Rehabilitation of Meirama Pit Lake

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ABSTRACT
Lignitos de Meirama SA (LIMEISA) has been producing lignite from its opencast operation in La Coruña, North West Spain, since 1980 at around 3.5 Mt/year, and is programmed to close in 2007 , when the reserves are expected to be exhausted.
Waste has been placed on the Inside Dump at the north-western side of the mine, and on the Outside Dump.
The pit is currently 200 meters deep. Coal mining operations at the pit are expected to cease in 2007 at a basal elevation of 25 meters below sea level, at which time dewatering of the pit will stop. From that time onward, a pit lake will be developed and water levels will continue to rise to a design elevation of 183 meters. Once the lake elevation reaches 183 meters, pit water will discharge through an engineered overflow and will be routed into the nearby Rio Barces.
The pit is located in a catchment that serves the water supply needs of the region including La Coruña City. Therefore, an evaluation of closure options for the pit and pit lake must take into account water quality issues. This includes addressing the potential for generation of acid rock drainage (ARD) from sulfide oxidation in the lignite and host rock.
The Technician Project of Closure must include several critical aspects, such as Water Quality, Geochemics, Hydrogeologics, Geotechnics and Environment. Those studies imply the use of powerful mathematical tools.
The study of future uses of this great mining area is also considered.

INTRODUCTION
LIGNITOS DE MEIRAMA S.A. is a company of UNION-FENOSA group, third electric company of Spain, created in 1.974 to develop a brown lignite open pit mine located in the Meirama valley, sited 25 kms away from La Coruña, in Spain NW . The lignite extraction began in 1.980 and all the coal is used to supply a Thermal Power Station that is part of the same proyect, with an installed power of 550 MW.
This proyect of mining exploitation, provided the folowing rates of lignite and spoil :

	RESERVE x 10^6	ANNUAL PRODUCTION x 10^6
LIGNITE, t.	90	3,0
CLAY, m^3	86	3.75
SCHISTS, m^3	35	1.7
GRANITE, m^3	45	2.2

The annual precipitation in this valley is about 1.500 mm/yr. The water is pumped from the bottom of the mine until an intermediate pumping station, and then pumped again to two decantation and regulation pools that feed a purifying plant with a capacity of 1.800 m3/h.

CLOSE TECHNICAL OF MINE PROJECT
Keeping in mind the reservations, the lignite already extracted and the annual production, we foresee the end of the exploitation in 2.007. So, the end of mining works and the technical closing of the mine have already been studied, in accordance with the actual legislation.
This close technical of mine project is managed by the company Golder Associates, and it has like main aspects the next:

PIT LAKE WATER BALANCE STUDY

Objectives
Specific objectives of this evaluation include the following:
- ✓ Estimate the time it will take for the pit to lake to reach its pre-determined design level of 183 m amsl;
- ✓ Determine rates of inflow and outflow to and from the pit for use in the detailed geochemical evaluation of future pit lake water quality including:
    - o Surficial inflow from the 13 sub-basins around the pit
    - o Surficial inflow from the pit walls
    - o Surficial inflow from the dump inside

  - o Direct precipitation to the pit lake
  - o Groundwater inflow through the granite
  - o Groundwater inflow through the schist
  - o Direct evaporation from the pit lake
  - o Overflow from the pit lake
- ✓ Estimate the uncertainty in predictions due to the data and analytical constraints and due to natural variation in the hydrogeologic properties;
- ✓ Incorporate this uncertainty into the model;

A dynamic systems modelling environment was used to develop the water balance model. GoldSim, an object-oriented, dynamic systems modelling environment developed by Golder Associates, allows flexible stochastic input and output, variable timesteps, and discrete random events (e.g. storms or slope failures)

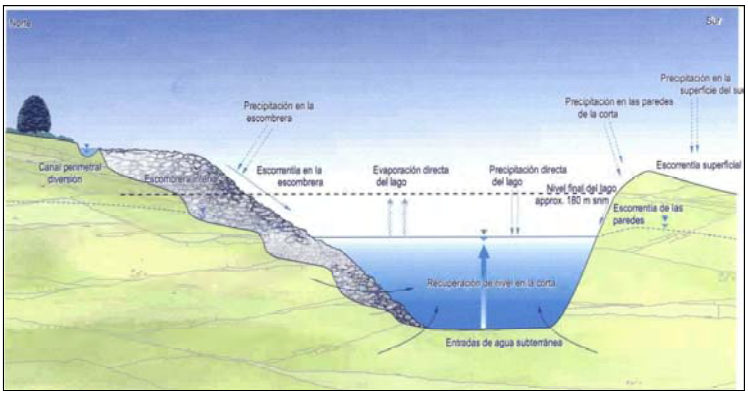
Conceptual model development

The pit lake water level changes due to groundwater inflow, precipitation, evaporation, runoff, and the magnitude of these fluctuations is controlled by the pit stage/area/storage relationships.

Groundwater inflow to the pit occurs via fractures and faults and depends on the water level in the pit; the hydraulic gradient into the pit is at its highest when the water level in the pit is lowest.

Climatic processes include precipitation and evaporation.

The quantity of precipitation that runs across the ground surface into the pit depends predominantly on the soil type in the catchment, vegetation type and quantity, and the antecedent moisture conditions. Runoff is the only portion of precipitation that is directly accounted for in this model.



Pit Lake Storage

A "reservoir" element was used as the central storage term representing the pit in the model. Reservoir elements track the volume of water held in storage through time including inflows and outflows and overflows, as necessary. Inflows to the pit include runoff into the pit, direct precipitation to the pit lake, and groundwater inflow. Pit lake outflow only occurs through evaporation and, if warranted, pit overflow. The model was run with daily time steps.

Precipitation

A rainfall record of sufficient duration to simulate the post closure period was generated using the Hydrologic Evaluation of Landfill Performance (HELP) software. HELP is a model for predicting landfill hydrologic processes. These 20-year records were used in two otherwise identical water balance models. The wet scenario used a rainfall average of 1,829 mm/year and the dry scenario used a rainfall average of 1,251 mm/year.

Evaporation

Pan evaporation rates have not been recorded at the site. However, daily temperature values have been well documented at the site. These data have been used to calculate monthly evapotranspiration (ET) values using the Thornthwaite method

Catchment Runoff

Runoff was estimated analytically using the Soil Conservation Service (SCS) method outlined in SCS (1972) and Maidment (1993). The basis of the method is an empirical curve number based on soil type. The curve number adopted is based upon the hydrologic soil group and cover type (e.g., trees and shrubs). The curve number varies according to the antecedent moisture conditions (sum of rainfall over the previous five days).

Similar estimations to those made for catchment runoff were made for runoff of precipitation that falls on the pit walls, and the Runoff from the inside Inside Dump

Groundwater Inflow

It was necessary to assume that porous-type flow dominates in the damaged rock zone (DRZ) around the pit. While at the small scale, fracture flow will dominate in the crystalline granite and schist, at the pit scale, the aquifer is likely to respond as a porous medium.

Ecological minimum flows

A minimum flow within the Rio Barces must be maintained in order to support the stream ecology. It is essential therefore that a proportion of total catchment runoff is routed to the river and the inflow to the pit from catchment runoff must be reduced accordingly. Monthly values of minimum flow within the Rio Barces were supplied, with a means value of 31,2 %. Several technical aspects advise to fill the lake in the less possible time

Results

The time for the pit water level to recover to the equilibrium level of 183 m amsl is summarised in next Table

YEARS	Minimum	Median	Maximum
Base Case			
Wet Conditions	**3,8**	**5,0**	**7,9**
Dry Conditions	**4,8**	**6,4**	**9,4**

The total inflow under dry conditions is 1.75 × 10^8 m^3 and the total inflow under wet conditions is 1.70 × 10^8 m^3. Greater total inflow values during dry conditions are due to the increased period until recovery and therefore an increased accumulated outflow through pit lake evaporation.

Following the recovery of the pit lake the median annual overflow value ranges between 2.07 × 10^7 and 2.13 × 10^7 m^3 under dry conditions and 2.50 × 10^7 and 3.07 × 10^7 m^3 under wet conditions.

PIT LAKE WATER QUALITY STUDY

The pit lake water quality modeling is aimed at predicting pit lake water quality for the LIMEISA open pit after cessation of mining. A pit water balance and results from a groundwater and surface water characterization program were combined to simulate the evolution of pit lake water quality over time

The majority of pit lake inputs used in this model were derived directly from the water balance study. The various inputs are presented in the following table.

PIT LAKE INPUTS		PIT LAKE OUTPUTS
Granite Groundwater	Clean	Evaporation
	Impacted	
Schist Groundwater	Clean	Overflow
	Impacted	
Catchment Runoff		
Pit Wall Runoff		
Dump Runoff and Seepage		
Precipitation		

Pit inputs were mixed in the appropriate proportions, and the chemical interactions between the various constituents were evaluated using a geochemical model, PHREEQC, developed by the U.S. Geological Survey

The modeling results for the average-case, worst-case, and best-case simulations show that the simulated pH of the pit lake varies over two orders of magnitude (i.e. from acidic to neutral). Not surprisingly, predicted trace metal concentrations can have significant ranges as well, as their behavior tends to be largely controlled by pH.

A comparison was conducted with Spanish water quality guidelines

One important consideration that was included in the sensitivity analyses is the assumption that the entire pit lake is in equilibrium with atmospheric carbon dioxide and oxygen. If atmospheric equilibrium is assumed, the pH of the pit lake rises and trace metal concentrations are reduced, although some remain above water quality criteria. However, due to the rapid filling of the pit, it is not clear if such equilibrium will indeed be achieved.

Another consideration is the potential for stratification of the pit lake. Based on a simple, one-dimensional limnological evaluation, it was determined that there is indeed a potential for pit lake stratification. If this were to be the case, atmospheric equilibrium might not be achievable for the deeper water layers. However, if the lake were permanently stratified, only the water in the upper strata would be discharged.

Parámetros	Unidad	Caso medio	Caso peor	Caso mejor	Limite de detección[a]	Parámetros de calidad del agua de vertido
pH	s.u.	6,2	4,2	7,1	-	5.5 to 9.5
Redox	mV	547	620	513	-	-
Alcalinidad	mg/L ($CaCO_3$)	2	0	5	-	-
Cloruros	mg/L	48	33	36	-	2000,0
Sulfatos	mg/L	31	98	17	-	2000,0
Calcio	mg/L	15	19	10	-	-
Magnesio	mg/L	6,2	5,0	4,4	-	-
Potasio	mg/L	2,0	26	1,8	-	-
Sodio	mg/L	17	14	14	-	-
Nitratos	mg/L	2,4	0,28	2,8	0,05	-
Aluminio	mg/L	0,020	1,25	0,048	1	1
Arsénico	mg/L	<0.001	0,001	< 0.001	0,004	0,5
Bario	mg/L	0,05	0,02	0,08	1	20,0
Boro	mg/L	0,97	0,97	0,97	1	2,0
Cadmio	mg/L	0,05	0,05	0,05	0,05	0,1
Cromo	mg/L	0,19	0,19	0,19	0,2	2,0
Cobalto	mg/L	0,11	0,12	0,11	0,1	-
Cobre	mg/L	0,07	0,10	0,09	0,1	0,2
Hierro	mg/L	0,01	2,6	< 0.01	0,1	2,0
Plomo	mg/L	0,15	0,17	0,17	0,2	0,2
Manganeso	mg/L	0,38	1,0	0,12	0,05	2,0
Mercurio	mg/L	0,004	0,004	0,004	0,004	0,05
Níkel	mg/L	0,17	0,15	0,21	0,1	2
Uranio	mg/L	0,0002	0,0007	0,0003	-	-
Zinc	mg/L	0,09	0,17	0,06	0,025	3,0

This water might be capable of establishing equilibrium with the atmosphere, and could therefore be of relatively good quality. Furthermore, the pit lake inputs in later years are almost exclusively catchment runoff and direct precipitation, which represent the inputs with the best quality water. It is therefore considered that the range between average-case and best-case simulations is the most likely to occur in discharge from the pit lake.

Entire Volume 150 Hm3
Surface water............................. 72.96 %
Underground water.....................21.28 %
Direct Rain ....5.75 %

Annual Discharge 25/30 Hm3

HYDROGEOLOGIC EVALUATION

Specific objectives of this evaluation included:

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- Characterize the current groundwater surface in the pit walls (or zero pressure line) and estimate current groundwater inflows to the pit.
- Predict time-varying groundwater surfaces and potential dewatering rates and subsequent pit inflows during the active mining period.
- Predict the response of groundwater surfaces to pit filling and pit wall dewatering under various closure scenarios.

Longitudinal Model

- Quantify the seepage rate out of the pit during the pit filling period.
- Characterize the groundwater flow regime in the vicinity of the inside dump during various pit filling scenarios.

Approach

The approach for the hydrogeologic evaluation was driven by the data requirements for the geotechnical and geochemical evaluations. The geotechnical evaluation required a detailed estimate of water levels in the pit through time. Pit water levels used as boundary conditions in detailed numerical flow modeling were relied on to predict the water levels and pore pressures in and adjacent to the pit walls. The geochemical evaluation required

a breakdown of all flows into and out of the pit. Each flow type was assigned unique water chemistry and then was used in conjunction with chemical equilibrium and mixing models to predict the water quality in the pit through time.
A conceptual model was developed for the evaluation from available information regarding the regional geology and hydrogeology of the site. The information included site meteorological data, site borehole and dewatering well data, dewatering well and pit pumping records, hydraulic testing data, and other available data pertinent to the evaluation. These data were evaluated and a conceptual model of the groundwater flow system was developed and refined during the course of the evaluation. The conceptual model was used as the basis for the numerical cross-sectional modeling effort. Uncertainties with data inputs were evaluated during model calibration. Numerical modeling was required for the analysis to adequately address the complexities in the hydrogeologic system, the interdependence of various processes, and the transient nature of the system.

Model Code Requirements and Selection
The model code FEFLOW (WASY, 1999), a three-dimensional finite-element model code was used for the modeling efforts. The FEFLOW model has been specifically designed to meet the advanced technology requirements involved in complex groundwater modeling projects

Model interpretation
Profile 19
The simulations show that additional dewatering wells pumping for a period of one year would reduce the total pit groundwater inflow from the current rate 1.21×10^5 m^3/month (1.45×10^6 m^3/year) to 1.10×10^5 m^3/month (1.32×10^6 m^3/year). As the pit is deepened, the hydraulic gradient correspondingly increases and the pit inflow increases slightly in response to the pit elevation changes.
The simulations show that during pit filling, the groundwater elevations in the vicinity of dewatering wells are comparatively lower than the water elevation of the pit even without active dewatering. The water-filling rate in the pit is comparatively faster than the rise of the groundwater table in the surrounding rock mass. In other words, groundwater recharge from precipitation is not significant compared to the outflow to the rock mass due to the reverse gradient caused by pit filling. Therefore, dewatering may be of limited effectiveness during the pit-filling period.
Longitudinal Model
In the northwestern area of the longitudinal model, the simulations show that the groundwater table was near the bottom of the inside dump. Though the inside dump is not fully saturated, the dump contributes more pit inflows than the underlying granitic rock. Nearly 80% of pit inflow from granite side passes through the dump. In other words, the inside dump receives more recharge from precipitation than the granite rock, and this recharge eventually reports to pit inflows.

PIT STABILITY
To assure the pit stability we carried out several actions:
- ✓ To continue the outlying pumping, until the filled of the lake. The height of pumping will be similar to the level of lake water.
- ✓ To place a buttress in the inferior part of the banks. Some approximate dimensions can be of 40 m. of height and 100 of width.

The increase of the level of the water in the the lake will make increase the security rates according to the following table:

	Without buttress	*With buttress*
FINAL WITHOUT WATER	0,9	1,1
FINAL WITH 70 m. WATER	1,16	1,24
FINAL WITH 100 m. WATER	1,22	1,31
FINAL WITH 150 m. WATER	1,36	+ 1,45

Future uses
The study of future uses of the mining surface, after the end of the exploitation, is an important one I surrender of this technical project of closing
These possible uses can be:
- ✓ Industry.
- ✓ Agricultural, Forest and Cattlemen
- ✓ Cynegetic
- ✓ Landscape
- ✓ Recreational
- ✓ Residential