Water Quality Models in Limeisa Mining Lake

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Abstract
The company Lignitos de Meirama, S.A. (Limeisa) has been mining lignite at an approximate rate of 3 M tonnes per year since 1980 in its open-cast mine at A Coruña, in the north-western coast of Spain. The activity finished on January 2008, when the reserves of 93 Million t were exhausted.
Owing to this fact, Limeisa has designed a closure project, in which the formation of a lake has been considered the best environmental solution. The lake will be 2,000 m long and 187 m deep and will have a capacity of 150 Hm3.
This project contains several studies regarding the stability of the pit and the water quality in the future lake, as well as other chapters related to rehabilitation actions in the area, studies on futures uses, effects of the lake on the nearby Barcés river or the influence on local climate.
The findings drawn by these quality models showed that the water stored in the lake shall meet all legal requirements, as well as any other environmental legislation which currently applies to the water daily purified and flowed into the Barcés river by Limeisa.

Key words: mining lakes, hygrogeology, hidrochemical, predictive modelling, Spain

Introduction
The extraction of lignite in the Meirama basin began in 1980 under the management of Lignitos de Meirama, S.A. (LIMEISA). The suspension of this activity owing to the exhaustion of the resources both technically and economically extractable, took place in January 2008. Over the course of nearly 30 years of operation, roughly 81 million m3 of clay, ~50 million m3 of granite, ~44 million m3 of schist and ~93 million ton of lignite have been removed from the mine pit. The total volume of material moved or used for profit amounts to a total of some 268 million m3, although it must be noted that part of this material has been returned to the pit, reducing the excavation volume to roughly 150 million de m3 at elevation level 177
The Final Reclamation Project of the hole of Meirama mine foresees the creation of a large lake – through a flooding process regulated with natural waters- which will occupy the physical space of the current mine pit. In accordance with preliminary estimations, it is predicted the filling of the pit will last at least 7 years.
The more important points of this Technical Project are the stability of the hole and the models of prediction of the water quality of the future lake
According to the conclusions drawn by different stability studies, a buttress was required so as to guarantee the stability of the slopes and, thus, increase form 0.9 to 1.45 the safety rate. This buttress is already finished, and has a thickness between 50 and 90 m.
The water quality that Meirama's lake will form is a subject of vital importance because the river is a source that contributes to the functioning of Cecebre reservoir, which constitutes the only supply of drinking water for the city of A Coruña and the surrounding towns.

The filling of the hole of Meirama mine
The waters that flow into the mining hole have different origins and their contributions may be separated into the categories of surface waters, groundwater and rainfall. Each of these waters has its own chemical quality which requires that, during the flooding process of the lake, the chemical quality of its waters must be under close scrutiny. Hence, while the unaffected natural waters (regardless of whether they are surface waters, groundwater or rainwater) contribute good quality waters, those flowing along the inside of the pit or interacting with some their units or materials (schist walls, waste dumps, etc.) take up pollutants and acids that condition their subsequent use and the impact they may

have – as a recreational space or as an area for aquatic life- and there is some concern as to the discharge –owing to overflow- into the the lower Barcés River basin.
From a hydrogeological point of view, the characteristics of the different outcrops in the basin where the Meirama mine is located, are strongly affected by the lithology and tectonics of the existing material. The granite massif and schist formations of the Órdenes Series are materials with very low hydraulic conductivity and little porosity, which means that the flow of deep waters is of little consideration. More specifically, the granite massif has been substantially disturbed and fractured in the area around the NE border of the mine pit, coinciding with the fault, which, to a certain extent, has individualized the tertiary sedimentary basin. This disturbance appears to have a primarily hydrothermal origin and corresponds to a major kaolinization of the granodioritic massif, in general, and to the fractures, in particular. The hydrogeological behavior of the granite is, therefore, highly varied. By contrast, the schist to the south of the basin has a very low permeability and a small storage coefficient
The first work about knowledge of the hydrology of the high basin of the Barcés River was carried out by Golder Associates Limited on the initiative of LIMIESA in 2002. It also provides the preliminary basis for the design of predictive models on the water quality of the prospective Meirama pit lake.
Another studies on the local hydrogeology of the Meirama mine together the Barces River was carried out by Padilla et al. (2006), in the context of a collaboration agreement between LIMEISA and the University of A Coruña (Water and Environmental Engineering Group). These authors analyzed the topographic , geological and hydrologic characteristics of the high basin of the Barcés River in relation to the hydrogeological conditions imposed by the mining operation. This study has also made it possible to make a preliminary calibration of the hydrodynamic parameters needed for the joint modeling –surface/underground- of the high basin of the Barcés River as well as an estimation of the evolution of the piezometric levels, depths and the time needed for the complete flooding of the pit. In this sense, the researchers concluded that it would take approximately 7 years to fill the lake.

Water quality models
The first hydrochemical models of Meirama lake was carried out for Golder Associates at 2002.
In order to accomplish this Model, Golder had gathered the previous information of studies hydrologics, of waters balance and hydrogeoligics was carried out for the surroundings of Meirama's mine. With these data, Golder accomplished a model based on PHREEQ II. The results foresaw that the water quality is going to be acceptable in almost all the parameters that are considered in a legal flow.
The next work about the hidrochemical of Meirama lake was carried out for the team of Santiago de Compostela Univesity, department of Applied mathematics, ("A Three Layer Model to Estimate Pit Lake Water Quality", Exposed in the IMWA 2007), who designed a complex mathematic model to foresee the quality of the water in the prospective lake.
Third model, accomplished for a research team of University of A Coruña (Water and Environmental Engineering Group), began also with a preliminary study carried out on the hydrologic behavior of the surface/underground waters of the high Barcés River basin. This study, which also includes a preliminary approach to the analysis of the flow in the lake's body of water (Padilla et al., 2006; Padilla et al. 2007) and the prediction of the filling time, provided the basis for the design of different models, some of which are as follows: 1) Prognosis of the chemical quality of the prospective pit lake based on available analytical data (Delgado et al. 2007); 2) A model of the evolution of lake water quality after filling, taking into account the role of the surface waters and the formation of a surface chemolimnion (Juncosa et al. 2007a); 3) A behavior model of pollutant discharges into the Barcés River and possible entry into Cecebre reservoir (Juncosa et al. 2007b y c).
The predictive modeling of the filling of the pit lake is supplemented by the design and development of different sampling campaigns targeting surface water and groundwater, followed by an in-depth analysis of the results and their interpretation. On the basis of the analysis of these data, the researcher applicants have been able to come to a conclusion regarding to the reference quality of the local surface water and groundwater.
The results obtained to date would indicate that the water quality of the prospective pit lake would be good. However, as yet there is no analytical database covering a wide enough range of time that would

guarantee the prognosis based on numerical models. Therefore, it is necessary to start compiling a historical data series sound enough to be able to make appropriate predictions and to be used in model comparison.

Mine waters refer to the outflow from surface or underground mining sites, either working or abandoned. There are no specific European regulations related to mine discharges. Therefore, given their general nature, the community framework for action in the area of water politics is established under Directive 2000/60/EC of the European Parliament and Council on 23 October 2000 (hereinafter WFD) which determined the legal reference framework. In view of the fact that the chemical characteristics observed in some of the waters around the mine pit might suggest that the water quality of the future lake could be endangered owing to the acidity and high metal content, it is fitting to raise the question of whether or not the artificial water body will be able to comply with the strict environmental objectives of the WFD and, more specifically, those laid down in the Hydrologic Management Plan Galicia-Coast, which will be available to the public in December 2008.

No less important are the regulations governing discharges into aquatic media and uses, such as Royal Decree 849/1986, of 11 April through which the Regulation of Hydraulic Public Dominion was passed, Royal Decree 995/2000, of 2 June which establishes the quality objectives for certain pollutant substances and modifies the Regulation of Hydraulic Public Dominion and Royal Decree 927/1988, of 29 July, whereby the Regulation of the Public Administration of Water is passed and the Hydrologic Management Plan which establishes the characteristics that pre-drinking waters are required to have.