulfate (total flux 12 t a^{-1})

The deep drainage reduces the sulfate flux in the groundwater downstream by around 4.7 t a^{-1}.

Benefits from Modelling – Prognosis



Simulation of the sulfate plume downstream the northern ring dike of the TSF

Transient flow and conservative sulfate transport

Current situation is 2019; 50 years after start of simulation in 1969

Implemented measures

- Extension of the seepage trenches by deep drains to NE
- Extension of the pond with technical sealing
- Passive treatment of sulfate e.g. by a vertical flow reactor for sulfate reduction

Conclusions

Sound understanding of mineralogy and hydrochemistry is mandatory

It saves money and time

In this case: re-assessment as non acid forming material, well buffered

Yet: sulfate flux of concern - sulfate flux is 12 t a^{-1} into groundwater (from modelling), good for 170 a

Modelling enables testing of and decision on mitigation options

In this case:

Reduction of seepage by higher evapotranspiration (afforestation, 5 – 10 % less – not shown)

Reduction of seepage by higher evaporation enlarging the pond area: 15 % less, ca. 1.7 t a^{-1} less sulfate

Improvement of sulfate collected by trenches (ca. 35 % improvement – from 3.5 up to 4.7 t a^{-1} sulfate)

Infiltration of treated seepage enables faster depletion of sulfate stored in the TSF section

Is there a feasible walk-away scenario?