First large mine lake successfully filled up in Czech Republic

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Abstract From 2001 to 2010, filling of the abandoned open cast mine Chabařovice took place. The resulting water quality is very good for recreational use of the lake. This work is based on the results of detailed monitoring carried out by mining company PKÚ Ústí nad Labem, s.p. It describes the development of important physical and chemical parameters of water quality, phytoplankton, zooplankton and zoobenthos. During the development of the lake, three phases of various space-time dynamics of the physicochemical properties of water as well as important components of its biota were identified.

Key Words lake Chabařovice, abandoned open cast mine, flooding, chemistry, plankton

Introduction

Between 2001 and 2010, filling of the abandoned open cast mine Chabařovice, situated on the outskirts of the town of Ústí nad Labem, was done. The bottom of the future lake was sealed with a layer of clay and the lake was filled with water from smaller streams in the area and mine water overflow. Also, certain amount of water was driven from its own drainage basin by surface trenches and underground seepage. The final surface of the lake is 252.2 ha, water volume 35.6 million m³ with the average depth of 14.1 m. The water level lies at an altitude of 145.7 m. The lake is relatively shallow, which makes it very susceptible to eutrophication.

Methods

The water quality was closely monitored at monthly intervals throughout the filling period in three vertical profiles in the lake and in all the major sources of filling water. Water samples were initially collected from the surface to the bottom at 1-meter intervals, and since 2005, when the depth increased, in 2-meter intervals. The water flowing from the drainage basin was monitored less frequently. Monitoring of lake water quality continued after the filling proces was completed. The basic physical and chemical analyses together with the evaluation of metals and a wide range of extraneous organic compounds were carried out. The number and species composition of zooplankton, zoobenthos and phytoplankton were also monitored as well as bacteriological indicators. The analyses of metals and extraneous organic compounds in the sediment were performed too.

Results

Physical and chemical water quality

Conditions in the lake gradually changed during the filling process and it was possible to distinguish three qualitatively different phases of water quality and associated groups of living organisms:

a) initial temporal and spatial fluctuation in water quality with increased level of trophy,

b) stabilization of the lake conditions and decrease of trophy,

c) hypolimnion formation and the first signs of internal eutrophication.

Temperature distribution of the lake water has changed with increasing depth of the lake (see fig. 1). During the first years, temperature was almost constant throughout the water column. Since 2005, typical lake stratification with division of the water column into epilimnion, metalimnion and later hypolimnion has been formed. Maximum annual water temperatures at the bottom gradually decreased during the filling period (from 24 °C in 2001 to 6,9 °C in 2010) and maximum annual temperature shifted from the summer months to the end of October and even to late November. By contrast, the annual range of fluctuation in water temperature or level of maximum and minimum values at the surface layer did not change during the filling period.

There is a relation between the thermal stratification and development of the oxygen profile (see fig. 2). Between 2001 and 2004, the concentration of oxygen throughout the water column was almost constant. In 2005, the concentration of oxygen at the bottom dropped down substan-

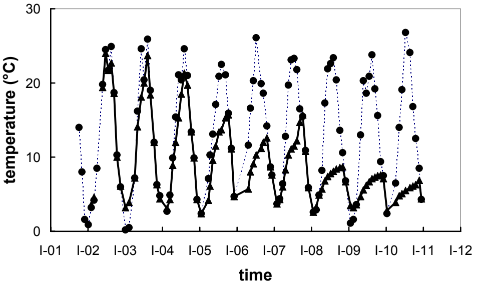

Figure 1 *Progress of the water temperature at the surface (circles) and near the bottom (triangles).*

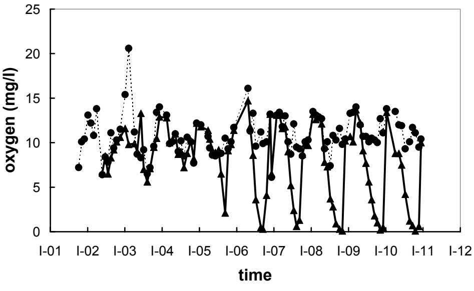

Figure 2 *Progress of the oxygen concentrations at the surface (circles) and near the bottom (triangles).*

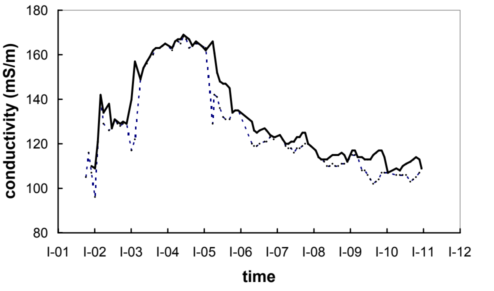

Figure 3 *Progress of the conductivity at the surface (broken line) and near the bottom (solid line).*

tially and since 2006, anoxic conditions at the bottom of about half of the the lake have been observed. The main reason for this phenomenon was a very small volume of hypolimnion with short supply of oxygen from the spring water circulation. Oxygen was quickly consumed by oxidation of organic matter falling from the epilimnion. Oxygen deficiency in the lake can also be caused by inflow of mine water overflow with high concentrations of iron and ammonia, which also undergo oxidation in the lake.

From 2001 to 2004, pH fluctuated irregularly with small differences between surface and bottom. Since 2005, during the summer, pH level at the surface has increased while pH at the bottom has decreased with the maximum difference of 1 to 1.5 units between surface and bottom. During the cold season, pH did not fluctuate throughout the water column with values between 8.1 and 8.2.

Water in the lake has a relatively high conductivity (see fig. 3) and during the filling period it ranged from 90 to 170 mS/m depending on the ratio of individual tributaries. The main source of filling water, the Kateřina Reservoir, had an average conductivity of only 55 mS/m. By contrast, the conductivity of inflows from its own catchment area (spoil dump) amounted to about 250 mS/m. High conductivity correlates with high concentration of dissolved anions and cations, namely sulphates, bicarbonates, and sodium. Since 2005, a difference between the surface and the bottom conductivity has regularly occured during the whole warm season. When the pH level in the upper part of the water body exceeds the value of 8.3, carbonates precipitation occurs and the conductivity consequently decreases. In the bottom layers with a low pH (7—7,7), carbonates dissolve and conductivity increases. The maximum difference between surface and bottom conductivities in that period reached 5 to 10 mS/m. Similar fluctuations can be observed in alkalinity, acidity, carbon dioxide, calcium, ammonia and manganese. During spring and autumn circulations the lake water was perfectly mixed and the concentrations of dissolved substances in the whole water column were equalized.

The most important factor influencing the water quality in the lake was the concentration of nutrients, particularly total phosphorus (see fig 4). Water from its own catchments area has a very low concentration of phosphorus (0,01 - 0,02 mg/L), while the phosphorus concentration in water from controlled sources (Kateřina Reservoir and mine water overflow) was about 0,1 mg/L. However, slow filling of the lake resulted in a gradual decrease in the concentration of total phosphorus, and therefore at the end of filling period phosphorus concentrations were below the detection limit (0,01 mg/L). Decline in total phosphorus concentration during the filling of lake caused a decrease in the concentration of phytoplankton (see fig. 5) and in the biomass of zooplankton as well. Since 2006, a slight increase in concentrations of total phosphorus during anoxic conditions at the bottom (about 50% of the concentration at the surface) has been repeatedly observed. We consider this an evidence of the starting internal lake eutrophication. In order to prevent the occurrence of cyanobacterial water bloom, high ratio of nitrogen to phosphorus in water is desirable. Despite the sharp decrease in nitrate nitrogen concentration from the initial excessive concentration of 90 mg/L, the N:P ratio is still positive at about 200 : 1.

Lake Chabařovice was not affected by acid mine waters, because the inflow of these waters is negligible. In general, none of monitored alien substances was considered problematic. Their concentrations are low enough to meet the requirements for surface water quality. Microbial contamination is also very low, several orders of magnitude below the limit values.

In the future, certain problem may pose elevated concentrations of dissolved solids (particularly sulphates) caused by high evaporation. However, this problem may be avoided by a suit-

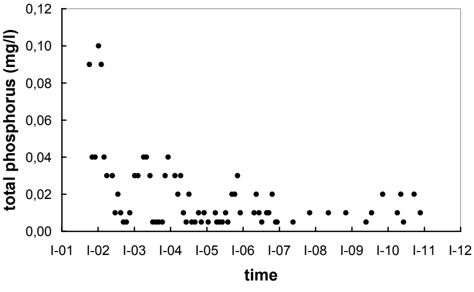

Figure 4 *Progress of the concentration of total phosphorus at the surface.*

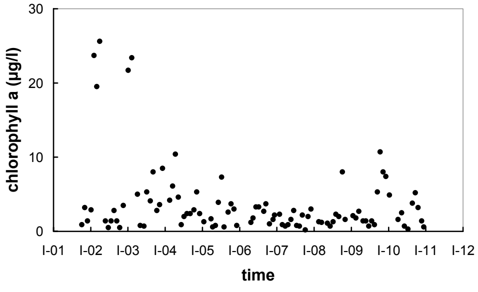

Figure 5 *Progress of the concentration of chlorophyll* a *at the surface.*

able choice of available inflows of water tributaries and their flow rate.

Phytoplankton

At the beginning of the filling process during the summer 2001, most of the lake bottom was already flooded and the entire water area had the character of shallow inundation with sparse ruderal vegetation. Phytoplankton community was composed mainly of several Chlorococcales species of the genera Chlorela, Desmodesmus, Scenedesmus, Crucigeniella, etc., few species of diatoms (Nitzchia spp., Cyclotella sp.) and Cryptophyceae. August maximum consisted just of Chlorococcales algae genera Chlorela, Oocystis a Lagerheimia with abundance of up to 42 000 ind./ml. Cyanobacteria were found rarely and were represented by species such as Woronichinia naegeliana, Coelomoron and Planktothrix agardhii. During the period of 2002—2003, the water depth in the lake gradually increased and seasonal changes in abundance and composition of communities were similar. Chrysophyceae (genera Chrysococcus, Chromulina, Synura, Kephyrion etc.) and planktonic Chlorococcales algae of the genus Ankyra etc. (up to 20 000 ind./ml) were dominant in the spring maximum developement. During the late spring and early summer the abundance of algae decreased („clear water" period). The species composition was not diverse and scarce populations of Chlorococcales algae (Chlorela spp., Planktosphaeria gelatinosa etc.) and centric and pennate diatoms (Cyclotella spp., Cyclostephanos dubius, Fragilaria sp. etc.) were identified. Further maximum of development occured in late summer and consisted of more diverse community of green algae (Chlorela sp., Oocystis spp., Planktonema lauterbornii etc.), Chlamydomonadales, Cryptophyceae and pikoplankton Cyanobacteria (Aphanothece sp.). During 2003 growing season, centric diatom Cyclotella ocellata, which is still an important part of the lake phytoplankton, appeared. In this initial development of the lake-type reservoir, large differences in the abundance of phytoplankton at various locations along the longitudinal profile were repeatedly found. The main source of inflow water substantially influenced the spatial distribution of phytoplankton.

In spring 2004, a large population of planktonic pennate diatom Fragilaria cf. acus occurred in the lake and together with Chrysophyceae (Uroglena sp. etc.) these species were responsible for majority of phytoplankton individuals with the maximum counts of 16000 ind./ml recorded in March. However, only small number of taxa was identified (< 10). After a sharp decline in number of individuals in early summer (the period of "clear water"), the green algae (Crucigeniella spp., Oocystis spp.) became dominant again with a peak in August (12000 ind./ml). In late autumn (October-November), Cyclotella ocellata increased its presence with maximum total phytoplankton counts of 12000 ind./ml. Number of identified taxa increased during these two periods at up to 19.

From 2005 to 2008, the volume of water in the lake gradually increased and Cryptophyceae (Plagiselmis lacustris, Cryptomonas cf. reflexa, Cryptomonas marssonii) and Haptophyta (Chrysidalis sp., Chrysochromulina sp.) were consistently present in the phytoplankton community of the reservoir. During the spring peak, centric diatoms (Cyclotella radiosa, C. ocellata, C. pseudostelligera, Thallasiosira sp.) and Chrysophyceae (Chrysococcus spp.) also occured in the phytoplankton community. In summer and autumn, Chlorococcales algae (Oocystis sp., Oocystis solitaria, Planktosphaeria gelatinosa etc.) were regularly detected. Few other taxa of planktonic algae were found irregularly and in sparse populations. In August 2008, pennate diatom Centronella reicheltii was present and pikoplankton Cyanobacteria of the genus Synechococcus appeared in the phytoplankton too. Other Cyanobacteria of the genera Anabaena, Pseudanabaena, Cylindrospermopsis, Merismopedia, Aphanothece, Aphanocapsa were detected in samples rarely. Water blooms forming Cyanobacteria - colonial Microcystis aeruginosa and filamentous Planktothrix agardhii - have been found only in net samples in very sparse populations. In total, 180 taxa were recorded in samples from the lake between 2004 and 2008. Average number of taxa per sample was 11, while the maximum number of taxa in one sample was 32 (August 2008). Total numbers of phytoplankton rarely exceeded a value of 1000 ind./ml with maximum abundance being recorded at the end of each growing season (maximum 9000 ind./ml).

Between 2009 and 2010, the water depth in the lake reached the maximum designed level. Algal communities in the epilimnion still regularly consisted of Cryptophyceae (Plagioselmis spp., Cryptomonas spp.), as well as centric diatom Cyclotella ocellata, green algae of the genera Oocystis, Planktosphaeria gelatinosa, Planktonema lauterbornii, genera Elakatothrix and Eutetramorus, Chrysophyceae (Chrysococcus spp.) and Dinophyceae (Peridinium sp.). In September 2009, Centronella reicheltii was found again. Other taxa were recorded temporarily or sporadically. Total phytoplankton counts remained stable and the maximum numbers were attained during the the spring and summer peaks (5000 ind./ml and 15000 ind./ml, respectively). Of the 127 taxa found in the lake, the maximum number of taxa per sample in the summer in this period was 22 with the average number of taxa being 14 per sample. Cyanobacteria in the plankton did not represent a significant part of the phytoplankton community - genera Aphanothece, Aphanocapsa, Synechococcus persisted and Snowella lacustris, Microcystis aeruginosa, Woronichinia naegeliana and genus Chroococcus were found only sporadically.

The total phytoplankton biomass (see fig 5 - chlorophyll *a* concentration) in the lake was relatively low and during the filling period the biomass gradually decreased. There was no apparent difference between surface and bottom biomass. The occasional increase in the biomass during the last filling period occured only in the upper layers of water. Although predation pressure of the developing fish stock (see J. Peterka et. al. in these proceedings) gradually affected the community composition of zooplankton, the composition of phytoplankton was unaffected.

Above the lake water level, so-called “anti-eutrophication” reservoir was built. This reservoir receives water from the Kateřina Resevoir, from part of the lake drainage basin and occasionally sewage water. In 2010, a massive development of planktonic Cyanobacteria Microcystis aeruginosa, M. flos-aquae and Merismopedia sp. with a maximum of 10^6 cells/ml in August was recorded there. Relatively small water body has an important role in negative selection and inoculation of lake with potentially risky type of water blooms-forming Cyanobacteria.

Banks of the lake were made of coarse gravel unsuitable for the development of macrophytes. In the littoral zone macroscopic filamentous algae (Chaetophora incrasata etc.) occured while in sublittoral zone Charophyceae (Chara sp.) grew to a depth of 10 meters.

Zooplankton

In 2001, the lake was very shallow and largely overgrown by water plants. Zooplankton community was formed by a mixture of pelagial and littoral species and it was very difficult to separate it from zoobenthos. The dominant species (over 5%) were Daphnia magna and Cryptocyclops bicolor, subdominant species (2—5 %) were Eudiaptomus gracilis, Eucyclops serrulatus, Bosmina coregoni, B. longirostris and species of the genus Chaoborus. Young larvae of Chironomidae occasionally occured in large numbers.

In 2002, Daphnia magna disappeared and rotifers of the genera Asplanchna, Keratella, Polyarthra and Hexarthra were dominant. Furthermore, copepods Cyclops vicinus, C. strenuus, Thermocyclops dybowski, T. crassus and Acanthocyclops trajani alternately occured.

In 2003, the dominance of Daphnia pulicaria species and of juvenile developmental stages of group Cyclopoida started. Subdominant species were identified as rotifers Keratella cochlearis and K. quadrata and diaptomid Eudiaptomus gracilis. During this year abundant occurrence of diaptomid identified as Mixodiaptomus laciniatus was recorded. This would be a new species for the Czech Republic. However, in the following years this species was not found, and unfortunately it was not possible to verify the accuracy of determination.

In 2004, stable zooplankton community was formed and only slight changes have been observed since then. Daphnia pulicaria and juvenile stages of group Cyclopoida dominate the zooplankton. The group Cyclopoida is represented by species Eudiaptomus gracilis, Cyclops vicinus, C. strenuus, Thermocyclops crassus, T. oithonoides, Metacyclops gracilis, Eucyclops serrulatus, Macrocyclops albidus, Mesocyclops leuckarti, Diacyclops sp. and Paracyclops fimbriatus. Daphnia pulicaria is alternately supplemented with species Daphnia longispina, D. galeata, Bosmina longirostris, Diaphanosoma brachyurum and Chydorus sphaericus. The group Rotifera is dominated by species Keratella cochlearis, K. quadrata, Asplanchna priodonta, Polyartha cf. vulgaris and Hexarthra cf. mira. During the winter months, Notholca acuminata usually occurs.

Since 2006, in relation to the growing fish stock parasitic crustaceans Argulus japonicus, A. foliaceus, A.coregoni and Ergasilus cf. sieboldi have appeared.

During the first sampling in 2001, extremely high zooplankton biomasses were occasionally detected due to presence of a large species Daphnia magna, in the absence of fish stock. The biomass values amounted up to 11 g/m^3 dry weight. In the remaining period of filling, the lake zooplankton dry mass was about 0.06 g/m^3, with a slight tendency to decline. Also, zooplankton density was low. In the beginning of the filling period the density amounted up to 250 ind./l and then gradually declined to the level of around 25 ind./l.

Zoobenthos

In the first stage of filling period, the bottom was inhabited by species that were introduced into the lake with water (molluscs) and by mobile species which were able to colonize newly formed water bodies (Ephemeroptera, Heteroptera, Coleoptera). Other species such as duck leech (Theromyzon tessulatum) could have been introduced by waterfowl. The bottom of the lake was virtually free of sediment and large areas were covered with aquatic vegetation (Utricularia sp., Chara sp.). The water column was oxygen-rich to the bottom and in these conditions community rich in species from groups Chironomidae, Ostracoda, Hydrachnellae, Coleoptera and Ephemeroptera was present. Also, some species more commonly found in running waters were recorded (Tipula lateralis, Centroptilum luteolum).

In 2004, submerged vegetation began to decrease with increasing water depth, thin layer of bottom sediment developed and the number of benthic species decreased. The groups Chironomidae, Oligochaeta and Molusca began to dominate and species diversity substantially increased in the littoral zone.

In 2005, the bottom fauna began to be restricted to species resistant to oxygen deficiency (Chironomidae, Oligochaeta) and total abundance significantly decreased. Other species occurred only randomly. Since 2006, anoxic conditions have occured at the bottom. The sediment layer became thicker and profile in the middle of the lake lacked zoobenthos. During the years 2007 – 2010, periods with very poor zoobenthos and without zoobenthos alternated in all profiles.

The development of littoral fauna was very dynamic and was influenced by several factors - rate of filling process, building activity in the riparian zone, the development of aquatic macrophytes, the presence of water birds and the composition and amount of fish stock. The community of littoral fauna was positively influenced by slow filling, rich submerged vegetation and small fish stock. The presence of waterfowl played primarily a role of a vector of the increasing diversity of invertebrates. Zoobenthos diversity in the littoral rich in macrophytes commonly ranged from 20 to 30 species. In addition, dozens of species which are difficult to determine, such as Ostracoda and Hydrachnellae, were present as well. The potential of the littoral zone overgrown by submerged vegetation was immense. However, due to construction activities along the banks and due to the rapid filling the potential was not fully used.

In 2010, rapid completion of filling process of the lake to a final water depth up to the level of stony reinforcement took place. As a consequence, this led to a substantial destruction of the littoral community. The main area of diversity of benthic invertebrates shifted to the submerged vegetation at depths of 1—5 m, thus reservoir monitoring should be supplemented by the evaluation of this zone.

Conclusions

Flooding of open cast mine Chabařovice is the first experience with controlled filling of large surface lignite mines in the Czech Republic.

After filling of the new lake, which has become one of the largest water bodies intended for recreation in the Czech Republic, no significant problems with water quality have occured.

During the filling process, three qualitatively distinct phases can be distinguished: a) initial temporal and spatial fluctuation in water quality associated with increased trophy, b) stabilization of lake water quality and decreasing trophy, c) hypolimnion formation and the first signs of internal eutrophication.

Relatively low water inflow allowed for significant oligotrofication of the lake during its filling. This was evident from a number of physicochemical and biological indicators. The negligible occurrence of cyanobacterial water bloom is important in terms of future recreational use.

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