Hydrology of Engineered Covers of Waste Rock Dumps towards Heavy Rainfall Phenomena: A Case Study in Uranium Mill Tailings Mitigation

Schneider, P.[1]; Schaffrath, M.[1]; Nindel, K.[2]

[1]Hydroisotop-Piewak GmbH, Oberfrohnaer Straße 84, D-09117 Chemnitz, [2]WISMUT GmbH, Jagdschänkenstraße 29, D-09117 Chemnitz

Abstract. The in-situ remediation of uranium mine dumps by engineered and planted mineral soil covers plays an important role in long-term mitigation of uranium mining sites in Eastern Germany. This case study discusses results of soil mechanical and hydrological investigations of a mine dump with a 10 years old engineered mineral soil cover. A heavy rainfall event was simulated using irrigation equipment including a precipitation measurement gauge assuming 120 mm precipitation within 24 hours ($N_{120/24}$). Soil moisture and water content were measured by a frequency domain response (FDR) sensor.

Introduction

The site understudy is Schüsselgrund Mine Dump, a uranium mine tailing constructed in 1967 as a part of the Königstein mine (see figure 1). After the end of the mining activities in 1990, Schüsselgrund Mine Dump is part of the remediation activities involving the Königstein mine. Schüsselgrund mine dump currently is made up from mining waste containing uranium and radium. The retrieved during the remediation activities at the Königstein site. The main data on hydrogeology, hydrology and geochemistry of the Schüsselgrund site are given in Schneider et al. 1999 and Schneider et al. 2001.

Schüsselgrund Mine Dump covers 24.2 ha (including 8.0 ha slopes) with a total volume of 3.9 mio m^3. The dump has a high priority in the complete remediation activities due to the chemical, mineralogical and radiological composition of the materials disposed at this site. Currently, a continuous release of radioactive materials occurs via air and water paths. The investigations reported in the following have been motivated by the need for estimates concerning the long-term stability of mineral soil covers. As a basis for this study the existing engineered soil covers have been investigated in order to obtain hydrological and soil mechanical data of the engineered covers of the slope during periods of heavy rain events. The long-term remediation strategy includes a greening of the dump plateau. For the dump plateau, a double layer mineral cover has been projected. The prospected utilisation of the site is forestry.

Site Characterisation

Location and structure of the tailings

The testground is located south-southeast to Dresden City, the capital of German Land Saxony. The site is situated in the environmental protection area ‚Sächsische Schweiz‘ in a distance of 5 km to Elbe river and about 2.5 km away from ‚Sächsische Schweiz‘ national park (see Fig. 1).

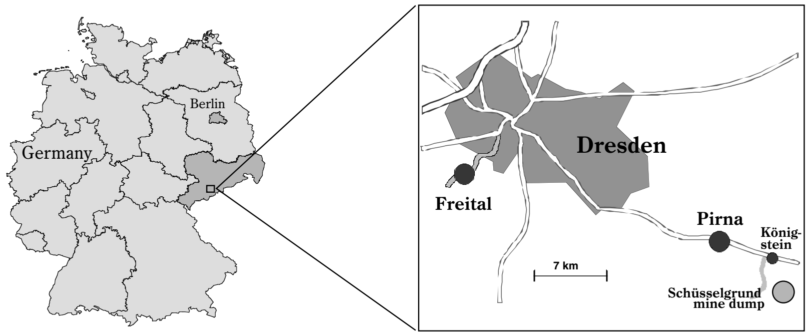

Fig. 1 Location of the study site

The area surrounding the site (except the western part) is under Forestry Commission. To the west facilities of the Königstein mining plant are located. Further beyond the facilities, areas are used agricultural. Height of the dump plateau is about +300 m NN, the base at +250 m NN. The slope at the northern and eastern side of the dump has been covered with mineral soils of about 1 m thickness between years 1991 and 1998. The mineral soil cover is constructed on an engineered basis of mining waste with a height of about 10 m. On a width of 60 m towards the center of the dump, tailings with increased radioactivity have been dumped.

Soil mechanical characterisation

The slopes are constructed with tips with a height of 10 m separated by almost horizontal sections with a depth of about 5 m. The slope of the visible side has an average of 1:2.5. The soil of the existing cover is made up from about 25 % silt and 75 % sand (result of a particle size analysis). At the time of construction, densities (dry) in the range 1.6 g cm^{-3} to 1.8 g cm^{-3} and permeabilities in the range $5.6 \cdot 10^{-10}$ m s^{-1} to $9.6 \cdot 10^{-10}$ m s^{-1} (kf; according to DIN 18130) have been obtained for the engineered layers. As a result of chemical analysis a pH 5.7, low amounts of humics (nearly 0.2 %), leachable phosphorus (nearly 18 ppm) and potassium (50 mg–70 mg) have been found. Leachable magnesium (50 ppm – 70 ppm) was in the average while leachable calcium (about 0.5 %) is above average.

Starting in 1988, tips and horizontal sections of the slopes have been successivley cultivated according to a planting schedule developed by Tharandt University of Forestry. A section of the tailings basement has been planted by coniferous and deciduous trees (pines, spruces, alders, beeches). The slopes have been covered with both spreading and grouping grass species together with brushwood fascicles for additional stabilisation. The covers on the slopes are drained by trenches and ditches to ease the run-off of surface water. In 1996, the engineered covers have been investigated at four locations to understand the effects of rootage. The measured permeabilities (Durchlässigkeitsbeiwert) (from infiltration measurements according to DIN 18162) have been in the range $4.4 \cdot 10^{-5}$ m s^{-1} and $6.6 \cdot 10^{-5}$ m s^{-1}. At the time of that study, the engineered covers have been in site for about 5 years with dry densities of 1.21 g cm^{-3} and 1.7 g cm^{-3}.

Climate and general hydrologic setting

The site has a moderate climate. Average annual precipitation is about 750 mm. Since the beginning of quantitative observations, German Meteorological Office (DWD) recorded an absolute annual high of 1172 mm and an absolute annual low of 484 mm. Average annual temperature is about 7.6 °C. DWD gives recurrence intervals for heavy rainfall events listed in Table 1.

Table 1: Recurrence intervals for heavy rainfall at Schüsselgrund Mine Dump.

Repetition period in years	**6**	**10**	**20**	**50**	**100**
mm precipitation	70	80	93	109	122

Field experiments

The stability of the engineered covers of the slopes has been investigated in the unsaturated (natural soil moisture) and saturated conditions in former geomechanical investigations. According to geomechanical modeling calculations, the stability of the engineered covers decreases with increasing penetration of the saturated zone. At a depth of 0.5 m, the stability limits will be reached. Such a penetration depth of the saturated zone may be possible only after a heavy rainfall event. In the course of a long-term performance assessment for the stability of the engineered covers, these modeling results have motivated irrigation experiments at four selected sections of the slopes, each covering an area of 20 m^2. As a scenario, a 100 year recurrence event was simulated (see Table 1). During the irrigation experiments, soil moisture was recorded continuously in a depth of 0.5 m. In addition, field measurements have been supplemented by laboratory experiments.

Irrigation studies

A 100 year recurrence rainfall event was simulated using irrigation equipment including a precipitation measurement gauge assuming 120 mm precipitation within 24 h ($N_{120/24}$). The water was provided in a 4 m^3 mobile tank above the irrigation fields. Irrigation was regulated by an irrigation computer. The amount of precipitation was diveded into 10 min intervals using an electronic rain recorder with 0.2 mm resolution. Soil moisture was measured by a frequency domain response (FDR) sensor in a depth of 50–60 cm. Selection of the irrigation fields intended to represent the variability in vegetation conditions of the slopes. The locations of the four selected sites, VF1 to VF4, are given in Figure 2.

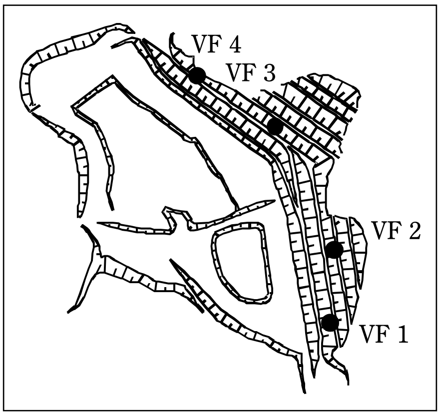

Fig. 2: Locations of the irrigation fields VF1 to VF4.

The water content (in vol-%) was recorded by the FDR sensor with a resolution of 0.1 vol-%. The resolution allowed to record minor variations in the water content during the irrigation period. Soil samples of the irrigated fields have been collected before and after the irrigation to obtain soil physical parameters of

- shear resistivity according to DIN 4096,
- density according to DIN 18125 – F 62,
- shear parameters (friction angle and cohesion) according to DIN 18137 Part 3 (E),
- grain size distribution according to DIN 18123,
- grain density according to DIN 18124,
- water content according to DIN 18121 T 1.

Density and water content of the engineered cover materials have been determined from two soil samples from each of the four irrigation fields taken from 30–35 cm, 50–55 cm and 50–60 cm, respectively. Shear resistivity, considered as a measure for stability of the engineered cover, has been obtained from one sample for each section taken in 50–60 cm depth. Because of a heavy natural rainfall immediately before starting the investigations, irrigation was reduced to 70 mm at section VF1.

Results and Discussion

Irrigation experiments

Soil status before irrigation

The soil in the irrigated sections consitst of silty fine grained sand to sandy silt. The clayey components, important for the water binding capacity, has a relative contribution of 5 to 9 percent. In section VF3 a higher content in gravel was found. Soils are classified as stiff to medium solidified. Furthermore, a decrease in soil moisture of 0.15 was found in the engineered cover going from the upper to the downer part of the slopes. A hydraulic gradient directing to the center of the mining waste has to be assumed because the dump material has a higher permeability compared to the engineered cover.

Evolution of soil moisture changes during irrigation

Results of continuous soil moisture measurements during irrigation are given in Figure 3 for the four irrigation sections. Soil moisture maxima have been observed for sections VF3 and VF4 after about 10 hours irrigation while soil moisture developed almost continuously for the other both sections. After irrigation, soil samples showed an increase in soil moisture between 1.7 vol-% (minimum; VF2) and 5.4 vol-% (maximum; VF3).

Table 2: Soil mechanic characteristics in 50–60 cm depth following irrigation.

irrigation field	**VF 1**		**VF 2**		**VF 3**		**VF 4**	
sample number	1	2	1	2	1	2	1	2
specific weight γ in kN/m³	20.4	20.2	20.1	20.7	18.8	19.3	20.1	20.7
angle of friction φ' in °	34.2		34.6		29.7		32.3	
cohesion c´ in kN/m²	25.55		35.09		15.27		24.54	

The soil was classified as stiff. A certain undersaturation of the soils was indicated by comparing calculated densities and measured bulk densities for 50–60 cm depth, while no significant changes could be observed for cohesion and density.

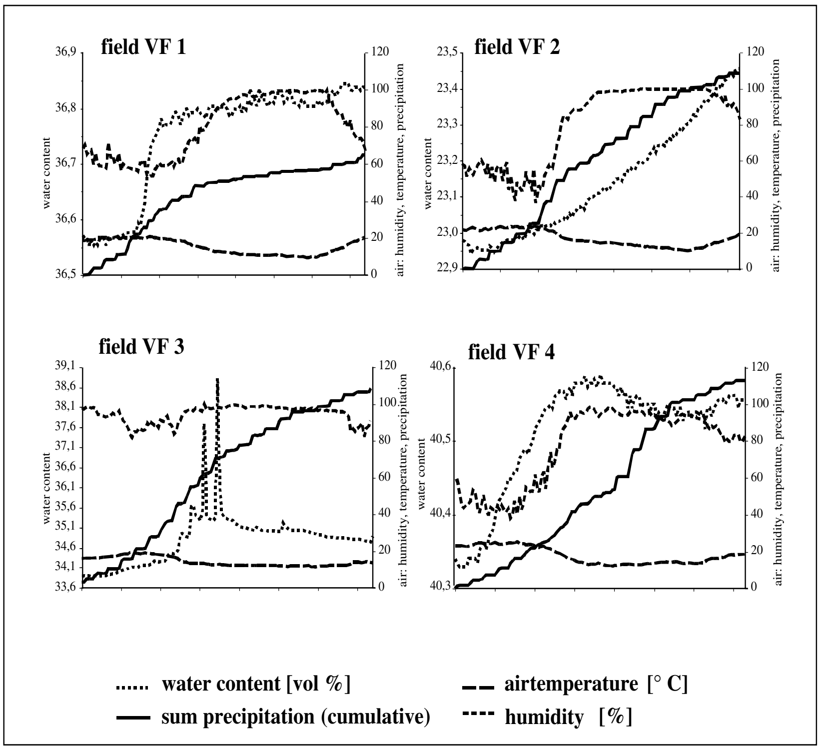

Fig. 3: Results of continuous soil moisture measurements during irrigation.

In the sloped sections (30 to 35 cm) a slight undersaturation of the pore volume was found on basis of measurement results given in Table 3. After irrigation, a local saturation could be observed in some upper parts of the slopes causing surface runoff.

Table 3: Soil mechanic characteristics in 30–35 cm depth.

30 – 35 cm depth	**VF 1**	**VF 2**	**VF 3**	**VF 4**
dry density [g/cm^3] before irrigation	1.488	1.8705	1.566	1.722
% water content before irrigation	24.95	12,7	24,55	17,7
pore volume	0.4404	0.2968	0.411	0.3761
calculated density at saturation g/cm^3	1.93	2.17	1.98	2.10
measured density g/cm^3	1.86	2.11	1.92	2.03

Due to surface run-off, the saturation zone of the slopes can be found in a depth between 0 cm and 35 cm. It is furthermore possible that in sandy locations observation of a saturation zone may fail as a consequence of local variability in material composition, that is indicative of a constant hydraulic gradient.

Results of hydraulic modeling

Hydrological modeling using HYDRUS-2D was prepared to verify the hydraulic and hydrologic processes in the mineral soil cover for mean climatic conditions and for the heavy rainfall phenomena. The computer program HYDRUS-2D was developed by the Soil Physics group (Simunek, J, Sejna, M. and M. Th. Van Genuchten 1999) of the U.S. Salinity Laboratory, USADA-ARS, Riverside, CA. It is a software package for simulating water, heat and solute movement in two-dimensional variably saturated media. The model numerically solves the Richards` equation for saturated-unsaturated water flow and the convection-dispersion equation for heat and solute transport. The flow equation incorporates a sink term to account for water uptake by plant roots. Model calibration and validation was made with the measured soil mechanical and hydrologogic data. The results are shown in Figure 4.

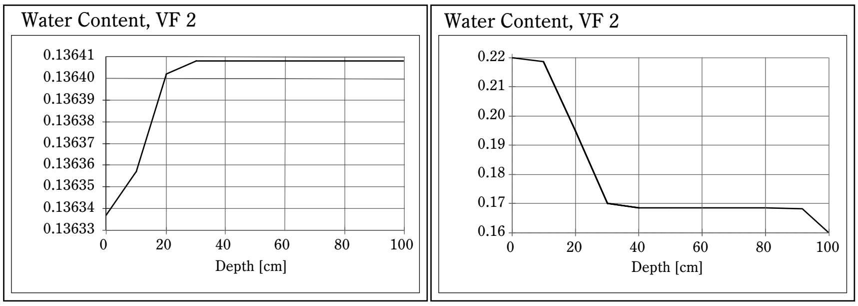

Fig. 4: Results of hydrologic modeling of heavy rainfall events at irrigation field 2. Picture 1 before irrigation, picture 2 after irrigation.

The results of the modeling confirm the measured data. Evaluation of experimental data indicates a stability of the covering layer even in case of a heavy rainfall events with recurration of one in hundred years. During the investigations it has been found impossible to reach a complete saturation of the covering mineral soil layers.

Conclusions

Based on field and laboratory experiments several conclusions concerning the engineered slopes of Schüsselgrund Mine Dump can be pointed out:

- the results of the irrigation experiments simulating a worst-case scenario with regards to rainfall and soil moisture indicate stability of the covers even for an heavy rainfall event with recurration of 100 years,
- locally, in the slopy sections of the engineered cover, erosion channels and partial land slides of limited extention may form during continuous precipitation periods,
- in these sections, additional drainage and bioengineering have to warrant a sufficient protection against erosion of the engineered covers.

References

Schneider P, Osenbrück K, Nindel K, Voerkelius S, Forster M, Schreyer J (1999) Current and future impact of a uranium mine waste disposal site on groundwater. Proc Symp of the International Atomic Energy Agency on Isotope Techniques in Water Resources Development and Management, Vienna, 1999. IAEA-SM-361-20. Published on CD-rom S4_Schneider.pdf.

Schneider P, Voerkelius S, Nindel K, Forster M, Schreyer J (2001) Release of Contaminants from Uranium Mine Waste–Laboratory and Field Experiments. Journal of Mine Water and the Environment, 20(1): 30-38.