Monitoring of Water Quality in Post-Mining Pit Lakes – Why, How and How Long?

Anne Weber[1], Katja Kunze[2], Susann Wilhelm[2], Felix Bilek[3], Elke Kreische-König[1]

[1]Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH (LMBV), Walter-Köhn-Straße 2, 04356 Leipzig, Germany, Anne.Weber@lmbv.de, ORCID 0000-0003-2582-5327

[2]Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH, Knappenstraße 1, 01968 Senftenberg, Germany, Katja.Kunze@lmbv.de, Susann.Wilhelm@lmbv.de

[3]GFI Grundwasser-Consulting-Institut GmbH Dresden (GFI), Meraner Straße 10, 01217 Dresden, Germany, fbilek@gfi-dresden.de

Abstract

Over a hundred lignite-mining pit lakes exist in East Germany, most of them flooded for more than a decade. A specially developed monitoring program tracks their hydrological and chemical conditions and, encouragingly, many lakes show progress towards stable conditions. In recognition, 16 pit lakes were included in a preliminary monitoring under the European Water Framework Directive, which provides a standardized framework for assessing lake water quality across Europe. The coexistence of these two monitoring systems has prompted consideration of potential synergies. However, a comparison reveals differences in frequency, parameters, and quality requirements. Ultimately, defining 'stable lake water quality' remains the key relinquishment criterion to conclude the mining-hydrological monitoring.

Keywords: European Union Water Framework Directive; Mine Closure; Lignite; Germany

Introduction

Monitoring is data collection for answering specific system questions. According to INAP (2018) it is 'routinely, systematically, and purposefully gathering information for use in management-decision making'. As such, when the system in consideration evolves over time or questions alter, the monitoring must be adapted. Regarding pit lakes – which are artificial, and as such juvenile, characteristic surface water bodies resulting from open cut mining (Lund & Blanchette, 2022) – monitoring must consider their typical evolution. Four typical stages of pit lake monitoring are described in Schultze *et al.* (2024) and encompass monitoring during a) mine planning and operation, b) pit lake filling, c) being full before closure, d) after closure.

During the 1970s and 1980s, the former East Germany was the world's largest producer of lignite. Surface mining devastated large areas and changed water resources in the two mining regions Lusatia and Central Germany. After German reunification in 1990, East German lignite mining largely ceased, and since 1994, the Central German Mining Administration Company (LMBV), a state-owned company, has been responsible for rehabilitation of these former lignite mines (LMBV, 2023).

Numerous lignite mining pit lakes have evolved in Lusatia and Central Germany. More than 200 are monitored and 75 of them will have a final area of more than 0,5 km^2. The majority of the larger pit lakes were flooded with river or mine drainage water, whereas others filled from groundwater rebound.

Mine-specific legal requirements from mining operation plans, water regulations, and planning approvals obligate LMBV to monitor the creation and restoration of water bodies.

Figure 1 *Cospuden: The lignite mine in 1993 a few months after mining ceased (left, source: LMBV); 30 years later as rehabilitated pit lake within a new landscape, lignite power plant Lippendorf in background (right, source: LMBV, Peter Radke).*

To ensure consistent monitoring practices across its operations, LMBV developed a Mining-Hydrological Monitoring (MHM) standard in the 2000s which, amongst others, targets pit lakes. Its overall purpose is to support the survey of geotechnical stability, to guide water management measures, and to verify the success of implemented water management measures during rehabilitation (LMBV, 2022). For this, the standard summarizes the generally applicable rules and establishes uniform company-wide practices for planning measurement points, sampling procedures, and analysis programs. This monitoring reveals that several pit lakes have been progressing towards stable (meaning steady) chemical composition since being flooded over a decade ago.

Parallel to LMBV's mining rehabilitation, the European Water Framework Directive (WFD) came into force in December 2000, with the primary purpose of establishing an integrated water protection policy across Europe. Its primary target is to achieve a 'good status' for all water bodies in Europe (EC, 2000). These overall regulations were implemented into national law, where the German Surface Water Ordinance ('Oberflächengewässerverordnung', OGewV) addresses the environmental quality standards for surface water bodies. The WFD recognizes lakes with a surface area > 0.5 km², and besides natural lakes it also includes artificial lakes such as mine pit lakes. For such artificial water bodies, the objective is to achieve a 'good ecological *potential*' and a 'good chemical status'.

In Germany, authorities at the *federal* level are responsible for conducting monitoring programs to assess the status of the surface water bodies according to the WFD. In perspective, this is relevant for about 75 of LMBV's pit lakes with a surface area larger 0,5 km². Given that these pit lakes are in their early stages of development, the LMBV and relevant authorities are still discussing how to monitor and manage these water bodies in accordance with the WFD. This, because it is not well-defined *when* lignite mining pit lakes can be considered 'ready' to fall under the WFD regulations. Further, the East German pit lakes are located on the territory of four federal states: Brandenburg, Saxony, Saxony-Anhalt, and Thuringia and practical application of the regulations differ slightly between them.

In preparation for the WFD reporting, 16 pit lakes in the Federal State of Saxony have been included in a preliminary sovereign monitoring under the OGewV mostly due to their stable hydrodynamic and hydrochemical conditions. For these 'candidate pit lakes', the temporally limited MHM has now been accompanied by a regulatory OGewV monitoring for several years. This raises the question of whether one or both monitoring systems could be optimized due to potential redundancies.

This work offers insight into the parallel implementation of LMBV's Mining-Hydrological Monitoring and the initial monitoring according to OGewV. To uncover potential synergies, both programs were compared in terms of monitoring frequency, location, parameter sets, and quality requirements (GFI, 2024). Two pit lakes are described in more detail. A dialogue, initiated by the Federal State of Saxony, revealed options for monitoring agreements between LMBV and the authorities. Finally, the work addresses the long-term challenges for LMBV, including establishing a definition of stable lake water quality as a criterion for discontinuing its mining-hydrological monitoring.

Comparison of Monitoring Systems for Mining Rehabilitation and EU Regulations

Characteristic of Two Example Pit Lakes

To exemplify the application of both monitoring systems, two pit lakes were selected which are included in both monitoring systems. Key characteristics of both pit lakes are provided in Table 1. Lake Cospuden was flooded with mine drainage from a nearby active lignite mine, whereas Lake Berzdorf received river water. Both are circumneutral (pH 7–8) and oligotrophic with Lake Cospuden having elevated concentrations of sulfate (800–1000 mg/L).

Monitoring Scope

For MHM as well as the preliminary regulatory OGewV monitoring, the main sampling location aligns to the coordinate of the lake's maximum depth. Additional sampling locations typically target sub-areas that are affected by acidic groundwater inflow. Both pit lakes differ in the number of current sampling points (see Fig. 2) with slight deviations in their locations.

Sampling and Analysis

Table 2 summarizes the main features of the MHM and the preliminary OGewV monitoring for both lakes. The list of analyzed biological parameters is comparable. However, only a part of the MHM's mining-specific chemical parameters is analyzed in the preliminary OGewV monitoring. On the other hand, the OGewV covers dozens of chemical parameters potentially relevant for this surface water monitoring, which are beyond the scope of MHM.

Comparability of Monitoring Results

The monitoring results were compared for several mining-specific parameters, among them pH, electric conductivity, alkalinity, acidity, concentrations of SO_4, Fe, Zn, Ni, NH_4, o-PO_4, P^{tot}, TOC, chlorophyll-a. These parameters were both collected in the MHM and used to assess the lakes according to the preliminary OGewV monitoring.

As an example, figure 3 shows alkalinity in Lake Cospuden from the two monitoring programs. The overall comparison shows that most analysis data are essentially congruent but allow for different evaluations due to widely differing sampling intervals. Besides differences in parameter lists, detection limits and norms (which are not discussed here) the obviously main difference is the sampling frequency of both monitoring systems, mentioned above.

***Table 1** Key characteristics of the two pit lakes where application and results of two monitoring programs are compared in this study (LMBV, 2025).*

Pit Lake		Lake Berzdorf (Lusatia)	Lake Cospuden (Central Germany)
Maximum depth	m	72.5	54.2
Final volume	Mio m^3	333	111
Start flooding		01.11.2002	05.08.1993
Flooding until		06.02.2013	02.08.2000
Flooding with		River water	Mine drainage
Lake area	km^2	9.56	4.39
Shoreline	km	16.5	12.5

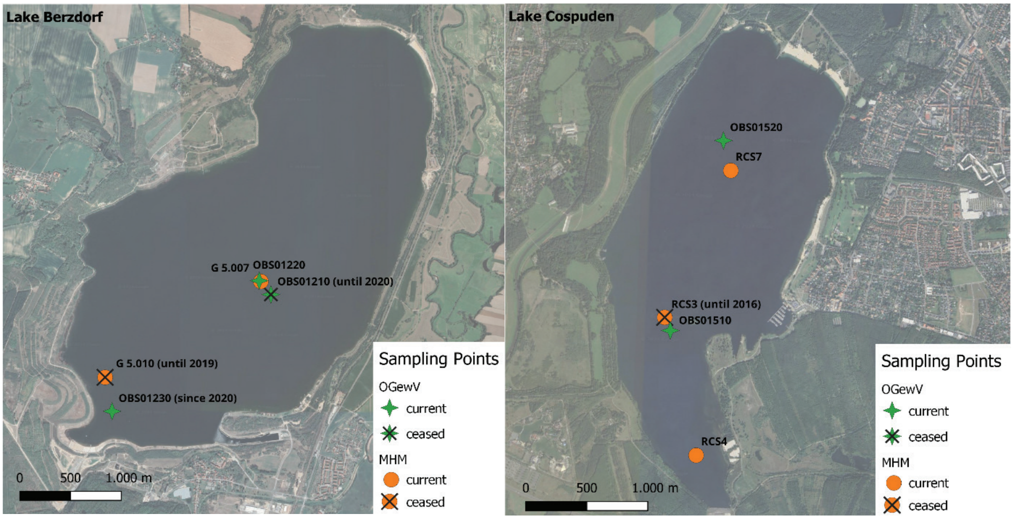

Figure 2 *Locations of sampling points for the two pit lakes Berzdorf (left) and Cospuden (right). Comparison of preliminary regulatory monitoring according to OGewV and monitoring for mining rehabilitation of LMBV.*

Table 2 *Comparison of the implementation of Mining Hydrological Monitoring and preliminary regulatory OGewV monitoring. S: Summer stratification, C: Circulation, *: Plus several lake specific parameters to define the chemical status or the ecological potential (GFI, 2024).*

Pit Lake	Lake Berzdorf		Lake Cospuden	
Monitoring	**MHM**	**OGewV**	**MHM**	**OGewV**
Sampling locations	2	1 (same location)	2	2 (1 slightly differing, 1 different location)
Frequency	annual	every 2–3 years	annual	every 2–3 years
Campaigns per monitoring year	3 × S, 1 × C	4-6 × S, 1 × C	2× S, 2 × C	4 × S, 2 × C
Sampling method	By boat, depth specific sample collectors, nets for plankton sampling (partly different mesh size); slightly differing practice in vertical sample location during stratification			
Chemical parameters	22	13 covered in MHM*	31	14 covered in MHM*
Biological parameters	Chlorophyll, Phaeophytin, phytoplankton cell numbers and volume, zooplankton cell numbers and volume			
Analytical norms	MHM refers to national and European norms, most of them compatible to international norms requested in OGewV			
Results due	Few weeks	6 weeks after a quarter of the year	Few weeks	6 weeks after a quarter of the year

Experiences for Monitoring Transition during Mine Closure and Relinquishment

For many of the 16 Saxon pit lakes with candidate status the preliminary bi- to triennial WFD assessment suggests that temporal changes are still too large to assume stable water quality and that continued measurements should be included in the assessment (GFI, 2024). On the other hand, with a frequency four times a year, LMBV's MHM can reveal stable conditions earlier.

Regarding the long-term perspective, all involved parties agree with a transition phase finally leading to cessation of MHM

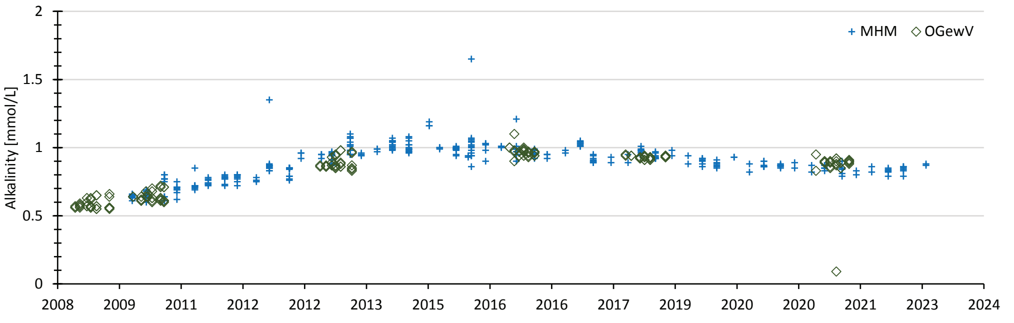

Figure 3 *Alkalinity ($K_{A4.3}$) in pit lake Cospuden. Comparison of preliminary regulatory monitoring according to OGewV and mining-hydrological monitoring of LMBV (basing on GFI, 2024).*

monitoring and sole continuation of the regulatory lake water monitoring. The difficulty now lies in shaping this transition phase. One consideration was to transfer the monitoring of the parameters which are measured in both programs to one monitoring program. However, in addition to the different sampling frequencies, the differences in the analytical requirements and reporting deadlines also proved to be an obstacle. As a result, the two monitoring programs still coexist.

On some points, however, optimization is possible. LMBV's monitoring and reporting could be streamlined or support the preliminary OGewV monitoring by the following: A) Besides monitoring itself, MHM includes reporting to authorities. Whereas monitoring should be continued annually, written reports and their discussion suffice every two years. This practice was already implemented for western Saxon pit lakes in 2021 and is now being discussed for East Saxon pit lakes. B) Since the benefit of plankton counting in MHM is considered disproportionate to the effort, it is currently discussed to conduct these determinations only through OGewV monitoring. C) There is a common understanding that parameters of OGewV monitoring should be included into MHM in case they are mining related (e.g. Ni, Zn, Se) and specific concerns exist. With annual results, authorities then have a broader basis for evaluation of these parameters which they would monitor every 2 or 3 years only.

Saxon authorities recommend and implement a preparatory OGewV monitoring already during the pit lake development. It is pointed out that finalization of pit lakes is generally not completed with the achievement of target water levels and the target quality values (e.g. pH) but sometimes requires further aftercare to achieve stable conditions. Further, the ecological potential of pit lakes can only be assessed once stable water quality conditions have been established and the species communities have been able to establish themselves as representative and stable colonization.

As mentioned above, implementation of regulatory OGewV monitoring differs between the involved federal countries. To date, discussions with the Federal State of Saxony have resulted in the biggest progress and most detailed agreements. As a crucial point to decide, when LMBV's MHM can be ceased the definition of '*stable lake water quality*' has emerged. A similar definitional question will also become relevant for terminating the monitoring of pit lakes in Saxony-Anhalt. There, the definition of a '*largely self-regulating water balance*' is crucial for the completion of post-mining lakes. The LMBV, in turn, is responsible for this verification.

Conclusion

The coexistence of the Mining-Hydrological Monitoring (MHM) and the preliminary regulatory monitoring under the European Water Framework Directive (WFD) for post-mining pit lakes in East Germany presents both challenges and opportunities. This study has revealed several key insights into the monitoring of these unique water bodies:

1. The MHM, developed by LMBV, is finite by definition and focuses on guiding

water management measures and verifying the success of rehabilitation efforts. In contrast, the preliminary WFD monitoring aims to assess the 'chemical status' and 'ecological potential' for these artificial water bodies, also for quantifying eventual future public costs of long-term rehabilitation.

2. While both systems target similar locations within the lakes, they differ substantially in sampling frequency, parameter sets, and quality requirements. Typically, MHM conducts more frequent sampling (4 times each year) compared to WFD monitoring (6 times every 2–3 years).
3. Despite some overlap, each monitoring system provides unique data. The MHM covers a broader range of mining-specific chemical parameters, while the WFD monitoring includes additional parameters relevant to surface water quality assessment.
4. The transition from MHM to sole WFD monitoring is complicated by differences in sampling frequencies, analytical requirements, and reporting deadlines. This requires the continuation of both monitoring programs to date.
5. Several potential improvements have been identified, including streamlining LMBV's reporting, adjusting plankton counting practices, and incorporating relevant WFD parameters into the MHM for mining-related concerns.
6. A crucial challenge lies in establishing a clear definition of 'stable lake water quality', which is one essential prerequisite for determining when LMBV's MHM can be discontinued.

These findings underscore the complexity of managing and monitoring post-mining pit lakes as they transition from rehabilitation to integration into natural water systems. The experience gained from the parallel implementation of these monitoring systems in East Germany provides insights for other regions facing similar challenges in mine closure and water body management.

A key challenge for future discussions with state authorities remains the definition of criteria for stable lake water quality. This is crucial for determining when these artificial lakes have reached a state of balance and are fully integrated into natural water management systems. Further investigation into the long-term ecological development of pit lakes could inform more effective management strategies and contribute to our understanding of ecosystem restoration in post-mining landscapes. As pit lakes evolve and stabilize, collaboration between mining companies, regulatory authorities, and researchers is crucial in ensuring the successful integration of these water bodies into the landscape.

References

EC (2000) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, OJ L 327, 22.12.2000, p. 1–73

Lund MA, Blanchette ML (2022) Closing pit lakes as aquatic ecosystems: Risk, reality, and future uses. WIREs Water e1648, doi:10.1002/wat2.1648

GFI (2024) Comparison between the LMBV's mining hydrological monitoring and the sovereign monitoring for the assessment according to the EC-WFD. GFI, Dresden, Germany, 14.06.2024. Report (in German)

INAP (2018) Global Acid Rock Drainage Guide. International Network for Acid Prevention https://www.gardguide.com

LMBV (2022) Mining-Related Hydrological Monitoring of LMBV mbH – Code of Practice for LMBV. LMBV Senftenberg, Germany, original version from 2007, last updated in June 2022 (in German)

LMBV (2023) Views – Redevelopment and recultivation of mining landscapes. Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH, available: https://www.lmbv.de/medium/lmbv-broschuere-einblicke-views-deutsch-englisch/

LMBV (2025) LMBV-Mapviewer. https://www.lmbv.de/service/geoportal/

Schultze M, Vandenberg J, Castendyk D, Schleußner H-P, McCullough CD (2024) Monitoring for pit lake planning, filling and use: Why? When? What? In: Fourie AB, Tibbett M, Boggs G (eds.) Mine Closure 2024: Proceedings of the 17th International Conference on Mine Closure, Australian Centre for Geomechanics, Perth, p 1049—1062, doi:10.36487/ACG_repo/2415_75