From remediation supervision to long-term surveillance – Ground and surface water monitoring at a former uranium processing site ◎

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Abstract

Starting in 1990, the clean-up of the former Crossen uranium mill near Zwickau in Germany has been a focal point in the Wismut remediation program which is dedicated to the legacy of large scale uranium mining and milling in East Germany.

The discharge of treated water, but also the still remaining release of contaminated seepage into aquifers and surface streams require the monitoring of the water-borne environmental impact. Key contaminants include uranium, arsenic and radium, accompanied by molybdenum, sulphate, chloride, hydrogen carbonate and sodium.

The current remediation monitoring is based on radiation protection licences and permits issued under water law. With the transition towards post-remedial and long-term activities after 2020 the monitoring requirements will substantially change regarding key function and scope. The presented paper describes the existing water monitoring system and key findings of the previous monitoring period. Finally, site conditions, constraints and remaining uncertainties for post-remedial monitoring will be discussed.

Keywords: ore processing, tailings pond, uranium, arsenic, radium, monitoring, groundwater, surface water

Introduction

The second largest tailings management facility (TMF) of the former East German uranium mining industry (former SDAG Wismut) is situated at Crossen and Helmsdorf near the city Zwickau, Saxony. Ore processing and the deposition of residues occurred on both sides of the river Zwickauer Mulde. First, three smaller tailings ponds (TP) were piled up from 1950 to 1958: Crossen (0.3 million tons), Dänkritz I (6.6 million tons) and Dänkritz II (1.2 million tons). After the depletion of storage capacity TMF Helmsdorf (49 million tons) was started in 1958 and worked until 1989.

Site remediation included

- the decommissioning of the processing plant including area clean-up (finished in 2008), other facilities on the left side of the Mulde were already dismantled before 2001;
- the relocation of the huge Crossen waste pile (3.3 million cubic meters) including the underlying older tailings from the floodplains of the Zwickauer Mulde river to the Helmsdorf TMF (terminated in 2018) and the rehabilitation of the footprint and reuse as a renaturalized floodplain;
- and the dry stabilization of the TMF itself on 200 hectares (to be finished in 2021).

The technology of in situ decommissioning includes the expelling of pond water, interim covering of the tailings surface, dewatering of the fine tailings, re-contouring of dams/ponds and final covering including re-vegetation (Neudert & Barnekow 2006). The water management strategy involves the treatment of contaminated pond, ground- and seepage water (Laubrich et al. 2018).

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With the transition towards the implementation of long-term tasks, the requirements regarding function and scope of the environmental monitoring will change.

Geological-hydrogeological site characterization

The Crossen-Helmsdorf site is located in the western part of a permian molasse basin between the Erzgebirge in the south and the Granulitgebirge in the north, which is based on old Paleozoic and Precambrian basement. The discontinuously outcropping sediments of the Upper Lower Carboniferous up to the Oberrotliegend II are continental sediment deposits of the eroded Variscan orogen.

The underground of the *Helmsdorf TMF* is determined by rocks of the Mülsen formation of the Oberrotliegend, which is intensively tectonically stressed in the vicinity of Helmsdorf TMF. The characteristic tectonic structural pattern combines structures which strike in ENE-WSW, NW-SE, N-S as well as NNW-SSE direction (fig 1).

Based on intensive drilling work from 1998 to 2003 and the gradual commissioning of groundwater monitoring wells during the rehabilitation period, it was recognized that all ENE-WSW striking fault zones on the eastern flank of the Helmsdorf TMF are involved in groundwater runoff affected by the tailings facility. Morphologically, these structures are visible through valley cuts, such as the Oberrothenbacher, Wüster-Grund, Niederhohndorfer, Zwischengrund and Trischgrund valleys. These structures extend into the area of the Zwickauer Mulde floodplain and pave the way for contaminated groundwater (Möckel & Neudert 2004).

The completely remediated *Dänkritz I TP* is located in an area of tertiary loose sediment deposits, having been subject to intensive sand and gravel extraction in earlier times. Tailings were deposited inside an exploited gravel pit. The clastic materials represent a pore aquifer of good water permeability along a SW-NE directed palaeo-channel. The relief of the underlying Rotliegend surface determines the groundwater flow direction within the Tertiary sediments towards the Zinnborn/ Zinnbach creek. Due to a high uranium contamination of groundwater downstream of the *Dänkritz I TP*, two extraction wells went into operation in 2002/2003, whose water is treated together with seepage water of the TMF Helmsdorf in the water treatment plant (WTP) Helmsdorf

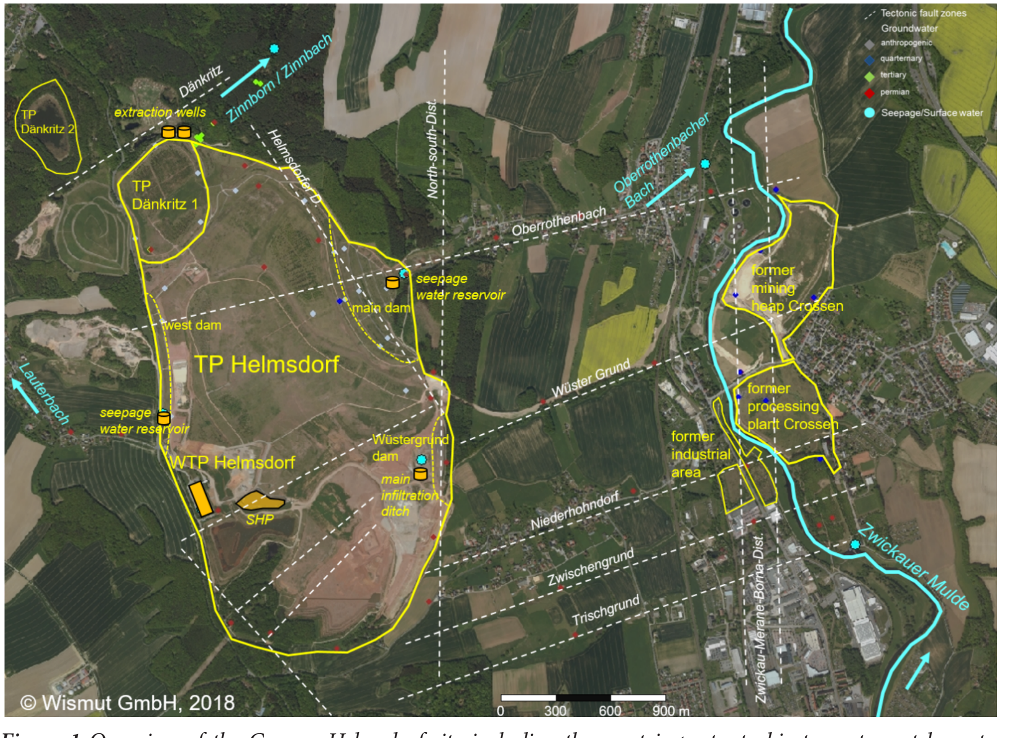

Figure 1 *Overview of the Crossen-Helmsdorf site including the most important objects, water catchments, schematized tectonic fault zones and points of key monitoring network 2018*

(Laubrich et al. 2018). The *Dänkritz II TP*, also situated inside of an exploited gravel pit, is not subject to the obligation of Wismut GmbH. The remediation will start in the near future.

The other objects (Crossen waste dump, processing plant and further industrial area) are located in the floodplain of the Zwickauer Mulde. It is characterized by quaternary loose sediments in the subsurface, which are extensively covered by alluvial loam.

Basics of monitoring networks development

Starting in 1990, first measuring networks of each compartment (water, air, soil) were installed in order to identify pollution sources and to describe their environmental impacts. After the deduction of remediation needs a selection of substantial (key) measuring points for the water path are defined as basic monitoring network which is legally based on the specifications of the REI Bergbau (1997). These points concisely characterize the site and serve for long-term oberservation. By setting limit values, water and radiation protection approvals determine the requirements for self-control with regard to parameters and sampling frequency. Aspects of monitoring tasks are summarized in table 1.

The remediation procedure requires the observation of each individual object, the compliance with limits and a flexible adaptation of monitoring elements to the clean-up progress. In expectation of the end of the physical remediation work the complex monitoring network will be reviewed and adapted to the needs of the post-remedial or long-term phase. In conjunction with resulting (long) time series the long-term monitoring network should reflect the success of remediation activities (Kreyßig et al. 2008).

Configuration and modification of key monitoring network

A key measuring network is composed of measuring points, which are needed for a sufficient characterization of the hydraulic and hydrochemical system behaviour in time during aftercare (Sporbert et al. 2006).

Decisive for the selection of key measuring points is the comprehensive knowledge of the geology and hydrogeology of the respective remediation object and the pathes of influence. All relevant aquifers or water-bearing units influenced by these objects be considered. Based on the groundwater flow regime, groundwater inflows and outflows are assigned to the object. The monitoring of the pollutant source (e.g. tailings pond) must be included in case of in-situ-remediation (Möckel 2006).

With the help of key monitoring networks, the fundamental, spatially substantial influences of groundwater by objects of Wismut GmbH are to be tracked in the long term and to be judged in terms of their dispersion dynamics as well as their trend behavior.

In the course of the transition from remediation to long-term monitoring, the water monitoring serves for:

- Evidence of hydraulic and geochemical stability after completion of remediation,
- Exclusion of a trend reversal of already decreasing or stable concentration values in groundwater,
- Prevention of health problems for the population from contaminants spreaded through the groundwater path, which could possibly lead to restrictions on its use for human consumption.

During the initial phase of the rehabilitation project until 2003, the groundwater surveillance network at the Crossen/Helmsdorf site embraced more than

***Table 1** Aspects of monitoring tasks*

Tasks	Classification of monitoring activities
Monitoring tasks:	screening, remediation, long-term
Temporal tasks:	before, during, past remediation
Object tasks:	background, source, path, effect
Permit tasks:	basis, remediation, after care
With respect to extent:	person-related, source-related
With respect to time:	limit-related, trend-related

600 groundwater monitoring wells. The remediation progress with the gradual completion of individual objects led to the initial establishment of a key monitoring network at site Crossen/Helmsdorf in 2006 with 129 groundwater and 10 surface water measurement points (Möckel 2006) (tab. 2).

With a view to the termination of the physical work (predicted for 2021), an optimized monitoring network has been established in 2018 which is dedicated to reflect the effect of the individual objects on the aquatic environment. The network can be understood as an optimized monitoring system for the immediate post-remedial and the long-term surveillance periods. It takes into account the hydrogeological site conditions, regulatory requirements, and cost aspects. Most recently, the Crossen key monitoring network involves 74 groundwater wells and 8 surface/seepage water monitoring stations (Möckel & Greif 2018). Table 2 shows the development of the number of measurement points in the individual objects.

The decline of 2018 compared to 2006 is particularly evident at the measuring points in the dams. This is related to the reduction of geotechnical investigations after complete removal of the freewater. Figure 2 shows stable or slightly decreasing uranium concentrations along the groundwater discharge channels allowing a gradual reduction of measuring points.

On the industrial area (temporary ore storage facility and assoziated technical structures) located at the left side of the Zwickauer Mulde remediation was completed in 2001. The uranium concentrations in groundwater are stable at a low level. Here, the measuring points of the key measuring network could be decommissioned. On the other hand, contamination in the groundwater can still be detected along the processing site (radiometric, chemical processing) on the right side of the Zwickauer Mulde, as residual materials had remained in the underground. The groundwater monitoring should be continued here with less measuring points. The waste dump Crossen is in the final stage of remediation, hence the temporal evolution must be further observed with the existing sampling sites.

Table 2 *Number of measuring points of the key monitoring network in 2006 and 2018.*

Object	Structure and path	2006	2018
Groundwater	tailings body (polluted source)	5^a	4^a
Tailings pond Helmsdorf	dam body (polluted source)	27^a	12^a
	tailings underground (geogenic background)	5^q	1^q
	Helmsdorf fault zone (upstream)	6^p	3^p
	Steinigtgrund fault zone (upstream)	2^p	1^p
	Engelsgrund fault zone (upstream)	4^p	2^p
	Oberhohndorf fault zone (upstream)	5^p	3^p
	Nord - Süd – jointed zones (up-/downstream)	2^p / 5^p	1^p / 4^p
	Oberrothenbach fault zone (up-/downstream)	3^p / 11^p	1^p / 6^p
	Wüster-Grund fault zone (downstream)	4^p	3^p
	Niederhohndorf fault zone (downstream)	6^p	3^p
	Zwischengrund fault zone (downstream)	4^p	2^p
	Trischgrund fault zone (downstream)	4^p	3^p
Tailings pond Dänkritz 1	tailings body/dam (polluted source)	4^a	4^a
	upstream	1^t 1^p	1t 1^p
	downstream	1^p 7^t	1p 7^t
Processing plant Crossen	area (polluted source)	3^a	1^a
	upstream	4^q	2^q
	downstream	5^q	3^q
Mining heap Crossen	upstream	1^p 1^q	1^p 1^q
	downstream	2^p 3^q	2^p 3^q
Other operation areas	upstream	2^q	cancelled
Crossen	downstream	3^q	
Surface water	seepage-/mixed/treated water	6	4
	river/stream	4	4

Stratigraphy: ^{p} permian (Rotliegendes), ^{q} quaternary, ^{t} tertiary, ^{a} anthropogenic

According to the 2018 key monitoring plan, quarterly measurements of groundwater level and annual groundwater sampling are required. In the case of surface water measuring points, the sampling frequencies range from monthly to quarterly. The parameter spectrum includes in-situ parameters, macro constituents, trace elements and radionuclides.

Use of key monitoring network and systematic long-term studies

Due to the long-term character of the monitoring programs, the concentration data series obtained reflects the spatial and temporal remediation status of the individual objects. In combination with the discharges, an accounting and thus an assessment of the relevance of individual emissions to the environment becomes possible. For the Crossen-Helmsdorf site, the following tasks can be derived from the current data:

- Examination of the groundwater quality for inflow, development within the pollution source and along outflow channels (e.g. fig. 2),
- Examination of surface water quality, including compliance with environmental quality standards in water and suspended matter in the surface water body according to the EU Water Framework Directive (currently no standard for uranium),
- Determination of water quality and amount of seepage and groundwater sub-streams to be treated as a precondition for effective water treatment,
- Balancing of the partial flows and determination of loads from point sources in relation to the increase in load in the receiving waters (Zwickauer Mulde), indirect estimation of loads from diffuse sources,
- Designation of the performance of the water treatment via the pollutant retention from the water system (also with regard to supraregional effects, in this case for river Elbe).

Analysis of long-term data series provide a powerful tool for the evaluation of the remediation success. Figure 3 shows, that the commissioning of the WTP Crossen (1995) in the middle course and the WTP Schlema-Alberoda (1998) in the upper course of Zwickauer Mulde led to the reduction of uranium emissions and consequently the improvement of water quality in the Zwickauer Mulde as shown at site Crossen-Helmsdorf.

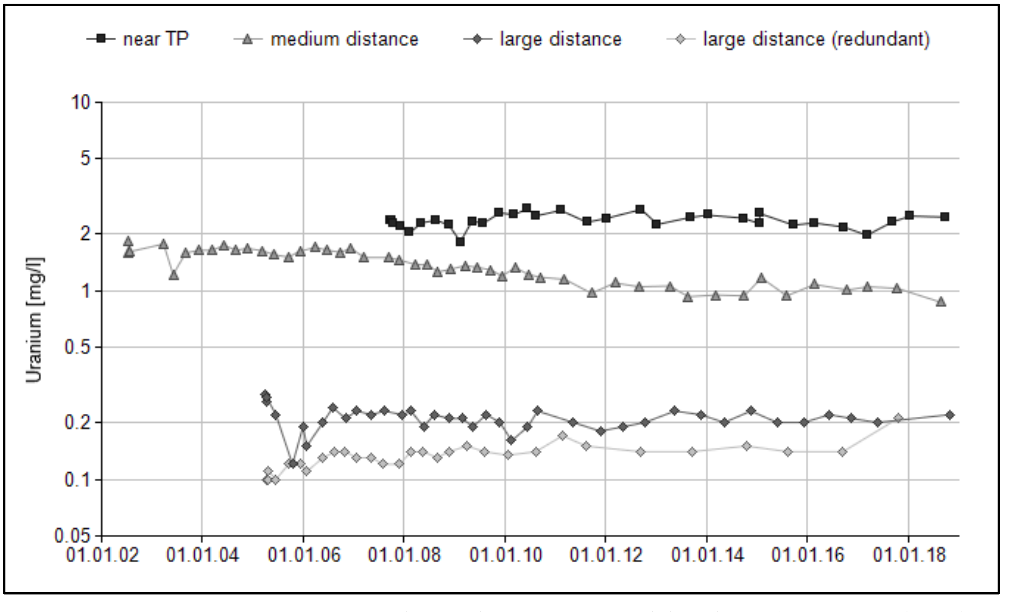

Figure 2 *Uranium concentrations in groundwater along Wüster Grund disturbance (permian) in dependence of distance to TMF Helmsdorf*

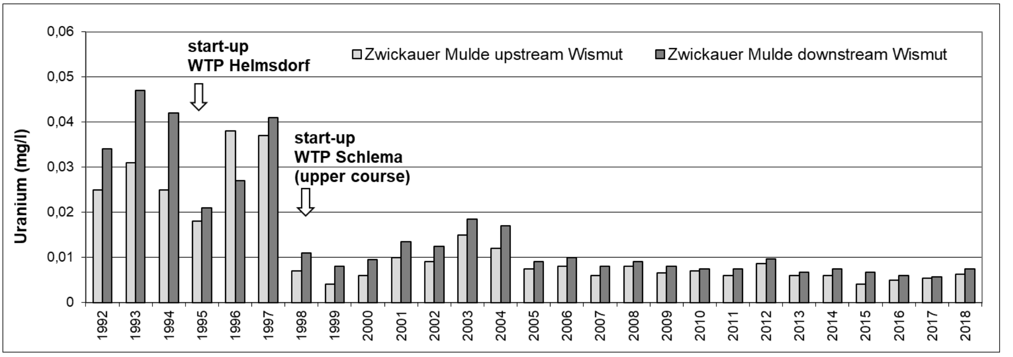

Figure 3 *Uranium concentrations (median) in surface water of Zwickauer Mulde upstream and downstream of remediation site Crossen-Helmsdorf*

Outlook

Depending on the future development, the network will be subject to regular revisions, with the goal of further optimization. Key monitoring networks should be reviewed at least every 10 years. Within one of the next adjustments at site of Crossen-Helmsdorf the consolidation of all remaining requirements should be checked.

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