Model Predictions of Water Chemistry for the Future Pit Lake in As Pontes, A Coruña (Spain)

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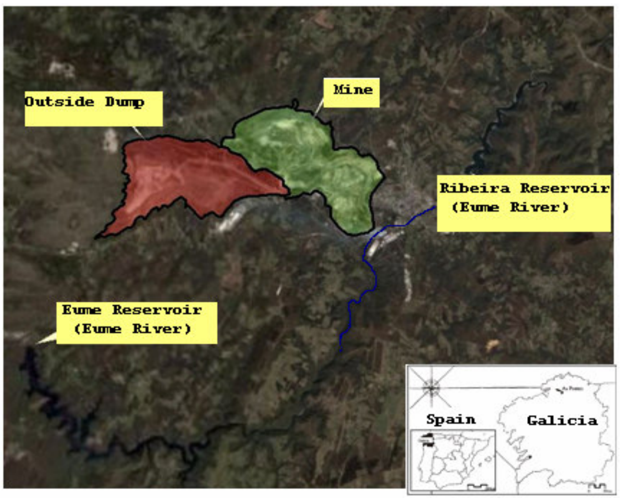
Abstract
An open pit lake is foreseen after closure of As Pontes coal mine in A Coruña (Spain) in December 2007. The lake will have a surface of 8.1 km^2 and a maximum depth of 194 m. It will be filled with rainfall on the drainage basin of the mine, runoff waters from outside dump and good-quality water imported from Eume river. A full-mixing geochemical model was constructed to predict water quality. Later it was improved by accounting for lake stratification. Model predictions show that there will be thermal stratification during spring, summer and most of the autumn. The most saline and acid waters will settle at the lake bottom. The quality of near-surface waters will meet the environmental standards required by the Galician Water Authority.

Key words: hydrodynamic model, stratification, geochemical model, pH, pyrite, ferrihydrite, surface complexation

Introduction
Closure of As Pontes coal mine in A Coruña (Spain) in December 2007 will give rise to one of the largest pit lakes in Europe. As Pontes coal mine is located in Galicia, Northwestern Spain. The climate is temperate and wet, favoring weathering and leaching. Pyrite in these materials causes rapid acidification during mine operation. The resulting acidity promotes the dissolution of aluminum and iron minerals. Quantification and prediction of pit lake water quality require the use of numerical models which take into account the relevant thermal, hydrodynamic and geochemical phenomena. There are many references on modeling water quality of natural lakes (Gal et al., 2003 and Yeates et al., 2003) suing codes such as DYRESM (Antenucci and Imerito, 2003), but much less on modeling pit lakes (Balistrieri et al., 2006 and Castendyk et al., 2007).

Figure 1 *Location of As Pontes mine in Coruña, Spain. Also shown is the location of dump area.*



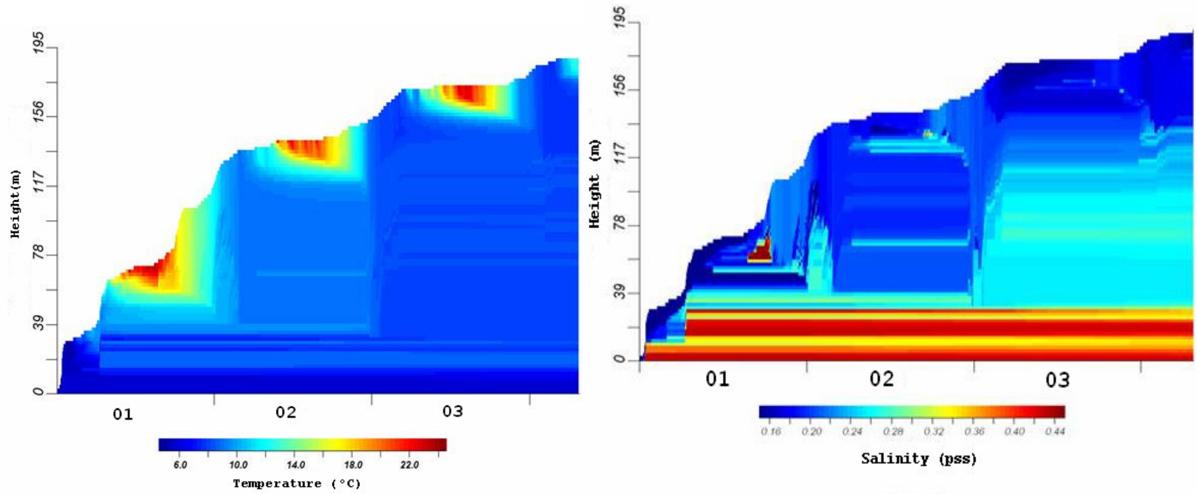
Hydrodynamic and hydrochemical model
Thermal and hydrodynamic processes are modeled first to get temperature, salinity and density profiles and quantify lake stratification. Hydrodynamic model of As Pontes pit lake was performed with the Dynamic Reservoir Simulation Model (DYRESM) of Antenucci and Imerito (2003). This is a

one-dimensional vertical, process-based hydrodynamic simulator of spatial and temporal variations in temperature, salinity, and density. This code has been widely used in hydrodynamic modeling of natural lakes, reservoirs and mine pit lakes (Gal et al., 2003 and Yeates et al., 2003).
Model predictions of As Pontes pit lake were performed using meteorological data from January 2000 to September 2005 collected at A Mourela weather station located South East of the lake. Such data include: air temperature, humidity, shortwave radiation, cloud cover, wind velocity and precipitation. Inflow data include: volume, temperature and salinity of lake inflows. Salinity in *pss* was calculated from available electrical conductivity data expressed in terms of µS/cm by using a conversion factor of $7.5 \cdot 10^{-4}$. The surface-elevation curve of As Pontes open pit lake was obtained from a Digital Terrain Model. The geochemical model includes as primary species: H^+, Fe, Mn, Al, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+ and HCO_3^-. The geochemical model also considers aqueous complexation, dissolution/exsolution of O_2(g) and CO_2(g), precipitation of ferrihydrite and surface complexation of proton on iron oxides. The main objective of this coupled thermo-hydro-geochemical model is to improve full-mixing models in which stratification phenomena were not considered. Particularly, stratification forces mixing phenomena in the surfaces waters. The most saline and dense waters will settle at the bottom of the lake due to stratification and will not mix fully with waters of better quality which will remain at the surface of the lake. Stratification would also affect to the different remediation actions, so the main effect would take place in the surface waters. Hydro-geochemical also considers a 30% reduction in acid-producing surface and addition of power plant effluents. Geochemical mixing calculations are performed with an in-house computer code, CORE$^{2D©}$ (Samper et al., 2003). For the stratified model, CORE was coupled to DYRESM (Antenucci and Imerito, 2003).

Model Predictions

Model predictions are performed using historical data corresponding to the period 2000-2004. Temperature and salinity contour plots are shown in Figure 2. Model predictions show that there will be thermal stratification during spring, summer and most of the autumn. More details can be found in Samper et al. (2008). The open pit will be filled with three types of waters: 1) Water diverted from Eume River, 2) Runoff from the external dumps and 3) Runoff from mine drainage basin. Knowing the vertical distribution of these waters within the water column is useful to study the time evolution of water quality during the filling of the lake as well as the vertical distribution for full lake. Figure 3 shows contour plots of mixing fractions of the three waters. Model results show that surface waters are composed mostly of Eume River while mine and dump waters dominate at the bottom of the lake.

Figure 2 *Contour plots of temperature and salinity for As Pontes open pit lake (Samper et al., 2008).*



The model has been used to evaluate the beneficial effect of various remedial actions on increasing pH and reducing sulfate and metal concentrations of lake-surface waters. Such remedial actions include: 1) Adding effluents from As Pontes thermal power plant, 2) Adding 1500 tons of CaO(s) and 3)

Tapping mine acid-producing zones with a thick layer of clay. Figure 4 shows model predictions of pH for a full-mixing model for the filling of the lake for such remedial actions. It can be clearly seen that both lime and effluents are equally efficient in improving the pH of lake water. Model results show that the stratified model leads to pH values which are larger than those of a full-mixing model. Figure 5 shows that the highest pH is obtained in surface waters while pH is smallest in middle and bottom waters.

Figure 3 *Contour plots of mixing fractions of Eume River (top) and mine water (bottom) during the filling of As Pontes open pit lake (Samper et al., 2008).*

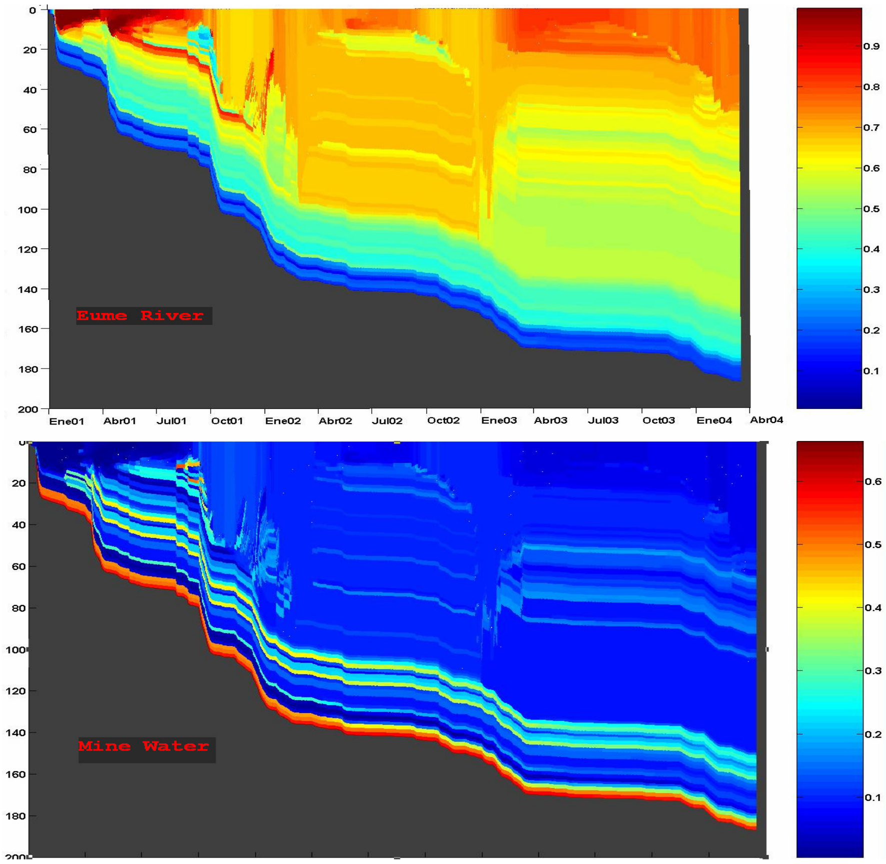


Figure 4 *Sensitivity of computed pH (with a full-mixing model) to remedial actions.Base run accounts for effluents from thermal power plant, but does not consider addition of lime (Samper et al., 2008).*

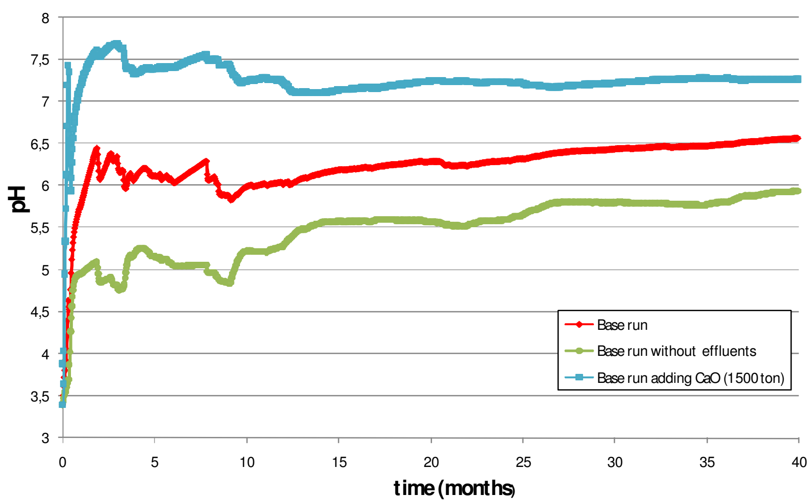
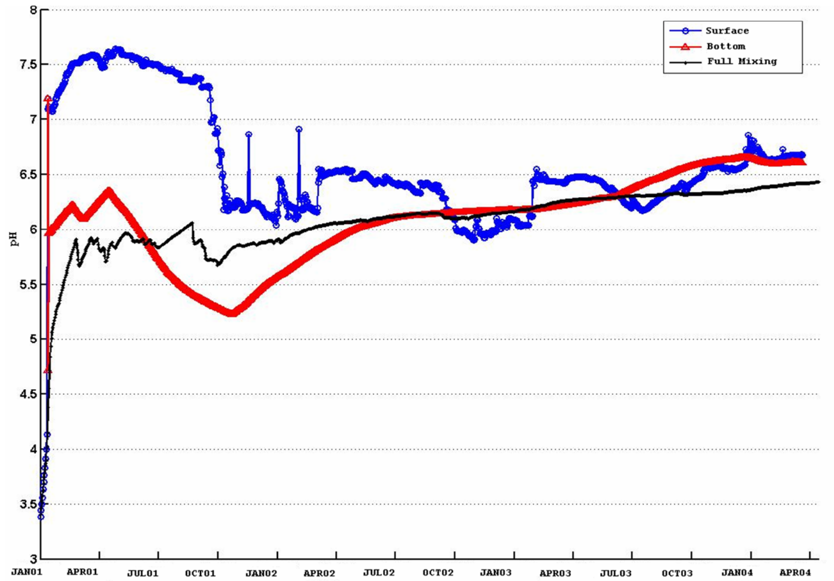


***Figure 5** Comparison of pH computed with full-mixing and stratified models. Results for the latter are shown at the surface and the bottom of the lake (Samper et al., 2008).*



Conclusions

Full-mixing and stratified geochemical models for the future As Pontes pit lake have been presented. Model results show that there will be thermal stratification during spring, summer and most of the fall. The most saline and dense waters will settle at the bottom of the lake and will not mix with the good-quality waters of the surface of the lake. Model results show that the stratified model leads to pH values which are larger than those of a full-mixing model. Similarly, the stratified model leads to species concentrations in surface waters which are smaller than those of the full-mixing model. The model has been useful to evaluate several remedial actions. The model will be tested and updated with data collected during filling of the lake which started in January 2008.

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