Pit Lake Runstedt as "Reactor" for Remediation – on the Way to better Energy Efficiency

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Abstract

Pit lakes with subaquatic dumps are rare and each of them provides a specific challenge. Between 1969 and 1995, 24 million m³ of waste were dumped at the Großkayna lignite mine, mostly ash from the nearby lignite power plant and waste from fertilizer production. An intensively discussed remediation concept included flooding the pit and using the resulting Lake Runstedt as an active part of the remediation of the – then subaqueous – landfill. Target contaminant is ammonium.

Since 2002, a deep-water aeration system (Tibean) promotes microbial nitrification during the summer stagnation period. Authorities require a minimum hypolimnetic oxygen concentration of 4 mg/L and, since 2013, a fixed switch-on time for aeration on June 1. However, aeration at high oxygen saturation, typical of early summer, is physically ineffective. In the interests of energy-efficiency, demand-driven operation times are aimed.

Hydrodynamic modelling based on monitoring data was applied as a tool for adjusting aeration times. Initial results provide information on the inertia of the hypolimnion response to aeration in terms of hydrodynamic and reactive transport. This was used to determine the hypolimnion oxygen concentration at which aeration should commence to not fail regulations. Concepts for future approaches towards even further reduction of aeration are derived.

Keywords: Subaqueous landfill, hydrodynamic modeling, ammonium, lignite mining

Previous development and motivation

Until the 1980s, lignite was the backbone of energy and material supply in the former East Germany. At that time, vast open-cast mines and accompanying industry shaped the landscape with environmental concerns being of minor importance. In this course, the pit of the Großkayna lignite mine – situated 30 km west of Leipzig – was used for disposal of waste. Between 1969 and 1995, some 24 million m³ were dumped, mostly ash from the nearby lignite power plant, but also waste from fertilizer production in the close by famous "Leuna Werke". After German reunification in 1990, East German industry and lignite mining ceased widely. The original plan to completely fill the remaining pit was abandoned and environmental concerns became more prominent.

Since 1994, the Lausitz and Central German Mining Administration Company (LMBV) manages the common burden of rehabilitating the former East German lignite mining areas. Under a special contract, LMBV is also responsible for remediation of the Großkayna mine site, posing unique challenges due to its industrial landfill.

Together with consulting and research institutions LMBV developed a **remediation concept** for the Großkayna landfill. This concept (CUI 2000) involved flooding the pit and utilizing the resulting **Lake Runstedt** as a compartment for active remediation of the – then subaqueous – landfill. Swift flooding in 2001 and 2002 was necessary to guarantee geotechnical stability of an overburden dam towards an adjacent pit, which now inhabits the largest artificial lake in Germany (Geiseltalsee). Lake Runstedt (fig. 1) developed to a monomictic lake with about 6 km shoreline and up to 33 m depth. Additional parts of the remediation concept include:

- maintaining circumferential groundwater inflow to Lake Runstedt to avoid spreading of contaminated landfill pore water into surrounding aquifers,
- understanding ammonium as target contaminant due to its high mass fraction and mobility in landfill pore water,
- hypolimnetic aeration to enhance natural nitrification of ammonium,
- supporting natural reed belts for denitrification.

Figure 1 Pit Lake Runstedt with Pit Lake Geiseltalsee in background and the narrow overburden dam separating them (image: LMBV, 2019).

In their Planning Resolution (RP Halle 2001) authorities require a minimum hypolimnetic oxygen concentration of 4 mg/L for the Runstedt pit lake. Reasons for this are a) to prevent nutrient re-dissolution from the sediment and ensure living conditions for aquatic organisms and b) no harmful outgassing of ammonium and hydrogen sulfide to be feared.

To comply with this limit, since 2002, a **deep-water aeration system** with three separate units promotes microbial nitrification within the hypolimnion during the summer stagnation (fig. 2). This process relies on initiating circulation in the hypolimnion and enriching oxygen concentration there. It is accompanied by a sophisticated **monitoring** of groundwater, limnic and pelagic lake water, lake sediment and soil gas to monitor remediation.

Along with monitoring, **modeling** enhances conceptual understanding of relevant processes at the site. Large-scale groundwater modeling was applied, predicting several centuries duration of ammonium release from the landfill to lake water (IHU 2012). Furthermore, hydrodynamic modeling was applied to design the deep-water aeration system (POLYPLAN 2003).

Since 2013, authorities order annually **fixed operation times for aeration**, with the first aerator starting on June 1 and a second August 1. However, aeration at high oxygen saturation – typical of early summer – is physically ineffective.

Figure 2 *Deep water aeration system, top: on shore during renovation in 2017 (image: Christian Bedeschinski), bottom: in operation in 2019 (image: Peter Radke).*

Current work

Since 2013 the permitted 4 mg O2/L was complied with. Volume averaged hypolimnetic oxygen concentrations together with aeration times are shown in fig. 3 for the years 2020 to 2022. After almost a decade of fixed aeration times, LMBV is aiming for **demand-based operation**. The motivation bases on the official Planning Resolution (RP Halle 2001) itself, which mandates a review to reduce aeration. Moreover, principles of energy-efficiency require demand-driven operation times. Economic pressure also increases due to rising energy prices. This is supported by declining ammonium fluxes from landfill pore water, observed much earlier than predicted by previous modeling.

As a first step away from fixed aeration times, **hydrodynamic modelling** should identify key figures for aerator-initiated flow in the hypolimnion. It is known that turning on the aerators does not immediately increase the oxygen concentration in the hypolimnion:

1. Flow through the hypolimnion must first be stimulated (hydraulic inertia).
2. So much oxygen must first be made available through the aerators to compensate for the loss through consumptive processes (reaction inertia). Here, oxygen is not only consumed due to microbial nitrification of ammonium from the landfill, but primarily by the decomposition of organic matter from the lake's internal biomass production.

Understanding times to compensate for these inertias, the next step was to derive oxygen concentrations at which aeration should start to ensure the 4 mg/L requirement.

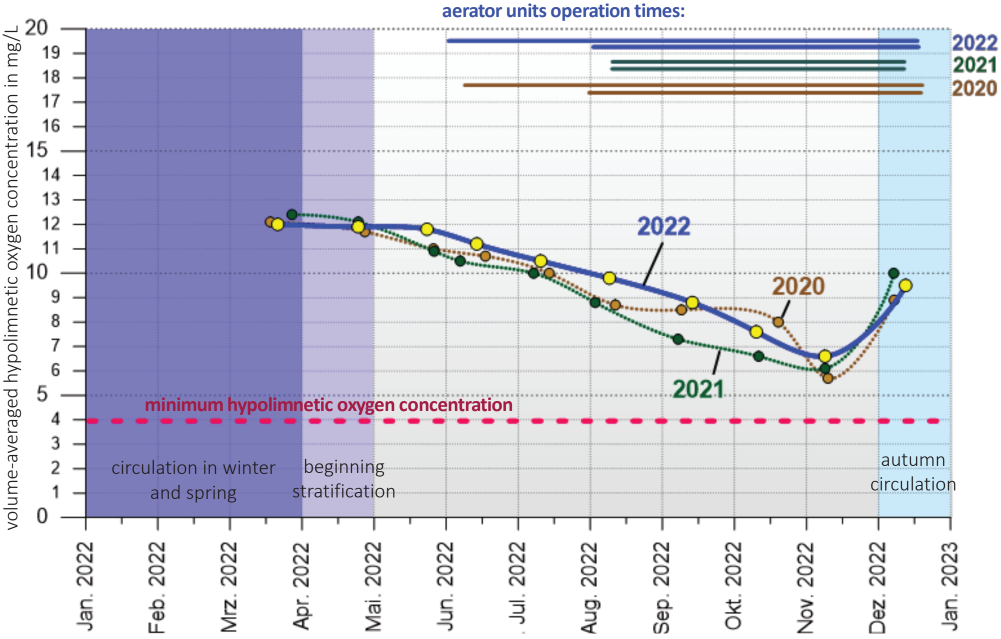

Figure 3 *Volume averaged oxygen concentrations in the hypolimnion from profile measurements.*

Hydrodynamic flow and transport models were set up in MIKE 3 (version 2019, DHI 2000) and in @SEA (scenario S2 see below, Bruns and Schubert 2023, Schubert 1994) to solve this task. The @SEA model is specified by:

- @SEA: 2.5D transient flow depending on density ratios, external buoyancy, and currents,
- a grid with 11235 elements and 2809 nodes representing morphometry of the lake's hypolimnion (from 12 m below surface),
- implementation of the three deep-water aerators with: 1220 m^3/h volume flow, oxygen enrichment by 8.8 mg/L, withdrawal at 30 m and discharge at 19.4 m and 17.4 m depth (discharge of aerator 1 was prolonged by 2 m in 2017),
- starting conditions from measurements July 2021,
- simulated time: 30 days.

Two scenarios were implemented:

1. S1 using 0 mg O_2/L as starting concentration to determine the time until 95 % of the hypolimnion ground was caught by flow initiated from the aerators (**hydraulic inertia**).
2. S2 using depth-dependent O_2 distribution and consumption from depth profile measurements in July and August 2021 to determine the time until the trend of decreasing oxygen concentration can be reversed by aeration from 1, 2 or 3 aerators (**reaction inertia**).

In 2021, on-demand aeration was tested, with aeration starting on August 5. It was therefore possible to use data from the two previous measurements, which represent the undisturbed (not aerated) system. Depth-dependent oxygen consumption was calculated from the depth-specific difference in oxygen concentration between these two measurements.

Fig. 4 shows a vertical cross section of oxygen concentration in S2 after 30 days. Starting from oxygen concentrations spanning from 12 mg/L down to 2.5 mg/L directly above ground, it can be concluded that three aerators cause sufficient mixing within the hypolimnion to avoid anaerobic zones.

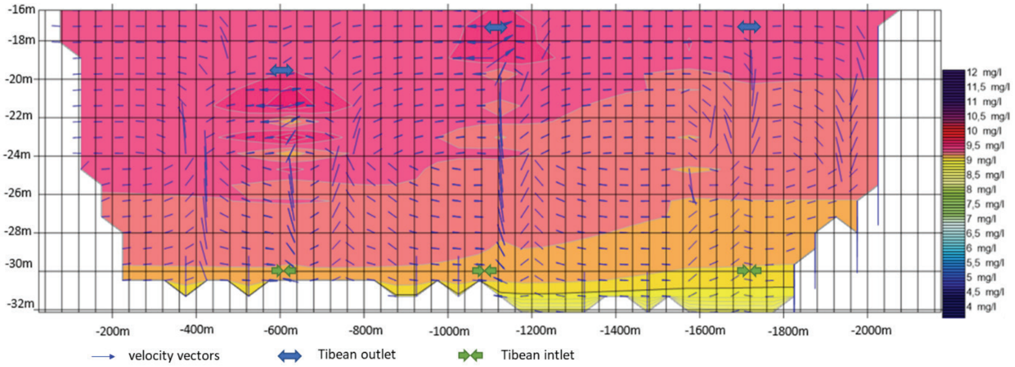

Figure 4 Modeled oxygen concentration and flow vectors. Vertical cross section with position of the three aeration units for scenario S2 after 30 days.

Results from hydrodynamic modeling can be summarized:

- After two weeks of operation, the aerators initiate flow in the hypolimnion.
- After 18 days, 80% (1 unit in operation) resp. 95% (3 units in operation) of the hypolimnion is reached by the initiated flow.
- No "dead water zones" develop.
- Above the lake bottom, after about 15 days, a reversal of the trend of decreasing O_2 concentration is modeled.
- Volume averaged O_2 concentration in hypolimnion 1 month after start of aeration show:
  - 1 aerator: decrease by 1.2 mg/L,
  - 2 aerators: decrease by 0.7 mg/L,
  - 3 aerators: increase by 0.3 mg/L.
- Considering depth-dependent oxygen consumption rates and the oxygen in the hypolimnion as a depot, the hypolimnion in July 2021 contained sufficient oxygen for about 4.5 more months (August to mid-December).

With these results concentration criteria were derived for a demand driven operation and proposed for the authorities. Accordingly, the first aerator should be switched on when the volume-averaged oxygen concentration in the hypolimnion falls below 9 mg/L, the second at less than 7 mg/L. As an additional criterion, the concentration of oxygen in the 5 m lamella above ground was assigned limit values. Furthermore, the monitoring interval (depth profiles) should be increased from every four to every two weeks to secure a quick reaction in case of rapid drop of O2 concentration (as e.g., in Oct/Nov 2020, see fig. 3).

Perspectives

The **overall methodology** towards energy efficient aeration bases on several approaches:

- increase system understanding by stepwise reduction of aeration and monitoring,
- applying models as a tool to quantify and predict relevant processes (hydrodynamic modelling of the lake and groundwater transport modeling),
- coordination with authorities on approvable procedures (changes in planning permissions).

Long-term goal of LMBV is a stepwise reduction of aeration and ceasing aeration as soon as it is warranted. Already now, monitoring data show decreasing ammonium fluxes from the landfill and hypolimnetic oxygen demand is dominated by internal biomass production.

In a first step LMBV aims to move away from fixed operation times towards **concentration criterion-based operation times** as described above. If agreement is reached with the authorities on demand-based operation times, the hydrodynamic model should be extended. It could then be used as a tool for predicting and controlling the seasonal state of the lake and for predicting on-demand activation times for aeration to meet the regulatory minimum of 4 mg/L oxygen in the hypolimnion. In addition, monitoring will be expanded to include a chlorophyll probe to estimate seasonal biomass production. This is important as the hypolimnetic oxygen demand is dominated by biomass decomposition, while ammonium fluxes from the subaqueous landfill are decreasing.

As understanding of the system increases, the regulatory limit of 4 mg/L oxygen as the minimum average concentration in the hypolimnion should also be questioned. The goal should be to avoid anaerobic conditions in an aboveground zone to prevent remobilization of contaminants from the landfill. As shown in current modeling, the **hypolimnion can be understood as a depot of oxygen** available during stagnation. Applying this approach, aerators would be used to induce hypolimnetic circulation that delivers oxygen vertically from the upper layers to the lower layers and to the critical zone above ground. Updated monitoring concepts and modeling should be tools to predict oxygen demand for the current season. With this hypolimnetic depot approach, a demand-driven supply could be implemented. However, the future approach depends on agreements with the relevant authorities.

Conclusions

With its former use as a landfill, the Runstedt pit lake is rather unique among the dozens of lignite pit lakes in eastern Germany. Its history shows that the environmental sins of the past will be costly for decades to come, in this case the aeration of lake water to oxidize ammonium from the subaqueous landfill. In this context, an efficient use of resources is particularly important. This in turn requires a deep understanding of the processes, supported by monitoring and modeling.

Moreover, the case is an example for competing interests regarding various nature conservation issues, here water quality versus energy consumption. It should be avoided that efforts for one protected good lead to compromising other protected goods more strongly. But guidelines for comparing potential hazards, especially those with effects farther in the future are lacking in everyday remediation practice.

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