Mine Water Monitoring in Abandoned Mines at RAG Aktiengesellschaft

Holger Witthaus[1], Christian Melchers[2]

[1]*RAG Aktiengesellschaft, Servicebereich Technik- und Logistikdienste, Im Welterbe 10, 45141 Essen*
[2]*Technische Hochschule Georg Agricola, Herner Straße 45, 44787 Bochum*

Abstract

The shutdown of hard coal production in 2018 implicates a challenge in deriving of physical and chemical parameters of mine water in situ. This report describes an application of underground probes in the abandoned coal mine Auguste Victoria. Four probes are dedicated to deliver information about the water rebound process in the mine. Beside a short description of the installation and local parameters of the probes the expected rebound process is figured out. Two years after installation and closing of the mine production some first results can be analysed. The whole rebound process will go on for more than 15 years.

Key words: Mine closure, underground probes, monitoring

Introduction

German hardcoal mining was shut down in Germany in the year 2018. The former production company RAG Aktiengesellschaft is responsible for future consequences of the mining activities. Mine water management is a long term task to fulfill beside regulation of damages caused by subsidence and management of groundwater. The regional concept of RAG Company includes a controlled rebound of mine water level, a reduction of pumping stations and installation of well pumps in shafts instead of underground pumps. The mine water will be controlled permanently on a level below the ground water reservoir, which is used for drinking water abstraction. Individual concepts had been developed also for other mining districts in the Saar area and Ibbenbüren.

In practice the concept includes a closure of the pumping station at the Auguste Victoria mine. Instead of heaving the mine water at this place, the water goes via underground connection to the Lohberg pumping station 35 kilometers away. At Lohberg station the mine water can be drained away to the Rhine river and so the load of mine water in the smaller Lippe river is reduced. In addition there is no need for a mine water preparation plant at the Auguste Victoria mine.

Monitoring of abandoned mines

Observation of abandoned mines includes several measures of monitoring, including observation measures before underground closure. This report will not describe the total range completely. All measures are aiming at supervision of safety, avoidance of risks and environmental protection.

An underground monitoring system was developed in the frame of a research project between Technical University Georg Agricola and RAG company (1). This system allows to gather additional information from abandoned mine districts. The pilot application has been installed at Auguste Victoria mine since 2017. The system includes probes with different sensors, electrical supply and data transfer units for the collection above ground. The complete system is intrinsically safe and approved by the mining authority in Germany. Following parameters are observed:

- Pressure
- Temperature
- Electrical conductivity
- Direction of velocity
- Flow rate

4 Probes are located on the levels of -1100 mNN (6th floor) and -990 mNN (5th floor). In addition 2 sensors at the level -885 mNN

(4th floor) collect data of barometric pressure and methane content of the atmosphere (figure 1).

Parameters of the lower levels are very important to proof the functioning of the planned water flow, therefore the probes are located in the main water gateways. In minimum the measurement system should deliver data about rebound between level -1110 mNN and -600 mNN. This process is prognosed with a duration of appr. 15 years.

Fundamental data for the interpretation of probe parameter are:

- Chemical and physical parameter of mine water analysis
- Amount of mine water inflow to the mine
- Geometrical data of mine infrastructure
- Prediction of mine water rebound process and mine water quality parameter
- Results of barometrical measurements and probe sensors

More than 13 Million data per year are collected by the system. Some 100 thousand data of geometry and prediction, which are extracted from specific data systems at RAG, are also part of the interpretation.

Basic elements of trial at Auguste Victoria mine

Figure 1 gives an overview to the underground mine Auguste Victoria in 2016. At that time production areas had been abandoned yet and only the main roadway system was still in use.

The analysis and interpretation are based on the information of the roadway profile on the level of floor 6 (figure 2). Three probes (1W, 3W, 4W) are located on the level in a depth of approximately -1110 mNN. A detailed analysis of the height profile clarifies local trough structure (figure 2). In addition there are junctions to the North and the South connecting to the levels of the upper and lower mine districts. These connections allow inflow and outflow from the 6th level. The picture also shows the measured level of mine water (dated from December 2018) at the probes.

The interpretation of sensor data also has to consider the detailed geometry of the installed probe. A schematic overview is given in Figure 3. The figure shows different sensors at a height of 0,4 meter to 0.6 meter above the floor and an additional mechanical

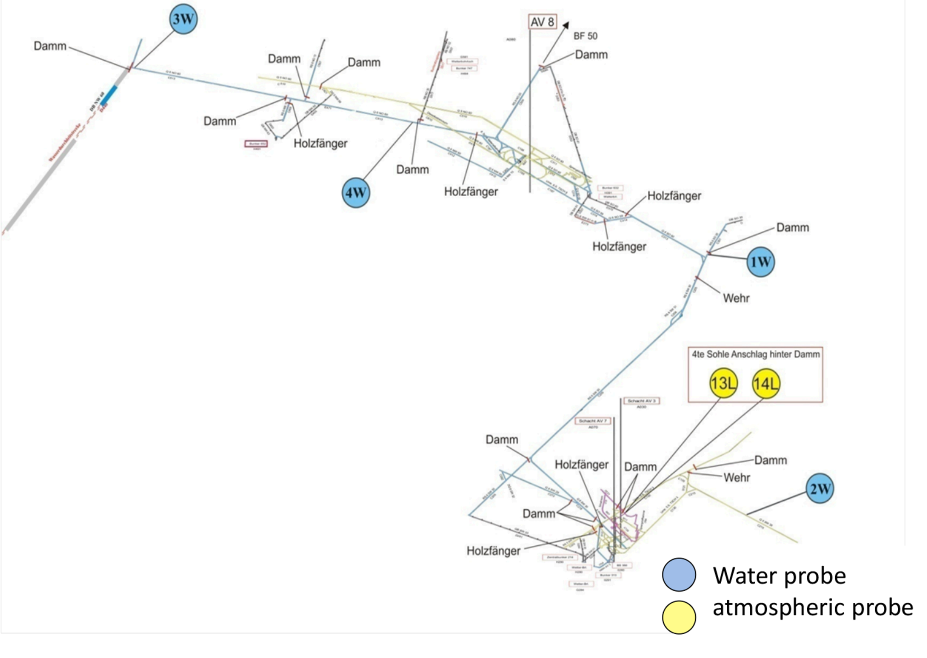

Figure 1:Perspective *view of Auguste Victoria – level 4, 5 and 6 – and probe locations (2016).*

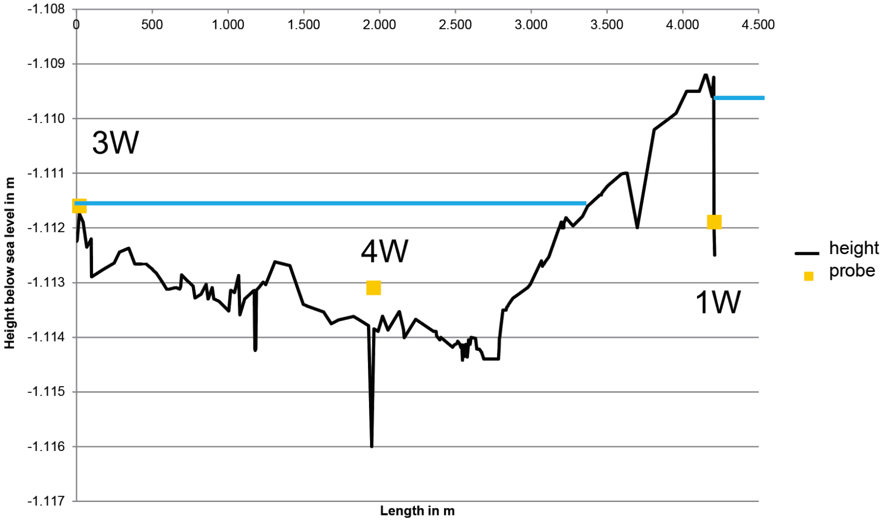

***Figure 2:** Profile of height of 6th floor and position of probe 1W, 3W and 4W.*

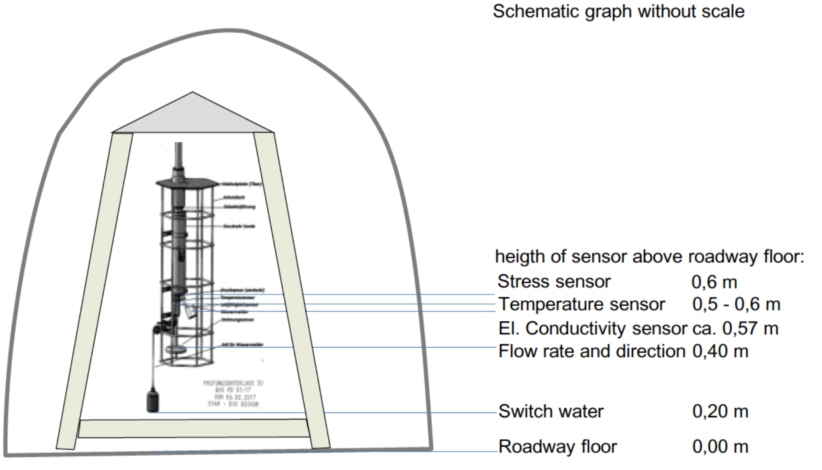

***Figure 3:** Schematic drawing of probe installation and protection frame.*

indicator to proof a water level at 0.2 meter above the roadway floor.

Prediction of mine water rebound

Water rebound of the former mines Auguste Victoria and the neighbour mine Lippe is planned as a process in different phases. In the figures 4 a to c these phases are explained by schematic vertical shape views between the shafts Fürst Leopold 1/2 in the West and Auguste Victoria 3/7 in the East. At the end of the year 2017 the mine water level in the East reached the level of appr. -860 m NN. At this level the connection to the eastern area was flooded and the water can flow to the former Auguste Victoria mine. The mine water level on that side was below -1110 mNN at that time. (figure 4a)

Rebound of mine water in the area of Auguste Victoria up to the level of 6st floor is characterising the second phase. This phase should have a duration of 9 months according to the simulation model results and will be finished by leaving and closing of the underground area Auguste Victoria. (figure 4 b)

In phase 3 the rebound process from the 6st up to the 5th floor in the eastern area

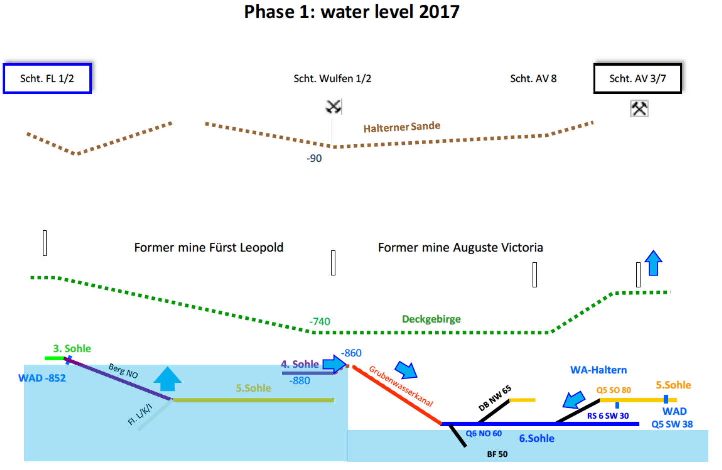

Figure 4a: Schematic shape and mine water level in 2017.

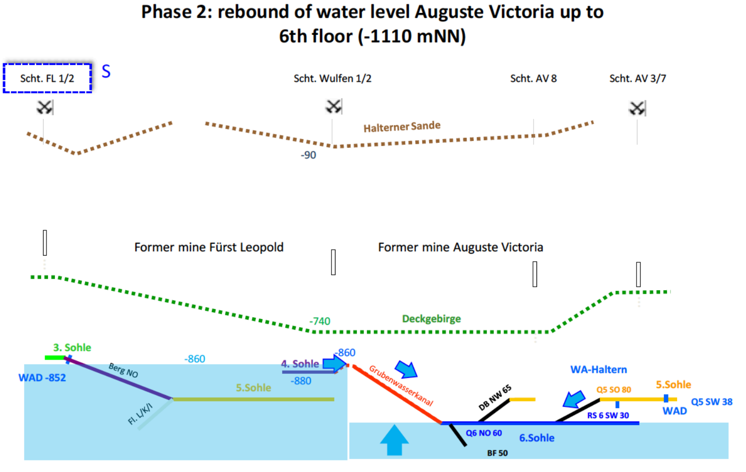

Figure 4b: Schematic shape and mine water level 9 month after shutdown.

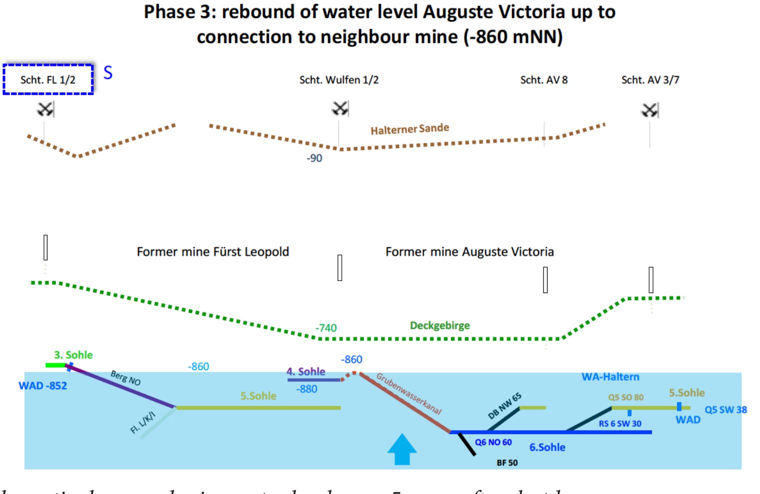

Figure 4c: Schematic shape and mine water level appr. 5 years after shutdown.

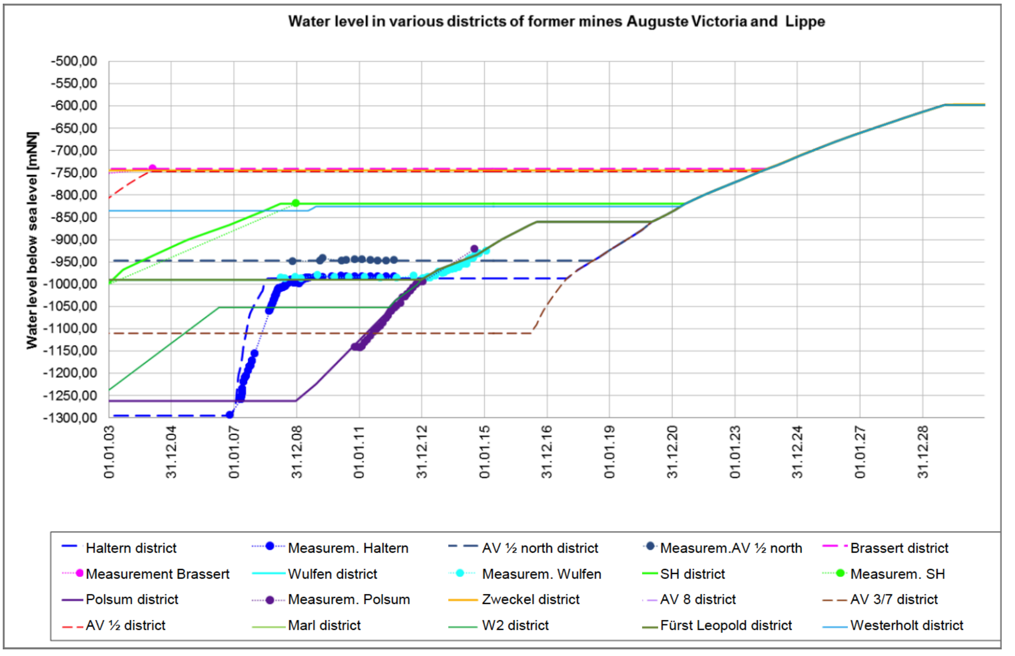

Figure 5: *Prediction of time dependent mine water rebound (2016).*

takes place and reaches up to a level of -990 mNN. At the end of this phase the mine water level will reach -860 m NN. At this height the connection point to the western part is flooded within a duration of 5 years according to simulation results (figure 4c). After achieving a common water level in the western and eastern part, the level will rise up to the connection point with the Zollverein water district (-598 m NN). After that, the mine water can flow to the pumping station of Lohberg through the network of roadways and former panels in the underground.

The process in total, up to a water level of -598 mNN, will take a time of appr. 15 years between the stop of pumping at Auguste Victoria mine until reaching the connecting level.

Prognosis is done by using a special planning tool of DMT GmbH company. This model is covering the whole district of mining in the Ruhr area. Figure 5 shows a description in the form of a diagram and timetable. Each line is representing the development of the water level in different parts (mined districts) of the former mine. Dots within the diagram show the results of additional measurements (e.g. water level of a shaft), which are used to proof the calculations. Beside prognosis and additional measurement of water levels the basics of the trial are the fundamental data of mine water chemistry and the parameter of sensor results.

Specific weight and electrical conductivity

For interpretation of the sensor data the context between electrical conductivity and specific weight of the mine water plays an important role. The results of different mine water samples, derived before leaving the underground areas, are shown in the diagram of figure 6. The mathematical analysis shows a linear function with a 98 % - coefficient of determination.

As a conclusion, from the measurement of electrical conductivity a quantification of specific mine water weight is possible. This is important for the interpretation of pressure results in a situation of higher water levels. Taking into account the exact specific weight allows the calculation of local water level above the probe.

Measurement results

Figure 7 gives an overview on the results of

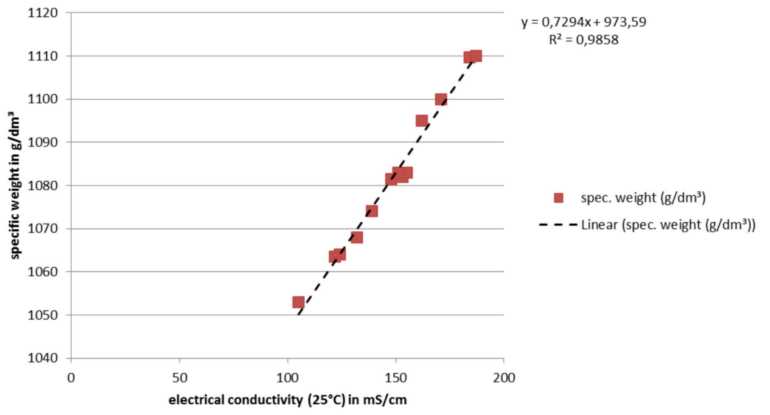

Figure 6: *Specific weight of mine water above electrical conductivity (in mS/cm 25°C) (correlation of underground analysis Auguste Victoria and Lippe mine).*

stress measurements by the water probes. This figure show the results of daily mean values calculated from each 1440 single data of the probe exemplarily.

Probe 2W (5th floor, - 990 m NN) is located above the mine water level and gives an example of barometric influence to the stress level with a mean value of 1.0 dbar. Very similar is the measurement result at probe 3W on the 6th floor (-1.110 mNN). This indicates a water level below the sensor at that location 3W. Probe 1W is installed in a local trough close to a leaky dam with inflow of mine water from the 5th level. This probe was 2.5 meter below the water level immediately after the installation. Obviously an outflow to lower areas occurs in a level 2.5 meter above. Probe 4W shows a time row with substantial increasing stress after October 2017. Considering the geometry of the roadway according to figure 2, the result of probe 4W can be interpreted. The next outflow to the lower mine areas must be appr. 1.5 meter above the probe.

Beside the exemplarily figured results, the temperature is measured. The probes below mine water level (1W and 4W) indicate a level of temperature between 38°C and 42°C. Probe 2W, which is proved to be above the water level, shows a lower level of temperature between 30°C and 37° C and a substantially more intensive change day by day. Probe 3W seems to be influenced by mine water, because the daily changes show a similar structure to probe 1W and 4W and a high level of appr. 40°C.

The range of electrical conductivity of mine water was expected to be > 100 mS/cm up to 180 mS/cm at maximum and the measurement of conductivity does prove the interpretation of local water level at the position of each probe. In addition, a detailed analysis of time row development at probe 4W shows, that the probe was temporary flooded twice in August and October 2017. The probe was under the water level for a time of up to 49 hours, before the water level did sink below the sensor again. This kind of result is typical for obstacles in the water way. In front of an obstacle the water level rises and at a level of sufficient water pressure, the release of water way is achieved.

In addition to water probes, the barometric pressure is collected at the 4th floor (-885 mNN). This probe should later give information about barometric conditions in the closed mine, up to now the shaft is still open. The results of 19 months of measurement are included in the data interpretation. The mean value is at 1110 mbar and changes include a bandwidth of 20 mbar.

Correlation of pressure and atmosphere

Time rows of barometric pressure and pressure measurement at probe 2W indicate a direct barometric influence to the probe at the 5th level. In figure 8 the time row of probe 3W and barometric pressure is shown. There

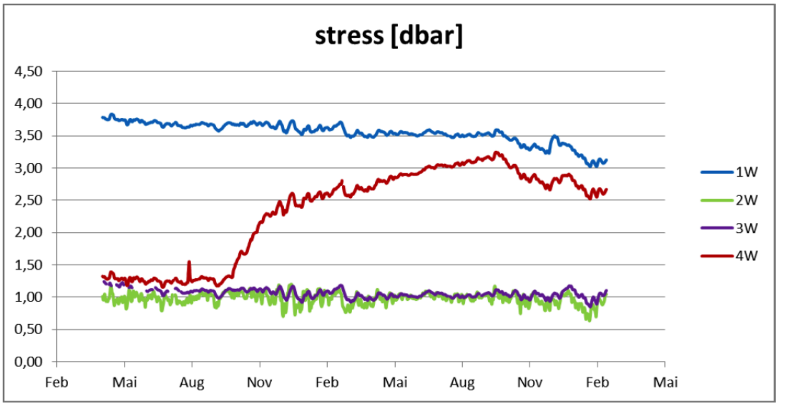

Figure 7: *Time rows of stress measurement probes 1W – 4W.*

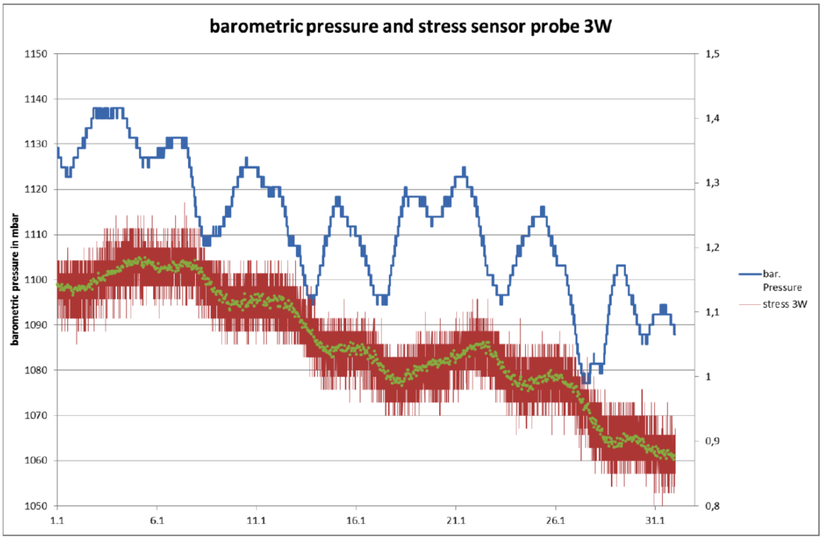

Figure 8: *Time rows of barometric pressure measurement probe 14L and pressure 3W.*

is no direct connection between both sensors and the distance between them is about 7.000 meter. For several months probe 3W was isolated from ventilated mine sections. It seems to be a delayed reaction of pressure at probe 3W to barometric changes. For elimination of sough signals at probe 3W, the light green dots mark the mean values of every 1 hour for an exemplary chosen time between January 1st and 31st 2019.

The linear dependency between barometric changes and stress at probe 2W can be determined by analysis of changes between the data of the time row. The correlation of differences at probe 2W and barometric changes have a coefficient of determination with 97.5 % (figure 9). The analysis today does prove the current reliability of the measurement system.

Current interpretation

Data collection of underground probes form the basic information about the water level. Density of water and barometric pressure have a proved influence on measured stress below the water level. These parameters can be quantified by the results of the trial at Auguste Victoria mine and the level of mine water can be estimated accurately because basic information about the correlation

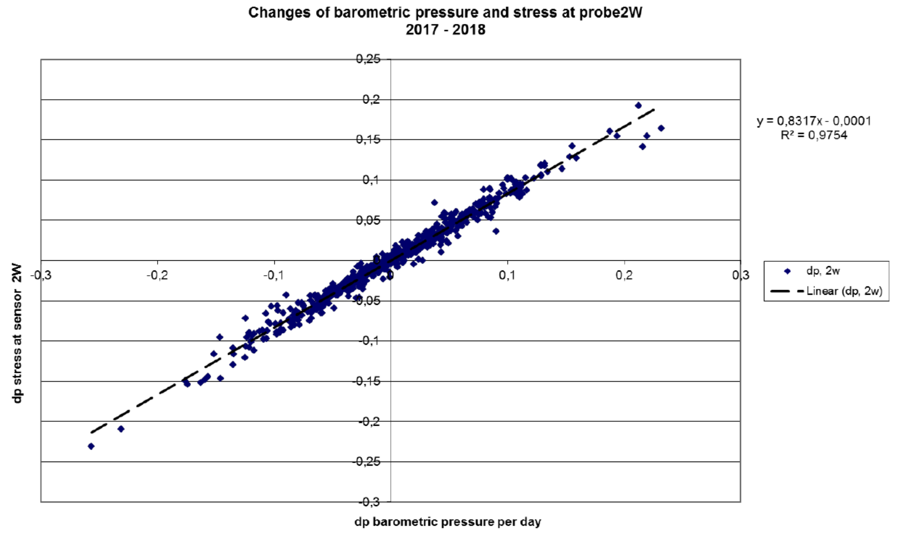

Figure 9: *Correlation analysis of changes in barometric pressure and pressure 2W.*

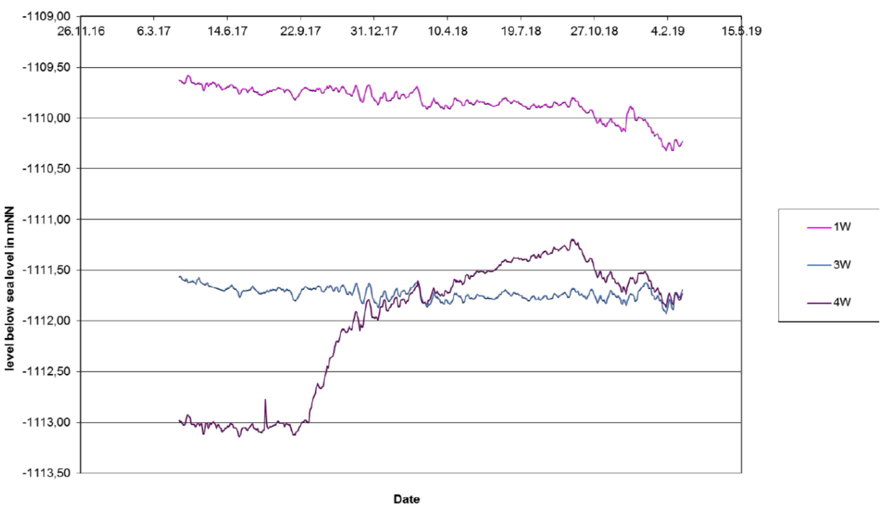

Figure 10: *Time rows of calculated mine water level at probes 1W, 3W, 4W (6th level).*

between electrical conductivity and water density could be derived from former tests. The fully encapsulated sensors of the water probes indicate a basic stress level, which must be considered for interpretation as well. The barometric influence within a range of less than 0.1 meter is not calibrated in current mathematical interpretation. Figure 10 represents the time row and actual mine water level of the 6th floor of the closed mine Auguste Victoria considering the quantified parameter of influence. In fact the probes 1W and 4W are substantially more than 1 meter below the water level. Probe 3W gives currently not a clear combination of signals – it seems to be very close to the water level, but there is no substantial indication up to now. The results of probes also show a very low level of flow rates at the 6th floor of the former mine. Ongoing measurement is focussing on higher flow rates in later phases of mine water rebound for interpretation of erosion processes within the flooded roadways. Up to now, the different probes below the mine water level show different temperature at points of installation. Continuous measurement will indicate mixing process, because the resolution of data collection fits to a difference of less than 1°C.

The electrical conductivity can be used as a fingerprint of water origin. The comparison of results indicates, that probe 1W is influenced by the mine water inflow from the north of the mine. Probe 4W is influenced by inflow from the upper level (5^{th} floor).

Future Application

RAG is preparing additional applications of the underground monitoring system at Prosper- Haniel and Ibbenbüren mines, as well as at pumping stations of the former Saar mine, Zollverein and Heinrich.

According to the planned water flow geometry and the planned rebound process, the number and locations of probes were defined. Data collection will be managed at the new central control room of RAG at the location in Herne. Data processing and visualisation of every probe will be centralized. The duration of usage is planned for the next 2 or 3 decades, so the total rebound process in all former hardcoal mines will be covered by this monitoring.

References

(1) Final report "Grubenwassermonitoring" project, RAG 2017, not published