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Dewatering requirements assessment for the Central Kalimantan NCP open pit gold mine

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Corresponding author:
Nico Anatoly
Email Address: nico001@brin.go.id

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Nico Anatoly[1], Siti Rofikoh[2]

[1]National Research and Innovation Agency, Jakarta, Indonesia
[2]Master Program of Groundwater Engineering, Bandung Institute of Technology, Indonesia

ABSTRACT One of the most critical aspects of open pit mining is the dewatering and mine drainage systems. The NCP Open Pit Gold Mine is located in Central Kalimantan. This study area has a range of rainfall intensities and durations from moderate to heavy. Good dewatering is required to manage runoff water and reduce runoff from entering the pit and mine front loading. The study used daily rainfall intensity data from 1994 to 2018. Using the Mononobe Method, the hydrological data for this area were evaluated by determining the value of the rainfall intensity plan. According to the evaluation of rainfall data from 1994 to 2018, the research area saw a rainfall intensity of 86.23 mm/day over a two-year return period. The majority of water extracted from mines is from precipitation and runoff rather than groundwater. An open channel was made around the open pit, flowing water naturally into the sump to reduce water entering the mining area. The water was pumped into the settling pond with 520 m^3/hour and 780 m^3/hour capacity pumps.

INTRODUCTION

As open pit mines grow in size, water evaluation and management become increasingly important. The overall objective of an open pit dewatering and mine drainage system is to divert or remove water from the excavation to improve operational conditions, minimize mining costs, and enhance safety performance (Beale and Read, 2014). Mine drainage systems refer to the process of preventing water from entering or draining water from the mine face (Cahyadi et al., 2018). This practice is designed to avoid mining operations being interrupted by excessive volumes of water, particularly during the rainy season (Syarifudin et al., 2017). In hydrology studies, surface water, groundwater, hydrometeorology, limnology, and cryology are included (Endhrianto and Ramli, 2013). The mining technology used is open pit mining, which results in a vast void where both surface runoff and groundwater can accumulate. Dewatering and mine drainage systems must be designed optimally to prevent water from pouring into the pit (Gautama, 2019). One of the requirements for mining activities to run as planned is to prevent water in front loading and mining areas. (Cahyadi et al., 2020). Based on the mining plan design at the open pit NCP, the area of the mine opening to be opened is 146,510 square meters with a mine opening diameter of 744 meters. Based on the data, the catchment area in the NCP area was 0.3 km^2. Mineralization at the open pit NCP is found in the form of veins.

Location

The research area is PT XYZ Gold Mine (Figure 1) which is accessible via small plane from Balikpapan (approximately an hour of flight time) and Palangkaraya (approximately 40 minutes) or by road from Balikpapan (10–15 hours) and Palangkaraya (9–11 hours).

Figure 1. Map of the PT XYZ Gold Mine location

Geology and Hydrogeology

The research area is located in the eastern section of the Sundaland Continent, which is bounded on the east by the Meratus Mountain and the north by the Kucing Mountains. The Meratus Mountains were developed during the Cretaceous along the south-eastern edge of the Sundaland Continent as a result of subduction activities (Figure 2). Borneo Island itself is the product of southwest trending accretion, as demonstrated by the existence of an ophiolite zone in the island's southwest corner. A similar process occurred in West Sulawesi and East Kalimantan, where accretion zones formed at the Sundaland Continent's margins before the Cenozoic era (Hamilton, 1979; Wakita et al., 1998). The research area's geological context is composed of tertiary volcanic rock, located in the eastern section of the Sundaland Craton (Simmons and Browne, 1990). The tertiary volcanic rock in this area consists of lava, tuff, and volcanic breccia with a calc-alkaline composition. Basalt with fine grain size is typically exposed as a result of the eruption's final phase. Additionally, tertiary sedimentary strata are exposed in the northern and southern portions of the geographic area. Sedimentary rocks of the Tertiary period include shale, sandstone, and limestone.

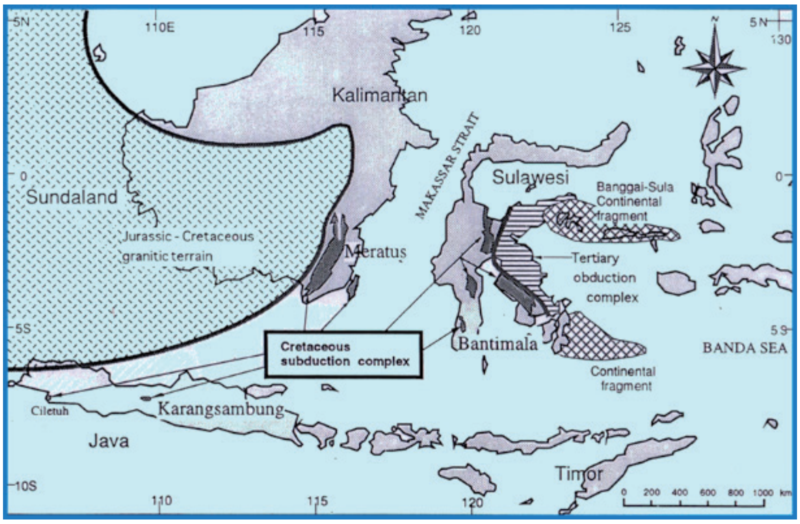

Figure 2. Distribution of Cretaceous Subduction Complexes in Kalimantan, Sulawesi, and Java (modification of Wakita et al., 1998).

The morphology of the NCP open pit reveals an undulating mountain range ranging in elevation from 200 to 300 mRL. The NCP deposit is made up of multiple steeply dipping veins with varying orientations (Figure 3). At least two key structural factors impact the development and mineralization of veins. The principal structure is the east-west vein, whereas the northwest-southeast vein is the dilational jog opening. Six major lithology units have been identified: soil, pyritic matrix hydrothermal breccia, multistage quartz veining, basalt, volcanic breccia, and andesitic tuff series.

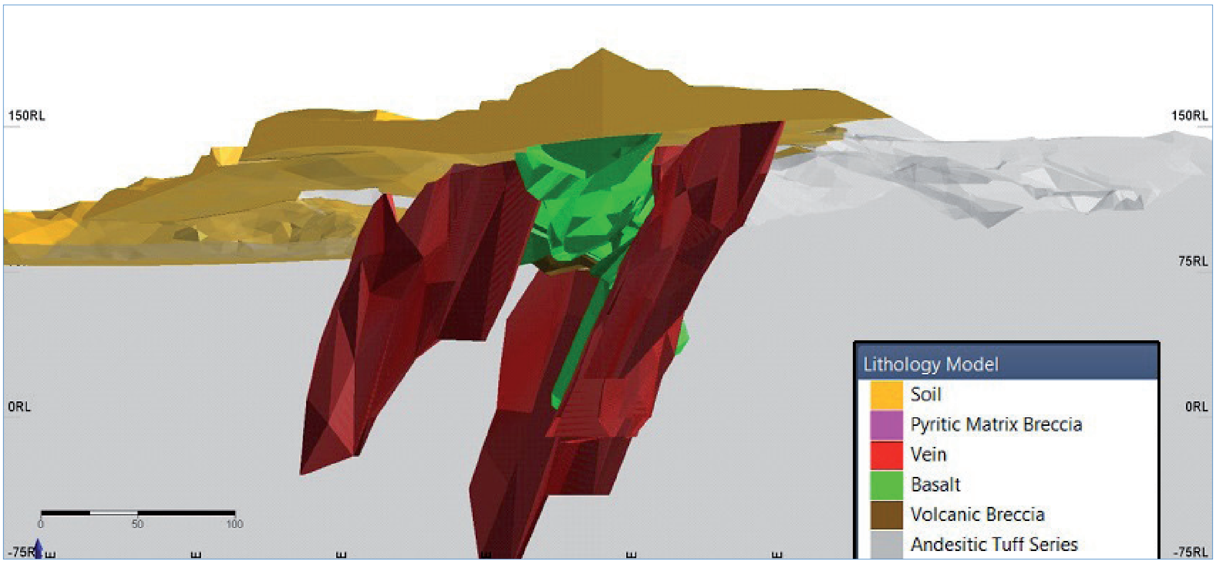

Figure 3. 3D lithology model of NCP deposit facing WNW N300°E (Exploration Department PT XYZ Gold Mine, 2018).

Soil covers almost the entire area of the NCP deposit (Figure 3). The unit is described as a mixture of quartz scree and highly weathered soil from eluvial deposits. The thickness of this soil varies between 1 and 7 meters. The pyrite matrix hydrothermal breccia is only found in the middle of the mineralization. There are angular polymict clasts in a dark gray matrix inside the unit. The quartz veining stage is the primary source of gold in the NCP deposit, and it is mostly hosted in andesitic tuff. Cross-cut veinlets or veins (stockworks, hydrothermal breccia, banded vein, or vein breccia, depending on the percentage of veinlets or veins in the rock) are the most common type of veining. Quartz, carbonate, ginguro which represent ore minerals with commonly dark gray to black (Tharalson et al., 2019); adularia, amethyst, and chlorite are the main minerals in the veining. Basalt can be found all over the central and western parts of the NCP, where it was deposited as lava lenses mixed with andesitic tuff. It is dark green to black, ferromagnetic, inequitable, porphyritic, and has medium-sized plagioclase as the main phenocryst. It has been hydrothermally changed to have mostly weak chlorite-pervasive strong carbonate-weak clay-hematite alteration or pervasive clay-carbonate-chloritic, moderately medium plagioclase-phyric, very fine grain groundmass, plagioclase and ferromagnesian. Volcanic breccia is composed of two distinct types of units: monomict and polymict. A monomict is a breccia in which all the components originated in the same type of rock. A polymict is a breccia in which the components originated in two or more rocks of differing compositions. Andesitic tuff is a volcanic ash tuff composed of andesite, lithic tuff, crystal tuff, and ash tuff with gradational contacts between each unit. The primary host rock for vein mineralization is andesitic tuff.

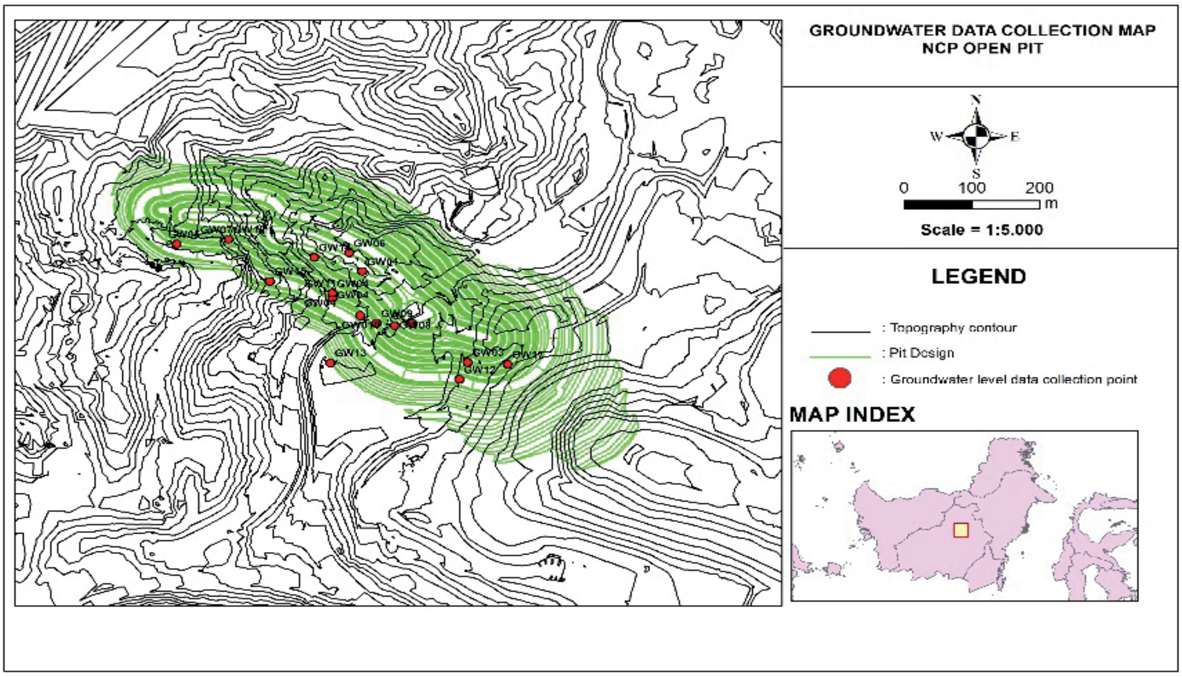

Figure 4. Groundwater data collection map at NCP Open Pit.

Since 2016, exploration boreholes have been used to study the groundwater conditions in the NCP area. From December 2016 to March 2017, this study used a series of piezometers installed in vertical piezometers or exploration boreholes to determine the groundwater level in exploration boreholes. The groundwater wireframe model was then interpreted using contour lines, which show the depth of each water level and link points with the same groundwater level. It is acknowledged that the majority of water levels observed throughout the drilling process do not reflect the continuation or variation of the water table. A conceptual hydrogeologic model was established based on groundwater system data obtained from field investigations (Wu et al., 2019). The groundwater wireframe model shall be updated regularly when new data becomes available, including seepages that may occur during starter pit or major pit development excavation. Groundwater levels were discovered at various depths below the ground surface, ranging from 0 m to 14.02 m (Figure 4). In general, groundwater in NCP was judged relatively shallow based on actual measurements. The data was then processed to establish the pattern and direction of groundwater flow into groundwater table contours that depict the area of concern's condition. According to the findings, the eastern section of the NCP open pit has a higher groundwater level than the western section of the research region. In Figure 5, groundwater arrows showed that it moves from east to west and also from southeast to northwest, which suggests that natural topography affects groundwater flow patterns. All mines that were excavated below the water table need some form of dewatering (Read and Stacey, 2011).

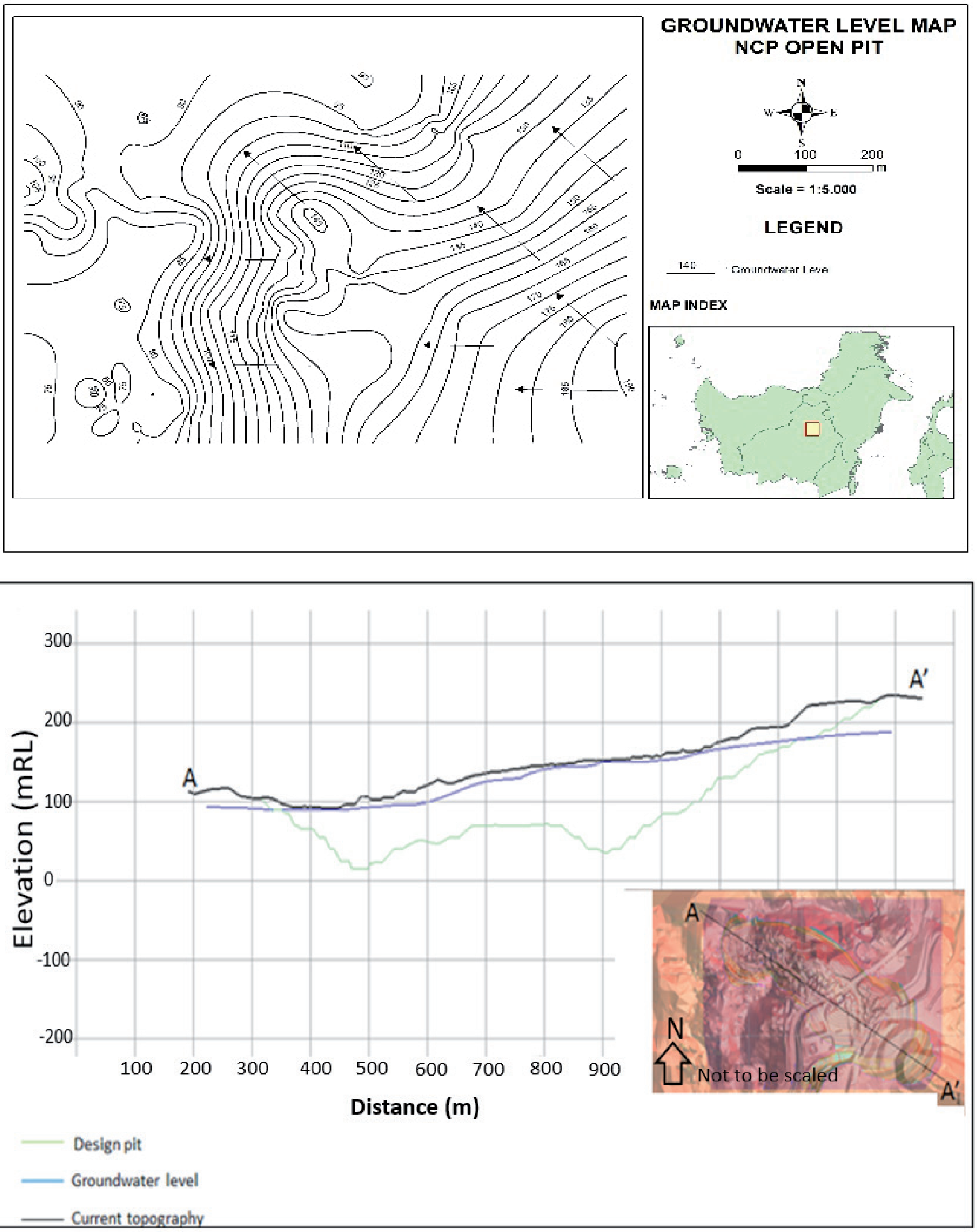

Figure 5. The output of NCP open pit groundwater level map and cross-section overlay topography, pit design, and groundwater level of NCP open pit.

The consequences of mining below the water table fall into two general categories: (i) groundwater inflow and the presence of saturated rock lead to reduced operational efficiency and increased mining costs; and (ii) groundwater has a detrimental effect on slope stability (Dowling et al., 2011). Additionally, slug permeability tests were conducted on chosen piezometers to provide an idea of bedrock permeability ranges. The Bouwer and Rice methods (1976) were used to evaluate the test results. Slug tests are designed to cause an instantaneous displacement of the water level in a groundwater monitoring well and to assess the well's subsequent recovery as a function of time. There are two ways to do a slug test: one is to make the water level rise quickly (called a falling head test), and the other is to make it fall quickly, which is called a rising head test. This slug test employs the falling head approach. The Bouwer and Rice methods were used to analyze the test results. This method is based on fitting a straight line to the normalized head (Ht/H0) vs. time and entails computing the slope of the straight line fit to the response data. The hydraulic conductivity is then estimated using the slope. Hydraulic conductivity is the ability of a rock to conduct the groundwater at a certain velocity (Cahyadi et al., 2021). Based on the slug test result, the hydraulic conductivity in this research area is 1x10^{-7} m/s (Figure 6).

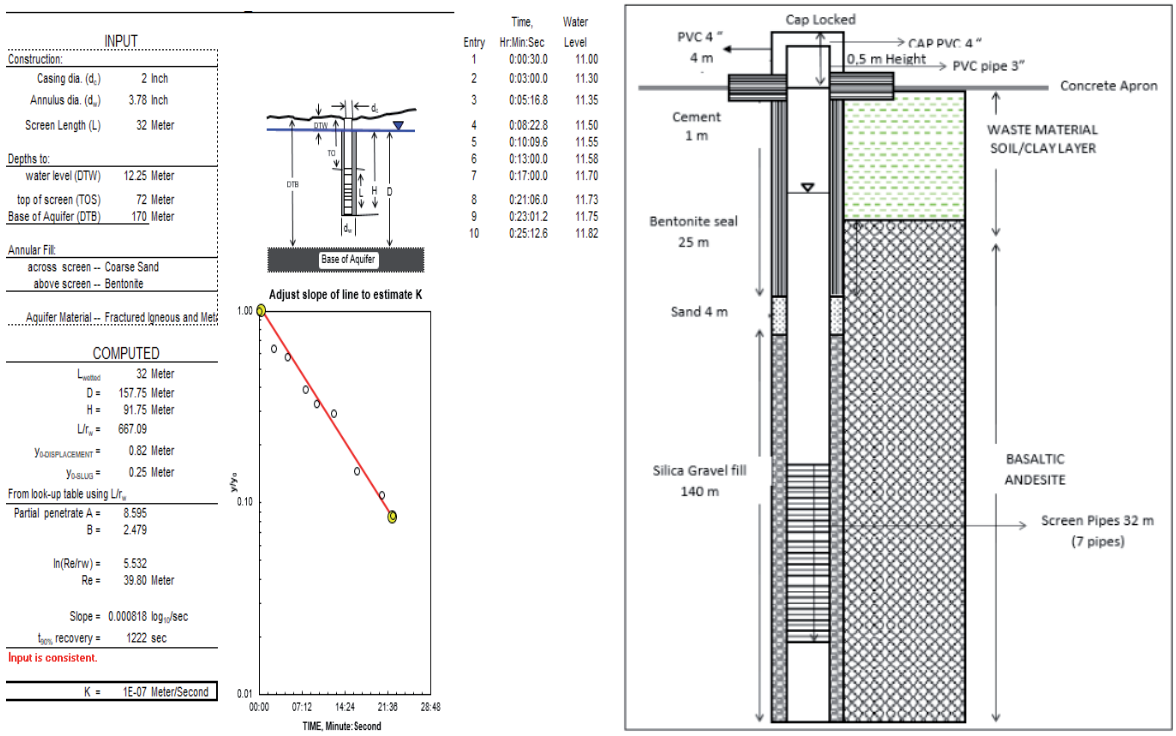

Figure 6. Hydraulic conductivity and piezometer construction result.

METHODS

The methods for predicting mine water inflow can be divided into two general categories: deterministic analysis methods and qualitative analysis methods (Liu et al., 2022). The research was conducted quantitatively (Dewi et al., 2021). When data has been acquired in the form of quantitative data or other sorts of data that can be quantified and analyzed using statistical techniques, quantitative research can be used. This study used two data collection methods: primary data were gathered directly during the study, and secondary data were gathered through firm archives and literature.

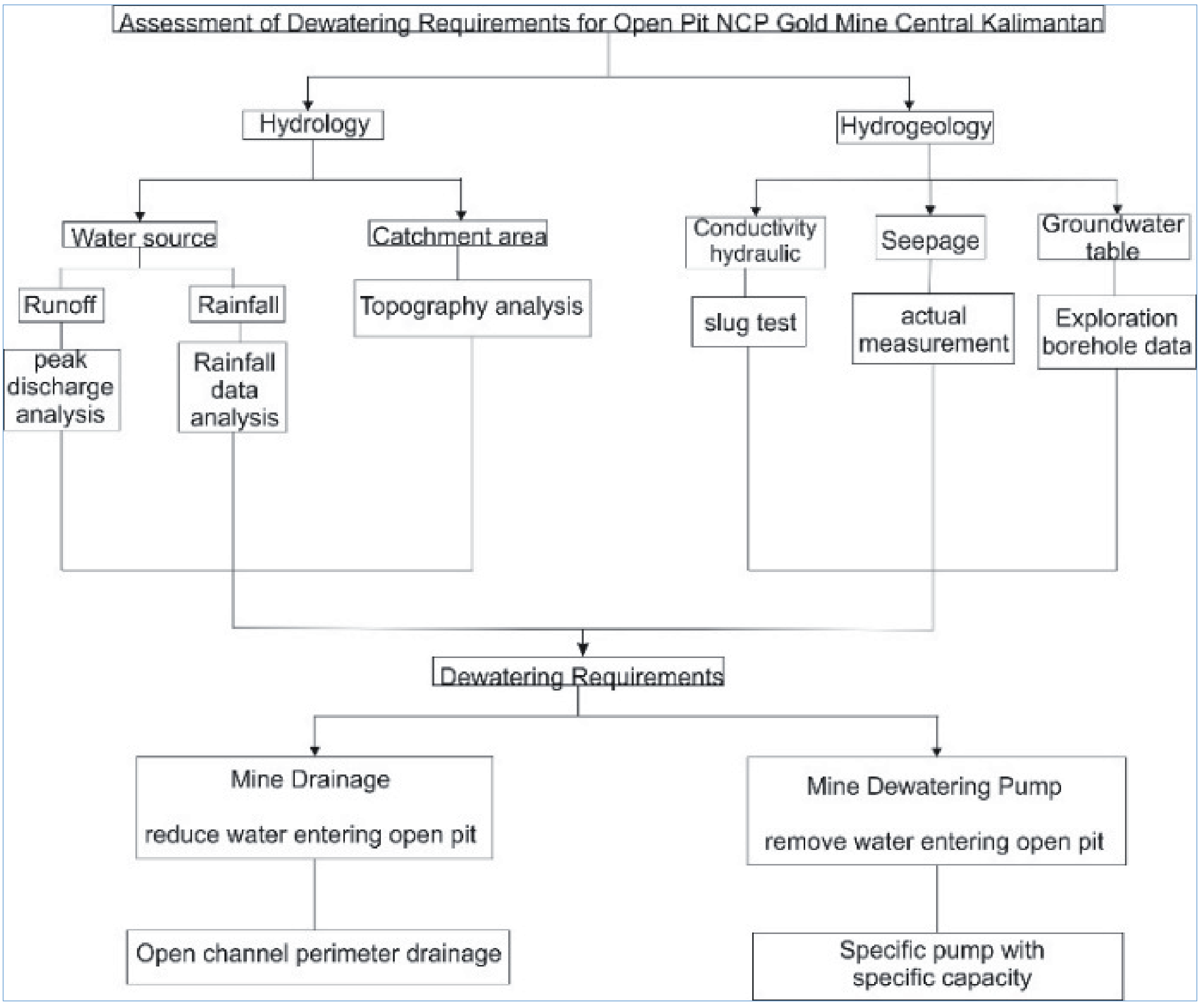

Figure 7. Flow chart assessment of dewatering requirements.

Mining drainage system planning was calculated based on the debit of water entering the front site of mining activities affected by the catchment region (Prahastini and Gautama, 2012). The catchment area is the area of the watershed defined by the highest elevation point, so the shape is a closed loop polygon with a pattern appropriate to topographic circumstances and following the direction of water flow. Some characteristics, such as runoff, rainfall, catchment area, seepage, and hydraulic conductivity, must be calculated in order to design an effective dewatering system (Figure 7).

Rainfall and evapotranspiration analysis

The amount of rainwater that falls on a unit area is measured in millimeters and is known as rainfall. The rainfall was measured with the help of rainfall measurement equipment. Rainfall data was required for the development of water usage planning and flood control designs, and this data was in the form of average rainfall across a defined area rather than precipitation at a specific place. The Gumbel equation was used to calculate the rainfall, and the results are as follows (Gumbel, 1941):

$$Xt = X + k.S \tag{1}$$

$$k = (Yt - Yn)/S \tag{2}$$

where:
Xt = Estimated value of the rainfall plan (mm)
K = Reduced variate factor
X = Rainfall average (mm)
Yt = Reduced variate
Yn = Reduced mean
S = Standard deviation
Sn = Reduced standard deviation

Evapotranspiration is a term that refers to a combination of two other processes: evaporation and transpiration. Evaporation is the process by which water evaporates or is lost from soil and water bodies (abiotic), whereas transpiration is the process by which plants release water through respiration and photosynthesis (biotic). Evapotranspiration is the term used to describe the combination of two distinct processes in which water is lost from the soil surface via evaporation and from plants via transpiration (ET). Evapotranspiration is the collective term for the process of water evaporating from the vegetated soil surface into the atmosphere. Thornthwaite's formula, which uses the monthly heat index, is one example of a formula for calculating potential evapotranspiration.

$$ET = 1{,}62\ (\frac{10.Tm}{I})^{a} \quad (3)$$

$$I = \sum_{m=1}^{12} (\frac{Tm}{5})^{1{,}514} \quad (4)$$

$$a = 675.10^{-9} I^{3} - 771.10^{-7} I^{2} - 179.10^{-4} I + 492.10^{-3} \quad (5)$$

Where:
Et = Monthly potential evapotranspiration (cm)
Tm = Monthly mean temperature (°C)
I = Heat index for the 12 months in a year
a = Constanta

Rainfall intensity

Rainfall intensity is the amount of rainfall per unit period that is relatively brief, usually measured in millimeters per hour. The number of raindrops in 1 (one) hour was computed using a partial series, i.e., rainfall data in one hour. Rainfall intensity is a formula for the amount of rainfall that is inversely related to the time of occurrence. In rainfall measurement, millimeters are the amount of rainfall collected on a surface area of 1 (one) m^2 at the height of 1 (one) mm. The Mononobe method is used to calculate rainfall intensity (I) as follows:

$$I = \frac{R_{24}}{24} \left(\frac{24}{t}\right)^{2/3} \quad (6)$$

where:
R_{24} = Rainfall per day (24 hours)
T = Concentration time

Water discharge

Runoff water is any water that moves because rainwater moves from a higher elevation to a lower elevation before it reaches a stream or river. The runoff that came into the pit was calculated based on the concentration time, rainfall intensity, runoff coefficient, and catchment area (Islamiaty et al., 2021). A catchment area is an area or region boundaries of rain catchment determined from the points of highest elevation of the surrounding area that forms a closed polygon, with the design adjusted according to the topographic conditions and following the direction of the water flow (Adnyano and Bagaskoro, 2020). The runoff debit was calculated using the rational equation (Dewi et al., 2021):

$$Q = 0{,}278\ C\ I\ A \quad (7)$$

Where:

Q = Maximum debit for runoff (m^3/s)

C = Runoff coefficient

I = Rainfall intensity (mm/hour)

A = Catchment area (km^2)

In 2018, a measurement of the actual discharge was done based on the fact that groundwater was coming in from the pit walls.

Dewatering and mine drainage system

An open channel system was used to create excellent dewatering and mine drainage system. This system is designed to drain water into a settling pond and sump. The settling pond and sump dimensions must be compatible with the hydrological and hydrogeological characteristics of the mining area to control water issues that could jeopardize the sustainability of mining operations. The Manning formula is used to calculate the size of an open channel in a mine drainage system (Fitri et al., 2018).

$$Q = VA = \left(\frac{1}{n}\right) A R^{\frac{2}{3}} \sqrt{S} \quad (8)$$

Where:

Q = Debit flow (m^3/s)

V = The speed of flow (m/s)

n = Mannings coefficient

S = Slope open channel

R = Hydraulic spokes (m)

A = Cross-sectional area (m^2)

Water and mud are temporarily stored in the sump until they are pumped out of the mine (Rinaldi, 2016). Sumps are classified into two categories: permanent sump and temporary sump. Permanent sumps are areas that are used during mining and are normally immobile. While temporary sump pumps operate for a limited period and frequently relocate. These sumps are typically used to collect runoff and seepage from the soil layer being excavated and are situated close to the permanent sump. The sump area was calculated by maximizing the amount of water entering the mine minus the amount of water that could be pumped out. The sump's dimensions are inverted trapezium in shape, making it simple to fabricate and ideal for use using field-available digging and loading tools. The calculation is performed using the frustrum of the cone equation, which has a substantially lower error value and serves as the foundation for all three-dimensional building computations.

The appropriate pump selection, particularly for dewatering activities, is a critical component of mine drainage system design. Overcoming mine water is contingent upon the accuracy with which the volume of mine water is calculated, the dimensions and placement of the drainage channel design, as well as the capacity and number of pumps used. The location and quantity of pumps will be adjusted based on the calculations. The capacity and number of pumps are based on how much water the pump can move, how high it can go, how much power it has, and how much it costs (Gultom et al., 2018)

RESULTS AND DISCUSSION

Rainfall and evapotranspiration analysis

Before determining the planned rainfall, the calculation required determination of probable maximum precipitation (PMP). The study used daily rainfall intensity data from 1994 to 2018, represented in Figure 8.

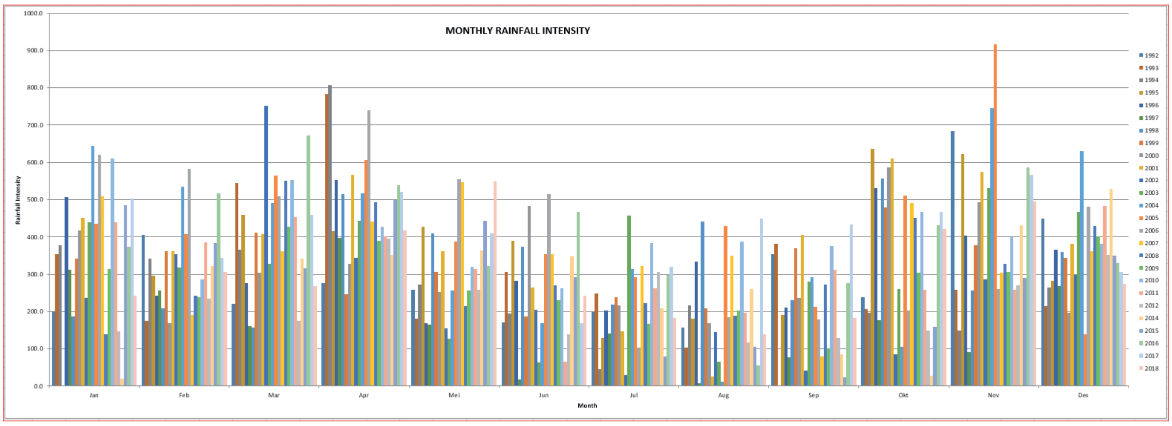

Figure 8. Rainfall intensity data from 1994 to 2018.

The PMP calculation is based on rainfall measuring point data and processed using the Hersfield Statistical method; the data used is maximum annual rainfall data (maximum daily rainfall in one year). The results of the calculation of the Probable Maximum Precipitation using the Hersfield statistical method are shown in Table 1.

Table 1. Probable maximum precipitation calculation

Measure point	*Outlier*	PMP	Km	Xn	Sn
NCP	149.00	170.34	2.48	95.17	30.28

Where:

Km = Function value of rain duration and annual maximum daily average rainfall

Xn = Annual maximum rainfall data average (mm)

Sn = Standard deviation of annual maximum daily rainfall data.

From the table above, it can be seen that the outlier value is the highest rainfall value that has ever occurred. The resulting PMP value is the maximum value of rainfall that may occur in one day, and it is believed not to be exceeded. PMP is generally used to estimate the Probable Maximum Flood (PMF) as a reference for flood management planning. The statistical analysis shows that the type of distribution that best fits the maximum daily rainfall data distribution in this study area is a normal distribution. The results of the design rainfall frequency analysis for various return periods are shown in Table 2.

Table 2. Rainfall frequency analysis for various return periods

Return periods (Year)	Rainfall design (mm/days)
2	86.23
5	110.64
10	123.43
25	135.93
50	145.81
100	153.95
1000	176.04

Using temperature data from 2018, the Thornthwaite method was used to calculate evapotranspiration. The result of evapotranspiration can be seen in Table 3.

Table 3. Rainfall intensity in various return periods

Month	Temperature (˚C)	Evapotranspiration (cm)
January	26.8	13.757
February	26.5	13.14
March	27	14.146
April	27.5	15.198
May	27.8	15.854
June	27.5	15.167
July	27.3	14.738
August	27.3	14.749
September	27.8	15.887
October	27.9	16.151
November	27.6	15.485
December	27	14.184

Rainfall intensity

To get the hourly rainfall intensity from the daily rainfall data, the Mononobe formula was used. The results of the analysis for the planned rainfall intensity with a certain time unit are shown in Table 4.

Table 4. Rainfall intensity in various return periods

Duration (Minutes)	Rainfall intensity for various return periods (mm/hour)						
	2	5	10	25	50	100	1000
5	148.45	203.59	240.11	286.24	320.47	354.44	466.70
10	93.52	128.26	151.26	180.32	201.88	223.28	294.00
15	71.37	97.88	115.43	137.61	154.07	170.40	224.36
20	58.91	80.80	95.29	113.60	127.18	140.66	185.21
30	44.96	61.66	72.72	86.69	97.06	107.34	141.34
60	28.32	38.84	45.81	54.61	61.14	67.62	89.04
120	17.84	24.47	28.86	34.40	38.52	42.60	56.09
240	11.24	15.41	18.18	21.67	24.26	26.84	35.34
300	9.69	13.28	15.67	18.68	20.91	23.13	30.45
720	5.40	7.41	8.74	10.42	11.66	12.90	16.99
1440	3.40	4.67	5.51	6.56	7.35	8.13	10.70

Catchment area

Water management has become an integral part of the mining cycle and often requires similar attention and maintenance as all other mining systems and equipment (Beale, 2018). The condition of the catchment area was open land of an ex-mining area, so the runoff coefficient was 0.9 (Gautama, 2019). Surface water from the catchment area flowed into the mine site in the form of runoff water. From the result of data processing of the topography in the study site, the possible direction of the runoff was known by looking at the highest elevation at the perimeter of the pit. Based on the data, the catchment area in the NCP area was 0.3 km^2 (Figure 9).

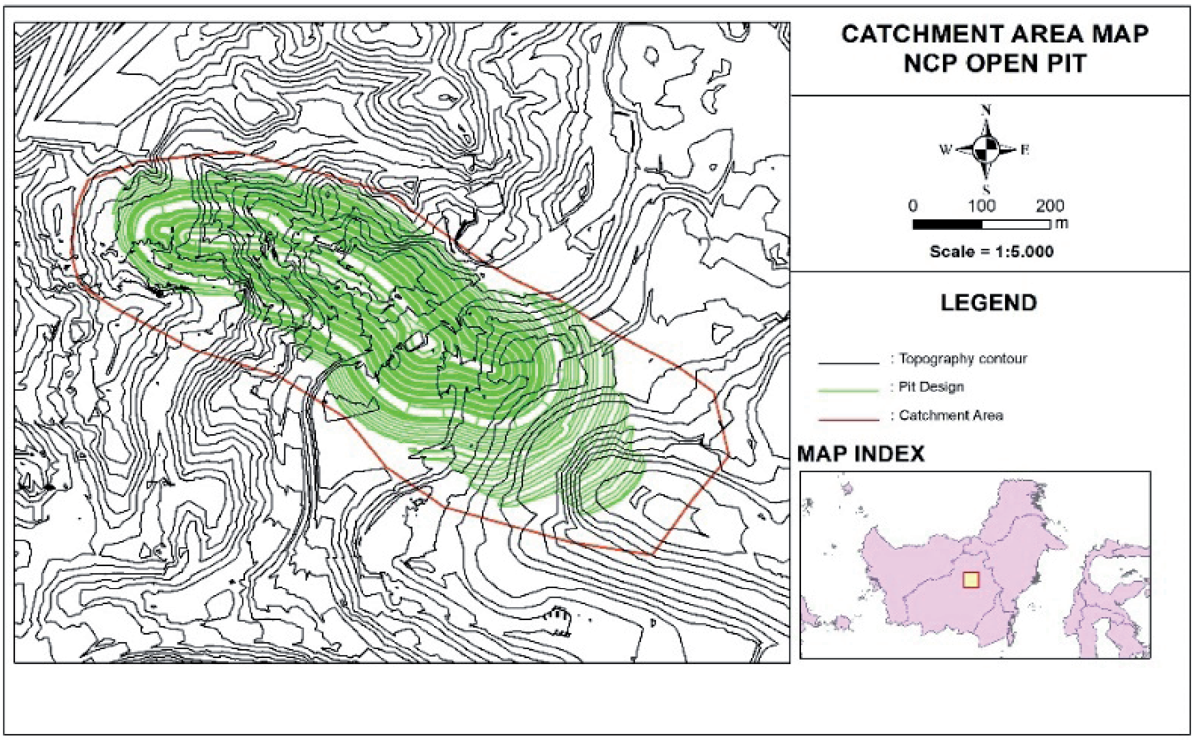

Figure 9. Catchment area map.

Water discharge

Determination of runoff coefficient by estimating slope and land cover. The value of the runoff coefficient (C) for the technical study of the drainage system was 0.9. Maximal runoff debit was rainwater that had been planned and estimated in a catchment area to enter the mine site. The debit calculation of the runoff that will enter the sump using rational equations was 0.72 m^3/s.

As one of the critical activities, dewatering requires a good monitoring process to achieve excellence dewatering and cost-efficient dewatering (Herawati et al., 2019). Most of the water pumped from mines comes from precipitation and runoff rather than groundwater. The host rock and the structural irregularities of the rock are not considered to be capable of producing water. Based on the actual measurement results, the groundwater discharge entering the NCP mining area is around 10 liter/ second. The measurement of groundwater discharge was carried out by the direct measurement method of groundwater seepage that appears on the mine walls and then converted into one flow using the open channel method, and then the actual discharge was measured. Most of the water pumped from the NCP pit comes from rain and runoff rather than groundwater due to the relatively massive rock conditions.

Dewatering and mine drainage system design

Using rational calculations, the amount of runoff that will enter the sump was calculated to be 0.72 m^3/s. The perimeter drainage system was designed to be passed by water with a discharge of 0.72 m^3/s. Channels for draining mine water generally consist of soil, so the coefficient of the roughness of the channel walls is obtained by the value of n = 0.03. The basic slope of the mine drainage channel is generally 0.026, so based on these data, the size of the open channel system for the mine drainage system for the largest runoff discharge for the NCP pit is as follows (Figure 10).

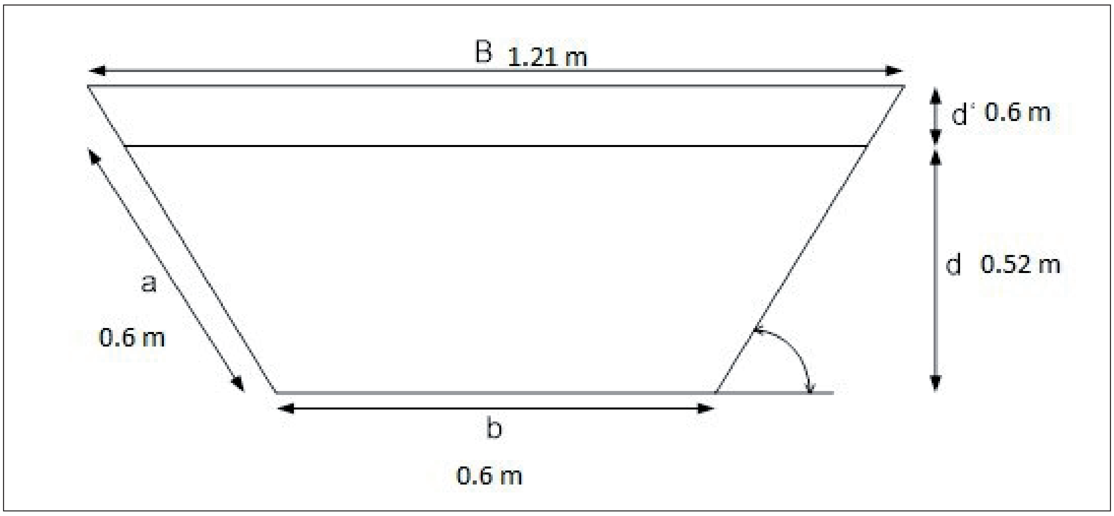

Figure 10. Open channel perimeter drainage section

This perimeter drainage plan will be made around the NCP open pit plan to reduce water from entering the mine, especially runoff water, so it will not enter the face and floor mining. This plan was expected to divert water entering the mine between 60%-75% of the total runoff discharge that will enter the mine.

The sump is also needed in the mine drainage system for water and mud before being pumped out of the mine. The planned channel slope for the sump is 60°, and the planned depth (Z) is 5 m. The dimensions of the sump for the NCP open pit can be seen in Figure 11.

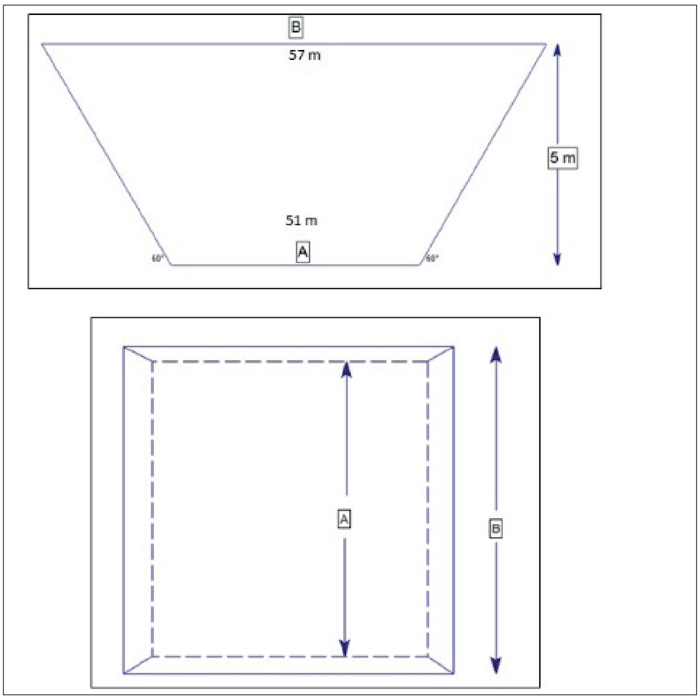

Figure 11. Sump dimension design

To maintain a balance between incoming and outgoing water, a dewatering pump is needed. For the dewatering pump, NCP open pit will use pumps with capacity 780 m^3/hour and 520 m^3/hour to pump the water into the sump (see Table 5). The pump's capacity can be seen from the graph curves in Figure 12. The water in the sump will be pumped into the settling pond.

Table 5. Dewatering pump calculation

Data	Result	Unit
Water Discharge	2,592	m^3/hour
Pump 1 flow rate	520	m^3/hour
Pump 2 flow rate	780	m^3/hour
Duty point Pump 1	1800	RPM
Duty point Pump 2	1300	RPM
Total head	105	m
Volume sump	15,390	m^3
Sump endurance duration without pumping	5.9	hour
Sump endurance duration with pumping	11.9	hour

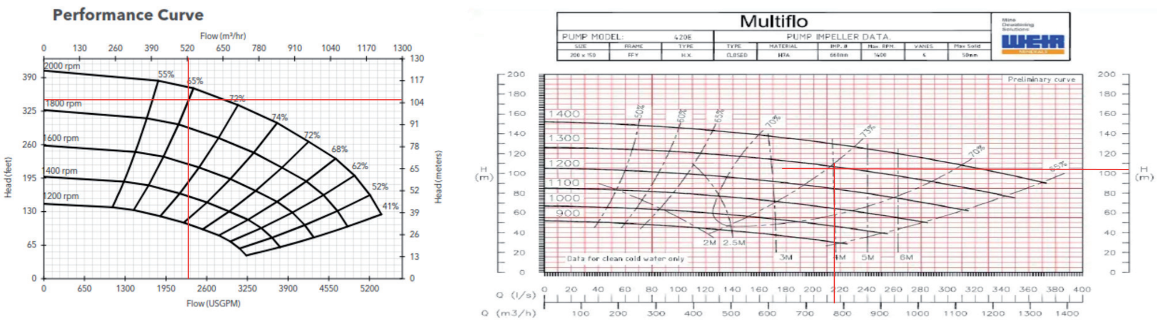

Figure 12. Pump 1 and Pump 2 characteristic curves (Weir Mineral, 2018; Godwin, 2012).

CONCLUSIONS

According to the evaluation of rainfall data from 1994 to 2018, the research area saw a high rainfall intensity of 86.23 mm/day over a two year return period. According to the rational equation, the observed runoff was 0.72 m^3/s. Due to the relatively massive rock conditions, the majority of the water drained from the NCP pit comes from rain and runoff rather than groundwater. To reduce water from entering the mine, an open channel perimeter drainage was constructed around the perimeter pit. The open channel has a depth of 0.52 meters and a freeboard of 0.6 meters, with an upper side of 1.21 meters and a base of 0.6 meters. Additionally, a dewatering pump was required to maintain a balance between incoming and departing water. The open pit at NCP will be equipped with two pumps with a combined flow rate of 1300 m^3/hour. According to the life of mine plan, this dewatering program at NCP open pit mine will last for a total of two years.

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