# Modelling of Coal Pit Lake Quantity and Quality for Mine Closure (Case Study ON2 Area, Lati Mine Operation, Berau Coal)

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## Abstract

Coal mining in Indonesia can cause long-term environmental impacts including acid mine drainage, which can lead to the formation of acidic pit lakes after mine closure. This study developed a model to predict pit lake quality and quantity based on acid mine drainage management plans, using PhreeqC software and considering land cover changes and mine water treatment. Results showed that managing acid mine drainage with revegetation and treatment could improve water quality and quantity, yet to comply with regulation needs a longer duration. The simple modelling process showed applicability and acted as a key role in predicting the water quality and quantity of pit lakes based on selected acid mine drainage management plans.

**Keywords:** Pit Lakes, Acid Mine Drainage, Mine Closure, Hydrochemistry, PhreeqC

## Introduction

Coal is one of the primary energy commodities in Indonesia, which is mainly mined in surface mining using the open pit method. Open-pit coal method exposes rock layers and potentially poses serious environmental impacts by alteration of the physical, chemical, and biological properties of rock layers including soils. The problems are fundamentally interrelated, requiring strategic reclamation management to produce good post-mining land (Feng *et al.*, 2019). On the other hand, the hydrological system changes in terms of water flow paths, quality and quantity of surface runoff will disrupt the overall land ecosystem condition.

Hydrological impact in the form of changing water quality and quantity are imminent in the mining operation stage by the alteration of catchment areas, yet the impact could be extended into post-mining stages as pit lakes formed and exacerbated by the emergence of acid mine drainage (AMD) (Asdak, 2010; Chow, 1988; Setyowati, 2011). These impacts, if not managed properly, could pose negative impacts towards the environment and become a burden for stakeholders. To meet the post-mining success criteria, corrective measurements and mitigation need to be taken, including the reclamation of disturbed areas and the implementation of active and passive treatment to improve water quality. This is to meet the needs of reclamation and post-mining which need to pay attention to fundamental things such as physical stability, chemistry, socio-economic level, land requirements, biodiversity, and culminating in further development. According to the regulation, mine water resulting from the coal mine is expected to meet the following standards: pH 6 – 9; Fe<7 mg/L; Mn<4 mg/L; and TSS/total suspended solid<300 mg/L.

Research related to the formation of pit lakes from the perspective of water quality and quantity in tropical areas/ Indonesia is still scarce and mostly to identify the source of problems and corrective means (Tuheteru, 2021). This research aims to develop a simple yet applicable model of pit lake quality and quantity prediction for the mine closure area, to comply with the regulation of effluent standards from coal mines. In addition, sensitivity analysis was carried out by considering land cover changes and various options for mine water treatments. The modelling is done by mixing surface runoff water quality in the catchment area before and after land cover changes and improvement and passive treatment implementation in selected locations based on previous research using the software PhreeqC.

## Methods

### *Study area*

Lati Mine Operation (LMO) mining area has been in production since 1992 and is located in the northeast mine permit area of Berau Coal. There are two main rivers, namely the Lati River to the east and the Ukud River to the west which flows into the Segah River. Geologically, the Lati site is dominated by sandstone, siltstone, and mudstone with a geological structure of syncline extended North-South of the LMO area.

As shown ON2 post-mining area is located in the northern part of LMO (Fig. 1). In 2022, the ON2 area (based on catchment delineation) covers a total area of 1,316.34 ha divided into naturally vegetated areas (21.72%), revegetation area (35.19%), ex-mining pit (7.50%), and open land/active areas (35.53%). There are three identified mine pits (voids), i.e. Southern ON2, void Northern ON2, and void Eastern ON2. Hydrological tree/water balances of these voids (Fig. 1) denotes that all surface water in this area will be directed to WMP-27 before it reaches the final natural streams (Lati River)

### *Mine water management plan*

The mine water management plan that will be applied to the ON2 post-mining area is described as follow:

1. The ON2 ex-mining pit consists of Southern, Northern, and Eastern ON2. All of the ex-mining pits will be developed into pit lakes.
2. The outlets of the post-mining lakes of Southern ON2 and East Northern ON2 are connected to Northern ON2. The outlet of pit lake Northern ON2 is connected to Sediment Pond WMP 27 before finally being discharged into Lati River.

The management plan is made to centralise the water management plan thus controlling the water quality and quantity into a single

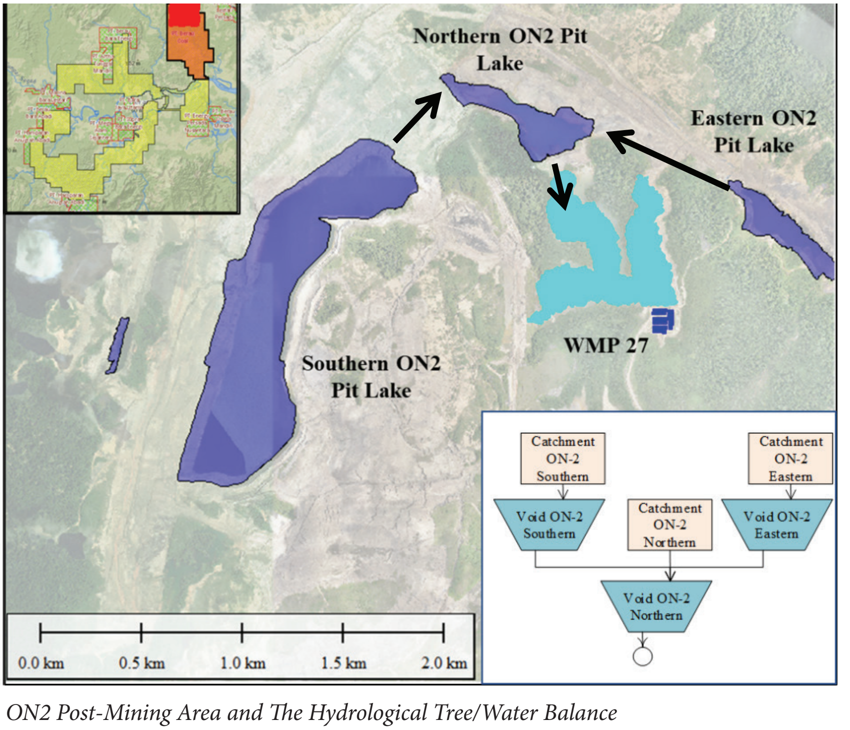


*Figure 1 ON2 Post-Mining Area and The Hydrological Tree/Water Balance*

outlet point of surface runoff water for the ON2 post-mining area.

To prepare for post-mining conditions in ON2, a model was developed for the revegetation and infrastructure of acid mine drainage. The areas to be revegetated or treated were identified using a 50 ha/year revegetation rate and a 100 ha/year infrastructure construction rate. Open limestone channel infrastructure was modelled based on previous research with adjustments made for ON2's conditions and installed on disturbed areas. Overall land changes will affect the quality and quantity of surface runoff flows into each void.

### *Water Quality and Quantity Modelling*

This study is using water quantity model from land changes using rational equation which differs each year and is assumed to change (Paramananda, et.al., 2022). On the other hand, the calculated water quantity is used as input for mixing processes which determines the ratio of mixing among each water yielded from different land cover/catchments area. The simple modelling process is explained below (Fig. 2).

The model initializes initial void water quality and quantity at t=0. For each increment of time (in this study, the selected time increment is a year), the water quality and quantity of each void will be updated using a mixing process in PhreeqC based on water quality and quantity for each land cover/catchment area, i.e., revegetated area, the disturbed area treated passively using OLC/open limestone channel and direct rainfall into the voids. The process is repeated until $t_n$=13 or thirteen years from now since the mining will cease in thirteen years. The model is neglecting another hydrological aspect (e.g., no groundwater fluxes, undetermined evaporation process since all other processes have been assumed by selected runoff coefficient) and using simple geochemical processes (instead of other complex models) therefore the model is a simple modelling process. This model is used as a preliminary overview and is expected to be used for a more comprehensive study in terms of predicting the quality and quantity of pit lakes.

## Result and Discussion

### *Water Quantity and Hydrological Characteristics*

The quantity of the runoff for each type of land cover is governed mainly by rainfall depth and coefficient of runoff. For the simplification of the model and accounting variability of rainfall, three different yearly rainfall amounts are used, i.e. 1st quartile of 1,690 mm/year, 3rd quartile of 3,647 mm/year, and a yearly average rainfall of 2,831 mm/year. The annual volume of surface

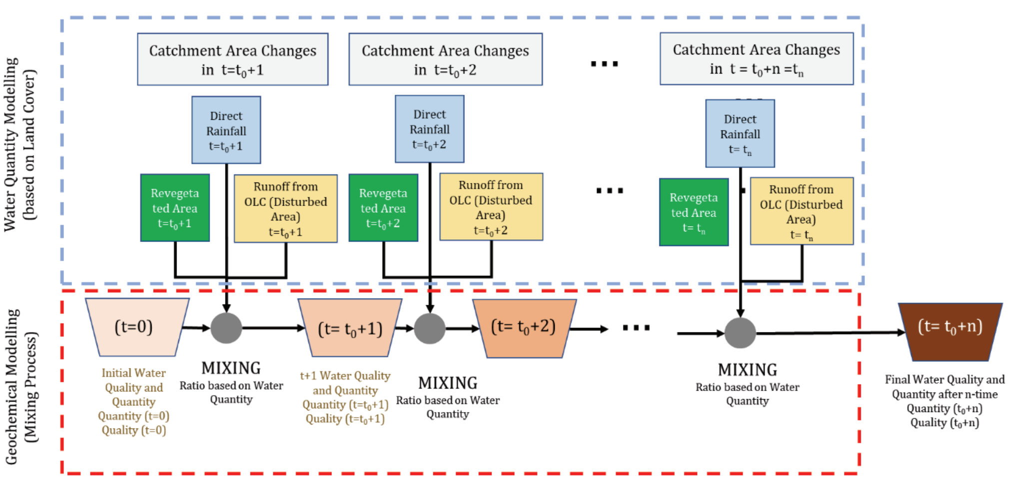


*Figure 2 Description of Mine Water Quality and Quality Modelling*

runoff is calculated using a rational equation (Gautama, 2019; Guo, 2001):

$$V=n.C.P.A$$

*n* is the unit conversion coefficient; *C* is the runoff coefficient; *P* is the yearly rainfall (L); *A* is the land cover area ($L^2$). The calculated volume is then to be used as a mixing ratio for geochemical modelling using PhreeqC as explained above-mentioned.

### *Water Quality Characteristics as Input*

The water quality of mine voids is determined by point sampling for each void. Full-suite water quality measurements are carried out in the field (pH, TDS, temperature, EC, ORP) as well as in the laboratory (anions, cations, alkalinity using ICP-MS, Ion Chromatography, AAS and titration. Selected water quality parameters are shown in Table 1.

Based on the physical properties test, the lowest pH was found in the Eastern ON2 post-mining lake with a pH of 2.86. Iron and manganese will be of concern according to applicable regulations. Based on the metal test results presented in Table 1, show a tendency for high Fe values to exceed the quality standard limit of 7 mg/l in all pit lake samples. Meanwhile, Mn is ranging from 2.06 – 6.49 mg/L. All of these data are used as initial conditions (t=0) for void/pit lake water quality.

As described previously, changes in land cover translate into different surface water quality and quality. The following water quality is assumed for the geochemical modelling/ mixing process as presented in Table 2. Water quality data other than assumed water quality from OLC are primary data.

All of these data are used as input alongside water quantity in the mixing process using PhreeqC.

### *Modelling results*

Table 3 presents changes in water quality parameters for post-mining lakes due to modelling the 13 years mixing of surface runoff water quality and post-mining lakes by PhreeqC with improvements in revegetation based on forementioned assumptions and acid mine drainage management.

***Table 1*** *Voids Water Quality*

| Parameter | Unit | Eastern ON2 | Southern ON2 | Northern ON2 |
|---|---|---|---|---|
| pH | | 2.86 | 3.03 | 3.00 |
| Al | mg/L | 4.13 | 8.40 | 3.58 |
| Fe | mg/L | 13.95 | 12.23 | 8.56 |
| Mn | mg/L | 3.28 | 2.06 | 6.49 |
| $SO_4^{2-}$ | mg/L | 357.00 | 387.00 | 380.00 |
| Alkalinity as $CaCO_3$ | mg/L | 0.00 | 0.00 | 0.00 |
| Si as $SiO_2$ | mg/L | 1.73 | 3.88 | 4.89 |

***Table 2*** *Other Water Quality Assumed in This Study (Swastika 2013)*

| Parameter | Unit | Revegetated Area | Outlet from OLC | Rainfall |
|---|---|---|---|---|
| pH | | 4.45 | 7.06 | 6.28 |
| Al | mg/L | 1.10 | 0.02 | 0.01 |
| Fe | mg/L | 1.18 | 0.86 | 0.01 |
| Mn | mg/L | 0.49 | 1.01 | 0.01 |
| $SO_4^{2-}$ | mg/L | 88 | 220.00 | 2.10 |
| Alkalinity as $CaCO_3$ | mg/L | 102 | 1.44 | 8.80 |
| Si as $SiO_2$ | mg/L | 0.01 | 9.70 | 0.23 |

*Table 3 Pit Lakes Water Quality Modelling Result*

| Parameter | Unit | Eastern ON2 | | | Southern ON2 | | | Northern ON2 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1st Quartile | Mean | 3rd Quartile | 1st Quartile | Mean | 3rd Quartile | 1st Quartile | Mean | 3rd Quartile |
| pH | | 5.44 | 5.55 | 5.65 | 3.50 | 3.71 | 3.93 | 4.21 | 4.65 | 5.09 |
| Al | mg/L | 0.49 | 0.37 | 0.24 | 1.19 | 0.74 | 0.30 | 0.81 | 0.61 | 0.40 |
| Fe | mg/L | 2.87 | 2.42 | 1.97 | 2.83 | 2.08 | 1.32 | 2.20 | 1.96 | 1.71 |
| Mn | mg/L | 0.57 | 0.58 | 0.58 | 0.82 | 0.83 | 0.85 | 0.73 | 0.72 | 0.71 |
| $SO_4^{2-}$ | mg/L | 61.55 | 62.18 | 62.82 | 243.65 | 250.85 | 258.05 | 163.87 | 152.40 | 140.93 |
| Alkalinity as $CaCO_3$ | mg/L | 205.30 | 212.30 | 219.30 | 0.01 | 0.01 | 0.01 | 99.47 | 117.14 | 134.80 |
| Si as $SiO_2$ | mg/L | 0.70 | 0.71 | 0.73 | 0.37 | 0.54 | 0.71 | 0.37 | 0.40 | 0.43 |

The mixing analysis of surface runoff water and the post-mining lake water was performed annually based on the variations in the surface runoff coefficient and pH. The changes in the volume and pH of surface runoff water that will flow into the post-mining lake under three different annual rainfall conditions are illustrated below (fig. 3), (fig. 4), (fig. 5).

Water quality for Southern ON2 is expected to reach a pH value between 3.50 – 3.93. Water quality for eastern ON2 and Northern ON2 is expected to reach pH values between 5.44 – 5.65 and 4.23 – 5.09, respectively. The differences are due to the larger volume of water in void Southern ON2 related to runoff water produced by its catchment area which produces a slower

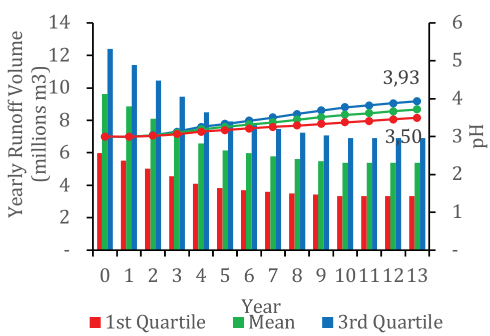


*Figure 3 Changes in Runoff Volume and pH of Southern ON2*

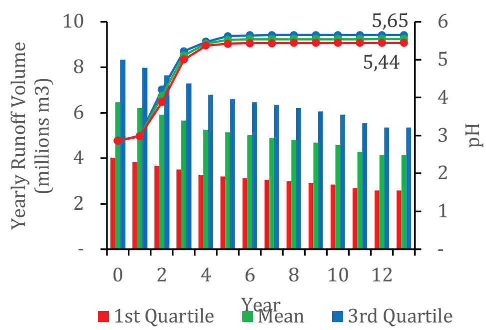


*Figure 4 Changes in Runoff Volume and pH of Eastern ON2*

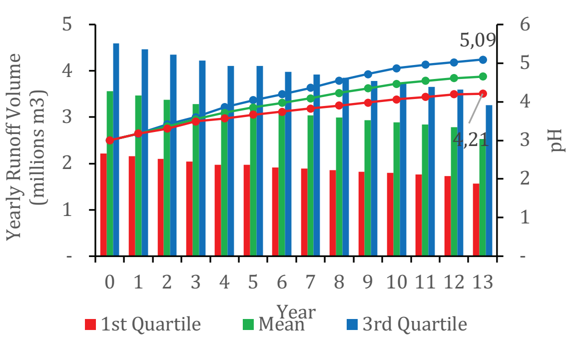


*Figure 5 Changes in Runoff Volume and pH of Northern ON2*

enhancement of pH value. Notably, the volume ratio of void water of ON2 Eastern to the volume of runoffs produced by its catchment area is lower and therefore elevating the pH condition of void water.

The improvement of the quality of surface water is deemed inadequate in achieving environmental quality standards since all voids are predicted to have pH values less than 6. It is expected to take a considerable amount of time to achieve the desired conditions. Consequently, it is essential to establish an infrastructure to manage final acid mine water as a means of maintaining the quality of water that flows into the Lati River. In addition, the implementation of in situ treatment methods within the pit lake offers the company an opportunity to enhance water quality, resulting in a more favorable outlet. This approach disregards cost considerations, emphasizing the importance of achieving optimal water quality conditions.

## Conclusions

Revegetation and integrated treatment infrastructure implementation in the upstream area can effectively manage acid mine drainage and enhance the water quality of post-mining systems. The same outcome is achieved by passive treatment installations such as open limestone channels. Improvement of the quality of surface runoff water in critical rain catchment areas yields a maximum increase of 2.1 points of pH value in the post-mining area. Nevertheless, the pH value achieved in year 13 is still inadequate in achieving environmental quality standards since all voids are predicted to have pH values less than 6. It may take a longer period and the water quality and quantity management options are imperative to achieve the regulated effluent standards

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