Measures for Lake Restoration at the Bärensee, City of Bruchköbel

- Application Report and Results --

1. Introduction

Bärensee Lake in Hanau in the district of Main-Kinzig (Bruchköbel City) is classified as an non-stratifying gravel lake according to the LAWA “Baggersee” Directives. It has a surface area of 6 hectares, a maximum depth of 3.8 m and an average depth of 2.63 m. The volume of water in the lake is 156,000 m³. The reference mesotrophic state has never been attained in the past and the lake is considered highly eutrophic.

The lake is located within the largest camping area in the Federal German State of Hessen and is managed by the City of Bruchköbel. Furthermore, it is a popular lake for swimming and fishing and as a result is used intensively (Photo 1). The heavy nutrient loadings in the lake were fought until now with external systems for phosphate elimination and the use of macrophytes or floating islands. These measures did lead to a stabilisation of the nutrient content in the water for a while, however intensive blooms of blue green algae could not be prevented (80 µg Chlorophyll-a/L in February 2007). In the sediment of the Bärensee there was approx. 700 mg phosphorus/kg dry weight, of which nearly 20% was biologically available. The goal of the restoration measures was to immobilize the phosphorus in the strongly anaerobic sediment with the application of 11.5 tonnes of Bentophos®.

2. Planning for the Treatment

On 12 and 13 June 2007, Bentophos® was applied to the lake in order to precipitate phosphate. This measure was necessary as a result of the regular heavy blooms of blue green algae and the intensive use of the lake for swimming and recreation. Immobilization of phosphorus, which is a limiting nutrient in water bodies such as the Bärensee, is especially necessary in a shallow lake. After comprehensive pre-treatment monitoring of the water and sediments of the Bärensee, the dosage of Bentophos® was calculated. The pre-treatment monitoring demonstrated that most of the phosphorus in the lake was used constantly for primary and secondary production. The optimal point in time for an application of Bentophos® would normally have been when most phosphorus is in the ortho-phosphate form, as Bentophos® binds with phosphorus that is in this form. Nevertheless, the effect of a Bentophos® application is long-lasting and therefore it is also possible to undertake an application when most phosphorus has been taken up into the biomass.
In the case of the Bärensee, the City of Bruchköbel wanted the application to take place before the main swimming season and as a result, the application took place in June.

Bentophos® dosages are calculated on the basis of long-term and non bio-available binding of the phosphorus in the sediment (Figure 1). Although, at most, only small anaerobic zones form in the water column as a result of the shallow depth of the lake, the sediment is consistently anoxic. Even in the shallow, sandy bank areas, anaerobic conditions were observed close to the sediment water interface. Due to the high nutrient load and the anoxic conditions in the sediment, the nitrogen pool had been reduced through the use of nitrate by the microbial community with the result that optimal conditions existed for blue green algae (cyano-bacteria), which can multiply greatly by fixing atmospheric nitrogen.

A total of 11.5 tonnes of Bentophos® were applied to the lake. This dosage was the sum of the 1.5 tonnes of Bentophos® required to remove a concentration of 96 µg/L of P from the water column and 8.5 tonnes of Bentophos® required to bind a total of 100 kg of measured bioavailable phosphorus in the sediment.

3. Application

The 11.5 tonnes of Bentophos® were delivered to the Bärensee on Monday 11 June 2007 and stored close to the beach near the entrance to the camping area. The pontoons necessary for the application were stored in front of the camping area and transported to the beach with a forklift made available by the city of Bruchköbel. The City of Bruchköbel, the water authorities of the district of Main-Kinzig, the health authorities, and the Hessen Land Office for Environment and Geology were informed about the application in advance. Swimming was banned on the lake during the application and for a few days afterwards.

After the arrival of the employees from the Institute Dr Nowak, the pontoons were brought to the beach area of the lake and mounted onto a platform. Pumps, mixers, and a propulsion system were installed and prepared for the treatment on the following day. While these activities were underway, further samples were collected for testing in order to determine the condition of the lake directly prior to the application. Water samples were taken in the middle of the lake at a depth of 3 m and close to the beach at a depth of 1 m. Sediment samples were also taken at both places and examined later in the laboratory.
The application of Bentophos® to the lake began on Tuesday 12 June 2007. Bentophos® is a lanthanum modified bentonite which is formulated in a granular form. When applied to a water body, it is mixed into a fine suspension using lake water and sprayed onto the surface of the water (Photos 2 and 3). It disperses finely and clouds the water while it settles and secchi depth is temporarily reduced. For this reason swimming was banned while the application was being undertaken. As it settles, Bentophos® adsorbs the available phosphate in the water column before settling on the lake sediments. As this happens, a reactive capping is formed on the sediments that continues to capture phosphorus released from the sediments.

During the application, the areas of the lake within 2m of the shore were not treated, as required by the authorities. The depth of the area being treated was monitored using a depth-sounder and the route taken was marked by means of a differential GPS receiver (DGPS device: Trimble Pathfinder Pro XT).

At 15:00 the application had to be stopped due to a storm. Until then, approx 6 tonnes of Bentophos® had been applied. The DGPS recording was only made on the first day of the application due to a technical problem that occurred on the final day (Photo 4).

On Wednesday 13 June, the application was continued and completed. The secchi depth had risen to more than one metre since the previous day. The equipment and pontoons were taken back to the shore prepared for transport. The application was concluded in the afternoon. One week later (21 June 2007), further water and sediment samples were collected as described above in order to monitor the effectiveness of the restoration measures.

*Photo 3: Application of Bentophos®*

*Photo 4: GPS-track of the first day of application*  
(map source: Google Maps®)
4. Post-treatment Monitoring

**Phosphorus Concentrations in the Lake after the Treatment**
Following the application, average phosphorus concentrations in the lake dropped within six months from 83 to 25 µg P/L, a reduction of nearly 70% (Figure 2).

![Figure 2](image2.png)

*Figure 2: Reduction in Total Phosphorus (Gesamt Phosphor) and Ortho-phosphate P (blue column) in the Bärensee following the application*

The best time for an application of Bentophos® would have been when there was the greatest availability of ortho-phosphate in the water column (e.g. in April). However, the ortho-phosphate pool in the Bärensee is constantly being recycled in the lake with the result that it was necessary to undertake the application at a point in time when little ortho-phosphate was available. In such a case, Bentophos® will only bind phosphorus after it has settled onto the sediment and is able to adsorb free ortho-phosphate during the exchange of lake and sediment pore water. This process, though, requires a longer period of time.

**Lanthanum Concentrations in the Lake Water**
The lanthanum content was measured at 130 µg/L following the application. During the monitoring period, lanthanum concentrations dropped to <10 µg/L (Figure 3). This means that both lanthanum and phosphate have been deposited firmly in the sediment.

![Figure 3](image3.png)

*Figure 3: Lanthanum concentrations in Bärensee water*

**Eco-toxicity Tests on Lanthanum Ions**
On account of concerns regarding the use of agents containing lanthanum in bodies of water, the Institute also conducted acute eco-toxicity tests on lanthanum. This involved determining the effective concentration at which lanthanum has a toxic effect on test organisms according to the appropriate DIN tests. Parallel to this, eco-toxicity tests were also undertaken using lanthanum solutions to which a corresponding amount of phosphate had been added.
For comparison:
Lanthanum concentrations in the water body after Bentophos®: ~20 µg/L (factor of 1000 lower)
When phosphate is present, no toxic effects were detected (i.e. lanthanum is no longer bio-available after the formation of lanthanum phosphate)

Bacterial luminescence test (ISO 11348-3)
EC₅₀ = 37 mg La³⁺/L

Toxicity test with Daphnia magna (DIN 38412-L30)
EC₅₀ = 103 mg La³⁺/L

Fish egg toxicity test (DIN 38415-T6)
EC₅₀ = 150 mg La³⁺/L

Figure 4: Dose-effect relationships between lanthanum and the respective test organism

Table 1: Fish Egg Test (pursuant to DIN 38415 Part 6, modified as “Contact”-Test)

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<th>Bentophos / cavity [mg]</th>
<th>pH</th>
<th>O₂ [mg/L]</th>
<th>Coagulated eggs (N)</th>
<th>No somite created (N)</th>
<th>Tail not separated from yolk (N)</th>
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Comment: external controls: 3.7 mg/l 3,4-Dichloanilin solution, N=number

Results:
The effective concentrations of the test organisms (EC₅₀) were at least 1000 times higher in the tests than the lanthanum levels measured following the application on the Bärensee (Figure 4). With the addition of phosphate in the corresponding amount to the concentrations found in the Bärensee, no toxic effect could be detected. The modified fish egg test shows that even direct contact with an amount of Bentophos® which was four times higher than the standard dosage would have no effects on sensitive water organisms (Table 1). After binding with phosphate, the lanthanum is no longer bio-available and therefore the amount of lanthanum used in the Bärensee would have had no toxic effect on the organisms in the lake.
Assessment of the Results

The results of the post-treatment testing since the Bentophos® application indicate that the situation in the Bärensee has developed positively. The secchi depth has improved markedly (Figure 5). Even though algal blooms reduced this improvement temporarily, no scum forming blooms have occurred near the shore as a result of the reduction in the phosphorus loadings. Algal blooms recorded in July and October were caused by diatoms. Ortho-phosphate concentrations have remained below detection levels and Total Phosphorus concentrations have dropped by 40 µg/L, despite the increase in temperature in the water column and the anoxic conditions in the sediment. This means that the P-release from the sediment has so far been completely prevented.

The application took place after a clear water phase, i.e. a phase in which zooplankton had reduced the phytoplankton biomass. As a result, an increased secchi depth and a slight reduction in total phosphorus levels had been recorded (Figure 6). The fact that the N:P ratio increased in spite of small algal blooms suggests that a long-lasting shift in the algal population can be established (Figure 7).

Although blooms of blue green algae could not be completely avoided this year, they were significantly smaller than in previous years. It was not necessary to impose any swimming bans on the lake during the summer. Even though the year was cooler than the year before making comparisons difficult, we are satisfied with the situation until now.

Unlike the previous year (2006), there were very high average temperatures in the spring of 2007 which accelerated growth processes in the lake. In February 2007, an algal bloom developed and chlorophyll a levels of nearly 80 µg were recorded. In 2008, the lake should be monitored further. In the summer of 2006, oxygen-free conditions directly above the sediment of the lake also arose. This condition cannot be avoided in the future, either. Sediment bacteria use up the oxygen in the decomposition of organic material. Then they change their respiration processes to use nitrate. Therefore, the nitrogen pool in the lake water (Figure 6) is
reduced, which in turn inhibits the growth of green algae and diatoms. Blue green algae, on the other hand, are able to fix nitrogen from the atmosphere and are independent of nitrogen in the water, which is available as ammonium and nitrate. They therefore have an enormous advantage under these conditions and can form massive blooms.

It is therefore very important to continue to control phosphorus loadings. If the phosphorus pool declines, the microbial decomposition of organic substances is also reduced, which in turn leads to a shortening of the anoxic period and a worsening in conditions for the growth of blue green algae. This year there are already signs that this is happening. This means that the biological oxygen demand in the sediment this year has been noticeably reduced. This can only have occurred if the loadings of phosphorus and other nutrients have been strongly limited.