Evaluation of Discharge Calculation in Open Pit Mining

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Abstract

This study presents the discharge calculation of open pit mining drainage system in open pit mine at PT Maruwai Coal, in Central Kalimantan. Several calculation methods are compared, including FJ Mock, HEC-HMS, and 2D HEC-RAS simulation. The open pit mine drainage system consists of sump storage with volume of 12.574 m^3 and discharged using 0,22 m^3/s pump. The loss method for HEC-HMS and HEC-RAS is modelled using Curve Number (CN) approach. CN value choice need to consider steep slope condition at the site. Storage elevation and pump operation at 10 rainfall event is observed and used as model validation. The calculation shows each method is capable to model the event reasonably well. The average run-off coefficient varies from 0.72 for FJ Mock and 0.63 for HEC-HMS. However, FJ Mock method gives daily average value and may underestimate the run-off discharge. Indeed, HEC-HMS and HEC-RAS model is more suitable for flood modelling because of unsteady nature of the flow.

Keywords

FJ Mock, HEC HMS, HEC RAS, Open pit mining, runoff

INTRODUCTION

PT Maruwai Coal is one of the subsidiaries of PT Adaro Energy that works in coal mining. The mining site for this research is located at Murung Raya Regency, Central Kalimantan Province. The coal mine uses the open pit mining method as shown in Figure 1. Open pit mining is heavily influenced by climate related to temperature, air pressure, and the hydrological cycle, which affects mining productivity [1]. Indeed, the site drainage system is crucial to ensure mining productivity. The Lampunut Open Pit Mine in Maruwai Coal consists of sump storage with volume of 12,574 m^3 and discharged using 0.22 m^3/s pump. It mostly used to drain the surface run-off generated by rainfall event on the site. The drainage system is designed based on rational method, which is found to over-estimate the discharge. Indeed, the rainfall loses in rational method is based on run-off coefficient (C) which usually chosen based on experience without calibration data. Therefore, another method with less uncertainty is important for drainage system designing purpose.

The open pit mine drainage analysis usually performed manually and tend to be tedious and time consuming [2]. Indeed, several alternatives method of calculating drainage is reported in previous studies. GIS applications to evaluate drainage process has been applied in Pasir open pit coal mine, in South Kalimantan [2]. However, it only considers flow accumulation to predict pump capacity in ponded area. No loss calculation is considered in the analysis. Numerical model is one of interesting options, which can give more detailed results. Previous example in analysing dewatering of open pit mine is done by using MODFLOW model [3]. The model is successfully model the inflow into open pit mine. However, this method is suitable for ground water modelling which is not the case in Lampunut open mine. Another case uses MELEF model in flooding problem in open pit mine at Barces River, La Coruna, Spain. The MELEF model considers the joint surface and ground water regional flows and already consider evapotranspiration for considering water losses. The model is calibrated using three years observations data and perform well [4].

The FJ Mock method is usually used to calculate monthly water balance for reservoir [5]. It considers several processes to account for water losses, such as: infiltration, evaporation, and soil moisture. Therefore, the losses prediction is considered more accurate than rational method. Indeed, its performance for daily discharge needs to be evaluated. Another popular method is given by Curve Number (CN) of USDA [6], [7]. The Curve Number, compared with run-off coefficient considers the hydrologic soil types and land slope other than the land cover.

In this paper, three methods will be used to calculate the surface runoff in Lampunut open pit mine. The first method is the FJ Mock method which will be used to calculate daily discharge based on conditions in the study area. Evaluation of Curve Number loss will be carried out using HEC-HMS model and 2D HEC-RAS model. The simulation will be validated using 10 rainfall event observation.

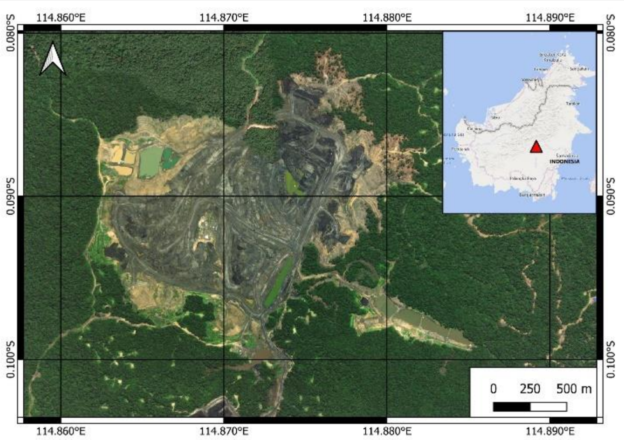

Figure 1 Lampunut Opet Pit Mine Site Location

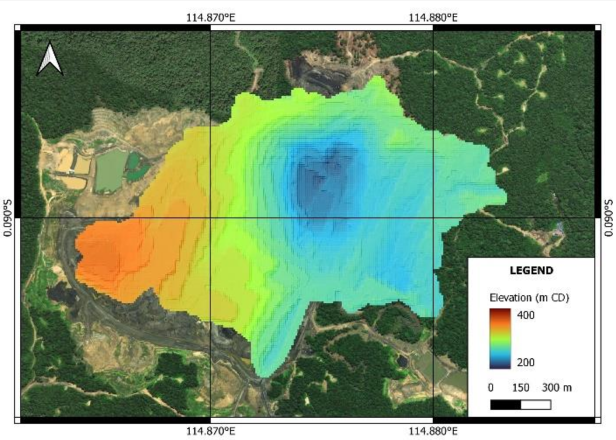

Figure 2 Lampunut Open Pit Mine DEM and Catchment Area

RESEARCH SIGNIFICANCE

This study aims to evaluate three methods in predicting surface run-off in open pit mines. The prediction of each method will be compared with observations to determine which method is suitable for open pit mine drainage system design.

METHODOLOGY

A. SITE OBSERVATIONS DATA

The site observations data consist of 10 daily rainfall events recorded on the Lampunut Open Pit from 2014 to 2018. The rainfall is recorded using automatic rain gauge. The sump storage elevation records and pump discharge are used to calculate the surface run-off volume from the events. The sump storage volume is obtained based on Digital Elevation Model (DEM) with 10 m resolution. The catchment area of Lampunut Sump Pite is calculated based on the DEM and considering drainage system around the mine. The catchment area used in this study is shown in Figure 2 with total area of 115.7 Ha. The total rainfall volume is calculated based on rainfall height and the total catchment area. The observed run-off coefficient is obtained from the ratio of surface run-off volume and the total rainfall volume. The rainfall volume, surface run-off volume and the run-off coefficient are shown in Figure 3. The average run-off coefficient from observations is found to be 0.62.

B. FJ MOCK METHODS

The FJ Mock method calculates the water balance for a hydrological system considering the baseflow (BF), direct run-off (DRO) and storm run-off (SRO). The FJ Mock uses Penman empirical evapotranspiration potential [8]. The total run-off (TRO) is calculated as the total of run-off component as follows:

$$TRO = BF + DRO + SRO \quad (1)$$

The daily climatological data for FJ Mock analysis is obtained from Geophysical and Meteorological Agency (BMKG) Tjilik Riwut, Beringin and Iskandar.

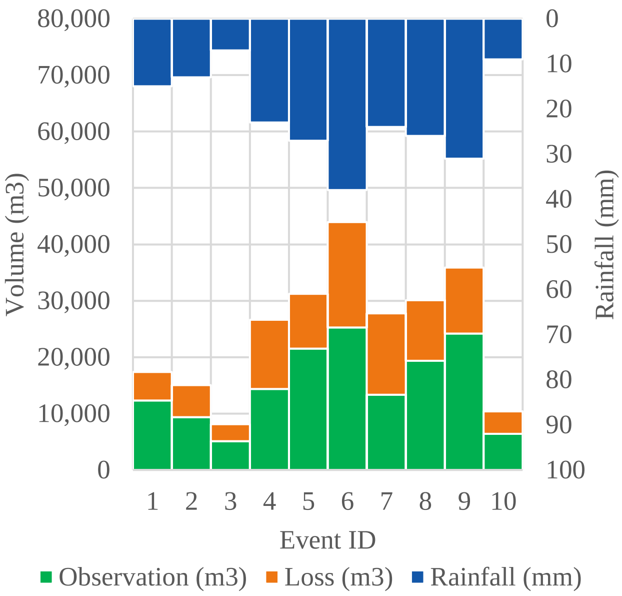

Figure 3 Rainfall, Discharge, and Loss Observation Data

C. HEC-HMS MODEL

The HEC-HMS is developed by USACE for watershed modelling [9]. The rainfall – runoff transformation uses the SCS Synthetic Hydrograph developed by USDA [8]. The Lampunut catchment area schematized as sub-basins as shown in Figure 4.

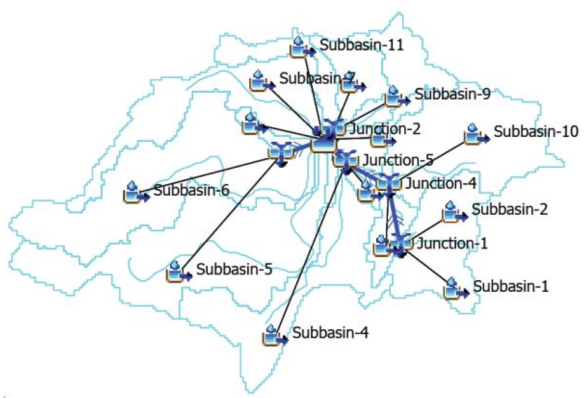

Figure 4 HEC-HMS Model Schematic

D. HEC-RAS MODEL

The HEC-RAS model is developed by USACE and solves the depth averaged shallow water equation (SWE). The mass conservation formula is given by:

$$\frac{\partial H}{\partial t} + \nabla \cdot h\boldsymbol{V} + q = 0 \qquad (2)$$

With t is time, V is velocity vector, and q is source/sink flux term. H is the water surface elevation, which obtained from:

$$H(x, y, t) = z(x, y) + h(x, y, t) \qquad (3)$$

With z is the bed elevation and h is water depth. The momentum conservation equation is described as follow:

$$\frac{\partial \boldsymbol{V}}{\partial t} + \boldsymbol{V} \cdot \nabla \boldsymbol{V} = -g\nabla \mathrm{H} + \nu_t \nabla^2 \boldsymbol{V} + c_f \boldsymbol{V} + fk \times \boldsymbol{V} \qquad (4)$$

with ν_t is the horizontal eddy viscosity, c_f is the friction coefficient and f are Coriolis factor. The HEC-RAS model domain in this research is shown in Figure 5. The rain-on grid boundary condition is used to take account of rainfall event.

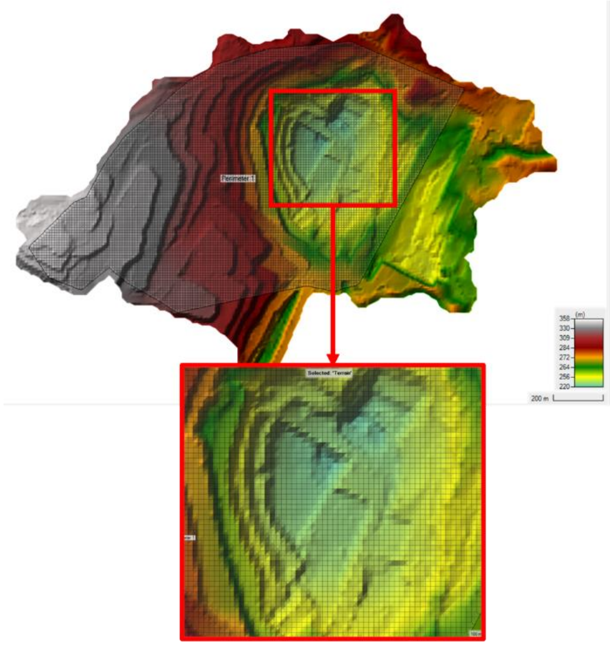

Figure 5 HEC-RAS Model Domain Configuration

E. CURVE NUMBER LOSS METHOD

The HEC-HMS and HEC-RAS model uses Curve Number to consider infiltration occurred at the site. The Curve Number (CN) is developed by USDA [6],[7] and based on landcover, soil type, and slope. The storage retention S (in inch) is given as:

$$S = \frac{1000 - 10CN}{CN} \qquad (4)$$

The precipitation excess, Pe, is given as:

$$Pe = \frac{(P - Ia)^2}{P - Ia + S} \qquad (5)$$

With P is the precipitation and Ia is the initial abstraction which can be estimated as 0.2S. In steep slope conditions, as the case in Lampunut mine, the rainfall infiltration will be decreased. Therefore, the Curve Number estimation needs to consider the slope conditions as given in Table 1 [10]. The CN value of 95 is used in HEC-HMS and HEC-RAS based on pasture in poor hydrological conditions with very steep slope.

RESULTS AND DISCUSSIONS

A. VOLUME ESTIMATION BASED ON FJ MOCK

The volume calculation using the FJ Mock methods is given in Figure 6. The FJ Mock calculation tend to overestimate the discharge and the run-off coefficient. Indeed, the climatological data is obtained from meteorological station near the site, where discrepancies of data may occur.

B. VOLUME ESTIMATION BASED ON HEC-HMS

The HEC-HMS simulation result shows in Figure 7. It shows that HEC-HMS model can gives reasonable results with maximum deviation at event 6, where the HEC-HMS overestimates the volume by 13%. Indeed, in some other event, the HEC-HMS model underestimates the volume prediction. The discrepancies may occur because of the initial abstraction is estimated as 0.2S which may not be the same for every rainfall event.

C. VOLUME ESTIMATION BASED ON HEC-RAS

The volume calculation from HEC-RAS is shown in Figure 8. It gives similar estimates as HEC-HMS models with slight differences. Indeed, the ponding area is not modelled in HEC-HMS and all water losses is considered based on catchment storage. The HEC-RAS inundation depth simulation results is given in Figure 9. It shows in addition of infiltration, water losses also existed as ponding area because of the terrain conditions.

D. SURFACE RUN-OFF COEFFICIENT

The surface run-off coefficients calculation shows a good agreement between the models and observations. Indeed, the FJ Mock overestimate the run-off coefficient, with highest error of 20.4%. The HEC HMS and HEC-RAS gives better estimates with relative error of 15.3% and 4.8% respectively. The ponding area that is captured in

HEC-RAS simulation is interesting features to investigate further.

Table 1 Curve Numbers Considering Soil Group and Land Slope

Landuse	Slope Class	Hydrologic Soil Group A	B	C	D
Rice fields or mangroves or swamps	I	0	0	3	5
	II	0	5	8	10
	III	5	10	13	15
	IV	*non-existent*			
	V	*non-existent*			
Pasture or range in good hydrological condition	I	33	55	68	74
	II	39	61	74	80
	III	42	64	77	83
	IV	44	66	79	85
	V	45	67	80	86
Woods in poor hydrological condition	I	39	60	71	77
	II	45	66	77	83
	III	49	70	81	87
	IV	52	73	84	90
	V	54	75	86	92
Pasture or range in poor hydrological condition	I	63	74	81	84
	II	68	79	86	89
	III	71	82	89	92
	IV	73	84	91	94
	V	74	85	92	95

Slope Class: Class I, < 1%, Flat; Class II, 1-5%, Slightly sloping; Class III, 5-10%, Highly sloping; IV, 10-20%, Steep; Class V, > 20%, Very Steep

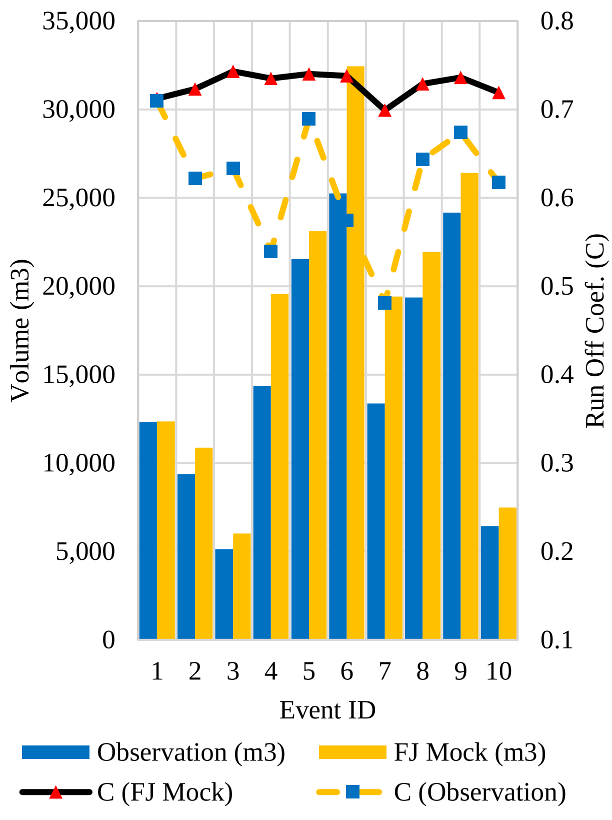

Figure 6 Volume Calculation using FJ Mock

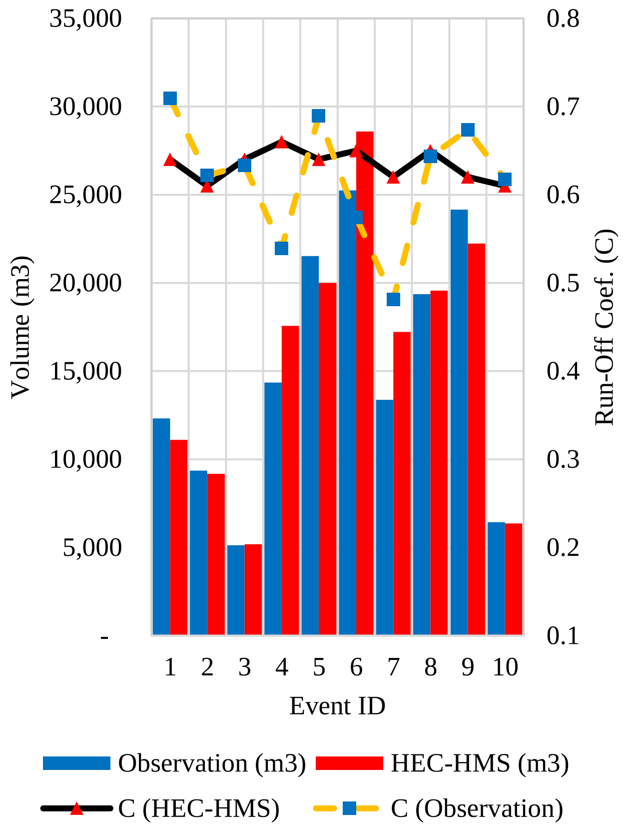

Figure 7 Volume Calculation from HEC-HMS Model

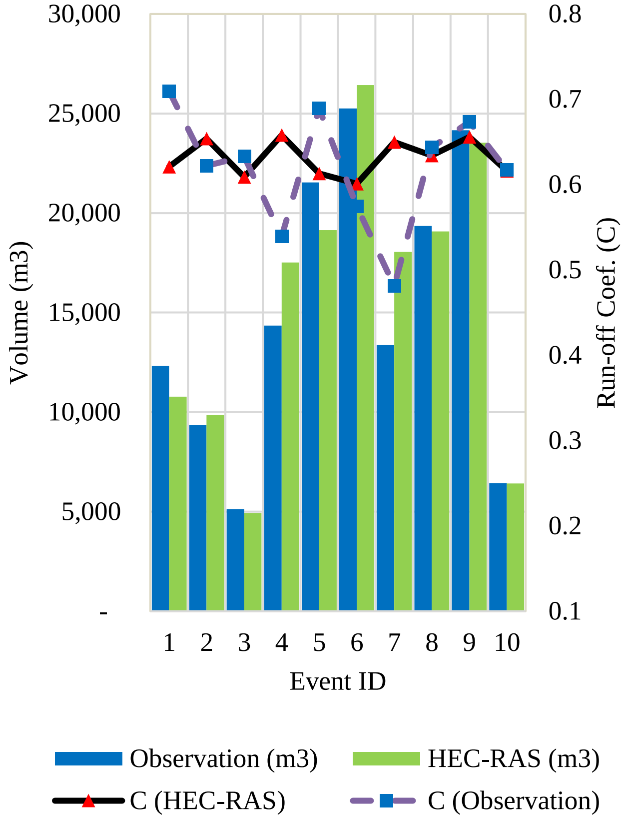

Figure 8 Volume Calculation from HEC-HMS Model\

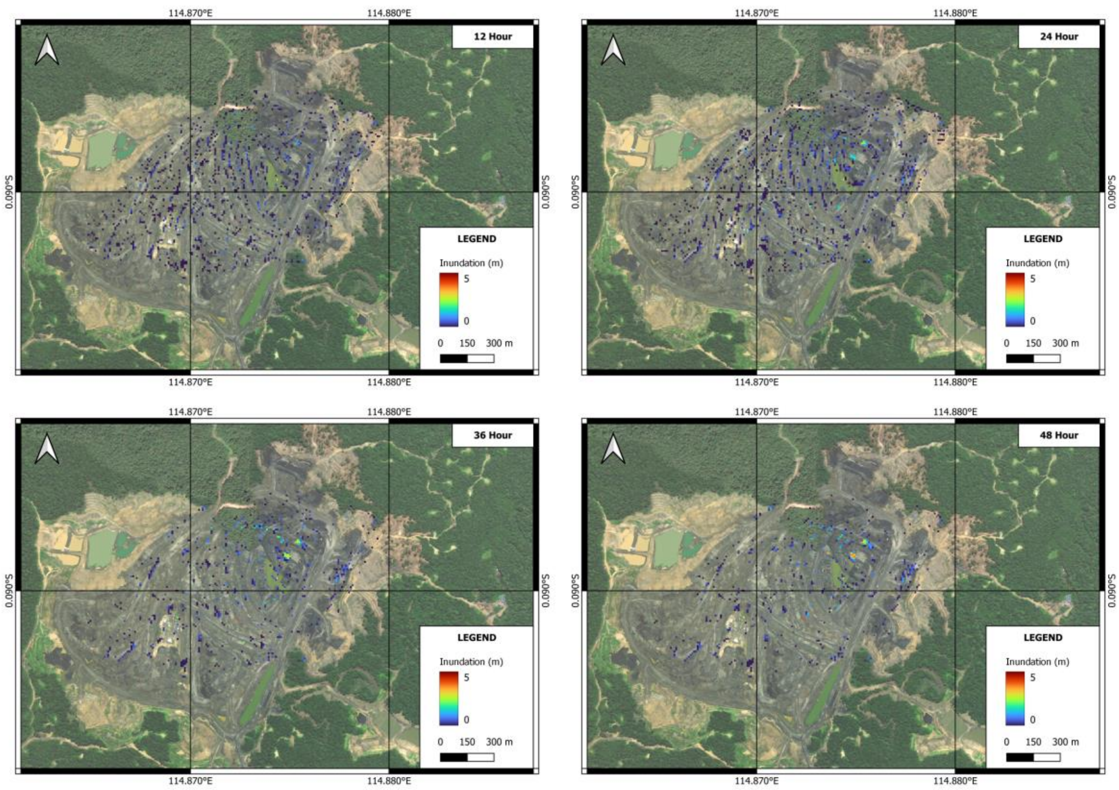

Figure 9 Inundation Depth from HEC-RAS Simulation

CONCLUSIONS

In this research three methods are applied to predict surface run-off in open mines. The rainfall loss is estimated using empirical formulation and Curve Number (CN). The empirical formulation is applied in FJ Mock Method, while the Curve Number is applied in the HEC-HMS and HEC-RAS Model. The loss prediction based on Curve Number gives better estimates with relative error of 15.3% in HEC-HMS model and 4.8% in HEC-RAS. The HEC-RAS model is an interesting tool to use in open pit mine drainage design. The 2-Dimensional HEC-RAS analysis gives more insight on site hydrological conditions. The detailed DEM data also can capture ponding area on site.

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