

# Hydrogeological exploration and field tests on vacuum wells in overburden sediments for determination and modelling of process parameters and dewatering construction

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## Abstract

To develop a further opencast mining area of MIBRAG's Profen Mine it is necessary to excavate a former dump of overburden sediments including ashes and coal residues of an old coal power plant, which have been purged in between 1930 and 1990 over an area of about 0.3 km<sup>2</sup> and a thickness of 40 m.

Due to the planned excavation these sediments must be characterized problematic from geotechnical and hydrogeological point of view.

Several investigations have been used to reconstruct the composition of the complex dump and to estimate hydrogeological and soil mechanical properties of the consisting substrates.

Within this study typical exploration drill holes with substrate sampling and geotechnical sounding for soil properties and geoelectrical measurements to determine spatial water saturation were carried out accompanied by groundwater monitoring.

With reference to the determined data a spatial block model for relevant substrate properties of the complex dump is set up.

Hence the areas with a high amount of water saturation in association with small hydraulic conductivities could be worked out. In addition to that multi-step-outflow lab experiments with overburden samples suggest that vacuum dewatering is the most promising technology for an effective drainage.

With two testing sites the feasibility and impact of vacuum wells could be proved. For the whole complex dump dewatering an amount of about 120 vacuum wells will be drilled during the next months. The disposal of the required arrays of vacuum wells is based on hydrodynamic calculations. It is continuously adjusted on the latest monitoring and exploration data.

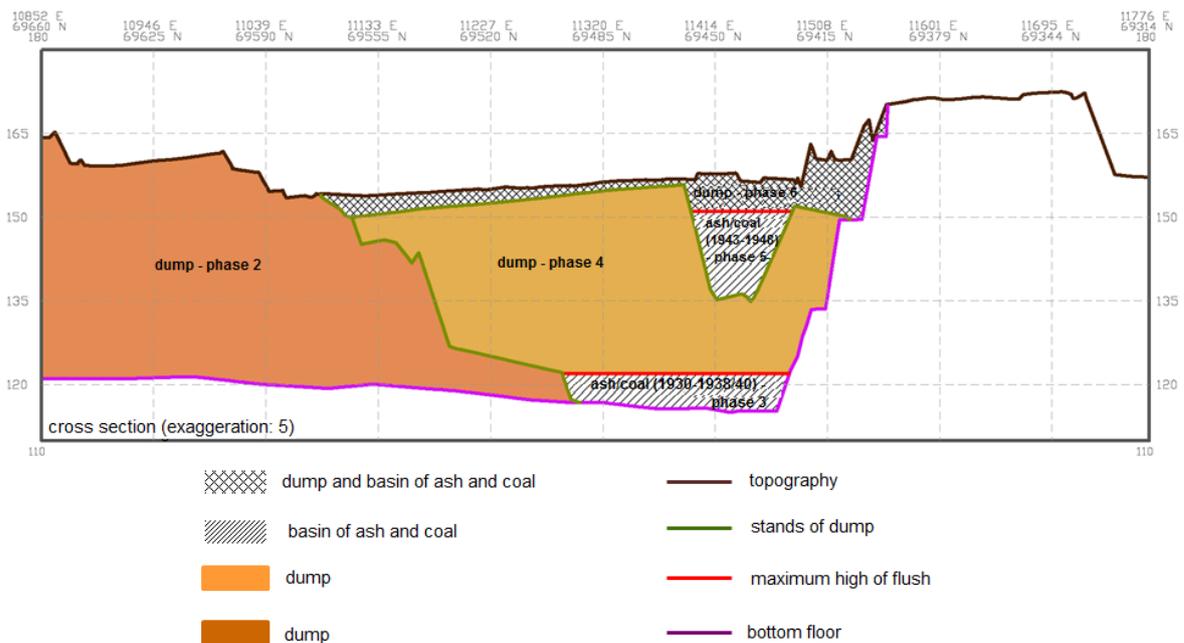
This paper shows possibility and limitations of exploration, modeling and subsequent planning of an opencast mining area by taking the example of a vacuum dewatering system on complex overburden sediments. At the end hydraulic and geotechnical conditions shall be enhanced whereby a save, efficient and economical excavation can be executed.

Key words: Exploration, Parameter Estimation, Spatial Modeling, Process simulation, Vacuum wells, Dewatering

## 1. Introduction

By developing the new mining field Domsen the mining company MIBRAG needs to excavate the Bösau dump amongst others within several former basins of ash and coal residual sediments which have been purged in. The further mining area is part of opencast mine Profen at the central German mining district in the southwest of Leipzig. The dump arises from a former mine which partly is designated for further exploitation of the underlying coal seam. It is suited at the edge of the actual opencast mine with its bedrock 30 m beyond the bottom of the adjacent hollow pattern. It is surrounded in one third by a typical dump with mixed substrates of overburden sediments and in two

thirds by bedrock. Whereby the fringe to the actual opencast mine is formed by a narrow bedrock pillar of 500 m width. The structure of the hydraulic dump system is visualized on **fig. 1**. The design of an appropriate technology for excavation of this dump requires a more detailed knowledge base of spatial extent and especially of its geotechnical characteristics and the related geohydraulic conditions. After primary investigations on about 40 exploratory drillings an approximate view of the situation was given. A highly water saturated and pasty sludge as main component of the overburden dump with an area of approximately 0.3 km<sup>2</sup> and an average thickness of 40 m have been first crucial insights. Due to these subsequent questions had to be answered: In which way according to the common used technics the exploitation of this area is possible? Is it possible to drain the substrates and how long does it take? How much water can be extracted from these sediments in a reasonable and effective way? To answer these questions a secondary exploration campaign including a historical inquiry, more detailed surveying methods and a testing site for vacuum wells was started.



**Figure 1:** Cross section through the Bösau dump system

## 2. Methods

### Exploration

The primary exploration campaign was realized with the objective to clarify basic geological structure of the Bösau dump system. Considering later recovery technology in detail the exploration focused on following aspects:

- geotechnical properties of border zone surrounding the dump system to be able to create a border slope for recovery
- completion of some parts of the Bösau dump system with insufficient amount of available geological data
- verification of historical data on structures that may have occurred during construction of the dump and that might be important for planning the recovery technology

During primary exploration campaign already 40 exploration holes have been drilled, 16 monitoring wells have been erected, 19 slug-and-bail-tests as well as 15 cone penetration tests have been realized.

At the end of this the knowledge of quantity and quality of the masses sedimented in the Bösau dump system could be improved. According to this the material deposited in the dump system, which needs to be recovered using special technology, has an overall volume of 6 Mill. m<sup>3</sup>. Although the structure of the dump turned out to be extremely heterogeneous, the material can be classified into 3 types:

- conventional overburden dump
- flushing dump consisting of ash- and coal-sludge residuals
- mixture of both

The sediments of the Bösau dump system can be identified as predominantly cohesive. Consistency varies significantly depending on water content. While in vadose zone solid to semi-solid material occurs, in the saturated zone dominates muddy material, settled irregularly.

But especially the mixture between conventional overburden and ash- and coal sludge, which makes around 30 – 60 % of the whole dump volume, are highly saturated. It is foreseeable, that slopes and working levels will show insufficient stability (highly problematical due to mine safety) unless measures are realized to improve soil quality.

Figure 2 shows drill core with dump material (from muddy on the left to semi-solid on the right).



**Figure 2:** Drill core with muddy (left) to semi-solid (right) material from Bösau dump.

Hydraulic conductivity  $k_f$ , derived from hydraulic tests (slug and bail) ranges from  $1 \cdot 10^{-6}$  to  $1 \cdot 10^{-8}$  m/s. The materials have very low conductivity and are hardly drainable. The inhomogeneity made it impossible to stratify the hydraulic characteristics.

As a result of the first exploration campaign with respect to the later recovery of the dump two resulting problems determined the next steps:

- In which way the Bösau dump system can be drained in an effective manner to improve mineability and transportability of the material?
- Is there some possibility in spite of heterogeneity of the dump to verify spatial distribution of geomechanical characteristics in order to improve extraction planning?

Answers of these two questions should be found with an additional exploration program on drainability and geomechanical characteristics.

As mentioned, after primary exploration hydrological characteristics could be named as low conductive and hardly drainable. Insofar to design an effective dewatering system special technology such as deep vacuum wells must be taken into account (Herth and Arndts (1994), Strzodka et al. (1975), Tudeshki (2014)). Therefore field tests were planned and realized.

With the objective of improving validity of geological, hydrological and geotechnical data exploration work continued with drilling 27 additional exploration holes, erection of 13 additional observation wells, realisation of about 40 cone penetration tests and soundings for determination of shear strength,

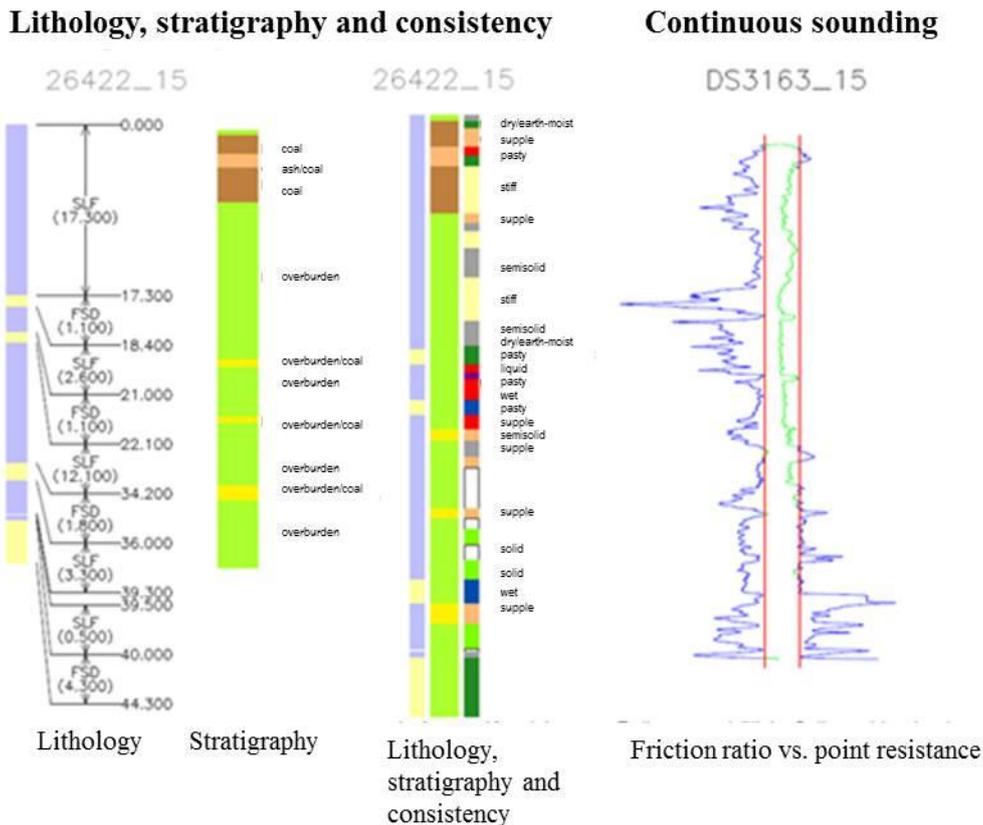
cohesion and consistency and realisation of geoelectric measurements (deep electrical well logging) for interpretation of registered electrical resistances due to water saturation of the dump.

The plurality of exploration methods and the plurality of exploration objectives (determination of dump composition and its geological, hydrological and geomechanical characteristics) applied with this spatially limited problem, differ significantly from those, who are commonly used with the operational deposit reconnaissance.

For this reason the exploration results are not analysed using the regular geological model, but special modeling turned out to be necessary. While the mine operator regularly runs stratigraphic models for its lignite operations, the dump and flushing dump system had to be modelled using block modeling. This, amongst others, commonly used for modeling impregnated ore deposits, required data preparation in a special database as well, which enables to integrate all the different exploration data in the analysis.

**Blockmodel**

Lignite deposits, mined in German open cast mines, are typically in its stratigraphic characteristics. To set up the geological model the lignite seams and corresponding overburden materials like sands and clays and the lithology information from drilling are correlated using stratigraphic codes for equal units. Between the drill holes these intervals are interpolated by empiric algorithm. This results in a quite accurate model prediction of the deposit. An abstract on geology of German lignite deposits can be found at Stoll et al. (2009).



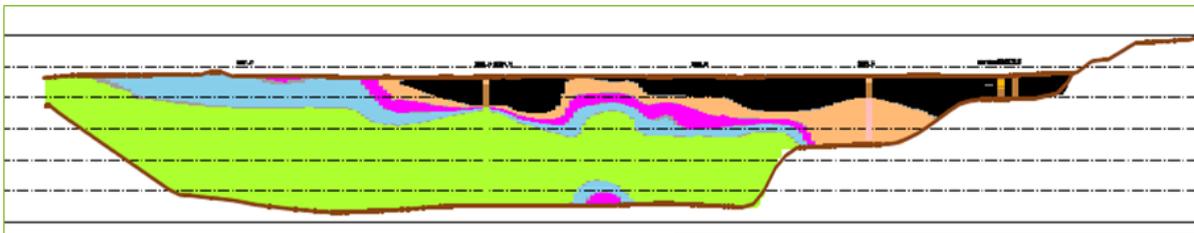
**Figure 3:** Examples of exploration results

However, stratigraphic models are not appropriate to reconstruct the lithology of old dumping sites, especially landfills with alternating emplacement and unknown origin of material. In case of the Bösau dump different sediments have been dumped and purged in over several years. To rebuild this

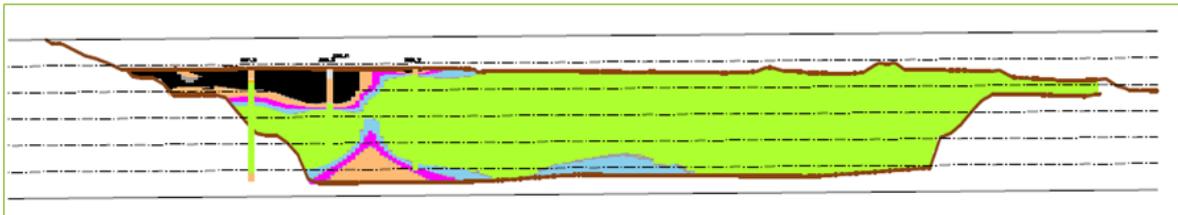
heterogeneous unit of sediments a block model for soil mechanic, hydrological and mine planning decisions had to be set up. All different exploration results collected during different exploration phases were supposed to be addressed by the model and a prediction between the boreholes was aspired.

Fig. 3 shows an example of different types of information acquired by drilling, analyzing or probing to describe lithology, texture, consistency and ground stability. Whereas regular dump material was spoiled from west, ash and coal residual sediments were purged in from east, partially at the same time, which caused locally a random mixture of materials. A high proportion of ash and coal residual sediments will cause more problems during mining because of its critical geomechanical properties. Therefore one main parameter of the block model is the ratio between expected regular dump material and ash/coal residual sediments and its spatial distribution of the Bösau dump. Vertical sections through the model are shown in fig. 4.

**Vertical cross section E-W**



**Vertical cross section N-S**



Percentage of overburden deposits	Color
0-20%	Black
20-40%	Orange
40-60%	Pink
60-80%	Light Blue
80-100%	Green

**Figure 4:** Cross Sections of Bösau dump showing the percentage of regular dumped material.

**Hydrology and Vacuum Well Tests**

Due to the maximum thickness of Bösau dump up to 45 m and an extent of 800 m North to South and 650 m East to West the hydrological situation is set by the adjacent dump and bedrock aquifers as well as groundwater recharge from precipitation at the area of about 0.3 km<sup>2</sup>, the surface of the dump complex is on +155 to +158 m a.s.l. The bottom of the dump is on +110 m a.s.l. hence the groundwater levels of the underlying aquifer complexes GWLK 5 (< +100 m a.s.l.) and GWLK 6 (< +95 m a.s.l.) are not recharging the dump. Rather a deep drainage can be assumed on discontinuities of the underlying clay.

East of the Bösau dump the unexploited bedrock pile contains the groundwater complex GWLK 3 with groundwater levels up to +140 m a.s.l. Given that there is no inflow to GWLK 3 at this remnant the only recharge is given by precipitation and effluent from surface water. Within the range of local depression zones the saturated thickness is about 15 m.

The groundwater levels at the dump Wählitz II west of Bösau dump are on 145 m a.s.l. Due to the heterogeneous distribution of overburden substrates with different soil physics a discontinuous

groundwater level can be assumed there. At this area groundwater recharge comes basically from precipitation.

The same can be supposed for the complex Bösau dump. The investigations on soil physics show highly cohesive soils by the majority with water contents up to 50 % Vol. The saturated thickness of the dump is up to 35 m or 5 to 10 m below ground level. Southbound the water level is slightly decreasing.

As a result of the high saturated substrates within the Bösau dump any additional hydraulic potential takes effect on large distances, too. For this reason recharge by precipitation or adjacent aquifers does not evoke a high amount of groundwater inflow. Rather on local depressions of groundwater levels inside the Bösau dump in case of dewatering the hydraulic gradient will effect a continuous subsequent delivery of groundwater from the outside aquifers with higher groundwater levels and higher hydraulic conductivities, too. Thus groundwater levels at the surrounding areas have to be lowered to comparable or subordinate levels.

### **Monitoring**

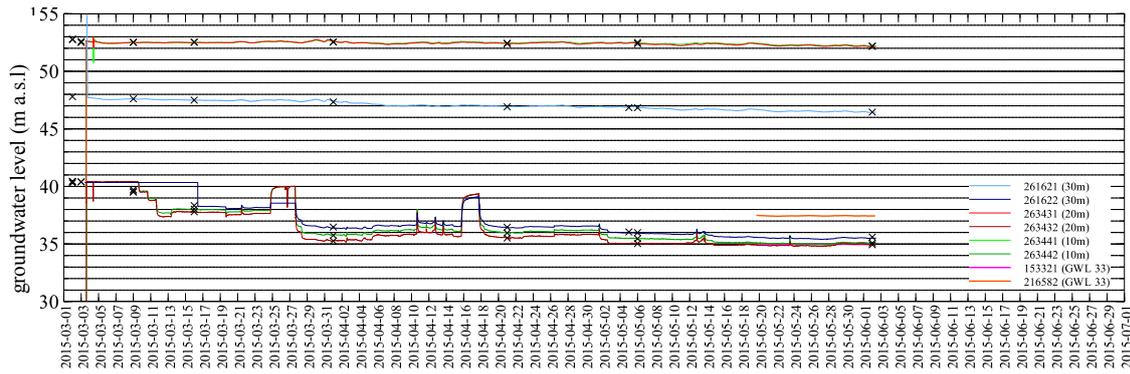
In March 2015 four vacuum wells were drilled on two different places to investigate the feasibility and influence of dewatering the cohesive substrates with negative pressure. Laboratory multi step outflow experiments on the dump substrates showed a significant higher drainage on increasing pressure compared to free drainage. On each site one well was drilled to the bottom of the dump, circa 40 m deep and one well was drilled as a shallow one, circa 25 m deep each with a 10 m screen above the well sump.

The adopted method for drilling and mounting the wells ensured a continuous pressure of -0.9 bar for the three month test phase at each of the four wells. On the very high cohesive substrates which were drilled the achieved discharge flow at the wells was between 0.5 and 2.0 L/min with a drawdown up to 10 m nearby the wells.

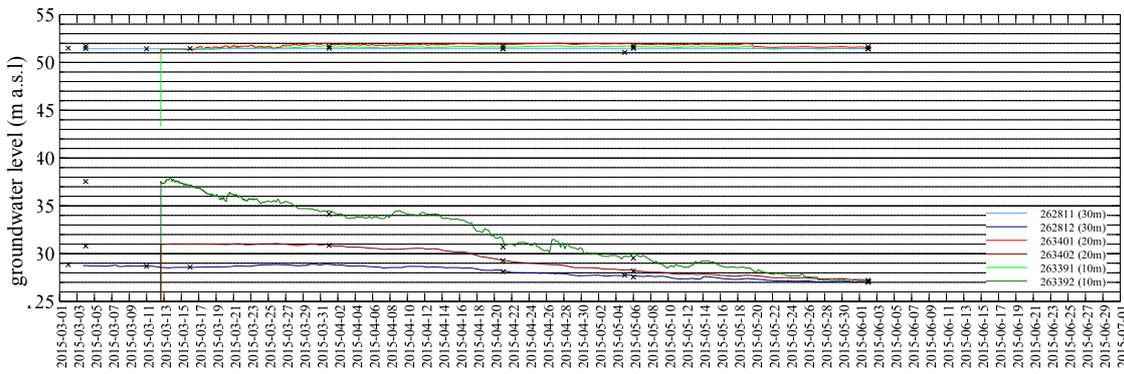
One well had a discharge flow between 100 and 120 L/min. It caused a drawdown of about 3 m on a diameter >30 m. Compared to the other experimental wells this one had a significant higher discharge flow. The reason for this is a sandy seam with a thickness between 4 and 10 m which shows the inhomogeneity of the dump (see figs. 5 and 6).

The following essential results were made on the experimental wells: The maximum vacuum could be achieved with levels from 0.9 to 0.92 bar. This was ensured by setting up the bentonite seal underneath the groundwater level. At both experimental sites the drilled substrates were typical inhomogeneous dump substrates by the majority. At the site in the north fine sandy medium clay and aquiferous fine sands (thickness up to 10 m) were detected. At the site in the south the substrates were almost the same, more silty and without the sandy seam. The thickness of the bentonite seals at the wells is about 10 m, generally. Therefore the wells do not discharge coal and ash slurry which are lying in the upper zones of the Bösau dump.

The silty dump substrates show hydraulic conductivities between  $1.1 \cdot 10^{-6}$  and  $2.0 \cdot 10^{-8}$  m/s. Significant higher values from  $1.4 \cdot 10^{-5}$  to  $2.9 \cdot 10^{-5}$  m/s are possessed from the fine sands in the lower part of the dump. According to this the wells screened in silty seams had lower discharge rates than the ones in the fine sands. The radius cones of influence were calculated between 5 m for the shallow ones and between 40 and 200 m for the ones drilled to the bottom of the dump. With continuous flow rates the pumped water contained no turbidity or sediments.



**Figure 5:** Time series for period of testing at observation wells in 10 m, 20 m and 30 m distance of the vacuum wells on the northern site with screens within the upper and the lower range of Bösau dump. (Crosses assign measurements by hand)



**Figure 6:** Time series for the period of testing at observation wells in 10 m, 20 m and 30 m distance of the vacuum wells on the southern site with screens within the upper and the lower range of Bösau dump. (Crosses assign measurements by hand)

A continuous and frequent hydrological monitoring of groundwater levels is executed at Bösau dump as well as at the adjacent dump and bedrock areas. 40 observation wells are measured every two months and 16 monitoring wells are equipped with data loggers.

### Geophysics

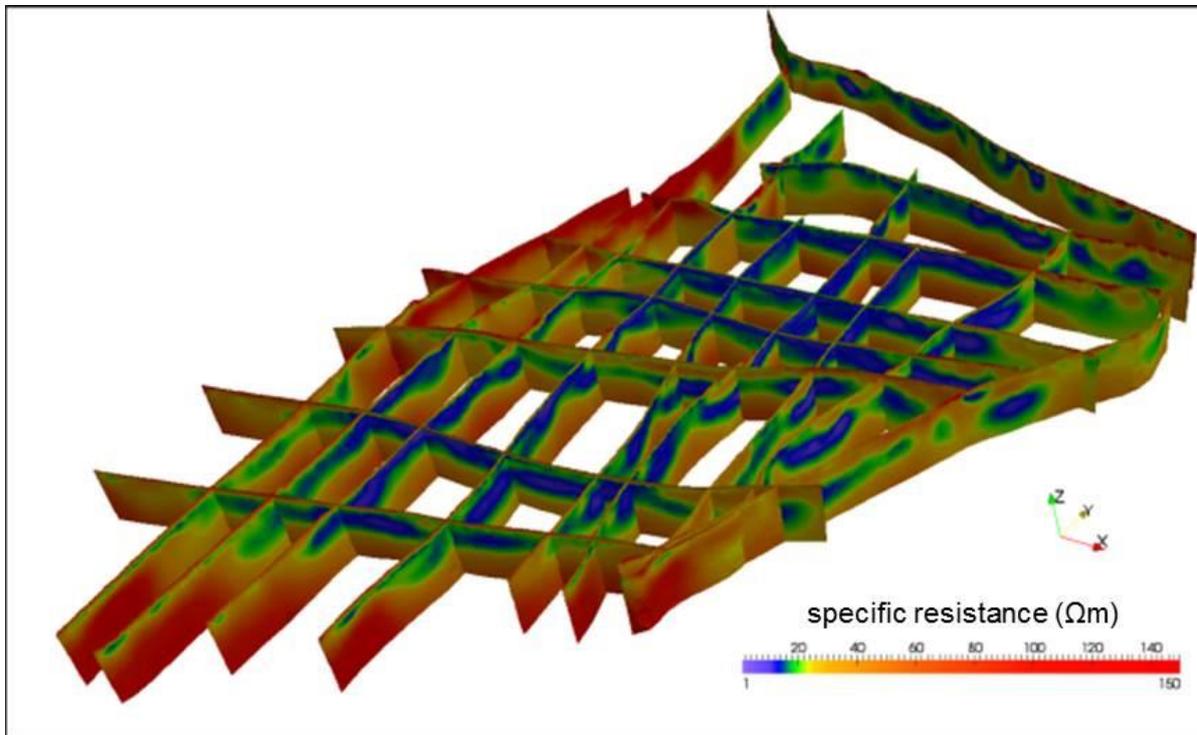
With prevent investigations and historical inquiry the boundary of the complex dump Bösau was described. To confirm this boundary and to locate possibly larger inhomogeneity within the Bösau dump, geophysical methods (geo-electric measurements, seismic reflection) were used. According to the structure of the vacuum dewatering system furthermore it should be investigated whether the geo-electric measurements are a suitable method of determining the dewatering success. These first measurements were carried out in the period from February to July 2015. A zero measurement took place in February/ March. Measurements have been repeated in May/June and in July 2015 (Hohlfeld et al. 2014).

The values of specific resistance are lower than expected. Only in boundary areas or in greater depths zones with values > 50 Ωm could be detected. Such very low values occur otherwise on saline groundwater.

Due to the complex genesis a clear allocation of specific resistances to certain materials is limited. However, highly saturated areas were identified, areas of influence of the flushing dump defined and distinguished from undisturbed areas. In all profiles a surface layer of low thickness with increased resistance could be detected. This might point to lower water contents caused by dehydration. With a thickness of about 15 – 20 m in all east-west profiles exists an area with high conductivities with clearly defined top and down boundary. The lower limit here is located approximately at the height of

131 m a.s.l. Further west the high conductive area becomes increasingly smaller and more heterogeneous.

The north-south extending profiles fit very well to the ones from west to east. Fig. 7 shows a 3D-panel of the geo-electric measurements.



**Figure 7:** *Specific resistance 3D-panel of the geo-electric measurements.*

The additionally performed seismic reflection measurements confirmed the results of the geoelectric measurements substantially. The low informative value of seismic measurements might be caused by the heterogeneous speed ratios, which were probably caused by the widely varying water saturations at the Bösau dump.

The monitoring during the dewatering with the vacuum wells on the test sites was carried out on three profiles. Due to the limited extent of the impact area of vacuum dewatering only a slight change on resistance values was expected. More significant results should occur on measurements during dewatering on larger areas. Looking at the single profiles a change between the several measurements can hardly be recognized.

### 3. Conclusions

The aim of further investigations is the extraction of authoritative properties of the deposit materials from the complex investigations (three divisions of deposit forms, consistency differences and soil physical parameters) and to figure out correlations between different sensing methods. The objective is a more detailed knowledge of the complex dump in terms of soil mechanics and soil physics.

Despite the better resolution of Bösau dump after performing a secondary more detailed exploration the demarcation of less problematic areas remains difficult due to the pronounced inhomogeneity of the total body of the dump which will lead to geotechnical defiance during the prospective mining.

The technical feasibility and the basic need to operate vacuum dewatering for the improvement of soil physical properties at Bösau dump is confirmed by the present results.

With expectable average flow rates from 2 to 5 L/min and according to current knowledge a recoverable volume of about  $0.65 \cdot 10^6 \text{ m}^3$  the operation of about 100 vacuum wells takes a time of 2.4 - to 6 years. Since the end of February 2016 five well clusters are operating in the south area of Bösau dump.

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