Analysis of Tailing Storage Facility Cover Design Alternatives using soil water atmosphere hydraulic performance modeling in Thailand

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Abstract

This research aims to analyze the Tailing Storage Facility cover design alternatives using soil water atmosphere hydraulic performance modeling. The analysis comprises of 3 steps: first, the potential infiltration in tailing is estimated by Green and Ampt method. Second, the water flow though the tailing is demonstrated under groundwater model. Third, TSF covers design alternatives is analyzed percolation performance between surface water and TSF based on the thickness of clay cover. Results of data analyzed show the percolation of 1-4 meters clay are lower than limited seepage (Percolation of 1 m thickness of clay in this study is 9800 m3/ 12 years < 0.88m/ha/day= 264,000 m3/ 12 years, (Billiton, 2009)).

Keywords ; Tailing Storage Facility, Soil water atmosphere hydraulic performance modeling, Cover design

I. INTRODUCTION

Nowadays, along with development of science and technology, the disposal of wastes in our world has become a serious issue. Special industry, open-pit mining involves the excavation of large quantities of waste rock (material not containing the target mineral) to extract the desired mineral ore. After recovered processing, the remaining rock becomes another form of mining waste called tailings. Mine tailings often contain the toxic heavy metal, acid-forming minerals, cyanide and sulphuric acid. Tailings are usually stored above ground in containment areas or ponds (and in an increasing number of underground operations they are pumped as backfill into the excavated space from which they were mined). In the early 1980s, tailings were considered as residue with no commercial value. Most of the small and medium-size mines directly discharged their tailings into the local valleys or rivers close to the mines. However, contaminants in mine waste can cause serious pollution that can last for many generations (Wild, 2006). With the enhancement of environmental protection awareness, both regulations and legislation were successively promulgated and implemented in the early 1990s, requiring mine owners to build tailings disposal facilities and water treatment systems before any commercial mining may commence. To store tailings and waste water from mineral processing, the impoundments are regarded as a major part of the mining facilities. (Kanagasabai, 1982; Kwak, James, & Klein, 2005). Lately, the numerical research provide the concept to design tailing storage (Billiton, 2009; Department of Energy, 1972; Kealy

& Soderberg, 1969). Nonetheless, the complex properties of ore and gangue mineralogy, fine grinding, and flotation geochemical properties at mine location cause clay layer selection challenges for sealed tailings storage.

This research aims to analyze the Tailing Storage Facility (TSF) cover design alternatives using soil water atmosphere hydraulic performance modeling. The analysis comprises of 3 steps: first, the potential infiltration in tailing is estimated by Green and Ampt method. Second, the water flow though the tailing is demonstrated under groundwater model. Third, the analyzed percolation performance between surface water and TSF is based on the thickness alternatives of clay cover.

METHODOLOGY

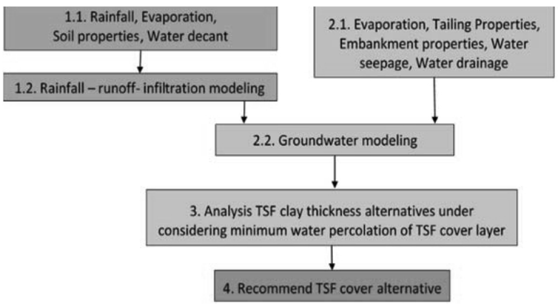

Figure 1. Methodology of study

In the study, HEC-HMS will use The Green and Ampt infiltration model to simulate the runoff volume and on the pervious area in a time interval as: the infiltration. The model computes the precipitation loss

$$\mathbf{f_t = K[\frac{1+(\Phi-\theta_i)S_f}{F_t}]} \quad (1)$$

Which f_t = loss during period t; K = saturated hydraulic conductivity; (Φ -θ) = volume moisture deficit; S_f = wetting front suction; and F_t = cumulative loss at time t (USACE-HEC, 2000).

The soil properties are applied from texture class estimates of J. Rawls, L. Brakensiek, and E. Saxtonn (1982).

Table 1: Texture class estimates (J. Rawls et al., 1982)

Texture class	Porosity Φ (cm^3/cm)	Hydraulic Wetting front, θ (cm^3/cm) conductivity	Wetting front suction(cm)
Sand	0.437	21.00	10.6
Loamy sand	0.437	6.11	14.2
Sandy loam	0.453	2.59	22.2
Loam	0.463	1.32	31.5
Silt loam	0.501	0.68	40.4
Sandy clay loam	0.398	0.43	44.9
Clay loam	0.464	0.23	44.6
Silty clay loam	0.471	0.15	58.1
Sandy clay	0.430	0.12	63.6
Silty clay	0.479	0.09	64.7
Clay	0.475	0.06	71.4

The groundwater water simulation method is based on finite difference-based solver (MODFLOW). Partial Differential equation which represents three-dimensional movement of ground water is (Hill, Banta, Harbaugh, & Anderman, 2000)

$$\frac{\delta}{\delta x}\left[K_{xx}\frac{\delta h}{\delta x}\right]+\frac{\delta}{\delta y}\left[K_{yy}\frac{\delta h}{\delta y}\right]+\frac{\delta}{\delta z}\left[K_{zz}\frac{\delta h}{\delta z}\right]+W=S_s\frac{\delta h}{\delta t} \quad (2)$$

Where Kxx, Kyy and Kzz are the values of hydraulic conductivity along the x, y, and z coordinate axes and may be function of space.
H is the potentiometric head (hydraulic head)
W is a volumetric flux per unit volume representing sources and/or sinks of water, where negative values are water extractions, and positive values are injections. It may be a function of space and time (i.e. W = W (x, y, z, t)).
Ss is the specific storage of the porous material and may be function of space.
t is time (month).

RESEARCH METHODOLOGY

The tailing storage facility is model base on the gold mine processing and soil properties in north central Thailand. The annual rainfall record on Taphan Hin Meteorological station is rather low. The annual rainfall from 2002 to 2013 exceeds from 263.4 mm to 1154.7 mm, mean 756.525 mm. The rainfall pattern is seasonal; with more than 85% of rainfall at Meteorological station falling during the wet season (May to October).

Based on the characteristics of TSF cover design (Billiton, 2009), the model is built in 6 layers to simulate the aquifer as follows (figure 2):

- The clay liner layer in the bottom will be considered as aquitard. The main hydro-geological parameters: permeability coefficient $K<1 \times 10^{-8}$ m/s and gravitational storability μ = 0.01 - 0.001.
- The embankment is considered as aquitard. The main hydro-geological parameters: permeability coefficient K= 2.8×10^{-8} - 1.8×10^{-6} m/s and gravitational storability μ = 0.01 - 0.001.
- The tailing is considered as an unconfined aquifer. The main hydro-geological parameters: permeability coefficient K= 2.8×10^{-8} - 1.8×10^{-6} m/s and gravitational storability μ = 0.01 - 0.001.
- Three top cover layer of TSF follow the guideline of TSF cover design. There are one clay fill layer, one rock/soil fill, and top soil to promote vegetation growth. The properties and the thickness of 3 layers will be analyzed by GMS modeling.

The infiltration is applied by the loss function of surface runoff modeling. During simulation, the soil properties of TSF applied to calibrate groundwater in TSF from April 2012 – December 2013 is shown in Table 2.

Table 2: The soil properties of TSF

Properties	Tailing	Embankment	Clay liner
Thickness (m)	40	5	0.6
Elevation (m)	82	82 - 125	75
Initial water level (m)	82.28	-	-
Soil type (m)	Ore	Oxide Mixed Soil	Clay
Hydraulic conductivity (Horizontal/ Vertical) (m/day)	0.03/ 0.003	1×10^{-5}/1×10^{-6}	1×10^{-5} /1×10^{-6}
Specific Storage/ Specific yield	0.01/ 0.21	0.01/0.06	0.01/0.06

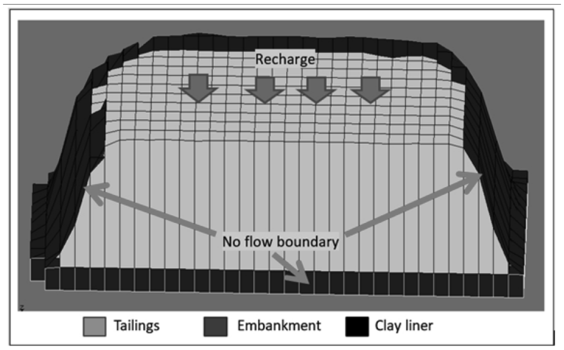

Figure 2. Cross-section of TSF

RESULTS AND DISCUSSIONS

The calibration of surface water in TSF under rainfall during year 2012-2013 is described in Figure 3. The stability of flow runoffs appears only in rainy season and fluctuates during rainy season. All the observed data of flow runoff in TSF is correspondence. Hence, the loss in surface modeling simulation could be applied to calibrate and compute the groundwater in the TSF. The surface model parameter estimated due to SW calibration presented in Table 3.

According to surface runoff simulation, the loss of rainfall in TSF are estimated and shown in Figure 4. In the figure, the estimated loss is 35 percentage of rainfall. Due to the good regression between observed and computed groundwater level in tailing, the estimated loss from surface runoff modeling can be considered as recharge to tailing TSF. The water recharges from surface to TSF occur during the rainy season with the maximum rate 10 mm/ day.

Table 3: Surface water model parameters

Area: 689 000 m^2			
Component		Value	Method
Loss	Initial content (mm)	0.2	Green and Ampt
	Saturated content (mm)	0.3	
	Suction (mm)	20	
	Conductivity (mm/Hr)	0.3	
	Imperious (%)	5	
Transform	Time of concentration (Hr)	1	Clark Unit Hydrograph
	Storage coefficient (Hr)	0.5	

Due to rainfall pattern during 2002 - 2013, the recharges to the tailing under duration rainfall 2002 – 2013 are simulated by surface modeling

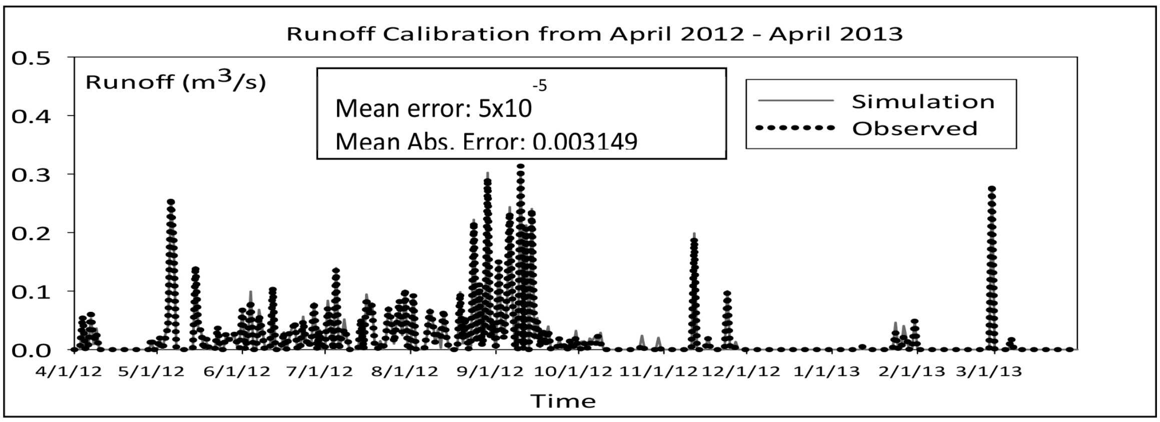

Figure 3. Runoff calibration in TSF from April 2012 – 2013

(HEC-HMS) and shown in Figure 5. The total amounts of precipitation in 12 years are 11,133,000 m3. Meanwhile, the recharges are estimated as 3,902,000 m3 with the high amount of recharge during 12 rainfall years in the past, the TSF need to be sealed by impermeable cover to sufficient prevent TSF from surface water seepage.

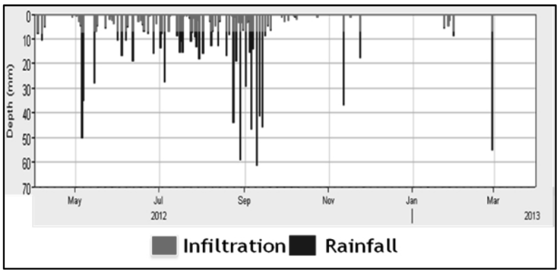

Figure 4. Estimated Loss in 2012 – 2013

According to groundwater simulation and observed data (Figure 6), the groundwater level in TSF created curve sine from dry season to rainy season in between the range of 90 m to 98 m. The trend of water level in TSF will maintain its stability from April 2012 to December 2013. Anyhow, with the amount of discharge water in tailing during rainy season, the cyanide could produce hydrocyanic acid and cause damage to the environment. Therefore, TSF need to be dried and sealed by preventable seepage cover.

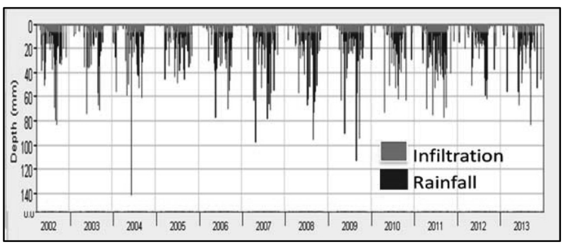

Figure 5. Simulated water recharge to TSF under rainfall pattern 2002-2013

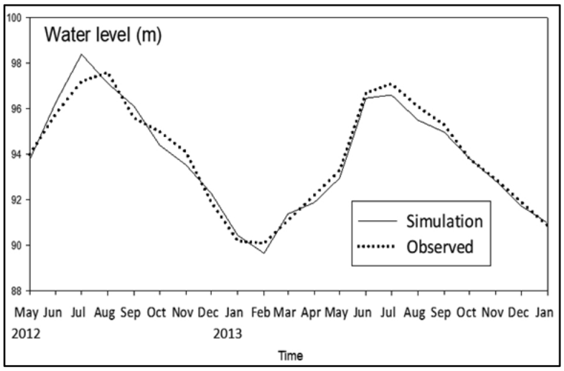

Figure 6. Water level calibration in TSF

According to TSF design (Billiton, 2009), the TSF cover involves 3 layers: first layer is vegetation topsoil, second layer is low permeability clay and the third is erosion rock/soil fill. The properties of TSF cover design are presented in Table 4. By applying the GMS-modflow, the estimated percolation of TSF is shown as Figure 7. The recharges to the top soil in 2012 - 2013 distribute large amount of water during the rainy season. The average estimated recharges are 10000 m3/ month. Meanwhile, the percolation of topsoil and clay are low amount of water. The estimate percolations of top soil and clay are in the range min 10 m3/ month and max 180 m3/ month. Then, the percolations of TSF propose cover design have potential prevent seepage from water surface to TSF.

To understand the sustainable of TSF cover design alternative under long period, the percolation of TSF is simulated by using rainfall pattern 2002 – 2013 and shown as Figure 8.

Table 4: Properties of propose TSF cover design alternative

Properties	Layer cover 1	Layer cover 2	Layer cover 3	Tailing	Embankment	Clay liner
Thickness (m)	1	1	1.5	40	5	0.6
Elevation (m)	125	124	122.5	82	82 - 125	75
Initial water level (m)	125	124	122.5	82.28	-	-
Soil type (m)	Soil	Clay	Soil	Ore	Oxide Mixed Soil	Clay
Hydraulic conductivity (Horizontal/Vertical) (m/day)	0.003/0.0003	$5x10^{-4}$ $/5x10^{-5}$	$3x10^{-3}$ $/3x10^{-4}$	$3x10^{-2}$ $/3x10^{-3}$	$1x10^{-5}/1x10^{-6}$	$1x10^{-5}$ $/1x10^{-6}$
Specific Storage/ Specific yield	0.01/0.21	0.01/0.06	$1x10^{-4}$ /0.21	0.01/0.06	0.01/0.21	0.01/0.06

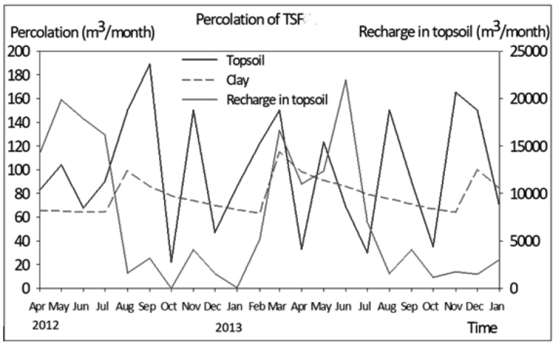

Figure 7. : Percolation of TSF covers design under rainfall year 2012 – 2013

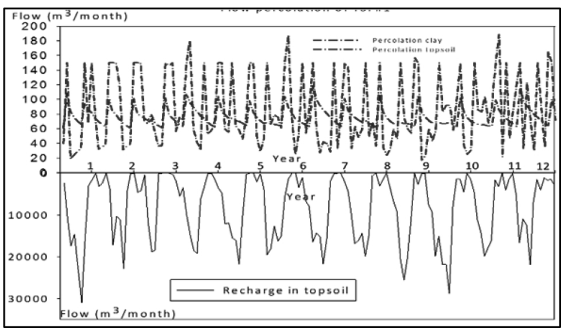

Figure 8. : Flow percolation of TSF#1 under rainfall 2002 - 2013

According to the simulation, the percolations of TSF cover design fluctuate due to the season. The recharges in the top soil of TSF are large amount of water during the rainy season in range 20000 m^3/ month – 30000 m^3/ month. However, with the impermeable cover, the percolations of TSF in topsoil and clay are less volume seepage to the TSF. The volume of percolation of clay cover of TSF is in the range 60m^3/month – 120m^3/ month. To select the suitable cover to reduce the seepage in TSF, the TSF cover is analyzed via flux in tailing.

The analysis TSF cover design based on comparison the 4 thickness of clay including: 1 m, 1.5 m, 2 m and 4 m. The function between percolation of clay and thickness of clay is distributed as Figure 9. The percolations are inverse proportion with the thickness of clay. The maximum percolation is 9800 m^3/ 12 years in case 1 m thickness of clay. The minimum percolation is 9100 m^3/ 12 years in case 4 m thickness of clay. Moreover, the reference limited percolation is 264,000 m^3/ 12 years (0.88m/ha/day) (Tailings Storage Facility Design Report, Olympic Dam Expansion Project). The percolations of clay in 4 cases are lower than the reference limited percolation. In other side, in Figure 10, the function of water level in TSF the thickness of clay cover in TSF show that the water level in TSF under 1 meter clay in rainfall pattern 2002 – 2013 is 2.2 meter. The simulations show that the percolation and water level in tailing could be reduced under increasing the thickness of clay. However, the amounts of flux in 4 cases are not much different. Therefore, for easy construction and prevent seepage in TSF, the TSF could apply the TSF cover involves 3 layers: first layer is vegetation topsoil, second layer is low permeability clay, and the third is erosion rock/soil fill. The thicknesses of 3 layers should be not less than 1 m, 1 m, and 1.5 m, respectively.

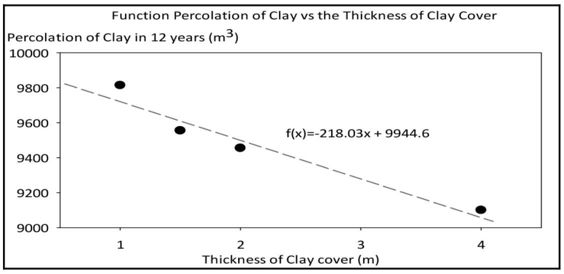

Figure 9 Function percolation of clay vs the thickness of the clay cover

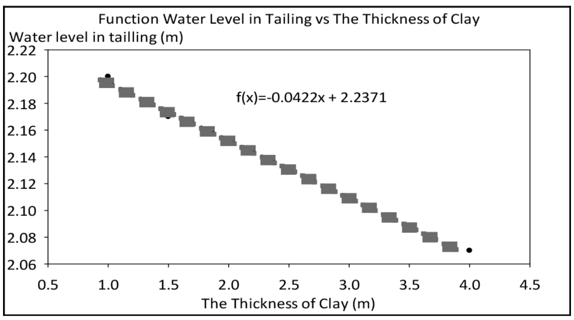

Figure 10. The function water level in tailing vs the thickness of clay

CONCLUSIONS

Based on the guideline of TSF cover design (Billiton, 2009), the TSF cover involve 3 layers: first layer is vegetation topsoil, second layer is low permeability clay, and the third is erosion rock/soil fill. The thicknesses of 3 layers respectively are 1 m, 1 m, and 1.5 m. Besides, the hydraulic conductivity of clay layer is less than 10-8m/s which is similar with clay liner properties.

According to surface – groundwater calibration, water level of tailing increase in rainy season and decease in dry season. During the rainfall season in year 2012, the tailing was discharged 72,823 m^3 which raise water level in tailing from 94 m to 98 m. Meanwhile, in dry season, water level was dropped from 98 m to 90 m. However, the high intensity precipitation in rainy season could reduce potential stability of residual cyanides in tailings. Therefore, the tailings need to impermeable cover to avoid the pollution impoundment.

Due to structure of TSF cover and duration rainfall in year 2002 -2013, the estimated recharge to the topsoil layer in TSF cover is approximate 1,159,379 m^3. Meanwhile, the percolation of topsoil covers 12036 m^3. Since, the analysis of TSF cover design to minimize the percolation of TSF is based on comparison of 4 thickness of clay layer of TSF cover. According to the result of simulation, the percolation of 4 thicknesses of clay are all lower than limited seepage (Percolation of 1 m thickness of clay is 9,800 m^3/ 12 years < 0.88m/ha/day= 265,000 m^3/ 12 years, Tailings Storage Facility Design Report, Olympic Dam Expansion Project). In addition, the water level in tailing fluctuates from 2.2 m to 2.07 m by the thickness of clay from 1 m to 4 m. Because the percolation of 4 alternatives are lower than reference limited seepage and the water level in tailing are not much difference, the alternative of 1 m thickness of clay is potentially suitable to prevent seepage to tailing and easy to operation.

According to the results of simulation, the surface water and groundwater simulation could be applied to analyze the interaction between TSF cover design and the tailings.

Acknowledgements

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Reference

Billiton, B. (2009). Olympic Dam expansion draft environmental impact statement 2009. Retrieved from

Department of Energy, M. a. R. C. (1972). Tentative Design Guide for Mine Waste Embankments in Canada. Retrieved from

Hill, M. C., Banta, E. R., Harbaugh, A. W., & Anderman, E. R. (2000). MODFLOW-2000, the US Geological Survey modular ground-water model; user guide to the observation, sensitivity, and parameter-estimation processes and three post-processing programs (2331-1258). Retrieved from

J. Rawls, W., L. Brakensiek, D., & E. Saxtonn, K. (1982). Estimation of Soil Water Properties. Transactions of the ASAE, 25(5), 1316-1320. doi:https://doi.org/10.13031/2013.33720

Kanagasabai, J. (1982). ANALYSES OF FLOW FAILURES OF MINE TAILINGS IMPOUNDMENTS.

Kealy, C. D., & Soderberg, R. L. (1969). Design of dams for mill tailings.

Kwak, M., James, D. F., & Klein, K. A. (2005). Flow behaviour of tailings paste for surface disposal. International journal of mineral processing, 77(3), 139-153.

USACE-HEC. (2000). Hydrologic Modeling System HEC-HMS Technical Reference Manual: US Army Corps of Engineers, Hydrologic Engineering Center.

Wild, B. (2006). Environmental Mining Council of BC (BC)(2006) Acid Mine Drainage: Mining and Water Pollution Issues in BC. http://www. miningwatch. ca/sites/www. miningwatch. ca/files/amd_0. pdf (last accessed 4 June 2014).