# Surface water monitoring in a mining impacted drainage basin with particular reference to bio-monitoring of protected species

Thomas Metschies[1], Heidrun Müller[2], Susan Skriewe[2], Michael Paul[1], Ariane Nowak[3], Robert Sieland[1]

[1] *Wismut GmbH, Jagdschänkenstraße 29, 09117 Chemnitz, Germany,* ✉ *T.Metschies@wismut.de*
[2] *KOWUG GmbH, Gera, Germany*
[3] *Limnolabor Nowak GbR, Berlin, Germany*

## Abstract

The Weiße Elster river drains a watershed characterised by an intensive industrial use and the existence of historic as well as ongoing mining operations in Central Germany. Besides lignite mining major impacts result from uranium mining which was conducted between 1949 and 1990 in the watershed. Remediation of uranium mining legacies still requires the treatment of significant volumes of contaminated mine and seepage waters. The discharge of treated waters influences the hydrochemical conditions in the river system. The present monitoring includes the hydrochemical analysis of water and sediments in the small receiving streams close to the mining areas but also extends further into the Weiße Elster river. Limit values are not only to be met in the treated water outflow but also in the more distant river system. The controlled discharge of salinity and hardness proved to be a crucial element of the water management since the existing water treatment technology does not account for desalination. Changing flow conditions in the Weiße Elster river form a risk for the compliance with the limit values especially during periods of low flow. In addition to a number of other technical and management measures Wismut GmbH applied for a temporal increase of the limit value of hardness concentration in the Weiße Elster river. A higher limit value was granted but an additional biological monitoring was required due to the needs resulting from the Water Resources Act as well as the Habitat Directive. The relevant aspects, the methodology used and the main findings of the already conducted monitoring are outlined in the paper. According to the results of a 4-year monitoring period none of the indicator biota including benthic invertebrate fauna (i.e. mussels), fish (bitterling = *Rhodeus amarus*) and the green club-tailed dragonfly (*Ophiogomphus cecilia*) has been adversely affected.

Key words: Uranium mining remediation, surface water, biological and geochemical monitoring

## Introduction

The Weiße Elster river drains a watershed of about 5,100 km² in Central Germany. It flows at a length of 257 km from the Elster mountains at the border of Czech Republic and Germany to the Saale river which is a tributary of the Elbe river. On its way it crosses areas which are densely populated, with intensive industrial and agricultural use as well as extensive historic and ongoing mining activities. While in its upper section the river has the characteristics of a stream in a mountainous area with respective flow velocities and river bed substrate (type 9.2 based on Annex II of the EU Water Framework Directive 2008/32/EC) the conditions change in the downstream area. Due to the reduced slope of the river bed the river was naturally characterized by meandering and braiding forming islands and oxbow lakes (type 17). For the respective river types a certain biocoenosis forms a general orientation as a target for a good condition of the surface water. Consequently, the present conditions are to be compared to this target. These natural flow conditions were partly destroyed in the river by flow regulation to use the fertile flood plains for agriculture and to realize open cast lignite mining during the past two centuries. Nevertheless, the natural conditions were conserved in sections of the river as e.g. a riparian forest around the town of Leipzig and therefore enjoy a distinct protection status.

In addition to extensive lignite extraction also large scale uranium mining and milling was conducted in the Weiße Elster watershed close to Ronneburg and Seelingstädt. The former joint Soviet-German

Wismut Company in charge of uranium mining and milling had started its activities in Eastern Germany right after the end of WW II. When uranium mining was stopped in 1990, about 50 % of the total mine extraction of about 230,000 metric tons of uranium had come from deep and open cast mines in the Ronneburg-Seelingstädt area. From 1960 to 1990 the vast majority of the mine production was processed at the Seelingstädt milling plant with a total output of 110,000 t of uranium (Barnekow et al. 2012). The residues were dumped in two tailings management facilities (TMF) located at former open cast mines close to the mill.

Remediation of the vast legacies is still ongoing at both sites. At Ronneburg the former open pit is already backfilled with about 131 million tonnes of mine waste rock which formerly had been dumped in 12 huge piles in the area. The presently realised flooding of the deep mine requires the management and treatment of contaminated mine waters which partly decant. However, for implementation of additional remediation measures the water level in the mine has to be managed in a given range to avoid uncontrolled outflow of the mine water to the surface.

At the Seelingstädt site stabilisation and contouring of the mill tailings is ongoing. The works at the Trünzig TMF are close to be finished. The regulation of the surface water discharge has to be finalised in the next years. The remediation of the Culmitzsch TMF containing about 85 million m³ of tailings is in progress with the present main focus on the stabilisation of the fine slime tailings at the bigger (61 million m³ tailings) of the two sub-impoundments. In addition to contaminated seepage, surface and ground waters from both sites a considerable volume of highly polluted pore waters have to be managed and treated during consolidation and contouring of the tailings.

**Management of mine water discharge**

At both remediation sites the treatment of collected waters is conducted by conventional lime precipitation which is effective for the removal of radioactive components such as U and accompanying metals from the water. On the other hand, salt concentrations especially sulphate, chloride and hardness are not decreased but even slightly increase due to the added lime and several pre- and post-treatment steps. The treated waters are discharged into small tributaries of the Weiße Elster river. The discharged maximum annual volume of treated mine waters reached 2.3 million m³ and 6.8 million m³ from Seelingstädt and Ronneburg, respectively. In the 5-year-periode between 2011 and 2015 the annual averages were 2.1 million m³ and 6.6 million m³. The composition of the mine waters to be treated at both remediation sites is characterised in Table 1 showing median and the 90percentile of the daily measured concentrations in 2015. While in the released treated water the annual average U-concentration is one order of magnitude lower (less than 0.1 mg/l) the released salt concentrations are at the same level as in Table 1.

***Table 1*** *Median/90Percentile concentration of selected parameters of treated water at remediation sites.*

| Data for 2015 | U [mg/l] | $SO_4$ [mg/l] | Cl [mg/l] | Ca [mg/l] | Mg [mg/l] | Hardness °German Hardness |
|---|---|---|---|---|---|---|
| Ronneburg (e-621) | 0.74/0.81 | 2,660/2,870 | 59/62 | 458/496 | 409/447 | 160/171 |
| Seelingstädt (E-306) | 1.27/1.51 | 6,800/7,900 | 1,290/1,400 | 361/407 | 745/880 | 222/258 |

The permit for the discharge of the treated waters requires among others to meet limit values for hardness and salts in the Weiße Elster river downstream of the inflow of waters from the mining sites. Based on the composition of the mine waters especially hardness and sulphate are critical parameters, while metals and especially uranium concentrations are generally below the limit values set for the discharged treated waters due to the appropriate treatment technology.

Compared to the active mining period the remediation activities partly lead to a significantly increased quantity of contaminated waters resulting from mine water management and the water release during the consolidation of fine slime tailings. In this respect, remediation measures had to be delayed because certain limit values could not be met in considerable time periods even with a number of additional management measures as discussed in Metschies et al. (2013). One of the active

management measures includes the amendment of the water discharge in the Weiße Elster river during periods of low flow from upstream storage reservoirs. This water management measure assures a minimum of 3.5 m³/s of river flow at an upstream stream gauge in Greiz used for management purposes. As a result the minimum discharge was temporarily increased on average by up to 50% compared to the unregulated conditions.

After reassuring that all technically feasible measures to manage the salt release were taken the permitting authority agreed to temporarily increase the limit of hardness to allow proceeding with the implementation of the remediation work. In the permitting procedure the relevant authorities of the Federal States of Saxony-Anhalt and Saxony responsible for the downstream river stretches were involved as well. In addition objections of individuals and legal entities exercising rights of water use downstream were considered. Special attention was paid to the aspect of environmental conservation. A number of areas protected by the EC Habitats Directive (Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora) are located downstream at the Weiße Elster river. Taking into account their special protection status WISMUT was required to plan and conduct a biological monitoring covering the protected areas as well as key species along about 100 km of the Weiße Elster river downstream the mining sites (Table 2).

**Methods of applied biological monitoring**

The procedures of the biological monitoring were agreed with the permitting authority and the involved nature conservation authorities responsible for various parts of the river downstream. The monitoring has to be conducted annually and focuses on fishes, mussels and macrozoobenthos including dragonflies.

***Table 2*** *Approximate distance of monitoring points from the river mouth and the mining sites.*

| location | Distance from Weiße Elster river mouth [km] | Distance downstream the mining sites [km] | comment |
|---|---|---|---|
| Seelingstädt site | 149 | -15 | Processing site |
| Ronneburg site | 134 | 0 | Mining site |
| e-423 | 124 | 10 | Sampling point with MLC |
| 5 | 82 | 52 | Biological monitoring |
| 6 | 81 | 53 | Biological monitoring |
| 9 | 70 | 64 | Biological monitoring |
| 7 | 65 | 69 | Biological monitoring |
| 1 | 48 | 86 | Biological monitoring |
| 2 | 46 | 88 | Biological monitoring |
| 3a+3b | 27 | 107 | Biological monitoring |

The monitoring program has a specific focus on a cyprinid fish called bitterling (*Rhodeus amarus*) which is a short-lived species, generally surviving only for about five years. Their maximum size is 11 cm, but they are usually much shorter. The bitterling inhabits slow-flowing or standing waters, such as ponds, lakes, marshes, muddy and sandy pools as well as river backwaters requiring dense river bank vegetation. It has a remarkable reproduction strategy where parents transfer responsibility for the care of their young to various species of freshwater mussels. Therefore, the occurrence is restricted.

*Rhodeus amarus* is considered as endangered species being on the Red List of the Federal Republic of Germany (category 2: strongly endangered). It belongs to the species of annex II of the EC Habitats Directive which contain species whose core areas of their habitat are designated as Sites of Community Importance (SCIs) and are included in the Natura 2000 network. These sites must be managed in accordance with the ecological needs of the species.

Monitoring for fish is conducted by electrofishing of 300 to 500 m long river stretches at 3 locations each. The fish species are recorded and their number is counted and compared to an evaluation criterion based on Schnitter et al. (2006). This criterion relates the fish population to the area

monitored and the distribution of the different age groups. Field work has to be conducted in late summer in order to also record juvenile individuals allowing to determine the state of preservation of the population.

At two locations in the river three transects of a total area of 12 m² each were monitored for the mussels needed for the reproduction of the bitterling. Here the river bottom is examined either using a rake, a sighting tube or screened by hand. At an additional location two riparian strips of 23 m² and 15 m² were intensively manually screened because of high turbidity and silt content of the river bed.

The evaluation of the macrozoobenthos considers organisms living at the bottom of the water column. Multi habitat sampling, collection by hand within the river water at relevant substrates such as stones, deadwood and detritus as well as brailer sampling along the beach vegetation are conducted to determine imagines. The abundance of the green club-tailed dragonfly (*Ophiogomphus cecilia*) is monitored at six locations along the river. In total 10 river stretches of 100 m length each are monitored along one or both river banks by collecting exuviae after the main emergence between mid of June and end of July at three dates and by visual observation of flying imagines. The determination of the state of preservation is done according to Schnitter et al. (2006). The determined status mainly depends on the number of exuviae counted in a section of 100 m or number of sections with more than five exuviae and is to a minor extend based on visual observation of imagines.

**Monitoring results**

Table 3 presents medians and 90 percentiles of daily measured sulphate, chloride and hardness concentrations at a key monitoring point in the Weiße Elster (e-423). The data are shown for time periods before and after the granted temporal increase of the hardness MCL. The data show the general tendency that the mean concentrations as well as the maximum concentrations increased between 2007-2011 and 2012-2015. While the existing limits for sulphate and chloride are still met the concentrations of hardness increased above the original limit value but remained well below the temporarily set limit of 24°dH. This also resulted from additional technical measures which were implemented to reduce the discharge of salt and hardness as outlined in Metschies et al. (2013).

***Table 3*** *Median/90 percentile concentration of parameters and resp. limits given in the Weiße Elster river (MCL ... Maximum concentration limit, °dH ... degrees German hardness).*

| Time period | $SO_4$ [mg/l] | MCL $SO_4$ [mg/l] | Cl [mg/l] | MCL Cl [mg/l] | Hardness °dH | MCL Hardness °dH |
|---|---|---|---|---|---|---|
| 2007 - 2011 | 168/312 | 450 | 77/109 | 250 | 13.1/19.0 | 19.0 |
| 2012 - 2015 | 217/322 | 450 | 88/115 | 250 | 15.0/19.7 | 24.0 |

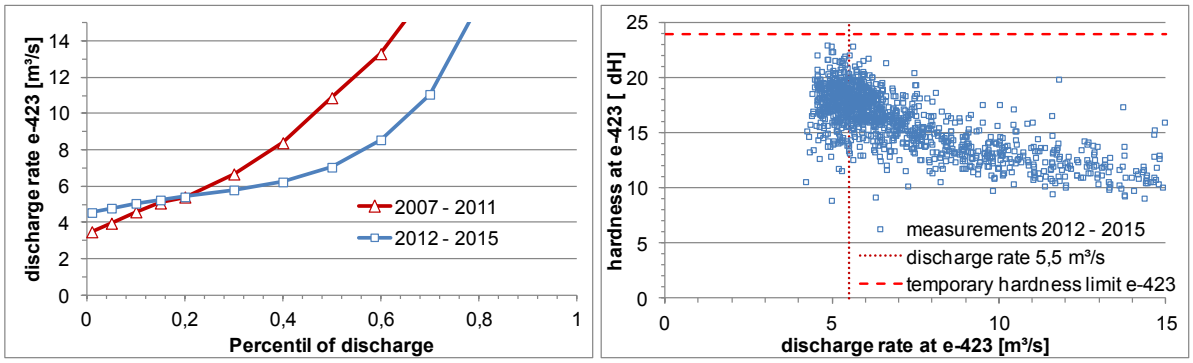


***Figure 1*** *Distribution of discharge before and after increase of limit (left) and the correlation of daily values of hardness measurements and discharge at measurement point e-423 in the Weiße Elster river.*

As shown in **Fehler! Verweisquelle konnte nicht gefunden werden.** the flow rate measured in the Weiße Elster river between 2012 and 2015 was in general considerably lower compared to the years before. Low discharge rates occurred significantly more often. The influence of the amendment of water from the upstream storage reservoirs is clearly visible for the discharge rates below 5.5 m³/s which account for more than 20% of the time period. Between 10 million m³ and 25 million m³ of

water were added from the upstream storage reservoirs annually under low flow conditions affecting the concentrations of salt and hardness in the Weiße Elster river. As a consequence possible effects of the salt discharges on the biota in the downstream river could be significantly reduced. Except some days the measured hardness was less than 20 °dH in the monitored period (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

Table 4 summarises the results of the fish monitoring with respect to the occurrence of the bitterling (Figure 2). The number of bitterling was related to the area influenced by fishing to determine the status of preservation. An abundance of more than 2,500 individuals at 1 ha and a sufficient number of juveniles is considered as excellent (grade A).

***Table 4*** *Results of electrofishing at monitored location (grade A: excellent, B: good, C: average to bad).*

| Location | Abundance of *Rhodeus amarus* | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| 1 | Number of individuals | 363 | 398 | 274 | 229 |
| | Individuals/ha | 9,190 | 8,652 | 5,957 | 4,978 |
| | grade | A | A | A | A |
| 3b | Number of individuals | 427 | 216 | 376 | 376 |
| | Individuals/ha | 9,085 | 4,596 | 8,000 | 13,383 |
| | grade | A | A | A | A |
| 9 | Number of individuals | 1 | 0 | 17 | 17 |
| | Individuals/ha | 33 | 0 | 486 | 171 |
| | grade | C | C | C | C |

***Figure 2*** *Bitterling (Rhodeus amarus) of 5 cm length.*

The duck mussel (*Anadonta anatina*) is an unpretentious species of freshwater mussel with a high adaptability. It becomes 10 to 15 years of age and has a length of up to 10 cm sometimes even 15 cm. It lives in standing as well as flowing waters but does not tolerate a strong oxygen depletion. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the number of mussels found along the monitored transects (3 times 12 m²) or beach stretches (23 m²). The transects had to be slightly moved at location 1 in 2014 because of high water level in the river and consequently worse conditions for the monitoring.

***Table 5*** *Results of mussel monitoring.*

| Location | Area | Abundance of mussels | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|
| 1 | 3 transects 12m² each | Vital individuals | 12 | 26 | 35 | 32 |
| | | Distribution status | frequent | frequent | frequent | frequent |
| 3b | Beach stretch 23 m² (2012: 15 m²) | Vital individuals | 8 | 12 | 15 | 39 |
| | | Distribution status | frequent | frequent | frequent | frequent |
| 9 | 3 transects 12m² each | Vital individuals | 82 | 49 | 62 | 37 |
| | | Distribution status | extensive | extensive | extensive | frequent |

Evidence of sufficient juvenile mussels representing a good reproduction state is documented in the detailed monitoring results (Figure 3) where the mussels are grouped according to the length of the shells for location 1.

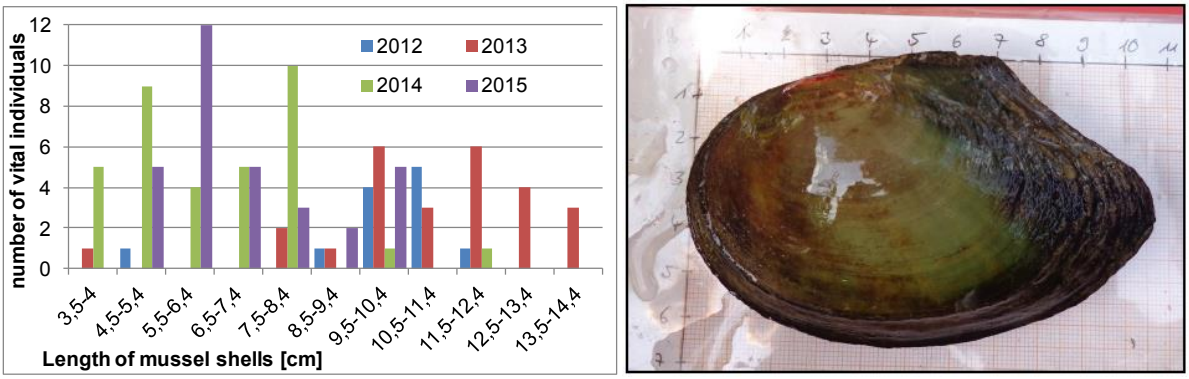


***Figure 3*** *Length distribution of the sampled mussels for the monitoring period at sampling location 1 (left) and a photograph of the Duck mussel (Anodonta anatina).*

Based on the monitoring of macrozoobenthos the ecological status of the water body is determined. The total number of individuals and of different taxa as well as the number of species of the orders commonly known as mayflies, stoneflies and caddisflies (*Ephemeroptera*, *Plecoptera Trichoptera* as EPT-taxa) are considered as important criteria. Table 6 shows the summarised results of the sampling campaigns during the past 4 years.

***Table 6*** *Results of macrozoobenthos monitoring.*

| Location | Abundance of mussels | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| 6 | Number of taxa | 44 | 24 | 49 | 50 |
| | EPT-variety | 21 | 16 | 22 | 23 |
| | Ratio EPT/all individuals | 48% | 55% | 44% | 50% |
| 7 | Number of taxa | 40 | 32 | 40 | 35 |
| | EPT-variety | 21 | 19 | 19 | 17 |
| | Ratio EPT/taxa | 51% | 54% | 49% | 50% |
| 2 | Number of taxa | 30 | 30 | 32 | 31 |
| | EPT-variety | 12 | 18 | 15 | 15 |
| | Ratio EPT/taxa | 41% | 47% | 43% | 46% |
| 3a | Number of taxa | 28 | 25 | 24 | 33 |
| | EPT-variety | 3 | 5 | 3 | 9 |
| | Ratio EPT/taxa | 8% | 7% | 0% | 22% |

The registered evidence of the stonefly *Brachyptera braueri* was remarkable. This stonefly was considered nearly extinct but was found again in the last years in the federal states of Saxony and Thuringia. In March 2015 a number of larvae were found at the locations 6 and 7.

Between 100 and 200 exuviae of the green club-tailed dragonfly (*Ophiogomphus cecilia*) were found in each of four out of six locations during the annual three site visits between mid June and end of July

throughout the monitoring period. At these locations the state of preservation of the dragonfly population is excellent without any significant trend. A good status was found for the location 7 with between 20 and 100 exuviae. At this location the river bank has eroded as well as rock stabilised bank sections. The natural eroded sections with overhanging roots represent a good dragonfly habitat. In contrast the remaining sections are less inhabited or even without any proof of evidence of the dragonflies. At one location (5) the results vary between average to bad and excellent with 2 exuviae (2012) and 98 (2013), respectively. At this location substantial morphodynamic relocations of the river bank material were found resulting in the great variability of the counted number of exuviae.

**Discussion of results**

In the Weiße Elster river at measurement point e-423 the increase of salt concentrations was on average about 15% compared to the time period before the temporal increase of the limit value for hardness. The elevated limit allowed a flexible water management at the remediation sites of Seelingstädt and Ronneburg ensuring an uninterrupted progress of the necessary physical works. In order to reduce the impact of the water discharge a number of additional technical measures had to be implemented in parallel. Nevertheless, changed chemical conditions were detected in the river at least during low flow conditions to which the monitored species have to adapt.

During the 4 year period 2012-2015 no change of the preservation status of the bitterling population was found in the monitored river stretches. The two areas with a high abundance of individuals are still in an excellent condition while at the other location only a small number of bitterling was encountered. This condition has been already reported for the first year of monitoring without influence of the higher hardness level. Structural deficits are the main reason for the limited fish population such as bank fixations and missing vegetation at the river banks.

The mussel population at the monitored transects was found to be frequent to extensive with a considerable amount of juveniles proving a stable population. Annual changes in the number of counted mussels can be attributed to different flow conditions which influence the effectiveness of the screening by hand. This could be the reason for the significant increase of the mussels counted at location 3b in 2015 (**Fehler! Verweisquelle konnte nicht gefunden werden.**). The variation of the number of mussels found at location 9 is mainly due to changes of the habitat conditions as a result of the flood in June 2013 when sediment such as sand bags was deposited in the river bed covering the mussels and forming a relevant migration obstacle.

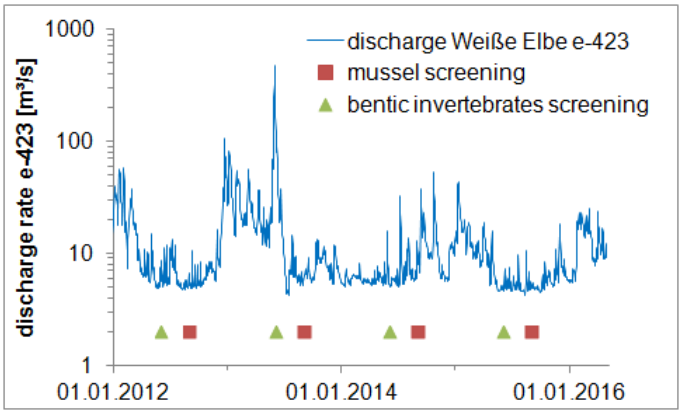


***Figure 4*** *Comparison of monitoring dates and flow in the Weiße Elster river (on logarithmic scale).*

The number of macrozoobenthos taxa was just slightly changing at the individual locations during the sampling campaigns in the past 4 years. The number of taxa was significantly lower at two locations only in 2013. This could be explained as an effect of an outstanding 2013 flood (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

A high percentage of the EPT-taxa among the collected individuals mark very good ecological conditions of the relevant river stretch. In near natural gravel dominated low land rivers (type 17) about 60% of all individuals belong to the EPT-taxa. At 3 out of 4 monitored locations this ratio was between 41% and 55% representing a good grade. This ratio varies from year to year in a range of up

to 10% resulting from the variation of hydrological conditions. A bad to moderate rating is given based on the sampled macrozoobenthos at location 3a. This location is the farthest from the discharges at the WISMUT sites even downstream of the town of Leipzig. It is situated in an area with intensive agricultural use. The river has strong structural deficits in this stretch with silt deposition at the river bank and a lack of hard substrates as well as uniform flow conditions. There are also additional salt sources, such as sulphate resulting from mine water discharge from lignite open pits, which influence the chemical conditions in the Weiße Elster river.

## Conclusions

The conducted biological monitoring along a 90 km long stretch of the Weiße Elster river gives a consistent long-term data base allowing to follow any systematic change of the biological conditions in the river. According to the results of a 4-year monitoring period none of the indicator biota including benthic invertebrates (i.e. mussels), fish (bitterling = *Rhodeus amarus*) and the green club-tailed dragonfly (*Ophiogomphus cecilia*) has been adversely affected while the average concentrations of salts and hardness increased. The increase of concentrations is more significant during the low flow conditions.

The average river discharge was more than 10% lower in the monitored 4-year period with more days with low flow conditions compared to the long-term average. The temporal increase of the hardness limit value in combination with additional water management measures such as the amendment of the river discharge at low flow conditions with water from the upstream storage reservoirs was important for an uninterrupted remediation work at the former mining and milling sites.

The biological monitoring shows that the fish and mussel populations are mostly in very good condition at the designated locations. No systematic influence of the temporarily increased limit value for hardness was found. Amount and number of taxa of the collected benthic invertebrates show a variability which is more likely to be caused by the annual changes of the discharge rather than the geochemical conditions. Flood events have a significant influence on the population due to the connected changes of the flow dynamics and the displacement of river bed substrate.

Biological monitoring will be continued at least till 2019 as long as the elevated hardness limit is in force. In the succeeding period additional activities would be necessary in case a deterioration of the monitored biological condition will be reported as an effect of the increased hardness.

## References

Barnekow U, Müller J, Metschies T, Paul M (2012) Experiences gained and major challenges for the remediation of Wismut's Culmitzsch tailings pond. In: Forrie A B, Tibbett (2012) Conference Proceedings Mine Closure 2012, Australian Centre for Geomechanics: 209-222.

Schnitter P, Eichen C, Ellwanger G, Neukirchen M, Schröder E. (2006) Empfehlungen für die Erfassung und Bewertung von Arten als Basis für das Monitoring nach Artikel 11 und 17 der FFH-Richtlinie in Deutschland. Berichte des Landesamtes für Umweltschutz Sachsen-Anhalt, Sonderheft 2.

Metschies T, Laubrich J, Müller J, Paul M, Barnekow U (2013) Management of water collection and treatment in the remediation of an uranium mill tailings site. In: Wolkersdorfer C, Brown A, Figuera L (2013) Conference Proceedings IMWA 2013 "Reliable Mine Water Technology", 1047-1054.