Developing a Hydrogeological Model for Aruwakkalu Limestone Mine, Puttalam

Dayarathna EAC, Pethum LLDI, Sunanda DJ,
Wedisinghe WMCC, *Dassanayake ABN and Wickrama MADMG
Department of Earth Resources Engineering, University of Moratuwa
Corresponding author - anjula.nayomi@gmail.com

Abstract: A hydrogeological model has been developed for the Aruwakkalu limestone mine to study the behaviour of groundwater flow, associate with specific problems within the mine, in this research. Groundwater flow model was constructed using Visual MODFLOW 3D Finite difference method. Five distinct types of material layers were identified for material property designation in the study area of the mine by using the borehole data report, which was completed in year 2008. The mine is mainly bounded by two water bodies; Puttalam lagoon and Kala Oya. Existing hydrogeology related data and the results of several field tests were used to develop the groundwater model initially with a conceptual model. Utilizing hydrogeological data gained from field works; specially the aquifer parameters gained from pumping tests, the model was developed and calibrated for steady state conditions. According to the model simulation, groundwater flow is mainly towards the west direction and it simulates sea water intrusions in some locations. Dewatering feasibility and cost associated with groundwater movement of the mine can be evaluated using the developed model by conducting predictive simulations.

Keywords: Aruwakkalu, limestone, Open cast mine, Theim-Dupuit's method, Visual MODFLOW

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1. Introduction

In Sri Lanka, limestone mining is mainly done for cement production and the main mine situated in Aruwakkalu is operated as an open cast mine to extract the sedimentary limestone deposit in North west coastal region of Sri Lanka.

Groundwater is one of the critical factors in limestone mining and upmost attention is needed to manage groundwater influence to effective and efficient mining. Due to the enormous demand on cement, most companies try to extract limestone below the groundwater table. This is a critical factor faced by mine personnel, because groundwater cause many operational problems; huge dewatering cost, ground subsidence, difficulties of explosive and equipment handlings, and transporting. Hence it is a must to manage the groundwater resources within the mine area.

The best tool for understanding the groundwater system within the mine area and its behavior and for predicting the responses is the hydrogeological model of the mine. Aruwakkalu (Figure 1) is the largest open cast limestone mine, administered by Holcim Lanka Ltd,

ABN Dassanayake, B Sc.Eng. (Hons) (Moratuwa), M Eng. (AIT), lecturer, Department of Earth Resources Engineering, University of Moratuwa
MADMG Wickrama, B.Sc.Eng. (Hons) (Moratuwa), lecturer, Department of Earth Resources Engineering, University of Moratuwa
EAC Dayarathna, LLDI Pethum, DJ Sunanda, WMCC Wedisinghe, Final year Undergraduate students in the Department of Earth Resources Engineering, University of Moratuwa

situated in Puttalam district, Sri lanka. It is extended more than 17 km^2.

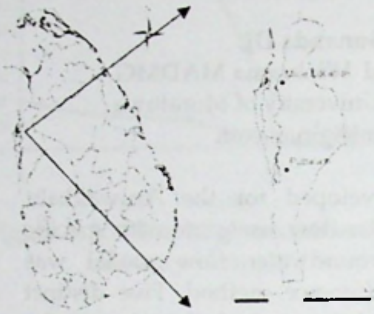

Figure 1- Site location of Aruwakkalu open pit limestone mine

1.1 Statement of the Problem

According to the current situation groundwater has become a momentous operating factor in the mine, due to groundwater seepage into the operational area. Furthermore, the company is expecting to excavate the virgin deposit below Mean Sea Level (MSL). But, at present, they do not have accurate and detailed groundwater data to implement their operational plan. Hence, exploring ground water flow pattern, water table and their sources are essential prior to the excavations. This research is mainly focused on those issues.

2. Methodology

2.1 Conceptual Model

Conceptual model is a pictorial representation of the groundwater flow (Figure 2) system from which the realistic model was developed. The conceptual model included the boundary conditions of the study area, general aquifer parameters and ground (Table 1) and water level elevations.

Table 1 – Material Type

Layer	Material type	Thickness(m)
1	Red earth	17-20
2	Sandy limestone	3-5
3	Whitish limestone	21
4	clayey limestone	20
5	Clay	1

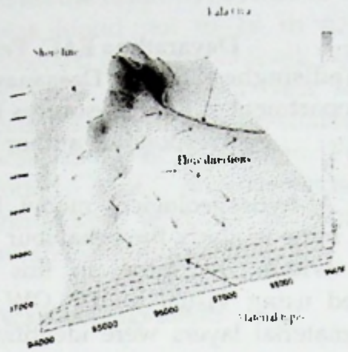

Figure 2- Conceptual Model

2.2 Obtaining Aquifer Parameters

Aquifer parameters (Hydraulic conductivity (K) of different material types were determined by performing pumping tests. Four pump arrays were sunk in the deposit namely CD23, CD31, CD42, and CD49 (Table 3). Each array consisted by a pumping well and 3 observation wells for monitoring the drawdown. Step drawdown tests were used to find the aquifer parameters. During all stages, the water levels at pump well and 3 observation wells were measured at standard time intervals. Electric conductivity was measured simultaneously from selected locations. Aquifers were assumed as Homogenous, Anisotropic and unconfined, and all the water levels were recorded after reaching steady state flow condition. Theim-Dupuit's method (Equation 1) was used to evaluate aquifer parameters (Figure 3).

$$K = \frac{q \ln\frac{r_2}{r_1}}{\pi (h_2^2 - h_1^2)} \quad \text{(David.K.T, 2004)......... (1)}$$

Where; pumping rate-q (m^3/s), distance to observation wells from pump well -r_1, r_2 (m), water levels in observation wells-h_1, h_2 (m), pump well radius- r_w (m)

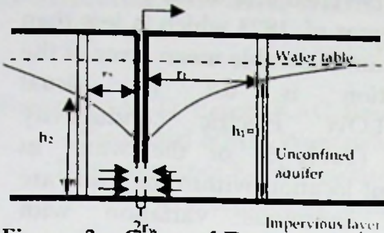

Figure 3 – Cone of Depression

2.3 Model Domain and Grid Design

Using existing borehole data of virgin deposit, 5 distinct layers were identified. Hence the model was designed using Visual MODFLOW 2.7.2 to 5 material types. A cell of the domain represents 50m×50m of actual terrain and which covers 6.55 km * 4.85 km of the terrain. Maximum height of the terrain and maximum depth were assigned as 70m MSL and -40m MSL respectively.

2.4 Hydrogeological Parameters and Boundary Conditions

Hydraulic conductivity (K-x,y,z directions) and Storage coefficient (S_s) values (Table 2) for each material type were assigned by using pumping test data and literature values (Groundwater hydrogeology, 2004). Constant head boundary of zero meters from MSL was assigned to the shore line while a river boundary was assign to Kala Oya.

Table 2- Aquifer parameter values

layer	Hydraulic conductivity			Storage coefficent
	K_X	K_Y	K_Z	
1	23	23	12	$1*10^{-4}$
2	21.5	21.5	8.2	$9*10^{-5}$
3	21	21	8	$8*10^{-5}$
4	20	20	6	$7*10^{-5}$
5	1	1	0.2	$7*10^{-5}$

2.5 Groundwater recharge

Groundwater recharge was assigned from one source; the rainfall recharge that has been infiltrated in to the ground. Recharge was simulated in the model and it was assumed that it infiltrates to the whole mine.

Average annual rainfall: 107.4cm/year
Percentage of infiltration : 15%
Average annual recharge : 16.11cm

2.6 Model Calibration

During the calibration time the aim was to match the actual and modelled groundwater head distributions. Model calibration was performed for steady state condition (assuming non pumping condition) using available water levels within the study area and was achieved through trial and error approach until the calculated potentiometric head values matched the observed values to a satisfactory level at the end of the simulation.

3. Results

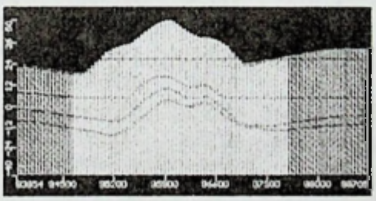

Figure 4 - Cross section along row 53

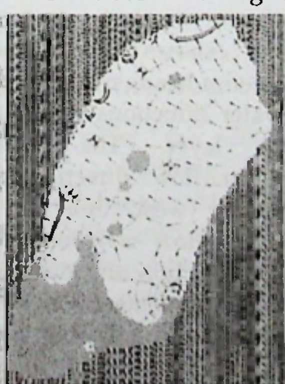

Figure 5- steady state calibrated potentiometric head distributions

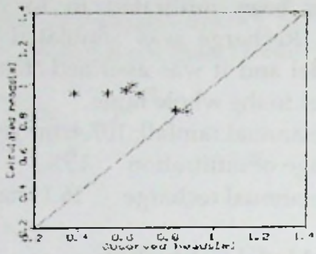

Figure 6- Steady State calibration - calculated Vs observed head values

Statistical values of model

Mean error = 0.1823

Mean absolute error = 0.1922

RMS error = 0.1991

Table 3 - Electric conductivity of the water in different locations

Name	E	N	EC μs/ scm
CD 23	94904	339985	12900
CD 29	96442	340451	7990
CD 31	95263	340907	17450
CD 42	96006	342093	27430
CD 49	97255	342804	19840
1	97174	342961	9240
2	94791	339022	11780
3	94952	339024	12660
lagoon	93861	337572	57400
Tube well	95372	337666	2538
Gage wadiya	97258	342961	23520
DW	Bottled drinking water		199.5

4. Discussion

Figure 5 shows the modelled potentiometric heads distribution and groundwater directions in the clayey limestone layer. The simulated groundwater flow direction mainly towards the west, but in some locations the flow is from centre to south east direction and due to these groundwater movements the river can be identified as loosing stream. Southern area in the model is indicated as dry as there are no groundwater movements and existences in this layer. The scatter graph (Figure 6) shows that the observed and calculated head are not highly deviated and to the presence of mean error of .1823 which is less than maximum allowable mean error of the calibration is 0.2 in Visual MODFLOW. Electric conductivity values (Table 3) of the water in different location within the mine are shows enormous variation with bottled drinking water.

5. Conclusion

The calibrated groundwater model for steady state condition has comparative accuracy since it shows lower mean error and to attain a higher accuracy, further hydrogeology related data; such as boundary values and water head observations should be collected to attain better accuracy.

Electric conductivity measurements and the model show that, salt water intrusion is significant in mine area.

By doing groundwater simulations using calibrated model, feasibility of dewatering and cost associate with it can be predicted.

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