Hydrogeology and Groundwater Modeling in the Mining Area of Pt. X in Berambai Area, Kutai Kartanegara Regency, East Kalimantan Province

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Abstract. The world of mining, especially coal mining, is an activity that can cause changes in geological, hydrological, morphological and land use conditions. Changes in these conditions also have an impact or influence on the mining and post-mining processes. The location of the research was carried out in the mining business area of PT. X which is located in the Berambai area, Kutai Kartanegara Regency with a research area of 2,6 km^2. This study aimed to determine the hydrogeological conditions and model the direction of groundwater flow in the research area. This study uses primary data like direct geological mapping and rainfall in the mining area, while secondary data in the form of regional geology, coring data, groundwater level observation data, climate data and literature studies. The method used in modeling the direction of groundwater flow is the finite difference grid method. The research area is part of the Separi Besar watershed so the research area is determined as a rain catchment area. The groundwater recharge value obtained is 930,4074 mm mm/year. The research area belongs to the Typology of Sandstone-Claystone Sedimentary Aquifer System, the types of aquifers found are unconfined aquifers and confined aquifers. The hydrostratigraphy of the research area consists of aquifer, aquitard and aquiclude layers. The hydrogeological boundaries of the research area are river boundaries, groundwater divide and impermeable boundaries. From the results of the model that has been calibrated and analyzed for sensitivity, that is, groundwater flow in the unconfined aquifer layer is not found in the Eastern part of the study area, while groundwater flow in the confined aquifer layer is still visible, this is because the unconfined aquifer layer is not continuous. The direction of groundwater flow is towards the lower area, namely the constant network (river) and the mining pit area.

Keywords: Berambai · Groundwater · Hydrogeology · Model

1 Introduction

The world of mining, especially coal mining, is an activity that can cause changes in geological, hydrological, morphological, and land use conditions. Changes in these conditions also have an impact or influence on the mining and post-mining processes.

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Hydrogeology is a branch of science in the study of hydrology and geology. Hydrology simply emphasizes the study of water (content, presence, quality, etc.) on earth. Whereas simple hydrogeology is more emphasis on the container than the groundwater itself. Groundwater is closely related to subsurface water that is between the water table on the ground and water-saturated geological formations. In the Regulation of the Minister of Energy and Mineral Resources Number 02 of 2017 [1] and the Regulation of the Minister of Environment and Forestry Number 5 of 2021 [2] of the Republic of Indonesia, groundwater is water that is contained or is in a water-saturated zone in the soil or rock layers below the ground surface and then the groundwater also affected by land use. The aim of this study was to determine the hydrogeological conditions of the research area consisting of groundwater recharge, aquifer system typology, aquifer type, and hydrostratigraphy as well as to model the direction of groundwater flow in the study area.

2 Methods

2.1 Regional Geology and Research Location

The regional geology of the study area is located in the kutai basin, samarinda sheet precisely in the Balikpapan formation and Pulau Balang formation (Fig. 1). The location of research was carried out in the mining business area of PT. X which is located in the Berambai area. Administratively, the research location is located in Tenggarong Seberang Sub-Regency, Kutai Kartanegara Regency, East Kalimantan Province with a research area of 2,6 km^2.

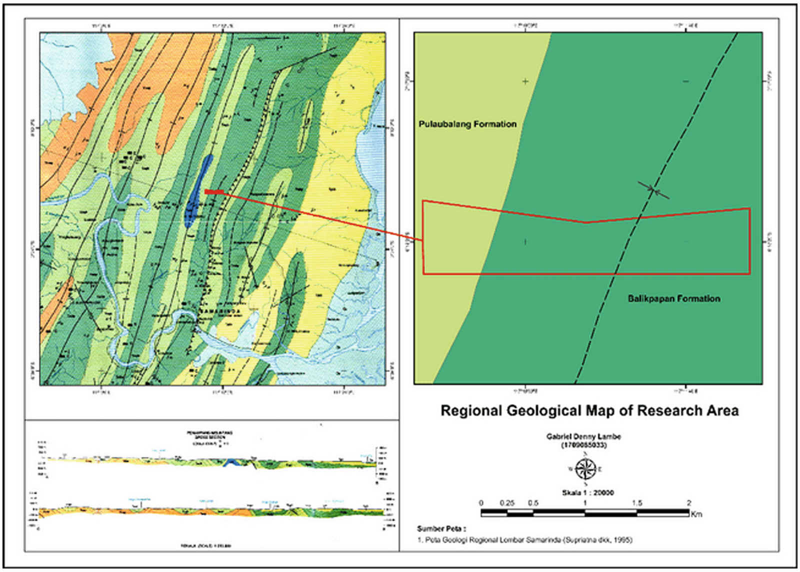


Fig. 1. Regional Geological Map of Research Area.

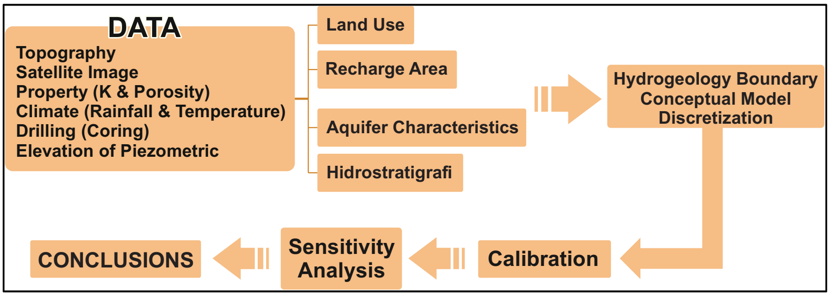


Fig. 2. Flow chart of the research.

2.2 Data Analysis

This study uses primary data like direct geological mapping and rainfall in the mining area, while secondary data in the form of regional geology, coring data, groundwater level observation data, climate data and literature studies. Hydrological analysis was carried out to determine the value of groundwater recharge, stratigraphic modeling was to determine the characteristics of the aquifer and prior to discretization, the model was made a conceptual model of the research area (Fig. 2). The method used in modeling the direction of groundwater flow is the finite difference grid method. Calibration and sensitivity analysis is needed to find out the error value and the similarity to the original.

3 Result and Discussion

3.1 Rain Catchment Area and Land Use

The rain catchment area in the study area is in the form of the Separi Besar Watershed, which is part of the Mahakam watershed (Fig. 3). The part of the Separi Besar Watershed which is the rain catchment area of the research location has an area of 30,749 km^2.

Through satellite imagery, the rain catchment area has been classified as land use in the area, based on the land use consisting of mining areas, agriculture, swamps, primary forests and secondary forests (Fig. 4).

3.2 Groundwater Recharge

Groundwater recharge is determined in the recharge area which is the research area within the scope of the rain catchment area in the period March 2021 to February 2022 (Table 1). The calculation of groundwater recharge is influenced by rainfall, evapotranspiration and surface runoff. Daily rainfall (precipitation) in the study area was measured directly using a rainfall gauge, the highest rainfall intensity from the rainfall data occurred on December 22, 2021 at 62 mm.

The time of concentration (Tc) of the flow in the rain catchment area was calculated using the Bayern method. The Tc value was 1,464 h for river 1 (crossing the west area) and 2,099 h for river 2 (traversing the east area). Rain intensity per unit time (hours)

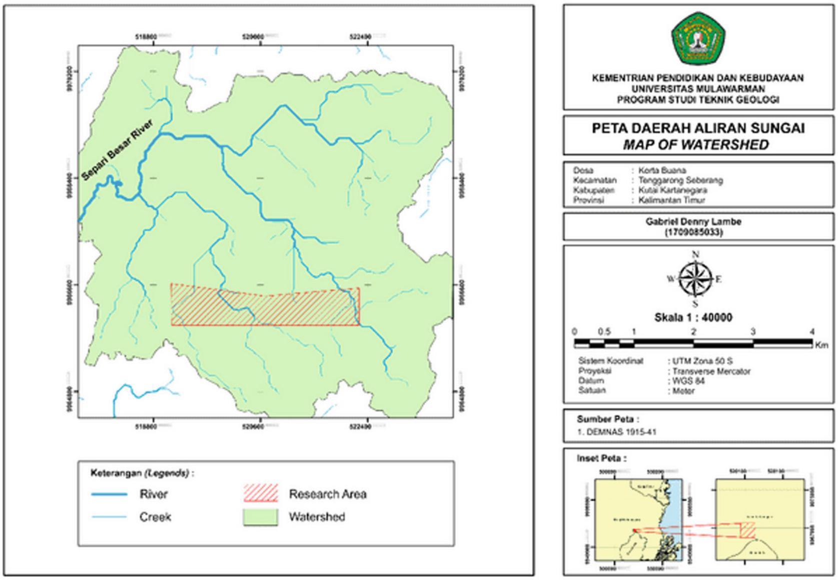


Fig. 3. Separi Besar Watershed Map.

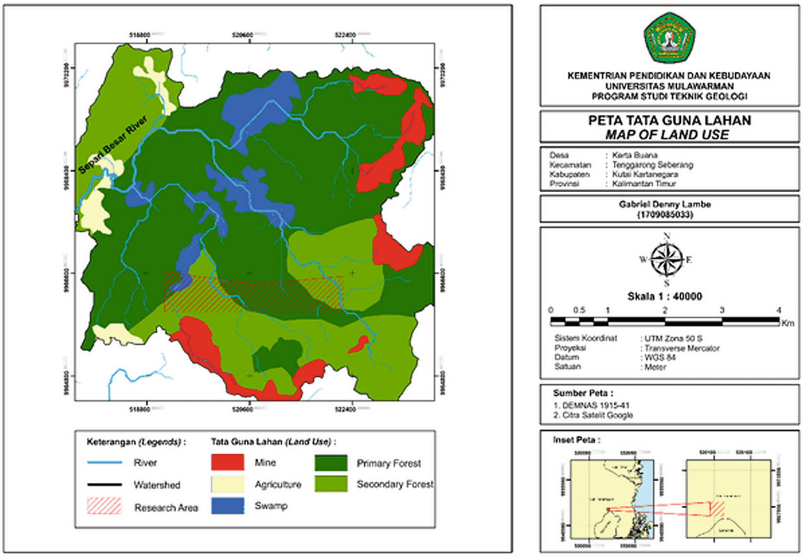


Fig. 4. Land Use Map.

is calculated using the Mononobe formula, the maximum rainfall intensity value in the rain catchment area is 14,8871 mm/hour.

The runoff coefficient (C) of the surface of the rain catchment area is 0,5874 [3]. The peak discharge of the surface runoff rational method is only calculated in the IPPKH

Table 1. Rainfall Data Period March 2021-February 2022.

Month-Year	**Rainfall (mm)**	**Daily Maximum Rainfall**
March-21	189	**62 mm (December 22, 2021)**
April-21	167	
May-21	100.9	
June-21	36	
July-21	3.08	
August-21	224.15	
September-21	268.6	
October-21	159.4	
November-21	157.23	
December-21	198.05	
January-22	196.08	
February-22	160.2	
AVERAGE	**154.97**	
TOTAL	**1859.69**	

area, the average value is 4,4319 m^3/second. The calculation of surface runoff in mm per year was carried out using the SCS method.

The annual surface runoff value for the SCS method can be seen in the classification in Table 2. The surface runoff value obtained is 732,792 mm. Thornthwaite's corrected evapotranspiration value was 196,4905 mm. The annual groundwater recharge is calculated using the groundwater budget principle so that the groundwater recharge value is 930,4074 mm.

Table 2. SCS Method Classification.

Land Use	**Area (Km^2)**	**Percentage (%)**	**Curve Number (CN)**	**Average (CN)**
Mine	2,3242	7,626	91	64,76606418
Agriculture	0,9078	2,978	74	
Swamp	2,2477	7,375	98	
Primary Forest	15,9003	52,168	55	
Secondary Forest	9,0993	29,854	66	
TOTAL	30,4793	100		

3.3 Aquifer System Typology

The aquifer system in the study area is interpreted according to the typology of the aquifer system as the Typology of the Sedimentary Aquifer System [4]. Based on the subsurface lithology of the drilling results and the geological structure of the research area, it is part of the Sandstone-Clay Aquifer System.

3.4 Aquifer Types and Characteristics

The research area is identified as having three aquifer layers, namely Aquifer 1, Aquifer 2, and Aquifer 3. Aquifer 1 has a dominant lithology of medium to coarse sandstone with a thickness of ± 10 m, Aquifer 1 layer has characteristics as an unconfined aquifer where this aquifer layer does not have an impermeable cover layer on the top and is only limited by one impermeable layer at the bottom.

Aquifer 2 has a dominant lithology of fine-medium sized sandstone with a thickness of ± 25 m, Aquifer 2 layer has characteristics as a confined aquifer where the aquifer layer is limited at the top and bottom by an impermeable or aquiclude layer (Fig. 5).

Aquifer 3 has a dominant lithology of fine-medium sized sandstone with a thickness of ± 15 m, Aquifer 3 layer has characteristics as a confined aquifer where the aquifer layer is also limited at the top and bottom by an impermeable or aquifer layer (Fig. 6). The research area also identified aquitard and aquiclude layers, the aquitard layer has dominant lithology characteristics of coal, shaly coal, and carbonaceous mud/siltstone where the lithology of these rocks can be semi-permeable (flowing water in limited quantities). The aquiclude layer has a dominant lithological characteristic of claystone where the rock cannot drain water or is impermeable.

3.5 Hydrostratigraphy

The hydrostratigraphy of the research area is divided into 11 sub-units, namely Aquifer 1, Aquitard 1, Aquiclude 1, Aquifer 2, Aquitard 2, Aquiclude 2, Aquifer 3, Aquitard 3, Aquiclude 3, Aquitard 4 and Aquiclude 4 (Fig. 7).

3.6 Hydrogeological Boundary

The hydrogeological boundary of the study area consists of an impermeable boundary determined from the aquiclude layer, a groundwater divide determined from hill topography, and a river boundary determined from the river (Fig. 8).

3.7 Groundwater Flow Pattern

The pattern of groundwater flow in the study area based on piezometric elevation was determined using the kriging method of interpolation. The groundwater flow pattern shows a piezometric elevation network or contour at 2-m intervals with an elevation value of 90 m to 112 m and the direction of groundwater flow is determined based on the piezometric elevation contour (Fig. 9).

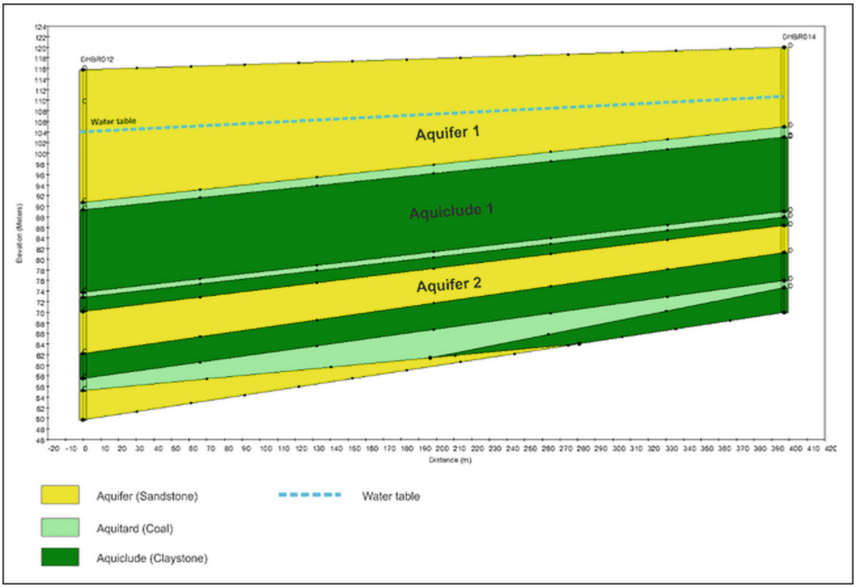


Fig. 5. Cross-section of drill points DHBR012 and DHBR014.

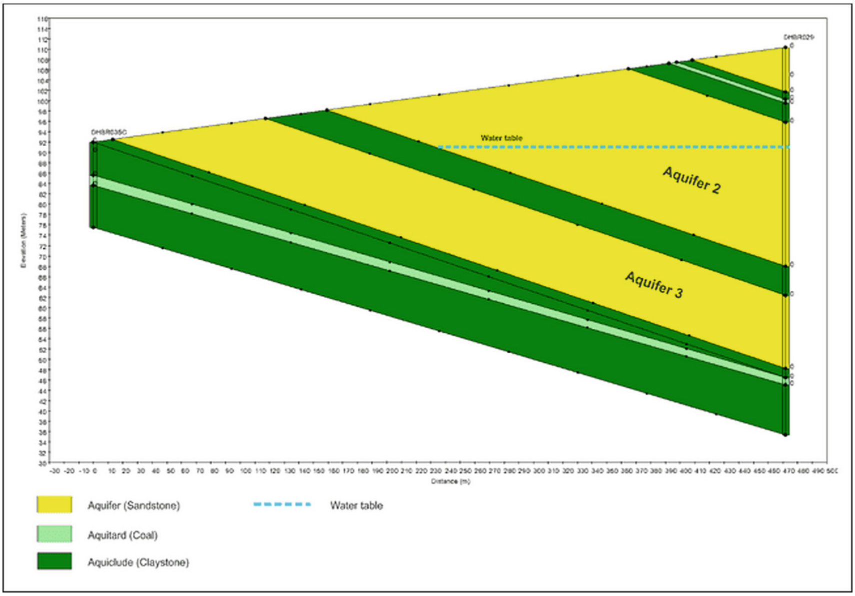
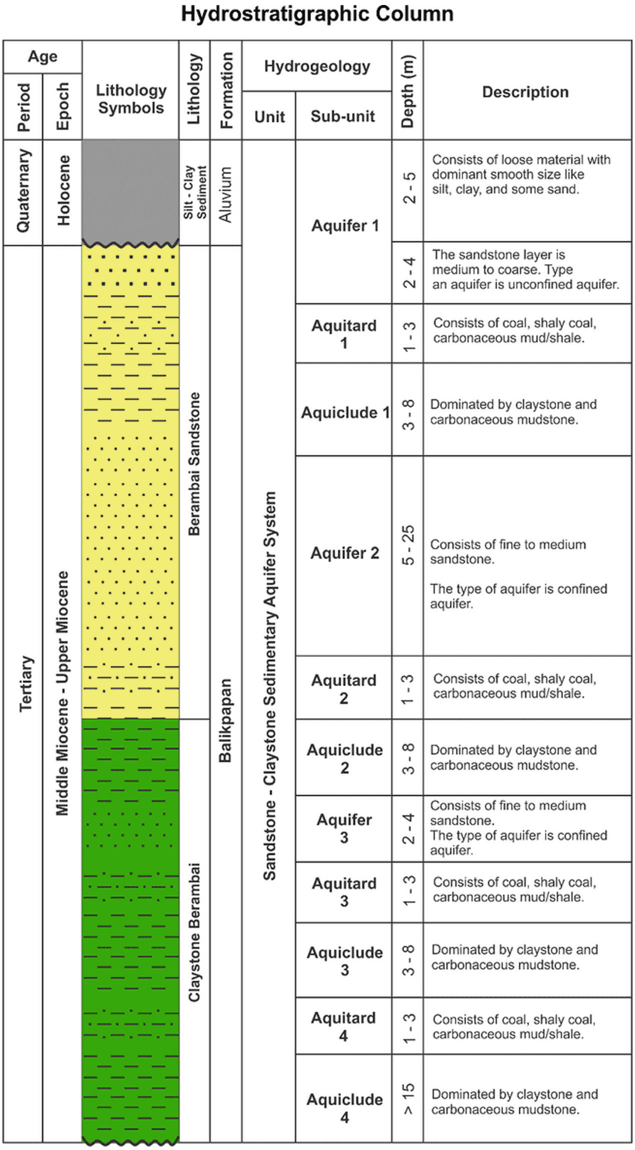


Fig. 6. Cross-section of drill points DHBR035 and DHBR029.



Hydrostratigraphic Column

Age		Lithology Symbols	Lithology	Formation	Hydrogeology		Depth (m)	Description
Period	Epoch				Unit	Sub-unit		
Quaternary	Holocene		Silt - Clay Sediment	Aluvium	Sandstone - Claystone Sedimentary Aquifer System	Aquifer 1	2 - 5	Consists of loose material with dominant smooth size like silt, clay, and some sand.
Tertiary	Middle Miocene - Upper Miocene		Berambai Sandstone	Balikpapan			2 - 4	The sandstone layer is medium to coarse. Type an aquifer is unconfined aquifer.
						Aquitard 1	1 - 3	Consists of coal, shaly coal, carbonaceous mud/shale.
						Aquiclude 1	3 - 8	Dominated by claystone and carbonaceous mudstone.
						Aquifer 2	5 - 25	Consists of fine to medium sandstone. The type of aquifer is confined aquifer.
						Aquitard 2	1 - 3	Consists of coal, shaly coal, carbonaceous mud/shale.
			Claystone Berambai			Aquiclude 2	3 - 8	Dominated by claystone and carbonaceous mudstone.
						Aquifer 3	2 - 4	Consists of fine to medium sandstone. The type of aquifer is confined aquifer.
						Aquitard 3	1 - 3	Consists of coal, shaly coal, carbonaceous mud/shale.
						Aquiclude 3	3 - 8	Dominated by claystone and carbonaceous mudstone.
						Aquitard 4	1 - 3	Consists of coal, shaly coal, carbonaceous mud/shale.
						Aquiclude 4	> 15	Dominated by claystone and carbonaceous mudstone.

Fig. 7. Hydrostratigraphic column of the research area.

3.8 Conceptual Model

The conceptual model is made in the model target area, namely the research area, and discretization of the model with the finite difference grid method using the input data that has been discussed previously (Table 3). The model is presented in the form of a 2d top-view map (Fig. 10).

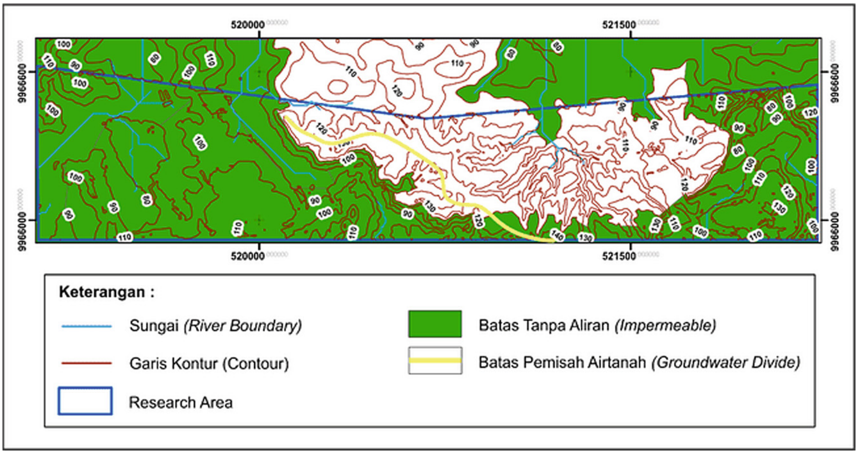


Fig. 8. Hydrogeological boundaries of the research area.

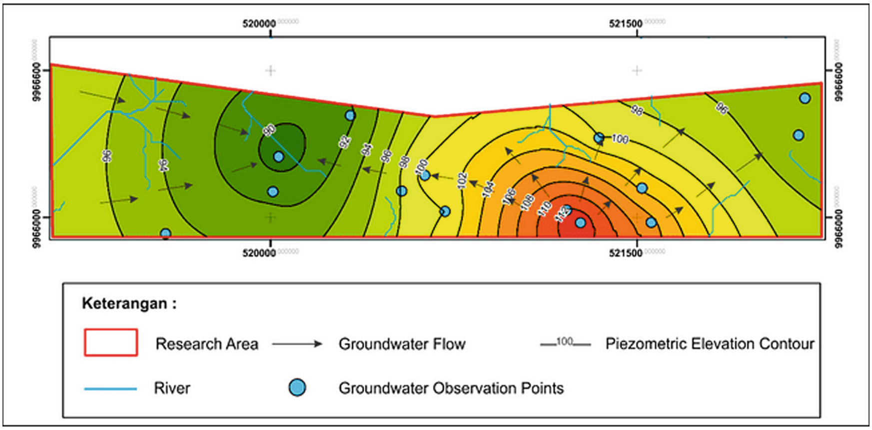


Fig. 9. The pattern of groundwater flow in the research area.

3.9 Calibration and Sensitivity Analysis

In the results of the model after being calibrated (Fig. 11) it is still found that the error value is quite high, namely –1.519 m (Mean Residual Value) and 8.411 m (Root Mean Square Value). To get a good model result (Error < 1), hydrogeological parameter analysis is carried out in accordance with the conditions in the field by testing the Parameter Sensitivity Analysis (PSA) by changing the aquifer conductivity value and the piezometric elevation (head) observation value.

PSA testing carried out is as follows:

1. PSA 1, which is the hydraulic conductivity value of the aquifer, is changed to 3.5×10^{-5} m/s while the piezometric elevation remains the same.

Table 3. Modeling Input Data.

Data	Unit	Quantity	Description
Nilai K	m/s	$3{,}6 \times 10^{-5}$	Aquifer
		$3{,}8 \times 10^{-7}$	Aquitard
		$0{,}3 \times 10^{-11}$	Aquiclude
Porositas	%	15	Aquifer
Coverage			
-River Boundary	m	108–86 (TIN)	River
-Initial Head	m	95–120	Observation Points
-Recharge	mm/year	930,4074	Area Model
-Evapotrans	mm/year	196,4905	Area Model

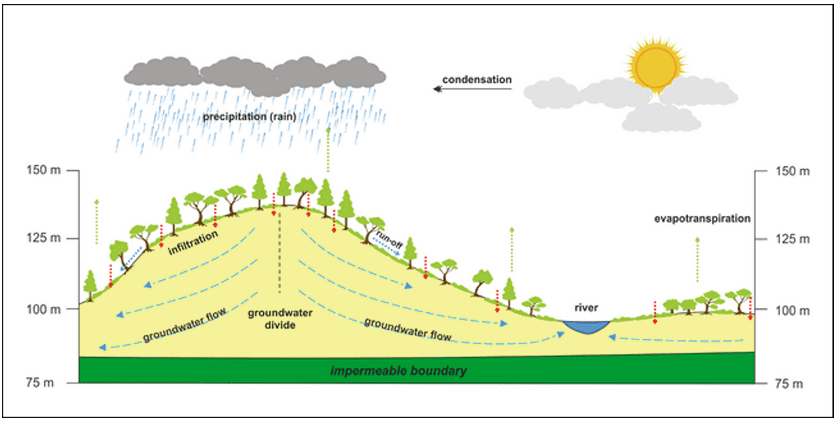


Fig. 10. Conceptual model of research area.

2. PSA 2 which is the hydraulic conductivity value of the aquifer is changed to 3.7 x 10^{-5} m/s while the piezometric elevation remains.
3. PSA 3 is the change in the piezometric elevation value (Table 4) while the net recharge and hydraulic conductivity remain.

The results of the PSA test are obtained from PSA which has a small error value (close to 0) so it can be assumed to be close to the actual conditions in the field (Fig. 12).

3.10 Groundwater Flow Model

Based on the results of the model calibrated with PSA 3 (Fig. 13) it can be seen that groundwater flow in the unconfined aquifer layer is the overall equipotential flow distribution of the head from areas with high elevations to lower areas in accordance with the principle of flow flowing from high to low places as can be seen. Seen from the model of

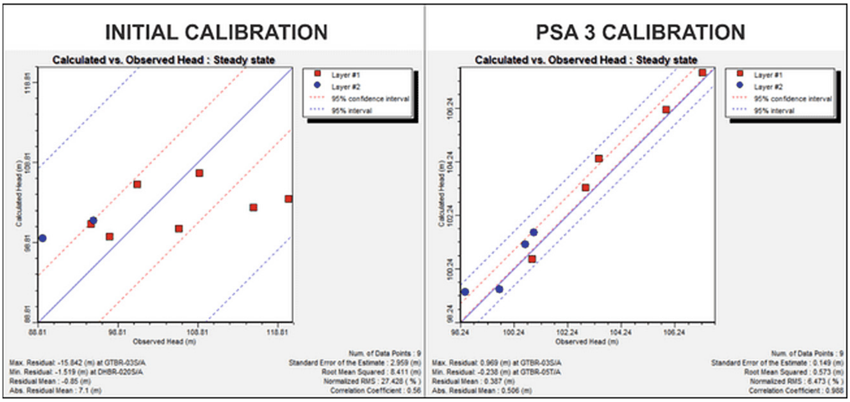


Fig. 11. Scatter diagram of modeling calibration (initial and PSA 3).

Table 4. Head Elevation.

Hole ID	Observation Head	PSA 3	Calibration Head
GTBR05	97,692	99,7	99,3
GTBR06	89,424	98,424	99,2
DHBR017	106,368	100,46	99,59
DHBR021	95,46	98,46	99,67
GTBR01	101,215	100,715	100,615
GTBR03	120,09	102,4	100,95
GTBR04	95,723	98,21	98,89
DHBR014	115,752	100,3	100,58
DHBR020	108,967	102,46	103,43

the research area around the river area. There is no groundwater flow in the unconfined aquifer in the eastern part of the study area, this is because the aquifer layer is not continuous. There is a groundwater divide condition where groundwater flows are in opposite directions, which is the condition of groundwater hydraulics in hilly/mountainous areas, as can be seen in the middle area of the research area model. The distribution pattern of equipotential head values in the unconfined aquifer layer also illustrates that the equipotential head value (contour) decreases and becomes denser when it reaches a network or constant flow (river).

Groundwater flow in the confined aquifer layer has an absolute difference with the unconfined aquifer layer, especially in the eastern part or area of the model, this is because the confined aquifer layer is still present (continuously) in the eastern area. Groundwater flow from the equipotential head distribution pattern in the confined aquifer layer is more dominant than the unconfined aquifer layer, this can be seen in the eastern area of the model results where groundwater flow changes direction because it is a lower area due

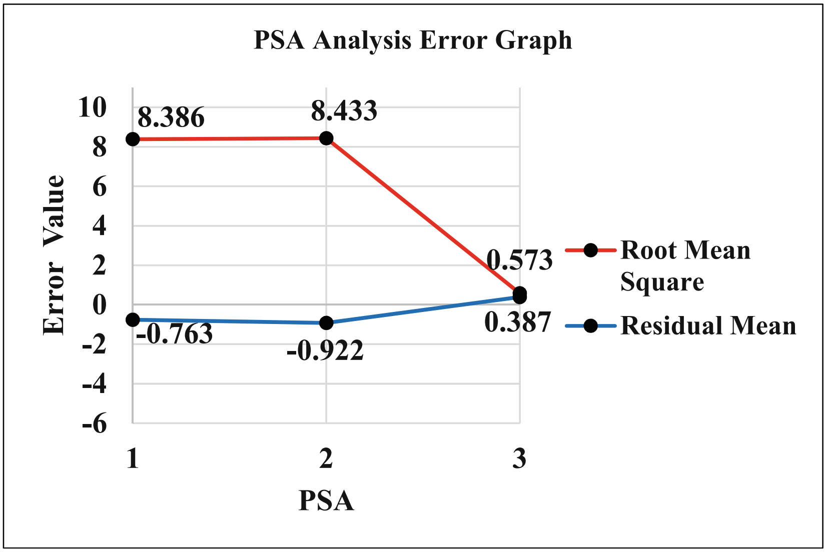


Fig. 12. PSA Analysis Charts.

to the slope of the layer and the mining process. The equipotential head distribution pattern in a confined aquifer also illustrates that the equipotential head value (contour) decreases and becomes denser when it reaches a lower area such as a river, or a low area such as a mining pit area.

Changes in morphology or landform due to the mining process have an influence or impact on the direction of groundwater flow, especially in the rock layers that become the cut aquifers due to the mining process. The direction of groundwater flow which initially (naturally) leads to the river area or lower plains becomes also leads to the mine opening area. From the model, checkpoints have also been determined which function as checking points or monitoring the groundwater flow.

3.11 Recommendations for Mining Activities

Groundwater that flows into the mine opening area (pit) can hinder the process or mining activities so it becomes a problem for the company. Problems due to groundwater are also a loss and endanger the mining process such as flooding in mine openings, the mobilization of loading and unloading equipment being hampered due to impassable roads, the influence on slope stability, and others. To control and control the flow of groundwater that enters the mine opening, dewatering can be carried out using an exclusion technique approach (Fig. 14), namely making ditches (drainage) and ponds (sumps). The trench is made right on the side of the cut aquifer layer and then directed to the pond.

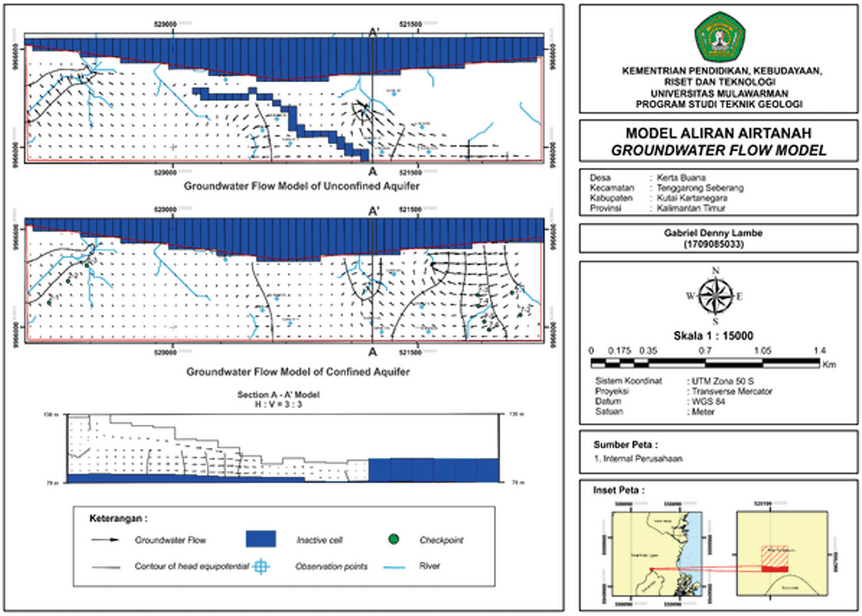


Fig. 13. Groundwater flow model of research area.

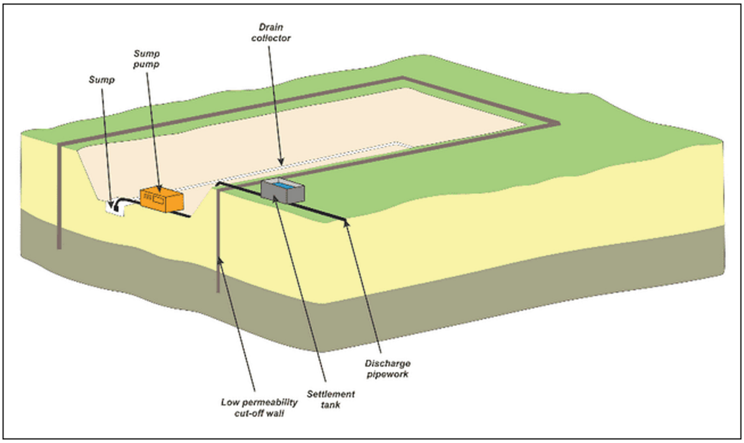


Fig. 14. Exclusion techniques to control groundwater.

4 Conclusion

The research area is part of the Separi Besar watershed, so the research area is designated as a catchment area. The groundwater recharge value obtained is 930.4074 mm/year. The research area belongs to the Typology of the Sandstone-Claystone Sedimentary Aquifer System, the types of aquifers found are unconfined aquifers and confined aquifers. The hydrostratigraphy of the research area consists of aquifers (sediments and sandstones), aquitards (siltstone, coal, carbonaceous shale, and shaly coal), and aquiclude (claystone). The direction of groundwater flow in the unconfined aquifer layer is not found in the eastern part of the research area, while the groundwater flow in the confined aquifer layer can be seen this is because the unconfined aquifer layer is not continuous. The direction of groundwater flow leads to a lower area, namely the constant network (river) and the mining pit area.

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