Quantification of water evaporation by open pit mining lake using lysimeters

Manoel Camilo Moleiro Cabrera[1], Cristian Youlton[2], Edson Wendland[3]

[1,2,3] *Laboratório de Hidráulica Computacional, Departamento de Hidráulica e Saneamento, Escola de Engenharia de São Carlos, Universidade de São Paulo. Av. Trabalhador São-Carlense 400, São Carlos – São Paulo – Brasil CEP 13566–590. [1]camilo@sc.usp.br, [2]cristian.youlton@usp.br, [3]ew@sc.usp.br*

Abstract Two lysimeters and a buried evaporation tank with simple control and regulation system were designed to investigate the water loss due to soil cover change by open mining pit. The obtained results indicate that water losses through the surface increase in 1104 mm when sandy soil is converted to an open water surface. The impact increases in 1218 mm when clayey soil is converted to an open water surface. This indicates that the installation of mining pits with consequent formation of lagoons contributes to increasing evaporative water loss and decreasing underground water reserves.

Keywords Water balance, 20 m^2 tank, Linacre, Class A pan, mining impact

Introduction

Groundwater resources have gained attention in recent years due to environmental problems related to land degradation. Mining is a very important activity for the society, but it is the major consumer of nonrenewable natural resources, causing significant changes in the landscape and water resources and it consumes large quantities of water; only the copper mining industry alone used over 1.3 Gm^3 of water in 2006 (Gunson *et al.* 2010). On a worldwide scale, however, mine water use accounts for a little portion of general water use. Even in countries with dry regions, intensive-mining countries like Australia, Chile, and South Africa, mine water consumption is only 2–4.5 % of national water demand (Brow 2003; Bangerter *et al.* 2010).

Mine acid drainage is a major world environmental problem that adversely affects both surface and groundwaters, causing also problems of ecological significance. In general it occurs when pumped mine water is of poor quality. Other negative impact of mining activities is the lowering of mine water table in the vicinity of water supply or irrigation wells, both especially due to dewatering mine (Cabrera *et al.* 1984; Gray 1998; Younger and Wolkersdorfer 2004). There are studies about surface water quality and evapoconcentration, including modeling the effects in open pit mining lake and also about monitoring the stability of steep slopes of open pit mines (Yoko *et al.* 1997; Eary 1998; Han and Zhang 2009).

However, impacts on the water cycle or groundwater resources before and after installation of the mining activities (*e.g.* mining pits) are not mentioned in environmental reports, not counting changes in the amount and flow of water lost to the atmosphere.

There is strong evidence that open water surface has a direct impact on the water balance, affecting evapotranspiration and subsequently groundwater recharge. This is partly due to increased evaporation compared to vegetation cover. Evaporation from open water surfaces such lakes and wetlands often represents the largest losses in the local hydrology and is one of the main components of the hydrologic cycle (Assouline *et al.* 2008; Mengistu and Savage 2010). In Brazil, during the last years there has been a strong expansion of mining pits in the Paraíba do Sul watershed, modifying soil cover and increasing lake areas in São Paulo state.

There are no scientific studies that estimate directly changes in water balance, especially the amount of water lost to the atmosphere due to soil cover changes (grass to open water surface) by mining activities. The main objective of this study is experimentally quantify the loss of water in mining pits by monitoring the following variables in the water balance: i) evaporation; ii) rainfall; iii) drainage; iv) water replacement to maintain the water table in lysimeters and evaporation tank during one year under natural tropical weather conditions.

Methods

The study was conducted at the Lobo watershed (extreme coordinates 22°10′ S lat. 22°20′ S lat.; 47°45′ O long. 47°55′ O long.) in Itirapina, state of São Paulo, Brazil (Fig. 1).

The experiment was conducted in the Climatological Station of the University of São Paulo. The site lies at an elevation of 733 above sea level with average annual rainfall, air temperature and relative humidity of 1493 mm, 21.5 °C and 71 %, respectively.

The climate classification by Wilhem Köppen is CWA, seasoned climate due to altitude (Machado and Mattos 2001). The classification of Thornthwaite and Matter (1955) describes the climate to be B_2 r B'_3 a’ (moist climate with few hydric deficiency in June, July and August)

Fig. 1 *Site of experiment.*

Annual potential evapotranspiration is 985 mm (Mattos *et al.* 1998).

This experiment used one buried tank and two lysimeters (Fig. 2) filled with sandy soil (lys-sand) and clayey soil (lys-clay) with water level maintained constant 1.0 m below surface. The lysimeters were made of fiberglass and have 1.88 m top diameter, 1.52 bottom diameter and 1.32 m depth. Each lysimeter has a surface area of 2.78 m^2. In the bottom of the lysimeter containers a drainage systems in “fish’s spine” shape was installed, to drain the excess rain water. The drainage from the lysimeters and evaporation tank were measured in containers with 310 L of capacity. The water table in a supply tank (for reposition of evaporated water) was monitored every day at 07:00 am.

The evaporation tank was exactly similar in shape to the lysimeter tank. The water level inside the tank was maintained at or slightly below natural ground level. In order to study evaporation conditions at the test site two Class A pan and two 20 m^2 evaporimeters were surrounded by short-cut grass, 6 – 12 cm, same as the lysimeter cover.

Data loggers were also installed to record meteorological observations. The temperature and relative air humidity were obtained using one Rotronic sensor with multi plate radiation shield and naturally aspirated, about 1.8 m above ground. Solar irradiation was measured with Licor pyranometer, wind (speed) at 2.0 m above ground was obtained with Fuess anemometer, rainfall was measured with a Ville de Paris pluviometer. The meteorological observations were used to calculate evaporation according to Penman, (1948), Snyder (1992), Linacre (1993) and Penman-Villa Nova *et al.* (2006).

The sandy soil was collected from Ribeirão da Onça watershed (22°10′33.9″ S lat.; 47°57′14.0″ W long), while clayey soil was collected from a mining area localized in Uberabinha watershed (19°20′41.1″ S lat.; 47°54′46.3″ W long). Clayey soil is feedstock to make firebrick used in ovens. The soil granulometry is indicated in Table 1

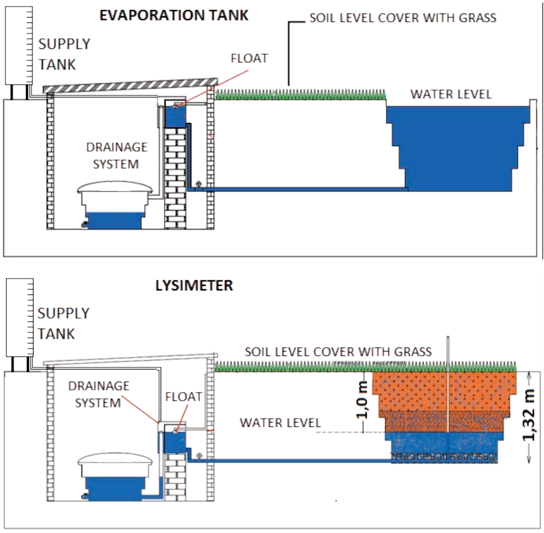

Fig. 2 *Lysimeter and Evaporation Tank with water supply, drainage system and float assemblage (not in scale).*

Particle Diameter (mm)	Granulometry (%)	
	Lys-Clay	Lys-Sand
Gravel>2.0	0.7	0.3
2.0>Coarse sand>0.6	2.6	8.8
0.6>Medium sand>0.2	8.8	63.6
0.2>Fine Sand>0.06	2.4	16.4
0.06>Silt>0.002	20.1	10.9
0.002>Clay	65.4	

Table 1 *Granulometric composition of soils in lysimeters*

Results and Discussions

The observed values of water supply to maintain the water table constant in the lysimeters are shown in Fig. 3. In the wet season (November to April) the sandy lysimeter consumed more water than the clayey lysimeter, due to the higher rain water retention in the clayey soil. During the dry season (May to October) the water supply increased strongly providing moisture to the grass covering. In this period there is no increase in water supply during the 15–20 days following an effective rain event, as observed in June. However it could be observed that the grass cover in the lys-clay did not present as good adaptation as in the lys-sand.

Fig. 4 shows the accumulated drained rain excess for the evaporation tank and for the lysimeters. The drainage (mm.m^{-2}) at the clayey and sandy lysimeters show identical values. The drainage at the evaporation tank follows the observed precipitation.

In this experiment the methods of Linacre (1993) and Class A pan with K_P=0.76 (Reis *et al.* 2006) present a good agreement with measurements at the evaporation tanks. The Snyder (1992), Penman-Villa Nova (2006) and Penman (1948) methods overestimated the accumulated evaporation (Fig. 5).

Conclusions

The soil cover changes (substitution of grass cover by open water surface) due to mining pits increase water losses. According with Fig. 5, the obtained results indicate that water losses through the surface increase in

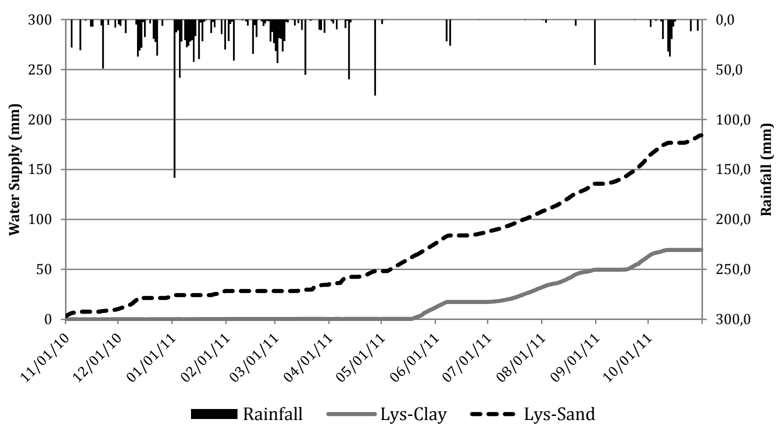

Fig. 3 *Comparison of accumulated water supply for the clayey and the sandy lysimeters. The rainfall in the period is shown as hanging bars.*

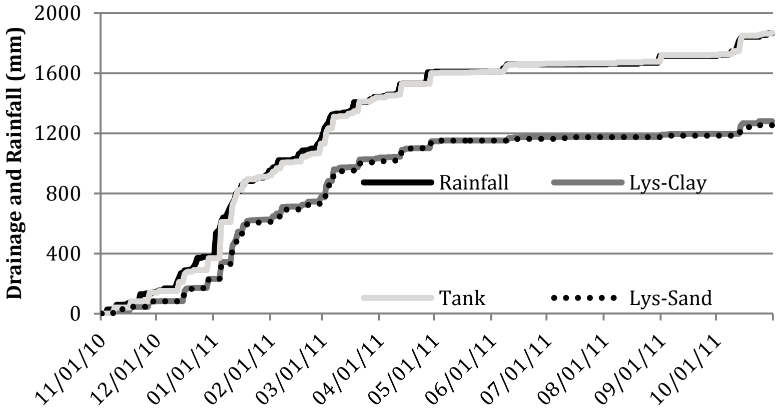

***Fig. 4** Values of drainage for the lysimeters and evaporation tank. The accumulated rainfall in the period is also shown.*

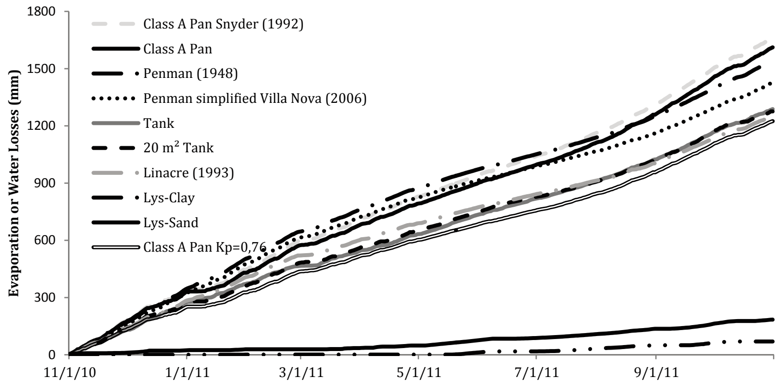

***Fig. 5** Comparison of accumulated evaporation measured by evaporimeters and calculated by estimation methods based on climatic data. In the bottom of the graphic the accumulated water supply in the lysimeters is shown.*

1104 mm when sandy soil (covered with well watered grass) is converted to an open water surface. The impact increases in 1218 mm when clayey soil (well watered grass but with environmental stress) is converted to an open water surface. Considering the meteorological conditions in the test site the Class A pan with K_p =0.76 and the Linacre (1993) methods for evaporation estimate showed good agreement with measured accumulated evaporation during the wet and dry periods.

References

Assouline S, Tyler SW, Tanny J, Cohen S, Bou-Zeid E, Parlange MB, Katul GG (2008) Evaporation from three water bodies of different sizes and climates: Measurements and scaling analysis. Advances in Water Resources 31:160–172

Bangerter P, Richard E, Villegas M (2010) Improving overall usage of water in mining - A sustainable development approach. In 2nd International congress on water management in the mining industry, p 403

Cabrera F, Toca CG, Diaz E, Arambarri P (1984) Acid mine-water and agricultural pollution in a river skirting the Doñana National Park (Guadiamar river, South West Spain). Water Research 18:1469–1482

Brow E (2003) Water for a sustainable minerals industry. In. Mining Conference, Brisbane, October 2003, p 3-14

Eary LE (1998) Predicting the effects of evapoconcentration on water quality in mine pit lakes. Journal of Geochemical Exploration 64:223–236

Gray NF (1998) Acid mine drainage composition and the implications for its impact on lotic systems. Water Research 32:2122–2134

Gunson AJ, Klein B, Veiga M, Keevil NB (2010) Estimating global water withdrawals due to copper mining. J. Wiertz (Ed.), II International Congress on Water Management in the Mining Industry, GECAMIN

Han X, He M, Zhang B (2009) Sensitivity analysis for parameters of a monitoring system for steep slopes of open-pit mines. Mining Science and Technology (China) 19:441–445

Linacre ET (1993) Data-sparse estimation of lake evaporation, using a simplified Penman equation. Agricultural and Forest Meteorology 64:237–256

Machado RE, Mattos A (2001) Construção e instalação de um lisímetro com sistema de drenagem. Revista Brasileira de Agrometeorologia 9:147–151

Mattos A, Ribeiro JBR, Mattos KMC, Villa EA (1998) Caracterização climática da represa do Lobo (Itirapina-SP) In Anais Reis C (ed) Congresso Brasileiro de Meteorologia, Univ de Brasília, p 43

Mengistu MG, Savage MJ (2010) Open water evaporation estimation for a small shallow reservoir in winter using surface renewal. J Hydrology 380:27–35

Penman HL (1948) Natural evaporation from open water, bare soil and grass. Proceedings of the Royal Society of London Mathematical and Physical Sciences 193:120–145

Reis B, Batista J, Teixeira G, Targa MS, Catelani CS (2006) Influência das cavas de extração de areia no balanço hídrico do vale do Paraíba do Sul. Revista Escola de Minas 59:391–396

Salazar O, Hansen S, Abrahamsen P, Hansen K, Gundersen P (2013) Changes in soil water balance following afforestation of former arable soils in Denmark as evaluated using the DAISY model. J Hydrology 484:128–139

Snyder R (1992) Equation for evaporation pan to evapotranspiration conversions. Journal of Irrigation and Drainage Engineering 118:977–980

Villa Nova NA, Miranda JH, Pereira AB, Silva KO (2006) Estimation of the potential evapotranspiration by a simplified penman method. Engenharia Agrícola 26:713–721

Yoko S, Axler R, McDonald M, Wilcox D (1997) Recovery of a mine pit lake from aquacultural phosphorus enrichment: model predictions and mechanisms. Ecological Engineering 8:195–218

Younger PL, Wolkersdorfer C (2004) Mining impacts on the fresh water environment: technical and managerial guidelines for catchment scale management. Mine water and the environment 23:s2–s80