UNIVERSAL CHROME MINERALS GEOHYDROLOGICAL IMPACT ASSESSMENT: FOR THE PROPOSED DEVELOPMENT OF A CHROME WASHING PLANT ON PORTION 50 OF FARM BOSCHFONTERN 458 JQ AT BRITS, MADIBENG LOCAL MUNICIPALITY, NORTH WEST PROVINCE

Geohydrological Report Draft

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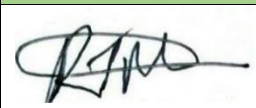
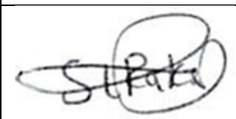
Reference Number: UCM_GEOHY_04/2025

April 2025

DOCUMENT CONTROL

Project Name	Water Use Licence Application for the Proposed Development of a Chrome Washing Plant at Universal Chrome Minerals within Portion 50 Of Farm Boschfontern 458 JQ at Brits, Madibeng Local Municipality, North West Province.		
Report Issue	Draft Report		
Our Reference No.	UCM_GEOHY_04/2025		
Report Title	Geohydrological Report: Universal Chrome Minerals (Pty) Ltd		
	Name	**Signature**	**Date**
Author	Tshimangadzo Rasifudi		04 April 2025
Reviewer	Dineo Makhubela		
Reviewer	Lorato Rakuba		22 April 2025
Director Approval	Letladi Maisela		

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NOTATIONS AND TERMS

Advection is the process by which solutes are transported by the bulk motion of the flowing groundwater.

Anisotropic is an indication of some physical property varying with direction.

Cone of depression is a depression in the groundwater table or potentiometric surface that has the shape of an inverted cone and develops around a borehole from which water is being withdrawn. It defines the area of influence of a borehole.

A ***confined aquifer*** is a formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

The ***darcy flux***, is the flow rate per unit area (m/d) in the aquifer and is controlled by the hydraulic conductivity and the piezometric gradient.

Dispersion is the measure of spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing due to microscopic variations in velocities within and between pores.

Drawdown is the distance between the static water level and the surface of the cone of depression.

Effective porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices that are connected.

Groundwater table is the surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

A ***fault*** is a fracture or a zone of fractures along which there has been displacement.

Hydrodynamic dispersion comprises of processes namely mechanical dispersion and molecular diffusion.

Hydraulic conductivity (K) is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured perpendicular to the area [L/T]. Hydraulic conductivity is a function of the permeability and the fluid's density and viscosity.

Hydraulic gradient is the rate of change in the total head per unit distance of flow in a given direction.

Heterogeneous indicates non-uniformity in a structure.

Karstic topography is a type of topography that is formed on limestone, gypsum, and other rocks by dissolution, and is characterized by sinkholes, caves and underground drainage.

Mechanical dispersion is the process whereby the initially close group of pollutants are spread in a longitudinal as well as a transverse direction because of velocity distributions.

Molecular diffusion is the dispersion of a chemical caused by the kinetic activity of the ionic or molecular constituents.

Observation borehole is a borehole drilled in a selected location for the purpose of observing parameters such as water levels.

Permeability is related to hydraulic conductivity, but is independent of the fluid density and viscosity and has the dimensions L^2. Hydraulic conductivity is therefore used in all the calculations.

Piezometric head **(h)** is the sum of the elevation and pressure head. An unconfined aquifer has a water table and a confined aquifer has a *piezometric surface*, which represents a pressure head. The piezometric head is also referred to as the hydraulic head.

Porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

Pumping tests are conducted to determine aquifer or borehole characteristics.

Recharge is the addition of water to the zone of saturation; also, the amount of water added.

Sandstone is a sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material.

Shale is a fine-grained sedimentary rock formed by the consolidation of clay, silt or mud. It is characterized by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

Specific storage *(S_o),* of a saturated confined aquifer is the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. In the case of an unconfined (phreatic, water table) aquifer, *specific yield* is the water that is released or drained from storage per unit decline in the water table.

Static water level is the level of water in a borehole that is not being affected by withdrawal of groundwater.

Storativity is the two-dimensional form of the specific storage and is defined as the specific storage multiplied by the saturated aquifer thickness.

Total dissolved solids (TDS) are a term that expresses the quantity of dissolved material in a sample of water.

Transmissivity *(T)* is the two-dimensional form of hydraulic conductivity and is defined as the hydraulic conductivity multiplied by the saturated thickness.

An ***unconfined-, water table- or phreatic-aquifer*** are different terms used for the same aquifer type, which is bounded from below by an impermeable layer. The upper boundary is the water table, which is in contact with the atmosphere so that the system is open.

Vadose zone is the zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.

Water table is the surface between the vadose zone and the groundwater, that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

LIST OF ABBREVIATIONS

Abbreviation	Description
DWS	Department of Water Affairs and Sanitation
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EMP	Environmental Management Programme
EMPR	Environmental Management Programme Report
IDW	Inverse Distance Weighted
LoA	Life of Asset
MAE	Mean Annual Evaporation
mamsl	meters above mean sea level
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
mbch	metres below collar height
mbgl	metres below ground level
mg/ℓ	milligrams per liter
NEMWA	National Environmental Management Waste Act
NO_3	Nitrate
R^2	Coefficient of determination
RMSE	Root Mean Square Error
NRMSE	Normalized Root Mean Square Error
SANS	South African National Standard
SAWS	South African Weather Service
SO_4	Sulphate
TDS	Total Dissolved Solids
TSF	Tailings Storage Facility
TSS	Total suspended solids
WR2012	Water Resources of South Africa 2012
WUL	Water Use Licence
WULA	Water Use Licence Application
UCM	Universal Chrome Minerals

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1. INTRODUCTION

1.1 Background

Segope Water and Environmental Services (Segope Consulting) has been appointed by Universal Chrome Minerals (UCM) to undertake a geohydrological impact assessment in support of the proposed chrome washing project in Brits Town. The format and content of this report follows the listed items as stipulated for an Integrated Waste Water Management Plan (IWWMP) in the Regulations regarding the procedural requirements for Water Use Licence (WUL) applications and appeals, Government Notice (GN) R267, Government Gazette 40713 24 March 2017.

UCM plans to establish a chrome processing plant within portion 50 of Farm Boschfontein 458JQ, focusing exclusively on mineral processing. The facility will process low-grade chrome minerals sourced from operating mines, utilizing a combination of mechanized processing equipment and manual hand-picking techniques to ensure efficiency and quality control.

The planned operations will encompass several key activities, including stockpiling, screening, washing, and loading of chrome minerals for further use or distribution. Given the nature of these activities, UCM's operations trigger the requirement for a Water Use Licence (WUL) under the National Water Act. Specifically, the project activates water uses under sections 21(a) (taking water from a resource), 21(b) (storing water), and 21(g) (disposing of waste in a manner that may affect water resources).

2. OBJECTIVES AND SCOPE OF WORK

2.1 Study objectives

The primary objectives of the study were to:

- Evaluate hydrogeological conditions within the site area in terms of groundwater quality.
- Conduct a preliminary risk assessment of the proposed development to groundwater quality and quantity;
- Classify the type(s) of the aquifer (Groundwater resources) present onsite.
- Provide technical recommendations of groundwater use based on the site conditions for portable water use and implementation of dust suppression for environmental compliance issues; and
- Design a monitoring plan/programme for the site during and after construction.

2.2 Scope of Work

The main purpose of this study was to determine the potential impacts of the proposed stockpiles, discard and recycling dams on the local groundwater quality conditions and water levels (if any). The scope of work and structure of the report can be summarized as follow:

The scope of work consisted of the following:

- All available data relating to the development area including geohydrology, hydrology, geochemistry, hydrochemistry and geology was reviewed
- Site-Conceptualization for utilizing groundwater during operational and implementing dust suppression for environmental compliance issues.
- A desktop level hydrocensus was conducted within a 2 km radius of the site. Both the National Groundwater Archive (NGA) and Groundwater Resource Information Project (GRIP) databases were assessed to identify existing groundwater users in the area.
- Field Investigation: A site walk over of the proposed study area was conducted, Sampling of groundwater sites based on hydrocensus information was conducted. Samples were submitted to a SANAS accredited laboratory for analysis.
- Reporting: Conclusions and recommendations.

3. GEOGRAPHICAL SETTING

3.1 Site Locality

UCM is located within the Brits town in the Madibeng Local Municipality within the Bojanala Platinum District Municipality. The area is situated within the Brits Town and can be accessed using R104 Road. The geographic location on which the water uses will take place is 25°43'14.42"S, 27°43'2.92"E. The location of the proposed project site is shown in **Figure 3.1** below.

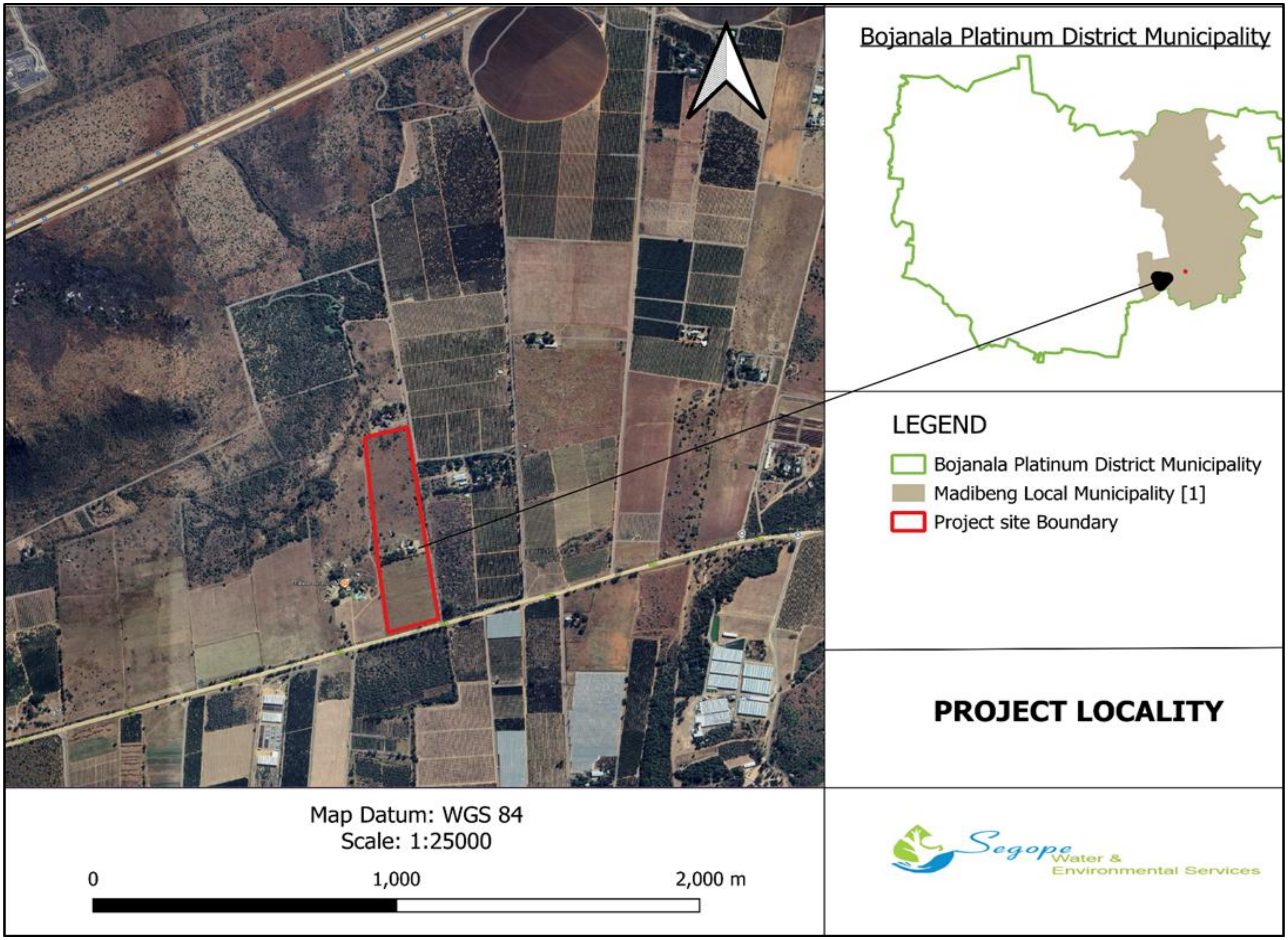

Figure 3.1: Locality Map showing the proposed UCM plant site

3.2 Topography and Surface Drainage

The topography of the project area characterized by a broad relatively flat land with an altitude of between 750-800 metres above mean sea level (mamsl). The topography of the project site is highly influenced and, in most cases, is directly related to the underlying geology, and the past and present climatic/drainage conditions. The topography of the project site is shown in **Figure 3.3** below.

The proposed chrome processing activity is situated in the Crocodile (West) and Marico (WMA), in quaternary catchment A21J. The A21J catchment is drained by the main Crocodile River. The hydrology of the project site is indicated in **Figure 3.2** below.

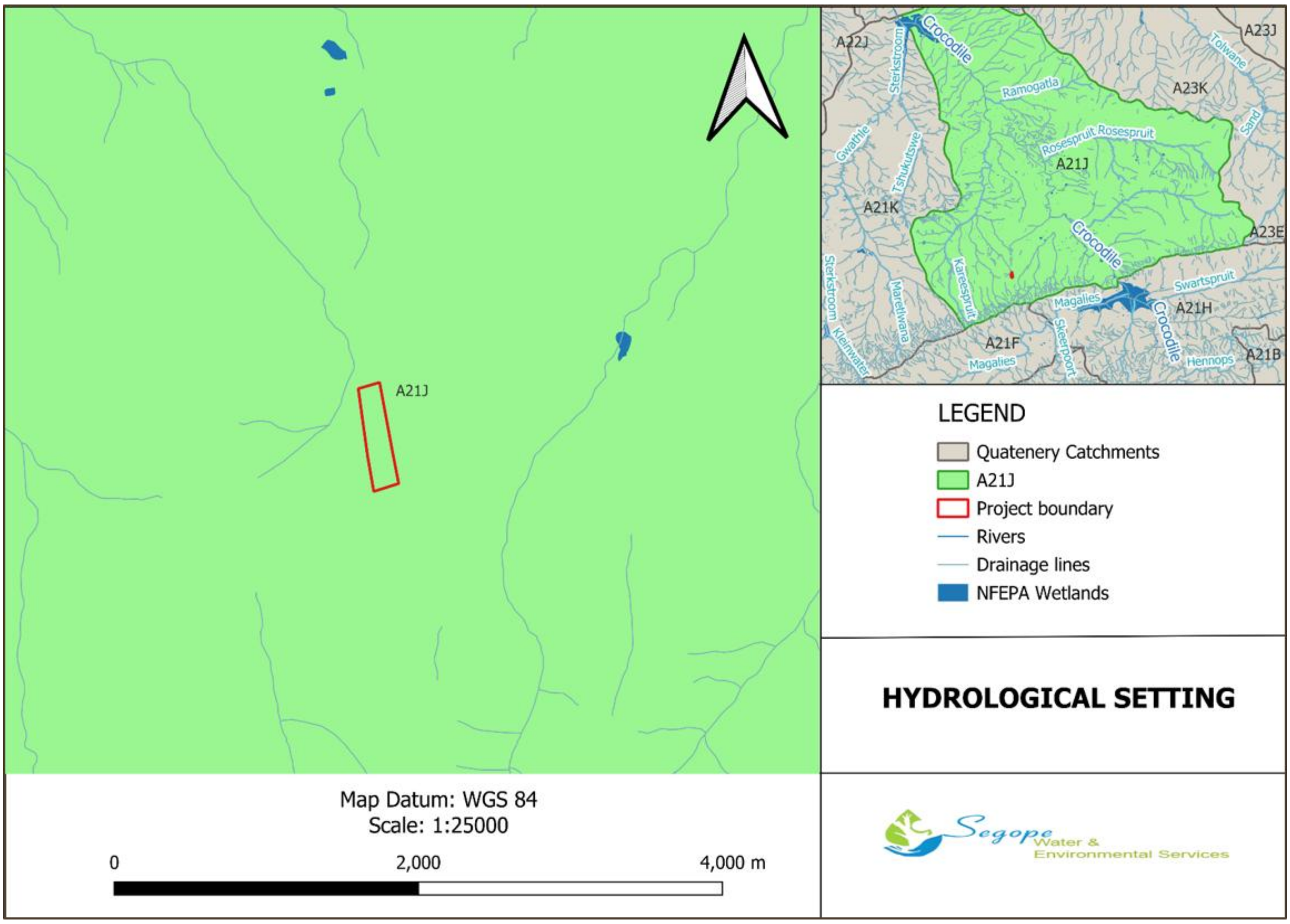

Figure 3.2: Hydrological Setting

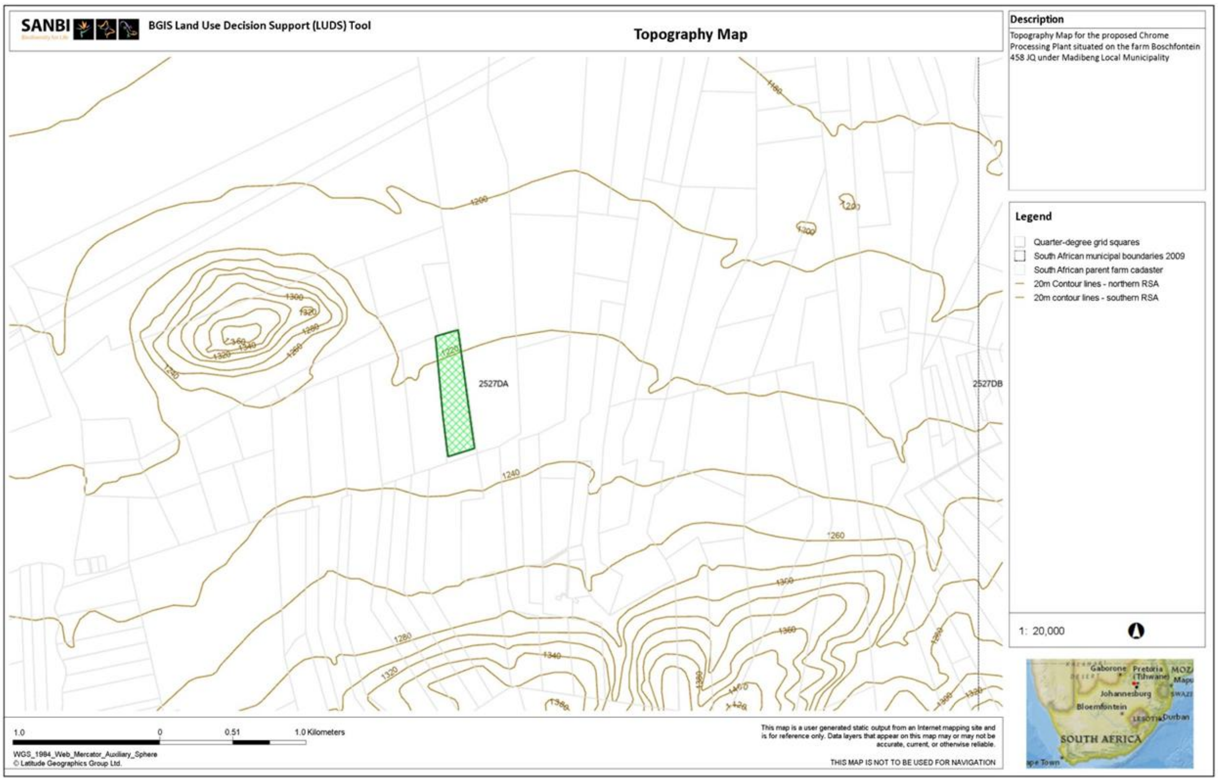

Figure 3.3: Topography of the project site

3.3 Climate

The study area is located in a semi-arid region in the North West Province of South Africa. The climate of the area is characterized by warm summers, cold to moderate winters, with the main rainy season being in summer from October through to April. Average daily maximum temperatures range from 30.3°C in January to 21.2°C in July, with daily minima ranging from 17°C in January to just above 1.3°C in July.

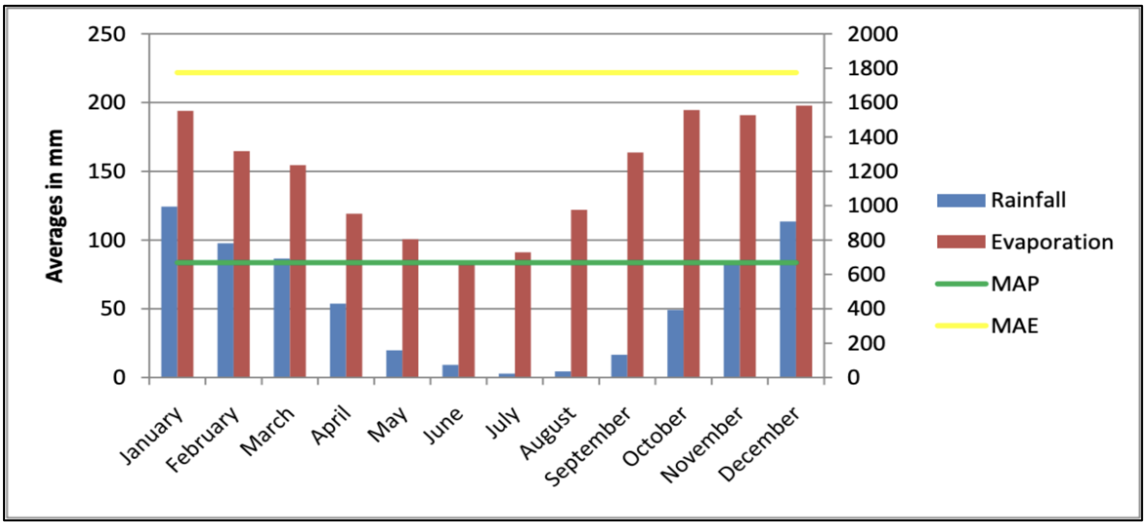

Figure 3.4: Climatic Condition of the study area

The average annual rainfall is 651 mm/year, which falls mainly as thundershowers during the summer months of October through April. The average annual evaporation is 2185 mm/year which means that the climatic water balance is therefore in deficit, resulting in an effective annual average evaporation of 1534 mm/year. Extreme conditions of rainfall can occur with the 24-hour events for various return periods which can vary between 79 mm (1:5 yrs.) to 125 mm (1:50 yrs.) to 138 mm (1:100 yrs.).

3.1 Geology

3.1.1 Regional Geology

The study area overlies the Vlakfontein Subsuite which along with Skilpadnest Subsuite, Norite Formation, Dwars River Subsuite, Kolobeng Norite Formation, and Croydon Subsuite Formation forms the Lower Zone of the Bushveld Igneous Complex within its Rustenburg Layered Suite. These formations are mafic and ultramafic layered deposits of igneous rock and can be classed under the Mafic Igneous Sulphides. The rocks in this study area are primarily pyroxenite, harzburgite and norite. Towards the South, The Vlakfontein Subsuite begins contact with the eastern Transvaal basin, particularly the Rayton Formation and Magaliesberg Formation. **Figure 3.5** below shows the geology of the project site.

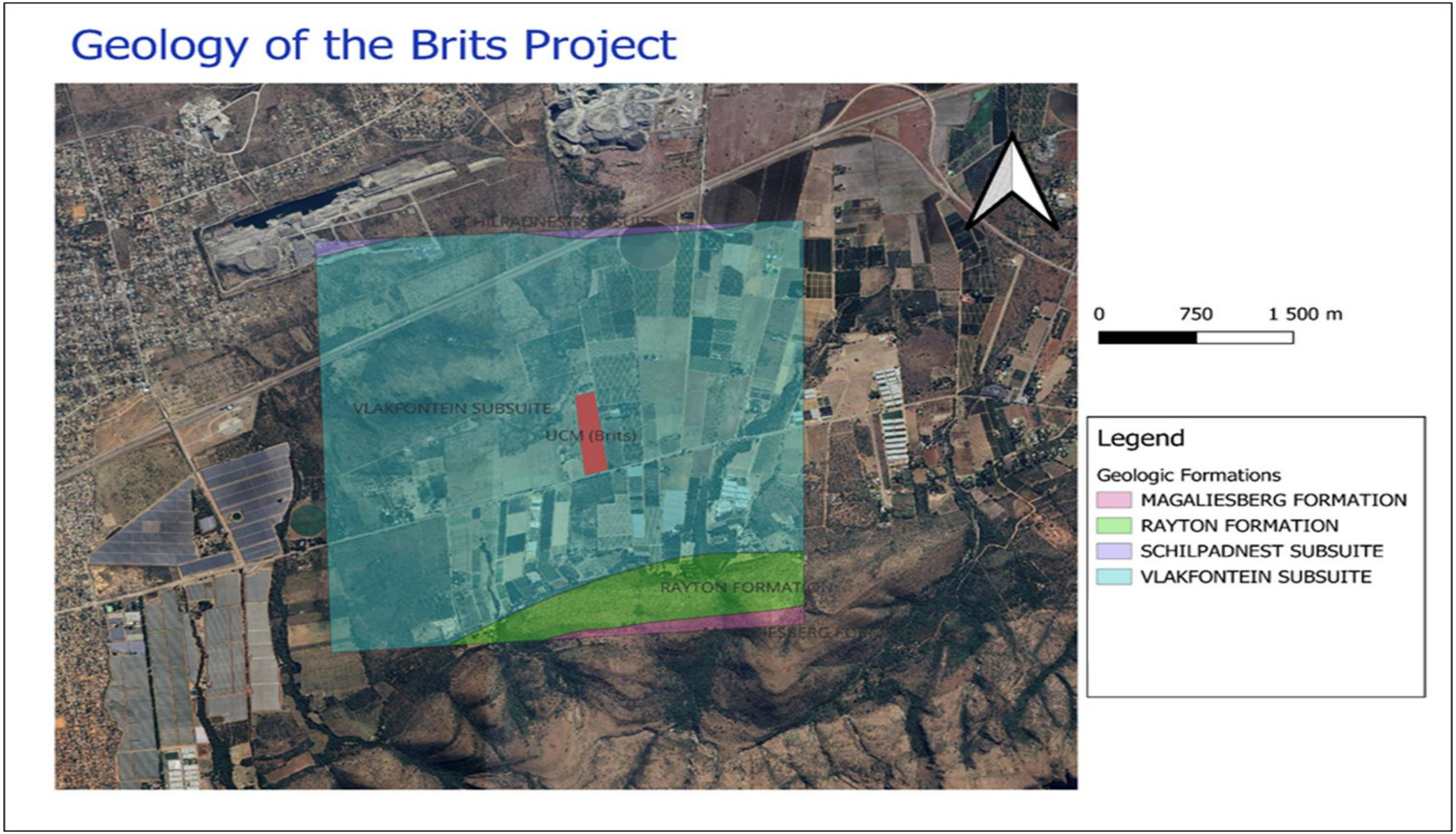

Figure 3.5: Geological Map of the project

3.2 Soil

Soils can vary widely in their color and base status (pH) due to different factors such as parent material, climate, vegetation, and human activities. Undifferentiated clays, red, yellow, and greyish soils with low to medium base status can be found in various parts of the world, and they each have specific characteristics and properties.

Sediments and minor carbonates and volcanics of the Pretoria Group (including the Silverton Formation) and some Malmani dolomites in the west, all of the Transvaal Supergroup (Vaalian). There is also some contribution from the mafic Bushveld intrusive. Soils are mostly stony with colluvial clay-loam but varied, including red-yellow apedal freely drained, dystrophic and eutrophic plinthic catenas, vertic and melanic clays, and some less typical Glenrosa and Mispah forms (**Figure 3.6**).

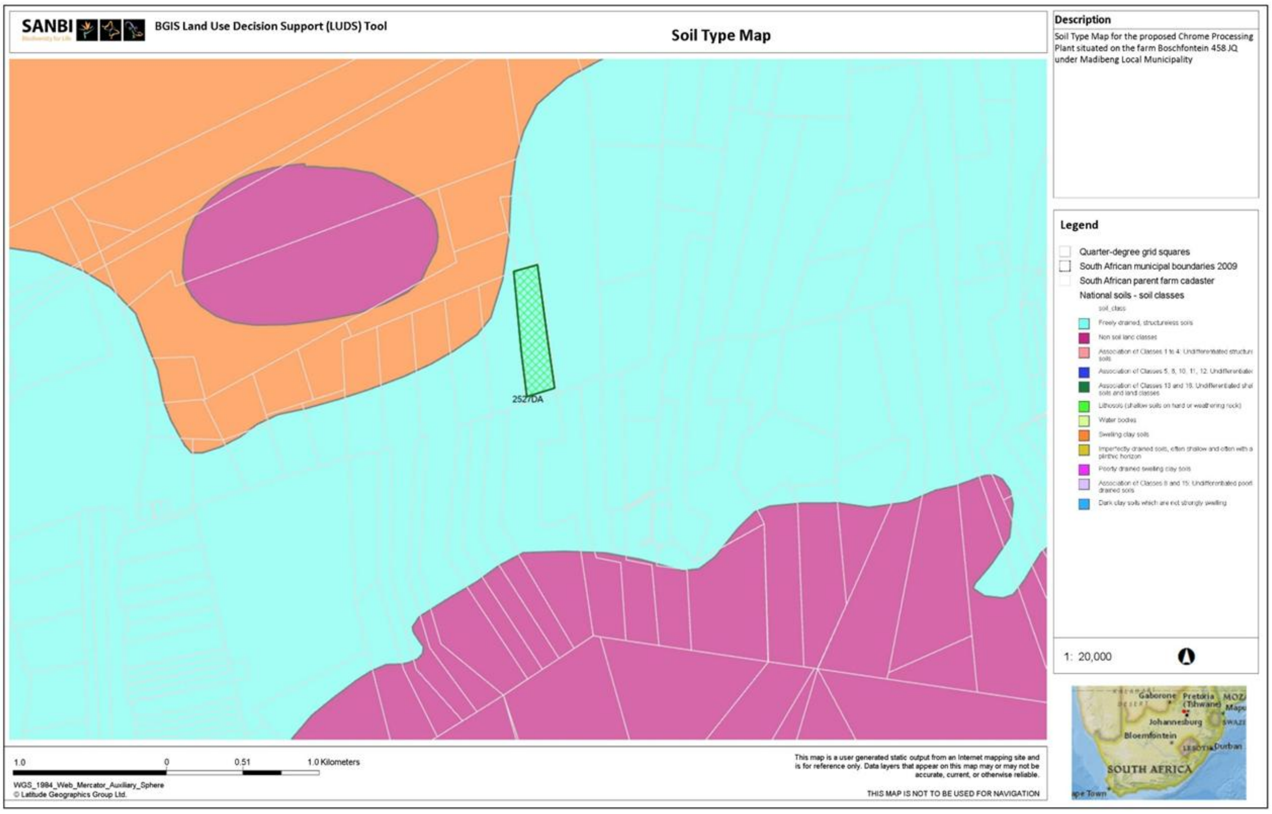

Figure 3.6: The soil types of the proposed project area

3.3 Regional Hydrogeology

The identified geological structure typically acts as secondary aquifers (intergranular and fractured rock aquifers) (Haupt, 1995). However, multi-layered weathering system present on these rocks could have up to two aquifer systems present in the form of a shallow, saprolitic aquifer with a weathered, intergranular soft rock base associated with the contact of fresh bedrock and the weathering zone, and a fractured bedrock aquifer. These aquifer systems are discussed below:

3.3.1 Shallow, saprolitic aquifer

The primary source of recharge into a shallow aquifer is rainfall that infiltrates the aquifer through the unsaturated (vadose) zone. In these systems, vertical movement of water is faster than lateral, as water moves predominantly under the influence of gravity. This aquifer may contain coarse, anorthositic sediment or turf clay sediment when underlain by Anorthosite or Gabbro-norite, respectively. The hydraulic conductivity of this aquifer ranges between 10^{-8} and 10^{-2} m/day, and porosity ranges between 0.4 and 0.7 for turf clay sediments. The hydraulic conductivity of the course, anorthositic sediment can reach up to 20 m/day with porosities ranging between values of 0.25 to 0.5.

3.3.2 Shallow weathered aquifer

This aquifer, which is recharged by rainfall, is often perched due to the impermeable clay horizons that might have developed underneath it. The recharge to this aquifer is estimated to be 3 - 5% of the annual rainfall. The well-developed clay layers in this aquifer restrict the downward filtration of recharged rainwater into the primary fractured aquifer. The most significant water accumulation is generally confined to the contact between the weathered and "fresh" bedrock. The borehole yields in this aquifer appear to be high due to the sandy/gritty nature of the weathered pyroxenite.

3.3.3 Fractured, bedrock aquifer

Groundwater movement is predominantly associated with secondary structures in this aquifer (fractures, faults, dykes, *etc*.). The average water level depth in the area ranges between 5 and 40 mbgl. Borehole yields in the Rustenburg Layered Suite fractured aquifers are generally low and can be expected to be between 0.1 and 2 l/s, with regional flow resembling flow in the porous medium and obeying the Darcy's law. These formations contain limited quantities of water resources due to the poor storage capacity of the igneous rock.

Groundwater quality in this area is also expected to be intermediate to poor, with EC values ranging from 4.4 to 120mS/m and possibly elevated Ca, Mg, Cl, and SO4 and carbonate alkalinity concentrations according to Haupt (1995). Both the porosity and the hydraulic conductivity of the Rustenburg Layered Suite fractured aquifers are known to be low (Williams *et al*., 2020). The commonly expected values of porosity and permeability for Igneous rock types, similar to those present in the Rustenburg Layered Suite, are 0.05 (porosity) and 10^{-5} $m.d^{-1}$ (hydraulic conductivity), respectively (Kruse man & de Ridder, 1994). Groundwater movement in this aquifer will be preferential in secondary structures such as joints, faults, and fractures.

3.3.4 Deeper fractured aquifer

The presence of weathering and fracturing zones within the country rock controls groundwater occurrence. Groundwater is generally restricted to depths of 40 – 70m below the surface, with most water strikes occurring in fracturing below the weathering. The most profound water strikes (70m) are associated with the contact zones of the main SW–SE trending dykes. Zones of high transmissivity are known to be associated with the dolerite dykes, and borehole yields varying from 2 to 20 l/s have been obtained in the general area. Aquifers are confined, anisotropic, and secondary with limited storage.

4. METHODOLOGY

The geohydrological report was constructed by first identifying what information is valuable or known as well as what gaps needs to be filled; then constructive recommendations were made. The impact of the proposed chrome wash plant and related infrastructures was investigated through field investigations, data analyses, and the use of numerical models (flow and transport models). The following subsections will discuss the work completed to compile the groundwater report.

4.1 Desktop Study

This included gathering of information through the collation, scrutiny and evaluation of available and relevant meteorological, geographical, geological, hydrogeological and water quality data.

4.2 Hydrocensus

The Hydrocensus was done to be familiar with the site and to collect data from the study area and surrounding environments. It comprised a census of key boreholes, wells, springs and any other groundwater related information.

4.3 Sampling and Chemical Analyses

4.3.1 Groundwater Sampling

Groundwater will be sampled by bailing according to the Standard Operating Procedure for groundwater sampling. Three boreholes will be sampled for chemical analysis. The water quality sampling work will be undertaken in accordance to the following guidelines:

- SABS ISO 5667-11: 2012 Guidance on sampling of groundwater
- SABS ISO 5667-2: 2012 Guidance on sampling techniques
- SABS ISO 5667-3: 2008 Guidance on the preservation and handling of samples

4.3.2 Groundwater Analysis

The following groundwater parameters listed **Table 4.1** will be analysed to understand the quality and hydrochemical facies of the groundwater samples taken.

Table 4.1 : Groundwater parameters to be analysed

Parameters	Parameters
Dissolved Aluminum	Fluoride
Dissolved Arsenic	Chloride
Dissolved Cadmium	Nitrite as NO_2
Dissolved Calcium	Nitrate as NO_3

Total Dissolved Chromium	Sulphate
Dissolved Cobalt	Ortho Phosphate as PO_4
Dissolved Copper	Ammoniacal Nitrogen as NH_4
Total Dissolved Iron	Hexavalent Chromium
Dissolved Lead	Total Alkalinity as $CaCO_3$
Dissolved Magnesium	Carbonate Alkalinity as $CaCO_3$
Dissolved Manganese	Bicarbonate Alkalinity as $CaCO_3$
Dissolved Mercury	Electrical Conductivity @25°C
Dissolved Molybdenum	pH
Dissolved Nickel	Total Dissolved Solids
Dissolved Potassium	Total Suspended Solids
Dissolved Selenium	Dissolved Zinc
Dissolved Sodium	

4.4 Quality Assurance and Quality Controls (QA/QC)

The SANAS-accredited Elements laboratory which is competent to carry out laboratory tasks in terms of the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act (Act 19 of 2006), will be used for samples analysis. The SANAS's purpose is to instill confidence and peace of mind to companies and individuals through accreditation required for economic and social well-being for all.

4.5 Aquifer Classification

The aquifer(s) underlying the subject area were classified in accordance with "A South African Aquifer System Management Classification, December 1995". The main aquifers underlying the area were classified in accordance with the Aquifer System Management Classification document (DWAF and WRC, 1995). The aquifers were classified by using the following definitions:

- **Sole Aquifer System**: An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
- **Major Aquifer System**: Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (Electrical Conductivity of less than 150 mS/m).
- **Minor Aquifer System**: These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable

permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.

- **Non-Aquifer System**: These are formations with negligible permeability that are regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

4.6 Aquifer Vulnerability

Aquifer vulnerability is the intrinsic characteristics that determine the aquifer's sensitivity to the adverse effects resulting from the imposed pollutants (Rivera and Guerrero, 2008). It is determined to indicate the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction of a contaminant at some location above the uppermost aquifer.

The following factors have an effect on groundwater vulnerability:

- **Depth to groundwater**: Indicates the distance and time required for pollutants to move through the unsaturated zone to the aquifer.
- **Recharge**: The primary source of groundwater is precipitation, which aids the movement of a pollutant to the aquifer.
- **Aquifer media**: The rock matrices and fractures which serve as water bearing units.
- **Soil media**: The soil media (consisting of the upper portion of the vadose zone) affects the rate at which the pollutants migrate to groundwater.
- **Topography**: Indicates whether pollutants will run off or remain on the surface allowing for infiltration to groundwater to occur.
- **Impact of the vadose zone**: The part of the geological profile beneath the earth's surface and above the first principal water-bearing aquifer. The vadose zone can retard the progress of the contaminants (DWAF, 2007).

4.7 Risk Assessment

The groundwater risk assessment was assessed by defining the three components, which are the source, the pathway and the receptor. The risk assessment approach is aimed at describing and defining the relationship between cause (source) through the groundwater pathway and the effect to the receptor. In the absence of any one of the three components, it is impossible to conclude that groundwater risk does/does not exist.

4.8 Mitigation and Management Measures

The groundwater management measures were developed by taking in consideration the National Water Act, Act 36 of 1998 (NWA) and, to a lesser extent, the Mineral and Petroleum Resources Development Act, Act No. 28 of 2002 (MPRDA) and the National Environmental

Management Act, Act 107 of 1998 (NEMA). The Chapter 4 of the NWA addresses uses of water.

The Department of Water and Sanitation (DWS), has recognised challenges facing both the water user and the authorities in managing groundwater in an integrated manner. This recognition has resulted in a number of guideline documents that provides the mining industry with an opportunity to marry together legislation and best practice into useable tools. The management measures discussed in this report was based on these Best Practice Guidelines (BPG) series (DWAF, 2008). The relevant guidelines for this report are listed below:

Activity Series Guidelines

- BPG A2. Water Management for Mine Residue Deposits
- BPG A4. Pollution Control Dams

Hierarchy Series Guidelines

- H1. Pollution prevention
- H2. Minimization of impacts

General Series Guidelines

- G3. Water monitoring systems
- G4. Impact prediction

5. DESKTOP STUDY

A desktop study was done on all available information pertaining to groundwater situation at the proposed plant.

5.1 Information Reviewed

The following information sources were reviewed:

- Geological Map (Scale 1:250 000) published by the Council for Geoscience.
- National Groundwater Database (NGDB) information managed by DWA (2005).
- General Surface Layout plan and Drawings by the UCM.
- DWA (2003) A Protocol to Manage the Potential of Groundwater Contamination from on-site sanitation. Technical Version. Edition 2, March 2003.
- Parsons R (1995) A South African Aquifer System Management Classification. Water.
- Research Commission Report no KV 77/95.

5.2 Activity Description

The plant activities will enclose an area of 11.7 hectares (ha) of Farm Boschfontein 458JQ. A WUL application is being made to include proposed processing plant activities and related infrastructures associated with the plant. The key components of the proposed infrastructures associated with the proposed plant includes:

- A waste rock dump for the storage of waste rock generated at the plant,
- Offices and associated infrastructure,
- Septic Tanks,
- Tailings.
- Product stockpile,
- Run of Plant (RoM)
- Stormwater management infrastructure.

Figure 5.1 shows the proposed site layout plan for UCM chrome washing plant.

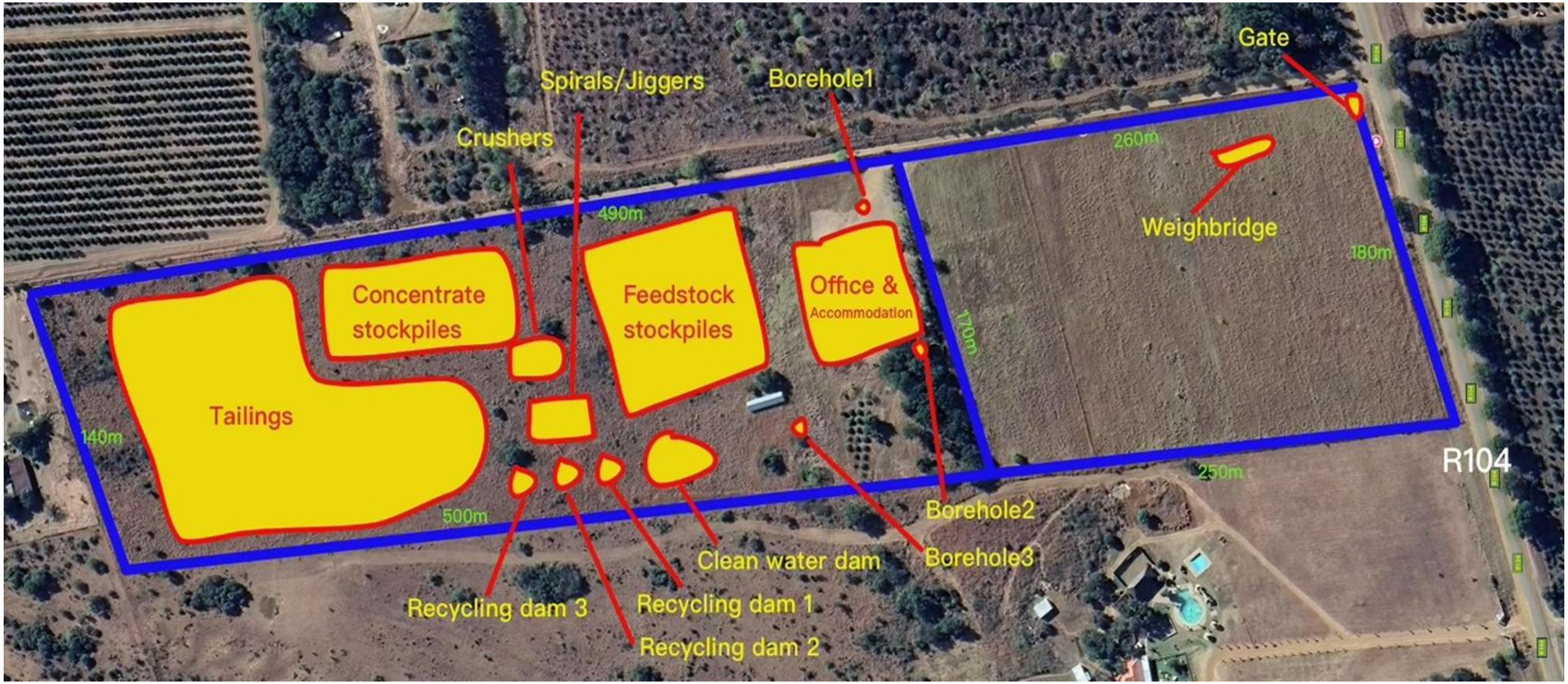

Figure 5.1: The Proposed site layout plan

Table 5.1: UCM Activities Summary

Infrastructure	Location	Expected Hydrochemical/Geochemical Description
Pollution Control Dam	Portion 50 of farm Boschfontein 458 JQ	Ca, Mg, Cl, SO_4, HCO_3, Elevated pH
Proposed Process Plant Area	Portion 50 of farm Boschfontein 458 JQ	Ca, Mg, Cl, SO_4, HCO_3, Elevated pH
RoM & Product Stockpile Area	Portion 50 of farm Boschfontein 458 JQ	Ca, Mg, Cl, SO_4, HCO_3, Elevated pH
Tailings Dam	Portion 50 of farm Boschfontein 458 JQ	Ca, Mg, Cl, SO_4, HCO_3, Elevated pH
Septic Tank	Portion 50 of farm Boschfontein 458 JQ	Coliform bacteria
Waste Rock Dump	Portion 50 of farm Boschfontein 458 JQ	Ca, Mg, Cl, SO_4, HCO_3, Elevated pH

6. PREVAILING GROUNDWATER CONDITIONS

The critical aspect of any groundwater impact assessment or management system is the understanding of the hydrogeological setting and how the potential stresses will influence the natural groundwater conditions. The hydrogeological setting of the project site is described below.

6.1 Hydrogeology

The prevailing hydrogeological conditions based on current information are discussed in the following subsections:

6.1.1 Hydrocensus

A Hydrocensus was conducted by Segope Consulting. Hydrocensus was conducted to locate existing boreholes, springs and surface water resources. A Hydrocensus was done within 2 Km radius from the central point of the UCM site.

6.1.2 Boreholes

Two boreholes were found at the project site.

6.2 Aquifer Characterization

An aquifer is described as a strata or group of interconnected strata comprising of saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater to boreholes and/or springs (Vegter, 1994). In the light of South Africa's limited water resources, it is important to discuss the aquifer sensitivity in terms of the boundaries of the aquifer, its vulnerability, classification and finally protection classification, as this will help to provide a framework in the groundwater management process.

6.3 Aquifer Classification

Based on information collected during the hydrocensus it can be concluded that the aquifer system in the study area can be classified as a "Minor Aquifer System". In order to achieve the Aquifer System Management and Second Variable Classifications, as well as the Groundwater Quality Management Index, a point scoring system as presented in **Table 6.1** was used.

Table 6.1: Ratings – Aquifer System Management and Second Variable Classifications

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	-
Major Aquifer System:	4	-
Minor Aquifer System:	2	2
Non-Aquifer System:	0	-
Special Aquifer System:	0 -6	-
Second Variable Classification (Weathering/Fracturing)		
Class	Points	Study area
High:	3	-
Medium:	2	2
Low:	1	-

Table 6.2: Ratings-Groundwater Quality Management (GQM) Classification System

Aquifer System Management Classification		
Class	**Points**	**Study area**
Sole Source Aquifer System:	6	-
Major Aquifer System:	4	-
Minor Aquifer System:	2	2
Non-Aquifer System:	0	-
Special Aquifer System:	0-6	-
Aquifer Vulnerability Classification		
Class	**Points**	**Study area**
High:	3	-
Medium:	2	2
Low:	1	-

As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required. The GQM Index is obtained by multiplying the rating of the aquifer system management and the aquifer vulnerability.

The vulnerability, or the likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer, in terms of the above, is classified as medium level.

The level of groundwater protection based on the Groundwater Quality Management Classification:

GQM Index = Aquifer System Management X Aquifer Vulnerability

= 2 X 2 =4

Table 6.3 : GQM Index for the Study Area

GQM Index	Level of Protection	Study Area
<1	Limited	
1 – 3	Low Level	
3 – 6	Medium Level	4
6 – 10	High Level	
>10	Strictly non-degradation	

6.4Aquifer Protection Classification

A GQM Index of medium was estimated for the study area from the ratings for the Aquifer System Management Classification. According to this estimate, a medium level groundwater protection is required for the aquifer. Reasonable and sound groundwater protection measures based on the modelling will therefore be recommended to ensure that no cumulative pollution affects the aquifer, even in the long term. DWS water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that measures must be taken to limit the risk, the protection of the underlying aquifer and the protection of potential groundwater users.

7. WASTE CLASSIFICATION

7.1 Sampling and Analysis

Sludge, ROM, and Product stockpile samples were collected by the UCM team from their supplier and directly delivered to Chemtech Laboratory Services for analysis. Chemtech

Laboratory Services is a SANAS-accredited laboratory. The analytical suite consisted of the following:

- Sample preparation;
- Total metal analysis – total digestion (aqua regia) followed by semi-quantitative ICP scan, including hexavalent chromium;
- Inorganic anions including Cl, F, NH_4, NO_3, SO_4, total CN; and
- Australian Standard Leaching Procedure (AS 4439.1, 4439.2, and 4439.3) followed by semi-quantitative ICP scan and analysis of anions including Cl, electrical conductivity, F, NH_4, NO_3, SO_4, TDS, Total alkalinity and pH.

A summary of the laboratory results, data analysis, and interpretation of the results is presented in this section.

7.2 Total Concentration (TC) Results

TC refers to the total concentration of a particular element or chemical substance in waste expressed as mg/kg. TCT refers to the threshold limit of total concentrations of particular elements or chemical substances in the waste, expressed as mg/kg. The regulations prescribe the TCT limits in Section 6 of the N&S for the Assessment of Waste for Landfill Disposal (No. R. 635).

As explained by the DFFE, the regulations derived the prescribed TCT limits as follows:

- ❖ TCT0 - obtained from the South African Framework for the Management of Contaminated Land Soil Screening Values (SSVs) that are protective of water resources. Where no standard was available in South Africa, the regulations adopted the State of Victoria value for fill material (EPA Victoria, Classification of Wastes). Where no standard was available in any of the references, the regulations obtained a conservative value by dividing the TCT1 value by 100;
- ❖ TCT1 - derived from the land remediation values for commercial and industrial land determined by the Framework for the Management of Contaminated Land;
- ❖ TCT2 - derived by multiplying TCT1 by a factor of 4, as used by the Environmental Protection Agency, Australian State of Victoria. Where South African limits for TCT1 were unavailable, in general, the regulations adopted the limits published by the Environmental Protection Agency, Australian State of Victoria; and
- ❖ The regulations have adjusted some TC limits using attenuation factors observed in landfills.

The Total Concentration Threshold (TCT) Limits (mg/kg) as listed in the Regulations to which the results of the analysis were compared are given below:

Table 7.1: Total Concentration Results

				Sludge Sample	Product Sample	ROM Sample
Sample Number				1	2	3

Units	TCT0	TCT1	TCT2	mg/kg	mg/kg	mg/kg
Arsenic as As	5,8	500	2000	<2	<2	<2
Boron as B	150	15000	60000	<3	<3	<3
Barium as Ba	62,5	6250	25000	20	<3	12
Cadmium as Cd	7,5	260	1040	<1	<1	<1
Cobalt as Co	50	5000	20000	<3	<3	<3
Chromium as Cr	46000	800000	N/A	206	10	146
Copper as Cu	16	19500	28000	18	<3	32
Mercury as Hg*	0,93	160	640	<1	<1	<1
Manganese as Mn	1000	25000	100000	8	<3	161
Molybdenum as Mo	40	1000	4000	<3	<3	<3
Nickel as Ni	91	10600	42400	56	<3	57
Lead as Pb	20	1900	7600	<3	<3	<3
Antimony as Sb	10	75	300	<4	<4	<4
Selenium as Se	10	50	200	<4	<4	<4
Vanadium as V	150	2680	10720	<3	<3	<3
Zinc as Zn	240	160000	640000	<3	<3	22
Fluoride as F^-	100	10000	40000	<10	<10	<10
Chloride as Cl^-				408	396	376
Nitrite as NO_2^-				<10	<10	<10
Nitrate as NO_3^-				124	304	68
Sulphate as SO_4^{2-}	14	10500	42000	236	196	28
Total Cyanide as CN^-*				<1	<1	<1
Hexavalent Chromium as Cr (VI)*	6,5	500	2000	<2	<2	<2

7.3 Leachable Concentration (LC) Results

LC refers to the leached concentration of a particular element or chemical substance in the waste expressed as mg/l. LCT refers to the threshold limit of leached concentrations of particular elements and chemical substances in the waste, expressed as mg/l. The regulations prescribe the LCT limits in Section 6 of the Norms and Standards (No. R.635).

As explained by the DFFE, the various TCT limits were derived as follows:

- ❖ LCT0 – are the drinking water standard for human health effects listed in South Africa (DWAF, SANS);
- ❖ LCT1 – derived from the lowest value of the standard for human health effects listed for drinking water (LCT0) in South Africa (DWAF, SANS) by multiplying with a Dilution Attenuation Factor (DAF) of 50 as proposed by the Australian State of Victoria, Industrial Waste Resource Guidelines: Solid Industrial Waste Hazard Categorization and Management. If no standard was available in South Africa then the regulations adopted the limits given by the World Health Organization (WHO) or other appropriate drinking water standard, such as those published in the California Regulations;
- ❖ LCT2 - derived by multiplying the LCT1 value by a factor of 2; and
- ❖ LCT3 - derived by multiplying the LCT2 value by a factor of 4.

The applied factors represent a conservative assessment of the decrease in risk achieved by the increase in environmental protection provided by more comprehensive barrier designs in higher classes of landfill and landfill operating requirements.

Table 7.2: Leachable Concentration results

					Sludge Sample	Product Sample	ROM Sample
Sample Number					**1**	**2**	**3**
Units	**LCT0**	**LCT1**	**LCT2**	**LCT3**	**mg/l**	**mg/l**	**mg/l**
Arsenic as As	0,01	0,5	1	4	<0.005	<0.005	<0.005
Boron as B	0,5	25	50	200	<0.008	<0.008	<0.008
Barium as Ba	0,7	35	70	280	<0.007	<0.007	<0.007
Cadmium as Cd	7,5	260	1040	1200	<0.003	<0.003	<0.003
Cobalt as Co	0,5	25	50	200	<0.008	<0.008	<0.008
Chromium as Cr	0,1	5	10	40	0,297	0,112	0,042
Copper as Cu	20	100	200	800	<0.008	<0.008	<0.008
Mercury as Hg*	0,006	0,3	0,6	2,4	<0.001	<0.001	<0.001
Manganese as Mn	0,5	25	50	200	<0.007	<0.007	<0.007
Molybdenum as Mo	0,07	3,5	7	28	<0.010	<0.010	<0.010
Nickel as Ni	0,07	3,5	7	28	<0.008	<0.008	<0.008
Lead as Pb	0,01	0,5	1	4	<0.010	<0.010	<0.010
Antimony as Sb	0,02	1	2	8	<0.010	<0.010	<0.010
Selenium as Se	0,01	0,5	1	4	<0.010	<0.010	<0.010
Vanadium as V	0,2	10	20	80	<0.008	<0.008	<0.008
Zinc as Zn	50	250	500	2000	<0.008	<0.008	<0.008

Fluoride as F^-	300	15000	30000	120000	<0.025	<0.025	<0.025
Chloride as Cl^-	11	550	1100	4400	7,56	0,81	2,36
Nitrite as NO_2^-	250	12500	25000	100000	<0.025	<0.025	<0.025
Nitrate as NO_3^-	0,07	3,5	7	28	1,71	1,45	0,75
Sulphate as SO_4^{2-}					6,26	0,93	0,59
Total Cyanide as CN^-*					<0.001	<0.001	<0.001
Hexavalent Chromium as Cr (VI)*	0,05	2,5	5	20	<0.005	<0.005	<0.005
pH					7,52	6,98	6,78

7.4 Discussion of the Results

The analytical results of the Sludge, Product, and ROM Samples presented above indicate that:

- TC<TCT0 in all 3 samples for other units except for Sulphate where SO_4^{2-} is TCT0<TC≤TCT1.
- Furthermore, LC < LCT0 in almost all samples (with most constituents being below the detection limit) except for two units namely
    - Cr (III) which exceeded the LCT0 threshold for sludge and product samples by just over one-fold.
    - NO_3^- where LCT0<LC≤LCT1 for all three samples

In terms of the classification system, the materials will be classified as **Type 3** waste requiring a **Class C** liner given that LCT0 < LC ≤ LCT1 and TC ≤ TCT1.

It is however important to note that:

a) The geological formation underlying the area, it is expected that the high clay content of the vadose zone will attenuate the potential chrome contamination, thus limiting the contamination profile and plume migration.
b) Due to the low leachable concentration of the Cr and NO_3^- as they are not exceeding LCT1, the material doesn't completely classify as Type 3 waste and will react more like Type 4 waste therefore the impact on the receiving environment is expected to be insignificant.
c) Furthermore, Cr (III) is well-known to be less harmful compared to Cr (VI). Analysis of this harmful portion of Chrome returned results indicating that the Cr (VI) in all Chrome tailings was below the detection limit. i.e. both TC and LC were below detection limit.

Section 7 of the GN R.635 lists the conditions to which the results must be compared to determine the type of waste in order to ultimately determine the barrier requirements for landfill disposal for the specific waste type. Based on the above, bearing in mind the risk-based approach, the materials will be classified as Type 4 waste requiring a Class D liner as depicted in Figure 7.1.

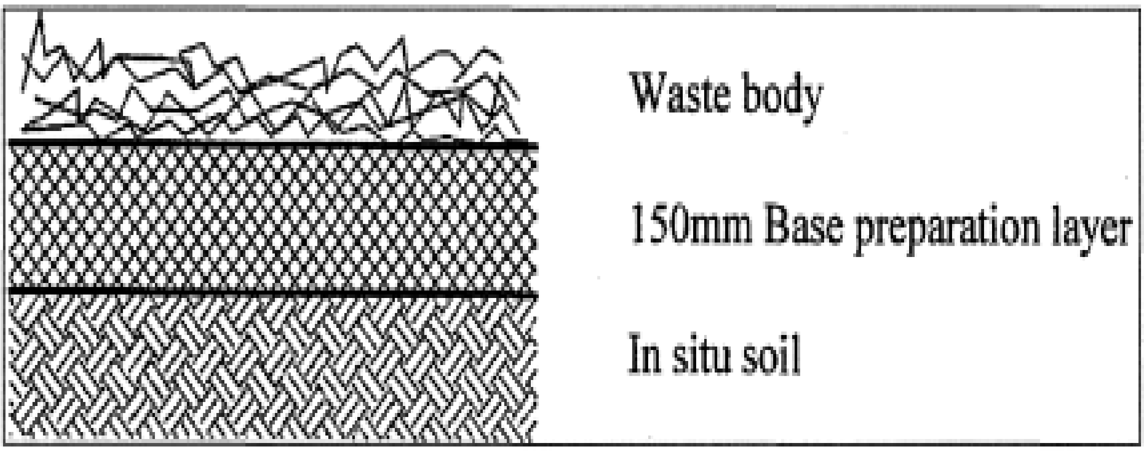

Figure 7.1: Class D Containment Barrier

8. CONCEPTUAL MODEL

The conceptual model describes the hydrogeological environment and was used to design and construct the numerical model to represent simplified, but relevant conditions of the groundwater system. The conditions were chosen in view of the specific objective of the modelling for the project. The conceptual model is based on the source-pathway-receptor principle. From the baseline assessment and available data, the following conceptual model was derived.

8.1 Source

The main potential on-site contamination sources area:

- The chrome processing workings
- Recycling dams
- Waste rock dump

8.2 Pathway

From the reviewed information the conceptual Model consists of two hydrogeological units:

- Weathered aquifer network
- Fractured aquifer network

The weathered layer has a thickness of approximately 30 m and is comprised of residual soils and weathered formations. Groundwater levels generally following topography and hydrocensus groundwater levels have an average groundwater level of 11.4 mbgl. Hydraulic conductivity values are estimated to be in the order of 10^{-2} m/d.

The underlying aquifer network is a deep fractured aquifer. Fracturing mainly occurs in the top of this unit and decreases with depth. Hydraulic conductivity typically decreases with depth and is estimated to range between 10^{-2} m/d in the upper layers and 10^{-4} m/d for the lower layers.

Based on the conceptual model, possible pathways for on-site contaminations are:

- The surface water runoff; and
- The weathered and fractured aquifers

8.3 Receptor

Potential receptors as seen in are:

Streams:

- One non-perennial stream.

9. PREDICTED GROUNDWATER IMPACTS

The aim of this chapter is to assess the likely hydrogeological impact that the proposed plant might have on the receiving environment. The typical operational stages that will be considered in this section are:

- **Operational Phase:** The conditions expected to prevail during the operation of the site.
- **Decommissioning Phase**: The closing of operations as well as site clean-up and rehabilitation.
- **Post-plant Phase**: This relates to the steady-state conditions following site- closure. A period will be considered after which it is assumed that impacts will steadily decrease and the system will commence its return to the natural state.

9.1 Operational Phase Impacts

The operational phase is interpreted as the active phase of the plant. It is inevitable that these effects will impact on the groundwater regime. During the operational phase of the project, minimal impact on the groundwater system/s is expected, due to UCM commitment to design and construct the recycling dams with a liner system to mitigate all adverse environmental impacts on groundwater resources.

Uncontrolled overflow at times of heavy rainfall is a potential risk, most likely when such rainfall coincides with peak inflow. The recycling dams therefore require a means of overflowing excess water if overtopping and/or embankment instability is to be avoided.

The installation of a comprehensive engineered barrier system reduces the recharge of aquifer/s due to containment. This is considered a low impact, localized and of long duration.

9.2 Water management

The following water management options are recommended during operations:

a) **General**

- Identify and where possible, maximize areas of the plant that will result in clean storm water runoff as well as infrastructure associated with the plant (for example office areas) and ensure that runoff from these areas is routed directly to natural watercourses and not contained or contaminated.

- Ensure that clean storm water is only contained if the volume of the runoff poses a risk, if the water cannot be discharged to watercourses by gravitation, for attenuation purposes, or when the clean area is small and located within a large dirty area. This contained clean water should then be released into natural watercourses under controlled conditions.

- Ensure the minimization of contaminated areas, reuse of dirty water wherever possible and planning to ensure that clean areas are not lost to the catchment unnecessarily.
- Ensure that seepage losses from storage facilities (such as polluted dams) are minimized and overflows are prevented.
- Ensure that all possible sources of dirty water have been identified and that appropriate collection and containment systems have been implemented and that these do not result in further unnecessary water quality deterioration.
- Ensure that less polluted water or that, moderately polluted water is not further polluted. Where possible less and more polluted water should be separated. This will assist in the reuse water strategy and improve possibilities for reuse based on different water quality requirements by different plant water uses.
- Store all potential sources of contamination in secure facilities with appropriate Storm Water management systems in place to ensure that contaminants are not released to the water resource through Storm Water runoff.
- Separate and collect all storm water that has a quality potentially poorer than the water quality specified and negotiated for the specific catchment into dirty water storage facilities for reuse within the plant operations.
- Ensure that all storm water structures that are designed to keep dirty and clean water separate can accommodate a defined precipitation event. (The magnitude of the precipitation event used in such an objective statement must, as a minimum, adhere to the relevant legal requirements.)
- Route all clean storm water directly to natural watercourses without increasing the risk of a negative impact on safety and infrastructure, e.g. loss of life or damage to property due to an increase in the peak runoff flow.
- Develop and implement proper environmental management and auditing systems to ensure that pollution prevention and impact minimization plans and measures developed in the design and feasibility stages are fully implemented.
- The size of unrehabilitated areas (pit, spoils, unvegetated areas) that produce contaminated runoff should be minimized.
- The clean and dirty water flow areas on a plant site should be identified.

b) Waste rock deposits and recycling dams

- Monitoring of water storage facilities, particularly recycling dams, is imperative to manage the risk of spillage from the dams. Stage-storage (elevation- capacity) curves are useful tools to monitor the remaining capacity within a water storage facility.

- Prevent the erosion or leaching of materials from any residue deposit or stockpile from any area and contain material or substances so eroded or leached in such area by providing suitable barrier dams, evaporation dams or any other effective measures to prevent this material or substance from entering and polluting any water resources.
- Water quantity and quality data should be collected on a regular, ongoing basis during plant operations. These data will be used to recalibrate and update the plant water management model, to prepare monitoring and audit reports, to report to the regulatory authorities against the requirements of the IWWMP and other authorizations and as feedback to stakeholders in the catchment, perhaps via the Catchment Management Agency (CMA).
- Should the above be insufficient to capture polluted surface water, interception trenches can be designed as follows:
  - The depth of the trench should be at least 4 mbgl (or 2 m below the groundwater level) to intercept polluted seepage that resulted from the WRD;
  - The design of the trench gradient must be such that the water is free-flowing without eroding the channel;
  - The water from the trench must be captured, retained and managed within the plant water systems.

9.3 Decommissioning and Post-Closure Phase Impacts

Apart from continuous monitoring, engineering and managerial mitigation measures, including the evaluation of newly identified impacts during the construction and operational phases, the key closure and post-closure objective would be to minimize infiltration of seepage.

In order to achieve this objective, it is proposed that the system is decommissioned and demolished. This will assist in the management of contaminated seepage to migrate from site.

9.3.1 Impacts on groundwater quantity

After closure, the water table will rise in the plant to reinstate equilibrium with the surrounding groundwater system.

9.3.2 Impacts on groundwater quality

Once the normal groundwater flow conditions have been re-instated, polluted water could potentially migrate away from the plant areas.

a. Spread of pollution

As some discards and exposed reactive plant surfaces will remain in the plant, this outflow could be contaminated as a result of plant drainage. As sulphate is normally a significant solute in drainage from plants, sulphate concentration from the plant has been modelled as a conservative (non-reacting) indicator of plant drainage pollution. A starting concentration of 50 mg/litre has been assumed as a worst-case scenario. However, geological material is a transient contaminant source and decreases in the concentration of released contaminants are expected over time. A 5% decrease in contaminant concentrations in the plant were incorporated into the transport modelling.

The migration of contaminated water from the plant areas and co-disposal facility was simulated for 25-, 50- and 100-years post-closure. The maximum extent of the contaminant plume (sulphate >50 mg/l) for the weathered aquifer was calculated to be approximately 360 m from the plant areas 100 years post-closure.

The contaminant migration indicates that the plumes will mainly flow towards and follow local drainage lines.

9.3.3 Groundwater contamination mitigations

To mitigate the contaminant plume migration the plant area should be properly rehabilitated, including reduction of recharge to these areas by properly top-soiling and vegetating the areas. This will reduce infiltration of water into the groundwater and reduce plume extents.

9.4 Cumulative effects

The cumulative pollution impacts of all current and historic recovery plants in addition to the plant could not be calculated as any data on surrounding plants is not available. However, it is highly recommended that a regional study be undertaken to quantify impacts on at least a quaternary scale or a data sharing agreement should be reached with neighboring plants.

10. GROUNDWATER RISK ASSESSMENT

The groundwater risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates, and finally the target that experiences the risk (receptor). The risk assessment approach is therefore aimed at describing and defining the relationship between cause and effect. In the absence of any one of the three components, it is possible to conclude that groundwater risk does not exist.

10.1 Source Term(s)

The approach to define the behavior of the source term will always start with the definition of the key questions that need to be answered for the source term:

- **Will any waste material be generated that has a potential to contaminate**?
- **Toxicity of the waste?** The potential for different wastes to pollute water resources

differs greatly, depending on the composition of the waste and its potential for degradation over time. South African legislation broadly classifies waste under two categories, namely general and hazardous waste. Between these two categories lies a continuum, with a transition from what could be described as nontoxic to toxic. When referring to a level of toxicity, then the constituent itself must be considered and also the potential user of the water, e.g. human, animal, aquatic life, or irrigation

- **Quantity of waste?** Toxicity and quantity of waste go hand in hand. Experience has shown that itis easier to dispose of, manage and contain small quantities of waste than large quantities. The risk for groundwater pollution is usually greater at large waste disposal facilities, where it is often impossible to prevent groundwater pollution because of the nature and scale of operations.
- **Potential for leachate generation?** It is theoretically possible, by using synthetic liners, to completely contain leachate from a waste site. This is, however, mostly impractical and very costly. It is also now generally accepted that all liners leak to a greater or lesser (or to some) extent. In reality, therefore, leachate that is generated in a disposal site may eventually reach the groundwater regime.

It needs to be recognized that source terms are dynamic in nature and could exhibit a variable quality over time, due to changes in hydrology and to changes in the chemistry. An impact assessment that defines the source term as a static constant feature over time is unlikely to be realistic and would be inappropriate for anything other than the most basic screening level assessment.

10.2 Pathways

With respect to potential impacts on the water resource, the groundwater pathways through which contaminants could move are the following:

- Movement through the vadose (unsaturated) zone;
- Movement through an aquifer;

Within the context of defining the pathways it is important to note that the pathways may have the following features:

- Hydraulic conduit (pathway) for the mobilization and movement of the contaminants of concern from the source term to the receptor.
- Attenuation of contaminants, release of new contaminants and alteration of the chemistry of the discharge from the source term through a variety of chemical reactions.
- Habitat for receptors.

10.3 Receptors

As the final component of the risk assessment, the receptors in the context of the water resource would be users of the water resource itself such as:

- Groundwater users abstracting contaminated groundwater through a borehole for domestic use, livestock watering or irrigation.
- Aquatic fauna and flora in a receiving watercourse.
- Any water user abstracting water from an impacted watercourse

11. GEOHYDROLOGICAL IMPACT ASSESSMENT

Table 11.1 below lists the groundwater related EMP's should be implemented during the various phases of plant. The EMP's were developed in accordance with the DWA Best Practice Guideline series.

11.1 Groundwater Impact Assessment Criteria

The criteria for the description and assessment of groundwater impacts were drawn from the EIA Regulations, published by the Department of Environmental Affairs and Tourism (April 1998) interims of the NEMA. In order to determine the significance of an impact, the following criteria would be used: extent, duration, intensity and probability. The extent and probability criteria have five parameters, with a scaling of 1 to 5. Intensity also has five parameters, but with a weighted scaling.

The assessment of the intensity of the impact is a relative evaluation within the context of all the activities and other impacts within the framework of the project. The intensity rating is weighted as 2 since this is the critical issue in terms of the overall risk and impact assessment (thus the scaling of 2 to 10, with intervals of 2). The intensity is thus measured as the degree to which the project affects or changes the environment.

The level of detail as depicted in the EIA regulations was fine-tuned by assigning specific values to each impact. In order to establish a coherent framework within which all impacts could be objectively assessed, it was necessary to establish a rating system, which was applied consistently to all the criteria. For such purposes, each aspect was assigned a value, ranging from one (1) to five (5), depending on its definition. This assessment is a relative evaluation within the context of all the activities and the other impacts within the framework of the project. An explanation of the impact assessment criteria is defined below in

Table 11.1.

Table 11.1: Explanation of the Impact Assessment criteria

Criteria	Description
Nature	Includes a description of what causes the effect, what will be affected and how it will be affected.
Extent	The physical and spatial scale of the impact.
Duration	The lifetime of the impact is measured in relation to the lifetime of the development.

Intensity	Examine whether the impact is destructive or benign, whether it destroys the impacted environment, alters its functioning, or slightly alters the environment itself.
Probability	This describes the likelihood of the impacts actually occurring. The impact may occur for any length of time during the lifecycle of the activity, and not at any given time.
Status	Description of the impact as positive, negative or neutral.
Significance	A synthesis of the characteristics described above and assessed as low, medium or high. A distinction will be made for the significance rating without the implementation of mitigation measures and with the implementation of mitigation measures.
Confidence	This is the level of knowledge/information that the environmental impact practitioner or a specialist had in his/her judgement.
Reversibility	Examine whether the impacted environment can be returned to its pre-impacted state once the cause of the impact has been removed.
Replaceability	Examine if an irreplaceable resource is impacted upon
Cumulative	Synthesis of different impacts in concert, considering the knock-on impacts thereof.

11.1.1 Nature and Status

The nature of the impact is the consideration of what the impact will be and how it will be affected. This description is qualitative and gives an overview of what is specifically being considered. That is, the nature considers 'what is the cause, what is affected, and how is it affected. The status is thus given as being positive, negative or neutral, and is deemed to be either direct or indirect in impact.

11.1.2 Extent

The physical and spatial scale of the impact as classified in **Table 11.2**.

11.1.3 Duration

The lifetime of the impact is measured in relation to the lifetime of the project, as per Error! Reference source not found..

11.1.4 Intensity

This will be a relative evaluation within the context of all the activities and the other impacts within the framework of the project.

11.1.5 Probability

This describes the likelihood of the impacts actually occurring. The impact may occur for any length of time during the lifecycle of the activity, and not at any given time.

11.1.6 Level of Significance

The level of significance is expressed as the sum of the area exposed to the risk (extent), the length of time that exposure may occur over in total (duration), the severity of the exposure (intensity) and the likelihood of the event occurring (probability). This leads to a range of significance values running from 'no impact' to 'extreme'. The significance of the impacts has been determined as the consequence of the impact occurring (reflection of chance of occurring, what will be affected (extent), how long will it be affected, and how intense is the impact) as affected by the probability of it occurring, this translates to the following formula:

Significance value = (Extent + Duration + Intensity) x Probability

Each impact is considered in turn and assigned a rating calculated using the results of this formula, and presented as a final rating classification. A distinction will be made for the significance rating of (a) without the implementation of mitigation measures, and, (b) with the implementation of mitigation measures.

Table 11.2: Criteria used for rating impacts

MAGNITUDE	DURATION
10 - Very High	5 – Permanent (more than 10 years)
8 – High	4 – Long term (7 – 10 years impact ceases after site closure)
6 – Moderate	3 – Medium term (3 months – 7 years, impact ceases after operation span)
4 – Low	2 – Short term (0 – 3 months, impact ceases after construction phase)
2 – Minor	1 – Immediate
SCALE	**PROBABILITY**
5 - International	5 – Definite/Unknown
4 – National	4 – High Probability
3 - Regional	3 – Medium Probability
2 – Local	2 – Low Probability
1 – Site Only	1 – Improbable
0 - None	0 – None

11.2 Identifying Potential Impacts with Mitigation Measures

In order to gain a comprehensive understanding of the overall significance of the impact, after implementation of the mitigation measures, it will be necessary to re-evaluate the impact.

Low (L): The impact is mitigated to the point where it is of limited importance.

Medium (M): Notwithstanding the successful implementation of the mitigation measures, to reduce the negative impacts to acceptable levels, the negative impact will remain of significance. However, taken within the overall context of the project, the persistent impact does not constitute a fatal flaw.
High (H): The impact is of major importance. Mitigation of the impact is not possible on a cost-effective basis. The impact is regarded as high importance and taken within the overall context of the project, is regarded as a fatal flaw. An impact regarded as high significance, after mitigation could render the entire development option or entire project proposal unacceptable.

11.3 Impact Assessment and Management Options

Based on the impact assessment criteria as detailed in the preceding paragraph an impact rating is given. All the groundwater related EMP's should be implemented during the operation and closure of the plant.

Table 11.3: Impact Rating

POINTS	SIGNIFICANCE	DESCRIPTION	COLOUR CODE
Very High (31 – 48)	High Environmental Significance	An impact which could influence the decision about whether or not to proceed with the project regardless of any positive mitigation	
Medium (11 – 20)	Moderate Environmental Significance	An impact or benefit which sufficiently important to require management, and which have an influence on the decision unless it is mitigated	
Low (3 -10)	Less Environmental Significance	Impact with little real effect and which will not have an influence on or require modifications	
+	Positive impact	An impact that is likely to result in positive consequences/effects.	
It is important to note that the status of an impact is assigned based on the status quo – i.e. should the project not proceed. Therefore, not all negative impacts are equally significant.			

Table 11.4: Groundwater impact assessment for planned Recovery plant activities

No	Activity	Impact	Without or With Mitigation	Nature (Negative or Positive Impact)	Probability		Duration		Scale		Magnitude/ Severity		Significance		Mitigation Measures	Mitigation Effect
					Magnitude	Score	Magnitude	Score	Magnitude	Score	Magnitude	Score	Score	Magnitude		
Operational Phase																
2.1	Construction and operation of recycling dams	Alteration of natural topography and drainage patterns	**WOM**	**Negative**	Highly Probable	4	Medium term	3	Local	1	Medium	6	40	Low	Adequate storm water management must be practiced, i.e. channeling of water so that increased suspended solids water during flood do not contaminate downstream clean water sources.	Can be reversed
			WM	**Negative**	Probable	2	Medium term	3	Local	1	Low	2	12	Negligible		Can be reversed
2.2	Construction and operation of recycling dams	Alteration of runoff and surface water volumes reaching downstream surface water system/water bodies	**WOM**	**Negative**	Highly Probable	4	Medium term	3	Regional	3	Medium	6	48	Moderate	Mitigation measure 1: During the operational phase the affected plant surface area will be minimized to maximized natural runoff and minimize processing plant "dirty") water runoff that will be captured and stored by the recycling dams . Channels will be	Can be reversed
			WM	**Negative**	Highly Probable	4	Medium term	3	Local	1	Low	2	24	Low		Can be reversed

														created to allow as much clean water runoff to be diverted around the recycling dams and plant area in order for the clean water runoff to still reach the downstream destined drainages and surface water bodies. Post-operational: Once the plant site has been cleaned runoff from the PCDs (which are now clean water dams) and storage will be a positive impact	
2.3	Construction and operation of recycling dams	Increased recharge due to permanent ponding of water on underlying soil and weathered rock	**WOM**	**Positive**	Highly Probable	4	Long term	4	Local	1	Low	2	28	Low	Mitigation measure 1: This impact will probably occur if the PCD is not lined, but the PCDs will be lined. Recharge of the PCD water is not necessarily negative unless PCD water is of poor quality. In the case of the PCD water being of acceptable drinking water quality, this impact will be positive. The PCD water quality should be monitored bi-annually, or if	Can be reversed
			WM	**Positive**	Definite	5	Long term	4	Local	1	Low	2	35	Low		Can be reversed

														required quarterly. In post-operational phase the PCD will become normal clean water dams, thus they will provide water storage dams for the communities and for e.g. for livestock watering.	
2.4	Groundwater monitoring: Failure to adhere to monitoring and maintenance requirements	Prolonged contamination of groundwater and surface water, erosion	**WOM**	**Negative**	Probable	2	Medium term	3	Site	2	Medium	6	22	Low	Mitigation measure 1: Monitoring should be performed. Process water should be properly contained in process water pipes, channels and storage facilities and the infrastructure regularly inspected and maintained if required. Process water should be treated to an acceptable quality if the goal is for it to be released or it should be removed by professional hazardous waste contractors and stored and disposed of in a manner that is in line with environmental legislation.	Can be avoided, managed or mitigated
			WM	**Positive**	Improbable	1	Short term	1	Local	1	Low	2	4	Negligible		Can be avoided, managed or mitigated
	Groundwater and surface	No indication of	**WOM**	**Negative**	Definite	5	Medium	3	Site	2	Medium	6	55	Moder	Mitigation measure 1: Same as mitigation	Can be

2.5	water monitoring: Failure to adhere to monitoring and maintenance requirements	how to manage process water infiltration into groundwater					term							ate	measure 1 for impact 3.1. A water balance should also be in place and implemented.	avoided, managed or mitigated
			WM	**Positive**	Improbable	1	Short term	1	Local	1	Low	2	4	Negligible		Can be avoided, managed or mitigated
2.6	Storm water management	Flooding of the processing plant and surrounding land uses	**WOM**	**Negative**	Highly Probable	4	Short term	1	Regional	3	Medium	6	40	Low	Mitigation measure 1: A storm water management plan should be put in place and its recommendations and designs implemented where required and feasible.	Can be avoided, managed or mitigated
			WM	**Negative**	Improbable	1	Short term	1	Local	1	Low	2	4	Negligible		Can be avoided, managed or mitigated

12. MONITORING PROGRAMME

12.1 Groundwater Monitoring Network

A groundwater monitoring system has to adhere to the criteria mentioned below. As a result, the system should be developed accordingly.

12.2 Source, plume, impact and background monitoring

A groundwater monitoring network should contain monitoring positions which can assess the groundwater status at certain areas. The boreholes can be grouped classification according to the following purposes:

- **Source monitoring:** Monitoring boreholes are placed close to or in the source of contamination to evaluate the impact thereof on the groundwater chemistry.
- **Plume monitoring:** Monitoring boreholes are placed in the primary groundwater plume's migration path to evaluate the migration rates and chemical changes along the pathway.
- **Impact monitoring:** Monitoring of possible impacts of contaminated groundwater on sensitive ecosystems or other receptors. These monitoring points are also installed as early warning systems for contamination break-through at areas of concern.
- **Background monitoring:** Background groundwater quality is essential to evaluate the impact of a specific action/pollution source on the groundwater chemistry.

12.2.1 System Response Monitoring Network

Groundwater levels: The response of water levels to abstraction is monitored. Static water levels are also used to determine the flow direction and hydraulic gradient within an aquifer. Where possible all of the above-mentioned borehole's water levels need to be recorded during each monitoring event.

12.2.2 Monitoring Frequency

In the operational phase and closure phase, quarterly monitoring of groundwater quality and groundwater levels is recommended. Quality monitoring should take place before after and during the wet season, i.e. during September and March. It is important to note that a groundwater-monitoring network should also be dynamic. This means that the network should be extended over time to accommodate the migration of potential contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources.

12.2.3 Monitoring Parameters

The identification of the monitoring parameters is crucial and depends on the chemistry of possible pollution sources. They comprise a set of physical and/or chemical parameters (e.g. groundwater levels and predetermined organic and inorganic chemical constituents). Once a pollution indicator has been identified it can be used as a substitute to full analysis and therefore save costs. The use of pollution indicators should be validated on a regular basis in the different sampling positions. The parameters should be revised after each sampling event; some metals may be added to the analyses during the operational phase, especially if the pH drops.

12.2.4 Abbreviated analysis (pollution indicators)

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
  - pH, EC
- Laboratory analyses:
  - Major anions and cations (Ca, Na, Cl, SO_4)
  - Other parameters (EC)

12.2.5 Full analysis

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
  - pH, EC

- Laboratory analyses:
  - Anions and cations (Ca, Mg, Na, K, NO_3, Cl, SO_4, F, Fe, Mn, Al, & Alkalinity)
  - Other parameters (pH, EC, TDS)
  - Petroleum hydrocarbon contaminants (where applicable, near workshops and petroleum handling facilities)
  - Sewage related contaminants (E. coli, faecal coliforms) in borehole in proximity to septic tanks or sewage plants.

12.2.6 Plant monitoring

DWAF (1998) states that "A monitoring hole must be such that the section of the groundwater most likely to be polluted first, is suitably penetrated to ensure the most realistic monitoring result."[14]

Currently a monitoring network does not exist for the proposed plant. The development of monitoring boreholes is recommended boreholes and the areas to site these monitoring boreholes. These boreholes can be utilised for water level monitoring during operations, as well as groundwater quality monitoring after decommissioning of the site.

However, a monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources. An audit on the monitoring network should be conducted annually.

13. CONCLUSIONS

- The regional groundwater potential of an area is generally influenced by the surface topography, drainage regime, climate, surface vegetation, and the underlying geology.
- The production borehole should be subjected to a full aquifer testing program every 4 to 5 years to ensure continued sustainability.
- Groundwater abstraction rate as per our recommendations from the production borehole must be adhered to. The boreholes are recommended for a 12-hour pumping schedule with a recovery schedule of 12 hours a day.
- Water levels must be monitored monthly to identify any possible dewatering from the water bearing zones.
- All mitigation measures recommended to protect groundwater during operation of the plant must be implemented.

14. REFERENCES

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