# The Influence of Water Balance for Slope Stability on the High Mine Waste Dump

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**Abstract:** One of the vital parts of mining activity is optimizing the mine waste dump. It means that the capacity needs to be conserved by the various aspects of feasibility study. Hydrogeology is one of the main aspects of mine waste stability that needs to be controlled to ensure slope stability. The research aims to determine the influence of water balance toward mine waste dump stability, especially for inclined basement. The analysis was carried out by distributing the constituent material grain size, mapping of permeability value, determining the water balance behaviour between recharge and discharge, and watering behaviour inside mine waste dump material. It was also about the fragmentation analysis that was carried out to determine the layer of porosity value, while the permeability test was used to examine the rainfall infiltration rate. It is important to decide on the equilibrium water flow between the recharge and the discharge rates to ensure no water accumulates to mine waste dump. The fragmentation analysis results showed that the top layer of the waste is composed of sand-boulder-sized material with porosity towards the contact zone and a little clay. The hydraulic conductivity material values range from 6 x $10^{-6}$ m/s and 3 x $10^{-2}$ m/s at the top and the bottom layers of mine waste dump. The rainfall and the seepage are interrelated because a rise follows an increase in rainfall in seepage debit. The large permeability difference between the in-situ material and the layer slope is approximately 14°, therefore, the water tends to flow following the contact zone and forms a seepage.Pore pressure can be minimized, and stability of the mine waste dump slope maintained.

**Keywords:**Water control, seepage, hydraulic conductivity, coarse, disposal, optimization.

## 1. Introduction

Open-pit mining is defined as a surface drilling procedure that involves the extraction of minerals or ore deposits discovered relatively close to the surface of the earth, therefore the safety of the work area is paramount [1]. The operation's progression involves the optimization of its spatial proximity to maximize the productivity and the cost-efficiency [2, 3]. A specific requirement in this circumstance is the need to optimize the disposal of tailings embankment. This research is carried out in one of the coal mines located at Asam-asam area, South Kalimantan. The company desires to optimally backfill the mine with waste dump at the low-wall part of the pit to gain accessibility and ensure the embankment's safety. This research aims to determine the influence of water balance on the stability of mine waste dump, particularly an inclined basement.

Maintaining slope stability is one of main aspects to determine the optimization of embankments [4]. Slope stability on the low wall part is controlled by material properties and geometries of the bedding separated by layering or bedding contact between both materials [5] and the interaction of the water body in the embankment [6]. In addition, the certain conditions need to be controlled to ensure the water does not affect slope stability [4]. Therefore, there is a need to establish the regulation on water balance to prohibit the gradual development of pore pressure in the embankment, there is by maintaining the slope's stability. This research is carried out to discover the importance of water balance on the embankment's hydrogeological condition.

Data acquisitions are carried out in the field to realize its actual condition. The electrical resistivity tomography is used to aid the interpretation of embankment's layer because it determines the distribution of the materials. The fragmentation measurements are carried out on the surface to acquire the grain-size distribution using photographic and image analysis techniques and scaling object [7]. The hydrologic conditions, such as seepage, are directly measured in the proximity of test site to acquire the volume of discharge in the area. The already measured rainfall intensity of the area is utilized in analyzing the water balance [8].

Finite element method for slope stability analysis uses transient finite element to analyze the groundwater capabilities [9]. Furthermore, it is considered to be reliable [10]. Geotechnical profiling of heap materials can be done by using a geophysical approach based on the assessment of rock resistivity results[11]. The rainfall intensity is represented as the infiltration in the embankment. The hydrogeological condition's dynamics were analysed by using the software [4], which was focused on the flow vectors, pore pressure, and discharge of water from the embankment [12]. Rainfall flows as the surface runs off and enters the mine waste dump material (see Fig.1). The direction of groundwater flow to the contact zone, which is the original rock layer, appears seepage [13].

Furthermore, the contact zone needs to be kept highly porous to maintain stability. Porosity is due to increased pore pressure, and it causes the zone to become a weak field. It is important to identify the characteristics of rocks as well as their geological conditions because it is the basis for mine waste management [14]. Subsequently, the geological block models are also used to determine the geomechanical and the geochemical conditions, that is including the fragmentation of mine waste dump. These outcomes are used to control risks during operation; it's particularly in the management of Acid Mine Drainage (AMD) [15]. A mine closure plan needs to be optimized based on operating procedures. The formation of seepage based on geochemical conditions is essential for controlling the development of Acid Mine Drainage [16]. Waste rock pile modelling was carried out based on groundwater behaviour. The distribution of water content is in accordance with the heterogeneity of the material [17]. All stages involved in mine water management is important, it's begun from the operational to the completion of construction [18].This research is carried out in one of the coal mines located at Asam-asam area, South Kalimantan, as shown in Fig.2. The company desires to optimally backfill the mine with waste dump at the low-wall part of the pit to gain accessibility and ensure the embankment's safety. This research is aimed to determine the influence of water balance on the stability of mine waste dump, it's particularly in an inclined basement. The material is dominated by sandstone and claystone with some carbonaceous minerals where the material is easily degraded after the rock is exposed[19]. Sandstone is composed by quartz material with a composition that is more than 80% [20] with a sandstone breaking angle is about 53 degrees [21]. Bedrock has a slope of 14 degrees but the bedding ratio has not yet been determined. Bedding ratio has an important role in lowall stability [22] where the bedding ratio is separated from the thin layer that has a high plasticity with a cohesion of 0 and friction angle of 13 [23].

Determination of lateral pressure coefficient uses back analysis in seepage zone on heap material those are yields 5% deviation [24]. In the analysis of mine waste dump should pay attention to the geotechnical – geochemical aspects and hydrogeology, hydrology. Each of these aspects plays an important role in the stability of mine waste dumps both short-term and long-term [25]. Reactive material especially acidic material can be placed in an encapsulated cell. And encapsulated cell is made from the impermeable material, so the material selection is very important in waste dump construction sequence. In reactive material must be maintained water content and encapsulated cells layer must be a protector with an impermeable layer [26]. Waste dump material construction must pay attention to the behaviour of groundwater, so the materials that have Acid Generation properties can be covered by impermeable coating. The porosity and the impermebaility factors must be maintained properly so that reactive acidic material does not occur [27]. The selective material in waste construction is indispensable for surface water management, so it does not increase the pore pressure material [28]. The previous Researchers have considered the selection and placement of materials but it would be an expensive cost in construction and operation, if active maintenance was to be carried out. It need a more detailed study of the water balance between incoming and outgoing water, so there is no increase in water content or pore pressure in mine waste dump. The rainwater, the groundwater and the seepage must form a constant cycle so that the stability of disposal can be observed. In this research, a study was conducted on how to make the construction of mine waste dump optimum, so the water balance can be maintained to the term stability Length can be achieved. The study was conducted starting from material identification, rain evaluation and correlation with seepage of mine waste dump.

Non-woven geotextile installation can increase the steady state shear strength, decrease the liquefaction potential and decrease the material degradation [29]. The permeability value of peat and organic materials decreases significantly when there is a decrease in void ratio as a result of consolidation [30]. Restructure and reorientation of constituent materials will occur during dnyacyle loading or loading that has an increased impact so as to increase pore pressure. In this process, it is necessary to control drained, so the pressure does not become a pushback that has an impact on the improvement of pore pressure [31]. The liquefaction of heap material depends on earthquake, type of soil, plastic limit, liquid limit, particle size distribution [32]. In the construction of the basic construction of landfill mine waste, it is necessary to consider hard materials with low plasticity. The determination of material properties of heap material is widely done with field testing such as N-SPT [33] however, this method cannot be performed on mine waste dumps that have hard material properties and are large (chunks). The method of analysis uses undrained on mine waste dump. It is very commonly used but once the selection of characteristic material and water balance conditions in the heap has not been done much research [33]

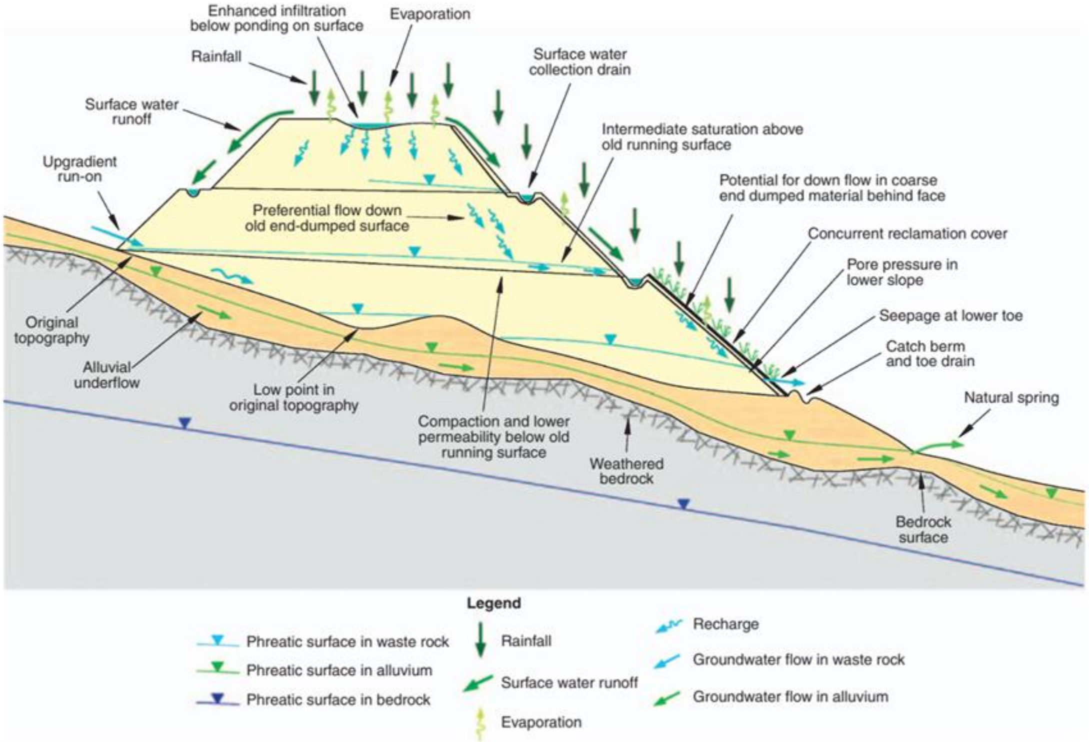


**Figure 1.** The conceptual hydrogeology models on mine waste dump of stockpile [13].

**Figure 2.** The research area in the Kintap area (yellow line), Tanah Laut, South Kalimantan.

## 2. Material and Method

Data analysis was carried out by mapping the grain size distribution on the surface slope, discharge area, and the slope's top. The fragmentation was carried out using a split engineering program with output in the form of grain size distribution. The analysis and evaluation of permeability were carried out at 20 locations within the study area using ASTM D6539-13. Furthermore, the daily amount of rainfall was measured at rainfall stations. The amount of discharge is directly measured on the field to obtain the actual debit value, and the time is also recorded to validate the rainfall data. Mapping of the discharge point is also carried out to determine the correlation of groundwater balance in the mine waste dump. The geohydrological evaluation was carried out using a finite element method to obtain groundwater distribution patterns and movements. The results of analysis shows that the values of flow velocity are compared based on field measurements. Consequently, the groundwater volumetric analysis was obtained at each location in the study area.

## 3. Research Result

The analysis is carried out based on certain parameters (Table 1), a transient groundwater finite element method, and a two-dimensional section of the embankment (Fig. 3). The distributions of the materials are shown in Fig. 3. Stratigraphy of heap material uses the previous research data. The material is composed by 3 layers consisting of upper zone, contact zone and basement zone [11]. Material properties use the results of back analysis on heap material consisting of disposal material, contact zone and bedrock. The contact zone material has a cohesion and friction angle of 2 KPa and 37 degree respectively and the upper waste dump material has a cohesion and frictian angle of 3 Kpa and 26 degrees respectively [5].

**Table 1.** Criteria of Analysis

| Criteria | Variable | | | |
|---|---|---|---|---|
| Surface Vertical Infiltration | 0.25; m/day | 0.5 m/day | 1 m/day | 2 m/day |
| Stages | Stage 1 | Stage 2 | Stage 3 | Stage 4 |
| | 3 hours | 6 hours | 12 Hours | 24 hours |
| Initial Stage | No water flow | | | |

**Table 2.** Layers Material on Mine Waste Dump

| Layers | Material | Hydraulic Conductivity |
|---|---|---|
| Upper Embankment Layer | Sand - gravel, with less clay | $6 \times 10^{-6}$ m/s |
| Lower Embankment Layer | Boulder with high porosity | $3 \times 10^{-2}$ m/s |
| Base (In situ) material | clay stone | Assumed Impermeable |

The variations in infiltration show the differences in rainfall intensity, which is used to determine its significance on hydrogeological conditions. The stages define the conditions per hour. It shows the duration of rainfall before it infiltrated the embankment. The vertical infiltration (rainfall) is only the source of water defined in the analysis. Therefore, in the initial stage, there is no flow of water.

The hydrological parameters reported in this study are flow vector, discharge, pore pressure, and seepage. The change of parameters helps in the identification of the hydro geological condition in each stage.

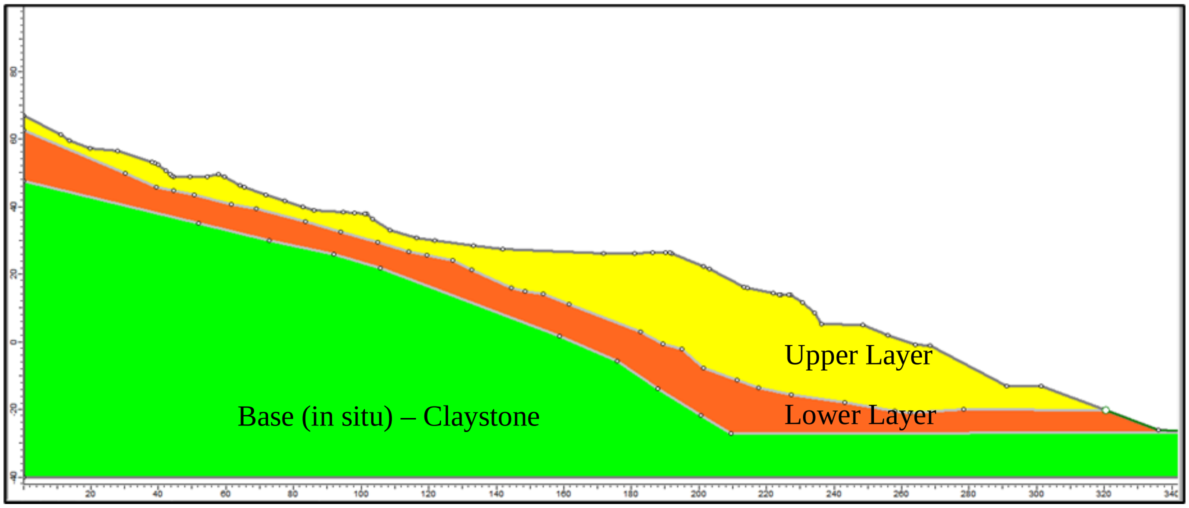


**Figure 3.** The Illustration of the two-dimensional models of analysis.

### *3.1 Evaluation Rainfall*

The daily amount of rainfall was measured at rainfall stations. This study was carried out during the rainy season in order to determine the behaviour of both surface and subsurface water. The measurement results show that the average rainfall intensity is 4 mm/hour, and its peak is 26 mm/hour, which was detected once during the research. The measurement of seepage was carried out at 35 slope locations, as shown in Fig. 4. Therefore, whenever it rains and at every 1-hour interval, it runs out of water or becomes stable at a certain discharge. The seepage debit was discovered to be stable after 12 hours of rainfall. According to the results from this measurement, the average seepage is 200 ml/hour.

The measurement from the rainfall intensity and seepage is shown in Fig. 5. In addition, the seepage debit increases 6 hours after heavy rainfall. It shows that, there is a correlation between rainfall intensity and seepage debit, which is important for slope stability. It implies that no water is retained in the mine waste dump material. However, when there is water excess in the material, it increases pore pressure, which shows that the water in the embankment is completely drained. It occurs when groundwater in the mass of the stack is dried properly, so it is necessary to verify the distribution of grain size from the material. The analysis of grain size distribution is carried out using digital methods such as split engineering software. The samplings of location are carried out at a minimum of 3 points, where each point is approximately 5 x 3 square meters. According to the processed data, the grain distribution ranges from sand to boulder (2-1000 mm), as shown in Fig. 6. The average value of D60 is approximately 100 mm therefore, the material is highly porous.

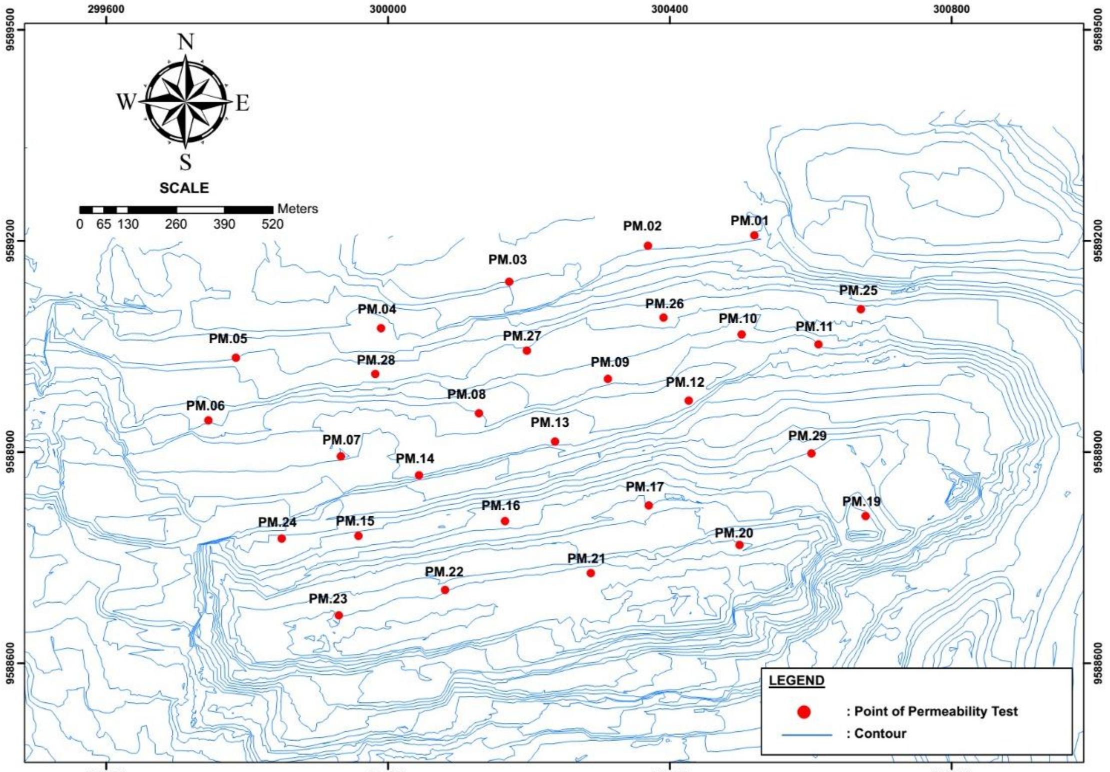


**Figure 4.**Actual rainfall intensity and seepage measurement data.

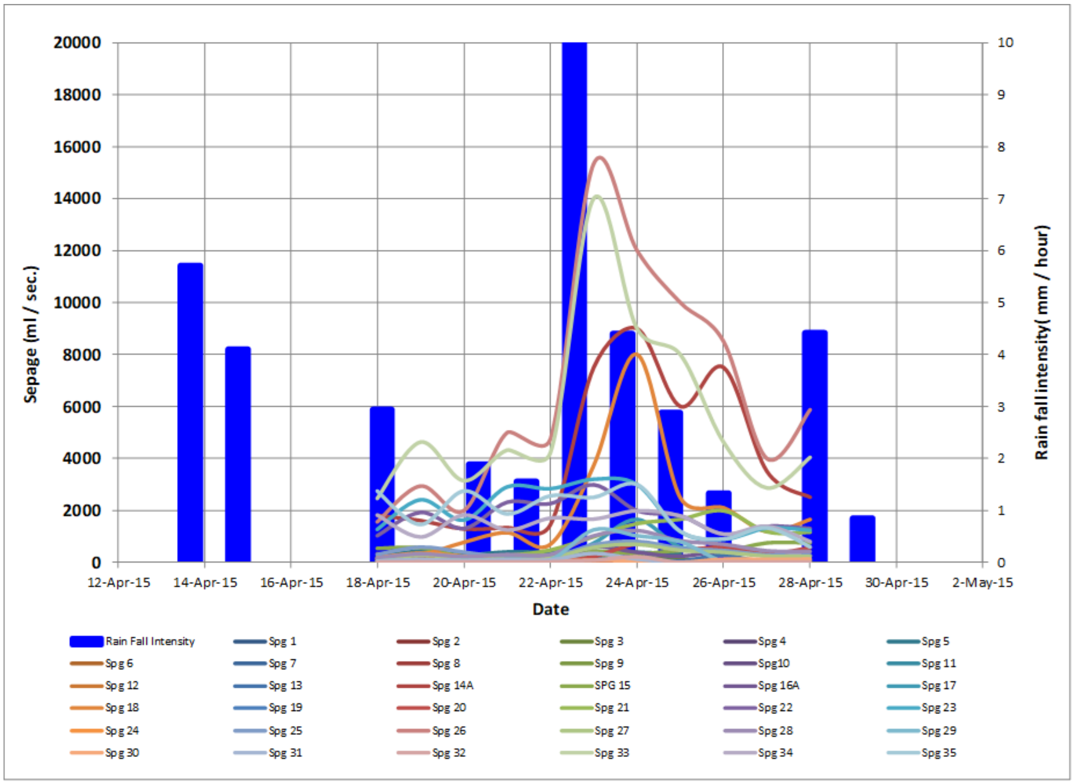
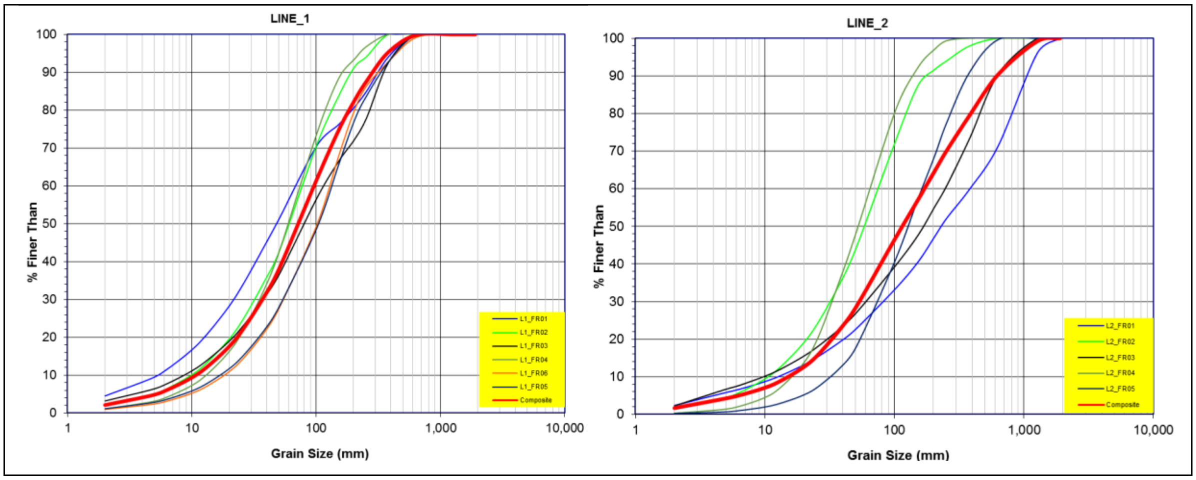


**Figure 5.** The correlation between rainfall intensity and seepage debit at the mine waste dump.



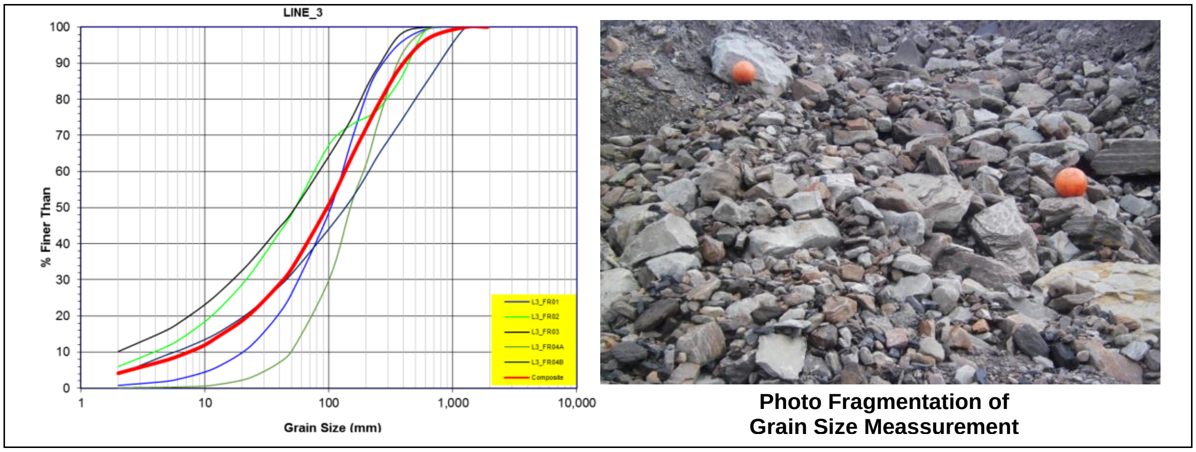


Photo Fragmentation of
Grain Size Meassurement

**Figure 6.**The results from the fragmentation analysis of mine waste dump material, particularly on the top side.

### *3.2Flow Vectors in The Embankment and Significance of Rainfall Intensity*

According to figure 7, the vertical surface infiltration in the embankment is the intensity of the rainfall. Some of the water infiltrate and percolate into the lower layer of the embankment, which functions as a drainage system. The total discharge velocity and the flow vectors in the body of embankment are also shown in fig.7. The right bottom part of the figure shows the discharges through the embankment.

The vectors in the upper part of the embankment are restricted. This condition's occurrence is due to the low hydraulic conductivity in the upper layer of the embankment. Therefore, this limits the percolation of water from the surface to the lower parts of the embankment. However, most of the water flowing through the surface is referred to as runoff water.

There is an insignificant change in discharge due to the increase in rainfall intensity, as shown in Fig. 8. The upper layer's hydraulic behaviour limits the flow of water in the lower part of embankment. It is confirmed by the value of discharge velocity on the upper layer of the embankment shown in Figure 7.

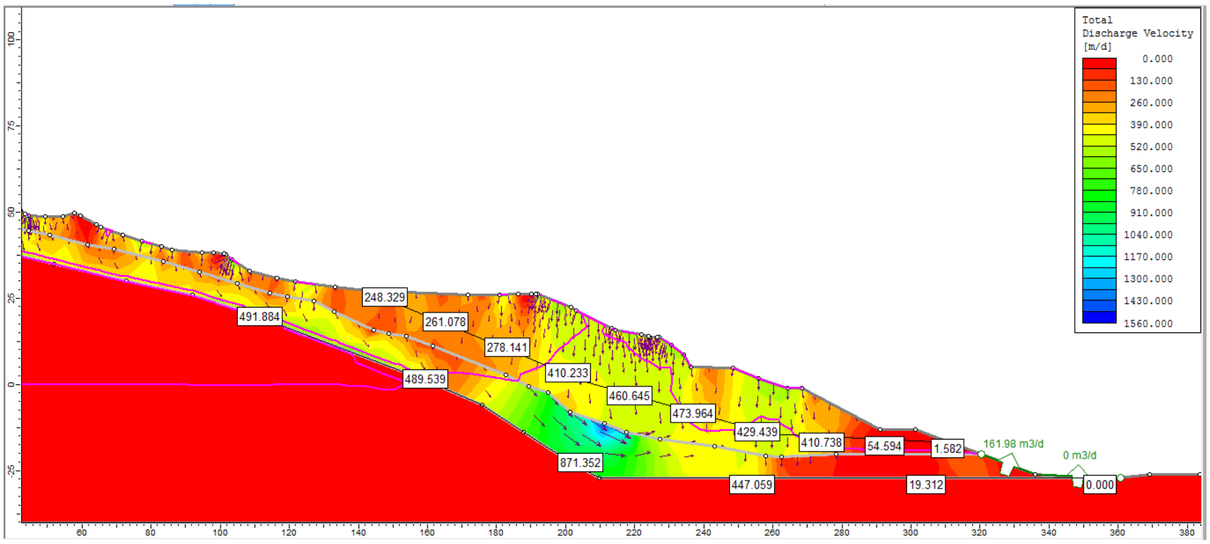


**Figure 7.**Distribution of total discharge velocity in the embankment (showing the vertical surface infiltration).

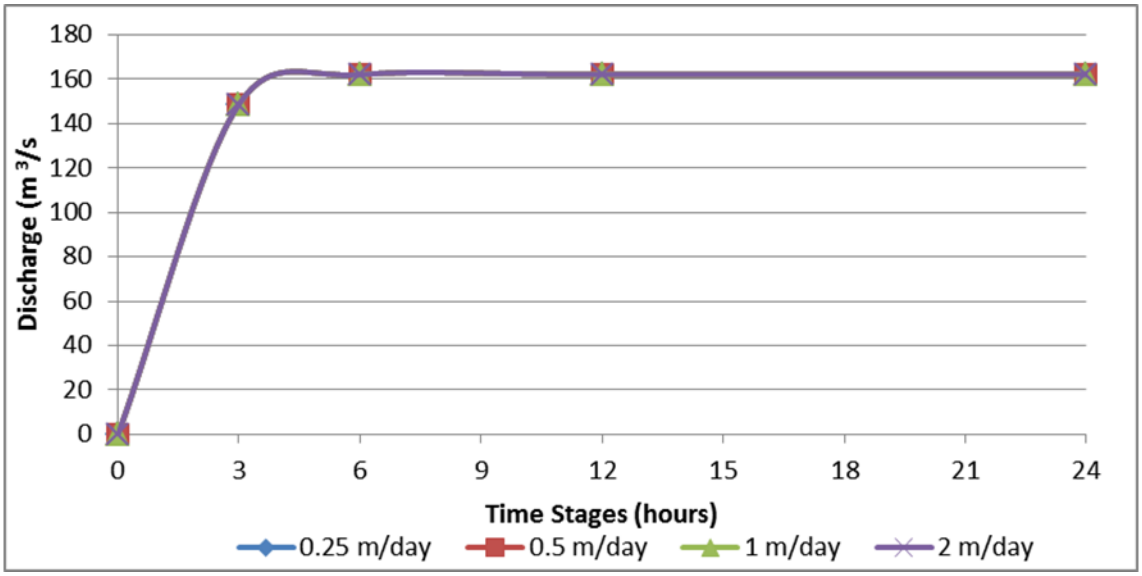


**Figure 8.** Correlation of time stages and water discharges for various vertical infiltration.

The total discharge velocity in the lower layer is significantly higher than the upper layer. The lower layer serves as a drainage system in the embankment. Meanwhile, the upper layer has an extremely low total discharge velocity and hydraulic conductivity. The percolation occurred gradually in the upper layer until it reached the lower layer. However, a significant increase was detected where the conductivity is higher. The following figures show the vertical and horizontal discharges of the embankment section, as shown in Figures 9 and 10.

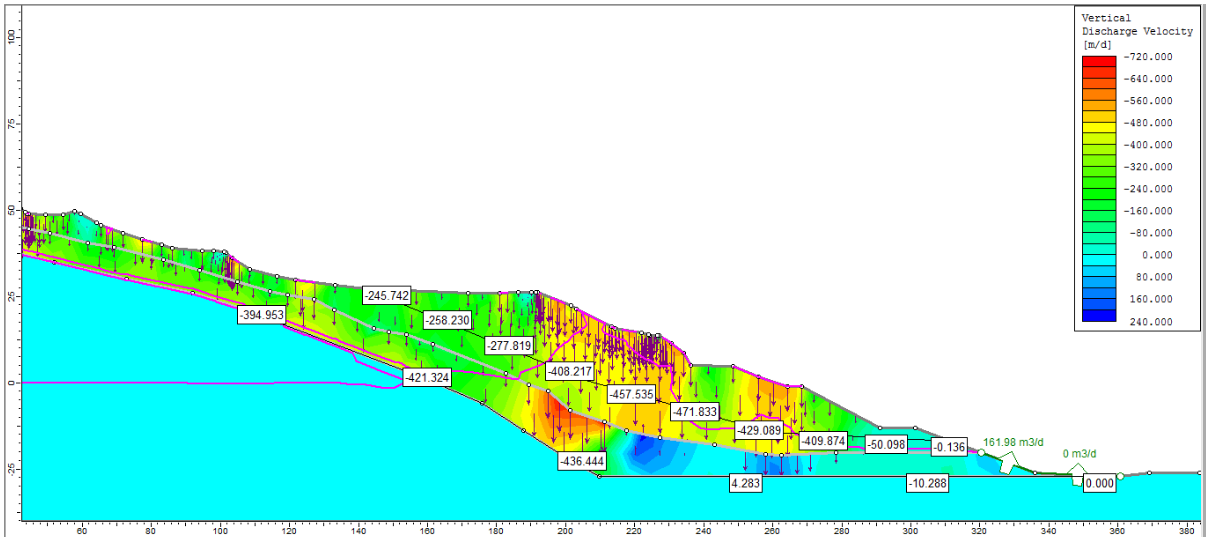


**Figure 9.** Distribution of vertical discharge velocity in the embankment.

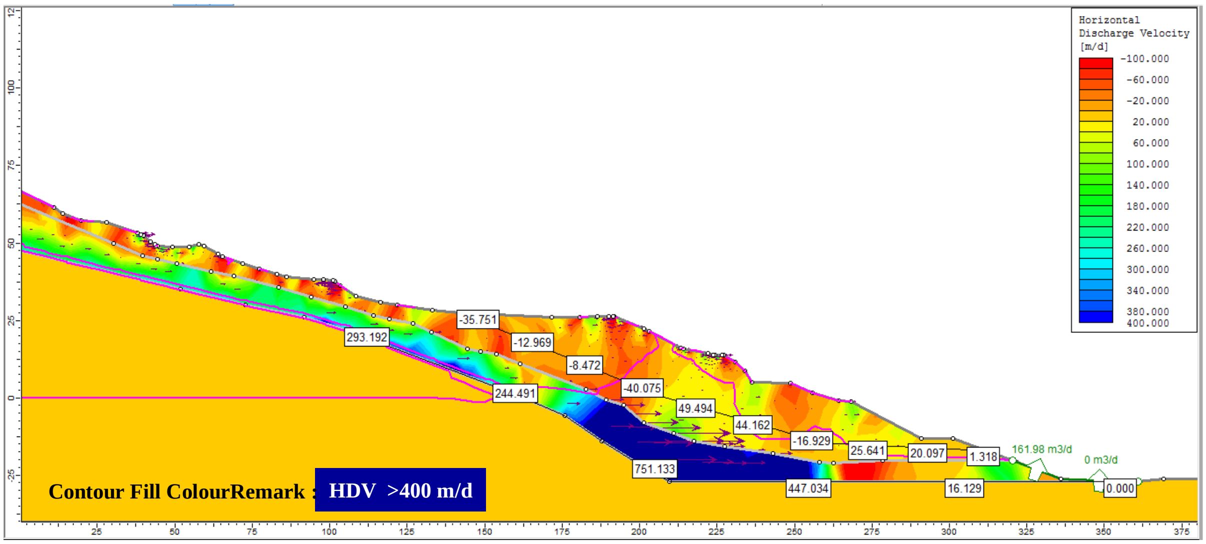


**Figure 10.** Distribution of horizontal discharge velocity in the embankment.

Vertical discharge has more significant effect than horizontal discharge during the percolation process in the upper layer of the embankment. Meanwhile, the discharge in lower layer tends to be horizontal due to restricted infiltration towards the base. It correlates to the hydraulic gradient of the embankment, as it's shown in Fig. 11, where the upper layer has a significant high hydraulic gradient, which is used to predict the discharge velocity in the embankment.

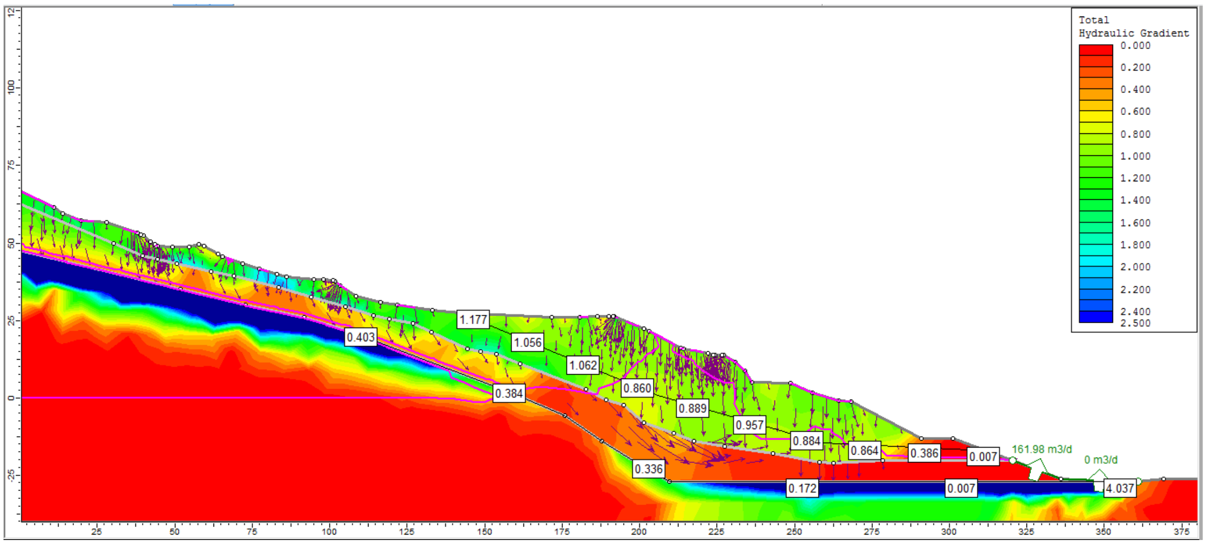


**Figure 11.** Distribution of hydraulic gradient in the embankment.

### *3.3Initial Pore Pressure Build Up and Drainage Characteristics of Lower Layer Embankment*

The section's pore pressure is reviewed by using the query point located on a certain part of the embankment. Figure 8 shows the pore pressure distribution of the embankment on the time stage, 6 hours after the initial rainfall. The query points are created in the contact zone between the embankment and in situ base materials.

Figure 12 shows the correlation of distance among query points (a) between time stages on the horizontal axis (b) against pore pressure in the vertical axis. The value of pore pressure on each of the query points is shown by each vertex of the correlation chart (a), while the values for the different stages are appeared as a single curve because they are relatively equivalent. Consequently, each query point's pore pressure needs to be compared with the different time stages to understand the dynamics of the hydro geological condition (b).

There is an insignificant increasing or changing in the pore pressure, it's due to the infiltration of water after the initial saturation. The only of noticeable increasing in pore pressure occurred in the initial stage because the saturation process was void. The other stages showed a decreasing in pore pressure due to elongated infiltration. It occurred when the water input and output is equivalent. The water balance is reached after the initial stage of 0.125 day (3 Hours) due to drainage caused by the porous and conductive lower layer.

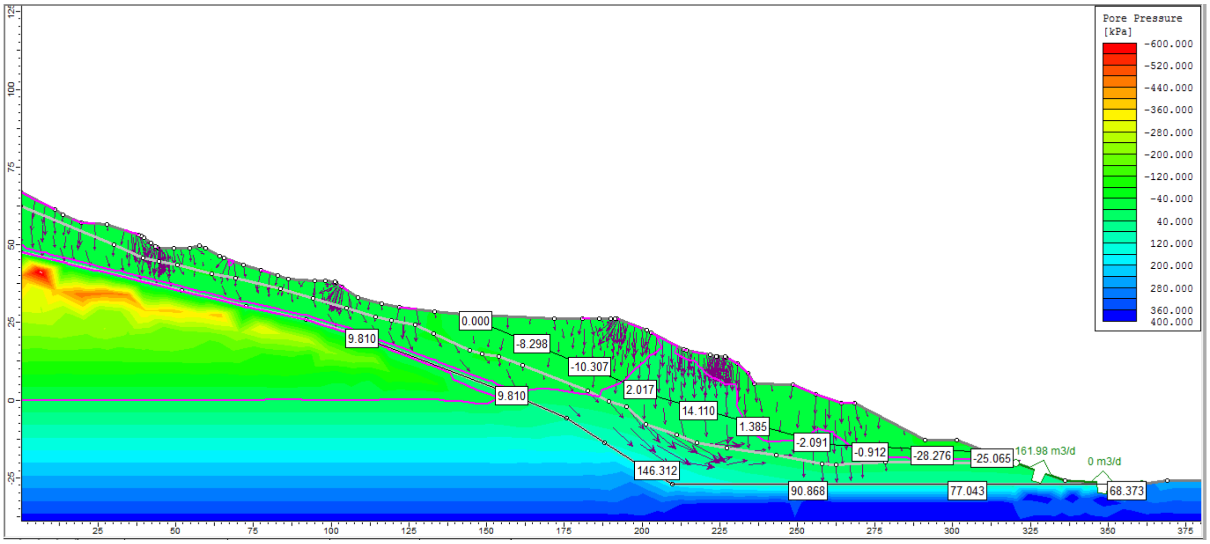


**Figure 12.** Query points on the contact zone between embankment material and in situ based on a cross-sectional pore pressure distribution.

In addition, the increasing in time causes an increasing in the amount of infiltrated water, thereby it causes a rise in its level in the embankment. The saturation and drainage process in each of the stages is illustrated on the two-dimensional distribution of the embankment's volumetric water content, as shown in Fig. 13.

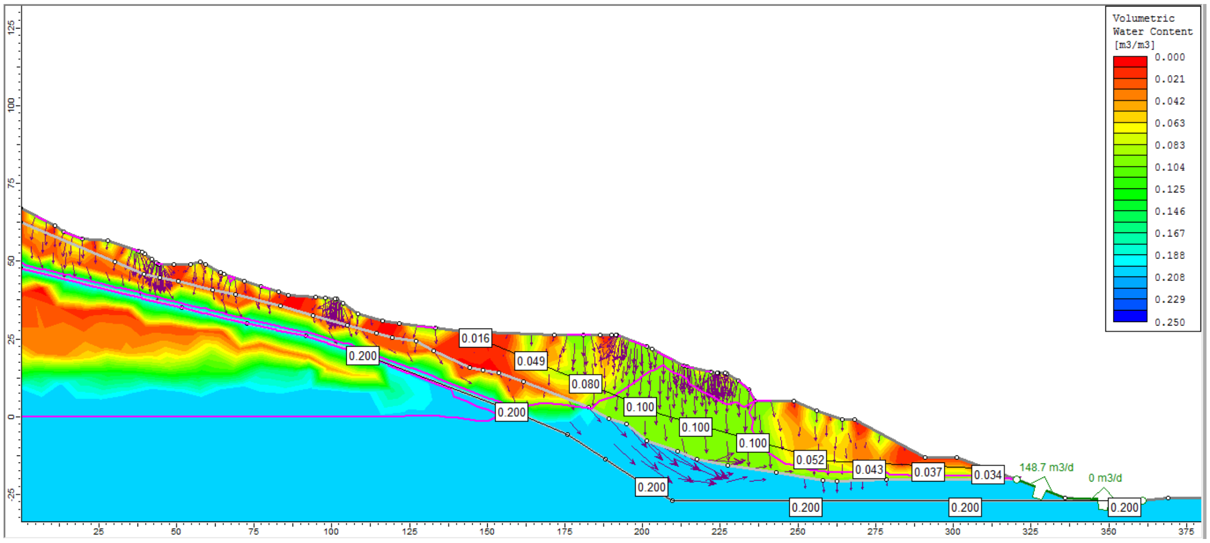


**Figure 13.** Models of volumetric water content in each of the 3-hour stages.

Figure 14 shows a 3-hour stage condition, there was a significant increasing in the saturation process of the material in the initial stage, as well as a large increasing in water content, it’s particularly in the lower layer of the pile top. The water balance starts at this stage.

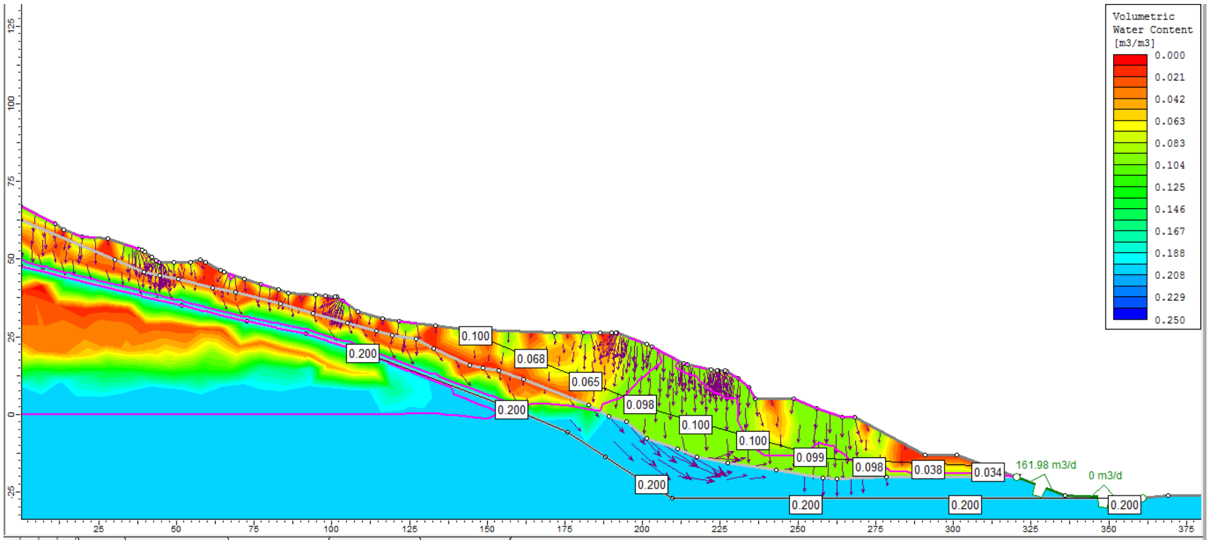


**Figure 14.** Models of volumetric water content on each of the stage 6-hour stage.

Subsequently, there is a decline in the discharge at the bottom layer of the pile from 3-hour to 6-hour stages. The maximum discharge at the bottom layer was reached at this stage, thereby the decreasing subsequent stages.

The maximum bottom discharge is achieved due to the continuation of rainfall, and desaturation kept occurring till the 12-hour stages. This was followed by a gradual increase in moisture content on the top layer of the pile to the 24-hour stage as shown in figures 15 and 16.

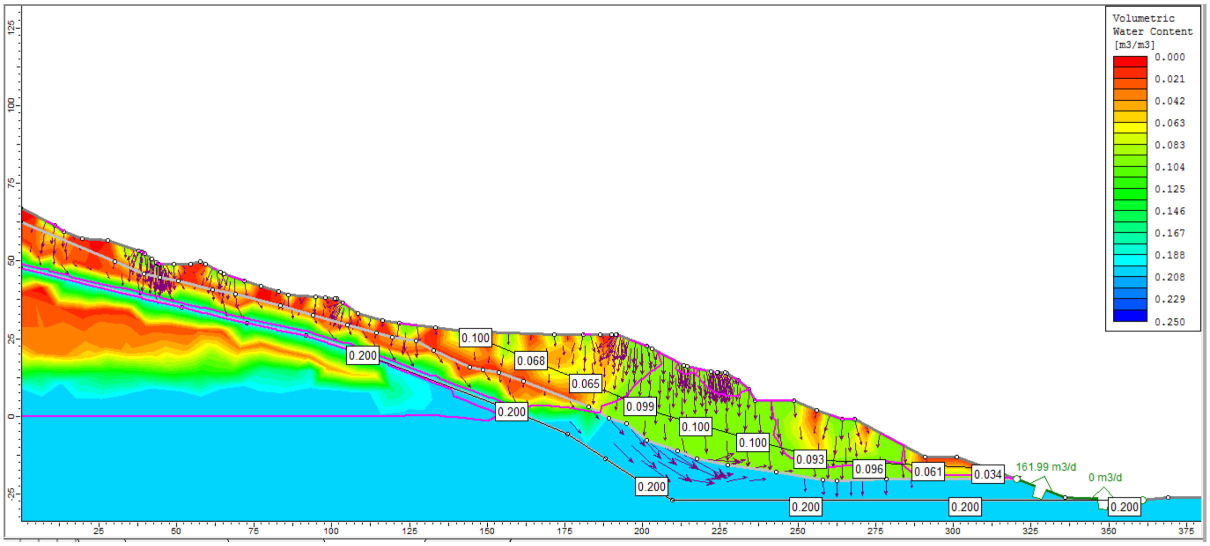


**Figure 15.** Models of volumetric water content on each of the 12-hour stages.

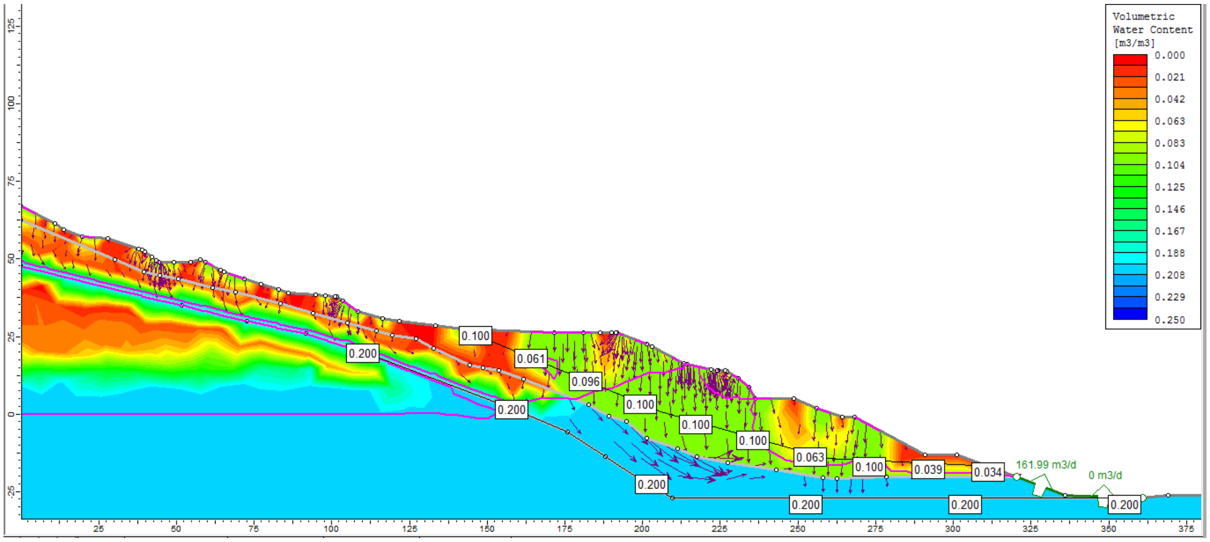


**Figure 16.** Models of volumetric water content on each of the 24-hour stages.

## 4. Conclusion

The groundwater is the major factor in determining the slope stability and safety of the embankment. The water balance in the embankment needs to be maintained to ensure that the hydro geological condition is regulated. In this circumstance, the layering of the material is selectively carried out to ensure the effective performance of the drainage system in the embankment. It is illustrated in the analysis where the hydro geological condition is controlled by the drainage system in the embankment body. The drainage system allows the groundwater to flow through the base of the embankment, which is consisted of coarse-grained materials while the finer and less conductive materials restrict water infiltration. Therefore, the source of water is limited, and the infiltrated water is easily extracted from the embankment. This study shows that the water balance is realized in 3-4 hours after the initial saturation of the embankment. The continuous rain causes the drainage process extracts the excess water; thereby it prohibits further saturation on the embankment.

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