Water Quality of a Deep Pit Lake: Case Study of Aguas Claras, Brazil

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Abstract
This paper presents the case study of the current formation of a Brazilian pit lake (area: 0.7 km^2, maximum depth: 234 m). The evaluation of a six years monthly monitoring programme in Lake Aguas Claras indicates that it has 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 frequent shift in algae dominance. The possible uses of the lake will be directed to recreation, amenity value and water supply.

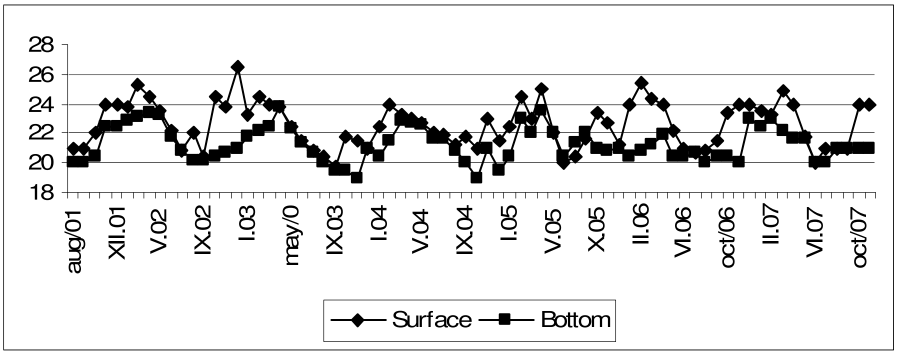
Key words: Mining lakes; water quality; plankton

Introduction
Open pit mining creates a new type of aquatic habitat, which is formed by force flooding or natural filling of the pit when it is mined out. Pit lakes are generally narrow and deep, enclosed by steep rock walls and usually without a littoral zone. Their morphological features, with a marked meromitic (only partial circulations) character, restrict the hydrobiological growth and the biodiversity in these habitats. Most of the technical papers related to the ecology of pit lakes deals 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).
The filling of the lake began in the year 2001 and a very detailed monitoring program (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 lentic system in the country. The water used for filling up the lake comes from rain, ground water and the supplementary pumpage 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 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

Methods
A 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.

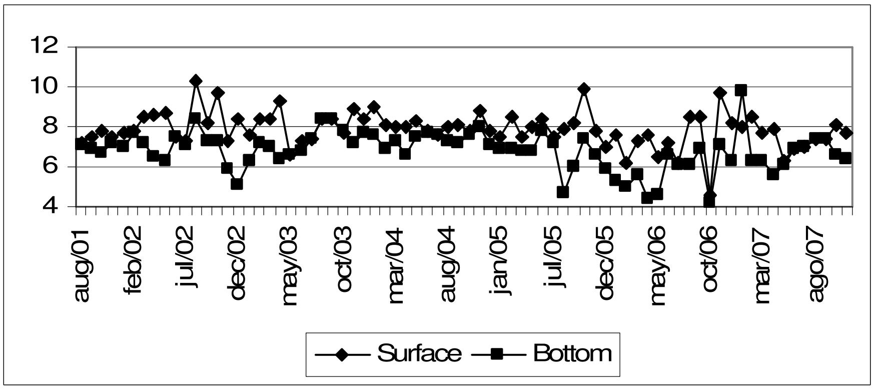
Results and Discussion
A summary of the evolution of the most relevant water quality parameters is presented below:
Water temperature: seasonal distribution, according to the local climatology: winter time (May-September), summer time (October-April); the lake presents a monomitic pattern, with only one period of circulation (June-August). In the rest of the year the lake remains stratified. At the lake surface temperature values range from 19.5 ^{0}C (June/2001) to 26.5 ^{0}C (December/2002) and at the bottom from 19 ^{0}C (October/2004) to 23.8 ^{0}C (August/2003) (Fig. 1).

Figure 1 *Water temperature*



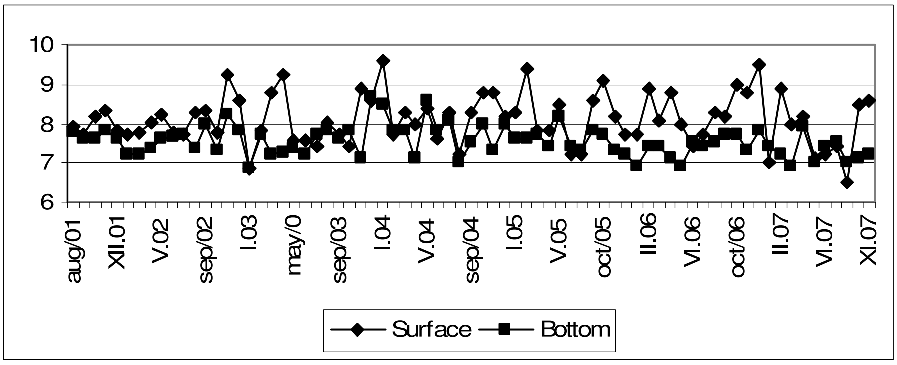
Dissolved oxygen*:* influence of the temperature in the rate of atmospheric oxygen transfer to the water, with higher values being obtained in colder months (Fig. 2). Algae photosynthetic activity increases DO concentrations in the upper layers, with occasional records of supersaturation .

Figure 2 *Dissolved oxygen*



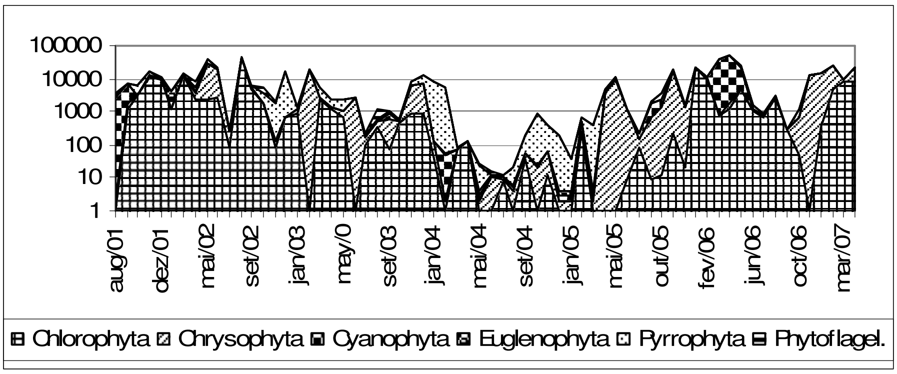
Alkalinity: values between 24 mg/L and 39 mg/L; low buffer capacity of the water, ***Hardness****:* values between 33 mg/L and 55 mg/L; low to moderate hardness; ***Turbidity****:* clear seasonal variations (increase in the rainy period); 84 % of the recorded values are under 10 NTU, indicating the prevalence of very clear waters;***Secchi depth****:* between 0.5 m and 6.5 m, with higher values registered at the winter time; ***Colour****:* very low values, most of them under 1 mg/L; ***pH****:* ranges from 6.4 to 9.6 (Fig. 3), with higher values at the surface of the lake (primary production, CO_2 absorption) in comparison with the bottom (decomposition of organic matter, CO_2 release);

Figure. 3 *pH*



Nutrients: 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 consequence of internal fertilization process. Ammonium nitrogen shows values between < 0.05 mg/L and 0.9 mg/L, while for nitrate nitrogen the concentrations range from < 0.01 mg/L to 1.3 mg/L; these results are consistent with the good oxygenation conditions in the lake. There is a trend in decreasing TN/TP values as the lake is being filled, indicating a possible nitrogen limitation in the future;
Electric conductivity: Values range from 55 µS/cm (surface) to 113 µS/cm (surface); since May/04 they are situated in the narrow range of 70-80 µS/cm, indicating that a stability in the amount of dissolved salts has been reached; *BOD:* Around 96 % of the concentrations are under 2 mg/L, with the maximum value of 5.8 mg/L; these results point out to a virtual absence of organic contamination, ***Fe and Mn:*** Iron concentrations range from < 0.05 mg/L (surface) to 1.73 mg/L (bottom). These values are typical for drainage basins with high iron contents from geochemical origin, as is the case of Lake Aguas Claras; manganese concentrations range between < 0.05 mg/L and 0.17 mg/L (at the bottom); ***Chloride:*** constant low values, from < 0.25 mg/L to 1.7 mg/L; ***Heavy metals*** *(Al, As, Cd, Cr, Cu, Hg, Pb) 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.
Hydrobiology: the most relevant aspect in the hidrobiology of Lake Aguas Claras is the frequent shift in algae dominance (Fig. 4). In a first phase (some few months after the beginning of the filling) there was the dominance of *Chlorophyta* and *Cyanophyta*; in a second moment (period of about 4 years): dominance of *Chrysophyta* and *Pyrrophyta*; in a third phase (2006) a short period of *Cyanophyta* dominance, followed by the current prevalence of *Chlorophyta* and *Chrysophyta*. It should be stressed that blue-green algae are a serious concern in Brazilian lentic waters, since the first worldwide 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 are 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) and in the period following the end of the rainy season. This pattern is a common feature in many 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.

Figure 4 *Phytoplankton*



Regarding the composition of the zooplankton community, a clear alternation in the dominance of Rotifera and Crustacea can be observed. The occurrence of frequent density variations can be probably associated to the natural instability of the new aquatic system. Peaks in the zooplankton population have been observed in the dry period (winter time), what could be caused by enhanced salinity due to evaporation. Researches in Brazilian lakes have shown an increase in zooplankton abundance in the rainy season (Sendacz, 1984), while some authors present rain as a lost factor for the zooplankton (Campbell et. al., 1998).

Conclusions

The evaluation of a monthly monitoring programme in Lake Águas Claras shows that the lake 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. One relevant point in the management of this valuable water resource is to create adequate conditions for the protection of the aquatic environment. Considering the very probable maintenance of these favourable characteristics in future years, the possible uses of the lake will be directed to recreation (swimming, diving, sailing, fishing), amenity value and water supply. Moreover the results of this extensive monitoring program could be used as background for water quality characteristics in other natural and protected areas in the region.

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