DESIGNS FOR DEWATERING AND OPTIMIZATION OF PIT SLOPES IN SAPROLITE OVERBURDEN: A CASE STUDY OF THE PT. KAYAN PUTRA UTAMA COAL PROJECT

by

Antony Lesmana

B.A.Sc., University of British Columbia, 2010

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in

The Faculty of Graduate Studies

(Mining Engineering)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

September 2012

ABSTRACT

Effective dewatering and environmental program poised to have a significant impact on the feasibility of saprolite mining operations. It is therefore necessary to strike a balance between an effective dewatering program and sound environmental policy. Using assessments such as rainfall, climate studies, groundwater flow, and aquifer characterizations, the Separi coal dewatering program includes the construction of water channels, flood protection levees, water wells, and placing various environmental monitoring sites. The construction of water channels and flood protection levees has reduced the water runoff that entered the mining area by approximately 75%. For a six-month testing period, the average pumping rate of the dewatering well was 24.78 m^3/day. These pumping rates were determined to result in groundwater level that would generally be 10 meters below the lowest mining benches at all times. Ten meters is the recommended single bench height based on the slope stability analysis. After six months of dewatering, the groundwater level was lowered 10.88 meters, permitting the mining project may begin its mining operation to commence. A re-design of maximum pit slope angle is indicated in this research. During the testing period, the environmental management plan did not show any negative impacts of dewatering programs on surface and groundwater resources. The monitoring sites all yield acceptable range of water quality parameters, such as Electrical Conductivity (EC), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and pH value. The company continues to monitor the water resources to maintain acceptable water quality in the study areas.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

EC	Electrical Conductivity
KPUC	PT. Kayan Putra Utama Coal
MT	Metric Tonnes
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UCS	Unconfined Compressive Strength

ACKNOWLEDGEMENT

I thank the generous support and funding of PT. Kayan Putra Utama Coal, whose guidance and support from the beginning to the end of the project enabled me to develop understanding of the project. I express my warmest appreciation to the residents of Kutai Kartanegara for their selfless contribution and sharing their precious time to the overall success of the project. I show my gratitude to Dr. Michael Hitch for his continued encouragement and support throughout my time at UBC. His enthusiasm and assistance in the duration of the study has been valuable and inspirational to me. You constantly demand the best of me and for that I give my deepest gratefulness. Thanks to Dr. Scott Dunbar for his continued assistance and finally, to the rest of my committee, Dr. Dirk van Zyl and the entire UBC Mining Department who have made this project possible.

1. INTRODUCTION

1.1 Research Overview

The mining industry has grown substantially worldwide, promoting serious competition among various mining companies to capitalize on the current high price of commodities (Roth, 2011). Roth (2011) stated that the Standard and Poors GSCI Index that tracks price inflation by commodity recorded an over 30% price increase for 2010. Demand growth for base metals in China remains high and will likely keep growing in the future (China Mining, 2011). This high commodity consumption will require a huge supply of metal that has to be mined from areas with very high and costly environmental, technological, and political risk (Roth, 2011). New discovery of mines with low mining cost and traditional technologies are no longer available. China, India, and many other developing countries including Indonesia continue to build new thermal power plants and this could have an effect on the coal supply for the rest of the world (McCawley, 2008). New power capacity in Indonesia requires more energy and estimates indicate that the county will be burning over 60 million tonnes of coal per year in the future (McCawley, 2008). Indonesia Energy Ministry officials have speculated that Indonesia will follow China in imposing export curbs and the country plans to ban exports of coal with an energy value of less than 5,600 kilocalories a kilogram starting in 2014 because of possible shortage of the country's power capacity (Djanuarto and Rusmana, 2011).

Saprolite is defined as soft, thoroughly decomposed and porous rock, often rich in clay, formed by the in-place chemical weathering of igneous, metamorphic, or sedimentary rocks (Haryoko, 2008). Saprolite is usually reddish brown or grayish white and contains those structures, such as cross-stratification, that were present in the original rock from which it formed. Saprolite is commonly found in humid and tropical climates (Haryoko, 2008). Due to the saprolite's high clay content, its water capacity tends to be very high (Webb, 2005). For this reason, saprolite can store large amounts of water, thus making areas saturated with water and difficult to mine. They commonly are the transition zone between the residual soil and the parent rock (Duchaufour, 1982).

Mincorp (1998) completed a pre-feasibility study on Brisas del Cuyuni gold project in Southeast Venezuela that involved mining clay-rich saprolitic overburden. According to the report, the dewatering design of the mine presented some unique challenges due to the presence of saprolite rocks and the wet climate of the region.

Mining in saprolitic regions thus require an effective dewatering program before any mining operation can take place. However, increased continuous withdrawal of groundwater may deteriorate the quality of groundwater in the region (Kumar, 2002). A Groundwater basin is defined as an alluvial aquifer or a stacked series of alluvial aquifers with reasonably well defined boundaries in a lateral direction and having a definable bottom (Doerge & Smith, 2008). In Indonesia, the potential areas are located on nine islands: Bali, Nusa Tenggara Barat (NTB), Nusa Tenggara Timur (NTT), Maluku, Sulawesi, Java and Madura, Kalimantan, Sulawesi, and Papua (Kodoatie, 2010). On these nine islands, there are 421 groundwater basins with an estimated total potential groundwater of 517 billion m^3 (Kodoatie, 2010). Kodoatie (2010) also stated that some of the groundwater basins in Kalimantan are found in saprolitic regions with large mining resources beneath it. The KPUC mine area is included in the CAT Tenggarong groundwater basin, which will be discussed in Chapter 3 (Watiningsih, 2009). The effects of mine dewatering might be immense to this groundwater potential (Kumar, 2002). Strategic mine design and an effective dewatering program is required before extending mining activities into these saprolitic regions in Kalimantan. This is to ensure that mining the resources beneath these areas are not compromised.

The issue of long-term water management and groundwater impact due to dewatering the saprolitic region needs to be understood, even after mining ceases in the region. The New South Wales Government examined the entire Upper Hunter Shire area for the potential of coal mining in the Upper Hunter Valley (NSW Government, 2005). The key issue for open-cut coalmine in that area was to reduce the effect of mine dewatering on the overall groundwater quality (NSW Government, 2005). In order to allow mining in a saprolitic region, there must be a balance between economic and environmental considerations and the overall integrity of the groundwater network. Being proactive in effective dewatering programs as well as planning for negative implications could ensure the viability of future mining projects in saprolitic regions.

This thesis describes the designs for dewatering and mine optimization of saprolite overburden in Indonesia. It consists of six chapters, which include a literature review of current research, results from regional climate and aquifers study, discussion of local dewatering and environmental programs, and subsequent analysis.

Chapter 2 details the methodology approach, data collection and processing, and case study from Malinau Coal site in Kalimantan, Indonesia. Data limitation is also discussed in this chapter.

Chapter 3 focuses on the current literature review on various dewatering programs, the strength of saprolite, and Indonesia environmental regulation on dewatering groundwater resources.

Chapter 4 discusses the regional climate, hydrogeological and aquifers results. Based on these data, the dewatering plan in the study areas will be presented. Environmental water management is in place and this section will describe this in detail. This chapter also details the geotechnical characteristics of saprolitic overburden and the layout of the maximum pit design.

Analysis of the recorded data from the dewatering and environmental program is presented in Chapter 5. The conclusion, presented in Chapter 6, summarizes the thesis findings and contributions.

1.2 Separi Coal Deposit

The focus on this research is the Separi Coal Deposit in Indonesia. In November 2006, the former governor of Kutai Kartanegara, Syaukani Hasan Rais, granted coal mining right No. 540/09/KP-Ep/DPE-IV/XII/2006 to PT. Kayan Putra Utama Coal (KPUC) (KPUC, 2006). The mining area is located at Tenggarong Seberang and Sebulu Regency, Kutai Kartanegara, East Kalimantan, Indonesia. The area, which is 2,315 ha in size, is located northwest of the capital city of East Kalimantan, Samarinda. The location of the mine is shown in Figure 1.1.

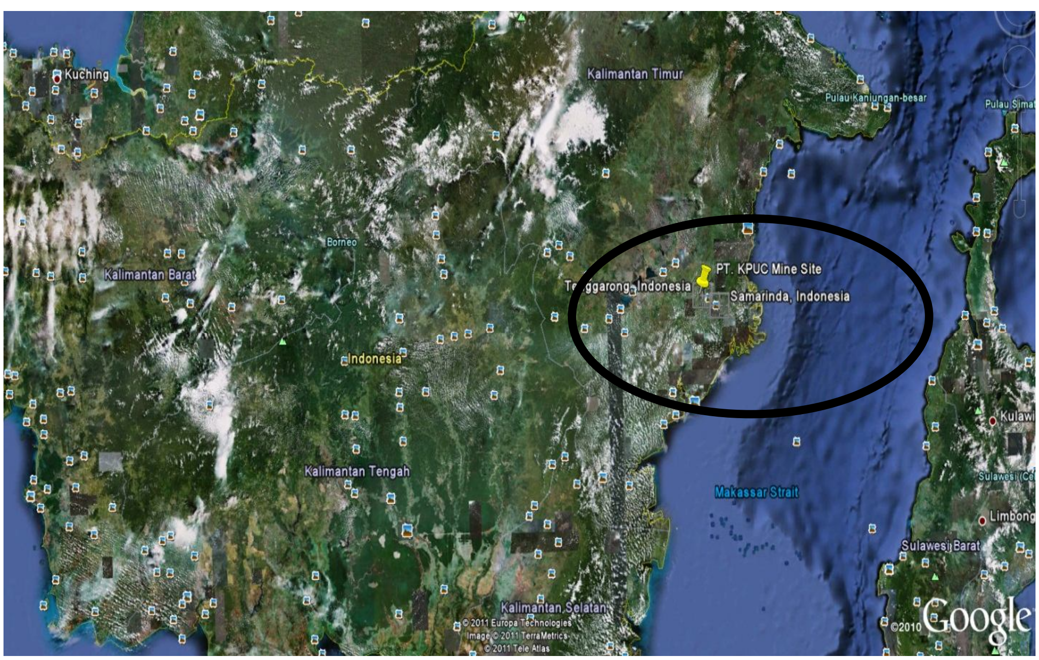


Figure 1.1 *Location of the KPUC mine (Source: Google Earth, 2011).*

KPUC's coal production in 2009 reached ± 2.0 million MT (metric tonnes), and in 2010, it reached ± 4 million MT (KPUC, 2010). Considering the large potential of coal mining in Indonesia and current high coal prices, KPUC plans to increase its annual production target to ± 6 million MT in 2011 and approximately to ± 7.5 million MT in 2012 (Lesmana, 2010). KPUC management has purchased new equipment in order to realize the new production target. The increase in planned mine production has generated much concern among the company's management. The main concern is that with the company's production growth, the mine area will advance southward at an increased rate. These areas are currently covered with saprolite and mud overburden. Mud is defined as a slimy sticky mixture of solid material with a liquid and especially water (Price, 2009). KPUC is seeking ways to continue open-cut mining operations in this saprolitic-covered region in a way that does not impede coal and waste production in any other location of the current pit and with minimal impacts on the local environment. Figure 1.2 identifies the saturated saprolitic overburden area of the pit. The surface is saturated with water from heavy rainfall, which is a common occurrence in project area. The close proximity to a small tributary river contributes to the saturation of the saprolite, especially if the water from the stream overflows into the study areas during periods of heavy rainfall.

Figure 1.2 *Section of the mining pit that is covered with saprolite (Willianto, 2011).*

KPUC management is concerned that mining in these areas will become a problem in the future, thus affecting the company's production output. This, in turn, would affect financing of the recently purchased dedicated fleets of equipment to meet the new production targets. In addition, drilling results and resource calculation show that the study areas are regarded as having high coal resource potential for the company (Harun, 2006). Because of the above concerns, PT. KPUC has decided to conduct extensive research on the most effective, economic and environmental friendly method of dewatering and mining in the area.

1.3 Hypothesis and Proposed Solution

Mining in saprolitic regions has the potential to be highly influential for future production, considering the huge resources found in some regions, particularly in tropical countries such as Indonesia (Kodoatie, 2010). Mining in these areas is not an easy process. At issues are the difficulties in mine planning, effective dewatering, and maximizing the responsible utilization of coal resources (Hansen Consulting, 2006). All of these are to be conducted under the mindful consideration of environmental affects (Hansen Consulting, 2006). This research examines how mining development in such a region can be effected, especially considering saprolite mining dewatering and environmental issues. The purpose of this research is to investigate how the introduction of a local mine dewatering and environmental programs might affect mining feasibility in a saprolitic region in Eastern Kalimantan Indonesia. The aim of this research is reflected in the research questions. The research objectives for this study are:

1. To determine recharge rates and develop mitigation structures.
2. To evaluate the dewatering/drawdown rate of surface and groundwater.
3. To design a maximum pit slope angle that considers not only the geotechnical characteristics of hard waste rock, but also saprolitic/semi-consolidated material.
4. To monitor the potential adverse impacts of the dewatering program on local water resources.

The hypothesis of the research questions is that by striking a balance between an effective dewatering program and sound environmental policy, saprolite projects such as the Separi Coal mine can become feasible and viable mining projects.

As described, the high water content found in the regions is derived from two main sources, which are surface water runoff that goes directly into the pit and groundwater discharge inside the pit. The rain catchment area, which will be described in chapter 4, is large, and flooding can occur readily, depending on the magnitude, intensity and duration of the rainfall. The percentage of rainfall that recharges to the water table will vary according to the nature of surficial outcroppings and topography as well as the intensity of the rainfall (Kodoatie, 2010). One solution is to consider the construction of water channels to reduce water runoff entering into the mining area. The Separi River is a narrow river, only a few meters at its widest. During a period of heavy rainfall, the riverbanks breech and overflow thus flooding the study areas. As such, open-cut mining in the region requires construction of levees to provide flood protection for active mining areas. The proposed level of flood immunity will be based on the rate of water discharge entering the study areas. With the construction of both water channels and flood protection levees, it is expected that the water runoff that enters into the mining areas will diminish.

Effective dewatering of groundwater may be achieved through the combination of an effective drainage system and dewatering through wells. The recommended method to control or reduce groundwater in the study areas is to construct drill wells that will serve to pump groundwater from the aquifer. The requirement for the supplementary bores and their locations will be determined and is based on the hydrogeological and aquifer conditions of the mines. Once all these evaluations are made, this research tests the effectiveness of the hypothesis in mining the study areas. Geotechnical and Slope stability analysis are done in the study areas to produce recommendations for the design of the maximum saprolitic slope permitted for safe mining operations.

Groundwater and surface water monitoring sites were placed at the aquifers and rivers respectively to determine any effects of the proposed dewatering program. The monitoring was carried out on a monthly basis for six months; and the parameters measured included were: Electrical Conductivity (EC), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and pH value. This will take into account the environmental impacts of the dewatering program.

Environmental monitoring of potential adverse effects on water resources must be incorporated into this research and resulting. The Separi Coal deposit in Eastern Kalimantan is an excellent site to implement a good dewatering program, and a feasible, economical mining project with minimum environmental impacts. Chapter 2 discusses the research methodology for this research.

2. METHODOLOGY

Several methods will be used for collecting and evaluating the empirical data. These include conducting quantitative experiments, direct observation, as well as reading and analyzing relevant research materials. The data will be managed through computer software. This chapter will describe the methods of data collection and analysis and interpretation.

2.1 Instrumentation and Data Collection

For this research, the required data included regional climate studies in the study areas, hydrogeological and aquifers assessment by the researcher, and analyze the morphology of the study areas. Digital compass, digital altimeter (to measure the ground surface elevation), EC meter (to measure the ground's electrical conductivity), digital cameras, Garmin 76CS GPS (to determine the coordinates of the measurement points' and samples' locations), and computer software (ArcMap/ArcGIS 9.1, Surpac Vision, Surfer 8, Global Mapper 10, RockWorks 2006, Modflow 2000 and Autodesk Land Desktop 2006) were the instruments and tools used to collect and manage the above data. In addition, the climate of the study areas will be determined through an Indonesia Map (scale 1:25,000) and historical data such as Tenggarong rainfall data (2000—2009), Tenggarong air temperature data (2000—2009), and Tenggarong humidity data (2000—2009). The study, data collection, and test-work will be conducted from September 2010 to September 2011.

The primary site data and relevant reports about the climate of the study area are essential for the study. Tenggarong rainfall, air temperature, and humidity data from 2000—2009 will be used to make 24-hour rainfall predictions over 2-, 3-, 5-, 10-, and 20-year time intervals. The result of the predicted daily rainfall of the study areas will be used to calculate the predicted rainfall intensity. The morphological condition of the area was analyzed based on the topographic maps provided by the company, lithological data, slope, observation of surface groundwater on exploration drill holes and dug wells, and, eventually, river flow patterns in the vicinity of the mining area. The company drilled the exploration drill holes and dug wells and the researcher oversaw and controlled the location of the dug wells. The study, together with the regional geology map of the area, will identify the lithological units that have hydrogeological significance to the study. The local hydrology of the area will be evaluated to study the catchment area, which is the watershed area, and to determine their respective dimensions. The locations of catchment areas and wetlands will be identified, if present. Five holes (DH-1, DH-2, DH-3, DH-4, and DH-5) were drilled and logged to characterize the local aquifers. A slug test is an aquifer test where water is quickly removed from the groundwater well, and the change in hydraulic head is monitored through time (Asdak, 1995). The test identified the characteristics of the aquifers such as thickness, hydraulic conductivity, transmissivity, and storativity value. This evaluation will be discussed later in Chapter 4. From these data, the groundwater discharge rate was calculated. The groundwater discharge rate was determined and the required dewatering rate at the study areas was established.

The main software used to process these data was Modflow. The well coordinates, thickness of the water-saturated zone, type of aquifer, porosity, initial head, groundwater discharge, and water pressure will be imported into the program. Given these data, a model of the contours of groundwater flow pattern was created. The database was updated continuously as new data became available. The hydrogeological aquifer system and groundwater interaction processes was defined. The output data was a contour map predicting a groundwater flow pattern. The map was then used to guide the decision-making process for KPUC’s dewatering program and mine plan by taking into account that the different groundwater flow patterns.

Other programs were used to process the primary data. Global Mapper 11 was used to analyze and edit raster maps, vectors, and area. ArcMap/ArcGIS 9.1 was used to store, analyze, and manage spatial data. RockWorks 2006 was used to make a model of soil material or rock formations and the surface of shallow groundwater originating from the research data, including shallow surface groundwater, materials constituting the unsaturated zone, and lithology of the research area. Autodesk Land Desktop 2006 was edit maps from Global Mapper 10. Surfer 8 will be used to determine the direction of groundwater flow, based on the groundwater contours. Lastly, Modflow will be used to create the three-dimensional model of the groundwater flow pattern in the study areas.

The dewatering program set up in the study areas involved controlling the surface water runoff and groundwater. This was based on the predicted rainfall intensity, groundwater flow pattern and the required dewatering rate. From this framework, a subsequent design and construction of water channels and flood protection levees are made to control the surface water runoff. In addition, design and construction of a full scale dewatering well/pump was developed.

Groundwater and surface water monitoring sites were placed within the mine site. The monitoring was carried out monthly for six-months and subsequently compiled into EXCEL spreadsheets. For this environmental study, the required data would include the Indonesia environmental law on water resources and review of relevant case studies on environmental water management. These will be presented in Chapter 3. The potential long-term issues on water quality will be assessed.

The researcher conducted geotechnical characterization and analysis to obtain data for optimum and safe mine design. The geotechnical review of the dewatered saprolitic rocks will produce the maximum pit slope plan that considers not only the geotechnical characteristics of hard rock, but also saprolitic/semi-consolidated material. The safe slope angle and height of a single bench and overall pit will be calculated. The results will be discussed in Chapter 4.

2.2 Data Validity and Limitation

In studies that involve results based on field data collection and evaluation, it is always necessary to discuss the validity of the survey tool. The validation of the survey instruments can be improved when data analysis is triangulated, that is to say, the use of multiple data collection devices, sources, to establish the validity of findings (Creswell, 2009). Any outliers should be examined and differences explained (Creswell, 2009).

In this research, the validity of the data is demonstrated by test-retest criteria, which involves repeating the same experiment and evaluating any discrepancies in results. If any discrepancies are found, a third round of data collection will be conducted.

The limitation of the data is based on the number of samples taken during the experiment. Only five logging drill holes are reviewed and used to characterize the aquifer, and this may not be representative enough. Estimating the rainfall intensity based on 10-year rainfall data may also be limited in accuracy mainly because of the error in estimation. Historical rainfall data in the study areas is restricted for the 10-year period. In addition, for the purpose of this research, the dewatering well and environmental management plan will only be monitored for six months. The results may therefore not be representative and longer testing period can be done in future to avoid this.

2.3 Data Analysis

The guiding principal of the research is twofold; first, is to design a mine that will strike a balance between an effective dewatering program and sound environmental policy, and second, to ensure that mining in saprolitic regions will be feasible. Based on research and data analysis, the dewatering program includes the construction of flood protection levees, water channels, and water wells. The effectiveness of this program will be analyzed based on:

1. How much the construction of water channels and flood protection levees has reduced the water runoff that entered the mining area?
2. The capability of the dewatering wells to achieve the desired dewatering rate and the decrease in groundwater elevation.
3. Any negative environmental impact caused by the dewatering program.

Finally, the researcher identifies the effectiveness of the proposed dewatering program and sound environmental policy in the study areas. The contribution of this research and recommendation for future research will be presented in the final chapter.

2.4 Case Study – Malinau Coal

Hamilton (1980) and Yin (1989) purported that significant learning can be acquired from comparing one case study to another. From case reports, researcher can increase both propositional and experiential knowledge (Geertz, 1983). The hypothesis of this research believes that by striking a balance between an effective dewatering program and sound environmental policy, saprolite projects such as the Separi Coal mine can become feasible and viable mining projects.

Mining in Indonesia and in its saprolitic region can be challenging, due to its high natural recharge rate, amongst other regions such as Malinau. The close proximity of Malinau and similar geological settings to KPUC mine site in Separi makes Malinau Coal an excellent case study. The company faces similar problems in dewatering the saprolite overburden at its current mining pit. The Malinau coal site has proved that proper mine dewatering program can result in a profitable saprolite mine operation. The company manages to dewater the saprolite effectively and its methods do not impact the local water resources negatively. Location of the Malinau coal site with respect to KPUC mine site in Separi is shown in Figure 2.1. Chapter 3 will outline the literature review of saprolite and the Malinau Coal case study is presented in great detail in Chapter 4.

Figure 2.1 *Location of the Malinau Coal and KPUC mine (Source: Google Earth, 2011a).*

3. SAPROLITE & WATER MANAGEMENT: A LITERATURE REVIEW

The critical issue when mining in a saprolitic region is a good dewatering program (Roth, 2011). Successful implementation of dewatering program would maximize the responsible utilization of coal resources, while also taking into account the environmental impacts (Roth, 2011). The Bickham Coal project is an open-cut mining operation located between Blandford and Wingen in the Upper Hunter Valley, Australia (Bickham Coal, 2005). Despite the absence of saprolite in Australia, this case study presents a good understanding of an effective surface water and rainwater management. In the mining plan, climate and hydrogeological investigations were undertaken before the proposed open-cut mining operation (Bickham Coal, 2005). The pits are recharged primarily through downward percolation of rainfall through the overlying regolith layer in areas of coal seam subcrop, with groundwater then flowing along the bedding within the more permeable layer (Bickham Coal, 2005). Saprolitic regions often experience high annual precipitate.

The Bickham Coal project involves the collection of rainfall data from the nearest Bureau of Meteorology station, which has recorded almost 130 years of daily rainfall data. Maximum, minimum, and long-term average monthly rainfall data were recorded for future estimation of rainfall intensity. Subsequently, hydrogeological conceptualization of the aquifer system was undertaken (Bickham Coal, 2005). This determined the groundwater discharge rate or withdrawal required for ongoing mining operation. Once dewatering rates required for the mining operation are identified, various dewatering wells can be installed. Understanding the climate and aquifers locally are critical in estimating the required dewatering rate in the study areas (Bickham Coal, 2005).

Breckenridge et al. (2005) also discussed the importance of hydrogeologic and rainfall investigations in saprolite mining in Venezuela. Venezuela is located in a tropical region, which is the same to where the study areas are found. The proposed dewatering system use a combination of permanent dewatering wells, in-pit temporary wells, and in-pit sumps to achieve the desired dewatering rate (Breckenridge et al., 2005). Most of the water in the saprolite aquifer was dewatered by the construction of permanent dewatering wells (Breckenridge et al., 2005). Similar method was done in Malinau Coal site to dewater the saprolitic overburden.

Similar strategies were tested in the study areas. First, the researcher identified climatic and rainfall conditions in the study areas. Once the percentage of rainfall that recharges the water table is identified, hydrogeological investigations and hydraulic testing will be conducted to study the aquifer hydraulic properties. After the required dewatering rates have been calculated, the locations of dewatering wells will be determined based on the hydrogeological and aquifer conditions of the area.

The Ensham mining project in Australia involves mining around the Nogoa River floodplain (Hansen Consulting, 2006). The company took a different approach in the Ensham project. It used a mine plan designed to mitigate impacts on the Nogoa River, its floodplain, and associated flood flows (Hansen Consulting, 2006). According to Hansen consulting (2006), the mining strategy involved construction of levees to provide flood protection to active mining areas within the floodplain that will prevent the overburden from becoming saturated with water. Similar approaches will be evaluated for the KPUC mine, and therefore a review of region topographic data and estimated region flood levels will be conducted. Flood protection levee heights will then be calculated to provide sufficient levels of appropriate mine flood immunity. Despite the absence of saprolite, this case study is useful in preventing the saprolitic overburden area of the study areas to be further saturated with water. Once all the strategies are in place, geotechnical characterization and analysis will be done to produce recommendations to design the maximum slope permitted for pit optimization and safe mine design in the study areas.

An environmental monitoring program will be established to evaluate the potential adverse impacts on water resources. BHP Biliton, at its Mount Arthur North coalmine project, developed a site water management plan to manage and minimize the impact of mining operations on surface and groundwater resources (McNaughton, 2010). In McNaughton's article, it is stated that the monitoring parameters that need to be recorded periodically are pit groundwater inflow, surface and groundwater qualities (that are pH, EC, TDS and TSS). These water quality parameters are also measured in Malinau Coal Site and thus will be measured monthly in the study areas to ensure minimum negative environmental impacts.

3.1 Saprolite Characteristics

Saprolite is derived from crystalline rock and clasolite and usually developed in tropical areas which are often between residual or colluvial soil and weathered bedrock (Zemin, 2009). Saprolite is considered a chemically weathered rock which is commonly soft, thoroughly decomposed and porous rock, often rich in clay, and which can be found in the lower horizons of soil and deep weathering of the bedrock surface. Saprolite is usually reddish brown or grayish in color white and has cross-stratification structures that were present in the original rock from which it formed (Zemin, 2009). According to Webb (2005), the water capacity of saprolite is very high primarily and due to its high clay content, its porosity tends to be very high. Saprolite can store large amounts of water making saprolitic areas often muddy and difficult to mine. On the other hand, saturated soil is a specific condition referring to water filling the pores between particles of soil without any forms of weathering (Dikinya, Hinz, & Aylmore, 2008). This condition is usually temporary and varies with rainfall or other sources of water flow over soil. Soil is considered saturated when it has reached its maximum water content. Thus, saprolite is a type of weathered rock/soil whereas saturated soil is just a condition of water filling of soil. Saturated saprolite overburden is often found in the study areas.

It is often easy to distinguish the color difference of saprolite from the parent rocks based upon the degree of weathering. The soil horizons are leached and consist largely of quartz sands, micas, clay minerals, and laterites (Jones, 1985). Saprolite often has spongy micro-texture and is characterized by high porosity, high intrinsic permeability, high specific water capacity, low specific yield and low density (Zemin, 2009). Normally, the degree of weathering will decrease downwards, and the porosity and permeability of the bedrock would decrease rapidly with depth. These, together with its high specific water capacity, which is the rate of change of water content with soil water pressure, will make the saprolite saturated with water (Zemin, 2009).

According to Zemin (2009), the development of saprolite is realized by the progressive propagation of the weathering front of low permeable rock blocks, the condensation of the moisture and the unsaturated seepage flow. Thus, relatively flat topography and tectonic stability is crucial to prevent erosion and to allow leaching of the products of chemical weathering (Zemin, 2009). Cawsey & Mellon (1983) also confirmed the importance of water in the dynamic of saprolite. During periods of high rainfall, the thin water film formed on the surface of rock blocks in unsaturated zones absorbs the dissolution components of the rock block solution (mainly consisting of rock-forming minerals) and carries them into the saturated zones (Zemin, 2009). Malinau coal mine site and the study areas experience high annual precipitate. This process will repeat over a period and eventually saprolitic crusts would form. According to Zemin (2009), the saprolitic crusts will absorb and store the liquid water flowing on their surfaces. In dry seasons, these saprolitic crusts will acts as unsaturated zones and weathering fronts rock blocks with moisture (Zemin, 2009). Over time, the saprolitic crusts become thicker and turn into a rock mass, which is then called saprolite. Saprolite can store large amounts of water, thus making the saprolitic areas often saturated with water and difficult to mine.

Therefore, circulating groundwater is essential in the formation of saprolite in any region. The basic requirement for deep weathering of saprolitic rock is a mean annual rainfall surplus to be available for groundwater recharge (Jones, 1985). Results of the climate and level of precipitate in the study areas are presented in Chapter 4.

3.2 Shear Strength of Saprolite

The upper clay-rich zones of saprolite are characterized by high porosity, low specific yield, and low water permeability (Jones, 1985). Saprolitic overburden is derived from in situ rock weathering and its strength is crucial to the stability of mining slopes. Fredlund, Gan and Rahardjo (1988) determined the shear strength parameters of an unsaturated soil using the direct shear tests. Triaxial test is also a common testing method widely used to measure shear strength parameters of soils under drained or undrained condition (Price, 2009). Haryoko (2009) performed direct shear tests and unconfined compressive strength tests (UCS) on dewatered saprolitic soils in Malinau. This will be a good reference to the research, due to similarity in the characteristics of the soils in Malinau and Separi, their close proximity to one another, and the fact that the test was done on dewatered saprolitic overburden. Triaxial test will not be conducted in this work, as it is time consuming and expensive. Table 3.1 will show the soil and rock parameters used for the design of the overall slope angle at one of the pit slopes in Malinau coal mine (Haryoko, 2009).

Rocks Parameter	Claystone	Siltstone	Sandstone
γ_{sat} (KN/m^3)	18.17	17.84	17.92
$c_{residual}$ (KPa)	282.5	434.5	460
$\phi_{residual}$ (…^{o})	28.8	28.2	31.4

Table 3.1 *Soil and rock parameters in Malinau coal mine (Haryoko, 2009).*

The clay-saprolite layers are found at the top. Based on this strength and characteristics, the overall pit slope is designed to achieve factor of safety greater than 1.5. The soil and rock parameters used at the Malinau coal site have provided insight into the understanding of the strength behavior of the materials. Similar geotechnical characterization and analysis will be done in study areas to develop recommendations for the design of maximum slope permitted for safe mine design. The results of the work will be presented in Chapter 4.

3.3 Hydrogeology and Aquifer

Hydrogeology is the science that studies the distribution and movement of groundwater in the soil (Freeze & Cherry, 1979). In their book, Freeze and Cherry (1979) stated that natural conditions and rock formation carriers (aquifer, aquitards, aquicludes and aquifuges) in geological systems are strongly influenced by the conditions of lithology, stratigraphy, and geological structure. They define an aquifer as a layer, formation, or group of units of the geological formation that has the ability to allow water to flow readily, while an aquiclude is an impermeable layer overlying an aquifer. Aquitard was defined as a region of low permeability that often serves as a storage unit for groundwater boundaries of an area of storage (Freeze & Chery, 1979). It is thus normally located next to an aquifer and it does not yield water as readily as an aquifer does. They defined aquifuges as rock type of negligible permeability and porosity.

Groundwater is water contained underground (in soil or rock below the soil surface) in the saturated zone of water that can be collected with wells, tunnels, or drainage systems by pumping (SDWF, 2007). Almost all groundwater is a component of the hydrological cycle, which includes surface water and water vapor (SDWF, 2007). The presence of groundwater is controlled by the historical and geological conditions of the area, delineation and boundary conditions of the soil, and rock formations in the area that is experiencing percolation (Hendrayana, 1994). Other factors that influence groundwater conditions are climatic conditions and man-made activities (Hendrayana, 1994). The volume of groundwater in the saturated zone is always fluctuating, and this is due to the process of replenishment (recharge) and discharge (Hendrayana, 1994). Groundwater replenishment results from rainwater, surface water bodies (rivers, lakes, and swamps), and artificial charging, which depend on the size of the recharge area while discharge may occur through seepage, pumping, or the presence of natural springs (Hendrayana, 1994).

In addition to the above three factors, according to Hendrayana (2000), determinants of the content and extensive spread of groundwater also depend on several additional factors: climate (rainfall), vegetation (water binding), slope/topography, type of lithology, rock porosity and structure, and the local environmental conditions.

Understanding the groundwater flow in aquifers in the study areas is critical in designing the dewatering program. Groundwater flow patterns and modeling can be a powerful tool for solving groundwater related problems in mining operation (Rapatonva et al., 2007). In their article, they assert that assessment to model the groundwater flow pattern is conducted in dewatering the Czech part of the Upper Silesian Coal Basin and optimizing the dewatering in the North Bohemian Coal Basin (Rapantova et al, 2007). In Malinau, Haryoko (2009) model the groundwater flow pattern before determining the location of dewatering wells.

A similar approach will be incorporated in this work. Once the groundwater flow pattern in the study areas is determined, the locations of the construction of experimental dewatering water wells will were identified. The results will be presented in Chapter 4.

3.4 Indonesia Environmental Regulation

Groundwater flow for the Indonesia Groundwater Basin is defined as the area bounded by hydrogeological boundaries and describes the amount of water moving through an area (Kodoatie, 2010). It is a combination of processes such as recharge, run-off and discharge of water taking place simultaneously. The Groundwater Basin is an underground reserve of water and has a whole system of aquifers, which can be unconfined or confined (Kodoatie, 2010). The determination of such a system was not based on administrative or political boundaries but rather on the hydrogeological boundaries. In Indonesia, more often than not, a specific groundwater basin can be found across two and sometimes even more administrative regions. According to Kodoatie (2010), determining the boundaries of a groundwater basin in Indonesia is not difficult because of clear geologic boundaries such as deposits of rocks, which make clear the starting and ending directions of water flow. In Indonesia, 421 groundwater basins with an estimated total potential groundwater of 517 billion m^3 can be found (Kodoatie, 2010).

In Kalimantan, where the study areas are found, according to data from the Center of Environmental Geology, Ministry of Energy and Mineral Resources (2009), there are 22 potential groundwater basins with an estimated 67.963 billion m^3 of groundwater in the unconfined aquifer and 1.102 billion m^3 groundwater in the confined aquifer. The resources cover a total area of 181,362 km^2 (Center of Environmental Geology, Ministry of Energy and Mineral Resources, 2009). The KPUC mine area is included in the CAT Tenggarong groundwater basin (Watiningsih, 2009). Figure 3.1 illustrates the groundwater basin is bounded by the eastern part of the CAT Loahaur groundwater basin; at the western part; it is bounded by a non-potential groundwater area. Planning for mining activities must take into account the potential development of water resources found in the groundwater basin to protect the local water resources (Notodarmojo, 2005). KPUC must take necessary actions for the protection of water resources.

It is thus necessary to determine the potential of the CAT Tenggarong groundwater basin in terms of water resources to the area. If there were large potential of water resources, necessary steps must be taken to protect the water resources. The groundwater potential of a basin is determined by two criteria (Minister of Energy and Mineral Resources Decree No. K/10/MEM/2000 1451, 2000):

1. Quantity: The parameters used are based on the parameters of aquifer and wells, which are: transmissivity (T), type of discharge (Q_s), and the optimum discharge (Q_{opt}). For the purpose of drinking water, groundwater quantity criteria in shallow wells are divided into three categories, namely:
   a. Large, if the Q_{opt} value is more than 10 L/s,
   b. Moderate, if the Q_{opt} value is between 10 and 20 L/s, and
   c. Small, if the Q_{opt} value is less than 2 L/s.
2. Quality: The quality criteria for a groundwater basin depend on the type designation, determination of key parameters, and government standards used to assess the quality of groundwater.

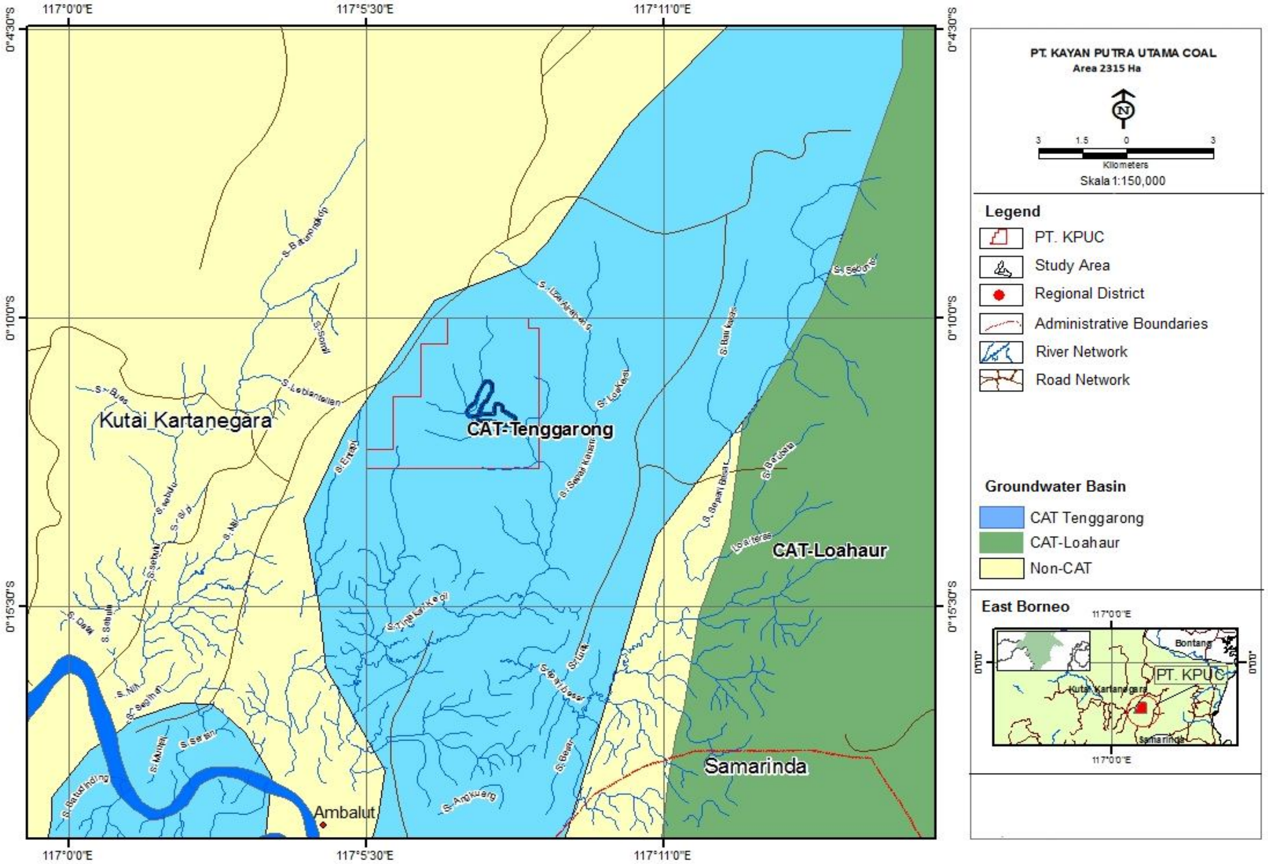


Figure 3.1 *Groundwater basins (Watiningsih, 2009).*

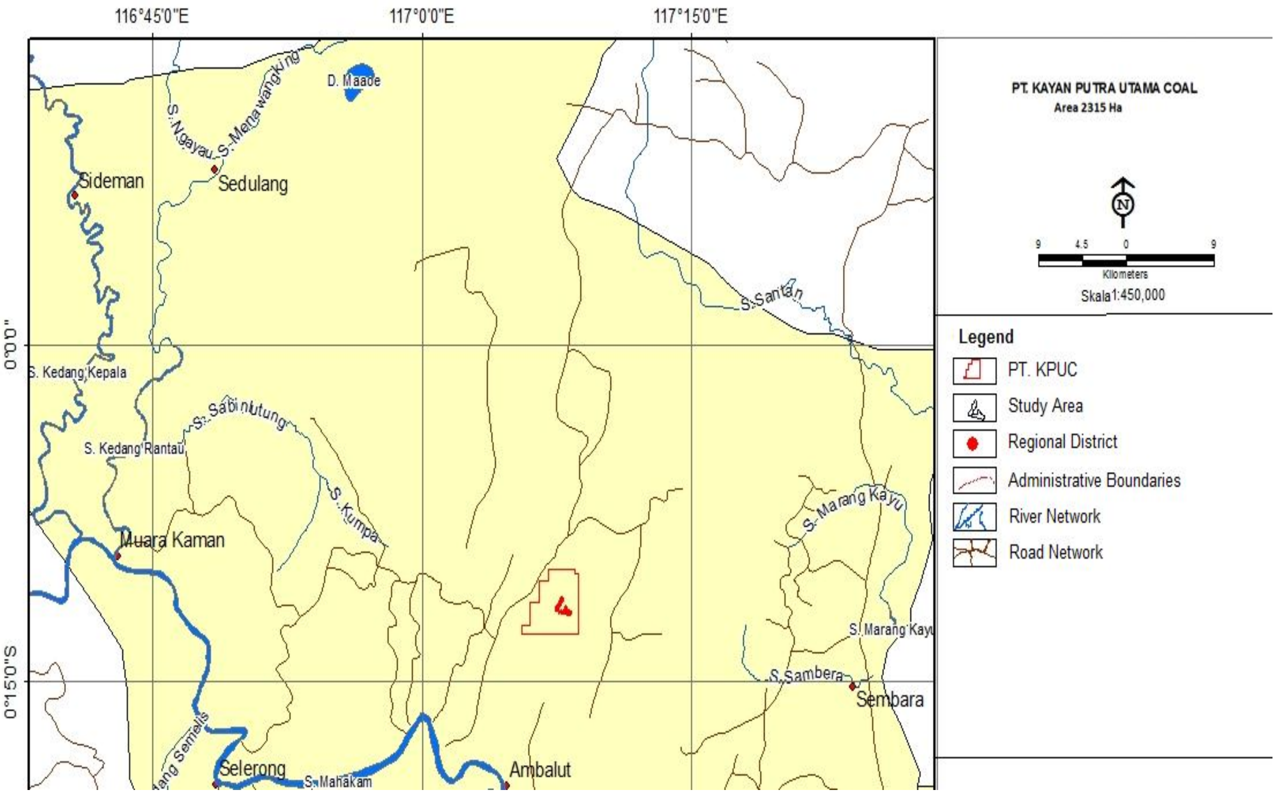


Figure 3.2 *Groundwater potential (Center of Environmental Geology, Ministry of Energy and Mineral Resources, 2009).*

According to the map of potential groundwater in Kutai Kartanegara given in Figure 3.2, the mine district where the study area is located has two types of potential groundwater: areas with limited local aquifers with groundwater flow rates of less than 2 L/s, and scarce areas (critical water resource areas), where the presence of groundwater in this area is very limited. The white region in Figure 3.2 shows the areas with moderate groundwater potential, while green denotes low groundwater potential in terms of drinking water purposes. Based on the criteria of quantity and quality of groundwater (Minister of Energy and Mineral Resources Decree No. K/10/MEM/2000 1451, 2010), the potential for groundwater as drinking water in the mining area falls into the category of low, (i.e. the optimum groundwater discharge value is less than 2 L/s). According to the decree, since there will be no long-term needs of groundwater users within the area, any dewatering program by KPUC is only required to maintain the groundwater quality of the water resources.

Based on this research, an environmental program is designed to maintain the local groundwater quality of the water resources. Water quality parameters (such as Electrical Conductivity (EC), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and pH) are measured monthly in the study areas to ensure minimum negative environmental impacts. The results of an initial six-month testing period are discussed in Chapter 5. Chapter 4 will outline the case study in Malinau and the dewatering plan for the study areas.

4. SEPARI DEWATERING PLAN

KPUC is searching for ways in which to help mitigate and mine the saprolitic overburden in the study areas. The literature review has produced a preliminary basis to perform the most efficient method to dewater and mine the saprolite that is found in KPUC's mine site. The Malinau Coal case study is presented in this chapter. The experimental work began in 2010, and was completed in September 2011. In this chapter, it is concluded that the study areas were in a region that has more than 50% of its morphology in low wetlands and that are saturated with water. Because of the huge economic potential and reserves of its coal deposits, treatments of the saprolite region have to be carried out before any form of economic open-pit surface mining can take place.

The study areas have high water content mainly because of their locations at low elevations. These areas, as a result of its morphology in low wetlands, have become water catchment areas. The groundwater seepage into the areas consists of two main components: direct contributions from local aquifers and indirect contributions from rainfall runoff (Harun, 2006). In this chapter, the technical aspects of the climatic conditions (that is, precipitate intensity and flood events) are presented. The construction of the water channels and flood protection levees are analyzed following case studies from Bickham Coal and Ensham Coal projects in Australia. This water channel is essential in allowing surface water originating from rainfall and water surface runoff to be channeled elsewhere, while the levees will provide the mining pit with flood protection.

Direct contributions from aquifers are discussed in this chapter. Case studies from Gold Reserves Inc. in Venezuela and Malinau coalmine in Indonesia in handling aquifers will be presented in detail. The study areas cover approximately hundreds square kilometers. The proposed future mine development requires the construction of a mine pit to a depth of approximately 50 metres below the existing groundwater levels. Draining the groundwater prior to mining will be necessary. Water wells will be constructed to pump groundwater contained in the aquifers. Direct shear tests and unconfined compressive strength tests (UCS) on dewatered saprolitic soils will be conducted subsequently. Recommendations to design the maximum saprolitic slope permitted is produced.

An environmental monitoring program of potential adverse impacts on water resources will also be explained. The Mount Arthur North coalmine project in New Zealand has developed a site water management plan, and its case study will be presented in this section. KPUC proposes a similar water resources management plan to maintain the quality of the region’s water.

Thus, great planning is required to ensure the success of dewatering and mining the clay-rich saprolite found in the KPUC Separi coal site. This chapter contains a discussion of the findings and calculations related to groundwater and surface water flow. These two types of flows will be briefly defined and compared. Groundwater flow results from precipitation that flows through the soil to a stream channel and results from precipitation. It can also be referred to as either dry-weather flow or baseflow. Surface water flow, on the other hand, refers to water collected either on the surface of the ground or in a variety of bodies of water such as oceans, wetlands, streams, rivers, or lakes.

4.1 Malinau Coal

This section discusses the hydrogeological investigation, groundwater studies, and pit dewatering system in the Rian pit, Malinau that is challenging due to the climate of the region and the presence of saturated saprolite overburden. Strength of the soils and rock parameters necessary for safe mine design has been discussed in Chapter 3.

One of the greatest challenges faced is the abundant groundwater recharge because of precipitation that averages more than three meters annually. The climate of the region is warm, with the average temperature recorded at 28 ^{0}C and high humidity of 85% (Badan Metereologi dan Geofisika Bandara Malinau, 2010). The study area experiences similar climates and high precipitate as well and this makes Malinau a suitable case study. There are two seasons— rainy and non-rainy —with non-rainy normally beginning in June and lasting through October. The mining pit has low-lying areas that consist of wetlands, suggesting that water is perched on the saprolitic soils (Mudjiarto, 2010). As such, both coal sites experience similar issues.

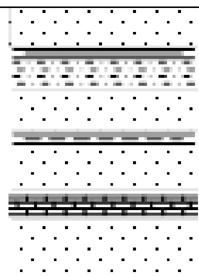
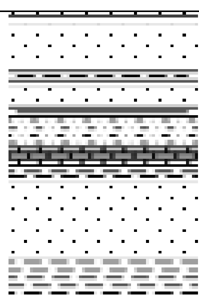
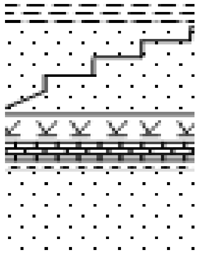
Thickness (m)	**Lithology**	**Description**
900		Clay/saprolite with insert of siltstone shale, limestone, and lignite
3000		Clay/saprolite, siltstone, limestone, shale, and coal
2750		Grey wacke, quartz sandstone, limestone, tuff, and coal horizon

Figure 4.1 *Stratigraphy geology of the Malinau Coal (Haryoko, 2008).*

Hydrogeological testing done by the company showed that the ground surface is a weathered saprolite layer above a hard rock layer (Mudjiarto, 2010). Figure 4.1shows the stratigraphy geologic of the Malinau coal. The clay-rich saprolite promotes recharge: thus, water infiltration is a slow process. Groundwater discharge in the region normally occurs through rivers in low-lying areas (Mudjiarto, 2010). According to the general manager, Mudjiarto, the groundwater level in the areas ranges from 80 m to 110 m, and the average groundwater discharge rate is 52.6 m^3/day.

To solve the problem, dewatering wells are installed to dewater the saprolite before any mining operations began. However, it is a difficult task due to the high rate of recharge in the region. The dewatering programs started before mining began in 2009, and four permanent dewatering wells and two in-pit temporary wells were constructed to achieve the desired dewatering rate (Mudjiarto, 2010). Now at Year two of the mining period, the company has managed to mine the thick saprolite overburden efficiently with a front-end shovel and truck method. The dewatering system managed to pump on average 59.8 m^3/day of groundwater (Mudjiarto, 2010).

Studies are currently being undertaken by the company to reduce the surface water flow into the pit. Mudjiarto believes that by constructing a water channel, the inflow of surface water into the pit because of heavy precipitation can be reduced. The priority for the next phase of the dewatering program is to minimize the pumping rate and reduce the water that enters into the mining pit. This approach will be taken into consideration for this research.

The similarities in climate, geology and hydrogeological nature of Malinau Coal and KPUC mine site make this case study an excellent choice. If the end result of the Malinau Coal was a successful dewatering and mine operation, KPUC can learn significantly from this case study.

4.2 Regional Climate

This section describes the regional climate studies in the study areas. All the results are based on the 10-year climatic data of the study areas.

4.2.1 Groundwater Recharge

Rainfall precipitation is the primary process of groundwater recharge in the study areas. The downward percolation of rainfall through the permeable layer of soil will allow groundwater to flow along the bedding within the permeable soil layer. In the Bickham Coal case study, the hydrogeological investigations, monitoring, and analysis showed that groundwater levels respond significantly to local rainfall events in such a way that high precipitation had caused infiltrating rainfall to reach the water table (Bickham, 2005). The nearest Bureau of Meteorology (BoM) station to the Bickham project area is Murrulla Station, which has recorded a continuous record of almost 130 years of daily rainfall data (Bickham, 2005). This data has been the basis for long-term prediction of rainfall to determine its effect on the groundwater flow model and forward predictions of mine dewatering (Bickham, 2005). The annual rainfall at the Bickham mining site exhibits a moderate seasonal pattern (Dundon and Associates, 2002). The highest median rainfall at the area occurs between November and February, while lower rainfall tends to occur between March and October (Dundon and Associates, 2002).

Climatic conditions of air temperature and rainfall data were collected from the Meteorology and Geophysics Station at Temindung Airport in Samarinda to analyze the regional climate at the study areas. From 2000 to 2009, the average monthly temperature recorded was

27.3 °C. Table 4.1 shows the monthly average temperatures for that 10-year period. Table 4.2 shows the rainfall data over the same 10-year period.

The criteria for assessment of wet or dry months will be based on the Mohr method (Irfan, 2006). In his article, Irfan (2006) quoted that Schmidt and Ferguson also used Mohr method to determine the number of wet month and dry month. As quoted by Irfan (2006), according to the Mohr method:

a. If the amount of rainfall in one month is greater than 100 mm, that month is deemed a wet month;

b. If the amount of rainfall in one month is in between 60 mm and 100 mm, that month is deemed a moist/humid month; and

c. If the amount of rainfall in one month is less than 60 mm, that month is deemed a dry month.

For determining the type of climate in the region, Schmidt and Ferguson (2006; as cited in Irfan, 2006) used the following formulation:

$$Q = Average\ number\ of\ dry\ months \div Average\ Number\ of\ wet\ months$$

Table 4.2 also shows the number of wet months and dry months for the 10-year period. Based on the Q value calculated above, Schmidt and Ferguson (as cited in Irfan, 2006) determined the regional climate of an area based on the eight zones shown in Table 4.4. From Table 4.2, the average number of dry months is calculated to be 1.0, and the average number of wet months is calculated to be 9.9. Q is calculated to be 0.111, and the climate classification in the study area is included in region type A (Very Wet; refer to Table 4.4). This is mainly because the study area is located adjacent to the equator and is in a tropical rainforest area. This climatic condition is very similar to the Malinau coal mine area. According to Irfan (2006), the characteristics of a very wet climate are:

a. The air temperature is hot, with a uniform air temperature of at least 27 °C;

b. The rain precipitation is about 2,500 mm yearly;

c. There are two seasons in a year: rainy and dry; and

d. There are two transition periods: rainy to dry and dry to rainy.

The average rainfall in each year (for the 10-year period from 2000 to 2009) amounted to 2,289.47 mm. Referring to Table 4.2, the highest monthly average rainfall occurred in March (278.55 mm) and the lowest monthly average rainfall occurred in August (90.29 mm). From Table 4.3, the highest average number of rainy days in a given month occurred in May (21.10 days) while the lowest average number of rainy days in a given month was in August (13 days). Every year, on average, there were approximately 223 rainy days. Figure 4.2 shows the map of rainfall precipitation in Kutai Kartanegara from 2000 to 2009, and Figure 4.3 shows the average temperature at Kutai Kartanegara for the same 10-year period.

Table 4.1 *Monthly average temperatures (Badan Metereologi dan Geofisika Bandara Temindung Samarinda, 2010).*

YEAR	**TEMPERATURE (°C)**												**AVERAGE**
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**	
2000	27.2	27.0	27.1	27.3	26.7	26.5	26.4	26.7	26.6	26.9	27.0	27.4	**26.9**
2001	26.8	26.6	26.9	26.9	27.2	26.4	26.5	26.5	26.9	27.0	27.6	26.6	**26.8**
2002	26.7	27.1	26.9	27.5	27.5	27.1	26.8	27.4	27.0	27.5	27.4	27.3	**27.2**
2003	27.5	27.5	27.1	27.7	27.6	27.2	27.2	27.3	27.4	27.9	27.6	27.8	**27.5**
2004	27.4	27.9	27.2	27.8	27.8	27.5	26.9	27.1	26.9	27.4	27.6	27.3	**27.4**
2005	27.6	26.9	27.4	27.4	27.6	27.5	26.6	27.1	27.1	28.5	27.8	27.1	**27,4**
2006	27.3	28.3	28.2	27.1	28.5	27.1	26.9	27.5	27.9	27.4	26.9	27.2	**27.5**
2007	27.1	27.7	27.7	27.5	27.3	26.7	27.7	27.2	32.1	27.8	27.6	28.0	**27.9**
2008	27.0	27.3	26.7	27.0	27.4	26.8	26.3	26.5	27.1	27.4	27.2	27.0	**27.0**
2009	27.0	27.0	27.2	27.5	27.8	27.7	27.3	27.9	28.5	27.4	27.7	27.7	**27.6**
AVERAGE	**27.2**	**27.3**	**27.2**	**27.4**	**27.5**	**27.1**	**26.9**	**27.1**	**27.8**	**27.5**	**27.4**	**27.3**	**27.3**

Table 4.2 *Total monthly precipitate (Badan Metereologi dan Geofisika Bandara Temindung Samarinda, 2010).*

YEAR	**TOTAL PRECIPITATION (mm)**													**TOTAL**	
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**	**WET**	**MOIST**	**DRY**
2000	188.8	308.3	265.9	138.5	249.4	279.6	118.2	101	209.1	175.3	381.4	168.7		2584.20	
	WET	WET	WET	WET	WET	WET	WET	WET	WET	WET	WET	WET	12	0	0
2001	156.4	307.3	235.7	157.6	187.1	109.7	98.4	26.4	167.7	134.1	220.8	112.1		1913.30	
	WET	WET	WET	WET	WET	WET	MOIST	DRY	WET	WET	WET	WET	10	1	1
2002	156.9	128.2	284.4	190.0	130.0	180.6	76.4	32.7	73.5	140.1	101.7	181.8		1676.30	
	WET	WET	WET	WET	WET	WET	MOIST	DRY	MOIST	WET	WET	WET	9	2	1
2003	253.3	157.9	417.3	135.7	244.9	79.8	44.5	95.6	273.8	220.9	203.7	217.9		2345.30	
	WET	WET	WET	WET	WET	MOIST	DRY	MOIST	WET	WET	WET	WET	9	2	1
2004	339.7	224.3	401.6	384.8	367.6	55.4	100.1	42.4	171.7	2.1	280.9	175.5		2503.70	
	WET	WET	WET	WET	WET	DRY	WET	DRY	WET	DRY	WET	WET	9	0	3
2005	200.7	38.9	225.4	336.3	199.4	98.6	271	145.4	94.1	339.6	304.5	296.5		2550.40	
	WET	WET	WET	WET	WET	MOIST	WET	WET	MOIST	WET	WET	WET	10	2	0
2006	227.8	206.8	214.6	206.6	306.5	184.6	24.4	97.5	107.1	69.6	190.6	110.0		1946.70	
	WET	WET	WET	WET	WET	WET	DRY	MOIST	WET	MOIST	WET	WET	9	2	1

YEAR	TOTAL PRECIPITATION (mm)												TOTAL		
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**	**WET**	**MOIST**	**DRY**
2007	306.8	220.4	260.3	339.7	112.3	213.4	278.5	132.9	182.6	181.4	84.6	141.2		2454.10	
	WET	WET	WET	WET	WET	WET	WET	WET	WET	WET	MOIST	WET	11	1	0
2008	142.6	194.4	211.4	259.4	50.9	205.2	333.3	148.7	153.4	207.5	501	349.7		2757.50	
	WET	WET	WET	WET	DRY	WET	WET	WET	WET	WET	WET	WET	11	0	1
2009	164.0	196.2	278.9	309.1	186.4	41.2	157.3	122.7	98.5	232.3	165.3	211.3		2163.20	
	WET	WET	WET	WET	WET	DRY	WET	WET	MOIST	WET	MOIST	WET	10	1	1
TOTAL	**2137.0**	**1982.7**	**2785.5**	**2457.7**	**2034.5**	**1448.1**	**1502.1**	**902.9**	**1532.1**	**1702.9**	**2434.5**	**1964.7**		**22894.70**	
													99	**11**	**10**
AVERAGE	**213.7**	**198.27**	**278.55**	**245.77**	**203.45**	**144.81**	**150.21**	**90.29**	**153.21**	**170.29**	**243.45**	**196.47**		**2289.47**	
													9.9	**1.1**	**1.0**

Note: DRY = Dry month (Precipitation < 60 mm).

MOIST = Moist/humid month (Precipitation > 60–100 mm).

WET = Wet month (Precipitate > 100 mm) (Irfan, 2006).

Table 4.3 *Total number of rainy days from 2000 to 2009 (Badan Metereologi dan Geofisika Bandara Temindung Samarinda, 2010).*

YEAR	**Number of Rainy Days (Days)**												**TOTAL**	**AVERAGE**
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**		
2000	4	2	1	6	18	17	23	26	22	24	20	28	**191**	**15.92**
2001	17	17	28	21	24	20	19	19	21	27	19	21	**253**	**21.08**
2002	21	21	21	24	21	26	18	21	24	24	21	18	**260**	**21.67**
2003	24	22	22	24	20	16	17	4	23	20	19	15	**226**	**18.83**
2004	16	14	22	19	18	20	10	6	10	11	24	17	**187**	**15.58**
2005	18	14	20	23	18	17	18	16	20	20	20	20	**224**	**18.67**
2006	18	22	24	21	24	13	23	1	21	7	19	23	**216**	**18.00**
2007	19	10	13	24	22	23	22	13	13	23	26	25	**233**	**19.42**
2008	19	18	18	21	22	22	5	10	9	6	20	22	**192**	**16.00**
2009	25	20	21	18	24	22	28	14	13	20	21	18	**244**	**20.33**
TOTAL	181	160	190	201	211	196	183	130	176	182	209	207	**2226**	**185.50**
AVERAGE	18.10	16.00	19.00	20.10	21.10	19.60	18.30	13.00	17.60	18.20	20.90	20.70	**222.60**	**18.55**

Table 4.4 *Type of climate based on Q value by Schmidt and Ferguson (as cited in Irfan, 2006).*

Q VALUE	**ZONE**	**CLIMATE**
0.000 ≤ Q < 0.143	A	Very Wet
0.143 ≤ Q < 0.333	B	Wet
0.333 ≤ Q < 0.600	C	Rather Wet
0.600 ≤ Q < 1.000	D	Medium
1.000 ≤ Q < 1.670	E	Rather Dry
1.670 ≤ Q < 3.000	F	Dry
3.000 ≤ Q < 7.000	G	Very Dry
7.000 ≤ Q < -	H	Extraordinarily Dry

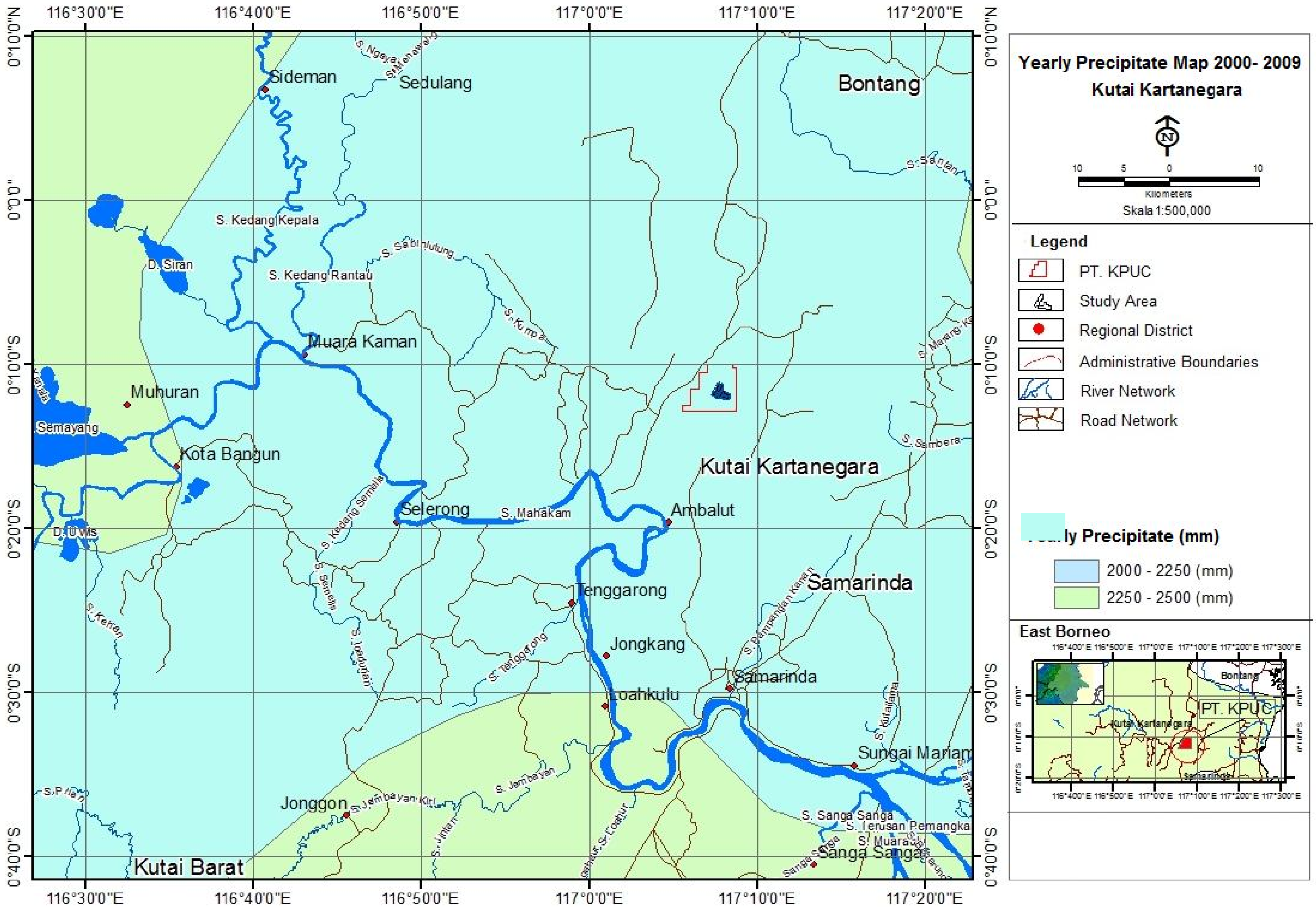


__Figure 4.2__ Rainfall precipitations in Kutai Kartanegara Regency (2000–2009) (Badan Metereologi dan Geofisika Bandara Temindung Samarinda, 2010).

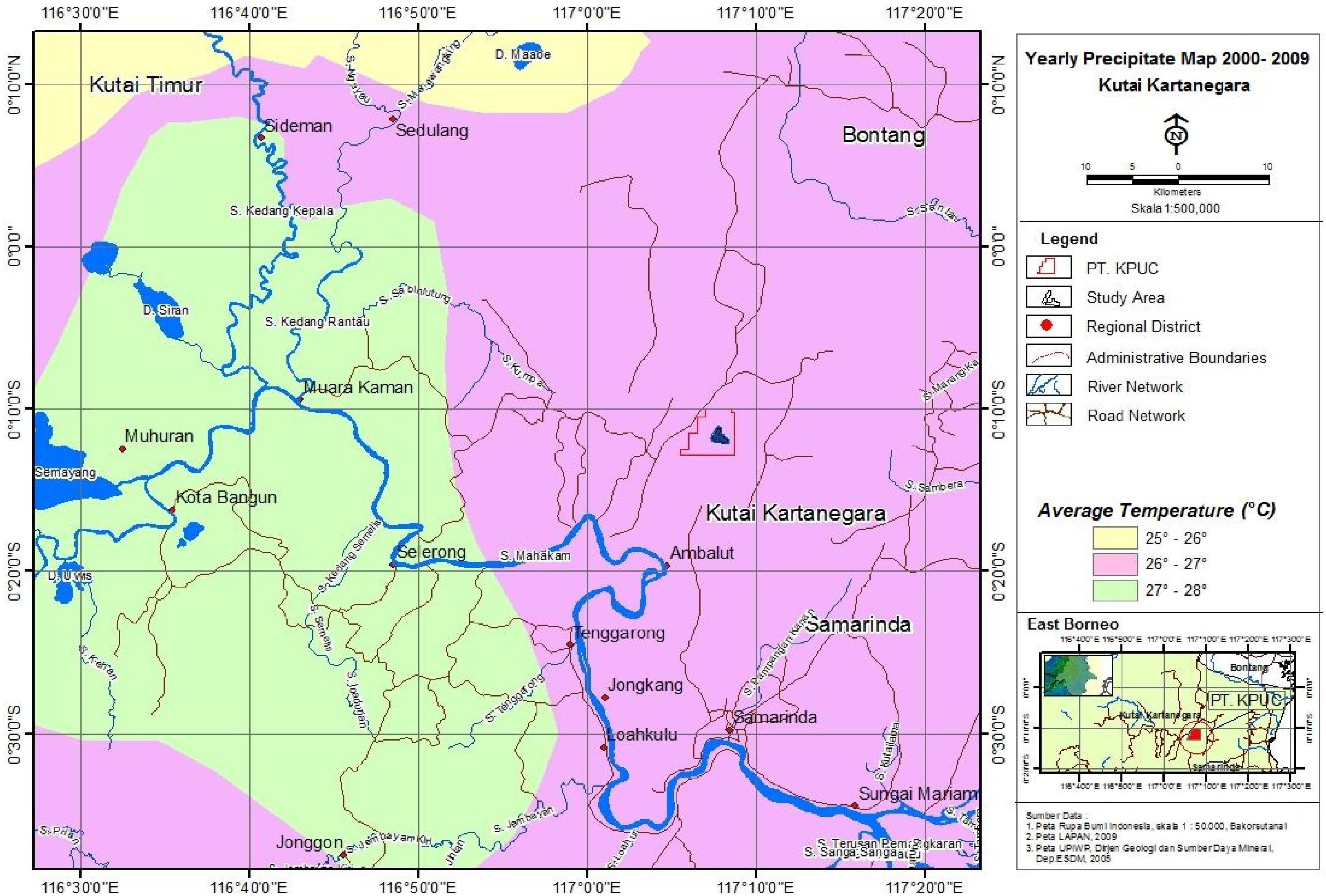


Figure 4.3 *Average temperature in Kutai Kartanegara Regency (2000–2009) (Badan Metereologi dan Geofisika Bandara Temindung Samarinda, 2010).*

4.2.2 Rainfall and Intensity Prediction

Bickham Coal (2005) performed forward predictions of rainfall and mine dewatering requirements. One of the parameters required for the creation of this model is the rainfall and intensity prediction. The rainfall intensity characteristics for the Bickham Coal site is obtained from the Bureau of Meteorology CDIRS database (Bickham Coal, 2009). The need for an accurate rainfall prediction for mining operation is readily apparent when considering the many benefits such information can provide for a mine planning and dewatering program. Such data is not available in the meteorology department in Indonesia and for the purpose of this research, the Gumbell method is used to make 24-hour rainfall predictions over 2-, 3-, 5-, 10-, and 20-year intervals. Ponce (1989) calculated flood frequency by using Gumbel Method. Samawi and Sabbagh (2006) also used the Gumbell distribution to provide calculations of rain intensity for the Meteorological Department of Jordan in areas of Israeli, Jordanian, and Palestinian interest. The results of the daily maximum rainfall of the study areas by using the Gumbell method are shown in Table 4.6. Table 4.5 provides the statistics of precipitation from 2000 to 2009.

Year	**Precipitation (mm)**	
	X	**X^2**
2000	86.14	7420.10
2001	63.78	4067.46
2002	55.88	3122.20
2003	78.18	6111.60
2004	83.46	6965.00
2005	85.00	7227.30
2006	64.89	4210.70
2007	81.80	6691.80
2008	91.92	8448.70
2009	72.10	5199.40
Total	763.16	59464.20
Mean ($\bar{X}$)	76.30	5946.40
$(\bar{X})^2$	5824.08	

Table 4.5 *Daily rainfall statistic precipitation at study areas.*

Interval (Years)	2	3	5	10	20
Average Precipitation	76.32	76.32	76.32	76.32	76.32
Y Value	0.4476	0.9027	1.4999	2.2504	2.9702
σ_y Value	11.06	11.06	11.06	11.06	11.06
y_t Value	0.4271	0.4271	0.4271	0.4271	0.4271
σ_y	0.9757	0.9757	0.9757	0.9757	0.9757
Predicted Rainfall (mm)/24 hour	76.55	81.70	88.48	96.98	105.14

Table 4.6 *Rainfall prediction for 24-hour periods.*

The calculation of rainfall prediction using Gumbell is shown in Appendix 2. Based on the calculation, it can be seen from Table 4.5 that using a 3-year interval, the predicted rainfall for 24-hour periods is 81.7 mm/day. The 3-year interval period is chosen based on various factors. From Table 4.5, the average daily precipitation is 76.3 mm and the highest precipitation is 91.92 mm (2008). The 2-year predicted interval value (76.55 mm) is far from the highest precipitation value, while the 10- and 20- year values do not correlate well with the data. The 5-year predicted interval value also seems appropriate, but the 3-year interval was chosen because of its shorter time interval. This value will be used as the predicted intensity of rainfall in the study areas. Using the 5-, 10-, and 20- year values will be a safer estimation but these values will represent more cost for the mine to dewater. A detailed cost analysis and risk assessment studies comparing the different intervals need to be conducted separately.

The rainfall intensity will be calculated using the Mononobe formula (Mori, 1993), as no rain intensity data in the study areas is available in the meteorology department in Indonesia. The calculation is shown in Appendix 1. Based on the daily maximum rainfall in 24 hours, time of concentrations, the length of the river, and height difference of the main river, the calculated rainfall intensity in the study areas is 5.44 mm/hour.

4.2.3 Surface Water Runoff

Surface drainage in the study areas mainly drains to east and west via the Separi Kiri watershed and Tinjakan Besar watershed. These watersheds are the two main watersheds in the study area. Separi Kiri is about 18.66 km^2 in size and Tinjakan Besar is about 3.34 km^2. The Separi Kiri flows for approximately another 20 km before being joined by the Mahakam River. Separi Kiri is one of the major tributaries of the Mahakam River. The Tinjakan Besar, on the other hand, is a minor headwater tributary that joins another major tributary before joining the Mahakam River. The respective discharge rate for each watershed was calculated.

As at Bickham Coal project, the rate of discharge of surface water runoff will be determined. In calculating that, some assumptions are needed to simplify the calculation. The method used to calculate the peak surface water runoff discharge is the rational method (US Soil Conservation Service, 1975). The formula is given as,

$$Q_p = 0{,}278 \times C \times I \times A$$

Where,

Q_p : Peak discharge rate (m^3/s).

C : Coefficient of water runoff (refer to Appendix 3).

I : Rainfall intensity (mm/h), the duration of the rain equals to the time of concentration (T_c).

A : Catchment area (km^2).

The rational model above assumes that the intensity of rainfall (I) is evenly distributed throughout the watershed areas. It also assumes that the duration of rainfall is equal to the time of concentration (T_c). Time of concentration is defined as the travel time required by the water from the most distant (upstream sub-basin / watershed) to the point of observation of surface water flow. A common formula used to calculate T_c is given below (Asdak, 1995):

$$T_c = 0.0195 \times L^{0.77} \times S^{-0.385}$$

Where,

T_c : Time of concentration (min).

L : Maximum distance of surface water flow from the watershed (m).

S : Difference in height between the observation points to the location furthest to the watershed divided by the maximum length of flow (m).

The coefficient of water runoff (C) is a ratio that indicates the amount of surface water runoff to rainwater. Factors that affect the coefficient of water runoff (C) include the conditions of the soil surface, rain catchment area, and condition of cover crops. Therefore, different location will have a different runoff coefficient. For this research, the study areas form an undulating morphology with heavy ground vegetation and shrubs, and with no excavation activities, land clearing for the mine, and no mining, the value of the water runoff coefficient (C) used will be assumed to be 0.4 (Asdak, 1995). With all the assumptions in place, the total rate of discharge for surface water runoff is calculated to be 13.3 m^3/s. The respective discharge rate for each watershed is given in Table 4.7.

Table 4.7 *Rate of discharge for each watershed calculated by the rational method (US Soil Conservation Service, 1975).*

No.	Watershed	C	I (mm/h)	A (km^2)	Q (m^3/s)
1	Separi Kiri	0.4	5.44	18.66	11.29
2	Tinjakan Besar	0.4	5.44	3.34	2.02
Total rate of discharge					13.3

4.3 Morphology of the Study Areas

The morphology of the study areas gradually forms a hill when travelling from south to north. In general, the rivers in the study areas have a tendency to flow from north to east (Figure 4.4). The higher elevations in the study areas are associated with localized hills, while the lower elevations are associated with creeks that drain the site. Low-lying areas consisting of wetlands suggest that water is perched on the saprolite soils (Figure 4.7).

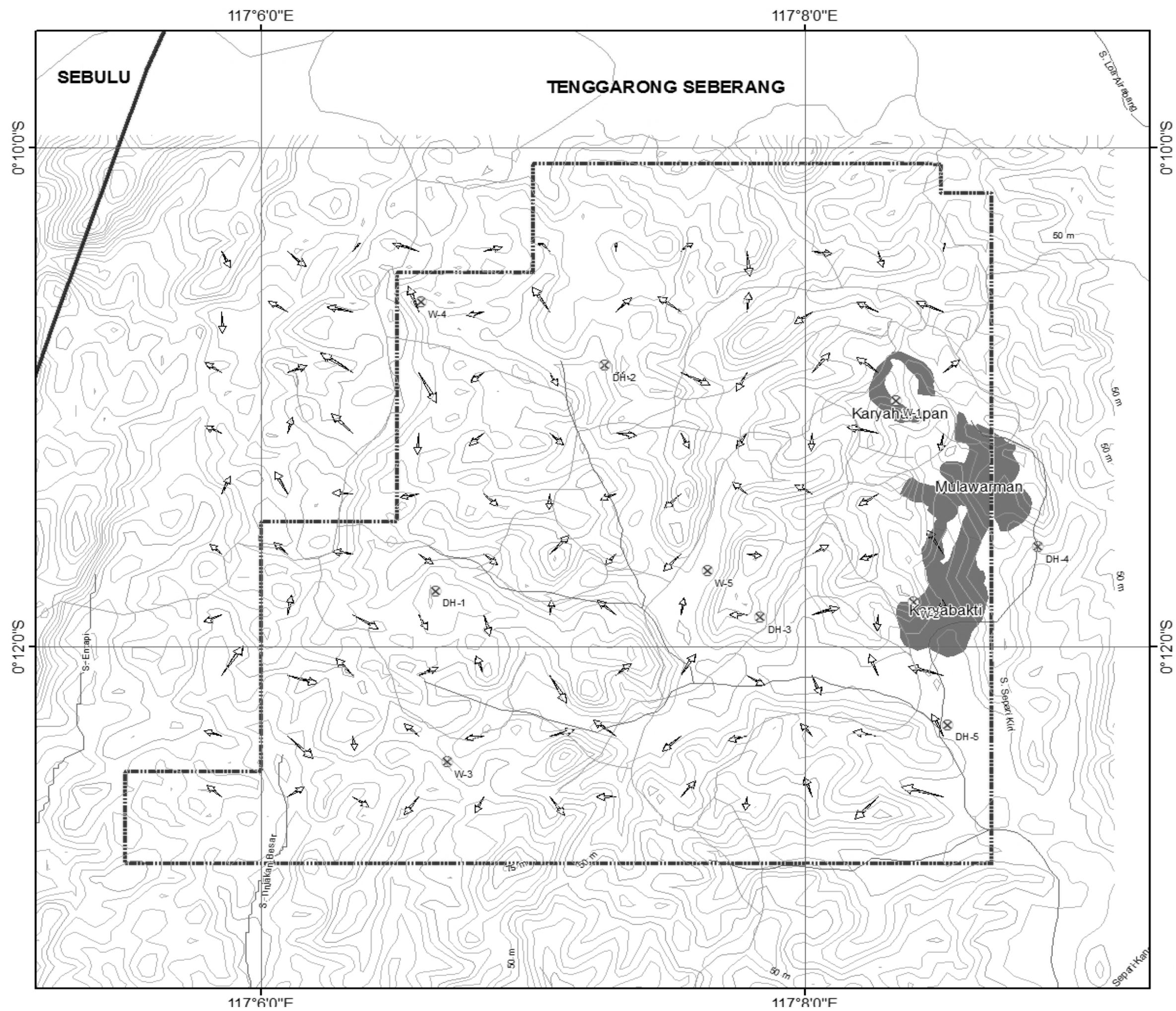


Figure 4.4 *Surface water flow in the study areas.*

The morphological condition of the KPUC mining area is analyzed based on topographic maps, lithological data, slope, observation of surface groundwater on exploration drill holes and dug wells, and, eventually, river flow patterns in the vicinity of the mining area. Gold Reserve Inc. in southeast Venezuela has completed similar studies. The studies identified the lithological units that had hydrogeological significance to mine dewatering (Breckenridge et al., 2005). The clay-rich saprolites inhibit recharge and slow infiltration to the water below. Beneath the saprolitic layers are the transition zone and the fractured zone, which can be grouped together as they had similar rock properties (Breckenridge et al., 2005). At the Brisas del Cuyuni mine site in Venezuela, the saprolite layers could be effectively dewatered by pumping the transition rock and fractured rock aquifer below them (Breckenridge et al., 2005).

Similarly, the rock formations in the KPUC can be divided into a number of separate lithological units based on hydraulic properties. The cross section AA' (KPUC, 2006) in Figure 4.5 identifies the lithological units in the study areas. Sandstone layers are found in both the overburden and interburden layers, while clay-saprolite layers are found at the top. The transition rocks (transition from clay to sand) above the coal seams have the potential to act as an aquifer, while the layers beneath the coal seams may serve as an aquiclude – an impermeable layer overlying or, in this case, underlying the aquifer – formed by the fractures in the coal seams. The series of rock layers (sandstone to coal seams) are of relatively significant hydraulic importance in this study, and as a whole form an aquifer layer (Figure 4.5). Chapter 4.4 discusses the hydrogeological and aquifers study.

Slug tests in Venezuela confirmed that the transition rock and fracture rock act as one unit and that the saprolite layers could be dewatered by pumping the transition rock and rock aquifer below them (Breckenridge et al., 2005). Similarly, five logging drill-holes were drilled in the study areas through the transition rocks and rock aquifer below them (the locations can be seen in Figure 4.5). The results of the aquifer study are presented in the next section.

The study areas also have great potential to become a rain catchment area. Figure 4.6 shows the catchment area map, which shows the area that can become a rain catchment area (on the left) and discharge area (on the right). The map is generated based on the topography of the area and soil type. Groundwater discharge occurs mainly to rivers in low-lying areas. Figure 4.7 shows the location of the low-lying areas that consist of wetlands, which suggests that the water is perched on the saprolitic soils.

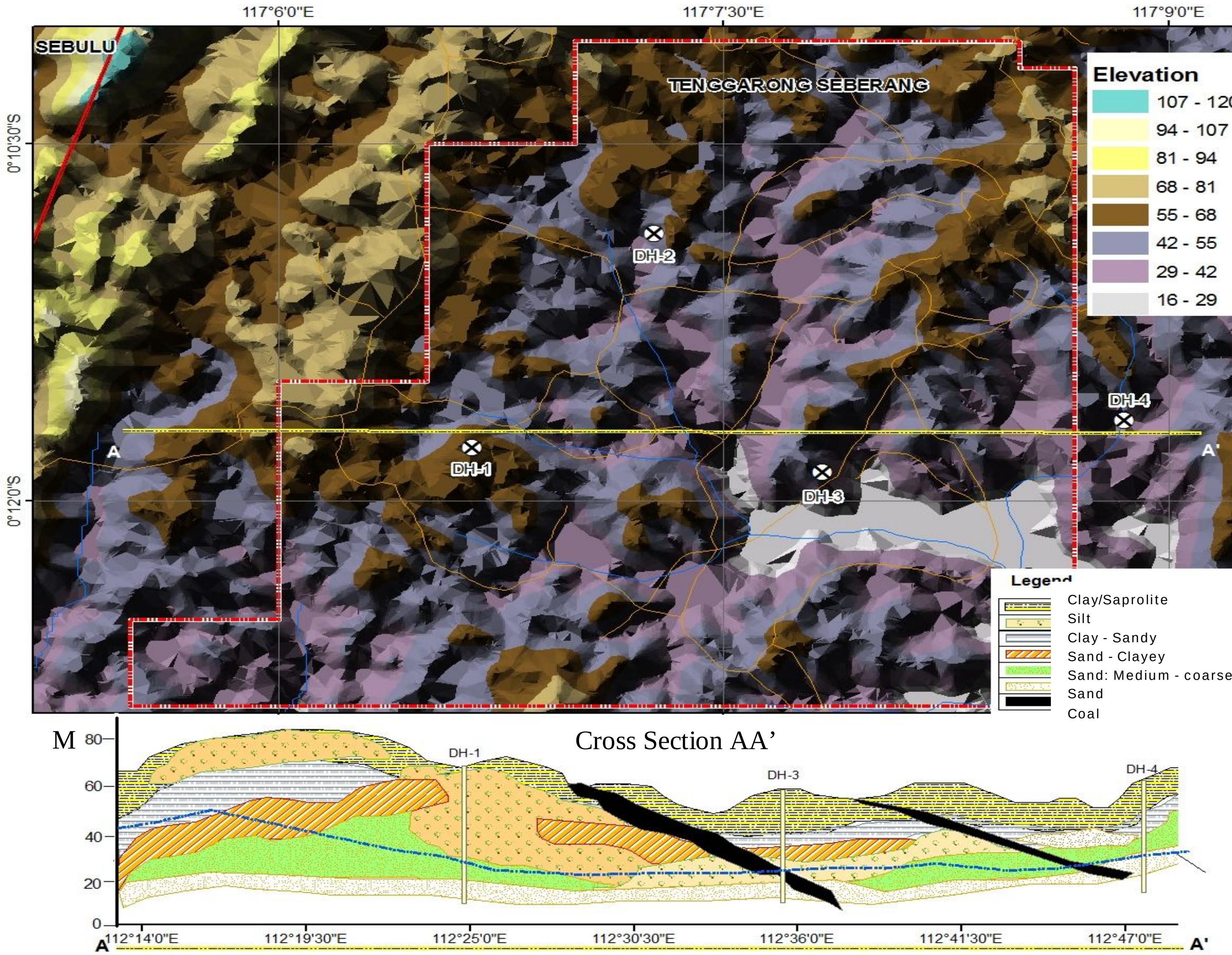


Figure 4.5 *Stratigraphic section of the study areas and cross section AA' (KPUC, 2006).*

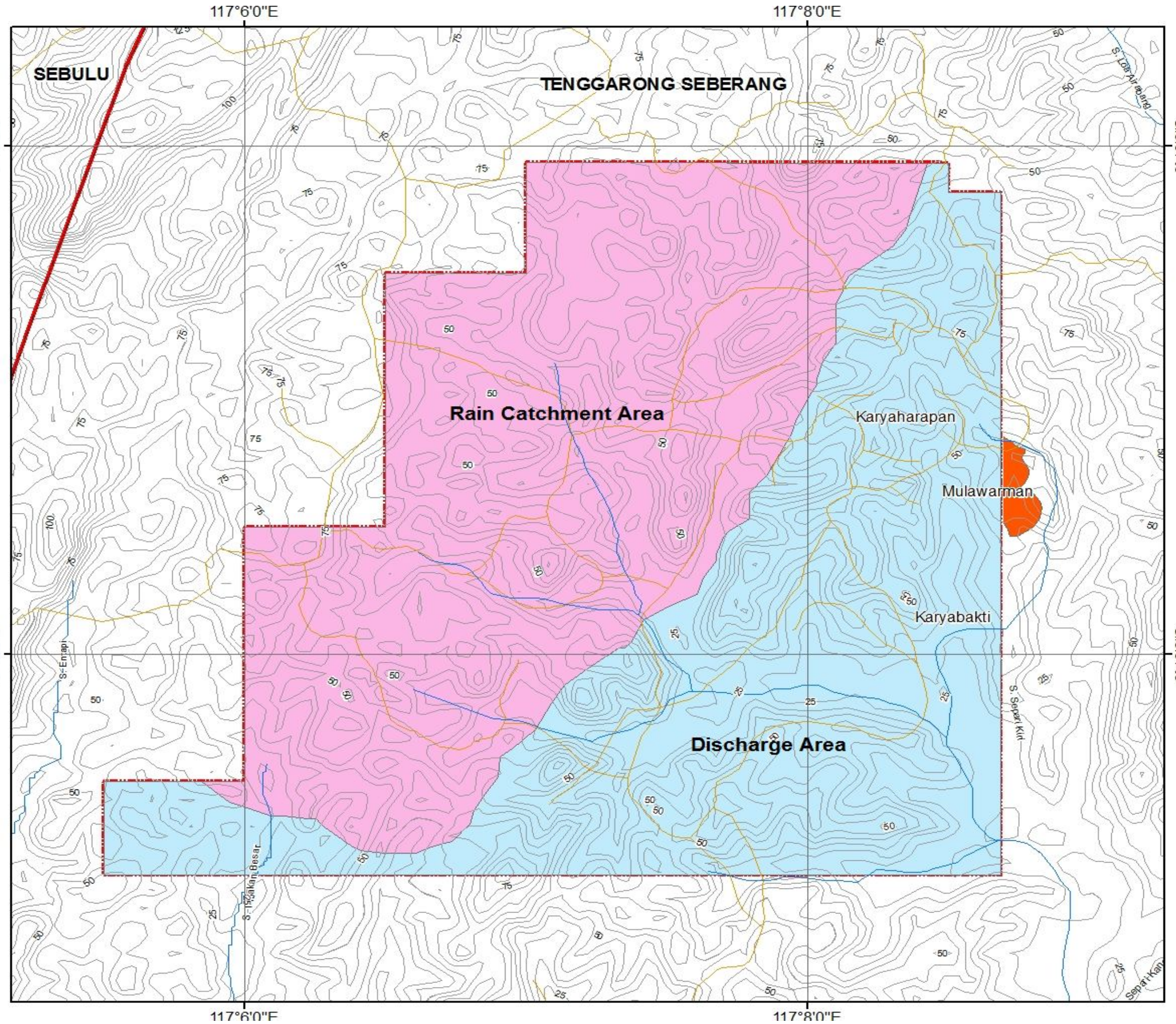


Figure 4.6 *Rain catchment areas based on topography and soil type.*

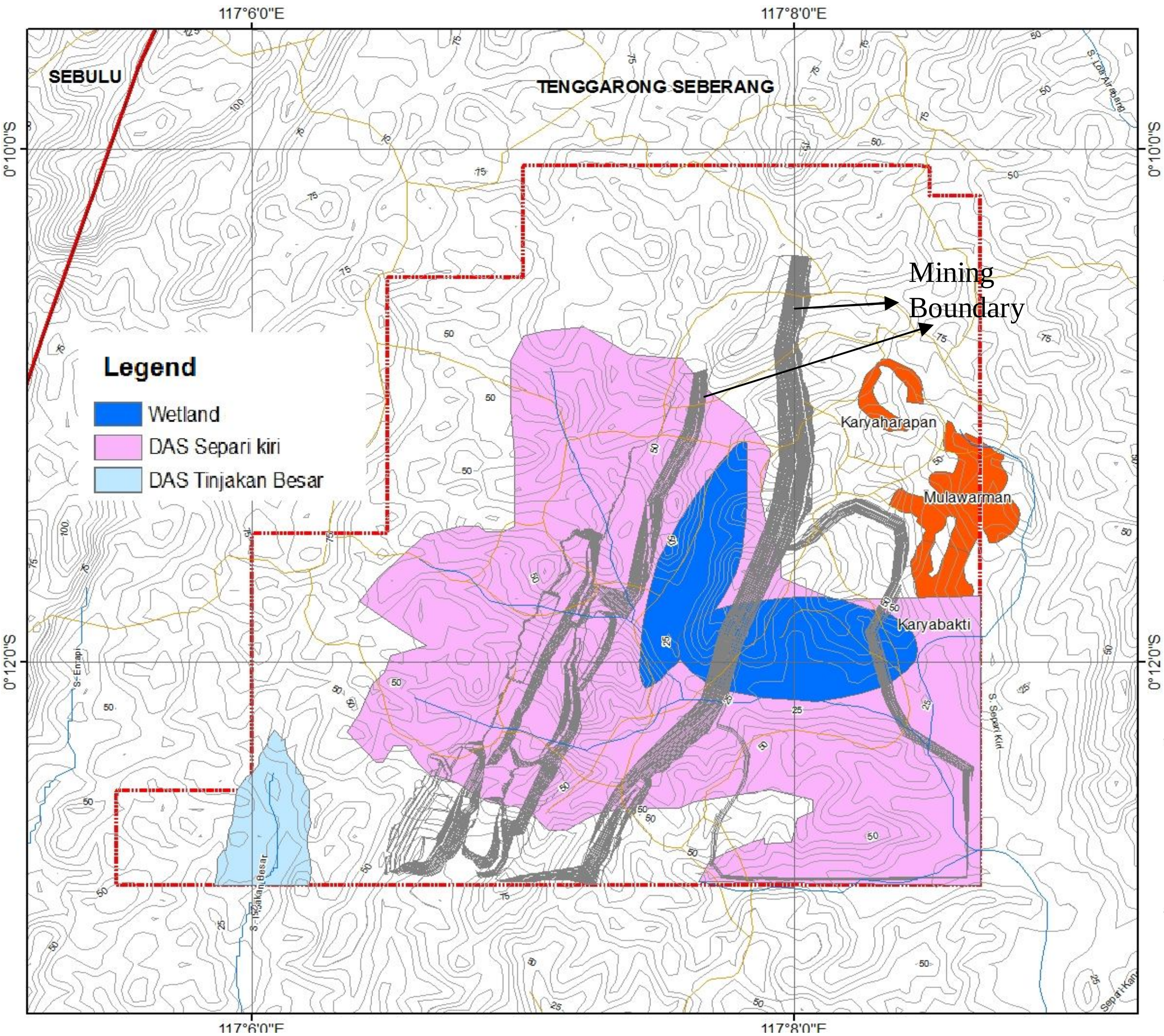


Figure 4.7 *Map of wetland areas.*

4.4 Hydrogeological and Aquifers Study

The Malinau coal mine and Brisas del Cuyuni performed hydrogeological and aquifers studies to identify the dewatering plan at their respective mine site. In the Brisas del Cuyuni case study, the groundwater flow pattern is observed and six observation wells were located in the transition rock (Breckenridge et al., 2005 to characterize the aquifers. According to Haryoko (2008), the aquifer study provided the characteristics of the aquifers in Malinau. Breckenridge et al. (2005) confirmed the dewatering plan that pumping the high yield transition aquifer dewaters the saprolite areas and this is only determined after the aquifer parameters are well understood. Figure 4.8 shows the schematic diagram of the dewatering plan in Brisas del Cuyuni (Breckenridge et al., 2005). According to the diagram, the authors believed that the dewatering plan will dewater the saprolite areas but the high hydraulic conductivity will cause some groundwater to seep out into the mining pit and this will be removed from the pit by an in-pit sump. Similar aquifer characterizations are conducted in the study areas.

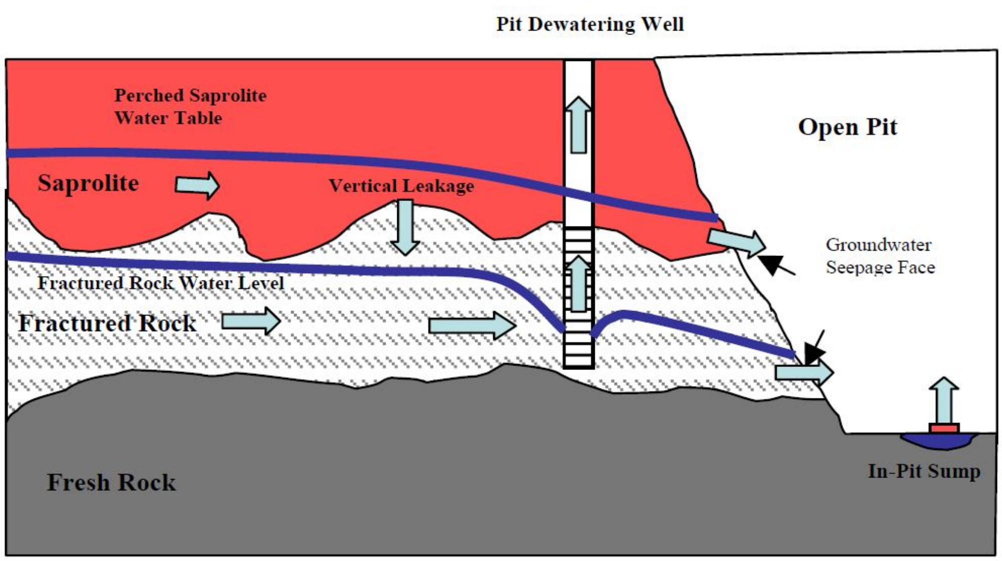


Figure 4.8 Schematic diagram of the dewatering plan in Brisas del Cuyuni (Breckenridge et al., 2005).

Figure 4.9 shows the groundwater flow pattern in the study areas in two dimensions. There are two main directions that can be observed–southeast and southwest – next to the groundwater divide line. Figure 4.10 shows the same flow pattern in three dimensions.

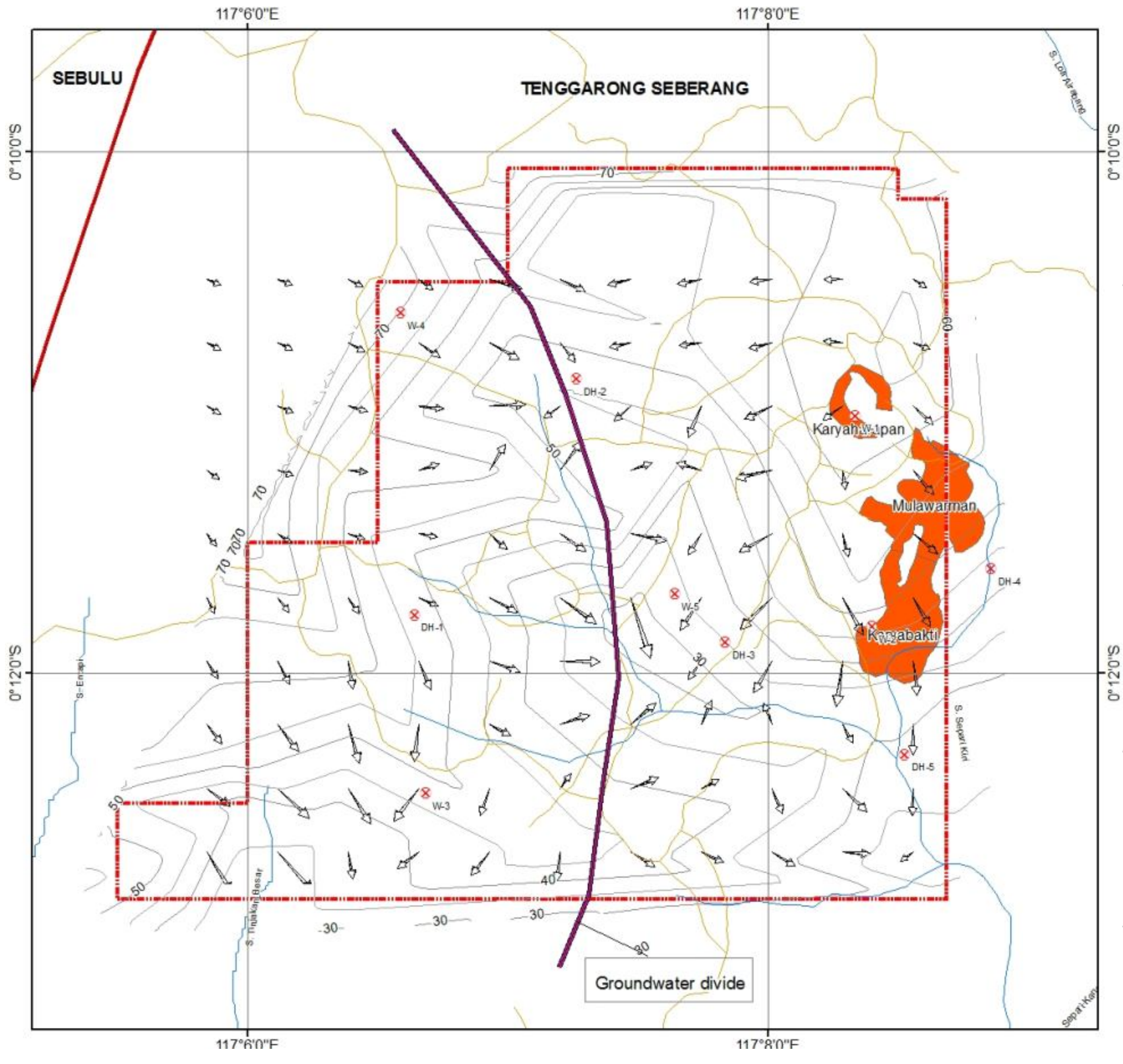


Figure 4.9 *Groundwater flow pattern in two dimensions - southeast and southwest.*

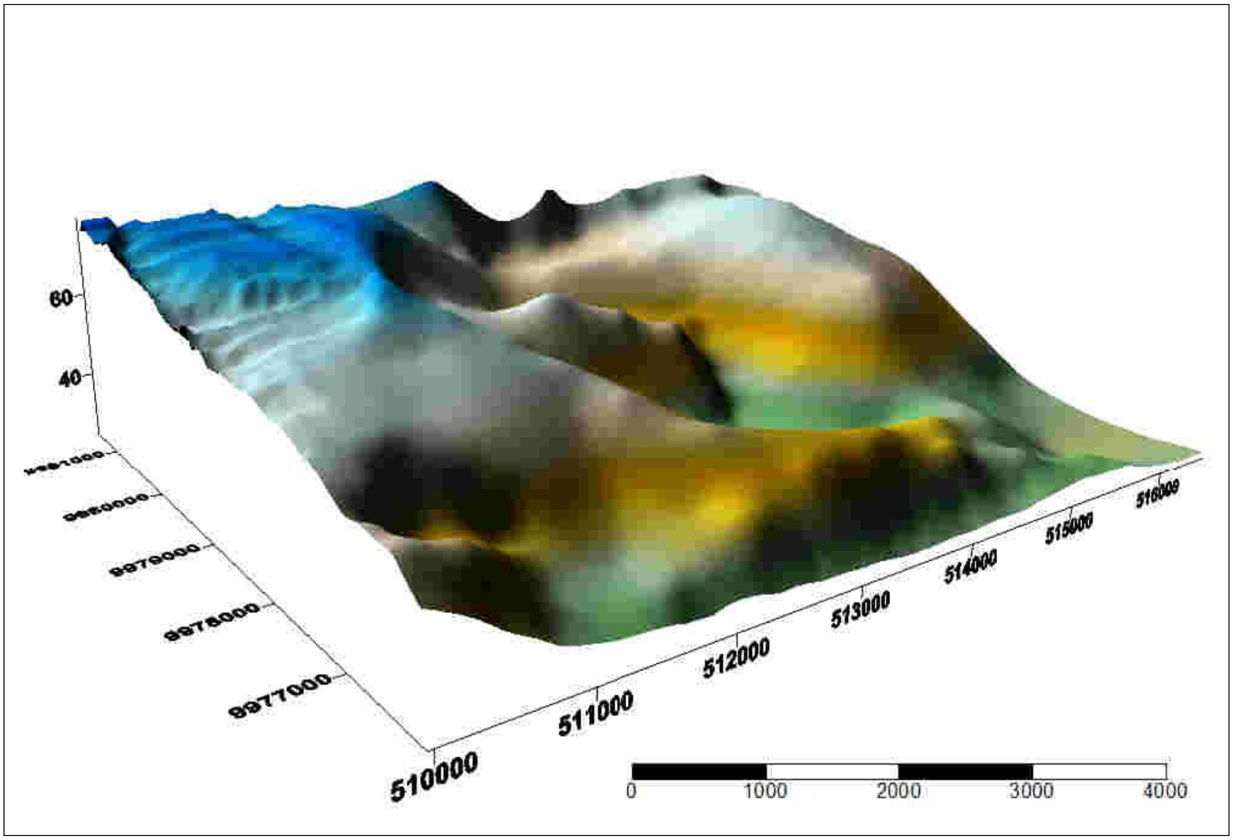


__Figure 4.10__ Groundwater flow pattern in three dimensions - southeast and southwest.

The aquifers conditions of the study areas are controlled largely by geological structures only. A slug test is an aquifer test where water is quickly removed from the groundwater well, and the change in hydraulic head is monitored through time (Asdak, 1995). An aquifer slug test was conducted to obtain the characteristics of the aquifers by drilling five boreholes. Figure 4.11 shows the location of the five logging drill holes (DH-1, DH-2, DH-3, DH-4, and DH-5) and two dewatering wells (W4 and W5) in the study areas, and Table 4.8 shows the characteristics of the aquifers in the study areas. The thickness of the aquifers ranges from 15.05 m to 32.00 m.

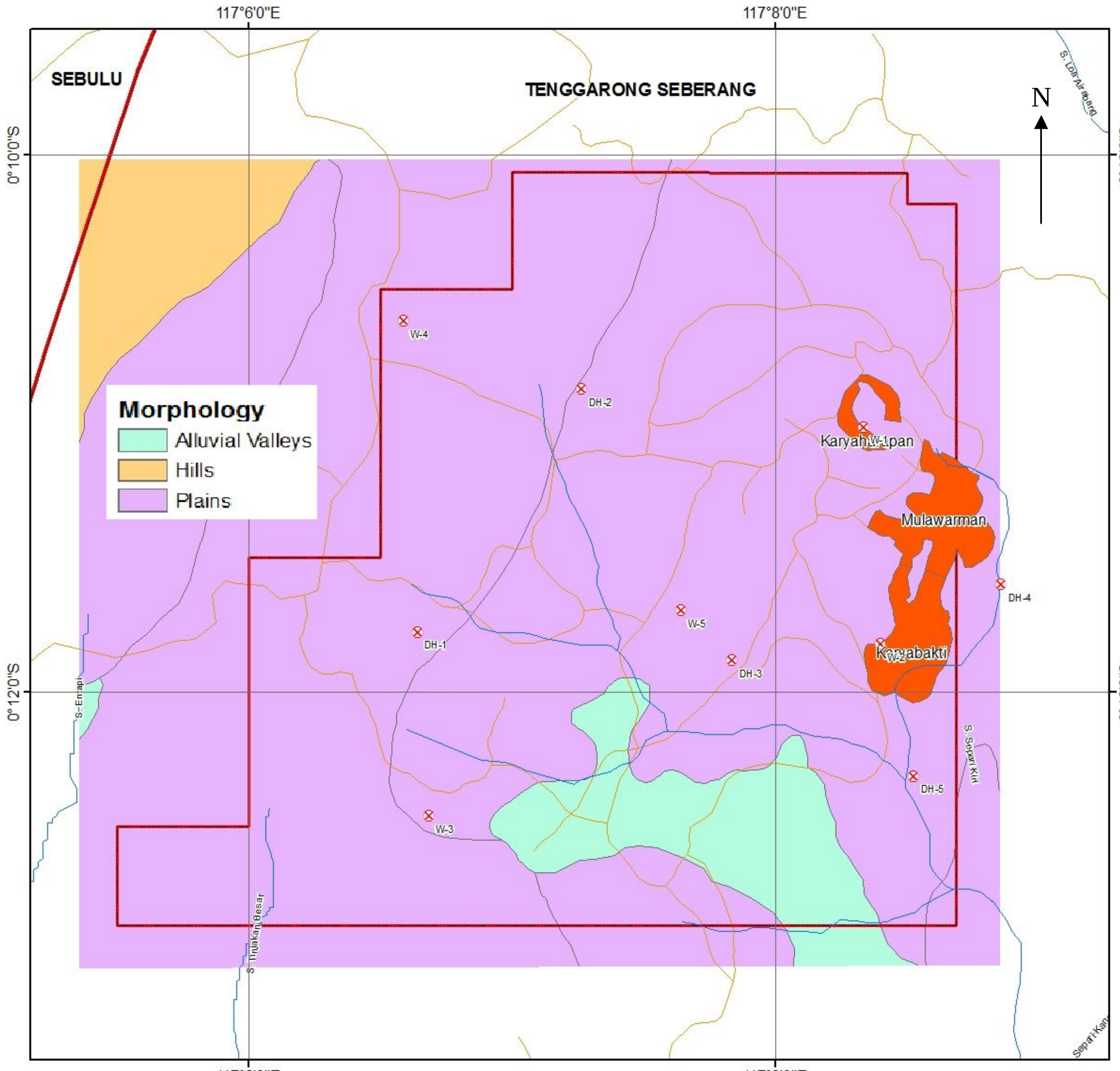


Figure 4.11 *Location of boreholes.*

Table 4.8 *Characteristics of the aquifers.*

Drill Hole	Coordinate			B Aquifer Thickness	K Hydraulic Conductivity	T Transmissivity	S Storativity Value
	X	**Y**	**Z**	**(m)**	**(10^{-7} m/s)**	**(10^{-3} m^2/s)**	**(10^{-3})**
DH-1	512316.5	9978304	63	17.50	6.65	1.163	5.25
DH-2	513473.5	9979968	45	32.00	9.82	3.142	9.60
DH-3	514532.1	9978110	43	15.05	5.11	0.769	4.51
DH-4	516423.8	9978628	38	24.00	4.23	1.015	7.20
DH-5	515809.3	9977317	27	30.00	7.81	2.100	8.82

The results show the largest hydraulic conductivity is 9.82×10^{-7} m/s in test well DH-2. Furthermore, the smallest hydraulic conductivity is 4.23×10^{-7} m/s in test well DH-4. The hydraulic conductivity values are about the same and it would not be easier to extract water from DH-2 than DH-4. Permeability tests carried out on core samples indicated that the study areas have low transmissivity values. Transmissivity values range between 0.769×10^{-3} m^2/s to 3.142×10^{-3} m^2/s. With such low transmissivity values, it would be harder to extract water from the aquifers. The storage coefficient (S) ranges between 4.51×10^{-3} to $9.60 \text{ x } 10^{-3}$ (Table 4.8).

Lithologically, the layers of sandstone and coal seams below them serve as an aquifer that can be classified as confined aquifer. The hydraulic conductivity of the confined aquifer will be relatively small (in the region of 10^{-7} m/s), and this is due to the characteristics of sandstone, which is generally relatively compact. Coal seams, on the other hand, generally consist of aquicludes because of fractures that are found in the coal.

The groundwater measurement in the study areas show that the groundwater level ranges from 30 m to 70 m. The average groundwater discharge rate in the study areas, based on the Darcy formula and slug tests above, is 21.6 m^3/day ($2{,}478.52 \times 10^{-7}$ m/s). The result of the groundwater discharge calculation is summarized in Table 4.9. Based on the characteristics of the aquifers, it can be estimated that the aquifers have high groundwater potential and their high productivity will contribute greatly to the groundwater discharge at the lower layer at the wetlands/study areas locations. Pumping the transition rocks and rock aquifers below them is thus required to dewater the saprolite unit. Table 4.9 shows the arithmetic average of the parameters calculated for the five drill holes.

Table 4.9 *Groundwater discharge rate.*

Drill Hole	Coordinate			A	Dh	Dl	I	Q
	X	Y	Z	Cross Sectional Area Aquifer (m^2)	Height Difference (m)	Distance (m)	Gradient (m)	Ground water Discharge (10^{-7} m^3/s)
DH-1	512316.5	9978304	63	35,472.50	4.2	2,027	0.00207	488.78
DH-2	513473.5	9979968	45	68,448.00	7.1	2,139	0.00332	2,231.10
DH-3	514532.1	9978110	43	29,528.10	23.3	1,962	0.01188	1,791.90
DH-4	516423.8	9978628	38	34,752.00	25.7	1,448	0.01775	2,609.06
DH-5	515809.3	9977317	27	87,660.00	22.5	2,922	0.00770	5,271.75
Average				51,172.12	16.56	2,099.6	0.00854	2,478.52

4.5 The Dewatering Plan

The dewatering program set up in the study areas involves controlling the surface water runoff and groundwater. The dewatering program set up involves construction of a water channel and flood protection levees, as well as pumping the aquifers. The results of the program will be discussed in Chapter 5.

4.5.1 Controlling Surface Water Runoff

The water found in the wetlands and mining pits, as described in the previous sections, are mainly derived from two main sources: surface water runoff and rainwater that comes directly into the pit. The rain catchment area is rather large, and flooding can occur readily depending on the magnitude, intensity, and duration of the rainfall. Based on previous section calculations, the intensity of the rainfall in the study areas and the wetlands around the mine is 5.44 mm/h, and the total rate of water discharge at the watersheds found in the mining areas is 13.3 m^3/s (translating to a total rate of discharge of 47,880 m^3/h).

According to the watershed map in Figure 4.12, approximately 80% of the mine pit locations are within the Separi Kiri watershed, which is 18.66 km^2 in size and has a water discharge rate of 11.29 m^3/s (translating to a rate of discharge 40,664 m^3/h). It was calculated that the total wetland area with saprolitic overburden in the study areas is 1.866 km^2, and that it represents 16% of the rain catchment area of the Separi Kiri watershed. Based on calculations (Appendix 3), the rate of water discharge entering the wetland areas is 6503.04 m^3/h (translating to a rate of discharge 156,073 m^3/day). This number is important in planning the flood mitigation program. It means that during the rainy season, the wetland area will be filled with water runoff approximately at a rate of 156,073 m^3/day. Stream flow data from the catchment area confirmed that this rate is not far off from the actual data and over a few months of testing there is no large variability evident in the data. However, long periods of consistent records would be required to make a more accurate future estimate.

Based on the long-term rainfall data, selection of an appropriate level of mine flood immunity is required. The amount of surface water runoff can be reduced by constructing water diversion channels around the wetlands and mining area. Newmont has done this in its Batu Hijau Mine in Indonesia. Critical to the success of its copper/gold mining project was the completion of its storm-water diversion channels (Denham and Jacobs, 2001). By constructing such water channels, the water from heavy rainfall (that is, water that does not enter into the pit) can be channeled into nearby streams and rivers near the areas to protect the mine (Denham and Jacobs, 2001). The other rainwater that falls into the wetland or mining pit area directly will have to be pumped out into the settling pond, using a water pump. Runoff from areas not affected by mining will be allowed to drain into the nearby streams directly and runoff that is affected has to be treated at settling pond before being checked for water quality and discharged to the receiving water (Bickham, 2009). The location of the open water channels in the study areas can be seen in Figure 4.13, and is mainly on the east of the river wetlands. In addition, flood protection levees will be constructed to ensure that there will be no flooding by the river during flood events.

Surface water that originates from outside the wetland or mining area flows at a rate of 4,877.28 m^3/h (1.35 m^3/s), as provided in Appendix 5. It is thus important to design the open water channels that are able to cope with the water discharge rate of 4,877.28 m^3/h. These water channels will not be built in the saprolite region due to stability issue. To do this, S (slope of the base line), R (hydraulic radius), and A (cross sectional area of the channel) have to be calculated. These calculations can be seen in Appendix 6. The design of the open water channel is shown in Figure 4.14. The channel will have the shape of a trapezoid with the following dimensions:

1. y (depth of flow) = 0.93 m,

2. B (width of the channel at the bottom) = 1.15 m,

3. T (width of the channel at the top) = 2.01 m,

4. m (slope of the channel) = 60°.

Open-cut mining in the saprolite region will require the construction of levees to provide flood protection for the active mining areas. A mine flood protection levee, a few kilometers long, has been constructed approximately 100 m from the top of high bank of the Nogoa River, and active open cut mining operation is contained within the flood protection levees (Hansen Consulting, 2006a). The proposed level of flood immunity in the study areas will be based on the rate of water discharge entering into the pit, as calculated earlier. The construction of the levees and its location can be seen in Figure 4.15. The strategy is expected to reduce the water runoff that will enter into the study areas. After the construction of both water channels and flood protection levees, it is expected that the water runoff that enters into the mining areas will be reduced by 75%. This means that water runoff that enters into the wetland is predicted to be the remaining 25% (i.e., 1,625.76 m^3/h). This calculation can be seen in Appendix 5.

Results of the effectiveness of both water channels and flood protection levees will be discussed in Chapter 5.

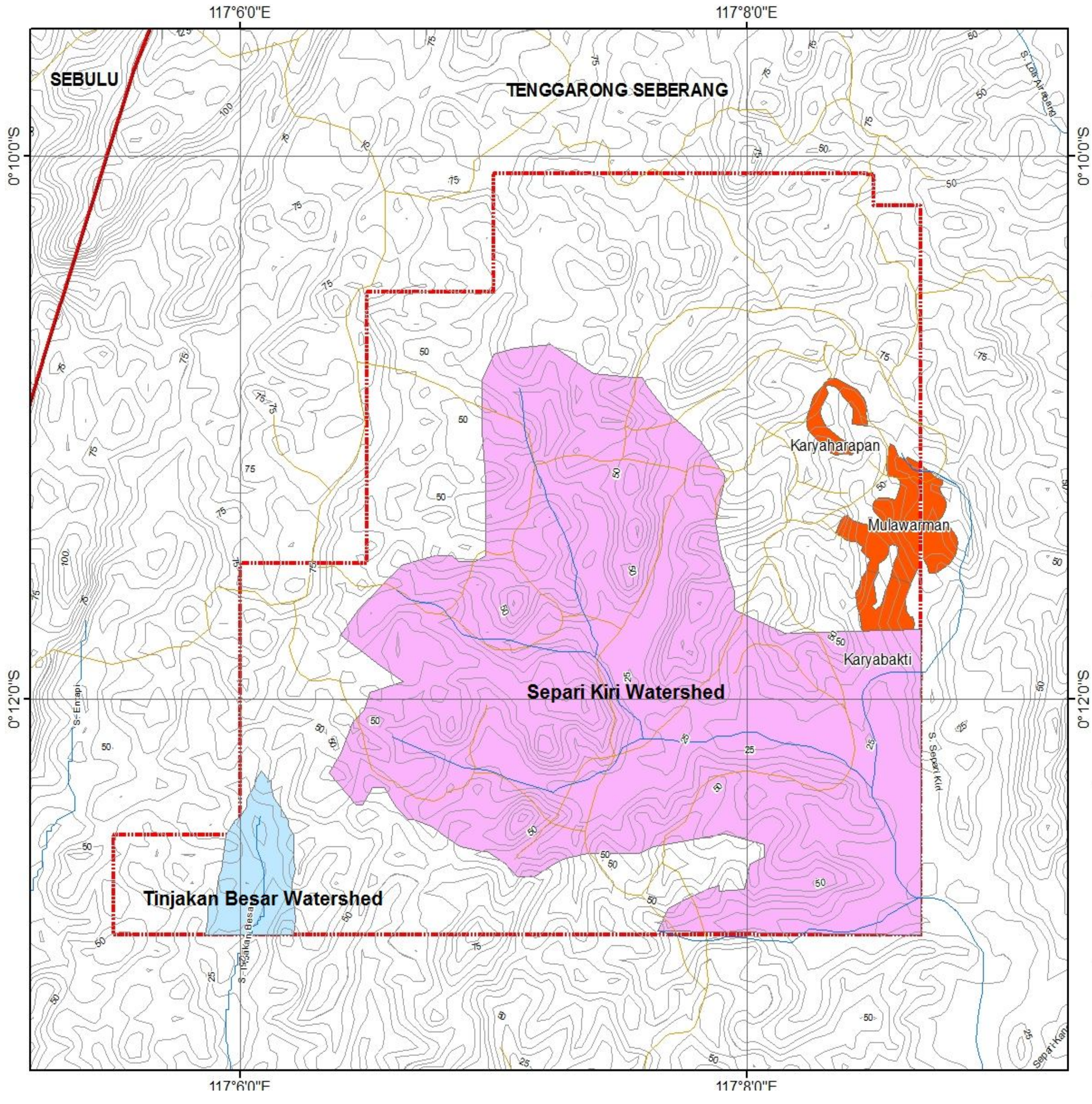


Figure 4.12 *Watershed map at KPUC mine site.*

.

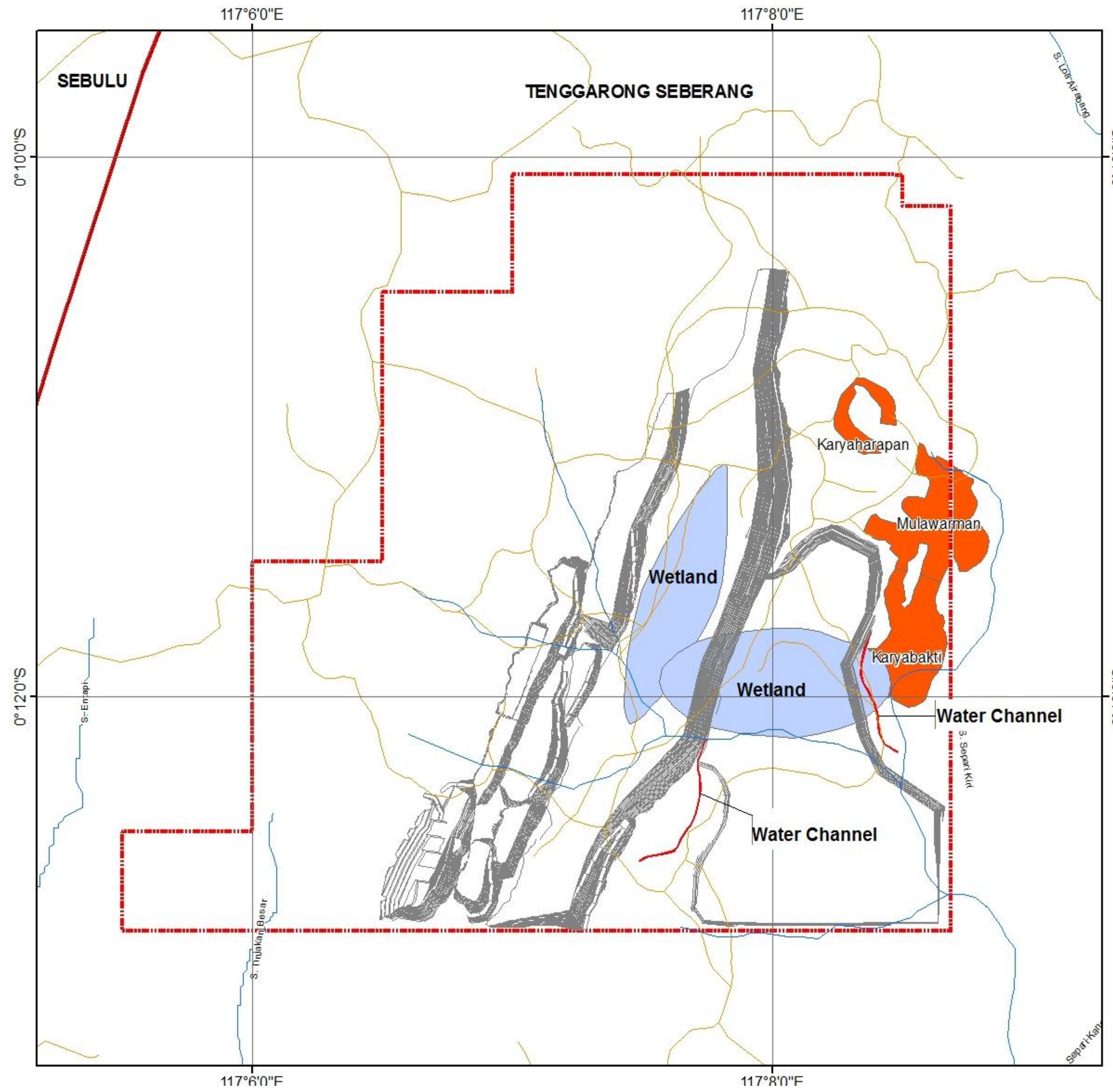


Figure 4.13 *Location of two open water channels at the study areas.*

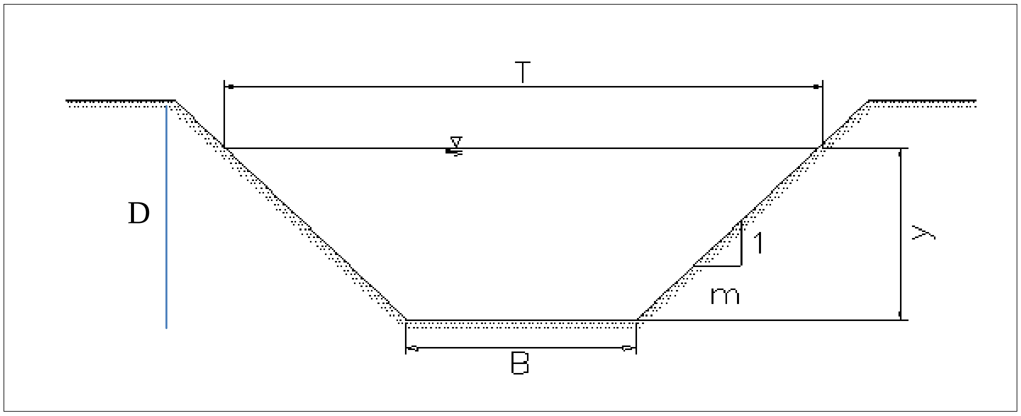


Figure 4.14 *Design of the open water channel***.**

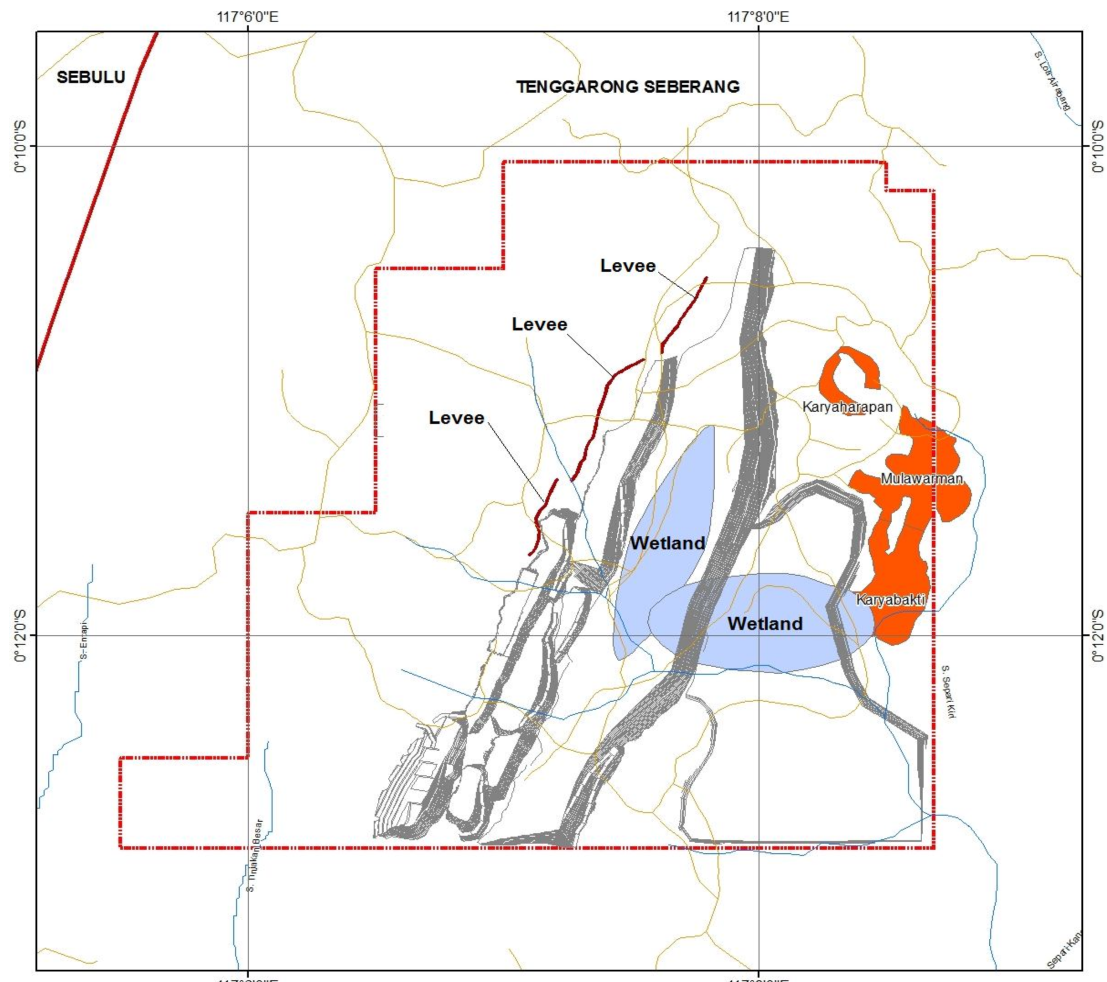


Figure 4.15 *Location of the flood protection levees at the study areas.*

4.5.2 Groundwater Control

Dewatering of the open cut mining pit area will be achieved by a combination of drainage system and pumping the water out as described in previous section. Natural inflow of water into the pit may account for most of the dewatering program, but it can be supplemented by some pumping from dewatering wells in order to assist pit working condition or for other operational purposes. The requirement for the supplementary bores and their locations will be determined in this section, and this is based on the hydrogeological and aquifer conditions of the mines.

Slug tests were conducted in the study areas to determine the characteristics of the aquifer. Its average transmissivity is calculated to be 2.45×10^{-2} m^2/s, while the average flow groundwater for the aquifer is 21.6 m^3/day. From the transmissivity and average flow results, the effect of groundwater to the amount of water in the wetlands areas is relatively high. Continuous pumping of water is deemed necessary to control the amount of groundwater into the study areas and reduce the amount of seepage. The recommended method to control or reduce the amount of groundwater in the study areas is by constructing drill wells that serve to pump the groundwater from the aquifer.

The aquifer slug test through boreholes (DH-1, DH-2, DH-3, DH-4 and DH-5) shows that the value of permeability (k) in the study areas is relatively low. The value of permeability (hydraulic conductivity) in drill hole DH-1 is 4.65×10^{-7} m/s, drill hole DH-2 is 9.82×10^{-7} m/s, drill hole DH-3 is 5.11×10^{-7} m/s, DH-4 is 4.23×10^{-7} m/s and drill hole DH-5 is 7.81×10^{-7} m /s. The average arithmetic mean of hydraulic conductivity of the five drill holes is 6.724×10^{-7} m/s. Based on the characteristics of the aquifer (see Table 4.8), it can be estimated that the potential for groundwater is high and will greatly contribute to the groundwater discharged in the lower layers of the wetlands.

The external dewatering well will be located at the low elevation areas, which is adjacent to the rivers. Looking at the ground flow pattern in Figure 4.9 and figure 4.10, the groundwater in the low elevation areas (that is, the eastern part of the mine) tends to flow southeast. Thus, the location of the boreholes should be located in the southeast portion of the wetlands and upstream of the river channel. By placing it upstream of the river channel, the rate of discharge for the watershed calculated earlier will not increase, as the groundwater flow has not entered the river channel. The location of the dewatering well can be seen in Figure 4.16. The result of the dewatering well will be discussed in next chapter. The dewatering well will be assessed based on its yield and its effectiveness in achieving the desired dewatering rate.

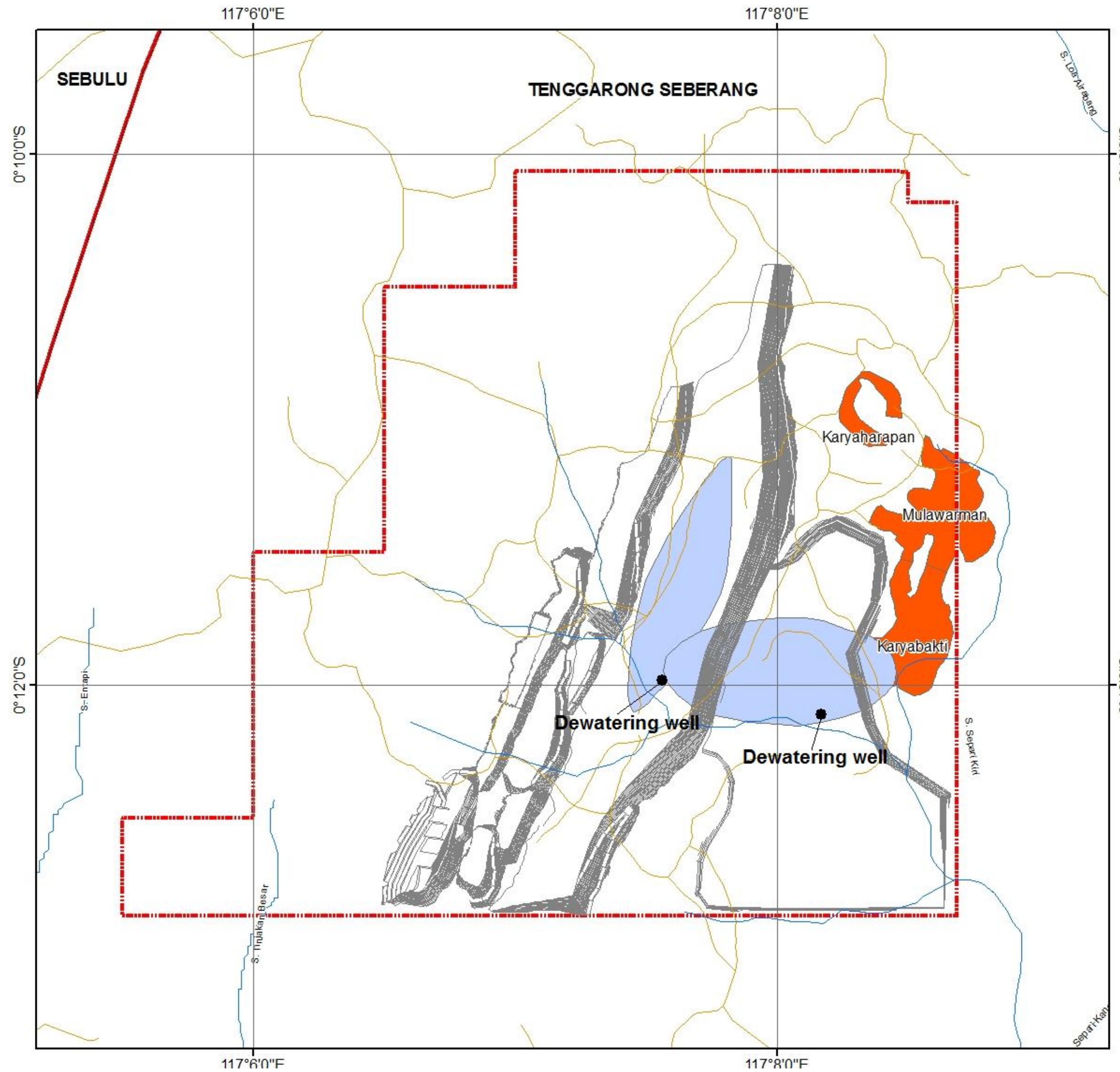


Figure 4.16 *Location of the dewatering wells.*

4.6 Environment Water Management

Groundwater monitoring sites will be placed at the aquifers within the mine site. Groundwater monitoring will be carried out monthly. McNaughton (2010), in his site water management plan for the Mount Arthur North coalmine, stated that the primary objective of the plan is to manage and minimize the impact of mining operations on surface and groundwater resources. Observations will be made to monitor the groundwater levels and water quality in the monitoring well (McNaughton, 2010). Since there will be no long-term needs of groundwater users within the study areas as explained in Chapter 3, any dewatering program by KPUC is only required to maintain the groundwater quality of the water resources.

At the Mount Arthur North coalmine, groundwater quality parameters (EC, TSS, TDS, and pH value) have been determined at a number of monitoring sites to monitor the groundwater quality (McNaughton, 2010). A surface water monitoring program was also established at the main creeks, and the Hunter River upstream and downstream of the site (McNaughton, 2010). Should the groundwater and surface water quality monitoring results indicate higher than expected normal values, appropriate investigations and necessary measures will be taken immediately.

At KPUC, the monitoring program will include regular sampling and monitoring. For every sample collected, the date, location, time, and sample number will be recorded. The samples collected will be analyzed by independent, and qualified laboratory, in this case PT. Geoservice Balikpapan, Indonesia. The samples' results will then be compared to the Indonesia water standards.

The results of the tests will be monitored continuously. Table 4.10 shows the data trigger level based on Indonesian water standards (Center of Environmental Geology, Ministry of

Energy and Mineral Resources, 2009). If these levels were triggered, any elevated values to either to the groundwater quality or rate of pit inflow have indicated adverse groundwater impacts. Further investigations by KPUC are necessary.

Parameter	Trigger Level
Pit groundwater inflow	
During any period of mining	The inflow > 5 times than the predictions (i.e., 10.03 m^3/day).
Groundwater quality parameter	
pH value	< 6 or > 8 (Over 3 successive testing events).
EC value	> 12,500 µS/cm (Over 3 successive testing events).

Table 4.10 *Groundwater monitoring data trigger levels.*

As for the surface water, TSS value that is greater than 150 mg/L over 3 successive testing events and TDS value that is greater than 500 mg/L over 3 successive testing events will require immediate investigations. All mine water from within the operating pit will be treated at a settling pond prior to discharge, or will be used for dust suppression on haul roads. The effect of the dewatering program on the environment during the test period will be discussed in Chapter 5.

4.7 Slope Stability Analysis

Direct shear tests and UCS tests on dewatered saprolitic soils are conducted in the study areas. Haryoko (2009) did similar tests in the Malinau coalmine. Direct shear tests is a quick and inexpensive test to obtain shear strength parameters of both fine and coarse grained soils either in undisturbed or remolded state. Meanwhile, UCS is one of the most basic parameters of rock strength. The UCS of a specimen is calculated by dividing the maximum load at failure by the sample cross-sectional area:

$$\delta_C = \frac{F}{A}$$

Where: δ_c = UCS
F = Maximum Failure Load
A = Cross-sectional area of the core sample (in^2)

The results for the geotechnical testing are shown in Appendix 7. From this data, recommendations to design the maximum slope permitted for safe mine operation has been made. Table J of Appendix 7 presents the physical properties of the three different drill holes to be considered in the geotechnical design. Physical properties that were considered were saturated density, dry density, specific density, percentage of water content, percentage of absorption, percentage of saturation, percentage of porosity, and void ratio. Table K of Appendix 7, on the other hand, presents the results of the Direct Shear and UCS tests conducted. The results revealed that for Drill 2 (DH-2) Silstone achieved higher value of UCS than Sandstone. For the Direct Shear test both Silstone and Sandstone achieved low to medium value for the slake test, and around 21.9 degree to 33.3 degree for angle of friction, and 90 KPa to 2166 KPa for cohesion.

With regards to Drill 3 (DH-3), Sandstone had achieved a highest UCS value of 5.6 MPa while Silstone achieved 3.0 MPa only. But for Direct Shear test, the results revealed that Sandstone and Silstone only managed to attain low value during the slake test, and around 15.6 degree to 33.3 degree for angle of friction, and 74 KPa to 2379 KPa for cohesion.

With regards to Drill 5 (DH-5), Siltstone had achieved a highest UCS value of 6.3 MPa while Sandstone and Clay stone achieved 0.9 and 3.8 MPa, respectively. On the other hand for Direct Shear test, the results revealed that all type of stones attained very low level value during the slake test, and around 15.1 degree to 34.4 degree for angle of friction, and 163 KPa to 2237 KPa for cohesion.

Slope stability tests will then be carried out for each type of material forming the bench (such as sandstone, siltstone, and clay stone) using the following ranges:

1. Bench height = 10 m and 15 m.
2. Slope angle = 60°, 65°, and 70°.

The results of the calculation are shown in Table 4.11.

No	Rocks	Bench Height (m)	Angle (°)	Factor of Safety
1	Siltstone	10	50	2.704
			55	2.553
			60	2.405
			65	2.254
			70	2.100
		15	50	1.818
			55	1.714
			60	1.616
			65	1.505
			70	1.398
2	Clay stone	10	50	1.765
			55	1.663
			60	1.571
			65	1.460
			70	1.410
		15	50	1.194
			55	1.122
			60	1.050
			65	0.977
			70	0.904
3	Sandstone	10	50	2.193
			55	2.067
			60	1.943
			65	1.817
			70	1.689
		15	50	1.482
			55	1.392
			60	1.304
			65	1.214
			70	1.123

Table 4.11 *Factor of safety for each rock material.*

Based on the factor of safety data (Factor of safety ≥ 1.5), the following recommendations are made for all rock materials to KPUC:

Single Slope (Individual).

1. Slope height (h) = 10 m, and berms = 4 m.
2. For active working bench, bench width = 15 meters and slope angle = 70^0. Refer to Figure 4.17 for the sketch of a single slope diagram).

The same calculation was carried out to calculate the factor of safety for the overall slope angle. The results are shown in Table 4.12.

Location	**Borehole Test Location**	**Height (m)**	**Slope (°)**	**Safety Factor**
Right Slope	DH-2	130 - 145	40	> 1.50
		145 - 160	35	> 1.50
	DH-3	130 - 145	35	> 1.50
		145 - 160	30	> 1.50
	DH-5	130 - 145	35	> 1.50
		145 - 160	30	> 1.50
Left lope	DH-2	130 - 145	40	> 1.50
		145 - 160	32	> 1.50
	DH-3	130 - 145	35	> 1.50
		145 - 160	32	> 1.50
	DH-5	130 - 145	40	> 1.50
		145 - 160	30	> 1.50

Table 4.12 *Factor of safety for the overall bench face angle.*

The recommendation for the overall design, based on factor of safety > 1.5 is as follows

1. Total height = 160 m. This is to maximize the amount of coal resources obtained in the study areas.
2. The planned overall bench face angle is 30º - 40º (i.e., the angle that is formed from the toe to crest). This is shown in Figure 4.17.

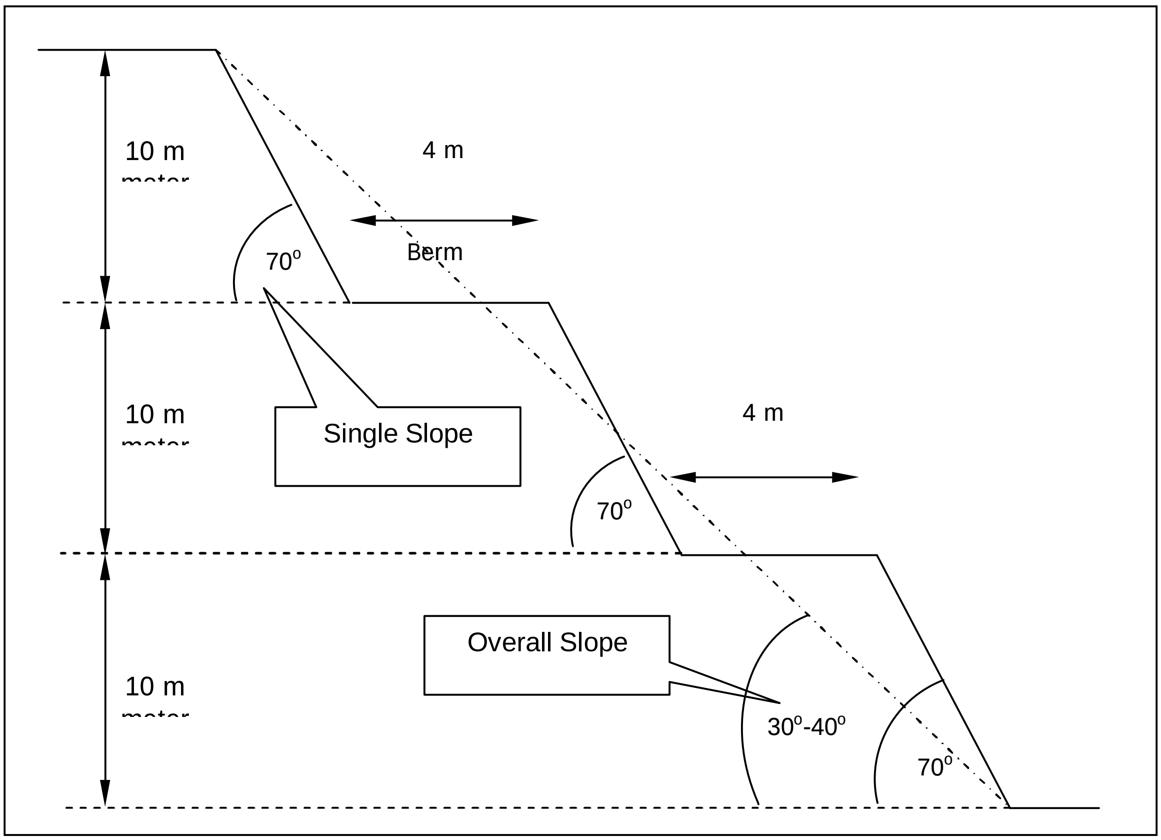


Figure 4.17 *Geotechnical mine design (Individual and overall slope angle).*

The findings of the analyses regarding surface water, ground water, water quality, and slope stability are summarized in Table 4.13.

	Surface Water		**Ground Water**
Flow rate	4,877.28 m3/h (1.35 m3/s)	Flow Rate	21.6 m3/day
Depth of flow	0.93m	Conductivity	6.724 x 10-7 m/s
	Water Quality		**Slope Stability**
Pit inflow	Triggered if >5x predictions	Factor of Safety	>1.5
pH value	<6 or >8 over 3 tests	Total Height	160m
EC Value	>12,500 μS/cm over 3 tests	Planned Angle	30^0 - 40^0

Table 4.13 *Summary of analytic findings.*

5. DISCUSSION, ANALYSIS, AND RECOMMENDATION

Research studies have been conducted to design dewatering program at KPUC Separi coalmine site using assessments such as rainfall, climate studies, groundwater flow, and aquifer characterizations. Full consideration and discussion of the dewatering results are necessary. These studies have provided critical information for designing a mine-dewatering program and for minimizing future potential environmental impact on regional groundwater resources.

The origin of the high water content in the saprolite region is the high precipitation intensity and the presence of aquifers in the study areas. The Separi coal-dewatering program includes the construction of water channels, flood protection levees, and water wells. This chapter will explore the effectiveness of the dewatering program, in addition to demonstrating the research significance of the contained work and indicating future suggestions for continuing research in this field.

5.1 Water Channels and Flood Protection Levees

One of the greatest challenges found in the study area is the high recharge rate resulting from the high annual precipitation rate. Based on the calculations in chapter 4, it is expected that during the rainy season, the wetland area will be filled with water runoff at a rate of 156,073 m^3/day. However, the data in Table 5.1 shows that the water runoff rate is slightly higher than expected at 169,367 m^3/day. This average stream flow data at Separi Kiri watershed was obtained by using an automatic sampler, set up by the author during the experimental periods. The variability evident in the data is mainly because stream flow data of the rivers is dependent on rainfall events and thus, in order to be accurate, both the rainy and non-rainy seasons' measurements have to be captured in the data. Table 5.1 only captures data for the six-month period from January 2011 to June to 2011. Consideration must also be given to the fact that long periods of consistent records would be required to make a more accurate future estimate.

Month (2011)	**Stream Flow (m^3/s)**	**Stream Flow (m^3/day)**
January	2.023	174,815
February	1.877	162,193
March	2.437	210,557
April	2.327	201,049
May	1.726	149,126
June	1.371	118,460
Average	**2.027**	**169,367**

Table 5.1 *Stream flow data at Separi Kiri watershed.*

The construction of water channels and flood protection levees, as expected, has reduced the water runoff that entered the mining area by approximately 75%. This means that the amount of water that actually entered the pit is the remaining 25% (1625.76 m^3/h). Reducing the amount of water entering the wetlands is crucial to dewatering the saprolitic region. The basic requirement for deep weathering in saprolitic soils formation is that a mean annual rainfall surplus be available for groundwater recharge. In addition, the more water that enters the wetlands, the more is required to be pumped out before mining operations take place.

The construction of water channels and flood protection levees will definitely reduce the amount of water that enters the mining pits. Focusing on these efforts will reduce the need for subsequent dewatering efforts. In this research, however, the flood impacts on neighboring properties and the stability impacts of the river (due to the dewatering program) are not determined. Constructing flood protection levees and channeling the rainwater into the main river will increase the flood levels of the nearby properties. The levees will restrict the potential width of flooding, and the water channels will increase the water levels at the river. The larger flood level impacts may potentially affect the adjacent landholders, but this can be fully assessed in future research.

The dewatering program, construction of water channels and flood protection levees may also affect stability impacts of the river. Factors such as changes in flow velocity, erosive capacity, and hydraulic flows are not considered, even though they may have potential long-term impacts on the morphology of the river. Detailed consideration of the river stability impacts would be a promising field for future research studies, especially considering that saprolitic soils are found in the areas of high recharge rate and that construction of water channels and flood protection levees has proven effective at reducing the amount of water entering the wetlands areas.

5.2 Dewatering Wells

Dewatering is a state where the inflow of water to the mine is reduced by removing water that is stored in the aquifer. When the aquifer is dewatered, the mine will still experience an inflow of water. Dewatering is only achieved when the pumping rate is at least equal to or greater than the recharge rate at the study areas. The dewatering program will start prior to the beginning of any mining operation by pumping the aquifers.

Based on the characteristics of the aquifer, the potential for groundwater in the areas is high, and this will greatly contribute to the groundwater discharge in the wetland areas. Transmissivity is calculated to be 2.45×10^{-2} m^2/s, while the average estimated groundwater discharge for the aquifer is 21.6 m^3/day. As such, to be effective, the pumping rate has to be greater than 21.6 m^3/day. The data on pumping rates in the study areas for six months have been recorded and are shown in Figure 5.1. During this period, the average pumping rate was 24.78 m^3/day. The negative flow rate in Figure 5.1 is due to experimental error and might be caused by the level logger being reset. A slight downtime on the pumping units has caused the pumping rates on some of the days to fall below the expected flow rate of 21.6 m^3/day. The decrease in cumulative water elevations in the study areas over six-month period is shown in Figure 5.2. These average pumping rates were predicted to result in groundwater level that would generally be 10 meters below the lowest mining benches at all times. 10 meters is the recommended single bench height, based on the slope stability analysis calculated in Chapter 4. After six months of dewatering, the groundwater level has decreased by 10.88 meters.

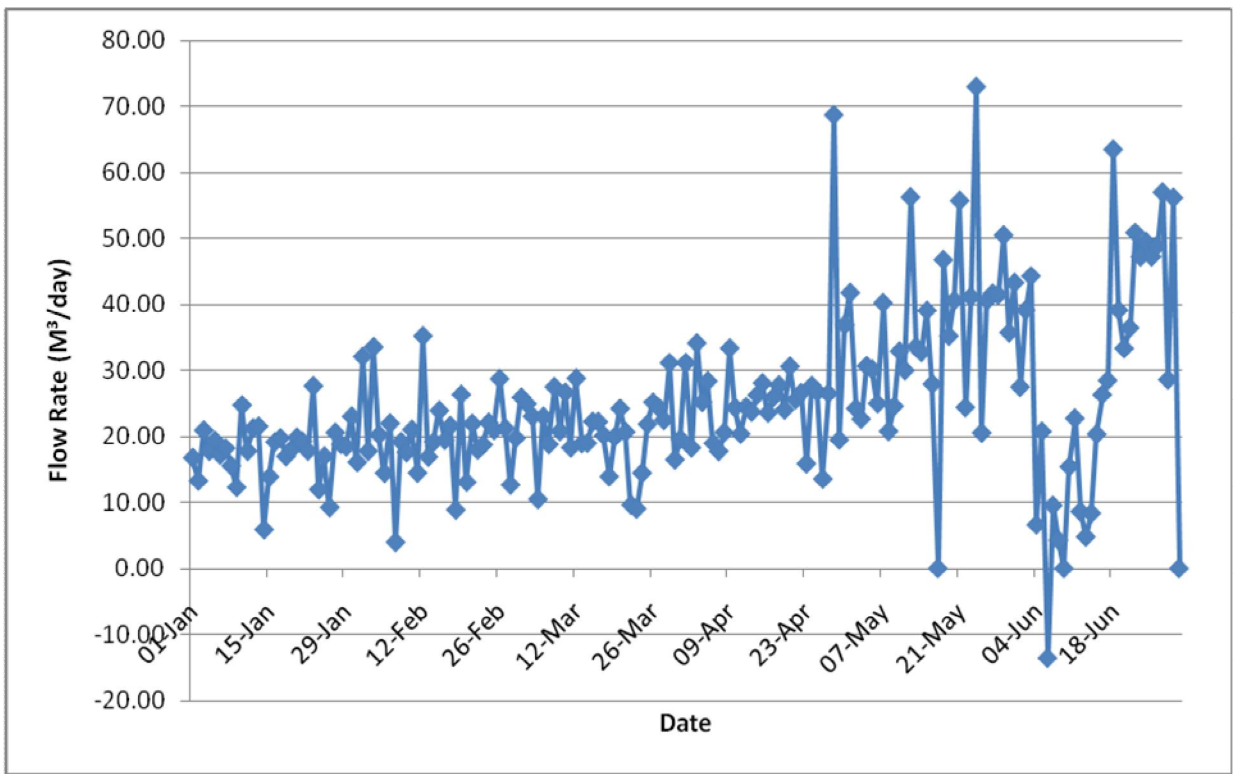


Figure 5.1 *Flow rate results.*

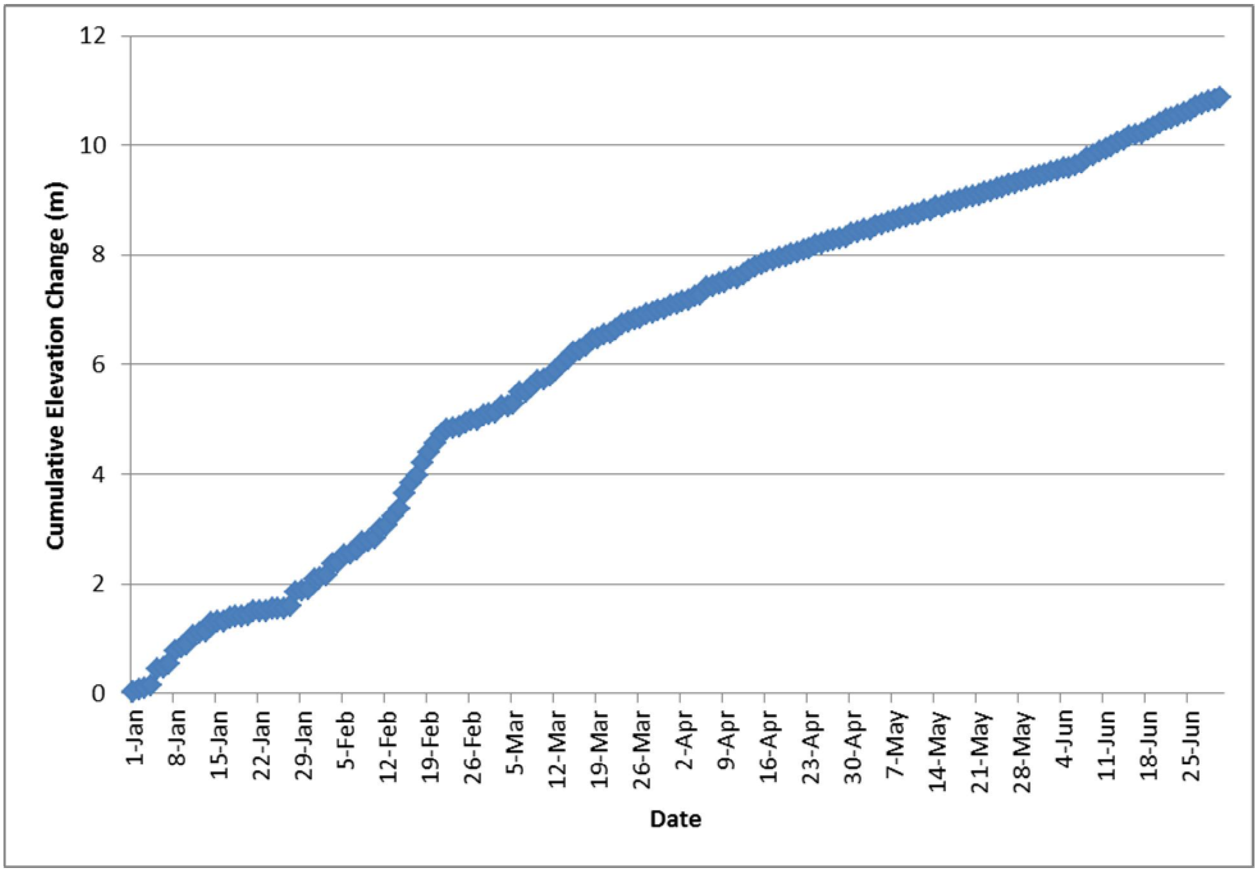


Figure 5.2 *Cumulative Elevation change results.*

Mining will begin once the groundwater level is no longer at or above the pit floor (10 to 20 meters below the mining bench). At this rate, mining in the saprolitic region can begin probably after further dewatering of the study areas for another six to twelve months. So far, the dewatering wells have been serving their functions well, and there has been no significant downtime. Validation of the results over a longer period is needed, and dewatering data (pumping rates and groundwater levels) have to be continuously updated. Future dewatering investigations will focus on the creation of a groundwater flow model to predict future dewatering requirements more effectively, based on the data from long-term aquifers' characteristics. In addition, future research can also focus on the costs of dewatering programs and sensitivity analysis in order to maximize the project's net present value.

5.3 Environmental Impact

In general, the water quality of the sampling sites shows that the dewatering program in Separi does not affect the quality of water resources in the study areas. It should be noted that this is only six months' worth of data, and longer periods of consistent record keeping are required. Groundwater quality parameters such as EC and pH value, and surface water quality parameters such as TSS and TDS, have been recorded at a number of monitoring sites to determine the groundwater quality. The station location map to measure surface water quality parameters is shown in Figure 5.3. Two stations are located at the rivers within the mine boundary, and one station is located at the river outside the mine boundary just before it joins the major river system.

The electrical conductivity at three sampling stations varies from 2200 to 7350 μS/cm. Figure 5.4 shows the results, which show that no test event produced results greater than 12,500 μS/cm. The range of TDS values in the study areas in the three stations is approximately less than 200 mg/L. It is within the permissible limits of no results being greater than 500 mg/L over three successive testing events. The results are shown in Figure 5.5. Figure 5.6 shows the TSS results. The TSS values range from 4.25 to 34.5 mg/L. The concentration is considered low and the acceptable value of TSS in the study areas is less than 150 mg/L. The pH results also do not show extreme acidity or alkalinity in the study areas. The results vary from 6.8 to 7.3, and they are within the tolerable range for the study areas (< 6 or > 8). The pH value results are shown in Figure 5.7.

To this point, the environmental management plan does not show a negative impact of dewatering programs on surface and groundwater resources. KPUC has to continuously monitor the water resources to confirm that the quality of the water is mainained, especially once the mining operations begin in the study areas.

Once all these are in place, analysis of the slope stability will be conducted. However, this cannot be presented, as mining has not progressed into the study areas.

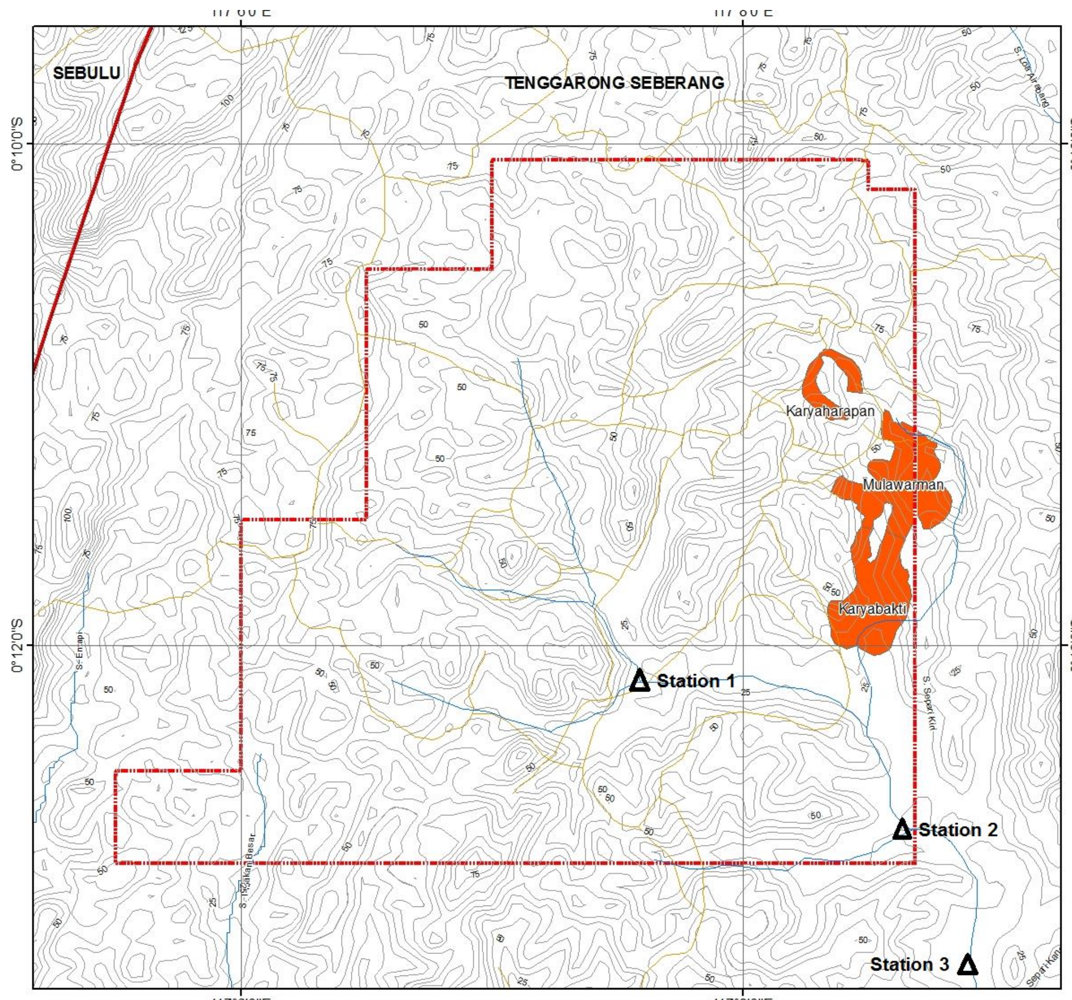


Figure 5.3 *Location of the environmental stations.*

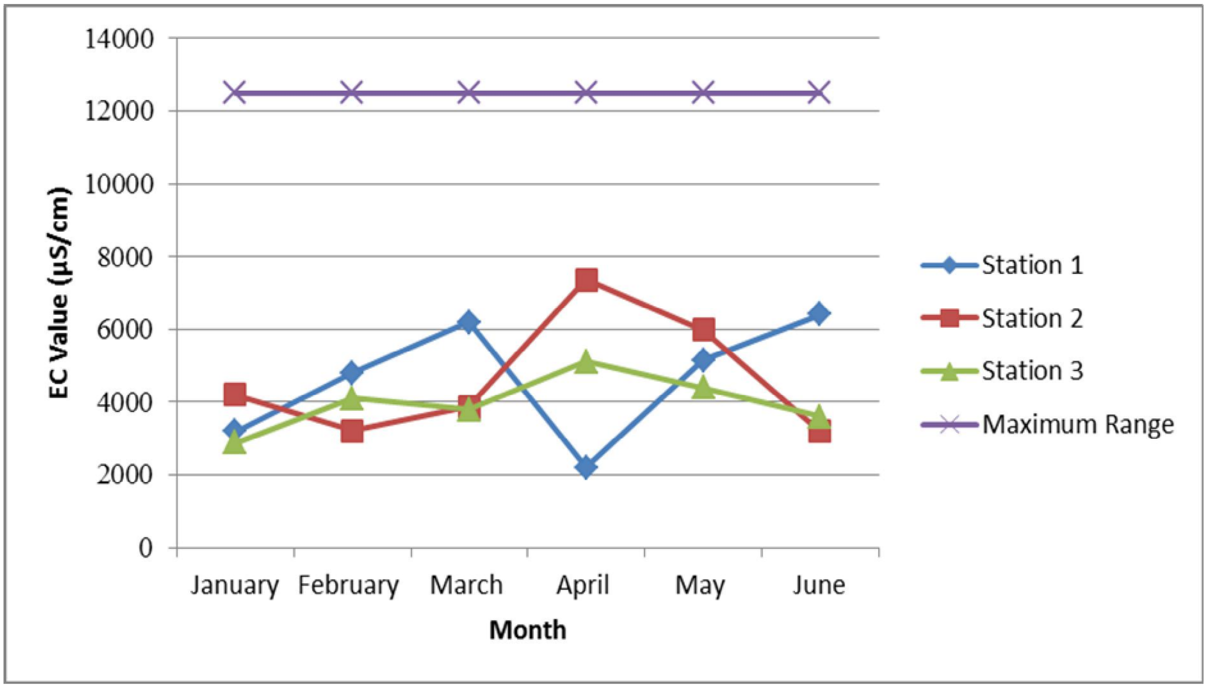


Figure 5.4 *Electrical conductivity results.*

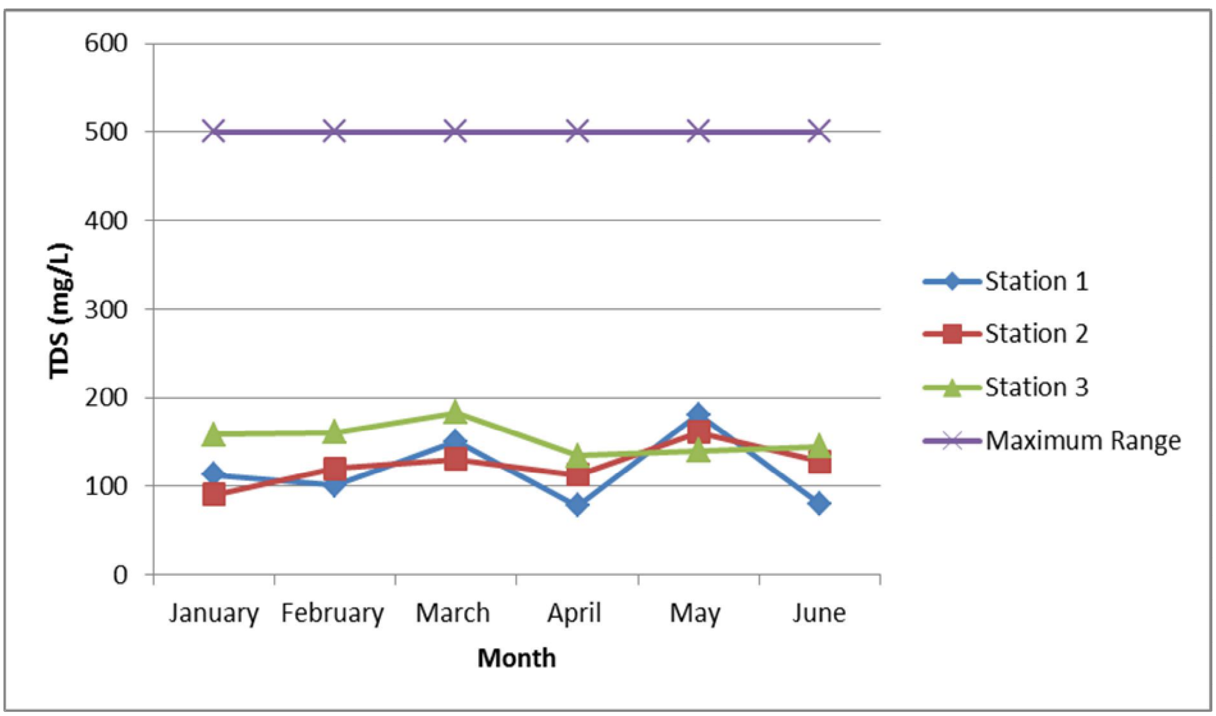


Figure 5.5 *TDS results.*

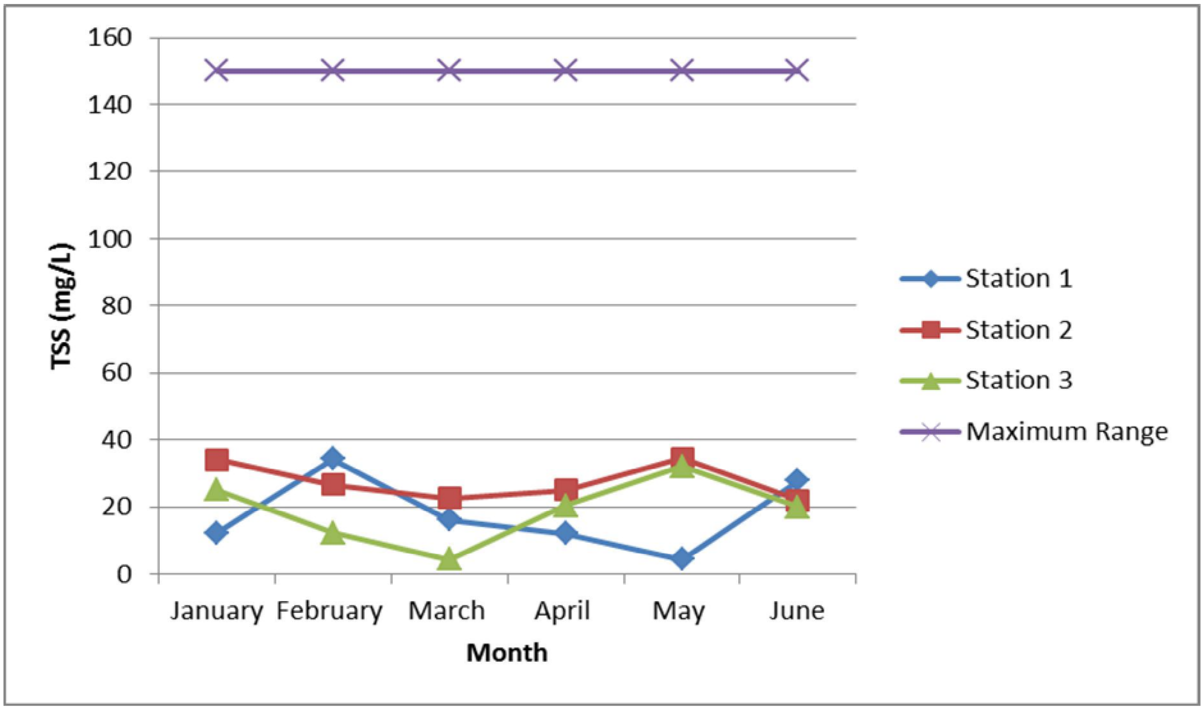


Figure 5.6 *TSS results.*

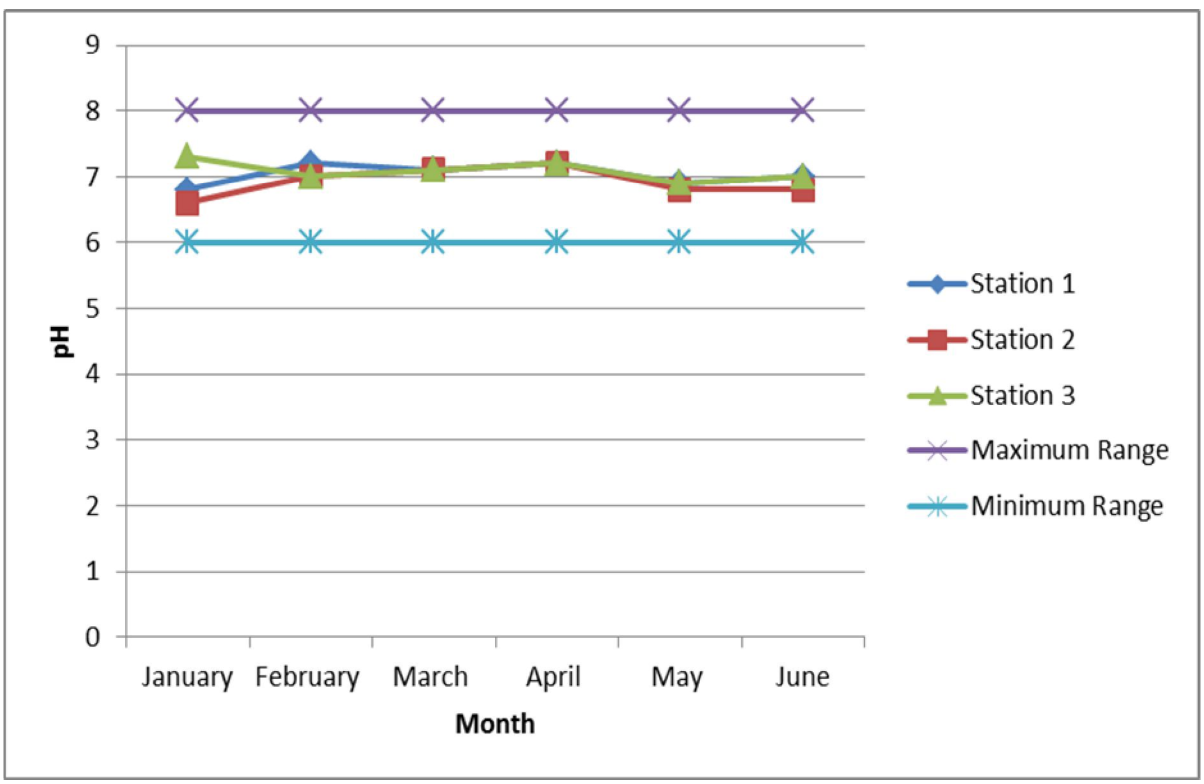


Figure 5.7 *pH value results.*

5.4 Effect of Dewatering on Mine Closure

Dewatering is a significant engineering design component and on-going operational cost at most large scale open pit and underground mining operations (Woldai & Taranik, 2007). There are numerous potential negative effects of dewatering on local water resources and environment. Concerns may rose from the mine dewatering on the water resources availability. As described in Chapter 3, the potential for groundwater in the study area as source of drinking water is low. There are no long term needs of groundwater users within the area and the company is required to maintain the groundwater quality of the water resources.

For mining operations to proceed, mining companies must pump and discharge ground water to another location. The pumping and discharging of mine water causes a unique set of environmental impacts that were reported by the European Union. The European Union report stated that the "impacts from ground water drawdown may include reduction or elimination of surface water flows; degradation of surface water quality and beneficial uses; degradation of habitat; reduced or eliminated production in domestic supply wells; water quality/quantity problems associated with discharge of the pumped ground water back into surface waters downstream from the dewatered area." It is clear that negative impacts of such activities may last for many decades. Therefore, mining companies should looked after not only on how they operate their business but as well considering proper activities to mitigate the negative effects of the harmful activities that they have done such as dewatering. Mining companies should take note that while dewatering is occurring, discharge of the pumped water, after appropriate treatment, can often be used to mitigate adverse effects on surface waters. This treatment includes the construction of settling pond at the study areas. Moreover, even after mining ceases, the water resource quality will be monitored continuously as stated in Section 5.3.

5.5 Risk Assessment

Risk is a part of any project or activities. For the purpose of this study, a risk assessment was done with regards to the proposed designs of water channels, flood protection levees, and dewatering wells. The main purpose of the construction of water channels and flood protection levees is to reduce the amount of water that enters the mining pits. However, the construction of flood protection levees and channeling the rainwater into the main river will also increase the flood levels of the nearby properties. This is viable situation for the reason that the levees will restrict the potential width of flooding, and the water channels will increase the water levels at the river. The larger flood level impacts may potentially affect the adjacent landholders which may be an agriculture area or residential area.

Even more, the construction of water channels and flood protection levees also the dewatering wells can affect the stability of the river. Factors such as changes in flow velocity, erosive capacity, and hydraulic flows are deemed to be affected when construction of these channels, levees, and wells are done. As such, environmental and wildlife concerns can also rise because of this. A detailed study is needed to be conducted by independent company to ensure that risks associated with the project are minimized throughout the lifetime of the project.

The risk assessment should be performed if the dewatering system does not work as expected and mining cannot commence in the study areas. If the risk is assessed to be high, additional measures must be implemented in order to reduce the risk. Thus, the dewatering program may be particularly risky in terms of finance, safety, and environmental impacts

6. CONCLUSION

6.1 Research Significance and Contributions

Prior research in this area has focused on the separate activities of constructing water channels, flood protection levees, and dewatering wells on their own; however, little research has been conducted to determine the effectiveness of integrating the various methods of dewatering into a single project. This research has developed an effective dewatering program at the Separi Coal site in Indonesia. A sound environmental plan has shown that the dewatering program may not have an extreme negative impact on the water resources. In other words, the negative impact can be minimized.

This research demonstrates that taking mine flood prevention measures, such as water channels and levees, is an integral factor in reducing the amount of surface water runoff into the mine. Aquifer characterization is essential in the construction of dewatering wells. This research has outlined the importance of focusing research efforts on aquifer characterization, in order to minimize the amount of dewatering well construction. This minimization will ultimately help ensure that the pumping rate is at least equal to or greater than the recharge rate. Demonstrating that a combination of dewatering schemes can lead to a more effective dewatering program, such as that proposed for the Separi Coal site, should encourage further development in dewatering saprolitic regions.

6.2 Conclusion

Mining in difficult regions such as saprolitic areas is an emerging field of research that is gaining the attention of many researchers, due to significant deposits found within saprolite regions worldwide. It is becoming increasingly evident that companies and governments are searching for ways to mine saprolite regions effectively, while limiting the environmental impact. It is likely that this will come in the form of dewatering the mining pits and aquifers prior to the beginning of any mining operation. Therefore, dewatering programs have become particularly important in the mining industry, especially since their effectiveness can influence the feasibility of a mining project in a saprolitic region.

This research indicates that an effective dewatering and environmental program can increase the feasibility of mining in a saprolite area in the Separi Coal site in East Borneo, Indonesia. Through rainfall and climate investigation, the study area was found to be in a very wet region where the precipitation is about 2,500 mm yearly, the air temperature is hot, and there are two seasons in each year: rainy and dry. This investigation was necessary in order to predict the rainfall intensity in the study areas. The calculated rainfall intensity in the study areas is 5.44 mm/hour. This research has also attempted to study the morphology of the areas. The morphology of the study areas gradually forms a hill when travelling from south to north, and the rivers in the study areas flow from north to east. Low-lying wetlands areas found in the study areas suggest that water is perched on the saprolite soils. The rate of surface water discharge at the watersheds found in the mining areas is 13.3 m^3/s. Based on these predictions and studies, water channels and flood protection levees have been constructed. These have reduced the water runoff that entered the mining area by approximately 75%

In addition, hydrological research was also conducted. It can be concluded that the confined aquifer, lithologically, consists of claystone at the top layers and sandstone layers at the overburden and interburden layers. The transition rocks (transition from clay to sand) that are above the coal seams have the potential to act as an aquifer, while the layers beneath the coal seams may serve as an aquiclude, as the groundwater can flow through its fractures. The groundwater in the study areas has the following characteristics: Average transmissivity of 2.45

× 10^{-2} m^2/s, average hydraulic conductivity of 6.724 x 10^{-7} m/s, aquifer thickness ranges from 15.05 m to 32.00 m, depth to groundwater ranges from 30 – 70 m, and the average groundwater discharge flow is 21.6 m^3/day. The groundwater has high productivity, and thus there will be discharge into the pit, contributing to the formation of wetlands. The construction of drill wells on the southeast portion of the wetlands will help to prevent an excessive inflow of water. During the six-month testing period, the average pumping rate was 24.78 m^3/day, which is higher than the estimated average groundwater discharge flow rate. At this rate, mining in the saprolitic region can begin in six to twelve months. To this point, the dewatering wells have served their functions well. The construction of settling ponds to treat the surface water in the wetlands is necessary to prevent sedimentation runoff from the wetlands from flowing into the nearby river. Environmental control performed in this research has yielded satisfactory results, and KPUC has managed to maintain the quality of the water resources. Based on factor of safety ≥ 1.5, the single slope design is 10 m high and has a slope angle of 70^{0}. For the overall design, based on factor of safety > 1.5, the total height of the mining face is 160 m and the planned overall slope angle is 30^{o} - 40^{o}. Evaluation of the slope stability was not conducted as mining has not progressed into the study areas.

This research demonstrates that while feasible for a six-month period, the effectiveness of dewatering in the saprolite region has to be monitored for a longer period. A risk assessment should be conducted by an independent company to review the risks associated with this project. However, this research has demonstrated that by striking a balance between an effective dewatering program and sound environmental policy, saprolite projects such as the Separi coalmine can become feasible and viable mining projects.

REFERENCES

Asdak, C. (1995). "Hidrologi dan Pengelolaan Daerah Aliran Sungai." Gadjah Mada University Press, Yogyakarta.

Badan Metereologi dan Geofisika Bandara Temindung Samarinda. (2010). "Laporan Curah Hujan Tahunan Samarinda dan Sekitarnya." Badan Metereologi dan Geofisika Bandara Temindung, Samarinda.

Badan Metereologi dan Geofisika Malinau. (2010). "Laporan Curah Hujan Tahunan Malinau dan Sekitarnya." Badan Metereologi dan Geofisika Malinau.

Basal Aquifer Dewatering Project Committee. (2002). "Report and Recommendations of the Basal Aquifer Dewatering Project Committee." Prepared for The Executive Director Environmental Assessment Office. Retrieved from http://a100.gov.bc.ca/appsdata/epic/documents/p152/1036005539711_7e4d91fa452e44b6a3cfce2ad945f564.pdf.

Bickham Coal. (2005). "Appendix 13 Groundwater Modelling." Retrieved from http://www.bickhamcoal.com.au/files/wra_files/Vol%202_Appendices1_16/Appendix%2013%20Groundwater%20Modelling.pdf.

Bickham Coal. (2009). "Water Resource Assessment and Draft Water Management Plan." Retrieved from http://www.bickhamcoal.com.au/files/wra_files/Vol%201_Part%20A_Part%20B_Part%20C/Vol%201%20Part%20B%20Water%20Resource%20Assessment.pdf.

Breckenridge, L., Hudson, A., Brown, P., & Henderson, M. (2005). "Hydrogeologic Investigation of the Gold Reserve Incorporated Brisas del Cuyuni Concession in Southeast Venezuela." 9th International Mine Water Congress. pp. 459.

Cawsey, D. C, & Mellon, P. (1983). "A review of experimental weathering of basic igneous rocks." Geol. Soc, Lond., Spec. Pub. No. 11. pp. 9-24.

Center of Environmental Geology, Ministry of Energy and Mineral Resources, (2009). "Keputusan Menteri Energi dan Sumber Daya Mineral, Nomor: 1451 K/10/MEM/2000, Lampiran I, Tentang Pedoman Teknis Evaluasi Potensi Air Bawah Tanah."

China Mining. (2011). "China base metals demand growing 10 pct more than GDP." Retrieved from http://www.chinamining.org/News/2011-09-22/1316655564d49784.html.

Creswell, J. W. (2009). "Research design: Qualitative, quantitative, and mixed methods approaches." Thousand Oaks, CA: Sage.

Davis, Mick. (2010). “Increase in demand for commodities, prices slowed.” X Strata’s Coal Projects. Retrieved from http://www.miningweekly.com/article/increase-in-demand-for-commodities-prices-slowed-but-not-ended-davis-2010-06-07

Department of water resources. (2009). “Groundwater Glossary.” Retrieved from http://www.water.ca.gov/groundwater/groundwater_glossary.cfm#gg.

Dikinya, O., Hinz, C., & Aylmore, G. (2008). Decrease in hydraulic conductivity and particle release associated with self-filtration in saturated soil columns.*Geoderma, 146(1-2),* 192-200.

Djanuarto, Bambang., Rusmana, Yoga., (2011). “Indonesia May Ban Low-Quality Coal Exports from 2014.” Retrieved from http://www.bloomberg.com/news/2011-01-20/indonesia-may-ban-low-quality-coal-exports-from-2014-update1-.html#.

Doerge, B. C., & Smith, C. (2008). “Mechanisms of Erosion of Volcanic Soils on Non-Agricultural Lands in Guam.” American Society of Agricultural and Biological Engineers. pp. 28-53

Duchaufour, P. (1982). “Pedology: pedogenesis and classification (translated by T. R. Paton).” London, George Allen & Unwin. pp. 448.

Dundon, P., Associates PTY LTD. (2002). “Proposed Bickham South Bulk Sample Groundwater Management” Retrieved from http://www.bcag.com.au/imageslinks/groundwater_management.pdf.

Eswaran, H. & Wong Chaw Bin. (1978). “A study of a deep weathering profile on granite in Peninsular Malaysia.” Soil Sci. Soc. Am. J. pp. 144-158.

Fredlund, D.G., Gan, J.K., Rahardjo, H. (1988). ‘Determination of the shear strength parameters of an unsaturated soil using the direct shear test.” Canadian Geotechnical Journal, 25. pp. 500-510.

Freeze, R., Allan and Cherry, A. (1979). “Groundwater.” Prentice-hall, inc. Englewood Cliffs, New Jersey. USA.

Geertz, C. (1983). “Local knowledge: Further essays in interpretive anthropology.” New York: Basic Books.

Google Earth. (2011). “Location of the KPUC mine.” Generated by Antony Lesmana May 15, 2011; using Google Earth.

Google Earth. (2011a). “Location of the Malinau Coal and KPUC mine.” Generated by Antony Lesmana May 15, 2011; using Google Earth

Gray, D., & Sotir, R. (1996). “Biotechnical and Soil Bioengineering Slope Stabilization” John Wiley & Sons, Inc: New York.

Hansen Consulting. (2006). “Ensham Central Project Environmental Impact Statement.” Retrieved from http://www.ensham.com.au.

Hansen Consulting. (2006a). “Ensham Central Project Surface Water.” Retrieved from http://www.ensham.com.au.

Hamilton, D. (1980). “Some contrasting assumptions about case study research and survey analysis.” Norwich England: University of East Anglia, Centre for Applied Research in Education.

Harun, Arifin. (2006). “Hasil Drilling 2006.” Unpublished Report - Prepared for PT. Kayan Putra Utama Coal.

Haryoko. (2008). “Aquifers di Malinau.” Unpublished Report - Prepared for PT. Kayan Putra Utama Coal.

Haryoko. (2009). “Hasil uji test tanah block Rian”. Unpublished Report - Prepared for PT. Kayan Putra Utama Coal.

Hendrayana, H. (1994). “Pengantar Model Aliran. Airtanah.” FT UGM, Yogyakarta.

Hendrayana, H. (2000). “ Konservasi Airtanah, Makalah Kursus Konservasi Sumberdaya Alam.” BAPEDALDA Prop. Daerah Istimewa Yogyakarta.

Irfan, M. (2006). “The Determination of Palembang Climate Type by Using Schmidt-Ferguson Method.” The 2nd Joint Internationa Conference on Sustainable Energy and Environment, Bangkok, Thailand. 21-23 November.

Jacobs, M., Denham, R. (2001). “Stormwater Management and The Limited Discharge System of The Batu Hijau Mine.” IMWA Symposium 2001.

Jones. M. J. (1985). “ The weathered zone aquifers of the basement complex areas of Africa.” Q. J. Eng. Geol. London, 1985, Vol. 18. pp. 35-46.

Kodoatie, R.J., Sjarief, R. (2010). “Tata Ruang Air.” ANDI Yogyakarta.

KPUC. (2006). “Feasibility Study, Separi Coal Project.” Prepared for Governor of Kutai Kartanegara regency. pp. 1-6.

KPUC. (2010). “Annual Company Report 2010.” Unpublished Report - Prepared for PT. Kayan Putra Utama Coal.

Kumar, C. P. (2002). “Assessment of Ground Water Potential.” National Institute of Hydrology, Case Study Report. Retrieved from http://www.angelfire.com/nh/cpkumar/publication/gwpot.pdf.

McCawley, Tom. (2008). “Indonesia plays power catch up.” Retrieved from http://www.atimes.com/atimes/Southeast_Asia/JC19Ae01.html.

McNaughton, J. (2010). “Site Water Management Plan.” Retrieved from http://www.bhpbilliton.com/home/aboutus/regulatory/Documents/macSiteWaterManagementPlan.pdf.

Merriam-Webster Dictionary. (2011). “Mud Definition.” Retrieved from http://www.merriam-webster.com/dictionary/mud.

Mincorp, J.E. (1998). “Detailed Pre-Feasibility Study, Brisas del Cuyuni Project.” Prepared for Gold Reserve Incorporated.

Mori, K. (1993). “Hidrologi Untuk Pengairan.” Translated by L. Taulu; edited by Suyono Sosrodarsono, Kensaku, Takeda. Pradnya Paramita, Jakarta.

Mudjiarto. (2010). “Coal Production Report 2010.” Unpublished Report - Prepared for PT. Kayan Putra Utama Coal.

Notodarmojo Suprihanto. (2005). “Pencemaran Tanah dan Airtanah.” Institut Teknologi Bandung, Bandung.

NSW Government. (2005). “Coal Mining Potential in the Upper Hunter Valley – Strategic Assessment.” Retrieved from www.planning.nsw.gov.au.

Ponce, V. M. (1989). “Engineering Hydrology, Principles and Practices.” Prentice Hall, pages 223-223.

Price, D.G. (2009). “Engineering Geology: Principles and Practice.” De Freitas, M.H.. ed. Springer.

Rapantova, Nadia., Grmela, Arnost., Vojtek, David., Halir, Josef., Michalek, Bedrich., (2007). “Groundwater Flow Modelling Applications in Mining Hydrogeology.” IMWA Symposium 2007: Water in Mining Environments. 27th – 31st May 2007. Cagliary, Italy.

Roth, Bill. (2011). “Commodity Price Crisis Driving Green Economic Revolution.” Retrieved from http://www.triplepundit.com/2011/01/commodity-price-crisis-driving-green-economic-revolution/.

Samawi, M., Sabbagh, N. (2006). “Application of Methods for Analysis of Rainfall Intensity in Areas of Israeli, Jordanian, and Palestinian Interest.” Jordanian Meterorological

Department, Ministry of Water and Irrigation. Retrieved from http://balwois.com/balwois/administration/full_paper/ffp-529.pdf.

Stoops, G. (1968). "Micromorphology of some characteristic soils of the Lower Congo (Kinshasa)." Pefologie, XVIII. pp. 110-149.

SDWF. (2007). "Groundwater." Safe Drinking Water Foundation. Retrieved from http://www.safewater.org/PDFS/resourcesknowthefacts/Groundwater.pdf.

Todd, D, K. (1995). "Groundwater Hydrology." John Wiley & Sons, Singapore.

U.S. Dept. of Agriculture. Soil Conservation Service. Soil Survey Staff. (1975). "Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys." U.S. Dept. of Agric. Handb. 436. U.S. Govt. Print. Off. Washington, DC. 754 pp., illus.

Webb. S. M. (2005). "A Survey of Ground Water Resources in the Cashiers, North Carolina Vicinity." North Carolina Department of Environment and Natural Resources. Division of Water Resources. Retrieved from http://www.ncwater.org/Reports_and_Publications/GWMS_Reports/cashiers.pdf.

Watiningsih, Ria. (2009). "Daerah Aliran Sungai Mahakam." Jurusan Geografi, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Indonesia.

Willianto, Sandi. (2011). "Section of the mining pit that is covered with saprolite." Generated by Sandi Willianto May 15, 2011; using Canon Camera.

Woldai, T., & Taranik, J. (2007). "Environmental impact assessment of mining related dewatering activities using integrated INSAR, optical remote sensing and pumping data." Retrieved from http://www.isprs.org/proceedings/XXXVII/congress/7_pdf/2_WG-VII-2/23.pdf

Yin, R. K. (1989). "Case study research: Design and methods." 2nd ed. Newbury Park, CA: Sage.

Zemin Zu. (2009). "Characteristics of saprolites formed from crystalline rock and dasolite in humid climatic regions and their development process." Earth Science Frontiers, 2009. pp. 364-373.

APPENDIX 1

Maximum Rain Intensity

Maximum rain intensity is defined as the highest precipitation per unit time. To obtain the maximum rain intensity during a certain time period, the formula derived by Mononobe (Mori, 1993) will be used. The formula is given as,

$$I = ((\frac{R_{24}}{24}) \times (\frac{24}{T_c}))^{2/3} \qquad (1)$$

T_c will be calculated using the formula derived by Kirpich (Asdak, 1995).

$$T_c = 0.945 \times (\frac{L^{1.156}}{D^{0.385}}) \qquad (2)$$

Where,

I = Rain intensity during the time of concentration (mm/h)

R_{24} = Daily maximum rainfall in 24 hours (mm)

T_c = Time (h)

L = Length of the river/stream (km)

D = Difference in height with the main river (m).

From the research in the field, this data is obtained:

Table A

No.	Watershed	Height Difference (m)	Length (km)
1	Separi Kiri	5.7	8.571
2	Tinjakan Besar	5.7	0.834
	Total		9.405

Therefore, using Equation (2),

$$T_c = 0.945 \times (\frac{L^{1.156}}{D^{0.385}}) = 0,945 \times \frac{13.34}{1.95} = 6.45$$

Thus the time of concentration in the study area is 6.45 h and the maximum rain intensity according to Mononobe formula is:

$$I = ((\frac{R_{24}}{24}) \times (\frac{24}{T_c}))^{2/3} = ((\frac{81.7}{24}) \times (\frac{24}{6.45}))^{\frac{2}{3}} = 5.44\ mm/h$$

From the above calculation**, <u>the rain intensity in Kutai Kartanegara regency is calculated to be 5.44 mm/h.</u>**

APPENDIX 2

Rainfall Prediction by Gumbell

Formula I:

$$X = \bar{X} + \frac{S}{S_n}(Y - Y_n) \quad (3)$$

Where,

X = Expected value

$\bar{X}$ = Average value

Y = Reduction value that is expected to occur at a certain period/interval (is deduced from the table that shows relationship between period T and Y). The value of Y can also be calculated using Equation (4).

$$Y = -\ln\left[-\ln\frac{T-1}{T}\right] \quad (4)$$

For $T \geq 20$, $Y = \ln(T)$.

With the following assumption,

Y_n = Average value of the variant reduction. The value depends on the value of n.

S_n = Standard deviation.

Formula II:

$$X_T = \frac{1}{a}Y_T + b \quad (5)$$

$$\frac{1}{a} = \frac{\sigma_y}{\sigma_x} \quad (6)$$

$$\sigma_x = \sqrt{\bar{X}^2 - (\bar{Y})^2} \quad (7)$$

Where,

X_T = Amount of rain that can occur in 1 day (24 hours) occurring in T years.

X^2 = Average mean value of X^2.

$(\bar{X})^2$ = The square of $\bar{X}^2$.

σ_y = Obtained from Table B (Standard deviation value for reduced variance).

Y_T = Obtained from Table B (Average value from reduced variance).

$\frac{Y_T}{Y}$ = Obtained from Table C (Reduced variance as a function of time)

Table B

Note: All the numbers in this table are formatted according to Indonesian standard i.e., It uses a comma (,) instead of a decimal point (.).

N	y_t	σ_y	N	y_t	σ_y
5	0,2935	0,8620	28	0,5137	1,1139
6	0,3403	0,8898	29	0,5155	1,1176
7	0,3719	0,9156	30	0,5172	1,1210
8	0,3950	0,9385	31	0,5188	0,1243
9	0,4128	0,9584	32	0,5203	1,1274
10	0,4271	0,9757	33	0,5217	1,1304
11	0,4388	0,9911	34	0,5231	1,1332
12	0,4486	1,0046	35	0,5244	1,1359
13	0,4570	1,0167	36	0,5256	1,1385
14	0,4642	1,0276	37	0,5268	1,1410
15	0,4706	1,0375	38	0,5279	1,1434
16	0,4762	1,0465	39	0,5289	1,1457
17	0,4811	1,0547	40	0,5299	1,1479
18	0,4856	1,0622	41	0,5390	1,1500
19	0,4896	1,0691	42	0,5318	1,1520
20	0,4933	1,0755	43	0,5327	1,1540
21	0,4966	1,0815	44	0,5335	1,1559
22	0,4996	1,0871	45	0,5343	1,1577
23	0,5024	1,0922	46	0,5351	1,1595
24	0,5050	1,0971	47	0,5358	1,1612
25	0,5074	1,1017	48	0,5365	1,1628
26	0,5096	1,1060	49	0,5372	1,1644
27	0,5117	1,1101	50	0,5379	1,1660

n = banyak tahun pengamatan

Table C

Note: All the numbers in this table are formatted according to Indonesian standard i.e., It uses a comma (,) instead of a decimal point (.).

T	Y	F (x)	T	Y	F (x)
2	0.4476	0.50	200	5.2958	0.995
3	0,9027	0,70	250	5,5194	0,996
5	1,4999	0,80	333	5,8067	0,997
10	2,2504	0,90	500	6,2136	0,998
20	2,9702	0,95	1000	6,9073	09990
33	3,4812	0,97	2000	7,6007	0,9993
50	3,9019	0,998	5000	8,5167	0,9997
100	4,6002	0,99	10000	9,2113	0,9999

Reduce variance (Y) can be calculated using Equation (8),

$$Y_{Tt} = -\ln(-\ln\{(T_r - 1)/T_r\}) \quad (8)$$

For example if, T = 5 years

$Y_5 = -\ln(-\ln\{(5_r - 1)/5_r\})$. $\quad Y_{TL} = 1.4999$

Table D shows the mean precipitation value in Kutai Kartanegara.

Table D

Year	**Precipitation (mm)**	
	X	**X^2**
2000	86.14	7420.10
2001	63.78	4067.46
2002	55.88	3122.20
2003	78.18	6111.60
2004	83.46	6965.00
2005	85.00	7227.30
2006	64.89	4210.70
2007	81.80	6691.80
2008	91.92	8448.70
2009	72.10	5199.40
Total	763.16	59464.20
Mean ($\bar{X}$)	76.30	5946.40
$(\bar{X})^2$	5824.08	

From the value found in the table,

$\sigma_x = \sqrt{5916.4 - 5824.08} = \sqrt{122.32} = 11.06$

n = 10 → $\bar{Y}_T$ = 0.4271 (Table A)

σ_y = 0.9757 (Table A)

$$\frac{1}{a} = \frac{\sigma_x}{\sigma_y} = \frac{11.06}{0.9757} = 11.34$$

$b = \bar{X} - \frac{1}{a}\bar{y}_T = 76.3 - 11.34 \times 0.4271$ = 71.47

For T = 2, 3, 5, 10, and 20 years, the results of predicted rainfall are shown in Table E.

Table E *Rainfall prediction for 24-hour periods.*

N	σ_y Value	1/a Value	b Value	Y (Table B)	T_r (mm/24 h)
2	0.9757	11.336	71.47	0.448	76.548
3	0.9757	11.336	71.47	0.903	81.707
5	0.9757	11.336	71.47	1.500	88.477
10	0.9757	11.336	71.47	2.250	96.985
20	0.9757	11.336	71.47	2.970	105.144

Based on calculation using the Gumbell method shown above, **it can be concluded that using the 3-year interval, the predicted rainfall is 81.7 mm/24 h. The 3-year interval period is chosen based on technical factors.** From Table C, the average daily precipitation is 76.3 mm and the highest precipitation is 91.92 mm (in 2008). The 2-year predicted interval value (i.e., 76.55 mm) is far from the highest precipitation value, while the 10- and 20-year values do not correlate well with the data. The 5-year predicted interval value seems appropriate but the 3-year is still chosen because of its shorter time interval. Using the 5-, 10-, and 20- year values will be a safer estimation but it will be much more expensive.

APPENDIX 3

Surface Water Discharge

The method used to calculate the peak surface water discharge is the rational method (US Soil Conservation Service, 1975). The formula is given as,

$$Q_p = 0{,}278 \times C \times I \times A \tag{9}$$

Where,

Q_p : Peak discharge rate (m3/s).

C : Coefficient of water runoff (refer to Appendix 3).

I : Rainfall intensity (mm / h) and it is for the duration of the rain which equals to the time of concentration (T_c).

A : Catchment area (km^2).

Table F

No.	Watershed	C	I (mm/h)	A (km^2)	Q (m^3/s)
1	Separi Kiri	0.4	5.44	18.66	11.29
2	Tinjakan Besar	0.4	5.44	3.34	2.02
	Total rate of discharge				13.3

So the **total rate of discharge in the study area is 13.3 m^3/s.**

Wetland area

Based on the watershed and catchment area and the progress mine map, 16% of the Separi Kiri watershed flows into the pit areas. Thus, according to the following calculation, Total area of watershed Separi Kiri = 18.66km^2.

Rate of discharge at Separi Kiri = 11.29 m^3/s.

If 16% of Separi Kiri watershed flows into the mine pit areas, rate of discharge of Separi Kiri at the pit is calculated as followed,

$11.29 \times 0.16 = 1.8$ m^3/second = 6503.04 m^3/hour = 156.073 m^3/day

The **rate of discharge of Separi Kiri that flow into the mine pit areas is 156.073 m^3/day.**

APPENDIX 4

<u>Groundwater Discharge</u>

The groundwater discharge can be calculated using the Darcy formula shown Equation (10).

$$Q - k \times A \times i - k \times A \times \frac{\partial h}{\partial l} \qquad (10)$$

Where,

Q = Groundwater discharge rate (m^3/s).

k = Hydraulic conductivity (m/s).

$\frac{\partial n}{\partial l}$ = Hydraulic gradient.

Measures used to calculate the groundwater potential are as follows:

1. Estimate the value of hydraulic conductivity (k). The value is adjusted according to the type of soil material in the study areas or determined by slug test.
2. Estimate the cross sectional area of the aquifer (A). The formula that can be used to determine A is given below:

$$A = T \times \left[\frac{n \times s}{100}\right] \qquad (11)$$

Where,

A = Cross sectional area of the aquifer.

n = Width of the study area in the direction that is perpendicular to isopiezometric line.

s = Map scale.

T = Thickness of the aquifer.

And T can be calculated by equation (12),

$$T - K - d \quad (12)$$

Where,

T = Thickness of the aquifer (m).

K = Depth of the well (m).

d = Depth of the groundwater advance.

Determine the hydraulic gradient by determining the distance between two isopiezometric lines based on the following equation:

$$i = \frac{\partial h}{\partial l x (\frac{s}{100})} \quad (13)$$

i = Hydraulic gradient.

∂h = Interval/height difference between two adjacent isopiezometric lines (m).

∂l = Distance between two adjacent isopiezometric lines (m).

S = Map scale.

The value of K for each soil material is shown in the table G (Todd, 1995).

Table G

Material	**m/day**	**Material**	**m/day**
Gravel, coarse	150	Pure sand	20
Gravel, medium	270	Loess	0.08
Gravel, fine	450	Peat	5.7
Sand, coarse	45	Schist	0.2
Sand, medium	12	Slate	0.00008
Sand, fine	2.5	Till, predominantly silt	0.49
Silt	0.08	Till, predominantly sand	30
Clay	0.0002	Tuff	0.2
Sandstone, fine-grained	0.2	Basalt	0.1
Sandstone, medium-grained	3.1	Gabro, weathered	0.2
Limestone	0.94	Granite, weathered	1.4
Dolomite	0.0001		

Groundwater discharge is calculated based on cross-sectional area of the aquifer per 1-m width and according to Equation (14):

$$A_p = Td_0 \quad (14)$$

Where,

A_p = Cross-sectional area of the aquifer per 1-m width (m^2).

T = Thickness of the aquifer (m).

d_0 = Width of the aquifer per unit meter (m).

Based on the above formula, it can deduced that A_p = T as the width of the aquifer per unit meter (i.e., d_0) is assumed to be 1 m. As such, the groundwater discharge is calculated by multiplying the hydraulic conductivity (K), gradient (i), and thickness of the aquifer (T) which can be assumed to be equal to the cross-sectional area of the aquifer per 1-m width (A_p).

The result of the calculated groundwater discharge per 1-m width of the aquifer can be seen in Table G. The result of the groundwater discharge, on the other hand, is summarized in Table H. **In conclusion, the average groundwater discharge in the study areas, based on Darcy formula and slug test above, is 10.03 m^3/day.**

Table H

Drill Hole	Coordinate			b Aquifer Thickness	K Hydraulic Conductivity	T Transmissivity	S Storativity Value
	X	Y	Z	(m)	(10^{-7} m/s)	(10^{-3} m^2/s)	(10^{-3})
DH-1	512316.5	9978304	63	17.50	6.65	1.163	5.25
DH-2	513473.5	9979968	45	32.00	9.82	3.142	9.60
DH-3	514532.1	9978110	43	15.05	5.11	0.769	4.51
DH-4	516423.8	9978628	38	24.00	4.23	1.015	7.20
DH-5	515809.3	9977317	27	30.00	7.81	2.100	8.82

Table I

Drill Hole	Coordinate			A	dh	dl	I	Q
	X	Y	Z	Cross Sectional Area Aquifer (m^2)	Height Difference (m)	Distance (m)	Gradient (m)	Ground water Discharge (10^{-7} m^3/s)
DH-1	512316.5	9978304	63	35,472.50	4.2	2,027	0.00207	488.78
DH-2	513473.5	9979968	45	68,448.00	7.1	2,139	0.00332	2,231.10
DH-3	514532.1	9978110	43	29,528.10	23.3	1,962	0.01188	1,791.90
DH-4	516423.8	9978628	38	34,752.00	25.7	1,448	0.01775	2,609.06
DH-5	515809.3	9977317	27	87,660.00	22.5	2,922	0.00770	5,271.75
Average				51,172.12	16.56	2,099.6	0.00854	2,478.52

APPENDIX 5

Water Runoff Calculation

1. Calculation of runoff water that enters the wetlands.

Making embankments/levees and open-water channels reduces 75% of runoff water that flow into the wetlands and mining area (pit), and as such the runoff water that flows into the wetland is only approximately 25% of the total water runoff entering the wetland (i.e., 6,503.04 m^3/h). The amount is equal to:

= (100-75)% x 6503.04 m3/h

= 0.25 x 6503.04 m4/h

= 1625.76 m3/h

The amount of runoff water that enters into the wetlands/mining area is 1625.76 m^3/h.

2. Calculation of surface water that originates from outside.

The surface water from outside the wetland or the mining area (pit) is given as,

= (6503.04 - 1625.76) m^3/h

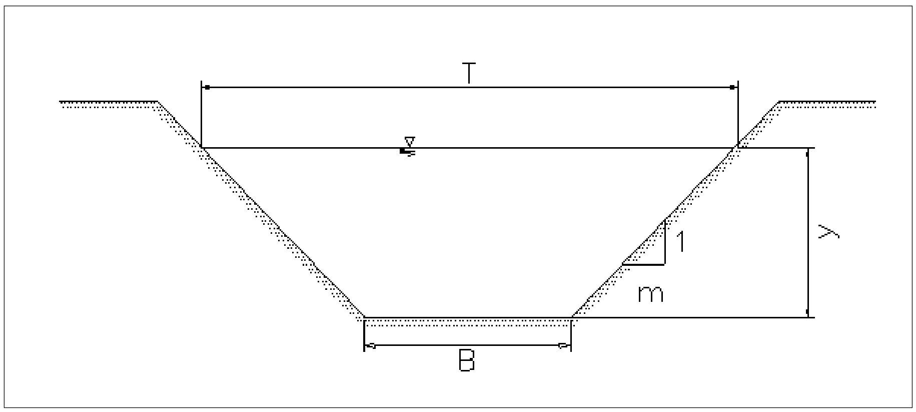
= 4877.28 m^3/hour = 1.35 m^3/s

Surface water that originates from outside the wetland or mining area is 4877.28 m^3/h = 1.35 m^3/s.

APPENDIX 6

Dimension of Water Channel

The trapezoid model is shown below:



Where,

y = Depth of flow (m).

B = Width of the channel at the bottom (m).

m = Slope of the wall.

T = Width of the channel at the top (m).

From the research experiment, the following data is obtained:

Q (discharge rate) = 1.35 m^3/s.

Slope = 0.5.

Average speed = 1 m/g.

Chezy coefficient, C = 50 $m^{1/2}/d$.

Thus the area of the flow is shown in Equation (15),

$$A=(B+my)y = (B+0.5y)y \qquad (15)$$

This area of the flow can also be calculated using the continuity equation, Equation (16).

$A=Q/v = 1.35/1 = 1.35\ m^2$ (16)

From Equations (15) and (16), Equation (17) can be derived as,

$1.35 = (B+0.5y)y$ (17)

To build or construct an economical water channel in the shape of a trapezoid, the following condition has to be followed:

$B + 2my = 2y\sqrt{m^2 + 1}$ → $B + y = = 2y\sqrt{0.5^2 + 1}$

$B = 1.24\ y$ (18)

Substituting Equation (18) into Equation (17),

$(1.24\ y + 0.5\ y)y = 1.35$

$1.74\ y^2 = 1.35$ → $y^2 = 0.86$

Thus y = 0.93, and B = 1.15

Also, $R = \frac{y}{2} = \frac{0.93}{2} = 0.465\ m$

The slope of the channel can be calculated using the Chezy formula as shown in Equation (19),

$v = \sqrt{RI}$ (19)

$I - 50\sqrt{0.465 \times 1}$

$I = 34.1$

The width of the channel at its top, T, is obtained as,

$T = B + 2\ my = 1.15 + (2 \times 0.5 \times 0.93) = 2.01\ m.$

From the above calculation, the channel will have the shape of a trapezoid with the following dimensions:

y	**= Depth of flow**	**= 0.93 m.**
B	**= Width of the channel at the bottom**	**= 1.15 m.**
m	**= Slope of the wall**	**= 0.5.**
T	**= Width of the channel at the top**	**= 2.01**

APPENDIX 7

Table J

No	Drill hole	Lithology	Depth (m)	Physical Properties								
				Nat, dens (g/cm^3)	Sat, dens (g/cm^3)	Dry dens (g/cm^3)	Specific density	Water content %	Absorption %	Saturation %	Porosity %	Void ratio
1	DH-2	Siltstone	28.45 – 29.10		2.225	1.984	2.643	12.12		97.00		0.332
		Sandstone	35.80 – 36.30		2.194	1.912	2.647	14.19		99.00		0.378
		Siltstone	50.60 – 51.20		2.140	1.842	2.634	16.15		99.00		0.430
		Siltstone	62.55 – 63.20		2.204	1.949	2.625	13.07		99.00		0.347
		Siltstone	78.60 – 79.35		2.376	2.203	2.666	7.86		100.00		0.100
		Sandstone	86.75 – 87.25		2.118	1.840	2.671	15.11		89.00		0.452
		Sandstone	91.00 – 91.60		2.329	2.177	2.645	6.99		86.00		0.215
		Sandstone	97.00 – 97.42		2.255	2.028	2.624	11.21		100.00		0.294
		Siltstone	110.50 – 110.95		2.317	2.118	2.642	9.37		100.00		0.247
		Siltstone	122.56 – 123.06		2.371	2.195	2.662	8.01		100.00		0.213
		Siltstone	139.25 – 139.75		2.323	2.151	2.663	8.02		90.00		0.238
		Sandstone	148.30 – 148.80		2.248	2.011	2.634	11.78		100.00		0.310
2	DH-3	Siltstone	4.80 – 5.25	1.307	1.737	1.185	2.641	10.29	46.50	22.12	55.12	1.228
		Sandstone	8.50 – 8.95	1.195	1.590	1.062	2.250	12.50	49.68	25.16	52.78	1.118
		Siltstone	9.95 – 10.40	1.507	1.831	1.343	2.623	12.25	36.34	33.70	48.80	0.953
		Sandstone	34.25 – 34.70	1.605	1.944	1.518	2.647	5.79	28.11	20.58	42.67	0.744
		Sandstone	41.00 – 41.50	1.523	1.828	1.376	2.512	10.66	32.84	32.46	45.20	0.825
		Clay stone	45.95 – 46.35	1.417	1.747	1.243	2.508	14.05	40.60	34.61	50.46	1.018
		Clay stone	59.00 – 59.50	1.451	1.841	1.375	2.576	5.53	33.91	16.31	46.62	0.873
		Sandstone	71.50 – 72.00	1.322	1.775	1.251	2.627	5.65	41.87	13.50	52.38	1.100
		Sandstone	79.16 – 79.65	1.239	1.667	1.120	2.471	10.58	48.78	21.68	54.65	1.205
		Clay stone	87.67 – 88.00	1.344	1.732	1.189	2.599	12.99	45.61	28.49	54.24	1.185
		Clay stone	102.50 – 103.00	1.638	1.948	1.524	2.645	7.45	27.81	26.78	42.38	0.736
		Sandstone	107.30 – 107.80	1.550	1.856	1.373	2.656	12.9	35.20	36.66	48.32	0.935
		Sandstone	115.50 – 116.00	1.355	1.812	1.302	2.656	4.12	39.17	10.53	50.99	1.040
		Sandstone	122.00 – 122.50	1.522	1.862	1.368	2.701	11.25	36.05	31.20	49.33	0.974
3	DH-5	Sandstone	8.50 – 8.95	1.276	1.749	1.194	2.683	6.86	46.5	14.75	55.50	1.247
		Siltstone	14.15 – 14.65	1.434	1.854	1.370	2.657	4.69	35.37	13.27	48.45	0.94
		Sandstone	22.05 – 22.50	1.493	1.844	1.358	2.642	9.92	35.79	27.71	48.60	0.95
		Siltstone	24.20 – 24.65	1.435	1.845	1.339	2.712	7.11	37.78	18.81	50.60	1.024
		Siltstone	30.70 – 31.05	1.42	1.771	1.321	2.402	7.48	34.07	21.96	45.01	0.818
		Siltstone	40.80 – 41.25	1.307	1.763	1.228	2.639	6.43	43.56	14.76	53.48	1.149
		Clay stone	59.40 – 59.90	1.397	1.796	1.282	2.640	9.03	40.14	22.49	51.45	1.06
		Sandstone	65.35 – 65.77	1.591	1.929	1.480	2.684	7.53	30.31	24.84	44.86	0.813
		Sandstone	73.35 – 73.85	1.238	1.752	1.180	2.760	4.94	48.51	10.19	57.24	1.339
		Sandstone	83.80 – 83.25	1.43	1.827	1.343	2.603	6.48	36.04	17.97	48.41	0.938
		Clay stone	92.45 – 92.90	1.526	1.876	1.416	2.621	7.74	32.45	23.85	45.96	0.851
		Clay stone	110.16 – 110.56	1.576	1.925	1.470	2.696	7.24	30.94	23.41	45.49	0.834
		Sandstone	134.28 – 134.67	1.324	1.776	1.255	2.621	5.52	41.52	13.29	52.11	1.088

Table K

No	Drill hole	Lithology	Depth (m)	UCS (MPa)	Triaxial Test		Direct Shear Test		
					Cohesion (KPa)	Angle of Friction	Cohesion (KPa)	Angle of Friction	Slake Test
1	DH-2	Siltstone	28.45 – 29.10	2.6394			297	30.03	
		Sandstone	35.80 – 36.30				648	33.49	low
		Siltstone	50.60 – 51.20				483	22.31	low
		Siltstone	62.55 – 63.20				792	21.93	
		Siltstone	78.60 – 79.35				569	34.78	medium
		Sandstone	86.75 – 87.25				347	34.68	
		Sandstone	91.00 – 91.60	0.4375			2166	27.68	medium
		Sandstone	97.00 – 97.42				84	29.19	
		Siltstone	110.50 – 110.95	4.1229			788	25.45	
		Siltstone	122.56 – 123.06				1177	28.72	medium
		Siltstone	139.25 – 139.75	5.9935			987	36.24	
		Sandstone	148.30 – 148.80				90	33.32	
2	DH-3	Siltstone	4.80 – 5.25				236	27.83	
		Sandstone	8.50 – 8.95				77	35.49	
		Siltstone	9.95 – 10.40	3.0105			633	28.63	very low
		Sandstone	34.25 – 34.70	5.6389			74	33.91	very low
		Sandstone	41.00 – 41.50				722	30.79	
		Clay stone	45.95 – 46.35				167	25.72	
		Clay stone	59.00 – 59.50				186	32.77	
		Sandstone	71.50 – 72.00				198	34.94	
		Sandstone	79.16 – 79.65				172	30.8	
		Clay stone	87.67 – 88.00				379	29.86	
		Clay stone	102.50 – 103.00				712	24.23	
		Sandstone	107.30 – 107.80	1.4897			1354	26.27	low
		Sandstone	115.50 – 116.00				2379	15.62	
		Sandstone	122.00 – 122.50				1092	24.09	

No	Drill hole	Lithology	Depth (m)	UCS (MPa)	Triaxial Test		Direct Shear Test		
					Cohesion (KPa)	Angle of Friction	Cohesion (KPa)	Angle of Friction	Slake Test
3	DH-5	Sandstone	8.50 – 8.95						
		Siltstone	14.15 – 14.65	0.2456			1229	26.44	very low
		Sandstone	22.05 – 22.50				349	32.09	
		Siltstone	24.20 – 24.65	6.2705			2237	15.14	very low
		Siltstone	30.70 – 31.05				727	26.05	
		Siltstone	40.80 – 41.25	3.4184			1523	24.87	very low
		Clay stone	59.40 – 59.90	1.9972			255	32.03	very low
		Sandstone	65.35 – 65.77		4.54	44.43			
		Sandstone	73.35 – 73.85	0.2761			163	34.37	very low
		Sandstone	83.80 – 83.25	0.9127			261	32.7	very low
		Clay stone	92.45 – 92.90				532	23.67	
		Clay stone	110.16 – 110.56	3.773			1284	22.84	low
		Sandstone	134.28 – 134.67				552	31.15	