# Four years of flooding WISMUT's Ronneburg uranium mine – a status report

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**Abstract.** The Ronneburg uranium mine is flooding since the turn of 1997/1998. Until May 2002 the mine water rise has reached levels of about 148 m a.s.l. in the southern mine fields and 90 m a.s.l. in the northern mine fields. For the southern mine fields a water treatment plant proved to be necessary. Test runs began in January 2002. As flooding of the northern mine fields will have much less impact on ground and surface water bodies, operation of a water treatment plant is not deemed necessary for that area. The flooding operation is expected to complete between 2004 and 2005.

## Introduction

WISMUT's Ronneburg uranium mine is flooding since the turn of 1997/1998. By May 2002 the mine water rise has reached levels of about 148 m a.s.l. (above sea level) in the southern mine fields and about 90 m a.s.l. in the northern mine fields of Drosen and Beerwalde.

This paper outlines important features of the flooding process observed so far, describes the technical measures undertaken for controlling the final steps of flooding, and gives an outlook on the further flooding process.

## Site characteristics

The Ronneburg mine which is located about 10 km east of Gera/Thuringia was the largest WISMUT mine site. It was active between 1951 and 1990. Its 3,000 km of mine workings covered an area of about 60 km$^2$ and caused a corresponding groundwater depression cone. Mining extended over 22 levels in depth between 30 m and 940 m.

The deposit is hosted in a blackshale-limestone-metasedimetary series of Ordovician to Devonian age. A more detailed description of the geological site features has been given elsewhere (Lange and Freyhoff 1991, Paul et. al. 1998).

The Ronneburg mine consists of six formerly separate mines comprising 14 mine fields with 40 shafts. These mines which accounted for about 50 percent of WISMUT's total uranium production of about 230,000 tonnes are (from southwest to northeast): Lichtenberg, Reust, Schmirchau, Paitzdorf, Beerwalde, and Drosen. The mine levels were numbered according to their vertical distance to the surface. The main activities were concentrated between the 120-m- and the 390-m-level.

The overall volume of the mine workings at the Ronneburg site amounted to about 68 million $m^3$ of which about 44 million $m^3$ were backfilled mainly with a special fly-ash cement as a characteristic feature of the cut and fill mining technology performed at Ronneburg since the late 1960s. About 4 million $m^3$ arose from caving which was practiced in the early mining period of the 1950s and 1960s.

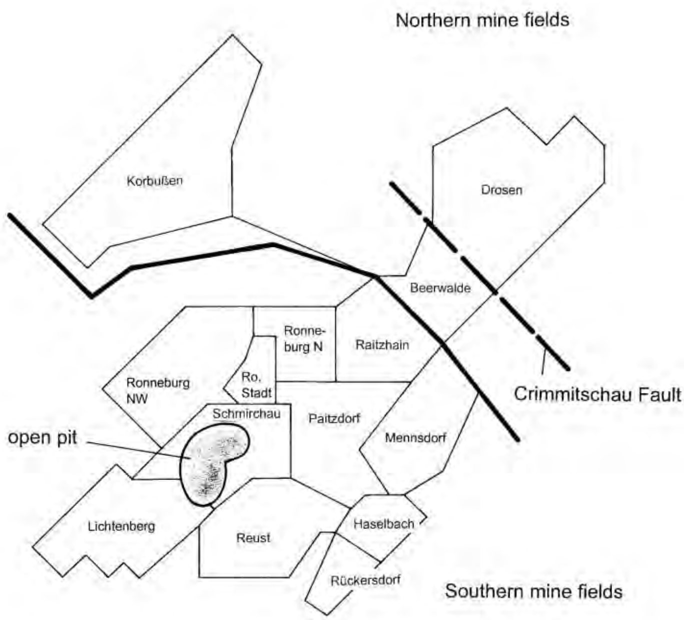


**Fig. 1.** Schematics of the Ronneburg mine site showing the different mine fields

In addition to the underground mine the Lichtenberg open pit with a total volume of 160 million m³ and a maximum depth of 240 m is located in the centre of the mine field. The open pit is in the process of backfilling with waste rock from Ronneburgs waste rock dumps which is planned to be finished in 2007. Inundation of the open pits so-called A-Zone is part of the rehabilitation concept (Paul 2002).

The flooding process of the Ronneburg mine is taking place within two hydraulically isolated areas (see Fig.1):

(1) Mine fields south of the federal motorway A 4 which comprises the former mines of Schmirchau, Reust, Lichtenberg and Paitzdorf,

(2) Mine fields north of the motorway A 4 including the Beerwalde and Drosen mines.

Both parts of the mine are separated hydraulically by six concrete plugs built at five mine levels which formerly connected the southern and northern mine fields.

## Flooding of the southern mine fields

Before the complete mine flooding started, deep and isolated mine sections had already been partially flooded since 1989 (Table 1).

**Table 1.** Mine sections of the southern mine fields flooded before 1997.

| Mine section | Mine levels | Flooding time | Open space flooded [ $Tm^3$] |
|---|---|---|---|
| Reust, blind shaft 4 | 485-m to 390-m-level | 12/89 – 02/91 | 347 |
| Lichtenberg, blind shaft 6 | 525-m to 345-m-level | 09/91 – 09/92 | 275 |
| Ronneburg NW, shaft 381 | 570-m to 480-m-level | 07/93 – 08/95 | 63 |
| Ronneburg N, shaft 396 | 570-m to 435-m-level | 04/95 – 03/96 | 100 |

Fully fledged flooding of the southern mine fields was initiated at the turn of 1997/1998 after a four-year-permitting and preparation process. The flooding operation is accompanied by a comprehensive monitoring program which provides detailed information on the time history of flooding, on the impact of hydrometeorological events on flooding dynamics and on water quality trends. Currently, about 20 wells are used for monitoring purposes.

The flooding process started at a water level of -168 m a.s.l. in the Ronneburg NW mine field whereas in Paitzdorf (-126 m a.s.l.) and Lichtenberg (-45 m a.s.l.) higher inundation levels had already been reached (see Table 1). Since 1999 all southern mine fields show the same water level. Meanwhile, the flooding water has reached a level of about 148 m a.s.l. Hydraulic consistent conditions in this part of the Ronneburg mine can be demonstrated by the water level differences between the various mine fields, which reach about 1 or 2 meters in maximum. A significant deviation from that general behaviour could only be detected for the mine field of Paitzdorf during 1999 as shown in Fig. 2.

During a particular period, the flooding process was faster than originally predicted. A revision of the floodable volumes and the inflow rates showed that a major reason for this wrong prediction was the overestimation of the various pore volumes and their dewatering/rewetting rates (Hähne et al. 2000, Table 2).

**Table 2.** Categorization of floodable mine space and pore volumes, southern mine fields, revised estimates, up to 270 m a.s.l.

| Category | volume [million $m^3$] |
|---|---|
| Open volume (mine workings) | 15.7 [a] |
| Floodable pore volume in the backfill | 4.1 ... 4.3 |
| Floodable pore volume in the caving area | 1.6 ... 2.3 |
| Floodable pore volume in the backfilled open pit | 1.8 ... 2.7 |
| Dewatered pore volume in the host rock (depression cone) | 3.8 ... 5.1 |

[a] Volumes of mine sections completely or partially flooded before 1997 (see also Table 1) are not included

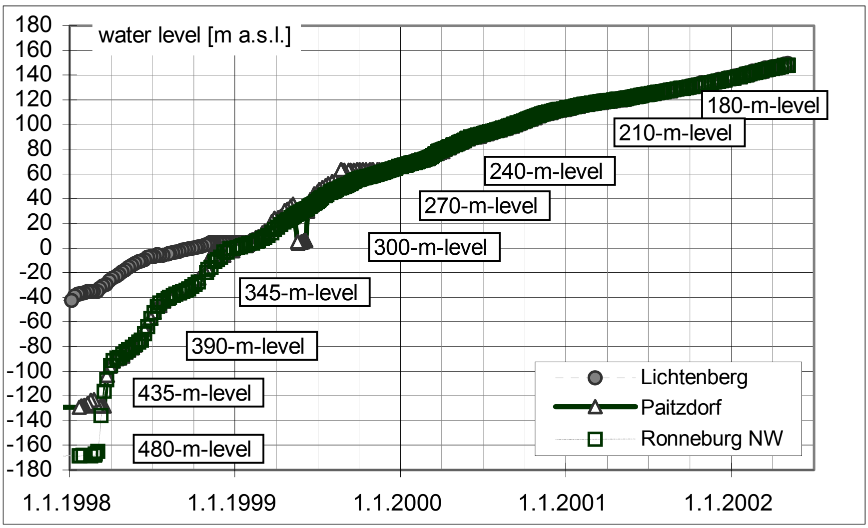


**Fig. 2.** Flooding curves for the mine fields of Lichtenberg, Ronneburg NW (belonging to the Schmirchau mine) and Paitzdorf

The velocity of the water table development as represented in Fig. 2 exhibits two significant phenomena:

(1) The annual rate of water rise shows a downward trend from 1998 to 2001 (1998: about 170 m p.a., 1999: 67 m p.a., 2000: 46 m p.a., 2001: 24 m p.a.). This is in general compatible with the vertical distribution of open mine space: in 1998 deep mine levels (480 up to 345) with only relative small amounts of open volume have been flooded whereas since 1999 the main levels (300, 240, 180) with more than 2 million $m^3$ each were inundated (Table 3).

(2) The steplike shape of the curve as typical between -160 and 100 m a.s.l. flattens more and more above 100 m a.s.l. since the various mine levels are vertically overlapping in the upper part of the mine. Additionally, the effect of several types of pore volumes is increasing.

**Table 3.** Ronneburg mine, southern mine fields, open volume by mine level [a]

| Mine level | Open volume [$Tm^3$] | Mine level | Open volume [$Tm^3$] |
|---|---|---|---|
| 30 m | - | 270 m | 931 |
| 60 m | 32 | 300 m | 3065 |
| 90 m | 87 | 345 m | 1649 |
| 120 m | 1118 | 390 m | 1368 |
| 150 m | 1443 | 435 m | 622 |
| 180 m | 2447 | 480 m | 388 |
| 210 m | 1093 | 525 m | 36 |
| 240 m | 2503 | 570 m | 74 |

[a] Volumes of mine sections flooded before 1997 (Table 1) are included

Mean annual precipitation in the Ronneburg region can be quantified at about 680°mm/a based upon a time serie from 1960 to present (DWD-German Weather Service). Annual variations can be characterized using years with extreme conditions: Low precipitation rates at about 400 mm/a are contrasting years with high precipitation rates at nearly 1,000 mm. Compared to those variations in the general hydro-meteorological regime the conditions in the four-year-period from 1998 to 2001 can be characterized with nearly medium precipitation rates; the measured values in this period exceed the long term average by about 3%.

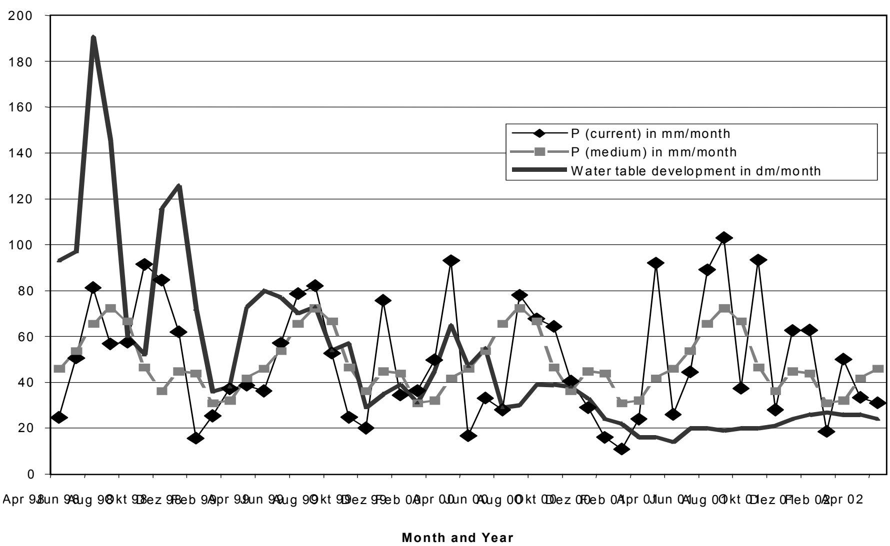


**Fig. 3.** Time series of non-corrected precipitation (P) and water level development in the southern mine fields

A more detailed description of the hydro-meteorological regime is possible using the monthly precipitation rates as shown as a time series diagram in Fig. 3 which also contains a time series of the monthly water level development data for the southern mine fields. The general retrograde trend represents the increasing values of floodable mining volume with the rising flooding water level as explained above. The variation of monthly precipitation values seems to entail an analogous variation in the monthly mine water flooding level developments with a typical time delay of two or three months especially during 1998 and 1999. Nevertheless, a simple correlation between the monthly rainfall and the rates of water rise cannot be derived, as the inundation rates are strongly related to the vertical distribution of mining voids.

In contrast to the long term trend the period from September to November 1998 was very wet and caused a high groundwater recharge rate. This is believed to be the reason for the only weak reduction of the flooding rate during the inundation of the 300-m-level which is the mine level with the highest open volume of all mine levels (Table 3).

An important question to be answered is to what degree the inflow rate into the depression cone will decrease with rising water table. Before flooding the average inflow into the southern mine fields amounted to about 650 $m^3/h$ with variations from < 500 $m^3/h$ up to 800 $m^3/h$ (based on monthly values, time series between 1991 and 1999; mine water flow rates from the period of active mining (before 1991) have been influenced by technical waters (dust control, drilling, mine back fill by concrete) and are suitable for plausibility considerations only). There are strong indications derived from monitoring and modelling of the regional water balance for a significant decrease of the inflow rates with higher inundation levels. For a flooding level of 232 m a.s.l. ("security level", see the last chapter) a decrease to some 450 $m^3/h$ is expected under average conditions which was important for the design of the water treatment plant.

In terms of water quality conditions it has to be mentioned that at Ronneburg a very serious acid mine drainage problem exists. During active mining the mine waters were characterized by acid to neutral pH and high concentrations of radionuclides, heavy metals, iron, sulphate, and magnesium. Because of the huge area of the mine and its very complicated structure with different geochemical and hydraulic conditions water quality differed substantially in the various mine fields and mine levels.

Monitoring data of the flooding process confirm the significant water quality differences between the various mine fields. Most contaminated waters are concentrated in the mine fields of Schmirchau and Lichtenberg. Mixing and horizontal flow in the course of flooding led to variations in the water quality of some of the monitoring wells over time.

Furthermore, internal hydraulic processes and conditions have to be considered. As an example for these Fig. 4 shows the results of conductivity- and temperature-logs of the flooding water body in the mine workings. The increasing temperature trend with depth refers to the regional geothermal conditions in the Ronneburg area. The conductivity profiles exhibit a density stratification in the flooding water body. These conditions could hitherto be observed as a stable situation in some of the monitoring wells, which was neither disturbed by the relatively weak geothermal gradient nor by other influences. Variabilities in the log measurement results over time as shown in Fig. 4 are considered to be relatively small and do not influence the general trend of density stratification. Nevertheless continued monitoring activities and further investigations of the observed stratification effects in the flooding water and of their implications for water quality seem to be important.

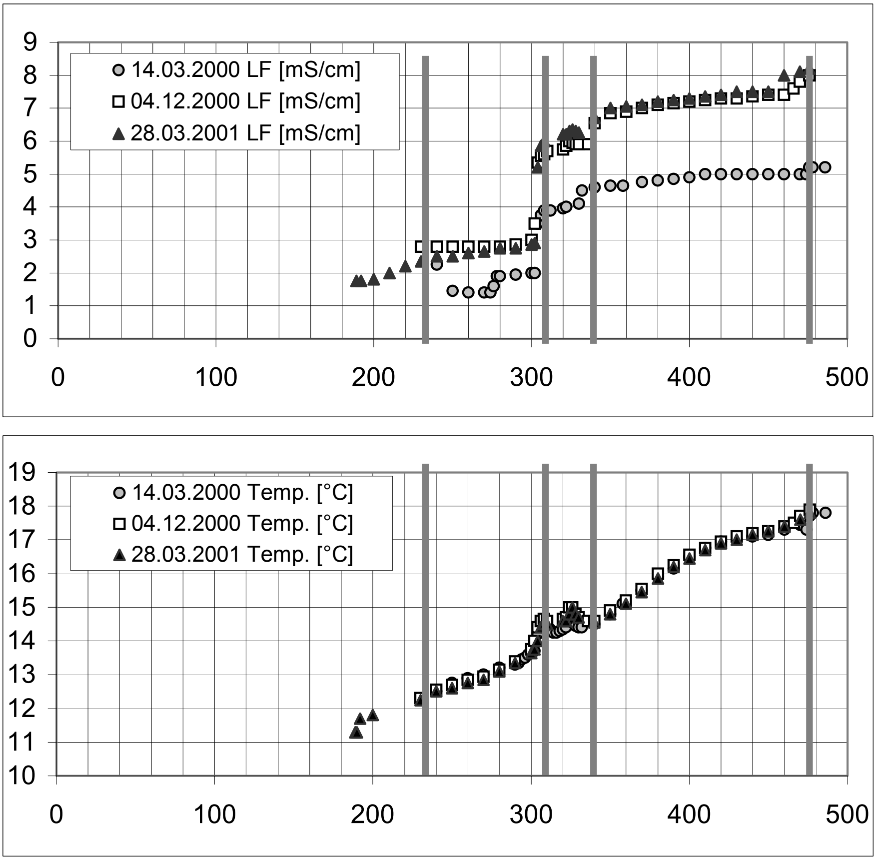


**Fig. 4.** Temperature and conductivity profiles (LF in mS/cm) at monitoring station e-1260 in the mine field of Ronneburg NW. Depth in meters below surface. Grey vertical bars indicating mine levels which are interconnected with the well.

The amount and degree of mine water contamination in the southern mine fields required the construction of a water treatment plant for the separation of iron, heavy metals, radionuclides, and arsenic. The water treatment plant is under test operation since January 2002. It is operating according to the HDS-lime precipitation scheme. Mine water supply is realized by pumping from a deep well situated in the Schmirchau mine field which is connected to the mine workings of the 240-m- and 180-m-level. The plant is constructed for a throughput of 600 $m^3$/h, an optional capacity extension is possible.

The mine water which is pumped from the Schmirchau mine field is weakly acid but very high in sulphate, iron, and magnesium (Table 4). Nevertheless the trial runs showed a sufficient removal rate for iron, heavy metals, radionuclides, and arsenic. Continued operation should be used to quantify the actual inflow rate into the depression cone of the mine and to examine the water quality trend.

**Table 4.** Results of the water treatment plant trial runs, Jan. to April 2002, average data

| | | Inflow water treatment plant | Outflow water treatment plant |
|---|---|---|---|
| Magnesium | [mg/l] | 725 | 700 |
| Calcium | [mg/l] | 550 | 900 |
| Total iron | [mg/l] | 775 | < 2 |
| Manganese | [mg/l] | 20 | < 1 |
| Aluminum | [mg/l] | 45 | < 2 |
| Sulphate | [mg/l] | 5750 | 5200 |
| Uranium | [mg/l] | 2.0 | < 0.5 |
| Radium-226 | [mBq/l] | ≈ 500 | < 400 |
| Cobalt | [µg/l] | 2000 | < 100 |
| Nickel | [µg/l] | 6500 | < 50 |
| Zinc | [µg/l] | 2300 | < 200 |
| Arsenic | [µg/l] | 130 | < 20 |
| pH | - | 4.7 | 6.5 - 8.5 |

## Flooding of the northern mine fields

The Beerwalde and Drosen mines north of the federal motorway A 4 are flooding since mid 2000 comprising the mine field of Korbußen. As already explained, the northern mine fields are hydraulically separated from the southern ones by six concrete plugs. The maximum water level difference between the northern and the southern fields of about 160 m was reached during the year 2000.

The mine fields of Beerwalde and Drosen are separated by the Crimmitschau fault, a supra-regional fault zone. Mine workings which connected both mine fields have been backfilled prior to flooding. In contrast to the rest of the mine site at the Drosen mine field the Palaeozoic host rock is covered by a series of platform sediments of Permian to Triassic age.

Flooding at Beerwalde and Drosen develops as expected. At Drosen the mine workings are already completely flooded and the depression cone is filling up. The water level differences between the two mine fields do not exceed 10 to 20m.

The Korbußen mine field is totally isolated from the rest of the mine. It is connected to the Beerwalde mine by only one working which has been sealed by a concrete plug. As a consequence of that the water level rose quickly from July 2000 to the spring of 2001. Since march 2001 the water level dropped from about 170 m a.s.l. to about 35 m a.s.l. before it began to rise again since August 2001. The reason for that phenomenon is under discussion but has no consequence for the general flooding strategy of the northern mine fields. At present the water levels in Beerwalde and Drosen are 50 to 70 m deeper as in Korbußen.

Since the platform strata northwest of the Crimmitschau fault are comprising three productive aquifers partially used for drinking water supply downstream the

Drosen mine field (distance 1 to 10 km) the effects of flooding on groundwater quality had to be considered. The investigations led to the conclusion that a significant impact of rising mine waters on groundwater quality can be excluded since the mine waters in the northern mine fields are much less contaminated than the mine waters of the southern fields. In addition preferred flow paths from the mine to the overlying aquifers could be sealed to a significant degree by concrete injections prior to flooding which minimize the post-flooding leakage rates. In the case of the Beerwalde and Korbußen mine fields it is also predicted that exfiltrating mine waters will have no or a just small impact on surface waters and local groundwater bodies so that the construction of a water treatment plant for the northern mine fields is not foreseen. Nevertheless, fall-back options are being drawn up should unacceptable situations occur, which would deviate substantially from the predicted scenarios. So a well has been established within the main shaft of the Beerwalde mine, and conceptual plans are at hand for water treatment should it become necessary.

## Conclusions for the further strategy of controlled flooding

Since the mine is completely backfilled in its uppermost 100 meters and has no dewatering adits rising flood waters are expected to eventually discharge "naturally" into local receiving streams at topographic low points, unless pumping or collection measures are taken during the final stages of the flooding process. As these low points have altitudes of 240 m a.s.l. or higher the flooding process is permitted so far up to "security levels" of 232 m a.s.l. in the south and of 230 m a.s.l. in the north. Strategies for the final steps are in the permitting process.

The flooding operation is expected to complete between 2004 and 2005 by reaching a quasi-steady state. There is much uncertainty on how fast the final water rise will happen especially in the south: After reaching an inundation level of about 200 m a.s.l. flooding should accelerate since there are no open mine workings above this level. On the other hand inundation of the dewatered weathering zone of the bed rock should provide considerable pore volume, and water inflow is expected to decrease with rising water table; both phenomena would delay the water rise. Moreover the operation of the water treatment plant will affect the final flooding phase for the southern fields substantially.

As discussed by Gatzweiler et al. (2002) the flooding strategy at the Ronneburg mine site aims at a high inundation level in order to minimize the catchment area of the mine, to limit the thickness of the unsaturated zone which is subject to further acid mine drainage (AMD) generation and to lower operational costs for water management, including water treatment and sludge disposal. For this purpose the pump-and-treat-strategy has to be replaced by a collect-and-treat-approach. Water catchment systems have to be installed at locations, where contaminated groundwaters are expected to exfiltrate to the local receiving streams. Since the Gessental valley west of Ronneburg is expected to be the area of highest priority a catchment system comprising linear strings of combined drainage and collection pipes has been designed and submitted for approval (see Unland et al. 2002). It is planned to build this system in 2003. Other potential exfiltration areas are subject of further investigation and monitoring.

The optimum final flooding/groundwater level has to be determined by a stepwise approach. Water management by shallow catchment systems, but without intervention by pumping from the flooded mine, will allow density stratification to stabilize within the mine water column which will minimize the contaminant loads leaving the mine over the long term.

After four years of flooding it is evident that this operation will be a major contribution to restoring the Ronneburg region to good environmental conditions.

## References

Gatzweiler R, Jakubick AT, Paul M, Schreyer J, Meyer J (2002): Flooding the WISMUT mines - Learning by doing or applying a comprehensive systematic approach?- UMH III, Freiberg, September 2002

Hähne R, Paul M, Schöpe M, Gengnagel M (2000): Abhängigkeit des Verlaufs der Grubenflutung des Ronneburger Uranerzbergbaureviers von der Beschaffenheit des Flutungsraumes und von den Neubildungsbedingungen.- Internationale Konferenz Bergbausanierung WISMUT 2000, Schlema, 11.-14. Juli 2000

Lange G, Freyhoff G (1991): Geologie und Bergbau in der Uranlagerstätte Ronneburg/ Thüringen.- Erzmetall 44: 264-269

Paul M (2002): Geochemische In-situ-Stabilisierung von Bergbaualtlasten.- In: Förstner U, Grathwohl P, Dahmke [Hrsg.]: Ingenieurgeochemie.- Springer, in Vorbereitung

Paul M, Sänger HJ, Snagowski S, Märten H, Eckart M (1998): Flutungsprognose am Standort Ronneburg - Ergebnisse eines integrierten Modellansatzes.- Uranium Mining and Hydrogeology II, Proceedings of the International Conference and Workshop, Freiberg, Germany, September 1998.- GeoCongress 5, Verlag S. v. Loga, 130-139

Unland W, Eckart M, Paul M, Kuhn W, Ostermann R (2002): Groundwater rebound compatible with the aquatic environment – technical solutions at WISMUT's Ronneburg mine.- UMH III, Freiberg, September 2002