Post-mining lakes – various types and their integration in river basin landscapes according to the European Water Framework Directive

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Abstract In terms of the European Water Framework Directive (WFD), post-mining lakes are defined as artificial water bodies (AWB). For AWB, the WFD demands to achieve a good surface water chemical status and a "good ecological potential", the sustainable integration in the groundwater and surface water landscape, and the consideration in river basin management plans. The undertaken efforts to meet the requirements of the WFD are presented for two post-mining lakes in East Germany and Northwest Spain, respectively, that they are still in development.

Key Words artificial water bodies, lignite coal mining, river basin management, management plans

Post-mining lakes and the European Water Framework Directive

Main aim of the WFD is to prevent the further deterioration and to protect and improve aquatic ecosystems aiming at the establishment of a good – ecological and chemical – water status. Thus, artificial water bodies such as post-mining lakes must not have significant adverse impacts on the good ecological status of downstream groundwater and surface water bodies.

The reference conditions which the status classification for artificial water bodies should be based on are called "Maximum Ecological Potential (MEP)". The MEP represents the maximum ecological quality that can be achieved for an AWB. For an AWB, it is required to achieve a good surface water chemical status and a "Good Ecological Potential (GEP)" that mostly relies on biological parameters (CIS, 2003). The aspired downstream biological quality parameters are mostly determined by upstream hydromorphological and physico-chemical conditions and only to a lesser degree by the upstream biological conditions.

Artificial post-mining lakes are not isolated but integrated in the hydrography. For a post-mining lake, the hydromorphological conditions are set by the coal excavation process. However, the physico-chemical and biological conditions will continuously undergo changes for an unknown period. The ecological system of post-mining lakes is influenced by strong hydraulic dynamics, changing conditions of feeding groundwater and surface water and by the fact that an ongoing adaptation on evolving physico-chemical conditions will take place over the next decades.

Post-mining lakes are often severely acidified and mineralised, but also characterised by a poor aquatic biological diversity. Comparable natural water bodies to present suitable reference conditions are hardly found. The formation of the lakes is still under development. The forecast of both the duration of the lake filling and the lake's water quality changes is accompanied by large uncertainties and not yet suitable for the reliable definition of the final restoration status.

Lake Bärwalde (Lusatian mining district, Eastern Germany) and lake As Pontes (autonomous region of Galicia, Northwest Spain)

Site description

Evolving lake Bärwalde is situated in the lower catchment of the river Spree in the south of the Lusatian lignite mining district, north of the Federal State of Saxony. Altitudes of the surrounding area vary from 130...135 m.a.s.l. in the southeast to 125...130 m.a.s.l. in the northwest. Prior to the mining activities, the landscape was characterised by wetlands due to a shallow groundwater table.

Main aims of the restoration process are the reorganization of the river Spree system with an almost natural constitution of the river system, the refilling of former ponds and their reuse for fishery, and the rehabilitation of the ecological functionality and viability of wetlands and lowlands. Furthermore, the discharge of river Spree in the summer period shall be supported (fig. 1). Therefore lake Bärwalde is created as a reservoir, with a storage space of 25.5 Mill. m^3.

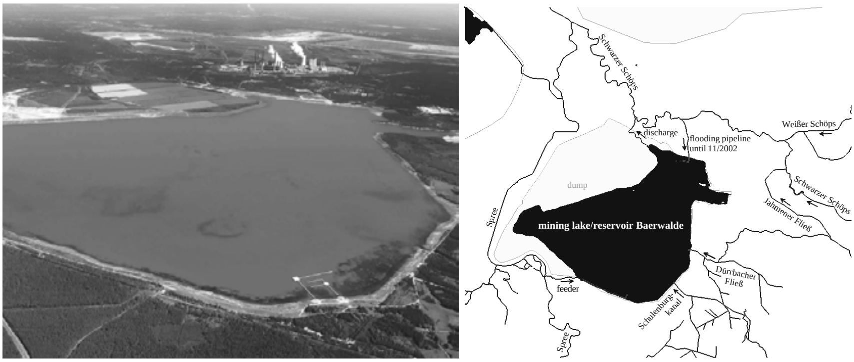

***Figure 1** left: Air photo of lake Bärwalde, in the background power station Boxberg (photo by LMBV), right: Lake Bärwalde and surrounding river net*

Regional climate conditions are characterised by precipitation rates of 626…641 mm/yr and a potential evapotranspiration of about 613 mm/yr resulting in only a small yearly runoff. However, the evaporation from the lake's open water surface is even higher with about 705 mm/yr which reduces further the potential runoff. This deficit water balance challenges the water distribution and management of the region.

The former lignite mine of As Pontes is located in the north western part of Spain in the region of Galicia (fig. 2). Embedded into a crystalline bedrock massif, the mine consists of two adjacent pits in a side valley of the river Eume. The mine has an extension of 11.8 km^2 and is surrounded by a catchment of 87.6 km^2. The topography is dominated by a mountainous character with varying altitudes between 332 m.a.s.l. (future surface water level of the lake) and 500… 700 m.a.s.l. in the surrounding hills. The evolving lake will have a volume of 547 Mill. m^3 (fig 3).

Local climatic conditions are determined by the exposed maritime position. The average annual precipitation is 1,642 mm. Most of the precipitation falls in winter but in summer the humidity is still quite high. This explains the high annual evaporation rates. On average 665 mm evaporate. As a consequence a mean annual runoff of 977 mm results.

Geo- and hydrochemical investigations of the dump material and the mining water of As Pontes proved that the occurrence of pyrite in some of the strata might have an acidification potential for the future lake. The criteria that the water quality finally will have to meet must be in accordance with the quality of the receiving river Eume which the lake will be connected to after reaching its final water level.

***Figure 2** left: geographical location of former opencast lignite mine of As Pontes, right: mine site with the outside dump and the flood canals of the evolving post-mining lake (source: http://maps.google.de/maps)*

Figure 3 *From the mine to the lake of As Pontes*
(photos by ENDESA, from left to right 04/2007, 02/2008, 03/2010)

Site comparision

The main morphometric parameters of the two lakes in the Lusatia and As Pontes, respectively, are given in tab. 1. External flooding of lake Bärwalde using river water started in 1997. Until 2009, the total volume of nearly 400 Mill. m³ by mining activities unaffected waters filled the lake. Tab. 2 shows high losses of water due to groundwater outflow.

Lake As Pontes is still in the flooding process. For this, all available water resources of the lake catchment are exploited which is equivalent to an estimated volume of yearly 58 Mill. m³ plus a contingent of approximately 97 Mill. m³ from the river Eume (tab. 2).

In Bärwalde, at the beginning of external flooding, an initial water body already existed originating from groundwater recovery. The initial lake water showed characteristic hydrochemical conditions of water influenced by mining activities (tab. 3). Flooding by unaffected natural waters supports the dilution and neutralisation processes in the lake. Furthermore, the large amount of groundwater outflow supports these processes. Respective this, the hydrochemical conditions developed positively (tab. 3). For steady state conditions, a neutral lake water with low mineralisation is predicted.

Just after the start of flooding the mining pit of As Pontes, ENDESA begun to add an alkaline suspension to ensure neutral chemical conditions in the evolving water body. As expected, this measure was successfully concerning the pH-value, alkalinity and metal concentrations (tab. 3). The sulphate concentration is decreasing due to dilution processes. The naturally unaffected river waters are only slightly mineralized due to geological causes and hence suitable as diluents.

Table 1 *Morphometric characteristics of lake Bärwalde and lake As Pontes*

Parameters	Units	lake Bärwalde min. storage water level 123 m.a.s.l.	lake Bärwalde max. storage water level 125 m.a.s.l.	lake As Pontes 332 m.a.s.l.
Surface area	km²	12.5	12.9	8.7
Lake Volume	Mill. m³	147.6	173.1	547
Maximum depth	m	45	47	206

Table 2 *Flooding data of lake Bärwalde and lake As Pontes, data source (LMBV 2010) and (ENDESA 2010)*

Parameters	Units	lake Bärwalde	lake As Pontes
Amount of flooding water (used waters)	Mill. m³	374 (Spree, Schwarzer Schöps, Schulenburgkanal, Dürrbacher Fließ) (flooding period 1997-2009)	323 (dump, mine, and lake area, and Rio Eume) (flooding period 01/2008-04/2010)
Groundwater inflow	Mill. m³	3.5 (2009)	Negligible
Groundwater outflow	Mill. m³	29.7 (2009)	Negligible

Table 3 Hydrochemical conditions of lake waters for the initial phase and the present situation

Parameters	Units	lake Bärwalde initial 1997	lake Bärwalde 2009	lake As Pontes initial	lake As Pontes 2010
pH-Value		<3.0	5.5	3.9	7.4
Alkalinity	mmol/L	-11.5	0.1	<0.01	0.2
Sulphate	mg/L	1,700	230	1,020	90
Iron total dissolved	mg/L	195.7	0.2	0.3	<0.2
Aluminium	mg/L	29.8	0.7	1.5	<0.3
Calcium	mg/L	236	57.2	214	35
Magnesium	mg/L	62.6	16.2	76.5	5.9

With an increasing water level, the pyrite containing slopes were submerged and so, the input of acid generating material decreased essentially. Determined discharge criteria will be reached until the lake will discharge into the river Eume.

Conclusions

Artificially formed post-mining lakes are not isolated but integrated in the river basin landscape. Consequently, the mining influenced surface water and groundwater bodies are interacting both quantitatively and qualitatively with the natural ones. According to the European Water Framework Directive, post-mining lakes are artificial water bodies that are not allowed to cause significant adverse impacts on the good ecological status of downstream groundwater and surface water bodies.

Due to the mostly poor groundwater and thus poor lake water quality, flooding with surface waters from neighbouring river basins presents the best opportunity to reach these criteria. Flooding will accelerate the lake filling, suppress the inflow of acidic groundwater, dilute and neutralise initial acidic lake waters, and support hydrochemical stabilization. Beside flooding additional specific chemical, electrochemical, or biological measures can be applied.

Sustainable adjusting of discharge criteria is of main concern to ensure designated uses and good ecological status of downstream water bodies. Furthermore, post-mining care of water quantity and quality must be linked to precautionary measures of the active mining.

Acknowledgements

This presentation is the result of different recent research projects, financially supported by the Federal states of Brandenburg and Saxony, and the companies ENDESA S.A. and LMBV mbH.

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