ISM Commission II meeting
28th November 2024

3D numerical modelling to predict surface subsidence and environmental impact of underground salt mining

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Background:

- Existing (very mature) underground salt mine, about 200 m below surface
- Surface densely populated with several protected areas (landscape, animal habitats, water, cultural goods etc.)
- Room and pillar mining with large openings approx. 15 x 10 m (width x height) and extraction ratio of around 60 %
- Backfill
- Current subsidence rates currently around 1-2 mm/a
- Renewal of framework operating plan for the next 20 years

→ Longt-term subsidence prediction in partnership with Technical University Freiberg, Germany

Regulation on the environmental impact assessment of mining projects (UVP-V Bergbau)

§ 1 Projects

The following projects subject to operational planning require an environmental impact assessment:

1. Extraction of hard coal, brown coal, bituminous rocks, ores and other non-energy sources Mineral resources:

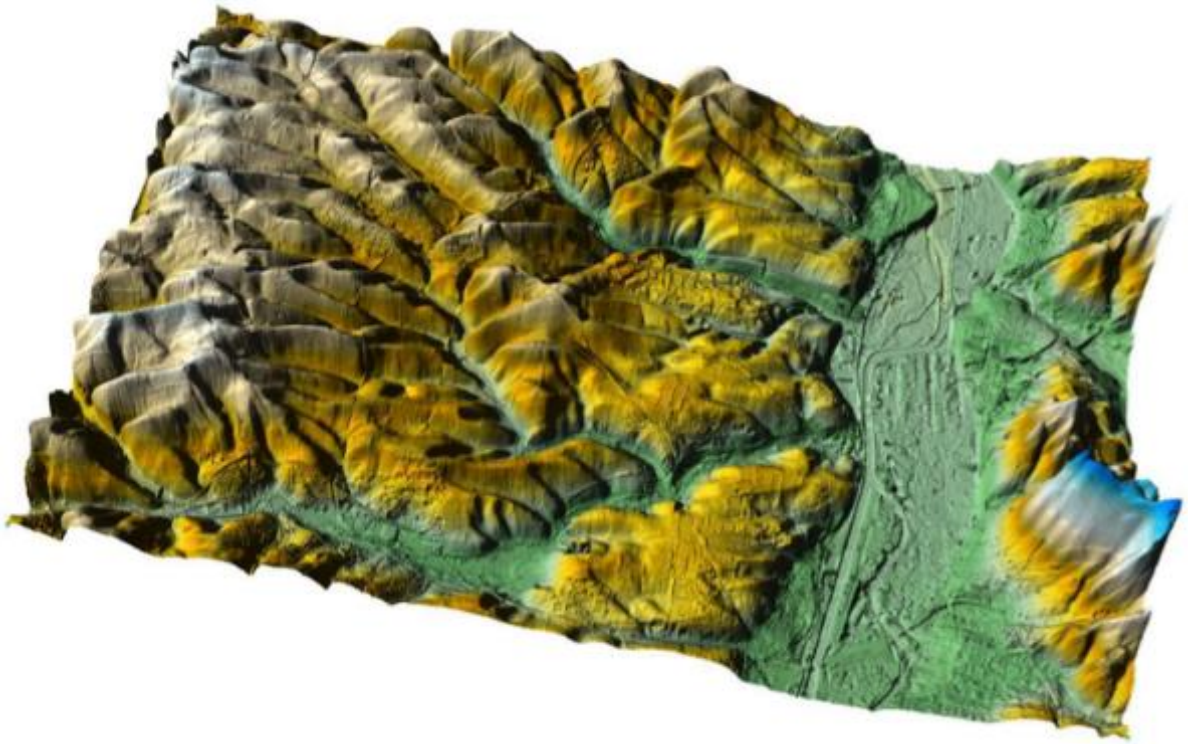
a) in underground mining

aa) space requirements for the above-ground operating facilities and facilities, such as shafts and tunnels, workshops, administration buildings, dumps (storage or dumping). of mineral resources, surrounding rock or other masses), processing facilities and loading, of 10 ha or more

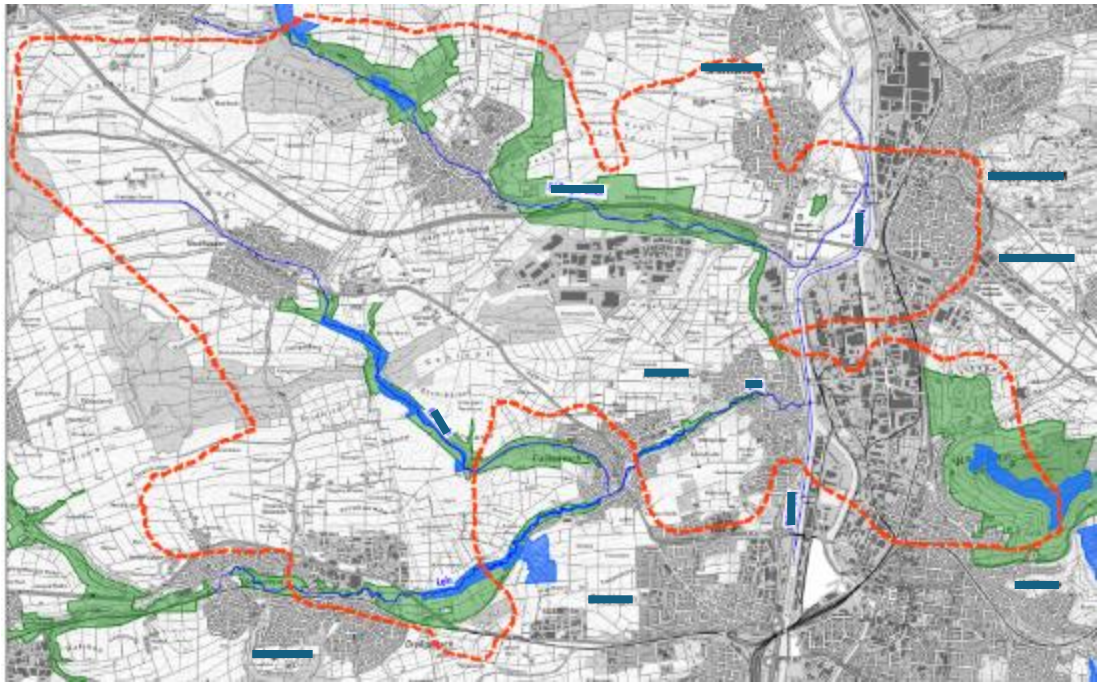
or taking into account the effects of previous operations requiring operational planning, started after August 1, 1990 or ongoing at that time and not already approved projects

bb) surface subsidence of 3 m or more, or

cc) surface subsidence of 1 m to less than 3 m, if significant impairments with regard to receiving water, groundwater, soils, protected cultural assets or comparable protected goods are to be expected; …

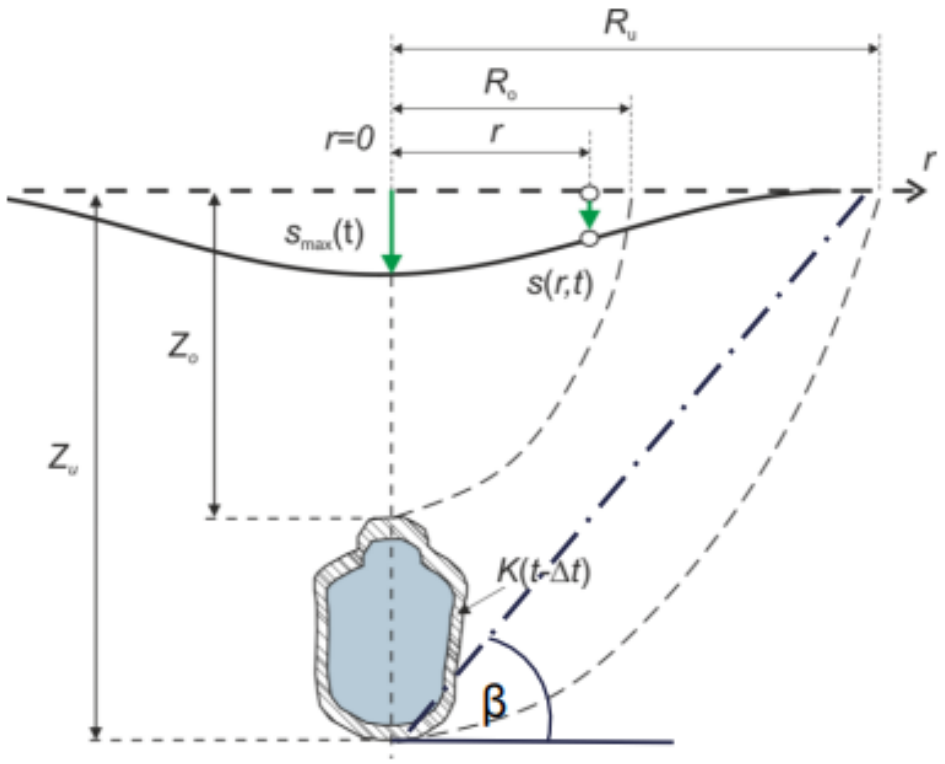


3D-Topology model of study area (exaggerated in vertical direction)



Area of influence (red-dotted) and examples of nature protection areas (blue, green)

Subsidence prediction („traditionally“)



nach Sroka (2015), unverö.

Konvergenzvolumen [m³]

$K(t-\Delta t) = k(t-\Delta t)\cdot V_E$ mit k = Konvergenzrate [%/a]
t, Δt = (Verzögerungs-/Übertragungs-)Zeit [a]
V_E = Anfangsvolumen für t = 0 [m³]

Haupteinwirkungsradius R [m]

$R = \sqrt{R_0 \cdot R_u}$ mit $R_0 = z_0 \cdot \cot\beta$; $R_u = z_u \cdot \cot\beta$

mit β = Haupteinwirkungswinkel [°]
z_o, z_u= Tiefe Kavernendach und –boden [m]
R_o, R_u = Radius bzgl. Kavernendach/-boden [m]

max. Senkung (direkt über Kaverne) [m]

$s_{max}(t) = \frac{a \cdot K(t-\Delta t)}{R^2}$, mit a = Abbaufaktor [ ]

Senkung in beliebigen Abstand r zur Kaverne [m]

$s(r,t) = s_{max}(t) \cdot \exp\left(-\pi \frac{r^2}{R^2}\right)$

3D numerical model for subsidence prediction

- Model covering 18 x 12 km horizontally
- up to 500 m vertical extend depending on topography
- application of backfill to underground voids

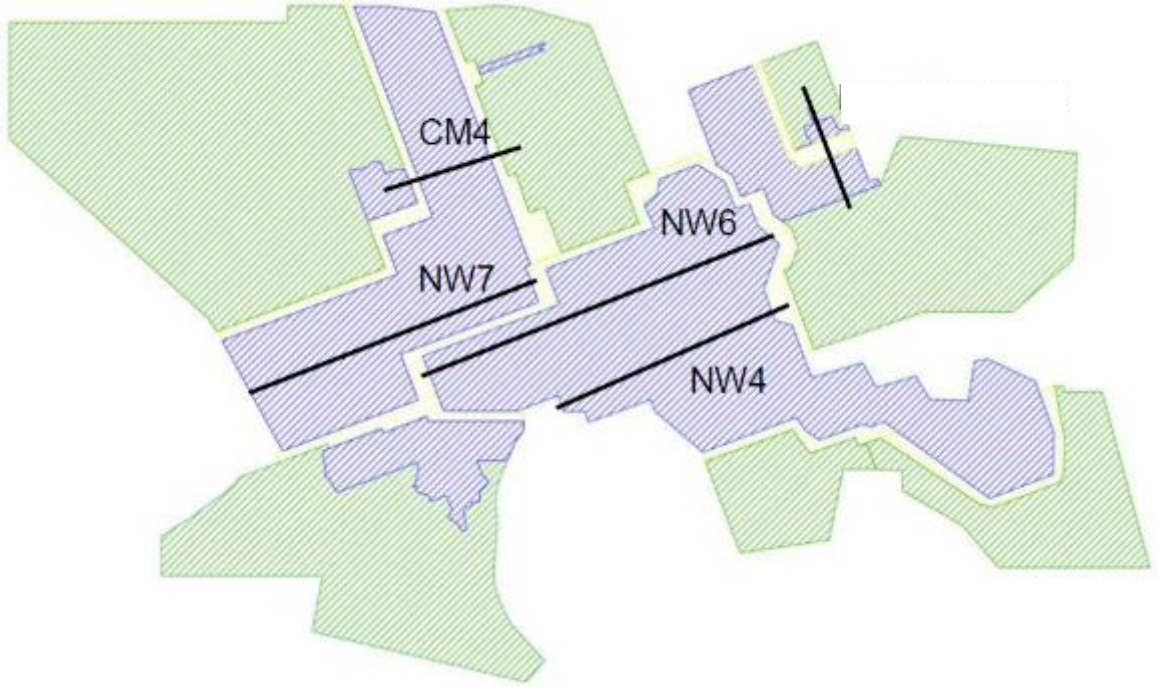
→ 3D model consists of approx. 4 Mio. gridpoints and 700.000 zones

Calibration against:
→ detailed 2D deformation modelling and detailed 3D pillar modelling
→ Areal convergence and stress-measurements across the mine

Required simplifications (for optimised running-time):

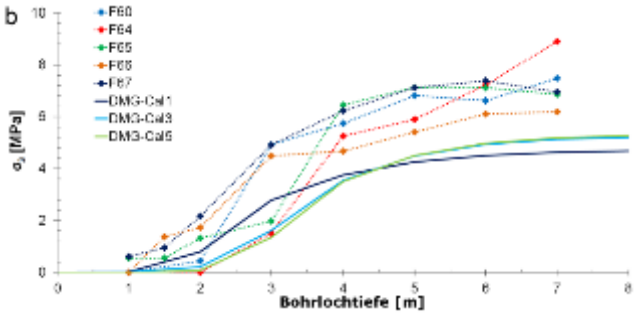
→ Simplify overbuden geology (but only if geotechnically similar)
→ Simplify pillar layout

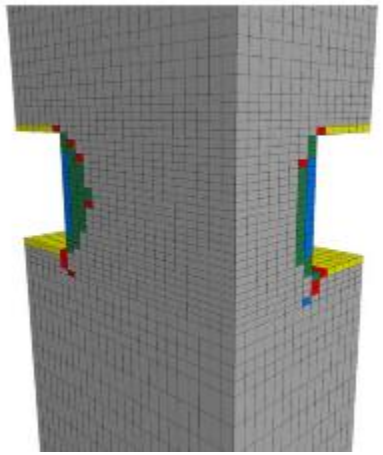
Detailed 2D subsidence modelling and 3D pillar modelling

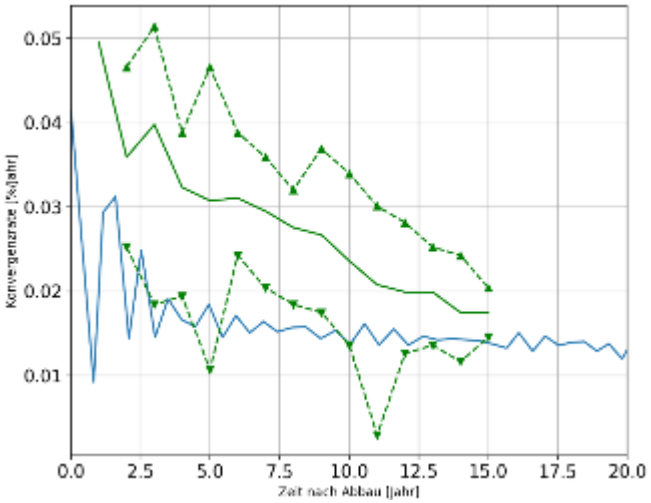


Sketch of mine layout
→ blue: existing mined out area (19 Mio. m^2, 10.000 pillars)
→ green: future developments

Pillar stress measurement + modelling







U/g convergence measurement and modelling

Constitutive material models in FLAC 3D

Geology	Mohr-Coulomb	Burgers-Mohr (Creep)	Double Yield
Overburden	x		
Salt	x	x	
Backfill			x

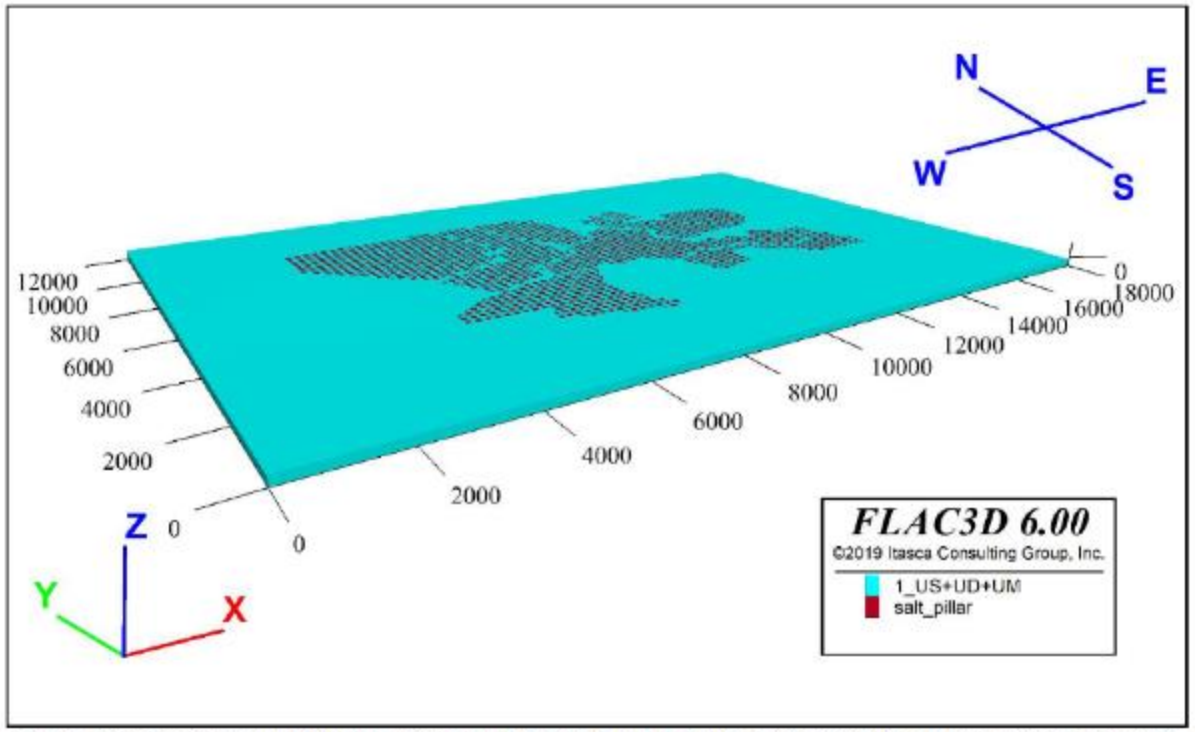


Abb. 6: Abgedecktes numerisches Modell mit Darstellung der Pfeiler in den Abbaufeldern (Angaben in m)

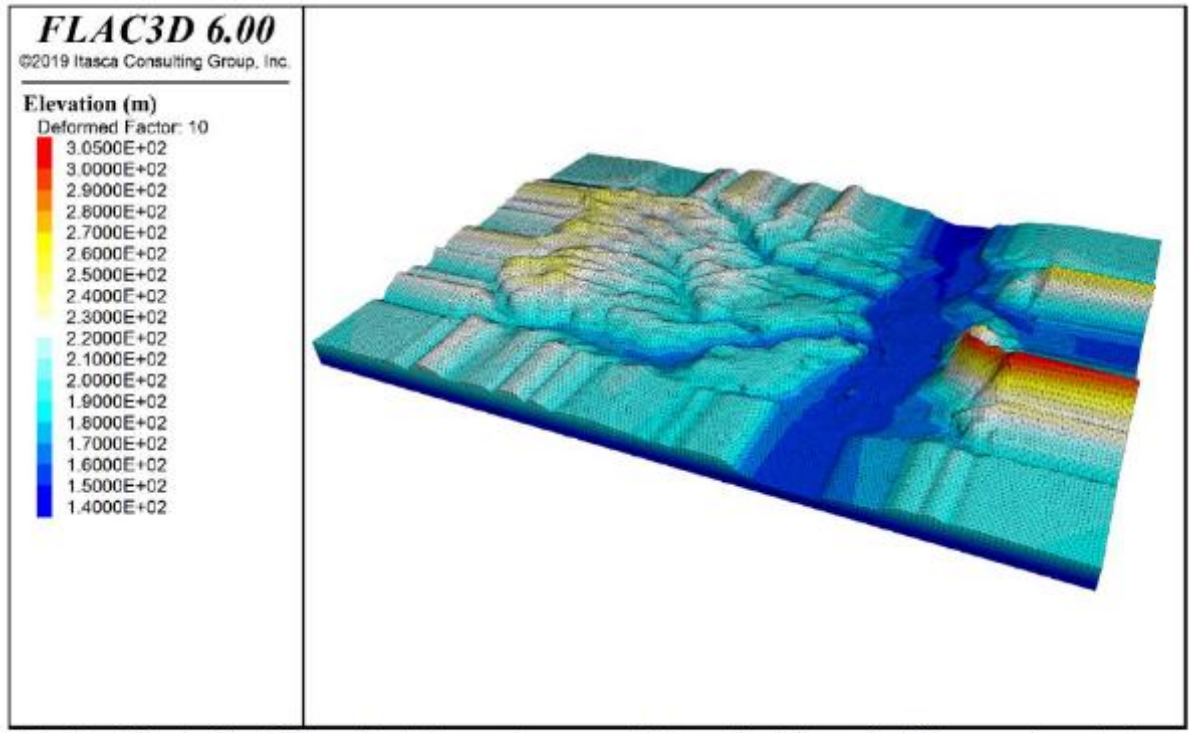
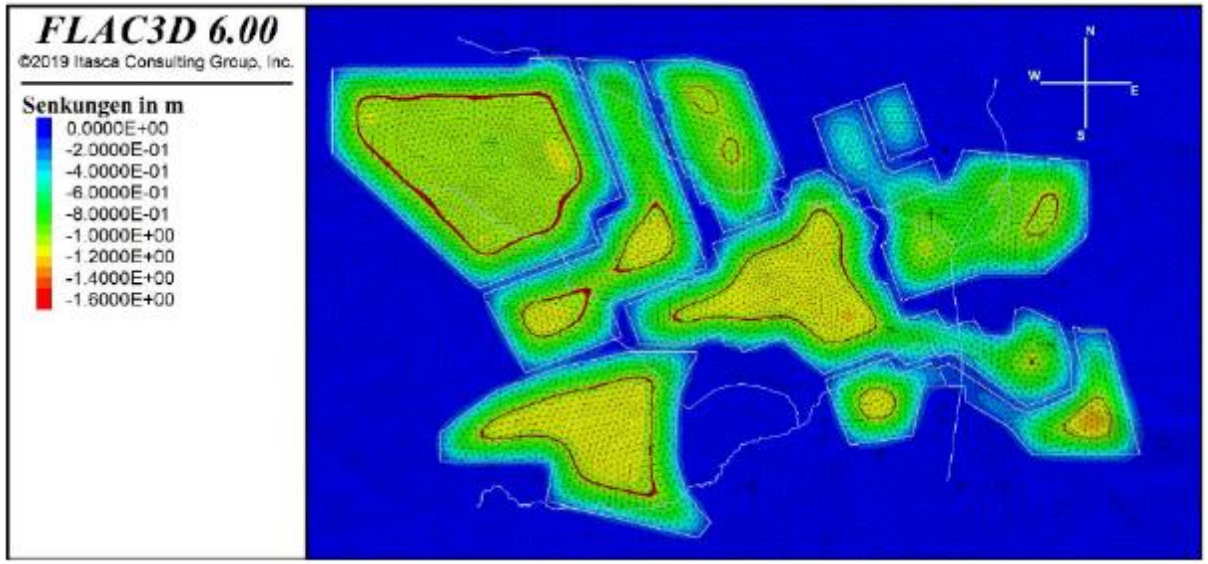
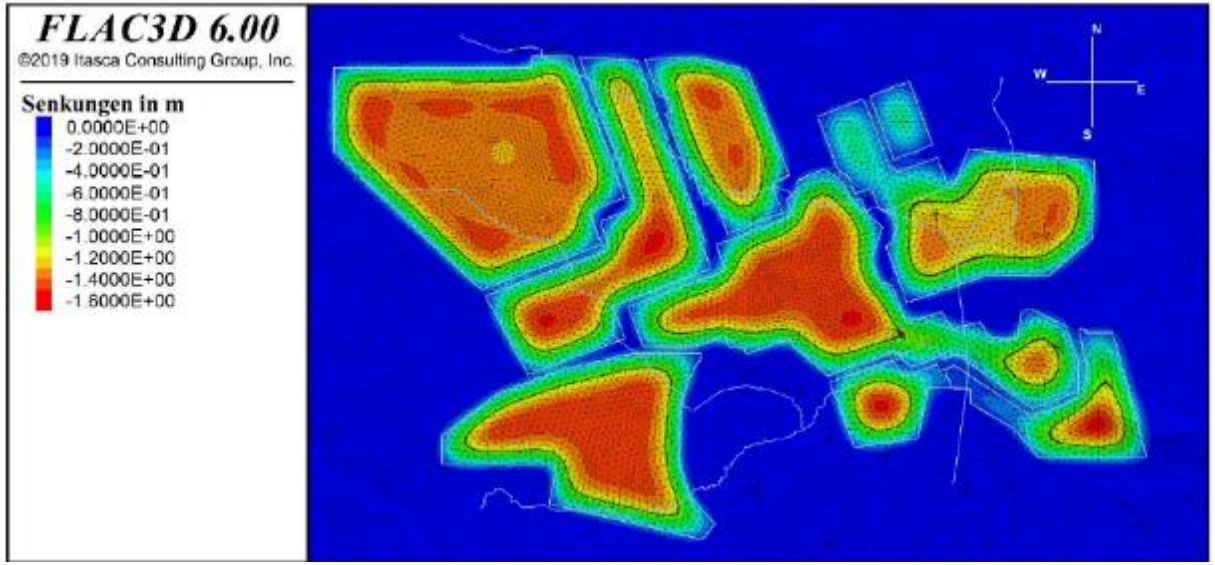


Abb. 7: 10-fach überhöhte Darstellung des numerischen Modells mit Höhenangaben [m] zur Veranschaulichung der Topographie (vgl. Abb. 2)

Predicted surface subsidence

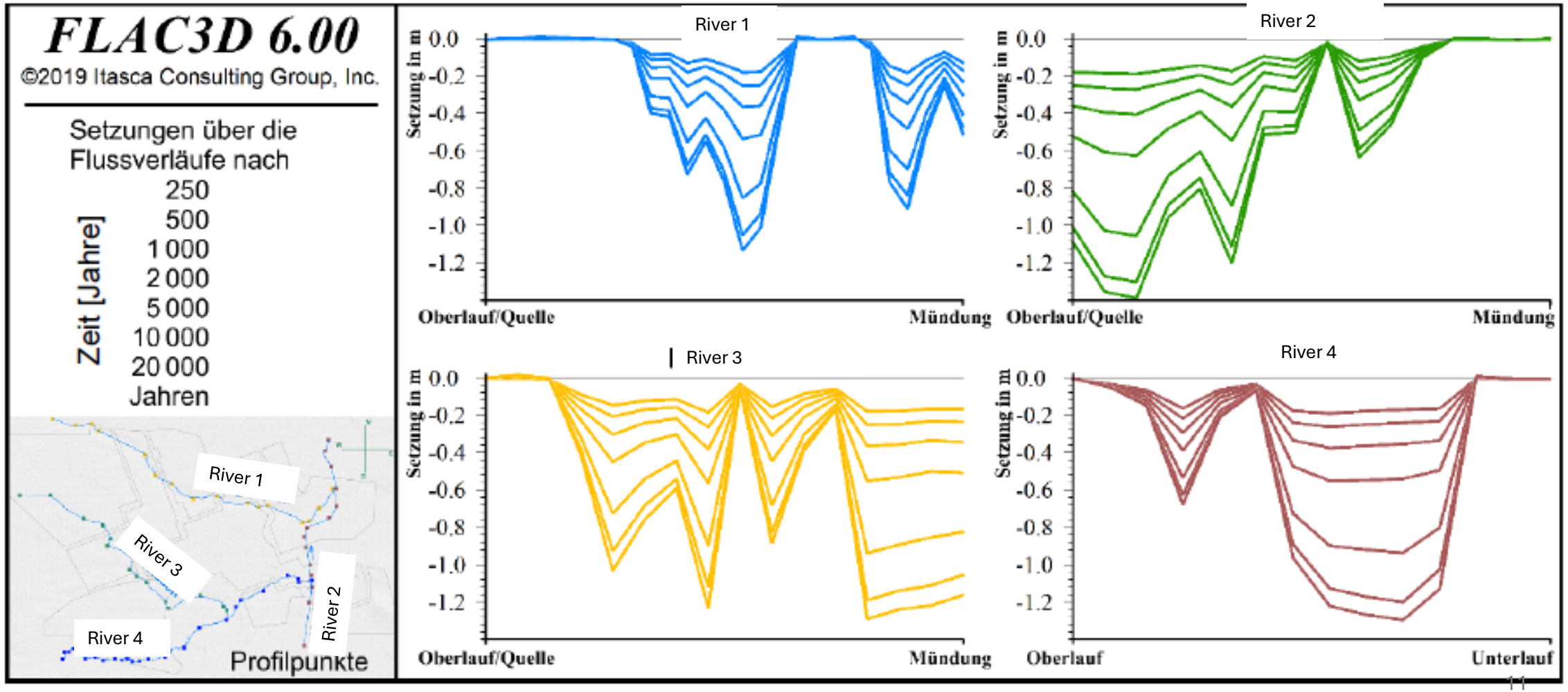


After 5.000 years



After 20.000 years (final)

Subsidence effect on river beds



Thank you!