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Possible water uses in mining lakes: Case study of Aguas Claras, Brazil

E. v. Sperling & C. A. P. Grandchamp, Brazil

The paper presents a Brazilian experience related with the decommissioning of an exhausted mining activity and the consequent formation of a pit lake. This water body, which is still in a process of filling, will reach the final depth of 234 m, being hence the deepest lake in the country. Since 2001 (first year of formation) the water quality has been monitored on a monthly basis. The aquatic environment is absolutely free from contamination and presents an excellent water quality. There is a marked shift in the dominance of algae groups, probably due to this early stage of creation of a new ecosystem. Some conflicts are now arising regarding the possible water uses. The high water quality allows a sound utilization for urban supply, but the manifestations of the population (through public hearings) is towards the utilization of the lake for recreational purposes and landscape harmony. The paper discusses the origin and possible solutions for these conflicts.

Introduction

Mining lakes constitute a new type of aquatic environment, which has been so far very little explored in the technical literature. These lakes are generally narrow and deep, presenting hence only partial vertical circulations. This feature restricts hydrobiological growth and biodiversity in these habitats. Most of the technical papers related to the ecology of pit lakes deal with the formation of acidic environments (Klapper & Schultze 1995; Miller *et. al*. 1996, Levy *et. al.* 1997; Geller *et. al.* 1998; Stevens & Lawrence 1998; Packroff 2000; Lessmann *et. al.* 2000; Kalin *et. al.* 2001; Boland & Padovan, 2002; Hindak & Hindáková, 2003; Lessmann *et.al.*, 2003; Frömmichen *et.al.*, 2004; Triantafyllidis & Skarpelis, 2006; Boldau, 2006). Moreover these lakes are able to fulfill a relevant landscape requirement, offering an harmonic component to the local environment and allowing adequate conditions for recreational activities. They may also act as water supply resources, provided that the water quality is good enough to avoid expensive treatment processes.

Case study

This paper presents the case study of the current formation of *Lake Aguas Claras,* located in the city of Belo Horizonte, Brazil (see Figure 1). The filling of the lake began in the year 2001 and a very detailed monitoring programme (physical, chemical and biological characteristics) is since then in course. This lake will have a final area of 0.7 km^2 and the impressive depth of 234 m, which will make it the deepest lake in the country. The water used for filling up the lake comes from rain, ground water and supplementary pumping of river water from the vicinity of the lake. Rainy season lasts from October to March, while the dry period extends from April to September.

The morphology of the lake points out a very high value of *relative depth* (relationship between maximum depth and mean diameter, i.e. diameter of a circle of the same area as the lake - 25 %), according to Håkanson (1981), indicating the existence of a meromitic behaviour (partial vertical circulations) and the probable anaerobic condition that will be obtained at the bottom of the water body. Meromoxis in mining lakes has been discussed in Stevens and Lawrence (1998). However, due to the high maximum depth, phosphorus remobilization should not reach the euphotic zone, preventing hence the onset of an eutrophication process.

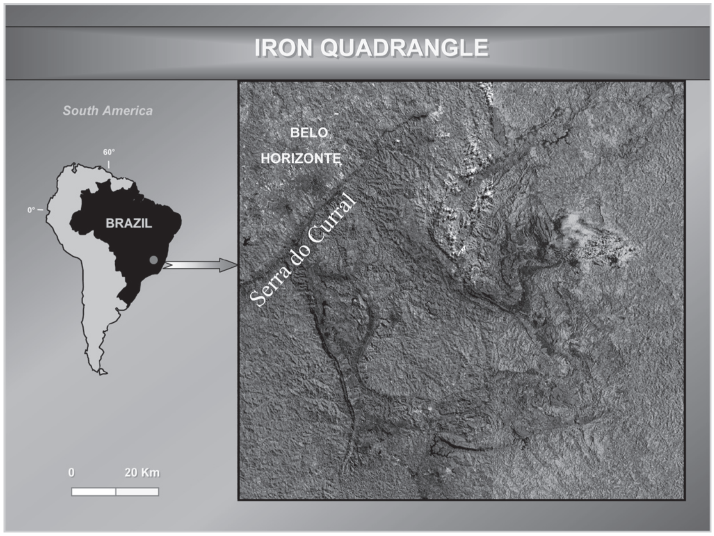

Figure 1. Location of *Lake Aguas Claras*

Materials and methods

An extensive monthly monitoring programme has been carried out since the beginning of the lake formation (August/2001).The most relevant physical, chemical and biological indicators for the evaluation of the water quality have been continuously analyzed. All employed analytical methods are based on the recommendations of the *Standard Methods for the Examination of Water and Wastewater* (APHA, 1998). Due to the small surface of the lake, there is just one sampling point, which is located in the central part of the water body, corresponding to its maximum depth. Samples have been taken at the surface (Secchi depth) and at the bottom of the lake.

Results and discussion

A summary of some of the most relevant water quality parameters is presented below:

Water temperature: a clear seasonal distribution of temperature values can be observed (Figure 2). The stratified condition dominates most of the year, while circulation takes place only during winter months (June to August). This *monomitic* (one circulation per year) behaviour is a typical feature in the majority of tropical lakes.

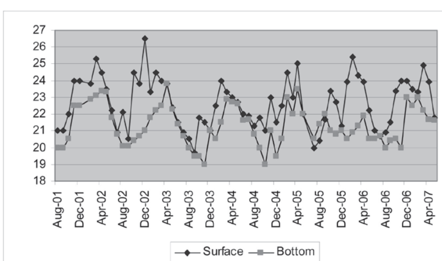

Figure 2. Water temperature

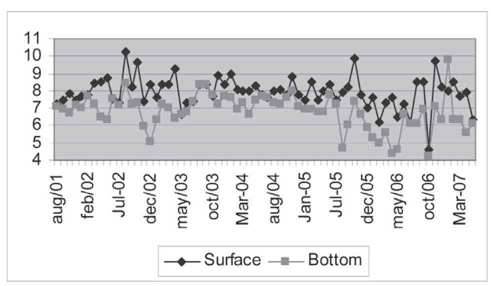

Figure 3. Dissolved oxygen

Dissolved oxygen; there is a marked influence of the temperature in the rate of atmospheric oxygen transfer to the water, with higher values being obtained in colder months (June to August) (Figure 3), due to the more intense process of gas transfer under lower temperatures; moreover the algae photosynthetic activity leads to the prevalence of higher concentrations in the upper layers, with occasional records of supersaturation (values over 9 mg/L); it should be observed that dissolved oxygen concentrations are always higher than 4 mg/L, even at the bottom layers; however a drastic fall of values is expected for the next years in this lower region of the water body;

Secchi depth: values between 0.5 m and 6.5 m ; there is an upward trend in the clarity of water as long as the lake is being filled (Figure 4);

pH: ranges from 6.9 to 9.6 (Figure 5); higher values are registered at the surface of the lake (primary production, CO_2 absorption) in comparison with the bottom (decomposition of organic matter, CO_2 release);

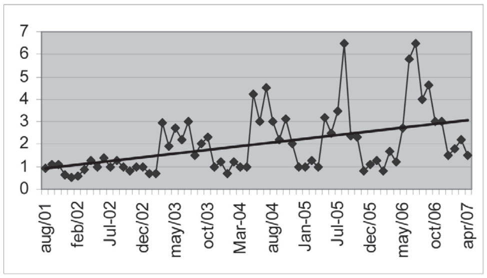

Figure 4. Secchi depth

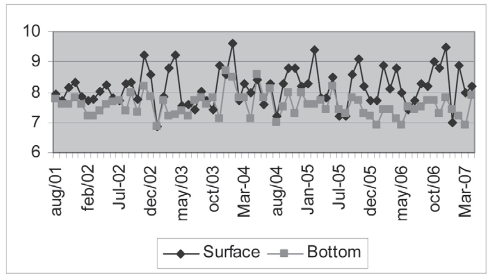

Figure 5. pH

Nutrients: Total phosphate concentrations show a slight trend of higher values (max. 0.18 mg/L) at the bottom layers during stratification periods, according to other experiences in tropical lakes (Tundidi & Saijo, 1997); these concentrations cannot be considered as elevated, since there is a noteworthy background presence of phosphate in the soils of the geological region of the State of Minas Gerais; almost all values of soluble phosphorus are below 0.01 mg/L, with a maximum concentration of 0.02 mg/L; in a future scenario this soluble fraction will probably predominate at the bottom of the lake as a consequence of internal fertilization processes. Ammonium nitrogen shows values between < 0.05 mg/L and 0.4 mg/L, while for nitrate nitrogen the concentrations range from < 0.01 mg/L to 1.3 mg/L with a clear dominance of the oxidyzed fraction (nitrate) over the reduced one (ammonium), what is consistent with the good oxygenation conditions in the lake.

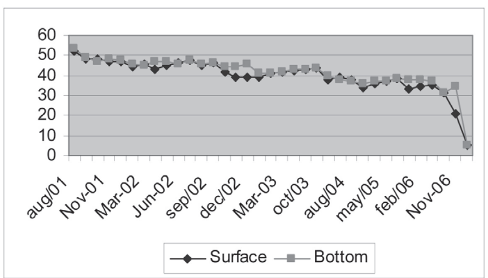

Figure 6. Hardness

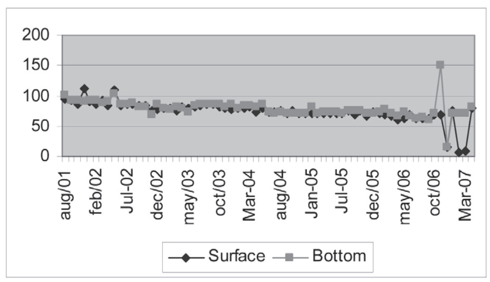

Figure 7. Electric conductivity

BOD: values range from < 0.1 mg/L to 4.3 mg/L, with about 80 % of the results under 1 mg/L;

Hardness: values generally between 30 and 50 mg/L (Figure 6). pointing to a low to moderate degree of hardness; since 2006 this parameter is monitored only every 3 months; in the last sample (February/07) a sudden fall (to 5 mg/L) has been observed, reinforcing a decreasing trend;

Electric conductivity: very low variations (Figure 7), with the majority of values in the amplitude from 60 to 80 µS/cm;

Turbidity: usually very low values (Figure 8), following the seasonal variations of rainy and dry periods;

Fe and Mn: Iron concentrations oscillate from < 0.05 mg/L (surface) to 1.73 mg/L (bottom) (Figure 9); such values are typical for drainage basins with high iron contents from geochemical origin, as is the case of Lake Aguas Claras; manganese values range between < 0.05 mg/L (60 % of the results) and 0.17 mg/L (at the bottom);

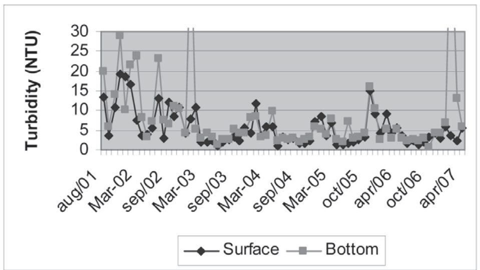

Figure 8. Turbidity

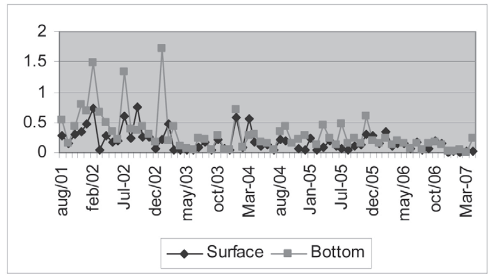

Figure 9. Iron

Chloride: permanently very low values, from < 0.25 mg/L (about 50 % of the results) to 1.7 mg/L;

Heavy metals and other pollutants (phenols, oil and grease, cyanide): virtually absent, only aluminium has been occasionally detected (0.12 to 0.22 mg/L).

Bacteriology: very good bacteriological quality; about 90 % of the results of faecal coliforms, Escherichia coli and faecal streptococci are lower than 2 MPN/100mL.

Phytoplankton: A marked shift in the dominance of phytoplanktonic groups can be observed (Figure 10). There is a general prevalence of Chlorophyta (35 % of the population), followed by Chrysophyta (32 %) and Pyrrophyta (23 %). Cyanophyta algae (Cyanobacteria), in spite of being present only in small populations (5 %) is always a serious concern in Brazilian lentic waters, since the first registers of human deaths due to ingestion of cyanotoxins happened in 1996 in the city of Caruaru, Brazil (Azevedo et. al. 1996). These frequent alternations in the algae dominance is typical of aquatic systems that are undergoing a process of formation, such as mining lakes. Due to an enhanced nutrient concentration in the dry season there is a trend in obtaining higher algal densities in the winter time (May to August). The occurrence of phytoplankton peaks in the period following the end of the rainy season (March to May) is a typical feature in some Brazilian lentic systems (Esteves 1998, Pinto-Coelho et. al. 2003), possibly as a consequence of the onset of favourable limnological conditions (decrease in turbidity, weaker winds) after the end of the wet period.

Zooplankton: clear dominance of Rotifera and Crustacea (Figure 11), as expected in the case of lakes; Protozoa is just occasionally present in the water samples.

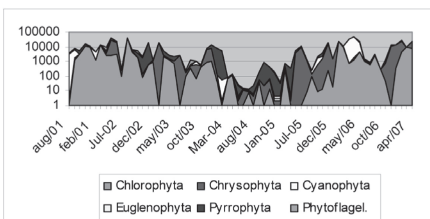

Figure 10. Phytoplanktonic groups

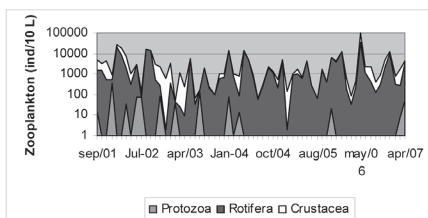

Figure 11. Zooplanktonic groups

The results show a very good water quality, practically free from contaminants. One of the most relevant issues in the environmental study of Lake Aguas Claras is the destination of the water body and its surrounding area. Due to the prognosis of the maintenance of a good water quality, the possible uses of the lake will be directed to recreation (swimming, diving, sailing, fishing), amenity value and water supply. This latter use will have a remarkable topographic advantage, since the lake location (a pit formed in the mountains) will enable a water distribution by gravity. On the other hand there is a strong anthropic pressure directed towards the urban occupation of one of the most valuable areas in the city of Belo Horizonte. How to harmonize this conflict has become a challenge for the local environmental agency. It should be stressed that the site is surrounded by mountains, what gives a nice sensation of privacy and intense contact with nature. On the other hand noble soil parcels are situated in neighbouring areas, so the investors are keen on establishing a proper urbanisation in the vicinity of Lake Aguas Claras, which would lead to the creation of probably the finest living place inside the city of Belo Horizonte. However, according to the local environmental agency, the decommissioning of the area should be followed by sound protective measures in order to ensure a broader use of this valuable water resource by the population. The good results that have been obtained in six years of water quality monitoring programme is surely one of the most relevant points that favour the solution of an adequate preservation of the natural area. Moreover these informations constitute a solid base for guiding future mining decommissioning processes that will take place in the same region, known as the Iron Quadrangle. Currently some ideas are being worked out by the environmental agency together with representatives of civil society in order to define the best way of land occupation, such as the use of lake surrounding areas as a sort of ecobusiness complex, i.e., hotels, convention centers and commercial buildings, which should gently harmonize with the local green areas.

Conclusions and learning points

Lake Águas Claras presents a very good water quality (well oxygenated, low values of colour and turbidity, limited degree of mineralization, pH slightly alkaline, low nutrient concentrations, excellent bacteriological conditions), together with a quite interesting shift in the dominance of phytoplanktonic groups, indicating the high instability of lakes that are undergoing a process of formation. The fact of being located in the tropical region of our planet causes an acceleration of all metabolic processes in the warm waters of the lake. This enhanced dynamics is one of the most relevant features of tropical environments. Consequently changes in the water quality don't follow regularly an annual pattern and daily variations can be often more significant. One relevant point in the management of this valuable water resource is how to create adequate conditions for the protection of the aquatic environment together with a sound occupation of the surrounding areas and the development of multiple uses in the lake.

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Contact details

Eduardo von Sperling
Av. Contorno 842, B. Horizonte, Brazil
Tel: 55 31 323811880
Fax: 55 31 323811879
Email: eduardo@desa.ufmg.br

César Augusto Paulino Grandchamp
Av. Ligação s/n, Nova Lima
Tel: 55 31 32893115
Email: cesar.grandchamp@cvrd.com.br