POST-FLOODING WATER MANAGEMENT AT THE RONNEBURG URANIUM MINE: LESSONS LEARNED AND REMAINING CHALLENGES

MICHAEL PAUL[1], DELF BAACKE[1], THOMAS METSCHIES[1] and WERNER KUHN[1]

[1]WISMUT GmbH, Chemnitz, Germany; E-mail: m.paul@wismut.de

ABSTRACT

Remediation activities at WISMUT's Ronneburg mine site, the formerly largest individual uranium mine in Europe, were focused on waste rock stabilization and the closure of the huge underground mine. After 9 years of mine flooding increasing groundwater levels reached the surface in mid 2006, and contaminated mine waters started to discharge to a water collection system which had been erected in a valley region. Due to the poor water quality mine waters as well as contaminated seepage and surface waters have to be treated for radionuclides, heavy metals and iron, a water treatment plant is operating since 2006. The paper compares model predictions with the real situation after mine flooding has been completed, in terms of water flow rates, exfiltration areas, and water quality. The recent water management practice is being described, discussing the key targets in terms of the water quality of different creeks and rivers downstream of the mine site. To sustainably run the water collection and treatment systems over at least two decades from now, adjustments to the existing technical systems are necessary, which will also be discussed. The experience gained so far underlines the need for comprehensive planning for flooding, but also for a flexible approach as part of a mine closure management plan which allows continuous updating of initial planning and corrective actions on the basis of monitoring data acquired during the flooding process.

1. INTRODUCTION

Since the termination of active uranium mining operations in Germany, Wismut GmbH conducts the rehabilitation of its former mining and milling sites. Site-specific rehabilitation concepts are complemented by strategies outlining individual flooding approaches for the large underground mine workings at the Königstein, Ronneburg and Aue as well as Pöhla and Freital-Gittersee sites (Gatzweiler et al. 2002).

This paper addresses the rehabilitation strategy pursued by Wismut GmbH at the conclusion of the largest sectional flooding of underground mine workings at the Ronneburg site (Paul et al. 2002, 2003). Factual realities discovered and experience accumulated during 2.5 years that have passed since the flooding water rose to an external impact level have, to some extent, led to new courses of action and somewhat different prospects with regard to the completion of the flooding process.

2. SITE CHARACTERIZATION

The Ronneburg uranium mining district in Eastern Thuringia is located on both sides of the water divide between the Weiße Elster and the Pleiße rivers, which are both tributary to the Elbe river basin. Geologicaly the district is situated at the so-called Ronneburger Horst, the north-eastern part of the Berga anticline of the Thüringer Schiefergebirge (Thuringian shale highlands), where the host rocks of the mineralized zones are outcropping. Mineralisation was present as lenses and stockworks within a package of slates, magmatites and limestones, together approximately 250 m thick, reaching from upper Ordovician to lower Devonian. By the end of production in 1990 a part of the mining legacy at the Ronneburg site consisted of a complex underground mine with 40 shafts and an open volume of about 24 million m^3 of mine workings to be closed. A groundwater cone of depression covered an area of some 40 square kilometers. In terms of water quality it is characteristic for the Ronneburg district that mine and seepage waters are carrying high concentrations of dissolved iron, sulphate and heavy metals (Mn, Ni, Co, Cu, Zn, Cd) and radionuclides due to iron sulfide concentrations of up to 5 % in the palaeozoic rocks. Since the prevailing rock forming carbonate mineral in the deposit is dolomite also very high magnesium in both acid and neutral rock drainage.

3. FLOODING STRATEGY

As at all other sites under remediation of WISMUT GmbH, flooding of the mine at Ronneburg was without alternative and was aimed in the first place at putting an end to radioactive emissions via the atmospheric and water pathways and at drastically reducing operating costs. As was provided for in the flooding concept, the final flood level had to be reached by uninterrupted flooding without imported water, fed only by natural ground water inflow. The flooding process was to be completed across all fields without any targeted, artificial point wise overflow such as an adit. As for the valleys incising into the mining district from the flanks, groundwater discharge into the valley bottom aquifers or receiving watercourses, respectively, was to be restored as from the final phase of flooding. Monitoring the change over time of groundwater volume and quality in those potential decant areas, as they are called, was a prerequisite for risk assessment and action planning. The principal decant area in the Gessental valley located to the west of Ronneburg was to be equipped for contaminated groundwater discharge with a water collection system installed in the Quaternary groundwater aquifer. Water collected at this location was to be pumped to a central water treatment plant.

The flooding strategy aimed at an ultimate flood water level that would be high above the valley level of the receiving watercourses. Such a situation was considered advantageous for the following reasons:

- reducing the thickness of the unsaturated zone (minimisation of oxidation – and hence of long term effective contaminant supply),
- minimising flows in the flooded mine (support of layering/stratification trends, minimisation of contaminant release and migration),
- minimising volumes of water emerging mainly in the Gessental valley and to be pumped for treatment and minimisation of water treatment costs.

Groundwater treatment had to be continued to a point in time where the quality of the mine water discharge would allow direct discharge to the receiving watercourses without prior treatment, with the understanding that the need for water treatment would not taper off before two to three decades.

4. START-UP AND IMPLEMENTATION OF MINE FLOODING

Early in 1998, cessation of water pumping in the mine fields located to the south of the federal motorway (BAB) 4 initiated overall flooding of the underground mine workings of the Ronneburg uranium mining district. In summer 2000, shutdown of mine dewatering in the Beerwalde mine field triggered off flooding of the northern mine fields of Beerwalde and Drosen. Before that could happen, comprehensive preparatory work had been accomplished since the termination of uranium ore mining in 1990 to ensure the proper decommissioning and closeout of the underground workings which included the removal of materials that might contaminate the incoming water, filling and plugging of all pit shafts and other surface openings, backfilling of near-surface mine workings, underground barrier construction and partial flooding of isolated, deeper-lying mine fields. Hydraulic separation was established in particular between mine fields located to the north and to the south of federal motorway BAB 4 as well as the isolated Korbußen mine field.

Groundwater rise in the mine and the surrounding rock up to the level of discharge into the valleys took place without any intervention, short-term mine water pumping from 2001 to 2003 merely served to feed the trial runs of the water treatment plant. Data collected during the accompanying monitoring process were continuously evaluated and used for detail adjustment and updating of the flooding strategy as well as for model calibration and verification. Prior to reaching the decant level, virtually all mine workings were completely flooded.

In order to prevent intolerable contaminant emissions with respect to ground and surface waters in the decant areas, the following set of preventive measures was taken (Unland et al. 2002):

- constructing a near-surface water collection system and pumping facility in the Gessental valley,
- constructing a water collection systems along the Northwest edge of the Lichtenberg open pit,
- keeping available technical equipment and supplies for water management in the Alt-Lichtenberger valley in stand-by,
- constructing and equipping of a well with a hydraulic connection to the flooded mine workings for the purpose of flood water level control in the mine workings.

In addition to the construction of technical systems a strategy of „reactive action“ was prepared and agreed with the licensing authorities. This strategy includes protective measures for the identified potential risks of environmental effects. The relevant actions should be implemented on call based on the results of the environmental and operational monitoring in the mining area.

To treat the waters collected in the Gessental valley, the Ronneburg water treatment plant (WTP) and the required feed and discharge pipelines were designed, built, tested and optimised during a number of test runs. The plant is used to separate radionuclides and heavy metals with a modified precipitation process using lime on the basis of the high density sludge process. There is no separation of sulphate or hardness in significant quantities by the plant. Residues of the WTP are safely deposited in an engineered area at the site of the backfilled Lichtenberg open pit mine.

5. FINAL STAGE OF FLOODING

During summer 2006, the flood water table in the Ronneburg mine workings reached a level of 235 m a.s.l., and from this level onward flooding induced groundwater discharges gained momentum in the Gessental valley as the principal decant area. Since then the groundwater collection system has been collecting most of the rising contaminated groundwaters. In 2008, collected contaminated groundwater amounted already to ca. 300 m^3/h which is routed via a pumping station and a pressure pipeline to the Ronneburg water treatment plant.

In the course of continued mine water level rise up to ca. 254 m a.s.l. it became clear, that additional technical measures would have to be taken to boost the water intake capacity of the collection system in order to protect the Gessenbach creek affected by localised water logging and uncontrolled exfiltration of contaminated groundwater from the flooded mine. In addition to locally differentiated hydraulic permeabilities of the basement, hydraulically insufficiently plugged boreholes turned out to be preferred pathways for the rise of contaminated groundwater from mine workings to the ground surface. Technical flaws in the existing collection system became evident.

Initiated during winter of 2006/2007, these measures included:

- Damming of the Gessenbach creek across the rehabilitation area, capture and treatment of the creek water,
- Optimisation and targeted upgrading of the existing water collection system including installation of a second penstock pipeline to discharge water out of the Gessental valley,
- Constructing a bypass channel to temporarily divert non contaminated surface water of the Gessenbach creek around the rehabilitation area,
- Post-remediation of selected technical and exploratory boreholes,
- Digging of two new wells with connection to the mine workings for flood control.

The measures are aimed at complying permanently with the following quality targets set for the Gessenbach creek: Ni 170 μg/L, Cu 30 μg/L, Zn 380 μg/L, As 30 μg/L, Cd 1 μg/L, U 50 μg/L.

Apart from the Gessental valley, other valley locations also showed surface water contamination which triggered intensified monitoring and in one case technical measures on call were implemented. Given the very small flow rates in local receiving watercourses and the high visibility of mine water influence to the public, even very small amounts of contaminated groundwater discharge necessitated to have technical measures implemented.

Owing to increasing volumes of contaminated runoff from plant areas and mine dump surfaces at the Ronneburg site the remaining capacity of the water treatment plant for groundwater treatment was reduced. Thus mine water levels could not yet be lowered as required for implementing a number of measures crucial to ensure long-term stable system behaviour in the Gessental valley. Corrective action to control the course of mine flooding was initially delayed among other things by damage to the central well.

6. MODEL BASED PROGNOSES COMPARED TO REALITY

In a preliminary evaluation, theories underlying the flooding strategy as well as system assumptions and prognoses are in retrospect compared to facts and experience gained so far.

Groundwater Recovery

The initial mine flooding concept was based on the assumption that it would take the flood waters 12 to 15 years to emerge at the mine's deepest overflow level (Gessental valley at ca. 235 m a.s.l.) (WISMUT, 1993). At that time, the earliest possible overflow was estimated at 8.5 years after the beginning of mine flooding, however, this scenario was considered as extremely unrealistic and therefore not considered in further planning stages to establish flood water collection and treatment facilities. The actual time span for groundwater to rise to the above mentioned reference level amounted to almost exactly 9 years (beginning of 1998 – end of 2006). Major reasons for this rapid rise included (i) a slight underestimation of average inflow volumes, more importantly, however, (ii) a considerable overestimation of flood-relevant pore volumes in the dewatered rock, in backfill material as well as in the floodable section of the backfilled Lichtenberg open pit mine. Nevertheless, the necessary technical facilities and structures were ready in time and on line when required.

Water Drainage

Water discharge from the Ronneburg mine started in August 2006 to use the near-surface collection system based in the Gessental valley consisting of horizontal, vertical, and surface drains, function wells and collectors. Further flood water rise above the valley bottom, which is still ongoing, made obvious, that an extension of the collection system designed as a basic structure is required, since uncontrolled discharges to the natural creek occurred. Engineering operations are under way to ensure stable and safe mine water collection without adversely impacting the receiving stream running through the valley. The need for the collection system to be extended arose from (i) an insufficient hydraulic range of the basic structure in high yield areas as well as from (ii) water creeping at old boreholes owing to their insufficient state of preservation.

With regard to absolute groundwater discharge volumes, initial estimates put the figure at ca. 180 m³/h to 280 m³/h, of which some 200 m³/h would discharge to the Gessental valley. In the course of flooding, these assumptions were stated more precisely. In the end, ca. 390 m³/h were predicted as the sum of all discharge areas, of which ca. 210 m³/h in the Gessental valley. Practical experience since discharges began (recording of the actual water balance is running for ca. 3 years now) would suggest an average discharge volume of about 330 m³/h.

Following conclusion of remediation (after borehole plugging) predictions for the Gessental valley put discharge at hydrostatic equilibrium at around 300 m³/h.

Fluctuation in groundwater recharge was estimated on the basis of test runs of the water treatment plant (mine water pumping) at ± 25 %, of the long-term average. It was anticipated that the impact of fluctuations would be strongly attenuated by the storage volume of the groundwater aquifer. In practice, the decant areas were subject to major fluctuations because of the direct feeding of the valley bottom aquifer or of the collection system, in case of heavy rainfall events or snowmelt, respectively. In a matter of days, these events produce surplus quantities of up to 80 m³/h that have to be captured and pumped away.

Post-Flooding Groundwater Level

Prior to groundwater emergence, the final flood level was estimated to be in the order of 275 m a.s.l. (± 12 m error margin). The analysis of discharge history during the first year would suggest a greater impact of local geological structures. Although boreholes with a potentially hydraulic effect remain to be plugged and verification of current system assumptions is still outstanding, final flood levels of about 260 m a.s.l. are expected today unless there is some corrective action.

Water Quality

The Ronneburg mine is a complex system of interconnected, formerly individual mines, which during operation were characterized by very different water qualities, since a substantial portion of the mine water contamination has its origin in contaminated seepage of huge waste rock piles, which were scattered over the entire site. Accordingly, a very inhomogeneous flood water body was developing during the flood water rise. Since 2006, when mine waters started to discharge into the water collection system described above, the water quality of the different mine fields exhibit a certain tendency of equalization due to mixing processes along the flow path. This is consistent with conclusions in Younger et al. (2002).

Prognosis of water quality of emerging groundwaters was based on numerous mine water and ground water analyses. Given the diversity of mining-induced seepage and groundwater, simplifications in modelling were inevitable. Consequently, prediction accuracy varies significantly. Practice has demonstrated that

- prognoses based on contaminant and groundwater flow models are superior to the more simple balance assessments and, the development of complex models was therefore justified,
- systematic errors in the model may result in major divergences in predicting average concentrations,
- divergences tend to strongly augment the shorter the period under observation is selected, the smaller the split flows considered and the more differentiated local contamination sources are.

The summary below compares predicted and actual water qualities of groundwaters captured in the Gessental valley and pumped away for treatment on the basis of selected parameters.

Table1. Comparison of water quality predictions for groundwater captured in the Gessental valley as average of daily measured values

	SO_4 mg/L	Fe mg/L	Ni mg/L	U mg/L
Prognosis, 1st year after start of discharge	2500	260	2.3	1.04
Actual, average in 1st year after start of discharge	4800	480	9.0	0.31
Actual, average in 2nd year after start of discharge	4600	440	6.5	0.22

Significantly higher actual values for sulphate and iron account for the relatively rapid transfer of highly contaminated mine waters into the decant area, something that had not been expected to happen that way. Initially elevated concentrations of nickel are due to the wash-out of seepage of two, subsequently relocated, large mine dumps that was stored in the pore space of the quaternary groundwater aquifer. On the other hand it appears that uranium concentrations are significantly lower than predicted. No reliable prediction can be made at the present time on the future decay behaviour of the ca. 20 million m³ groundwater reservoir. After 3 years, cumulative discharge and withdrawal, respectively, amount to ca. 7 million m³ (about 30% of the reservoir). Concentrations in collected groundwater are currently significantly higher than average concentration levels in the mine workings; future decline of contaminant release is therefore expected.

With regard to the other periphery decant areas, groundwater flow and mass balance models had above all investigated potential mine water impacts. So far, flooding-induced changes have been observed in two of these decant areas. These processes are not caused by straight contaminant transport from the flooded mine, but have to be construed as a result of re-wetting of formerly drained rock formations (see Table 2).

Table 2. Comparison of water quality predictions for the Sprotte valley decant area with actual values

	As mg/L	Cu mg/L	Ni mg/L	U mg/L
Prognosis, 1st year after start of discharge	0.013	0.05	0.29	0.06
Actual, 1st year after start of discharge in emergence area (maximum)	0.001	0.63	2.10	0.05
Quality target for Sprotte creek (1 km downstream emergence area)	0.020	0.02	0.115	0.05

Dissipating of these local impacts in periphery valleys cannot be predicted with accuracy at the present time. It is expected though that within two years conditions will stabilise to a point where trends will emerge to allow long-term measures to be implemented for the protection of the receiving watercourses.

Operation of the Basic Structure in the Gessental Valley

The basic structure to capture groundwater in the Gessental valley has been built on the basis of geohydraulic modelling results. Virtually from the outset operators had to fully utilise all features of the system. The rise of the flooding level to more than 250 m a.s.l. brought about a groundwater inrush into the Gessental valley which could not be reliably controlled by the existing collection structures. Therefore, an optimisation and extension of the water collection system is on the agenda. Given the sensitivity of small streams such as the Gessenbach, it proved to be necessary to intercept and divert virtually all groundwaters in order to comply with water quality criteria. The captured groundwater from the Gessental valley is routed via a pipeline to the water treatment plant. As the discharge increased, construction of an additional pipeline proved to be necessary. Known as the back-up pipeline, it is now normally used on 70 percent of all days along with the standard pipeline to ensure (at least partial) removal of surplus ground water.

Originally, a central well was established for interventions during the flooding process. Damage to this well made it inoperative. As a consequence, a new well had to be installed. For safety reasons, a second well is currently being installed as back-up in the Gessental valley.

Water Treatment Plant Capacity Dimensioning

The Ronneburg WTP was designed for a treatment capacity of 450 m^3/h with an option to expand the capacity to 600 m^3/h by converting the sludge lines. Actual mine water volumes since the WTP went on line varied between 350 and 420 m^3/h depending on hydrometeorological conditions; of that volume ca. 300-320 m^3/h are collected by the Gessental valley facilities which is in fairly good agreement with earlier estimates (250-300 m^3/h, WISMUT 1993).

However, for reasons unrelated to mine flooding the water treatment plant has to treat waters from other sources as well (contaminated surface waters which were originally intended for direct discharge). Therefore, the nominal capacity of the plant is to be upgraded to 750 m^3/h.

7. CONCLUSIONS

Predictions made for the mine flooding operation at WISMUT's Ronneburg mine, with regard to groundwater recovery, flood water decant and future mine water quality, were not always correct in practice.

The above qualification notwithstanding, the original flooding strategy proved feasible, although a number of adaptations became necessary. Actual contaminant concentrations and loads sometimes differ considerably from predictions. The main reason for this is the underestimation of contributions from near-surface contaminant storage. Higher than expected iron concentrations in particular caused a drop in the water treatment plant capacity in the beginning. With regard to the volumes of water to be treated, predictions were on average correct.

The basic water interception structure put in place in the Gessental valley is running according to design expectations and intercepts > 90 % of rising groundwaters, while shortcomings in some cases required considerable rectification efforts. Due to relatively high system permeabilities in the Gessental valley in particular, the ultimate mine water table will settle at a lower level than predicted. Discharges of contaminated groundwater in periphery zones are manageable, requiring however, considerable efforts in particular cases and are sceptically perceived by the public.

The experience gained so far emphasises the need for comprehensive planning for flooding, but also for a flexible approach as part of a mine closure management plan which allows continuous updating of initial planning and corrective actions on the basis of monitoring data collected during the flooding process. It is expected that these activities will be finished by 2012/2013.

8. REFERENCES

Gatzweiler, R., Jakubick, A. T., Meyer, J., Paul, M., Schreyer, J. (2002): Flooding of the WISMUT mines – learning by doing or applying a comprehensive systematic approach? – In: Merkel, B. J., Planer-Friedrich, B., Wolkersdorfer, Ch.: Uranium in the Aquatic Environment. – p. 745-754; Heidelberg (Springer).

Paul, M., Gengnagel, M., Vogel, D., Kuhn, W. (2002): Four years of flooding WISMUT's Ronneburg uranium mine – a status report. – In: Merkel, B. J., Planer-Friedrich, B., Wolkersdorfer, Ch.: Uranium in the Aquatic Environment. – p. 783-792, 4 fig., 4 tab.; Heidelberg (Springer).

Paul, M., Gengnagel, M., Eckart, M. (2003): Groundwater modelling approaches as planning tools for WISMUT's remediation activities at the Ronneburg uranium mining site. – In: Krásný. J., Sharo, J. M.: Groundwater in fractured rocks: selected papers from the Groundwater in Fractured Rocks International Conference, Prague, 2003. - 646 Seiten, Chapter 36 (Routledge, 2007).

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. – In: Merkel, B. J., Planer-Friedrich, B., Wolkersdorfer, Ch.: Uranium in the Aquatic Environment. – p. 667-676, 5 fig., 1 tab.; Heidelberg (Springer).

WISMUT GmbH. 1993. Flutungskonzept Ronneburg.- Unpublished report, 1993.

Younger, P.L., Banwart, S.A. and Hedin, R.S., 2002. Mine water – Hydrology, Pollution, Remediation.- Kluwer Academic Publishers, 422 pp.