International Journal of Hydrological and Environmental for Sustainability
Volume 1, Issue 1, 41 -53
e_ISSN: 2828-5050
https://www.journal.foundae.com/index.php/ijhes

The Effectiveness of Sump Dimension Design: A Case Study in Nickel Mining

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Article Info

Article history:

Received: January 05, 2022
Revised: February 01, 2022
Accepted: February 18, 2022

Abstract

The presence of water in mining activities is common, especially in tropical areas that have high rainfall, such as the research location at PT ANTAM Maluku Utara at the Moronopo Site. While the sump maintenance needs to be considered so that the sump can accommodate the incoming discharge. The purpose of this research is to calculate the total discharge entering the mine and to design the dimensions of the sump according to the incoming water discharge. The research method used is the Gumbel method starting from the analysis of rainfall data at the research location starting in 2004-2013 and then continuing with 2019-2020 data, the planned rainfall value is 96.56 mm/day, rainfall intensity is 15.63 mm/day hours with a rain return period of 25 years and a hydrological risk of 18.46 % and the total inflow of mine water is 17,556 m^3/hour. After calculating the sump capacity in the Danis 2 area, it still has not accommodated the incoming discharge with the remaining unaccommodated discharge of 2,319.1 m^3/hour.

Keywords: mine water discharge; sump; sump volume; sump dredge time; ANTAM

To cite this article: Kapugu, E, R., Adnyano, A, I, A., Prastowo, R., Zamroni, A., Kaur, M. and Brahme, N. (2022). The Effectiveness of Sump Dimension Design: A Case Study in Nickel Mining. *International Journal of Hydrological and Environmental for Sustainability, 1*(1), 41-53. https://doi.org/10.58524/ijhes.v1i1.69

INTRODUCTION

PT Antam North Maluku has three sites, namely the Moronopo site, the Tanjung Buli site, and the Pakal site. The location of this research is at the Moronopo Site, Maba District, East Halmahera, North Maluku. This company uses the open pit method with a selective mining system in its mining activities. Open-pit mining operations will be significantly affected by weather conditions, especially rain (R. J. Lad and J. S. Samant., 2015). The presence of water in mining activities is expected in various mining activities, especially in tropical areas with high rainfall (Gautama, 1999). In extreme weather conditions in the form of high rainfall, the water can inundate the ground floor and result in muddy mining fronts (A. Chiarucci and A. J. M. Baker., 2007). Observations in the field show that there is a significant rain catchment area that the problem that often occurs at the Moronopo site is the condition of the sump, which is not able to accommodate the incoming water discharge, resulting in overflowing water around the mine area which does not rule out the possibility of causing pollution in the coastal area near the Moronopo site. The presence of stagnant water on the ground floor of the mine disrupts the excavation, loading, and transportation processes (Iskandar et al., 2017). This problem will undoubtedly hamper mining activities, resulting in not achieving production targets causing losses to the company.

Coal mining is a very influential thing for the availability of energy at this time, whether it is used as a power plant, cement manufacturing industry, iron ore smelting, and others (A. Kumar and S. K. Maiti., 2013). This can be seen from the increasing demand for coal, both from the domestic and foreign markets. So it demands that many mining companies are competing to increase their coal production to compete to meet the demands of the world coal market (A. R. Taylor and H. Y. H. Chen., 2011). In achieving the production target, the smooth running of a mining activity is the most important factor, namely by minimizing the obstacles that can hinder mining activities (Prastowo et al., 2021). Water constraints are a vital aspect that cannot be separated from the open mining system, the more land that will be mined, the more water will enter the mine (Krisnawati et al., 2011). Therefore, it is necessary to design a good drainage system to prevent the mining front from being flooded.

Mine drainage is a business or activity of managing water that enters the mine so as not to interfere with mining activities. The handling of water problems in an open pit mine can be divided into two types, namely (Metsaranta et al., 2018): a. Mine drainage is an effort to prevent the entry of water into the mine pit. This is generally done for the treatment of groundwater and water originating from surface water sources. For this reason, an open ditch water drainage system was created, this trench was made to drain water to all places so as not to interfere with mining activities; b. Mine dewatering is an effort made to remove water that has entered the mining area, especially for handling rainwater (Cahyani., (2021). Efforts to handle the use of pumps so that the production area is not submerged in water and mining activities can continue to operate.

The mine drainage system plays a significant role in overcoming these problems, significantly facilitating mining activities and meeting the production targets desired by the company, and preserving the environment (Moffat et al., 2016). Therefore, handling or controlling the water entering the mining area is necessary. Mine drainage can be grouped into two systems, namely mine dewatering and mine drainage (Gautama, 1999).

Mine drainage design requires calculations, data processing, and decision-making in several alternatives in the drainage process. Handling of water entering the mining area can be done by adding a sump and maintaining the sump with scheduled dredging. Sump is the lowest place (a kind of small pond) in a mine (deep mine or open pit) to collect water and from where water is pumped out of the mine (Prasad et al., 2016). Sump serves as a reservoir for water before it is pumped out of the mine. Thus, the dimensions of this well depend on the amount of water entering and leaving the well. In the implementation of mining activities, temporary wells are usually made which are adjusted to the state of progress of the mining front (Prematuri et al., 2020). The amount of water that enters the well is the amount of water that flows through the channels, the amount of surface runoff that directly flows into the well and the rainfall that directly falls into the well. While the amount of water that comes out can be considered as successfully pumped, because evaporation is considered not too significant. By optimizing the input (input) and output (output), it can be determined the volume of the well. Sumps for water reservoirs must be appropriately planned based on the flow of water entering the sump and the sump manufacturer's location so that the sump's dimensions can be made according to needs (Putri MRA, 2015). Calculation of rainfall data can be done using the Gumbell method. The Gumbell method is a theory used to determine the distribution of planned rainfall which is carried out using a partial method with maximum rainfall data.

METHOD

Field data collection was carried out after the literature study and field orientation. The data taken in the form of primary data and secondary data. Primary data is data obtained by collecting data directly in the field, including observations of the surrounding environment and interviews with relevant sources for primary data consisting of infiltration data, rain catchment areas, and field documentation. Secondary data is supporting data from primary data. Secondary data were obtained from literature books, reports, and company archives such as location and area maps, topographic maps, regional geological maps, rainfall data, mine layout maps, water flow maps, and TSS data in sumps.

In the process of making drainage channels, small and medium size Komatsu Hydraulic Exa PC 200 heavy equipment are used as diggers. The process takes 1 month. For tool specifications and the shape of the Komatsu Hydraulic Exa PC 200 can be seen in **Table 1** and **Figure 1**.

Table 1. Machine specifications of Komatsu Hydraulic Exa PC 200

	Model	PC200-8MO		
	Arm Length	3600 mm	2945 mm	3600 mm
A	Max digging height	9.500 mm	9.800 mm	10.000 mm
B	Max dumping height	6.630 mm	6.890 mm	7.110 mm
C	Max digging depth	5.380 mm	6.095 mm	6.620 mm
D	Max vertical wall digging depth	4.630 mm	5.430 mm	5.980 mm
E	Max digging depth of cut for 2440 mm level	5.130 mm	5.780 mm	6.370 mm
F	Max digging reach	8.850 mm	9.380 mm	9.875 mm
G	Max digging reach at ground level	8.660 mm	9.190 mm	9.700 mm
H	Min swing radius	3.010 mm	3.090 mm	3.040 mm
SAE J 1179 Rating	Bucket digging force at power max.	157 kN 16000 kg	138 kN 14100 kg	138 kN 14100 kg
	Arm crowd force at power max.	139 kN 14200 kg	124 kN 12600 kg	101 kN 10300 kg
ISO 6015 Rating	Bucket digging force at power max.	177 kN 18000 kg	149 kN 15200 kg	149 kN 15200 kg
	Arm crowd force at power max.	145 kN 14800 kg	127 kN 13000 kg	108 kN 11000 kg

(**Source :** Machine manual book)

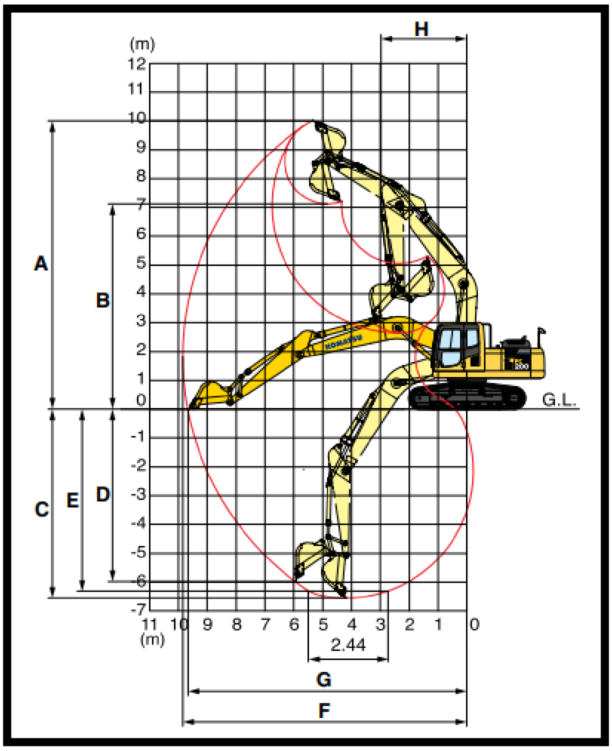

Figure 1. Machine shape and specifications (Komatsu Hydraulic Exa PC 200)

For data processing **(Figure 2)**, starting from calculating rainfall data using the Gumbell method, then calculating the intensity of rainfall using the Mononobe equation. To calculate the total flow of incoming water, runoff, rainwater, and infiltration data are needed. To find runoff water discharge data is needed from the rain catchment area, and to find rainwater discharge data is needed to find the area of mine openings. After obtaining the total discharge of incoming water, determine the recommendation for sump dimensions. From the sump dimensions, the sump dredging time is then determined using TSS data in the sump.

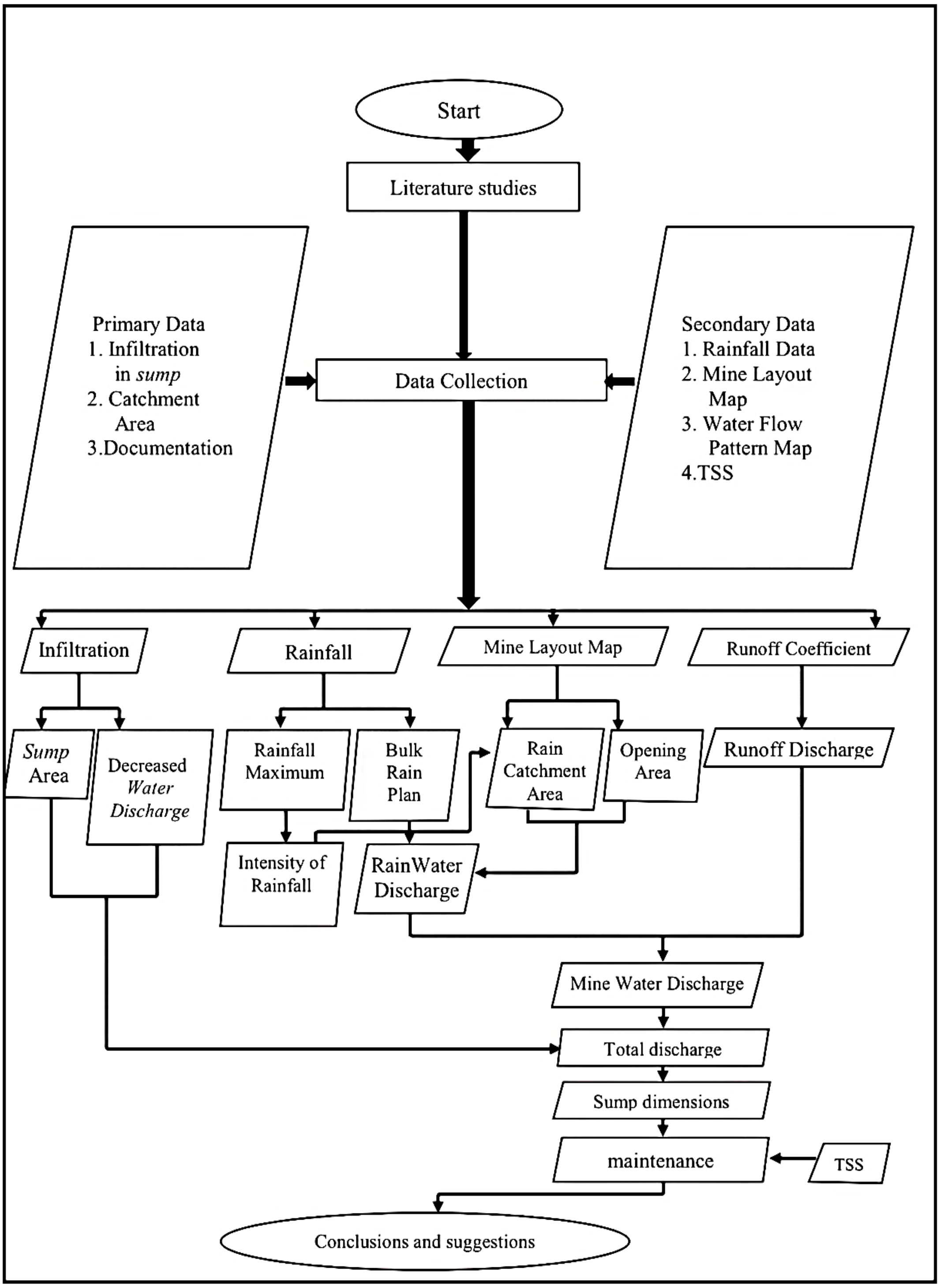

Figure 2. Research Flowchart

RESULTS AND DISCUSSION

Rainfall data

Rainfall significantly affects the mine drainage system because the size of the rainfall will affect the amount of water that must be accommodated in the mine opening. Rainfall data obtained from the research area is 12-year rainfall data from 2004-to 2013, followed by rainfall data for 2019-2020. The rainfall used in the calculation is from the maximum rainfall data every year for 12 years. For rainfall data can be seen in **Table 2** Maximum Rainfall below:

Table 2. Maximum rainfall

Year	Maximum Rainfall (X)
2004	113.0
2005	75.0
2006	67.5
2007	96.3
2008	105.5
2009	107.0
2010	134.4
2011	174.5
2012	183.0
2013	205.0
2019	85.0
2020	99.0
Amount	1445.20
Average	120.43

(**Source :** Data of this study)

Rainfall Plan

Every year, the maximum rainfall data for 12 years from 2004-2013 then continued in 2019-2020 were analyzed to find the planned rainfall. After calculating the Gumbel method, the planned rainfall value is 96.56 mm/day.

Rainfall Intensity

Rainfall intensity is the amount of rain expressed in height or volume of rain in units of time. Based on the high and low value of rainfall intensity, rain can be classified into several levels which can be seen in **Table 3**. Calculation of rainfall intensity can be done by several methods, one of which is the mononobe method. The calculation of rainfall intensity aims to convert daily rainfall into hourly rainfall. In this study, after obtaining the planned rainfall and the length of time it rains, namely the data of rainy hours, the intensity of rainfall can be calculated using the mononobe formula. After calculating the rainfall intensity value of 15.63 mm/hour.

Table 3. Degree and intensity of rainfall

No	Rain Degree	Intensity of Rainfall	Condition
1	Very weak rain	< 0,02	The soil is slightly wet or slightly moistened
2	Weak rain	00,02 – 0,05	The ground got all wet
3	Normal rain	0,05 – 0,25	The sound of raindrops is heard
4	Heavy rain	0,25 – 1,00	Water stagnates all over the ground and a sound is heard from the puddle
5	Heavy rain	> 1,00	It looks like it's raining, and the drainage canal is overflowing

(**Source:** Rudy Sayoga, 1999)

Rain Catchment Area

The catchment area is the surface area where when it rains, the rainwater will flow to a lower area to the point of drainage (Singh et al., 2012). Some of the water that falls to the surface will seep into the ground (infiltration), some will be retained by plants (interception), and some will fill the twists and turns of the earth's surface and will flow to a lower place. The rain catchment area is an area that can cause run off water to flow into a lower mining area (Macdonald et al., 2015). In determining the limits of the catchment area **(Figure 3)**, it can be limited from the pit limit mining area (V. Yuskianti and S. Shiraishi., 2010), while the area outside the mining area is not included in the catchment area.

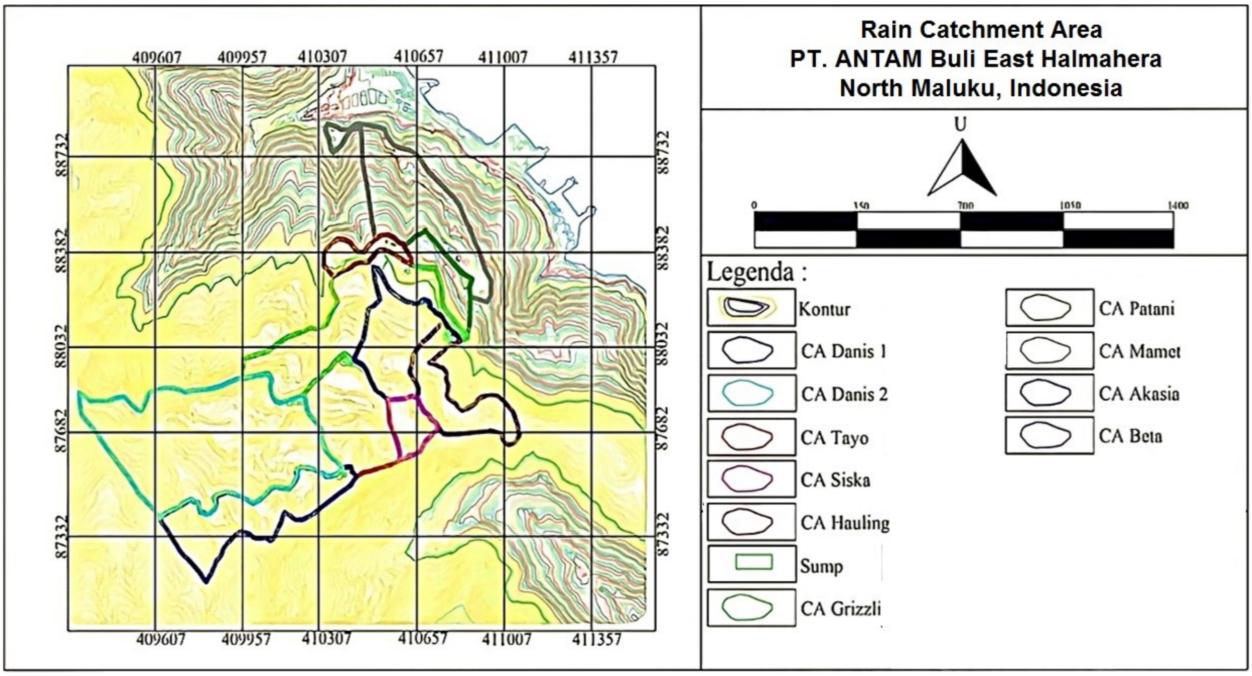

Figure 3. Rain Catchment Area

Determination of the rain catchment area using the Moronopo topographic map in April 2021. The area of the rain catchment area is determined by observing the direction in which the water will flow. The way to determine the rain catchment area is by drawing a line from the highest point around the sump to form a closed polygon. The area of the rain catchment area is calculated using the Surpac software program. The rain catchment area can be seen in **Figure 3**, and the data for the rain catchment area can be seen in **Table 4**.

Table 4. Rain catchment area

Area	Catchment Area
Danis 1	119.533 m2
Danis 2	345,928 m2
Tayo	111,139 m2
Siska	30,239 m2
Beta	74,983 m2
Acacia	90.301 m2
Grizzli	154,015 m2
Hauling	25.007 m2
Patani	42,534 m2
Mamet	151,402 m2

(**Source :** Data of this study)

Runoff Coefficient

The runoff coefficient (C) value is influenced by various surfaces and the area of the rain catchment area, where each surface has its runoff coefficient. Based on field observations, the coefficient value used at the Moronopo Site is 0.9 because it is by the conditions in the sump in the mining area and without plants. The runoff coefficient can be seen in **Table 5**.

Table 5. Runoff coefficient

Tilt	Land Cover/ Type	Coefficient
	Rice fields and swamps	0.2
< 3% (flat)	Forest and plantation	0.3
	Housing area	0.4
	Forest, plantation	0.4
3% - 15% (medium)	Housing area	0.5
	The bushes are a bit sparse	0.6
	Open field	0.7
	Forest	0.6
> 15% (steep)	Housing area	0.7
	The bushes are a bit sparse	0.8
	Open land and mining area	0.9

(**Source :** Data of this study)

Runoff Water Discharge

The water entering the sump comes from rainwater. The calculation of runoff water discharge can be determined after knowing the area of the rain catchment (DTH), and the runoff coefficient value of 0.9 can be seen in **Table 5**. The calculation of runoff water discharge uses the Gumbell method. The results of the runoff water discharge can be seen in **Table 6**.

Table 6. Runoff water discharge

Area	C	I (mm/hour)	A (km^2)	Q (m^3/hour)
Danis 1	0.9	15,30	0.12	1683
Danis 2	0.9	15,30	0.35	4870
Tayo	0.9	15,30	0.11	1565
Siska	0.9	15,30	0.03	426
Beta	0.9	15,30	0.07	1056
Acacia	0.9	15,30	0.09	1271
Grizzli	0.9	15,30	0.15	2168
Hauling	0.9	15,30	0.03	352
Patani	0.9	15,30	0.04	599
Mamet	0.9	15,30	0.15	2131

(**Source :** Data of this study)

Rainwater Discharge

Calculation of rainwater discharge based on mine opening area (A) and planned rainfall. The size of the mine opening influences the discharge of rainwater directly into the mine opening. The wider the mine opening, the greater the resulting discharge. The results of the Rainwater Discharge can be seen in **Table 7**.

Table 7. Rainwater discharge

DTH	Opening Area (m^2)	Opening Area (ha)	CH Plan		Rainwater Discharge
			mm/hour	m/hour	m^3/hour
Danis 1	987.87	0.099	4.023	0.004023	3.975
Danis 2	923.62	0.092	4.023	0.004023	3.716
Tayo	911.09	0.091	4.023	0.004023	3.666
Siska	287.74	0.029	4.023	0.004023	1.158
Beta	1585.51	0.159	4.023	0.004023	6379
Acacia	736.93	0.074	4.023	0.004023	2,965
Grizzli	931.50	0.093	4.023	0.004023	3.748
Hauling	540.09	0.054	4.023	0.004023	2.173

Patani	734.26	0.073	4.023	0.004023	2,954
Mamet	2146.18	0.215	4.023	0.004023	8,635

(**Source :** Data of this study)

Infiltration

Infiltration is the absorption of water into the soil. The measurement of infiltration in this study uses a simple tool in the form of a ruler plugged into the sump, which is still holding water by recording the data every hour and then multiplying it by the sump area. The obtained infiltration data and bias infiltration results are seen in **Table 8**.

Table 8. Infiltration

Sump	Sump Area (m^2)	Infiltration (m^3/hour)
Danis 1	987.87	2.96
Danis 2	923.62	2.77
Tayo	911.09	2.73
Siska	287.74	0.86
Beta	1585.51	4.76
Acacia	736.93	2.21
Grizzli	931.50	2.79
Hauling	540.09	1.62
Patani	734.26	2.20
Mamet	2146.18	6.44

(**Source :** Data of this study)

Total Mine Water Discharge

Mine water discharge is runoff water entering the mine opening plus the amount of rainwater that directly enters the mine opening and is then reduced by infiltration. To determine the amount of mine water, it is necessary to know the runoff water discharge, rainwater discharge, and infiltration.

Water Debit Not Accommodated

After calculating the discharge, the results are obtained if the sump Danis 2 still cannot accommodate the total debit that enters the Danis 2 area while at sump Danis 1, Tayo, Siska, Beta, Acacia, Grizzli, Hauling, Patani, and Mamet the total debit that enters still corresponds to the volume of each sump. For unaccommodated water discharge, it can be seen in **Table 9**.

Table 9. Unaccommodated water discharge

Catchment Area	Sump Volume (m^3)	Incoming Debit (m^3/hour)	Unaccommodated Water Debit m^3/hour
Danis 1	2943	1684	
Danis 2	2552	4871	2,319.1
Tayo	2301	1566	
Acacia	2440	1272	
Grizzli	2375	2169	
Hauling	898	353	
Patani	1965	600	
Mamet	4681	2134	
Siska	1900	609	
Beta	2803	2300	

(**Source :** Data of this study)

Sump Dimension Recommendation

Based on the amount of water that has not yet entered the sump, which is 2,319.01 m^3/hour, it is planned to add a sump with a location in the Danis 2 road area with a sump capacity of 2810 m^3 which is designed using Surpac software in order to accommodate the remaining 2,319.01 discharge.

m³/hour and the possibility of increasing the amount of discharge, the sump volume is made more than the remaining discharge that has not been accommodated with the recommended sump dimensions can be seen in **Table 10**, and the sump recommendation image can be seen in **Figure 4**.

Table 10. Recommended sump dimensions

Parameter	Dimension
Overall Area	894 m^2
Depth (h)	4 m
tilt	600
Overall Sump Length	52 m
***sump*1**	
P1	25 m
P2	20 m
L1	17 m
L2	12 m
Sump Area	420.722 m^2
Sump Volume	1313 m^3
***sump*2**	
P1	27 m
P2	23 m
L1	17 m
L2	12 m
Sump Area	473.278 m^2
Sump Volume	1497 m^3
Sump Total Volume	2810 m^3

(**Source :** Data of this study)

The sump design **(Figure 4)** is obtained from observations and calculations of the problem, namely high rainfall with solutions, namely evaluating the sump, evaluating open channels, evaluating pump performance. The research method is observation, data collection, the dependent variable consists of (maximum rainfall data, catchment area, water elevation in the sump, runoff coefficient value), the independent variable consists of (pump rpm, sump dimensions using the mononobe formula versus time, intensity rain using the mononobe formula, the dimensions of the open channel using the robert manning formula). After processing the data, the results obtained are sump dimensions which are considered suitable for the dimensions of the open channel.

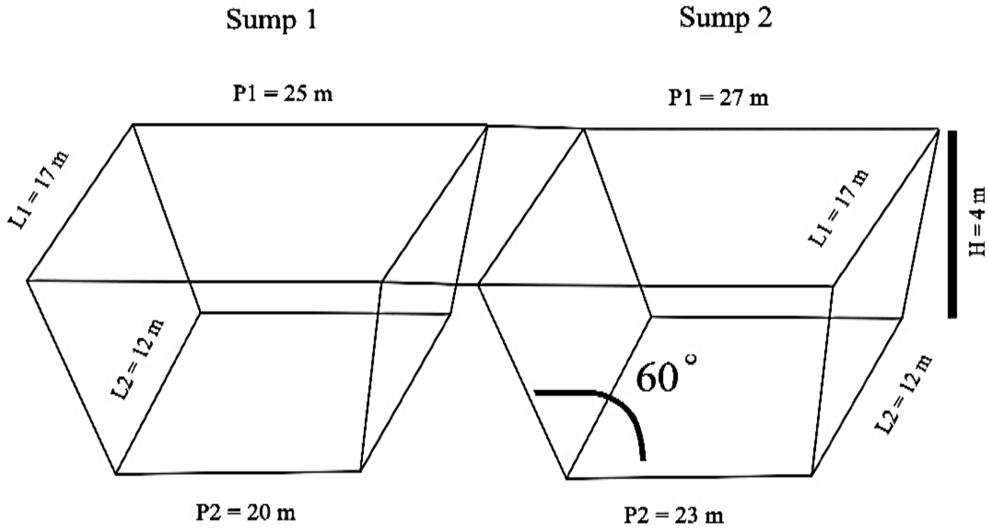

Figure 4. Recommended Sump Dimensions

Calculation of Total Suspended Solid (TSS)

Analysis of water quality, namely total suspended solid (TSS) was carried out after processing the data and calculation results were obtained, namely being able to determine the amount of water entering the mine site, being able to determine the use of pumps and good sludge settling ponds, being able to carry out good liming activities. The TSS value used is the TSS sump data in March 2021.

Table 11. Total TSS in Sump

Sampling Time	TSS (mg/L)
March 01	16.00
March 02	22.00
March 03	18.00
March 04	66.00
March 05	22.00
March 06	18.00
March 07	16.00
March 08	52.00
March 09	42.00
March 10	20.00
March 11	18.00
March 12	20.00
March 13	20.00
March 14	20.00
March 15	20.00
March 16	26.00
March 17	26.00
March 18	26.00
March 19	24.00
March 20	22.00
March 21	72.00
March 22	52.00
March 23	24.00
March 24	21.00
March 25	24.00
March 26	20.00
March 27	20.00
March 28	55.00
March 29	36.00
March 30	36.00
March 31	40.00
Amount	914.00
Average	29.48

(**Source :** Calculation data of this study)

The amount of TSS = 29.48 mg/L

$= 29.48 \text{ x} \frac{1}{1000} \text{x gr/cm}^3 \frac{1}{1000}$

$= 0.0294840 \text{ gr/cm}^3$

Sump recommendation with a capacity of 2810 m3 with an incoming discharge of 0.78 m3/second.

Suspended residue $= 0.0294840 \text{ gr/cm}^3 . 3{,}784 . 106 \text{ cm}^3\text{/sec}$

$= 0.0294840 \text{ x } 780{,}000$

$= 22{,}994.4$ g/second

Using the equation if we know (solid particles) $= \frac{m}{V}$

V $= 0.0143 \text{ m}^3\text{/second}; \frac{22.994{,}4 \text{ gr/s}}{1.600.000}$

The percentage of incoming solids to the total water and solids (pulp) is:

%Solid = x 100% $\frac{V}{Debit}$

% Water = 100% - % Solid

then , %Solid = $\frac{0{,}0143\ m^3/s}{0{,}78\ m^3/\ s}$ x 100%

= 1.833%

% Water = 100% - % Solid

= 100% - 1,833 %

= 98,167%

Based on the calculation data, the percentage of solids is 1.833% and the percentage of water is 98.167%, it can be calculated that the volume of solids and the volume of water is:

Solid Weight = % solids . Q. solid ρ

= 0.0183 . 2810 m^3/hour . 2,500 kg/m^3

= 128.557.5 kg/hour

Weight of water = % water . Q. waterρ

= 0.98 . 2810 m^3/hour . 1,000 kg/m^3

= 2,753,800 kg/hour

Volume of solids per second = $\frac{solid\ weight}{(\rho\ solid\ .\ 3.600)}$

= $\frac{128.557{,}5\ kg/hour}{(2.500\ kg/m^3\ .\ 3.600)}$

= 0.014 m^3/second

Volume of water per second = $\frac{water\ weight}{(\rho\ water\ .\ 3.600)}$

= $\frac{2.753.800\ kg/hour}{(1.000\ kg/m^3\ .\ 3600)}$

= 0.76 m^3/second

Total Volume per second = V. solids per second + V. water per second

= 0.014 m^3/sec + 0.76 m^3/sec

= 0.78 m^3/second

Sump Maintenance

Sump maintenance activities must be carried out so that the sump can function properly and can be used longer. The sump maintenance process can be carried out by cleaning the solid particles that have settled on the sump, namely by scraping the solid particles at the bottom of the sump. Following the rules determined by the company, the tool used to dredge solid particles in the sump is the Komatsu PC 200 Excavator. The time required for maintenance is once in 24 days.

Based on the calculations, the percentage of solids obtained is 1.833 %, and the percent water is 98.167%, with a total volume of solids and water entering 0.78 m3/second. For percent solids less than 40% using the Stokes equation.

Calculation:

V_t = $\frac{9{,}8\frac{m}{s^2}.\ (4 \times 10^{-6}\ m)^2.\ \left(2500\frac{kg}{m^3} - 1000\frac{kg}{m^3}\right)}{18\ .\ \left(1{,}31 \times 10^{-6}\frac{kg}{s}\right)}$

= $\frac{2{,}352 \times 10^{-7}}{2{,}358 \times 10^{-5}}$

= 0.0099 m/sec

Time required for particles to settle:

t_v = $\frac{H}{V_t}$

= $\frac{4}{0{,}0099}$

= 404.04 seconds

= 6.73 minutes

Horizontal velocity of the particle:

$(V_h) = \frac{Q_{total}}{A}$

A = Bottom width . H

= 24 . 4

= 96 m^2

$V_h = \frac{0{,}78\ m^3/s}{96\ m^2}$

= 0.00812 m/sec

Thus, the time is taken for the water, and the particles to leave with velocity V_h is:

$t_h = \frac{P}{Vh}$

$= \frac{52\ \text{m}}{0{,}00812\ \text{m}/detik}$

= 6,403 seconds

= 106.71 minutes

From the above calculation, it is obtained that $t_v < t_h$ is 6.73 minutes < 106.71 minutes.

Precipitation percentage= $\frac{t_h}{t_h + t_v}$. 100%

$= \frac{106{,}71}{106{,}71 + 6{,}73}$. 100%

= 94.06 %

The solid material dissolved in water is not all deposited with the percentage above. The solids that have been successfully deposited in a day with 2.5 hours of rain per day are:

= 0.014 m3/second . 3600 seconds/hour. 2.5 hours/day. 94.06 %

= 118.44 m^3/day

Maintenance $= \frac{\text{volume } sump}{\text{total volume of solids that have been deposited}}$

$= \frac{2810}{118{,}44}$

= 23.72 or 24 days (so thus dredging is done 1 time in 24 days).

CONCLUSION

Based on rainfall calculations, the total discharge entering the Danis sump to the Mamet sump is 17,556.49 m^3/hour. The total flow of incoming water is not by the capacity of the existing sump with an unaccommodated discharge of 2,319.1 m^3/hour. The existing sump capacity has not been able to accommodate the total incoming discharge, so it is necessary to add a sump so that when high rainfall occurs the water does not flood the mining front and mining activities can run smoothly. It is necessary to carry out periodic maintenance of the sump so that there is no deposition of excess material to function correctly. To maintain the sump on the recommended sump, it is necessary to drill the sump on a schedule once in 24 days.

ACKNOWLEDGMENT

The authors are grateful to PT Antam Maluku Utara for providing the opportunity to conduct research and provide direction and guidance during the research.

CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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