

**THE USE OF MINE WATER BALANCES TO  
OPTIMISE WATER MANAGEMENT IN OPENCAST  
AND UNDERGROUND COLLIERIES IN THE  
WITBANK COALFIELDS OF SOUTH AFRICA**

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## ***ABSTRACT***

Mine water management continues to become ever more important with the continual increase and expansion of coal mining operations within already water stressed and contaminated catchment areas in South Africa. Mine water balances are one of the most effective methods to assist in optimising the management of water reticulation and storage in opencast and underground collieries. Before developing a water balance, it is crucially important to have a clear understanding of the parameters that play a role in the recharge and water make into the mining operations. Different methods of data gathering may be employed in order to develop the conceptual model for a mine water balance. A literature review is done in order to obtain generic values relevant to the entirety of the Witbank Coal Field and a case study is done in order to obtain site specific parameters. The case study is done for a typical mine which included both opencast and underground sections in the pre-mining, operational and post closure phases of mining. Both generic and site specific parameters is used in order to create three mine water balance scenarios. The water balance scenarios investigated indicate the sensitivity and importance of collecting accurate and representative data when developing a mine water balance. The mine water balance calculations together with the associated storage capacity assessments for each of the mine workings is used to assess and highlight the sensitivity of the input data used as well as to indicate the importance of ensuring that accurate and representative data is used when undertaking water balances as a water management tool.

## ***DECLARATION***

I, Jan-Michael Lombard, hereby declare that the dissertation submitted by me to the Institute for Groundwater Studies in the Faculty of Natural and Agricultural Sciences at the University of the Free State, in fulfilment of the degree of Magister Scientiae, is my own independent work. It has not previously been submitted by me to any other institution of higher education. In addition, I declare that all sources cited have been acknowledged by means of a list of references.

I furthermore cede copyright of the dissertation and its contents in favour of the University of the Free State.

Jan-Michael Lombard

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## ***LIST OF ACRONYMS***

<b>AWIRU</b>	:	African Water Issues Research Unit
<b>BPGs</b>	:	Best Practice Guidelines
<b>DWA</b>	:	Department of Water Affairs
<b>DWAF</b>	:	Department of Water Affairs and Forestry
<b>IWMI</b>	:	International Water Management Institute
<b>LOM</b>	:	Life of Mine
<b>M</b>	:	Meters
<b>MAMSL</b>	:	Meters Above Mean Sea Level
<b>MBGL</b>	:	Meters Below Ground Level
<b>NWA</b>	:	National Water Act
<b>SABS</b>	:	South African Bureau of Standards
<b>WC/WDM</b>	:	Water Conservation and Water Demand Management

## ***APPENDICES***

APPENDIX I	:	BOREHOLE LOGS
APPENDIX II	:	HYDRAULIC CONDUCTIVITY REPORT
APPENDIX III	:	STORAGE CAPACITY ASSESSMENT

# 1. INTRODUCTION

Coal is one of the most important mining commodities in South Africa contributing not only as a source of economic value, but also as a source of employment. Coal is also a source of energy and is used by the country's power producers to generate the bulk of the electricity. More than 80% of the historically mined coal in South Africa originates from the Mpumalanga Province which is the setting for the Witbank Coal Field. Although coal mining is dwindling in the Province, the impact that coal mining had and will have on the environment, in particular the groundwater and surface water resources cannot be ignored.

South Africa is a semi-arid country with a growing population and growing demand for water. Water is not only important for domestic use, but also plays a significant role in the agricultural sector. Water management is thus of utmost importance to all the people and economy of South Africa as encompassed in the Country's legislation.

Section 24 of the Constitution of South Africa (Act 108 of 1996) states that everyone has the right to an environment that is not harmful to his or her health or well-being, and to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures. This is fully supported and regulated through legislation such as the National Water Act (Act 36 of 1998) (NWA). The NWA states that the country's water resources need to be protected by reducing and preventing pollution and degradation of water resources. Section 19(1) of the NWA states that a person in control of water use must take reasonable measures to prevent any occurring and recurring pollution. Section 21(a) governs the taking of water from a water resource such as groundwater and Section 21(j) governs the removal, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people.

The Department of Water Affairs (DWA), now the Department of Water and Sanitation, created a guideline in support of the legislation that will give effect to water conservation and water demand management (WC/WDM) in South Africa. This guideline assists the mines along with the Department to highlight the connection between the WC/WDM measures and the Best Practice Guidelines (BPG's) for Water Recourse Protection in the South African Mining Sector. One of the BPG's specifically addresses the development of mine water balances. This dissertation will mainly focus on the importance of developing an accurate and representative mine water balance to optimise water management in opencast and underground collieries in the Witbank Coal Field.

## 2. OBJECTIVES AND METHODOLOGY

The aim of this dissertation is to illustrate the importance of accurate and representative mine water balances as a management tool in opencast and underground collieries in the Witbank Coal Field. In order to illustrate this, the objective of this research project is to:

- Understand the role and significance of mine water balances associated with the coal mining operations within the Witbank Coal Field.
- Understand the conceptual components and input parameters needed in order to develop a mine water balance for a coal mine in the Witbank Coal Field.
- Gain an understanding of the generic values obtained from the literature review that is relevant to the entire Witbank Coal Field, and site specific inputs needed to populate a mine water balance.
- Illustrate the significance of collecting accurate data in order to optimise the mine water balance calculations and subsequent water management in a coal mine.
- Identify critical parameters and requirement for a mine water balance and illustrate the significance of a mine water balance as part of mine water management in a coal mine.

In order to meet the objectives the following methodology is followed:

- To understand the role and significance of a mine water balance in the Witbank Coal Field, an investigation is done on the Water Conservation and Water Demand Management Guideline and the Water and Salt Balance Best Practice Guideline. These guidelines clearly indicate the role, purpose and significance of water balances in the mining sector.
- To better understand the components needed to develop a mine water balance, a conceptual model is set up to schematically illustrate the variables needed to calculate an accurate water balance for both underground and opencast collieries in the Witbank Coal Field. Data collection methods are discussed and in order to determine whether generic or site specific data or a combination of the two should be used in order to develop a mine water balance.
- To gain an understanding of the generic inputs needed to develop a mine water balance, a literature study regarding parameter ranges that are typically used in the Witbank Coal Field is discussed. A typical “hypothetical” mine site is created in order to illustrate a combination of opencast and underground mine workings in pre-mining, operational as well as post closure stages of mining. Actual data provided by JMA Consulting is used as site specific parameters in the conceptual model.

- To illustrate the significance of collecting accurate data to optimise water management in a coal mine, a sensitivity analysis is done on water balances using three scenarios. The first two scenarios are done using the highest and lowest possible parameter ranges typically observed in the Witbank Coal Field according to literature. The third scenario is done using the site specific parameters. The three parameters are compared in terms of the natural recharge per day as well as per annum. As part of the sensitivity analysis a storage capacity assessment is done on the three scenarios in order to assess and compare the time that it will take to flood the respective mine workings under the conditions of the three scenarios, and hence the importance of accurate water balance calculations.
- The outcome of the sensitivity assessment is to determine the most critical parameters that are needed in order to do an accurate mine water balance for opencast and underground mines in the Witbank Coal Field and the importance thereof in order to optimise the management of water.

## **3. THE ROLE AND SIGNIFICANCE OF A WATER BALANCE IN MINE WATER MANAGEMENT**

### **3.1 THE ROLE AND PURPOSE OF A WATER BALANCE IN THE COAL MINING INDUSTRY OF SOUTH AFRICA**

The setup of a water balance is of utmost importance for the management of water in the coal mining industry of South Africa (DWAF, 2006). The WC/WDM Guidelines set out by the DWA highlight the importance of an accurate water balance by placing the water and salt balance at the top of the hierarchy, after a status quo assessment, for the recommended steps to be followed in the assessment, planning, implementation and management of WC/WDM at a mine as indicated on Figure 3-1.

Water balances can be used as a tool to audit the use of water, identify areas with high water usage and wastage, identify and quantify imbalances, locate and quantify seepage and leakage, identify and quantify pollution sources, simulate and evaluate different management options before implementation and finally assist in the general decision making process.

The purpose of water and salt balances according to the Best Practice Guideline G2 (DWAF, 2006) is to:

- Provide the necessary information to assist in defining and driving different management strategies.
- Audit and assess the water reticulation system (water usage and pollution sources) by identifying and quantifying points of pollution sources and high water usage points, seepage and leakage points.
- Identify and quantify decanting from the opencast and underground workings.
- Assist with storage requirements and minimising the risk of decant and acid generation.
- Assist in the decision making process by considering different water management strategies.

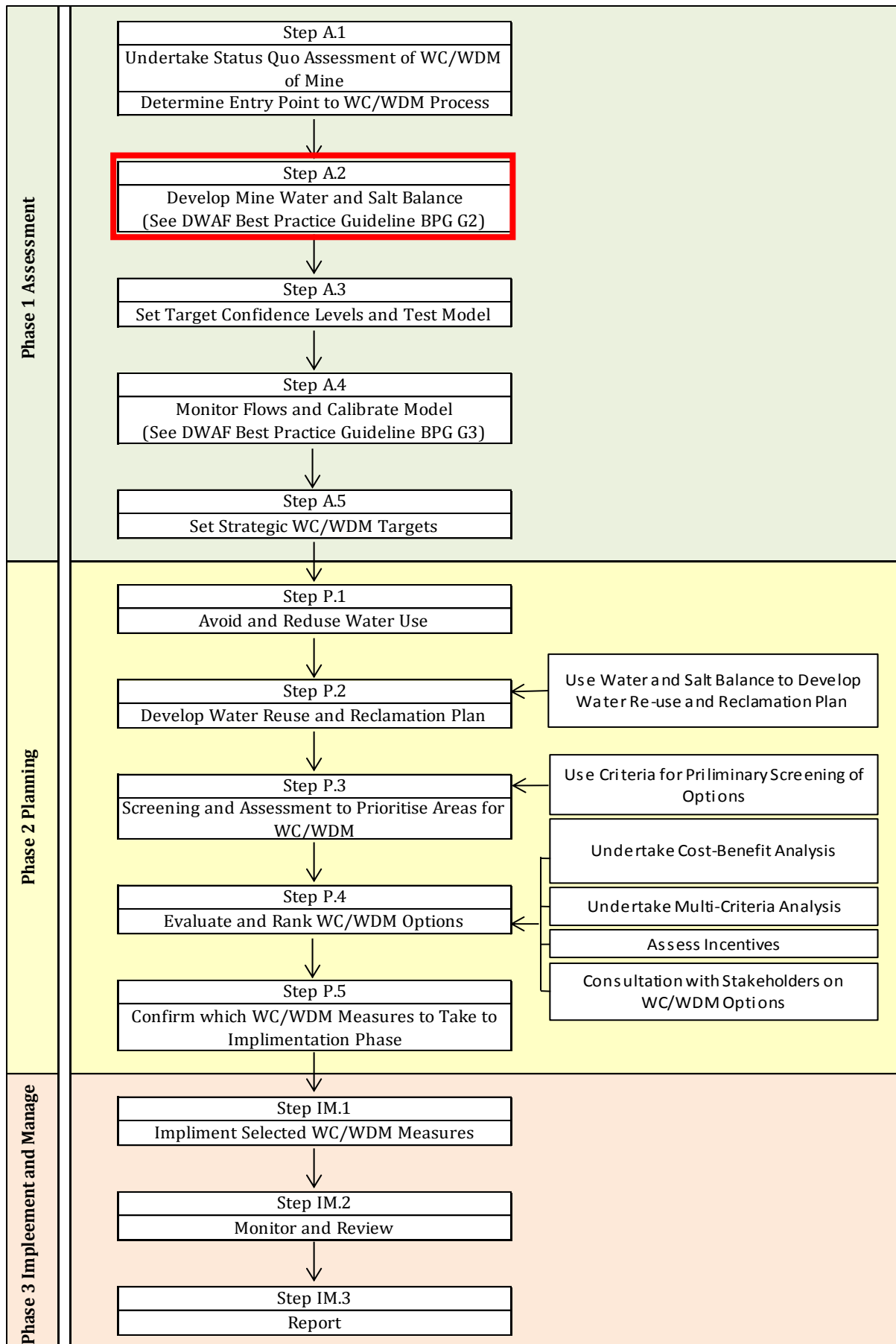


Figure 3-1: Detailed Steps in the WC/WDM Process (DWA, 2011)

### **3.2 THE SIGNIFICANCE AND PRINCIPLES OF AN ACCURATE MINE WATER BALANCE IN OPENCAST AND UNDERGROUND COAL MINES IN THE WITBANK COAL FIELD**

A water balance is one of the most important management tools available for managing mine water, and without an effective and accurate water balance it is not possible to conduct proper assessment, planning and implementation of water management at a mine.

With reference to the Best Practice Guideline G2: Water and Salt Balances (DWAF, 2006), the following **procedural principles** should be considered when developing a mine water balance:

- Clear objectives should be set for the water balance taking into consideration the current situation as well as the probable/desirable future situation.
- Large mines should be compartmentalised into smaller sections in order to manage the different sections separately.
- In order to accurately develop a water balance, the accuracy level for all of the flows should be considered down to an accuracy level of between 1% and 5% of the total flow. Taking into account measurement errors an accuracy of 5% to 10% is acceptable for a unit and 10% to 15% for the overall mine.
- Uniform formats and procedures should be used for all of the separate units to ensure effective correlation between units.
- The water balance should be regularly updated.
- The water balance system must be flexible enough to accommodate any changes to the mine water reticulation system.

### **3.3 SIGNIFICANCE OF A MINE WATER BALANCE IN MINE WATER MANAGEMENT IN THE WITBANK COAL FIELD**

Due to the hydrogeological and hydrological setting of the Witbank Coal Field, precipitation and groundwater will accumulate in the mine workings. The mine water needs to be re-used, stored or treated before it can be discharged into the water resources. The re-use of water alone is not sufficient and the water will need to be stored or treated post closure. Storage in water containment facilities such as dams and reservoirs is currently employed by a number of mines, but it is very expensive and will have to be rehabilitated post closure. Storage of water in mined out areas of the workings is a method that is investigated in terms of optimising the water management at a mine. The recharged water can either be stored in backfilled opencast pits or in underground mine voids.

Mine water balances are the most effective method to calculate the amount of water make into the mine and can be used to audit possible storage in rehabilitated mine workings.

### **3.4 CONCLUSION**

The role and significance of implementing a mine water balance as part of the water management process cannot emphasised enough. Although the implementation of mine water balances is very important in all mines, this dissertation will focus on the implementation thereof within the Witbank Coal Field. Misuse and contamination of the water resources cannot be tolerated and is against the law. Implementing accurate mine water balances is inevitable in water management.

In order to develop the most effective and accurate water balance, it is of utmost importance to understand the components needed to do a mine water balance. Chapter 4 sets out to investigate and conceptualise the components and input parameters of a mine water balance in typical opencast and underground workings in the Witbank Coal Field.

## **4. CONCEPTUALISING THE COMPONENTS OF A MINE WATER BALANCE IN OPENCAST AND UNDERGROUND WORKINGS IN THE WITBANK COAL FIELD**

### **4.1 INTRODUCTION**

The focus of this chapter is to conceptually distinguish between the components contributing to both the natural water recharge into the mine as well as water losses from the mine in either an opencast and underground mine in the Witbank Coal Field. This will further contribute to the specific input parameters that should be used in order to calculate the mine water balance accurately. Different data collection methods are investigated in order to quantify the parameters used to calculate the mine water balance.

A mine water balance is simply a calculation of the water makes and losses from different sources and sinks in mine workings (opencast or underground) over a specific period of time. The planning and development of the mine plays a very important role due to the specific hydrogeological and hydrological environments that exist in the mining area, as these conditions are the main factors influencing the amount of water make and losses into and from the mining environment. The development and layout of the mine has a significant influence on the input parameters that will be used for the water balance. Site specific data is also needed in order to get accurate mine plans in order to calculate areas of the sections of the water balance. It is very important understand the components and input parameters of a mine water balance in order to collect the most relevant and accurate data and information.

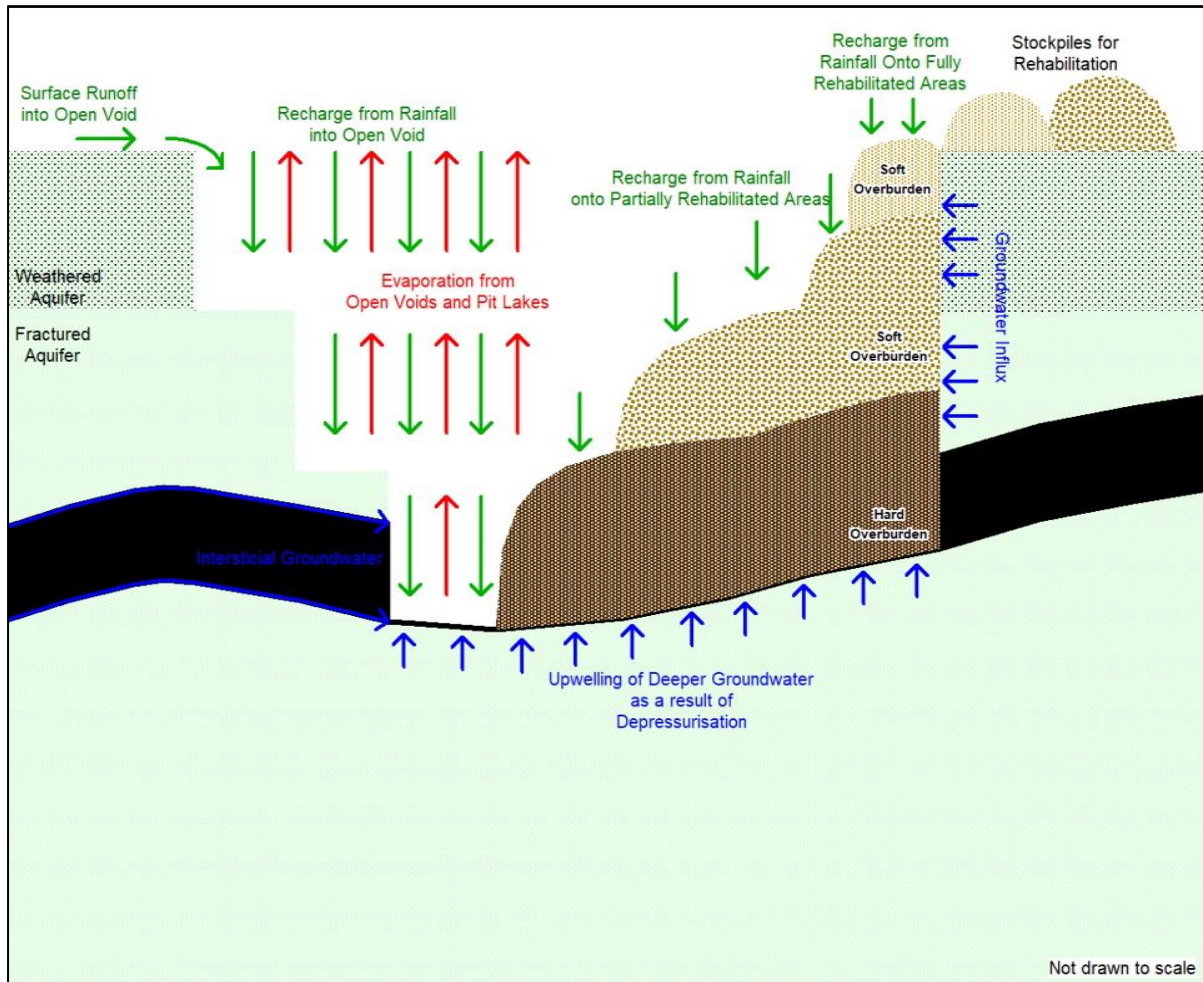
### **4.2 CONCEPTUAL UNDERSTANDING OF NATUAL WATER RECHARGE AT AN OPENCAST COAL MINE**

The main sources of inflows contributing to the natural water recharge into an opencast mine originates from **rainfall** and **groundwater**. Recharge from rainfall is sub-characterised by the area of the opencast mine into which it gets recharged (Hodgson et al., 1998). For the purpose of a working mine water balance, the recharge from rainfall and groundwater is characterised as follows:

- **Recharge from rainfall onto open void;**
- **Recharge from rainfall onto partially rehabilitated areas; and**
- **Recharge from rainfall onto fully rehabilitated areas;**
- **Groundwater influx from surrounding aquifers.**
- **Interstitial Groundwater.**

Evaporation from open voids and pit lakes and water lost with coal are the major contributing factors leading to water losses from an opencast mine.

The different sources of water recharge into and water losses from an opencast mine are conceptually illustrated in Figure 4-1 below.



**Figure 4-1: Conceptual Illustration of Parameters contributing to Water Recharge and Water Losses at an Opencast Mine**

#### 4.3 INPUT COMPONENTS OF A MINE WATER BALANCE AT AN OPENCAST MINE

In order to develop a mine water balance, it is critically important to define and quantify the components needed, to do it as accurately as possible. The mine water balance for an opencast mine is made up of two sections. The first section contains the recharge parameters and the second part contains the water losses. Evaporation takes place only when water accumulates in the opencast pit or in remaining voids after mining is complete. The components and parameters for a water balance at an opencast mine is summarized in Table 4-1 below. Each of the following three chapters (chapter 5, 6 and 7) further address the parameters that are needed to do the calculations for the respective components.

**Table 4-1: Components and Parameters of an Opencast Mine Water Balance**

Mining Schedule and Recharge Areas	Water recharge contributing parameters and components	Recharge From Rainfall	Groundwater Influx and Interstitial Groundwater
			Average Annual Rainfall Figures ( <i>mm/annum</i> ) Recharge percentages (%)
Mine Layouts and Mine Schedule Plans	Water losses contributing parameters and components	<b>Evaporation From Voids (Only if Full Rehabilitation have not taken place Post Closure)</b>	
			Average Annual Evaporation ( <i>mm/annum</i> )

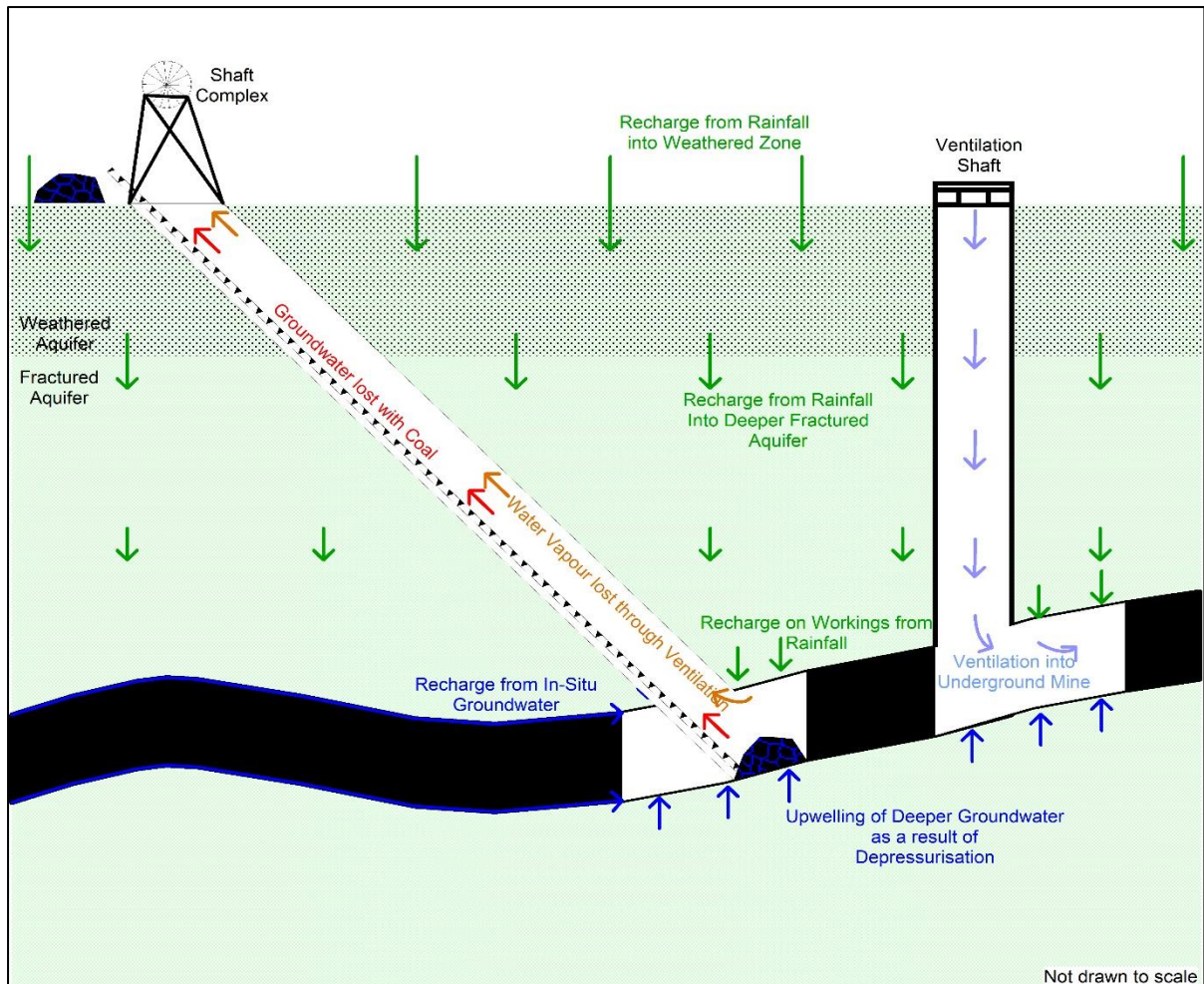
#### 4.4 CONCEPTUAL UNDERSTANDING OF NATURAL WATER RECHARGE AT AN UNDERGROUND COAL MINE

The main sources of inflows contributing to the water recharge into an underground mine are from **rainfall** and **groundwater**. Recharge from rainfall is a function of the mining method (Hodgson et al., 1998) and the depth of the underground workings (Lukas and Vermeulen, 2015). It is therefore important to get accurate mine plans in order to determine the depth and mining methods employed at the mine.

**Groundwater lost with coal**, and **water vapour lost through ventilation** is the only contributing parameters leading to water losses from an underground mine. The different sources of water recharge into and water losses from an underground mine can be conceptually illustrated in Figure 4-2 below.

#### 4.5 INPUT COMPONENTS OF A MINE WATER BALANCE AT AN UNDEGROUND MINE

The components and parameters for a water balance at an underground mine are summarized in Table 4-2 below. Each of the following three chapters (chapter 5, 6 and 7) further address the parameters that are needed to do the calculations for the respective components.



**Figure 4-2: Conceptual Illustration of Parameters contributing to Water Recharge and Water Losses at an Underground Mine**

**Table 4-2: Components and Parameters that contributes to Water Recharge into and Water Losses from an Underground Mine**

Mining Schedule and Recharge Areas		Recharge From Rainfall	Groundwater Influx and Interstitial Groundwater	Water vapour gained through ventilation
Mine Layouts and Mine Schedule Plans	Water recharge contributing parameters and components	Average Annual Rainfall Figures ( <i>mm/annum</i> ) Recharge percentages (%)	Aquifer Thickness ( <i>m</i> ) Hydraulic Conductivity ( <i>m<sup>2</sup>/day</i> ) Hydraulic Gradient Storativity (%) Removed Overburden ( <i>m<sup>3</sup></i> )	
	Water losses contributing parameters and components		Water vapour lost through ventilation	Groundwater lost with coal
			Airflow from mine through ventilation ( <i>m<sup>3</sup>/day</i> ) Humidity of the underground workings (%)	Total amount of coal removed from the mine ( <i>m<sup>3</sup></i> ) Total moisture present in the coal removed from the mine (%)

## **4.6 DEFINING THE PARAMETERS**

In order to understand the parameters that are quantified for the purpose of the mine water balance, a discussion about each of the parameters is of utmost importance. An explanation of the parameters and the reason for the use thereof is explained in this section. The definitions of the parameters were obtained from the second edition of the Groundwater Dictionary published on the DWA website.

### **4.6.1 Recharge from Rainfall**

Recharge from rainfall is the addition of water to the subsurface aquifer by means of downward percolation of precipitated water. The recharge from rainfall is the biggest natural contribution to water make into a mine.

### **4.6.2 Hydraulic Conductivity**

The hydraulic conductivity is the measure of ease with which water will pass through the subsurface material measured as meters per day (*m/day*). Hydraulic conductivity is used in order to calculate the rate of groundwater influx into the mine workings from adjacent aquifers.

### **4.6.3 Hydraulic Gradient**

The hydraulic gradient is the rate of change in the total hydraulic head per unit distance of flow in a given direction. The hydraulic gradient not only provides the direction of groundwater flow, but also plays a role on the specific yield of the aquifer. The specific yield is a measure of water released from an unconfined aquifer.

### **4.6.4 Effective Porosity**

The effective porosity or storativity of an aquifer is the volume of water an aquifer takes into storage or releases per unit surface area of the aquifer per unit change in head. Effective porosity is used in order to calculate the groundwater influx and interstitial groundwater in the surrounding of the mine section.

### **4.6.5 Porosity**

Porosity is the ratio of the volume of void space to the total volume of the rock or other materials such as backfill into rehabilitated opencast pits. Porosity is of critical importance when calculating the amount of available and taken up storage in the rehabilitated opencast pits.

#### **4.7 DATA COLLECTION METHODS**

The parameters that plays a role in the water make and loss need to be addressed as part of the conceptual model, and should be as accurately and site specific as possible. There must be sufficient level of confidence in the conceptual model before the water balance is calculated.

Data can be collected either by obtaining site specific or by using literature in order to quantify the necessary parameters used to develop a mine water balance.

In order to calculate the available storage for water during the operational and post closure phase in historic and rehabilitated mine workings, a storage capacity assessment is done. Accurate data collection for the storage capacity assessment and the mine water balance is crucial and surveyed mine plans and mining schedules needs to be obtained from the mine in order to accurately calculate available storage space in the mine. Accurately surveyed surface and mining floor and roof contours must also be obtained in order to calculate volumes in the mine workings.

For the calculation of available storage at a rehabilitated pit, the porosity of the backfilled material is needed in order to calculate the available storage within the pit. The porosity value can also be obtained from either literature or site specific measured data.

A literature study will be done (Chapter 5) to obtain generic data ranges for all the parameters contributing to water make and water losses in a typical mine setting in the Witbank Coal Field. Site specific parameters will also be obtained through a conceptual case study (Chapter 6) in order to get the most accurate and site specific values for the mine water balance parameters.

The highest and lowest values in the literature study ranges together with the site specific data will be compared by doing a sensitivity analysis (Chapter 7) on the data. The sensitivity analysis will include the individual water balance summaries as well as storage capacity assessments for each of the respective mine workings.

#### **4.8 CONCLUSION**

The understanding of the conceptual components of an opencast and underground mine is crucial in order to obtain the correct input measures that are used to calculate a mine water balance. Without having an understanding of the needed parameters, the data collection will be unsuccessful and insufficient for the calculation of an accurate mine water balance.

## **5. GENERIC PARAMETERS FOR POPULATING A MINE WATER BALANCE IN THE WITBANK COAL FIELD**

### **5.1 INTRODUCTION**

In order to gain an understanding of the generic inputs that is used to populate a mine water balance, a literature study is investigated on the regional setting of the Witbank Coal Field. The type of mining and hydrogeological environment within the area is investigated. The different input ranges is compared in order to quantify input parameters such as the recharge from rainfall, hydraulic conductivity, porosity and effective porosity within the different aquifers and mine workings. The values for the different parameters are primarily indicated as a range (high and low values).

Finally the value ranges for the different aquifers and mine workings are summarised in order to get usable data to quantify the mine water balance for both opencast and underground sections. The highest and lowest values within the ranges will form part of a mine water balance and storage capacity assessment sensitivity study in Chapter 7.

### **5.2 THE REGIONAL SETTING OF THE WITBANK COAL FIELD**

South Africa is divided into 19 coalfields based on the variations in various factors such as distribution and formation of the coal (Hancox and Götz, 2014). This dissertation will focus specifically on the Witbank Coal Field which is situated around the town of Emalahleni, Mpumalanga. Mining and exploration in the Witbank Coal Field goes back 125 years and is still active in most areas. It supplies more than 50% of South Africa's coal (Hancox, 2016). The Witbank Coal Field extents from Springs in the west to Belfast in the east (Figure 5-1) (Pone et al., 2007). The location of the Witbank Coal Field in relation to the Coalfields in the Mpumalanga Province of South Africa is portrayed in Figure 5-2.

The five major coal seams hosted by the Witbank Coal Field, (Pone et al., 2007) occurs in the Vryheid Formation of the Ecca Group of the Karoo Supergroup and formed in an epicontinental environment (Bell et al., 2001). The No.1 & No.2 were deposited in a braided stream fluvial setting under glacial and post glacial conditions. Coal seams No.2 & No.3 were deposited in fluvial deltaic settings in a variety of temperatures. The No.5 coal seam was deposited in lake settings (Glasspool, 2003). The No.2 & No.4 Coal Seams are the most economically viable seams across the area with sediments ranging from 20 m to 30 m in thickness separating the seams. Coal seams No.1 and No.5 are only mined locally (Hodgson et al., 1998).

Jurassic aged dolerite dykes and sills occur widely across the area. The area has stayed relatively tectonically stable throughout time. Although faults and other structures are rare in the area, fractures commonly occur in the sediments and coal in the area (Hodgson et al., 1998).

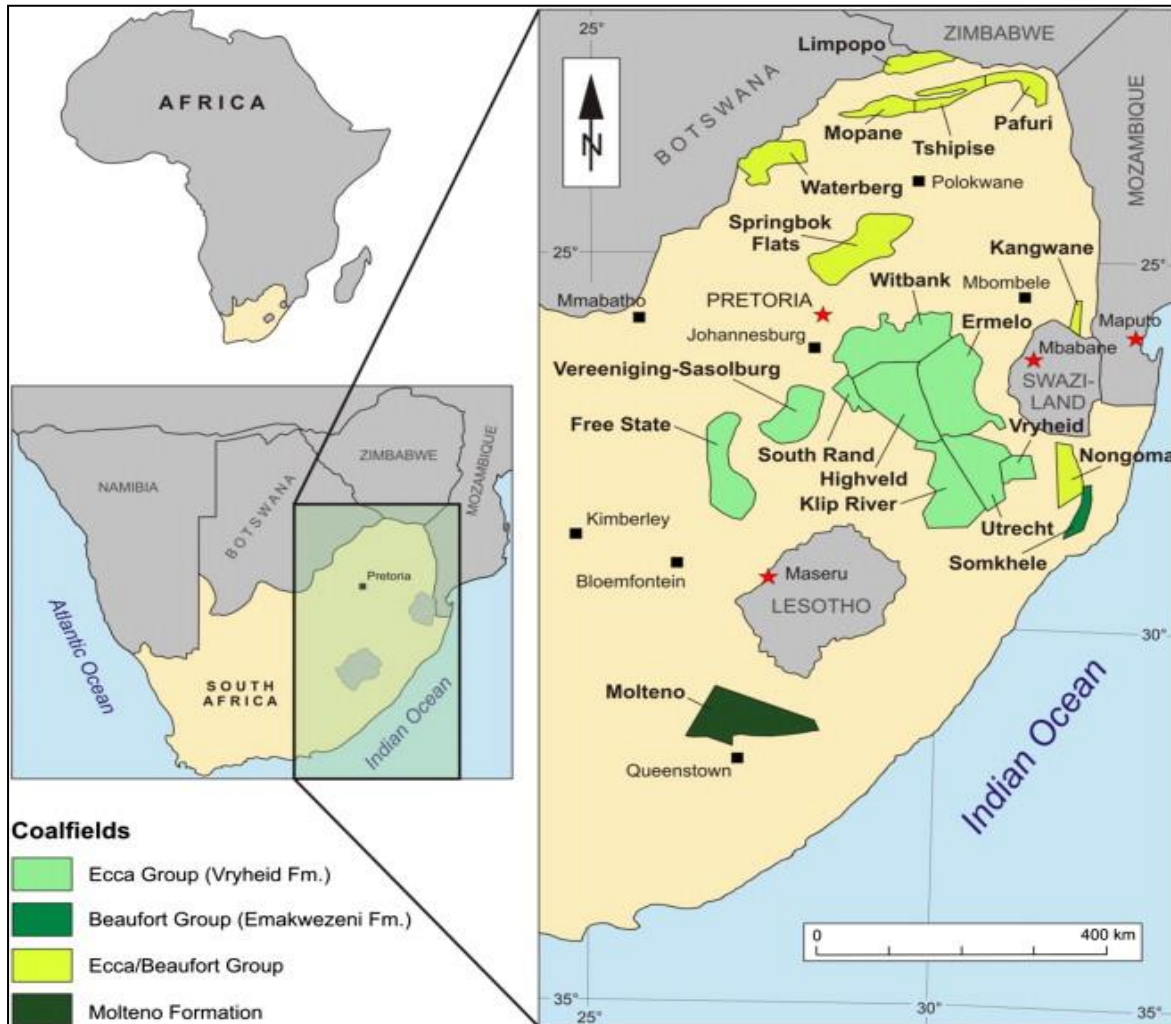


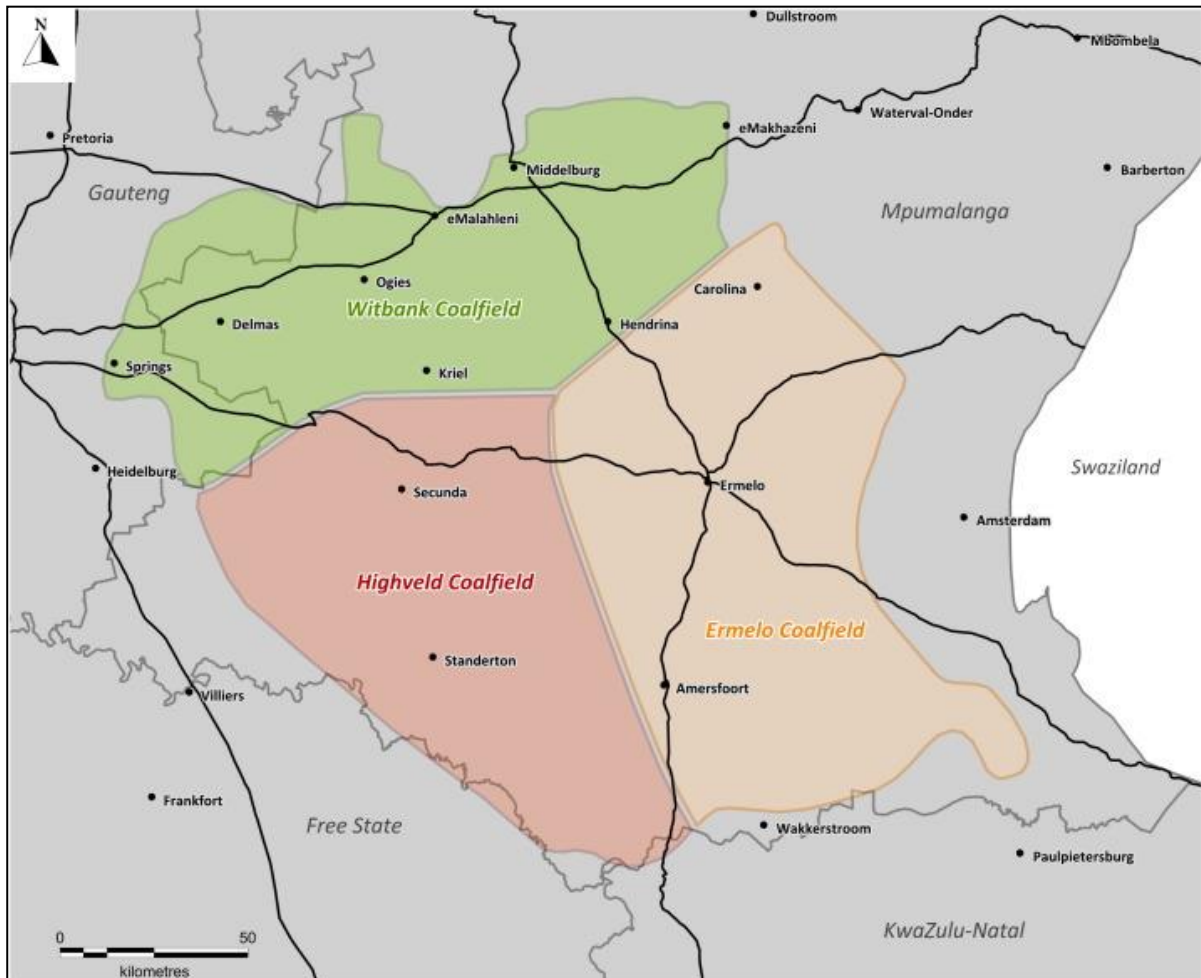
Figure 5-1: The 19 Coalfields of South Africa (Hancox and Götzt, 2014)

### 5.2.1 Regional Geohydrology of the Witbank Coal Field

Two types of aquifers are generally present within the Witbank Coal Field. These aquifers can be classified as the upper weathered and fractured Ecça aquifers within the Vryheid formation (Hodgson et al., 1998)

#### 5.2.1.1 Upper Weathered Aquifer

The upper weathered aquifer is recharged by means of rainfall. It is estimated that 1 – 3% of the annual recharge infiltrates and recharges the aquifer (Sami and Hughes, 1996). The weathering generally occurs to depths in the range of 5 - 12 m (Grobbelaar et al., 2004).



**Figure 5-2: Location of the Witbank Coalfield in Relation To the Other Coalfields in the Mpumalanga Province of South Africa (Huisamen and Wolkersdorfer, 2016)**

Water movement in the weathered zone aquifer is generally lateral and the aquifer typically follows the surface topography. Recharged rainwater infiltrates the weathered zone, and moves down to the impermeable shale from where it moves according to the slope of the sedimentary layer (Hodgson et al., 1998).

Around 60% of recharged water ends up in streams. The other 40% is either evapotranspired or drained into the fractured system (Sami and Hughes, 1996). All of the properties in the weathered zone aquifers are highly variable due to the fact that the different sedimentary rocks within the aquifer has a wide range of differences in grain size, from fine to coarse grained sandstone to very fine shale made up of clay (Hodgson et al., 1998).

#### 5.2.1.2 Fractured Aquifer

The fractured aquifer usually occurs directly below the weathered aquifer. Due to the well cemented and fresh sedimentary rock water flow is restricted to fractures and other structural voids inside the rocks (Grobbelaar et al., 2004). Competent rocks such as

sandstone and coal have very well developed structures and thus have higher yielding properties (Hodgson et al., 1998).

### **5.3 MINING METHODS USED IN THE WITBANK COAL FIELD**

Different types of mining methods are used in order to mine coal in the Witbank Coal Field. The typical types of surface and underground mining are discussed in the following sections.

#### **5.3.1 Surface Mining**

Surface mining is a type of mining where the ore beneath the surface is reached by removing all of the overburden that overlies the deposit.

##### **5.3.1.1 Opencast Mining**

Opencast or strip mining is done in areas where the ore is close enough to the surface to allow the overburden to be “stripped” away in order to expose the underlying ore. Rehabilitation is typically done concurrently, while a section is being stripped. The stripped overburden is used to backfill the mined out sections of the mine. The overburden is drilled and blasted in order to expose the ore which is mined out with excavators and draglines (DWAF, 2008). A typical section through an opencast mine is portrayed in Figure 5-3 below. The depths of mining in opencast operations range from 0 to 60 *m* below the surface (Grobbelaar et al., 2004).

#### **5.3.2 Underground Mining**

Underground mining is a type of mining used to extract ore from a seam or orebody that is too far below the surface to obtain with surface mining.

##### **5.3.2.1 Bord and Pillar Mining**

Bord and Pillar Mining is a type of underground mining method in which pillars of original bedrock are left in the underground section in order to support the pressures from the overlying strata. The openings and pillars are typically left at regular intervals which gives it a chessboard appearance from above (Horikawa and Guo, 2009). A typical section through a Bord and pillar is portrayed as Figure 5-4.

##### **5.3.2.2 Stooping**

Stooping is a type of mining where the remainder of the pillars in bord and pillar mining sections area either partially or completely extracted. (Grobbelaar et al., 2004).

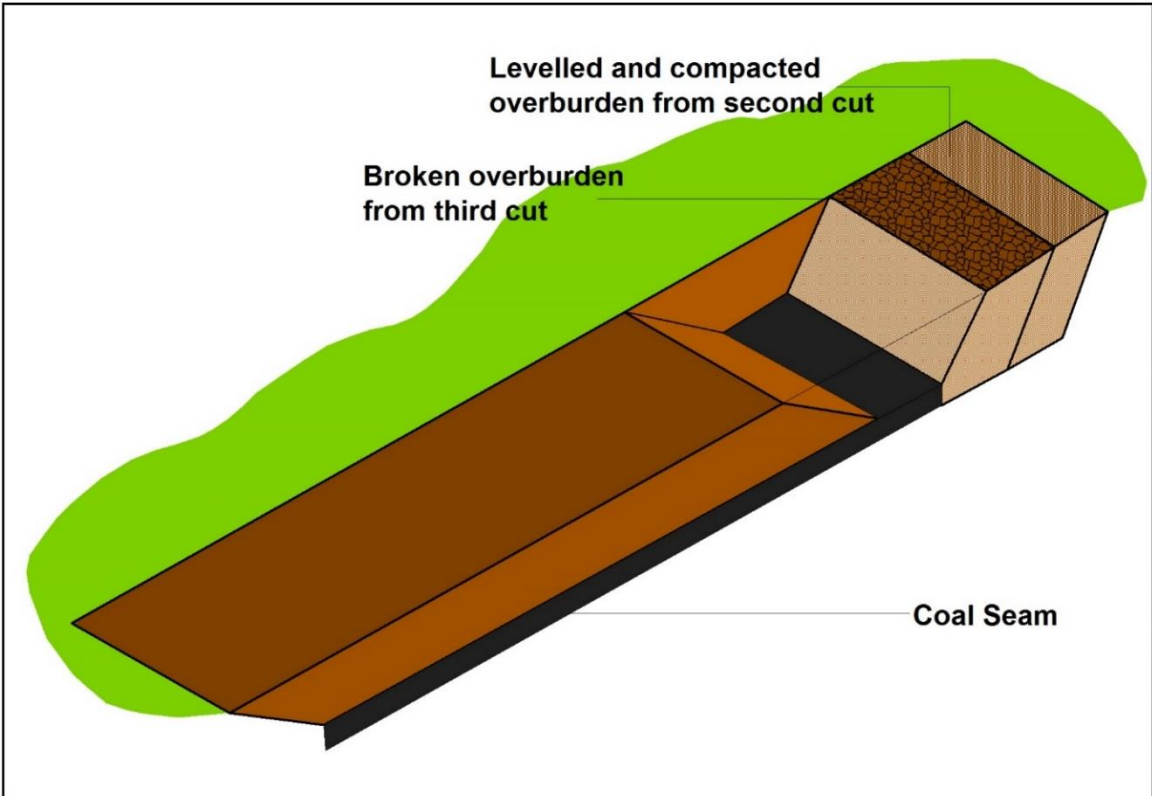


Figure 5-3: Section through an Opencast Section (DWAF, 2008)

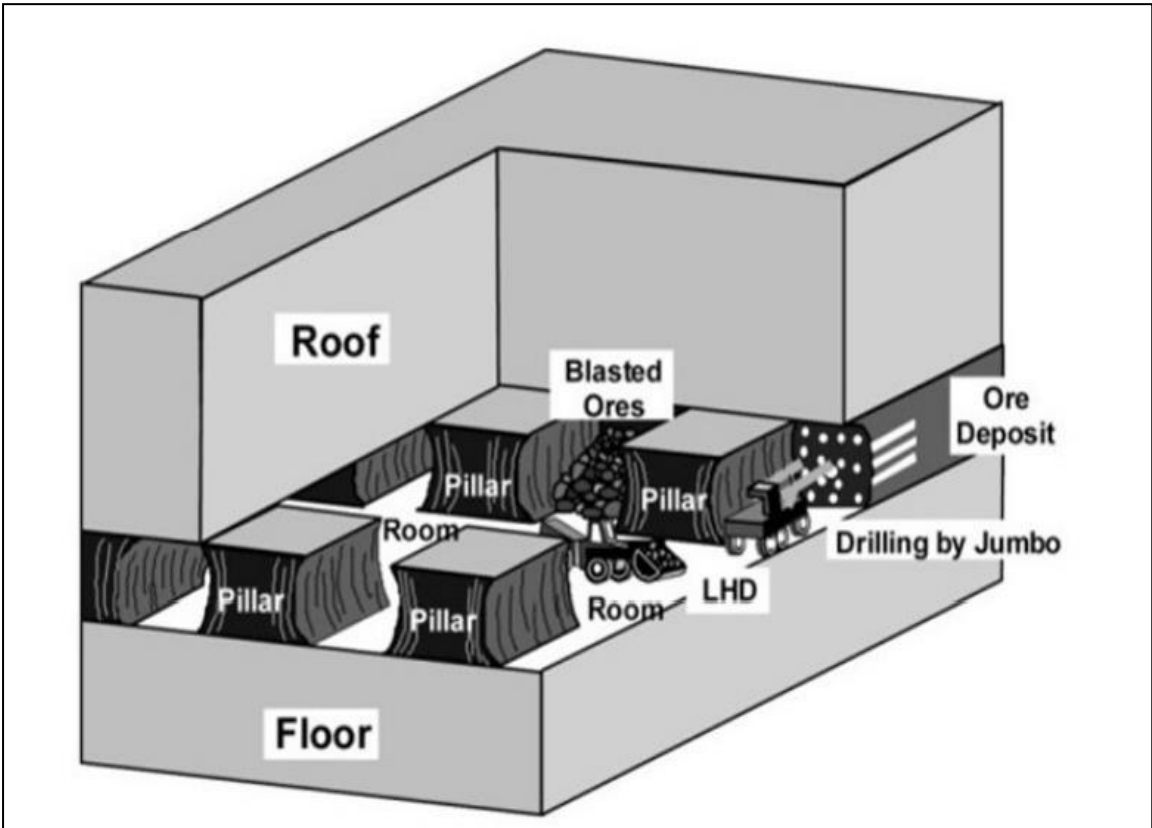


Figure 5-4: Typical Section of a Bord and Pillar Mine (Horikawa and Guo, 2009)

### 5.3.2.3 Longwall Mining

Longwall mining is a type of mining where long thin stretches of a coal seam is removed by machinery. With this method of mining, the coal is removed completely, and the entire roof over the mined out area is allowed to collapse into the void. Supports are moved according to the mining direction in the mining face in order for mining to commence.

The collapsing of the roof causes fracturing in the overlying strata and may cause subsidence of the surface above the mined out areas (McCarthy and Pretorius, 2009).

## **5.4 INPUT RANGES FOR A MINE WATER BALANCE**

Groundwater recharge is a function of different parameters including the amount of rainfall, hydraulic conductivity and porosity of the aquifer. The vegetation as-well as the rainfall intensity may also have an influence on the recharge. The influence by man-made infrastructure might be one of the biggest determining factors of the amount of recharge that will occur in a specific area (Aston, 2000).

### **5.4.1 Recharge from Rainfall into the Undisturbed Weathered Aquifer**

Recharge from rainfall into the weathered zone aquifer can vary a lot due to the characteristics of the different sediments that makes up the aquifer. The weathering depth in the Olifants River Catchments generally varies between 5 *m* and 12 *m* below the surface (Hodgson et al., 1998). According to (Vermeulen and Usher, 2006) the depth of weathering in some areas range between 5 *m* and 15 *m*.

Since the material may range from clay to very coarse sandstone, the recharge percentage from rainfall may vary between 1% and 15% (Hodgson et al., 1998).

In a study by Van Tonder and Kirchner (1990) it is suggested that the recharge within Karoo Aquifers varies between 2% and 5% of the annual rainfall in the area. The literature further suggested that the recharge in areas with thick soil cover have lower recharge values than that of hilly areas with thin soil cover. The reason for this is the high porosity and low permeability of the clay within the soil. The clay acts as a low to impermeable layer.

According to (Aston, 2000) the recharge in the Olifants River basin is estimated between 3% and 6% of the MAP. In different reports done by JMA Consulting (Pty) Ltd, the recharge is reported to range between 2% and 7% of the annual rainfall in the area (Müller and Turner, 2016; Turner, 2014; van der Berg, 2012, 2013, 2015; van der Berg and Turner, 2013).

### **5.4.2 Aquifer Hydraulics of the Weathered Zone Aquifer**

#### **5.4.2.1 Hydraulic Conductivity**

In a study by Annandale et al (2007) it was determined that the hydraulic conductivity in areas to the west of Witbank range between 0.01 *m/day* and 0.2 *m/day*.

In various studies done by JMA Consulting (Pty) Ltd in the Witbank Coalfields, 407 boreholes have been analysed. Statistical parameters have been calculated and are summarized in Table 5.1 below.

**Table 5-1: Summary of Calculated Aquifer Hydraulic Conductivity within the Witbank Coal Field**

Statistical Parameters	Value
No. of Boreholes	407
Minimum	0.0003
Maximum	4.89
Average	0.25
Harmonic Mean	0.01
Geometric Mean	0.04
25% Quartile	0.007
50% Quartile	0.031
75% Quartile	0.183

It was determined that the hydraulic conductivity in areas all over the Witbank Coal Field ranges between 0.0003 *m/day* and 4.89 *m/day*. The statistical parameters have been calculated in order to demonstrate that even though there is a very large range in values within the data, 75% of the values are below 0.183 *m/day*. The harmonic and geometric means is calculated in order to get a representative hydraulic conductivity of the area, as these types of means takes into consideration the outliers in the data series.

Due to the heterogeneities characteristic to weathered zone Karoo aquifers, statistical assessments indicate that the hydraulic conductivity distribution will be log-normally distributed and that the actual k-value for the aquifer is bound by the calculated geometric and the harmonic means (Müller and Turner, 2016). The combination of the harmonic and geometric means takes into account the outliers in the data.

The data by JMA Consulting was used to calculate a realistic bulk value of 0.022 *m/day* for the Witbank Coalfield.

#### 5.4.2.2 Porosity

Different studies have been done in order to determine an average porosity for the Ecca Group sediments. A publication by Huisamen and Wolkersdorfer (2016) suggests that the porosity of the Ecca Group shale in the Mpumalanga region range between 2% and 10%.

According to (Hodgson et al., 1998) the porosity ranges from 5 – 12% in the natural state of the Ecca Group sediments.

Porosity values between 7.3% and 11.6% have been confirmed in a study by van der Berg (2015).

#### 5.4.2.3 Effective Porosity

In a study by Annandale et al (2007) it is stated that the assumed effective porosity for the weathered aquifer in the Witbank/Highveld Coal Fields can be expected to be in the magnitude of  $10^{-1}$  (0.1% – 0.9%). The author states that the reason for the higher effective porosity in the weathered aquifer is due to the fact that almost all of the calcite which holds the grains has been leached. For this same reason the hydraulic conductivity is expected to be higher within the weathered matrix than in the fresh bedrock.

It is reported that the storativity of the weathered zone aquifer for an area in the Witbank coalfield ranges between 0.0365 (3.65%) and 0.058 (5.8%) (van der Berg, 2015).

#### **5.4.3 Recharge from rainfall into Undisturbed Fractured Aquifer**

The Ecca Group sediments are very well cemented and the main water movement is along sedimentary structures such as fractures and joints or along contacts between the coal seams and different sedimentary layers (Hodgson et al., 1998).

Around 40% of the rain water recharged into the weathered aquifer ends up as part of the fractured aquifer in the shale and sandstones below the weathered zone. It is suggested that around 60% of the recharged water in the fractured aquifers moves along the lateral, topographically parallel and impermeable shale layers below the weathered aquifers and ends up in rivers springs in lower topographical regions as well as at areas where the flow is obstructed by dykes and paleo topographical highs in the rock (Hodgson et al., 1998).

In a different study by (Sami and Hughes, 1996) it is suggested that the recharge values for the sedimentary fractured aquifer are generally between 1 and 3% of the Mean Annual Precipitation (MAP).

#### **5.4.4 Aquifer Dynamics of the Fractured Aquifer**

##### 5.4.4.1 Hydraulic Conductivity

The hydraulic conductivity for the fractured aquifers in the Vryheid Formation is generally very low and this aquifer is mainly recharged directly from the shallow weathered aquifer (Sami and Hughes, 1996)

In a study done by JMA Consulting (Pty) Ltd on an area within the Witbank Coal Field a hydraulic conductivity value of 0.004 *m/day* have been calculated and used (van der Berg, 2015)

In a Hydrogeological Study done by Delta H Consulting the hydraulic conductivity for the deeper aquifers ranges between 0.001 *m/day* and 0.007 *m/day* (Holland and Witthüser, 2016)

#### 5.4.4.2 Porosity

In a study done by JMA Consulting (Pty) Ltd on the lithology of the deeper fractured aquifer, porosity values between 4.2% and 5.5% have been reported (van der Berg, 2015).

#### 5.4.4.3 Effective Porosity

An effective porosity value of 0.1% has been assigned to the fractured aquifer within the Witbank/Highveld Coalfields by scrutinizing pump test data (Hodgson et al., 1998), (Annandale et al., 2007). The suggested reason for the relatively low storativity value is due to the fact that within the fractured aquifer, only a small portion of the pores and fractures partake in the water flow within the aquifer.

It is reported that the storativity for the deeper fractured aquifer for a site in the Witbank coalfield ranges between 0.0043 (0.43%) and 0.0055 (0.55%) (van der Berg, 2015).

#### 5.4.5 **Recharge from Rainfall into Opencast Mines**

In a study done by Vermeulen and Usher (2006) on the recharge into South African Collieries, a recharge value of 14 – 20% was obtained for rehabilitated opencast mines.

Studies by Hodgson et al (1998) have been done and various opencast collieries in the Olifants River Catchment have been observed in order to estimate an average recharge percentage of rainfall from different contributing sources towards opencast mining. These estimations are summarized in Table 5-2 below.

**Table 5-2: Recharge from Rainfall for Opencast Mining (Hodgson et al., 1998)**

<b>Contributing Sources</b>	<b>Average Values</b>
Rain onto ramps and voids	70% of rainfall
Rain onto un-rehabilitated spoils (run-off and seepage)	60% of rainfall
Rain onto levelled spoils (run-off)	5% of rainfall
Rain onto levelled spoils (seepage)	20% of rainfall
Rain onto rehabilitated spoils (run-off)	10% of rainfall
Rain onto rehabilitated spoils (seepage)	8% of rainfall
Surface run-off from pit surroundings into pits	6% of total pit water
Groundwater seepage	10% of total pit water

#### Voids and Ramps

A large part of the water accumulates into localized depressions from where it evaporates. The topography and the decant position may also have a great influence on the recharge from ramps and voids. In cases where some of the ramps and voids are topographically situated above the decant elevation these ramps and voids may stay dry even after the opencast pit has been closed up to the decant elevation. The recharge percentage through ramps and voids are thus a function of the slope of the opencast pit floor and the degree in which these structures are filled with water. Standing water may have a positive outcome on the water balance as the evaporation potential exceeds the rainfall in South Africa, but in contrast will have a negative effect on the quality of the water.

#### Un-rehabilitated Spoil Heaps

The recharge potential is very high for the spoil heaps and may contribute a very large amount to the recharge if the concurrent rehabilitation is not done efficiently. From a water management point of view, (Hodgson et al., 1998) suggests that the rehabilitation should not be more than two cuts behind the operational cut.

#### Levelled Spoils

It is very likely that surface runoff may cause erosion of levelled spoils. These erosion channels create an uncontrolled recharge into the pit. The levelled spoils may become less permeable with time as the argillaceous material is decomposed and the channels are silted up. The hydraulic conductivity through these spoils may depend on the amount of compaction, slopes, composition of the spoils and age.

#### Rehabilitated Spoils

In the event where the spoils have been covered with topsoil and vegetated, the recharge is highly variable and depends on many different factors. In some cases, the topsoil has been eroded and therefore the spoils are once again exposed. The exact methods and types of vegetation differ from mine to mine.

#### Surface run-off from Pit Surroundings into Pits

The run-off from surrounding areas can be effectively managed by diverting the water away from the pits by means of cut-off trenches.

#### Groundwater Seepage

Seepage into the opencast pits is mainly from the shallow weathered zone which is recharged by rainfall. The other seepages are usually very small due to the low yielding Ecca rocks. The seepage occurs at the bottom of the weathered zone, at the coal seams

themselves and also from fractures in the Eccra Rocks. The groundwater seepage has a very small effect on the total water balance as it contributes a negligibly small amount of the total water recharge.

#### **5.4.6 Groundwater Flow and Storage Properties for Rehabilitated Opencast Workings**

##### **5.4.6.1 Hydraulic Conductivity**

The backfill material used during rehabilitation of the opencast voids is highly heterogeneous and the hydraulic conductivity will vary greatly. Poorly sorted sediments within the backfilled opencast pits will greatly increase the hydraulic conductivity. Smaller sediments within the pore spaces will decrease the ease of water flow and therefore the hydraulic conductivity will be lower. It is also stated that the increase in hydraulic conductivity will decrease the filling rate of the rehabilitated pits (Du Plessis, 2010).

##### **5.4.6.2 Porosity**

The nature of the material significantly changes after the rock have been removed by mining operations and replaced again during rehabilitation. The porosity of the backfill material may be in the range of 20% to 30%. A porosity of 26% is generally used as a bulking factor by the coal mining industry to determine the porosity of post rehabilitated backfill material (Hodgson et al., 1998).

Sorting of the backfill material plays a major role in the porosity of the backfilled void. Factors such as size and shape of the material may also increase or decrease the porosity. In the event that the pore spaces are to be filled with smaller sediments, porosity will decrease.

It is further suggested that since the matrix of the fresh bedrock has practically no effective porosity, the bulking factor may be used in order to measure the total porosity of the spoil. Measurements and calculations were further done by Hodgson et al (1998) which determined a much lower drainage porosity than the total porosity of the spoil.

##### **5.4.6.3 Effective Porosity**

Effective porosities of the spoils have been calculated to be between 5% and 10% which is usually due to the finer material in the spoils with a usual high clay content (Du Plessis, 2010) (Hodgson et al., 1998)

#### **5.4.7 Recharge from Rainfall into Underground Mines**

Case studies have been investigated by Vermeulen and Usher (2006) at 5 different collieries in Mpumalanga in order to calculate a recharge value for the different types of underground

mining methods which are used in the Coal deposits of South Africa. The results of the findings are summarized as Table 5-3 below.

**Table 5-3: Recharge Influx from Rainfall into underground Collieries (Vermeulen and Usher, 2006)**

Underground Mining Method		Recharge Percentage of Rainfall
Shallow Bord and Pillar Mining		6.0 – 9.0%
Deep Bord and Pillar Mining		3.6 – 4.2%
Stooping	Partial Extraction	5.0 – 12.0%
	Total Extraction	>15.0%
Longwall Mining		6.0 – 15%

Recharge into bord and pillar mining as a function of depth have been given by Hodgson et al (1998) and was further illustrated by Lukas and Vermeulen (2015). The recharge values are summarized as Table 5-4 below.

**Table 5-4: Bord and Pillar Recharge versus Depth of Mining (Lukas and Vermeulen, 2015)**

Depth of Mining (m)	Recharge Percentage of Annual Rainfall
10	3.0 – 10.0
20	2.5 – 5.0
30	2.0 – 3.0
40	1.5 – 2.0
>60	1.0 – 1.5

#### **5.4.8 Groundwater Flow and Storage Properties for Underground Workings**

##### **5.4.8.1 Hydraulic Conductivity**

The hydraulic conductivity of the underground workings is much higher than that of the surrounding aquifers. The water will follow the path with the least resistance and therefore flow through the underground workings if connected (Lukas, 2012).

##### **5.4.8.2 Porosity**

The porosity value that can be defined for an underground mine depends on the type of mining and secondly on the porosity of the surrounding host rock. With bord and pillar mining, between 30% and 50% of the original rock is left behind in the underground workings for stability reasons. Therefore a porosity of between 50% and 70% can be expected with bord and pillar underground mining (Lukas, 2012).

## 5.5 USING THE GENERIC PARAMETERS TO POPULATE THE WATER BALANCE

The hydraulic parameters from the weathered and fractured aquifers as well as from the opencast and underground workings are summarized in the Table 5-5 below. Due to the size and variation within the Vryheid formation and the Witbank coalfields, ranges are given rather than average values.

**Table 5-5: Summary of the Hydraulic Parameters in the Weathered & Fractured Aquifers and the Opencast & Underground Workings**

Aquifer Type/Mining Operation	Parameter	Range
Weathered Aquifer	Recharge from Rainfall	2 – 7%
	Effective Porosity (Storativity)	~1 – 10%
	Porosity	7 – 12%
	Hydraulic Conductivity	0.01 – 0.4 <i>m/day</i>
Fractured Aquifer	Recharge from Rainfall	1 – 3.5%
	Effective Porosity (Storativity)	~0.1 – 0.9%
	Porosity	4.2 – 5.5%
	Hydraulic Conductivity	0.001 – 0.007 <i>m/day</i>
Partially Rehabilitated Opencast	Recharge	65 – 75%
Fully Rehabilitated Opencast	Recharge	14 – 25%
	Porosity	20 – 30%
Bord & Pillar Underground Workings	Recharge	1 – 10%

The quantified parameter ranges tabulated in Table 5-5 above are used as part of the sensitivity analysis of the mine water balance as well as for the storage capacity assessment in Chapter 7. The ranged values are used in order to create a high and low water make scenario for the mine water balance and storage capacity assessment.

In terms of the third scenario for the sensitivity analysis, a conceptual case study is assessed in Chapter 6.

## **6. SITE SPECIFIC PARAMETERS FOR POPULATING A MINE WATER BALANCE**

### **6.1 INTRODUCTION**

After the gathering of generic data ranges for two of the three scenarios for the sensitivity analysis, a third scenario needs to be quantified. The third scenario will be quantified by means of obtaining site specific parameters. A hypothetical mine site within the Witbank Coal Field was created for the purpose of this dissertation. The site specific data will not only be used for the purpose of the mine water balance, but also for the optimised management of mine water during the operational phase.

Firstly it is important to illustrate the details about the mining infrastructure, such as the surveyed layout plans of the opencast and underground sections, surveyed information of both the mining horizon and the surface topography. The layouts and survey information will be used to create accurate storage capacity assessments for all of the mine workings. The timeline is also obtained in order to better optimise the timeframe of water storage in the different mine workings.

The site specific hydrological and geohydrological conditions of the site is also investigated in order to get information about the long term rainfall figures as well as to get a better understanding of the types of aquifers and the dynamics that will play a role on the mine water balance.

The aquifer matrix description is very important, due to the heterogeneity between the different layers of the aquifers, and information about the magnitude of the aquifers and the extent thereof is investigated. This is important to understand before the water balance can be done so that the parameters of the mine water balance are correctly quantified.

The site specific parameters is further quantified by investigating the site specific aquifer hydraulics (borehole yields, hydraulic conductivity, transmissivity, storativity and porosity) and aquifer dynamics (Recharge from rainfall and natural groundwater levels).

A detailed conceptual model is developed in terms of the mine water balance with reference to the information that is gathered from the conceptual case study. The conceptual model displays the factors that have an influence on the possible outcome of the mine water

balance. The conceptual model is used to assure that all of the relevant parameters are used in the calculation of the mine water balance.

## **6.2 MINING INFRASTRUCTURE, LAYOUT & DESCRIPTION**

For the purpose of the conceptual case study, a “hypothetical site” was created by using realistic parameters. The mining operations within the mining right area comprise of both opencast and underground workings. The opencast and underground workings are delineated in Figure 6-1.

### **6.2.1 Underground Mine Workings**

Two Underground mine workings exist within the mining right boundary, namely the:

- Block Underground Workings. (Operational)
- Block B Underground Workings. (Decommissioned)

#### 6.2.1.1 Block A Underground Workings

The Block A Underground Workings are situated in the southern part of the mining right area and are accessed by means of a shaft in the northern extent of the workings. The workings cover an area of 1 080 *ha*. The average mining height within the Block A underground workings is 3.5 *m*. Approximately 65% of the coal is extracted from the underground workings. The remaining 35% is left as pillars. Once the mining is complete, the shaft will be sealed off (no ventilation post closure) and the underground workings will be left to be flooded. The theoretical decant elevation is at 1568 *mamsl*. A layout plan of Block A is illustrated in Figure 6-2.

#### 6.2.1.2 Block B Underground workings

The Block B underground workings are situated within the south-eastern extent of the mining right boundary and were accessed via the shaft in the northern part of Block B. The workings cover an area of 215 *ha*. The average mining height within the underground workings is 3.5 *m*. Approximately 65% of the coal was extracted from the underground workings. The remaining 35% was left as pillars. The shaft has been sealed off (no ventilation) and the workings have been left to flood. The theoretical decant elevation is at 1588 *mamsl*. A layout plan of Block B is illustrated in Figure 6-3.

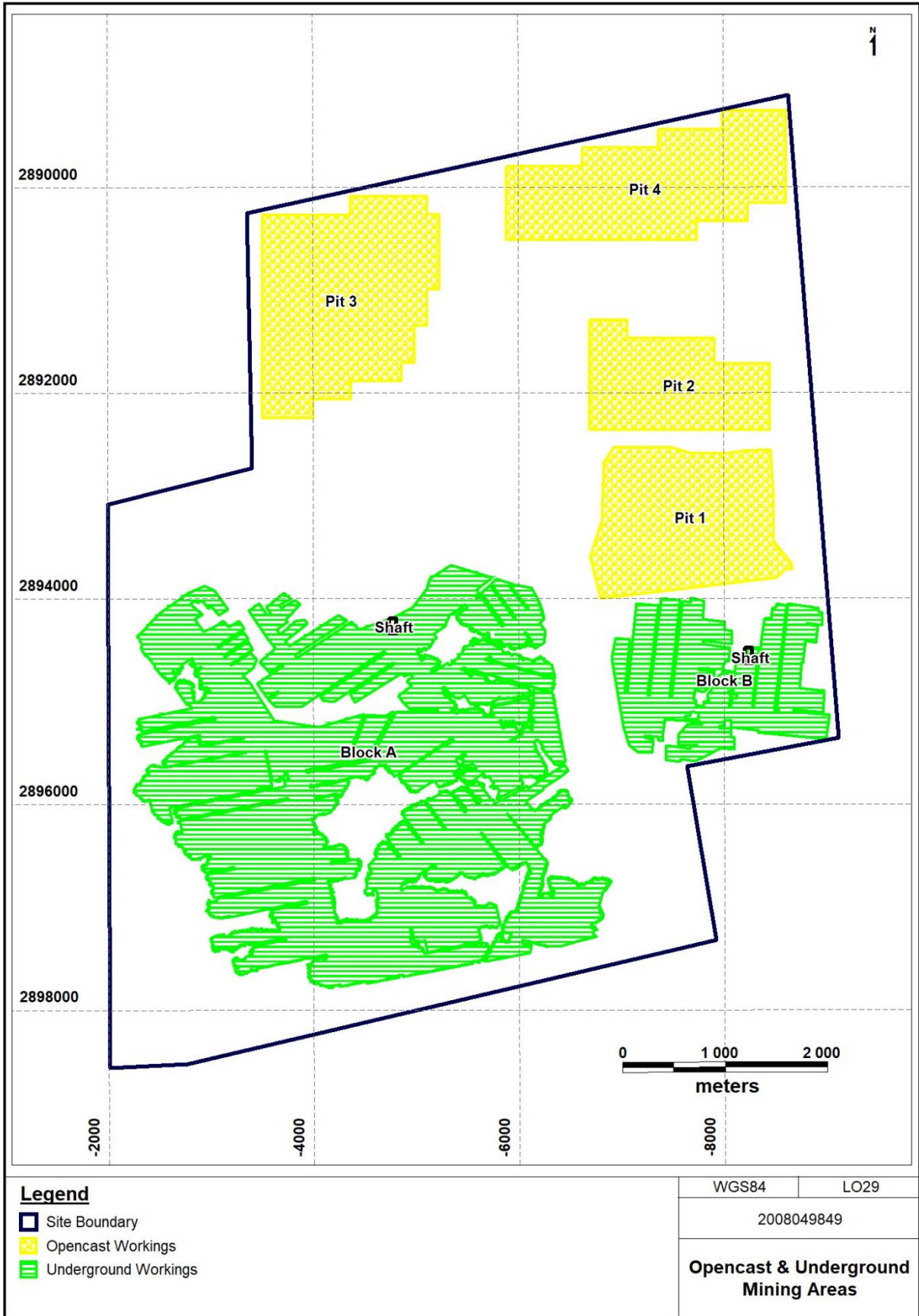


Figure 6-1: Delineated Mine Workings

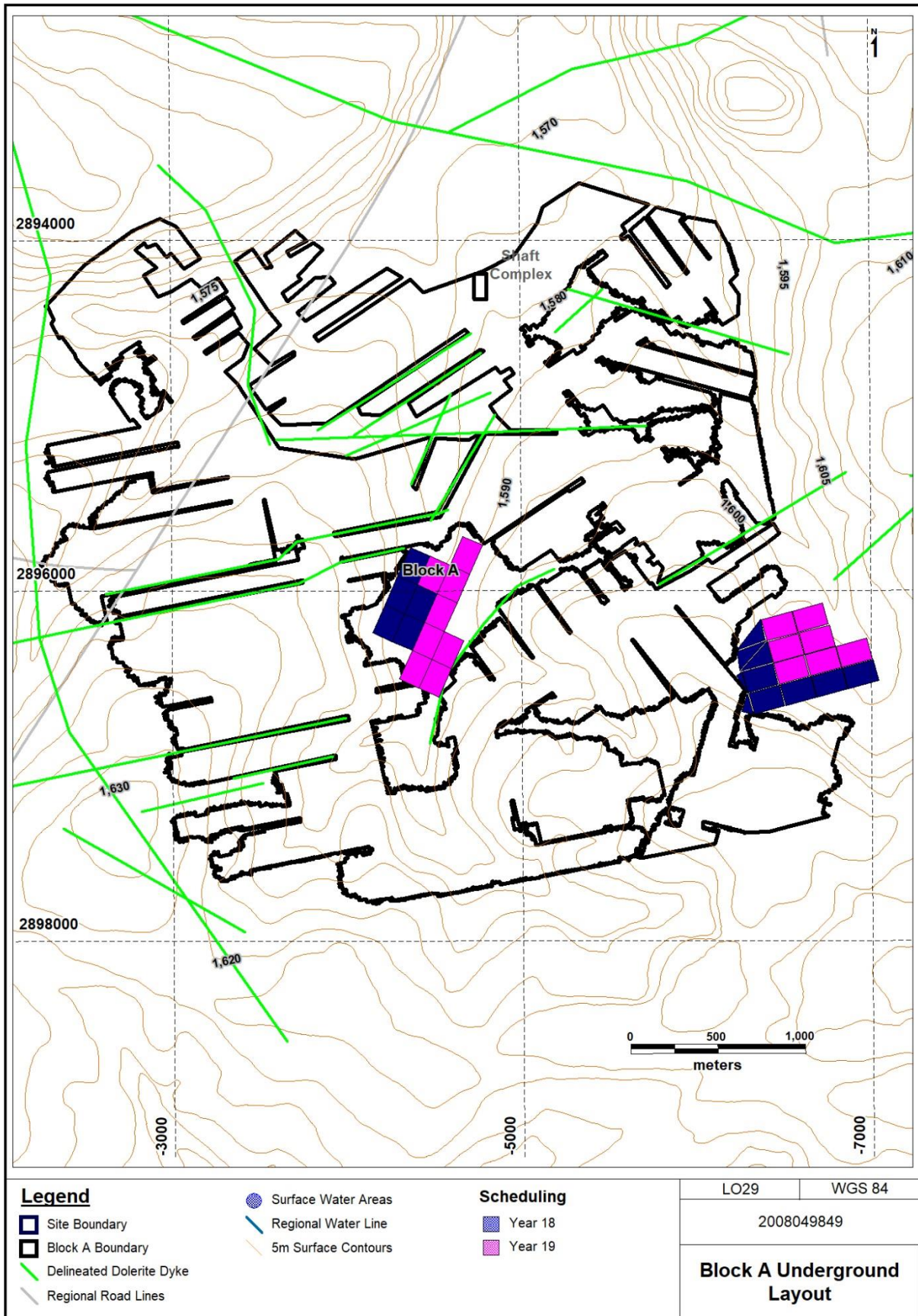


Figure 6-2: Block A Underground Workings Layout Plan

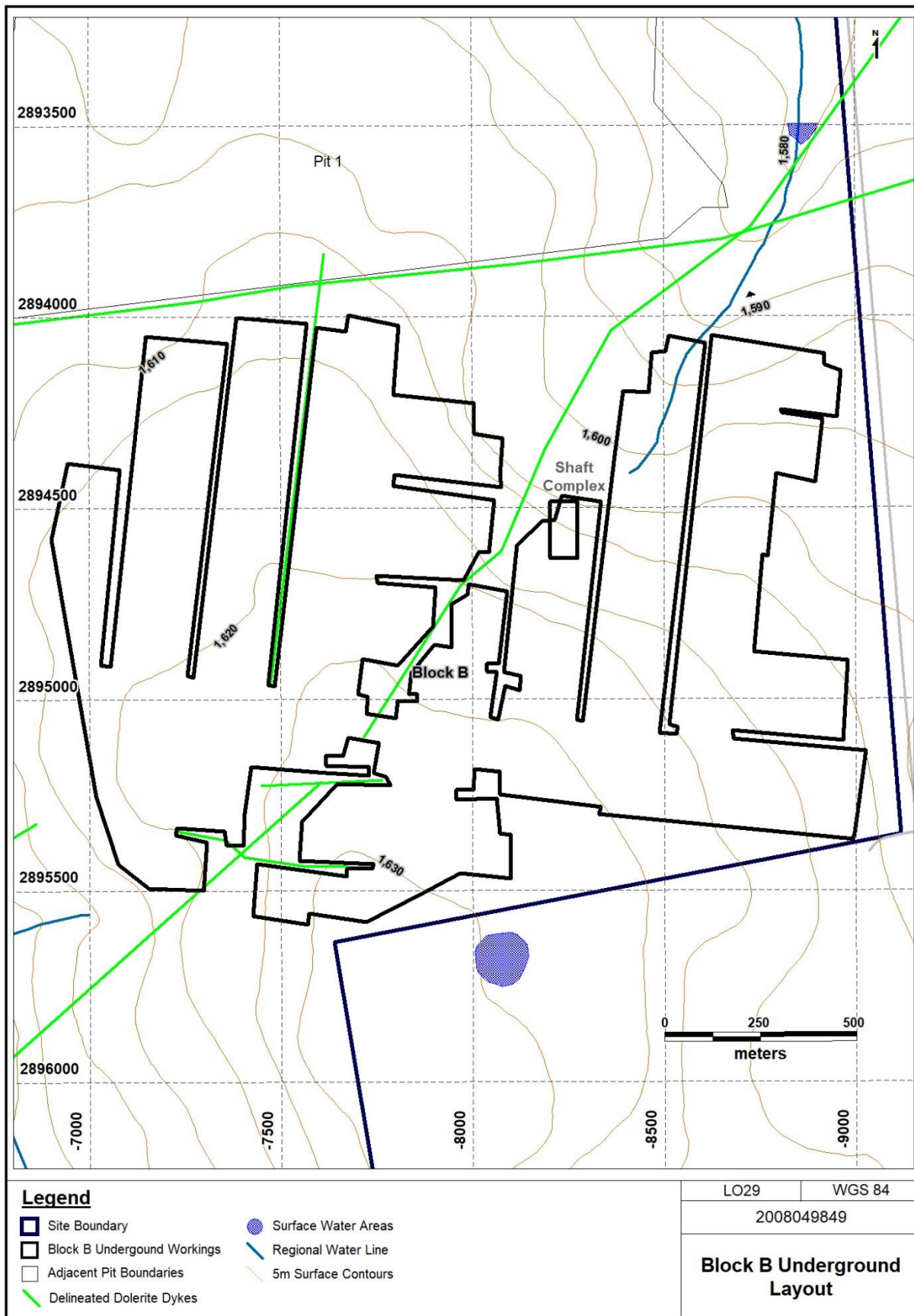


Figure 6-3: Block B Underground Layout Plan

## 6.2.2 Opencast Mine Workings

There are currently 4 opencast mining sections within the mining right boundary. These opencast pits are:

- Pit 1. (Rehabilitated)
- Pit 2. (Operational)
- Pit 3. (Proposed)
- Pit 4. (Proposed)

### 6.2.2.1 Pit 1

Pit 1 has been fully rehabilitated and re-vegetated. The pit covers a total surface area of 230 *ha*. The theoretical decant elevation is at 1572 *mamsl*. A layout plan of Pit 1 is illustrated in Figure 6-4.

### 6.2.2.2 Pit 2

Pit 2 is currently operational and mining commenced in year 14. A total of 66% of the pit has already been mined out. It is anticipated that the mining operations at Pit 2 will be complete by the end of year 19. The pit covers a total surface area of 149 *ha*.

Full rehabilitation will commence concurrently, therefore no losses due to evaporation will occur during the operational, decommissioning or post closure phases at Pit 2. The theoretical decant elevation is at 1553 *mamsl*. A layout plan of Pit 2 is illustrated in Figure 6-5.

### 6.2.2.3 Pit 3

Pit 3 is a proposed pit and mining will commence in year 18. It is anticipated that the mining operations at Pit 3 has a Life of mine (LOM) of 8 years and the operations will be completed by the end of year 25. The pit covers a total surface area of 297 *ha*.

Full rehabilitation will commence concurrently and rehabilitation will be complete by the end of year 27. The area will be re-vegetated and free draining (Porous material allowing free recharge into the sub-surface). Both dragline, and truck and shovel operations will be used in order to remove the overburden from the pit. The theoretical decant elevation is at 1559 *mamsl*. A layout plan of Pit 3 is illustrated in Figure 6-6.

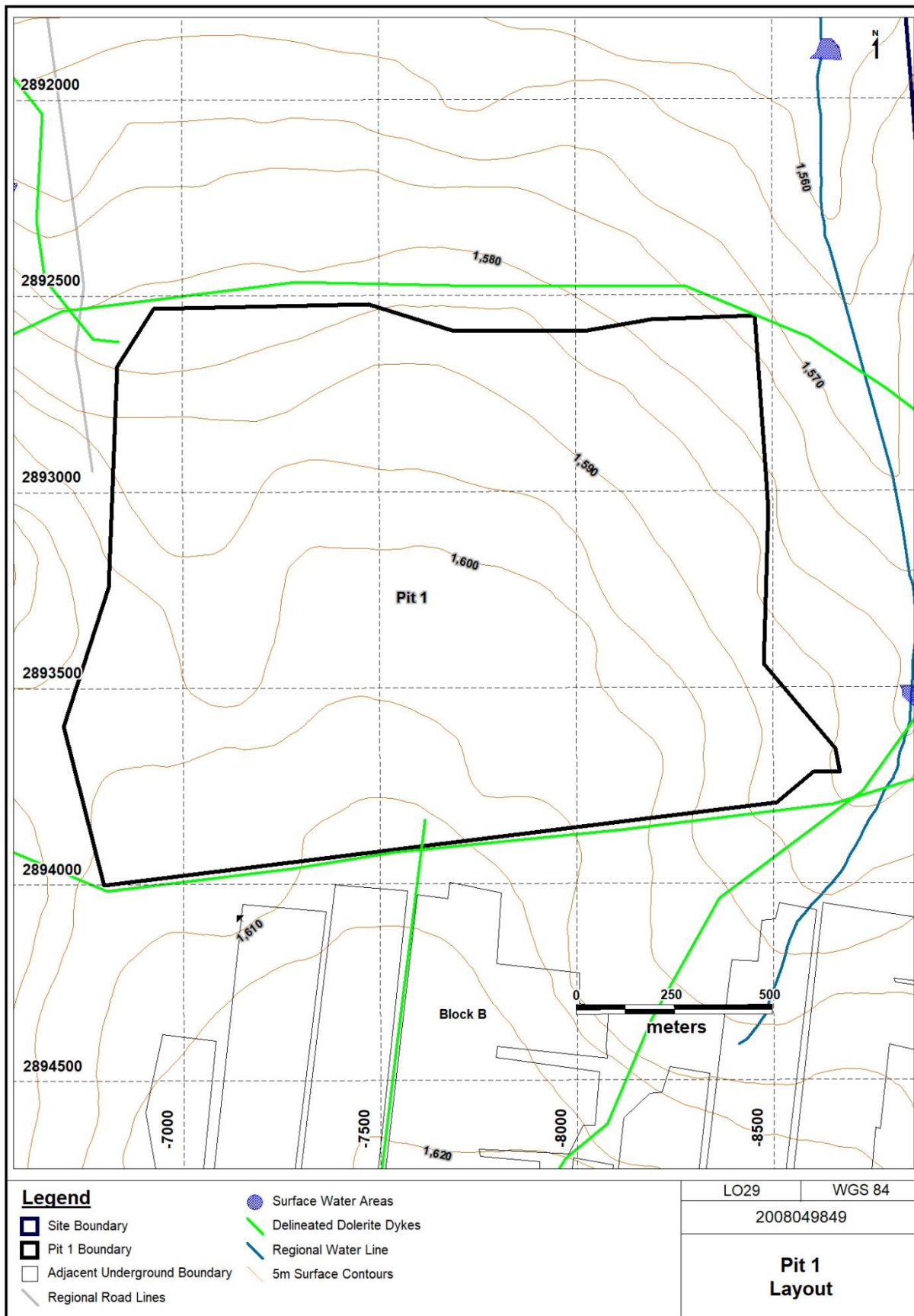


Figure 6-4: Pit 1 Opencast Workings Layout Plan

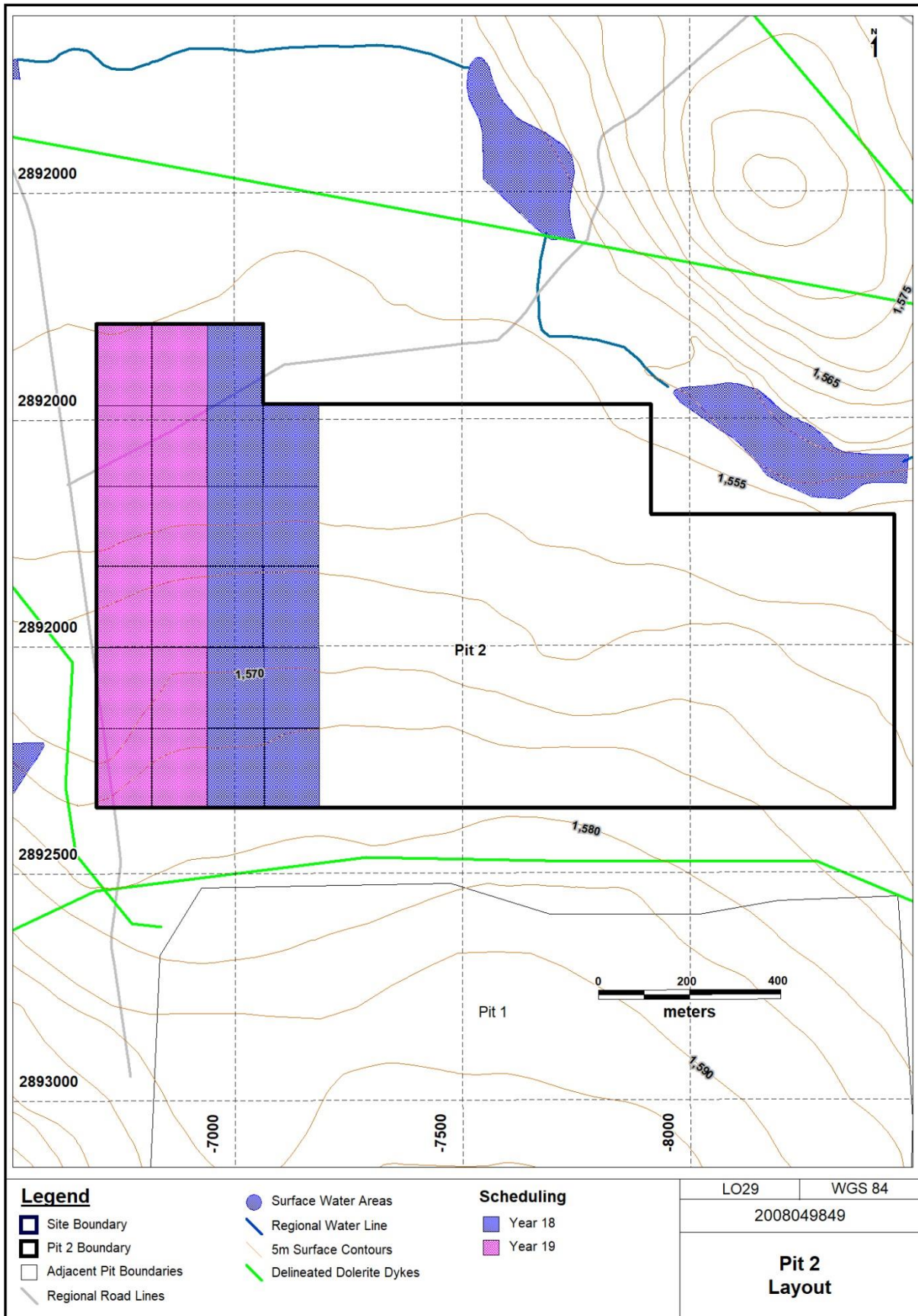


Figure 6-5: Pit 2 Opencast Workings Layout Plan

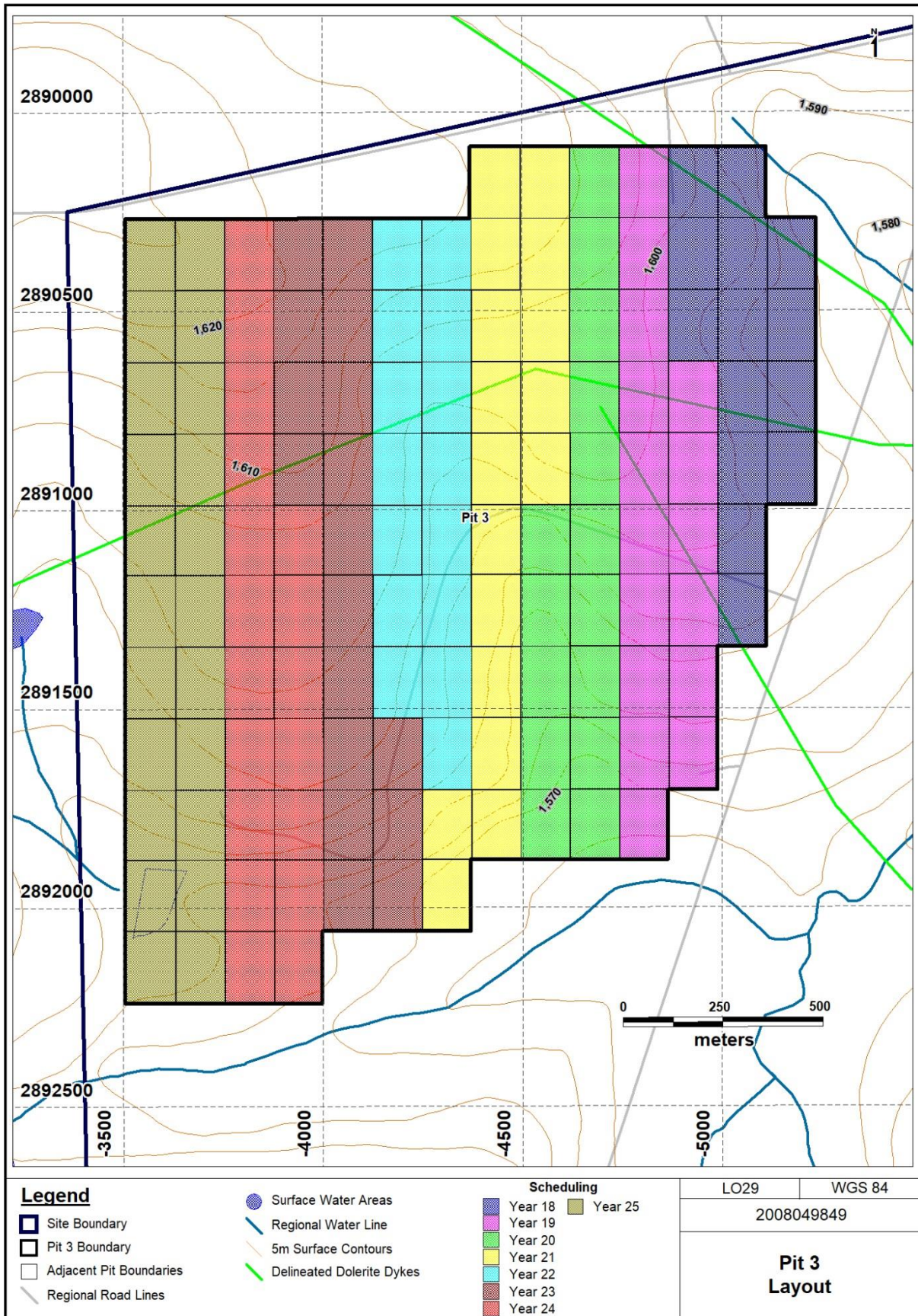


Figure 6-6: Pit 3 Opencast Workings Layout Plan

#### 6.2.2.4 Pit 4

Pit 4 is a proposed pit and mining will commence in year 18. It is anticipated that the mining operations at Pit 4 has a LOM of 7 years and the operations will be completed by the end of year 24. The pit covers a total surface area of 242 *ha*.

Full rehabilitation will commence concurrently and rehabilitation will be complete by the end of year 26. The area will be revegetated and free draining. Both dragline and truck and shovel operations will be used in order to remove the overburden from the pit. The theoretical decant elevation is at 1554 *mamsl*. A layout plan of Pit 4 is illustrated in Figure 6-7.

#### 6.2.3 Mining Schedule

The mining schedule since the commencement of the mining operations at the conceptual case site is summarised as table 6-1 below.

**Table 6-1: Summarised mining timeline**

Year	Block A	Block B	Pit 1	Pit 2	Pit 3	Pit 4
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
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25						

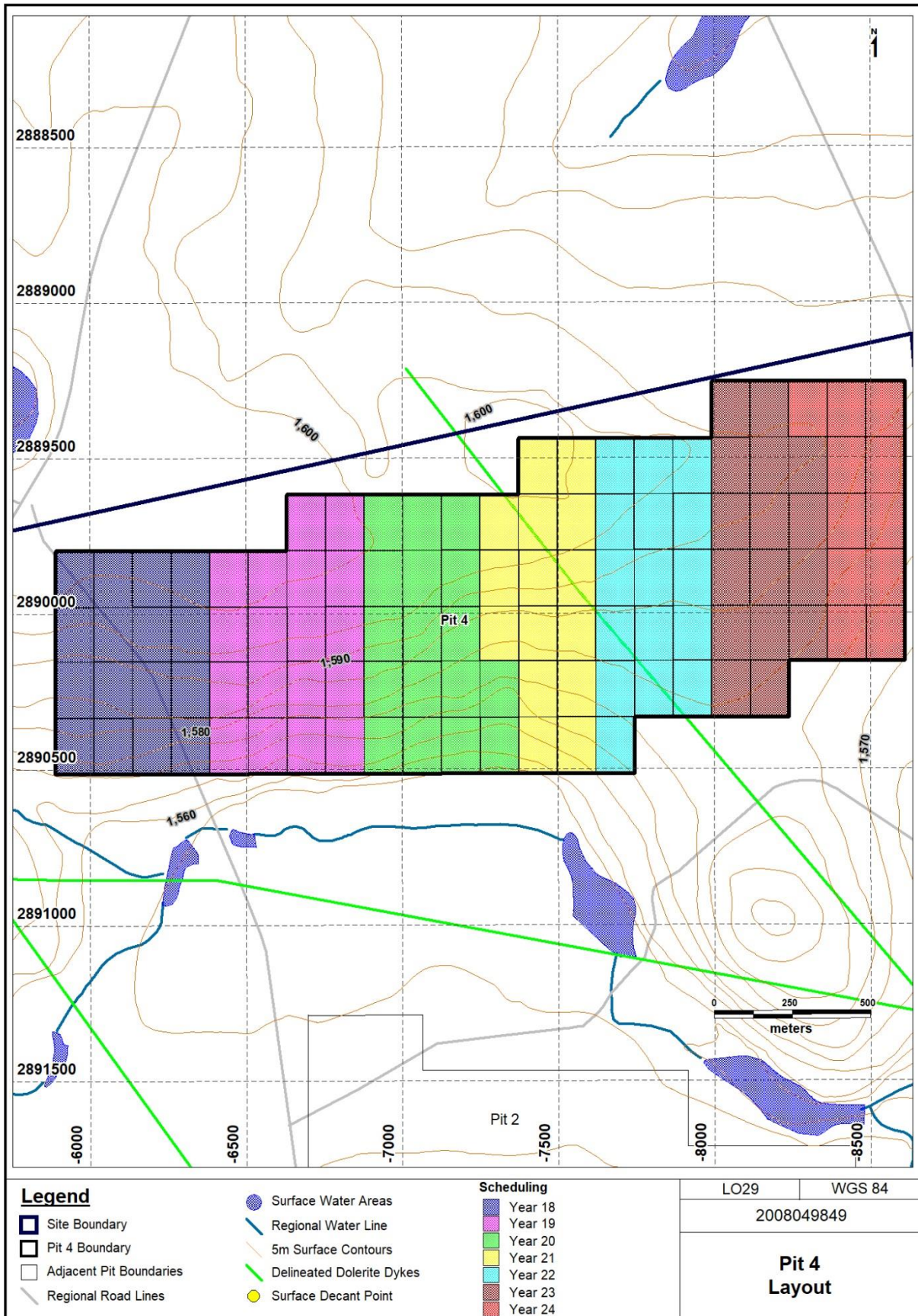


Figure 6-7: Pit 4 Opencast Workings Layout Plan

### 6.3 SITE SPECIFIC HYDROLOGICAL AND GEOHYDROLOGICAL DESCRIPTION

The geohydrological conditions of the study area are dependent on different factors including the regional topography and drainage, regional meteorology, regional geology and the regional hydrogeology. Each of the factors is discussed using published information.

#### 6.3.1 Topographical Setting and Drainage

The topography of the conceptual site is discussed with reference to a clipped area of the Topographical Sheet 2629AA. The topography of the mining right area is portrayed as Figure 6-8. The regional drainage lines, inland water bodies as well as the regional roads are indicated on the map as well.

The area within the mining right boundary has a gently rolling to flat topography. The elevations vary from 1560 *mamsl* to 1630 *mamsl*. The highest topographical areas are situated in the south-west of the study area with the highest areas being in the north-east.

#### 6.3.2 Meteorology

The mining right area falls within an area with a typical Highveld-type climate. The summer temperatures are typically hot (27°C) with cold winters (15°C). The average daily temperature within the study area is 23°C with an average daily relative humidity of 61%. Rainfall within the study area (Mpumalanga Highveld Region) predominantly occurs as thunderstorms during the summer months.

The average monthly and daily temperatures as well as the average monthly rainfall and evaporation figures are indicated in Table 6-2.

**Table 6-2: Average Temperatures, Rainfall and Evaporation within the study area.**

Month	Average Daily Temperature (°C)		Average Monthly Rainfall (mm)	Annual Monthly Evaporation (mm)
	Min	Max		
October	10.9	24.8	79.8	223.1
November	12.4	25.1	125.5	203
December	13.6	25.8	101.9	202.3
January	14.3	26.1	119.8	193.7
February	13.8	26.0	97.5	163.1
March	12.1	25.0	97.0	153.4
April	7.9	22.9	33.1	135.3
May	3.8	20.7	10.8	145.8
June	0.1	17.8	6.5	125.3
July	0.1	18.1	4.2	138.3
August	2.9	20.8	9.6	176.9
September	7.6	24.1	30.4	201.0
Annual (Total)	<b>8.29</b>	<b>23.10</b>	<b>(716.10)</b>	<b>(2061.20)</b>

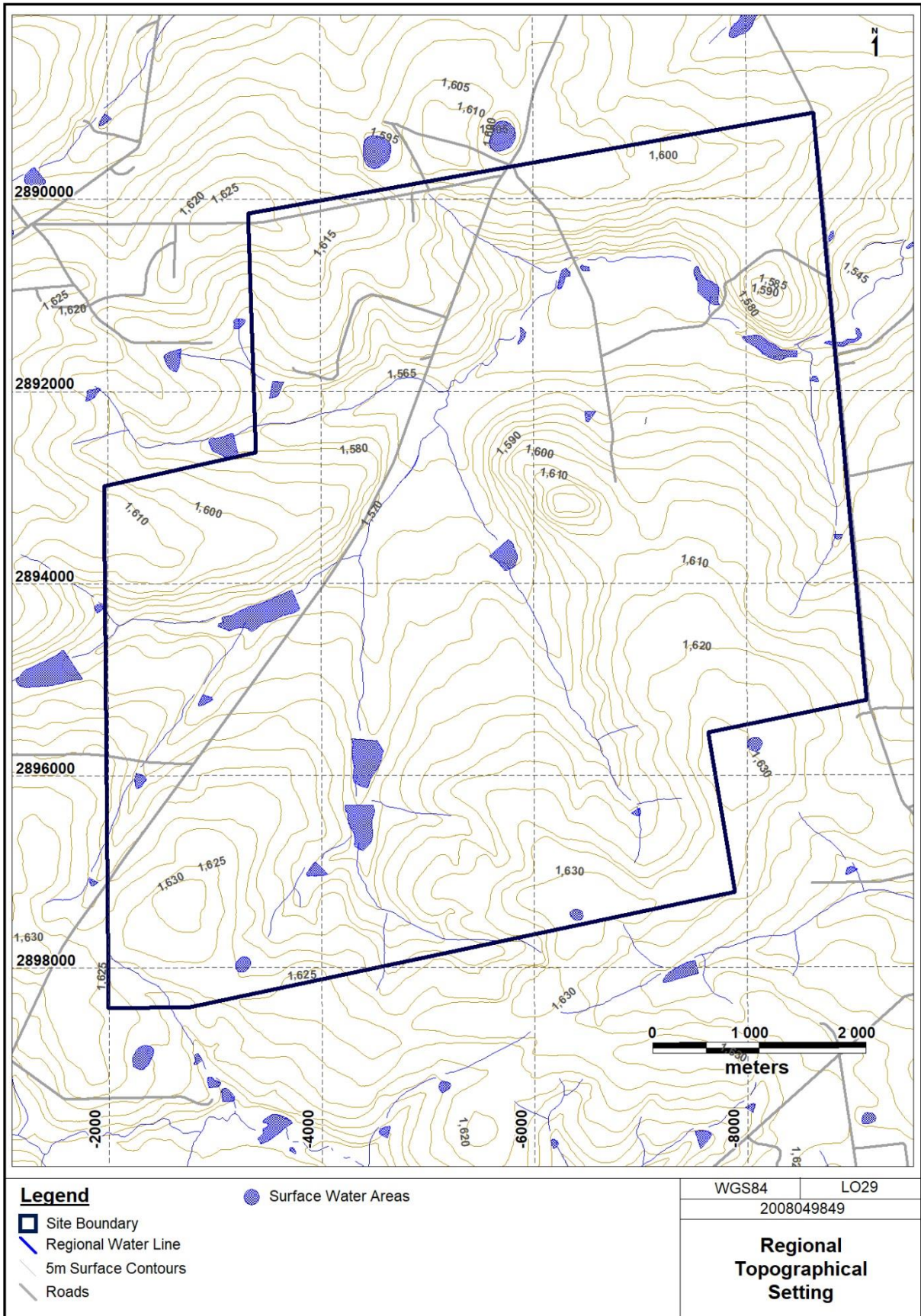


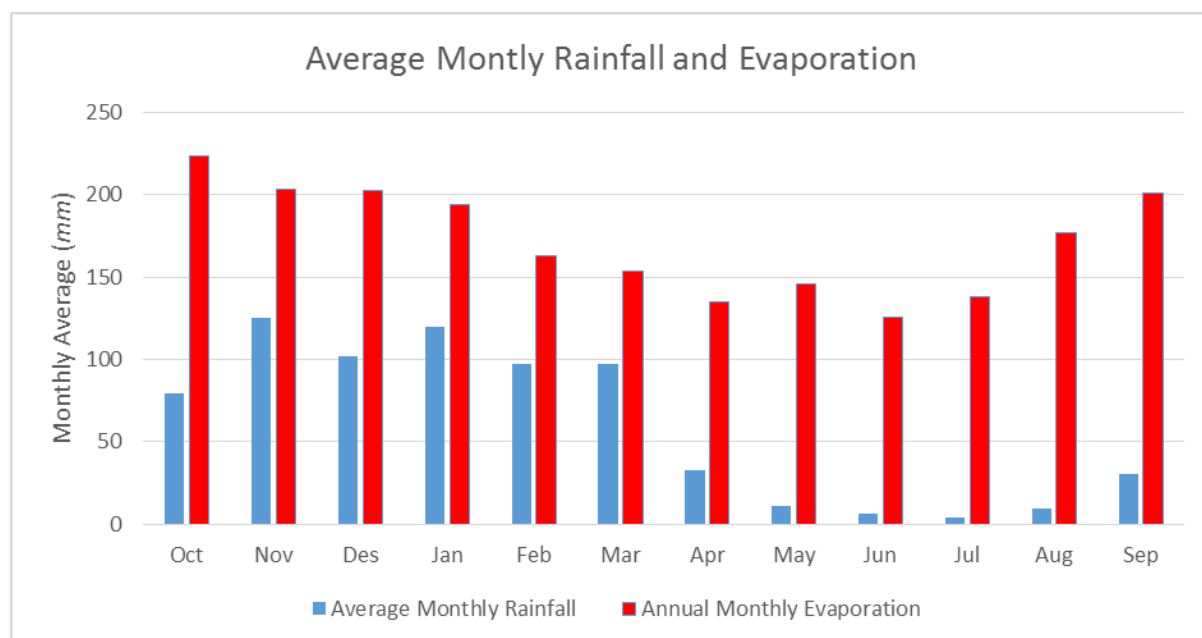
Figure 6-8: Regional Topography

The average monthly and annual evaporation were obtained from the Institute for Soil, Climate & Water (ISCW) Computer No: 19977 (Delmas Sensako) which has a record length of 22 years.

The average monthly and annual rainfall depths were recorded at Station: Delmas, grid no: 0472 which have a record length of 101 years.

The area has been assigned a Mean Annual Precipitation (MAP) of **716 mm/annum** and a Mean Annual Evaporation (MAE) of **2061 mm/annum**. The average monthly rainfall and evaporation figures for the study area are depicted on Figure 6-9.

Rainfall as well as the evaporation for the study area is highly seasonal. This is evident from Figure 6-9. A negative climatic water balance of 1 348 mm/annum is clear in the area based on the MAP of 716 mm/annum and a MAE of 2 061 mm/annum.



**Figure 6-9: Average Monthly Rainfall and Evaporation Figures**

### 6.3.3 Surface Water Drainage

The mining right area is situated within the southern extent of the Olifants River (B) Catchment (Figure 6-10) and the Olifants Water Management Area (WMA). The mining right area falls predominantly within the B11F and partially in the B11E quaternary catchment (Figure 6-11). The major surface water drainage bodies within the mining right boundary are indicated in Figure 6-12.

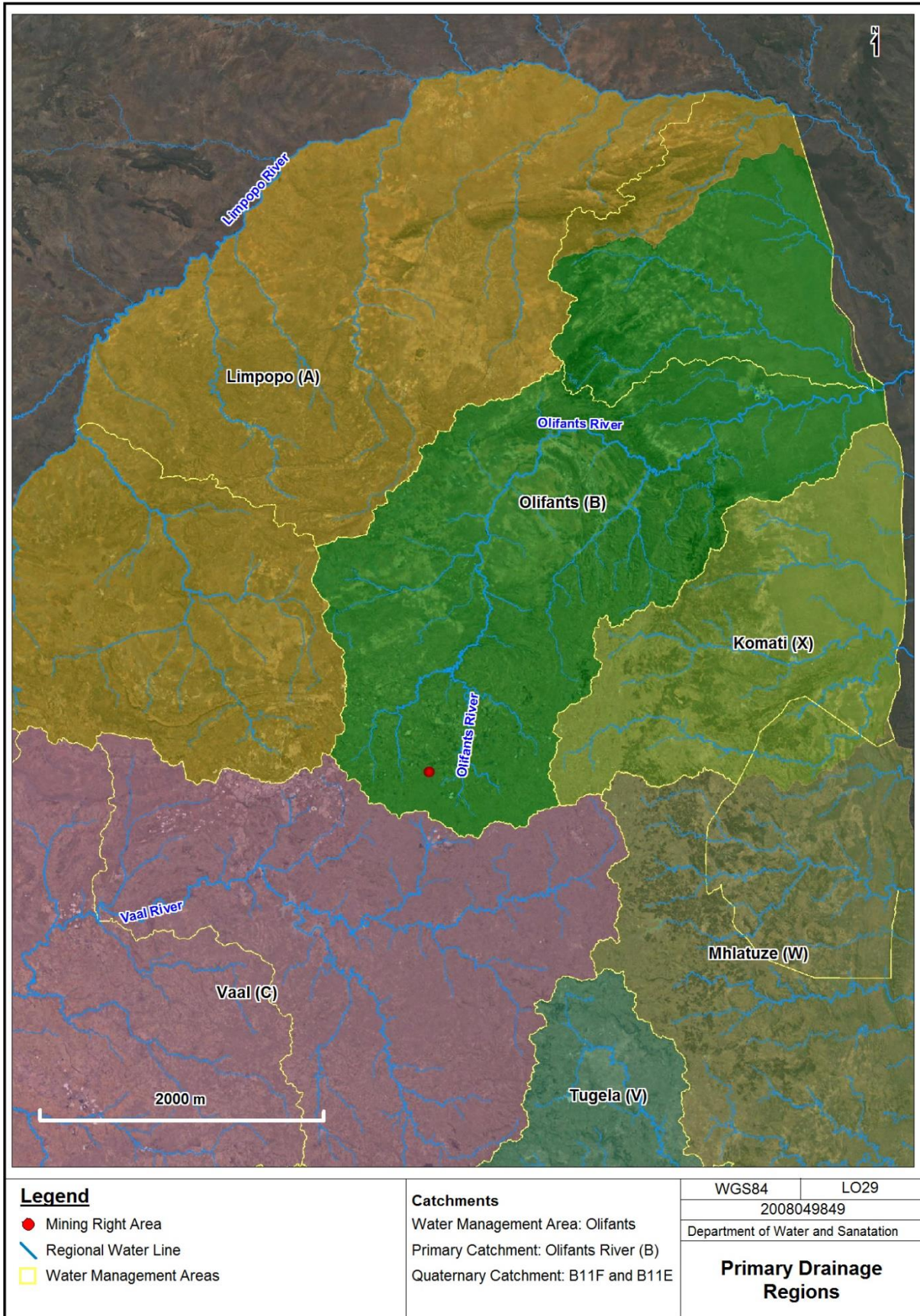


Figure 6-10: Primary Drainage Region

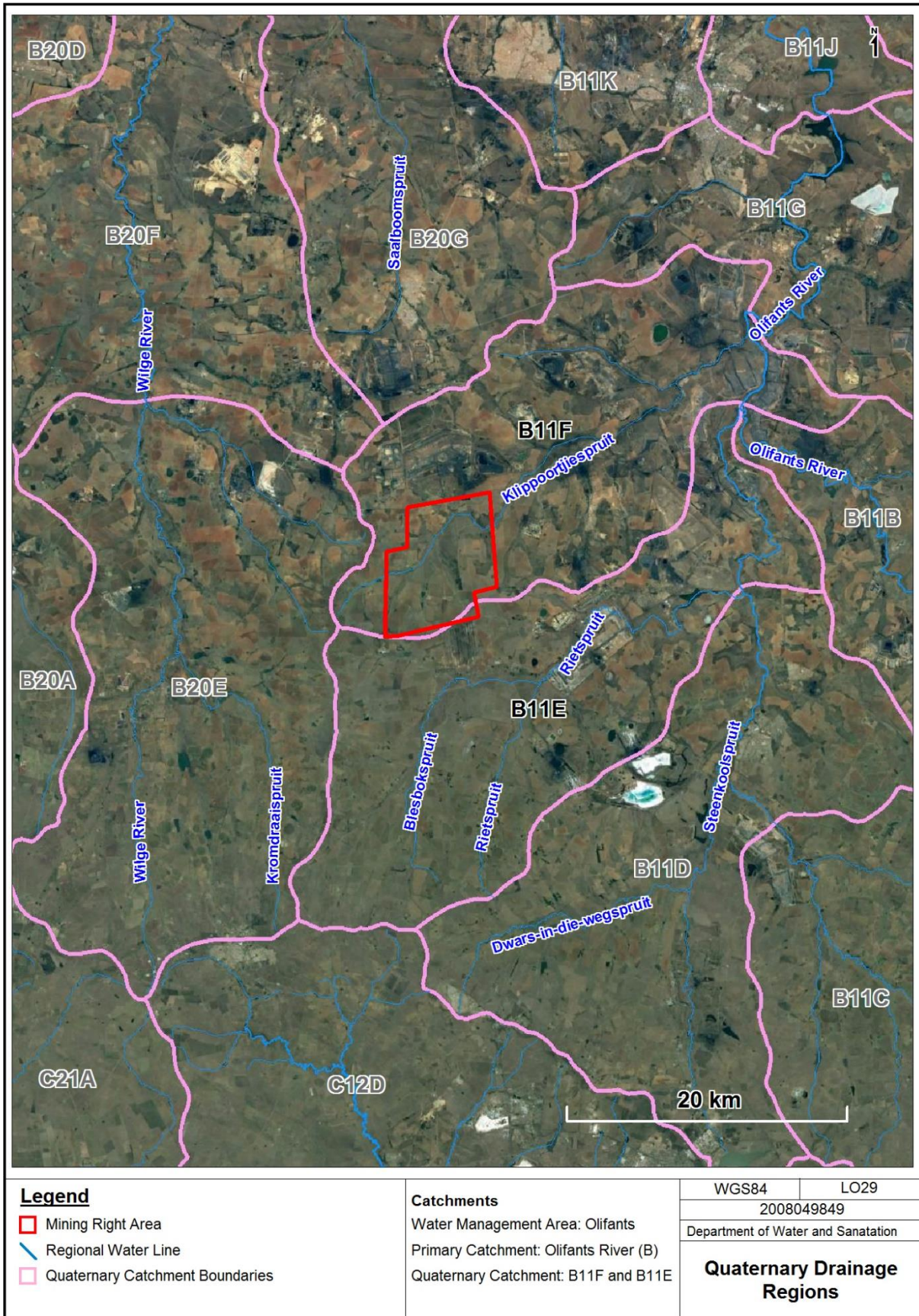


Figure 6-11: Quaternary Drainage Regions

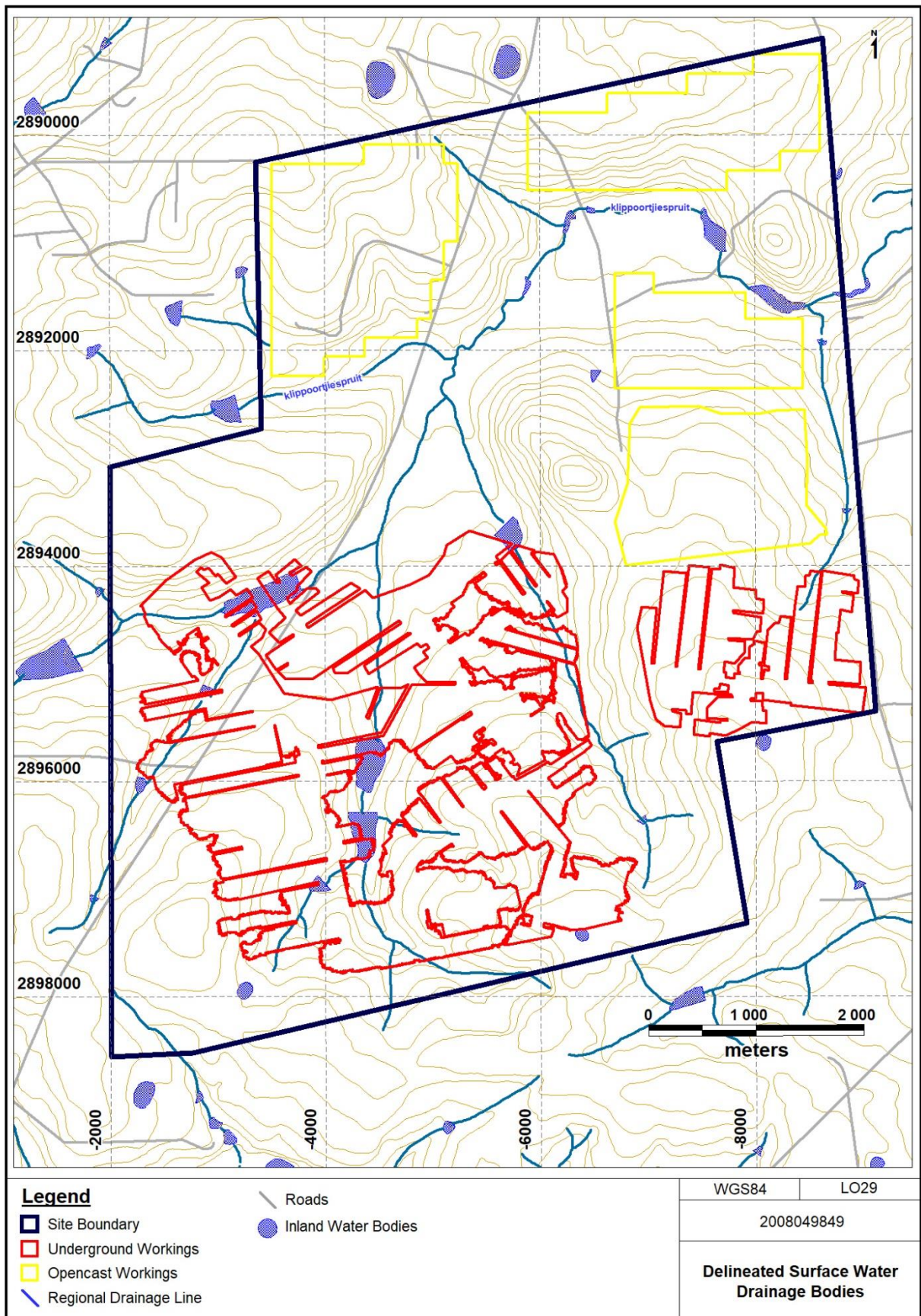


Figure 6-12: Layout of the Delineated Surface Water Drainage Bodies

The results obtained from the WR90 assessment (Water Resources of South Africa 90 Study) indicate that the Mean Annual Runoff for the B11F quaternary catchment is 20 *mm* – 50 *mm*, whilst the Mean Annual Runoff for the B11E quaternary catchments is between 10 *mm* and 50 *mm* per annum (WR90 / WR2005).

#### **6.3.4 Geological setting**

The regional geology of the study area is discussed with reference to the clipped region of the 1:250 000 Geological Map Series of South Africa – Sheet 2628 East Rand (1986), indicated as Figure 6-13.

The site is entirely underlain by the sandstone and shale of the Vryheid Formation (Pv) with the exception of the dolerite sill (Jd) splitting into two directions towards the north to where it occurs in the southern extent of the site. A large dolerite dyke intruded the Vryheid Formation with a south-west to north-east strike direction. Porphyritic rhyolite interbedded with mudstone and sandstone of the Selons River Formation (Vse) occurs in the central parts of the site to the north as well as in the north-eastern corner of the site.

#### **6.3.5 Geohydrological setting**

The regional geohydrology of the study area is discussed with reference to the published 1:500 000 Hydrogeological Map Series of the Republic of South Africa – Sheet 2526 Johannesburg, 1999, depicted as Figure 6-14.

The geohydrology of the area is influenced by the geology underlying the study area. The study area is mainly underlain by the argillaceous and arenaceous rocks of the Vryheid Formation (Denoted as Pe on Figure 6-14) of the Eccca Group of the Karoo Super Group.

Some areas around the study area are intruded by Ultramafic/mafic intrusive rocks (Dolerite) (Denoted as Jd and Vb on Figure 6-14).

#### Argillaceous and arenaceous rocks of the Vryheid formation

The lithology of the aquifers underlying the study area comprise mainly of sandstone and shale of the Vryheid Formation of the Eccca Group. The groundwater occurs between grains (intergranular), fractures or contacts between different lithologies. The groundwater of the study area falls in a yield class of 0.1 *l/s* – 0.5 *l/s*.

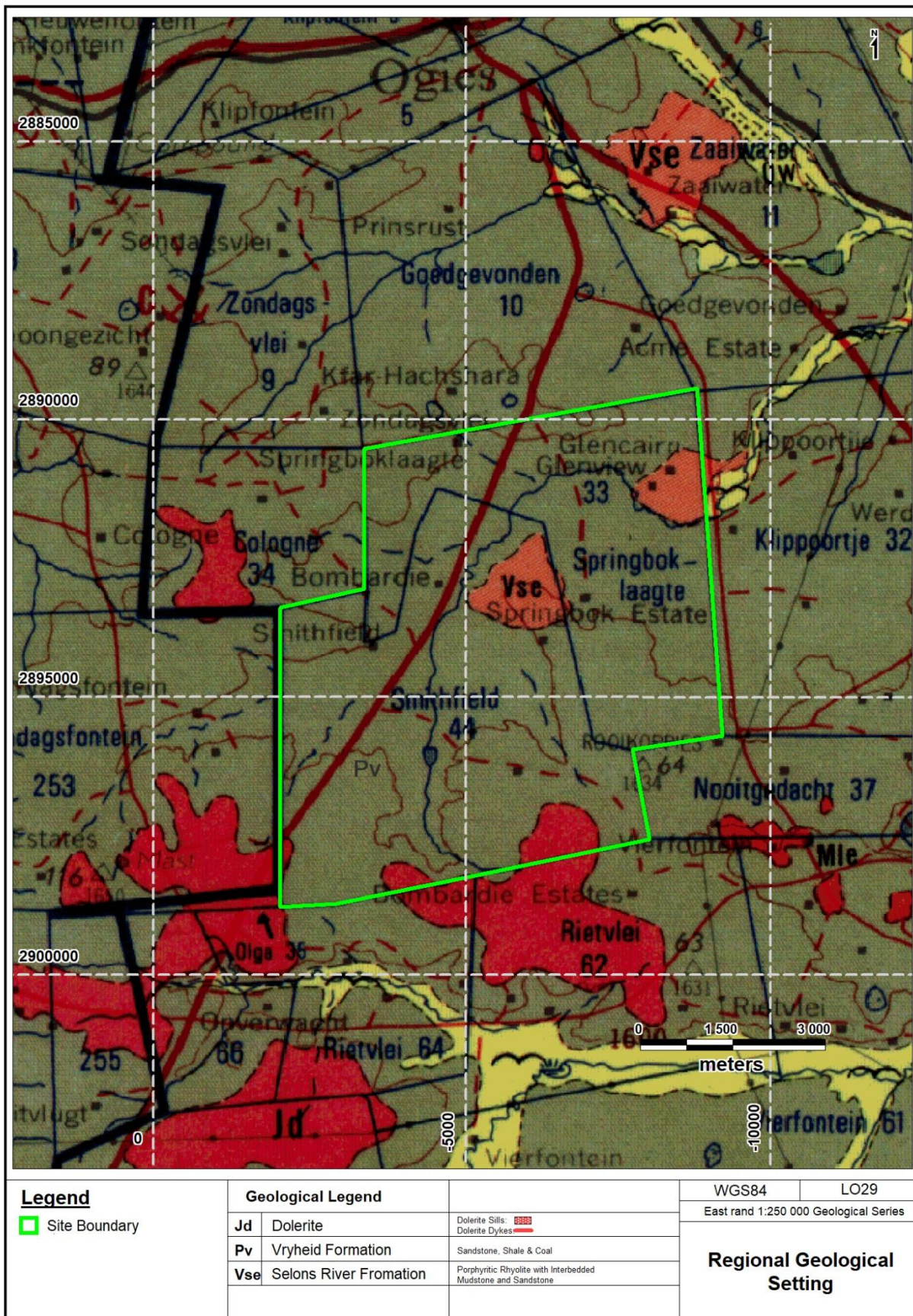


Figure 6-13: Regional Geological Setting

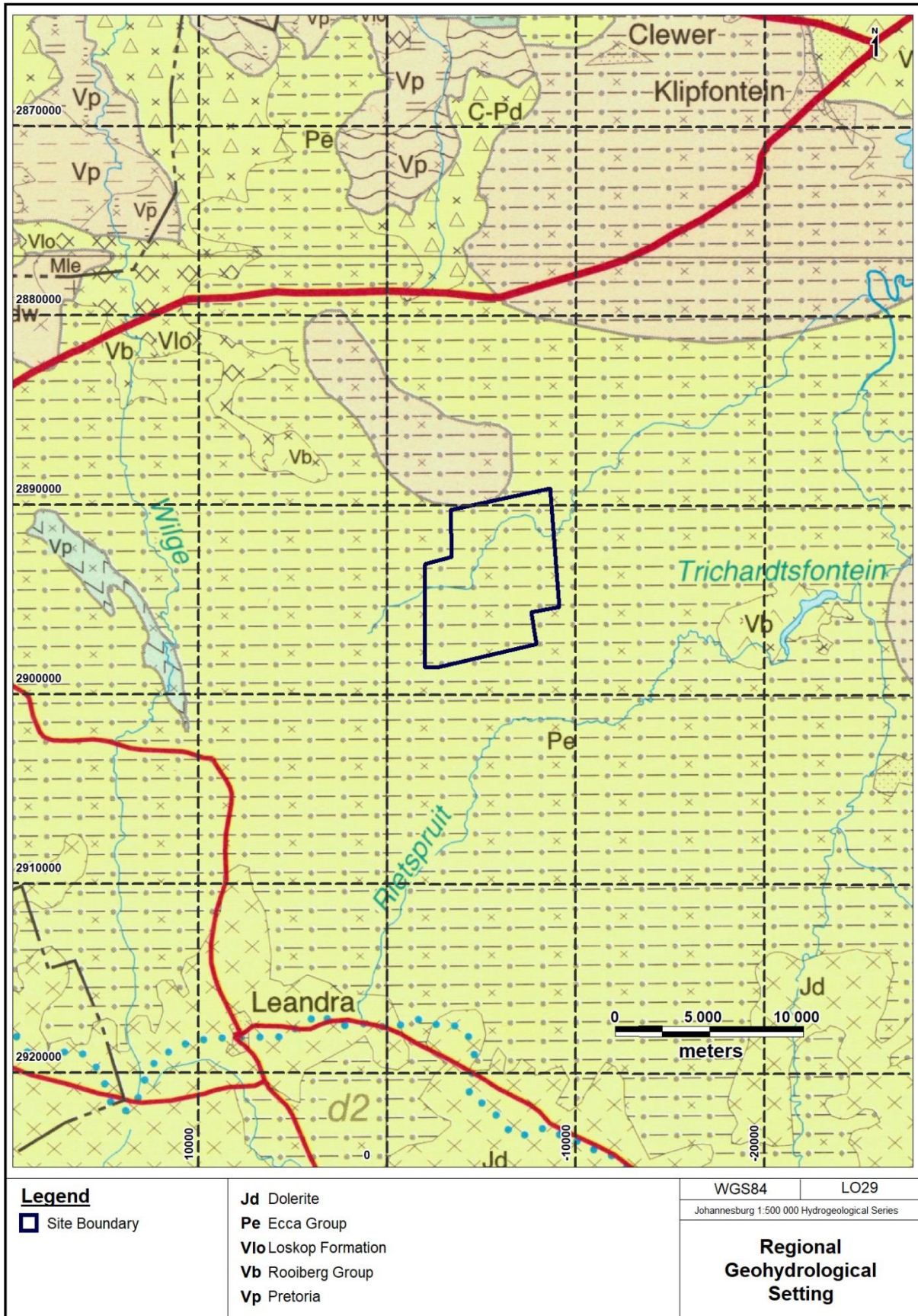


Figure 6-14: Regional Geohydrological Setting

The probability of drilling a successful borehole is between 40% and 60% with a probability of between 10% and 20% of drilling a successful borehole yielding greater than 2 l/s. (DWAF (1995) Sheet 1). The storativity of the study area varies between 0.001 and 0.01.

The mean annual recharge is estimated to be between 25 and 37 *mm/annum*. The mean depth to the groundwater table in the area is between 8 *m* and 25 *m* below the surface, and the water table varies in elevation along with the surface topography. Seepage from groundwater has some contribution to the stream base flow in low lying areas (DWAF (1995) Sheet 2).

#### **6.4 AQUIFER MATRIX DESCRIPTION**

The description of the aquifer matrix is addressed with reference to information generated from 23 geohydrological investigative boreholes and from more than 1200 geological exploration boreholes drilled within the surrounding areas. The borehole data was obtained from the JMA Consulting (Pty) Ltd Database.

The weathered / fractured aquifer zones are of great importance to the mine water balance calculations and hydraulic conditions that exist in aquifers as the opencast mine workings are situated within these aquifers. The conditions of the aquifer play a major role in the amount of recharge from rainfall as well as the groundwater influx into the mine workings.

The borehole information generated during field investigations by JMA Consulting contains information about the weathering / fracturing depth as well as the dynamics of the water within the aquifers. The borehole logs are attached as APPENDIX I to this dissertation.

The Karoo Sequence within the study area has been intruded by Jurassic aged dolerite dykes which typically exist as off-shoots from the dolerite sills in the matrix. The dolerite intrusions are also known to have an influence on the extent of mining. Some parts of the coal seams alongside the dolerite intrusions have been burnt and are unusable.

The exploration boreholes verified the existence of a number of vertical dolerite dykes in the area. The surrounding aquifers are not well known for geological structures such as faults which may act as high preferential flow paths for recharge.

The mining right area falls within the Witbank Coal Field which typically hosts five major coal seams. The five seams (No. 1, 2, 3, 4 and 5) all occur within the sandstone, siltstones and

shale of the Vryheid Formation. The No.4 Coal Seam is the most economically viable coal seam within the area.

The geological borehole localities, dolerite dykes and the No.4 Coal Seam floor elevations are illustrated on the following figures:

- Figure 6-15: Geological Exploration Boreholes
- Figure 6-16: Delineated Dolerite Dykes
- Figure 6-17: No.4 Coal Seam Floor Contours

The lithology directly above the coal seam typically consists of interbedded argillaceous units of carbonaceous shale and siltstones as well as arenaceous sandstones ranging in grain size from fine to coarse grain. A typical profile representing the matrix of the Vryheid Formation within the Witbank Coal Field is depicted in Figure 6-18.

The aquifer matrix overlying the No.4 Coal Seam is of great importance to the specific geohydrological conditions. The thickness of the aquifer matrix overlying the floor of the No.4 Coal Seam has an average thickness of 64 *m* ranging between 10 *m* and 92 *m*. The depth distribution down to the No.4 Coal Seam floor is depicted in Figure 6-19.

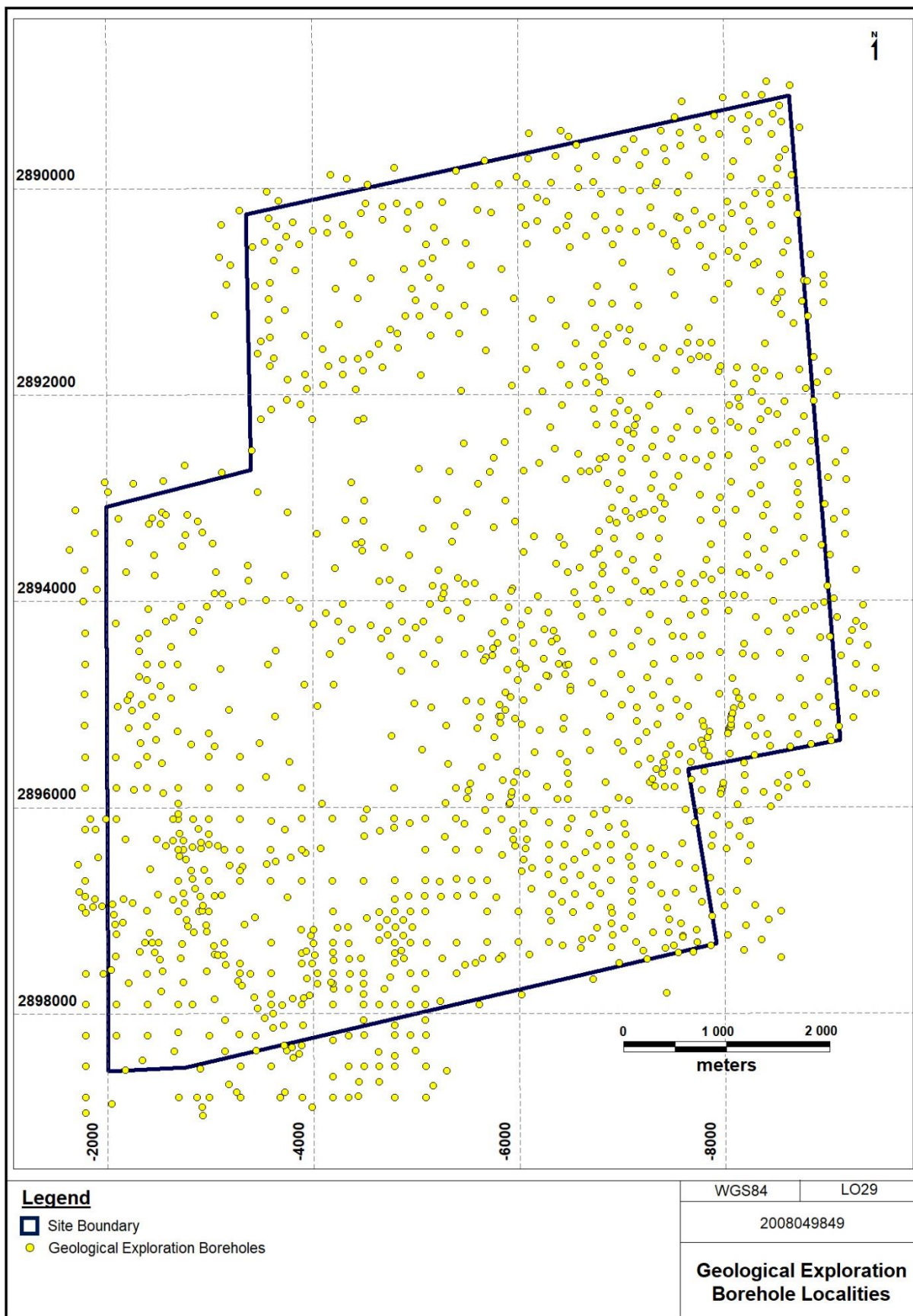


Figure 6-15: Geological Exploration Boreholes

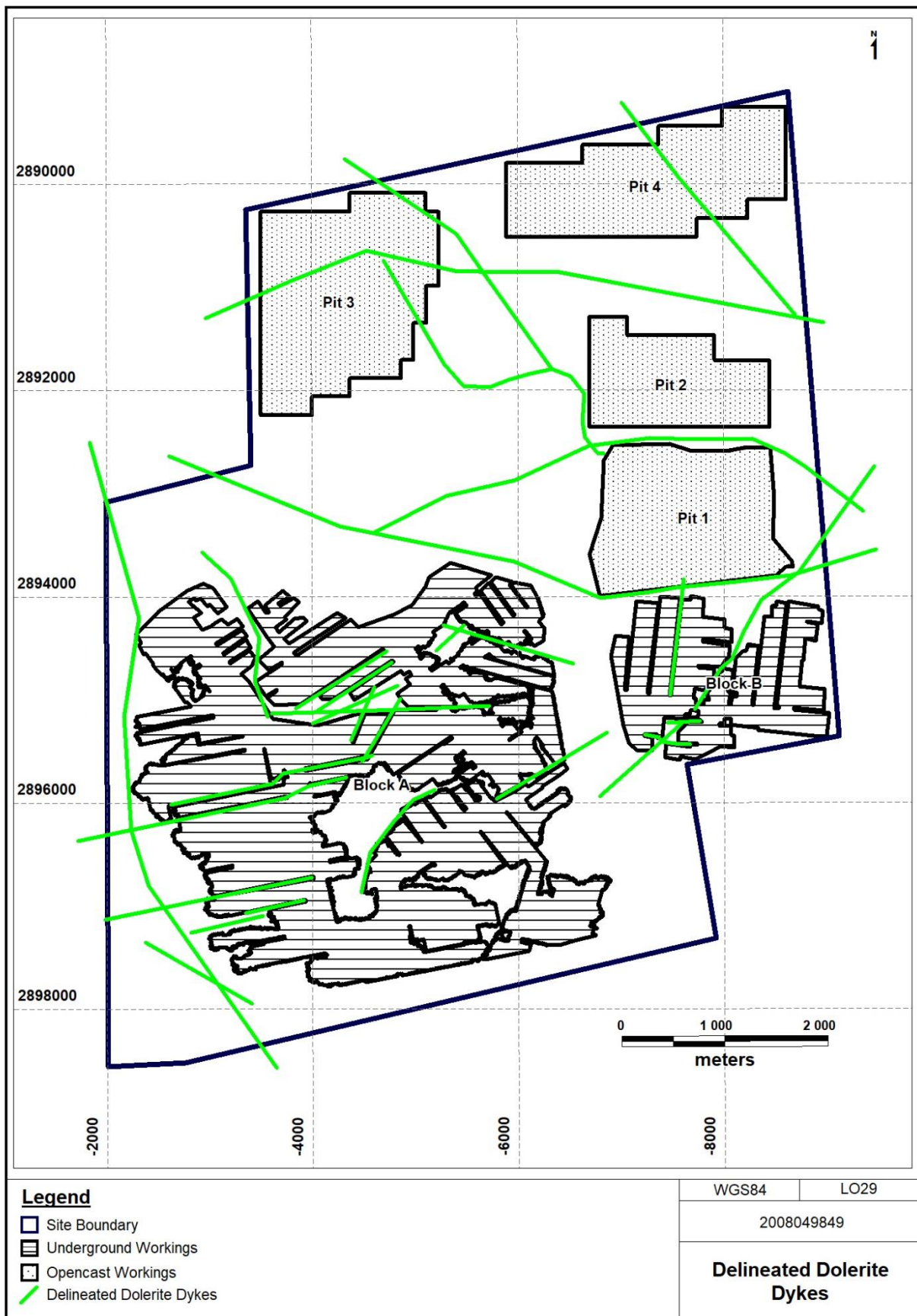


Figure 6-16: Delineated Dolerite Dykes

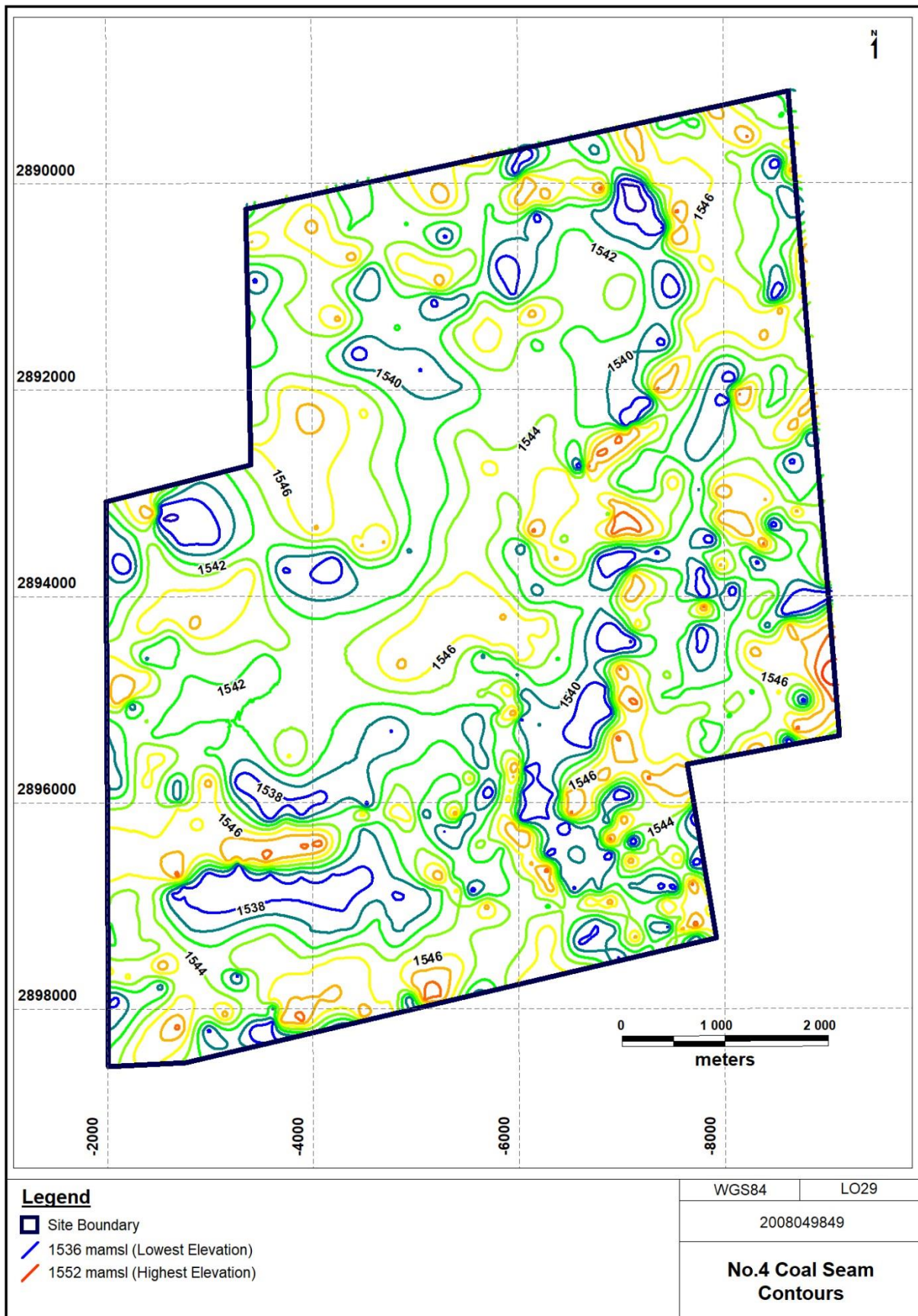
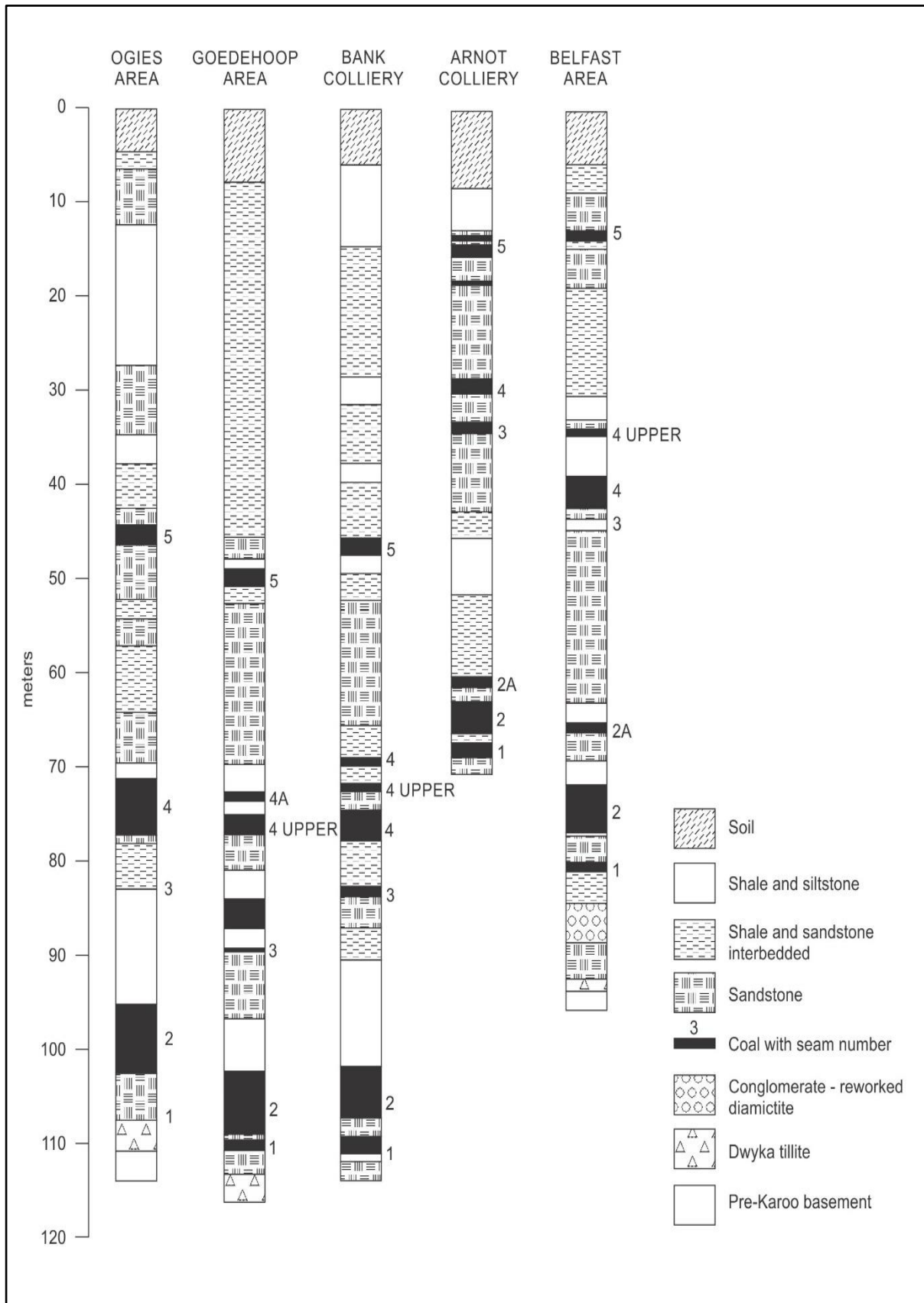


Figure 6-17: No.4 Coal Seam Floor Elevation Contours



**Figure 6-18: Typical Geological Profiles of the Witbank Coal Field (Wilson and Anhaeusser, 1998)**

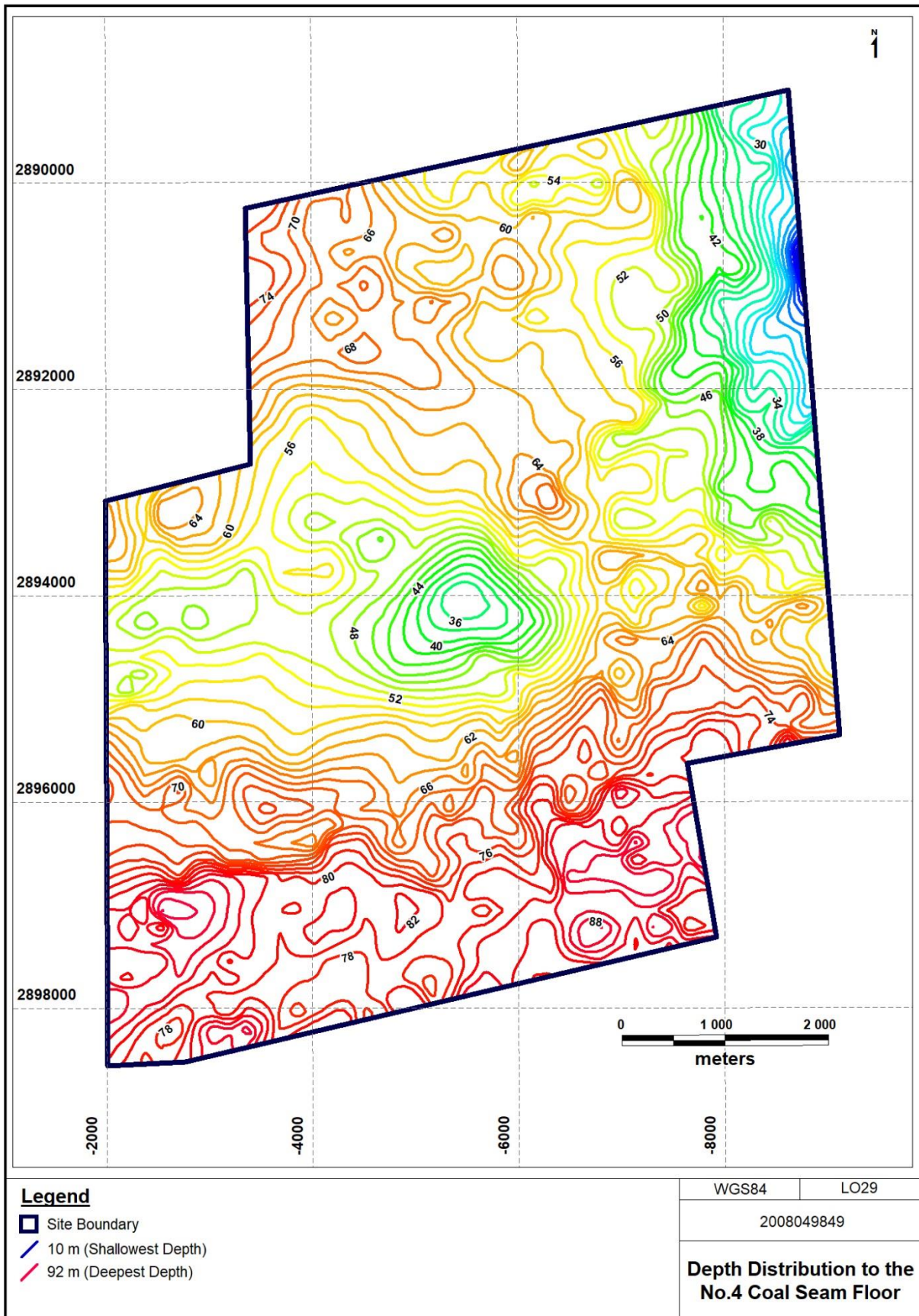


Figure 6-19: Depth Distribution down to the No.4 Coal Seam

#### **6.4.1 Aquifer Types**

The matrix within the study area is mainly made up of 2 aquifer types namely: 1) an extensive shallow weathered zone aquifer and 2) localized fractured aquifer systems.

The weathered aquifer in the surrounding areas is the most dominant aquifer type and is laterally extensive. The average thickness of the aquifer (Calculated using data from the 23 geohydrological investigative boreholes) in the area is 15.45 *m* ranging between 3.5 *m* and 33 *m*. This aquifer is typically unconfined to semi-unconfined with the topographical surface forming the top of the aquifer.

The weathered aquifer hosts the majority of the groundwater due to the properties of the material thereof. Groundwater in the deeper aquifers is recharged directly from the overlying weathered zone aquifer.

The localized fractures within the matrix above the coal seam are usually, due to the magnitude thereof, also considered as part of the transitional zone between the weathered aquifer and the fresh bedrock.

Although none of the boreholes from the surrounding areas intersected any perched systems, they may still occur locally. These systems also display unconfined to semi-unconfined piezometric conditions and will as a result be highly susceptible to the opencast mining operations and associated surface activities and impacts.

#### **6.4.2 Saturated Thickness**

The natural saturated thickness within the area is defined by the depth of weathering / fracturing at the bottom and by the groundwater level at the top. The average natural saturated thickness based on water levels obtained from the 23 geohydrological investigative boreholes is 11.57 *m* ranging from 0.66 *m* and 25.9 *m*.

Mining operations within the mining right boundary will have an influence on the natural water level within the study area. The dewatering of the aquifers surrounding mining during the operational phase will bring down the natural water levels in the area resulting in a much thinner vertical saturated thickness.

The effects of the mining on the saturated aquifer will be further discussed and visualized as part of the conceptual model in Section 6.7.

## **6.5 AQUIFER HYDRAULICS**

The purpose of the hydraulic aquifer description is to determine the hydraulic groundwater properties within the aquifers penetrated by the 23 geohydrological investigative boreholes. The hydraulic properties include the occurrence, storage and movement of the groundwater within the shallow weathered / fractured aquifers.

All of the boreholes were drilled to depths which fully intersected the shallow weathered / fractured aquifers and were drilled to a depths varying between 25 *m* and 30 *m* with an average depth of 29 *m*.

### **6.5.1 Borehole yields**

Blow yields were recorded during the drilling of the 23 investigative boreholes using a V-Notch. During the drilling of the 23 boreholes, only 6 boreholes had recorded blow yields. An average yield of 0.11 *l/s* was measured varying between 0.02 *l/s* and 1.0 *l/s*.

### **6.5.2 Hydraulic Conductivity & Transmissivity**

Hydraulic conductivity is defined as the volume of water that will move through a unit time under a unit hydraulic gradient through a unit area angle to the direction of flow. Hydraulic conductivity is usually measured in unit distance and unit time, for instance, meters per day (*m/day*).

A number of different methods may be used in order to calculate hydraulic conductivity of an aquifer such as pumping tests and slug tests. Slug tests or bail tests are quick and easy methods to determine a localised hydraulic conductivity in the surrounding of the borehole.

Slug tests are done in 2 main ways, the first way is to lower the instrument called a slug into the water in order to displace the water upwards. As the water level returns back to its original position, the level is measured over time in order to determine a stage-water level curve. The second way is to lift the slug out of the water in order to displace the water in an instantaneous downwards position. Again the water is allowed to return back to the original water level and measured over a time in order to determine a stage-water level curve.

Both the slug and bail test measures the amount of water flow through the aquifer in in the vicinity of the tested borehole. Although only one method of slug testing is necessary, both slug and bail tests can be done in order to confirm the stage-water level curve that was obtained. The site specific conditions can also have an influence on the choice, especially

where the water level is too close to the top of the borehole. In this instance a bail test should be done in order to get the most accurate data from the test.

Slug tests were done on the 22 boreholes in the study area in order to calculate the hydraulic conductivity.

Slug test data can be analysed with a number of different methods in order to determine the hydraulic conductivity. The Hydraulic Conductivity Report is attached as APPENDIX II.

The slug test data was analysed using the *Waterloo Hydrogeologic Aquifer Test Pro 3.5*. Two different methods of analysis were used in order to get an average hydraulic conductivity value for the aquifers. The methods used are the:

- Bouwer-Rice Method(unconfined or leaky confined, fully or partially penetrating well)
- Hvorslev Method(confined or unconfined aquifer, fully or partially penetrating well)

#### Bouwer-Rice Method

$$K = \frac{r^2 \ln\left(\frac{R_{cont}}{R}\right)}{2L} \cdot \frac{1}{t} \cdot \ln \frac{h_0}{h_t}$$

Where:

r = piezometer radius (or  $r_{eff}$  if water level change is within the screened interval)

R = radius measured from centre of well to undisturbed aquifer material

$R_{cont}$  = contributing radial distance over which the difference in head,  $h_0$ , is dissipated in the aquifer

L = the length of the screen

$h_t$  = displacement as a function of time ( $h_t/h_0$  must always be less than one, i.e. water level must always approach the static water level as time increases)

$h_0$  = initial displacement

t = time

### Hvorslev Method

$$K = \frac{r^2 \ln\left(\frac{L}{R}\right)}{2LT_L}$$

Where:

K = hydraulic conductivity

r = radius of well casing

R = radius of well screen

L = length of well screen

T<sub>L</sub> = time it takes for water level to rise or fall 37% of initial change

The results of the slug tests (average of the Bouwer Rice and Hvorslev methods) done at 22 of the geohydrological investigative boreholes are tabulated below in Table 6-3.

**Table 6-3: Aquifer Hydraulic Conductivity Distribution**

No. of boreholes	Minimum (m/day)	Maximum (m/day)	Harmonic Mean (m/day)	Geometric Mean (m/day)	Average (m/day)
22	0.001	0.83	0.009	0.02	0.09

Statistical analysis indicates log-normal distribution on the hydraulic conductivity within the weathered / fractured aquifers of the Karoo Supergroup. The K-value for the aquifer is thus bound by the calculated geometric and the harmonic means (Müller and Turner, 2016).

An aquifer hydraulic conductivity of 0.09 m/day is allocated to the shallow weathered aquifer in the study area. An aquifer hydraulic conductivity of 0.006 m/day is deemed realistic for the deeper fractured Karoo aquifers (van der Berg, 2012).

Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

The transmissivity of the aquifers have been calculated by multiplying the hydraulic conductivity of the respective boreholes with the saturated aquifer thickness of the aquifer calculated at each borehole.

A summary of the calculated transmissivity is given in Table 6-4.

**Table 6-4: Aquifer Transmissivity Distribution**

No. of boreholes	Minimum (m <sup>2</sup> /day)	Maximum (m <sup>2</sup> /day)	Harmonic Mean (m <sup>2</sup> /day)	Geometric Mean (m <sup>2</sup> /day)	Average (m <sup>2</sup> /day)
22	0.001	19.17	0.009	0.221	2.096

An aquifer transmissivity of 0.12 m<sup>2</sup>/day is allocated to the shallow weathered / fractured aquifer in the study area.

### 6.5.3 Storativity

Storativity is the amount of water storage released or taken into over the area of an aquifer after a change is observed in the head.

Storativity (Effective Porosity) plays a significant role within the weathered aquifers as it forms part in calculating the groundwater flow velocities. The flow velocity takes into consideration the advection from smaller particles in determining the velocity at which particles will be transported. A greater effective flow velocity within the aquifer is a result of areas with smaller effective porosity.

Groundwater within the mining right area is mainly stored within the interstices and small fractures within the weathered as well as the deeper fractured aquifer. The calculated storativity values for the weathered and the deeper fractured aquifer down to the No.4 Coal Seam are tabulated in Table 6-5 (van der Berg, 2012).

**Table 6-5: Aquifer Storativity Distribution**

Aquifer Type	Minimum	Maximum	Average
Weathered Zone Aquifers	3.65%	5.80%	4.45%
Fractured Aquifers	0.43%	0.55%	0.49%

### 6.5.4 Porosity

The porosity of the aquifer is defined as the amount void space in relation to the total volume of the aquifer. The porosity of the backfill material is critically important in the calculation of available storage in the rehabilitated open pits, because it is the percentage of available space for water storage in relation to the total volume of the open pit.

Mining operations create voids in the subsurface and thus disturbs the natural porosity of the aquifer. The post closure porosity (backfill material) is crucial to the calculation of groundwater storage within the mining operations, because it is the percentage of available space for water storage in relation to the total volume of the open pit.

As pointed out in the literature review a porosity of 25% can be assigned to the backfill material of an opencast mine. As underground workings are not backfilled, the porosity will be 100% within the workings.

Cores from two geological exploration boreholes drilled into the lithology of the Vryheid Formation were analysed for porosity testing. The lithological units mainly comprised of

sandstone, siltstone, shale and grit. The porosities of each of these units were tested and are reported below.

The saturation and buoyancy method, done according to the SABS 0259 protocol, was used for the porosity tests, the results of which are given in Table 6-6 (van der Berg, 2012).

**Table 6-6: Saturation and Buoyancy Method Porosity Results**

Depth (m)	Lithological Description	Porosity (%)
	<b>Geological Exploration Borehole 1</b>	
11.58	SANDSTONE/SILTSTONE Medium grey, medium to fine grained, interlaminated, micaceous, moderately weathered, very thinly bedded 10-30 mm, cross laminated.	7.7
20,03	No.4 Coal Seam.	-
29.58	SANDSTONE/SILTSTONE	4.3
35.58	Medium grey, medium to fine grained, interlaminated, micaceous, very thinly bedded 10-30 mm, cross laminated.	4.2
36.65		4.4
42,65	No. 2 Coal Seam.	-
50,79	No. 1 Coal Seam.	-
51,46	GRIT Light greyish-white, coarse grained, medium bedded 100-300 mm.	4.1
	<b>Geological Exploration Borehole 2</b>	
10.00	SANDSTONE/SILTSTONE Medium grey, medium to fine grained, interlaminated, micaceous, highly weathered, very thinly bedded 10-30 mm, cross laminated.	11.6
17.60	No. 5 Coal Seam.	-
23.60	SANDSTONE Light greyish-white, coarse grained, medium bedded 100-300 mm dips at 2 degrees, cross bedded.	7.3
40.00	SANDSTONE/SILTSTONE Medium grey, medium to fine grained, interlaminated, micaceous, very thinly bedded 10-30 mm, cross laminated.	5.5
59.04	No.4 Coal Seam.	-
74.60	SANDSTONE/SILTSTONE Light whitish-grey, medium to fine grained, interlaminated, micaceous, very thinly bedded 10-30 mm dips at 2 degrees, cross laminated.	4.8
83.47	No. 2 Coal Seam.	-
93.17	No. 1 Coal Seam.	-
94.08	SHALE Dark greyish-black, fine grained, interbedded, gritty, laminated < 10 mm.	4.5
96.30	GRIT Light greyish-white, coarse grained, medium bedded 100-300 mm.	4.2
96.30	Top of the No. 1 Coal Seam.	-

Based on the results of the porosity testing listed in Table 6-6, the bulk aquifer porosity values assigned to the weathered zone as well as to the deeper fractured aquifers are summarized in Table 6-7 (van der Berg, 2012).

**Table 6-7: Summarized Aquifer Porosities**

<b>Aquifer Type</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Average</b>
Weathered Zone Aquifers	7.3%	11.6%	9.5%
Fractured Aquifers	4.3%	5.5%	4.9%

### **6.5.5 Lateral Aquifer Boundaries**

The area in which groundwater will be influenced may be defined by setting up specific aquifer boundaries. Three main types of aquifer boundaries exist, namely, physical boundaries (linear geological features e.g. Dykes and contacts between rocks), hydraulic boundaries (dams, rivers, streams and by groundwater & Surface water divides) and arbitrary boundaries (parallel to groundwater flow directions) (van der Berg, 2015).

A boundary has been chosen around the area that will act as a lateral aquifer boundary. Only data gathered within the lateral aquifer boundaries will be deemed site specific.

The extent of the lateral aquifer boundary for the study area is delineated in Figure 6-20.

The lateral aquifer boundary for the study area consists mainly of hydraulic aquifer boundaries and arbitrary boundaries. The following summary is relevant to the lateral aquifer boundaries in the study area:

- The southern, eastern and northern boundaries have been selected along topographical low lying areas in which non-perennial streams exist. These boundaries have been defined as groundwater discharge boundaries.
- The western, north-eastern and south-eastern boundaries were delineated on natural surface water divides and have been defined as no-flow boundaries.
- The constant head boundary to the west has been selected along a surface elevation contour which acts as a boundary parallel to groundwater flow.

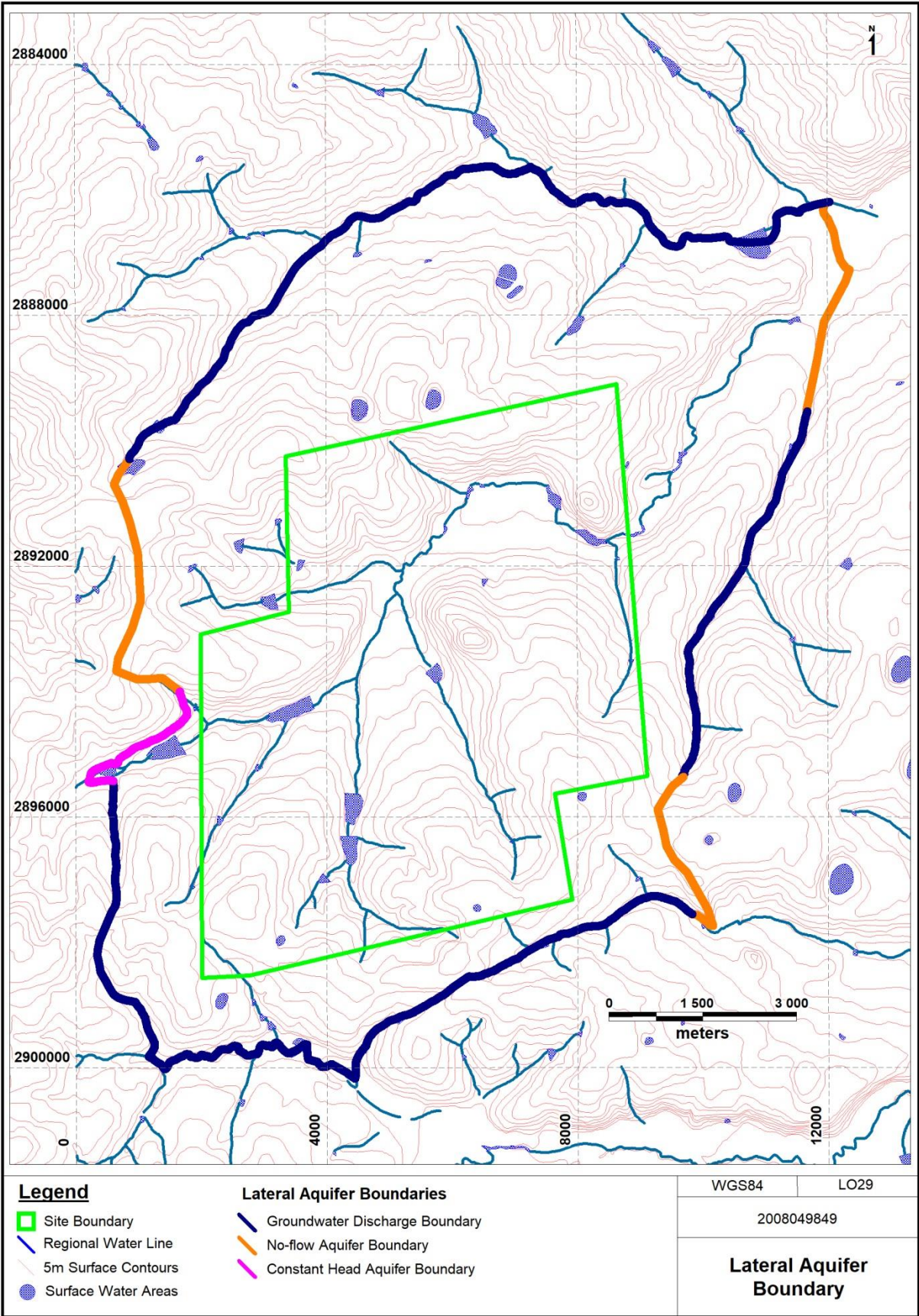


Figure 6-20: Delineated Lateral Aquifer Boundaries

## 6.6 AQUIFER DYNAMICS

### 6.6.1 Recharge from Rainfall

It is already clear that the recharge from rainfall into the mine workings plays a major role on the water balance and the management of mine water in the operational phase of mining. It is very important to use recharge values that is site specific.

The recharge into Pit 1 and Block B was observed during the operation thereof in order to accurately determine the amount of recharge from rainfall into the different stages of opencast mining. The results are indicated in Table 6.8

**Table 6-8: Recharge from Rainfall into Opencast Pits and Underground Workings**

Area of Recharge	Recharge from Rainfall (%)
Into Opencast Mine Void (Not considering evaporation)	100%
Into Partially Rehabilitated Opencast Mine	65%
Into Rehabilitated Opencast Mine	14%
Into Underground Mine	1.5%

The amount of recharge from rainfall into the opencast and underground operations based on an annual recharge of 716 *mm/annum* are tabulated in Table 6-9.

**Table 6-9: Calculated Rainfall Recharge into the Opencast and Underground Workings**

Area of recharge	Recharge from Rainfall	Recharge into aquifer <i>mm/annum</i>
Into Opencast Mine Void	100%	716.00 <i>mm/annum</i>
Into Partially Rehabilitated Opencast Mine	65%	465.40 <i>mm/annum</i>
Into Rehabilitated Opencast Mine	14%	100.24 <i>mm/annum</i>
Into Underground Mine	1.5%	10.74 <i>mm/annum</i>

### 6.6.2 Natural Groundwater Levels

A total of 22 water levels are summarised in Table 6-10. The groundwater levels vary between 1.59 *mbgl* and 17.27 *mbgl* with an average groundwater level of 7.16 *mbgl*. Taking into consideration that 4 boreholes have relatively deeper recorded groundwater levels in relation to the rest, a harmonic mean of 4.68 *mbgl* can be used as the natural groundwater level for the area. The natural groundwater level in the area can therefore be taken as 4.68 *mbgl*.

**Table 6-10: Measured Groundwater Levels**

Borehole Name	Water Level (mbgl)	Borehole Name	Water Level (mbgl)
WCW-1	1.59	WCW-12	3.39
WCW-2	3.08	WCW-13	3.54
WCW-3	4.19	WCW-14	3.89
WCW-4	6.76	WCW-15	5.22
WCW-5	7.64	WCW-16	4.72
WCW-6	4.78	WCW-17	16.29
WCW-7	14.43	WCW-18	17.27
WCW-8	4.42	WCW-19	5.05
WCW-9	16.77	WCW-20	7.45
WCW-10	4.73	WCW-21	7.22
WCW-11	13.33	WCW-22	1.83
<b>Min</b>		1.59	
<b>Max</b>		17.27	
<b>Average</b>		7.16	
<b>Harmonic Mean</b>		4.68	

At a storativity of 0.045, the groundwater level response to 1 mm of rainfall recharge would be 0.222 m. For every 4.4 mm recharge the change in storage would manifest as a rise in water level of 1 m. The maximum possible fluctuation in level would then be in the order of 4.7 m (3% of MAP of 716 mm = 21 mm) for the shallow weathered zone aquifer. In view of the fact that all the recharge will not take place at the same time but indeed more spread out over the summer months, groundwater level fluctuations in excess of more than 4.7 m/annum is not expected.

## 6.7 SITE SPECIFIC CONCEPTUAL MODEL

Conceptual models are developed in order to get an understanding of the geological and geohydrological conditions in the areas of investigation. In order to get a clear understanding of all the influencing factors, certain concepts and site specific conditions are also indicated on the conceptual models. The conceptual models created for the water balance will put into perspective the difference between the geohydrological environments before mining commences, during mining and after mining took place. This is done specifically in order to optimise current and future management of groundwater in the mining operations. Conceptual models play a very big role in the planning of future mine workings as it clearly shows the conditions that will come about after mining have started. Mining can thus be planned in order to optimise the water management within a mine before the mining commences. The conceptual model in this dissertation also serves to summarise the data that was gathered as part of the conceptual case study.

### **6.7.1 Conceptual Models for the Respective Mine Workings**

Schematic 2-dimensional conceptual models have been developed for the different mine workings within the mining right boundary. Each of the mine workings is conceptualised for the current stage of mining. The models will indicate the changes of topography, surface water, geological, geohydrological and mining related conditions throughout the 3 mentioned stages. The current situation at each of the mine workings will be portrayed as one of the three stages and will be indicated in such a way. The schematic 2-dimensional conceptual models, illustrating the major geohydrological features for each of the mine workings are depicted as the following figures:

- Figure 6-21: Conceptual Model Plan View
- Figure 6-22: Conceptual Model for Block A Underground Workings
- Figure 6-23: Conceptual Model for Block B Underground Workings
- Figure 6-24: Conceptual Model for Pit 1 Opencast Workings
- Figure 6-25: Conceptual Model for Pit 2 Opencast Workings
- Figure 6-26: Conceptual Model for Pit 3 Opencast Workings
- Figure 6-27: Conceptual Model for Pit 4 Opencast Workings

Although the cross sections are exaggerated in the vertical and over simplified for demonstrative purposes, the surface topography, weathering depths, water levels, coal seam distribution, mining depths etc. are all relative and have been drawn according to the same exaggerated scale.

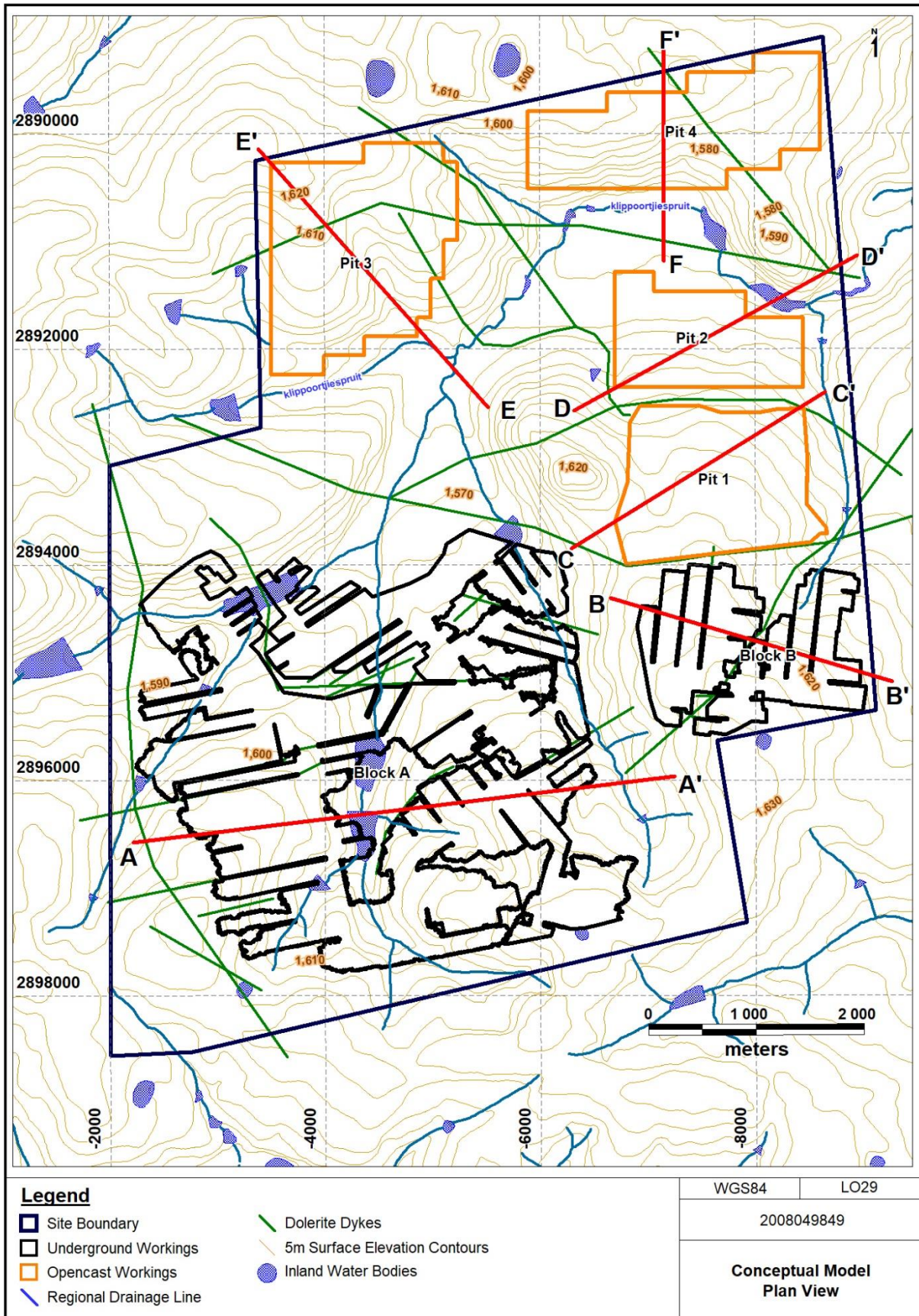


Figure 6-21: Conceptual Model Plan View

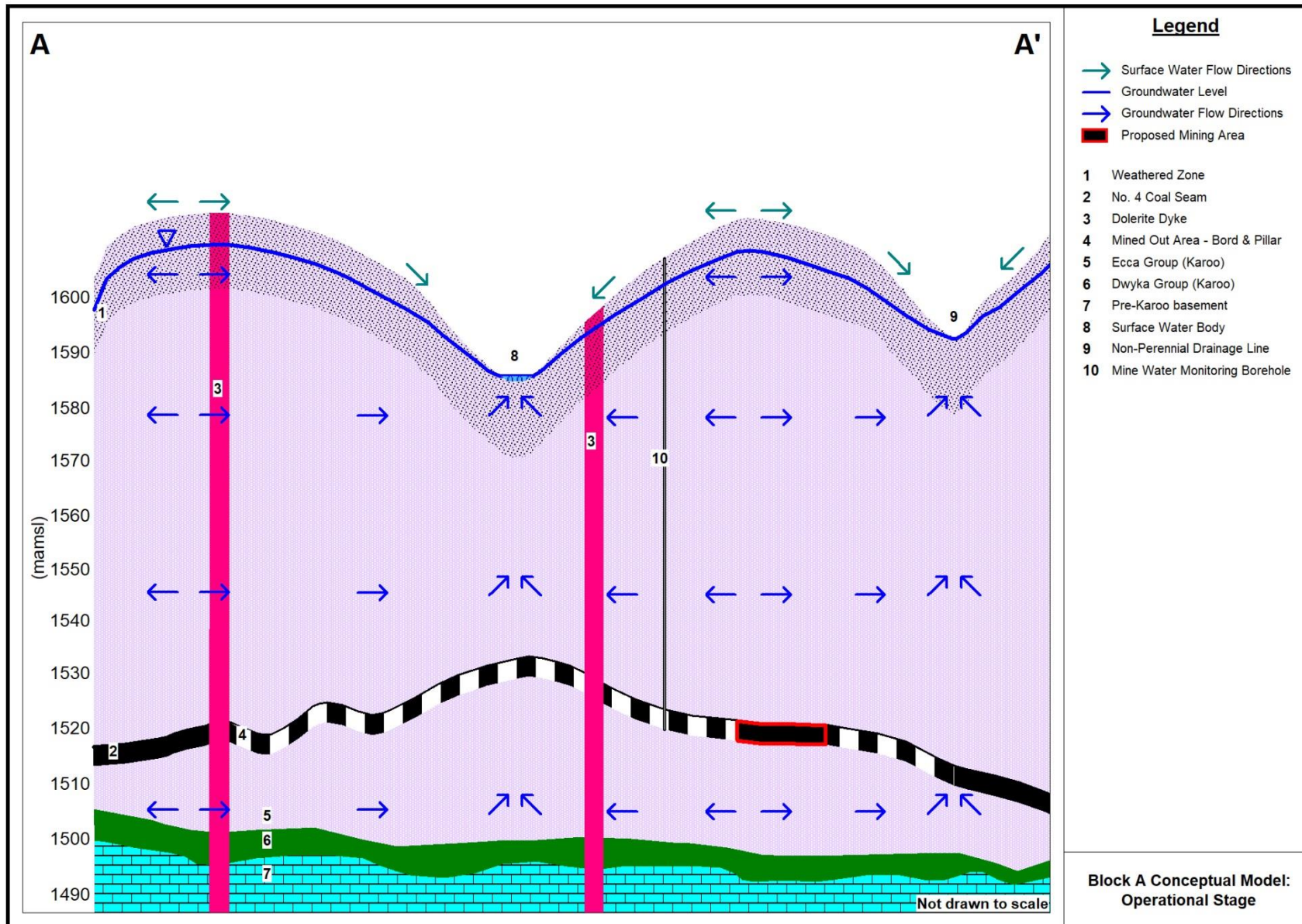


Figure 6-22: Conceptual Model for Block A Underground Workings

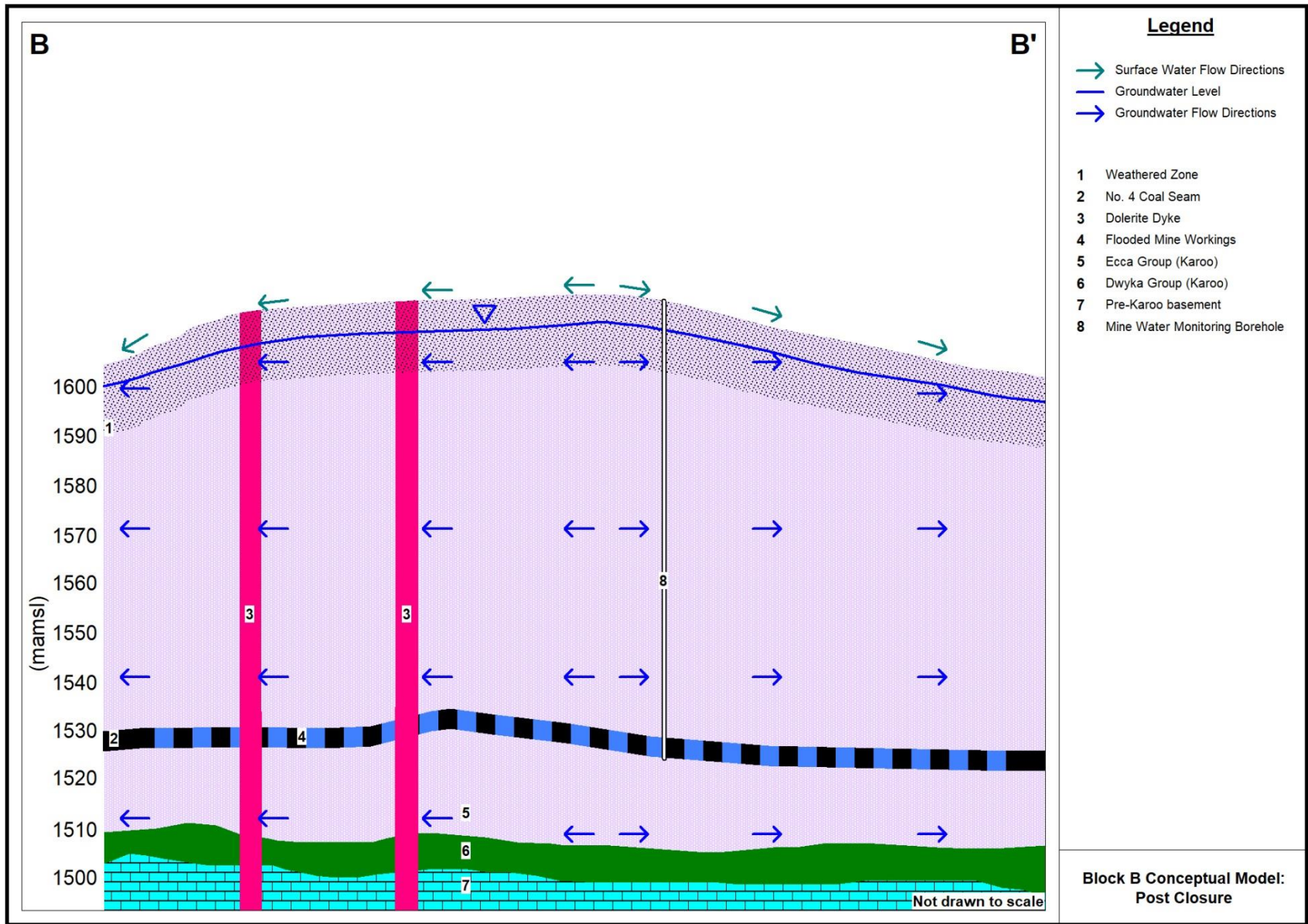


Figure 6-23: Conceptual Model for Block B Underground Workings

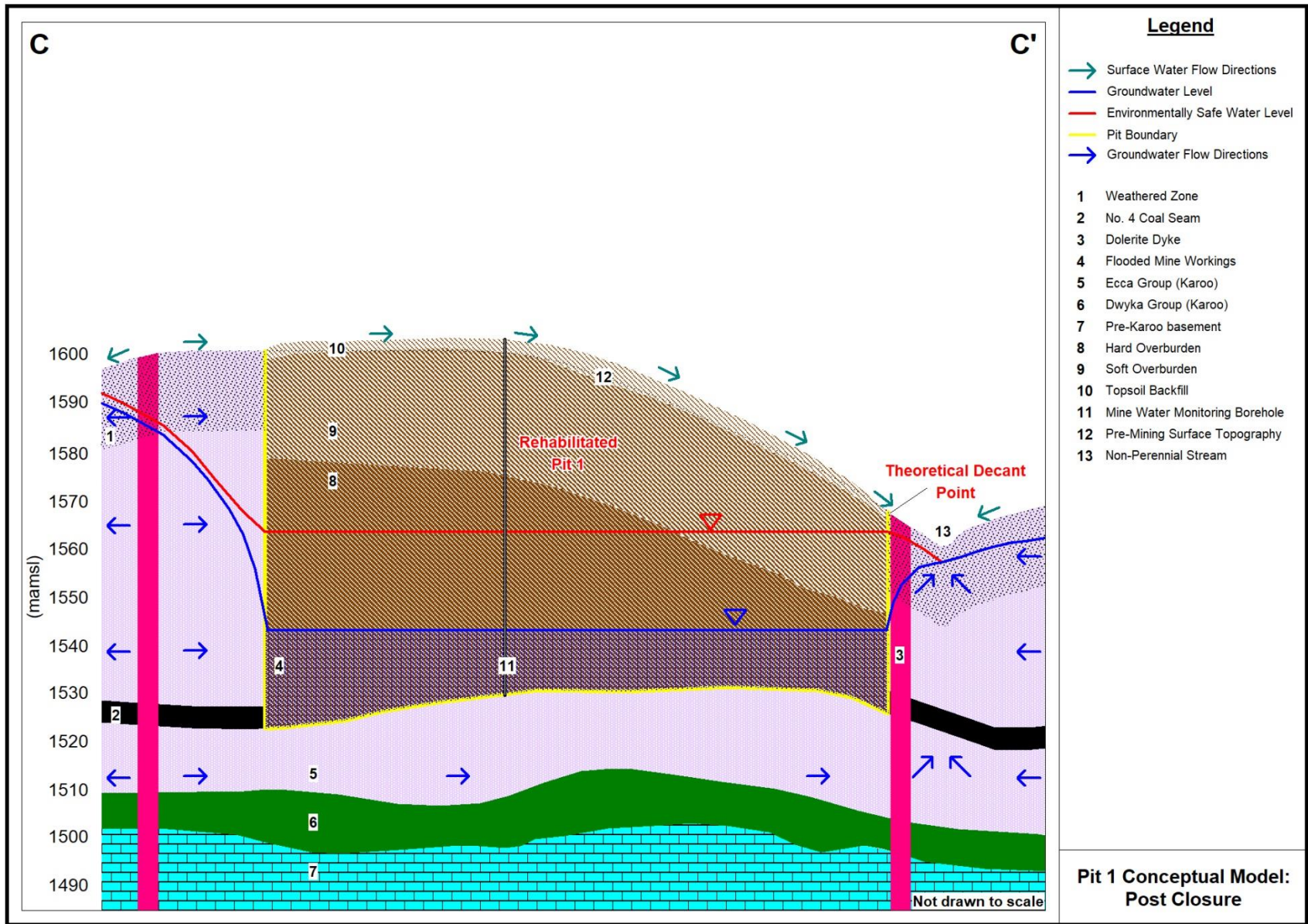


Figure 6-24: Conceptual Model for Pit 1 Opencast Workings

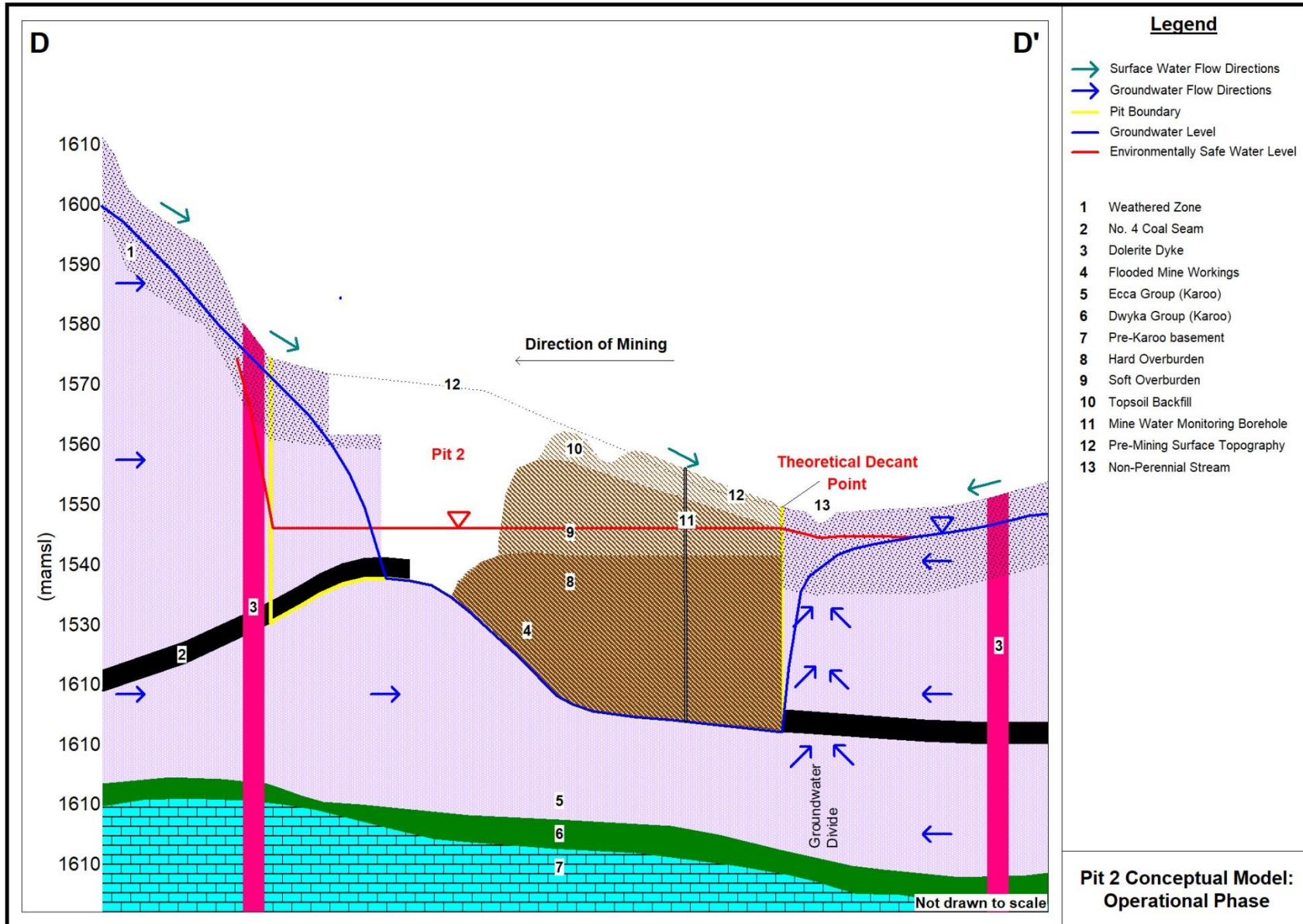


Figure 6-25: Conceptual Model for Pit 2 Opencast Workings

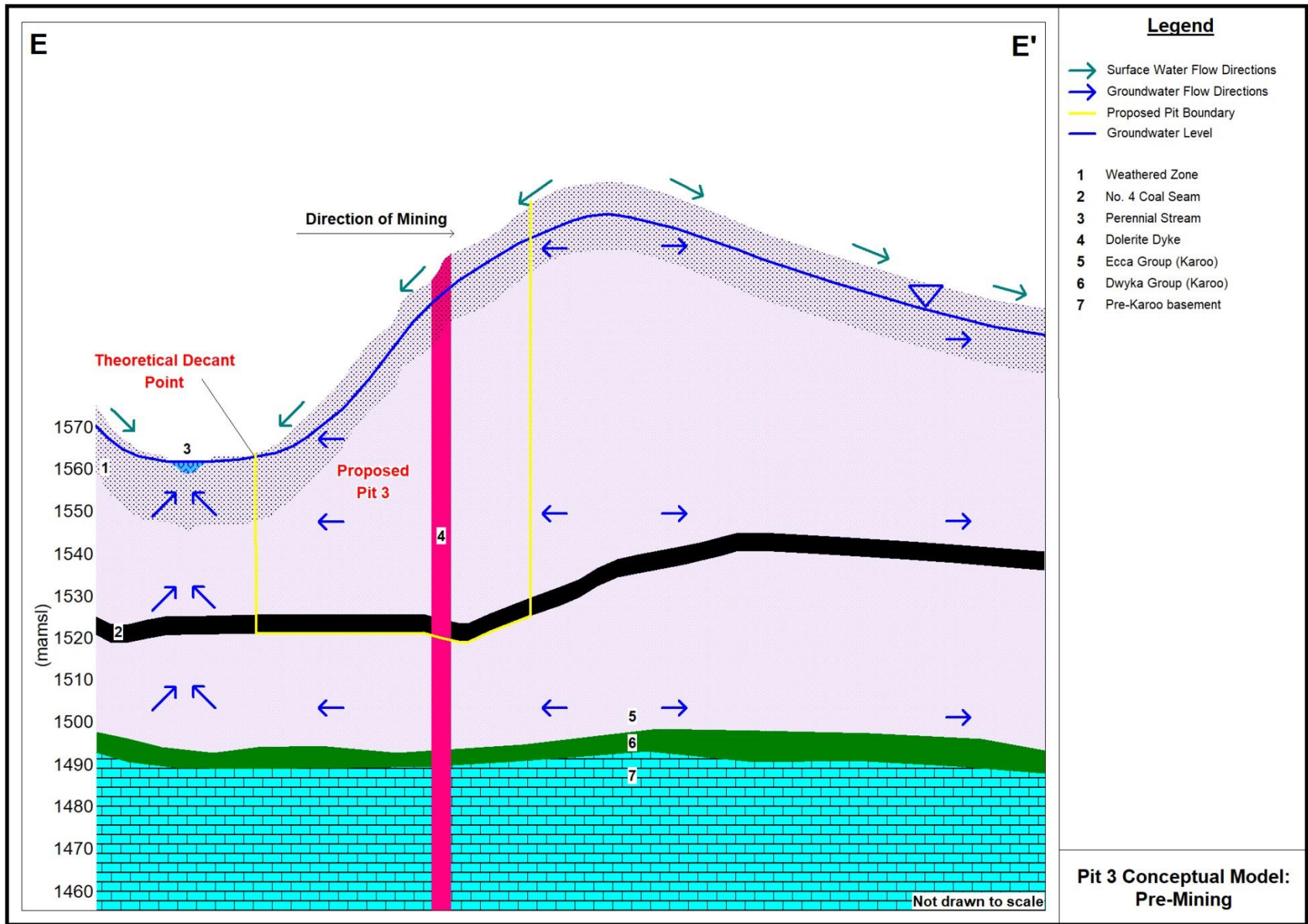


Figure 6-26: Conceptual Model for Pit 3 Opencast Workings

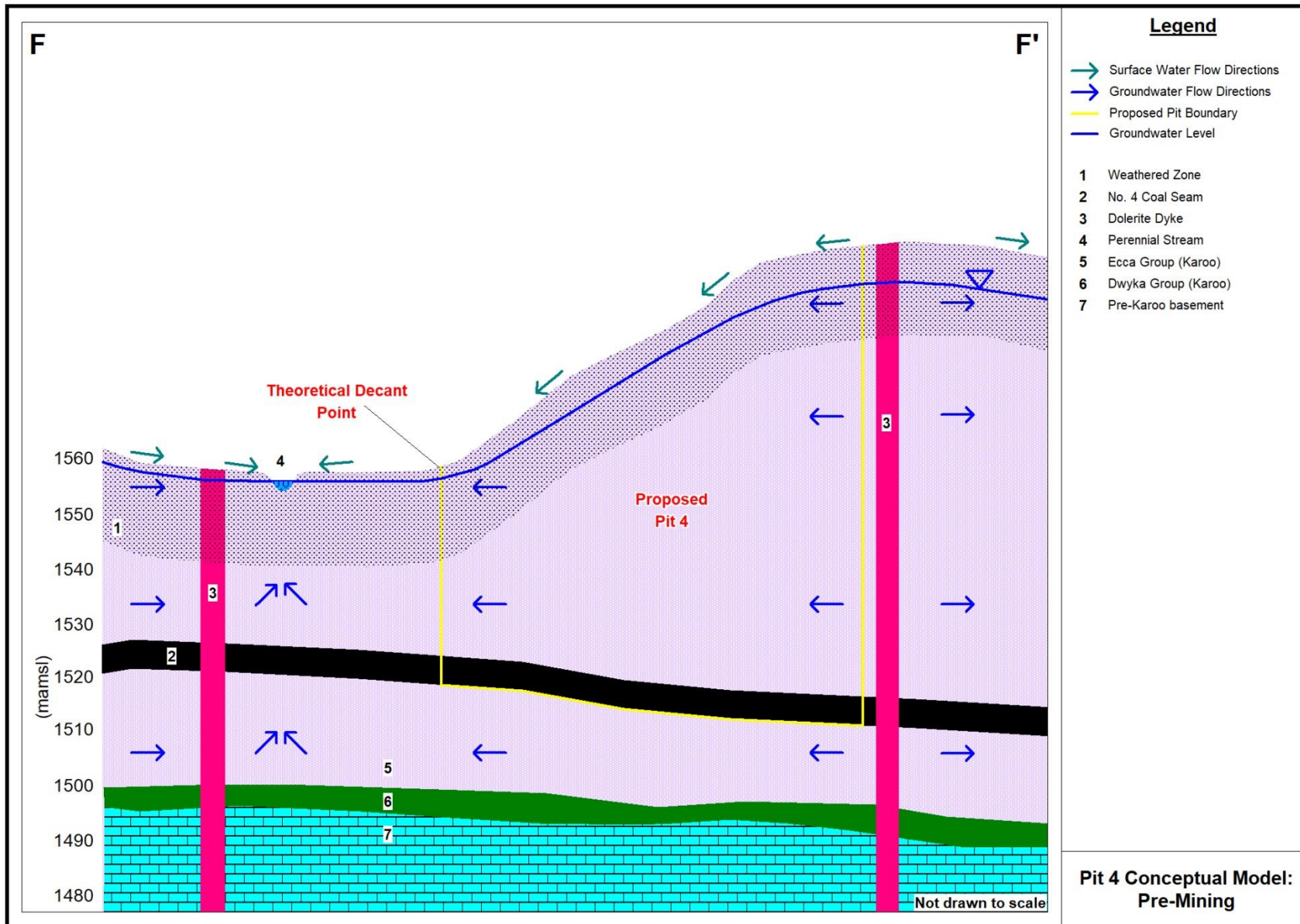


Figure 6-27: Conceptual Model for Pit 4 Opencast Workings

### 6.7.2 Underground Mining

Coal in the study area is only mined from the No.4 Coal Seam of the Witbank Coal Field. The floor of the coal seam varies in depth between 10 *mbgl* and 92 *mbgl* with an average depth of 64 *m*. These values are based on the data collected from the more than 1200 exploration boreholes in the study area. The matrix above the coal seam is mainly made up the weathered zone aquifer and the deeper fractured aquifer with the possibility of localised perched conditions in certain areas.

Bord and pillar is the only underground mining method employed in the study area with an average mining thickness of 3.5 *m*. Roughly 65% of the coal seam in the underground sections will be removed with the remaining 35% staying in tact as pillars. Underground mining in the study area is limited to the deeper aquifers.

3-Dimensional conceptual models have been created in order to demonstrate the geohydrological changes that are associated with the pre-mining, operational and post closure stages of mining for a typical underground section. The 3-dimensional conceptual models are depicted as the following figures:

- Figure 6-28: Conceptual Sketch of Underground Mining Area – Pre-Mining Phase
  - Figure 6-29: Conceptual Sketch of Underground Mining Area – Operational Phase
  - Figure 6-30: Conceptual Sketch of Underground Mining Area – Post Closure Phase
- Pre-mining conditions

Mining in an area will result in various changes to the geohydrological conditions of an area. In order to effectively manage the use of groundwater in an area, it is very important to have a good idea of the geohydrological conditions before mining commences. The following conditions were measured in the study area:

- The natural water levels range between 1.59 *m* and 17.27 *m* with a harmonic mean of 4.68 *m*.
- The hydraulic conductivity of the deeper aquifers in the study area is expected to be 0.006 *m/day*.
- The measured storativity for the deep aquifer in the area ranges between 0.43% and 0.55% with an average storativity of 0.49%
- An average porosity of 4.9% was measured from a range varying from 4.3% to 5.5%.
- Natural recharge from rainfall into the deeper aquifer is expected to be at 1% (7*mm/annum*) with an average total rainfall of 716 *mm/annum*.

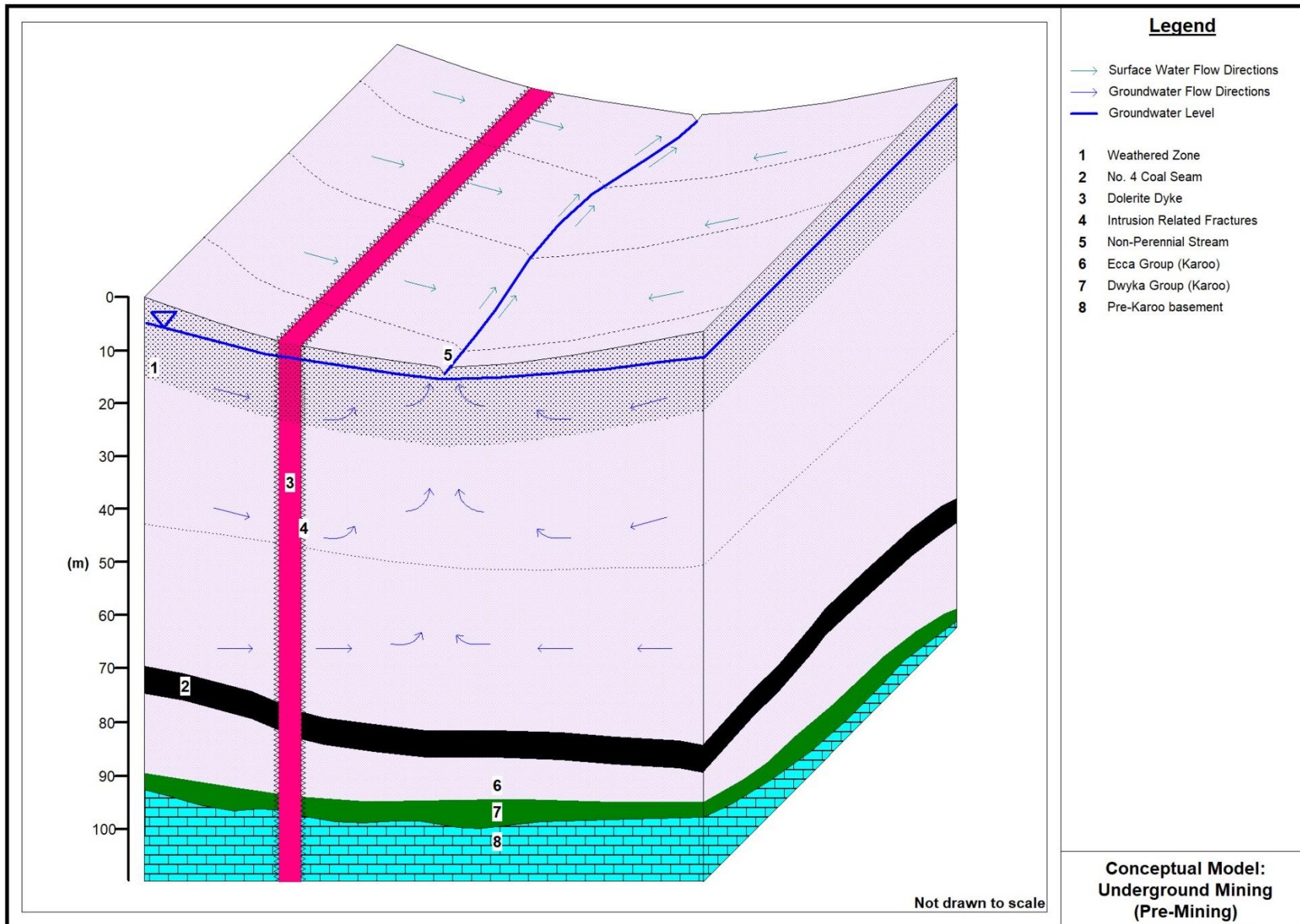


Figure 6-28: Conceptual Sketch of Underground Mining Area – Pre-Mining Phase

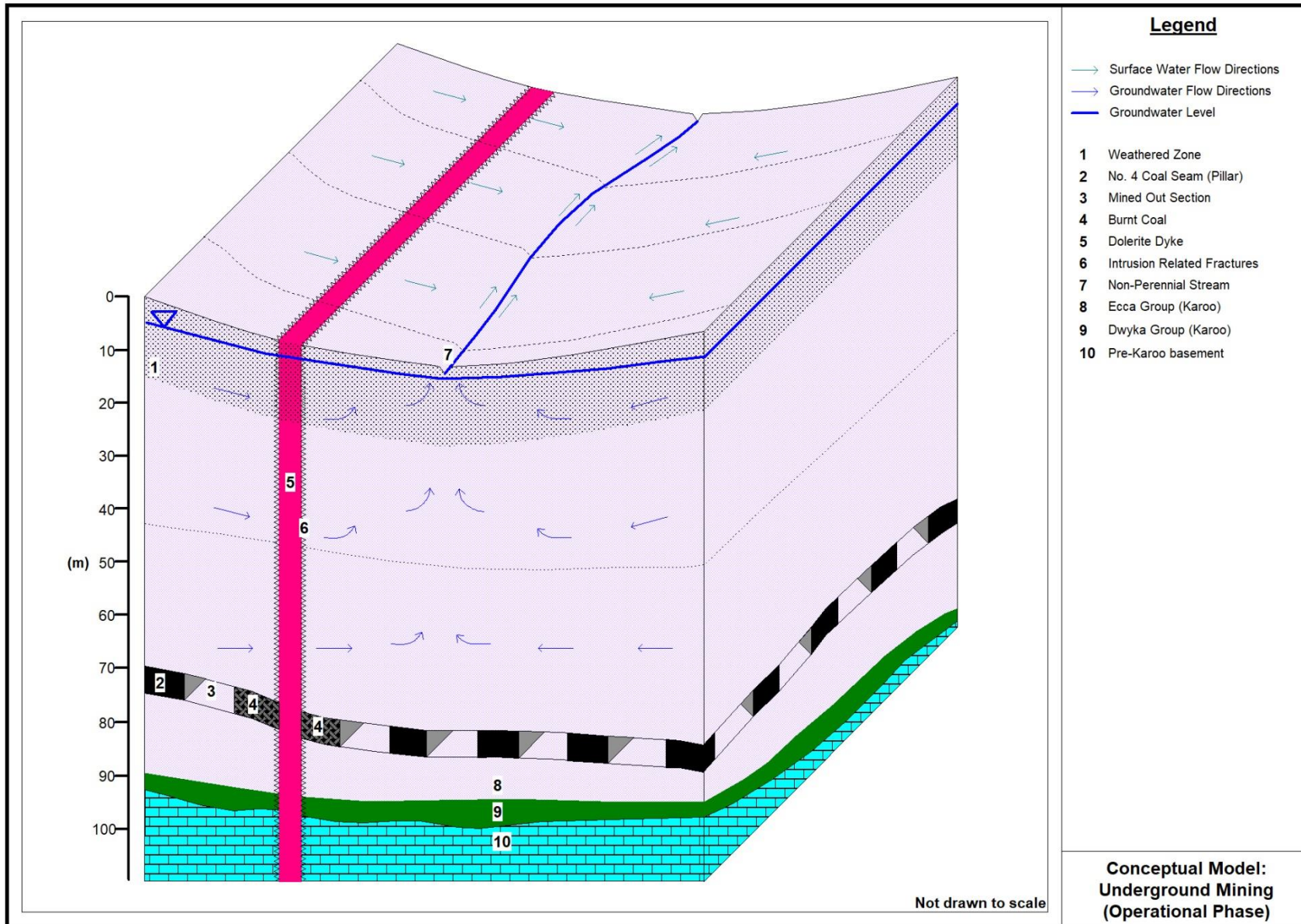


Figure 6-29: Conceptual Sketch of Underground Mining Area – Operational Phase

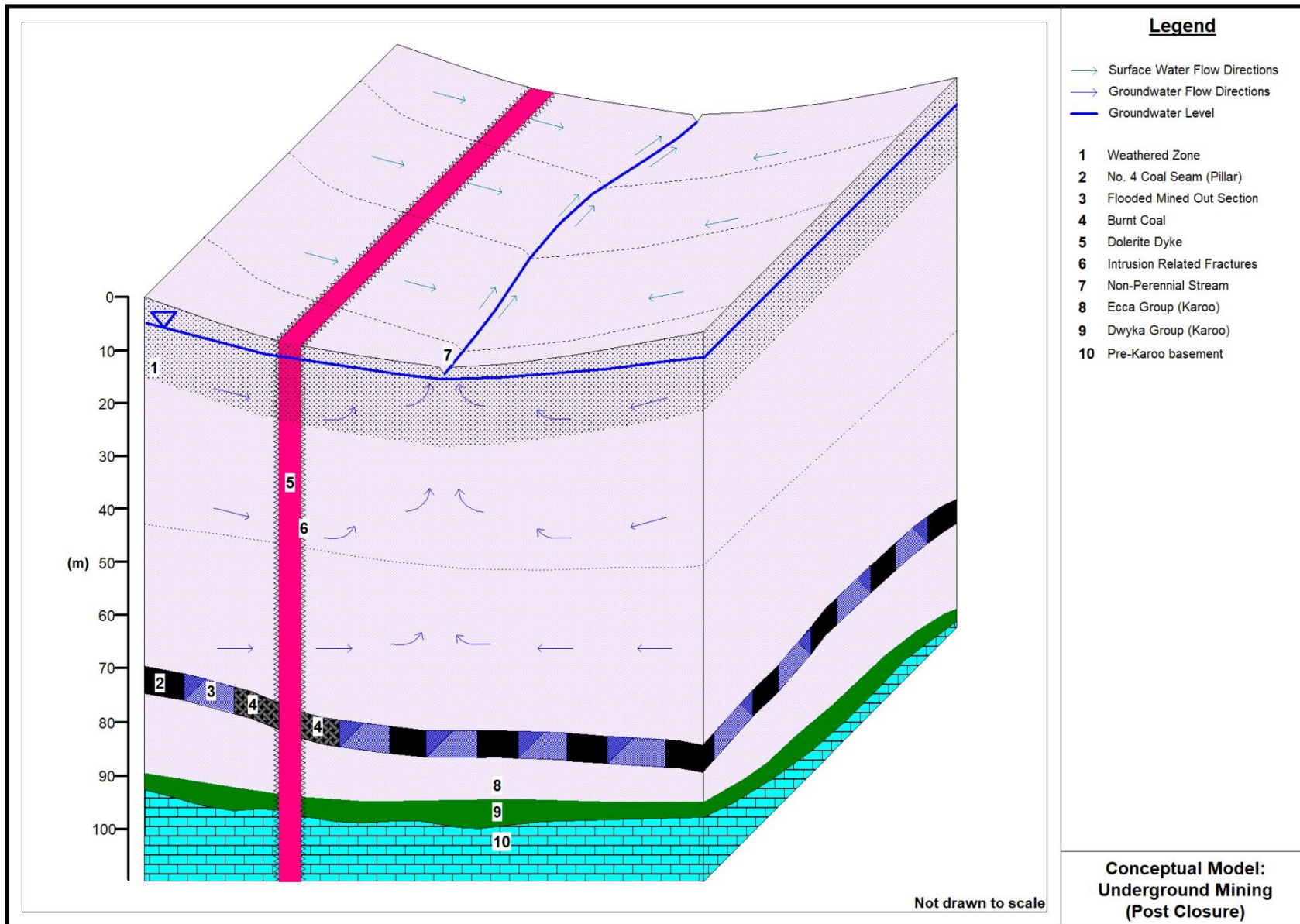


Figure 6-30: Conceptual Sketch of Underground Mining Area – Post Closure Phase

#### 6.7.2.1 Operational Phase

During the operational phase, all the active sections as well as the main underground roadways between active sections and the shaft is kept dry. Due to the depth of mining and coal safety factors employed, the bord and pillar underground mining will have no major geohydrological impact on the overlying aquifers. No goaf formations are expected to occur and the formations above the underground workings will remain intact and no preferential pathways will form as a result of mining. Natural groundwater levels in the area will remain intact during the operational phase. The recharge from rainfall into the underground workings will remain the same as the recharge from rainfall into the surrounding aquifers. A recharge of 1% (7mm/annum) is thus expected in both the aquifer and 1.5% for the underground workings. Storage in the total underground mining area will be 65% in the void as 35% of the workings are left as pillars.

#### 6.7.2.2 Post Closure Phase

Once the coal has been mined, the underground workings will be allowed to flood (Figure 6-30). Certain sections of the underground workings can be sealed off and flooded during the operational phase already, whilst underground mining still takes place in other sections. The rate at which the underground workings will flood is dependent on the rainfall, recharge from rainfall and influences from groundwater influx driven by the hydraulic conductivity of the surrounding aquifers.

The rate of recharge from rainfall into the underground working will increase if there are any preferential pathways above the mining. Dykes, faults and other geological fractures may also act as preferential pathways into the void.

#### **6.7.3 Opencast Mining**

Opencast mining in the study area generally employs the roll over mining method. During the operational phase the topsoil, soft overburden and hard overburden is removed from the opencast workings and stockpiled in designated areas. As mining commences, the material gets backfilled into the mined out sections. The hard overburden is backfilled first, followed by the soft overburden and finally the soft overburden on top. The topsoil is re-vegetated at the surface in order to create stability in the backfill material.

3-dimensional conceptual models have been created in order to demonstrate the geohydrological changes that are associated with the pre-mining, operational and post

closure stages of mining for a typical underground section. The 3-dimensional conceptual models are depicted as the following figures:

- Figure 6-31: Conceptual Sketch of Opencast Mining Area – Pre-Mining Phase
- Figure 6-32: Conceptual Sketch of Opencast Mining Area – Operational Phase
- Figure 6-33: Conceptual Sketch of Opencast Mining Area – Post Closure Phase Pre-mining conditions

The following conditions exist within the aquifers surrounding the opencast mining in the study area:

- The natural water levels range between 1.59 *m* and 17.27 *m* with a harmonic mean of 4.68 *m*.
- The average weathering depth in the study area is 15.45 *m*.
- The hydraulic conductivity of the shallow weathered zone aquifers in the study area is expected to be 0.01 *m/day*.
- The measured storativity for the weathered aquifer in the area ranges between 3.65% and 5.80% with an average storativity of 4.45%
- An average porosity of 8.9% was measured from a range varying from 7.3% to 11.6%.
- Natural recharge from rainfall into the shallow weathered aquifer is expected to be at 3% (21 *mm/annum*) with an average total rainfall of 716 *mm/annum*.

#### 6.7.3.1 Operational Phase

Recharge from rainfall during the operational phase is expected to be the most, in relation to the recharge in the post closure and pre mining phases, with an estimated 70% recharge into the aquifer as a result of rainfall directly into open voids and an additional 6% of recharge from surface runoff into the pits. The backfill material has a porosity of between 20% and 30% depending on the ratio of backfill material.

It is very important to regularly update the water balance of the mine in order to have a safe working environment as well as an optimized water reticulation in the mine. This is especially important during the operational phase as recharge is very high during this phase and possibilities for water storage need to be investigated.

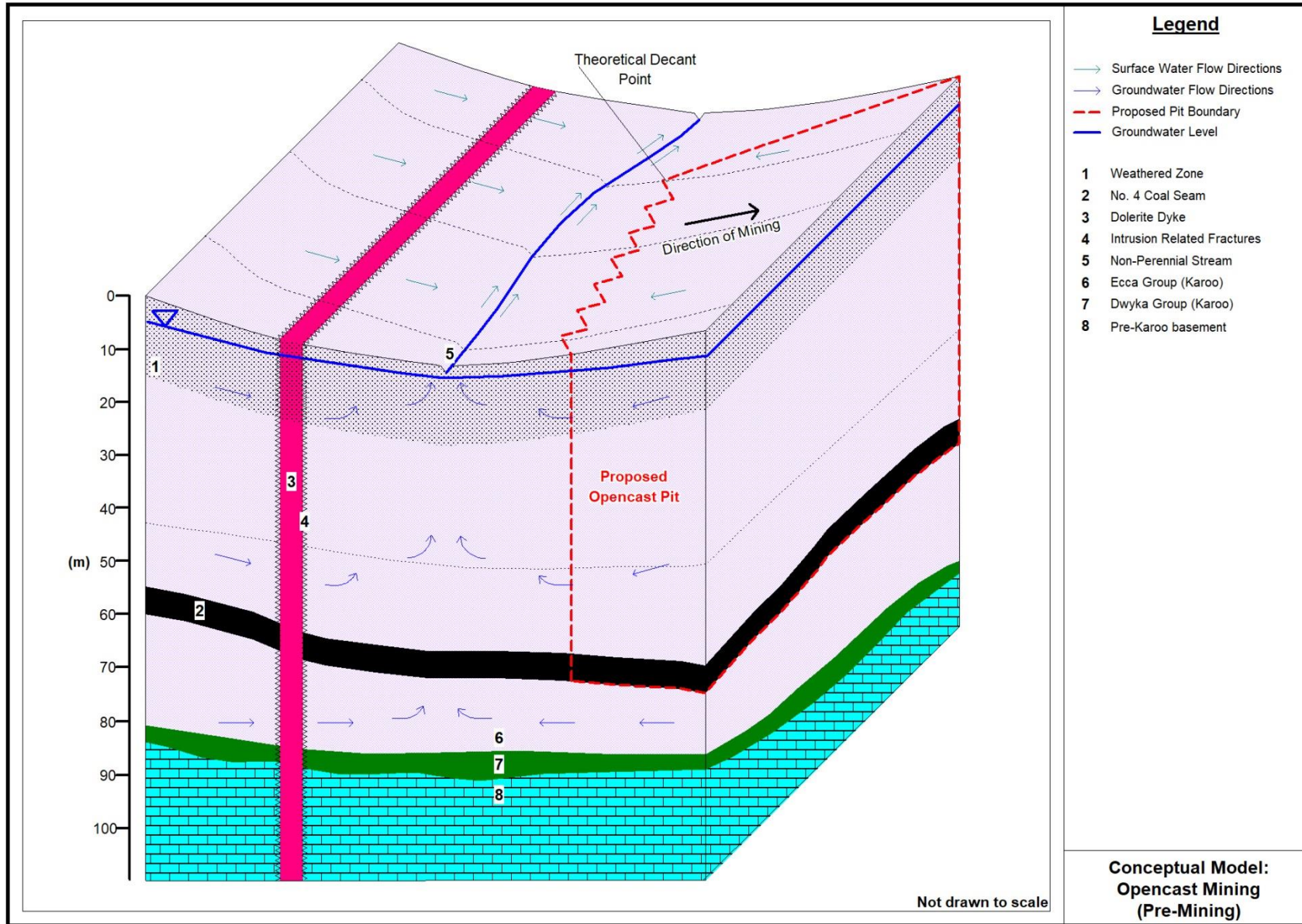


Figure 6-31: Conceptual Sketch of Opencast Mining Area – Pre-Mining Phase

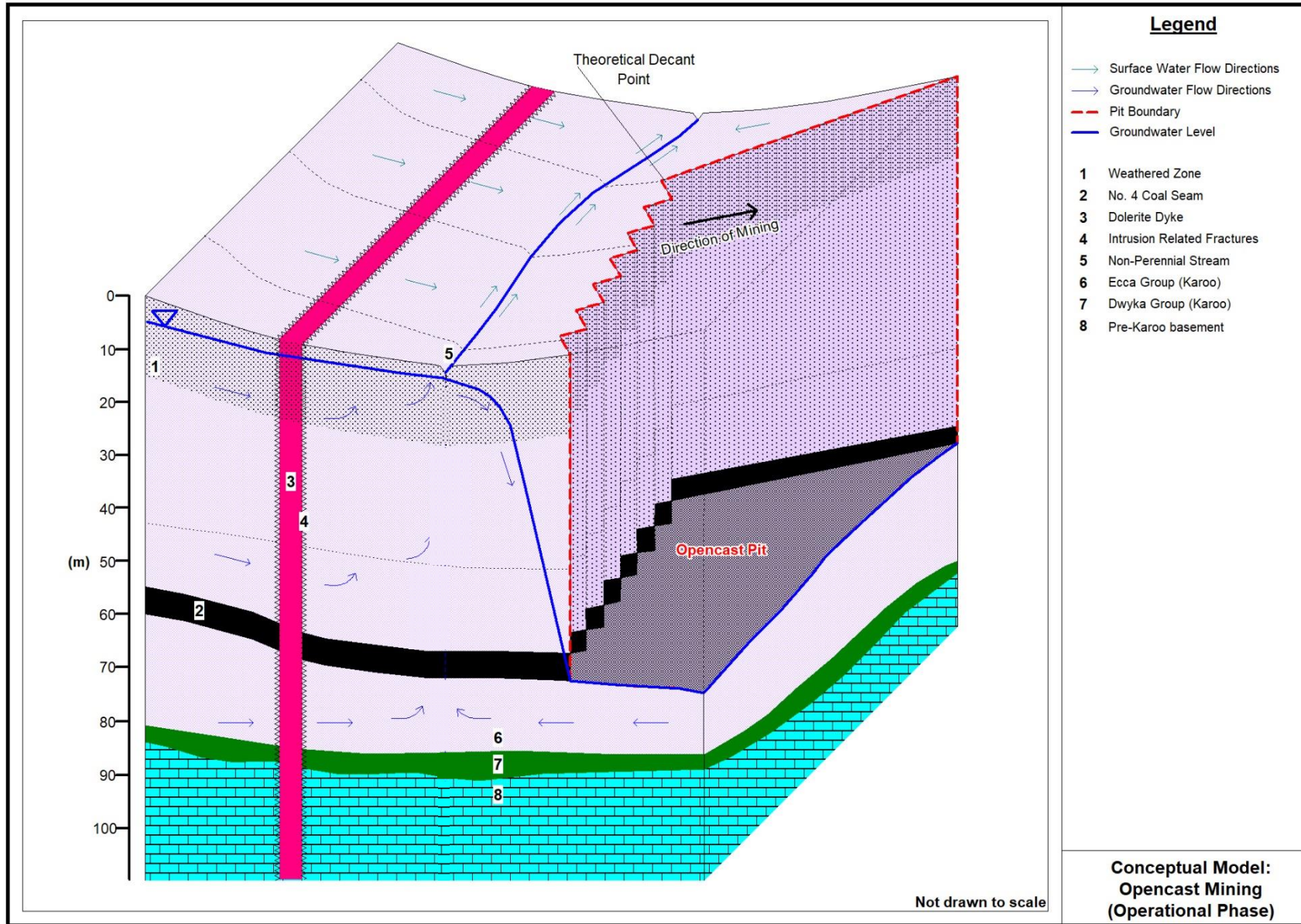


Figure 6-32: Conceptual Sketch of Opencast Mining Area – Operational Phase

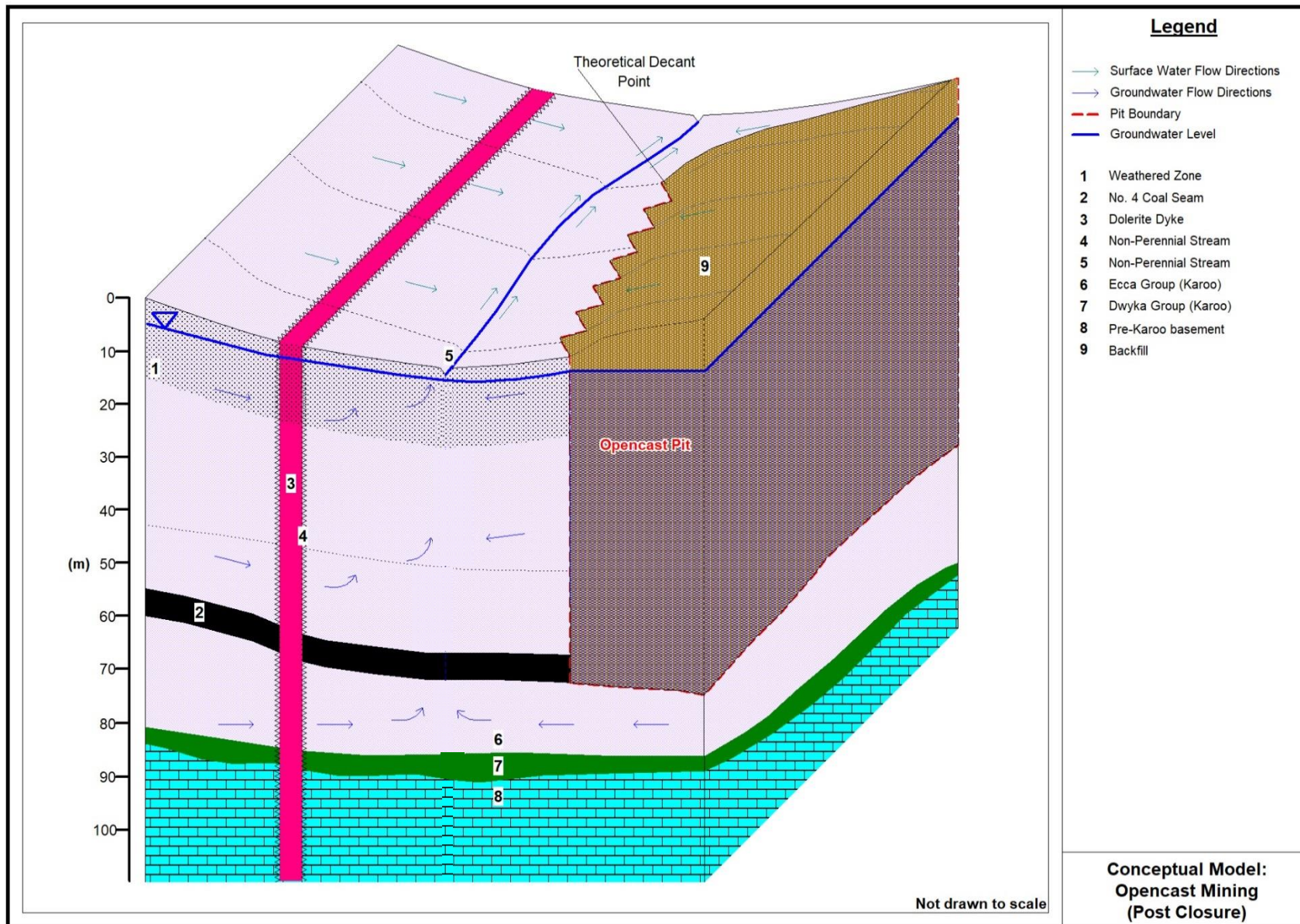


Figure 6-33: Conceptual Sketch of Opencast Mining Area – Post Closure Phase

Water is constantly abstracted from opencast sections in order to mine safely and effectively. This pumping creates a cone of depression around the operational opencast sections. The shape and magnitude of the cone of depression is dependent on many factors including the depth of mining, abstraction position, and rate of pumping as well as the hydraulic conductivity of the surrounding aquifers. This creates a disturbance (reverse) in the natural flow direction of the groundwater in the aquifers and causes water from aquifer to move towards the mine workings, as seen in Figure 6-32.

#### 6.7.3.2 Post Closure Phase

After mining is completed at an opencast pit, the final backfilling, shaping and re-vegetation can commence. The rate at which the pit will flood is dependent on the porosity (20% - 25%) and the rainfall recharge. Recharge from rainfall into a fully rehabilitated opencast pit ranges between 14% and 25%, whereas recharge into a partially rehabilitated pit can be as high as 65% (Muller and Turner, 2016).

As the rehabilitated pits are flooded, the water level within the pit will rise until it reaches the decant elevation. If the water level is not kept at an optimised management water level below the decant elevation, mine water will decant on surface. The 3 dimensional post-closure conceptual models display a water level which is kept at an optimised management level.

# **7. SENSITIVITY ANALYSIS FOR A MINE WATER BALANCE AND SUBSEQUENT OPTIMISATION OF MINE WATER MANAGEMENT**

## **7.1 INTRODUCTION**

In order to illustrate the significance of collecting accurate data to calculate a mine water balance, a sensitivity analysis is illustrated to differentiate between three outcomes of a mine water balance using input parameters collected from both literature and a conceptual case study.

Due to the depths of mining operations within the mining right boundary of the conceptual case study, as well as the nature of the geohydrological environment in which the mining takes place, groundwater and rainfall recharge will accumulate in both opencast and underground workings. Any water which accumulates in the workings is classified as mine water and may not be directly discharge into the water recourses. The water needs to be re-used, stored or treated before it can be discharged into any surface water resource. For this reason it is vital to calculate the amount of water that will accumulate in the workings during the operational and post closure phases of mining. An inadequate amount of water is being re-used during the operational phase and no water will be reused during the post closure phase. Using storage facilities such as dams and reservoirs are an option that has been employed by a lot of mines in the Witbank Coal Field for the purpose of storing mine water during the operational phase. However, the storage of mine water in defunct and rehabilitated workings is an option that must be investigated as part of the management of mine water. For this reason, it is important to also calculate the storage capacities associated with the workings from a water management perspective. The storage capacity for each of the workings is calculated by means of a storage capacity assessment. The results from the three mine water balance scenarios is further employed to calculate the time in years that it will take in order to fill up each of the mine workings post closure as well as to manage the reticulation thereof during the operational phase.

The relevance of an accurate mine water balance is discussed in terms of the different outcomes of the mine water balance and storage capacity assessment. Critical parameters and requirements of a mine water balance is discussed in terms of optimising the management of mine water in opencast and underground sections of a coal mine in the Witbank Coal Field.

## **7.2 ASSUMPTIONS**

### **7.2.1 Opencast Mining Operations**

The following assumptions were made during the calculations of the mine water balance for the opencast sections:

- There will be no deviation from the planned yearly mining schedules.
- Mining will only take place on the No.4 Coal Seam by means of roll over opencast mining methods as indicated previously.
- The topsoil and overburden will be stripped and stockpiled separately.
- The pits will be backfilled and rehabilitated with overburden and topsoil.
- The backfill material of the current and proposed pits will be shaped to ensure that the surface is free draining and will be re-vegetated.
- The backfill material is expected to have a porosity of 25%.
- The rehabilitation of the final cut and final rehabilitation of the pits will be completed within 2 years of active mining at the pit.
- A total of 50% of the section completed within the last 2 years will be seen as fully rehabilitated and the other 50% as partially rehabilitated.
- The groundwater recharge will be uniform across each of the respective recharge surface areas.
- Surface water runoff will be directed away from the opencast workings. No surface water runoff will accumulate in the opencast workings.

### **7.2.2 Underground Mining**

The following assumptions were made during the calculation of the groundwater balance for the underground mining operations within the mining right area:

- There will be no deviation from the planned yearly mining schedules.
- Mining will only take place on the No.4 Coal Seam by means of bord and pillar mining.
- The height of the underground workings will remain 3.5 m across the entire extent of the underground workings.
- Only 65% of the coal will be extracted from the underground workings. The remaining 35% will remain in the workings as pillars. No increased coal extraction will take place.
- No goaf structures will occur above the underground workings.
- The coal has an in-situ moisture content of 7%.
- No ventilation compartments exist within the underground workings.
- Water loss through ventilation is consistent throughout the life of mine.

- The coal that is removed from the underground workings has a moisture content of 5% at the surface.
- The average expected temperature and relative humidity of the underground workings is 25 °C and 75% respectively.
- The ventilation from the underground workings is proportional to the number of sections being mined in the underground workings.
- The underground workings and ventilation shafts will be sealed off at the end of the Operational & Post Closure Phase Water Balance(s)

### 7.3 MINE WATER BALANCE SCENARIOS

A summary indicating the areas of the sections, mining years and theoretical decant elevations of the opencast and underground mining operations is given as Table 7-1.

**Table 7-1: Summary of the mining operations**

Description	Total Area (m <sup>2</sup> )	Year Start(ed)	Year End(ed)	Decant Elevation (mamsl)
<b>Opencast Mining Operations</b>				
<b>Pit 1</b>	2 306 202	Year 10	Year 14	1572
<b>Pit 2</b>	1 496 653	Year 15	Year 19	1553
<b>Pit 3</b>	2 974 748	Year 18	Year 25	1559
<b>Pit 4</b>	2 415 295	Year 18	Year 24	1554
<b>Underground Mining Operations</b>				
<b>Block A</b>	11 421 085	Year 1	Year 19	1568
<b>Block B</b>	2 150 400	Year 4	Year 9	1588

Three scenarios with different parameters are developed in order to demonstrate the sensitivity of a water balance. The three scenarios will be as follows:

- Highest parameters from the generic ranges (Table 7-2)
- The lowest parameters from the generic ranges (Table 7-3)
- Measured site specific parameters (Table 7-4)

The following parameters will be varied in the three scenarios:

- Recharge from rainfall into the mine workings
- Hydraulic conductivity and storativity of the aquifer

**Table 7-2: Water Balance Scenario 1 Varying Parameters**

Parameter		Value
Recharge from Rainfall	Into Opencast Mine Void	100%
	Into Partially Rehabilitated Opencast Mine	75%
	Into Fully Rehabilitated Opencast Mine	25%
	Into Underground Mine	10%
Hydraulic Conductivity	Weathered Karoo Aquifer	0.4 m/day
Storativity	Weathered Karoo Aquifer	9%

**Table 7-3: Water Balance Scenario 2 Varying Parameters**

Parameter		Value
Recharge from Rainfall	Into Opencast Mine Void	100%
	Into Partially Rehabilitated Opencast Mine	65%
	Into Rehabilitated Opencast Mine	14%
	Into Underground Mine	1%
Hydraulic Conductivity	Weathered Karoo Aquifer	0.01 m/day
Storativity	Weathered Karoo Aquifer	1%

**Table 7-4: Water Balance Scenario 3 Varying Parameters**

Parameter		Value
Recharge from Rainfall	Into Opencast Mine Void	100%
	Into Partially Rehabilitated Opencast Mine	65%
	Into Rehabilitated Opencast Mine	19%
	Into Underground Mine	1.5%
Hydraulic Conductivity	Weathered Karoo Aquifer	0.09 m/day
Storativity	Weathered Karoo Aquifer	4.45%

The recharge into the mine workings is calculated with the mine water balances presented in the following sections:

- Water Balance Scenario 1 (Section 7.4)
- Water Balance Scenario 2 (Section 7.5)
- Water Balance Scenario 3 (Section 7.6)

## 7.4 WATER BALANCE SCENARIO 1

### 7.4.1 Underground Mining

**Table 7-5: Mine Water Balance for Block A (Scenario 1)**

Year	Yearly Mining Area (m <sup>2</sup> )	Mined Out Area (m <sup>2</sup> )	Cumulative Area (m <sup>2</sup> )	In-situ Ground-water (m <sup>3</sup> /day)	Recharge on Workings (m <sup>3</sup> /day)	Water vapour gained through ventilation (m <sup>3</sup> /day)	Total Recharge (m <sup>3</sup> /day)	Coal Extracted (m <sup>3</sup> )	Ground-water lost with Coal (m <sup>3</sup> /day)	Water vapour lost through ventilation (m <sup>3</sup> /day)	Total Losses (m <sup>3</sup> /day)	Nett Water recharge (m <sup>3</sup> /day)
Year 18	273 938	10 806 130	11 080 068	294	2 174	250	2 716	1 532 523	-210	-520	-730	<b>1 986</b>
Year 19	341 017	11 080 068	11 421 085	237	2 240	256	2 733	1 235 925	-169	-523	-692	<b>2 041</b>
Post Closure	0	11 421 085	11 421 085	0	2 240	0	2 240	-	0	0	0	<b>2 240</b>

**Table 7-6: Mine Water Balance for Block B (Scenario 1)**

Year	Yearly Mining Area (m <sup>2</sup> )	Mined Out Area (m <sup>2</sup> )	Cumulative Area (m <sup>2</sup> )	In-situ Ground-water (m <sup>3</sup> /day)	Recharge on Workings (m <sup>3</sup> /day)	Water vapour gained through ventilation (m <sup>3</sup> /day)	Total Recharge (m <sup>3</sup> /day)	Coal Extracted (m <sup>3</sup> )	Ground-water lost with Coal (m <sup>3</sup> /day)	Water vapour lost through ventilation (m <sup>3</sup> /day)	Total Losses (m <sup>3</sup> /day)	Nett Water recharge (m <sup>3</sup> /day)
Post Closure	-	2 150 400	2 150 400	-	422	-	422	-	-	-	-	<b>422</b>

## 7.4.2 Opencast Mining

**Table 7-7: Mine Water Balance for Pit 1 (Scenario 1)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Post Closure	-	-	2 306 202	2 306 202	-	-	1 131	192	-	<b>1 323</b>

**Table 7-8: Mine Water Balance for Pit 2 (Scenario 1)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Year 18	242 346	0	993 293	1 235 639	475	0	606	182	15	<b>1 278</b>
Year 19	261 014	121 173	1 114 466	1 496 653	512	178	734	212	16	<b>1 653</b>
Post Closure	0	0	1 496 653	1 496 653	0	0	734	212	0	<b>946</b>

**Table 7-9: Mine Water Balance for Pit 3 (Scenario 1)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Year 18	310 638	0	0	310 638	609	0	0	156	19	<b>784</b>
Year 19	354 249	155 319	155 319	664 887	695	229	76	158	22	<b>1 179</b>
Year 20	332 055	177 125	487 763	996 942	651	261	239	229	20	<b>1 401</b>
Year 21	377 262	166 028	830 915	1 374 204	740	244	407	151	23	<b>1 566</b>
Year 22	330 436	188 631	1 185 573	1 704 640	648	278	581	288	20	<b>1 816</b>
Year 23	376 911	165 218	1 539 422	2 081 551	739	243	755	361	23	<b>2 121</b>
Year 24	396 201	188 456	1 893 096	2 477 752	777	277	928	195	24	<b>2 203</b>
Year 25	496 996	198 101	2 279 652	2 974 748	975	291	1 118	194	31	<b>2 609</b>
Post Closure	0	0	2 974 748	2 974 748	0	0	1 459	220	0	<b>1 678</b>

**Table 7-10: Mine Water Balance for Pit 4 (Scenario 1)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Year 18	353 886	0	0	353 886	694	0	0	59	22	<b>775</b>
Year 19	398 448	176 943	176 943	752 334	782	260	87	89	25	<b>1 243</b>
Year 20	376 754	199 224	553 110	1 129 088	739	293	271	134	23	<b>1 461</b>
Year 21	332 205	188 377	940 711	1 461 293	652	277	461	181	20	<b>1 592</b>
Year 22	354 404	166 103	1 295 191	1 815 697	695	244	635	181	22	<b>1 778</b>
Year 23	355 244	177 202	1 638 495	2 170 941	697	261	804	181	22	<b>1 964</b>
Year 24	244 354	177 622	1 993 319	2 415 295	479	261	978	315	15	<b>2 048</b>
Post Closure	0	0	2 415 295	2 415 295	0	0	1 184	315	0	<b>1 499</b>

## 7.5 WATER BALANCE SCENARIO 2

### 7.5.1 Underground Mining

**Table 7-11: Mine Water Balance for Block A (Scenario 2)**

Year	Yearly Mining Area (m <sup>2</sup> )	Mined Out Area (m <sup>2</sup> )	Cumulative Area (m <sup>2</sup> )	In-situ Ground-water (m <sup>3</sup> /day)	Recharge on Workings (m <sup>3</sup> /day)	Water vapour gained through ventilation (m <sup>3</sup> /day)	Total Recharge (m <sup>3</sup> /day)	Coal Extracted (m <sup>3</sup> )	Ground-water lost with Coal (m <sup>3</sup> /day)	Water vapour lost through ventilation (m <sup>3</sup> /day)	Total Losses (m <sup>3</sup> /day)	Nett Water recharge (m <sup>3</sup> /day)
Year 18	273 938	10 806 130	11 080 068	294	217	250	760	1 532 523	-210	-520	-730	<b>30</b>
Year 19	341 017	11 080 068	11 421 085	237	224	256	717	1 235 925	-169	-523	-692	<b>25</b>
Post Closure	0	11 421 085	11 421 085	0	224	0	224	-	0	0	0	<b>224</b>

**Table 7-12: Mine Water Balance for Block B (Scenario 2)**

Year	Yearly Mining Area (m <sup>2</sup> )	Mined Out Area (m <sup>2</sup> )	Cumulative Area (m <sup>2</sup> )	In-situ Ground-water (m <sup>3</sup> /day)	Recharge on Workings (m <sup>3</sup> /day)	Water vapour gained through ventilation (m <sup>3</sup> /day)	Total Recharge (m <sup>3</sup> /day)	Coal Extracted (m <sup>3</sup> )	Ground-water lost with Coal (m <sup>3</sup> /day)	Water vapour lost through ventilation (m <sup>3</sup> /day)	Total Losses (m <sup>3</sup> /day)	Nett Water recharge (m <sup>3</sup> /day)
Post Closure	-	2 150 400	2 150 400	-	42	-	42	-	-	-	-	<b>42</b>

## 7.5.2 Opencast Mining

**Table 7-13: Mine Water Balance for Pit 1 (Scenario 2)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Post Closure	-	-	2 306 202	2 306 202	-	-	633	5	-	<b>638</b>

**Table 7-14: Mine Water Balance for Pit 2 (Scenario 2)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Year 18	242 346	0	993 293	1 235 639	475	0	339	5	2	<b>821</b>
Year 19	261 014	121 173	1 114 466	1 496 653	512	155	411	5	2	<b>1 085</b>
Post Closure	0	0	1 496 653	1 496 653	0	0	411	5	0	<b>416</b>

**Table 7-15: Mine Water Balance for Pit 3 (Scenario 2)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Year 18	310 638	0	0	310 638	609	0	0	4	2	<b>615</b>
Year 19	354 249	155 319	155 319	664 887	695	198	43	4	2	<b>942</b>
Year 20	332 055	177 125	487 763	996 942	651	226	134	6	2	<b>1 019</b>
Year 21	377 262	166 028	830 915	1 374 204	740	212	228	4	3	<b>1 186</b>
Year 22	330 436	188 631	1 185 573	1 704 640	648	241	326	7	2	<b>1 224</b>
Year 23	376 911	165 218	1 539 422	2 081 551	739	211	423	9	3	<b>1 384</b>
Year 24	396 201	188 456	1 893 096	2 477 752	777	240	520	5	3	<b>1 545</b>
Year 25	496 996	198 101	2 279 652	2 974 748	975	253	626	5	3	<b>1 862</b>
Post Closure	0	0	2 974 748	2 974 748	0	0	817	5	0	<b>822</b>

**Table 7-16: Mine Water Balance for Pit 4 (Scenario 2)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Year 18	353 886	0	0	353 886	694	0	0	1	2	<b>698</b>
Year 19	398 448	176 943	176 943	752 334	782	226	49	2	3	<b>1 061</b>
Year 20	376 754	199 224	553 110	1 129 088	739	254	152	3	3	<b>1 151</b>
Year 21	332 205	188 377	940 711	1 461 293	652	240	258	5	2	<b>1 157</b>
Year 22	354 404	166 103	1 295 191	1 815 697	695	212	356	5	2	<b>1 270</b>
Year 23	355 244	177 202	1 638 495	2 170 941	697	226	450	5	2	<b>1 380</b>
Year 24	244 354	177 622	1 993 319	2 415 295	479	226	547	8	2	<b>1 263</b>
Post Closure	0	0	2 415 295	2 415 295	0	0	663	8	0	<b>671</b>

## 7.6 WATER BALANCE SCENARIO 3

### 7.6.1 Underground Mining

**Table 7-17: Mine Water Balance for Block A (Scenario 3)**

Year	Yearly Mining Area (m <sup>2</sup> )	Mined Out Area (m <sup>2</sup> )	Cumulative Area (m <sup>2</sup> )	In-situ Ground-water (m <sup>3</sup> /day)	Recharge on Workings (m <sup>3</sup> /day)	Water vapour gained through ventilation (m <sup>3</sup> /day)	Total Recharge (m <sup>3</sup> /day)	Coal Extracted (m <sup>3</sup> )	Ground-water lost with Coal (m <sup>3</sup> /day)	Water vapour lost through ventilation (m <sup>3</sup> /day)	Total Losses (m <sup>3</sup> /day)	Nett Water recharge (m <sup>3</sup> /day)
Year 18	273 938	10 806 130	11 080 068	120	326	250	695	623 209	-85	-520	-605	<b>89</b>
Year 19	341 017	11 080 068	11 421 085	149	336	256	741	775 814	-106	-523	-629	<b>112</b>
Post Closure	0	11 421 085	11 421 085	0	336	0	336	-	0	0	0	<b>336</b>

**Table 7-18: Mine Water Balance for Block B (Scenario 3)**

Year	Yearly Mining Area (m <sup>2</sup> )	Mined Out Area (m <sup>2</sup> )	Cumulative Area (m <sup>2</sup> )	In-situ Ground-water (m <sup>3</sup> /day)	Recharge on Workings (m <sup>3</sup> /day)	Water vapour gained through ventilation (m <sup>3</sup> /day)	Total Recharge (m <sup>3</sup> /day)	Coal Extracted (m <sup>3</sup> )	Ground-water lost with Coal (m <sup>3</sup> /day)	Water vapour lost through ventilation (m <sup>3</sup> /day)	Total Losses (m <sup>3</sup> /day)	Nett Water recharge (m <sup>3</sup> /day)
Post Closure	-	2 150 400	2 150 400	-	63	-	63	-	-	-	-	<b>63</b>

## 7.6.2 Opencast Mining

**Table 7-19: Mine Water Balance for Pit 1 (Scenario 3)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Post Closure	-	-	2 306 202	2 306 202	-	-	860	43	-	<b>903</b>

**Table 7-20: Mine Water Balance for Pit 2 (Scenario 3)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Year 18	242 346	0	993 293	1 235 639	475	0	461	41	7	<b>984</b>
Year 19	261 014	121 173	1 114 466	1 496 653	512	155	558	48	8	<b>1 280</b>
Post Closure	0	0	1 496 653	1 496 653	0	0	558	48	0	<b>606</b>

**Table 7-21: Mine Water Balance for Pit 3 (Scenario 3)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Year 18	310 638	0	0	310 638	609	0	0	35	9	<b>654</b>
Year 19	354 249	155 319	155 319	664 887	695	198	58	36	11	<b>997</b>
Year 20	332 055	177 125	487 763	996 942	651	226	182	52	10	<b>1 121</b>
Year 21	377 262	166 028	830 915	1 374 204	740	212	310	34	11	<b>1 307</b>
Year 22	330 436	188 631	1 185 573	1 704 640	648	241	442	65	10	<b>1 406</b>
Year 23	376 911	165 218	1 539 422	2 081 551	739	211	574	81	11	<b>1 616</b>
Year 24	396 201	188 456	1 893 096	2 477 752	777	240	706	44	12	<b>1 779</b>
Year 25	496 996	198 101	2 279 652	2 974 748	975	253	850	44	15	<b>2 136</b>
Post Closure	0	0	2 974 748	2 974 748	0	0	1 109	49	0	<b>1 158</b>

**Table 7-22: Mine Water Balance for Pit 4 (Scenario 3)**

Year	Open Void (Active Mining) Area (m <sup>2</sup> )	Partially Rehabilitated Area (m <sup>2</sup> )	Fully Rehabilitated Area (m <sup>2</sup> )	Total Pit Area (m <sup>2</sup> )	Recharge into Open Void (m <sup>3</sup> /day)	Recharge into Partially Rehabilitated Area (m <sup>3</sup> /day)	Recharge into Fully Rehabilitated Area (m <sup>3</sup> /day)	Groundwater Influx (m <sup>3</sup> /day)	Interstitial Groundwater (m <sup>3</sup> /day)	Total Water recharge (m <sup>3</sup> /day)
Year 18	353 886	0	0	353 886	694	0	0	13	11	<b>718</b>
Year 19	398 448	176 943	176 943	752 334	782	226	66	20	12	<b>1 105</b>
Year 20	376 754	199 224	553 110	1 129 088	739	254	206	30	11	<b>1 241</b>
Year 21	332 205	188 377	940 711	1 461 293	652	240	351	41	10	<b>1 293</b>
Year 22	354 404	166 103	1 295 191	1 815 697	695	212	483	41	11	<b>1 441</b>
Year 23	355 244	177 202	1 638 495	2 170 941	697	226	611	41	11	<b>1 585</b>
Year 24	244 354	177 622	1 993 319	2 415 295	479	226	743	71	7	<b>1 527</b>
Post Closure	0	0	2 415 295	2 415 295	0	0	900	71	0	<b>971</b>

## 7.7 SENSITIVITY ANALYSIS

A summary of the recharge into the different mine workings across the mining area is tabulated as follows:

- Table 7-23: Natural Water Recharge into the Mine Workings (Scenario 1)
- Table 7-24: Natural Water Recharge into the Mine Workings (Scenario 2)
- Table 7-25: Natural Water Recharge into the Mine Workings (Scenario 3)

**Table 7-23: Natural Water Recharge into the different Mine Workings (Scenario 1)**

Year	Water recharge to Opencast Mining Operations (m <sup>3</sup> /day)				Water recharge to Underground Mining Operations (m <sup>3</sup> /day)		TOTAL (m <sup>3</sup> /day)	TOTAL (m <sup>3</sup> /annum)
	Pit 1	Pit 2	Pit 3	Pit 4	Block A	Block B		
Year 18	1 393	1 278	784	775	1 986	422	6 638	2 422 718
Year 19	1 393	1 653	1 179	1 243	2 041	422	7 931	2 894 663
Year 20	1 393	946	1 401	1 461	2 240	422	7 863	2 869 843
Year 21	1 393	946	1 566	1 592	2 240	422	8 159	2 977 883
Year 22	1 393	946	1 816	1 778	2 240	422	8 595	3 137 023
Year 23	1 393	946	2 121	1 964	2 240	422	9 086	3 316 238
Year 24	1 393	946	2 203	2 048	2 240	422	9 252	3 376 828
Year 25	1 393	946	2 609	1 499	2 240	422	9 109	3 324 633
Year 26 onwards	1 393	946	1 678	1 499	2 240	422	8 178	2 984 818

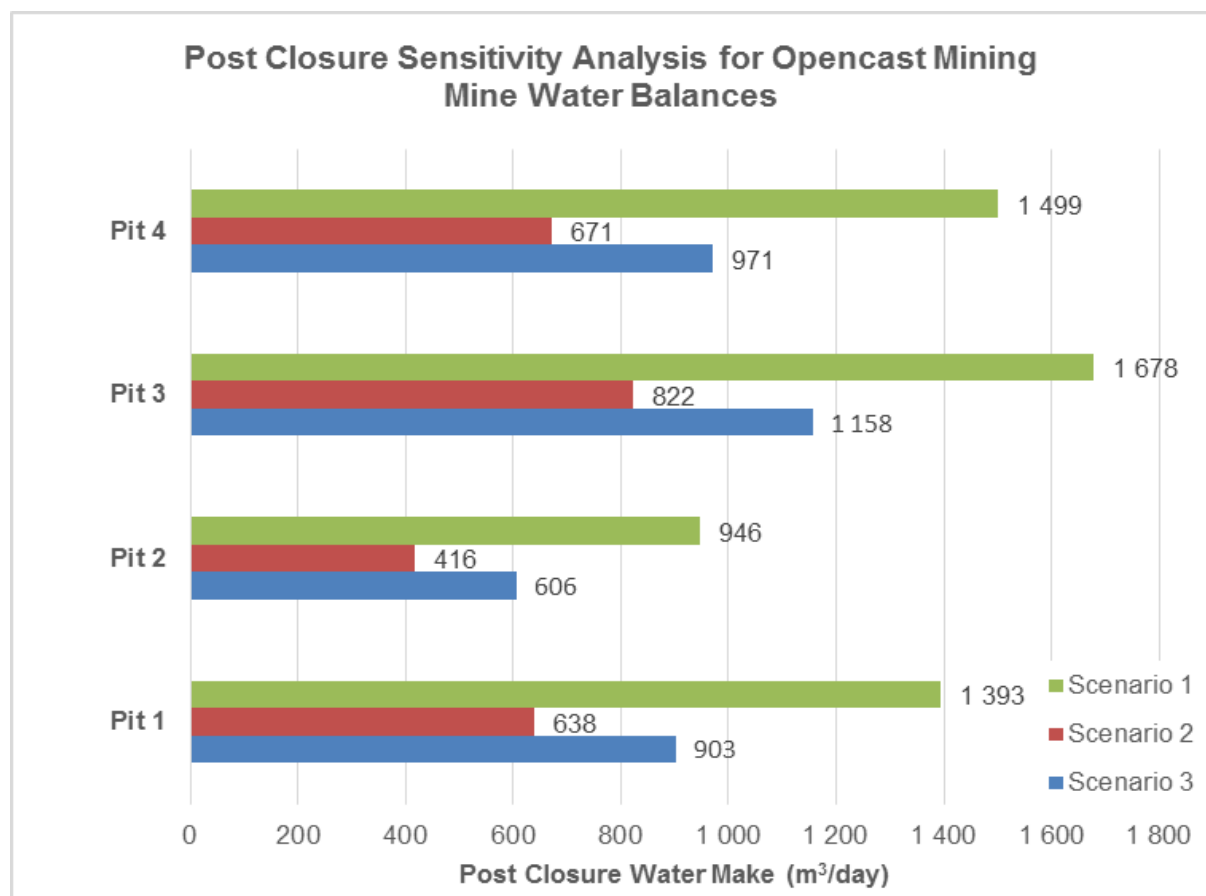
**Table 7-24: Natural Water Recharge into the different Mine Workings (Scenario 2)**

Year	Water recharge to Opencast Mining Operations (m <sup>3</sup> /day)				Water recharge to Underground Mining Operations (m <sup>3</sup> /day)		TOTAL (m <sup>3</sup> /day)	TOTAL (m <sup>3</sup> /annum)
	Pit 1	Pit 2	Pit 3	Pit 4	Block A	Block B		
Year 18	638	821	615	698	30	42	2 844	1 038 117
Year 19	638	1 085	942	1 061	25	42	3 793	1 384 502
Year 20	638	416	1 019	1 151	224	42	3 490	1 274 029
Year 21	638	416	1 186	1 157	224	42	3 663	1 337 174
Year 22	638	416	1 224	1 270	224	42	3 814	1 392 289
Year 23	638	416	1 384	1 380	224	42	4 084	1 490 839
Year 24	638	416	1 545	1 263	224	42	4 128	1 506 899
Year 25	638	416	1 862	671	224	42	3 853	1 406 524
Year 26 onwards	638	416	822	671	224	42	2 814	1 026 991

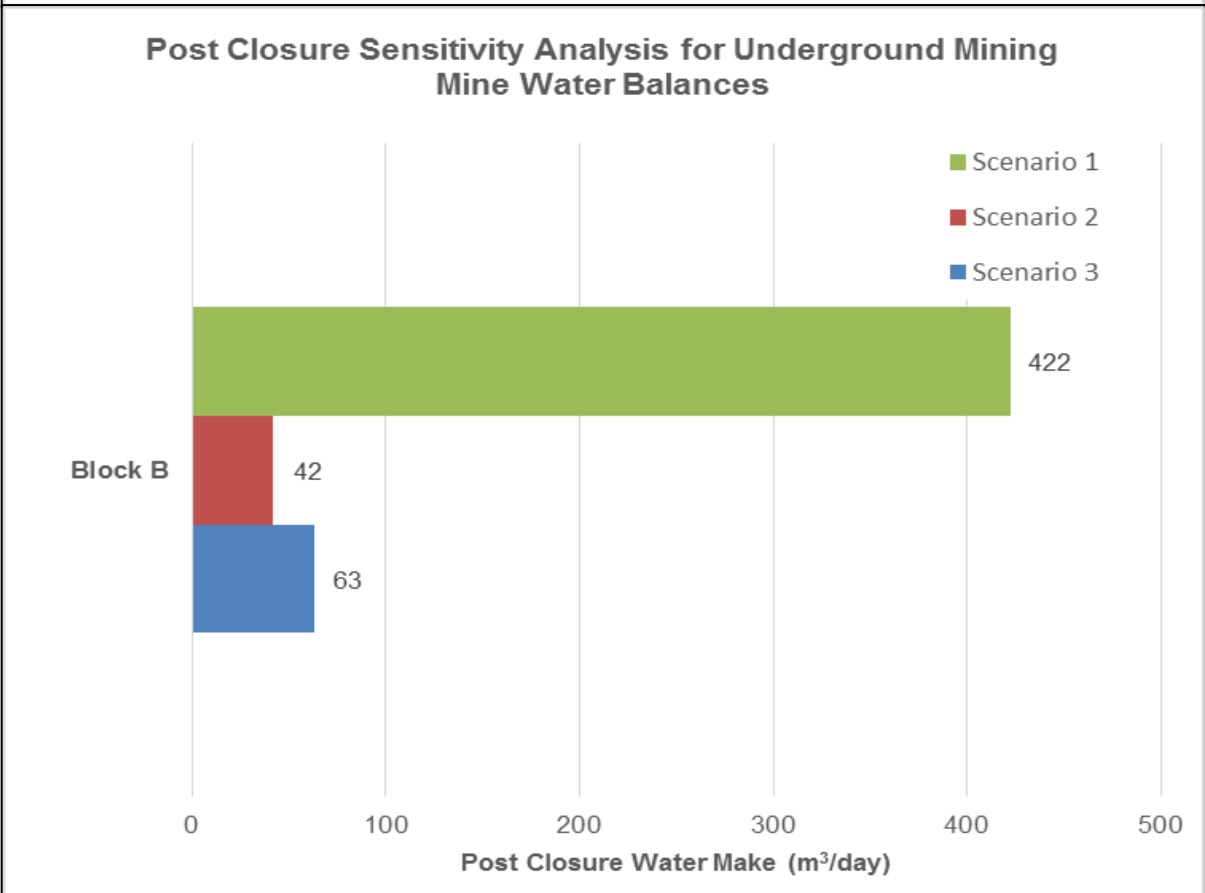
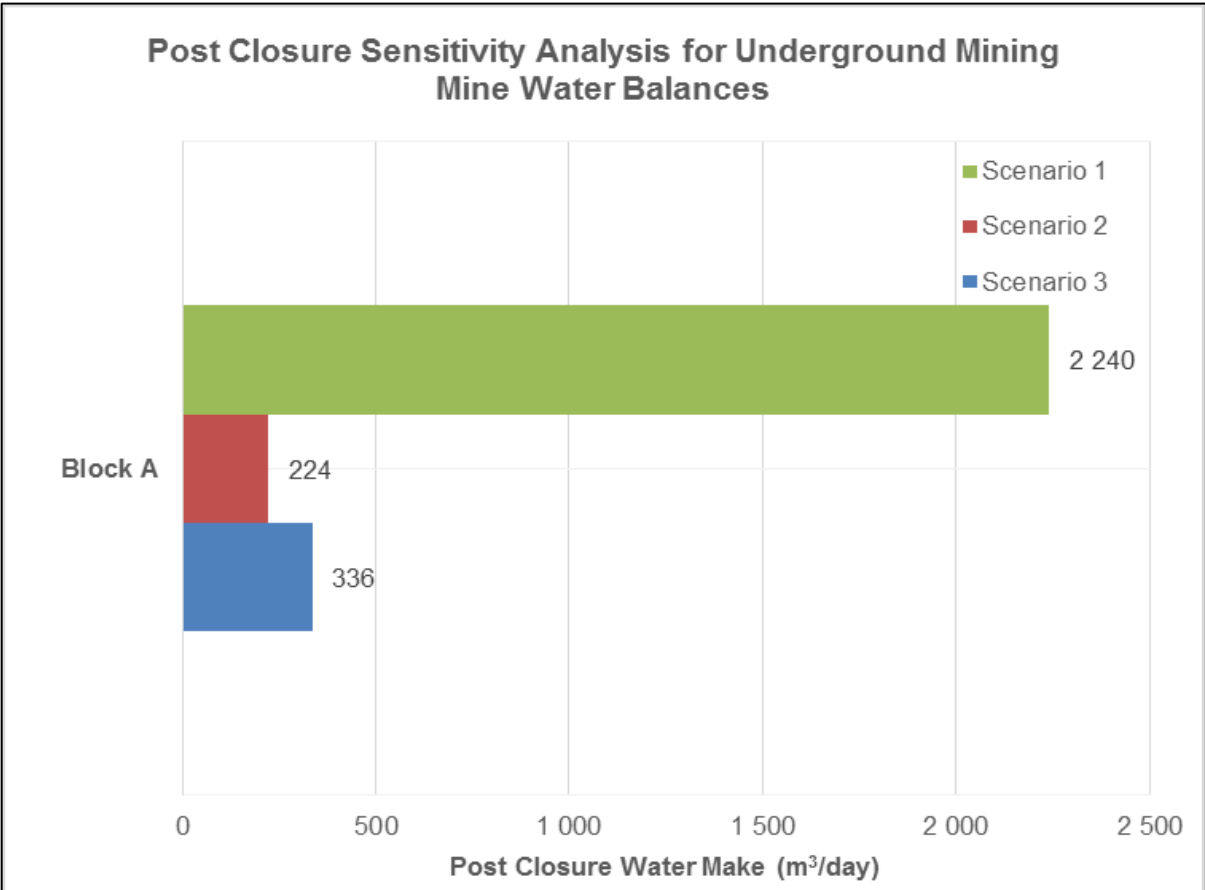
**Table 7-25: Natural Water Recharge into the different Mine Workings (Scenario 3)**

Year	Water recharge to Opencast Mining Operations (m <sup>3</sup> /day)				Water recharge to Underground Mining Operations (m <sup>3</sup> /day)		TOTAL (m <sup>3</sup> /day)	TOTAL (m <sup>3</sup> /annum)
	Pit 1	Pit 2	Pit 3	Pit 4	Block A	Block B		
Year 18	903	984	654	718	89	63	3 411	1 244 932
Year 19	903	1 280	997	1 105	112	63	4 460	1 627 817
Year 20	903	606	1 121	1 241	336	63	4 270	1 558 467
Year 21	903	606	1 307	1 293	336	63	4 507	1 645 189
Year 22	903	606	1 406	1 441	336	63	4 754	1 735 344
Year 23	903	606	1 616	1 585	336	63	5 108	1 864 554
Year 24	903	606	1 779	1 527	336	63	5 213	1 902 879
Year 25	903	606	2 136	971	336	63	5 014	1 830 244
Year 26 onwards	903	606	1 158	971	336	63	4 036	1 473 294

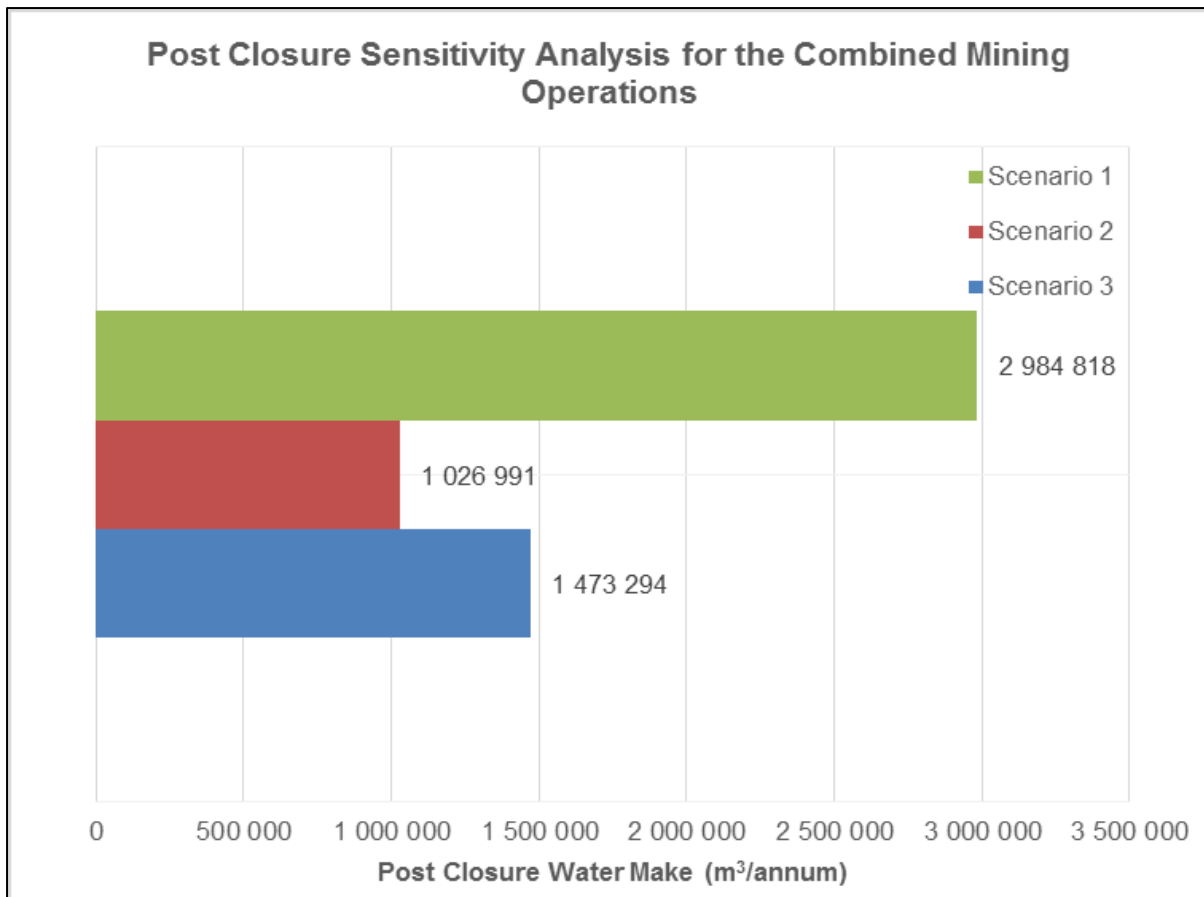
Figure 7-1 and Figure 7-2 are graphical illustrations of the natural recharge into the different opencast and underground workings as a result of the three scenarios. Figure 7-3 illustrates the annual post closure water make into the combined mine workings in the mining right boundary.



**Figure 7-1: Graphical Illustration of the Post Closure Sensitivity Analysis for Opencast Mine Water Balances**



**Figure 7-2: Graphical Illustration of the Post Closure Sensitivity Analysis for Underground Mine Water Balances**



**Figure 7-3: Graphical Illustration of the Annual Post Closure Water Make Into the Combined Mining Operations**

From the two methods of data collection that was collected and compared in terms of the mine water balance, it is clear to observe that there is a significant difference in outcome between the three scenarios that was created. In terms of the opencast workings the following is observed:

- The post closure daily water make calculated in Scenario 1 is double the amount that is observed from Scenario 2.
- The post closure daily water make calculated for Scenario 2 is 30% less than the water make calculated in Scenario 3.

The following observations are made in terms of the underground workings:

- The post closure daily water make calculated in Scenario 1 is ten times the amount that is observed from Scenario 2.
- The post closure daily water make calculated for Scenario 2 is 30% less than the water make calculated in Scenario 3.

There is a very significant difference in the total annual water make in the combined mine workings in the study area. Even though the difference is clearly observed in the daily water make it is still important to note that:

- The post closure annual water make calculated in Scenario 1 is three times the amount that is observed from Scenario 2.
- The post closure annual water make calculated for Scenario 2 is 7% less than the water make calculated in Scenario 3.

The difference in the outcomes of the three mine water balance scenarios is very significant and can have a serious impact on the effective management of mine water during both the operational and post closure phases of mining. From the observations it is clear that site specific data collection is critical in the calculations of mine water balances. The outcomes of the mine water balance calculations will be used to determine the time in years that it is expected to take for the mine workings to be fully after the closure of the mine as part of the storage capacity assessment.

## **7.8 STORAGE CAPACITY ASSESSMENT AND SENSITIVITY ASSESSMENT**

In order to investigate the possibility of storage of mine water in the mined out areas of the workings, potential storage capacities are calculated for the opencast and underground sections. It is important to know exactly where and how much storage is available and furthermore when the storage becomes available.

The interpolated No.4 Coal Seam floor elevations are used in order to calculate the storage capacities of the respective underground and opencast workings. The interpolated No.4 Coal Seam elevation contours for the respective mine workings are indicated in Figure 7-4. A map indicating the mine water monitoring borehole locations as well as the most recent calculated groundwater elevations is depicted as Figure 7-5. The storage capacities per meter interval for the mine workings across entire study are attached as APPENDIX III.

### **7.8.1 Underground Mining Operations**

#### **7.8.1.1 Block A**

Block A is an operational underground mine within the mining right boundary. Due to the location of the shaft, distribution of the floor elevations and the past as well as future mining schedule for the Block A workings, no mine water storage is available within the workings before closure in Year 20. The layout of the mining floor elevation contours within the delineated extent of Block A is depicted as Figure 7-6. The mining floor elevations range between 1536 *mamsl* and 1551 *mamsl* within the delineated Block A mining extent.

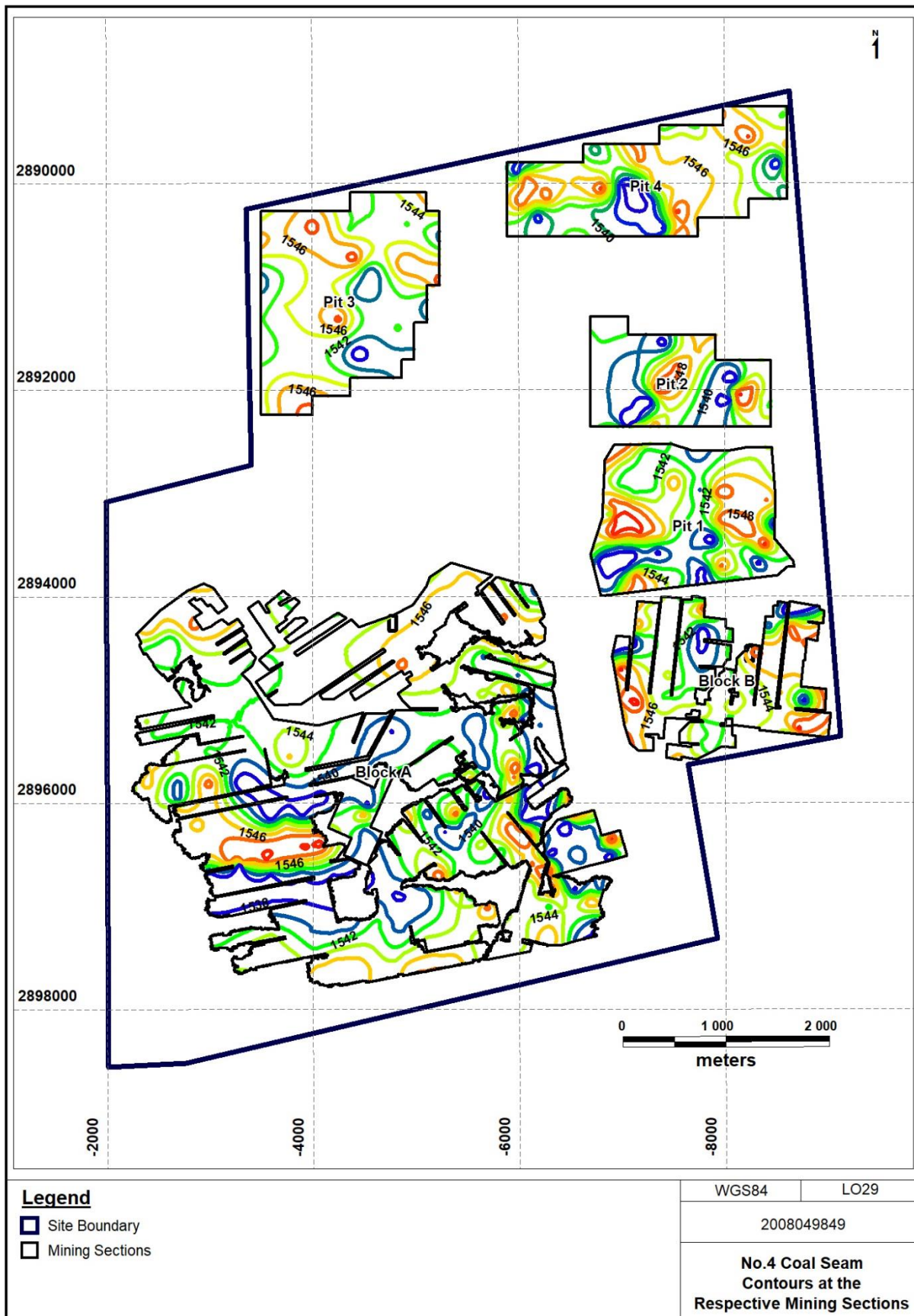


Figure 7-4: Interpolated No.4 Coal Seam Floor Elevations

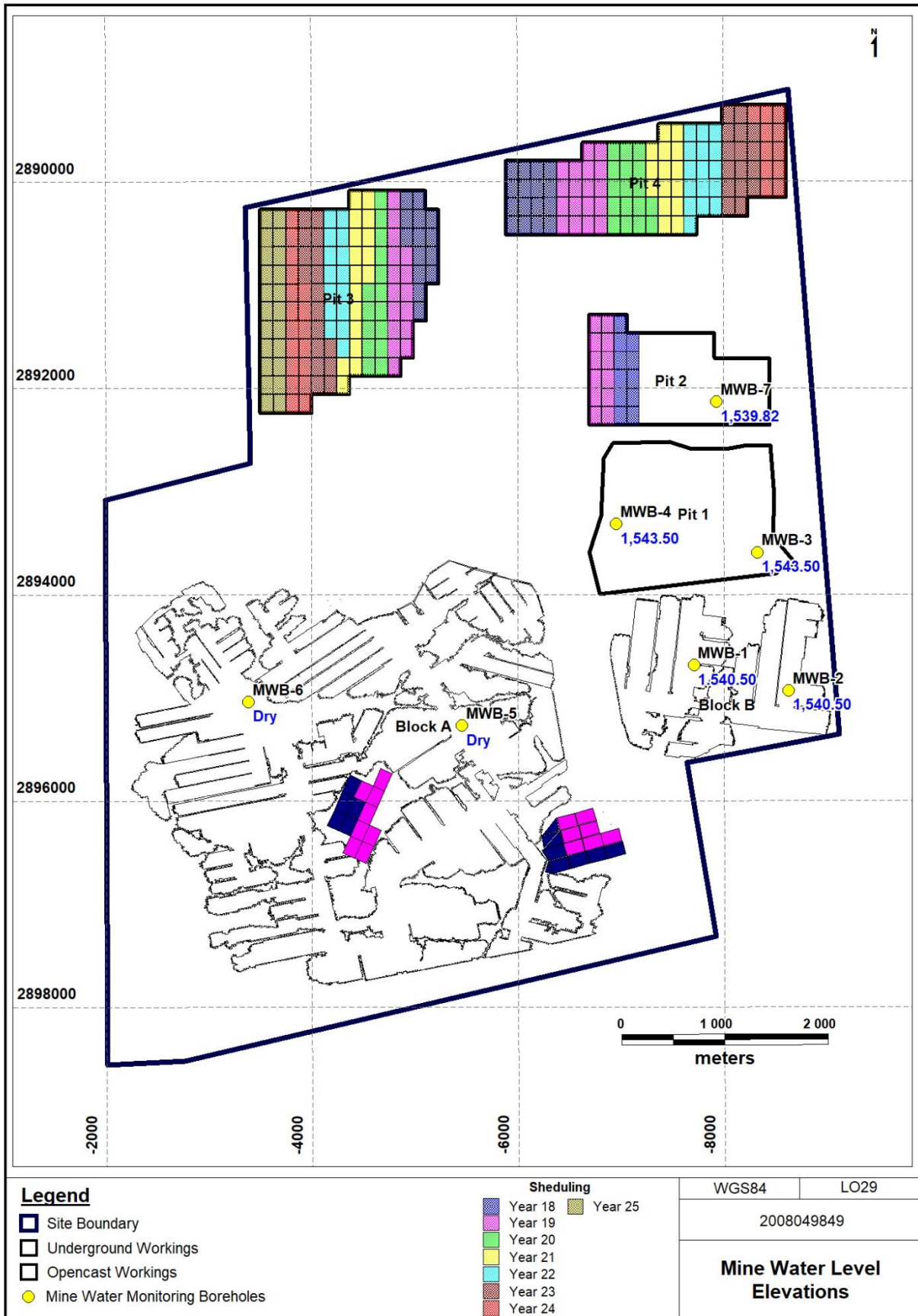


Figure 7-5: Mine Water Level Elevations

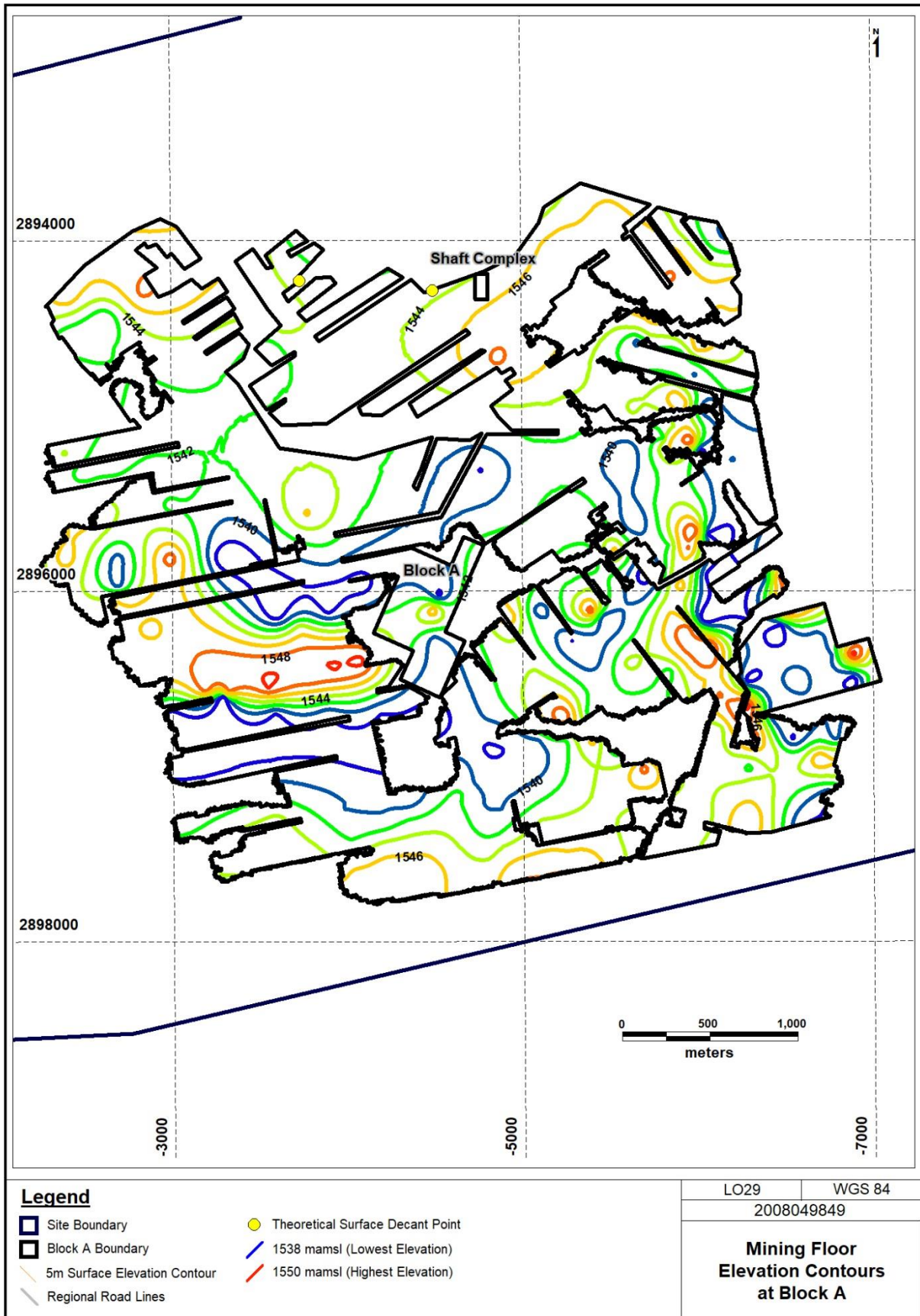
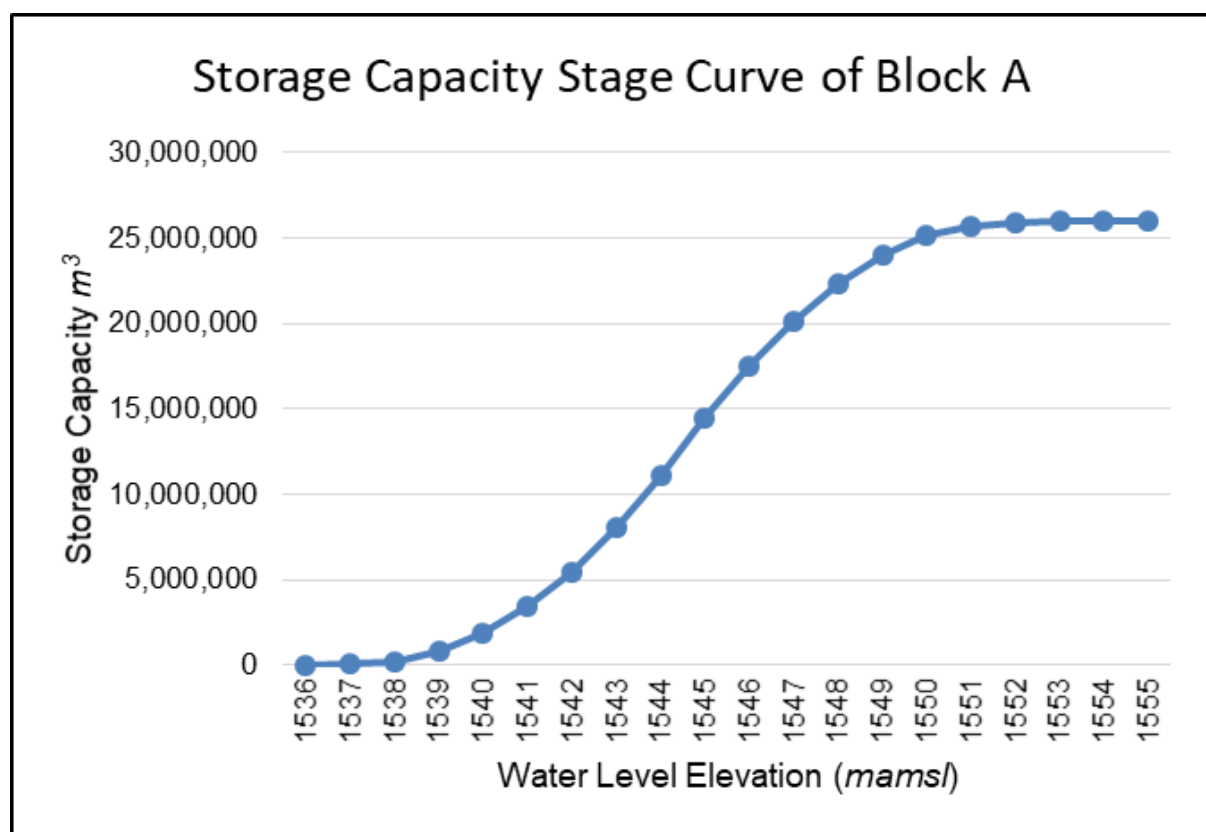


Figure 7-6: Mining Floor Elevations at the Block A Underground Workings

With an average roof height of 3.5 m and a coal extraction ratio of 65 % it is calculated that Block A underground workings will be able to store an amount of 25 966 224  $m^3$  before it becomes fully flooded. A summary of the storage assessment for Block A is provided in Table 7-26 below. The storage capacity stage curve, per meter interval for Block A is indicated in Figure 7-7.

**Table 7-26: Annual Natural Recharge into Block A and Expected time to be Flooded**

Mine Workings	Year	Post Closure Water recharge $m^3$ /annum			Time before completely Flooded		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Block A	Post Closure	817 750	81 775	122 662	32 Years	318 Years	211 Years



**Figure 7-7: Storage Capacity Stage Curve of Block A**

#### 7.8.1.2 Block B

Block B is a historic underground mine within the mining right boundary. The layout of the mining floor elevation contours within the delineated extent of Block B is depicted as Figure 7-8. The mining floor elevations range between 1536 *mamsl* and 1550.5 *mamsl* within the delineated Block B mining extent.

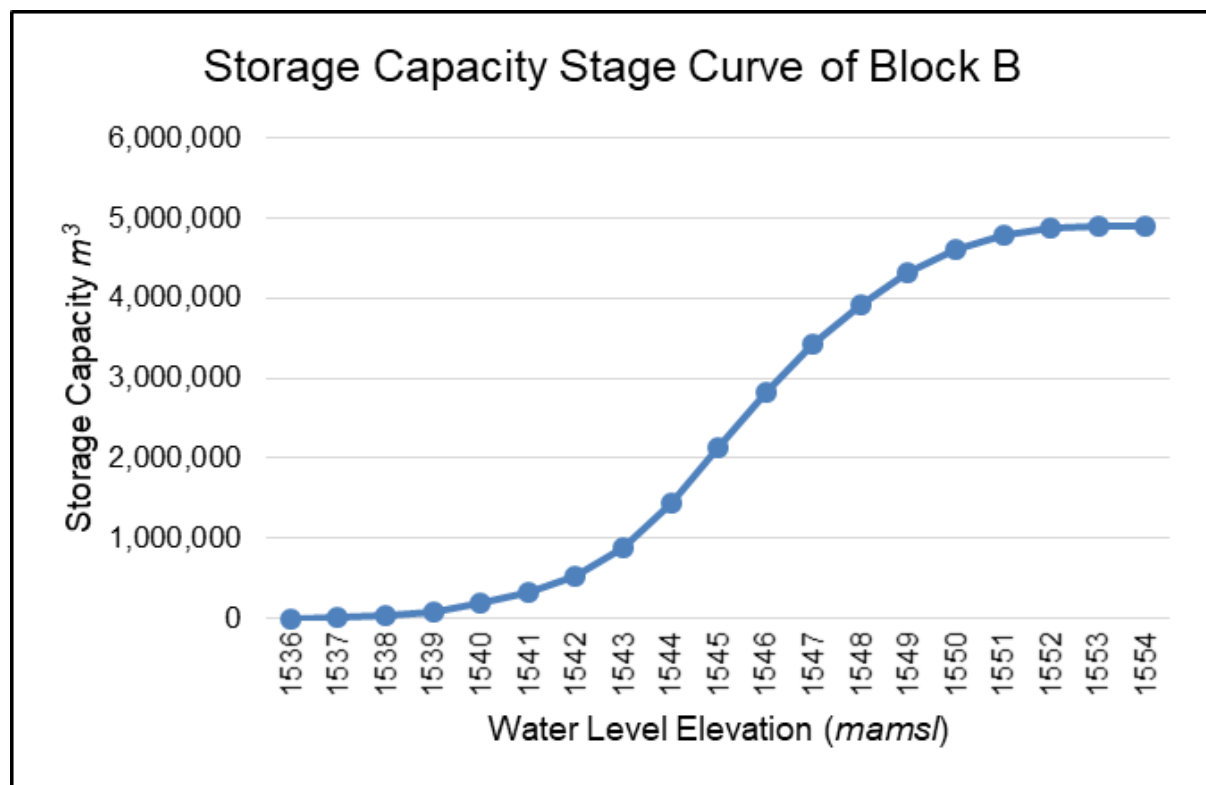


Figure 7-8: Mining Floor Elevations at the Block B Underground Workings

With an average roof height of 3.5 m and a coal extraction ratio of 65 % it is calculated that Block B underground workings has a total storage capacity of 4 892 672  $m^3$  before it becomes fully flooded. The water level elevation within the workings is currently at 1540.5 *mamsl*, which indicates the current storage to be at 207 000  $m^3$ . The total available storage for Block B is 4 685 672  $m^3$ . A summary of the storage assessment for Block A is provided in Table 7-27 below. The storage capacity stage curve, per meter interval for Block B is indicated in Figure 7-9.

**Table 7-27: Annual Natural Recharge into Block B and Expected time to be Flooded**

Mine Workings	Year	Post Closure Water recharge $m^3$ /annum			Time before completely Flooded		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Block B	Post Closure	154 030	15 330	22 995	30 Years	305 Years	204 Years



**Figure 7-9: Storage Capacity Stage Curve of Block B**

## 7.8.2 Opencast Mining Operations

### 7.8.2.1 Pit 1

Pit 1 is a historical opencast mine within the site boundary. The pit is currently partially flooded. The layout of the mining floor elevation contours within the delineated extent of Pit 1 is depicted as Figure 7-11. The mining floor elevations ranges in elevation between 1536 *mamsl* and 1551 *mamsl* within the delineated Pit 1 mining extent. The theoretical surface decant elevation for Pit 1 is at 1572 *mamsl*. Pit 1 can thus be completely flooded to an elevation of 1567 *mamsl* (management water level, 5 m below decant elevation).

The total post closure storage capacity of the pit is 14 135 334  $m^3$ . The water level elevation measured in Pit 1 is currently at 1543.5 *mamsl*. It is calculated that Pit 1 is currently filled up to a capacity of 720 998  $m^3$  with an available storage of 13 414 336  $m^3$ . The storage assessment summary for Pit 1 is summarised in Table 7-28 below. The storage capacity stage curve, per meter interval for Pit 1 is indicated in Figure 7-10.

**Table 7-28: Annual Natural Recharge into Pit 1 and Expected time to be Flooded**

Mining Operation	Post Closure Water recharge $m^3$ /annum			Time before completely Flooded		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Pit 1	482 925	232 927	329 512	27 Years	57 Years	41 Years

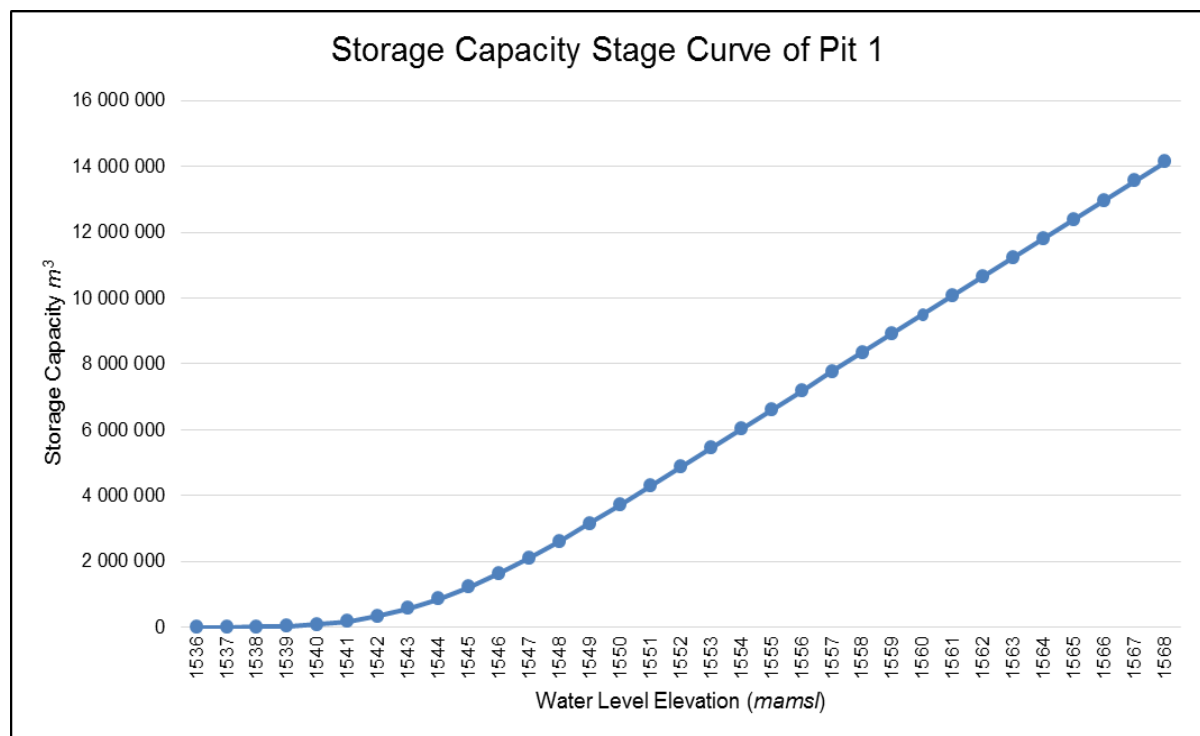


Figure 7-10: Storage Capacity Stage Curve of Pit 1



Figure 7-11: Mining Floor Elevations at Pit 1

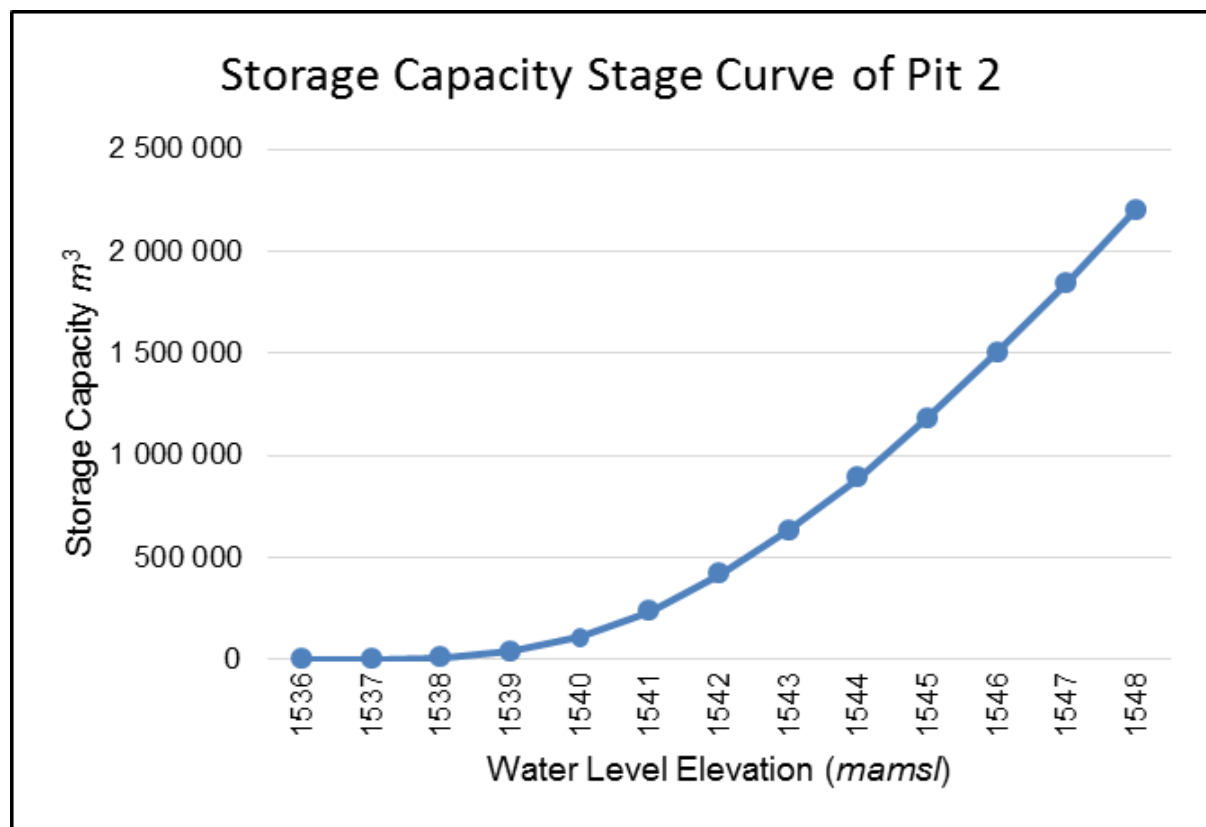
### 7.8.2.2 Pit 2

Pit 2 is an active opencast mine within the site boundary. The layout of the mining floor elevation contours within the delineated extent of Pit 2 is depicted as Figure 7-13. The mining floor elevations range in elevation between 1536 *mamsl* and 1550.5 *mamsl* within the delineated Pit 2 mining extent. The theoretical surface decant elevation for Pit 2 is at 1553 *mamsl*. Pit 2 can thus be completely flooded to an elevation of 1548 *mamsl* (management water level, 5 m below decant elevation). The storage capacity stage curve, per meter interval for Pit 2 is indicated in Figure 7-12.

The total post closure storage capacity of the pit is 2 204 467  $m^3$ . The storage assessment summary for Pit 2 is summarised in Table 7-29 below. Storage is already available in rehabilitated sections of Pit 2 up to an elevation of 1539.82 *mamsl*. A volume of 108 090  $m^3$  is currently available and the remainder of the storage will become available after Year 19.

**Table 7-29: Annual Natural Recharge into Pit 2 and Expected time to be Flooded**

Mine Workings	Year	Post Closure Water recharge $m^3$ /annum			Time before completely Flooded		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Pit 2	Post Closure	345 400	151 962	221 042	6 Years	15 Years	10 Years



**Figure 7-12: Storage Capacity Stage Curve of Pit 2**

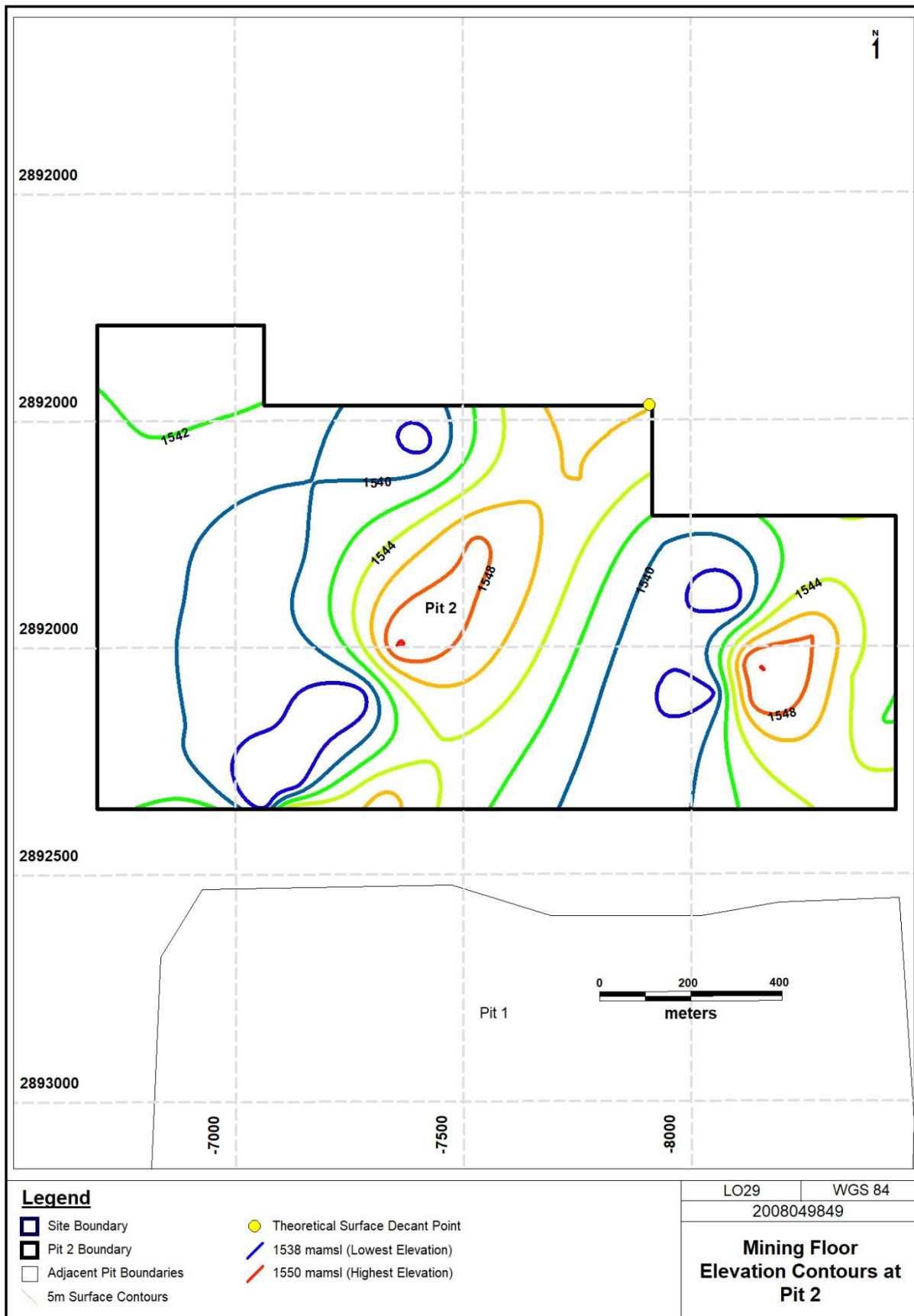


Figure 7-13: Mining Floor Elevations at Pit 2

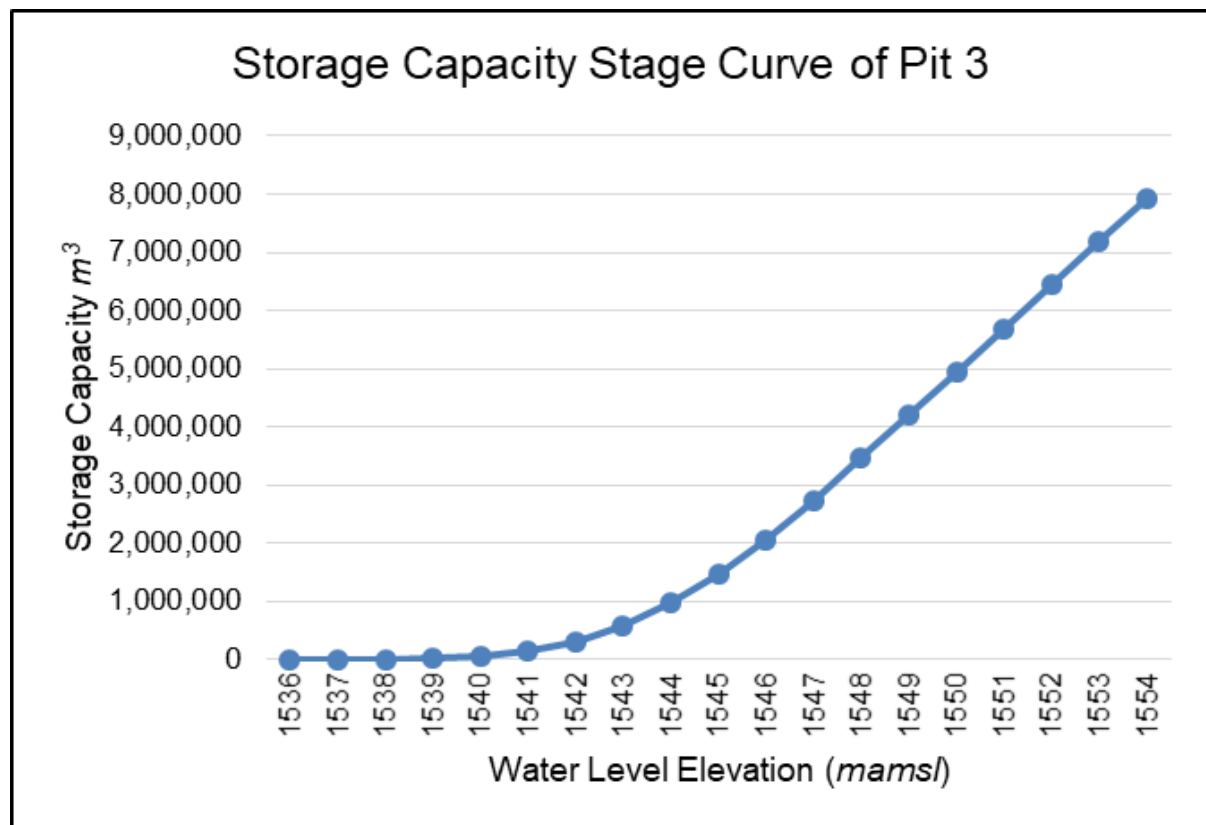
### 7.8.2.3 Pit 3

Pit 3 is a proposed opencast mine within the site boundary. The layout of the mining floor elevation contours within the delineated extent of Pit 3 is depicted as Figure 7-15. The mining floor elevations ranges in elevation between 1536 *mamsl* and 1549 *mamsl* within the delineated Pit 3 mining extent. The theoretical surface decant elevation for Pit 3 is at 1559 *mamsl*. Pit 3 can thus be completely flooded to an elevation of 1554 *mamsl* (management water level, 5 m below decant elevation).

It is calculated that Pit 3 will have a management storage capacity of 7 925 595  $m^3$ . The storage assessment summary for Pit 3 is summarised in Table 7-30 below. The storage capacity stage curve, per meter interval for Pit 3 is indicated in Figure 7-14.

**Table 7-30: Annual Natural Recharge into Pit 3 and Expected time to be Flooded**

Mine Workings	Year	Post Closure Water recharge $m^3$ /annum			Time before completely Flooded		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Pit 3	Post Closure	612 621	300 192	422 716	13 Years	26 Years	19 Years



**Figure 7-14: Storage Capacity Stage Curve of Pit 3**

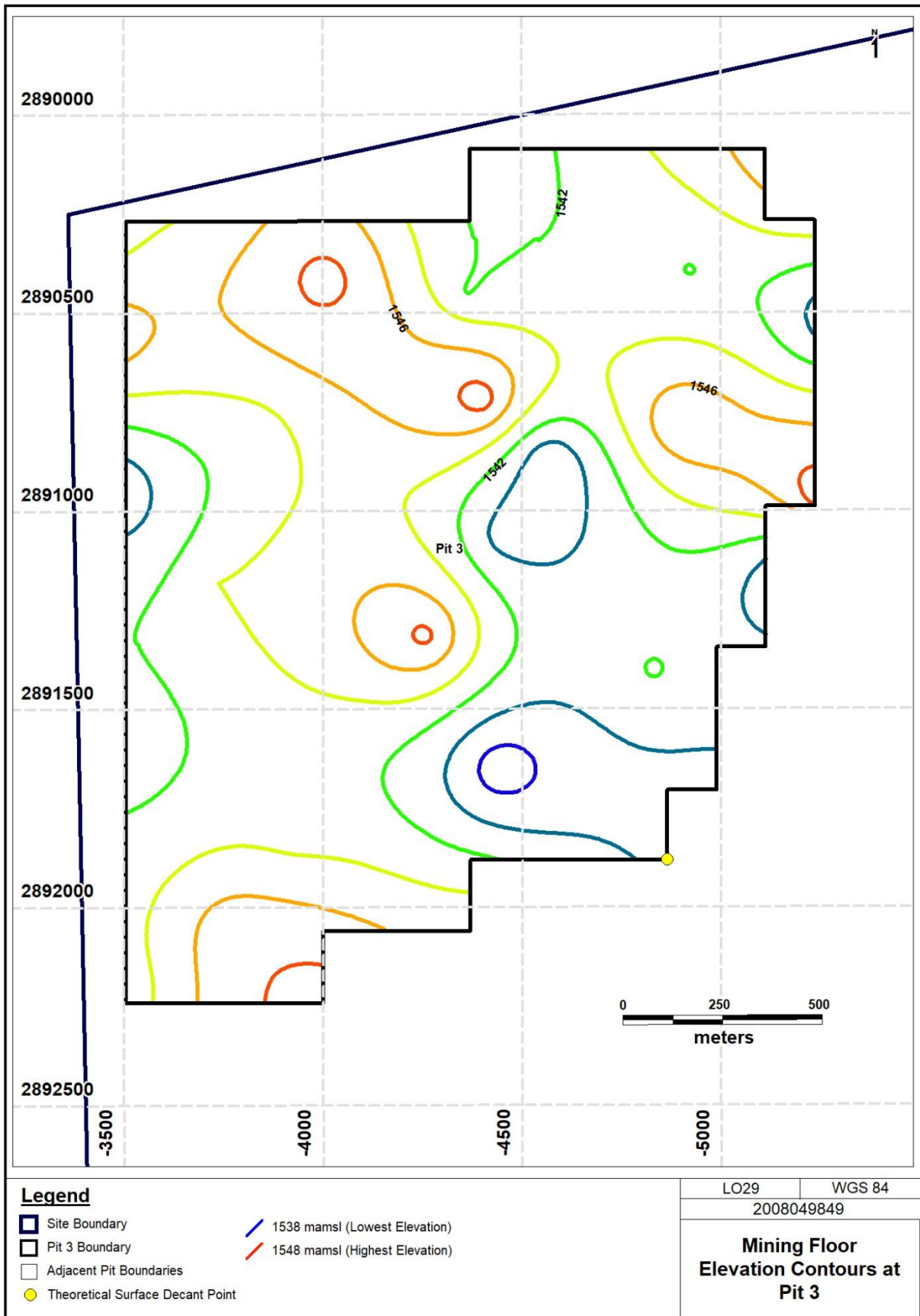


Figure 7-15: Mining Floor Elevations at Pit 3

#### 7.8.2.4 Pit 4

Pit 4 is a proposed opencast working within the site boundary. The layout of the mining floor elevation contours within the delineated extent of Pit 4 is depicted as Figure 7-17. The mining floor elevations ranges in elevation between 1535 *mamsl* and 1549 *mamsl* within the delineated Pit 4 mining extent. The theoretical surface decant elevation for Pit 4 is at 1555 *mamsl*. Pit 4 can thus be completely flooded to an elevation of 1550 *mamsl* (management water level, 5 m below decant elevation).

The storage capacity stage curve, per meter interval for Pit 4 is indicated in Figure 7-16. It is calculated that Pit 4 will have a management storage capacity of 3 025 722  $m^3$ . The storage assessment summary for Pit 4 is summarised in Table 7-31 below.

**Table 7-31: Annual Natural Recharge into Pit 3 and Expected time to be Flooded**

Mine Workings	Year	Post Closure Water recharge $m^3/annum$			Time before completely Flooded		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Pit 4	Post Closure	547 266	244 982	354 435	6 Years	12 Years	9 Years

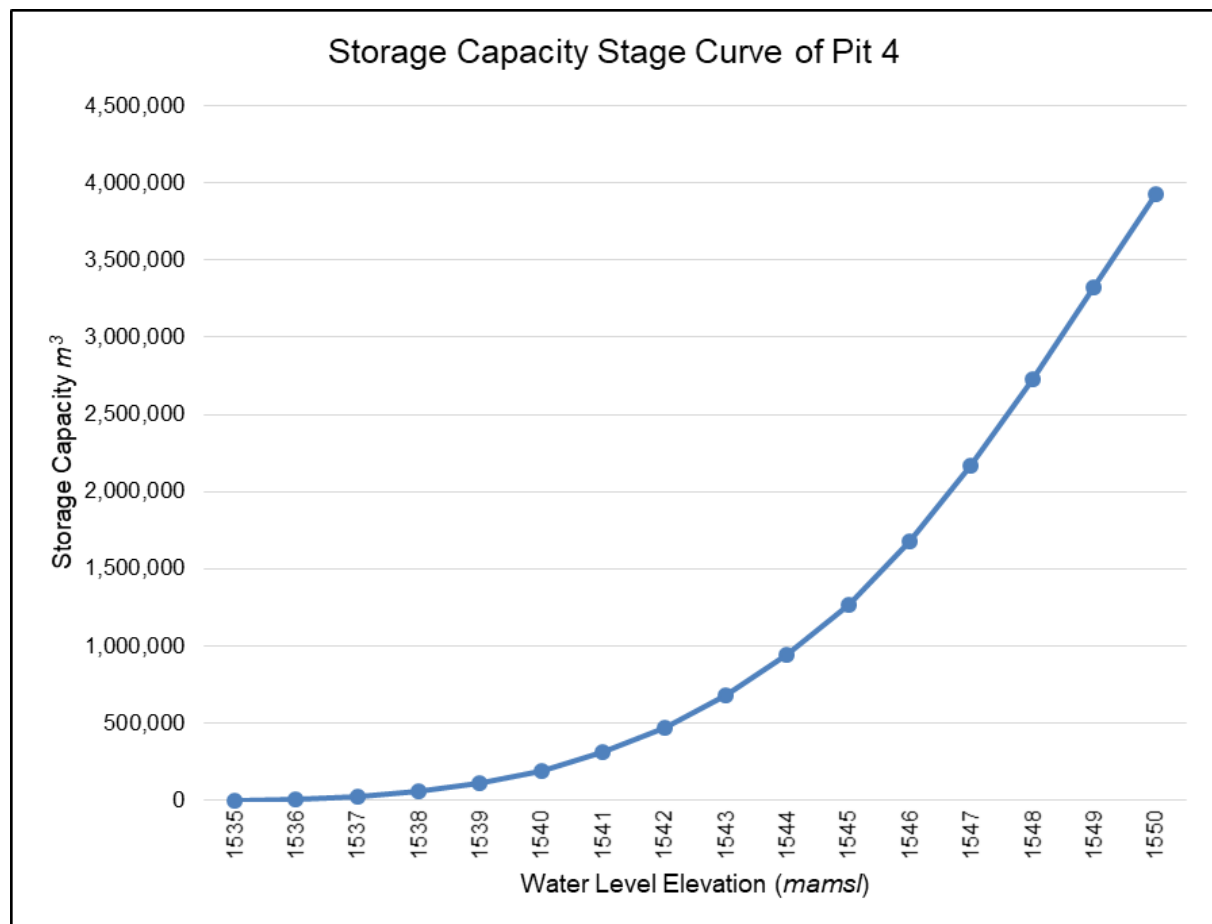


Figure 7-16: Storage Capacity Stage Curve at Pit 4

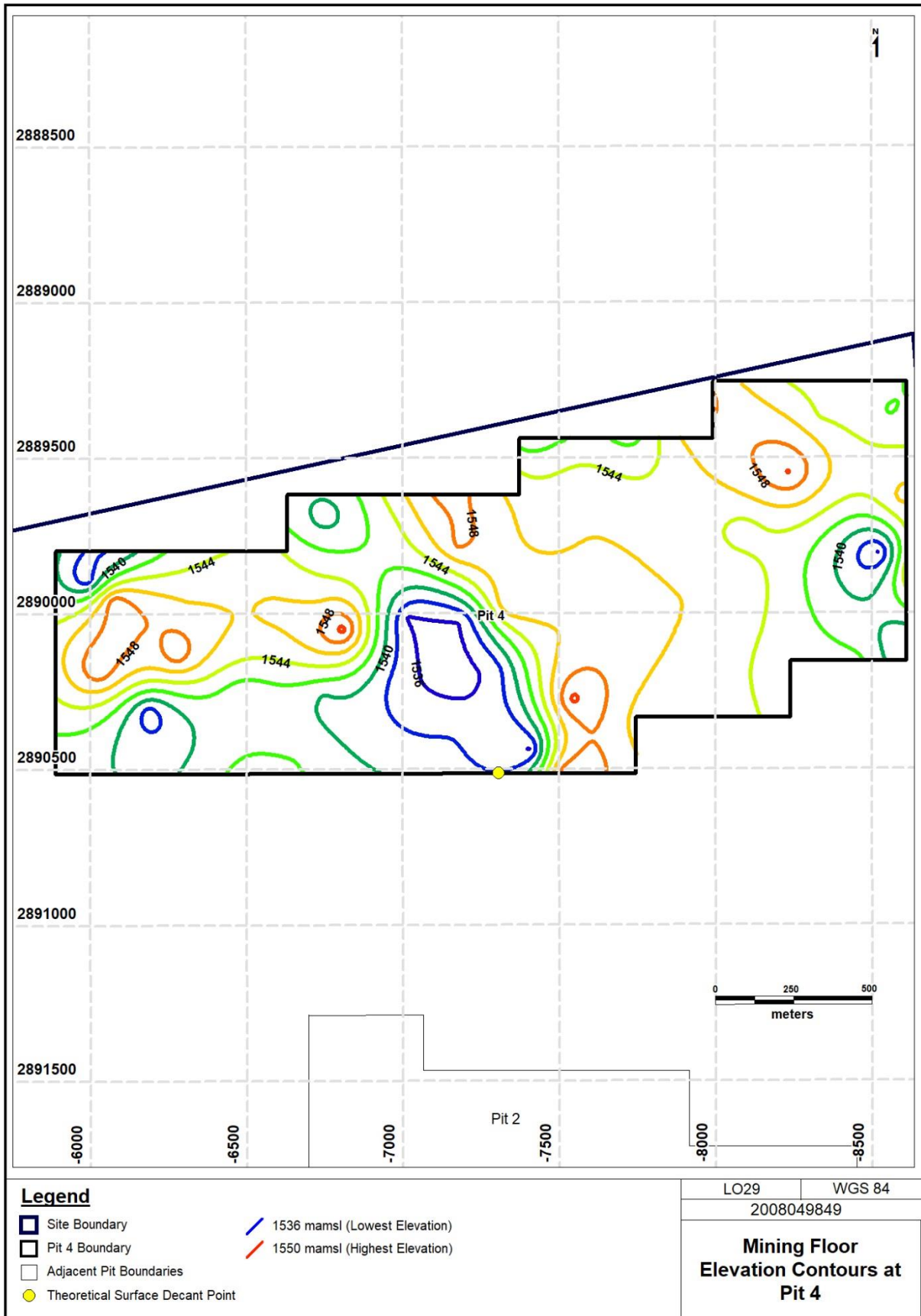


Figure 7-17: Mining Floor Elevations at Pit 4

## **7.9 THE RELEVANCE OF A MINE WATER BALANCE IN THE OPTIMISATION OF WATER MANAGEMENT**

The water mine water balance in terms of mine water management is very important in order to evaluate different management options before implementation. The mine water balance allows for management of the water reticulation system at the mine by identifying and quantifying water make into and water losses from the workings. The mine water balance can assist with the storage requirements and minimising the risk of decanting in the future by accurately determining when the mine water will reach the decant elevation.

## **7.10 CRITICAL PARAMETERS AND REQUIREMENTS FOR A MINE WATER BALANCE**

The following parameters are deemed critical in the calculation of an accurate water balance:

- **Surface elevation contours**

The elevation contours are used to determine the decant elevation on surface of the mine workings.

- **Detailed mine layout plans, surveyed mine floor and roof elevations and schedules**

It is critical to obtain accurate mine plans and schedules from the mine in order to accurately calculate the areas of the workings that is used in the calculation of the mine water balance. The layouts of the workings are also used in order to calculate the volume of available storage in the workings. The surveyed mine floor and roof elevations are used in order to calculate the volume of the workings.

- **Surveyed mine water level elevations**

In relation with the volume stage curves an accurate calculation can be made to determine the volume of water that is stored within the workings at the time that the water level elevation was measured.

- **Site specific recharge into mine workings**

The accurate determination of the recharge from rainfall is very important in order to accurately determine the mine water balance. Recharge into the mine workings from rainfall is the largest source of water make into the mine.

- **Rainfall figures, average rainfall for area**

The rainfall figures are used in order to accurately calculate the amount of recharge from rainfall into the mine workings. It is important to update the rainfall figures with every update of the mine water balance.

- **Site specific recharge into mine workings**  
The accurate determination of the recharge from rainfall is very important in order to accurately determine the mine water balance. Recharge into the mine workings from rainfall is the largest source of water make into the mine.
- **Saturated thickness of aquifer**  
The saturated thickness of the aquifer is a critical parameter in determining the amount of groundwater influx into the mine. The thickness of the aquifer is multiplied with the hydraulic conductivity and gradient in order to calculate the amount of groundwater influx into the workings.
- **Hydraulic conductivity of the aquifers**  
The hydraulic conductivity is the ease at which groundwater will move into the mine workings and is critical in determining the accurate amount of groundwater influx into the workings.
- **Storativity and Porosity of the aquifers**  
The storativity is used to determine the amount of interstitial groundwater in the workings in relation with the mining area and the porosity.
- **Coal Extraction Percentages and tonnes**  
It is very important to obtain the extraction percentages in order to accurately calculate the available storage of an underground mine. The amount of coal that is extracted is used to calculate the amount of in-situ moisture in terms of water make into the mine and the amount of moisture leaving the mine by means of coal extraction.

In order to actively manage the water recharge and water storage in a mine, the following requirements is deemed relevant for the calculation of a mine water balance:

- **The mine water balance should be updated annually**  
The updating of a mine water balance is very important in order to validate the previous mine water balance by calibrating the new mine water balance.
- **Concurrent updating of the conceptual model**  
It is very important to update the conceptual model with new site specific data as soon as ne data is made available in order to calibrate the mine water balance for the next annum.
- **Update deviations in the mine plans and schedules**  
As soon as there are deviations within the mine plans or schedule, an update should be made to the current water balance as well as to the mine water balance for the next annum.

## 8. CONCLUSION

With reference to the objectives of the dissertation, I now wish to conclude.

- The role and significance of an accurate mine water balance cannot be overlooked. The use thereof will become more important and significant in the future as the proper management of mine water becomes more important in a water scarce country like South Africa.
- A mine water balance can be used as a management tool by continuously updating it in house, or as part of a standalone groundwater/surface water study. It may also be used as part of a risk based assessment.
- Due to the fact that a lot of mines in the past neglected proper mine water management, the use of mine water balances will become more important not only in current and future mines, but also in historical mining operations.
- It is very important to understand the sources of natural water recharge into and water losses out of the mine before a water balance can be developed.
- In order to understand the sources of natural water recharge into and losses out of the mine, it is very important to set up a conceptual model for the mine indicating the magnitude and dynamics of the parameters.
- After the natural components of a mine water balance are determined, one can start adding the artificial parameters that will influence the outcome of the mine water balance.
- Using the generic input parameters obtained from the literature study alone is too risky and the collection of accurate site specific data is critical in the development of a mine water balance and the subsequent optimisation mine water management.
- The generic input parameters are a good way to do a baseline type of water balance scenario for the mining operations. The site specific parameters can be introduced into the conceptual model over time.
- Due to the fact that the generic parameters obtained from literature usually gets reported as ranges, an experienced estimate of a value to be use should still be made.
- As indicated in the sensitivity study, the magnitude of the difference between the outcomes of the bottom and to ranges varies as much as ten times.
- It is also clear that an average value alone is not sufficient. In fact, the actual site specific outcome was more in line with the bottom range of the generic inputs.
- Storage of water in defunct mine workings is one of the best and most effective management options for the optimisation of mine water storage in the operational and the post closure phases of mining.

- Accurate data is thus very important in order to make the best management decisions for the current and future optimisation of mine water storage.
- It is clear that the site specific data is very important. In the results of the storage capacity assessment it is seen the difference between the scenarios are very large. In some cases the time that it will take to flood the mine is doubled by using the upper value of the ranges from the generic inputs. In the case of the underground mines it is even as much as ten times higher.
- It is very important to get detailed and accurate mine plans, surveyed mine water level data, accurate rainfall figures, aquifer storage and flow parameters (porosity, storativity and hydraulic conductivity) and recharge percentages into the respective mine workings that is representative of the site specific conditions. It is also very important to ensure continual improvement in the accurate collection of data and to regularly update the conceptual model used to calculate the mine water balance.
- It is thus of utmost importance to collect site specific data in order to effectively do a mine water balance in order to optimise mine water management in underground and opencast collieries in the Witbank Coal Fields.
- The mine water balance calculations are also relevant in other mining environments and must be approached in exactly the same way that is approached in this dissertation. The most important aspect is the setup of a conceptual model in support of the mine water balance.

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# APPENDIX I

Borehole Logs

# Borehole Construction and Geological Log

**BASIC SITE INFORMATION:** Site Identifier: 01 Number: WCW-1 Site type: Borehole

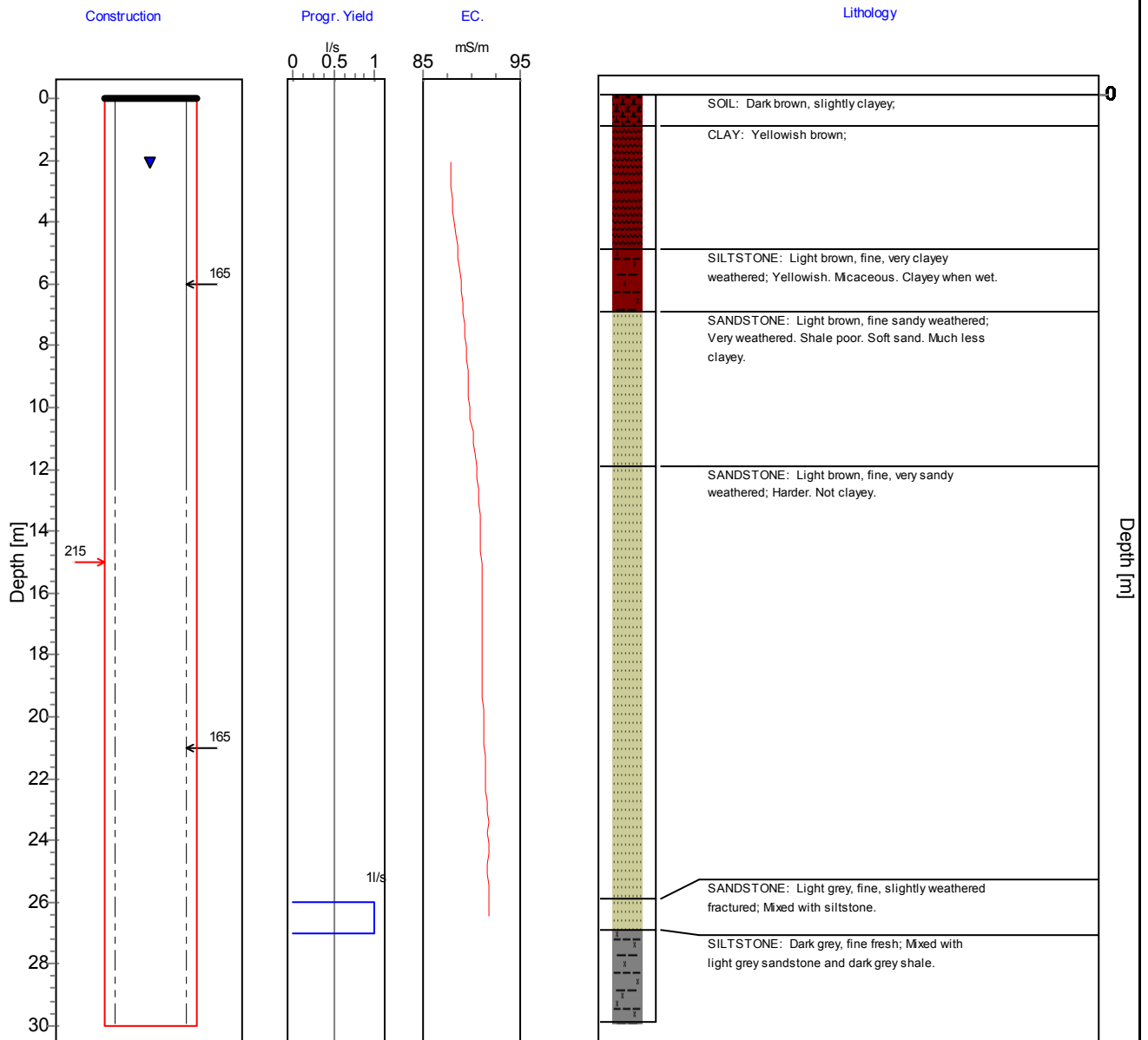
Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 30.00
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.49
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

## Construction and Geohydrological Legend

- Hole
- Casing (plain / perforated, slotted)
- Screen / Mesh Screen
- Piezometer
- Hole diameter [mm]
- Casing diameter [mm]
- Waterlevel measured: 20/09/02
- Piezometer (Nr. & Diameter [mm])



COMMENT:

# Borehole Construction and Geological Log









**BASIC SITE INFORMATION:** Site Identifier: " 02 Number: WCW-2 Site type: Borehole

Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 30.00
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.51
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

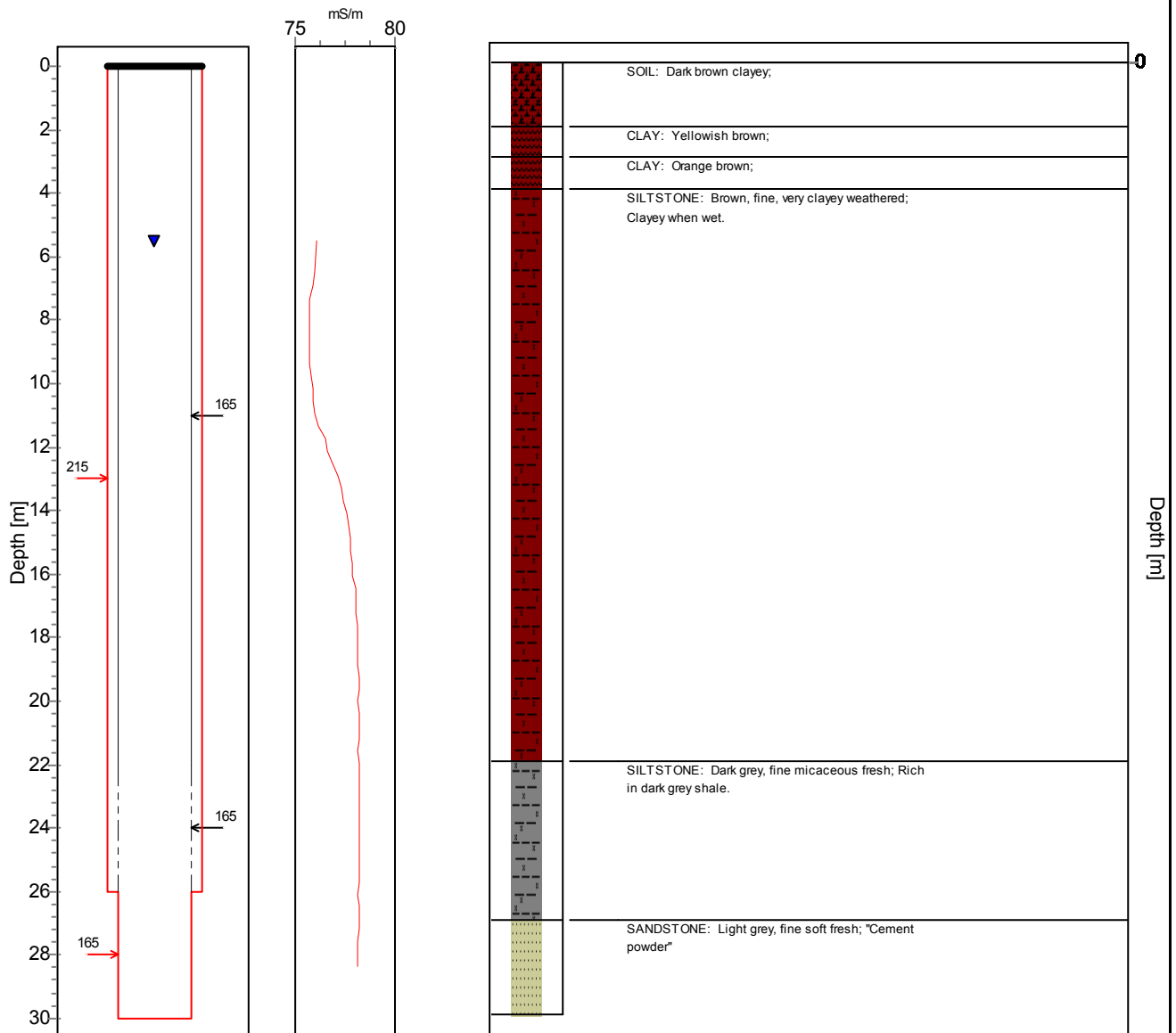
## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  165 Hole diameter [mm]
-  152 Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  0:50 Piezometer (Nr. & Diameter [mm])

Construction

EC.

Lithology



COMMENT:

# Borehole Construction and Geological Log

**BASIC SITE INFORMATION:** Site Identifier: 03 Number: WCW-3 Site type: Borehole

Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 29.80
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.54
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

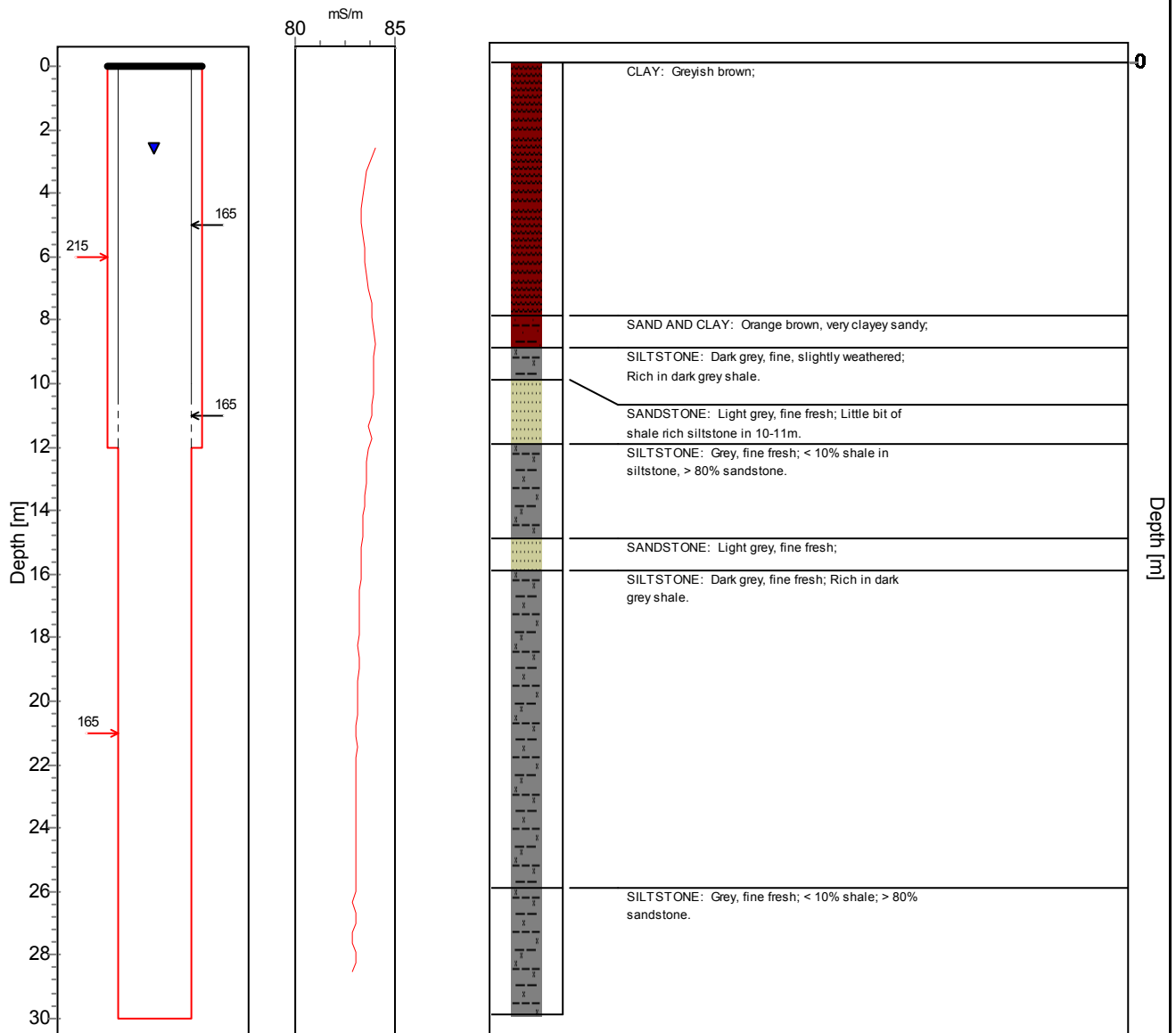
## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  165 Hole diameter [mm]
-  152 Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  0:50 Piezometer (Nr. & Diameter [mm])

Construction

EC.

Lithology



COMMENT:

# Borehole Construction and Geological Log







**BASIC SITE INFORMATION:** Site Identifier: 04 Number: WCW-4 Site type: Borehole

Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 29.20
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.33
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

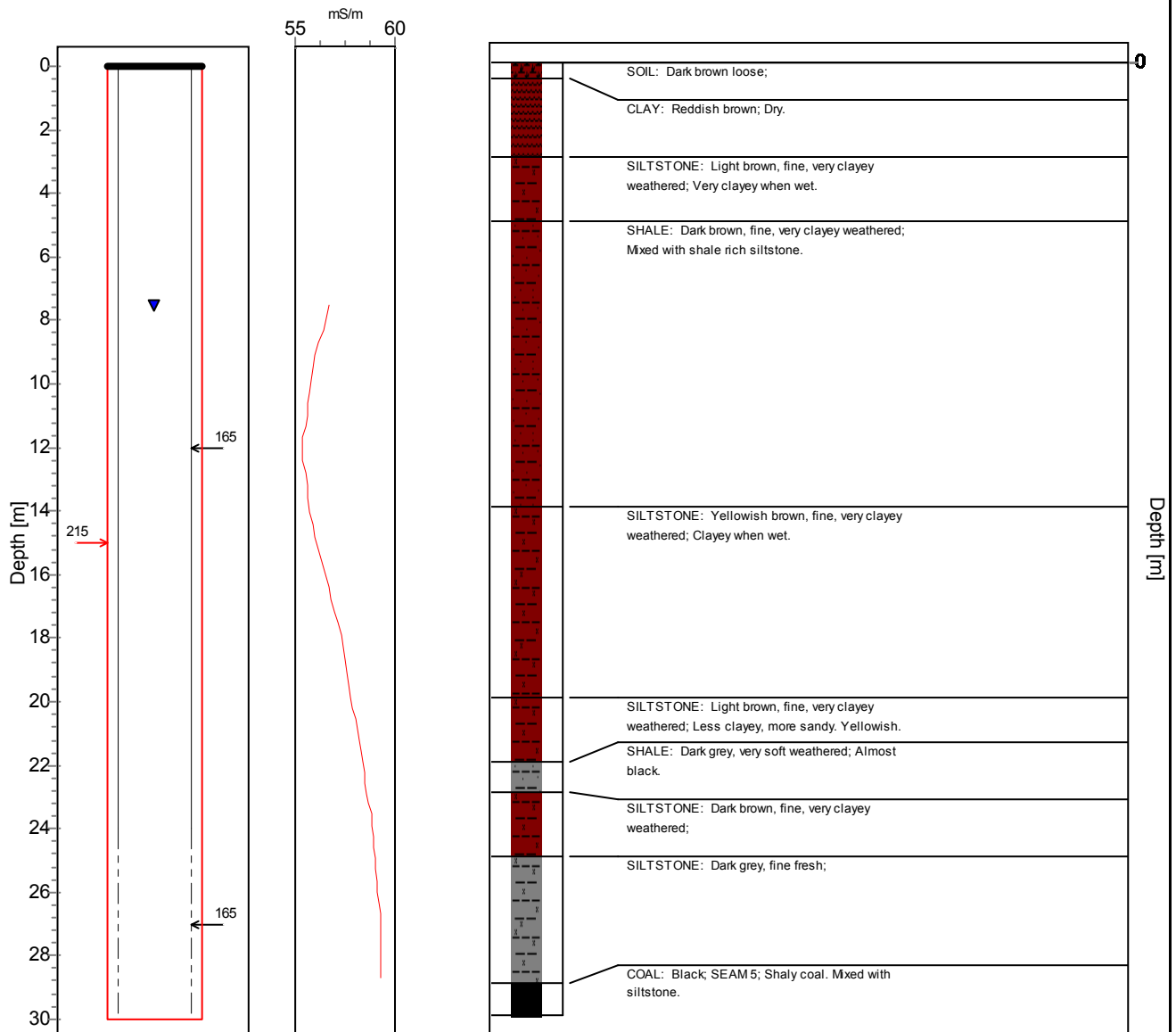
## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  Hole diameter [mm]
-  Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  Piezometer (Nr. & Diameter [mm])

Construction

EC.

Lithology



COMMENT:

# Borehole Construction and Geological Log









**BASIC SITE INFORMATION:** Site Identifier: 05 Number: WCW-5 Site type: Borehole

Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 30.00
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.46
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

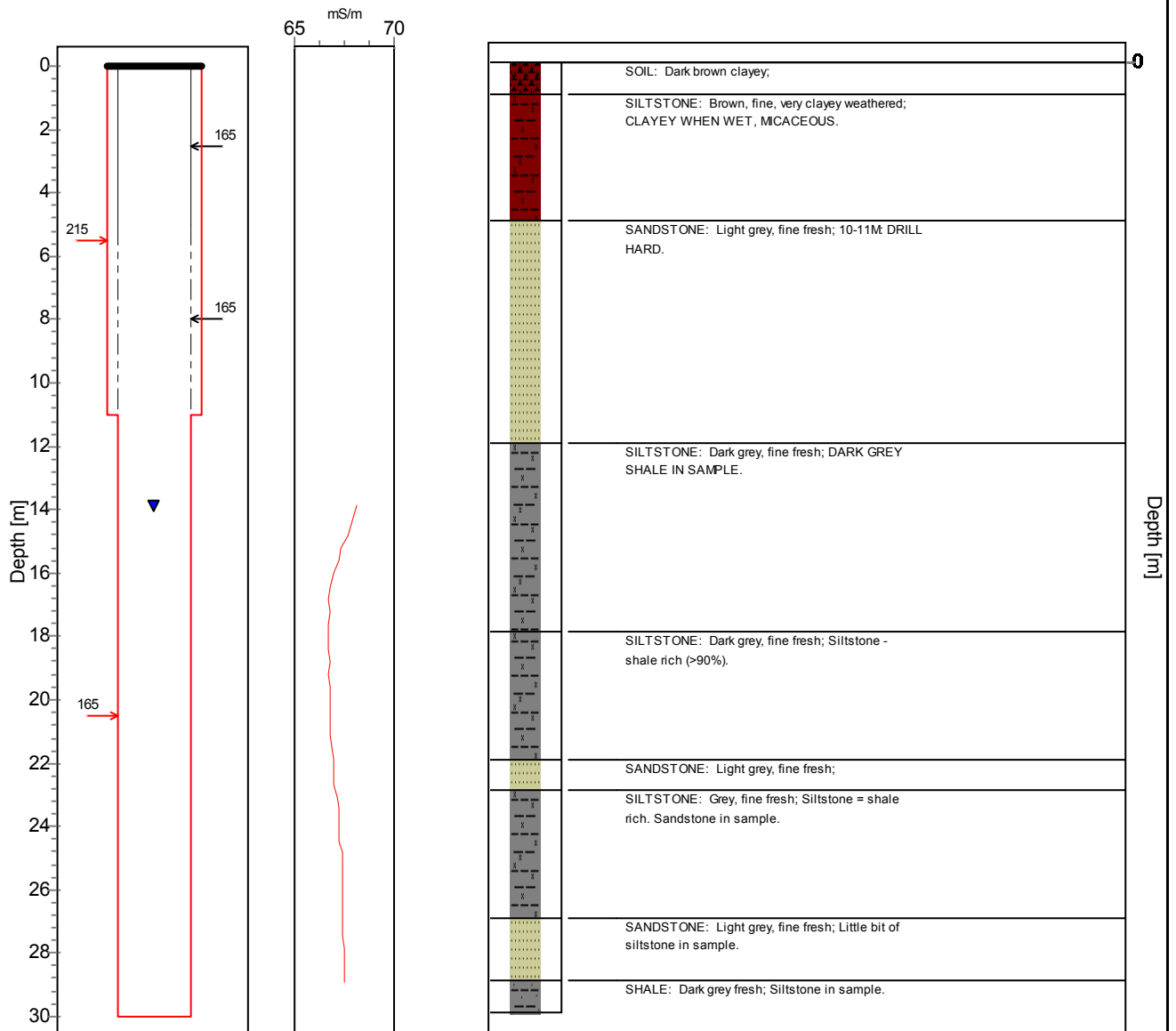
## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  165 Hole diameter [mm]
-  152 Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  0:50 Piezometer (Nr. & Diameter [mm])

Construction

EC.

Lithology



COMMENT:

# Borehole Construction and Geological Log

**BASIC SITE INFORMATION:** Site Identifier: 06 Number: WCW-6 Site type: Borehole

Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 26.60
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.58
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

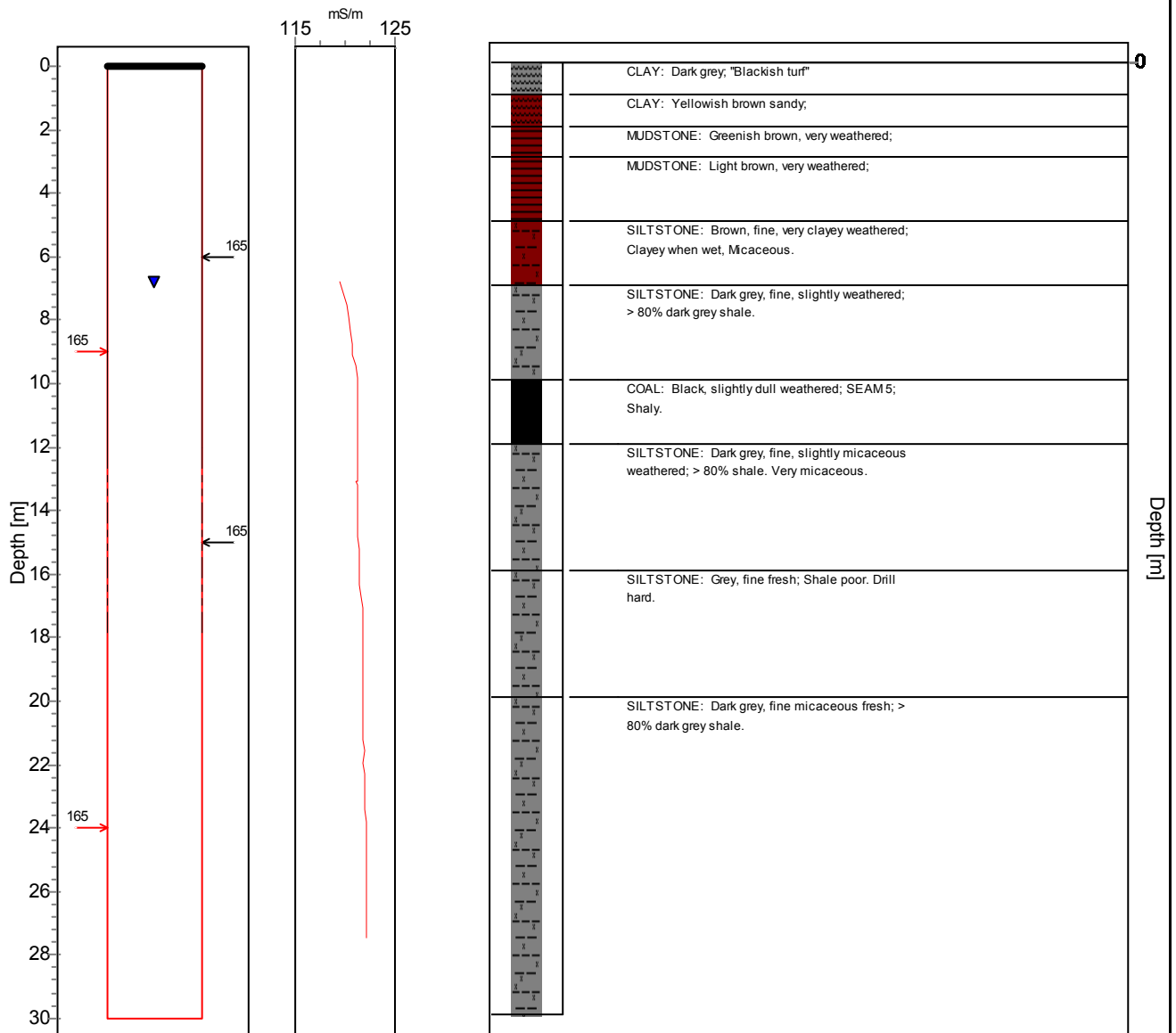
## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  165 Hole diameter [mm]
-  152 Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  0:50 Piezometer (Nr. & Diameter [mm])

Construction

EC.

Lithology



COMMENT:

# Borehole Construction and Geological Log






**BASIC SITE INFORMATION:** Site Identifier: 07 Number: WCW-7 Site type: Borehole

Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 27.06
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.46
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

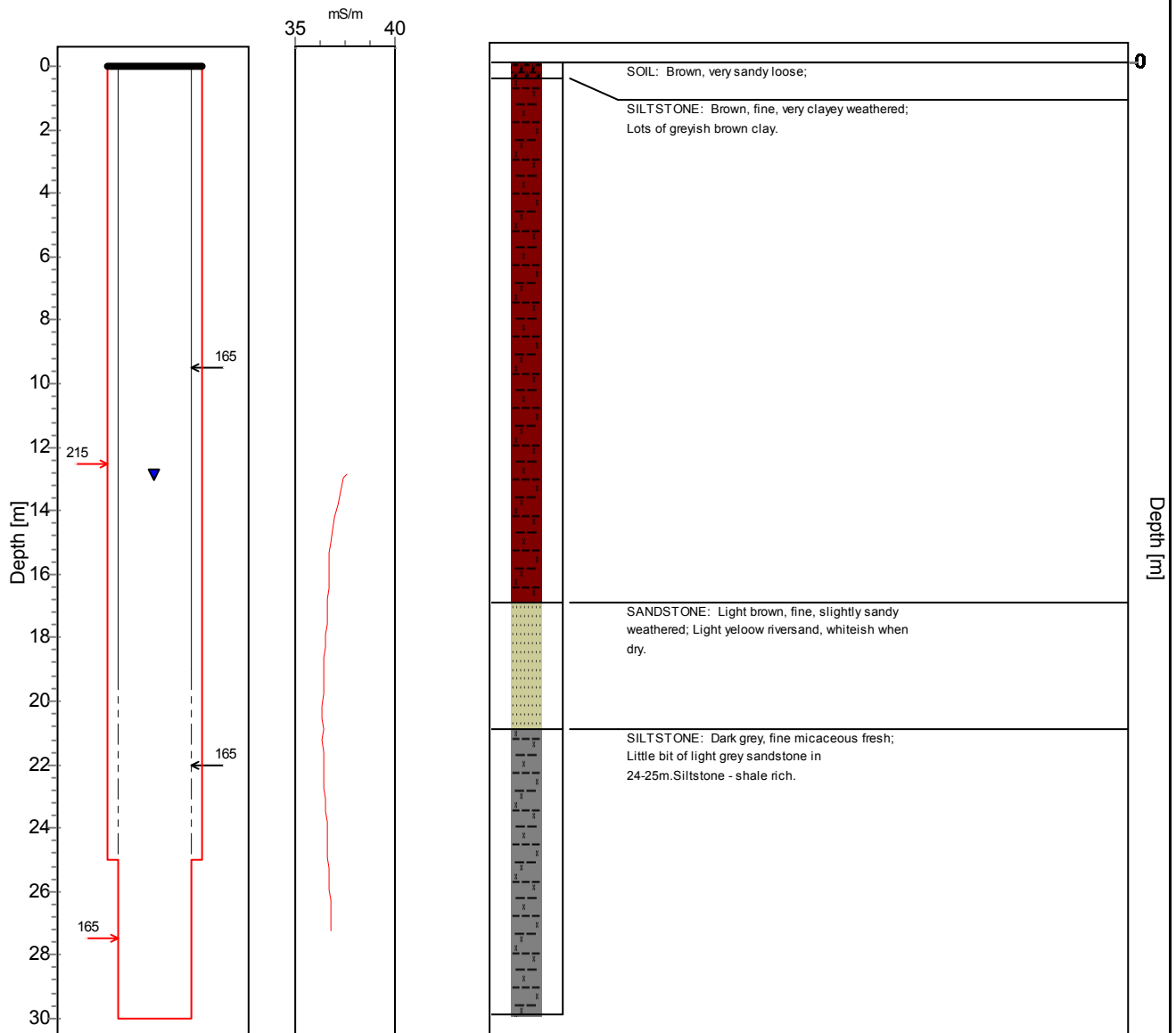
## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  165 Hole diameter [mm]
-  152 Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  0:50 Piezometer (Nr. & Diameter [mm])

Construction

EC.

Lithology



COMMENT:







# Borehole Construction and Geological Log

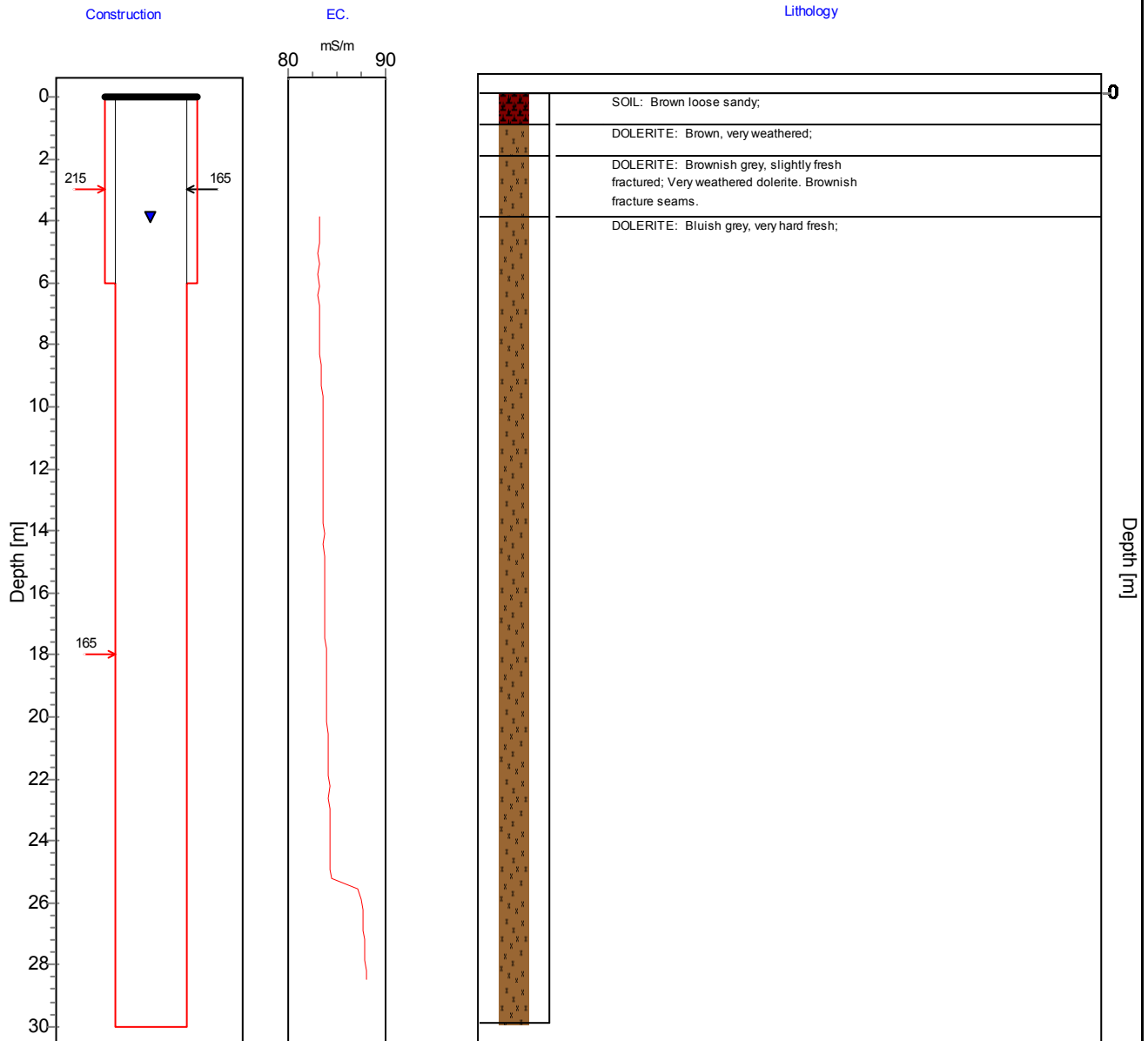
**BASIC SITE INFORMATION:** Site Identifier: 08 Number: WCW-8 Site type: Borehole

Region Type: No information Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 29.70
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.35
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  Hole diameter [mm]
-  Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  Piezometer (Nr. & Diameter [mm])



COMMENT:

# Borehole Construction and Geological Log

**BASIC SITE INFORMATION:** Site Identifier: 09 Number: WCW-9 Site type: Borehole

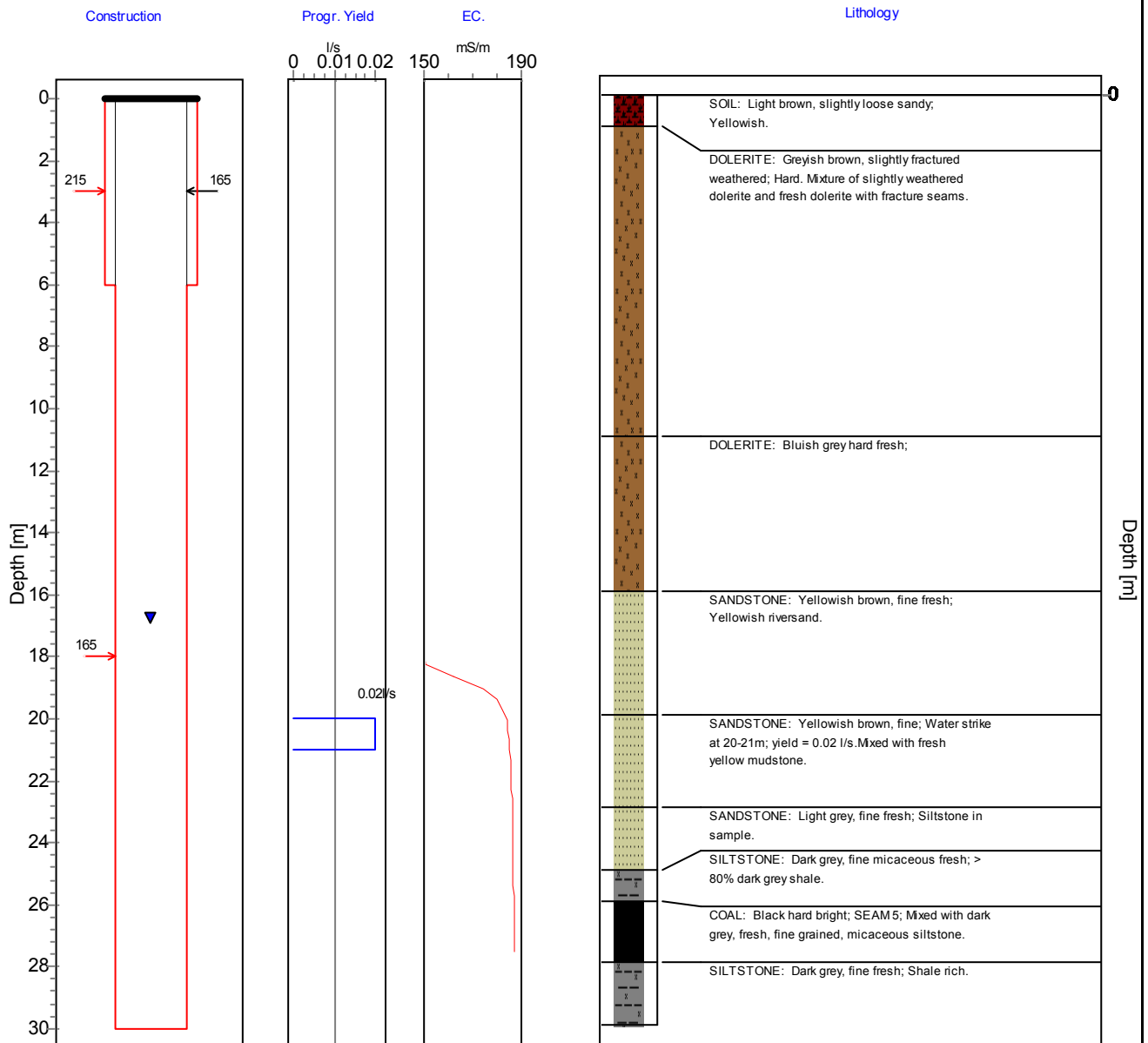
Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 30.00
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.30
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

## Construction and Geohydrological Legend

- Hole
- Casing (plain / perforated, slotted)
- Screen / Mesh Screen
- Piezometer
- Hole diameter [mm]
- Casing diameter [mm]
- Waterlevel measured: 20/09/02
- Piezometer (Nr. & Diameter [mm])



COMMENT:

# Borehole Construction and Geological Log









**BASIC SITE INFORMATION:** Site Identifier: 10 Number: WCW-10 Site type: Borehole

Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 30.00
Longitude [° ' "]: -6.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.67
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

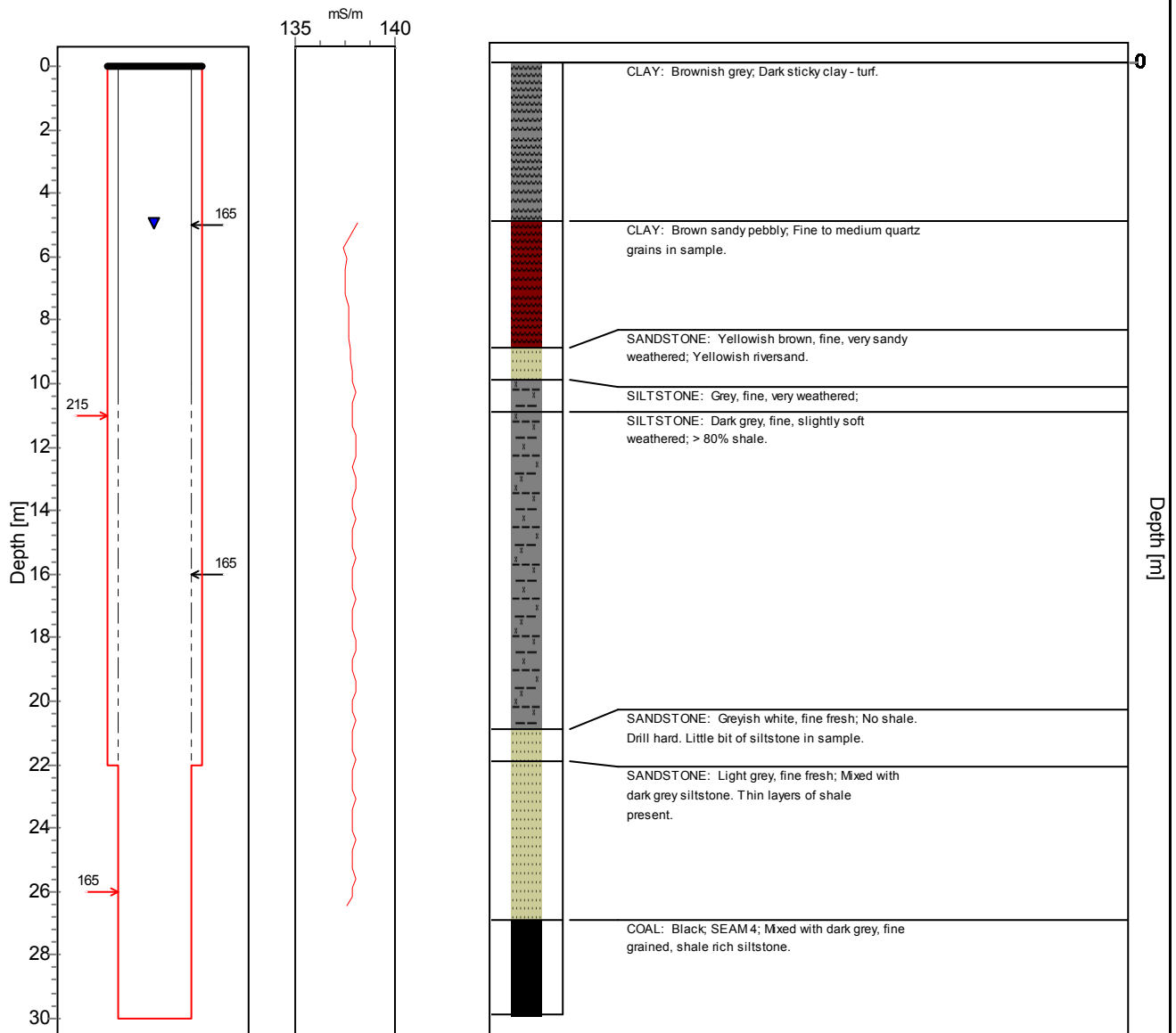
## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  165 Hole diameter [mm]
-  152 Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  0:50 Piezometer (Nr. & Diameter [mm])

Construction

EC.

Lithology



COMMENT:

# Borehole Construction and Geological Log

**BASIC SITE INFORMATION:** Site Identifier: 11 Number: WCW-11 Site type: Borehole

Region Type: No information Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 27.80
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.52
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

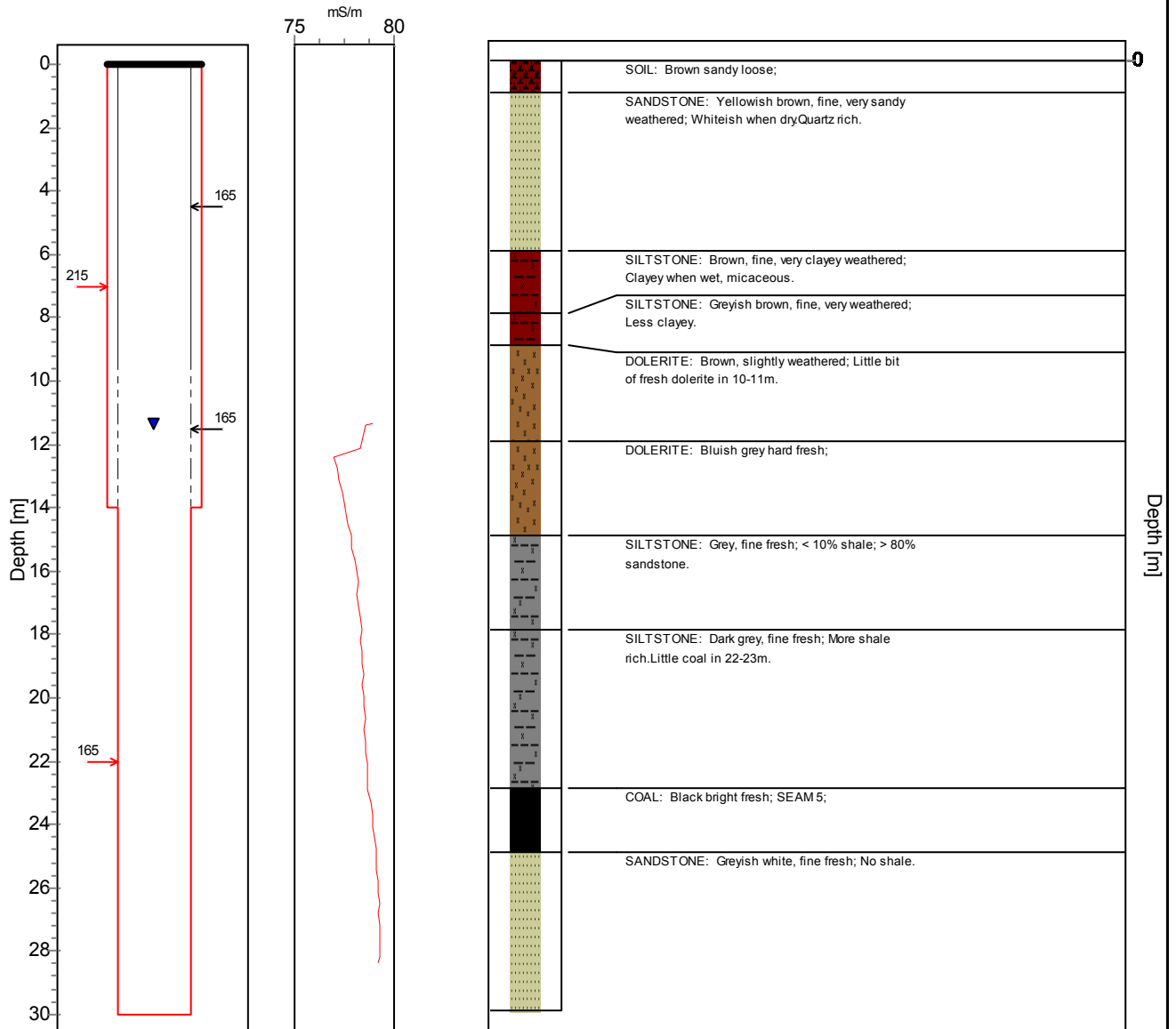
## Construction and Geohydrological Legend

	Hole		Hole diameter [mm]
	Casing (plain / perforated, slotted)		Casing diameter [mm]
	Screen / Mesh Screen		Waterlevel measured: 20/09/02
	Piezometer		Piezometer (Nr. & Diameter [mm])

Construction

EC.

Lithology



COMMENT:

# Borehole Construction and Geological Log








**BASIC SITE INFORMATION:** Site Identifier: 12 Number: WCW-12 Site type: Borehole

Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 30.00
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.57
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

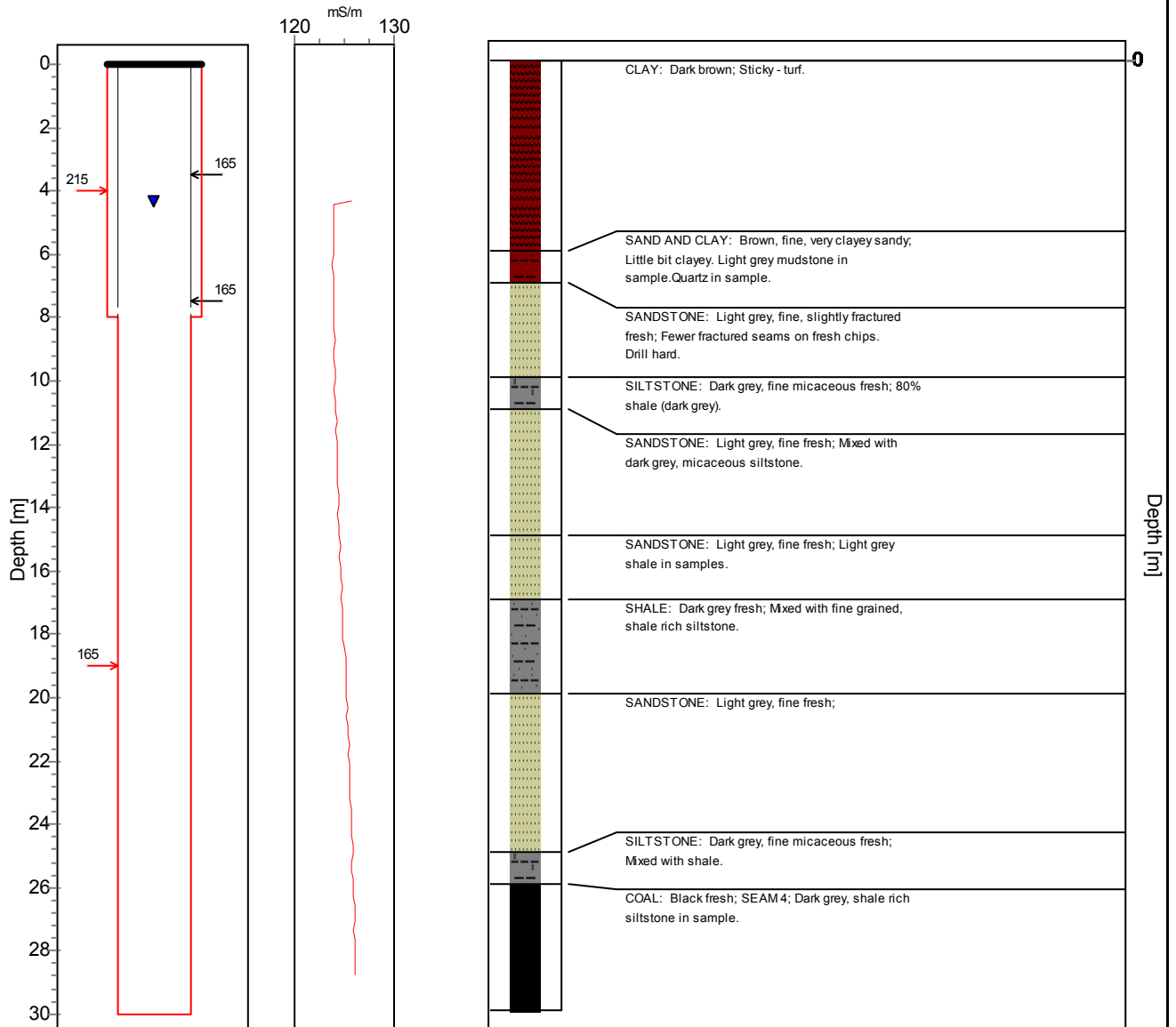
## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  165 Hole diameter [mm]
-  152 Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  0:50 Piezometer (Nr. & Diameter [mm])

Construction

EC.

Lithology



COMMENT:

# Borehole Construction and Geological Log







**BASIC SITE INFORMATION:** Site Identifier: 13 Number: WCW-13 Site type: Borehole

Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 23.80
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.54
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

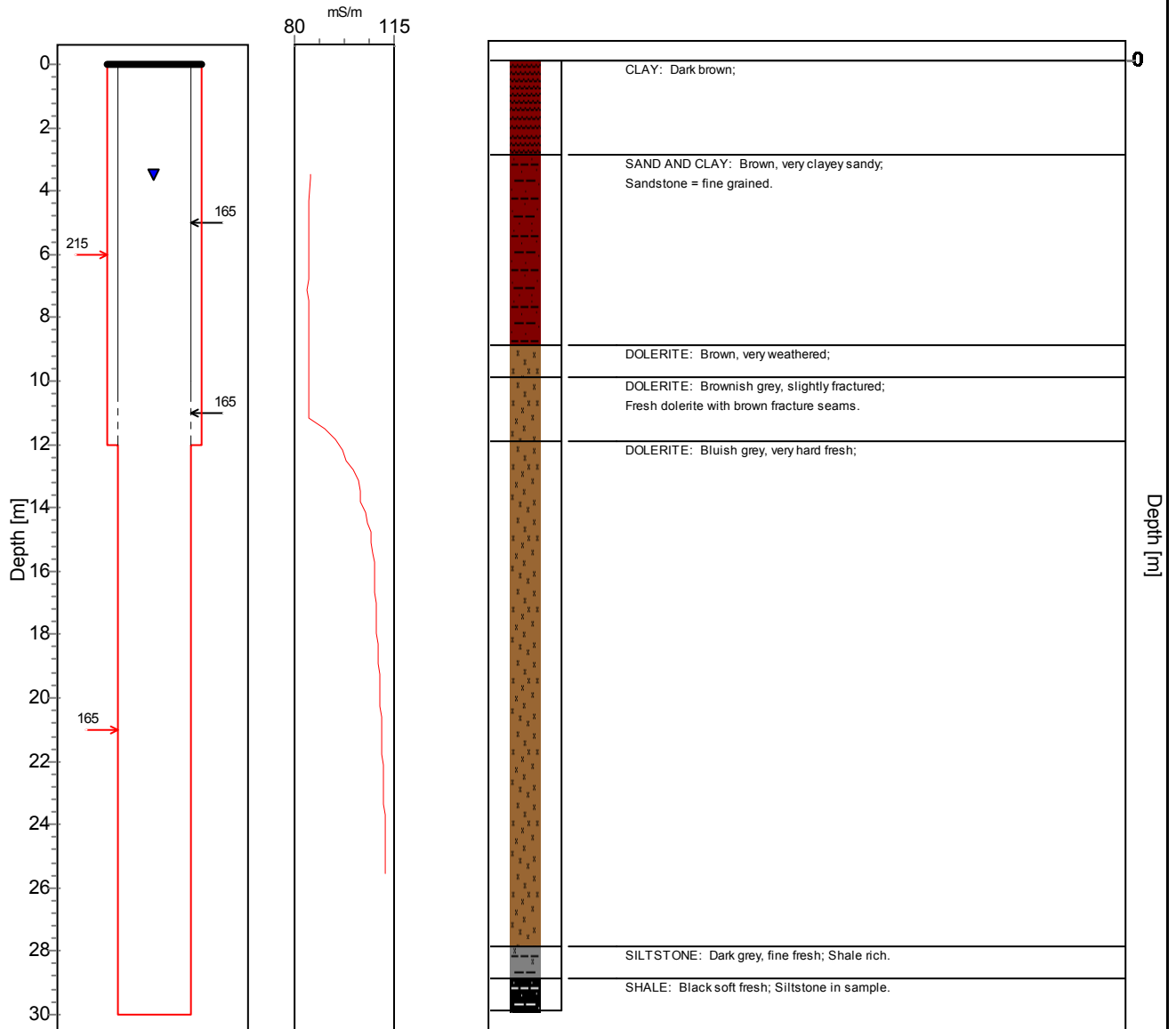
## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  Hole diameter [mm]
-  Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  Piezometer (Nr. & Diameter [mm])

Construction

EC.

Lithology



COMMENT:

# Borehole Construction and Geological Log


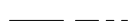




**BASIC SITE INFORMATION:** Site Identifier: 14 Number: WCW-14 Site type: Borehole

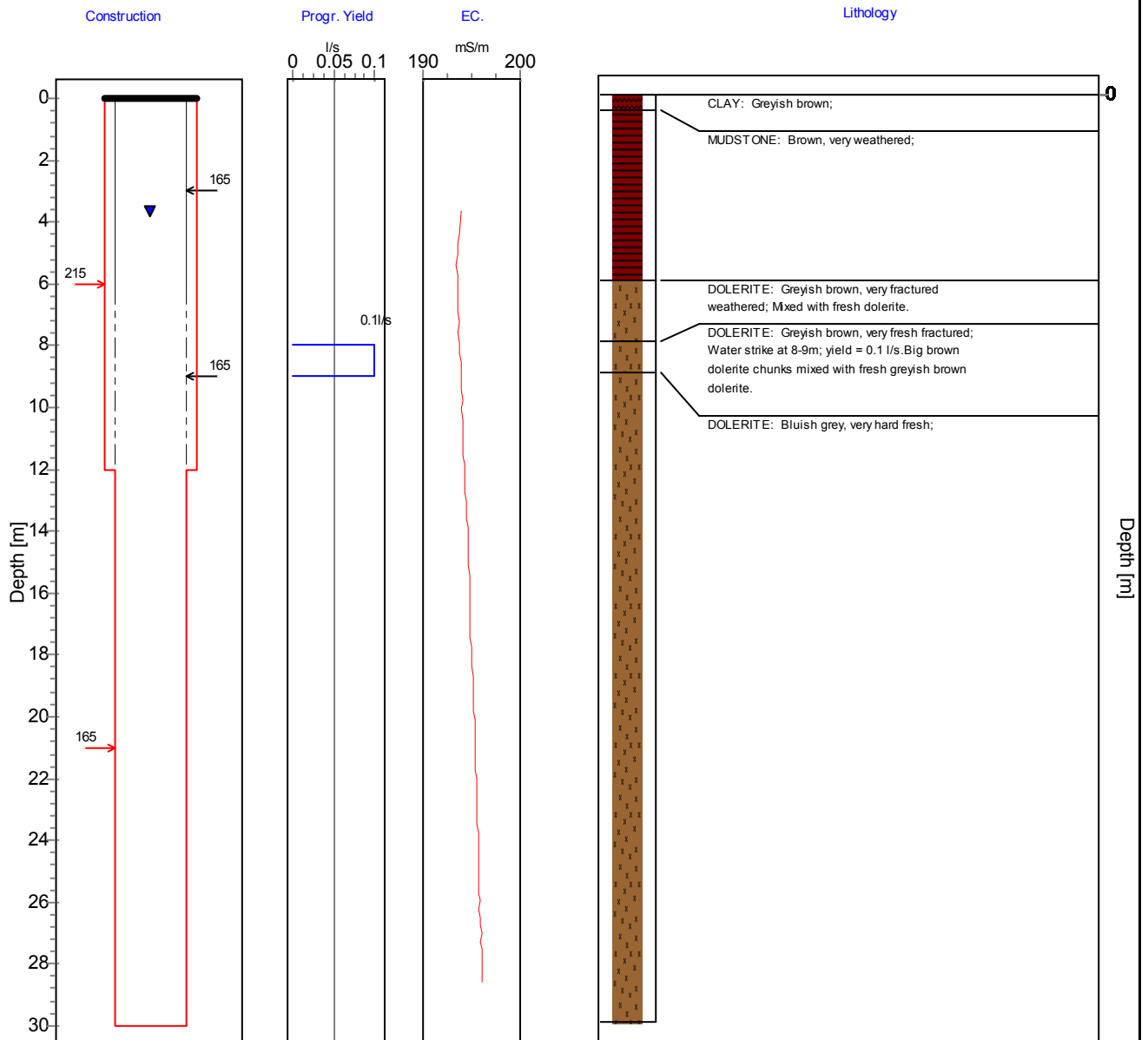
Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 29.50
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.48
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

## Construction and Geohydrological Legend

	Hole		165	Hole diameter [mm]
	Casing (plain / perforated, slotted)		152	Casing diameter [mm]
	Screen / Mesh Screen			Waterlevel measured: 20/09/02
	Piezometer		0:50	Piezometer (Nr. & Diameter [mm])



COMMENT:






# Borehole Construction and Geological Log

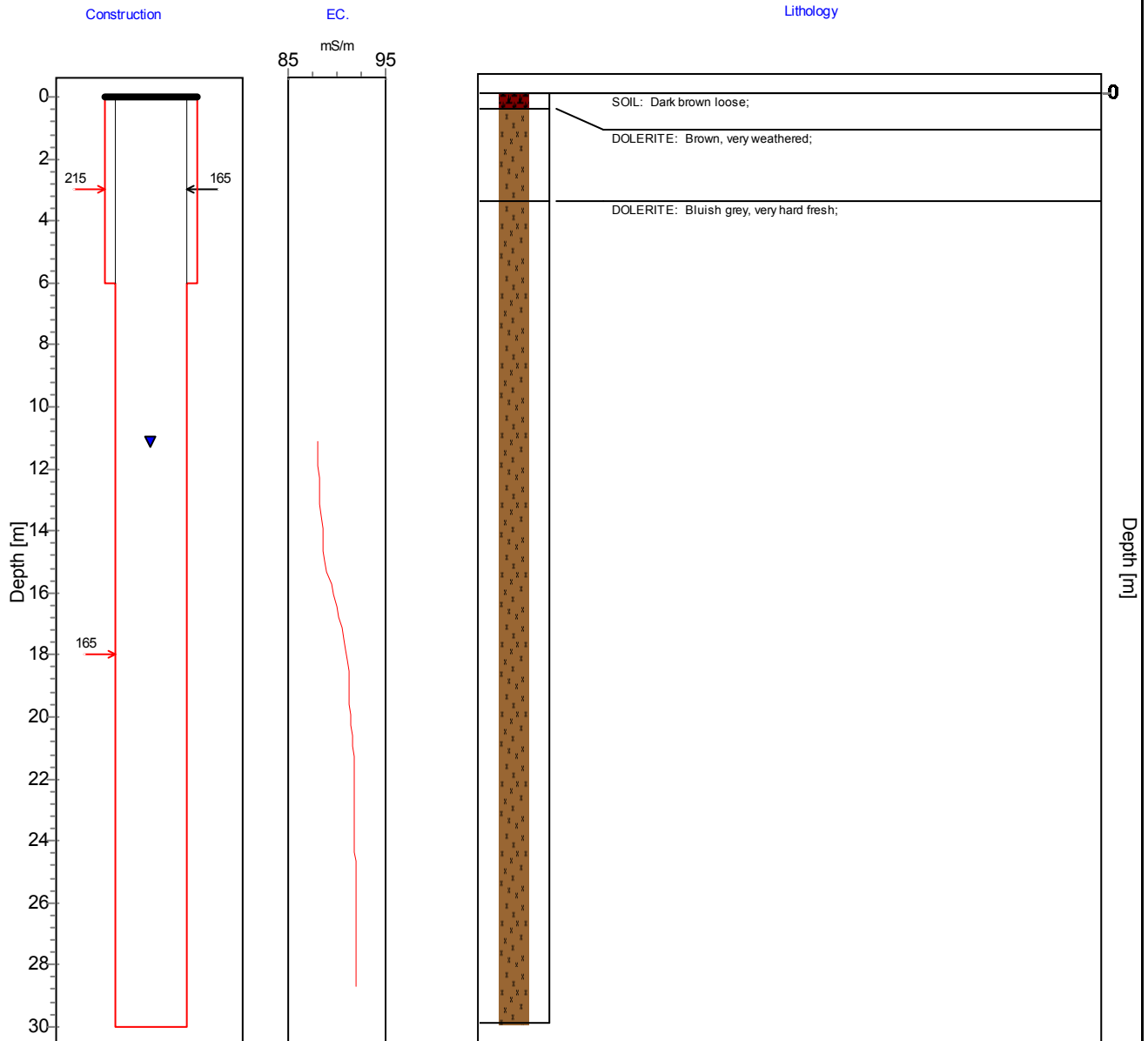
**BASIC SITE INFORMATION:** Site Identifier: 15 Number: WCW-15 Site type: Borehole

Region Type: No information Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Latitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 29.70
Longitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.52
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]: 165
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

## Construction and Geohydrological Legend

-  Hole
-  Casing (plain / perforated, slotted)
-  Screen / Mesh Screen
-  Piezometer
-  Hole diameter [mm]
-  Casing diameter [mm]
-  Waterlevel measured: 20/09/02
-  Piezometer (Nr. & Diameter [mm])



COMMENT:

# Borehole Construction and Geological Log

**BASIC SITE INFORMATION:** Site Identifier: 16 Number: WCW-16 Site type: Borehole

Region Type: No information

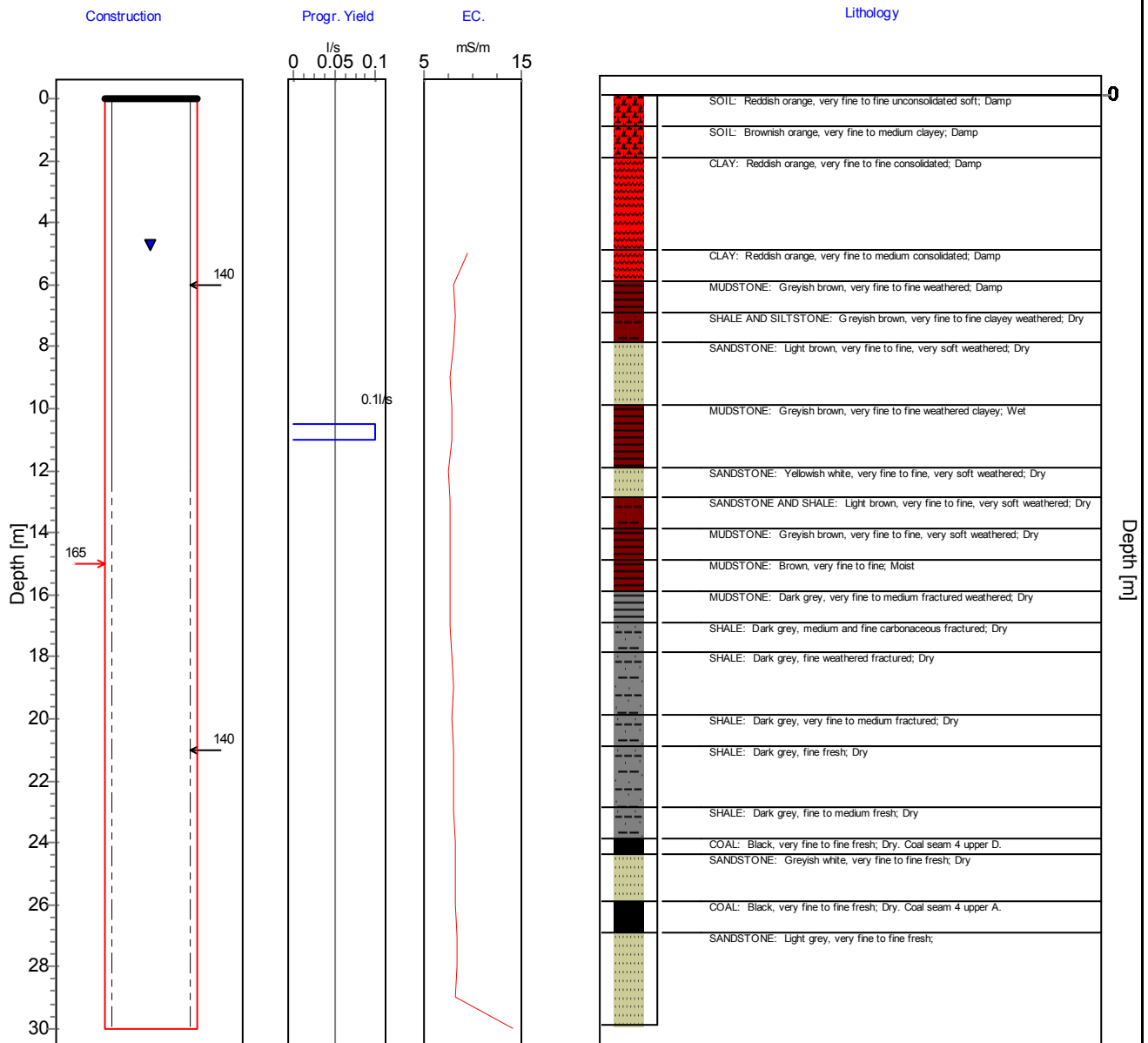
Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Longitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 0
Latitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.61
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]:
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

Coordinate System: Geographic Coordinates (deg, min, sec), WGS 1984

## Construction and Geohydrological Legend

	Hole		Hole diameter [mm]
	Casing (plain / perforated, slotted)		Casing diameter [mm]
	Screen / Mesh Screen		Waterlevel measured: 05/03/12
	Piezometer		Piezometer (Nr. & Diameter [mm])



COMMENT:

# Borehole Construction and Geological Log


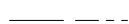




**BASIC SITE INFORMATION:** Site Identifier: 17 Number: WCW-17 Site type: Borehole

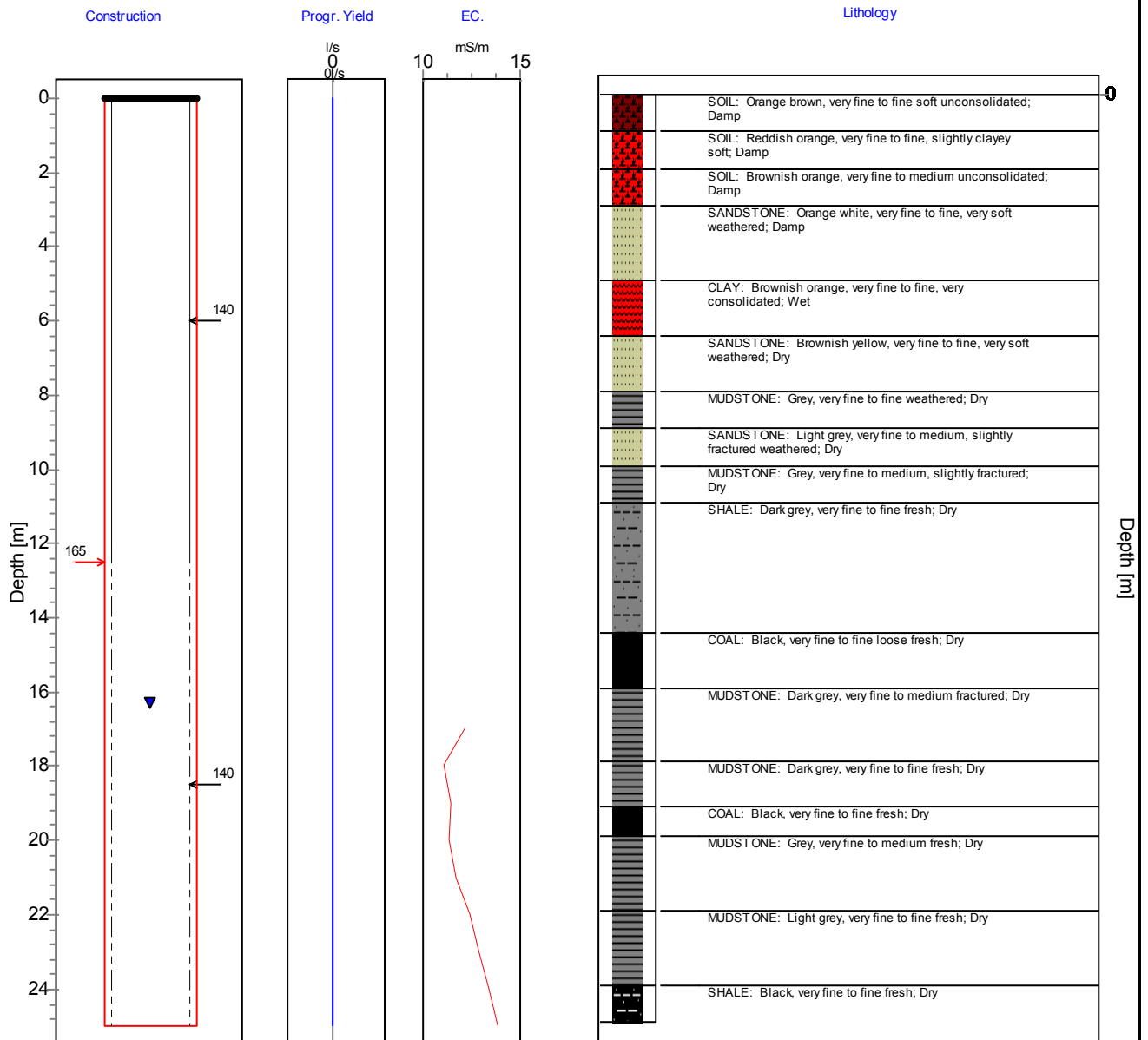
Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

<b>Longitude [° ' "]:</b> 0.00	<b>Reg./BB.:</b>	<b>Topo-set.:</b> No information	<b>Depth [m]:</b> 0
<b>Latitude [° ' "]:</b> 0.00	<b>G-Nr.:</b>	<b>Site status:</b> In use	<b>Col. ht. [m]:</b> 0.55
<b>Altitude [m]:</b> 0		<b>Site purp.:</b> Observation	<b>Diam. [mm]:</b>
<b>Coord. acc.:</b> No information		<b>Use applic.:</b> Industrial - mining	<b>Drain. reg.:</b> B11F
<b>Coord. meth.:</b> No information		<b>Equipment:</b> No equipment	<b>Rep. inst.:</b>

## Construction and Geohydrological Legend

	Hole		Hole diameter [mm]
	Casing (plain / perforated, slotted)		Casing diameter [mm]
	Screen / Mesh Screen		Waterlevel measured: 05/03/12
	Piezometer		Piezometer (Nr. & Diameter [mm])



COMMENT:

# Borehole Construction and Geological Log











**BASIC SITE INFORMATION:** Site Identifier: 18 Number: WCW-18 Site type: Borehole

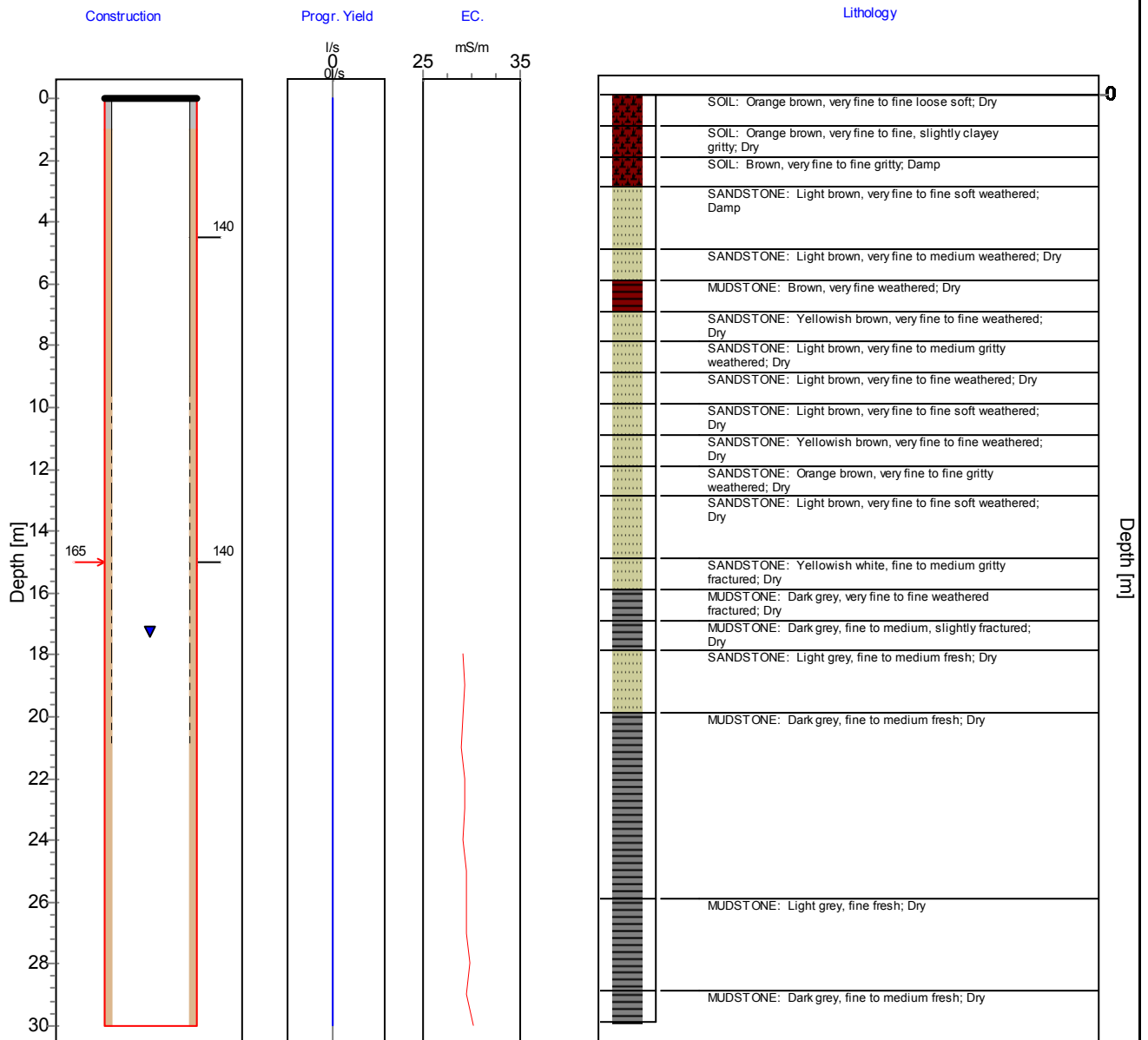
Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Longitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 0
Latitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.60
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]:
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

## Construction and Geohydrological Legend

	Hole		165	Hole diameter [mm]		Bentonite or clay
	Casing (plain / perforated, slotted)		152	Casing diameter [mm]		Gravel (> 2mm)
	Screen / Mesh Screen		0:50	Waterlevel measured: 05/03/12		
	Piezometer			Piezometer (Nr. & Diameter [mm])		



COMMENT:

# Borehole Construction and Geological Log











**BASIC SITE INFORMATION:** Site Identifier: 19 Number: WCW-19 Site type: Borehole

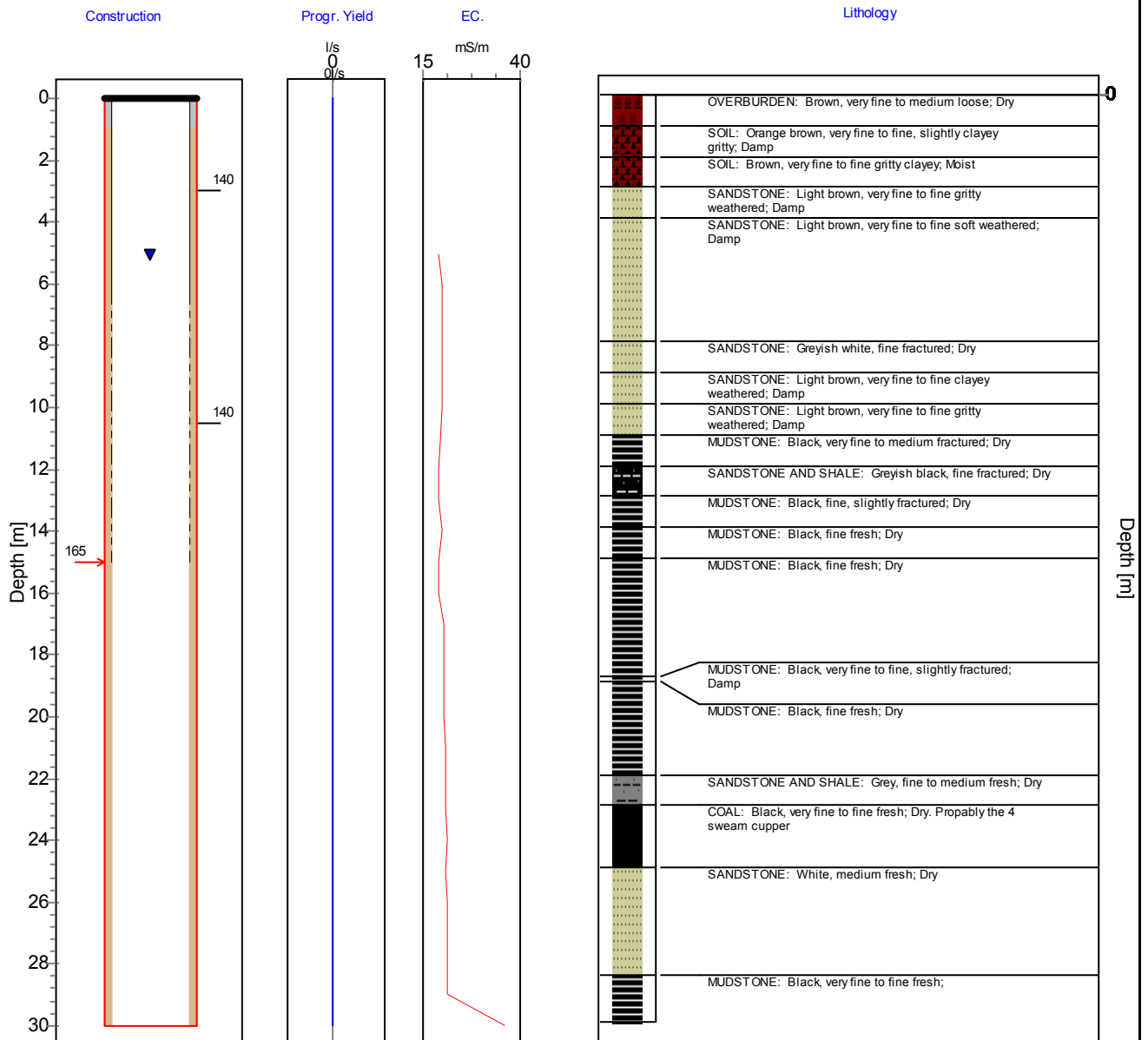
Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Longitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 0
Latitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.69
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]:
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

## Construction and Geohydrological Legend

	Hole		165	Hole diameter [mm]		Bentonite or clay
	Casing (plain / perforated, slotted)		152	Casing diameter [mm]		Gravel (> 2mm)
	Screen / Mesh Screen		0:50	Waterlevel measured: 05/03/12		
	Piezometer			Piezometer (Nr. & Diameter [mm])		



COMMENT:

# Borehole Construction and Geological Log

**BASIC SITE INFORMATION:** Site Identifier: 20 Number: WCW-20 Site type: Borehole

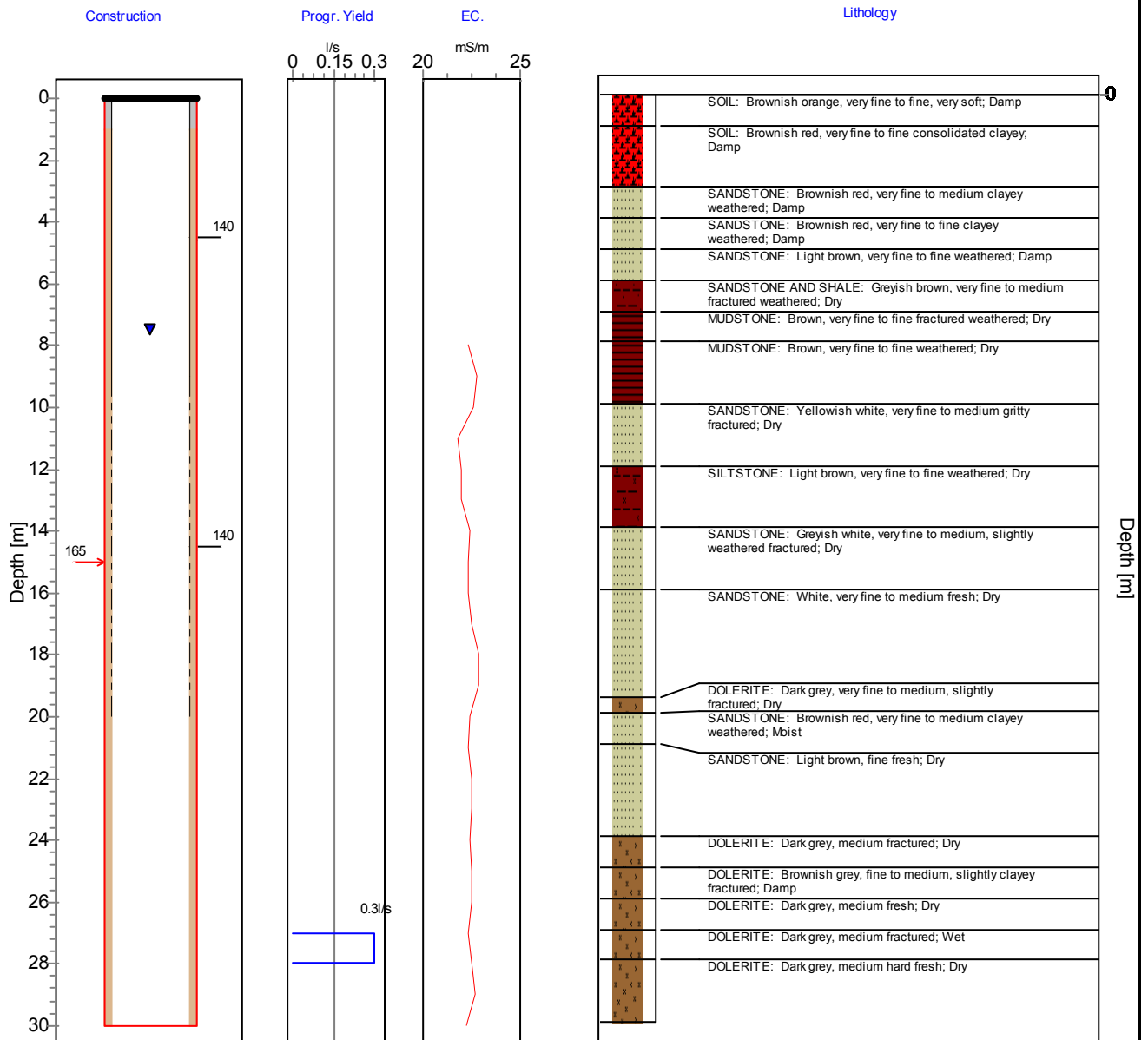
Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

Longitude [° ' "]: 0.00	Reg./BB.:	Topo-set.: No information	Depth [m]: 0
Latitude [° ' "]: 0.00	G-Nr.:	Site status: In use	Col. ht. [m]: 0.57
Altitude [m]: 0		Site purp.: Observation	Diam. [mm]:
Coord. acc.: No information		Use applic.: Industrial - mining	Drain. reg.: B11F
Coord. meth.: No information		Equipment: No equipment	Rep. inst.:

## Construction and Geohydrological Legend

- Hole
- Casing (plain / perforated, slotted)
- Screen / Mesh Screen
- Piezometer
- Hole diameter [mm]
- Casing diameter [mm]
- Waterlevel measured: 05/03/12
- Piezometer (Nr. & Diameter [mm])
- Bentonite or clay
- Gravel (> 2mm)



COMMENT:

# Borehole Construction and Geological Log





**BASIC SITE INFORMATION:** Site Identifier: 21 Number: WCW-21 Site type: Borehole

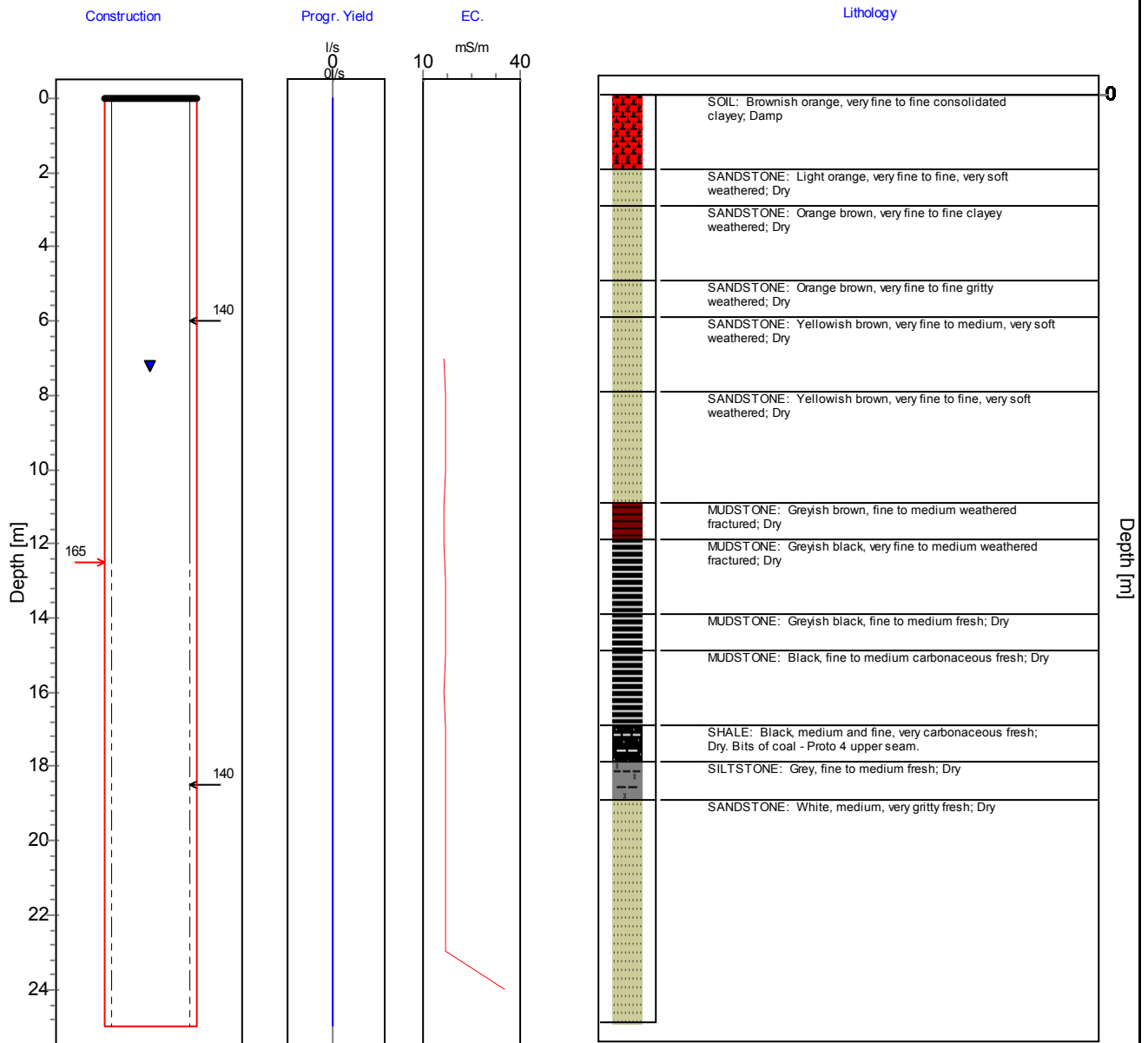
Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

<b>Longitude [° ' "]:</b> 0.00	<b>Reg./BB.:</b>	<b>Topo-set.:</b> No information	<b>Depth [m]:</b> 0
<b>Latitude [° ' "]:</b> 0.00	<b>G-Nr.:</b>	<b>Site status:</b> In use	<b>Col. ht. [m]:</b> 0.58
<b>Altitude [m]:</b> 0		<b>Site purp.:</b> Observation	<b>Diam. [mm]:</b>
<b>Coord. acc.:</b> No information		<b>Use applic.:</b> Industrial - mining	<b>Drain. reg.:</b> B11F
<b>Coord. meth.:</b> No information		<b>Equipment:</b> No equipment	<b>Rep. inst.:</b>

## Construction and Geohydrological Legend

	Hole		Hole diameter [mm]
	Casing (plain / perforated, slotted)		Casing diameter [mm]
	Screen / Mesh Screen		Waterlevel measured: 14/02/12
	Piezometer		Piezometer (Nr. & Diameter [mm])



COMMENT:

# Borehole Construction and Geological Log



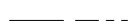




**BASIC SITE INFORMATION:** Site Identifier: 22 Number: WCW-22 Site type: Borehole

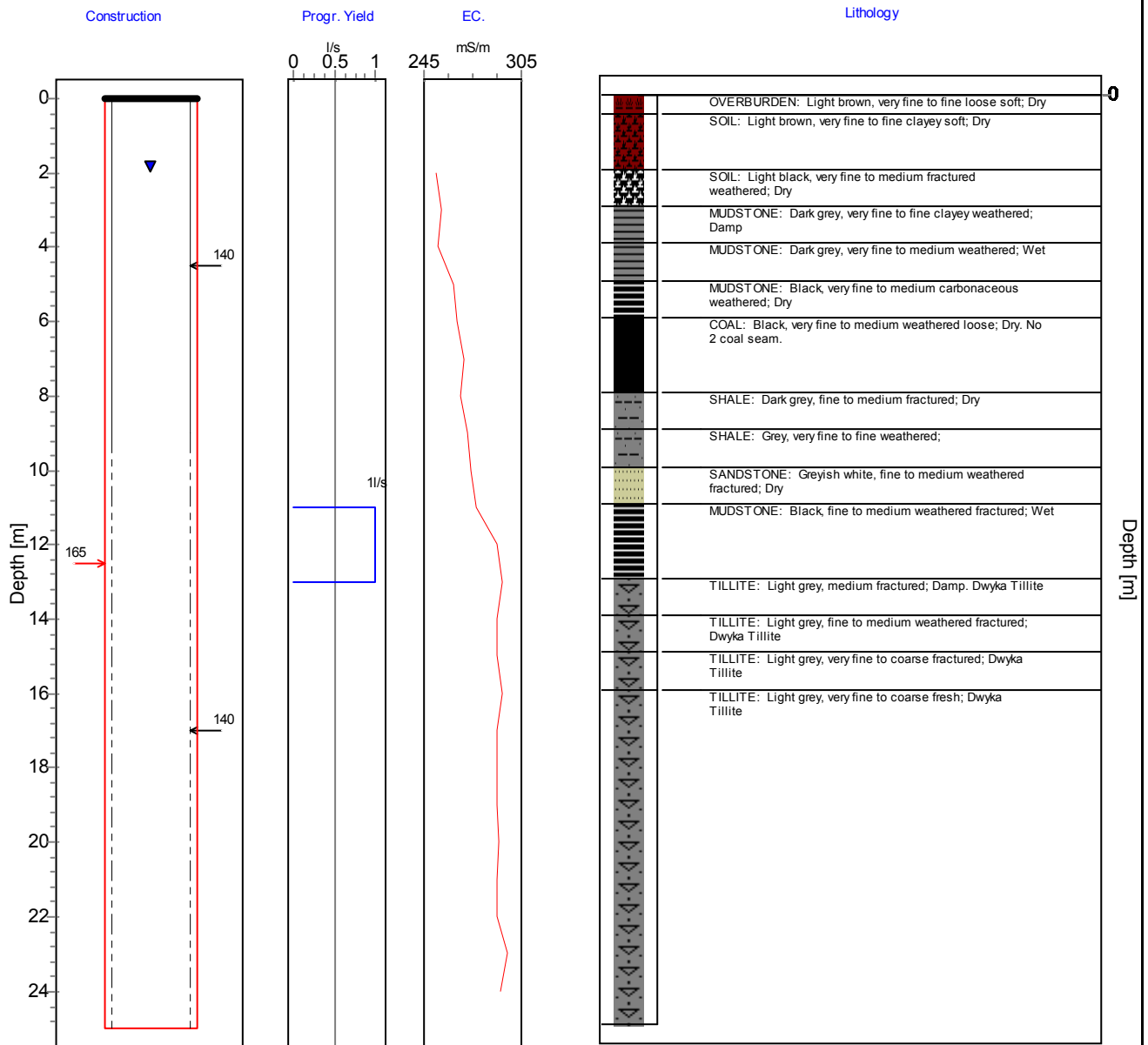
Region Type: No information

Region Descr.: SHALLOW WEATHERED ZONE AQUIFER

<b>Longitude [° ' "]:</b> 0.00	<b>Reg./BB.:</b>	<b>Topo-set.:</b> No information	<b>Depth [m]:</b> 0
<b>Latitude [° ' "]:</b> 0.00	<b>G-Nr.:</b>	<b>Site status:</b> In use	<b>Col. ht. [m]:</b> 0.66
<b>Altitude [m]:</b> 0		<b>Site purp.:</b> Observation	<b>Diam. [mm]:</b>
<b>Coord. acc.:</b> No information		<b>Use applic.:</b> Industrial - mining	<b>Drain. reg.:</b> B11F
<b>Coord. meth.:</b> No information		<b>Equipment:</b> No equipment	<b>Rep. inst.:</b>

## Construction and Geohydrological Legend

	Hole		Hole diameter [mm]
	Casing (plain / perforated, slotted)		Casing diameter [mm]
	Screen / Mesh Screen		Waterlevel measured: 14/02/12
	Piezometer		Piezometer (Nr. & Diameter [mm])



COMMENT:

# **APPENDIX II**

Hydraulic Conductivity Report

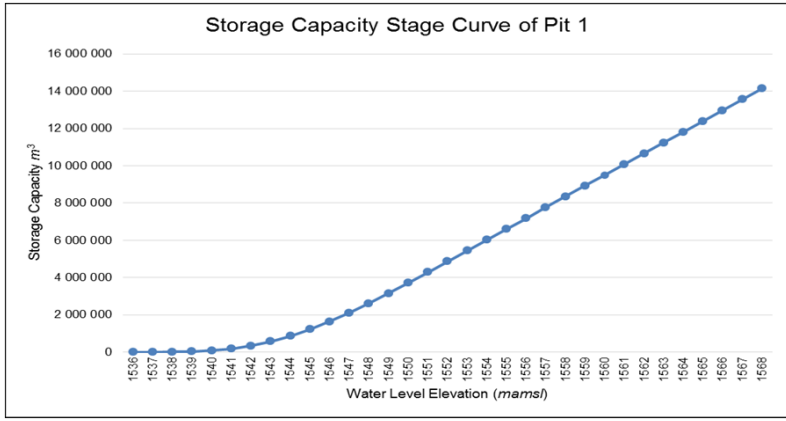
### Hydraulic Conductivity Report

Borehole Number	Hydraulic Conductivity (m/day)	Borehole Number	Hydraulic Conductivity (m/day)
WCW-1	0.740	WCW-12	0.015
WCW-2	0.010	WCW-13	0.030
WCW-3	0.004	WCW-14	0.014
WCW-4	0.074	WCW-15	0.009
WCW-5	0.003	WCW-16	0.007
WCW-6	0.008	WCW-17	0.095
WCW-7	0.019	WCW-18	0.001
WCW-8	0.009	WCW-19	0.011
WCW-9	0.014	WCW-20	0.070
WCW-10	0.041	WCW-21	0.012
WCW-11	0.015	WCW-22	0.830

# **APPENDIX III**

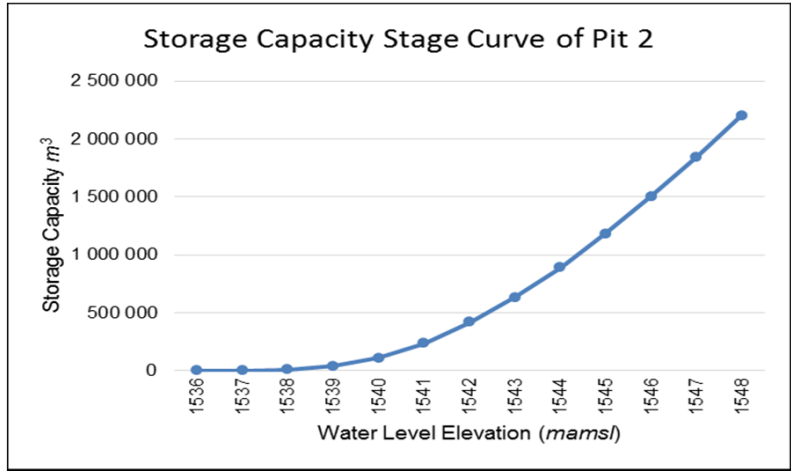
Mine Wide Storage Capacity Assessment

Pit 1			
Elevation	Total Volume (m <sup>3</sup> )	Storage Capacity (m <sup>3</sup> )	Available Storage (m <sup>3</sup> )
1536	0.00	0.00	16 451 158.51
1537	9 196.45	2 299.11	16 448 859.40
1538	55 194.02	13 798.51	16 437 360.01
1539	161 127.74	40 281.94	16 410 876.58
1540	359 054.21	89 763.55	16 361 394.96
1541	725 271.91	181 317.98	16 269 840.54
1542	1 359 106.51	339 776.63	16 111 381.89
1543	2 289 010.30	572 252.58	15 878 905.94
1544	3 478 983.01	869 745.75	15 581 412.76
1545	4 928 631.90	1 232 157.98	15 219 000.54
1546	6 589 180.12	1 647 295.03	14 803 863.48
1547	8 421 332.41	2 105 333.10	14 345 825.41
1548	10 438 280.43	2 609 570.11	13 841 588.41
1549	12 612 278.09	3 153 069.52	13 298 088.99
1550	14 871 034.90	3 717 758.72	12 733 399.79
1551	17 172 309.06	4 293 077.26	12 158 081.25
1552	19 488 134.06	4 872 033.51	11 579 125.00
1553	21 803 959.06	5 450 989.76	11 000 168.75
1554	24 119 784.06	6 029 946.01	10 421 212.50
1555	26 435 609.06	6 608 902.26	9 842 256.25
1556	28 751 434.06	7 187 858.51	9 263 300.00
1557	31 067 259.06	7 766 814.76	8 684 343.75
1558	33 383 084.06	8 345 771.01	8 105 387.50
1559	35 698 909.06	8 924 727.26	7 526 431.25
1560	38 014 734.06	9 503 683.51	6 947 475.00
1561	40 330 559.06	10 082 639.76	6 368 518.75
1562	42 646 384.06	10 661 596.01	5 789 562.50
1563	44 962 209.06	11 240 552.26	5 210 606.25
1564	47 278 034.06	11 819 508.51	4 631 650.00
1565	49 593 859.06	12 398 464.76	4 052 693.75
1566	51 909 684.06	12 977 421.01	3 473 737.50
1567	54 225 509.06	13 556 377.26	2 894 781.25
1568	56 541 334.06	14 135 333.51	2 315 825.00
1569	58 857 159.06	14 714 289.76	1 736 868.75
1570	61 172 984.06	15 293 246.01	1 157 912.50
1571	63 488 809.06	15 872 202.26	578 956.25
1572	65 804 634.06	16 451 158.51	0.00



Management Elevation	1568 mamsl
Decant Elevation	1572 mamsl

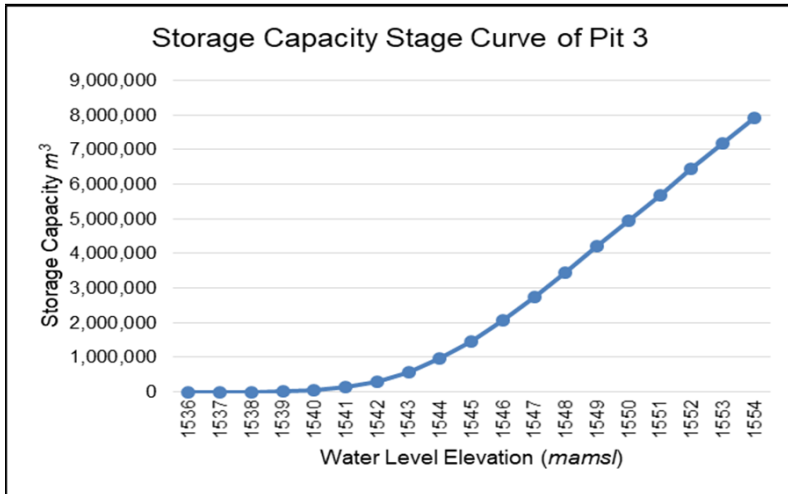
Pit 2			
Elevation	Total Volume (m <sup>3</sup> )	Storage Capacity (m <sup>3</sup> )	Available Storage (m <sup>3</sup> )
1536	-	-	4 069 183.30
1537	6 431.57	1 607.89	4 067 575.41
1538	41 314.76	10 328.69	4 058 854.61
1539	152 913.53	38 228.38	4 030 954.92
1540	432 360.47	108 090.12	3 961 093.19
1541	951 502.62	237 875.66	3 831 307.65
1542	1 674 223.28	418 555.82	3 650 627.48
1543	2 540 218.28	635 054.57	3 434 128.73
1544	3 568 642.98	892 160.75	3 177 022.56
1545	4 739 481.72	1 184 870.43	2 884 312.87
1546	6 015 723.17	1 503 930.79	2 565 252.51
1547	7 391 451.29	1 847 862.82	2 221 320.48
1548	8 817 866.33	2 204 466.58	1 864 716.72
1549	10 288 356.84	2 572 089.21	1 497 094.09
1550	11 780 713.82	2 945 178.46	1 124 004.85
1551	13 279 383.22	3 319 845.80	749 337.50
1552	14 778 058.22	3 694 514.55	374 668.75
1553	16 276 733.22	4 069 183.30	-



Management Elevation  
1548 mamsl

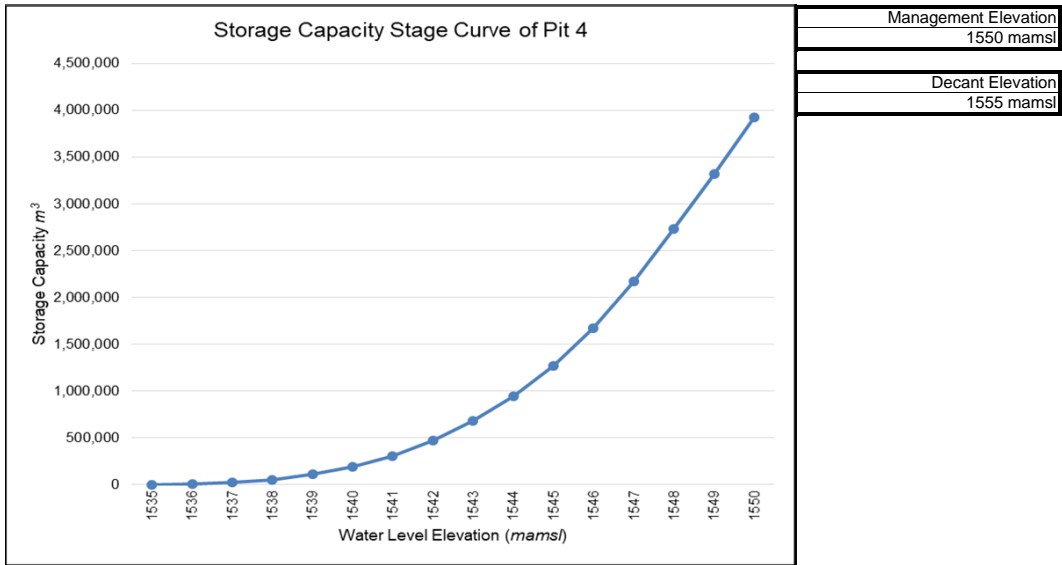
Decant Elevation  
1553 mamsl

Pit 3			
Elevation	Total Volume (m <sup>3</sup> )	Storage Capacity (m <sup>3</sup> )	Available Storage (m <sup>3</sup> )
1536	0.00	0.00	15374157.27
1537	123.11	30.78	15374126.49
1538	6003.67	1500.92	15372656.35
1539	36767.66	9191.92	15364965.35
1540	180804.00	45201.00	15328956.27
1541	520676.86	130169.21	15243988.05
1542	1161307.59	290326.90	15083830.37
1543	2246126.67	561531.67	14812625.60
1544	3835085.67	958771.42	14415385.85
1545	5856299.12	1464074.78	13910082.49
1546	8248924.89	2062231.22	13311926.04
1547	10942962.81	2735740.70	12638416.56
1548	13836574.58	3459143.64	11915013.62
1549	16805260.80	4201315.20	11172842.06
1550	19784679.06	4946169.77	10427987.50
1551	22764104.06	5691026.02	9683131.25
1552	25743529.06	6435882.27	8938275.00
1553	28722954.06	7180738.52	8193418.75
1554	31702379.06	7925594.77	7448562.50
1555	34681804.06	8670451.02	6703706.25
1556	37661229.06	9415307.27	5958850.00
1557	40640654.06	10160163.52	5213993.75
1558	43620079.06	10905019.77	4469137.50
1559	46599504.06	11649876.02	3724281.25
1560	49578929.06	12394732.27	2979425.00
1561	52558354.06	13139588.52	2234568.75
1562	55537779.06	13884444.77	1489712.50
1563	58517204.06	14629301.02	744856.25
1564	61496629.06	15374157.27	0.00

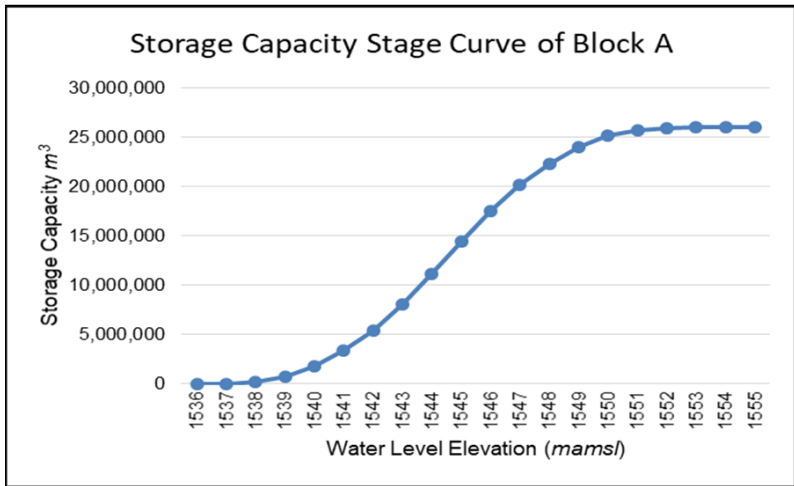


Management Elevation	1554 mamsl
Decant Elevation	1559 mamsl

Pit 4			
Elevation	Total Volume (m <sup>3</sup> )	Storage Capacity (m <sup>3</sup> )	Available Storage (m <sup>3</sup> )
1535	0.00	0.00	6950530.79
1536	14879.95	3719.99	6946810.81
1537	84512.96	21128.24	6929402.55
1538	221253.96	55313.49	6895217.31
1539	436872.79	109218.20	6841312.60
1540	760974.43	190243.61	6760287.19
1541	1233181.22	308295.30	6642235.49
1542	1884644.80	471161.20	6479369.59
1543	2725004.70	681251.18	6269279.62
1544	3770258.79	942564.70	6007966.10
1545	5058726.83	1264681.71	5685849.09
1546	6692413.57	1673103.39	5277427.40
1547	8685639.32	2171409.83	4779120.96
1548	10914590.34	2728647.59	4221883.21
1549	13284060.90	3321015.22	3629515.57
1550	15699236.87	3924809.22	3025721.58
1551	18119723.18	4529930.79	2420600.00
1552	20540323.18	5135080.79	1815450.00
1553	22960923.18	5740230.79	1210300.00
1554	25381523.18	6345380.79	605150.00
1555	27802123.18	6950530.79	0.00

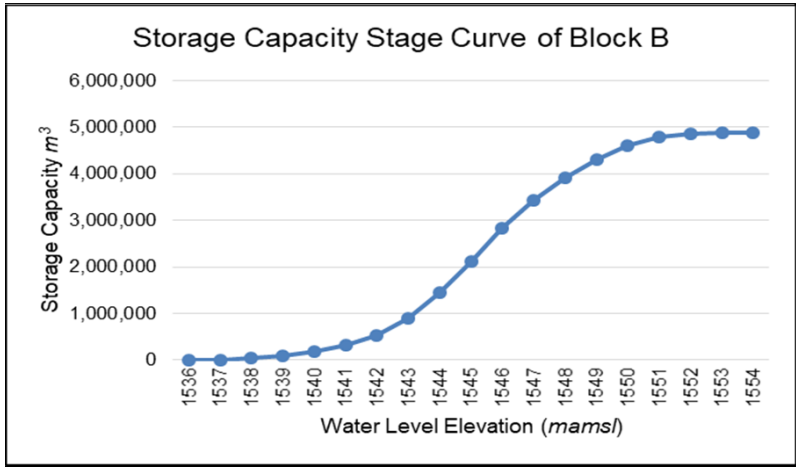


Block A					
Elevation	Volume above Floor (m <sup>3</sup> )	Volume above Roof (m <sup>3</sup> )	Total Volume (m <sup>3</sup> )	Storage Capacity (m <sup>3</sup> )	Available Storage (m <sup>3</sup> )
1536	0.00	0.00	0.00	0.00	25966224.38
1537	35472.53	0.00	35472.53	23057.15	25943167.23
1538	322063.13	0.00	322063.13	209341.04	25756883.34
1539	1165419.31	0.00	1165419.31	757522.55	25208701.82
1540	2784074.96	3896.99	2780177.96	1807115.68	24159108.70
1541	5381404.72	119885.35	5261519.37	3419987.59	22546236.79
1542	9024176.62	662328.61	8361848.01	5435201.20	20531023.17
1543	14243798.71	1854102.06	12389696.65	8053302.83	17912921.55
1544	21049131.25	3969404.24	17079727.02	11101822.56	14864401.81
1545	29214124.74	7032284.35	22181840.39	14418196.25	11548028.12
1546	38379039.46	11447917.49	26931121.97	17505229.28	8460995.10
1547	48409819.91	17439457.95	30970361.95	20130735.27	5835489.11
1548	59322782.44	24990450.95	34332331.49	22316015.47	3650208.91
1549	70545286.39	33690975.60	36854310.79	23955302.01	2010922.36
1550	81896830.23	43274327.02	38622503.21	25104627.09	861597.29
1551	93308997.74	53791688.86	39517308.88	25686250.77	279973.60
1552	104722722.74	64917277.32	39805445.42	25873539.52	92684.85
1553	116136447.74	76206396.25	39930051.49	25954533.47	11690.91
1554	127550172.74	87602148.80	39948023.94	25966215.56	8.82
1555	138963897.7	99015860.24	39948037.50	25966224.38	0.00



Management Elevation
1555 mamsl
Decant Elevation
1568 mamsl

Block B					
Elevation	Volume above Floor (m <sup>3</sup> )	Volume above Roof (m <sup>3</sup> )	Total Volume (m <sup>3</sup> )	Storage Capacity (m <sup>3</sup> )	Available Storage (m <sup>3</sup> )
1536	0.00	0.00	0.00	0.00	4892671.88
1537	12720.13	0.00	12720.13	8268.08	4884403.79
1538	55394.64	0.00	55394.64	36006.52	4856665.36
1539	141541.62	0.00	141541.62	92002.06	4800669.82
1540	286788.34	2219.65	284568.68	184969.64	4707702.23
1541	521760.69	29850.40	491910.29	319741.69	4572930.18
1542	897443.49	92346.90	805096.59	523312.78	4369359.09
1543	1571001.35	205287.05	1365714.29	887714.29	4004957.58
1544	2615447.96	390490.76	2224957.19	1446222.17	3446449.70
1545	3959050.10	683866.55	3275183.55	2128869.31	2763802.57
1546	5540551.86	1187156.55	4353395.31	2829706.95	2062964.92
1547	7308766.79	2045945.08	5262821.71	3420834.11	1471837.76
1548	9263116.40	3254732.96	6008383.45	3905449.24	987222.63
1549	11349393.77	4724312.74	6625081.03	4306302.67	586369.21
1550	13484534.13	6402695.49	7081838.63	4603195.11	289476.76
1551	15634654.74	8262816.22	7371838.52	4791695.04	100976.84
1552	17785279.74	10296728.86	7488550.88	4867558.07	25113.81
1553	19935904.74	12413649.71	7522255.02	4889465.77	3206.11
1554	22086529.74	14559342.24	7527187.50	4892671.88	0.00



Management Elevation	1554 mamsl
Decant Elevation	1588 mamsl