RAINBOW
RARE EARTHS

PHALABORWA RARE EARTHS PROJECT

Preliminary Economic Assessment (PEA)

30 September 2022

epoch resources (pty) ltd K-TECHNOLOGIES, INC. METC Metallurgical Engineering Technology & Construction PARAGON Tailings

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ACRONYMS AND *ABBREVIATIONS*

3D	Three-Dimensional
Ac	Actinium
Al	Aluminium
AMP	Aminophosphonic
ANSTO	Australian Nuclear Science and Technology
ASX	Australian Securities Exchange
BD	Bulk Density
BEV	Battery Electric Vehicle
BFD	Block Flow Diagram
BOQ	Bill Of Quantities
BP	Bosveld Phosphate (Pty) Ltd
C&I	Control and Instrumentation
Ca	Calcium
$CaCO_3$	Calcium Carbonate
CaF_2	Calcium Fluoride
CAPEX	Capital Expenditure
$CaSO_4$	Calcium Sulfate
CBD	Central Business District
CBO	Community-based organisation
CCL	Counter Current Leach
Ce	Cerium
CIC	Continuous Ion Chromatography
CIL	Carbon-in-leach
CIP	Clean-In-Place
CIX	Continuous Ion-Exchange
CP	Competent Person
CREO	Critical Rare Earth Oxide
CRO	Control Room Operator
DFS	Definitive Feasibility Study
DNA	Delayed Neutron Analysis
DSF	Dry Storage Facility
DTM	Digital Terrain Model
Dy	Dysprosium
EA	Environmental Authorisation
EC	Electrical conductivity
EDS	Energy-Dispersive X-Ray Spectroscopy
EPCM	Engineering, Procurement & Construction Management
EPFI	Equator Principles Financial Institution

Er	Erbium
ESIA	Environmental and social impact assessment
ESMP	Environmental and social management plan
ESMS	Environmental and social management system
Eu	Europium
EU	European Union
EV	Electric Vehicle
F	Fluoride
Fe	Iron
Foskor	Phosphate Development Corporation
G&A	General and Administration
G.N.	Government notice
g/ℓ	Gram Per Litre
GCL	Geosynthetic Clay Liner
Gd	Gadolinium
GIIP	Good international industry practice
GPS	Global Positioning System
H_2SO_4	Sulfuric Acid
HCl	Hydrochloric Acid
HDPE	High-density polyethylene
HF	Hydrofluoric Acid
HNO_3	Nitric Acid
Ho	Holmium
HREO	Heavy Rare Earth Oxide
HV	High Voltage
IAEA	International Atomic Energy Agency
ICP-MS	Inductively Coupled Plasma – Mass Spectrometry
ICP-OES	Inductively Coupled Plasma – Optical Emission Spectrometry
IDP	Industrial Development Plan
IFC	International Finance Corporation
IRR	Internal Rate of Return
ISE	Ion-Selective Electrode
IWWMP	Integrated Water and Waste Management Plan
JORC	Joint Ore Reserves Committee
K	Potassium
kg/t	Kilogram Per Tonne
K-Tech	K-Technologies Inc.
La	Lanthanum
LiDAR	Light Detection and Ranging

LNW	Lepelle Northern Water
LoO	Life of Operation
LREO	Light Rare Earth Oxide
Lu	Lutetium
LV	Low Voltage
MAP2	Mean Annual Precipitation
MCC	Motor Control Centre
MEL	Mechanical Equipment List
Mg	Magnesium
MPRD	Mineral and Petroleum Resources Development
MRE	Mineral Resource Estimate
MV	Medium Voltage
NaCl	Sodium Chloride
Nd	Neodymium
NdPrDyTbO	Rare earth product suite
NEM:WA	National Environmental Management: Waste Act
NEMA	National Environmental Management Act
NF	Nanofiltration
NO_3	Nitrate
NPV	Net Present Value
NTU	Nephelometric Turbidity Units
NWA	National Water Act
OK	Ordinary Kriging
OPEX	Operational Expenditure
P	Phosphorus
P&G	Preliminary and General
Pa	Protactinium
Pb	Lead
PBC	Process Block Concept
PCD	Pollution Control Dam
PEA	Preliminary Economic Assessment
PEA	Preliminary Economic Assessment
PF	Primary Filtrate
PFS	Pre-Feasibility Study
PG	Phosphogypsum
PHEV	Plug-in Hybrid Electric Vehicle
Phosacid	Phosphoric Acid (H_3PO_4)
PLC	Programmable Logic Controller
PLS	Pregnant Leach Solution

PMC	Phalaborwa Mining Company
Po	Polonium
Pr	Praseodymium
PREP	Phalaborwa Rare Earths Project
PSD	Particle Size Distribution
QAQC	Quality Assurance/Quality Control
QEMSCAN	Quantitative Evaluation of Materials by Scanning Electron Microscopy
Ra	Radium
RE	Rare Earths
REE	Rare Earth Elements
RIL	Resin-In-Leach
RIP	Resin-In-Pulp
RPEEE	Potential Eventual Economic Extraction
RRE	Rainbow Rare Earths (Pty) Ltd
RWS	Return Water Sump
S	Sulfur
SA	Strong Acid
SAAB	Sulfuric Acid Agitated Bake
Sasol	Sasol Chemical Industries Limited
SAWS	South African Weather Service
SEM	Scanning Electron Microscopy
SGS	SGS South Africa
Si	Silicon
SiO_2	Silica
Sm	Samarium
SP&L	Small Power and Lighting
Sr	Strontium
Tb	Terbium
TBP	Tributyl Phosphate
TDS	Totally Dissolved Solids
Th	Thorium
TIC	Total Installed Costs
Tm	Thulium
TREO	Total Rare Earth Oxides
TREO (+Y)	Total Rare Earth Oxides plus Yttrium
TSF	Tailings Storage Facility
TSS	Total Suspended Solids
TVET	Technical and Vocational Education and Training
U	Uranium

UF	Ultrafiltration
UK	United Kingdom
UPVC	Unplasticized Polyvinyl Chloride
USA	United States of America
VAT	Value-Added Tax
VCF	Volume Concentration Factor
VOIP	Voice Over IP
VSP	Vertical Spindle Pump
WBS	Work Breakdown Structure
WML	Waste Management Licence
WRC	Water Research Commission
XRF	X-Ray Fluorescence
Y	Yttrium
Yb	Ytterbium

UNITS AND SYMBOLS

°	degrees
°C	degrees Celsius
%	per cent
% w/w	weight to weight ratio, percentage by weight
Bq/g	Becquerel per gram
g	gram
GJ/h	gigajoules per hour
ha	hectare
kg	kilogram
kg/y	kilogram per year
kL	kilolitre
km	kilometre
km^2	square kilometre
kV	kilovolt
MVA	mega volt-ampere
kW	kilowatt
kWh	kilowatt hour
L	litre
L/h	litres per hour
L/y	litres per year
m	metre
MAMSL	metres above mean sea level
MASL	metres above sea level
µg	microgram
µm	micrometre
mg	milligram
mg/ℓ	milligram per litre
mm	millimetre
m^2	square metre
m^3	cubic metre
m^3/d	cubic meter per day
m^3/h	cubic meter per hour
Mm^3	million cubic metres
mS	millisiemens
mS/m	millisiemens per metre
mSv	millisieverts
Mt	million tonne

Mt/a	million tonnes per annum
MW	megawatt
t	tonne
t/a	tonnes per annum
t/h	tonnes per hour
t/m^3	tonnes per cubic metre
t/y	tonnes per year
y	Year
USD	United States Dollar
ZAR	South African Rand

1 EXECUTIVE SUMMARY

1.1 Introduction

The Phalaborwa Rare Earths Project (the Project) offers a long life, and financially robust, opportunity to become a significant supplier of high purity rare earth oxides to the rapidly expanding permanent magnet market.

Apart from delivering a product into the increasingly important green economy, the Project has strong environmental credentials in terms of reducing legacy risks (from previous operations on site) to an environmentally sensitive area. The Project development will be undertaken fully in line with International Finance Corporation Performance Standards and the Equator Principles.

The Project's rare earths resource is contained in two phosphogypsum stacks which are the waste from historic phosphoric acid production on the site, which ceased in 2014. The Project is located on an industrial site adjacent to the mining town of Phalaborwa in South Africa and benefits from excellent national, regional, local and site-specific infrastructure. The industrial nature of the Project provides considerable advantages over similar mining projects with the ability to produce rare earth oxides directly from the large resource in a single process. Rainbow Rare Earths Limited (Rainbow) has developed a process to extract the rare earths from the host phosphogypsum, through an extensive process test work program conducted at highly regarded international laboratories, that unlocks the value of the Project.

Following the publication of the Preliminary Economic Assessment (PEA) Rainbow intends to advance the Project to feasibility study, identify all permits required for the Project to be developed, engage with the relevant authorities to expedite permitting and undertake further process optimisation tests culminating in an extensive process pilot plant operation. The PEA envisages first production in 2026.

1.2 Key Economic Parameters

The key economic parameters for the Project base case are presented in Table 1.1.

Table 1.1: Summary of Base Case Project Economic Parameters

Parameter	Units	Value
Treatment Rate	Mt/a	2.2
Production NdPr, Dy, Tb Oxides	t/a	1,848
Life of Operation	years	14.2
Capital Cost	USDm	295.5
Operating Cost per Tonne Treated	USD/t	28.95
Operating Cost per kg Product[1]	USD/kg	33.86
Revenue per Tonne Treated	USD/t	117.91
Payback Period (post tax)	years	2.0
NPV_{10} (post tax)	USDm	627.0
IRR (post tax)	%	40
Average base-case revenue per annum	USDm	254.8

Parameter	Units	Value
Average EBITDA[1] per annum	USDm	192.2
EBITDA margin	%	75

[1] The operating cost in USD/kg given here (33.86 USD/kg) differs marginally from the 34.35 USD/kg given in Section 14, due to the fact that the number above is an average over the life of the project, considering variations in feed composition between Stack A and Stack B, as well as ramp-up and ramp-down. The number given in Section 14 is an average number for the period of one year, based on a non-weighted average feed gypsum composition, and no ramp-up and ramp-down, for the purposes of the steady-state mass balance.

The base case uses the projected rare earth oxides price for 2023, lower than the average price for 2022 to date or long-term forecast prices received from Argus Media Group as set out in the Table 1.2 below:

Table 1.2: Rare Earth Oxide Prices Used

		Base case	2022 YTD[2]	Forecast[3]
Neodymium oxide	USD/kg	110.00	146.36	128.82
Praseodymium oxide	USD/kg	112.50	140.25	204.51
Dysprosium oxide	USD/kg	340.00	403.70	489.08
Terbium oxide	USD/kg	1,875.00	2,117.56	4,068.07
Basket price	USD/kg	137.92	175.89	199.30

The majority of the capital and operating costs are incurred in South African Rands (ZAR). These have been converted in the base case at an exchange rate of 16.50 ZAR/USD. A corporate tax of 27% has been allowed for in the economic analysis.

Sensitivity analyses for variations in rare earth prices have been calculated by reference to both historical and forecast prices. The results demonstrate that the project can be expected to generate strong returns in a market underpinned by strong demand growth for the separated magnet rare earth oxides that will be produced. The sensitivity of the economics to capital cost, operating cost, and USD:ZAR exchange rate have also been modelled, demonstrating that the Project is not sensitive to changes in costs due to the strong EBITDA margins generated. The results of the sensitivity analysis are set out in Table 1.3 below:

Table 1.3: Sensitivity Analysis

				Price sensitivities		Cost sensitivities	
		Base case	2022 YTD[4]	Forecast[5]	+10% OPEX	+10% CAPEX	US$1: ZAR17.5
Basket price	USD/kg	137.92	175.89	199.30	137.92	137.92	137.92
NPV	USDm	627.0	933.7	1,027.6	599.0	610.4	652.2

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[1] Earnings Before Interest, Tax, Depreciation and Amortisation

[2] Derived from weekly data collated by Rainbow from price reporting agencies up to 23 September 2022

[3] Based on the long-term price forecasts received from Argus, with the first year of production assumed to occur in 2026 and prices assumed to remain constant from 2031 to the end of the project life

[4] Derived from weekly data collated by Rainbow from price reporting agencies up to 23 September 2022

[5] Based on the long-term price forecasts received from Argus, with the first year of production assumed to occur in 2026 and prices assumed to remain constant from 2031 to the end of the project life

				Price sensitivities		Cost sensitivities	
		Base case	2022 YTD[4]	Forecast[5]	+10% OPEX	+10% CAPEX	US$1: ZAR17.5
IRR	%	40%	51%	44%	39%	37%	42%
Operating margin	%	75%	81%	83%	73%	75%	77%
Payback	Years	2.0	1.7	2.4	2.1	2.2	2.0
Change in NPV	USDm	N/A	306.7	400.6	(28.0)	(16.6)	25.2

1.3 Project Location and Infrastructure

The Phalaborwa Rare Earths Project is located within the jurisdiction of the Ba-Phalaborwa Local Municipality in the Limpopo Province of the Republic of South Africa. Phalaborwa is a significant mining and industrial centre located approximately 500 km or 5 hours' drive from Johannesburg's OR Tambo airport on high-quality bitumen roads. The location of the Project is shown in Figure 3.1.

Figure 1.1: Location of the Project

The project benefits from the advanced national infrastructure such as road, rail and air links with two local airports. Phalaborwa town has significant support services of use to the Project, including engineering and technical services. The site has a full suite of infrastructure that will service the Project including: access control, offices, stores, workshops, laboratory, power and water supply.

1.4 Mineral Resource

The phosphogypsum residue resource to be processed at the Project is contained in two separate stacks, Stack A and Stack B as shown in Figure 1.2.

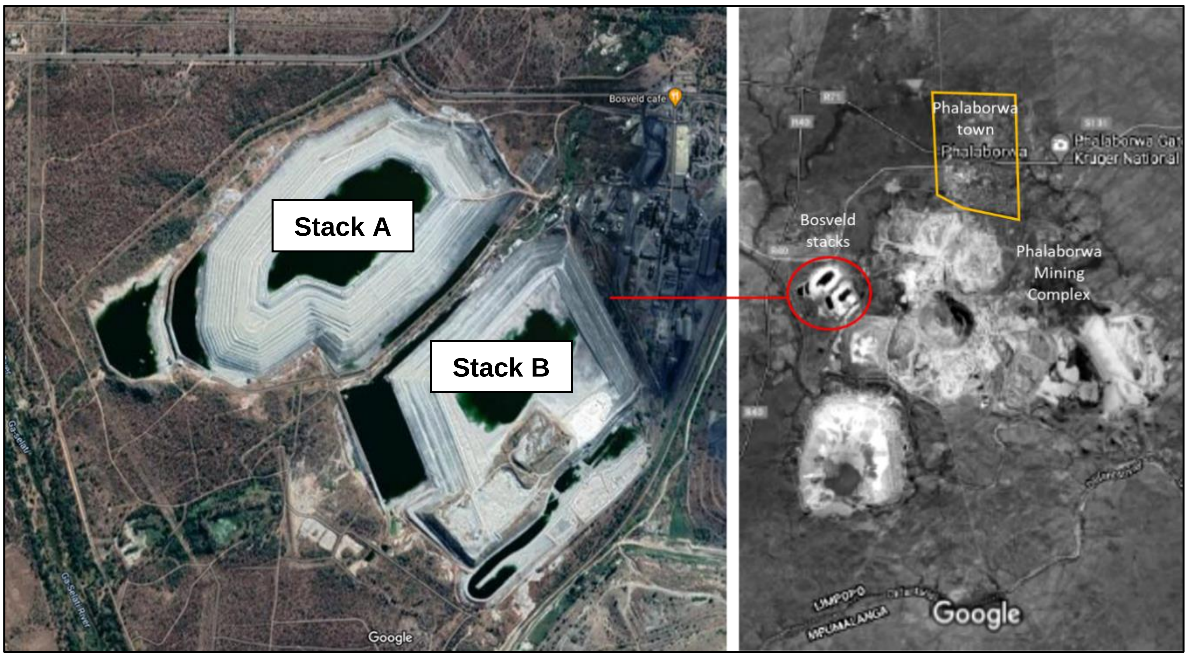


Figure 1.2: Google images of the Bosveld stacks. Right: the position of the stacks in relation to the Phalaborwa mining complex and town. Left: close-up of the stacks annotated as A and B

Rainbow completed a drilling program on the stacks in December 2020 consisting of 1,056 m over 72 holes which produced 702 samples that were analysed at SGS Laboratories in Johannesburg. The results from this are the basis for the mineral resource estimate presented in Table 1.4. Bulk density was changed from 1.5 t/m^3 to 1.2 t/m^3 after a June 2022 drilling program presented updated data, and was cross-checked with LiDAR and current site operations data.

The mineral resource estimate for the Bosveld phosphogypsum REE Stacks A and B is presented in. The resource has been estimated by the independent Competent Person and is classified as an Inferred Resource based on the guidelines defined in JORC 2012. The in-situ dry bulk density has been re-assessed following further drilling carried out in 2022 and the overall tonnage set out in Table 1.4 has been amended compared to the resource initially reported in June 2021.

Table 1.4: Mineral Resource Estimate for the Bosveld Phosphogypsum Stacks

JORC 2012 Classification	Stack Name	Tonnes (Mt)	TREO %	NdPr Prop %	Nd Prop %	Pr Prop %	Dy Prop %	Tb Prop %	LREO Prop %	HREO Prop %	CREO Prop %	Th ppm	U ppm	In Situ dry BD
Inferred	Stack A	21.9	0.42	29.0	23.3	5.7	1.0	0.4	92.1	7.9	27.8	49.0	1.8	1.20
	Stack B	8.7	0.46	29.4	23.6	5.7	1.0	0.3	92.6	7.4	27.8	44.1	2.0	1.20
	Total Inferred	**30.7**	**0.43**	**29.1**	**23.4**	**5.7**	**1.0**	**0.3**	**92.2**	**7.8**	**27.8**	**47.6**	**1.8**	**1.20**

Reported at 0.2% TREO cut-off grade. No constraining shell required as stacks above ground level. Adequate processing test work completed to satisfy RPEEE

1.5 Process Development and Test Work

The recovery of rare earths from phosphogypsum arising as a residue from phosphoric acid production has been the subject of international research for many years. The extraction and recovery of rare earths (REEs) at Phalaborwa has been investigated since the early 1980’s by Fedmis, Mintek and later, briefly, by Bosveld Phosphates.

Rainbow acquired access to the Phalaborwa phosphogypsum stacks in 2020 and initiated a test work program to support a technically and economically feasible flow sheet for rare earths extraction.

The test work program was established and managed by Rainbow and conducted at: ANSTO Minerals in Sydney Australia, SGS Laboratories in Johannesburg South Africa and K-Tech’s laboratory in Florida USA.

The test program culminated in a technically and economically feasible flowsheet which is the basis of this PEA.

1.6 Reclamation, Processing and Stacking of Phosphogypsum

Phosphogypsum residue is hydraulically reclaimed from the stacks and pumped to the process plant for trash and coarse waste removal delivering a feed to the process plant of 2.2 Mt/a dry solids equivalent. The screened slurry is thickened and filtered, with the reclaimed water being neutralised and recycled as process water.

The dewatered solids are treated to remove impurities.

The phosphogypsum is then delivered to a counter current leach circuit for extraction of rare earth elements using sulfuric acid. The filtered leach residue is conveyed to one of two new, HDPE lined residue disposal stacks.

The pregnant leach solution for the rare earth leach is pumped to a rapid consolidation circuit for primary rare earth concentration, prior to the refinery section, and acid recovery to the counter-current leach circuit.

The rare earth refining circuit combines ion exchange, chromatography, nanofiltration, precipitation and calcining to produce three saleable separated rare earth oxide products: neodymium/praseodymium oxide, dysprosium oxide, and terbium oxide at an average production rate of 1,848 t/a. The remainder of the rare earth basket is stored for future consideration as an intermediate salt.

A simplified block flow diagram (BFD) is shown in Figure 1.3.

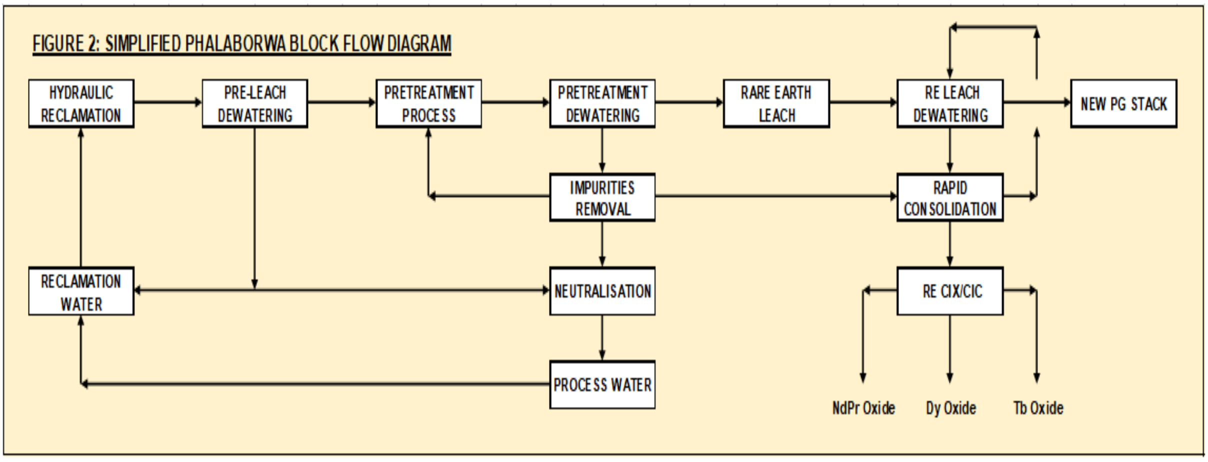


Figure 1.3: Simplified Process Block Flow Diagram

1.7 Environmental & Social Impact

The Project will be constructed on an existing industrialised site without impacting land use. No new infrastructure is required outside of the existing property. Rehabilitation of some previously disturbed land will be accelerated during the project.

The Project will play a crucial role in environmental remediation and improvement as well as providing economic and social benefits:

- Polluted water on the existing stacks, in the existing ponds and in the groundwater will be neutralised and used as process water.
- Seepage of polluted water from the unlined existing stacks will be eliminated and the residue phosphogypsum from the process will be placed on new lined stacks.
- It is anticipated that a significant proportion of the residual phosphogypsum will be sold for agricultural and industrial use and removed from site. The beneficial economic impact of this has not been included in the PEA.

Rainbow will work closely with previous owners of the property to accelerate the rehabilitation of unused areas in accordance with the closure plans and funding already in place.

The project will create numerous employment opportunities during construction and c. 300 direct job opportunities (excluding contractors, suppliers, vendors, consultants etc.). Priority will be given to the people in the Ba-Phalaborwa area with the requisite skills and experience for these jobs.

Rainbow will give preference to local contractors and where contractors are imported from other areas, Rainbow will encourage the employment of local labour.

1.8 Rare Earths Market

The project will be a significant producer of separated Neodymium/Praseodymium, Dysprosium, and Terbium oxides which are expected to represent 98% of the total rare earth market value by 2030, up from 92% in 2020.

The demand for these four magnet rare earth metals, which are required in electric vehicles and offshore wind turbines, is forecast to grow as global pressure to decarbonise increases. Growth in electric vehicle demand is expected to increase by 22.4% per annum between 2020 and 2030, from a 1.5% passenger vehicle market penetration in 2020 to 45% by 2040. Global demand for direct drive wind turbines is expected to grow at approximately 25% per annum between 2020 and 2030, further driving the demand for rare earth metals.

As a result, Argus are forecasting strong compound annual growth rates for the Magnet Rare Earth Metals over the next decade (Nd 6.4%, Pr 6.7%, Dy 7.4% and Tb 33.4%) as shown in Figure 1.4 below.

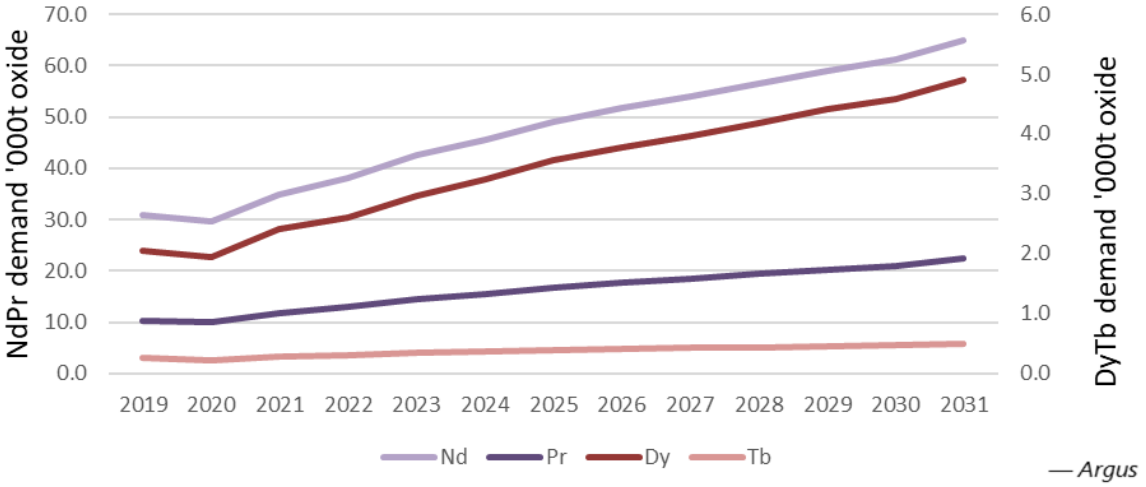


Figure 1.4: Anticipated Magnet Rare Earth Metal Oxide Demand

Highlighting the urgency for near-term production of rare earths from new sources, Argus is forecasting a 25% supply deficit by 2030 from existing projects. Analysts are forecasting that this supply deficit will drive strengthening prices for the magnet rare earth oxides over the next decade, as shown in Figure 1.5.

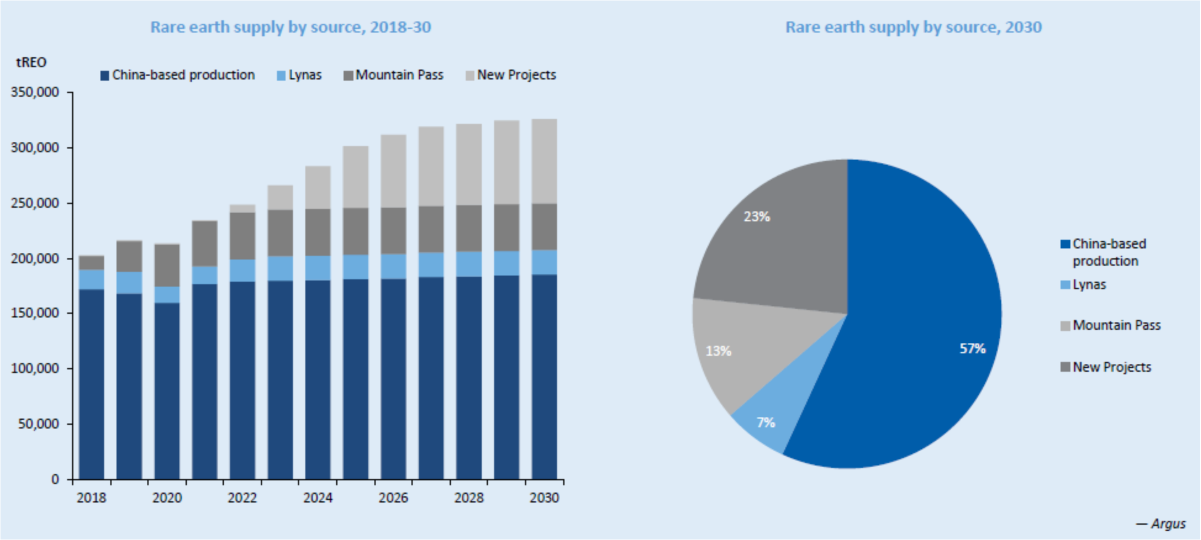


Figure 1.5: Forecast Existing Project Supply Deficit

Argus undertook a market review for Rainbow in January 2022 and provided price forecasts for individual rare earth oxide products, which Rainbow has converted into a weighted average basket price for Phalaborwa. Price forecasts have indicated that the Phalaborwa product basket price will increase from around 100 USD/kg in 2022 to 227 USD/kg in 2030.

2 INTRODUCTION

The Phalaborwa Rare Earths Project (PREP, or Project) aims to extract rare earth elements from two phosphogypsum stacks created as residue from a phosphoric acid (phosacid) plant. The project site was part of a larger, previously operated, integrated fertiliser production facility located in the Ba-Phalaborwa district of the Limpopo Province of South Africa.

The original plant was built by Federale Volksbeleggings in 1964 and produced phosphate-based granular fertilisers. The plant changed ownership several times, including to Sasol Chemical Industries Limited (Sasol) who owned it from 2001 to 2012 and then to Bosveld Phosphates (Pty.) Ltd. (BP) who ran it until 2014, when it became economically non-viable, and was placed on care and maintenance. During the plant's life, approximately 30 million tonnes of phosphogypsum residue from the phosphoric acid process was deposited on two stacks at the site.

The phosphogypsum contains rare earth elements (REEs). In 1987 a programme of studies was initiated at Mintek to develop a process for recovering these elements from the phosphoric acid sludges derived from the phosphate rock digestion. This programme was terminated prior to implementation on a commercial scale. Bosveld Phosphates (Pty) Ltd (BP) restarted this work and commissioned Mintek to develop a process to recover the REEs culminating in the construction of a pilot plant, which successfully produced 3 tonnes of mixed rare earth carbonate and associated cerium depleted oxide, before the plant was decommissioned.

In 2020, RRE signed an agreement with BP to extract the rare earth elements contained in the two stacks.

This PEA is the culmination of the process work undertaken by RRE and their technology partner K-Technologies Inc. (K-Tech), to extract rare earth elements from the phosphogypsum stacks.

The PEA achieved the following objectives:

- The development of a recovery process for the rare earth elements contained in the two phosphogypsum stacks.
- The development of a capital cost estimate to build a processing plant to process 2.2 million tonnes of feed material per annum.
- The development of an operating cost for the plant.
- The completion of a PEA Study has provided the basis to allow the development and engineering for the project to progress to the pre-feasibility study (PFS) phase.

The technical and financial components of the PEA are detailed in independent sections of this report, together with sections covering market pricing for rare earth elements, human resources, conclusions, and recommendations.

This report is authored by METC and includes key contributions from independent consultants with specialist competencies as follows:

- **METC Engineering** – METC, a minerals processing engineering firm, undertook the engineering and development of a cost estimate of all the process plant, equipment, and associated infrastructure facilities such as water, power and transportation requirements.
- **Paragon Tailings** – Paragon is a specialist company focussing on the hydraulic reclamation of tailings deposits. Paragon undertook the engineering and development of capital and operating cost estimates for the hydraulic reclamation using high-pressure and slurry reticulation equipment.
- **Epoch Resources** – Epoch, a consulting firm of civil engineers specialising in residue storage facilities, undertook the engineering and development of a cost estimate of the new residue stacks, including preparatory works and residue handling at the stack.

- **Maja Mining Limited** – Maja was established in 2013 and is an independent UK-based mining consulting company. Maja was responsible for planning, collection and validation of drill hole sample, bulk density data and survey data and compiled the Mineral Resource Estimate.
- **ANSTO –** Australian Nuclear Science and Technology Organisation (ANSTO) is a chemical and nuclear laboratory located in Sydney and Melbourne. ANSTO has extensive experience with rare earth chemistry and has the capability to pilot complex chemical processes. ANSTO designed and performed the first series of bench-scale tests on extraction and purification of rare earths from Phalaborwa phosphogypsum.
- **K-Technologies Inc. –** K-Tech is a specialized chemical technology development firm that offers unique process technology and development capabilities for the minerals and chemicals industries, particularly involving various advanced separations processes. K-Tech performed the bench-scale test work for phosphogypsum leaching, impurity rejection, RE concentration, and subsequent RE extraction and separation, which led to the development of a successful process flowsheet.

3 PROJECT DESCRIPTION

3.1 Location

The Rainbow Rare Earths Ltd (RRE) Phalaborwa Rare Earths Project (PREP, or Project) is located within the jurisdiction of the Ba-Phalaborwa Local Municipality in the Limpopo Province of the Republic of South Africa. Phalaborwa is a significant mining and industrial centre located approximately 500 km or 5 hours' drive from Johannesburg's OR Tambo airport on high-quality bitumen roads. The relative geographic location of the Project is shown in Figure 3.1.

Figure 3.1: South Africa, showing the location of the PREP Project.

The proposed project site is situated approximately 4 km southwest of the town of Phalaborwa and directly south of the heavy industrial area of Phalaborwa on the farm Wegsteek 30 LU, within 5 minutes' drive from Phalaborwa central CBD, as shown in Figure 3.2.

The site is located at coordinates X = -10153.653, Y = 2652868.648 (WGS84 – Lo 310 coordinate system) and is at an elevation of 375 mAMSL.

Figure 3.2: Phalaborwa Satellite Image with PREP site shaded in red

3.2 Resource History

The 2-billion-year-old (Archean) Phalaborwa Carbonatite Complex contains apatite-bearing zones, the primary source of South African phosphate production. Phalaborwa carbonatite contains two types of apatite ores: foskorite and pyroxenite. The Phalaborwa carbonatite reserve base is estimated at 2,500 Mt, making it the third largest in the world.

The discovery of phosphates led to the formation of the Phosphate Development Corporation (Foskor (Pty.) Ltd.) in 1951 and the establishment of the town of Phalaborwa in 1957. At the time, South Africa wanted to be independent of imported phosphate, and due to the quantity and quality of phosphate rock available in the Phalaborwa area, Federale Volksbeleggings embarked on a program to produce phosphoric acid from processing phosphate rocks (primarily apatite) on the farm “Wegsteek”, near Phalaborwa. The products from the plant at the time included phosphoric acid (phosacid), mono-calcium and mono-ammonia phosphates, sulfuric acid, and superphosphate, all used in the production of fertiliser.

Through various takeovers and name changes, the company was taken over by Sasol Chemical Industries Limited (Sasol) in 2001 and operated under Sasol Nitro’s banner. In 2009, Sasol identified possible contraventions of the Competition Act of South Africa after an internal investigation, which ultimately led to the reaching of a settlement with the South African Competition Commission. Part of the settlement was that Sasol would divest its fertiliser blending businesses. In 2012 Sasol Nitro sold the assets to Bosveld Phosphates (Pty) Ltd (BP), who operated the plant until 2014, when it was no longer economically viable. The plant complex was placed on care and maintenance.

During the ~50 years of operation of the phosacid plant, approximately 30 million tonnes of phosphogypsum, a residue from the phosacid process, was deposited on two residue stacks located on the site.

3.3 Project History

It is well known that certain deposits of the mineral apatite contain significant amounts of rare earth elements. In the case of the Phalaborwa deposit, the apatite ore was used as feed material for the wet process phosphoric acid plant. The apatite concentrate, sourced from the adjacent mine operated by Foskor, was dissolved in a mixture of sulfuric acid and recycled dilute phosphoric acid. The bulk of the rare earth elements (70-85% of those contained in the feed) reported to the phosphogypsum stream, generated as a by-product of the process. The phosphogypsum residue containing the rare earth elements was deposited on the two stacks that form the resource for this project. The balance of rare earths migrated with the weak phosphoric acid stream and ultimately reported to the sludges generated in the vacuum evaporation towers employed for acid upgrade to commercial strength.

BP operated the phosacid plant from 2012 to 2014. During this time, BP took a renewed interest in the rare earth elements and investigated options to recover these from the phosacid process. BP built and commissioned a pilot plant in 2013 and 3 tonnes of mixed rare earth carbonate and associated cerium depleted oxide was produced before it was decommissioned. The pilot plant is on site and could be recommissioned if required.

In 2020, RRE reached a binding agreement with Bosveld Phosphates to co-develop the Project to recover and process rare earth elements from the two phosphogypsum stacks at the project site. As part of the agreement, RRE investigated the extent of the rare earth elements in the two stacks at the site through a series of drilling, assay, and survey programmes and, in 2021, declared a maiden resource of more than 30 million tons of phosphogypsum containing 0.43% total rare earth oxides (TREOs).

3.4 Site Development

Due to historical activities at the BP site, significant infrastructure is in place and not fully utilised, e.g., an HV powerline, HV substation, LV reticulation, security gate, road access, water reticulation, site buildings, etc. The site has multiple environmental authorisations and permits (e.g., water use license, and air emissions license).

Part of the existing disused phosacid plant will be demolished and rehabilitated before the commencement of construction of the Project, and it is planned that this rehabilitated area will be used for the Project. This strategy will reduce the capital cost expenditure and project timeline by utilising existing infrastructure and permits already in place, where appropriate. It also has the environmental benefit of re-use of already disturbed land.

Two magnetite recovery operations have been set up on the site by independent operators on the BP site with the requisite approval and permissions from BP. Personnel and vehicles from these operations access the site daily.

4 OWNERSHIP AND SECURITY OF TENURE

LEGAL STATUS OF GYPSUM STACKS AND PROPERTY RIGHTS

1 Rainbow Rare Earths is in possession of a legal opinion by MalanScholes attorneys prepared in August 2022 on the items dealt with in this section.

2 Bosveld Phosphates Proprietary Limited (“**Bosveld**”), acquired assets, property rights and certain gypsum stacks (“**Gypsum Stacks**”) from Sasol Chemical Industries Limited (“**Sasol**”) **(Sasol Agreement”)** situated on the farm Wegsteek 30 LU (“**Property**”) in 2011.

2.1 PROPERTY DESCRIPTION AND RIGHTS

2.1.1 The State Department of Public Enterprises is the owner of the surface rights to the Property.

2.1.1.1 Bosveld has the exclusive right to utilise the surface where the Gypsum Stacks and Plant are situated on the Property;

2.1.1.2 Bosveld has taken transfer of the following surface right permits, which have been re-registered in accordance with Item 9 of the Transitional Arrangements, as contemplated in Item 9 of Schedule II to the MPRD Act, and are registered over the Property for an indefinite period and for the following uses, namely:

- surface right permit no 8/1964, diagram no: RMT 15, in favour of Bosveld granting the rights to manufacture chemical products, and which surface right permit was re-registered on 18 November 2005 under permit no 4384/2005;
- surface right permit no 8/71, diagram no: RMT 35/69, which stand no 17 was awarded to Bosveld for industrial purposes and which surface right permit was re-registered on 18 November 2005 under permit number 4398/2005;
- surface right permit no 71/1971, with diagram no: RMT O 123/69, in favour of Bosveld for purposes of constructing slime dams as well as the erection of fences and which surface right permit was re-registered on 18 November 2005, under permit number 4382/2005;
- surface right permit no 157/76, with diagram no: RMT O 240/74, in favour of Bosveld, for purposes of constructing slime dams and which surface right permit was re-registered on 18 November 2005 under permit number 4383/2005;
- surface right permit no F5/1964, with diagram no: RMT 364, in favour of Bosveld for purposes of constructing slime dams and which surface right permit was re-registered on 18 November 2005 under permit number 4380/2005;
- surface right permit no 92/1969, with diagram no: RMT O 211/68, in favour of Bosveld for purposes of constructing slime dams and which surface right permit was re-registered under permit number 4381/2005 on 18 November 2005;
- surface right permit no 63/82, with diagram no: RMT012/82, in favour of Bosveld for parking of motor vehicles as well as fencing and which surface right permit was re-registered on 18 November 2005 under permit number 4378/2005; and
- surface right permit no 34/87, with diagram no: RMT 0 141/87, in favour of Bosveld for purposes of constructing slime dams and gypsum stacks and which surface right permit was re-registered on 18 November 2005 under permit number 4379/2005.

2.1.1.3 The “factory and site layout” mapping the RMT’s is attached. The surface right with title of RMT M 82/72 was not re-registered.

2.2 LEGAL STATUS OF THE GYPSUM STACKS

2.2.1 A tailings dump which constitutes a movable Historic Dump (created before 1 May 2004) can be sold by the owner of the Historic Dump as one would sell a movable in the normal course and in accordance with the common law principles of sale. Accordingly, no formal registration procedure is necessary for the sale and transfer of ownership in Historic Dumps;

2.2.2 The Gypsum Stacks are movable in nature, were created prior to 1 May 2004 and have not acceded to the land where they are located;

2.2.3 None of the material added to the Bosveld Gypsum Stacks by Bosveld, after 1 May 2004, was material which arose because of the conduct of "*Mining Operations*", as defined in section 1 of the MPRD Act;

2.2.4 As the Gypsum Stacks comprise Historical Dumps as well as material not arising from the conduct of Mining Operations as they were originally bought from Foskor by Bosveld, Bosveld does not require a Mining Right in order to process the Gypsum Stacks which are not subject to the provisions of the MPRD Act. The Property, where the Gypsum Stacks will be processed, therefore also does not comprise a "*Mine*", as defined in section 1 of the MPRD Act and will not ever qualify as a Mining Area for purposes of the MPRD Act as a Mining Right will never be required to process the Gypsum Stacks.

2.2.5 Although the Sasol Agreement does not specify the Gypsum Stacks separately, it isa mutual understanding between Sasol and Bosveld that the Gypsum Stacks form part of the Sasol Agreement.

2.2.6 Bosveld is the exclusive owner of the Gypsum Stacks and all minerals in the Gypsum Stacks;

2.3 PERMITTING

2.3.1 Bosveld does not currently have any environmental authorisations specifically authorising the processing of the Gypsum Stacks but does have the necessary authorisations for the other activities currently being conducted on the Property;

2.3.2 The reclamation of a Historic Dump, which Historic Dump has not been created in terms of a Mining Right, i.e., it was created before the MPRD Act Effective Date, may require certain environmental approvals and in particular an Environmental Authorisation ("**EA**"), as defined in section 1 of the National Environmental Management Act 107 of 1998, as amended ("**NEMA**") or a Waste Management Licence ("**WML**"), as defined in the National Environmental Management: Waste Act 59 of 2008, as amended ("**NEM:WA**")

2.3.3 However, for deposition that will occur after the MPRD Act Effective Date and depending on certain technical specifications relating to the operations conducted, an EA may be required if certain of the listed activities as set out in the Environmental Impact Assessment Regulations Listing Notice 1 of 2014, published under NEMA in GNR.983 in *Government Gazette* 38282 of 4 December 2014, as amended and Environmental Impact Assessment Regulations Listing Notice 2 of 2014, published under NEMA in GNR.984 in *Government Gazette* 38282 of 4 December 2014, as amended ("**Listing Notices**"), are triggered.

2.3.4 Similarly, a Water Use Licence (WUL) is required under circumstances where any number of the listed water uses set out in section 21 of the National Water Act, 36 of 1998 ("**NWA**"), as amended are triggered.

2.3.5 Rainbow Rare Earths may require a WML, as provided for in the NEM:WA, to process the Gypsum Stacks and, only if ancillary activities referred to in the Listing Notices or water uses referred to in section 21 of NWA are triggered, will an EA and WUL be required.

5 MINERAL RESOURCE

5.1 History

The source of the rare earth elements (REE) is the Phalaborwa Igneous Complex (PIC) discovered by ET Mellor in 1904. The apatite/phosphate mineralisation containing the REE in the PIC was identified in 1931 and in 1951 The Industrial Development Company (IDC) acquired the PIC ownership and established Phosphate Development Company Limited (PDC). PDC commissioned a concentrator plant in 1953 treating foskorite ore mined from the Loolekop orebody situated in the central part of the PIC (Figure 5.1). In 1987 PDC was renamed Foskor Limited (Foskor)

Since the mid 1970's the PIC has been mined using both Open Pit and Underground mining methods by Foskor and others to produce products including copper, vermiculite, magnetite, zirconium, phosphoric acid, and nickel sulphate.

A processing plant, with a capacity of 200 tonnes per day, was built in 1964 by Bosveld Phosphates (Bosveld) to produce Phosphoric acid (PA) from the phosphate concentrate. A second PA plant was added by Fedmis Phalaborwa (Pty) Ltd in 1968 with a capacity of 160 tonnes per day. The current PA plant was built in 1976 with a capacity of 575 tonnes per day, and the first two plants decommissioned. Production of phosphoric acid was halted in 2014 and the phosphoric acid plant placed on care and maintenance.

The manufacture of phosphoric acid from phosphate concentrate produced a phosphogypsum waste which has been deposited on 2 large stacks. The REE in the phosphate ore reports primarily to the phosphate concentrate delivered to the PA plants. During PA production, the RE minerals are broken down and the REE re-precipitated with the phosphogypsum as calcium-aluminium-REE-fluoride minerals. As a result, the REE from the phosphate ore have been upgraded and represent a resource of potential economic interest.

In November 2020 Rainbow Rare Earths (RRE) signed an agreement with Bosveld for the co-development of the Phalaborwa Rare Earth Project (the Project). In December 2020 RRE completed an auger drilling program on the two stacks to estimate the REE mineral resource.

RRE conducted an infill drilling program during 2022 which will be used for a mineral resource update once the sample analyses have been received. The mineral resource estimate (MRE) presented in this document is based on the results of the first drill program but considers the in-situ dry bulk density estimates derived from both drilling campaigns.

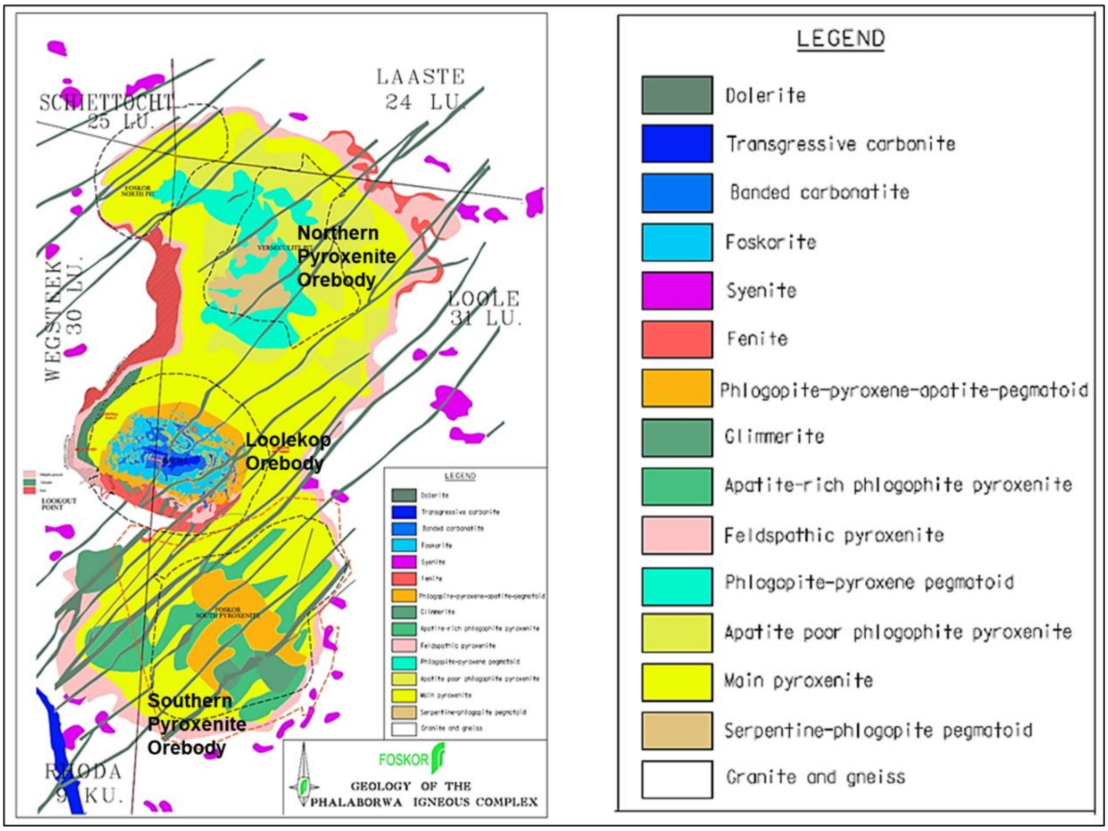


Figure 5.1: Schematic geological map of the PIC

5.2 Property Geology and Deposit Type

A Google Earth image of the Bosveld processing complex is presented in Figure 5.2 and shows the 2 phosphogypsum stacks containing the residue from the production of phosphoric acid. The two stacks (annotated as “A” and “B” in Figure 5.2) are situated to the West of the Phalaborwa mining complex. The residue stacks were deposited on a relatively flat base, consisting of soil and gravel, which was intersected in some of the drill holes (Titley, 2021).

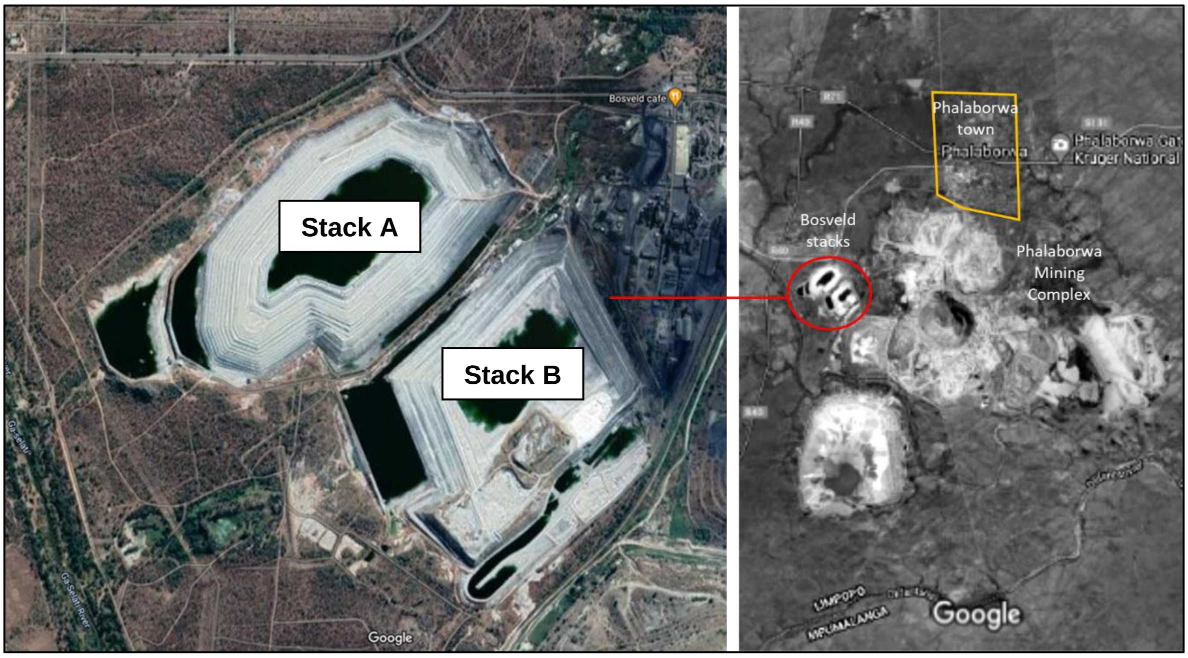


Figure 5.2: Google images of the Bosveld stacks. Right: the position of the stacks in relation to the Phalaborwa mining complex and town. Left: close-up of the stacks annotated as A and B

Stack A, the largest of the 2 stacks, with an approximate basal dimensions of 1,200 m x 700 m, has a higher surface elevation and steeper slopes. An acidic water pond (with a depth of c.4 m at its deepest central part) covers most of the top centre of the stack (Figure 5.3). Some gypsum has been mined for agriculture purposes has been removed from the NE corner of stack A.

Figure 5.3: Top of stack A (looking approx. SE)

Stack B, with an approximate basal surface of 800 m x 650 m, is lower and has gentler slopes than stack A (Figure 5.4). The acid pond on top is smaller, but with a depth virtually the same as for stack A. Some gypsum quarrying and mining has taken place in the SE and SW corners of stack B.

Figure 5.4: Stack B (looking from stack A approx. SE)

In both stacks, the material is made of white, fine-grained, friable phosphogypsum which is indurated/cemented at surface. The gypsum residues have been deposited as a thinly bedded layered sediment pack (Figure 5.5 A); however, various other facies have also been observed at surface depth (Figure 5.5 C and D). The gypsum takes a grey colouration at surface (caused by magnetite dust from the nearby dump used to feed to the magnetite plant) but becomes white underneath (Figure 5.5 E and

F). Around and probably in the floor of the acid water ponds, the surface material is made of a hard/cemented gypsum crust 5 to 10 cm thick (Figure 5.5 B).

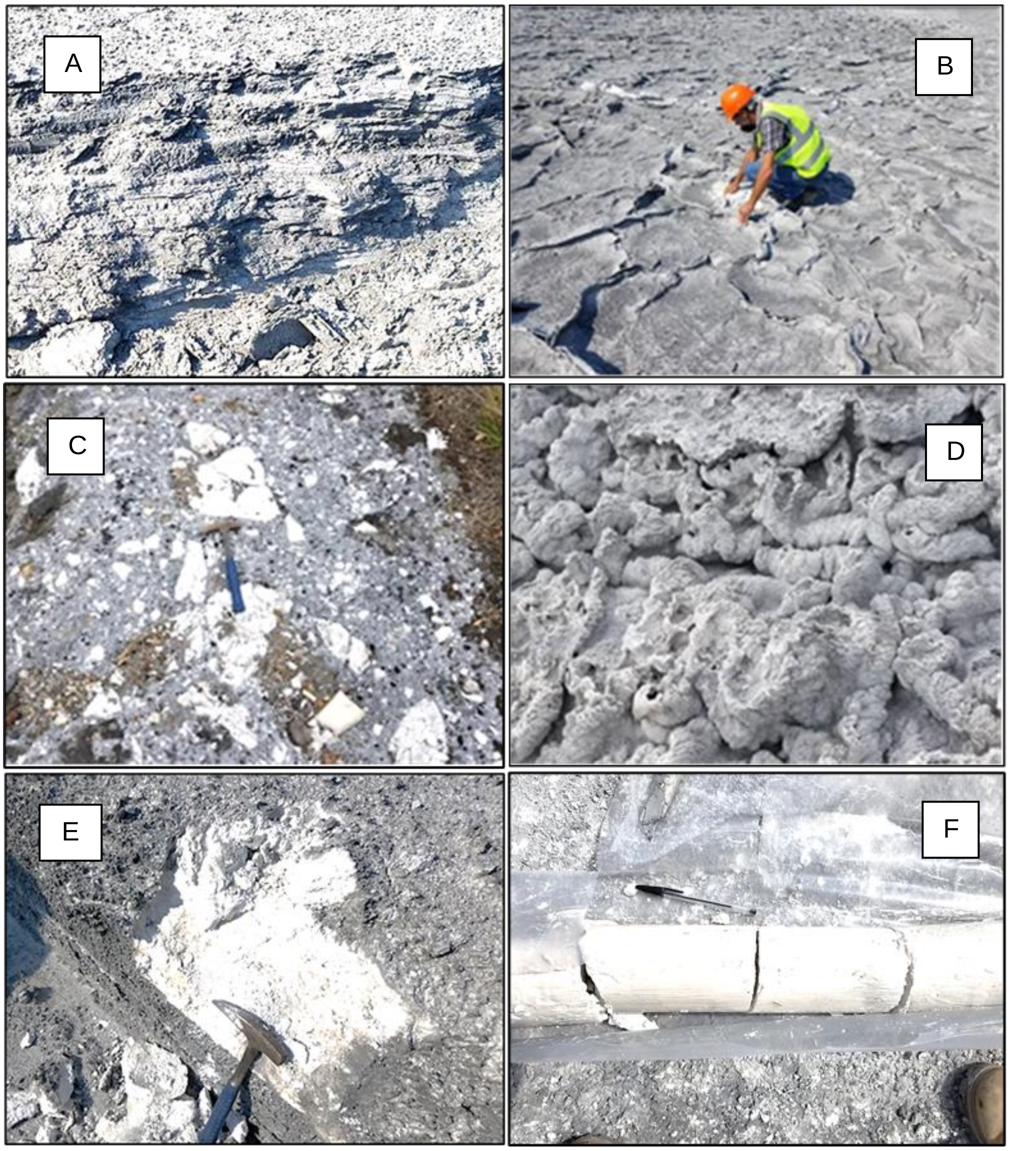


Figure 5.5: A: horizontally laminated facies; B: indurated crystalline carapace; C: breccia facies; D: botryoidal-like crystalline surface; E: grey crust and white phosphogypsum; F: sonic drill core of white phosphogypsum (collected from c.7 m below surface)

Auger and open-hole drilling carried out by RRE in 2020 and 2022 has showed that the phosphogypsum material is very uniform in colour and grain size from surface to the bottom of the stacks. Moisture content increases with depth ranging from relatively dry to totally sloppy to a point that samples cannot be recovered using conventional drilling methods. The homogeneity of the stacks was confirmed by the relative uniformity of the REE grades, laterally and at depth.

The host apatite ore that originally contained the REE's has a favourable distribution of individual elements dominated by Neodymium (Nd), Praseodymium (Pr) and Dysprosium (Dy). The REE's were upgraded by the Foskor concentration process and then again during the phosphoric acid production process where REE reported to the phosphogypsum residue deposited on the stacks.

5.3 Volume Survey

Stack A and B plus local surrounds were surveyed by Drone Solutions International (DSI) during the period 27th April to 1st May 2021. Ground control points were positioned and surveyed to provide accurate controls. The survey grid was WGS84/36S.

The survey was conducted at a height of 75 m and 8 m/s flight speed generating 80 - 100 survey points per square metre employing a LiDAR scanner attached to a multi-copter drone.

A bathymetric survey was conducted on the acid water ponds located in the centre of both stacks using a floating sonar depth sensor. This data was used to calculate the pond basal surface.

A high-resolution ortho-mosaic image was captured with a mirrorless Sony A600 camera mounted to a fixed-wing drone at 120 m above ground level. The resultant 2.5 cm resolution ortho-mosaic was geo-referenced using the surveyed ground control points.

The combination of the LiDAR survey, bathymetric survey and photographic imagery was used by DSI to create the XYZ points representing the upper surface of the phosphogypsum material for both Stack A and B at a 0.5 m XY resolution.

The Competent Person (CP) created a digital terrain model (DTM) for both Stack A and B at a 1 m XY resolution of the gypsum upper surface to estimate the volume of phosphogypsum, as shown in Figure 5.3.

Surface mapping identified an area (shown in brown in Figure 6) that contains a mixed zone of rubble and phosphogypsum. The depth of the rubble is unknown but based on personal communications with Bosveld staff (email to D Dodd 23rd May 2021) it is understood that rubble and gypsum were dumped simultaneously in the designated area since 1965, so the complete area beneath the rubble was excluded from the mineral resource. This rubble contaminated area contains an unknown resource of REE’s and will be the subject of later evaluation. The central areas containing residual solution (acidic water and dissolved minerals) are shown in blue. These areas could not be pumped dry at the time of drilling to enable access.

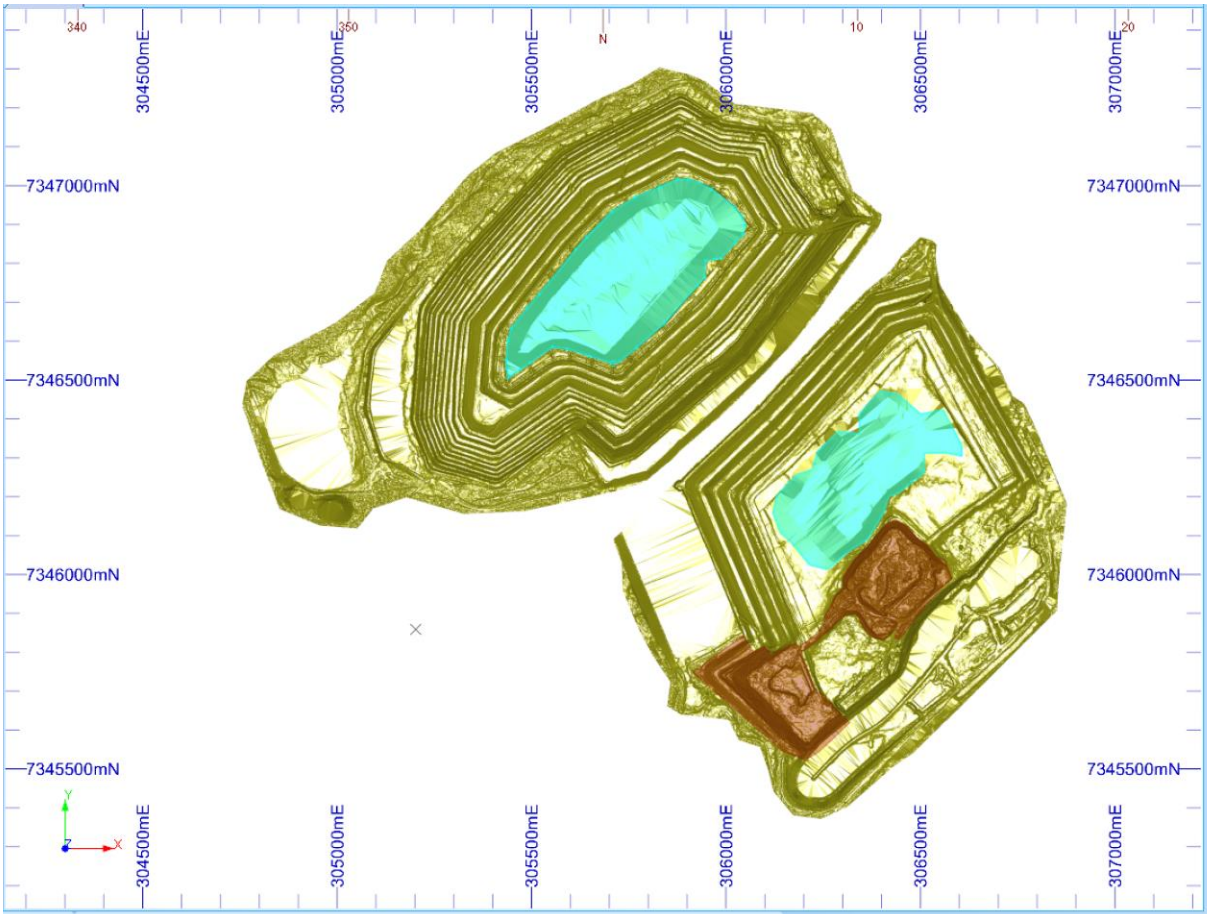


Figure 5.6: DTM surface of Stack A and B, with ponds in blue and mixed rubble and phosphogypsum zone in brown

The topographical surface derived from the LiDAR survey at the edge of each stack was isolated and projected underneath each stack to create a basal DTM representing the original topography surface prior to the construction of the stacks. This basal layer was further refined, utilising drill hole data, where the base of the stack was intercepted during drilling. Refer to Figure 5.7. The yellow periphery zone is the ‘natural topography’ at the edge of each stack. The blue dots are the base of the last sample of REE gypsum before intercepting the base of the stack. The pale green surface is the interpolated ‘natural topography’ prior to stack dumping of residue. The blue outline is the footprint of each stack used for estimation of REE mineral resource, which excludes areas currently being reclaimed for small-scale agricultural use.

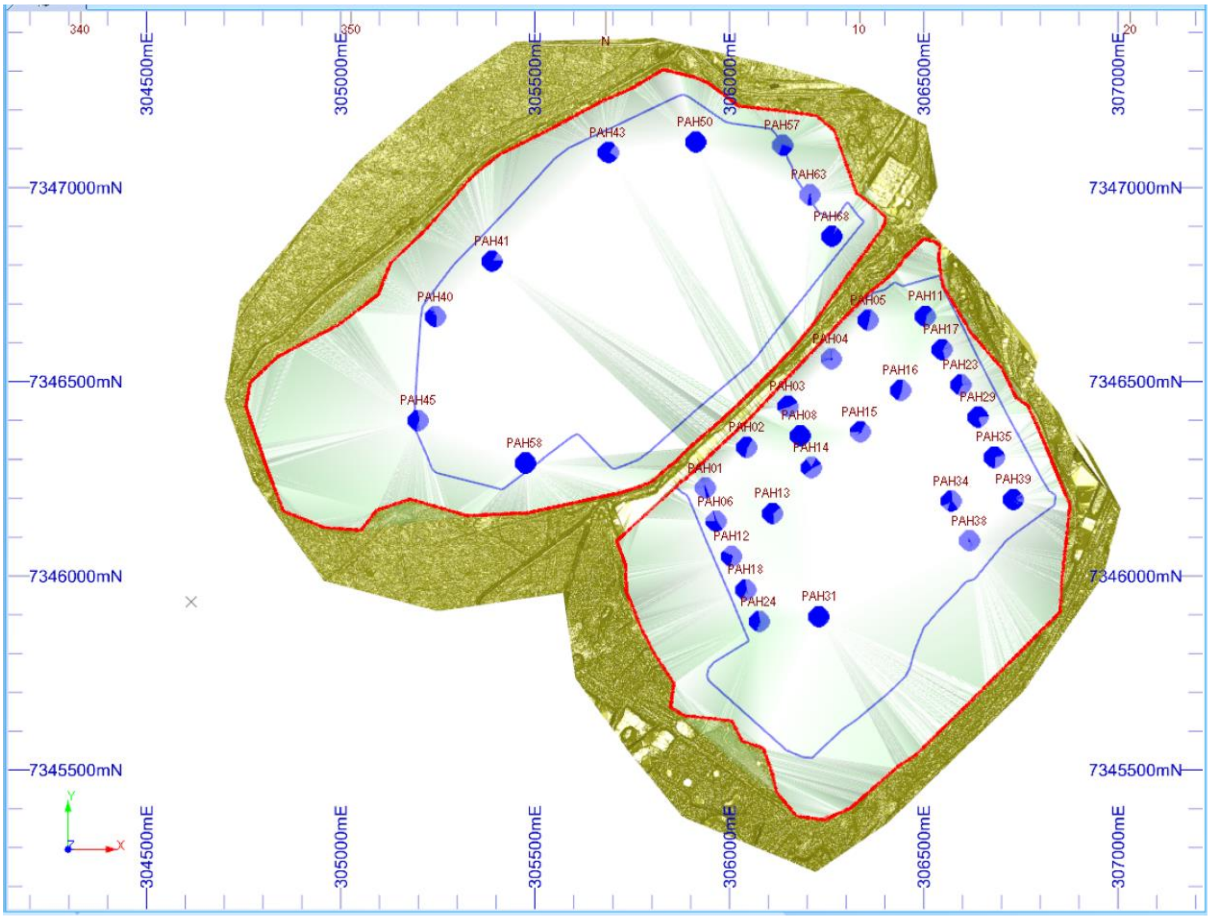


Figure 5.7: Basal surface beneath each Stack interpolated from surrounding topography and drill hole intercepts (blue)

5.4 Drilling and Sampling

The Phase 1 resource drilling was completed during the period 2nd to 17th of December 2020. The drilling was conducted by SGS South Africa and was undertaken using a hand-operated power auger. In total 1,056.3 m was drilled from 72 holes over the two stacks, Stack A and Stack B.

Stack B was mostly drilled from top to the natural topography basal surface. Unfortunately, the SGS auger drill had inadequate power to drill to the bottom of Stack A from the top surface for all 8 of the planned holes in this area, with the deepest hole in Stack A only reaching 27 m (Stack A is estimated to be up to 45 m thick).

The drill holes were located on the ground using a hand-held GPS based on planned grids.

Stack A holes were drilled on a nominal 200 m x 150 m grid with 33 holes for 501.2 m drilled. 27 of the initially planned 29 holes were drilled, the remaining 2 were not drilled due proximity to the pond in the centre of Stack A. An additional 4 holes were drilled at a right angle around PAH08 at 10 m spacing to test close spaced grade variability, with a further 2 holes drilled to fill gaps in the planned grid.

Stack B holes were drilled on a nominal 150 m x 100 m grid with 39 holes for 555.1 m drilled. 33 holes of the original planned 41 holes were completed, 5 of the undrilled planned holes were in areas mapped as containing rubble which prevented drilling, and 3 holes were inaccessible due proximity to the pond in the centre of Stack B. The 39 holes drilled included 6 that were drilled at a 10m right angle around hole PAH52 to test close-spaced grade variability.

The SGS auger drill rig utilises a rotating spiral auger encased in a stainless-steel core barrel to advance into the phosphogypsum material. This method ensures that contamination of the sample is minimised because the sample is contained within the barrel and not mixed with material above the drilling face.

The SGS rig utilises a 50 mm nominal bore drill rod, producing between 3.5 and 7 kg of sample per 1.5 metre increment. On withdrawing of the core barrel, the contents recovered are extruded onto a 5 m plastic half-pipe located on a trestle to ensure total sample collection. The spiral is then removed from the core barrel and any remnant sample removed and added to the material on the half-pipe.

Auger sampling was completed on 1.5 m intervals The 1.5 m interval samples were bagged in pre-marked and numbered plastic bags with 702 samples collected and sent, for preparation and chemical analyses, to SGS in Randfontein, Johannesburg. 1 sample (70600 - PAH85 4.5 to 6 m) was lost and 35 samples (70713 to 70751) did not have assay results for Thulium (Tm) and Thorium (Th).

The average dry mass of the 702 auger samples was 4.375 kg with an average moisture content of 18% (with 15% of the samples having a moisture content between 25% and 47%).

QAQC samples (certified standards, blanks and duplicates) were inserted at a ratio of 12%. Umpire analysis was completed at ALS Johannesburg with 35 samples (5%) submitted. Due to the complexity of the digestion methods used to extract REEs, there was some variance between standards, duplicates and umpire analysis. However, the CP is satisfied that the QAQC results adequately support the REE grades, and the results of the sample analysis are suitable for the MRE.

Drilling data used in the MRE derived from the Auger drilling program is presented in Table 5.1.

Table 5.1: Drilling and sampling data used in the MRE

Prospect	Holes	Metres Drilled	Assay Sample Length	Assays used in MRE
Stack A	33	501.2	1.50	333
Stack B	39	555.1	1.50	369
Total	**72**	**1,056.3**	**1.50**	**702**

Note: 1.8 m of drilling was into basal gravels – samples not used for MRE. 1 sample interval was lost during processing

5.5 In-Situ Dry Bulk Density Determination

During the Phase 1 drilling campaign 2 types of samples were collected for bulk density (BD) estimation from the surfaces of the two stacks:

1. 234 samples were collected using a one litre volume steel mould hammered into selected surfaces of the stacks (e.g., access cuts and mining faces).
2. 33 had specimen lumps weighing in average 364 g of reasonably competent gypsum found at the surface on the stacks.

The 234 1ℓ samples yielded BD values ranging from 0.60 t/m^3 to 1.45 t/m^3 with an average of 1.0 t/m^3. The 33 hand specimen lumps samples were dried, and the BD analysed using the wax coated water immersion method. 14 had an average BD of 1.27 t/m^3, the remaining 19 samples floated (BD < 1.0). The potential issue with these 2 sample types is that they represent the weathered top 10 to 50 cm of the stacks, where weathering processes have affected the porosity of the original precipitate, making these samples unrepresentative of the BD of the entire stacks.

A literature review of phosphogypsum tails deposits indicated a BD of around 1.1 to 1.3 t/m^3, which also correlates with the estimated stack volumes and stated historical production of around 35 million tonnes of tailings. This information justified further work to obtain a representative set of samples from the stacks to estimate the BD. A bulk density drilling program was initiated in April 2021. The program included a Sonic drilling method as an attempt to recover competent sections of core at depth (Figure 5.5).

The recovery of intact, unbroken core from the phase 2 sonic drilling was below expectation, with only 19 pieces of core recovered from the drilling which were competent enough to determine BD using the measured volume of the core cylinder divided by dry mass of core method. Five of the samples were cross-checked using the wax immersion method with identical results (within +/- 1 to 3%). The BD values were plotted in 3D (Figure 5.8) and reviewed spatially to determine if there were any obvious depth trends and statistically to review the data distribution. A histogram of the results is presented in Figure 5.9. The results show a normal distribution of values with a mean and median of 1.66 and 1.67 t/m^3, respectively.

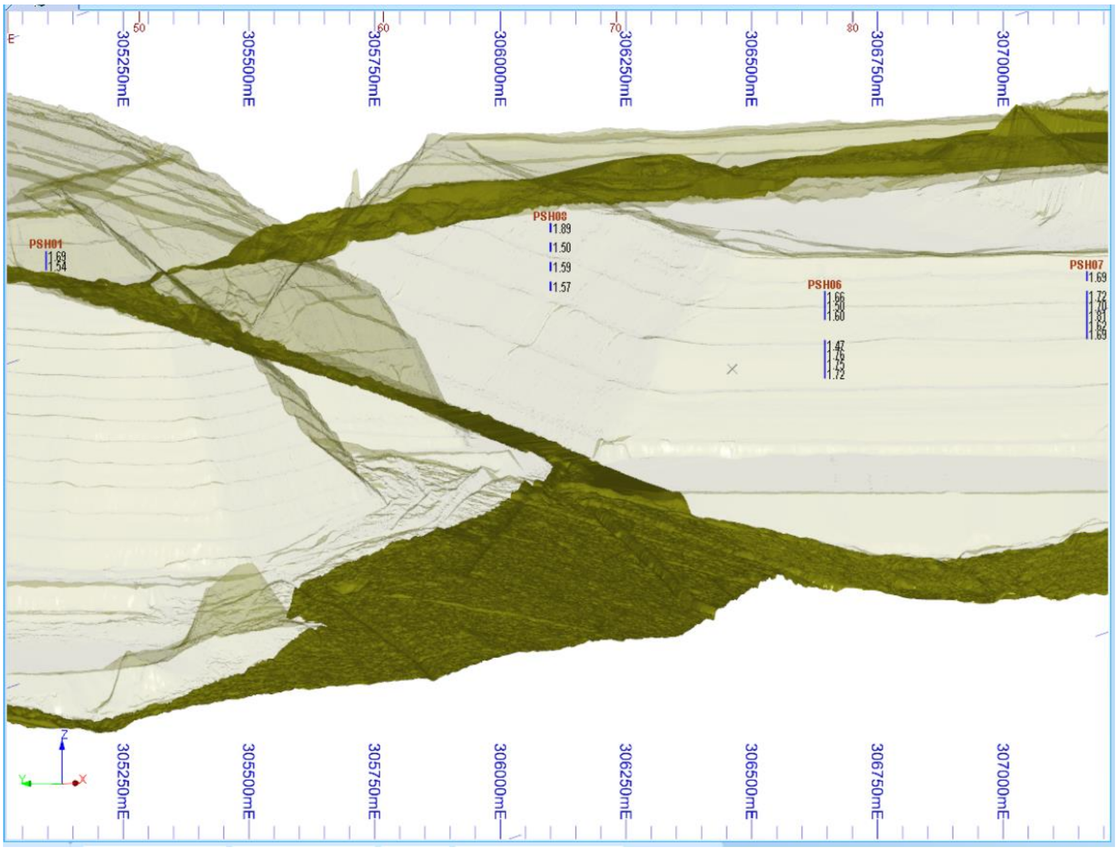


Figure 5.8: 5X vertical exaggeration 3D image, showing BD results from 4 sonic drillholes completed on Stack A (1 hole) and Stack B (3 holes) during the phase 2 drilling program

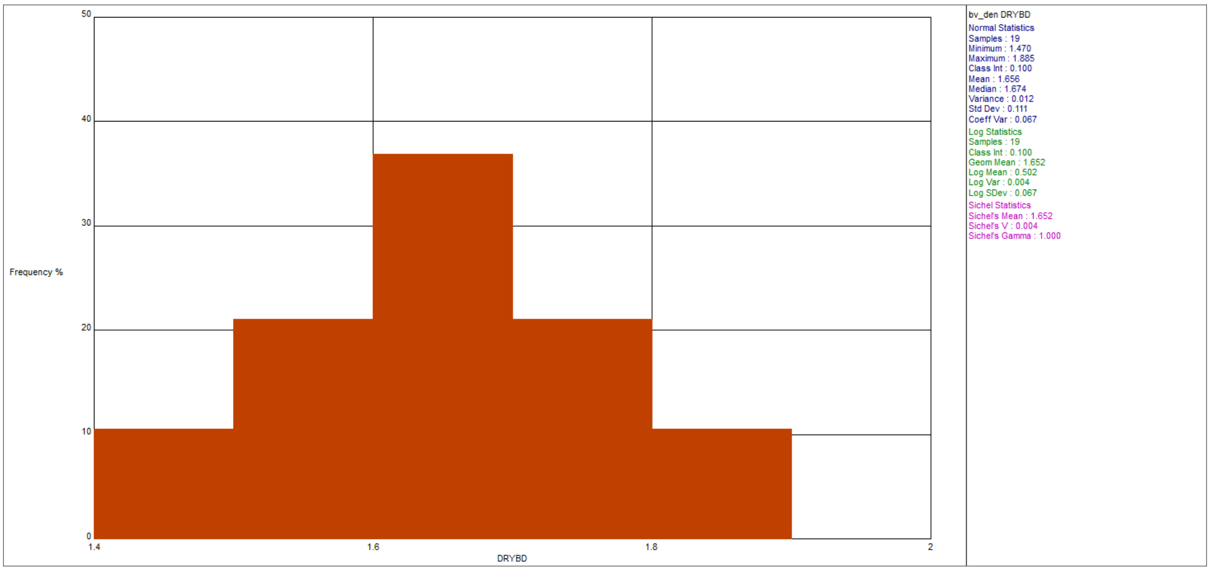


Figure 5.9: Histogram of BD distribution from the 19 sonic drilling core samples

The moisture content of the stacks is variable. Near-surface moisture content averages around 10 - 15%, increasing with depth below 10 m to 20 - 30%, with some areas being saturated near the base of the dumps and proximal to the central solution ponds.

In June 2022 an infill drilling program was completed with the following objectives:

1. Obtain assay samples from areas not accessed in the previous drill campaigns
2. Collect at least 20 tonnes of representative bulk sample for metallurgical pilot plant test work
3. Using a higher-powered sonic drill, attempt to obtain intact in-situ core samples suitable for dry bulk density determination.

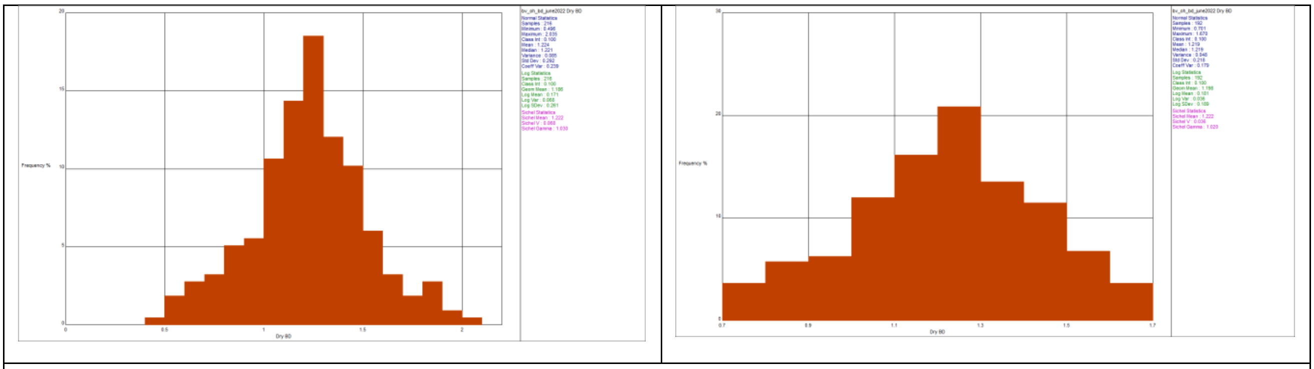
The sonic drill was expected to deliver all 3 objectives but struggled to achieve reasonable production rates, failed to obtain intact samples suitable for BD and was subsequently abandoned after drilling 26 m of the first hole planned on Stack A. The sonic drill was replaced by a 216 mm (8.5 inch) open hole percussion (OHP) drill rig (Figure 5.10).

Figure 5.10: Open hole percussion rig used in the June 2022 drilling program

The OHP drilling had good production rates and good sample recovery (as chips / powder) in dry and damp areas. Near the base of the stacks and proximal to the ponds the material was saturated and unable to be efficiently recovered and also due to mixing / contamination unlikely to be representative of the drilling interval.

OHP assay sampling was completed at 1 m intervals with moisture samples collected every 2 m. Every 1 m sampled was weighed and the sample recovery estimated by the drilling geologist. A total of 713 m was sampled.

Sample intervals with recovery greater than 70% and moisture recorded as dry or damp were considered suitable for dry bulk density determination. A total of 216 samples were available. Dry mass was calculated by application of the laboratory determine moisture content and volume estimated from the drill hole volume multiplied by the recovery. Figure 5.11 presents a histogram of the dry bulk density results. Outliers with values <0.7 and >1.7 t/m^3 were removed to avoid any bias. In both cases the resulting average dry bulk density was 1.2 t/m^3.



Histogram of OHP samples selected for in-situ dry bulk density estimation. Left image showing full data set of 216 samples. Right image showing distribution after removal of outliers leaving 192 samples. Note: The mean values are both 1.2 t/m^3

Figure 5.11: Histograms of OHP samples used to estimate in-situ dry bulk density in September 2022

Correlation of BD with drilling depth was reviewed. There is a possible positive correlation with a regression coefficient of 0.36, with average BD around 0.9 to 1.1 at the surface increasing to 1.2 to 1.6 at depths greater than 20 m.

On the 22nd of June 2022, DSI completed a LiDar survey of the SE sector of Stack B. Mining of the dump as a gypsum source for local farmers has continued throughout the period from the previous LiDar survey in April 2021 to the current survey. DSI estimated the volume difference in the area of mining as 50,081 bcm. Maja verified the result using a block modelling method with a volume estimate of 51,110 bcm. All material mined was weighed over a weigh bridge with a moist weight of 65,793 tonnes. Moisture sample of the dump (10 samples) gave an average moisture content of 13.8%. Using this information, the near surface BD of the mined material ranges from 1.11 to 1.13 t/m^3, which supports the results from the OHP drilling program.

In conclusion the Competent Person is satisfied that an average BD of 1.2 t/m^3 is suitable for the Bosveld gypsum stacks tonnage estimate. Further work is required to determine if the indicative increase in BD with depth is correct and should be applied to future MRE updates.

5.6 Volume Block Models

Using the Lidar stack DTMs and the interpolated basal DTMs, a 3D block model was constructed using Datamine mining software. The dimensions of the block models are presented in Table 5.2.

Table 5.2: Datamine 3D block model dimensions

Prospect	Origin			Maximum			Parent Block Size			Boundary Resolution		
	Easting	Northing	Elev'n	Easting	Northing	Elev'n	Easting	Northing	Elev'n	Easting	Northing	Elev'n
Stack A	305,150	7,346,200	350	306,350	7,347,250	430	50	50	3	5	5	0.5
Stack B	305,850	7,345,500	350	306,850	7,346,800	410	50	50	3	5	5	0.5
Combined	305,150	7,345,500	350	306,850	7,347,300	430	50	50	3	5	5	0.5
	Origin			Extent in Metres			Parent Block Size			Boundary Resolution		
Stack A	305,150	7,346,200	350	1,200	1,050	80	50	50	3	5	5	0.5
Stack B	305,850	7,345,500	350	1,000	1,300	60	50	50	3	5	5	0.5
Combined	305,150	7,345,500	350	1,700	1,800	80	50	50	3	5	5	0.5

The model was constrained using a limiting boundary for each stack. The limiting boundary perimeter (Figure 5.7 - blue outline) defined the potential mineable base of each stack and excluded areas currently affected by current and historical reclaim activity. It is important to note that the centre surface of each stack is currently filled with solution produced from the processing plant, which is acidic and cannot be readily pumped to alternative storage areas. This solution prevented drilling in the centre of each stack and also likely impacts the moisture content of the phosphogypsum within the stacks.

5.7 Statistics and Variography

The ratio between the REE elements is relatively consistent with a reasonable correlation between the REEs and TREO. Examples are presented in Figure 5.12 - Figure 5.17. Showing the Light REEs (LREO - Ce, La, Nd, Pr, Sm), Heavy REEs (HREO - Dy, Er, Eu, Gd, Ho, Lu, Tb, Tm, Y, Yb), Critical REEs (CREO - Dy, Eu, Nd, Tb, Y), Nd and Pr compared to the Total REO (TREO). Interestingly Pr shows an unusual correlation trend for the lower grades, possibly related to the assay analytical method. As there is adequate correlation of all elements to TREO, this was used as the master grade variable for statistical analysis, variography and grade estimation.

TREO was subdivided by stack. Figure 5.18 and Figure 5.19 present histograms of the TREO grade distribution. Stack A - MINZON 1 - contains 332 1.5 m samples with an uncut mean of 0.425%. Stack B MINZON 2 - contains 369 1.5 m samples with an uncut mean of 0.464%. Both distributions are close to normal with a small +ve skewed higher grade tail. A top cut of 0.63%TREO was applied to both distributions to avoid local grade bias, with little to no impact on the cut means of 0.424% and 0.464%, respectively. FiguresFigure 5.20 andFigure 5.21 present the probability plots after top cutting. Figure 5.22 presents the location of the top cut samples. They are not clustered and relatively randomly distributed through the stacks justifying use of a top cut to remove outliers.

TREO Variography was completed for each stack. Downhole variograms used to determine the nugget and close-spaced vertical continuity were completed for both stacks independently. The resulting variogram models were very similar, so the data was combined, which produced the same result. Figure 5.23 presents the combined downhole variogram, which has a nugget of 40% and a vertical range of 8.6 m. Note that 70% of the sample variance occurs at 4m.

Directional variograms were modelled by stack with the results presented in Table 5.3. An example of a modelled directional variogram is presented in Figure 5.24 for stack B. The variogram directions of major continuity were reviewed visually and appeared to make geological sense - being generally horizontal with a small dip following the dip of the basal topography.

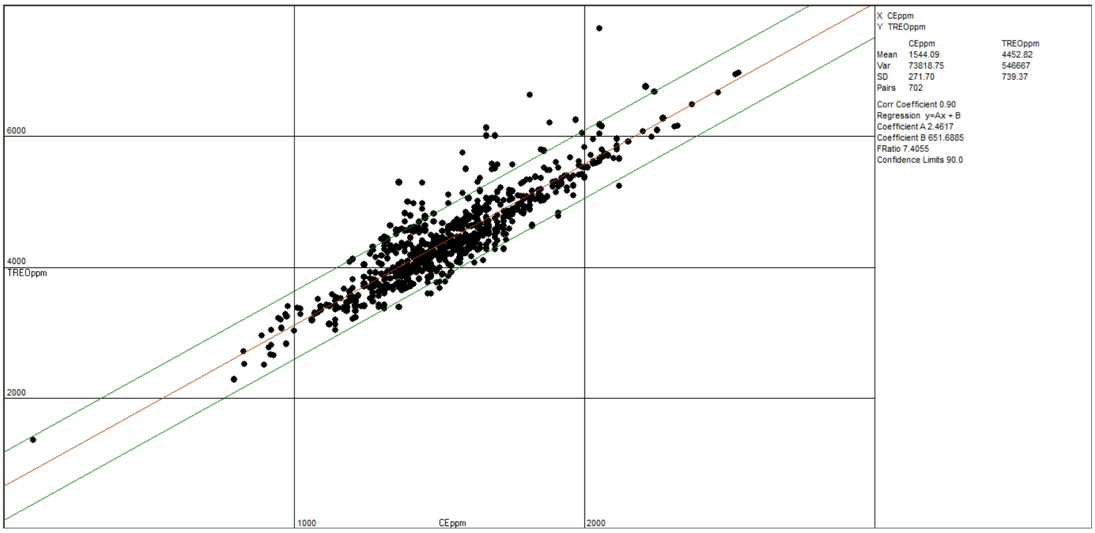


Figure 5.12: Cerium (ppm) vs. TREO (ppm)

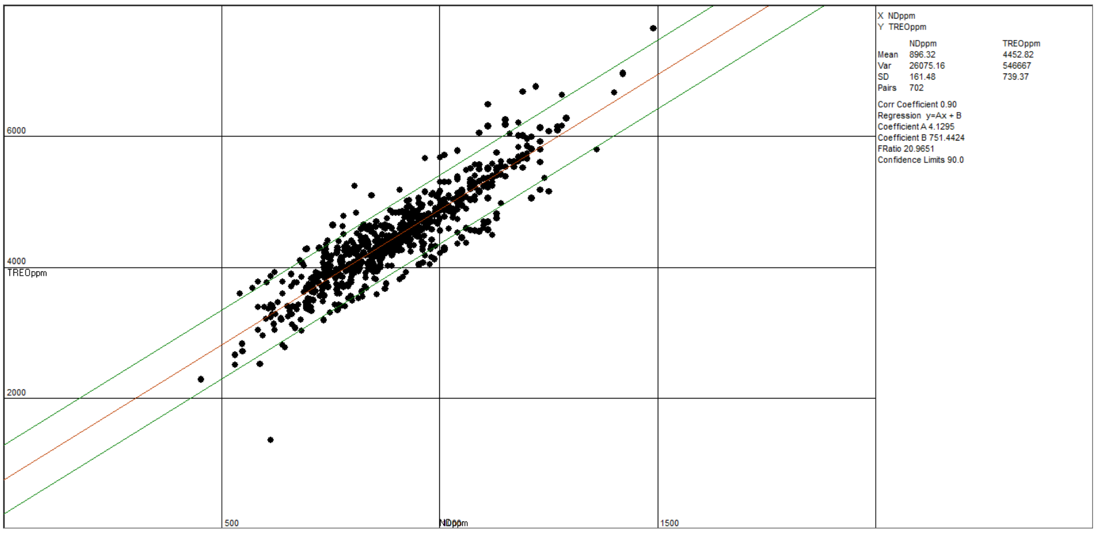
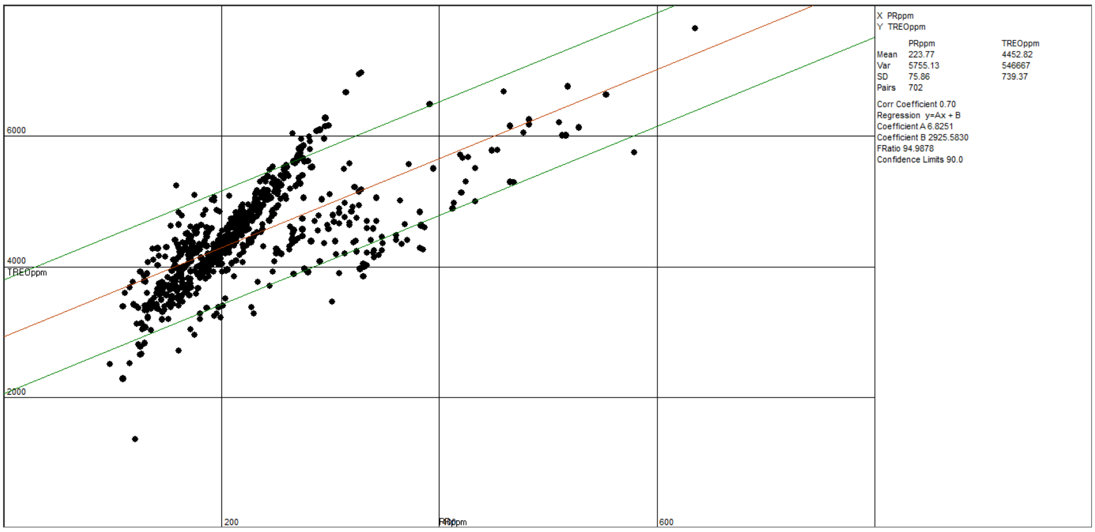


Figure 5.13: Neodymium (ppm) vs. TREO (ppm)

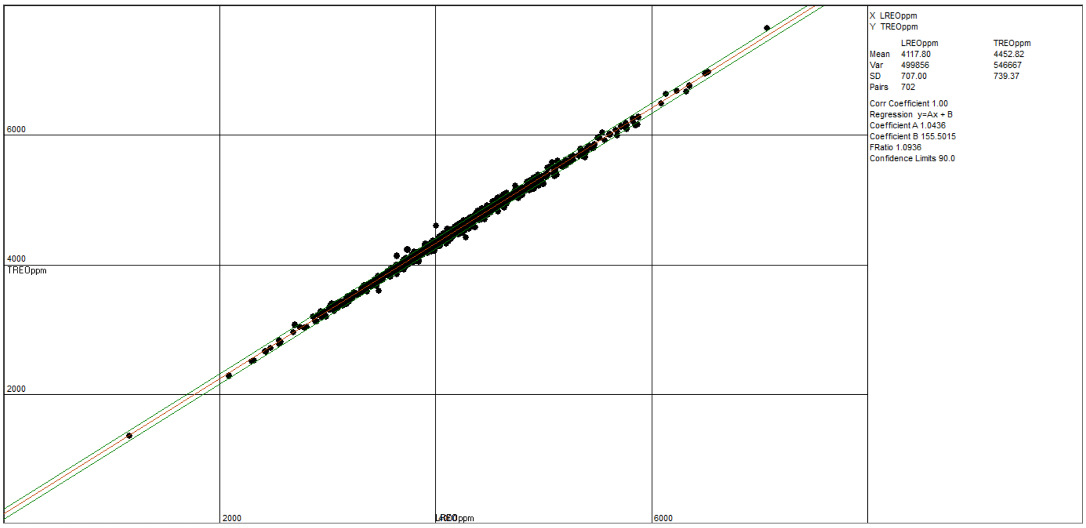


X PRppm
Y TREOppm

	PRppm	TREOppm
Mean	223.77	4452.82
Var	5755.13	546667
SD	75.86	739.37
Pairs	702	

Corr Coefficient 0.70
Regression y=Ax + B
Coefficient A 6.8251
Coefficient B 2925.5830
FRatio 94.9878
Confidence Limits 90.0

Figure 5.14: Praseodymium (ppm) vs. TREO (ppm)

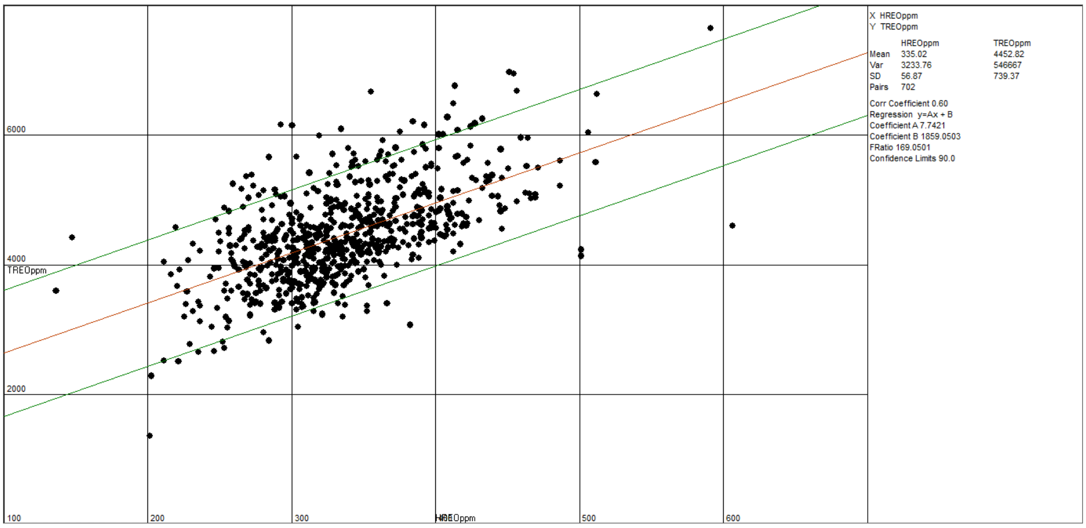


X LREOppm
Y TREOppm

	LREOppm	TREOppm
Mean	4117.80	4452.82
Var	499856	546667
SD	707.00	739.37
Pairs	702	

Corr Coefficient 1.00
Regression y=Ax + B
Coefficient A 1.0436
Coefficient B 155.5015
FRatio 1.0936
Confidence Limits 90.0

Figure 5.15: LREO (ppm) vs. TREO (ppm)

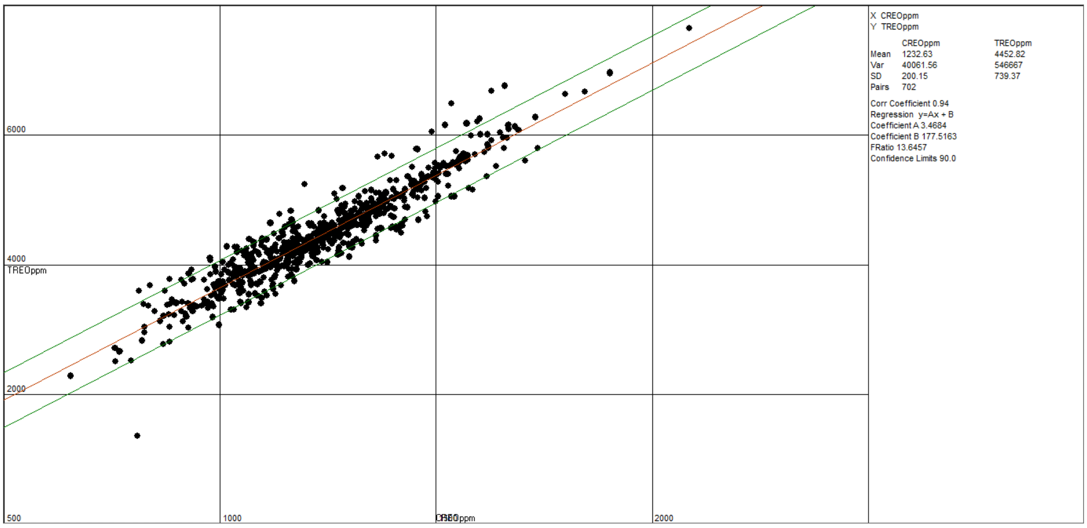


X HREOppm
Y TREOppm

	HREOppm	TREOppm
Mean	335.02	4452.82
Var	3233.76	546667
SD	56.87	739.37
Pairs	702	

Corr Coefficient 0.60
Regression y=Ax + B
Coefficient A 7.7421
Coefficient B 1859.0503
FRatio 169.0501
Confidence Limits 90.0

Figure 5.16: HREO (ppm) vs. TREO (ppm)

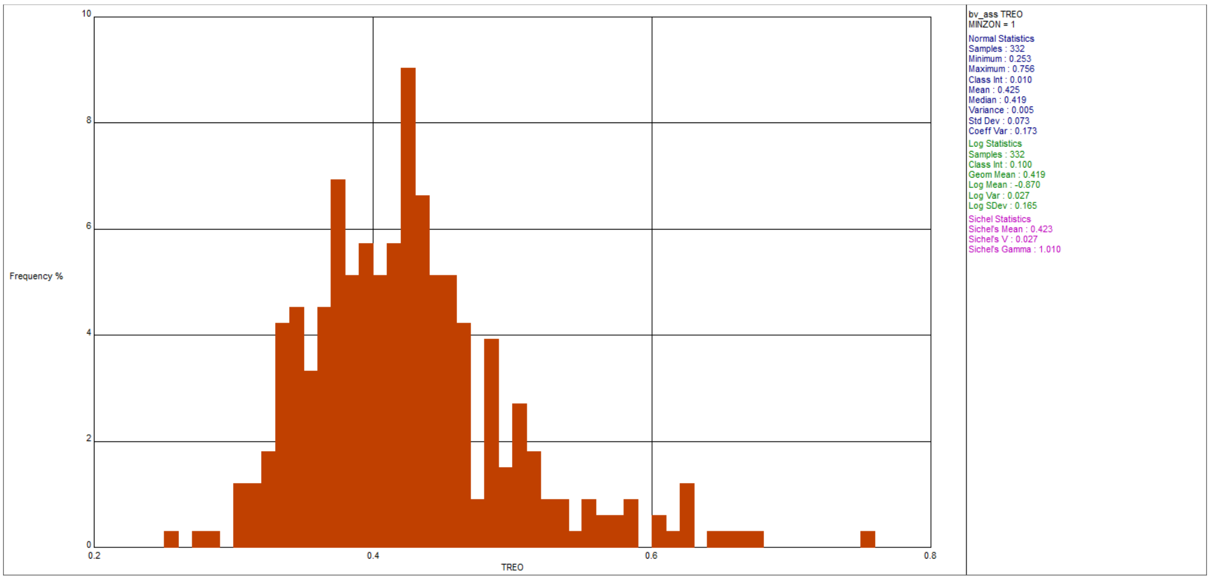


X CREOppm
Y TREOppm

	CREOppm	TREOppm
Mean	1232.63	4452.82
Var	40061.56	546667
SD	200.15	739.37
Pairs	702	

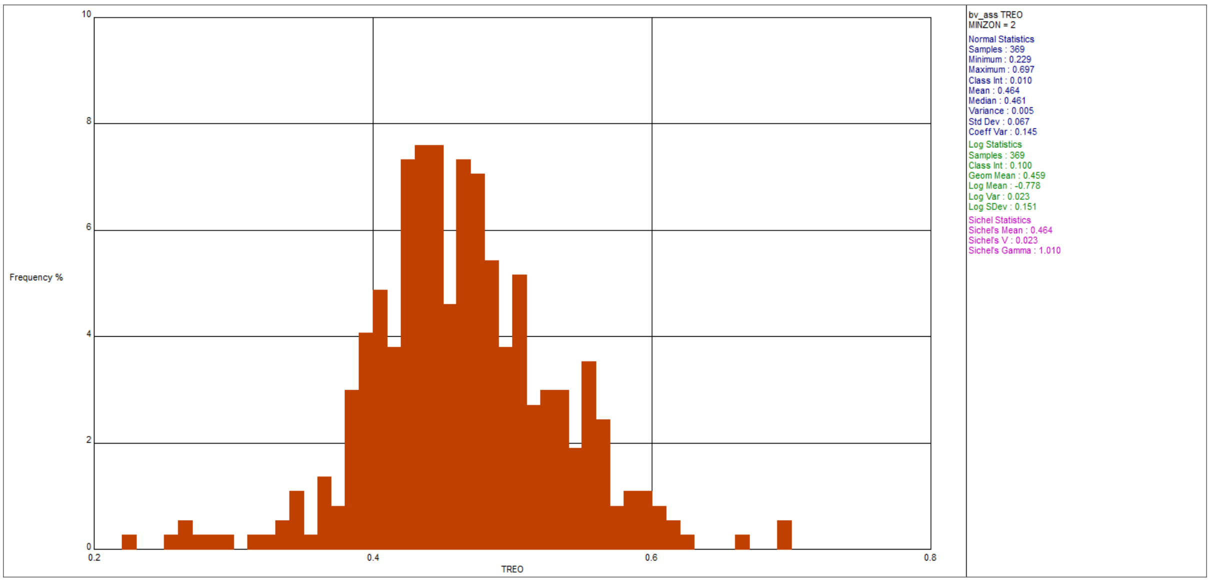
Corr Coefficient 0.94
Regression y=Ax + B
Coefficient A 3.4684
Coefficient B 177.5163
FRatio 13.6457
Confidence Limits 90.0

Figure 5.17: CREO (ppm) vs. TREO (ppm)



bv_ass TREO
MINZON = 1
Normal Statistics
Samples : 332
Minimum : 0.253
Maximum : 0.756
Class Int : 0.010
Mean : 0.425
Median : 0.419
Variance : 0.005
Std Dev : 0.073
Coeff Var : 0.173
Log Statistics
Samples : 332
Class Int : 0.100
Geom Mean : 0.419
Log Mean : -0.870
Log Var : 0.027
Log SDev : 0.165
Sichel Statistics
Sichel's Mean : 0.423
Sichel's V : 0.027
Sichel's Gamma : 1.010

Figure 5.18: Histogram showing distribution of TREO for Stack A (MINZON 1)



bv_ass TREO
MINZON = 2
Normal Statistics
Samples : 369
Minimum : 0.229
Maximum : 0.697
Class Int : 0.010
Mean : 0.464
Median : 0.461
Variance : 0.005
Std Dev : 0.067
Coeff Var : 0.145
Log Statistics
Samples : 369
Class Int : 0.100
Geom Mean : 0.459
Log Mean : -0.778
Log Var : 0.023
Log SDev : 0.151
Sichel Statistics
Sichel's Mean : 0.464
Sichel's V : 0.023
Sichel's Gamma : 1.010

Figure 5.19: Histogram showing distribution of TREO for Stack B (MINZON 2)

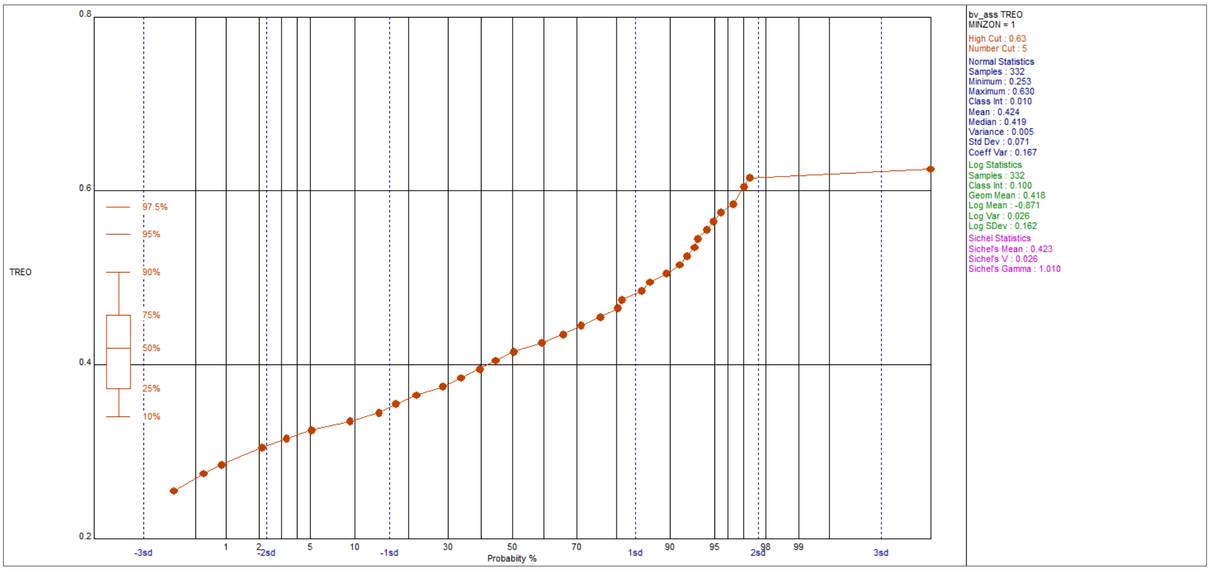


Figure 5.20: Probability plot showing TREO after top cutting at 0.63% for Stack A (MINZON 1)

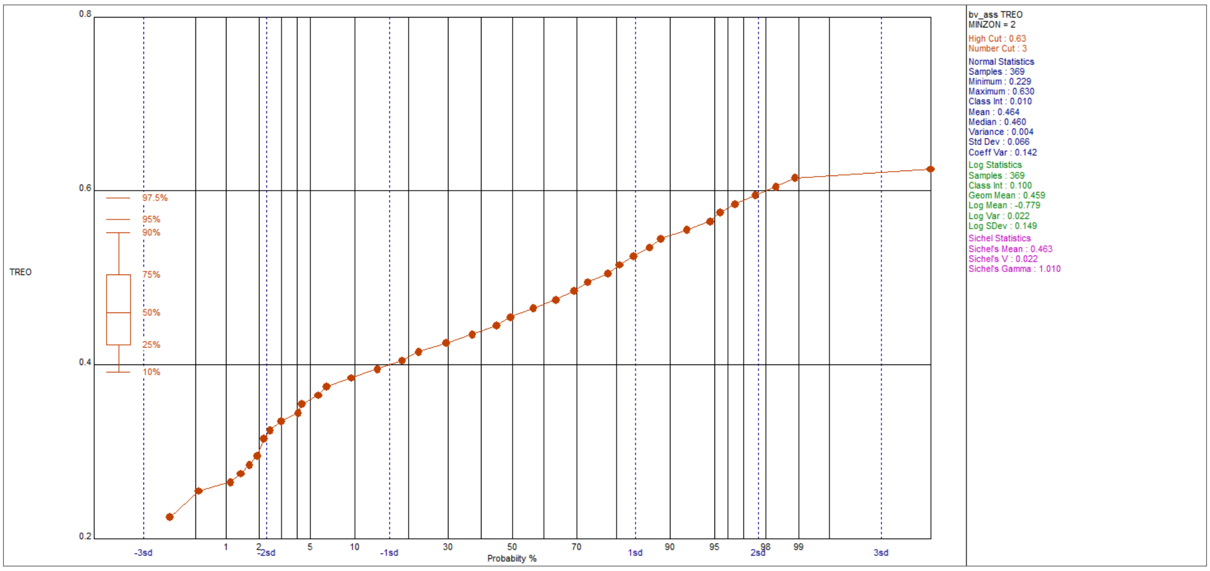


Figure 5.21: Probability plot showing TREO after top cutting at 0.63% for Stack B (MINZON 2)

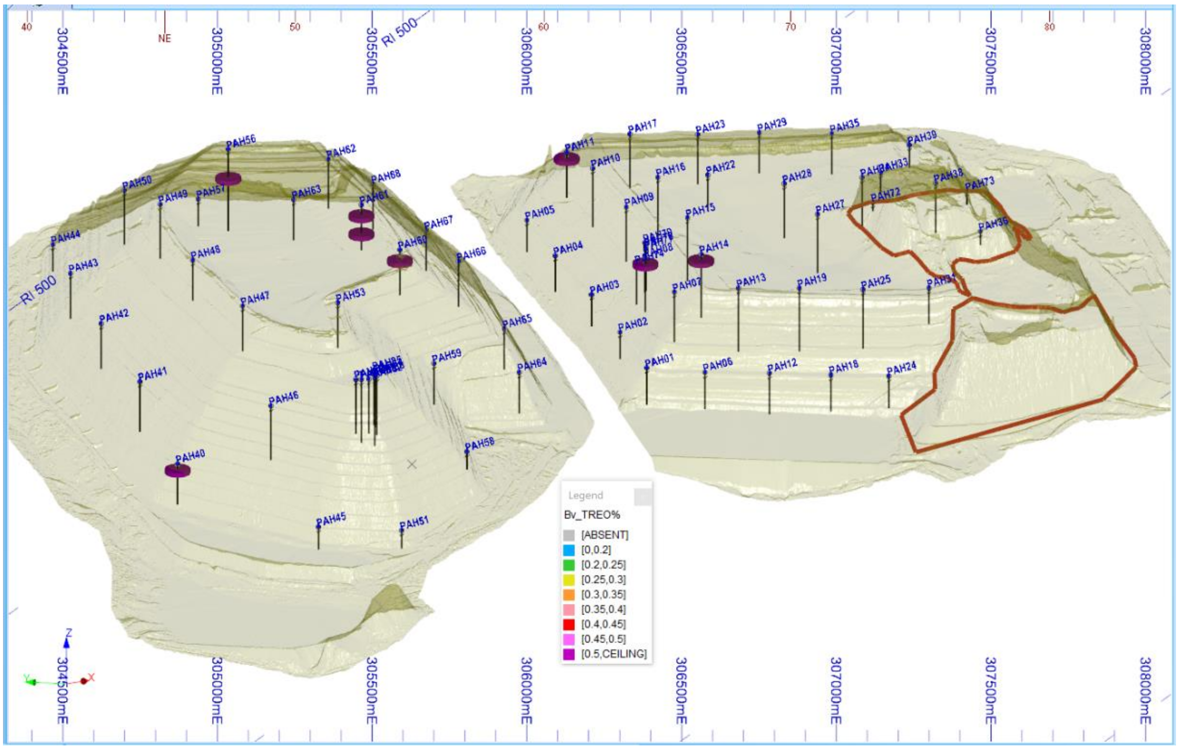


Figure 5.22: 3D view with 5x vertical exaggeration showing location of samples top cut in purple

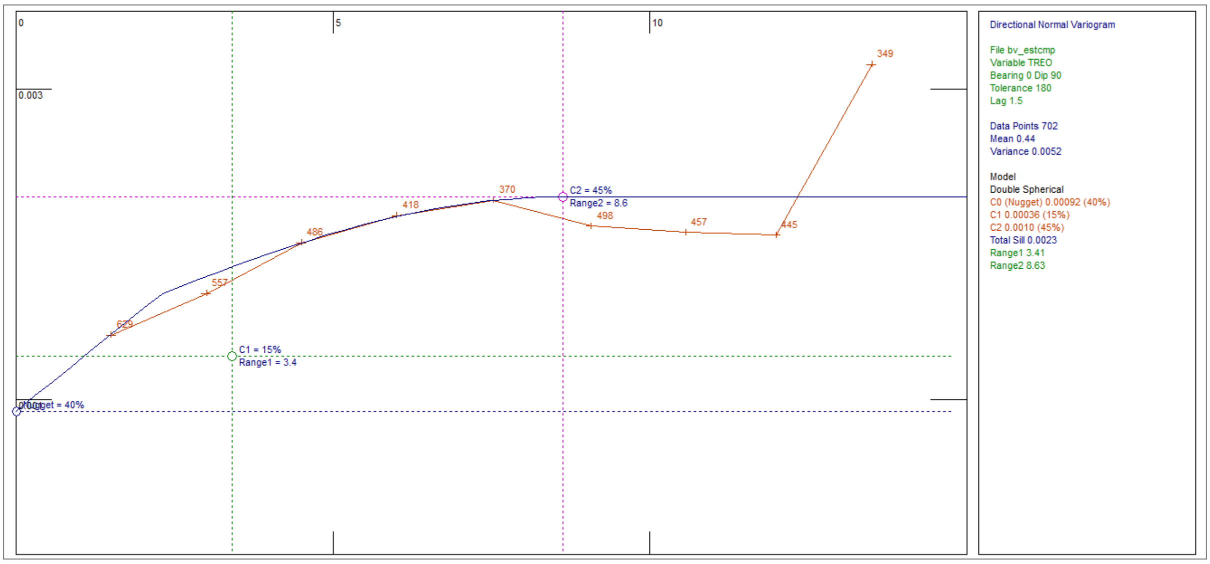


Figure 5.23: Combined downhole variogram for Stack A + B

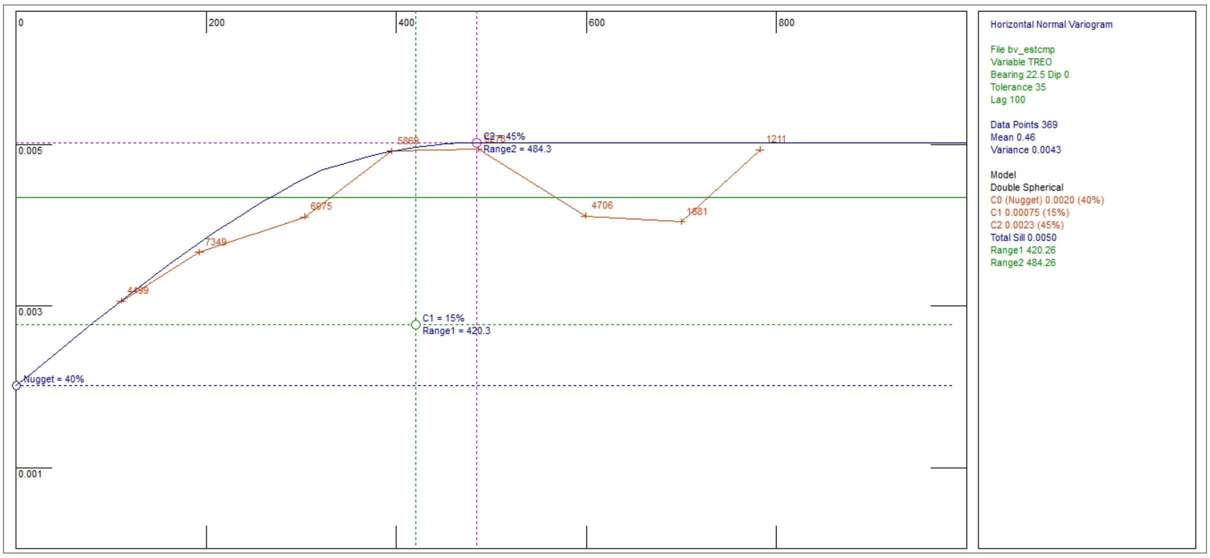


Figure 5.24: Example of a Major Direction variogram - Stack B MINZON 2

Table 5.3: Modelled variogram parameters

Deposit	Grade	Nugget	Structure 1				Structure 2			
			Sill 1	Range 1	Range 2	Range 3	Sill 2	Range 1	Range 2	Range 3
Stack A	TREO	0.40	0.15	313	317	3.4	0.45	445	347	8.6
Stack B	TREO	0.40	0.15	420	258	3.4	0.45	484	309	8.6
Variogram Axis Rotation – based on variography and visual validation, DIP DIR, DIP and PLUNGE										
	Axis 1	Axis 2	Axis 3	Rotation 1	Rotation 2	Rotation 3				
Stack A	Z	X	Z	67.5	0.0	0.0				
Stack B	Z	X	Z	20.0	3.0	0.0				

5.8 Grade Estimation

TREO, Thorium and Uranium grades plus ratios of REEs to TREO were estimated using Ordinary Kriging (OK). The advantage of estimating the ratio and then back-calculating the individual REE grade is that the sample relationship between the elements is maintained at the estimation panel size. Table 5.4 presents the OK search neighbourhood parameters used to estimate all grade data. The ratios were estimated for Nd, Pr, Dy, Tb, LREO, HREO and CREO using the same variogram and search parameters as for TREO %.

Table 5.4: Ordinary Kriging sample search parameters

Deposit	Grade	Range 1	Range 2	Range 3		Min Sample	Max Sample	Search Factor 2 & 3
Stack A	TREO	350	320	10	Search Ellipse rotation defined based on variogram DIP DIRECTION, DIP and PLUNGE	15	21	2, 5
Stack B	TREO	450	300	10		15	21	2, 5

Kriging Panel Size 50 x 50 x 3 m; Discretisation to 5 x 5 x 1.5 m; Maximum of 3 samples allowed from each drillhole

5.9 Model Verification

The volume and grade model was validated by visual checks of the block volume against the LiDAR DTM surface, by comparing the average composite grades with the block model grades and using swath plots and visual correlation of drill hole grades with block model grades.

Figure 5.25 to Figure 5.28 present plan and cross-section views with 5X vertical exaggeration showing the grade model, drill hole data and LiDAR DTM.

Figure 5.29 and Figure 5.30 present an example of the validation swath plots comparing model grade with weighted drill hole grade by Northing, Easting and Elevation.

Table 5.5 and Table 5.6 present the statistical comparison of mean sample grades with the mean block model grades for all grades and proportions estimated.

The biggest variance between the block model averages and the input samples is U ppm for stack A with a 14% difference, most likely due to clustering of lower U grades. Most other comparisons are within +/-1%, with a few differences up to +/-3 to 5 %.

The CP concludes that the tonnage and grade estimate for the Bosveld stacks A and B appropriately represents the volume, tonnage and grade of the input data. The spatial distribution appropriately follows the grade trends where adequate drilling data exists. At the central lower portions of stack A, where limited drilling was completed, the grade estimate is extrapolated horizontally between the available drill data. Further drilling is required to improve the confidence in the grade estimates for this zone.

Table 5.5: Comparison of mean grades between model and sampling data – Stack A

Stack A	Num Samples	Sample Mean %	Num Blocks	Model Mean	% Compared to Samples	Num Blocks 1st Search	Model 1st Search Mean	% Compared to Samples
TREO %	333	0.424	3,311	0.422	99.5%	1,460	0.433	102.1%
Nd Prop %		23.3		23.3	99.9%		23.6	101.1%
Pr Prop %		5.7		5.8	101.0%		2.7	100.4%
Dy Prop %		1.0		1.0	100.9%		1.0	101.6%
Tb Prop %		0.4		0.4	99.7%		0.1	99.7%
LREO Prop %		92.1		92.1	99.9%		92.2	100.1%
HREO Prop %		7.9		7.9	101.0%		7.8	99.3%
CREO Prop %		27.7		27.7	100.0%		27.9	100.7%
Th ppm		46.0		49.2	106.8%		48.5	105.3%
U ppm		1.5		1.8	114.3%		1.7	112.8%

Table 5.6: Comparison of mean grades between model and sampling data – Stack B

Stack B	Num Samples	Sample Mean %	Num Blocks	Model Mean	% Compared to Samples	Num Blocks 1st Search	Model 1st Search Mean	% Compared to Samples
TREO %	369	0.464	2,000	0.450	97.0%	1,333	0.462	99.6%
Nd Prop %		23.7		23.6	99.7%		23.7	100.1%
Pr Prop %		5.9		5.8	98.3%		5.7	96.7%
Dy Prop %		1.0		1.0	102.6%		1.0	99.4%
Tb Prop %		0.3		0.3	99.7%		0.3	97.8%
LREO Prop %		92.6		92.6	100.0%		92.7	100.1%
HREO Prop %		7.4		7.4	100.3%		7.3	99.2%
CREO Prop %		27.8		27.8	100.0%		27.8	100.1%
Th ppm		45.2		44.4	98.3%		44.6	98.8%
U ppm		2.0		2.0	98.7%		2.0	100.2%

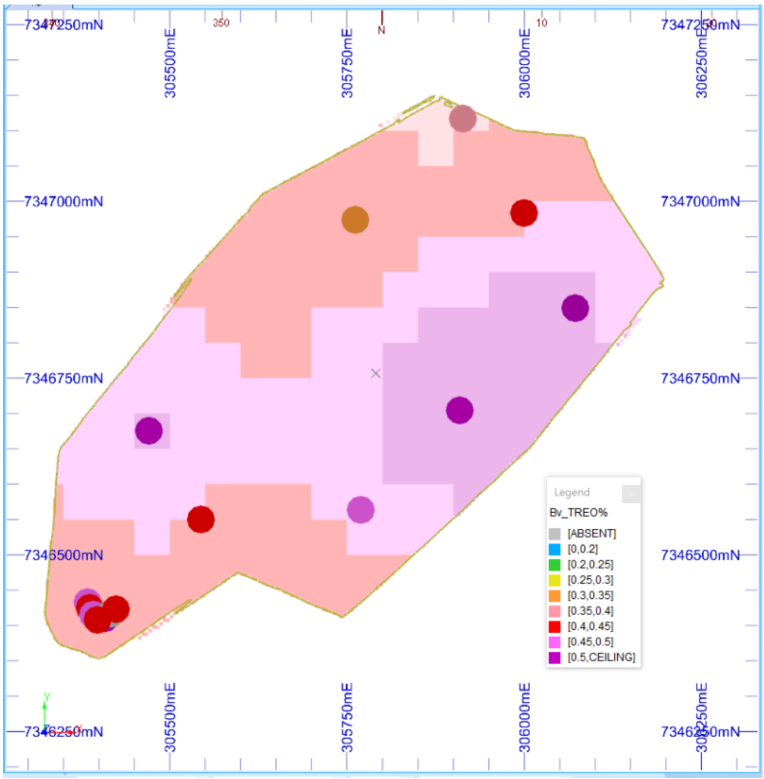


Figure 5.25: Plan section through the Stack A block model - Elevation 397 m

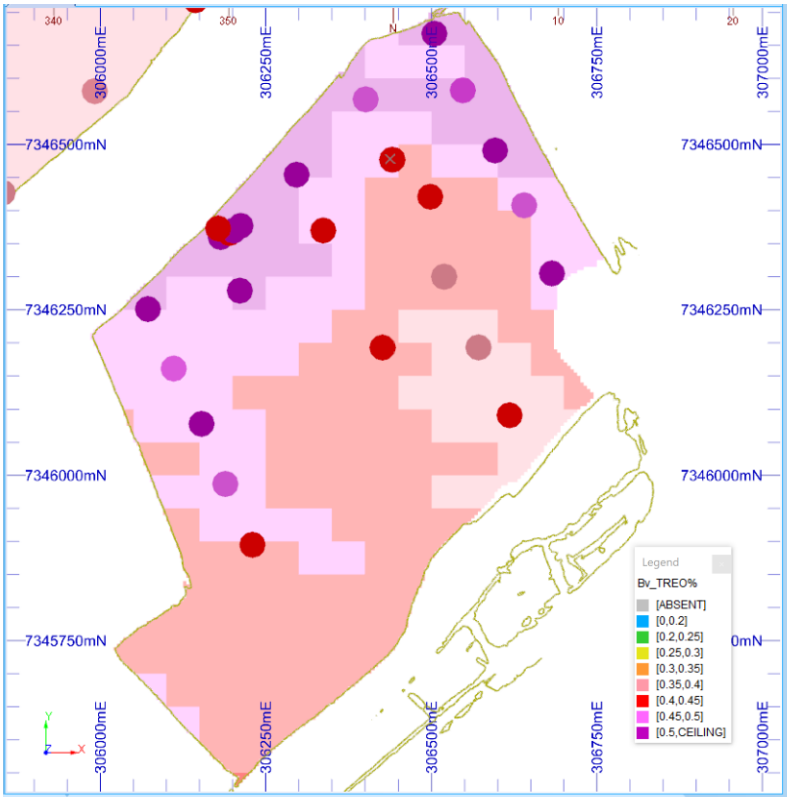


Figure 5.26: Plan section through the Stack B block model - Elevation 382 m

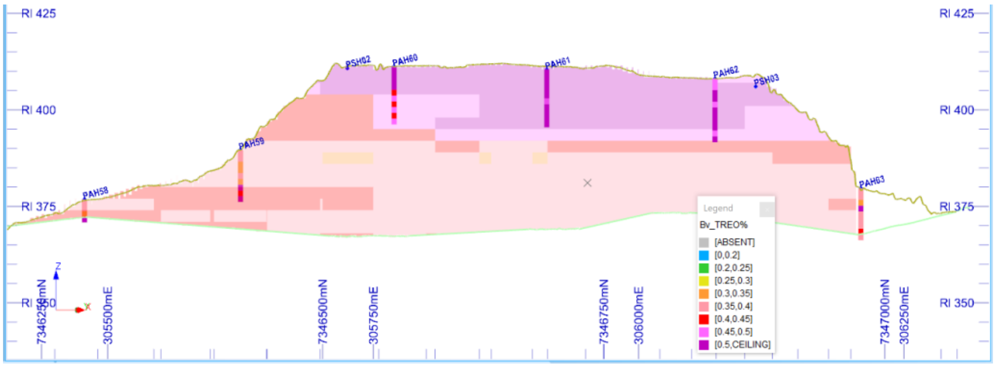


Figure 5.27: Cross section through the Stack A block model 5X vertical exaggeration - Azimuth 316

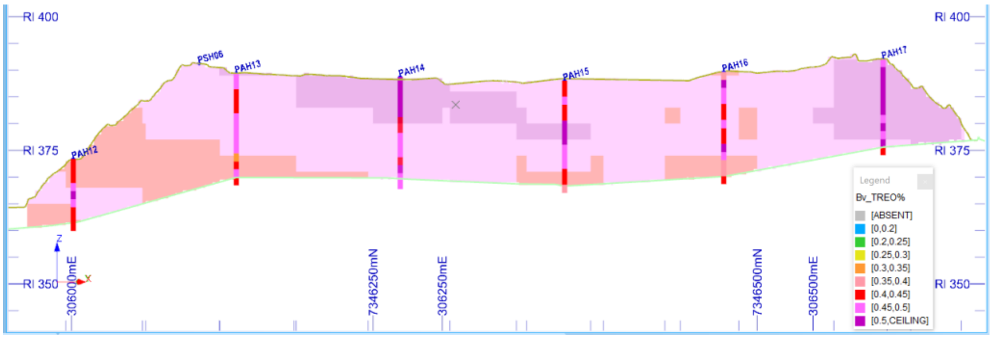


Figure 5.28: Cross section through the Stack B block model 5X vertical exaggeration - Azimuth 316

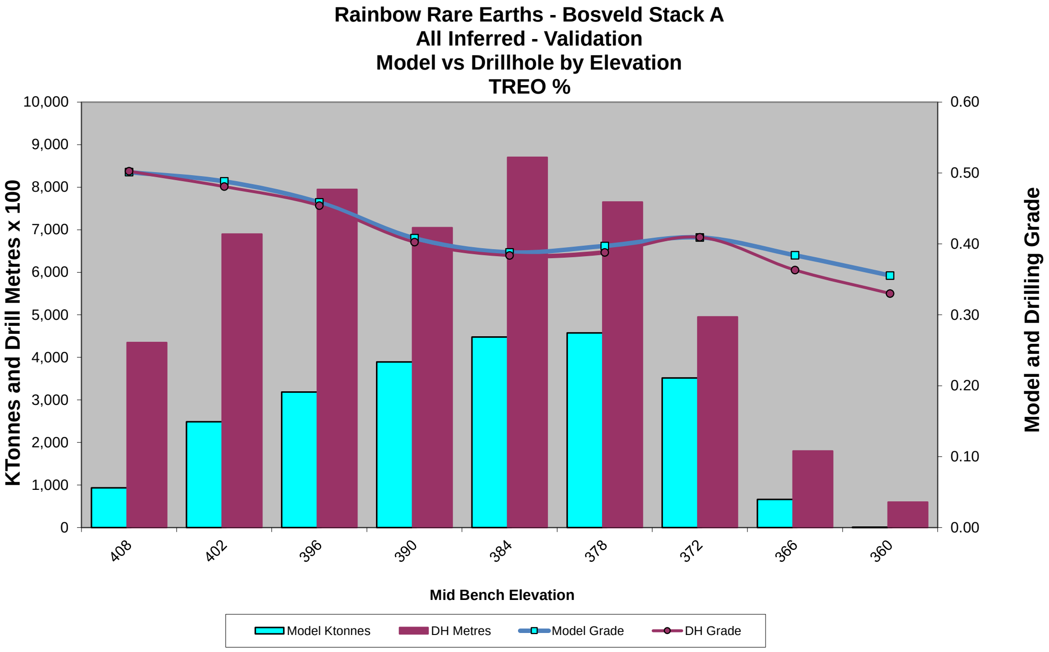


Figure 5.29: Stack A swath plot by elevation

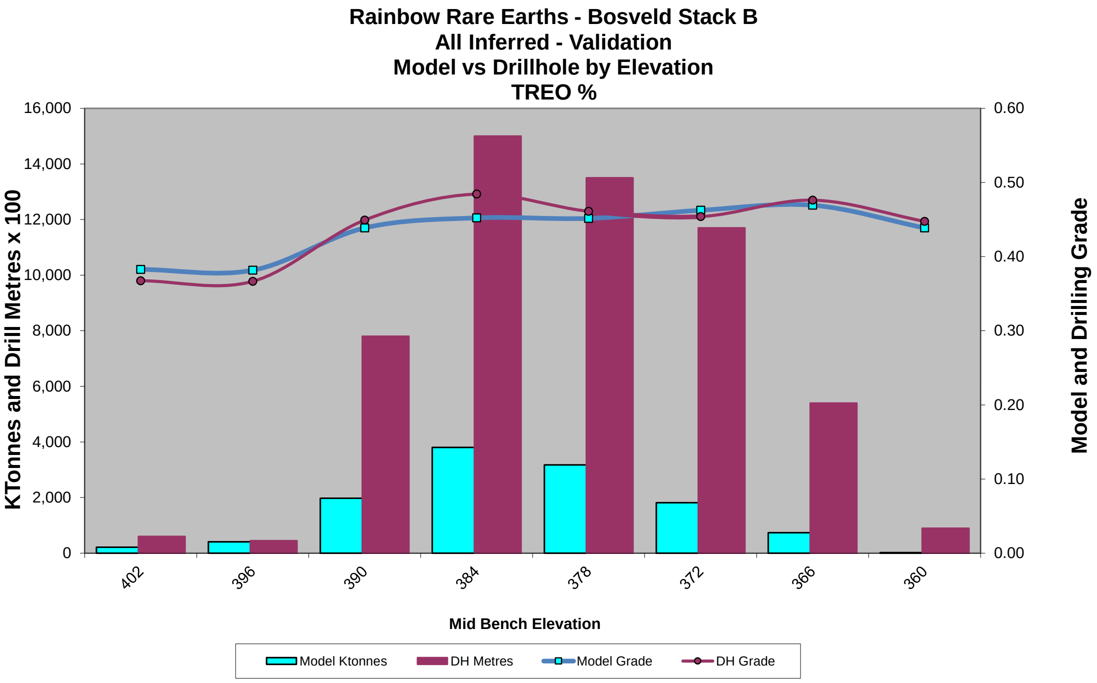


Figure 5.30: Stack B swath plot by elevation

5.10 JORC Classification and MRE Reporting

The mineral resource estimate for the Bosveld phosphogypsum stacks A and B is presented in Table 5.7. The resource is classified based on the guidelines defined in JORC 2012. The resource is classified as an Inferred Mineral Resource for the following reasons:

- Completion of site visit by the CP from 11 to 12 December 2020 for 2 days to review the suitability of the auger drilling program, the overall stack geometry and geology, and the BD surface sampling process.
- Adequate definition of TREO and REE mineralisation continuity derived from the auger drilling and sampling program.
- Appropriate sample assay analysis techniques with QAQC controls to define the tenor of TREO and REE grades.
- Adequate survey control using LiDAR to define the surface topography of both Stack A and B, combined with a reasonable estimate of the pre-stacking topography at the base of the stacks using surface trends from the topography around the edge of the stacks together with results of the drilling that penetrated the basal topography, to define the volume of each Stack.
- Geological mapping used to excise areas where rubbish material was dumped together with the residue, and to excise areas currently being reclaimed for agricultural uses.
- An estimate of the average in-situ dry bulk density of 1.2 t/m^3 is used to estimate the mineral resource tonnage. The CP acknowledges further BD test work is required to improve the BD estimate based on potential variability with stacking depth, surface weathering and water saturation.
- Adequate initial metallurgical test work and financial analysis completed to satisfy the requirement for potential eventual economic extraction (“RPEEE”)

Table 5.7: Mineral Resource Estimate for the Bosveld Phosphogypsum Stacks

JORC 2012 Classification	Stack Name	Tonnes (Mt)	TREO %	NdPr Prop %	Nd Prop %	Pr Prop %	Dy Prop %	Tb Prop %	LREO Prop %	HREO Prop %	CREO Prop %	Th ppm	U ppm	In Situ dry BD
Inferred	Stack A	21.9	0.42	29.0	23.3	5.7	1.0	0.4	92.1	7.9	27.8	49.0	1.8	1.20
	Stack B	8.7	0.46	29.4	23.6	5.7	1.0	0.3	92.6	7.4	27.8	44.1	2.0	1.20
Total Inferred		**30.7**	**0.43**	**29.1**	**23.4**	**5.7**	**1.0**	**0.3**	**92.2**	**7.8**	**27.8**	**47.6**	**1.8**	**1.20**

Reported at 0.2% TREO cut-off grade. No constraining shell required as stacks above ground level. Adequate processing test work completed to satisfy RPEEE

5.11 Competent Person’s Declaration

The information in this report that relates to the Mineral Resources for the Bosveld Project is based on, and fairly represents, information compiled or reviewed by Mr Malcolm Titley, a Competent Person who is a Member of The Australasian Institute of Mining and Metallurgy and the Australian Institute of Geoscientists. Mr Titley is employed by Maja Mining Limited, an independent consulting company. Mr Titley has sufficient experience which is relevant to the style of mineralisation and type of deposit under consideration and to the activity which he is undertaking to qualify as a Competent Person as defined in the 2012 Edition of the ‘Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves’. Mr Titley consents to the inclusion of information from this report in Rainbow public releases using his information in the form and context in which it appears.

6 STACK RECLAMATION

6.1 Introduction

Rainbow Rare Earths (RRE) appointed Paragon Tailings to develop a high-level design and cost estimate for the reclamation of phosphogypsum residue from historically deposited stacks at RRE's Phalaborwa Rare Earth Project. Two stacks (Stack A and Stack B) comprising of phosphogypsum residue from a chemical phosphoric acid production process have been identified as the target of reclamation operations. Paragon will operate as a contractor on site and manage the reclamation process and all associated equipment, personnel, and other services.

Due to the mechanical characteristics of the phosphogypsum, the stacks will be hydraulically reclaimed and pumped to the processing plant as opposed to being mechanically reclaimed by excavation. The phosphogypsum contains a significant quantity of moisture and has been exposed to rain which has caused large quantities of water to accumulate on and permeate through the stacks.

Table 6.1 shows the high-level design basis used for the sizing and costing of the equipment within Paragon's supply. It must be noted that the nominal reclamation rate is marginally higher than the nominal process plant throughput rate. This is because test work results indicate an oversized fraction of approximately 4% of unwanted material that is screened out prior to being hydrometallurgically treated. The nominal reclamation rate must be high enough for this fraction to be screened out, and the screened material to be equal to the design process plant feed rate of 2.2 Mt/a. Water from the hydraulic reclamation process will further dilute the solids content of the feed stream such that it can be pumped as a slurry.

Table 6.1: Reclamation Design Basis

Parameter	Units	Value
Reclamation Rate	Mt/a (dry solids)	2.29
	t/h (dry solids)	291
Oversized Material Screened Out	%	4.0
Process Plant Throughput	Mt/a (dry solids)	2.20
	t/h (dry solids)	279
Stack Phosphogypsum Moisture Content	% w/w	18
Phosphogypsum Feed Stream Moisture Content	% w/w	65 - 75

Hydraulic reclamation is the process whereby stored residue material is hydraulically sluiced using water from the storage facility and transferred in slurry form to a collection sump via a system of drains or launders. This material is then transferred to a pump station, from where it is pumped away to the process plant.

The material is sluiced using high-pressure water monitor cannons. The required water pressure is achieved through the installation of pumps in series, which are then directed to the monitor cannons on top of the residue storage facility through a system of manifolds and interconnecting piping.

The monitoring cannons are used to erode the residue storage facility in sections, washing the material through a launder system to the launder collection sump. This material then flows in slurry form within the launder by gravity or assisted by a series of satellite barge pumps placed within the launder that transfers the slurry to the collection sump. In-dam static screens positioned in the launders at the satellite pumps assist with the removal of unwanted debris and vegetative material.

The launder collection sump collects the slurry and regulates the transfer to the central pump station vibrating screen via a drainpipe at the penstock system or a satellite barge system. This infrastructure is also used to assist with stormwater control.

Once the required slurry level is attained in the sump and screening has prevented unwanted foreign objects from reaching the pump station, the slurry is pumped to the process plant.

Instead of creating airborne dust problems, as is often the case with conventional mechanical reclamation, hydraulic reclamation reduces airborne dust during operation. This is becoming more important as society becomes less tolerant of the environmental impact of reclamation projects.

6.2 Hydraulic Reclamation Methods

Setting up a hydraulic reclamation operation requires the same planning process as any other mechanical loading operation and requires skills, expertise, and experience to obtain the optimum results.

A single monitor cannon can deliver a substantial tonnage (typically between 10,000 – 12,000 tonnes per day, indicating the effectiveness of hydraulic reclamation. The reclaimed resource's characteristics will determine the pressure required to monitor the material. Typical tailings deposits are readily monitored between 25 and 30 bar, whilst loose sands only need about 20 bar, but much higher volumes to maintain them in suspension. Suitably sized high-pressure pumps and high-pressure pipelines are used. The shape and form of the resource dictate how the deposit is reclaimed. Criteria considered include the slope of the ground to maximise gravity transport, safe slope angles and height, and minimum pipe and monitor cannon moves for maximum production. Stormwater control also needs to be addressed.

If the gravitation of the slurry to the slurry pump station is not possible, satellite pumps are included in the system to transfer the slurry to the pump station. Satellite systems are ideal for clean-up operations if the slope of the ground doesn’t favour gravity feed.

6.3 High-Pressure Pumps

Different high-pressure pump-station configurations are used depending on the pressure and volumes required. Centrifugal pumps can handle high flows but are generally limited to generating less than 10 bar per stage, so multistage pumping systems are mostly required. Single multistage pumps can be used for smaller volumes but are also more complicated, temperamental, and difficult to maintain.

6.4 Monitor Cannons and Monitoring

The basic monitor cannon comprises a vertical and a horizontal swivel, a balancing loop, a barrel, and a nozzle. These cannons are mounted onto various chassis on four-wheelers or, most recently, track-mounted units operating via remote control. Although the balancing loop neutralises the forces at the nozzle, the pressure in the feed pipe, particularly above 30 bar, can cause the whole monitor cannon and chassis to move. Stabilising anchors are advisable in these instances for safety. The monitor barrel also needs to be anchored in a harmless position, usually pointing upwards, during start-up. Monitor cannons can be controlled manually or by hydraulics directly or remotely.

The water jet primarily breaks up the material's structure mechanically through the jet stream's contained energy. This energy is more effective when the jet stream is intact. Dependent upon the hydraulic characteristics of the nozzle, energy losses will occur, and these losses are increased with turbulence. Stream formers of various designs can be included in the barrel to reduce turbulence.

There are principally two methods of operation, “bottom-up” and “top-down”:

- In the case of the “bottom-up” method, the monitor cannon is placed at the base of the material face, with the barrel pointed upwards into the face, thereby undermining the slope by focusing the jet stream near its base. This causes the slope to collapse through shear failure. The energy of the collapse causes much of the material to break up, leaving a pile that can be readily slurried. High faces can be reclaimed with greater production per cannon position. Working below slopes has inherent dangers; however, skills and techniques can be applied to reduce the risks for manually operated monitor cannons. A further drawback is that conditions underfoot are always wet and challenging. This technique is not advisable if reclaiming a saturated facility.

- The second method is the “top-down” method. In this instance, the monitor cannon is positioned on top of the resource, with the jet stream aimed down into the material. The total effect of the stream from just beyond the nozzle is used to cut the material to a pre-described angle. The height of the face being reclaimed is defined either by the footwall or a pre-installed drainage point. Consequently, the reclamation plan can be precisely defined, allowing greater control and management of production. The face angle is specified to provide safe conditions for the operators and equipment at the top of the slope. All this is also in the dry.

The “top-down” method is the preferred methodology for most operations, whereby the liquefied material is transported from one terrace to another through screened decant pipes. The material gravitates through a 30 mm aperture in-dam screen into the penstock outlet pipe, or if satellite stations are required to pump the material, it is picked up and pumped to the slurry transfer station.

One of the keys to effective hydraulic reclamation is achieving consistent slurry densities. In virtually all cases, the slurried material needs to be kept “contained”, typically achieved through adopting an effective reclamation plan. Solid material needs to be concentrated in a “pool” where the water jet can pulverise the material against the pool's boundaries. The slurry stream can be kept against the toe of the reclamation face if the plan is appropriately developed. This ensures a concentrated stream flow inhibiting meandering, velocity losses and settlement of solids.

Slurried material or granular materials tend to flow at a natural beach angle that is generally self-correcting. Flow velocities increase if the slope gets too steep, causing erosion until the equilibrium slope is attained. If the slope is too flat, the solids settle out, reducing the height of the reclamation face until the equilibrium slope is achieved. Coarse materials, (i.e., sands and materials with high specific gravity), settle out rapidly and hence beach at steeper angles. In these instances, it is preferable to collect the slurry into a sump with a pump as close to the reclamation face as possible.

When using the top-down method, the resource is typically reclaimed in benches of safe heights. The safe height is dependent upon the material strength, which is influenced by the phreatic surface. Provided the phreatic surface is sufficiently below the surface to support the monitor cannon and pipework, it is possible to reclaim into the saturated zone below the phreatic surface. Reclaiming below the phreatic surface and creating a free face reduces the effective stress as the overburden load is removed whilst the pore pressure remains the same. Analysis indicates that it is possible to mine to a depth below the phreatic surface before liquefaction occurs.

Experience shows that there is a time delay in liquefaction failures, which is believed to be related to the readjustment of stresses. Therefore, it is possible to reclaim deeper, provided one is retreating the monitor cannon away from the face since the failures only occur sometime (hours to days) after the creation of the slope.

Experience also shows that by the time the next cut of the same face occurs, the phreatic surface will have dropped, making the conditions more manageable and safer. This is particularly so if multiple benches are reclaimed, with the lowest bench effectively acting as a sump, drawing down the phreatic surface. This lowest bench can be limited in extent for safety reasons, with most reclamation activity occurring on the upper “drained” benches. In this manner, an initially saturated deposit can be entirely reclaimed by progressively creating a drainage sump ahead of the reclamation production areas.

Figure 6.1 depicts a terrace operation, a decent face height monitored at a safe angle, with the slurry flow at the toe of each face allowing for seepage to consolidate each bench.

Figure 6.1: A terrace operation

6.5 Reclamation Methodology

The main input parameters for this reclamation design are based on delivering a design material flow of 312 t/h to the processing plant at an average solids' concentration of 25 to 35 %w/w and with a single monitor cannon being able to produce 7,000 tonnes/day. The number of monitor cannons required will be 2 x operating 24/7 with two complete standby units connected to ensure flexibility and continuity of supply to the process plant.

The proposed methodology for the reclamation of the RRE Bosveld resource is to hydraulically reclaim both stacks – starting with Stack B and then moving over to Stack A once B has been depleted. The top-down method in 8 to 10 m benches will be used on both stacks. This is determined by the material's behaviour and considering the high moisture content on the facilities.

Large amounts of water are currently stored on both residue storage facilities. This water will need to be decanted from the facilities to allow the material to consolidate before reclamation. The material at the face will be reclaimed using a 150 mm track-mounted remote-controlled monitor cannon. The hydraulic reclamation will be done using the top-down method at approximately 20 to 25 degree face angles with a minimum of 25 bar water pressure. Each slice of the material will be taken at a depth of 8 to 10 m and a width of 15 to 18 m.

A satellite barge will be positioned in the south-western corner of Stack B, which will pump the reclaimed material to the Main Pump Station located at the toe of the two stacks. This position will facilitate the successful reclamation of both stacks due to the natural fall of ground sloping towards this area, maximising gravity transport and preventing material from being left on the floor. Another advantage is that both stacks can be reclaimed without the need to relocate the Main Pump Station once Stack B has been depleted. This Main Pump Station layout is shown in our Main Pump Station GA&L drawing (Figure 6.6).

A monitor cannon will focus on creating a slurry transport trench in a north-easterly direction at a face height of 8 m, creating a safe and sufficient gulley to allow slurry to flow by means of gravity from the toe of the face to the satellite barge unit. As the operation moves further away from this lowest area, the material will gravitate in the created transport trench to the slurry satellite barge unit.

The outer walls will be left intact, which will allow containment of all slurry and rainwater inside the formed compartment, thus reducing the risk of environmental spills.

6.5.1 Phase 1

- The reclamation operation will be a 24/7/365 operation.
- A satellite barge fitted with a vertical spindle pump (VSP) will be positioned approximately 30 m inward in Stack B to allow crane access for maintenance and inspections. In front of the VSP, a static in-dam grizzly screen (30 mm aperture) will be installed to prevent large sticks, reeds, rocks etc. from entering the VSP pump. This will be installed at a depth of approximately 8 to 10 m (depending on the face height and the moisture content of the TSF). This will be in preparation to start removing the first layer of material (Figure 35).
- The satellite barge pump will be positioned in an area with sufficient catchment to contain any slimes and rain/stormwater reporting to the satellite in case of any emergency stoppage, power outage or storm event.

Figure 6.2: Typical Satellite Barge Installation

- A box cut will be created in front of the barge for rain purposes, power failures and any unforeseen emergency stoppages. The reclaimed material and rain/stormwater will be contained within the facility and not at the pump station, thus avoiding any environmental spills.

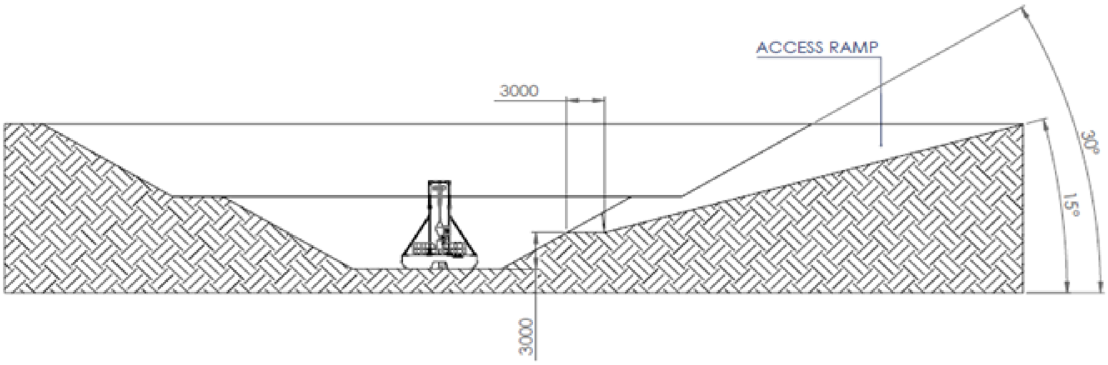


Figure 6.3: Initial Catchment Area of The Box Cut Where The Satellite Barges Will Be Installed

- A gulley (Figure 37) will then be created in a north-easterly direction of the barge for transporting the slimes by gravity flow to the inlet of the VSP suction, from where the slimes will be pumped to the main pump station for further screening. The width of the gulley (toe to toe) should not exceed 7 to 10 m to keep the flow of the material channelled to prevent it from meandering. Due to the high % fines in the material, the challenge is for the slurry to report to the barge on the shortest route, not allowing the slimes to meander all over the basin.

Figure 6.4: A Slimes Transport Gully Being Created Within a Residue Storage Facility

- 2 x Monitor cannons will be positioned on the eastern side of the sluiced gulley, and the other two monitor cannons will be placed on the western side of the gulley. 2 x monitor cannons will be the production cannons, and the other two will be the standby monitor units which will, provide operational flexibility.
- The reclamation plan will focus on exposing the basin of the facility by removing the top layer in a herringbone formation to the same elevation as the suction of the VSP, creating a void on the inside of the facility. All outer walls will remain intact to avoid any environmental spills.
- Figure 38 illustrates the herringbone formation used to expose the basin of the facility.

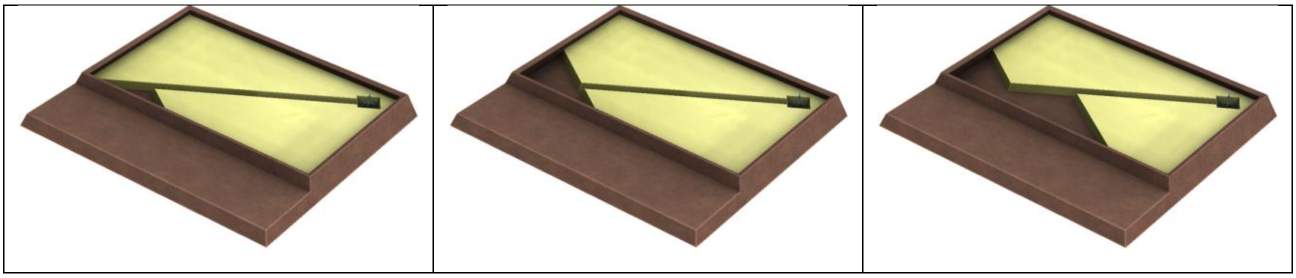


Figure 6.5: The Herringbone Formation Used to Expose The Basin Of The Facility

- The division wall will be left in place to access the barge for maintenance and operational purposes.
- Once the slimes reach the suction of the VSP, it will be pumped to the main pump station's vibrating screen, which will screen the material through a 2 mm aperture before being pumped to the process plant.

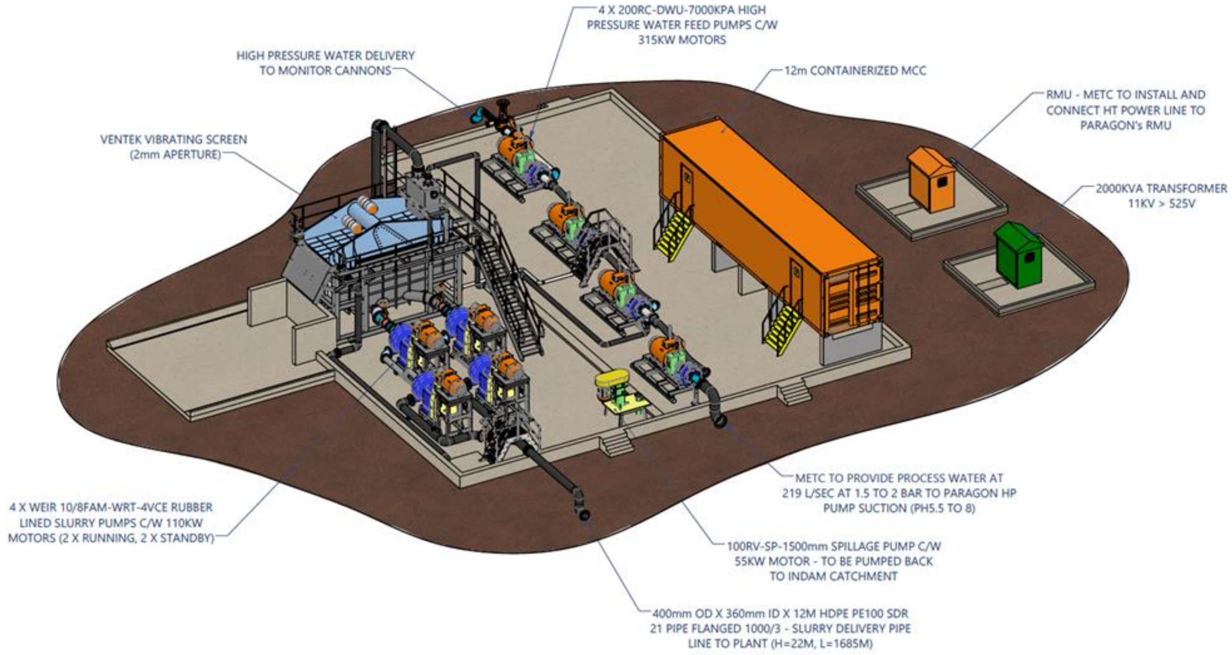


Figure 6.6: The Pump Station Layout

6.5.2 Phase 2

- Preparations to create the second terrace will begin while Phase 1 is in operation. A sump will be excavated another 8 to 10 m deep in the same location as Phase 1 to ensure the satellite barge remains at the lowest point of the compartment to proceed with a box cut for the second cut.
- A box cut will be created in front of the satellite barge (as per Phase 1).
- A gulley will then be created from the barge, again in a north-easterly direction, for slimes to gravitate to the inlet of the VSP suction. The purpose of the installed barge pump is to pump the slimes in a controlled manner. This is done to eliminate having a free exit of slimes from the facility, which can be catastrophic to any hydraulic reclamation operation.
- The reclamation plan will focus on exposing the basin by removing the material in layers, to as close as possible to NGL, and creating a void inside the facility. The previous cuts' outer wall will remain intact to avoid any environmental spills, i.e., only once the second cut has been removed will the first cut's wall be removed, thereby facilitating full containment by always maintaining a wall.
- The same herringbone method will then be carried out as per Phase 1; the only difference is that the gulley will now be a further 8 to 10 m deep. This same procedure will be followed until the entire footprint has been reclaimed and used for stack A's reclamation.
- Once the slimes reach the suction of the VSP, it will be pumped to the main pump station vibrating screen, which will screen the material at a 2 mm aperture before being pumped to the process plant.

6.5.3 Floor Clean-up

- Floor clean-up keeps close to the toe of the operation will be continuously achieved to reduce costs at the end of the project when commencing rehabilitation.
- The floor clean-up operation will be a dayshift operation to avoid low densities throughout the 24-hour production shift and operate in daylight hours when there is sufficient supervision on site.

- A dozer will be used to doze windrows, and then the monitor unit will clean to natural ground level allowing for the flow to be channelled in a launder directly to the satellite station to avoid meandering.
- The floor which has been cleaned will be paddocked, thus eliminating rainwater reporting into the reclamation works.

6.5.4 Stormwater Management

- All stormwater will be contained within the facility, avoiding any environmental spills. As seen from the above-mentioned hydraulic reclamation process, a void will be created in the facility, resulting in increased capacity for stormwater containment.
- Stormwater will be additionally managed by constructing paddocks (Figure 40) in the surface areas outside the reclamation operation to store rainwater in compartments and release it in a controlled manner through UPVC drainpipes. These paddock walls can be constructed using residue material. The height and width of such a wall is indicated in Figure 6.7.

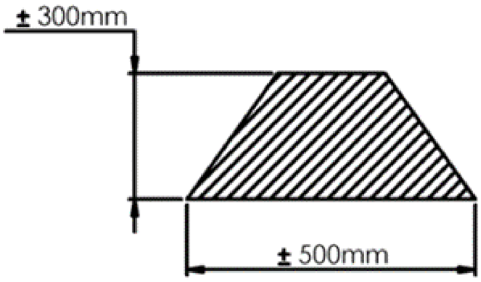


Figure 6.7: Typical Height and Width of Paddock Wall

These paddocks will store most of the rainwater within their individual compartments. The water will be released in a controlled manner to the satellite barge unit for pumping to the process plant.

- There are two approaches to dealing with the rainwater inside the paddocks, decanting it through the decant pipes or evaporation by containment of the water inside the paddocks.
- The main advantages of the paddocking option are that it will allow for the controlled release of water through the decant pipes and will assist in controlling dust on large sections of the dam due to the paddocks being covered in water from time to time.
- It is anticipated that maintenance required on the walls during the rainy season will be done manually due to wet ground conditions that will prevent the use of an excavator.

Figure 6.8: A Paddocked Facility, Illustrating How the First Cut's Outer Walls Are Left Intact to Contain Rain/Stormwater Inside The Facility

- The system will be designed to remove stormwater off the facility as quickly as possible to minimise downtime from pumping rainwater and allow the reclamation operation to start as soon as possible.
- The satellite barge pump and main pump station will be designed to pump a volume of 20,640 m^3/day, which will minimise downtime after a rain/storm event to allow the operation to get back online much sooner.
- This excess water will be pumped via the reclamation pumping infrastructure to the process plant or a designated storage pond.

6.6 Personnel Requirements

Table 12 illustrates the recommended staff complement required for the safe and successful reclamation operation. The execution of the operation then requires the necessary skills, expertise, and experience to ensure the tonnage is delivered to the plant. Careful planning and 24-hour supervision also play a significant role in achieving operational success.

Table 6.2: Reclamation Personnel Requirements

Reclamation Operation	
Production Manager	**1**
Site Manager	**1**
Fitter artisan	**1**
Team Leader	**4**

Reclamation Operation	
Pump Station Operator	**4**
Barge/Indam Operator	4
Monitor Gun Operator	8
Screens	4
Pipe Crew	12
Reliever	4
Site Clerk	1
Total Compliment	**44**

7 PROCESS DEVELOPMENT AND TEST WORK

7.1 Historical Test Work

The extraction and recovery of REEs at Phalaborwa has been investigated since the early 1980's by Fedmis, Mintek and later, briefly, by Bosveld Phosphates.

The phosphogypsum stacks at Phalaborwa are a by-product from the phosphoric acid process, where locally mined apatite rock, containing rare earth minerals, is digested in concentrated sulfuric acid to yield phosphoric acid and calcium sulfate dihydrate (phosphogypsum). The resultant slurry is filtered, and the phosphoric acid is further processed to increase the acid strength to commercial quality.

During the primary sulfuric acid digestion (primary attack) process, the rare earths are solubilized and roughly 85% precipitate and report to the phosphogypsum. The balance is contained in the phosphoric acid and then reported to the small volume evaporator sludges.

Mintek briefly considered processing the phosphogypsum for rare earth recovery but shifted focus to the higher-grade calcium sulfate hemihydrate sludges that formed in the evaporator units during the phosphoric acid upgrade process. These sludges contained anywhere from 4% to 7%, by mass, total rare earth oxides (TREO). Standard practice was to return these sludges to the primary attack stage to be separated with the phosphogypsum and transferred to the gypsum storage stacks.

Various laboratory studies were completed that considered a range of variables, including types of lixiviants, temperatures during leaching, leach contact time and dilution, to manage the rare earth solubility constraints in weak acid solutions. Mintek found that the current arisings of phosphogypsum did not yield acceptable rare earth extraction, considering the range of leach lixiviants tested. This caused them to focus on the high-grade sludges produced in the process.

The bench scale program culminated in a pilot plant trial, located on-site at the Fedmis plant that processed high-grade sludge from the phosphoric acid plant lamella filters and produced approximately 3 tonnes of mixed rare earth oxalate that was calcined in a rotary kiln to yield 1,600 kg of mixed oxide of 89-94% purity.

Mintek favoured the use of a nitric acid lixiviant for the high-grade sludge. The key reason relates to the opportunity to directly feed the resultant leach liquor to a tributyl phosphate (TBP) solvent extraction plant for impurity rejection and rare earth recovery. The leach rate was slow at 72 hours total leach time, but since the total annual sludge production was only 10,000 tonnes it was deemed feasible.

The pilot plant consisted of the following main sections:

- Sludge filtration and re-slurry employing raffinate from the solvent extraction plant.
- Nitric acid leach and post leach filtration.
- Cerium rejection.
- Solvent extraction.
- Mixed rare earth precipitation and calcination.

The pilot plant was supported by various study phases, including mini laboratory plants that produced several kilograms of magnet-grade neodymium oxide product.

Mintek achieved recoveries up to 85% of TREO from the feed sludge and successfully produced high-grade products. It was realised at the time that various processing opportunities exist, for example, cerium rejection and alternative precipitation techniques.

In 2013 Bosveld Gypsum briefly investigated the use of hydrochloric acid as an alternative lixiviant and concluded that it yielded acceptable results and can be employed for leaching the sludge material.

The key learnings from a detailed review of the historical work can be summarised as follows:

- No meaningful work was concluded on the phosphogypsum component except some bench scale tests.
- Various lixiviants can be employed but at varying degrees of extraction and economic considerations, with each lixiviant showing differing economics.
- Nitric acid coupled to TBP solvent extraction can successfully reject impurities and produce a high purity product for further processing at acceptable overall rare earth extraction from the evaporator sludge. This sludge is a small volume product from the phosphoric acid upgrade section of the processing facility.
- It was postulated that not all the rare earths were solubilised in the primary attack stage due to its presence in the host rock as rare earth phosphates that require more intense processing to render it soluble as a sulfate.
- Temperature does not improve overall extraction during leaching.
- Nitric acid with calcium nitrate was preferred since it couples well with direct TBP solvent extraction. Additionally, it was theorised that the excess calcium in the lixiviant would displace rare earths in the gypsum lattice, increasing extraction.
- Most of the rare earths were present in the phosphogypsum as discrete fluorides and phosphates.

7.2 Process Development and Test Work

RRE acquired access to the phosphogypsum stacks located on the Bosveld Phosphates owned property near Phalaborwa in December 2020/January 2021 and initiated a detailed review of all historical work, as discussed above. The key objective of the review was to develop a test work program that can support a technically and economically feasible flow sheet for rare earths extraction from the phosphogypsum stacks.

A drill program (Figure 7.1) to delineate the ore body yielded 707 spatially distributed samples of the two stacks located at Phalaborwa that constitute the target of the current project.

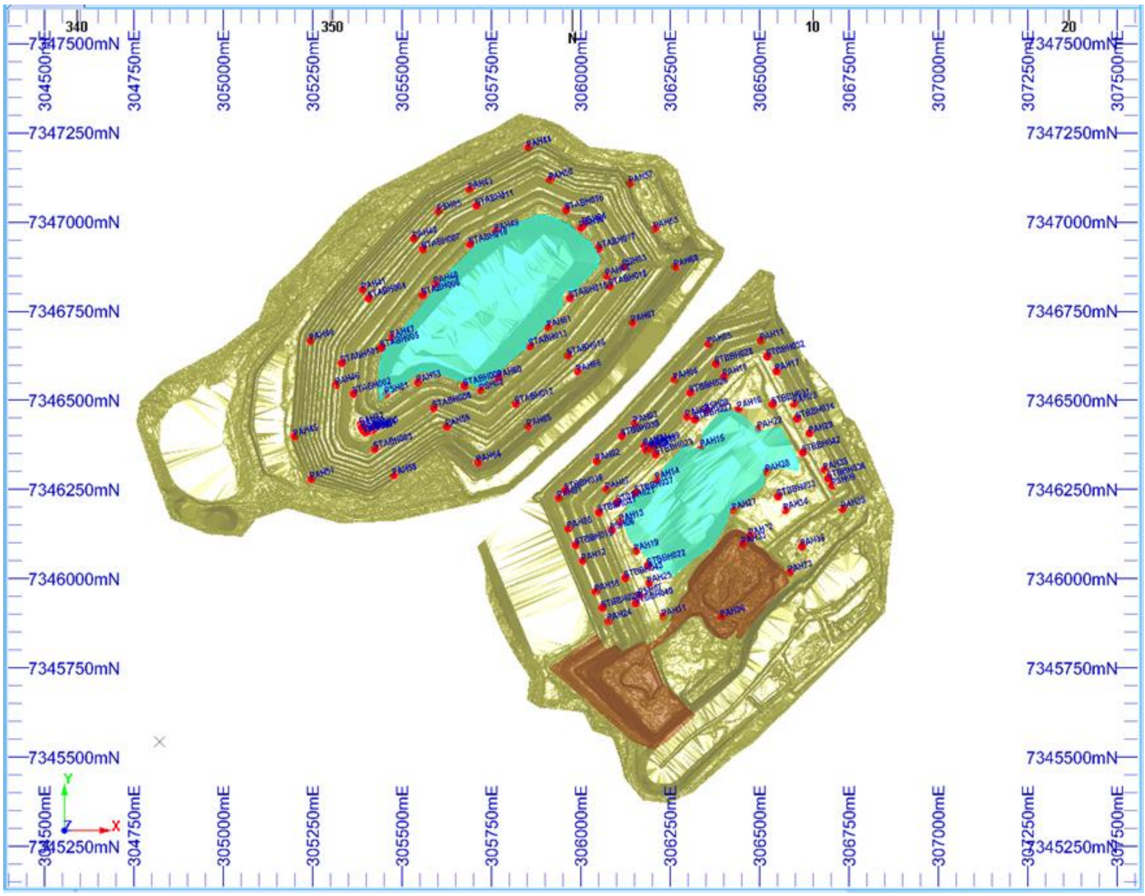


Figure 7.1: Initial Drill Pattern of Phalaborwa Stacks

7.3 Phase 1 Test Work Program - ANSTO

40 spatially distributed samples of 2.5 kg each were selected at SGS South Africa (SGS), Johannesburg, and shipped to ANSTO Minerals (ANSTO), Sydney, Australia, for the first phase of testing to establish an economical processing route.

This initial phase of work focused on material characterisation and leach behaviour when subjected to various lixiviants and processing conditions. These initial findings were then translated into a design basis for a conceptual flowsheet and further test work programs.

Ten samples were selected to prepare a composite sample representative of the whole resource (Table 7.1). The 2 kg samples were blended and contained 1.6 % w/w moisture and therefore, the 1 kg portion removed for head analysis and sizing was dried at 55°C.

Table 7.1: Samples selected for phosphogypsum composite

Sample #	Sample ID	Hole ID	Stack ID	Blend Mass (kg)
1	70403	PAH46	A	2
2	70624	PAH50	A	2
3	70633	PAH50	A	2
4	70341	PAH56	A	2
5	70653	PAH59	A	2
6	70388	PAH63	A	2
7	70286	PAH07	B	2
8	70066	PAH10	B	2

Sample #	Sample ID	Hole ID	Stack ID	Blend Mass (kg)
9	70265	PAH19	B	2
10	70206	PAH34	B	2

7.3.1 Sample Characterisation

7.3.1.1 Head Assay

The pulverised master composite sample was analysed by XRF, Digest/ICP-MS/ISE and DNA for uranium. The elemental composition is presented in Table 7.2.

Table 7.2: Elemental Composition of Phosphogypsum Composite

Element	Unit	PHOSPHOGYPSUM	Element	Unit	PHOSPHOGYPSUM
La_2O_3	ppm	737	Al	% w/w	0.15
CeO_2	ppm	2,014	Ba	% w/w	0.03
Pr_6O_{11}	ppm	267	Ca	% w/w	23.1
Nd_2O_3	ppm	1,085	F	% w/w	0.6
Sm_2O_3	ppm	201	Fe	% w/w	0.05
Eu_2O_3	ppm	39	K	% w/w	0.02
Gd_2O_3	ppm	128	Mg	% w/w	0.03
Tb_4O_7	ppm	12	Mn	% w/w	<0.001
Dy_2O_3	ppm	41	Na	% w/w	0
Ho_2O_3	ppm	5	P	% w/w	0
Er_2O_3	ppm	8	S	% w/w	18
Tm_2O_3	ppm	3	Sc	ppm	<2.2
Lu_2O_3	ppm	3	Th	ppm	48
Y_2O_3	ppm	119	U	ppm	1.7
Yb_2O_3	ppm	3	Si	% w/w	0
LREO	ppm	4,102	Zn	% w/w	0.002
MREO	ppm	368			
HREO	ppm	73			
TREO (incl. Y)	**ppm**	**4,662**			

All the elemental analyses are depicted in the converted oxide format.

A method for providing confidence in the accuracy of the analysis of samples containing rare earths is to produce a Chondrite plot. Normalisation against the Chondrite meteorite concentrations removes the normal 'saw tooth' distribution obtained from the % w/w concentration profile and readily highlights differences in the relative concentrations of individual REEs in a given mineral phase or sample. The Chondrite plots should produce a smooth plot across the REE series if the sample being examined has not experienced preferential removal of one element versus another.

The normalised values for the composite PG sample have been plotted versus atomic number in Figure 7.2. The plot shows a relatively smooth transition in normalised concentration from element to element, down to detection limits for all samples, which provides confidence in the accuracy of the analytical method and results.

The europium anomaly (63) is normal and is indicative of weathering through the geological history of deposits (and is seen in clays and monazite, xenotime or bastnaesite deposits). Positive and negative anomalies for cerium and europium are also expected in nature due to their variable oxidation states.

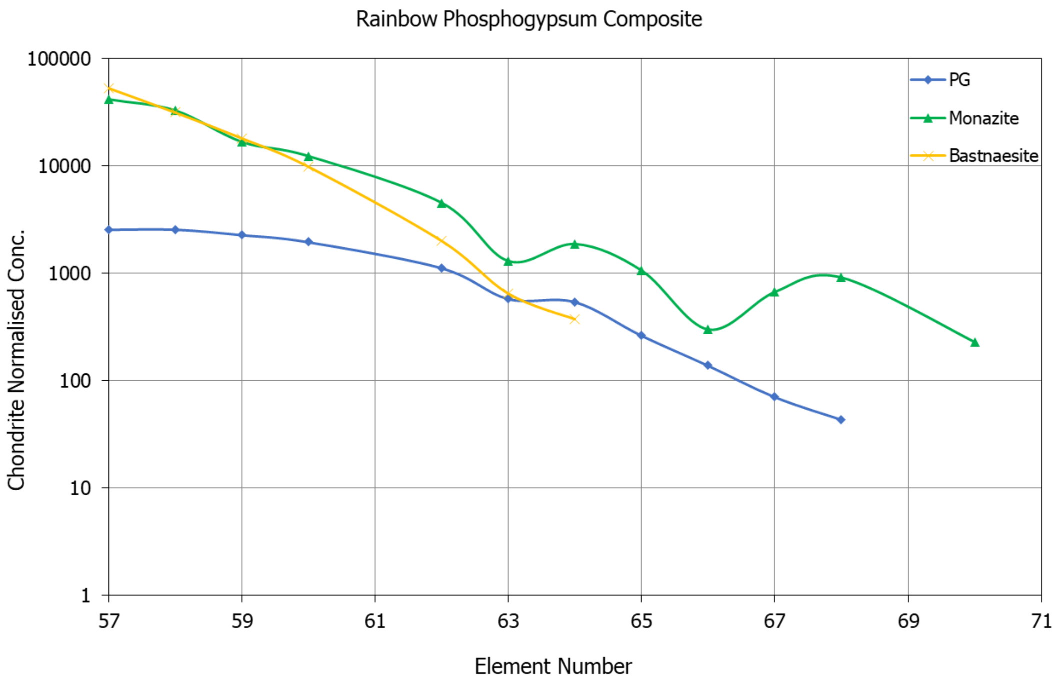


Figure 7.2: Normalised Chondrite Plot

Examples of monazite and bastnaesite deposits are also presented in Figure 7.2 for comparison. The phosphogypsum (PG) appears somewhat enriched in Pr and Nd compared to monazite due to the shape of the normalised curve in the region of element 59 (praseodymium) and 60 (neodymium) in relation to lanthanum (element 57) and cerium (element 58).

This indicates a higher basket price with reduced low-value lanthanum and cerium present in the resource.

7.3.1.2 Radionuclide Analysis

The PG composite was analysed for radionuclides by gamma spectrometry, and the results are presented in Table 7.3. The levels of radioactivity in the sample were all low.

Table 7.3: Radionuclide Analysis

ANSTO ID	RRE Phosphogypsum		
U-238 Decay Chain	**Bq/g**		**Bq/g**
U-238 (a)	0.021	±	0.002
Th-230 (b)		< 0.18	
Ra-226 (b)	0.087	±	0.009
Pb-210 (b)	0.12	±	0.01
Po-210 (c)		not requested	
U-235 Decay Chain	**Bq/g**		**Bq/g**
U-235 (d)	0.001	±	0.0001
Pa-231 (b)	< 0.036		
Ac-227 (b)	< 0.0067		
Th-232 Decay Chain	**Bq/g**		**Bq/g**
Th-232 (e)	0.19	±	0.02

ANSTO ID	RRE Phosphogypsum		
Ra-228 (b)	0.21	±	0.02
Th-228 (b)	0.22	±	0.02
K-40 (b)		< 0.048	
Total Contained Activity (f)		**3.1**	
U (ppm) (a)	1.7	±	0.2
Th (ppm) (e)	48	±	5

The uranium content is only 1.7 ppm (0.021 Bq/g), but its Ra-226 and Pb-210 progeny are present at higher activity (~ 0.1 Bq/g). Thus, the U-238 chain is not in secular equilibrium. This indicates that some uranium was dissolved from the fluor-apatite in the process of phosphoric acid production, but the Ra-226 and Pb-210 mainly reported to the PG.

The PG contains 48 ppm Th-232 (0.19 Bq/g), and its two long-lived progeny (Ra-228 and Th-228) are also present and in secular equilibrium with the Th-232. The Th-232 is probably present in a monazite phase, which was detected by QEMSCAN (see paragraph 7.3.1.4 below).

Actinium-227 will follow the rare earths in downstream processing of the PG and it is present at low concentration (<0.0067 Bq/g) in the PG. Since historical pilot plant operations produced around 3 tonnes of rare earth oxides that were sold in the open market, no issues are expected from product radioactivity.

The International Atomic Energy Agency (IAEA) guidelines for exemption from regulation pertaining to radioactivity is that all radionuclides should be less than 1 Bq/g, so from this perspective, the PG would not be subject to the requirements of any regulations.

7.3.1.3 Sizing Analysis

The particle size distribution of the P_{100} 800 µm PG composite was determined by laser sizing in ethanol (Figure 7.3). The P_{80} was determined to be 117 µm. The composite sample was mixed with ethanol to reduce particle interference and a laser sizing Malvern instrument was used to determine the particle size distribution.

It must be noted that the composite sample was screened at 800 µm with the oversize ground to pass the screen aperture and recombined with the undersize material. This was done to simulate material preparation in the industrial facility, where all PGs will be pre-screened before leaching.

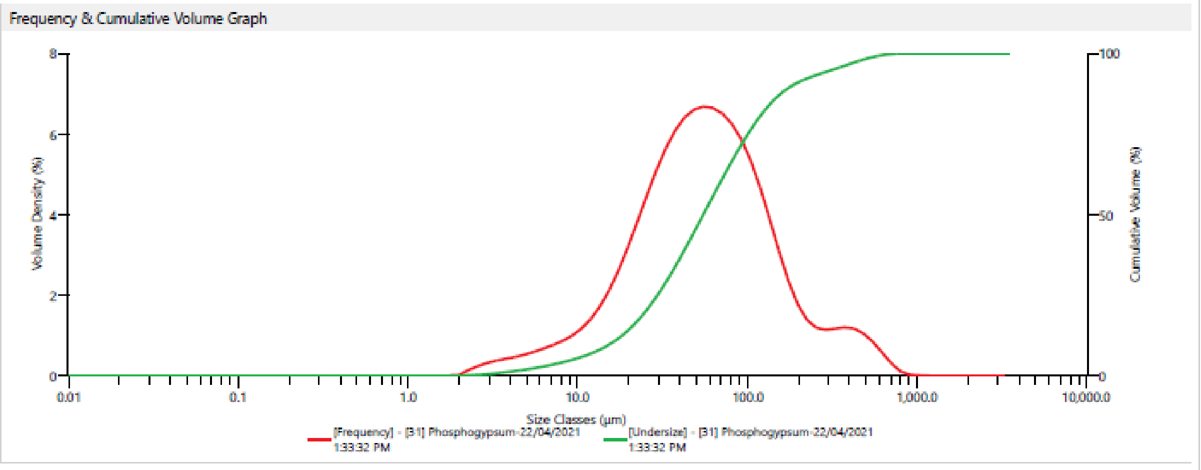


Figure 7.3: Laser Sizing of PG Composite

7.3.1.4 Mineralogy

The master composite sample (P_{100} 800 µm) was analysed by QEMSCAN (automated SEM) to determine the abundances and associations of the minerals within the sample and their degree of liberation. The sample was also analysed by manual SEM to assess the composition and location of the rare earth elements (REE) (by EDS), the textural and mineralogical associations, and liberation characteristics.

The QEMSCAN modal mineralogy (Table 7.4) results indicate that the composite sample is predominantly comprised of calcium sulfate (96 % w/w), with 3 % w/w of a calcium, aluminium, rare earth element (REE) fluoride rich mineral (shortened to Ca,F phase). Monazite-Ce (0.06 % w/w) and bastnaesite (0.001 % w/w) were present as trace components, with an additional 0.04 % w/w as unclassified “REE Minerals”. Silicates and Fe-oxides/hydroxides were present as trace species only.

Table 7.4: QEMSCAN modal mineralogy

Mineral	Chemical Formulae	% w/w
Bastnaesite	$(Ce,La,Nd)(CO_3)F$	0.001
Monazite-Ce	$(Ce,La,Nd,Th)PO_4$	0.06
REE Minerals	REE, Y, CO_3, PO_4, O	0.04
Ca,F Phase	$Ca,(Ce,La,Nd),Al,S,O,F\bullet X(H_2O)$	3.0
Quartz	SiO_2	0.12
Fe-Oxide/Hydroxide	FexOy/FeO(OH)	0.01
Clay & Mica Minerals	Various	0.03
Ca-Sulfate/Gypsum	$CaSO_4\bullet XH_2O$	95.9
Others	Various	0.03
Unclassified	-	0.80

Some of the REE-bearing phases could not be conclusively identified due to their small grain size and/or being inter-grown with other phases. The unidentified REE containing phases are reported as “REE Minerals” in the QEMSCAN results. Subsequent SEM examination indicated that the majority of these unclassified pixels were Monazite-Ce.

Liberation statistics showed that the calcium sulfate particles and the monazite and bastnaesite, were predominantly well liberated, but the Ca,F phase particles (20-50 µm in size) were varied, with 45% at >70% liberated and 37% of the particles <30% liberated (Figure 7.4).

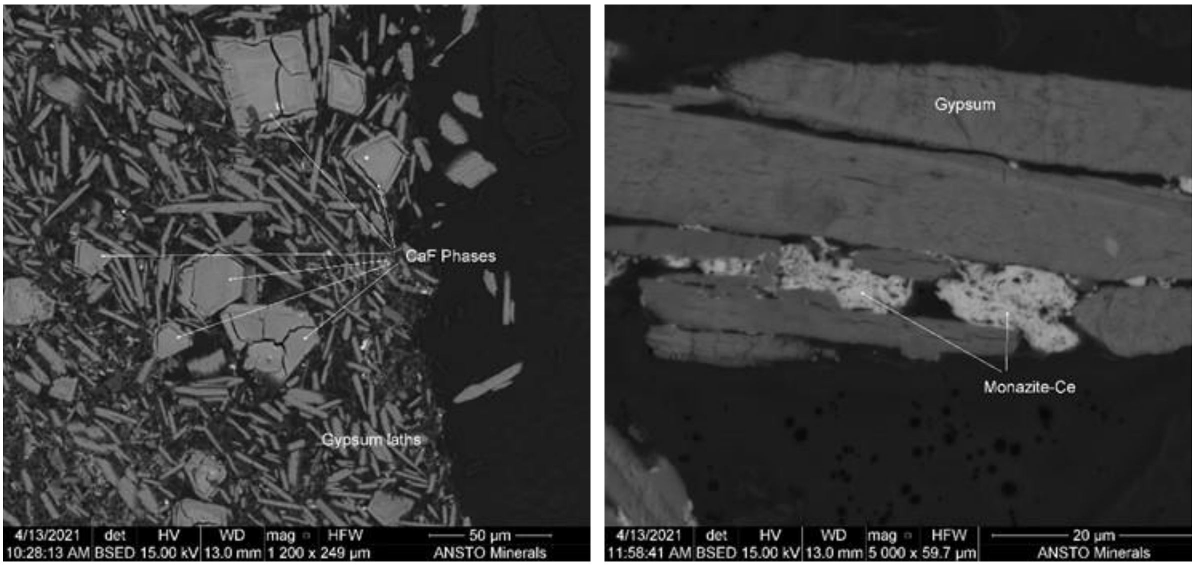


Figure 7.4: REE Phases in Composite Sample

Mineral association data for the REE-containing phases showed high association with the background, which supports the liberation data. The monazite, REE Minerals and Ca,F phases also showed significant association with calcium sulfate, which may indicate some intergrowth between these phases.

The indicative deportment of the major RE elements in the sample was calculated using the QEMSCAN software. The calculated Ce, La and Nd deportment for the REE bearing minerals in the sample are shown in Table 7.5. This data suggests that most of the Ce, La and Nd (81%, 86% and 83% of the total of each REE, respectively) is hosted within the Ca, Al, REE fluoride phase. On this basis, the maximum extraction of the light rare earths would be expected to be ~80% under conditions which do not attack monazite.

Table 7.5: Deportment of Ce, La and Nd Phases in the RRE Composite

	Element Mass % in Sample		
	Ce	La	Nd
Bastnaesite	0.1	0.1	0.04
Monazite-Ce	10.0	7.8	9.6
REE Minerals	8.7	6.4	6.9
Ca,F Phase	81.2	85.7	83.4

SEM/EDS examination concluded that no REEs could be detected within the calcium sulfate.

7.3.2 Slurry Leach Tests

The leach program was designed to consider the three historical leach lixiviants, namely:

- Nitric acid and calcium nitrate.
- Hydrochloric acid.
- Sulfuric acid.

The three lixiviants were compared under similar conditions over an extended 72-hour leach period.

The first three tests were designed to compare the lixiviants and determine the optimal leach duration. Therefore, 3 tests were completed for 72 hours on 15 % w/w slurries at 20°C. Sub-samples were taken from the slurries periodically to monitor the kinetics of the dissolution in each lixiviant. At the end of the leach, the slurry was filtered, and the residue was washed with gypsum-saturated lixiviant (3x), and then gypsum-saturated water (1x). The washed wet cake was then dried in a low-temperature oven (55°C). The dry residue was weighed and assayed by XRF and digested in nitric acid before analysing by ICP-MS for REEs. The results of the initial 72-hour leach tests are presented in Table 7.6.

The highest REE extraction was obtained from leaching with 3 M HCl (total REE + Y = 74%) followed closely by H_2SO_4 (total REE + Y = 69%). The mass loss and leaching of gangue elements were also higher with HCl, and hence the higher acid consumption.

Kinetic plots of key REEs measurable in the leach solutions are presented in Figure 7.5, Figure 7.6, and Figure 7.7. In all cases, the plots show the majority of the dissolution occurs in the first 4-8 hours. There was some minor increase in elements in solution up to 24 hours, more so for the H_2SO_4, but for the HCl and H_2SO_4 leaches, there was little change thereafter up to 72 hours. There was, however, continuation of the leaching in the nitric lixiviant for up to 72 hours.

Based on the superior leach performance of HCl and H_2SO_4, it was decided to continue leach tests with these two lixiviants only and no further nitric testing was completed. The leach duration was limited to 24 hours in all further tests.

Table 7.6: Leach Lixiviant Comparative Tests

Test ID	Rain 1	Rain 4	Rain 10
Lixiviant	1 M HNO_3 + 3 M $Ca(NO_3)_2$	3 M HCl	150 g/ℓ H_2SO_4
Slurry Density (% w/w)	15	15	15
Temperature (°C)	20	20	20
Duration (h)	72	72	72
Acid Cons. (kg/t)	13	60	21
Mass Loss (%)	6	27	13
Element	% Extraction		
Al	68	95	94
Ca	4	26	11
Fe	98	98	98
Mg	71	77	73
P	65	72	68
S	7	27	14
Si	49	26	33
Sr	41	33	20
F	58	97	98
Th	89	92	90
La	56	74	69
Ce	60	75	70
Pr	56	73	68
Nd	54	72	67
Sm	53	71	66
Eu	48	70	63
Gd	51	72	67
Tb	49	69	64
Dy	48	67	61

Test ID	Rain 1	Rain 4	Rain 10
Ho	42	55	-
Er	53	70	64
Tm	-	-	-
Yb	-	-	-
Lu	-	-	-
Y	49	75	72
LRE	57	74	69
MRE	52	71	66
HRE	53	70	65
TOTAL REE (+Y)	**57**	**74**	**69**

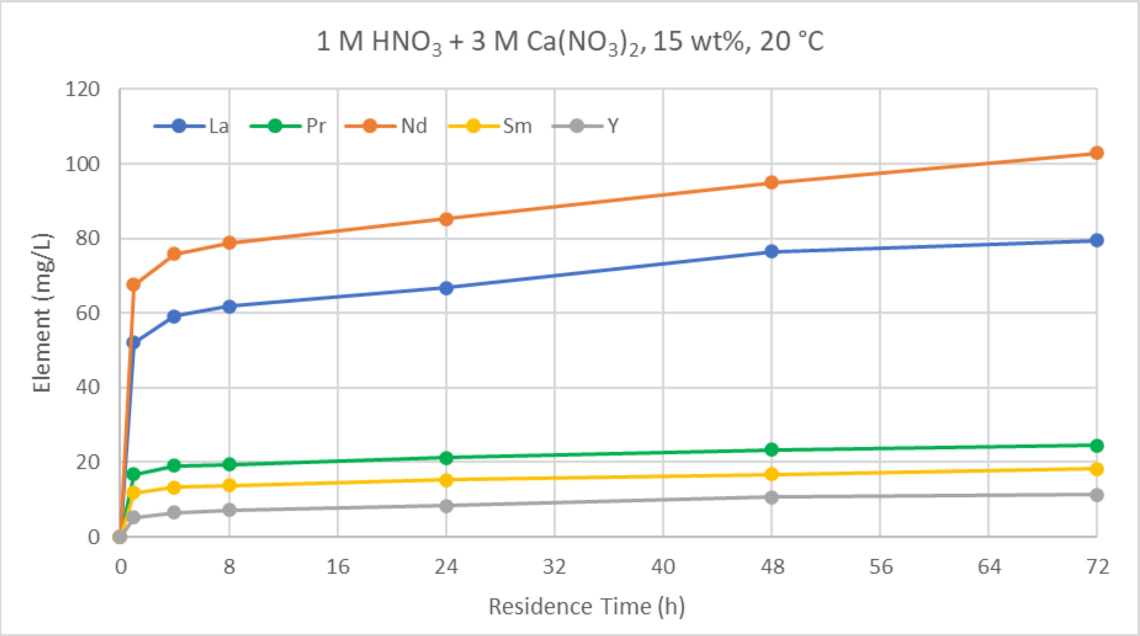


Figure 7.5: Kinetic Plot of Rare Earth Extraction in Nitric System

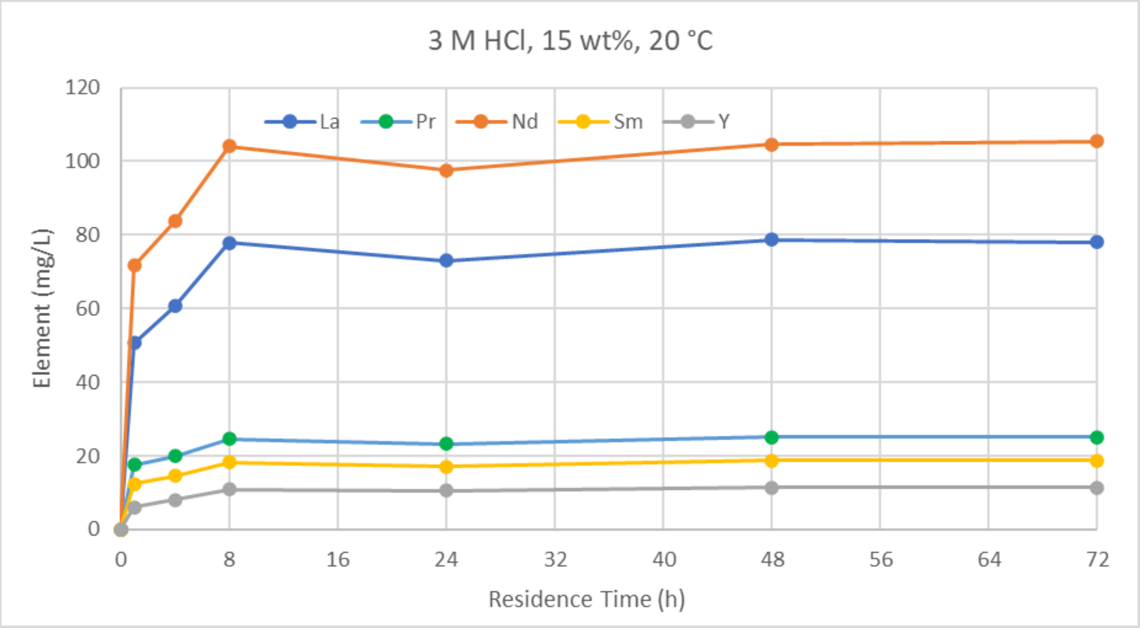


Figure 7.6: Kinetic Plot of Rare Earth Extraction in Hydrochloric Acid System

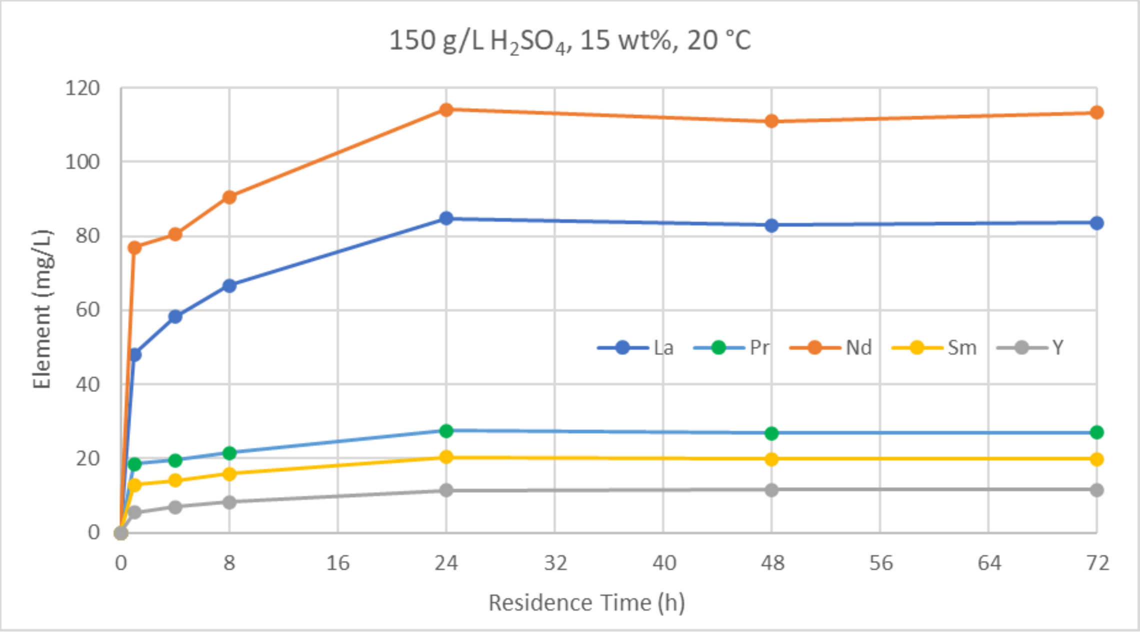


Figure 7.7: Kinetic Plot of Rare Earth Extraction in Sulfuric Acid System

The next set of leach tests explored the parameters of slurry density and temperature at the same initial HCl and H_2SO_4 lixiviant concentrations. Tests were conducted for 24 hours.

In the case of HCl leaching, the increase in slurry density from 15 % w/w resulted in a small reduction in total REE extraction, from 74% at 15 % w/w to 69% at 25 % w/w, and 65% extraction at 35 % w/w slurry. Note, the higher slurry density tests were completed for 24 hours only, instead of for 72 hours at 15 % w/w. However, as shown in Figure 7.6, there was little increase in REEs in solution after 24 hours, indicating the difference in extraction is not a result of extended leach time.

The increase in temperature from 20 to 50°C (at 15 % w/w slurry) produced a similar final extraction, but a review of the kinetic liquor samples at 50°C (Figure 7.8) indicates the dissolution of REEs was effectively complete after only 1 hour.

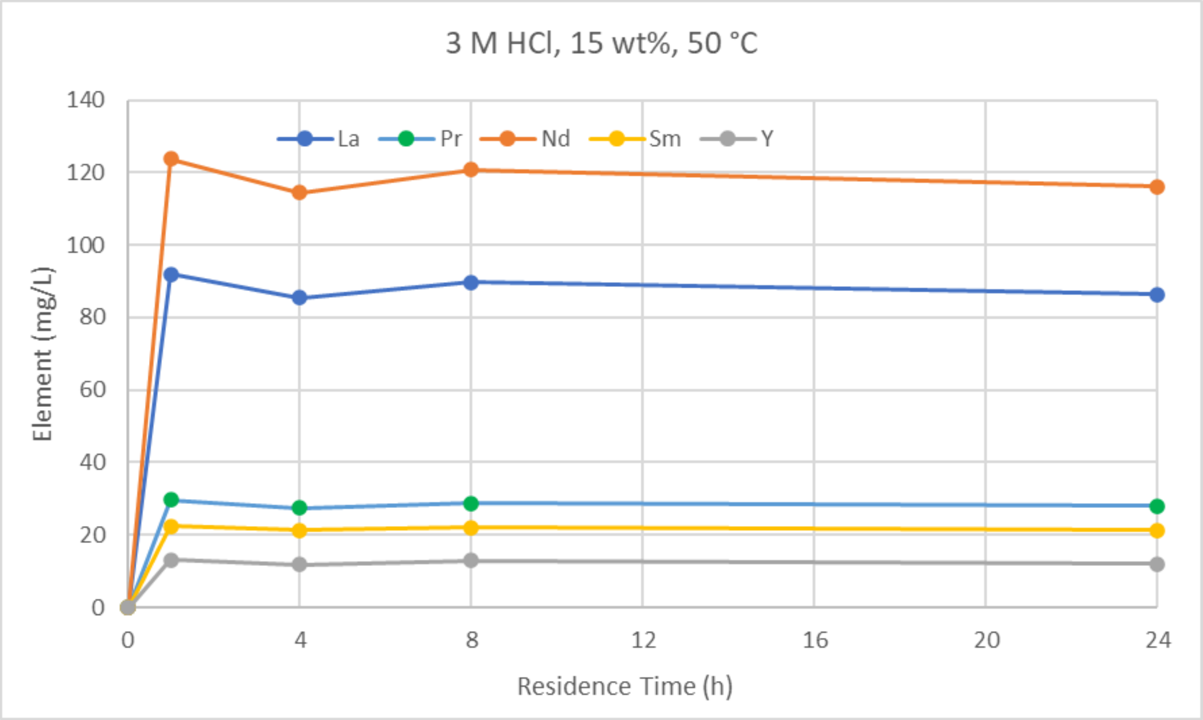


Figure 7.8: Kinetic Plot of Rare Earth Extraction at Elevated Temperature in HCl Environment

Similar observations were made for tests with 150 g/ℓ sulfuric acid, with only small reductions in extraction with increasing slurry density but comparable extractions at 30 and 50°C after 24 hours, compared to 72 hours at 20°C. The kinetic profiles of key REEs in solution in the 30 and 50°C tests, shown in Figure 7.9 and Figure 7.10, respectively, demonstrate once again the kinetic impact of temperature on extraction. At 50°C, extraction appears complete at 1 hour, whereas at 30°C, the reaction continues until ~8 hours. By comparison, at 20°C, as shown in, leaching continues for up to 24 hours.

It is not clear whether the slight decrease in concentration in Figure 7.9 and Figure 7.10 after 1 hour is a phenomenon of leaching at 50°C or whether it is simply an analytical error.

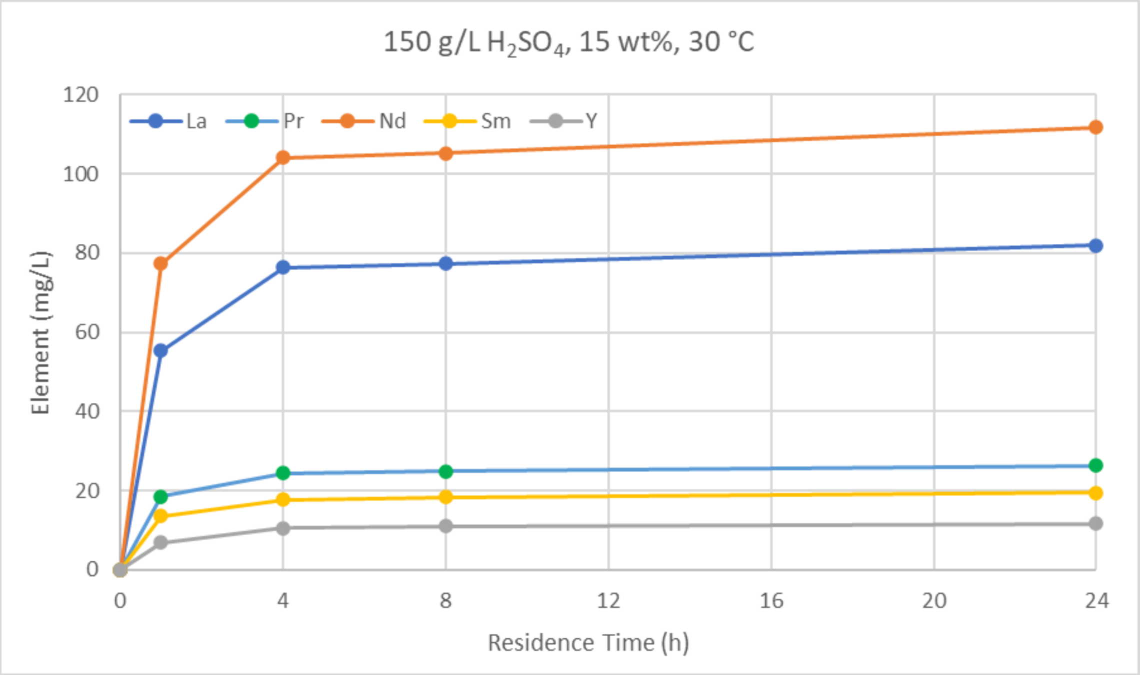


Figure 7.9: Kinetic Plot of Rare Earth Extraction at Elevated Temperature – Sulfuric Acid

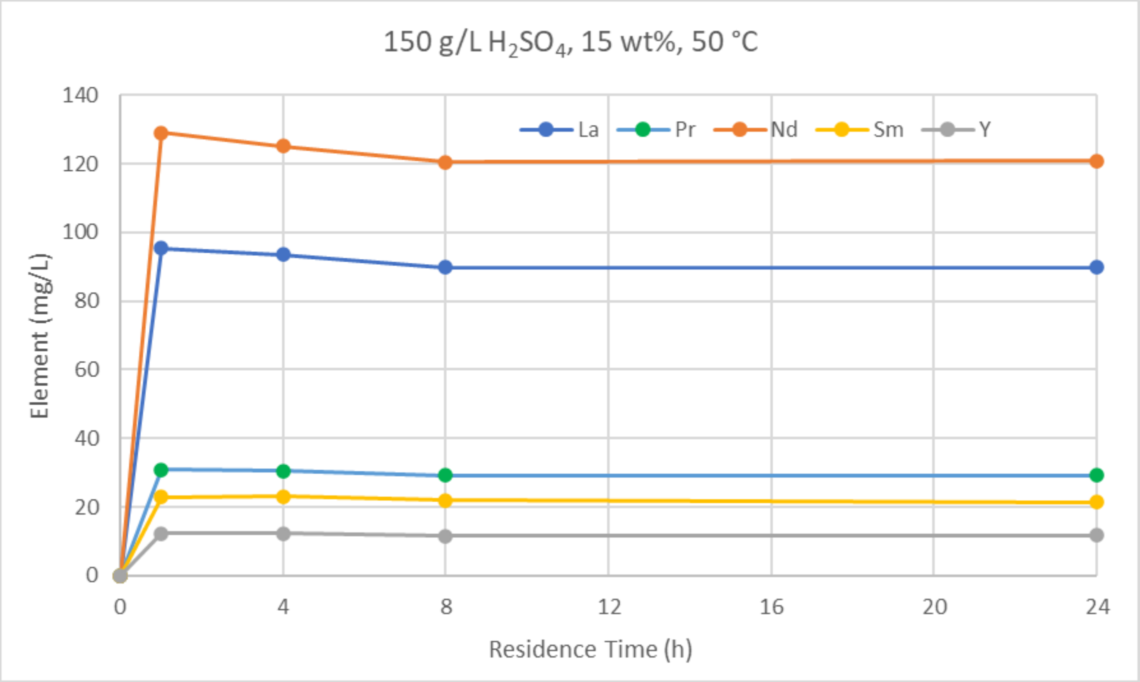


Figure 7.10: Kinetic Plot of Rare Earth Extraction at Elevated Temperature – Sulfuric Acid

The total REE extractions from HCl and H_2SO_4 are compared in Figure 7.11 and Figure 7.12. Extraction was slightly higher (5%) in HCl at 15% w/w slurry, but the difference decreased as the density increased (1% difference at 35% w/w). The extraction was ~5-6% higher in HCl at both 20 and 50°C (at 15% w/w).

Whilst slightly higher extractions were obtained overall in 3 M HCl, compared to 150 g/ℓ H_2SO_4, the differences were not so significant that other advantages of selecting sulfuric acid as a preferred lixiviant could be overlooked. The advantages for sulfuric acid include ease of use, compatibility of materials and cost of reagent. However, another important consideration was the potential application of resin for improved REE recovery and its suitability for use in sulfate matrices, as opposed to chloride, where, calcium dissolution would be much greater.

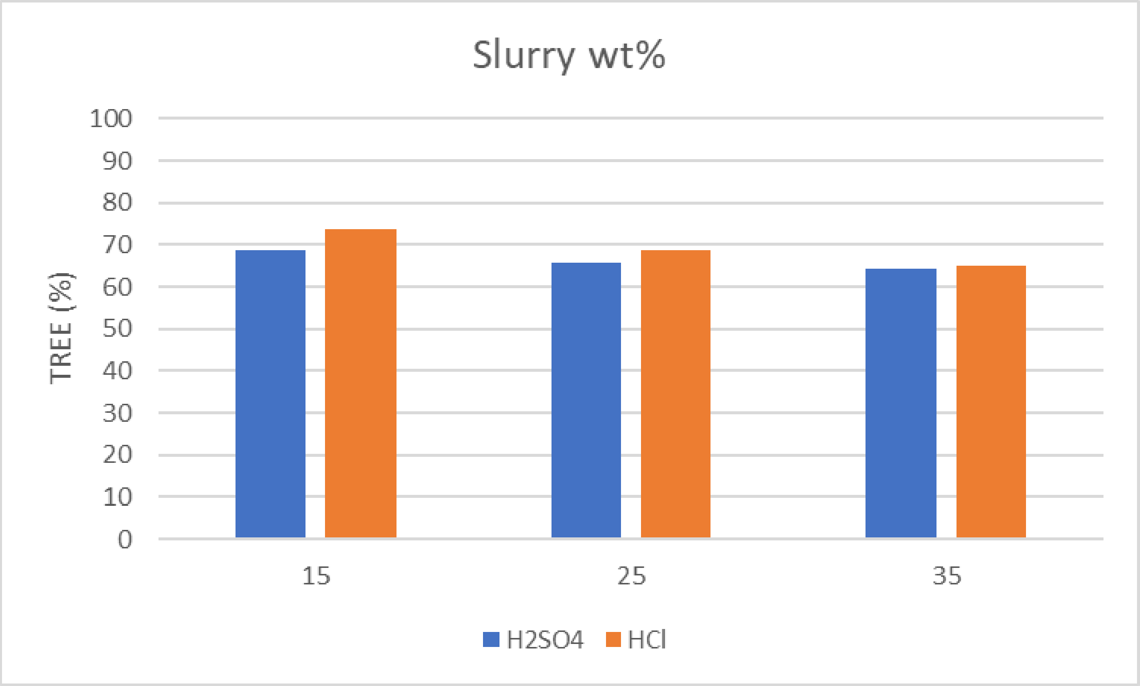


Figure 7.11: REE Extraction at Various Leach Solids Concentration

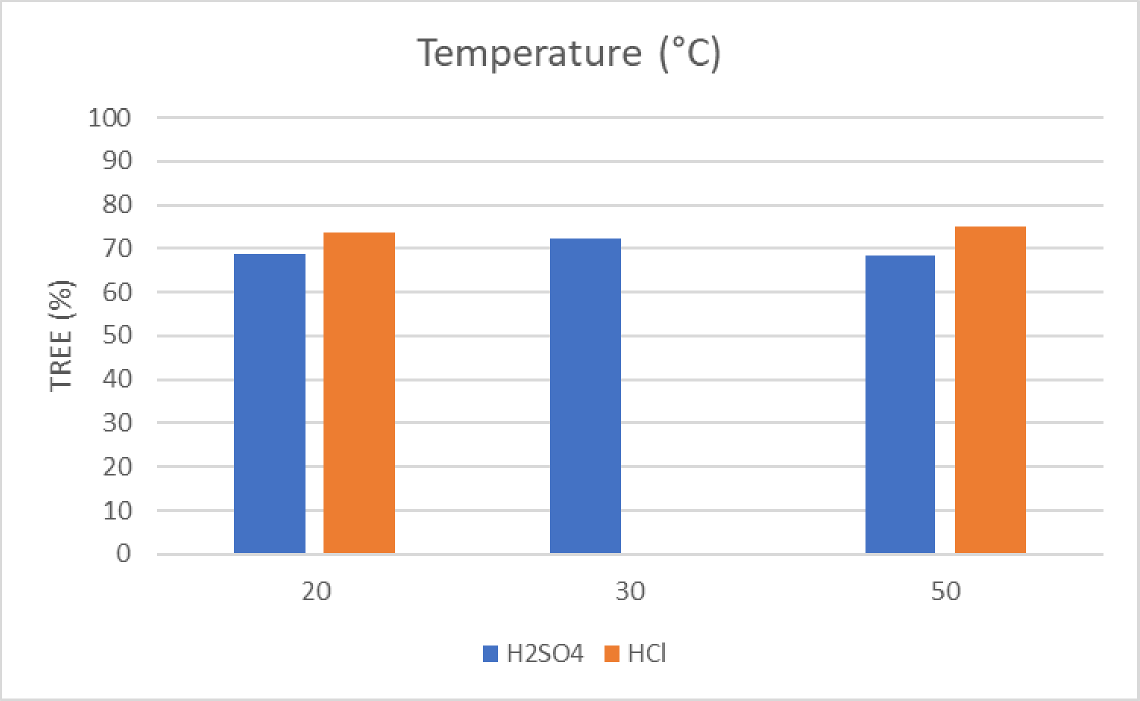


Figure 7.12: REE Extraction at Various Leach Temperatures

With sulfuric acid identified as the preferred lixiviant, tests at reduced acidity were conducted to understand the minimum acid requirement for adequate extraction. Tests were completed at 5, 15 and 25 g/ℓ H_2SO_4 at 30°C for 24 hours. The results are compared to the test completed at 150 g/ℓ H_2SO_4 under the same conditions (Table 7.7).

There was a significant reduction in total REE recovery with a reduction in acidity, with little overall difference between 5 and 15 g/ℓ H_2SO_4. Extraction improved to 41% at 25 g/ℓ H_2SO_4 but was still considerably lower than the 72% achieved at 150 g/ℓ H_2SO_4. The reduction in Al and F extraction at lower acidity is also noteworthy as it supports the mineralogical identification of the REEs being primarily associated with the Ca/F/Al phase.

Sulfuric acid consumption was stable over the test series with between 14 to 22 kg/t consumed for the 150 g/ℓ tests with no significant reduction to the lower acid tests. The 5 g/ℓ leach test consumed 12 kg/t and the 25 g/ℓ test very similar to the high acid tests at 18 kg/t.

Table 7.7: REE Extraction Data at Various Sulfuric Acid Leach Concentrations

Test ID	Rain 9	Rain 15	Rain 17	Rain 16
Lixiviant	150 g/ℓ H_2SO_4	5 g/ℓ H_2SO_4	15 g/ℓ H_2SO_4	25 g/ℓ H_2SO_4
Slurry Density (% w/w)	15	15	15	15
Temperature (°C)	30	30	30	30
Duration (h)	24	24	24	24
Acid Cons. (kg/t)	22	12	16	18
Mass Loss (%)	4	4	3	3
Element	% Extraction			
Al	94	25	42	60
Ca	2	3	2	2
Fe	98	69	98	94
Mg	70	-	-	-
P	62	53	57	59
S	1	4	2	2
Si	64	20	25	32
Sr	12	7	6	9
F	96	22	50	71
Th	88	49	27	46
La	70	18	25	41
Ce	76	24	25	42
Pr	71	24	25	41
Nd	69	23	24	41
Sm	70	25	24	40
Eu	68	21	23	39
Gd	70	26	24	39
Tb	67	30	63	71
Dy	66	29	20	35
Ho	-	29	21	36
Er	66	33	32	43
Tm	-	-	-	-
Yb	-	-	-	-
Lu	-	-	-	-
Y	67	33	20	35
LRE	73	23	25	42
MRE	70	25	24	40
HRE	69	30	22	36
TOTAL REE (+Y)	**72**	**23**	**25**	**41**

To improve the overall recovery of REEs at lower acidity, the application of resin-in-leach was tested to reduce the concentrations of the REEs in solution and hence drive the dissolution of solubility limited REE phases, and to also overcome the potential re-adsorption/co-precipitation of REEs onto the gypsum following dissolution. Two different resin types were considered: Lewatit TP260 and Purolite MTC1600. The Lewatit resin is a chelating amino phosphonic (AMP) resin, while the Purolite is a strong acid (SA) type. Both are known to show an affinity for REEs in moderately acidic solutions. However, they both show poor selectivity over calcium and no selectivity over iron and aluminium.

Initially, resin-in-leach (RIL) tests were selected in preference to resin-in-pulp (RIP) as the goal was to adsorb the leached REEs and hence drive further dissolution. The first two tests compared the two resin types at 15 g/ℓ H_2SO_4 at 15 % w/w slurry, 30°C for 24 hours. The Lewatit resin was conditioned in 1 M H_2SO_4 to convert to the H^+ form and screened at 500 µm, prior to the test. The Purolite resin was used as received (in the H^+ form).

The results of the first two RIL tests (13 and 18) are compared, in Table 7.8, to the same test in the absence of resin (17) at 15 g/ℓ H_2SO_4. There was a clear improvement in total REE recovery in the RIL tests, increasing from 25% TREE to 58% with the AMP resin and to 65% with the SA resin.

However, it is worth noting that despite the 15 g/ℓ H_2SO_4 target in the test with the SA Purolite resin, the actual test acidity was closer to 25 g/ℓ due to the H^+ exchanging from the resin. Therefore, it is difficult to determine whether the improved recovery with the SA resin was a result of the resin type or the test acidity. The amount of resin added to this test, relative to the dry solid, was double that of the AMP resin test. The amount of resin was increased to ensure there was sufficient resin present to adsorb the REEs, as the loading of REE on the SA resin was anticipated to be lower.

The SA Purolite resin was preferred for subsequent testing due to its potential for eluting under milder conditions (e.g., NaCl solution) to recover the REEs. Two further RIL tests were completed at 40 g/ℓ H_2SO_4 and 30 or 15 % w/w slurry (tests “Rain 2” and “Rain 3” in Table 7.8) to gauge the performance of the resin at higher acidity. To ensure the acidity was maintained at the target, the initial starting solution was ~25 g/ℓ H_2SO_4, and once the resin was added, the test solution was titrated for acidity and adjusted to 40 g/ℓ H_2SO_4 by the addition of concentrated H_2SO_4 in the first 15-30 minutes.

The results in Table 7.8 show that the resin performance was still good at higher acidity, but the overall recoveries were similar to those at 15-25 g/ℓ H_2SO_4. It is unclear whether the reduced resin to slurry ratio may have impacted the tests at 40 g/ℓ H_2SO_4, but a comparison of the 15 and 30 % w/w slurries showed that recovery was better at lower slurry density.

Table 7.8: REE Extraction Behaviour at Various Resin Test Conditions

Test ID	Rain 17	Rain 13	Rain 18	Rain 2	Rain 3	Rain 7
Lixiviant	15 g/ℓ H_2SO_4	15 g/ℓ H_2SO_4	15-25 g/ℓ[#] H_2SO_4	40 g/ℓ H_2SO_4	40 g/ℓ H_2SO_4	80 g/ℓ H_2SO_4
Slurry Density (% w/w)	15	15	15	30	15	15
Temperature (°C)	30	30	30	20	20	20
Duration (h)	24	24	24	24	24	48
Test Type	Control	RIL	RIL	RIL	RIL	Neut. + RIP
Resin*	None	Lewatit	Purolite	Purolite	Purolite	Purolite
Volume (wsr)	-	40	80	80	80	80
mL wsr : ℓ slurry		42	99	99	45	46
mL wsr : g dry solid		0.27	0.54	0.27	0.27	0.27
Element	% Extraction					
Al	42	70	85	77	90	90
Ca	2	5	14	7	8	-

Test ID	Rain 17	Rain 13	Rain 18	Rain 2	Rain 3	Rain 7
Fe	98	98	87	98	98	97
Mg	-	-	-	71	71	-
P	57	62	67	62	63	60
S	2	7	14	7	7	-
Si	25	56	67	54	56	60
Sr	6	16	31	18	22	11
F	50	69	85	69	86	81
Th	27	84	87	85	86	57
La	25	54	65	54	64	39
Ce	25	62	68	55	63	35
Pr	25	57	64	59	66	42
Nd	24	56	62	57	64	41
Sm	24	56	62	57	64	46
Eu	23	53	61	54	62	45
Gd	24	53	62	54	62	49
Tb	63	75	60	53	-	-
Dy	20	50	58	53	60	49
Ho	21	43	47	50	-	-
Er	32	55	61	57	62	50
Tm	-	-	-	-	-	-
Yb	-	-	-	-	-	-
Lu	-	-	-	-	-	-
Y	20	48	59	51	60	45
LRE	25	59	66	56	63	38
MRE	24	54	62	56	63	47
HRE	22	55	62	54	63	53
TOTAL REE (+Y)	**25**	**58**	**65**	**56**	**63**	**39**

- At the conclusion of this phase of testing at ANSTO, the following observations and conclusions could be drawn: The Phalaborwa PG contains very low levels of uranium and thorium coupled with overall low total radioactivity levels. It is thus not expected that the final products will have radioactivity problems once purified and separated.
- The average total rare earth oxides plus yttrium (TREO (+Y)) grade of the drilled samples were 0.46%, with a 29% neodymium (Nd) and praseodymium (Pr) oxide ratio. The other target elements for RRE are dysprosium (Dy) and terbium (Tb).
- The main rare earth-bearing phase in the phosphogypsum was identified as a precipitated calcium fluoride (Ca,F) that contained 80% of the available, non-refractory rare earths in the deposit.
- Diagnostic leach tests, designed to quantify the maximum extractable rare earth component, confirmed the mineralogical findings of 75% TREO extraction employing either hydrochloric acid or sulfuric acid.
- It was established that the nitric acid lixiviant had slow kinetics and could not achieve comparable levels of extraction. This, coupled with issues around construction materials,

environmental concerns and overall costs, led to the shelving of this leach lixiviant going forward.

- HCl was also parked at this point since it yielded similar extraction potential compared to sulfuric acid and indicated higher reagent consumption and associated costs related to materials of construction.
- Sulfuric acid emerged as the lixiviant of choice due to its availability in Phalaborwa from neighbouring Palabora Mining Company (PMC), materials of construction, compatibility to various resin technologies, cost, and operational safety.
- Sulphuric acid achieves acceptable rare earth extraction, and the leaching kinetics can be significantly improved with mild temperatures. The slurry density can be adjusted to allow for economic process design considerations.
- It was established that resin could perform well under mild sulfuric acid concentrations as resin in leach technology, but the relativity low rare earth loadings will require large resin inventories and resin movement rates through the leach. This will require the design of large resin handling facilities and leach tankage.

These preliminary findings led to the conceptualisation of the initial processing considerations for Phalaborwa:

- The phosphogypsum will be reclaimed by employing hydraulic reclamation techniques to recover and transport the material from the stacks to the processing facility.
- Pre-leach filtration will be employed to provide a break in the water balance and separate the reclamation and processing plant solution streams.
- Sulfuric acid will be employed as the leach lixiviant and levels around 150 gram per litre (g/ℓ), as free acid, are required to maintain rare earth solubility. Acid consumption is moderate, however, at around 15 to 20 kilogram per tonne (kg/t).
- Leach residence time will be in the range of 12 to 24 hours and can be influenced by the use of moderate temperatures.
- Leach solids concentration will be in the range of 30 to 35 % by mass, which will facilitate an economic process design.
- Due to the high acid requirement in the leach process, rare earth recovery techniques from the loaded leach solution (PLS) will need to be carefully considered since acid recycling back the leach will be critical from a feasibility perspective.
- Post-leach filtration with washing will form a critical part of the overall extraction process to ensure maximum rare earth extraction.
- Since the host mineral phases contain various impurities, these will leach in conjunction with the rare earths and build up in the leach solution. These impurities form strong complexes with rare earths and will impact on the solubility and thus extraction potential of rare earths in a commercial leach system with recycling streams.

With these building blocks in mind and an improved understanding of the processing requirements, the following steps were identified to be explored as critical to finalising a flowsheet for Phalaborwa:

- Filtration testing pre- and post-leach.
- Acid recycling possibly employing Nanofiltration (NF).
- Rare earth purification and separation technologies confirm a technology partner for RRE.
- Refine the processing criteria established thus far.

- Impurity control techniques.

RRE, at this time, embarked on a detailed review of available technologies that could be employed for rare earth purification and separation that do not involve the use of solvent extraction.

7.3.3 Filtration Test Work

A composite sample representative of the whole was composed and used to prepare a pre- and post-leach sample for filtration testing.

CM Solutions in Johannesburg performed the sample preparation by leaching the required sample mass at specified conditions and then transferred the sample to Roytec Global, also in Johannesburg, for filtration testing and to establish filtration design criteria.

The following findings can be reported and are in line with typical phosphoric acid plant filters.

7.3.3.1 Pre-leach Belt Filters

At a 25 % plant feed solids concentration, the tests were able to achieve a filtration rate of 920 kg/m².h (dry solids basis) using a 15 mm cake formed in 23 seconds and dried for 31 seconds (54 seconds cycle). This yields a cake moisture of <25 % w/w. While the above results confirm that 2 x 163 m² belt filters are suitable for the proposed 280 t/h (solids) plant feed, the belt speed to achieve a 54 second vacuum cycle is on the high side at 42 m/min.

It was recommended that optimization work is done during later stages on increasing the % solids in the filter feed.

Tests were done on thickened material to investigate the benefits of thickening before filtration. At a 42 %w/w thickener underflow feed, total cycle time without washing was 75 seconds with a total flux of 2,011 kg/m².h. Increasing the feed solids to 50 %w/w, total cycle time decreased to 65 seconds with a flux of 2,300 kg/m².h. For 280 t/h solids, a 121 m² filtration area is required, and Roytec recommended one standard 126 m² vacuum belt filter. The belt filter speed will be 37 m/min for a 30 mm cake, and 27 m/min for a 40 mm cake (nominal).

7.3.3.2 Post-leach Belt Filters

With a leach residue of 35% solids, the tests were able to achieve a filtration rate of 570 kg/m².h (dry solids) using a 25mm cake as follows;

- Cake formation in 26 seconds.
- Cake washing with a wash ratio of 0.6 (liquid/solid), in a 3 stage counter-current configuration using a wash time ~33 seconds.
- Cake drying time of 30 seconds yields a discharge moisture of <27 % w/w.

This produces a 155-second vacuum cycle and a conservative belt speed of 15 m/min.

The cake washing tests show a single-stage soluble recovery of +90% with a wash ratio of 0.6 (liquid/solid). Modelling this single stage recovery into a 3-stage counter-current wash, it can be expected to obtain >99 % recovery of soluble REE elements over the belt filter.

It was recommended that 4 x 163 m² belt filters are consider for the post-leach duty. 3 filters will be able to filter the design tonnage, and this will effectively allow 1 unit to be on standby. In the final plant configuration, it may be possible for the standby filter to service both the post-leach and pre-leach duties.

These filtration tests proved that vacuum belt filters will perform well for the selected duties in the processing facility and that the phosphogypsum performs as expected for this type of material. It is recognised that further optimisation will be required in future for the overall filtration design.

7.3.4 Acid Recycling, Nanofiltration

NF proved effective on various other studies and applications to recycle acid and other reagents with subsequent upgrading of the PLS.

In the absence of NF test work at the time, an engineering company, Chimerical Technology, Cape Town was approached to perform a desktop study to evaluate the application and performance of NF on a typical PLS stream composition from the rare earth leach as established during the phase 1 ANSTO program.

The feed stream composition assumed for the desktop study is depicted in Table 7.9.

Table 7.9: Typical PLS Stream Composition

Element	Primary Filtrate (mg/ℓ)
Al	805
Ca	629
Fe	292
Mg	196
P	1,572
S	45,175
Si	1,082
Sr	114
F	4,510
La	221
Ce	556
Pr	84
Nd	348
Sm	62
Eu	13
Gd	40
Tb	3
Dy	12
Y	32
Th	24
H_2SO_4	151,180
TOTAL REE	**1,343**

Comments related to the feed stream:

- pH – The stream pH would be in a favourable range for good acid passage through the membrane. Low pH conditions are more favourable for the suppression of impurity saturation limits that could result in scaling, such as Si, Sr, Al, Fe, Mg and Ca.
- Calcium – Will be saturated in the solution throughout the process. Various measures can be taken to suppress calcium for processing through the membrane system including acid-stabilized antiscalant, elevated temperatures and acid recycle dosing.
- Silica – Silica is present as a neutral component in acidic solutions and will be only partially rejected (40 to 60% is typical) where all other multivalent elements have >90% rejection by the membrane.
- Phosphates – P in solution will be present as phosphoric acid, and its dissociation species will be recovered to a similar extent as the sulfuric acid.

- Fluoride in an acidic solution will partially dissociate as hydrofluoric acid, which passes through the membrane with other acids.

Nanofiltration membranes selectively reject multivalent ions, whilst monovalent ions such as H^+, Cl^- $HSO4^-$ and water pass through the membrane, subsequently splitting the feed stream into two separate streams. The separation of ions across a membrane from a stream containing rare earth elements is shown in Figure 7.13.

The membranes aim to selectively separate the acid used in the leach (H^+, $HSO4^-$) from the REE and other metals in the solution. This is achieved by high-pressure filtration through a membrane with a charged active surface. This results in a concentrated product stream known as the concentrate and an acidic stream known as the permeate.

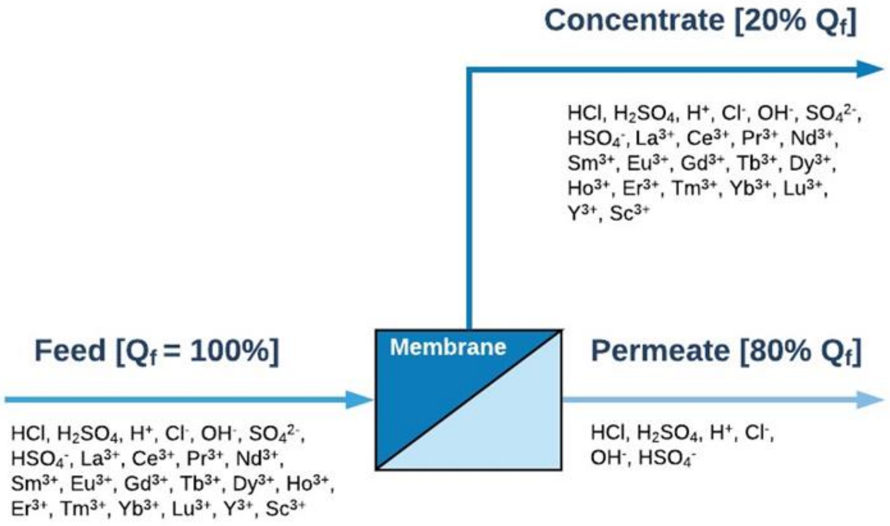


Figure 7.13: Separation of Ions from an REE Leach Solution using a Nanofiltration Membrane

The REE elements are concentrated by a factor of 1.5 to 5, depending on the achievable permeate recovery. Recovery typically ranges from 60 - 80% for the acid component. Divalent elements such as Ca, Mg, Fe, Mn and Al will also be rejected by the membrane and follow the rare earth elements into the concentrate stream. The acid can be recirculated back to the leach, subsequently lowering fresh acid demand. Additionally, capital cost on the back-end processing is reduced as a result of a reduced volume of the REE stream at higher concentrations and improved REE product quality

The following performance parameters dictate the operation of the membrane system:

- Stream pH – Higher acid concentrations and low pH streams are more favourable for acid dissociation and suppression of fouling component saturation.
- Total dissolved solids (TDS) – Higher TDS requires higher operating pressure.
- Total suspended solids (TSS) – Solids content dictates the pre-treatment requirement for the membranes.
- Metals concentration – Recovery is tailored to achieve the highest REE metals concentration at >98% rejection of REE into the concentrate stream.

7.3.5 System Modelling

7.3.5.1 Ultrafiltration Pre-treatment System

The nanofiltration system will require an ultrafiltration (UF) system as TSS need to be removed from PLS to protect the nanofiltration membranes from damage. The general ultrafiltration process flow is shown in Figure 7.14. It outlines the feed to the pre-treatment system with internal recirculation to maintain a high cross-flow velocity for efficient solids removal. A buffer tank, which has a low quantity filtrate hold-up volume, is periodically back pulsed to remove solids build up on the UF surface.

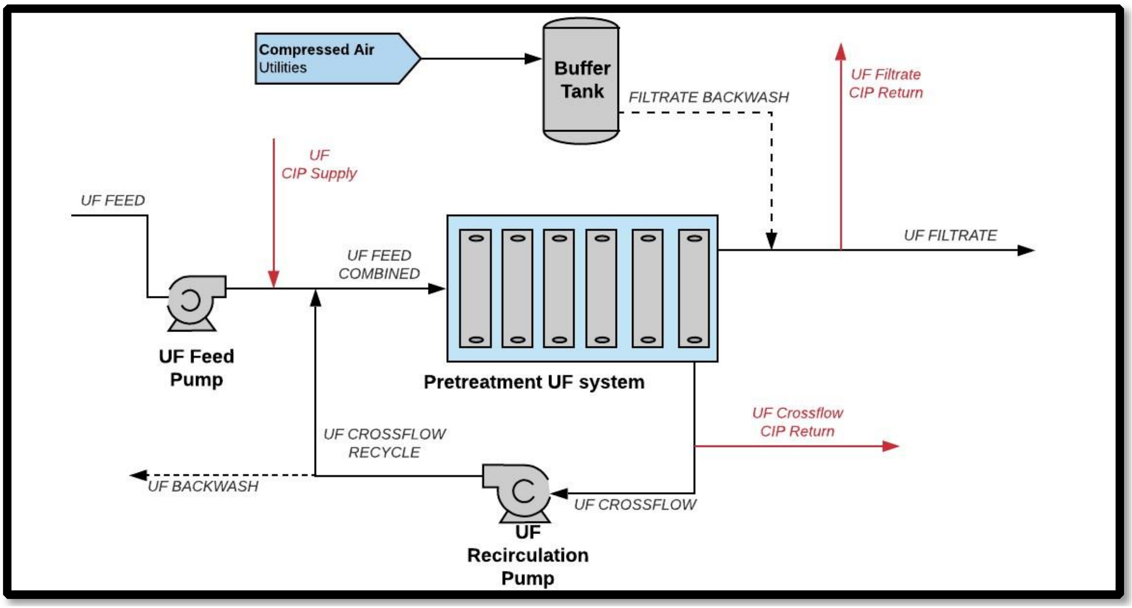


Figure 7.14: Ultrafiltration Process Flow Layout with Internal Recirculation and Back Pulsing

The model assumes the total suspended solids content of the PLS stream to be 80 mg/ℓ, typical for PLS streams. The ultrafiltration system provides absolute solids filtration, resulting in a filtrate with zero TSS. There is no chemical change to the stream composition through the UF, only the TSS is affected as shown in Table 7.10.

Table 7.10: Resulting Filtrate and Backwash TSS and Flows from UF Pre-treatment

Parameter	Units	Feed	UF Backwash	UF Filtrate
Flow rate	(m^3/h)	650	11	639
pH	(-)	0.02	0.02	0.02
*TSS	(mg/ℓ)	80	4,800	-
System recovery	(%)	98.3%		
Description	**Units**	**Feed**	**UF Backwash**	**UF Filtrate**
Solids mass flow	kg/h	52.00	52.00	-
Solids volume flow	m^3/h	0.021	0.021	-
Solids density	kg/m^3	2,450	2,450,	-
Liquid mass flow	kg/h	718,055	11,968	706,087
Liquid volume flow	m^3/h	650.0	10.8	639.2
Liquid density	kg/m^3	1,105	1,105	1,105
Total mass	**kg/h**	**718,107**	**12,020**	**706,087**
Total volume	**m^3/h**	**650.02**	**10.85**	**639.17**
Stream density	**kg/m^3**	**1,105**	**1,107**	**1,105**
Solution pH	-	0.02	0.02	0.02

The UF backwash stream can be returned to the leach settling ponds to minimise product losses. The system operates at a 98.3% recovery, assuming a back pulse is required every 30 minutes for 30 seconds as a conservative assumption.

UF filtrate will be fed to the NF membranes at a rate of 639 m^3/h. Clean-in-Place (CIP) cycles are employed periodically with a combination of alkaline and acid cleaning processes to remove more difficult fouling and restore operating flux. The frequency between CIP cycles will be evaluated during piloting when the system can operate for extended periods of time.

7.3.5.2 Nanofiltration System

NF is the process where the rejection of metals and acid separation takes place. NF aims to recover the monovalent and neutral ions to the permeate stream while the desired materials report to the concentrate. A process flow diagram of an NF system can be seen in Figure 7.15. The UF filtrate stream feeds to the NF booster pump, which provides the minimum pressure (2 bar) required for the high-pressure pump to start and operate efficiently. High-flow, inline cartridges are installed between the booster and high-pressure pumps to capture any dust or solids from the tanks and act as a safety polishing step for NF protection.

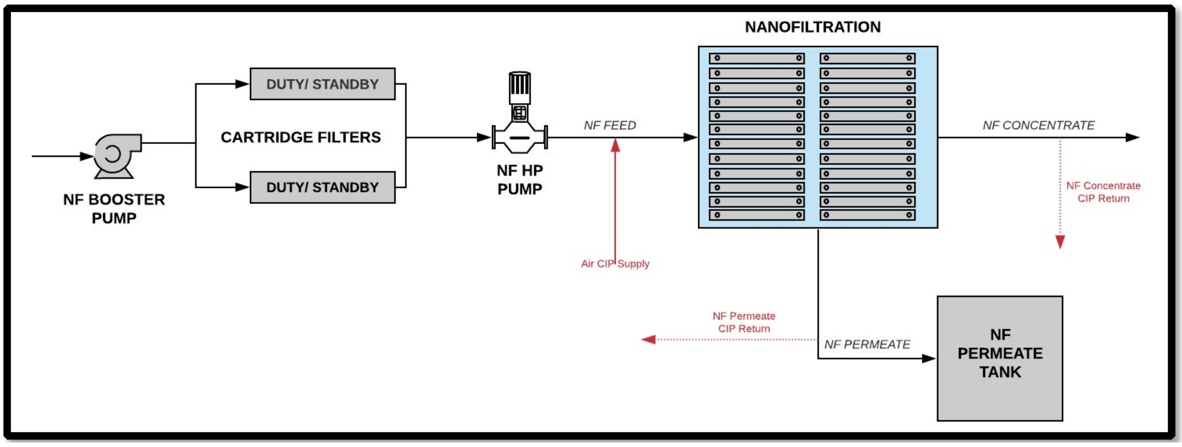
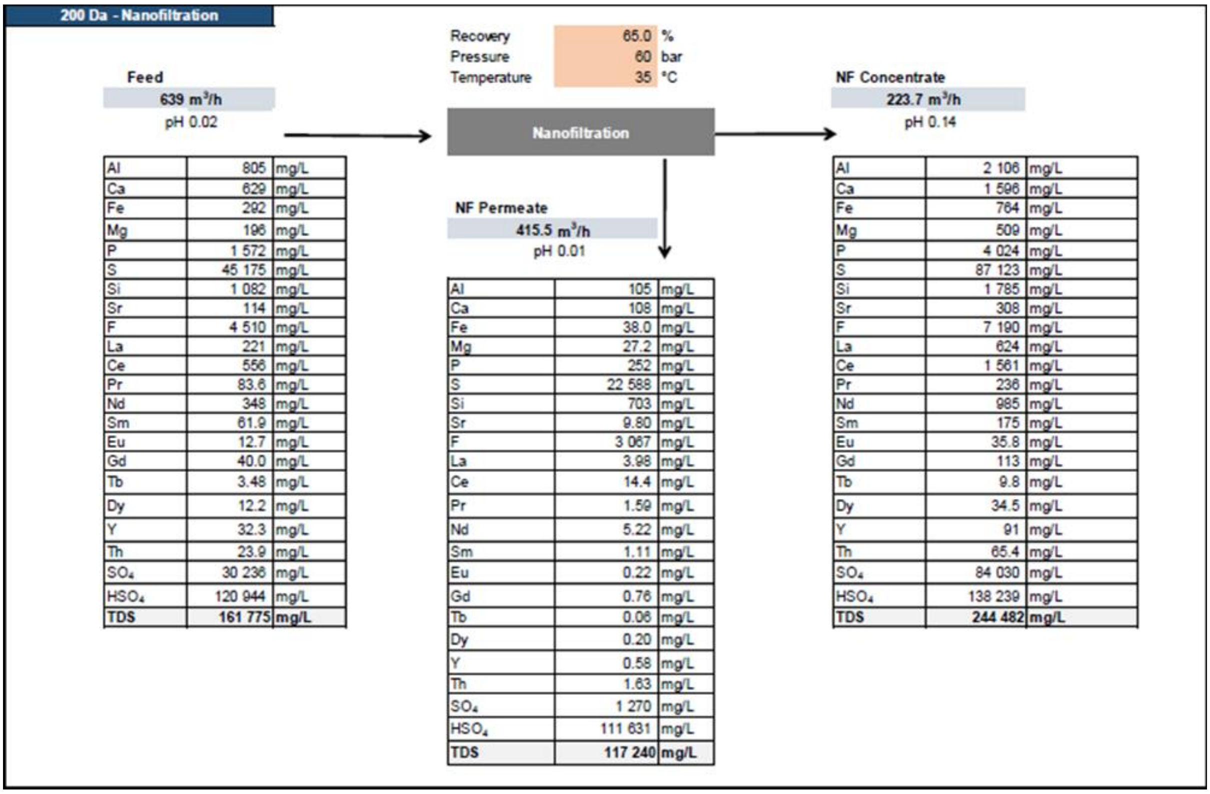


Figure 7.15: Nanofiltration Process Flow Diagram

The model is based on a database of information collected on various high concentration streams utilizing nanofiltration membranes with pore sizes from 80 to 700 daltons (Da) to achieve the required stream objectives. The achievable concentration factor takes into consideration the saturation limits of typical impurities such as Mg, Mn, Ca, Fe and Al. The specific rejection of each element depends on the molecule size and charge coupled with the system operating conditions.

7.3.5.3 System Recovery

The stream compositions achievable at 65% acid recovery operating at 60 bar using a 200 Da NF membrane are given in Figure 7.16. The feed solution with a flowrate of 639 m^3/h, pH of 0.02 and 117,240 mg/ℓ TDS produces a concentrate stream of 223.7 m^3/h at pH of 0.14 and 244,482 mg/ℓ TDS and a permeate stream of 415.5 m^3/h at pH of 0.01 and 135,991 mg/ℓ TDS. The volume concentration factor (VCF) for the operating case is 2.9.



Feed

639 m^3/h

pH 0.02

Al	805	mg/L
Ca	629	mg/L
Fe	292	mg/L
Mg	196	mg/L
P	1 572	mg/L
S	45 175	mg/L
Si	1 082	mg/L
Sr	114	mg/L
F	4 510	mg/L
La	221	mg/L
Ce	556	mg/L
Pr	83.6	mg/L
Nd	348	mg/L
Sm	61.9	mg/L
Eu	12.7	mg/L
Gd	40.0	mg/L
Tb	3.48	mg/L
Dy	12.2	mg/L
Y	32.3	mg/L
Th	23.9	mg/L
SO_4	30 236	mg/L
HSO_4	120 944	mg/L
TDS	**161 775**	**mg/L**

NF Permeate

415.5 m^3/h

pH 0.01

Al	105	mg/L
Ca	108	mg/L
Fe	38.0	mg/L
Mg	27.2	mg/L
P	252	mg/L
S	22 588	mg/L
Si	703	mg/L
Sr	9.80	mg/L
F	3 067	mg/L
La	3.98	mg/L
Ce	14.4	mg/L
Pr	1.59	mg/L
Nd	5.22	mg/L
Sm	1.11	mg/L
Eu	0.22	mg/L
Gd	0.76	mg/L
Tb	0.06	mg/L
Dy	0.20	mg/L
Y	0.58	mg/L
Th	1.63	mg/L
SO_4	1 270	mg/L
HSO_4	111 631	mg/L
TDS	**117 240**	**mg/L**

NF Concentrate

223.7 m^3/h

pH 0.14

Al	2 106	mg/L
Ca	1 596	mg/L
Fe	764	mg/L
Mg	509	mg/L
P	4 024	mg/L
S	87 123	mg/L
Si	1 785	mg/L
Sr	308	mg/L
F	7 190	mg/L
La	624	mg/L
Ce	1 561	mg/L
Pr	236	mg/L
Nd	985	mg/L
Sm	175	mg/L
Eu	35.8	mg/L
Gd	113	mg/L
Tb	9.8	mg/L
Dy	34.5	mg/L
Y	91	mg/L
Th	65.4	mg/L
SO_4	84 030	mg/L
HSO_4	138 239	mg/L
TDS	**244 482**	**mg/L**

Figure 7.16: Permeate and Concentrate Stream Flows and Compositions at NF acid Recovery of 65%

It can be seen from Figure 7.16 that the acid recovery for the defined operating conditions is 65%. It can also be seen that 99% of Nd, Pr, Dy, Tb is rejected by the membrane consistent with the lower recovery case. Rejection decreases slightly as recovery increases. However, for the membrane model, this was kept constant. The separation of acid from the metals can be seen in the notable change in pH of the permeate stream as seen in Figure 7.16. Total dissolved solids in the feed stream are at a favourable level to achieve high recovery and subsequent concentration factors.

Calcium sulfate ($CaSO_4$) has a solubility limit of 2.6 g/ℓ in a solution at a pH of 3. Figure 7.16 shows Ca in the concentrate stream at 1.6 g/ℓ, which would result in a $CaSO_4$ concentration of 5.4 g/ℓ. As the concentrate stream is far below a pH of 3 at 0.14, speciation modelling predicts that $CaSO_4$ will remain below the solubility limit at this pH. Test work will need to be conducted in order to confirm the solubility and any other ion interaction which could lead to precipitation.

With the relatively high concentration of fluoride ions in the PLS stream, the formation of CaF_2 precipitate was of concern. The solubility of CaF_2 is 16 mg/ℓ and is independent of pH for solutions above a pH of 4. However, the PLS pH is less than 0.1 and the solubility of CaF_2 increases drastically below 4 where the formation of HF is predominant.

The concentrations of the potential scaling components are all below the solubility limits for the system modelled at 65% recovery. Saturation, co-precipitation and solubility need to be benchmarked against speciation models with test work.

Nanofiltration can be a feasible solution for acid recovery and PLS upgrading to reduce downstream processing volumes. The desktop study is viewed as conservative without supporting test work at the time, and it is suspected that higher acid recovery potential exists with subsequent concentrate stream volume reduction.

7.4 K-Technologies Rare Earth Purification and Separation (Phase 0)

In conjunction with the nanofiltration desktop study RRE selected K-Technologies (K-Tech), Florida, USA as the preferred technology partner to develop the downstream rare earth purification and separation flowsheet.

The initial intention was to consider the concentrate stream from NF as a feed stream to the K-Tech continuous ion exchange (CIX) and continuous ion chromatography (CIC) technology section.

K-Tech initiated a conceptual desktop study to evaluate the feed stream composition in terms of their technology and develop high-level design criteria and process costing for such a section that will produce neodymium-praseodymium oxide (NdPr oxide), dysprosium oxide (Dy oxide) and terbium oxide (Tb oxide) products for sale.

7.4.1 Process Concept

The original basis for the PLS flow rate was around 650 m^3/h. Subsequent work by RRE indicated that initial treatment of the PLS by an NF membrane system would reduce and concentrate the PLS flow to K-Tech's 3-stage CIX/CIC processing facility to about 223 m^3/h.

This is still a relatively large flow, and based on previous work by K-Tech, it would likely be possible to have one overall efficient NF system that would further reduce the PLS volume that would feed to the first ion exchange step in the K-Tech process to a range of 40-60 m^3/h.

The reduced volume PLS is fed to the Stage 1 K-Tech continuous ion exchange system, where the rare earths are extracted from the PLS, and the level of impurities is reduced in the subsequent ion exchange regeneration solution. This allows for the initial separation to be carried out in a continuous fashion, which is more efficient than a fixed bed column approach.

The regeneration solution from the Stage 1 CIX is then sent to a Stage 2 system which utilizes continuous ion chromatography. This approach allows for continuous treatment of the regeneration solution and begins the separation of the REs from each other as groups.

The regeneration effluents (or eluants) from the Stage 2 operation then proceed to the Stage 3 systems which are also CIC units, but much smaller. In Stage 3, the REs are further separated from each other to recover the target products as purified materials.

The recovered purified products are further treated for solution recovery (for recycle), and then the targeted REs are precipitated and calcined to produce the RE oxide products. The target products for this assessment and the target purity are as follows:

- Nd/Pr: 99.5% Nd/Pr relative to the contained RE.
- Dy: 99.5% Dy relative to the contained RE.
- Tb: 99.99% Tb relative to the contained RE.

Key findings can be summarised as follows:

- Critical to reduce PLS volumes and improve rare earth grades in the PLS to ensure a feasible long-term processing solution.
- Product options that can be considered range from NdPr oxide, Dy oxide, Tb oxide, low-cerium mixed rare earth concentrate or a low-cerium Nd,Pr,Dy,Tb product. The balance of the rare earths can be stored for future use.
- The estimated opex and capex can be significantly improved if the PLS volume can be reduced to the 40-60 m^3/h range feeding the K-Tech process.
- The desktop study includes a duplicate NF system to further reduce the volumes predicted by Chimerical Technology as K-Tech is confident that further upgrading using NF should be possible based on their experience and pending test work to confirm parameters.

- The forecast, pending test work, indicates that purity levels for the oxide products in the range of 99.5 to 99.9% will be achievable.
- A conservative overall circuit recovery of 80% for the oxide products, based on the initial PLS from the primary leaching process, is assumed for the desktop study, but a higher overall system recoveries should be achievable once test work has been concluded and improved circuit models constructed. It is expected that once into the purification circuit, the circuit recovery, i.e., the final solution entering the CIX/CIC systems should be close to 99%, since there are internal recycle streams to avoid rare earth losses.
- It might be possible to employ a cheaper carbonate intermediate product and tailor the product suite to phases of project implementation with deferred capex and opex impacts.
- Can produce a cerium-depleted mixed rare earth carbonate product with capex and opex reduction as a starter project with a phased move to the refined products.
- K-Tech supports a pre-wash prior to the leach as currently planned for Phalaborwa.
- K-Tech supports the use of the existing gypsum stack water post neutralisation as process water for a large portion of the process, with the exception of high purity water requirements for certain aspects in the CIX and CIC sections. The high purity requirements are low in terms of overall volumes.
- K-Tech can also consider their water treatment technology that can remove impurities and generate saleable products, not just a mixed waste that requires storage, to improve opex costs.

K-Tech recommended the following:

- Investigate counter current leaching to improve PLS tenor and reduce volumes
- Alternative concentration techniques that can negate the use of NF altogether or implicate a lot smaller NF circuit.
- Consider alternative impurity sequestration techniques that include patented and demonstrated K-Tech technology.

Upon completion of the above-mentioned desktop studies by Chimerical Technology and K-Tech, further work was initiated in Australia that constituted the Phase 2 test program at ANSTO.

The conceptual processing options had been defined at this stage with exception of the following sections that have been dealt with in the subsequent test phases:

- Impurity management.
- Reduction of PLS volumes to improve downstream processing costs.

7.5 Phase 2 Test Work Program – ANSTO

With the first phase of testing at ANSTO confirming the key processing requirements and material characterisation information, a preliminary variability study was concluded.

This study focused on applying a standard leach test to 14 selected samples from the individual samples dispatched to ANSTO as part of the phase 1 test work campaign.

The preliminary variability samples were selected based on the following criteria at the time:

- Spatially distributed throughout the two stacks
- Based on the inferred mineral resource estimate, the 14 selected samples covered 70% of Stack A and 30% of the smaller stack B.

The study indicated that the material is very homogenous and behaves consistently under similar leach conditions. The leach extractions range from 60% to 72% total rare earths, with an average extraction of 67%. The phase 1 composite sample yielded a 63% extraction under these conditions.

It must be noted that the conditions at the time were not optimised and served purely to evaluate the performance of the material from various spatially distributed samples in relation to each other.

The primary objective of the Phase 2 work program was to obtain a further definition of the optimised leach conditions and assess potential upfront treatment processes before leaching to remove impurities that could affect downstream processing.

The scope of work completed in this program included:

- Pre-washing the PG feed to remove soluble impurities.
- Optimisation leach tests to refine leach parameters, including temperature, acidity, type of lixiviant and slurry density.
- Testing of PLS recycle, in both sulfuric and hydrochloric acid leach matrices.
- Solution speciation modelling.

7.5.1 Head Sample

The same original Phase 1 Phalaborwa PG composite was used in this program. As per the previous Phase 1 program, all head samples and residues were dried at 55°C prior to analysis and use in leach tests, with the aim of not removing waters of hydration associated with the gypsum. However, during the course of this test program, it was identified that slurrying of the PG feed in gypsum saturated water, as occurred in the upfront pre-washing step, changed the waters of hydration associated with the phosphogypsum.

Therefore, head and residue samples were dried at 105°C to remove all associated waters of hydration from the samples and allow direct comparison of the samples before and after pre-washing and leaching. A comparison of the initial head sample and a pre-washed sample, after drying at 55°C and 105°C, is shown in Table 7.11. All test residues were subsequently dried at 105°C before analysis throughout the program.

The results on the bulk sample showed complete dissolution of magnesium from the phosphogypsum, along with ~75% sodium, ~40% potassium and ~35% phosphorus dissolution.

The removal of magnesium and sodium present in the PG feed, along with some phosphorus and potassium, will positively impact the purity of the downstream PLS after leaching.

Table 7.11: Comparison of Head and Washed Residue Dried at Elevated Temperature

ID	Phase 2 Composite		Pre-Wash Bulk 2	
Drying Temperature	55 (°C)	105 (°C)	55 (°C)	105 (°C)
	% w/w		**% w/w**	
Mg	0.017	0.039	<0.01	<0.01
Na	0.045	0.064	0.013	0.015
P	0.449	0.518	0.273	0.312
	ppm	ppm		
La	588	690	543	694
Ce	1,578	1,828	1,275	1,851
Pr	199	229	200	231
Nd	903	1,055	861	1,055
Sm	161	190	160	189

ID	Phase 2 Composite		Pre-Wash Bulk 2	
Drying Temperature	55 (°C)	105 (°C)	55 (°C)	105 (°C)
Eu	32	37	31	37
Gd	104	123	103	123
Tb	9	11	9	11
Dy	33	38	32	38
Ho	4	4	4	4
Er	6	7	6	7
Tm	<2	<2	<2	<2
Yb	2	2	<2	2
Lu	<2	<2	<2	<2
Y	98	114	99	116
Total REE (incl. Y)	**3,715**	**4,330**	**3,323**	**4,358**

7.5.2 Sulfuric Acid Leach Optimisation

7.5.2.1 Washed vs Unwashed Feed

The rare earth extraction was essentially the same from the unwashed and pre-washed PG feed under the same leach conditions (150 g/ℓ H_2SO_4, 12 h, 40°C, 35 % w/w). However, comparing the leach primary filtrates demonstrated the value of the pre-washed feed, with considerably less potassium, phosphorus and sodium and almost negligible magnesium present in the primary filtrate (PF). The acid consumption was also lower with pre-washed feed.

7.5.2.2 Comparison of Temperature

Three tests were completed at 150 g/ℓ H_2SO_4, 35 % w/w slurry for 12 hours, and temperatures of 30, 40 and 50°C. The final leach extraction was similar for all tests. However, there was a kinetic effect, with the extraction complete by 8 hours at 40 and 50°C, whereas at 30°C, the reaction continued to 12 hours.

7.5.2.3 Comparison of Slurry Density

Tests were completed at 110 g/ℓ H_2SO_4 for 12 hours at 20, 25 and 30 % w/w to compare the effect of slurry density on leach extraction. The results showed only a slight reduction in REE extraction as the slurry density increased.

7.5.2.4 Comparison of Leach Acidity

Prior to commencing PLS recycle tests, three leaches were conducted at 75, 110 and 150 g/ℓ H_2SO_4 to determine the preferred acidity for optimum REE extraction in sulfuric acid. The results in Table 7.12 show similar extractions were obtained at 110 and 150 g/ℓ H_2SO_4 (66% total REE+Y) compared to 62% at 75 g/ℓ H_2SO_4.

Based on these results, the PLS from test L2 (110 g/ℓ H_2SO_4) was taken forward into the PLS recycle tests.

Table 7.12: Comparison of Leach Acidity Optimisation

Test ID	Rain-2-L1	Rain-2-L2	Rain-2-L3
Target Acidity (g/ℓ H_2SO_4)	**75**	**110**	**150**
Temperature (°C)	40	40	40
Duration (h)	12	12	12
Acid Cons. (kg/t)	14	15	15

Test ID	Rain-2-L1	Rain-2-L2	Rain-2-L3
Mass Loss (%)	2	5	3
	Extraction (%)		
Nd/Pr	59	64	64
Dy/Tb	56	61	59
LRE	62	66	67
MRE	59	63	63
HRE	65	71	71
TOTAL REE (+Y)	62	66	66

1.1.1 PLS Recycle Tests

The primary filtrate (PF) from test L2 (110 g/ℓ H_2SO_4) was carried forward and recycled a further four times by contacting the PF with fresh pre-washed PG feed with each cycle. With the first recycle (i.e., cycle 2), the REE extraction was slightly lower but then decreased significantly on the third cycle. The extractions continued to decline in the fourth and fifth cycles (Table 7.13).

Table 7.13: Acid PLS Recycle Tests

Test ID	Rain-2-L2	Rain-2-L9	Rain-2-L10	Rain-2-L11	Rain-2-L12	Rain-2-L16
Acidity	110 g/ℓ H_2SO_4	110 g/ℓ H_2SO_4	110 g/ℓ H_2SO_4	110 g/ℓ H_2SO_4	110 g/ℓ H_2SO_4	110 g/ℓ H_2SO_4
Feed	Pre-Washed	Pre-Washed	Pre-Washed	Pre-Washed	Pre-Washed	Rain-2-L12 Residue
Leach Solution	**110 g/ℓ H_2SO_4**	**L2 PF**	**L9 PF**	**L10 PF**	**L11 PF**	**110 g/ℓ H_2SO_4**
Slurry (% w/w)	30	30	30	30	30	30
Temp. (°C)	40	40	40	40	40	40
Duration (h)	12	12	12	12	12	12
P in PLS (mg/ℓ)	504	674	1,443	1,763	2,064	69
	Extraction (%)					
Nd/Pr	64	58	42	36	31	47
Dy/Tb	61	56	40	36	30	41
LRE	66	61	44	39	33	47
MRE	63	58	41	36	30	46
HRE	71	65	52	49	45	56
TOTAL REE (+Y)	**66**	**61**	**44**	**39**	**33**	**47 (70[#])**

The high gangue element concentrations in the recycled PLS, were assumed to be contributing to the lower REE recoveries.

To understand whether the lower recovery was due to re-precipitation or to the inhibition of extraction, an additional leach test (L16) was conducted where the cycle 5 leach residue was re-leached with fresh lixiviant. The test showed that the un-leached or re-precipitated REEs could be recovered in a two-stage process and confirmed that the likely cause of reduced/inhibited REE recovery with multiple recycle stages was the composition of the leach liquor.

7.5.3 Solution Speciation Modelling

Solution modelling identified >400 species potentially present in the Phalaborwa sulfuric acid leach system.

Calculations were performed using a base case liquor composition (based on the results of the laboratory work at ANSTO and the assumption that 50-80% of the leach solution would be recycled back to the leach

The calculations performed in the presence of Al^{3+}, Si^{4+} and B^{3+} showed Al^{3+} prevented the rare earth elements from precipitating but the addition of B^{3+} or Si^{4+} had no effect.

At the conclusion of this phase of testing at ANSTO, the following observations and conclusions could be drawn:

- The phosphogypsum (PG) appears homogenous spatially and responds with a consistent rare earth extraction to standard leach conditions.
- The PG is present in the stacks in a dual hydration state and pre-washing changes the hydration state of the PG.
- A gypsum-saturated pre-wash removes various impurities from the solid PG stream prior to leaching.
- The effects of temperature, solids concentration and acid strength were confirmed for the PEA study.
- Loaded leach solution (PLS) when recycled over the leach in a counter current fashion will reduce the downstream processing volumes but impurities will build up and suppress rare earth extraction.

These findings led to the conceptualisation of the following processing considerations for Phalaborwa:

- Impurities will need to be controlled in the leach circuit to ensure economic rare earth extraction and reduce downstream processing volumes. Pre-washing alone due to hydraulic reclamation will not be sufficient from an impurity control perspective.
- It appears, pending further confirmation, that 110 g/ℓ sulfuric acid strength will be required for the rare earth leach.
- A pretreatment leaching process can allow for impurity removal from the gypsum and can be coupled to patented K-Tech impurity removal technology to isolate the removed impurities. This would be carried out prior to the main rare earth leaching step. This strategy will allow for successful PLS recycling and reduced downstream processing volumes.

A strategy that consisted of impurity control and reduced PLS volumes was developed, in collaboration with K-Tech, with a test program at the K-Tech facilities in Florida employing a 100 kg composite phosphogypsum sample from Phalaborwa.

In order to support this work and finalise the final building blocks for the PEA flowsheet, the following additional test programs were concluded:

- Stack water neutralisation test work at SGS Johannesburg.
- Thickener settling test work at Roytec Global in Johannesburg.

7.6 Stack Water Neutralisation Test Work

Stack water collected from the stacks at Phalaborwa was shipped to SGS South Africa in Johannesburg for neutralisation test work. The criteria for the test work was to demonstrate the reagent demand and neutralised water quality post neutralisation as this will form an important basis to treat current site water for use as process water.

7.6.1 Head Analysis

A 100 ml sub-aliquot sample of the composite solution was submitted to SGS laboratory and X-Lab Earth Science laboratory for the analysis of the following (Table 7.14 and Table 7.15):

- Multi-element Analysis by ICP-OES.
- Multi-element Analysis by ICP-MS.
- pH.
- Conductivity.
- Total hardness as mg CaCO3 / litre.
- TDS mg/ℓ.
- Cl^-
- NO_3.

Table 7.14: Head Analysis of Stack Water from Phalaborwa

Ag	As	Bi	Cd	Ce	Co	Ga	Ge	Hg	Ho	In
mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
0.006	1.31	0.004	0.022	1.214	2.261	0.218	<0.02	0.001	0.048	<0.001

La	Lu	Mo	Nb	Nd	Ni	Pb	Pr	Sb	Sc	Se
mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
0.624	0.01	0.066	0.03	0.662	4.56	0.058	0.155	0.012	0.301	<0.05

Sm	Sn	Ta	Te	Tl	Tm	U	W	Y	Yb
mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
0.181	0.01	0.024	<0.02	0.016	0.014	0.734	0.03	0.658	0.074

Table 7.15: Stack Water Quality

pH	Total Hardness as $CaCO_3$	Conductivity	TDS	Chloride	Nitrate	Magnesium
	mg/ℓ	Ms/m	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
1.4	11,000	1,880	69,000	1,580	50	2,120

The data correspond well with that for site water monitoring over extended periods of time.

7.6.2 Neutralisation Tests

Tests were concluded with both limestone and lime but only the lime data is presented below from a process development perspective.

The data for the acid solution neutralized using lime slurry is shown in Table 7.16. The lime addition to attain a final pH of 7.2 was 34.3 g/ℓ. The total mass of the filtered precipitates was 399 grams generated from a starting solution of 4 litres of stack water.

Table 7.16: Lime Neutralisation Data

Time (Hours)	pH Before	Lime Addition	PH After	Precipitate Mass	Lime Addition
Units		mℓ		(g)	(g/ℓ)
0.25	1.40	150	1.74	99.5	3.8
0.5	1.74	240	2.16		6.0
1	2.16	150	3.40		3.8
1.5	3.37	200	4.22	172.2	5.0

Time (Hours)	pH Before	Lime Addition	PH After	Precipitate Mass	Lime Addition
Units		mℓ		(g)	(g/ℓ)
2	4.22	130	5.24		3.3
2.5	5.25	250	6.02	127.4	6.3
2.75	6.02	200	6.75		5.0
3	6.75	50	7.20		1.3
Total		**1,370**		**399.0**	**34.3**

The reduction in the concentration of chlorine, calcium and magnesium elements in the solution is shown in Table 7.17. Chlorine precipitation was limited, with an overall reduction of 21.5%. Overall reduction was calculated based on the feed value and the final value at pH 7.

Table 7.17: Elemental Reductions

Stage	Chloride		Calcium		Magnesium	
	mg/ℓ	% Reduction	mg/ℓ	% Reduction	mg/ℓ	% Reduction
pH 1.4	1,580		891		2,120	
pH 3	1,450	8.23	2,340	-162.63	2,310	-8.96
pH 5	1,540	-6.21	161	93.12	1,480	35.93
pH 7	1,240	19.5	50	68.9	294	80.1
Total		**21.5**		**94.4**		**86.1**

The decrease in multi-elements at each stage is shown in Table 7.18. Approximately 56% of all the listed elements precipitated out of solution by a magnitude of at least 85%.

Table 7.18: Multi-element Reduction by the Addition of Lime

% Reduction	**Ag**	**As**	**Bi**	**Cd**	**Ce**	**Co**	**Ga**	**Ge**	**Hg**	**Ho**	**In**
pH 3	27%	0%	25%	0%	100%	22%	98%	0%	0%	96%	0%
pH 5	82%	15%	25%	82%	100%	32%	100%	0%	0%	96%	0%
pH 7	*9%*	*54%*	*25%*	*95%*	*99%*	*99%*	*100%*	*0%*	*33%*	*96%*	*0%*
% Reduction	**La**	**Lu**	**Mo**	**Nb**	**Nd**	**Ni**	**Pb**	**Pr**	**Sb**	**Sc**	**Se**
pH 3	100%	70%	63%	93%	99%	7%	71%	98%	0%	18%	0%
pH 5	100%	70%	63%	97%	99%	15%	78%	98%	0%	35%	0%
pH 7	*99%*	*70%*	*69%*	*97%*	*99%*	*93%*	*97%*	*98%*	*0%*	*91%*	*90%*
% Reduction	**Sm**	**Sn**	**Ta**	**Te**	**Tl**	**Tm**	**U**	**W**	**Y**	**Yb**	
pH 3	98%	0%	91%	0%	25%	71%	83%	25%	100%	97%	
pH 5	98%	0%	91%	0%	38%	71%	98%	51%	100%	97%	
pH 7	*98%*	*0%*	*87%*	*0%*	*75%*	*71%*	*95%*	*77%*	*99%*	*97%*	

The lime utilized had a purity of 96%. The impurities associated with the lime were: As 0.0003%, Cu 0.001%, HCl insoluble matter 0.5%, Pb 0.001% and Zn 0.002%. It must be noted that laboratory-grade hydrated lime was used for the testing.

It was demonstrated that neutralised stack water would be suitable as general process water and the neutralisation plant will successfully control major impurity levels in the pre-leach wash circuit employed for hydraulic reclamation.

7.7 Thickening Test Work

A composite sample was composed and dispatched to CM Solutions / Roytec Global facilities for testing.

7.7.1 Sample Preparation

The leached sample was prepared and supplied to Roytec Global by CM solutions.

For settling test work, the supplied samples were diluted using process water provided by CM Solutions to produce feed solids concentrations of 10, 12.5 and 15 % w/w.

The preparation procedure by CM Solutions was as follows:

Leach test work conditions:

- 25 % w/w solids (made up of provided phosphogypsum solids and site stack water neutralised using lime to a pH of 6.5).
- Temperature of 40˚C.
- 24-hour residence time.
- Lixiviant consisted of 150 g/ℓ acid in neutralised stack water.

The key findings from the test work can be summarised as follows:

- The results show that flocculant SC510A produced favourable settling, solids flux rates and overflow clarities based on a free settling rate target of 20-30 m/h.
- At 10 % w/w feed solids concentration and with Setchem’s SC510A flocculant, free settling rates above 20 m/h were achieved at a dosage of 10 g/t or more.
- At 12.5 % w/w feed solids concentration, a dosage of 30 g/t was required to achieve a settling rate above 20 m/h.
- At 15 % w/w, dosages up to 40 g/t yielded settling rates lower than 14 m/h.
- The overflow clarity, below 15 Nephelometric Turbidity Units (NTU), was acceptable for all dosages.
- Fluxes between 2.0 t/m^2.h and 2.8 t/m^2.h were achieved at 10 % w/w.
- The achieved terminal underflow density was 65.3 % w/w.
- The yield stress at terminal underflow density was 240 Pa. Dilution to 55 % w/w reduced the yield stress to less than 60 Pa.

The test work concluded that the material exhibits acceptable settling characteristics and that the inclusion of thickeners in the flow sheet can be beneficial from a vacuum filtration design perspective and solid-liquid separation stages in a counter current leach circuit.

A test work campaign has supported this work at K-Tech facilities in Florida, USA.

7.8 K-Tech Phase 1 Study and Test Work Campaign

RRE in collaboration with K-Tech, formulated a strategy for impurity sequestration technology demonstrated and patented by K-Tech for the extraction of impurities from phosphoric acid gypsum stack and cooling pond water systems.

K-Tech then detailed a test program, capturing all previous test work and learnings that considered the following key aspects to finalise a process flow sheet for the PEA study:

- Impurity control.
- Rare earth leach system.
- Rapid consolidation stage to eliminate the use of NF in the main circuit.
- Continuous ion exchange and continuous ion chromatography for rare earth purification and separation.

The K-Tech test work program is ongoing and will progress through various stages of continuous refinement, culminating in an integrated pilot plant operation for the total process. A secondary NF test program at Membrane Development Specialists (MDS), California, USA was commissioned to prove the concept of maximum acid recovery and upgrade potential defined during the previous NF desktop study. This program will generate information that can be employed on the PLS or on small streams in the CIX and CIC sections of the process for reagent recovery and solution upgrade duties.

Key aspects from the K-Tech test program that have been tested and incorporated in the current PEA flowsheet can be summarised as follows:

- Phosphogypsum (PG) will be pretreated for impurity removal prior to the primary RE leach.
- Various techniques were tested for the rapid consolidation stage. The resultant PLS from the rare earth leach circuit will be treated in a continuous consolidation section that yields a small volume, high-value rare earth stream, for further processing, and a bulk acid solution for recycling back to the leach circuit.
- The impact of recycling streams is currently being tested and no red flags have been raised thus far.
- The rapid consolidation step also indicates good impurity rejection capability prior to the CIX/CIC system, as well as reducing the RE-containing solution volume to amounts below those earlier estimated in the desk study
- Current test work is focused on separating the main rare earth groups employing the K-Tech technology in continuous ion exchange configuration, followed by separating and isolating the target products. K-Tech is confident that high recovery will be possible and high purity final rare earth oxides will be produced in the circuit based on testing with other rare earth systems.

This concludes the PEA study's test work and process development section that culminated in the simplified block flow diagram shown in Figure 7.17 below.

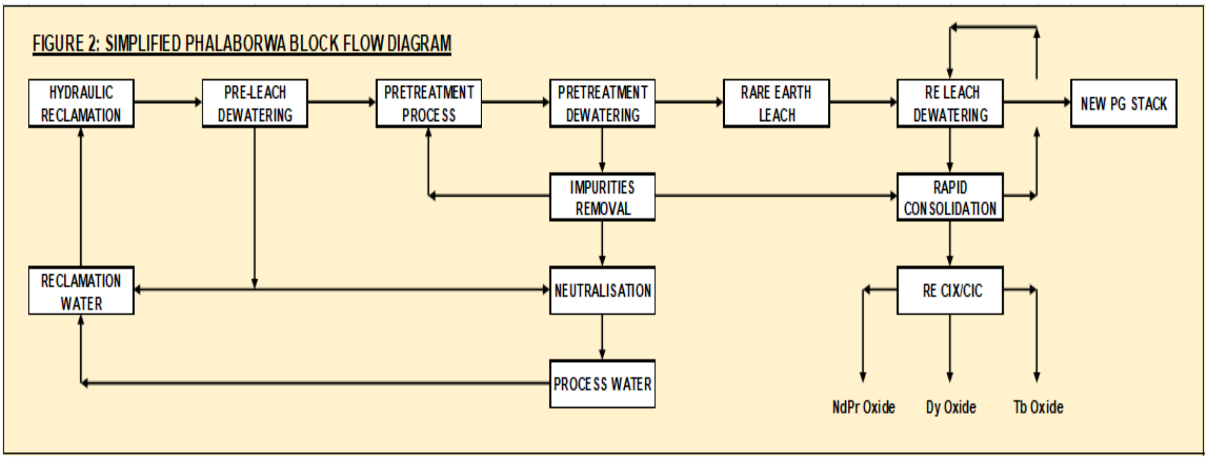


Figure 7.17: Simplified Block Flow Diagram

With reference to the above BFD the following key comments are applicable

- Phosphogypsum will be reclaimed hydraulically from the existing stacks and pumped to the processing facility. This process allows for a wash action on the reclaimed gypsum and the pre-processing dewatering will allow for a water balance break. It will also remove soluble impurities prior to the leach process. This has been conclusively proved in the latest test work programs.
- During the phase 1 and 2 ANSTO test work programs, supported by the K-Tech test program, an impurity leach regime was established that allows for the removal of impurities from the gypsum stream, thereby allowing rare earth grades in the PLS to be maximised.
- The PLS from this section can then be processed using K-Tech patented technology for the sequestration of impurities.
- The rare earth leach system consists of multiple leach and solid-liquid separation stages for the efficient recovery of the rare earth elements and allows for successful recycling of the various acid streams to optimise the overall processing costs and solution balance.
- With PLS recycling the rare earth leach system serves as a primary PLS volume reduction system and allows for upgrading of the PLS rare earth solution tenor.
- The PLS stream from the rare earth leach circuit is then treated in a rapid consolidation section where the rare earths are concentrated with primary impurity rejection and a high degree of lixiviant recycling to the primary leach circuit.
- The rapid consolidation circuit significantly reduces the feed flow to the downstream CIX and CIC circuits, resulting in capital and operating cost savings.
- Various recycling streams will ensure a high degree of overall rare earth recovery in the circuit, with an overall recovery of 65% to 70% of the contained rare earths from the gypsum stacks.
- A neutralisation plant will process raw stack water, rendering it suitable as general process water. This approach will also, in due time, reduce major impurities in the raw water system on-site with a positive site wide environmental impact.
- In conjunction with by-product sales of high-quality gypsum, various final stacking options are being considered to offset on-site long-term stacking requirements.

This section must be read in conjunction with the process description, overall block flow diagram and process design criteria as presented in other sections of the PEA document.

8 PROCESS PLANT

8.1 Overall Description

Phosphogypsum (PG) residue is hydraulically reclaimed from the stacks at a rate of 2.29 Mt/a dry solids equivalent and pumped to the process plant for trash and coarse waste removal using linear screens. The design feed rate to the hydrometallurgical plant is 2.2 Mt/a dry solids equivalent. The screened slurry is dewatered using thickening and vacuum belt filtration with the reclaimed water being recycled and a portion neutralised for use as process water.

The dewatered solids are first treated to control impurities, and to prepare the phosphogypsum, for subsequent leaching to extract the rare earths contained in the solids. The spent pretreatment solution is further processed to recover various materials for potential use or recycle.

The pretreated phosphogypsum is then transferred to rare earth leaching using sulfuric acid to remove the rare earths from the pre-treated gypsum. The leached gypsum is then filtered, washed, and transferred to a new, lined gypsum disposal stack.

A counter current acid leaching process is included to increase rare earth concentration in leach solution. Multiple leaching stages facilitate maximum rare earth extraction from the phosphogypsum with minimal solution volume, with the optimisation of solid/liquid contact and kinetics.

The pregnant leach solution (PLS) from the RE leach is pumped to a rapid consolidation circuit for rare earth concentration prior to recovery.

The concentrated rare earth solution from rapid consolidation is transferred to a continuous ion exchange (CIX) system for extraction of the RE’s from the solution. The spent (low rare earth) solution is recycled within the process.

Once loaded onto the ion exchange resin, the resin is further treated to remove the co-extracted impurities that may load with the rare earths. This treatment technique allows for multiple functions to be carried out within the overall CIX system. The resin is regenerated, and the recovered rare earths are sent to a continuous ion chromatography (CIC) system, where the rare earths are separated from each other.

The separated rare earths then transfer to a recovery system where they are precipitated and recovered as individual specific products of a desired product purity.

The rare earth refining circuit combines ion exchange, chromatography, nanofiltration, precipitation and calcining to produce three saleable products: neodymium/praseodymium oxide, dysprosium oxide, and terbium oxide at a total production rate of 1,848 t/a. The remainder of the rare earth basket is stored for future consideration as an intermediate salt.

8.2 Gypsum Feed Preparation

The reclaimed PG must be delivered to the process plant at the highest density possible, but this will vary depending on stack conditions and reclaim operations. The average solids content of the slurry delivered to the process plant is estimated to be between 25 and 35 %w/w solids.

The slurry is received from hydraulic reclamation onto two linear degrit screens, operating in parallel, for the removal of trash and any entrained coarse material from reclamation. The oversize of the degrit screens is discharged via gravity, over static screens into two concrete bunkers for safe disposal, using mobile equipment

The screen undersize gravitates into two feed surge tanks installed below the screens. The feed surge tanks ensure a stable feed rate to the pre-leach thickener.

8.3 Pre-Leach Dewatering

The slurry from the feed surge tanks is transferred to two high-rate pre-leach thickeners for primary dewatering. Flocculant is added to the thickener feed to increase the solids settling rate.

The thickener overflow gravitates to overflow tanks and is pumped to two reclaimed water tanks.

The thickener underflow is pumped into the feed tanks of two parallel pre-leach vacuum belt filters for further dewatering of the solids. The primary duty of the pre-leach belt filters is the separation of reclamation and processing solution and as such, no washing of the filter cake is required here.

The filter cake is discharged via gravity into the pretreatment repulp tank for mixing with pretreatment solution and recycled solution from impurity removal before being pumped into the pretreatment tanks.

The filtrate from the belt filters is recycled back to the thickener feed tank to assist in the dilution of thickener feed for flocculant addition and further solution clarification and eventually exits as thickener overflow.

A bleed stream from the clarified water stored in the reclaimed water tanks is transferred to the neutralisation plant for neutralisation with lime to produce process water suitable for reuse in hydraulic reclamation and the process plant.

8.4 Pretreatment

The phosphogypsum filter cake from pre-leach dewatering is repulped in pretreatment solution for impurity control prior to the rare earth leach circuit. Reagents are added to the repulp and pretreatment tanks at a controlled ratio to the pre-leach filter cake.

The pretreatment takes place in closed top, agitated pretreatment tanks. The tanks are sparged with low pressure steam to maintain design reaction temperature,

Pretreatment discharge slurry is pumped to the pretreatment thickener for dewatering, assisted by the addition of flocculant. Thickener underflow is pumped to belt filters for further dewatering. A counter-current filter cake wash is utilised on the belt filters for maximum moisture and impurity displacement to the filtrate. The filter cake is discharged via gravity into the primary extraction step repulp tank, while filtrate is collected and recycled to the thickener feed.

Thickener overflow gravitates to the thickener overflow tank and is pumped to two pretreatment solution tanks. The discharge of the pretreatment solution tanks is split between the pre-treatment and further processing steps to recover re-usable components in the solution. A portion of the pretreatment solution is further treated in the impurity removal circuit while the remainder is recycled to the pretreatment solution preparation tanks.

8.5 Impurity Removal

The pretreatment solution is pumped to a continuous ion exchange circuit for extraction of impurities. A portion of the reduced impurity solution is recycled for reuse in the pretreatment and as wash solution during filtration, and the balance is recycled to other process steps.

The ion exchange resin is regenerated, and the spent regeneration solution is further treated for recovery of the impurities, which can be stored in an isolated fashion for possible future treatment or recovery. A portion of the lowered impurity regeneration solution can be recycled to various process steps for overall fluidity control.

8.6 Rare Earth Leach and Filtration

The pretreatment filter cake is discharged by gravity into the RE leach repulp tank for repulp with RE sulfuric acid leach solution. The bulk of the rare earths is extracted from the phosphogypsum, using a multi-stage, temperature controlled, leaching system.

The RE-loaded leach solution is the pregnant solution and referred to as the PLS, and is stored for feed to the downstream processing steps.

The leached solids are transferred to a belt filter system for dewatering and washing for recovery of entrained rare earth-containing PLS.

The filtered gypsum cake is transferred to a new, lined residue gypsum stack for safe storage and/or disposal. The rare earth PLS is pumped to the next step in the process i.e., the rare earth rapid consolidation system.

The post-leach filter cake is stacked onto the new gypsum stack via a conveyor belt system.

The off-gas generated from the leach tanks is collectively treated in a common leach scrubber to control any potential emissions.

8.7 Rapid Consolidation

The rare earth PLS from the RE leach is stored in PLS surge tanks. The PLS is then pumped to the rapid consolidation system.

The PLS is treated to allow for the consolidation of the rare earths into a much smaller amount of fluid, thus significantly reducing the size of the downstream processing systems which has a significant positive impact on the overall plant capital costs, as well as downstream operating costs. This also allows for improvements in overall impurity control in the systems.

The consolidated rare earths are separated from the RE leach solution and the low rare earth solution is reused within various process steps.

8.8 REE Refining

The concentrated rare earth solution is pumped to the rare earth purification and separation circuit to produce the three saleable products: neodymium/praseodymium oxide, dysprosium oxide, and terbium oxide. It must be noted that various intermediate product options will be possible depending on final economic considerations.

The first refining stage uses a continuous ion exchange system to extract rare earths and further reduce trace impurities. Make-up solutions are sent to the CIX system for regeneration purposes and recovery of rare earths as a concentrated solution for final downstream separations.

The purified RE solution is next transferred to the CIC systems. The low RE solution exiting the CIX system is returned to up-stream processing steps for reuse. A portion can be purged to the gypsum stack as needed for overall process water balance.

The second refining stage consists of a CIC system that separates the rare earths into various groups, e.g., lights, mids, and heavies. The system is configured so that the target rare earth groups can be changed, or recovery of a certain rare earth group increased if required.

The third/final stage is again based on a CIC system. In this stage, the purification of the three targeted rare earth product streams is carried out. The three high-purity streams from the third stage of the REE refining circuits are pumped to separate precipitation steps. The three precipitation slurry streams are filtered to produce high purity rare earth products. The products can be produced as carbonates or as oxides, depending on specific client requirements.

8.9 Neutralisation Plant

The neutralisation plant treats a portion of the reclaimed water from pre-leach dewatering and effluent streams from the process plant to precipitate dissolved metals, neutralise residual acids, and remove other impurities from the aqueous phase. The neutralised water is discharged into the process water pond for reuse in the process plant. The neutralisation plant achieves impurity control of reclamation and process water in all process sections, including processes post-rare earth recovery. Site water is of poor quality and requires purification in the neutralisation process before use.

The discharge of the neutralisation tanks contains precipitated solids which are pumped to the neutralisation thickener for solids removal and recovery of process water at the overflow.

The underflow of the neutralisation thickener is pumped to the neutralisation belt filter for further dewatering to maximise process water recovery and produce a suitable product for dry disposal.

The overflow of the thickener is pumped to the process water pond, while the filtrate of the neutralisation belt filter is recycled to the neutralisation thickener.

8.10 Reagents

The following reagents are to be utilised in the process plant:

- Flocculant.
- Impurity control agent.
- Burnt lime.
- Pretreatment solution reagents.
- Sulfuric acid.
- CIC eluants.
- Purified RE precipitation agents.
- Primary leaching reagents.

The storage capacity for on-site for reagents varies and is based on consumption, safety, the potential for interruptions in supply, etc. Site storage capacities have been provided based on the reagent's supply chain and the risk/probability matrices of each reagent. Reagents that are consumed at a lower rate have longer relative inventory capacities on site, whereas reagents that are used at a higher mass rate have somewhat lower inventory allowances to optimise storage costs and footprint. The source of the reagents has also been considered, and larger allowances have been made for reagents that are imported to mitigate the risk of supply interruptions.

Flocculant is received in a powder form contained in bags and stored on site. The powder is diluted and hydrated in a flocculant make-up tank, and then transferred to a dosing tank from where it is supplied to the process areas.

The impurity control agent is stored in a vertical bin and receives material via truck. The material is transferred to the process via a screw conveyor.

The burnt lime area comprises silos for dry storage followed by a slaking plant for delivery of a lime slurry. The silo and slaking plant are a vendor package designed for the maximum feed rate into the plant.

Pretreatment solution reagents are received via truck and stored in vertical tanks, if in liquid form. Gaseous reagents are received and stored in pressurized bullets. The liquids are then pumped to the usage points and the gaseous reagents transferred via the storage tank pressure via pipelines.

CIC eluent is allocated a drum storage area on site with drums being discharged into a day storage tank. The storage tank is used for supply into the process for surge capacity provision in the case of an interruption in supply.

The purified RE precipitation reagent is received in bulk bags from an international supplier and stored to the design storage capacity in a cool, dry storage area until collected for use.

The sulfuric acid is delivered to the site in liquid bulk tankers and transferred to storage tanks with distribution to the process plant via fixed dosing systems.

8.11 Utilities

The following utilities are available at the process plant and where required, at the administration offices:

- Steam.
- Raw Water.
- Potable Water.
- Compressed/Instrument Air.
- Gland Service/Fire Water.

The steam to be utilised in the plant is delivered at 6 bar(g) from three 20 t/h steam plants supplied as vendor packages with raw water as a water source. A water softening plant is included in the vendor package to reduce scale build-up on the shell/water side of the boilers. Sufficient fuel storage is supplied to allow for 14 days of operation of all the steam plants.

Raw water is available on site from three reservoirs under the management of Lepelle Northern Water. The plant site will have raw water tanks for a storage capacity of 14 days with usage primarily in the steam plants.

Potable water is utilised primarily as the water supply for ablutions and offices. An existing potable water infrastructure from the local municipality is utilised as source for offices and process plant.

The compressed/instrument air to the process plant is supplied by compressor packaged plants including an instrument air dryer to deliver both plant and instrument air at maximum 8 bar.

The fire water system contains tanks for storage, two fire water pumps for distribution to the process plant with a diesel jockey pump on standby for instances of no electricity supply. The fire water is delivered to various fire water hoses strategically positioned to cover the entire process plant.

Gland service supply systems are fed from an independent, higher-pressured raw water system that is fed from raw or purified water supply to prevent scaling and suspended solids in the water.

9 RESIDUE DEPOSITION AND STACK DESIGN

RRE appointed Epoch Resources (Pty) Ltd to undertake a PEA level design for dry stacking of the residue from a processing plant, that will be constructed to re-process existing phosphogypsum stacks to recover rare earth elements. The Epoch scope of work also includes a lined water dam.

9.1 Test Work

Compaction tests and foundation indicator tests were carried out on a small sample of residue. An insufficient sample was available for a full compaction test and only two points on the compaction curve were produced. Therefore, the maximum dry density couldn't be confirmed. However, the results were used as the basis of the design.

The particle size distribution (PSD) was determined through sieving and hydrometer tests to produce the curve, as shown in Figure 9.1. Others also carried out a laser PSD. The cause of the difference between the two curves may be due to the test method or the effects of the leach tests carried out on the sieved and hydrometer test sample. Additional test work is required to clarify the difference between the PSDs. However, this is not expected to affect the design at this stage.

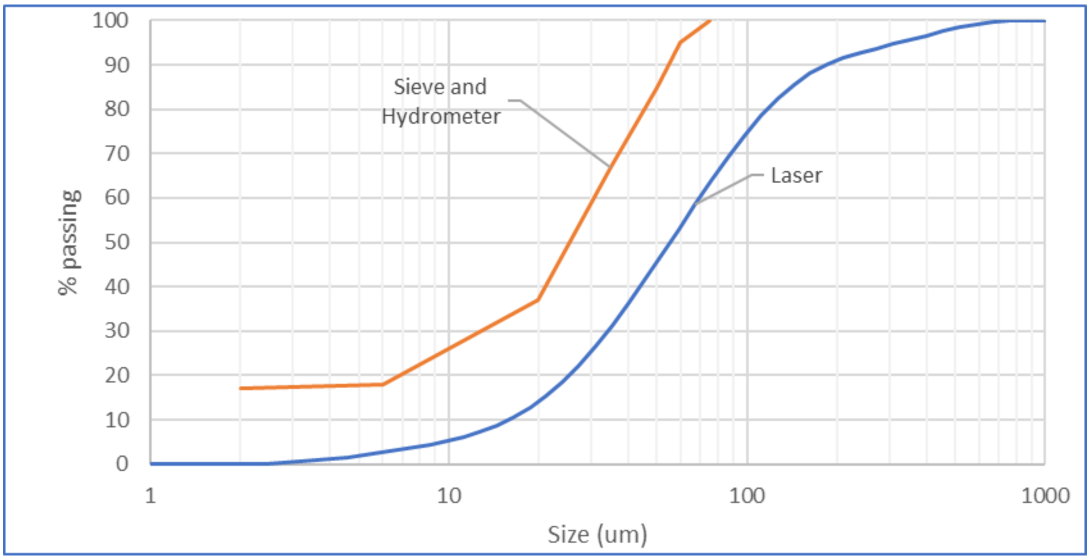


Figure 9.1: Particle Size Distribution Curves

The area of the proposed retreatment project includes two, previously hydraulically deposited, PG stacks (Stack A and B), and an existing process plant (Figure 9.2). A number of water storage dams are spread amongst the existing stacks to contain contaminated water.

9.2 Site Location

Site C, located north of Stack A, and another site south of Stack B were considered to store the residue. Site C was selected as the preferred site for the new Dry Storage Facility (DSF) for the following reasons:

- The site was previously earmarked for a new stack.
- The site is located within an already contaminated catchment downstream.
- It is located near the proposed process plant site (shorter conveyor distance).
- Other options were further from the proposed process plant site and within a more environmentally sound area.

It was determined that sufficient capacity exists at Site C to contain all the residue from the reprocessing of Stack B and some of Stack A. Therefore, a second DSF on the cleared footprint of Stack B has been proposed for the remainder of the residue. Further studies are required to confirm that these sites will be suitable for storing the residue over the Life of Operation. It is recommended the southern site is also investigated in case the other sites are not suitable, particularly as the new Stack B will be located over a reclaimed footprint.

Once the reclamation of Stack B commences, a large portion of the water storage capacity will be lost. Therefore, a new water storage dam may be required to accommodate the water currently stored on Stack B. Epoch was requested to design the new water storage dam. Two locations were identified, as shown in the layout in Figure 9.2.

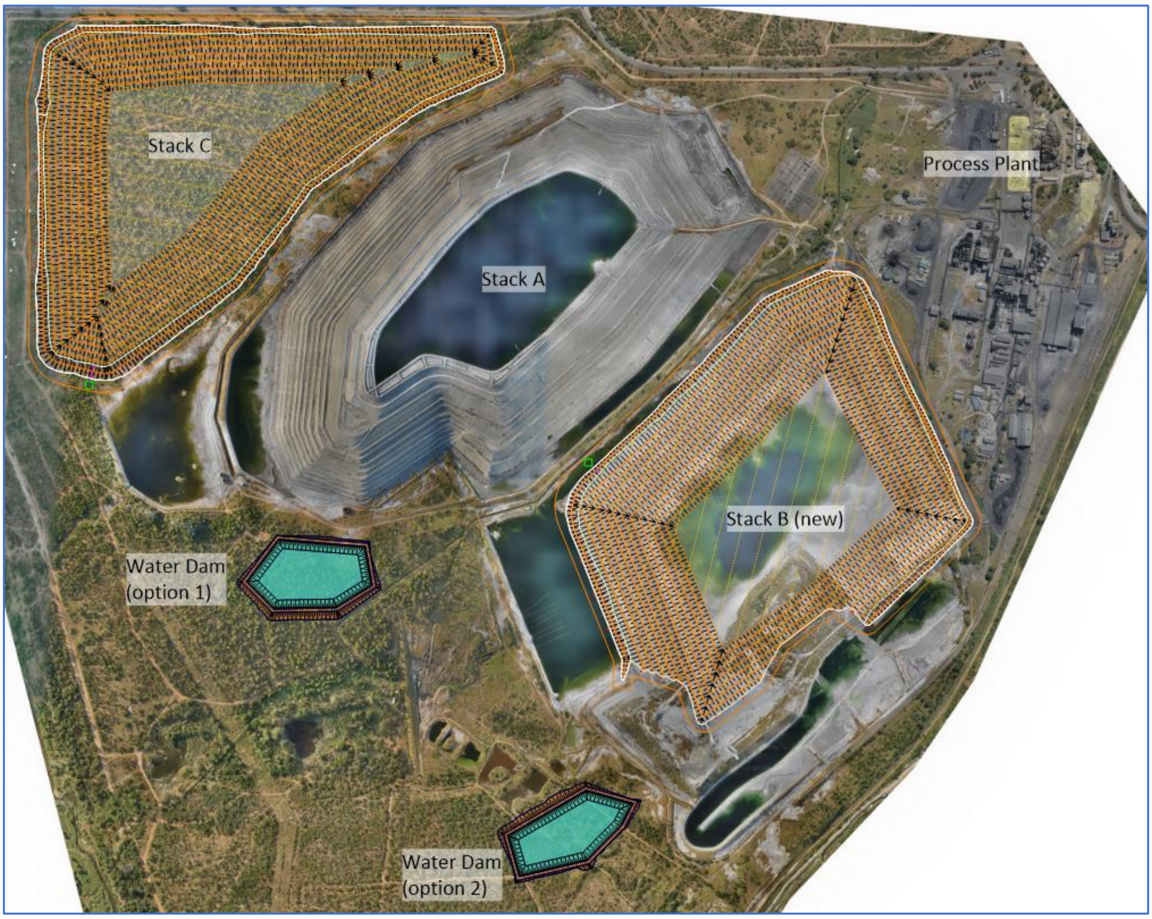


Figure 9.2: Site Layout

9.3 Dry Stacking Facilities - Design

The DSFs are required to accommodate a volumetric storage capacity of 30,700,000 dry tonnes, corresponding to 25,580,000 m^3, over a 14-year Life of Operation and comprise the following:

- Two DSFs (Stack C and B).
- Class C Liner (described below), with a sand protection layer.
- A perimeter earthfill bund wall.
- Toe drains.
- Toe catchment paddocks.
- Drainage collection sump.

The general arrangement of the proposed DSFs is shown on the drawing in Appendix J. The key design features of the DSFs are as follows:

- A perimeter compacted bund wall to contain the initial production of residue and to contain seepage water collected by the drains. The bund wall height will vary between 7 m and 2 m, depending on the topography. It was assumed that *in situ* soils within the footprint of the DSF will be suitable for this construction. However, Stack B may require an external source of borrowed material to construct the starter bund wall.
- A filter toe drain will be placed on the inside toe of the bund wall, to convey any seepage that may percolate through the residue to the Return Water Sump (RWS).
- The drain will convey seepage water to a sump from where it may be returned to the plant or discharged (depending on water quality and environmental constraints).
- Toe paddocks at the outer toe of the bund wall will contain run off and residue sediment eroded from the side slopes of the stack.
- It has been assumed that the base of the stack will be lined with a Class C liner; however, the waste classification test work is required to confirm the necessary level of containment. A Class C liner comprises a 1.5 mm HDPE geomembrane, Geosynthetic Clay Liner (GCL), leakage detection and a sand protection/cover layer.

The residue will be conveyed to the site, from where it will be spread and allowed to dry sufficiently to allow compaction. The residue will be shaped with outer slopes of 1V:2.5H, with 5 m benches, every 5 m.

9.3.1 Stage Capacity and Site Planning

The residue will be stacked at Stack C during the reclaiming of Stack B. Following the reclaiming of Stack B (3.96 years), reclamation of Stack A will commence. The capacity of Stack C will be reached after 9.15 years, after which the footprint of Stack B will be used for the new Stack B. Stack B will last for the remaining 4.85 years.

A summary of stage capacity information is shown in Table 9.1, which shows the residue elevation and rates of rise for each Stack.

The final rate of rise at Stack C is high. To reduce this to ±8 m/year it may be required to truck a third of the residue to Stack B, until Stack C has been completed (last 5 m of the stack or 7 months), before moving the conveyor to Stack B. This may be confirmed during operations if the residue dries well and is trafficable.

Table 9.1: Stage Capacity Information

Stack	Life of Stack	Final Elevation (MAMSL)	Height (meters)	Capacity (million cubic meters)	Capacity (million tonnes)	Final Rate of Rise (m/year)
Stack C	9.15	420	61	14.9	20.1	13 (8.6)
Stack B	4.85	390	40	7.85	10.6	7.3

A starter bund has been provided around the DSFs to contain the initial production of residue and to contain seepage, which the toe drains collect. The height of the starter bund will have an average height of 2 m and a maximum of 6 m at the lowest point. The crest will be 5 m wide, where the line will be anchored.

The residue will be conveyed from the process plant and onto the stack at the zones currently being deposited at. Dozers will be used to loosely spread the residue to allow the residue to dry to its optimum moisture content. Once the optimum moisture content has been reached, the residue will be compacted using drum rollers. The residue will be placed, compacted and raised upwards in 300 mm layers. A 5 m bench will be created every 5 m gained in height. The side slopes will be 1V:2.5H.

9.3.2 Residue Storage Facility Preparatory Works

The preparatory works associated with the DSF comprise the following:

- Topsoil stripping to a depth of 300 mm beneath the DSF footprint.
- A box cut to a depth of 500 mm beneath the starter bund wall.
- A compacted starter bund wall with the following dimensions:
  - 2 to 6 m high.
  - 5.0 m crest width.
  - 1V:2H internal side slope.
  - 1V:3H external side slope.
- A toe-drain inside the starter bund wall to collect seepage water within the DSF. This will comprise the following:
  - A 500 mm deep, 3 m wide trench above the liner.
  - Filter sand, 6 mm stone and 19 mm stone layers.
  - A 160 mm perforated pipe at the base of the drain.
  - A 160 mm non-perforated outlet pipe, conveying water out of the stack.
  - 3 x 160 mm non-perforated pipes to convey water to the RWS.
- A Class C liner at the base of the DSF, comprising:
  - A 100 mm sand protection layer.
  - 1.5 mm HDPE geomembrane.
  - Geosynthetic Clay Liner (GCL).
  - Leakage detection drains.
- Toe catchment paddocks at the toe of the stack. Comprising 500 mm high earth bunds.

As no stability analyses have been conducted in this project stage, the DSF side slopes configuration will need to be re-evaluated in the project's next phase, as well as the size of the drains.

10 INFRASTRUCTURE

The PREP will be constructed adjacent to the phosphogypsum stacks on the BP property located near Phalaborwa in the Limpopo province of South Africa. The BP site covers ~650 hectares, of which around 300 hectares have been developed and used for operations (e.g., processing plants, water dams, gypsum stacks etc.).

Figure 10.1: Bosveld Phosphates Property Location

Most of the infrastructure is positioned in the northern part of the property, with the south being largely undisturbed virgin bush.

The project is located on the outskirts of Phalaborwa, a well-established mining and services town with ~150,000 inhabitants (2011 census). Phalaborwa has good infrastructure such as roads, power and water supply. There are a number of large-scale mines in close proximity, including the Foskor (Pty.) Ltd. (Foskor) open pit and Palabora Mining Company Ltd. (PMC) open pit, now converted into an underground mine.

A phosphoric acid plant was constructed on the BP site and commissioned in 1965 and underwent several expansions until it was mothballed in 2014. During its operation, the site catering for up to 600 personnel (including shift workers) and has significant infrastructure to serve the needs of the plant and operational personnel, much of which will be retained for the RRE project.

Existing infrastructure that will be used for the project includes:

- HV switchyard.
- Perimeter security fence and operational manned security gate.
- Electricity reticulation.
- Workshops, store buildings, and machine shops only require minor refurbishment.
- An operational laboratory which will be equipped to cater for specific operational needs.
- Two operational rail sidings.
- Operational administration buildings.
- Bitumen surfaced roads from Johannesburg to the gate of the Bosveld property.

- Fully operational weighbridge.
- An airport within a 5-minute drive of the site.
- Ablution blocks and change house.
- Fully operational sewerage reticulation and treatment system.

Although the operation of the phosphoric acid plant ceased in 2014, the site is still active. Bosveld have 27 personnel on site, primarily to maintain existing infrastructure and to ensure conditions of environmental permits are met (e.g., managing water storage levels on the phosphogypsum stacks).

Part of the original plant was converted, in 2018, into a dry magnetite concentrating facility (MP2) that is owned and operated by the KBH Group (Pty.) Ltd. (KBH). A second (wet) magnetite concentrator (SAOB), also owned by KBH Group and operated under contract by Minerals Operations Executive (Pty.) Ltd. (Minopex), was constructed in an open area between the phosphoric acid plant and the HV substation in 2019. Approximately 80,000 tonnes of magnetite is processed between the two plants monthly. The feed to both plants is delivered by truck from the nearby Foskor waste stockpile. Concentrate leaves the site either by rail or by road.

The phosphoric acid plant will be partly demolished and rehabilitated before BP's construction of the RRE project so that the new processing plant can be constructed within this area and utilise as much of the existing infrastructure as possible. Critical infrastructure to be retained includes HV power lines, HV substation, bulk water supply, security infrastructure, water drainage systems and various buildings such as workshops, machine shops, laboratory and stores.

10.1 Bulk Infrastructure

10.1.1 Power Supply

Power is supplied by Eskom, the state-owned national power company, to the existing HV substation on the site via a high-voltage overhead power line. The line enters the BP property in the southwestern corner, from where it is routed in a northerly direction, parallel to the Ga-Selati River to the north-western corner of the property, where it exits the property. The line then runs parallel to the northern border until it re-enters near the HV yard, where it terminates.

Figure 10.2: HV Power Line Route

The existing HV (66/11 kV) substation is rated at 60 MVA, with 3x20 MVA main incomer transformers connected to the 3 incoming 66kV ESKOM lines. At peak, BP had an Eskom reserved network capacity of 20MVA. Only one of the main incomer transformers is currently in operation and the Eskom reserved network capacity has been reduced to 5 MVA to supply the current demand at the site.

10.1.2 Water Supply

Bulk water is supplied to the BP property by Lepelle Northern Water (LNW), a state-owned water utility that supplies the area. Water is supplied as “domestic” and “industrial” (river) water to 3 existing bulk storage reservoirs located northeast of the BP property, from where it is reticulated to users on the site. Both sources are regularly tested, and water quality exceeds the requirements for the project.

BP is currently permitted to use 2,000 m^3 of domestic and 5,000 m^3 of industrial water per day from this source. Current consumption is 20 m^3 of domestic and 250 m^3 of industrial water per day.

10.1.3 Fuel Supply

Diesel will be supplied to the plant via diesel road tankers operated by the local fuel suppliers. The diesel will be decanted into an existing 23,000-litre underground storage tank and petrol in an adjacent 14,000 tank. Mobile equipment utilised in the plant will refuel from these facilities, and records will be kept of all vehicles utilising the facility and consumptions recorded for reconciliation purposes.

10.2 General Infrastructure

10.2.1 Road Transportation

Phalaborwa is located in Limpopo province, 522 km by road from Johannesburg. The town is well developed and has significant usable infrastructure.

Phalaborwa is accessible by good bitumen surfaced road infrastructure from Johannesburg via either Polokwane (522 km) or Lydenburg (527 km). The route via Lydenburg is commonly used for transporting goods between South Africa and Mozambique, particularly via the port of Maputo. The journey by car takes around 6 hours via Polokwane, or 6-7 hours via Lydenburg with moderate traffic. Figure 10.3 shows the road routes from Johannesburg to Phalaborwa.

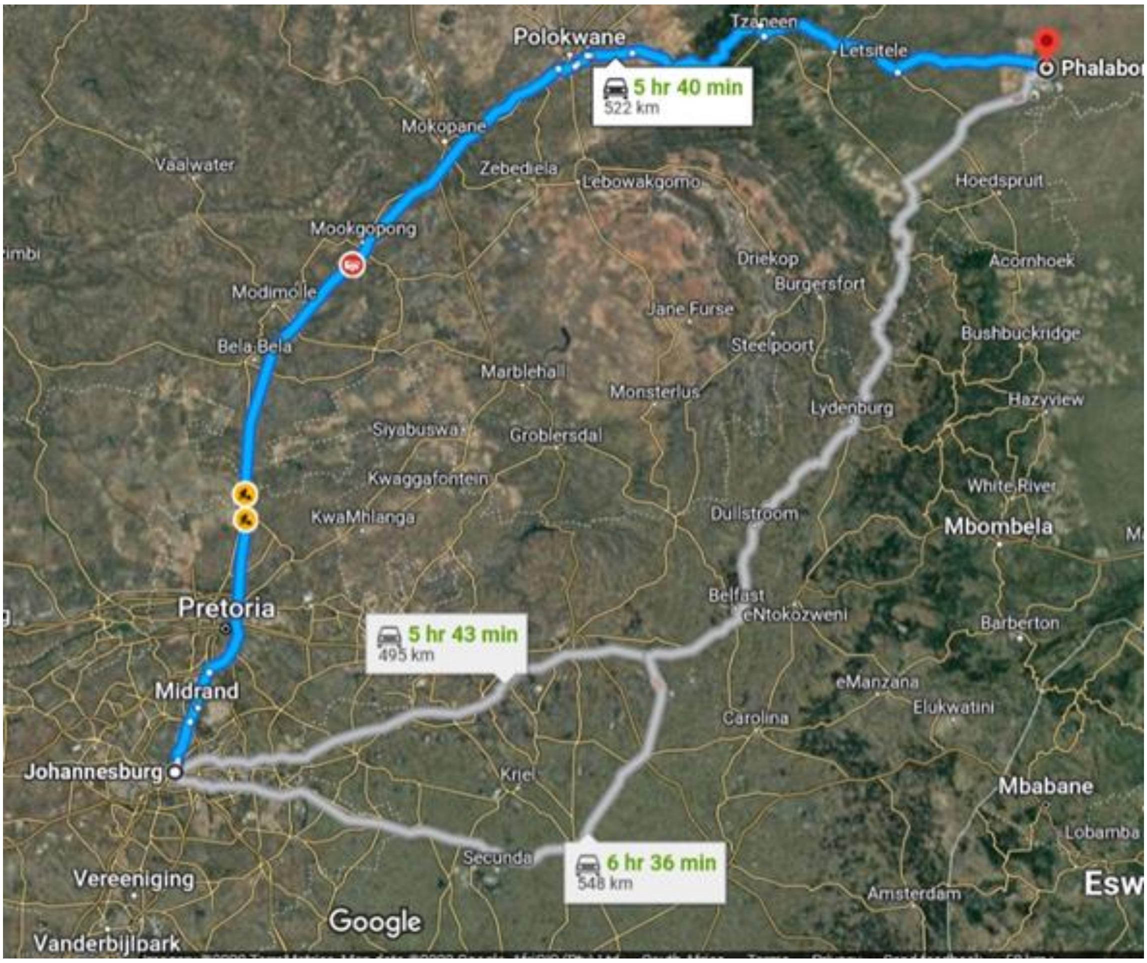


Figure 10.3: Road Access Johannesburg to Phalaborwa

The BP property is located on the outskirts of town, approximately 6.5 km from the centre of Phalaborwa via a Foskor maintained road that passes the BP site, or 8.6 km via the municipal Potgieter Street.

Figure 10.4: Road Access Phalaborwa to Bosveld Phosphates

10.2.2 Air Transportation

There are two airports near Phalaborwa. The nearest, Hendrik Van Eck Airport (IATA: PHW), is located on the outskirts of Phalaborwa and has a relatively short surfaced 1,373 m long by 18 m wide runway. The airport is predominantly used for tourism to service the nearby Phalaborwa Gate into the Kruger National Park.

The second is Hoedspruit Air Force Base (IATA: HDS), an airbase of the South African Air Force, of which a portion was converted, in the late 1990s, to a civilian airport (known as Eastgate Airport) and is located approximately 80 km from Phalaborwa. The airport has two runways at 2,115 m and 3,991 m long. It was also an emergency landing site for the Space Shuttle (Wikipedia). The airport has a very small terminal and limited loading facilities, but the long runways would make this ideal if a large cargo plane (e.g., Antonov An-124) needs to be used to airfreight emergency spares or breakdown replacement equipment.

10.2.3 Rail Infrastructure

Transnet, the state-owned railway enterprise, owns and operates a railway line that runs on the property’s eastern border up to the nearby Phalaborwa station. The railway line is predominantly used to rail phosphate rock, magnetite, and other bulk products to Richards Bay for processing by Foskor and for export and is connected to the private site rail infrastructure.

10.2.4 Housing Infrastructure

The project site is located near the well-developed town of Phalaborwa, and no new housing infrastructure will be required for the project. All personnel can be accommodated in existing commercially available housing.

10.2.5 Communications

Although the site is located near Phalaborwa, no fibre connections are available at the site. A dedicated point-to-point link is required from a local internet service provider to connect the site to major internet infrastructure in Phalaborwa. This is commonly used by tourist-focused lodges in the area for Voice Over IP (VOIP) and data connection. The site also falls within the coverage of several South African cellular networks, which can be used as a backup for both voice and data requirements.

10.3 Site Infrastructure

10.3.1 Security

Access control on the site is well established, including a manned security gate and an 11 km long perimeter security fence, which is electrified. An existing manned security gate is operated by a specialist security service provider appointed by Bosveld Phosphates. Access is controlled by a biometric (fingerprint) scanning system at both the vehicle boom and pedestrian turnstile gates. This system can also be used for time and attendance recording purposes.

The perimeter security fence consists of a 2.2 m high mesh fence with razor wire, and in places, this has been upgraded to an electric fence, predominantly to keep wild animals (e.g., elephants) out of the property.

10.3.2 Site Power

From the HV substation, power is distributed via cable to 3 existing MV feeders (11 kV) located in various positions in the existing plant. Power is distributed from these feeders to existing low voltage substations and remote 11kV MV substations in the plant area.

The project will retain, refurbish, and utilise the three 11 kV secondary substations and related cabling by extending the existing MV switchboards to supply the feeders to the existing LV Substations.

The existing 1,600 kVA, 11/0.55 kV transformers will be refurbished and utilised to provide power to new containerised LV substations where required. The Motor Control Centre (MCC) panels and related LV cabling for the new process plant will be provided as new.

The existing Small Power and Lighting (SP&L) electrical infrastructure equipment, i.e., mini substations and lighting transformers, will also be refurbished and reinstated to provide 400V three-phase and 230V single-phase power where required for small power and lighting loads. All new distribution boards, related SP&L cabling, and luminaires will be provided as new.

10.3.3 Site Water

Process and potable water will be sourced from Lepelle Northern Water (LNW) (see bulk Infrastructure section).

Water for hydraulic reclamation of the stacks will be sourced from the storage ponds located on and adjacent to the stacks. This water is contaminated, has low pH, and will be neutralised before the start-up of the project. A new lined pond with ~300,000 m^3 will be constructed to temporarily store this water.

The existing network of borehole pumps located around the stacks could also be used as a source of contaminated water for reclamation. It will be integrated into the stack reclamation water system.

10.3.4 Site Rail Infrastructure

An on-site railway system is integrated onto the Transnet line, consisting of ~11 km of rail and a shunting yard on the eastern side of the property where trains enter and exit from the Phalaborwa station. Another yard on the western side of the phosphoric acid plant was originally used for phosphoric acid loading and sulfur offloading but is now used for loading magnetite concentrate produced on site. The system includes an inline weighbridge and a loco shed where the locomotives are serviced. BP own two locos used for shunting on the property, and a third, larger one is rented. The on-site rail system is operated and maintained by Tengwa Africa (Pty.) Ltd. under contract from BP.

10.3.5 Roads and Transportation

Existing plant roads will be used as far as possible. These roads connect all major infrastructure and the main security entrance. New surfaced roads will be constructed where necessary to facilitate vehicle and equipment access to the new plant and associated infrastructure.

10.3.6 Site Buildings

Where possible and practical, existing infrastructure will be refurbished for use on the project. The structures include:

10.3.6.1 Administration Offices

Part of the existing Bosveld Phosphates double-story administration building will be used for the project. Bosveld Phosphates personnel occupy the top floor of the building, but the ground floor is vacant. The ground floor consists of 9 individual offices (~14 m^2 each), an open-plan area of 53 m^2 and a drawing office of 30 m^2 for a total of 209 m^2. In addition, the office building has a large board room, kitchen and ablution facilities, which will be shared with Bosveld personnel. Covered vehicle parking for vehicles is available next to this building. The building is generally in good condition and only requires some minor maintenance (i.e., cleaning, painting and some minor refurbishment).

The old Phosphoric Acid plant offices are in close proximity to the proposed plant location and can be refurbished if needed. The Phosphoric Acid plant offices cover ~275 m^2, consisting of 9 offices and a meeting room, and a small kitchen and ablution facilities. This building is generally in poor condition and would require extensive renovation if it is to be recommissioned.

10.3.6.2 Canteen

No food will be prepared on-site, and it is envisaged that personnel will bring their own food to work, as is currently the practice. Administrative and maintenance personnel will make use of the existing tea-room and kitchen facilities in the administration building and workshops, respectively. A new kitchen/tearoom adjacent to the control room will be provided for operational personnel.

10.3.6.3 Change House

The existing change house at the main entrance gate, opposite the security offices, will be used for the project. The facility is currently used by others but has sufficient spare capacity for 100-150 additional shift personnel, which is more than adequate for the project.

10.3.7 Ablution Facilities

There are two ablution facilities on the site, located near the old phosphoric acid plant. The larger facility is located on the eastern side of the old plant, and the second, smaller one is near the boiler workshop to the south of the old phosphoric acid plant. Both these facilities will be refurbished and reused for the project.

10.3.7.1 Clinic/Medical Treatment Facility

The old Occupational Health Clinic, a brick building of approximately 270 m^2 near the main entrance, will be refurbished for the project. The building is generally in good condition, needs only minor refurbishment, and needs to be suitably equipped.

10.3.7.2 Stores

The existing main store building will be refurbished. The building consists of a ~2,000 m^2 sheeted and brick structure fitted with shelving for small items (e.g., nuts and bolts etc.), and has offices for store personnel. There is also additional fenced outdoor storage available for equipment and/or consumables that can be stored outdoors.

10.3.7.3 Weighbridge

The existing truck weighbridge, located at the main security entrance, will be used for the project. The system is currently used to weigh trucks hauling magnetite onto and magnetite concentrate off the site and is well maintained and regularly calibrated.

10.3.7.4 Vehicle Repair Shop

The existing vehicle repair shop will be refurbished and used to service large earthmoving machinery (e.g., dozers and rolling compactors) associated with the operation of the gypsum residue dry stacking facility. Small vehicles will be serviced and maintained by independent service providers in the nearby town of Phalaborwa.

10.3.7.5 Operations Control Room

A ~100 m^2 prefabricated airconditioned structure will be procured and fitted for use as the control room. The control room will house the operator workstations, engineering station, process logic controller (PLC), and computer hardware.

The facility will be dust proof and sealed with no external openings or vents. Access to the control room will be via a two-door airlock system and fresh air will be provided via a ducted filtering system to prevent the ingress of dust.

The control room will have a meeting table and chairs so that impromptu meetings with the Control Room Operators (CROs) can be held to discuss changes to the process parameters. To ensure the CROs are not away from their workstations for extended periods, the control room will be equipped with a food preparation and eating area. Ablution facilities will also be available to the CROs at the control room.

10.3.7.6 Laboratory

The old site laboratory, consisting of a 360 m^2 brick building next to the administration offices, will be reused. RC Inspection, an independent laboratory, currently use around 25% of this building to service clients on-site and in the area. The rest of the space in this building will be used for the project laboratory. Minor refurbishment will be done to the building only.

10.3.8 Facilities not allowed for in the project

The following facilities have not been allowed for in the project:

10.3.8.1 Construction Camp

Specialised contractors and their employees will be responsible for their own accommodation during construction. No provision will be made for a construction camp on site due to the proximity to Phalaborwa, which has sufficient accommodation available.

10.3.9 Waste Management

10.3.9.1 Solid Waste

Domestic waste generated at the process plant will be disposed of in waste skips strategically placed around the plant. The waste skips will be loaded by the skip loader vehicle and the waste will be disposed of at the local municipal solid waste site.

Due to the proximity of Phalaborwa and the well-developed infrastructure in the region, the disposal of other waste generated at the process plant, such as oils and grease from the workshops, medical waste, etc., will be managed through local service providers and contractors.

10.3.9.2 Sewage Disposal

The existing sewage treatment plant will be retained and operated. The system is fully operational and catered for around 600 personnel when the phosphoric acid plant was operational. Although around the same number of employees pass through the gates now daily, a significant number of them report to the two magnetite plants, which are not tied into the system. Only about 300 people currently rely on the system, and there is sufficient spare capacity to cater for the needs of the project.

10.4 Stormwater Management

A detailed site-wide water balance model will be built during the next phase of the study, which will inform the overall water management strategy, including stormwater management. This study envisages that the project will tie into the existing stormwater infrastructure and that only minor additional infrastructure will be required to tie into the system, including:

- Cut-off berms.
- Terraces sloped to “vee” drains.
- All rainwater falling in the bunded areas will be collected in the spillage sumps and pumped as per the process flow diagrams to the in-plant process sections.
- All rainwater falling outside bunded areas of the process plant will be collected and channelled to the process water and/or reclamation system.

10.5 Servitude

The Eskom power line that feeds into the on-site HV substation is the only known servitude on the site.

11 ENVIRONMENTAL AND SOCIAL IMPACT

11.1 Environmental

11.1.1 Greater Phalaborwa Area

Phalaborwa is a mining town in the Ba-Phalaborwa Municipality in the Mopani District of the Limpopo Province with ~150,000 residents (2011 census). Phalaborwa began as a mining town and still is home to various mining operations and mineral processing plants. There are two large open mining pits on the outskirts of the town, one of which is nearly 2,000 meters across, Africa's widest manmade hole.

Copper mining was first undertaken here in 1904, but this was soon suspended because of the high transport cost. Open-pit copper mining was restarted in 1956 by Palabora Mining Company (PMC) and continued until 2005, when a large block-cave underground mine was opened next to the old open pit. During the 1960s, 1970s and 1980s, the company's open-pit copper mine and associated processing plants produced over 2,7 million tonnes of copper. Today the company supplies most of South Africa's copper needs and exports the balance.

Thus, Phalaborwa has a long mining history, dating back to the 1950s, when environmental standards were different from today. Mining and mining-related activities have resulted in an area of approximately 75 km^2 being significantly impacted through the operation of two large open pits and the construction of various stream diversions, tailings dams, phosphogypsum stacks, waste rock dumps and various other infrastructure, as can be seen in the satellite image in Figure 11.1.

Figure 11.1: Phalaborwa Satellite Image

The proposed project site is located on the Bosveld Phosphates property that lies on the western border of this area, shaded in red in Figure 11.1.

Phalaborwa is located near the Kruger National Park, one of South Africa's largest tourist attractions, with the Phalaborwa gate into the Kruger Park located a mere 2 km from the town. The Kruger National Park is a South African National Park and one of the largest game reserves in Africa. It covers an area of 19,623 km^2 in the provinces of Limpopo and Mpumalanga in north-eastern South Africa and extends

360 km from north to south and 65 km from east to west. The administrative headquarters are at Skukuza within the park. Areas of the park were first protected by the government of the South African Republic in 1898, and it became South Africa's first national park in 1926.

Six major rivers and many tributaries stretch across the Kruger National Park, with the Crocodile River forming the southern boundary and the Limpopo River the northern boundary. The other major rivers in Kruger are the Olifants, Sabie, Letaba, and Luvuvhu. The Olifants River and one of its major tributaries, the Ga-Selati River, flows mere kilometres from some of the most significant mining infrastructure around Phalaborwa.

Other nearby natural attractions are Blyde River Canyon, the Three Rondavels, God's Window, and Bourke's Luck Potholes. The Tzaneen fruit farms and Hoedspruit game farms can all be visited within a day.

11.1.2 Property Location

Figure 11.2 shows the surface rights and extent of the property within the Phalaborwa mining area. There are several river diversions, pollution control dams and bunded areas, and other disturbed and sensitive areas present on the site. A major powerline also crosses the site near two archaeological sites.

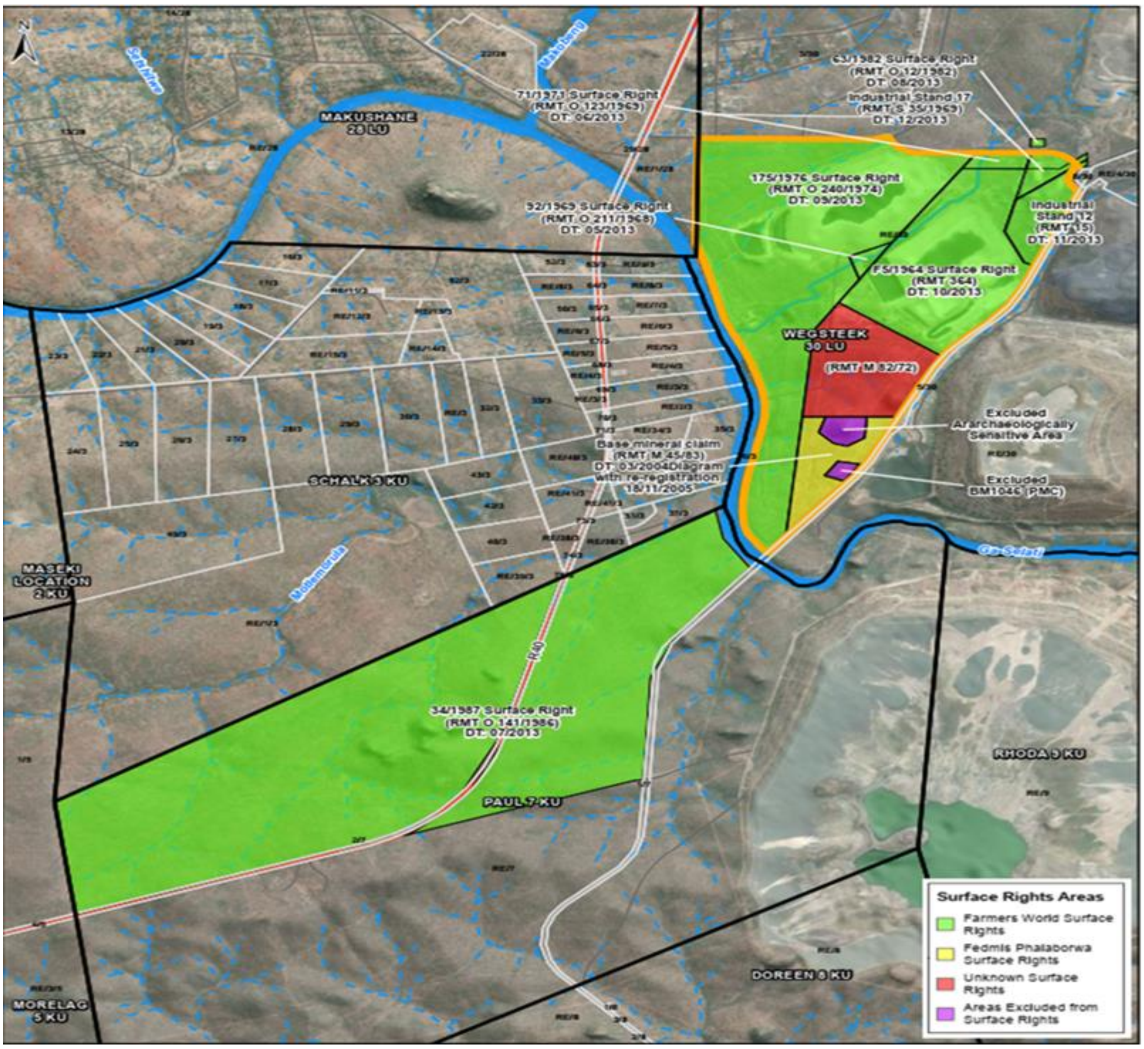


Figure 11.2 - Bosveld Phosphates Surface Rights

The southern part of the property is regularly visited by different species of fauna, ranging from giraffes and buffalo to the occasional elephant.

The property borders the Ga-Selati River, a major tributary of the Olifants, one of the six major rivers flowing through the Kruger National Park.

11.1.3 Climate

The BP property is situated in the Limpopo Province Lowveld Climatic Zone and experiences typical sub-tropical, summer-rainfall climatic conditions with hot summers and warm to cool winters.

Features of this climatic zone are:

- Warm to hot with high humidity.
- Rain from November to March with a maximum in January/February.
- Most rain falls in the form of thunderstorms and heavy showers.
- Daily temperatures generally range from 18ºC to 40ºC in summer and from 10ºC to 23ºC in winter. Temperature extremes range from 43ºC in summer to 5ºC in winter.

11.1.3.1 Average Monthly Rainfall Distribution

The average monthly rainfall distribution assigned to the site has been calculated using the rainfall figures recorded from seven South African Weather Service (SAWS) monitoring stations in the Phalaborwa region.

A summary of the average rainfall statistics from the SAWS monitoring stations for the Phalaborwa region is given in Table 11.1 and illustrated in Figure 11.3. The average monthly rainfall on site is highly seasonal, with 422.2 mm (85.5%) of the rainfall occurring during the six wet months (October to March) of the year.

The Mean Annual Precipitation (MAP2) assigned to the site, as indicated in Table 11.1, is 494 mm/annum.

Table 11.1: Average Monthly Rainfall

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Total
Rainfall (mm)	33.9	67.1	88.6	91.3	79.2	62.1	29.7	9.4	5.6	7.5	3.9	15.2	494
Rainfall %	6.9	13.6	18.0	18.5	16.0	12.6	6.0	1.9	1.1	1.5	0.8	3.1	100.0

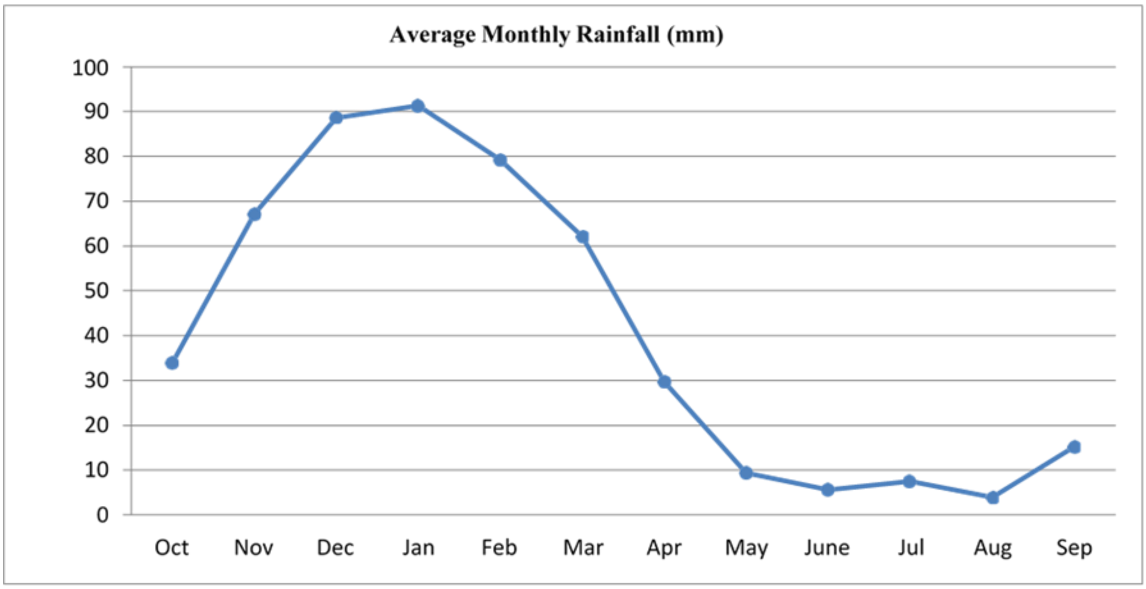


Figure 11.3: Typical Average monthly rainfall distribution (2016)

11.1.3.2 Storm Rainfall

The 24-hour design storm rainfall data has been obtained from the W0681180 Rainfall Station, which is situated 2.2 km from the site, as detailed in the Water Research Commission Report titled "Long Duration Design Rainfall Estimates for South Africa" (Smithers, J.C., and Schulze, R.E., WRC report No. 811/1/00). The 24-hour design storm rainfall depths for the various recurrence intervals assigned to the site are indicated in Table 11.2.

Table 11.2: 24 Hour Design Storm Rainfall Information

Rainfall Station	Distance from Site	Recurrence Interval				
		1:2	1:10	1:20	1:50	1:100
W0681180 - Phalaborwa	2.2 km	64 mm	114 mm	136 mm	167 mm	192 mm

Of specific importance is the 1:50 year 24-hour design storm rainfall figure (167 mm), which will be used during the capacity calculations and design of the stormwater containment facilities on site.

11.1.4 Evaporation

The values noted at the Phalaborwa weather station 681/266B2 (during a normal year) are as follows:

Table 11.3: Simons Pan evaporation (mm/month)

Month	Average monthly evaporation (mm)
January	159
February	137
March	134
April	108
May	93
June	75
July	83

Month	Average monthly evaporation (mm)
August	113
September	146
October	173
November	163
December	166
Total yearly evaporation	**1,550**

Based on the Mean Annual Precipitation (494 mm/annum) and Mean Annual Evaporation (1,550 mm/annum) assigned to the site, it is calculated that the site has a negative Climatic Water Balance of 1,056 mm/annum.

This negative climatic water balance is important from a water management perspective. This indicates that surface water containment facilities that do not have catchment runoff, like the storage of water on top of Gypsum Dam A and Gypsum Dam B, will lose a head of 1,056 mm/annum across the entire surface area of the facility. This can contribute to significant water loss for the facility over the course of a year.

11.1.5 Bosveld Phosphates

11.1.5.1 Site History

A phosphoric acid plant was constructed on the site and commissioned in 1964 to produce feed material for the fertiliser industry. The products from the plant, at the time, included phosphoric acid, mono-calcium - and mono-ammonia phosphates, sulphuric acid, and superphosphate. The plant underwent several expansions and changes of ownership until BP acquired it in 2012 from Sasol, who had owned and operated the plant since 2001. BP placed the plant on care and maintenance in 2014.

Two magnetite concentrating plants have been constructed on the site since 2014 and these remain active today, processing 80,000 tonnes per month of magnetite. The magnetite processed by the two plants is sourced from waste dumps on the neighbouring property owned and operated by Foskor. Magnetite concentrate leaves the site either by the existing rail network or by road.

11.1.5.2 Property Status

Historical processing of phosphate rock has resulted in the deposition of ~30.4 million tonnes of phosphogypsum on two stacks located on the property. The first of these stacks (Stack A) was commissioned in 1964 and in accordance with the lower environmental standards at that time, resulting in the stacks being unlined. Stack B was commissioned later and is also unlined. Despite the phosphoric acid plant not being operational for many years, the water that remains on the stacks is of poor quality and has a low pH. The volume of water stored on the stacks and storage pond system varies from around 650,000 m^3 to 1,200,000 m^3 seasonally.

The groundwater underneath the stacks has been contaminated through seepage of water through the unlined stack system. A network of bores surrounding the stacks is used to monitor this contamination by informing a groundwater model last updated in 2016. Water samples from the monitoring bores are taken and tested quarterly.

A water stream entering the property on the northern boundary, north of Stack B, has been diverted through the construction of a canal that channels the water between the stacks and back into the Ga-Selati River on the western boundary of the property.

The condition and stability of the stacks are regularly monitored by an independent consultant (currently Knight Piesold Consulting). The phreatic surface is monitored through piezometers installed in boreholes on the stacks.

11.1.6 Historical Environmental Liability

Historical industrial activities on the site dating back to 1964 have resulted in various environmental liabilities. Sasol Nitro, who owned and operated the site from 2001 to 2009, established a closure fund. Bosveld Phosphates agreed to further contribute to this fund for liabilities incurred from 2012 when they purchased the property from Sasol. This fund will be used for site rehabilitation, as described below.

11.1.6.1 Plant and Infrastructure

Various industrial plants and associated infrastructure (e.g. sulfuric acid plant, phosphoric acid plants, magnetite concentrating plant) have been erected on the site and will have to be demolished at the end of the operation.

11.1.6.2 Soil Contamination

Soil contamination has occurred in the plant areas. This soil should be removed and safely disposed of possibly in the new lined gypsum residue storage facilities, which will be constructed as part of the Project. Borrow material must be used to restore the terraces where the contaminated soils are removed.

11.1.6.3 Surface Water Contamination

Water currently stored on the stacks and associated catchment pond systems is contaminated with heavy metals and has a low pH. This water poses a risk to the surrounding environment in the event of a spillage. This water should be neutralized and decontaminated to the extent that it no longer poses a threat to the environment.

11.1.6.4 Asbestos

Asbestos sheeting was extensively used during plant infrastructure construction and must be removed and disposed of in an environmentally acceptable manner. All sheeting must be replaced with an alternative form of sheeting.

11.1.7 Phalaborwa Rare Earths Project

RRE proposes extracting rare earth elements from the two phosphogypsum stacks on the property. The stacked phosphogypsum will be hydraulically reclaimed using stack water currently stored on the stacks and associated ponds. Infrastructure associated with the reclamation process will include high-pressure water cannons (monitoring cannons), pipelines, pump stations and sumps, workshops, offices, contractor laydown areas, and ablution facilities that are already present on the site.

The bulk of operational water requirements will be sourced from this water and only small quantities of potable water will be required for offices, ablutions, laboratory, and reagents make-up. Industrial and potable water is available on the site from LNW, a state-owned water utility that supplies water to various industrial customers in the area.

A comprehensive water management strategy will be developed for the project and integrated with the current closure plans to maximise the use of poor-quality water on the site. This will include the development of a site-wide water balance to minimise clean make-up water requirements for the reclamation, processing, and waste disposal processes. The water balance for the property was last updated in 2016. The strategy will also consider using poor-quality underground water near the stacks to mitigate environmental impact within the bounds of the existing closure plan and available funding.

A new pollution control dam (PCD) to store the reclaimed contaminated water from the active reclamation stack will be constructed at the site before starting the new process plant. It is important to note that a PCD is already authorised for the site (Bosveld Phosphates) but has not yet been constructed. The reclaimed water will be neutralised using lime and used for hydraulic reclamation of the stacks once the process plant is operational.

The reclaimed phosphogypsum will be processed at a newly constructed processing facility to produce separated rare earth oxides. Reagents to be used in the processing plant will include sulfuric acid, lime, pretreatment solution reagent, purified rare earth precipitation agent, CIC eluants, impurity control agents, and various flocculants. Reagents will be stored in new storage facilities constructed at the proposed processing facility per international principles and best practices.

The phosphogypsum residue from the plant will initially be stacked on a new, lined dry stack (Stack C) which will be constructed in the north-western corner of the property. This residue will be conveyed to the stack by a network of conveyors to a central deposition point, from where it will be evenly distributed and compacted using earthmoving equipment (bulldozers and vibrating compactors).

Stack B will be reclaimed first and will be depleted before stack C's storage capacity has been exhausted. The area where stack B is located now will then be rehabilitated and a new lined dry stack constructed there. Once stack C has reached maximum capacity, the residue will be deposited on the newly prepared stack B site.

RRE is investigating the sale of phosphogypsum for use in the agricultural and construction industry, where phosphogypsum is used as a component in the manufacture of cement and plasterboard. Initial testing of the residue indicated that this would meet the quality specification for both agricultural and industrial use. This strategy would decrease the amount of residue being stored on the site. Initial research has also indicated that the production of the phosphogypsum residue at the project site will likely exceed the combined local agricultural and industrial requirements annually.

11.1.8 Legislative Requirements

As the gypsum stacks comprise material not arising from the conduct of mining operations, BP does not require a mining right to process the gypsum stacks as they are not subject to the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA). The property where the gypsum stacks will be processed, therefore, does not comprise a “Mine”, as defined in section 1 of the MPRD Act and will not qualify as a Mining Area for purposes of the MPRD Act.

BP does not currently have any environmental authorisations specifically for processing the gypsum stacks but does have the necessary authorisations for the other activities currently being conducted on the property.

The reclamation of a historic dump which has not been created in terms of a Mining Right, i.e. it was created before the MPRD Act effective date, may require certain environmental approvals and in particular, an Environmental Authorisation (“EA”), as defined in section 1 of the National Environmental Management Act 107 of 1998, as amended (“NEMA”) or a Waste Management Licence (“WML”), as defined in the National Environmental Management: Waste Act 59 of 2008, as amended (“NEM:WA”).

11.1.9 Permitting and Licensing

Bosveld Phosphates holds numerous permits, licenses, and authorisations on the property, most of which would apply to the proposed project. The project will apply for new licenses and permits that are required to operate or for an amendment to existing permits and licenses, whichever the case might be. To understand the full extent of licenses and permits available and required, RRE appointed Golder Associates Africa (Pty.) Ltd. (Golder) to conduct a review. An extensive document lays out the requirements in Appendix M. Golder has recommended an allowance of 18 – 24 months to complete the integrated regulatory processes.

The final requirement will be determined once the project scope and the ESIA have been conducted. Figure 5 shows the locations of WUL areas. These are registered under Bosveld Phosphates. The Golder Associates report (Nov 2021) elaborates on this matter and a summary of authorisation and licenses is shown in Table 11.4.

Table 11.4: Existing Environmental Authorisations and Licences

Type	Description	Date
Environmental Authorisations		
EA	Construction and operation of a single super phosphate plant to manufacture single super phosphate fertiliser, issued by the Limpopo Department of Economic Development, Environment and Tourism (LEDET) (Ref. No. 12/1/9/1-M101).	July 2015
EA	Construction and operation of a stormwater pollution control dam, issued by LEDET (Ref. No. 12/1/9/2-M29).	Nov 2015
EA	Construction and operation of a magnetite drying facility, issued by the LEDET (Ref. No. 12/1/9/1-M170).	February 2019
EA	Magnetite waste stack under application	
Water Use Licences		
Water Use	Licence Water Use Licence (Licence No. 04/B72K/ACGI/866) issued to Sasol Nitro by DWS.	09 June 2011
Water Use Licence	Water Use Licence (Licence No. 04/B72K/ACGI/866) issued to Sasol Nitro by DWS. 09 June 2011 Water Use Licence Amendment. Amendment Licence in terms of Section 50 and 158 of the NWA, issued to Bosveld Phosphates by DWS.	2 October 2017
Water Use Licence	Water Use Licence (Licence No. 06/B72K/G/6015) issued to Bosveld Phosphates (Pty) Ltd by DWS.	12 October 2017
Atmospheric Emission Licence (AEL)		
Atmospheric Emission Licence	Issued by the LEDET (AEL No. 12/4/12L-M7/A1) for the following listed activities:	01 August 2019 (expires 31 July 2024)

The Water Use Licences are important. The site has numerous uses as can be seen in Figure 5. The project will identify further licence requirements and manage these accordingly.

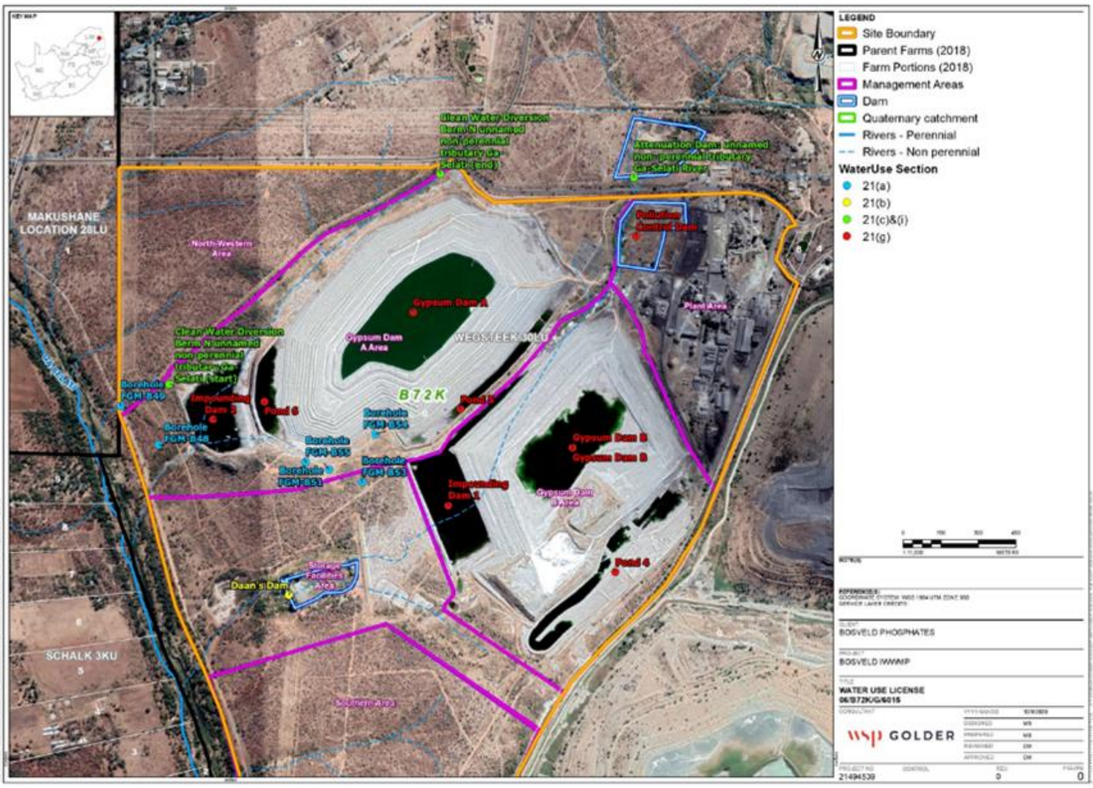


Figure 11.4: Water use licenses at Bosveld

Many of these will remain in operation and thus need to be maintained and amended or renewed.

An Integrated Water and Waste Management Plan (IWWMP) is in place, and over 80 monitoring holes are being sampled and tested regularly. However, the IWWMP was developed in 2016 and requires an update. This process has commenced but will need to be again updated once the project commences.

It is important to note that all environmental recommendations and advice are based on assumptions made because the Project is currently at the initial scoping stage.

11.1.10 International Standards and Principles

Depending on finance requirements, the Equator Principles and International Finance Corporation (IFC) Standards might be the norm for applicant compliance.

The Equator Principles are a financial industry benchmark for determining, assessing, and managing social and environmental risk in project financing and have been adopted by major project finance banks, and the IFC Performance Standards developed by the IFC/World Bank Group are now in effect. These standards are the dominant social and environmental benchmarks for extractive operations seeking project finance, export credit agency support and political risk insurance. As well as incorporating the changes resulting from the IFC's standards review, the revised Equator Principles also incorporate the lessons learnt from the implementation of the original principles and from an external comment process involving many stakeholders.

The revised Equator Principles consist of the following ten Principles:

- Principle 1: Review and Categorisation.
- Principle 2: Social and Environmental Assessment.
- Principle 3: Applicable Social and Environmental Standards.
- Principle 4: Action Plan and Management System.

- Principle 5: Consultation and Disclosure.
- Principle 6: Grievance Mechanism.
- Principle 7: Independent Review.
- Principle 8: Covenants.
- Principle 9: Independent Monitoring and Reporting.
- Principle 10: Equator Principles Financial Institutions Reporting.

The above principles require that the project completes the following activities:

- Categorising the project to determine its sensitivity.
- Undertake an environmental and social impact assessment (ESIA) in line with the IFC Industry Specific Performance Standards.
- Compile environmental and social management plans for the project.
- Biophysical and socio-economic specialist studies and reviews.
- An independent review of ESIA report for proponents applying for funding.
- Public consultation and disclosure process.

RRE, being an environmentally compliant company, will, as a minimum, adhere to local South African legislation and standards. However, the company will comply to the internationally accepted Equator Principles and the IFC Performance Standards.

11.2 Social Impact

11.2.1 Phalaborwa Rare Earths Project Location

The Project is situated approximately 4 km south-west of the town of Phalaborwa and falls within Ward 2 of the Ba-Phalaborwa Local Municipality (LM) boundary. The Ba-Phalaborwa LM is one of four Municipalities comprising the Mopani District Municipality of the Limpopo Province.

Land near the Project includes residential, agricultural, recreational, and industrial land. Most of the larger residential areas in the Ba-Phalaborwa LM are located more than 4 km from the site. However, a portion of the Namakgale residential area (an area under traditional leadership) is located within 1.5 km.

11.2.2 Demographic and Human Behavioural Characteristics

11.2.2.1 General

The purpose of this section is to provide a summary description of the population and their behavioural characteristics as observed near the site. The human behaviour and interaction with the environment study report prepared in support of the 2020 Bosveld Phosphates Radiological Public Safety Assessment in 2020 (Equispectives, 2020) were used as a basis for this description. Although not always referenced explicitly, text from this report_ENREF_14 was used extensively to ensure consistency in the description of the population potentially impacted by the processing activities.

11.2.2.2 Locality Description

The following municipal wards and residential areas are located fully or partially within a radius of approximately 6 km around Bosveld Phosphates (Equispectives, 2020) - as shown in Figure 11.5:

- Ward 1 (only a small corner of the ward falls within the 6 km radius): Part of Namakgale (part of Nyakelang 1, part of Nyakelang 2, Namakgale D, and part of Zone A)

- Ward 2: Villages under traditional authority (part of Nyakelang 1, part of Nyakelang 2, Honeyville, Tipeng, Loss my cherry, Hlakisi, Changaan, Gardenview, Kanana 1, Kanana 2), Bosveld Phosphates, Palabora Copper Mine, Daan se Dam.
- Ward 9 (only a small corner of the ward falls within the 6 km radius): Villages under traditional authority (Maune, Mapikiri, Mosemang, Sebera).
- Ward 10: Schalk AH, Villages under traditional authority (Boyelang, Maseke, Tshubye (Mashimale R1), Griek), private game reserves and game farms.
- Ward 11: Industrial area, part of Phalaborwa town, Kruger National Park (Mopani Camp, Olifants camp, up to Giriyondo border post).
- Ward 12: Part of Phalaborwa town, Solinkie Farm, Hebron (Skitogh), smallholdings/farms
- Ward 19: Villages under traditional authority (Malungane (from Namakgale entrance to Tselang-gape, Makhushane Camp, part of Buffer Zone).

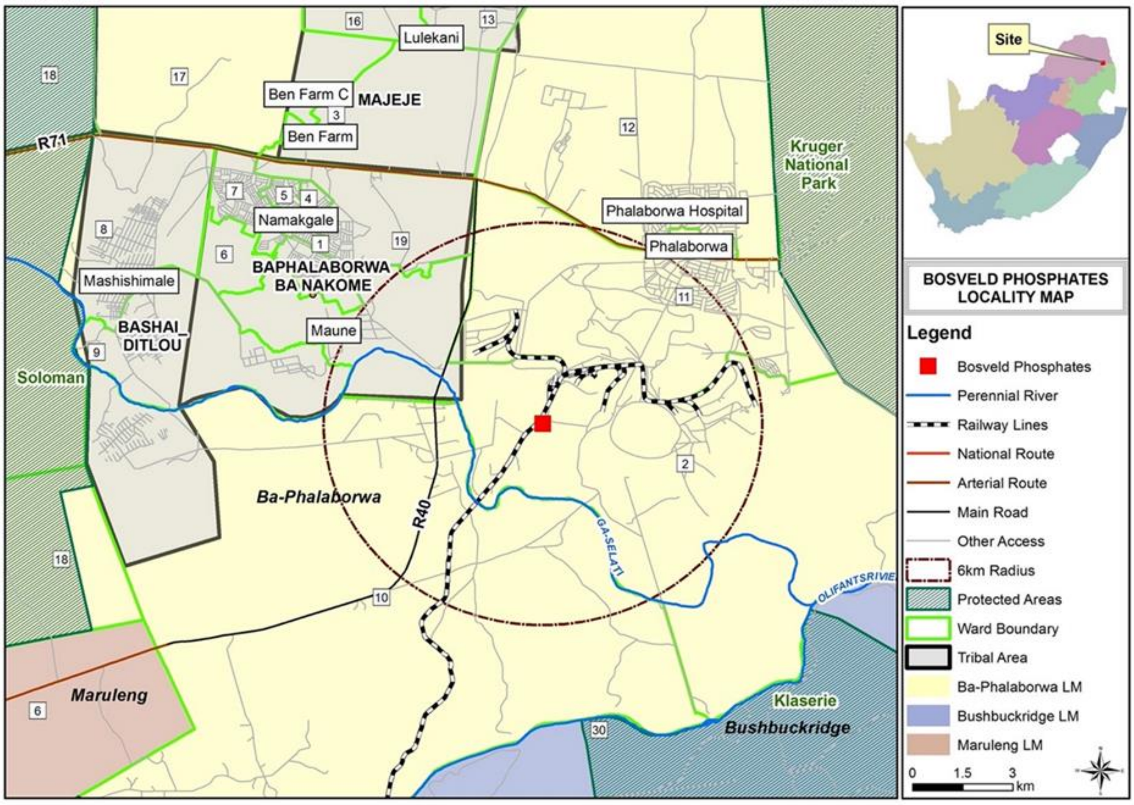


Figure 11.5: PREP site relative to surrounding communities (Equispectives, 2020)

11.2.3 Land Use and Community Types

11.2.3.1 General

Land use in the areas surrounding the Project fall within four main types; residential, agriculture, recreation and industrial.

The locations of the different land-use types are presented in Figure 11.6. Bosveld Phosphates and the other industries and mines surrounding it have been operational for many years. The residential and agricultural areas close to the Project are also well established and unlikely to expand. However, Equispectives (2020) noted some changes since the 2014 report that includes the following:

- A new agricultural area opposite the Mogoboya Community Garden.
- New agricultural areas between Namakgale and the Mixed-Use area.

- New agricultural areas between Namakgale and the Industrial area.
- Expansion and more dwellings in the Mixed-Use area.
- New dwellings adjacent to the Mixed-Use area.
- New dwellings on the edges of Namakgale.

The agricultural area in the Schalk area appears to no longer be in use, but this may be a temporary result of the Covid-19 pandemic.

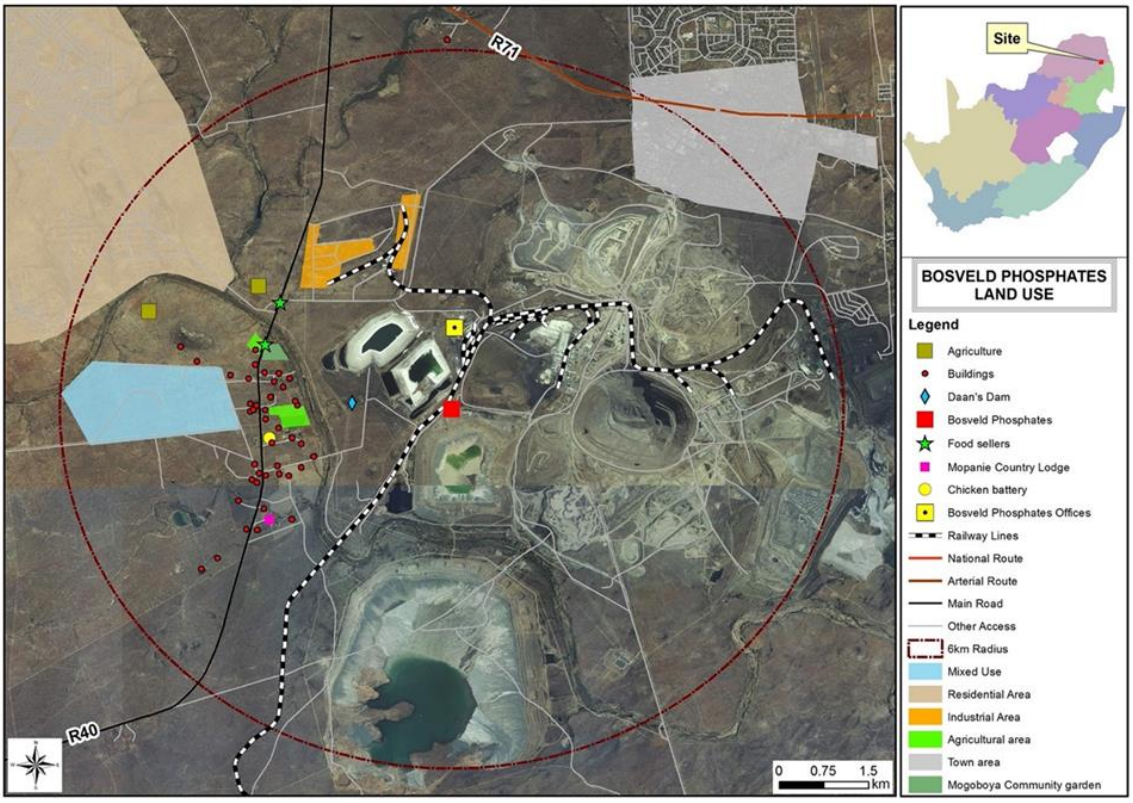


Figure 11.6: Land use in the area close to PREP site (Equispectives, 2020).

Table 11.5 presents the breakdown for households according to the type of land use as per Census 2011. Most of the households in the area reside in areas classified as tribal or traditional, except in Ward 11 and Ward 12 where most households live in areas classified as urban (town of Phalaborwa). Ward 11, which includes part of the Kruger National Park, is the area with the highest incidence of households living on farms.

Table 11.5: Households according to geo types (Census 2011)

Geo Type	Ba-Phalaborwa	Ward 1	Ward 2	Ward 9	Ward 10	Ward 11	Ward 12	Ward 19
Urban area	3,931	117	0	0	26	1,656	2,059	0
Tribal or Traditional Area	33,996	1,614	2,914	1,821	1,604	13	1	1,856
Farm area	3,527	0	198	0	150	420	46	0
Total	**41,454**	**1,731**	**3,112**	**1,821**	**1,781**	**2,089**	**2,105**	**1,856**

Equispectives (2020) divided communities into those living in formal structures, communities living in informal structures, commercial agricultural communities, and small-scale subsistence farming communities.

- **Formal Residential Structure Communities**: A formal dwelling can be described as "A structure built according to approved plans, i.e., house on a separate stand, flat or apartment, townhouse, a room in a backyard or rooms or flatlet elsewhere" (Statistics South Africa, 2012). In some areas there may be a formal as well as an informal dwelling on a stand, creating a community with mixed dwelling types.
- **Informal Residential Structure Communities:** An informal dwelling can be described as "A makeshift structure not approved by a local authority and not intended as a permanent dwelling." Typically built with found materials (corrugated iron, cardboard, plastic, etc.), and is contrasted with formal dwellings and traditional dwellings (Statistics South Africa, 2012).
- **Commercial Agricultural Communities:** Commercial agriculture includes farms where the farmer earns a livelihood from agriculture, such as crop, livestock or game farming. Areas with smallholdings are categorised according to their character. If the residents of the smallholdings practise agriculture, they are grouped with commercial agriculture, if they just reside in the area or have a business on the smallholding not related to agriculture, the area is classified as formal residential.
- **Small-Scale Subsistence Farming:** Small-scale subsistence farming can be described as large-scale food gardening on a piece of land that is not in someone's backyard. The land is usually cultivated by different members of the community, and they may belong to a formalised group. Food gardens in the backyard of an organisation like a school or crèche are grouped in this category. Keeping livestock in the community or on the outskirts of the community forms part of this group.

11.2.3.2 Residential Land Use

Residential areas closest to Bosveld Phosphates include the town of Phalaborwa and the Namakgale residential area. The town of Phalaborwa borders the Kruger National Park, which is South Africa's best-known game reserve. Many local and international tourists pass through the town on their way to the park.

The Namakgale residential area is home to almost 6,000 households and represents a significantly larger proportion of residential land use compared to the town of Phalaborwa. The portion of the Namakgale area closest to the Project site is within 1.5 km of the site, while the town of Phalaborwa is more than 4 km away. Some of the quantitative information presented by Equispectives (2014) for residential land use, is reported for specific municipal wards. Namakgale is an area that is under traditional leadership. Residents of the area live in small brick structures with flat zinc roofs or traditional structures made of clay. The houses all have their small yards (Equispectives, 2014).

According to Equispectives (2014), the residents of Namakgale cultivate food crops and keep livestock for their consumption. Fruit and vegetables that have been observed include sugar cane, maize, peanuts, mangoes, pawpaw, lemons, bananas, avocadoes, and Cassava. People produce their maize meal by either sending it to be milled in Tzaneen, or by milling it manually themselves. Livestock observed in the area include goats, chickens and cattle.

11.2.3.3 Agricultural Land Use

Agricultural land use within the study area consists mainly of small scale commercial and subsistence agriculture plots. Near the Project site, the Schalk AH and the Mogoboya Community Gardens represent the small-scale commercial agricultural sector.

The Schalk AH is adjacent to the R40 main road to Hoedspruit. According to, Equispectives (2014), many of the plots in the Schalk AH no longer practice any form of agriculture but are utilised as business premises. On some of the plots, lodging and accommodation are offered to clients ranging from tourists to migrant workers, while other services such as repairs, plumbing, electrical and engineering are provided. Some of the business owners also reside on the smallholdings, while others reside in Phalaborwa and rent the buildings on the smallholding as accommodation to employees or family members. The houses on the smallholdings are mostly brick structures with metal roofs.

Many of the plot owners that have practised agriculture felt that they could no longer do so because of issues with the water quality. These commercial farmers currently use municipal water for irrigation and believe that poor groundwater quality in the area prevents them from expanding their farming activities. Some of the farmers in the area use water from the Selati River to irrigate Lucerne.

Several types of livestock were observed in the area, including goats, cattle and pigs. Some residents keep chickens for their use. Equispectives (2014) report that some residents of the Schalk AH keep small household gardens where vegetables and fruits (such as spinach and pawpaw) are grown.

The Mogoboya Community Gardens are also located adjacent to the R40 main road, to the north of the Schalk AH. The community gardens are limited in terms of variety due to a lack of water. There is a borehole, but the pipes and equipment have been stolen. According to the workers at the garden, potatoes and sweet potatoes are not planted any longer, as the elephants and cattle eat the produce. Cultivation of cabbage, butternut, pumpkin, sorghum and string beans was stopped due to a lack of water. When it rains spinach and carrots are planted.

According to residents, there are only about three to four smallholdings left with ongoing agricultural activities such as commercial production of cabbage, tomatoes, maize, green pepper and eggplant.

Currently, only maize, mangoes and peanuts are grown. Mangoes are sold to people that produce atchar and maize is sent to a mill in Tzaneen to produce maize meal for use at a food stall run by the community. The food stall is located just outside the fence of the community gardens and it sells food to passers-by on the R40. The trucks that transport products to Mozambique are the most frequent clients. The same person that owns the food stall indicated that, except for the maize meal, all the food sold at the food stalls are purchased in town.

11.2.3.4 Industrial Land Use

The mining and industrial activities taking place in the Phalaborwa area play an important role in the economy of the area and employ a significant portion of the local communities.

The major activities in the area include phosphate opencast mining and beneficiation (Foskor, ±2.1 km east-south-east of Bosveld Phosphates), copper mining and smelting (Palabora Copper, ±5.3 km east-south-east), production of zirconium, secondary mining and beneficiation of magnetite as well as the mining and beneficiation of base minerals for the production of glass.

The Phalaborwa Industrial Area (±1km north-west of Bosveld Phosphates) is classified as both light and heavy industrial. Many of the industrial sites in the area also include residential accommodation, with business owners or employees residing on the site. Businesses in the industrial area include a nursery, abattoir, electrical training centre, transport, fibreglass, canine unit, food processing plants, chicken batteries, engineering equipment, recycling, automotive and general engineering, vehicle repairs, vermiculite beneficiation, plant hire, steel fabrication and a processing plant for marula fruit. There is also a church in the area, as well as a tavern.

A large number of residences in the industrial area keep vegetable gardens. Equispectives (2014) observed the following commodities being cultivated in the industrial area: tomatoes, root vegetables (sweet potatoes, cassava, carrots, beetroot and onions), leafy vegetables (spinach), other vegetables (such as maize), and fruits (pawpaws, mango trees, granadillas, avocado trees, orange trees, lemons, prickly pears). Livestock observed in the industrial area include chickens, chicken batteries, cattle, and goats. The produce and animal products are presumably produced for own use by the residents but are also being offered for sale.

11.2.3.5 Other Land Use Considered

Although the Kruger National Park is located further than 5 km from Bosveld Phosphates, the operation can have a potential indirect impact on the Kruger National Park via the Selati River and downstream to the Olifants River that eventually flows through the Kruger National Park

Some Kruger Park employees live with their families in the Kruger Park staff villages.

The Satara, Olifants and Balule rest camps, as well as the Olifants trail, extract water from the Olifants River for potable use after treatment. Also, staff catch and eat fish from the Olifants River, and tourists and guides on the Olifants trail swim in the river. They also drink water from the river after purification with tablets.

According to Equispectives (2014), untreated water from the Olifants River is used to water the lawns as well as for the staff vegetable gardens at the Olifants camp.

11.2.4 Social Infrastructure and Services

11.2.4.1 Social Infrastructure

The infrastructure that households have access to indicates the vulnerability of the residents of a specific area. Lack of infrastructure, or using a specific type of infrastructure, can make residents more vulnerable to interacting with pathways of exposure. The 2020/21 Ba-Phalaborwa Industrial Development Plan (IDP) indicates the following infrastructure on a municipal level:

- One District hospital, the Maphutha L Malatji Hospital. The hospital has a backlog of 24 doctors and 137 nurses. The former Phalaborwa Hospital was turned into a private clinic but was closed in 2017 due to financial challenges.
- Ten primary health care facilities.
- Eleven Drop-In Centres are funded by the Department of Health and Social Development as well as sponsors. These centres have been established in communities to care for orphans and vulnerable children, particularly due to HIV/AIDS. Safety and Security.
- Four police stations, namely Phalaborwa, Namakgale, Lulekani and Gravelotte.
- Several creches, 40 primary schools, 14 secondary schools, one special school and one institution of further education, namely the Mopani South East Technical and Vocational Education and Training (TVET) College.

11.2.5 Socio-Economic Conditions

Census 2011 data summarised in Table 11.6 shows that the employment levels for the economically active part of the population (aged 15-64 years) vary. Ward 12 (63.35%) and Ward 11 (49.62%) have the highest levels of employed people, higher than on local, district and provincial level.

Table 11.6: Employment status (persons aged 15 to-64 years in age, source: Census 2011, shown in percentage) (Equispectives, 2020).

Employment status	Ba-Phalaborwa	Ward 1	Ward 2	Ward 9	Ward 10	Ward 11	Ward 12	Ward 19
Employed	35.66	41.25	30.66	28.43	32.30	49.62	63.35	34.73
Unemployed	21.30	23.67	32.74	33.27	27.86	3.92	6.92	21.52
Discouraged work-seeker	4.29	0.74	6.93	6.11	5.59	2.04	1.11	1.44
Other not economically active	38.75	34.34	29.67	32.19	34.25	44.43	28.62	42.30

Employment status	Ba-Phalaborwa	Ward 1	Ward 2	Ward 9	Ward 10	Ward 11	Ward 12	Ward 19
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Census 2011 data summarized in Table 11.7 shows that Ward 19 (15.75%) has the highest incidence of households with no income. In Ward 2, Ward 9 and Ward 10 more than half of the households earned less than USD 1,414.21 in 2011 and would be below or just above the lower bound poverty line.

Table 11.7: Annual household income (source: Census 2011, shown in percentage) (Equispectives, 2020).

Annual household income	Ba-Phalaborwa	Ward 1	Ward 2	Ward 9	Ward 10	Ward 11	Ward 12	Ward 19
No income	12.59	11.07	12.88	13.90	12.20	8.57	10.25	15.75
USD 0 - 346	5.50	4.08	7.63	7.44	7.89	1.88	1.03	3.67
USD 346 - 693	10.63	8.83	12.59	12.29	11.72	3.59	0.78	7.01
USD 693 - 1414	18.62	12.59	19.47	20.49	25.13	5.37	3.78	13.05
USD 1,414 – 2,756	18.88	15.63	19.67	22.76	25.60	10.88	4.08	16.23
USD 2,756 – 5,512	11.89	13.58	12.99	12.34	9.70	14.76	6.53	13.86
USD 5,512 – 11,097	10.02	20.93	8.33	6.40	4.45	14.88	14.69	16.40
USD 11,097 – 22,193	7.10	9.67	4.55	3.07	2.02	20.90	26.86	10.06
USD 22,193 – 44,329	3.66	3.38	1.55	1.18	0.96	14.85	21.93	3.43
USD 44,300 – 88,658	0.76	0.24	0.25	0.12	0.13	2.67	8.12	0.29
USD 88,658 – 177,316	0.18	0.00	0.04	0.00	0.13	0.70	1.06	0.11
USD 177,273 - or more	0.18	0.00	0.05	0.00	0.07	0.95	0.89	0.13
Unspecified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*Rate of exchange used is USD 1.00 = ZAR 13.86, the average rate for 2011 when the baseline date of the underlying data.

11.2.6 Phalaborwa Rare Earths Project

The Project is anticipated to impact on communities in the following ways:

11.2.6.1 Land Use

The processing plant will be constructed on an existing industrialised site, not impacting land use. No new roads or other infrastructure is required outside of the existing property. Rehabilitation of some previously disturbed land will be accelerated during the project, funded from closure funding put in place by previous owners of the property.

11.2.6.2 Employment

- **Construction:** RRE will extensively use local contractors during the project's construction to benefit the communities around the Project site. Specialised contractors mobilised from outside the Ba-Phalaborwa area will be encouraged to maximise local employment where the requisite skills are available.
- **Operation:** The project is expected to create more than 300 direct job opportunities (excluding contractors, suppliers, vendors, consultants etc.) and priority will be given to the people in the Ba-Phalaborwa area with the requisite skills and experience for these jobs. In addition, RRE

will work closely with local contractors, vendors, suppliers and consultants to build long term supply chain solutions from within the local area.

11.2.6.3 ESIA

RRE will conduct a detailed Environmental & Social Impact Assessment (ESIA) as part of the next feasibility study, which will also support the application of various permits and environmental authorisations.

12 HUMAN RESOURCES

The general philosophy by which personnel roles are structured during project development and the subsequent operation of the plant excludes detail on any organisational structures within RRE that are outside of the project. Two main project phases are considered: project development and operation. Project development describes the distribution of responsibility and chain of command during the construction and commissioning of the project, while operation explains the proposed organisational structure once it has been successfully commissioned and has reached a state of normal operation.

12.1 Project Team

RRE will commission an Engineering, Procurement & Construction Management (EPCM) company to provide engineering services and complete engineering deliverables required prior to execution. The engineering company is responsible for managing equipment and reagent suppliers for the purposes of developing cost estimates. Jointly, the engineering company and Rainbow will cooperate with other key contractors, including those responsible for reclamation and residue storage. The project team comprises Rainbow staff, EPCM company personnel, and external consultants. The team established to complete the project's design phase will grow and be supplemented with additional personnel as the project transitions from design to construction phase. Most of the design & development team will form part of the operations team.

At commencement, the project team comprises the following key roles: RRE will commission an EPCM company to provide engineering services and complete engineering deliverables required prior to execution. The engineering company is responsible for managing equipment and reagent suppliers for the purposes of developing cost estimates. Jointly, the engineering company and RRE will cooperate with other key contractors, including those responsible for reclamation and tailings storage. The project team comprises of RRE staff, EPCM company personnel, and external consultants. The team established to complete the project's design phase will grow and be supplemented with additional personnel as the project transitions from design to construction. Most of the design and development team will form part of the operations team.

At commencement, the project team comprises the following key roles:

- Owner’s Project Manager

  Responsible for oversight and review of project development deliverables, as well as due diligence on information that is the responsibility of RRE to source. The owner’s project manager serves as the liaison between the EPCM company and RRE.

- Owner’s Process Consultants

  Responsible for liaising with process development and test work contractors and providing guidance on process design-related issues, recommending of test work, and decision-making on process issues. Also responsible for reviewing and approving of project documentation.

- Owner’s Metallurgists

  Responsible for review of process-related design documentation and deliverables. Responsible for providing support related to sourcing of information. Performing literature reviews on key issues, interpreting test work results, and assisting with process design deliverables. The Owner’s metallurgists are also responsible for the process development in collaboration with technology development companies, with the detailed engineering responsibilities falling to the EPCM contractor. Currently, this team comprises an RRE in-house metallurgist and an external consultant.

- Owner’s Engineer

  Responsible for due diligence on the detailed design and costing of the plant. The owner’s engineer will liaise with the EPCM contractor and but report within RRE. This role will develop into the Engineering Manager role during operation.

- Safety Manager

  Responsible for safety during construction and operation of the plant. The safety manager will report to the operations manager on all issues related to employee working conditions and safety regulations.

- Environmental Advisor

  As part of the owner’s team, the environmental manager is responsible for overseeing of the impact that site activities have on the surrounding area. The environmental manager arranges for ongoing environmental studies, sampling surrounding water sources, and ensuring that no waste or residue from site contaminates the plant's natural environment. The environmental advisor is also responsible for liaising with the inhabitants of the surrounding communities, from within the town of Phalaborwa to the borders of the sphere of influence of the plant. The community manager will deal with grievances from the surrounding communities and find amicable solutions to issues that may arise from the economic impact of the Project, such as employment strategies.

- EPCM Contractor

  Responsible for managing a multi-disciplinary team of engineers, planners, estimators, and support personnel in developing detailed engineering deliverables and cost estimates. The EPCM contractor collaborates with other contractors to enable the integration of designs such as the residue storage facility and reclamation. The EPCM contractor will provide other key roles during execution, such as the construction manager and commissioning manager.

- Gypsum Restacking and Residue Disposal Contractor

  Responsible for all aspects relating to the design and costing of the new gypsum stacks and storage and disposal of impurity residue generated during processing, including all auxiliary equipment and personnel.

- Reclamation Contractor

  Responsible for all aspects relating to the design and costing of the reclamation system, associated equipment and personnel.

A simplified project team organogram is shown in Figure 12.1.

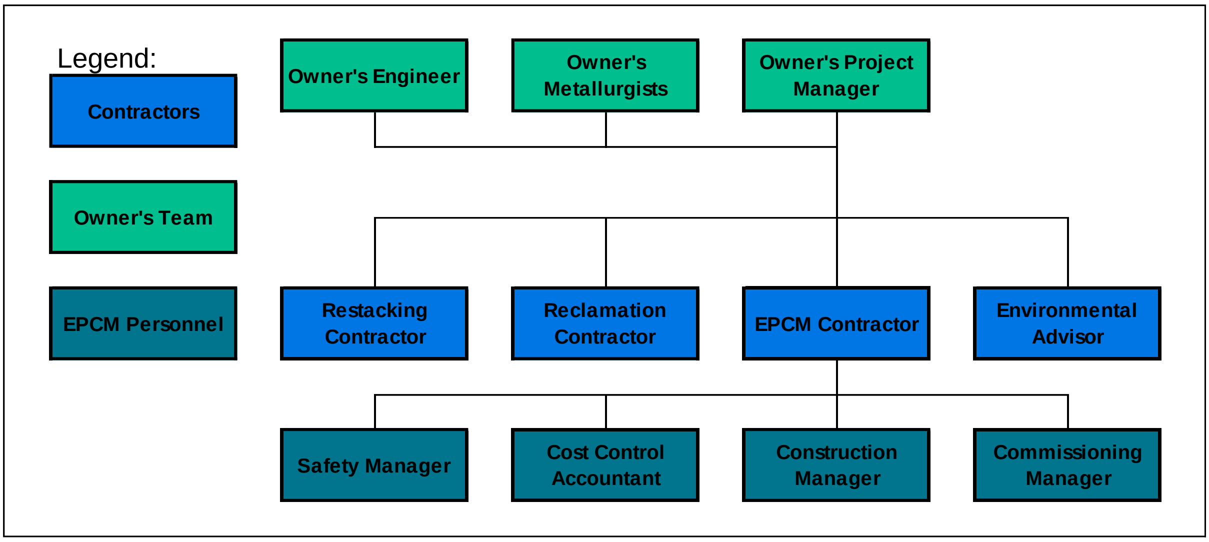


Figure 12.1: Simplified Project Development Team Organogram

12.2 Operations Management Team

12.2.1 Summary

The operations management team will be responsible for the plant's continued operation once it has been commissioned. The operations team will support activities and operate the plant in a limited manner under the direction of the EPCM contractor’s team until handover. A summary of the overall plant labour complement is shown in Table 12.1. Security personnel are not included in the Owner’s employee structures as security personnel will be employed by a contracted security company. The security company representative will report directly to the Site General Manager.

Table 12.1: Overall Plant Labour Summary

Section	Labour Complement
Total Plant Operations	213
Total Plant Maintenance	45
Laboratory	21
Total Admin	12
Total HSE	5
Total Security	0
Stores & Procurement	16
Total	**312**

A simplified organogram for the operations management structure is shown in Figure 12.2. This organogram does not include lower-level operators and labourers but focuses on the general management structure and key roles within each section.

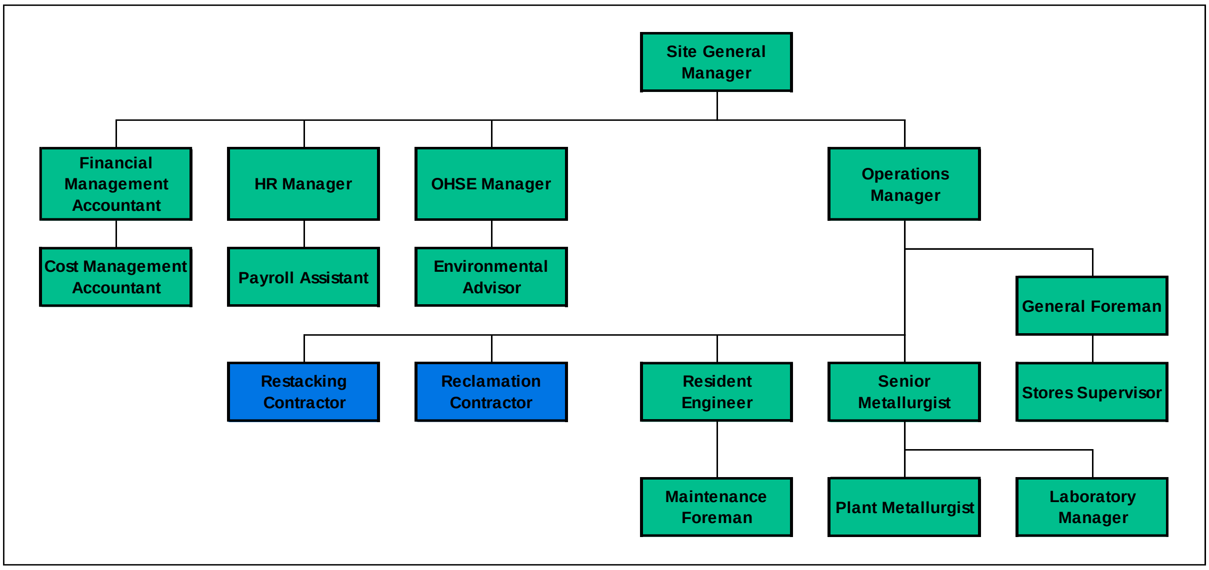


Figure 12.2: Simplified Operations Management Organogram

12.2.2 Shift Breakdown

The plant will operate on three shifts: day, afternoon, and night. A fourth shift is allowed for leave rotation so that each shift worker will work for three periods, followed by one period of leave. On any given day, three shifts will be on duty and one shift will be off. Plant management will work the day shift permanently, with leave allocated annually. Table 12.2 shows the distribution of workers by shift.

Table 12.2: Overall Labour Summary by Shift

Section	Day shift	Afternoon shift	Night shift	Relief shift	Total
Operations (Total)	76	47	45	45	**213**
Plant Operations	65	47	45	45	**202**
Plant Management	11	0	0	0	**11**
Laboratory	15	2	2	2	**21**
Maintenance	36	3	3	3	**45**
Security	0	0	0	0	**0**
HSE	5	0	0	0	**5**
Stores & Procurement	16	0	0	0	**16**
Administration	12	0	0	0	**12**
Total	**160**	**52**	**50**	**50**	**312**

12.2.3 Key Managers, Roles & Departments

The total labour complement was arrived at by subdividing the plant into sections, not just by physical plant area but also by general management sections, which include administration, health and safety, maintenance, laboratory, security, and stores. The layout, shifts, equipment size and complexity, requisite technical skills, and required supervision were considered to determine the personnel in each plant area. Real-world operational experience and available data from operational plants were used to allocate operators and labourers to each section and as such, the complement is tailored to this specific plant and not a generic breakdown.

Each role will be classified according to the Patterson job grading system for remuneration and responsibility. The Patterson system is an alphanumeric system that assigns a letter and a number to each job in order of complexity, responsibility and decision making. The grading system is shown in Table 12.3.

Table 12.3: Patterson Job Grading System

Banding	Sub-banding	Sub-grading
Type of decision / judgement required	**Coordinate or supervise/ Continuum of skills/ sapiential authority**	**Complexity, variety, physical effort, preciseness (1 is low, 5 is high)**
F - Top Management	F Upper	4, 5
	F Lower	1, 2, 3
E - Senior Management	E Upper	4, 5
	E Lower	1, 2, 3
D - Mid-management and professionally qualified	D Upper	4, 5
	D Lower	1, 2, 3
C - Skilled technical and junior management	C Upper	4, 5
	C Lower	1, 2, 3
B - Semi-skilled	B Upper	4, 5
	B Lower	1, 2, 3
A - Unskilled	A	1, 2, 3

The site is managed by a general site manager, who is the chief authority for everything related to and happening on site. The general site manager has various administration roles reporting to him that do not relate directly to operation of the processing plant, such as financial management, human resources, and health and safety. An Occupational Health, Safety and Environment (OHSE) manager reports to the general site manager and directs the duties of all first aid personnel and safety officers, as well as ensuring that all environmental regulations are being adhered to and that plant operations have no negative impact on the surrounding environment and population.

Operations management report to the general site manager and comprises mostly of the metallurgical and engineering expertise required to drive production. The operations manager is responsible for the processing plant's daily technical workings, ensuring that production targets are met, the laboratory is on schedule, and every unit operation is functioning nominally. The senior and plant metallurgists oversee the site laboratory's operation and liaise with the laboratory manager to fulfil all site metallurgical testing requirements.

The operations manager is also responsible for liaising with other contractors on site such as the reclamation contractor and restacking contractor. Shift supervisors, operators, control room operators and general labourers have been allocated to plant areas and report to the general foreman. The operations manager and general foreman are responsible for maintaining the stores function, which includes reagents and all critical spares, tools and consumables. A store supervisor reports to the general foreman, with various storemen, assistants, and drivers reporting to him.

The resident engineer is responsible for maintenance and also reports to the operations manager to optimise planned down time and minimise unplanned failures. The resident engineer is responsible for directing the maintenance foreman and all technicians, fitters, boilermakers, and mechanics, and setting up maintenance schedules for all equipment on site.

13 CAPITAL COST ESTIMATE

The estimated total capital cost for the project, including contingency, is reflected in Table 13.1. The estimate is considered to have an accuracy within 35%.

Table 13.1: Summary Capital Cost

Area	Cost (USD)
Stack Reclamation	2,473,027
Process Plant	216,064,119
Residue Stacking	5,435,479
Infrastructure Cost	1,995,576
Owner’s Cost	10,425,030
Contingency (25%)	59,098,308
Total Capital Cost	**295,491,538**

13.1 Stack Reclamation

The estimated capital cost of the stack reclamation plant, including contingency, is listed in Table 13.2.

Table 13.2: Stack Reclamation Capital Cost

Area	Cost (USD)
Mechanical	536,723
Electrical	744,131
Structural Steel	83,639
Piping	713,357
Valves	48,462
Civil Works	74,787
Spares	210,536
Site Establishment	61,391
Total	**2,473,027**

13.1.1 Basis of Stack Reclamation Capital Cost Estimate

A preliminary design was developed for the reclamation system using typical layouts for mechanical equipment and typical designs for electrical systems and a bill of quantities was developed for all equipment and civil works. Current market rates from similar projects were then used to complete the estimate. The estimate is deemed to be at an accuracy of ±15% accuracy.

13.2 Process Plant

The estimated capital cost to supply, install and commission the process plant is summarised in Table 13.3. The estimate is deemed to be at an accuracy of ±30% accuracy.

Table 13.3: Process Plant Capital Cost

Area	Supply (USD)	Install or Construct (USD)	Total Cost (USD)
Earthworks		3,099,539	3,099,539
Civil Works	15,497,697		15,497,697
Mechanical Equipment (supply and install)	53,792,116	6,252,706	60,044,822
K-Technologies Package (supply and install)	51,140,000	-	51,140,000
Platework (supply and install)	12,683,797	1,902,570	14,586,366
Piping (supply and install)	6,640,817	996,123	7,636,940
Valves (supply and install)	4,826,030	723,904	5,549,934
Structural Steel (supply and install)	12,269,810	1,840,471	14,110,281
Electrical (supply and install)	8,091,847	2,022,962	10,114,809
Control & Instrumentation (supply and install)	5,898,481	1,474,620	7,373,101
Logistics	1,498,544		1,498,544
Engineering, Procurement and Construction Management (EPCM)	18,351,203		18,351,203
Plant Mobile Equipment	1,330,459		1,330,459
Spares	5,730,424		5,730,424
Total Capital Cost	**197,751,224**	**18,312,895**	**216,064,119**

13.2.1 Basis of Process Plant Capital Cost Estimate

13.2.1.1 Earthworks

Earthworks were factorised as a percentage of mechanical equipment, using factors derived from other projects and using industry norms. Prior to factorisation, the additional cost of specialised materials was removed from the mechanical cost so that this was not unnecessarily carried forward into the factorised cost of earthworks.

Cognisance was taken of the fact that the process plant will be constructed in part of the area currently occupied by a phosphoric acid plant. This plant will be demolished and partly rehabilitated (by others), resulting in significantly reduced earthworks as this is a brownfield site with existing terraces and in-plant roads. There are also no required earthworks typically associated with a comminution circuit, as this plant treats waste residue from another primary process.

13.2.1.2 Civil Works

Civil works were factorised as a percentage of mechanical equipment, using factors derived from other projects and using industry norms. Prior to factorisation, the additional cost of specialised materials was removed from the mechanical cost so that this was not unnecessarily carried forward into the factorised cost of the civil works. However, the corrosive nature of some of the process streams could also impact on civils and, as a result, a higher factor was used to make allowance for protection against corrosion of concrete (e.g., acid proofing).

13.2.1.3 Mechanical Equipment

A preliminary mass balance and a Mechanical Equipment List (MEL) were developed in Excel. A preliminary Work Breakdown Structure (WBS) was developed, and the MEL was coded such that individual pieces of equipment have unique identifiers and descriptions, with appropriate sizing and electrical loads. Datasheets and specifications were developed for critical and major equipment and issued to the vendors to obtain market budget pricing. Prices, from the METC recent project database, for minor equipment were used and adjusted up or down to suit the duty for this PEA.

Cognisance was taken of the highly corrosive nature of some of the process streams in the plant and suitable materials of construction were selected for major equipment (e.g., solution pumps, belt filters and thickeners).

Mechanical equipment was mostly priced in South African Rand (ZAR) and converted to United States dollars (USD) at a rate of exchange of ZAR 16.50 = USD 1.00 for the PEA estimate. In some cases, specialised equipment was quoted with a foreign currency portion. Only the belt filters supplied from Roytec was priced in USD, totalling USD 17,845,000 of the total plant CAPEX.

The mechanical equipment list can be seen in Appendix H.

13.2.1.4 K-Tech Technology Package

K-Tech's portion of the capital cost estimate for the Phalaborwa project was prepared from the latest revised process block concept (PBC) flowsheet by first estimating the cost of the major equipment systems that would be needed. This was generally done by factoring known similar equipment systems from other operations that K-Tech has designed and costed working in conjunction with its engineering subcontractor(s). Generally, these "proxy" major equipment items had been quoted by the manufacturers and in some cases, have been actually purchased and installed by EPC contractors.

The "proxy" equipment system items were adjusted in cost, and generally, by comparing the flow rates, they were designed to accept to the flow rates of the current project in which they would be used. They were also adjusted for factors that represent peripheral equipment that would normally be associated with them (e.g., tanks, pumps, agitators, filters, heaters/coolers, etc.). Then a general construction factor was applied to represent such items as site preparation, bulk materials (concrete, steel, piping, valves, E&I, etc.), indirect costs (construction equipment, tools, etc.), as well as construction labour, supervision, detailed engineering, contractor's overheads and profit, etc. An inflation factor was then applied to each of these as-built equipment systems costs depending on when the base equipment was initially priced.

The as-built equipment system factors vary by the type, complexity, and function for each equipment system. This resulted in a total installed cost (TIC) for each major equipment system. These TIC factors were based on K-Tech's experience in other projects. In the case of this project, many of the major equipment items had been modularized and pre-assembled before shipment to the site. This resulted in a relatively low total as-built cost factor compared with some conventional industrial projects that have been built from scratch on-site. These TIC factors are usually based on U.S. or Western European construction costs and conditions. After totalling the TIC costs of all of the individual equipment systems, the total as-built equipment systems cost was adjusted for location. For South Africa, a 0.9 x U.S./Western Europe cost factor was used.

The K-Tech Technology package was priced in USD, totalling USD 51,140,000.

13.2.1.5 Platework

All platework (tanks, chutes, bins etc.) was identified during process design and listed on the MEL with the required volume based on required process parameters (e.g., residence time). These volumes were then used to estimate the mass (kg) for each piece of platework, to which rates for platework, from current execution projects, were applied to estimate the cost.

The required material of construction was considered and in cases where corrosive process liquor would pose a risk to carbon steel platework, provision was made for the application of specialised rubber lining to protect the platework against corrosion.

13.2.1.6 Piping

The capital cost of piping was factorised as a percentage of mechanical equipment, using factors derived from other similar projects and using industry norms. Before factorisation, the additional cost of specialised materials was removed from the mechanical cost so that this was not unnecessarily carried forward into the factorised cost of piping.

The factor used for piping is typical for a project of this nature and no additional provision was made for the use of exotic materials as it is anticipated that the project will make extensive use of High-Density Polyethylene (HDPE) piping.

13.2.1.7 Valves

The estimated cost of valves was factorised as a percentage of mechanical equipment, using factors derived from other similar projects and using industry norms.

The factor used for valves was increased to make provision for the extensive use of specialised materials to protect valves against the corrosive nature of some of the process streams.

13.2.1.8 Structural Steel

Structural steel cost was factorised as a percentage of mechanical equipment, using factors derived from similar projects and industry norms. This factor was then increased to take into account the corrosive nature of the process streams, resulting in the need for specialised corrosion protection.

13.2.1.9 Electrical

The electrical cost was factorised as a percentage of mechanical equipment, using factors derived from other similar projects and using industry norms. Prior to factorisation, the additional cost of specialised materials was removed from the mechanical cost so that this was not unnecessarily carried forward into the factorised cost of the electrical cost.

This factor was then decreased to allow for the existing electrical reticulation that is in place on the site.

13.2.1.10 Control & Instrumentation

The cost of control and instrumentation (C&I) equipment was factorised as a percentage of mechanical equipment, using factors derived from other similar projects and using industry norms. Prior to factorisation, the additional cost of specialised materials was removed from the mechanical cost so that this was not unnecessarily carried forward into the factorised cost of control & instrumentation.

The factor used for C&I equipment was increased from that typically be used to make provision for the high level of automation that will be implemented on this project. The complexity of the process and extensive handling of highly corrosive solutions dictate that a high level of automation be used to ensure the safety of personnel and equipment.

13.2.1.11 Logistics

The cost of logistics was based on a recent similar-sized project in South Africa. The estimate was adjusted to take cognisance of the significant increase in the cost of fuel in 2021/2022.

13.2.1.12 Installation

The installation cost was based on experience gained from similar previous and current projects and, where applicable, estimated as a factor of the cost of the equipment being installed. This was estimated individually for each section and then included with the supply cost of that section.

13.2.1.13 EPCM

The cost of engineering, procurement and construction management (EPCM) was estimated as 10% of the total value of the value of equipment being engineered, procured and installed, based on previous projects and industry norms. A figure of 12% would typically be used for African projects of similar nature, but there are well-established EPCM contractors in South Africa and the project is on the outskirts of a well-established mining town, the cost of travel and accommodation during construction & commissioning is significantly reduced.

13.3 Residue Deposition

The estimated capital cost of the residue storage facility and reclaimed water storage dam is summarised in Table 13.4. The estimate is inclusive of contingency and is deemed to be at an accuracy of ±50%.

Table 13.4: Residue Deposition Capital Cost Estimate

Area	Cost (USD)
Detailed Design	484,848
Preliminary & General	1,142,453
Site Clearance	434,528
Excavation	88,765
Base Preparation	29,517
Earth Fills	635,097
Composite Liner system	2,445,292
Drainage	166,536
Concrete	8,443
Total Capital Cost	**5,435,479**

13.3.1 Basis of Residue Deposition Cost Estimate

A provisional design of the new Residue Storage Facility (RSF), Stack C, and a reclaimed water storage dam to be used for reclamation activities was developed, taking into consideration the required deposition methodology (dry stacking), deposition rates and available site survey (from LiDAR) and rate of rise. Environmental requirements were also considered, including the likely requirement for the installation of an HDPE liner. A provisional bill of quantities (BOQ) was developed and then populated with rates from similar current projects to complete the cost estimate.

Preliminary and general (P&G) costs were estimated at 30% of construction cost, typical for a project of this nature in South Africa.

All costs were estimated in ZAR and converted to USD.

Staging of the construction of the stacks was considered such that only the minimum required stacking area will be constructed prior to plant start-up and the balance being deferred to a later date, when required. Only the construction of the initial stack was included in the capital cost estimate, with the deferred cost being relegated to sustaining capital.

13.4 Infrastructure

The estimated capital cost of infrastructure is summarised in Table 13.5.

Table 13.5: Infrastructure Capital Cost

Area	Cost (USD)
HV power supply	265,466

Area	Cost (USD)
Reclamation Powerline	56,200
Site Buildings	1,667,850
Site Internet Connection	6,061
Total Capital Cost	**1,995,576**

13.4.1 Basis of Infrastructure Capital Cost Estimate

13.4.1.1 HV Power

An HV powerline and substation is in place, but part of the HV substation hasn't been in operation since 2014. A provision of 5% of the estimated cost of a new substation has been made for refurbishment.

13.4.1.2 Reclamation Powerline

The cost of the 11kV powerline was estimated based on the measured distance from the HV substation to the mini substation located at the central infrastructure point from where all movable reclamation equipment will be powered. The required line capacity was used to develop a preliminary design and a cost per kilometre from a current project for a similar power line was applied to complete the estimate.

13.4.1.3 Site Buildings

All of the site buildings required for the project are in place. However, some of these buildings have not been utilised since 2014 and will require refurbishment and also fitment with the necessary tools & equipment, depending on the purpose of each building. The cost estimate was developed considering the floor area of each building and the current condition and a cost per m^2 was then estimated for refurbishment as a percentage of the cost of a new building. An allowance was made to fit and equip each building based on similar scopes of supply from historical projects.

13.4.1.4 Site Internet Connection

No fibre is available at the site and provision was made for the installation of a point-to-point radio internet connection to a service provider in Phalaborwa.

13.5 Owner's Cost

The estimated capital requirement for the Owner's Cost is summarised in Table 13.6. The estimate is inclusive of contingency.

Table 13.6: Owner's Cost

Area	Cost (USD)
Environmental Management and Permitting	127,879
Travel & Accommodation	231,273
Owner's Team	960,000
Operational Readiness	662,530
First Fills	2,276,247
Firs Fill CIX/CIC Resin	5,670,000
Construction	497,102
Total Capital Cost	**10,425,030**

13.5.1 Basis of Owner's Capital Cost Estimate

13.5.1.1 Environmental Management and Permitting

The cost required to complete the required ESIA processes and apply for an amendment to existing environmental authorisations and permits has been estimated based on work done by Golder in 2021, as given in Appendix M.

13.5.1.2 Travel and Accommodation

The cost of travel, local and international, for the RRE project team during project execution has been estimated based on reasonable assumptions and the prevailing cost of flights and accommodation.

13.5.1.3 Owner's Team

The labour cost of the owner's team has been estimated based on the anticipated skills required and execution strategy. The EPCM engineer will make provision for construction management and no provision has been made for construction personnel on the owner's team.

13.5.1.4 Operational Readiness

Provision has been made for the deployment of the operations team prior to the handover of the plant. Senior personnel will be deployed 6 months before plant handover, supervisory personnel and operators 3 months before and the rest of the team 1 month before. The EPCM company will make provision for a commissioning team.

13.5.1.5 First Fills

Provision has been made for first fills of reagents as shown in Table 13.7, depending on the complexity of the supply chain. For instance, stock levels of reagents with a low-risk supply chain (e.g., sulfuric acid sourced from the neighbouring PMC smelter) will be low and reagents with complex supply chains (such as internationally sourced purified rare earth precipitation reagent) will be high.

Table 13.7: First Fill Capital Cost

Reagent	Inventory (days)
CIC Eluants	90 days
Pretreatment Solution Reagent	30 days
Impurity Control Agent	90 days
Purified RE Precipitation Agent	90 days
Lime	14 days
Flocculant	90 days
Sulfuric Acid	3 days
Nano Filtration Membranes	365 days
Impurity IX Resin	365 days
REE IX Resin	365 days
REE CIX Resin	365 days

13.5.1.6 First Fill CIX/CIC Resin

First fill of resin for CIC/CIX resin was received as a dollar amount from K-Tech based on the loading and volumetric characteristics of all IX and chromatography processes. Furthermore, this amount has been used to estimate the cost of procuring the desired quantity of replacement inventory for storage on site, to use as required. The estimate used in the OPEX is that there is an associated replacement cost per annum equal to 20% of the first fill quantity. Therefore, aside from first fills for start of operations, the first fills of the resins in storage been included in the overall first fill cost.

13.5.1.7 Construction

Provision has been made for construction costs, such as insurance of the works during construction at 0.175% per annum of total capital, based on previous projects. Electrical power, water consumption, and site security during construction has also been allowed for, as shown in Table 13.8.

Table 13.8: Construction Capital Cost

Reagent	Inventory (days)
Construction All Risk Insurance	241,046.83
Construction Power	109,090.91
Construction Water	27,272.73
Construction Security	119,691.16
Total Capital Cost	**497,101.63**

13.5.1.8 K-Tech License Fee

License fee charged by K-Tech for the use of their technology for the downstream process incorporating Continuous Ion Exchange (CIX) and Continuous Ion Chromatography (CIC).

13.6 Contingency

A global contingency of 25%, deemed appropriate for a study of this level, was applied to all capital costs.

13.7 Sustaining Capital

Provision has been made for the following items in Sustaining Capital and incorporated in the project financial evaluation:

Table 13.9: Sustaining Capital

Item	Year 3 (USD)	Year 9 (USD)
Construction of Stack C (Phase 2)	3,946,061	
Constriction of Stack B		686,845

13.8 Foreign Currency

All Capital Costs were estimated in ZAR and then converted to USD, with the exception of the below items.

Table 13.10: Foreign Currency

Item	Currency	Total (USD)
Mechanical Equipment	USD	17,845,000
K-Tech Technology Package	USD	51,140,000
K-Tech License Fee	USD	4,400,000
Total Cost		**73,385,000**

*The costs in Table 13.10 are exclusive of contingency

13.9 Closure Costs

Provision for the rehabilitation of the stacks and major infrastructure on the site has already been made in existing closure plans and associated closure funds, held by Sasol and BP. These provisions are deemed to be sufficient, and no provision have been made in the cost estimates for additional closure costs.

14 OPERATING COST ESTIMATE

14.1 Operating Cost Estimate

Table 14.1 shows a summary of the OPEX split by cost item and given relative to solids feed rate into the plant and products delivered.

Table 14.1: OPEX Summary

Operational Expense Type	Base Estimate, USD/a	% OPEX	USD/t Feed	USD/kg NdPrDyTbO
Reagents	35,432,667	55.8%	16.11	19.18
Other Consumables	5,934,173	9.4%	2.70	3.21
Power	9,722,778	15.3%	4.42	5.26
General and Administration	1,473,001	2.3%	0.67	0.80
Labour	5,426,400	8.6%	2.47	2.94
Maintenance – Process Plant	3,261,400	5.1%	1.48	1.77
Potable Water	18,716	0.0%	0.01	0.01
Raw Water	194,190	0.3%	0.09	0.11
Stack Reclamation - Paragon	1,169,894	1.8%	0.51	0.63
Residue Handling – Epoch	642,575	1.0%	0.29	0.35
Cost of Sales	188,066	0.3%	0.09	0.10
Total	**63,463,859**	**100%**	**28.83**	**34.35**

Key inputs into the OPEX calculation are shown in Table 14.2.

Table 14.2: Key OPEX Input Parameters

Description	Units	Value
Reclamation Rate	Mt/a (dry solids)	2.29
Annual Process Plant Feed Rate	Mt/a (dry solids)	2.20
Design Plant Operating Time	h/a	7,884
Exchange Rate	ZAR/USD	16.50
Production of NdPrDyTb Oxide	t/a (average)	1,848
Total Production of NdPrDyTb Oxide	Million tonnes	26,208

14.2 Reagent Operating Cost

The process plant requires a suite of chemical reagents and equipment consumables like filter cloths and ion exchange resins. The reagents and consumables have been divided into those regarded as chemical reagents required to extract, purify, and produce rare earth oxides and consumables that are required for equipment or other processes.

Respective reagent supply rates and annual costs are given in Table 14.3, and the proportional expense of each reagent to the total reagent OPEX is shown in Figure 14.1. Lime accounts for the largest reagent cost (53.3%) due to the high consumption for neutralising waste streams and reclamation water.

Most of the reagent cost quotes are from local suppliers. The preference will be to source reagents locally to mitigate vulnerability to foreign exchange rates and supply interruptions. In the case of purified rare earth precipitation agent, costs from a Chinese supplier have been used, who quoted the reagent delivered to Durban port. Steinweg Bridge provided cost estimates for transport by road from Durban to Phalaborwa.

Table 14.3: Reagent OPEX Summary

Reagent-Process Plant	Base Estimate (USD/a)	Supply Cost (USD/t, DAP)	USD/t Feed	USD/kg NdPrDyTbO
Flocculant	434,150	3,580	0.20	0.23
Lime	18,895,440	270	8.59	10.23
CIC Eluants	2,199,329	5,424	1.00	1.19
Purified RE Precipitation Agents	2,312,221	416	1.05	1.25
Pretreatment Solution Reagents	4,000,348	713	1.82	2.17
Sulfuric Acid	7,361,157	95	3.35	3.98
Impurity Control Agent	230,023	848	0.10	0.12
TOTAL	**35,432,667**		**16.11**	**19.18**

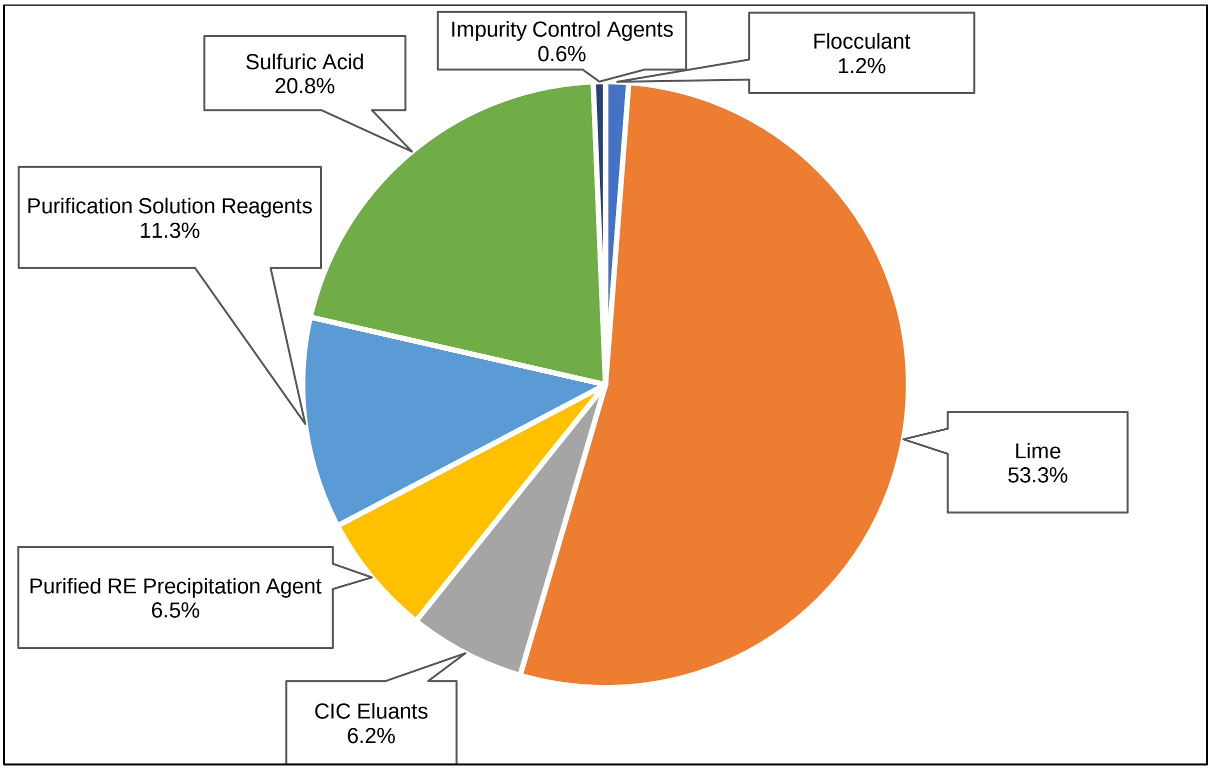


Figure 14.1: Proportional Reagent Cost Breakdown

14.3 Other Consumables Cost

There are several consumables in the OPEX that are not classified as process reagents, such as coal consumed in the steam boilers, laboratory consumables, dewatering consumables such as filter cloths, and dispatch consumables such as product packaging. The cost summary for these consumables is given in Table 14.4.

Table 14.4: Summary of Non-Reagent Consumables

Cost Item	Base Estimate USD/a	USD/t Feed	USD/kg NdPrDyTbO
Laboratory Consumables	331,128	0.15	0.18
Dewatering Consumables	364,203	0.17	0.20
Coal	3,516,669	1.60	1.90
Dispatch Consumables	588,173	0.27	0.32
IX Resins	1,134,000	0.52	0.61
TOTAL	**5,934,173**	**2.70**	**3.21**

Most of the costs for consumables have been received in the form of budget pricing from suppliers, and delivered to the site. Where required, costing was estimated from METC's database or current projects with the same consumables, with transport factored if required.

The laboratory operating cost was estimated using similar test work requirements on a current project, adjusted for this process flow sheet and expected frequency and types of analyses.

Coal consumption was calculated using typical calorific values for B-grade coal and efficiency of coal-fired steam boilers, in conjunction with energy requirements from the mass balance.

Dewatering consumables primarily include filter cloths for the large number of filters on site, based on filter cloth rates received by the equipment suppliers and typical replacement rates of filter cloths.

Dispatch consumables were calculated using rare earth oxides' plant production rate and drum capacity for shipping.

The annual resin cost was calculated using the first fill quantities provided by K-Tech, and a replacement rate of 20% per annum advised by K-Tech.

14.4 Power Cost

The mechanical equipment list (MEL) was generated and populated with the required equipment and their motor sizes. The power draws were summed per area to give a combined plant installed capacity and estimated absorbed power. Eskom was approached and provided a fixed annual power cost and the rate at which variable power consumption would be charged. The power cost summary is given in Table 14.5.

Table 14.5: Power Cost Summary

Parameter	Unit	Value
Plant Installed Power	kW	16,600
Plant Absorbed Power	kW	13,280
Averaged Power Cost	USD/kWh	0.08
Variable Power Consumption	kWh/a	104,700,833
Variable Power Cost	USD/a	8,877,361
Fixed Power Cost	USD/a	845,416
TOTAL POWER COST	**USD/a**	**9,722,778**

14.5 General and Administration Cost

RRE determined General and Administration (G&A) costs. Several factors were considered when generating the G&A estimate, such as that the plant is close to the town of Phalaborwa and therefore no on-site accommodation is required. There is a security contractor on site, towards which RRE will contribute a monthly portion of the total costs, shared with Bosveld. Communications, Personal Protective Equipment (PPE), IT requirements, training & recruitment costs, legal & professional costs, and office costs were all based on similar operating plants and adjusted where necessary to compensate for number of personnel. Vehicle maintenance costs were estimated at 5% of surface mobile equipment capital costs, including forklifts, site vehicles, etc. Administrative labour comprises personnel required for administration, health, safety & environmental, and stores management. Insurance costs were estimated at 0.175% of project capital costs, based on current insurance costs of similar projects.

Table 14.6: General and Administration Cost Summary

Parameter	Unit	Value
Communications	USD/a	12,000
Personal Protective Equipment	USD/a	36,000
Security	USD/a	96,000
Insurance	USD/a	176,990
IT (Software and Hardware)	USD/a	30,000
Training & Recruitment	USD/a	100,000
Legal & Professional	USD/a	100,000
Office Costs	USD/a	12,000
Administration Labour	USD/a	843,488
Vehicle Maintenance	USD/a	66,523
TOTAL G&A Cost	**USD/a**	**1,473,001**

14.6 Labour Cost

Labour includes personnel classified as operational personnel but excludes personnel given in the General and Administration section. Current labour rates from a similar operating plant in South Africa were used. A detailed breakdown of human resources, pay grades, roles, and hierarchies is given in Section 12: Human Resources. A summary is shown in Table 14.7.

Table 14.7: Operational Labour Cost Summary

Parameter	Unit	Value
Total Plant Operations	Personnel	213
	USD/a	3,491,604
Total Plant Maintenance	Personnel	45
	USD/a	1,305,000
Laboratory	Personnel	21
	USD/a	629,796
Total Operational Labour Cost	**Personnel**	**279**

Parameter	Unit	Value
	USD/a	**5,426,400**

14.7 Maintenance Cost

Plant maintenance and supplies costs refer to the cost of operational spares and lubricants for equipment. It has been assumed that equipment wear and maintenance annual costs will amount to 5% of the mechanical equipment CAPEX. The maintenance portion of the OPEX associated with the stack reclamation has been included in the overall reclamation OPEX. The maintenance cost associated with the ion-exchange and chromatography equipment packages has been included in the overall plant maintenance cost. The maintenance cost associated with residue handling and disposal has been included in the overall annual cost for residue stacking and disposal.

14.8 Potable Water Cost

Potable water is available on site and supplied by local water authority Lepelle Northern Water. Potable water is used for consumption and sanitation and is not for use in the process. The potable water unit cost was provided by Lepelle Northern Water (LNW), and consumption per person was taken from a similar project. A breakdown of the cost is shown in Table 14.8.

Table 14.8: Potable Water Cost Summary

Parameter	Unit	Value
Number of People	#	312
Consumption	kl/person	0.15
	kl/day	47
	kl/mth	1,404
Potable Water Cost (incl. vat)	ZAR/kl	18.08
	USD/kl	1.10
Potable Water Cost	**USD/a**	**18,716**

14.9 Raw Water Cost

Raw water is used to generate steam which provides heating to process streams. The energy requirements were calculated from the mass balance, and the typical performance of coal-fired steam boilers, with B-grade coal, was used to size the boiler plant. LNW provided the unit cost for industrial water. A breakdown is given in Table 14.9.

Table 14.9: Raw Water Cost Summary

Parameter	Unit	Value
Water Consumption	kℓ/h	60
	kℓ/a	473,040
Raw Water Cost (incl. vat)	ZAR/kℓ	6.77
	USD/kℓ	0.41
Raw Water Cost	**USD/a**	**194,190**

14.10 Stack Reclamation Cost – Paragon

A monthly operating rate for all reclamation activities was received from Paragon, inclusive of everything except electrical power and water for the monitor guns and cranes. A maintenance component was allowed for at 5% of the CAPEX and added to the monthly operating rate. Electrical power for the reclamation has been included in the overall power cost. Similarly, the cost to neutralise and pump the water for reclamation has been included in the equipment sizing and associated costs.

14.11 Residue Disposal Cost – Epoch

The operating cost associated with residue restacking and disposal was received from Epoch in the format of a cost per hour, with the total number of working hours per annum set at 2,080 or 23.7% utilisation. Residue is produced by the processing plant and deposited on the new facility 24/7, but is only spread and compacted during the day shift. Costs were received from Epoch in ZAR and converted to USD. Maintenance cost has already been factored into the hourly rates received by Epoch. The hourly rate for each piece of equipment was given on a wet-hire basis, requiring no maintenance cost on the part of RRE. A breakdown of the costs is shown in Table 14.10, and include stack building.

Table 14.10: Residue Disposal Cost Summary

Cost Item	Quantity	Unit Rate per Hour (USD/h)	Total per Hour (USD/h)
Dozer	2	75.24	150.48
Roller	3	27.73	83.20
Water Truck	1	59.80	59.80
Spotter	2	4.55	9.09
Supervisor	1	6.36	6.36
Hourly Total (USD/h)			**308.93**
Annual Total (USD/a)			**642,575.03**

14.12 Cost of Sales

An allowance of USD 100/tonne cost of sales was made for a batch of 25 tonnes, shipped to China. This number will be further developed once longer-term agreements have been put in place.

14.13 Foreign Currency

Operating costs were estimated in ZAR and then converted to USD with the exchange rate given in Table 14.2. The items in Table 14.11 are exposed to foreign currency fluctuations as these items have been costed in dollars.

Table 14.11: Foreign Currency Items

Item	Currency	Total
Sulfuric Acid	**USD/a**	7,361,157
Purified RE Precipitation Agent	**USD/a**	1,637,882
Flocculant	**USD/a**	434,150
Laboratory Consumables	**USD/a**	331,128
Dewatering Consumables	**USD/a**	364,203
IX Resins	**USD/a**	1,134,000

Total Cost		**11,262,519**

*Supply portion is in USD. Transport has been excluded from this amount

15 RARE EARTHS MARKET

15.1 Market Studies

The rare earth market and forecast information is based on the Rare Earth Pricing Study[i] (the "Study") completed in January 2022 by Argus Media Ltd ("Argus"), an independent metal price reporting and advisory firm contracted by Rainbow for the purposes of the PEA. The full rare earth pricing study is set out in Appendix L. Extracts from the Study are included in this chapter of the PEA report.

Subsequent to the completion of the Study, rare earth prices rose substantially in Q1 and Q2 2022. Prices have subsequently fallen in Q3 2022, which is in line with the price forecasts which predominantly assumed that prices would be weaker on average in 2023 than in 2022. Rainbow considers that the pricing assumptions from the Study remain valid.

The Study includes data on all rare earth elements and includes pricing information for both separated rare earth oxides and a mixed rare earth carbonate. The PEA is based on the production of separated Neodymium/Praseodymium (NdPr), Dysprosium (Dy) and Terbium (Tb) oxides, together the ("Magnet Rare Earth Metals") that represented 92% of the value of the global rare earth markets in 2020 and are forecast by Argus to reach 98% of the value by 2030. Only the demand and pricing of these four metal oxides has been considered for the PEA. No other separated rare earths are expected to be produced at Phalaborwa.

15.2 Rare Earth Demand

The market for the Magnet Rare Earth Metals is driven by the demand for rare earth permanent magnets (RE Magnets), which are used in high performance motors, actuators, speakers, hard disk drives, sensors, and numerous other fields. Growth in RE Magnet demand is associated with the global target to de-carbonise the world economy, which is driving substantial growth in both electric vehicles and offshore wind turbines, where significant quantities of RE Magnets are used.

15.2.1 Electric Vehicle Demand

RE Magnets are used in both conventional and electric vehicles. The average plug-in hybrid electric vehicle (PHEV) or battery electric vehicle (BEV) uses between 2 kg and 5 kg of RE Magnets, depending on the design. BEVs use 3 to 4 times the amount of RE Magnets compared to a conventional internal combustion engine vehicle, whereas PHEVs consume 2 to 3 times as much.

Demand for both BEVs and PHEVs is forecast to grow substantially by 2030. Argus forecast average annual growth of 22.4% per annum from 2020 to 2030 as shown in Figure 15.1 below:

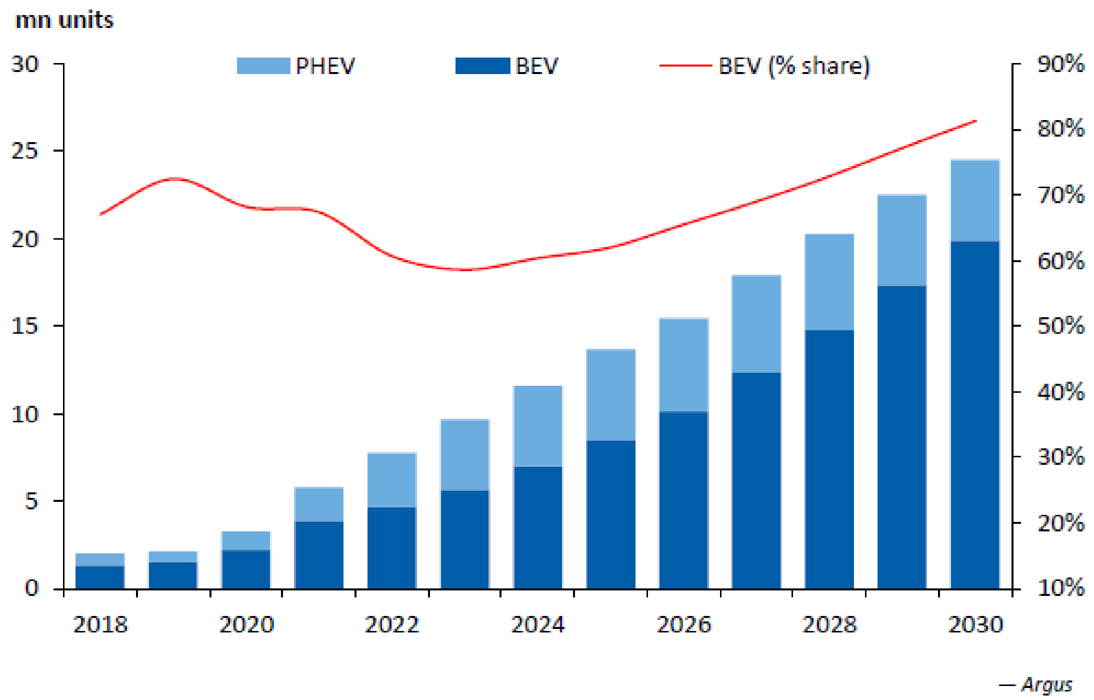


Figure 15.1: Total Growth 2020 – 2030 = 22.4 % pa; PHEV Growth = 30.9% pa; BEV Growth = 21.4 % pa

The growth in electric vehicle demand is expected to continue. Argus forecasts that electric vehicle penetration will grow from 1.5% of the total passenger vehicle fleet in 2020 to 12.5% in 2030 and 45% by 2040 as shown in Figure 15.2 below:

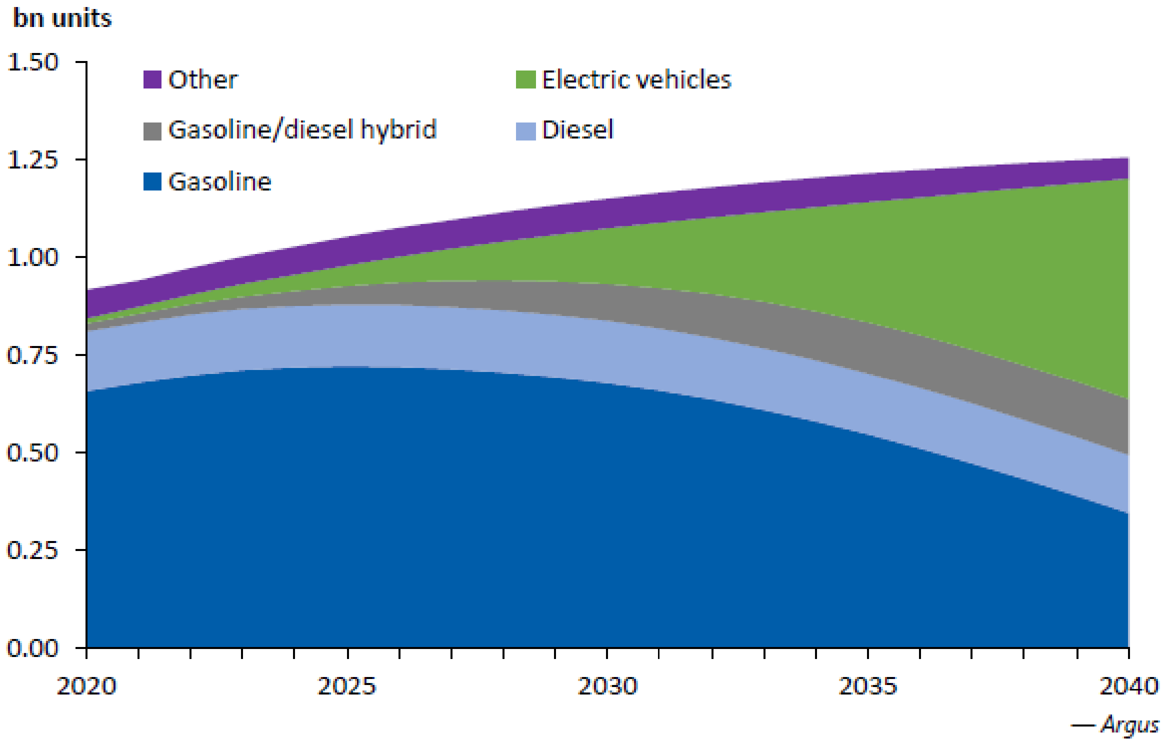


Figure 15.2: Total Fleet Growth 2020 – 2040 = 1.6% pa; EV Fleet Growth = >20% pa

This growth in electric vehicles is expected to be a key driver of demand growth for RE Magnets and Magnet Rare Earth Metals.

15.2.2 Offshore Wind Turbine Demand

Wind turbines use the impact of wind to turn two or three propeller like blades around a single rotor, which is connected to a main shaft. It is the spinning of this shaft that creates electricity. Many conventional wind turbines use a gearbox, which connects the blades to the generator and is one way to increase blade rotation speed in order to generate electricity in low to moderate wind speeds.

Direct Drive turbines do not use a gearbox and are therefore cheaper to make and maintain and provide a better yield, especially in light winds. This technology is expected to become the technology of choice in the coming years, especially for offshore wind turbines (where low maintenance is vital) and because many of the available high wind locations have already been used.

A 3 MW direct drive turbine consumes close to 2 tonnes of rare earths permanent magnets. Argus forecasts that the offshore wind turbine market will grow at close to 25% per annum between 2020 and 2030, based on data from the global wind energy council as set out below:

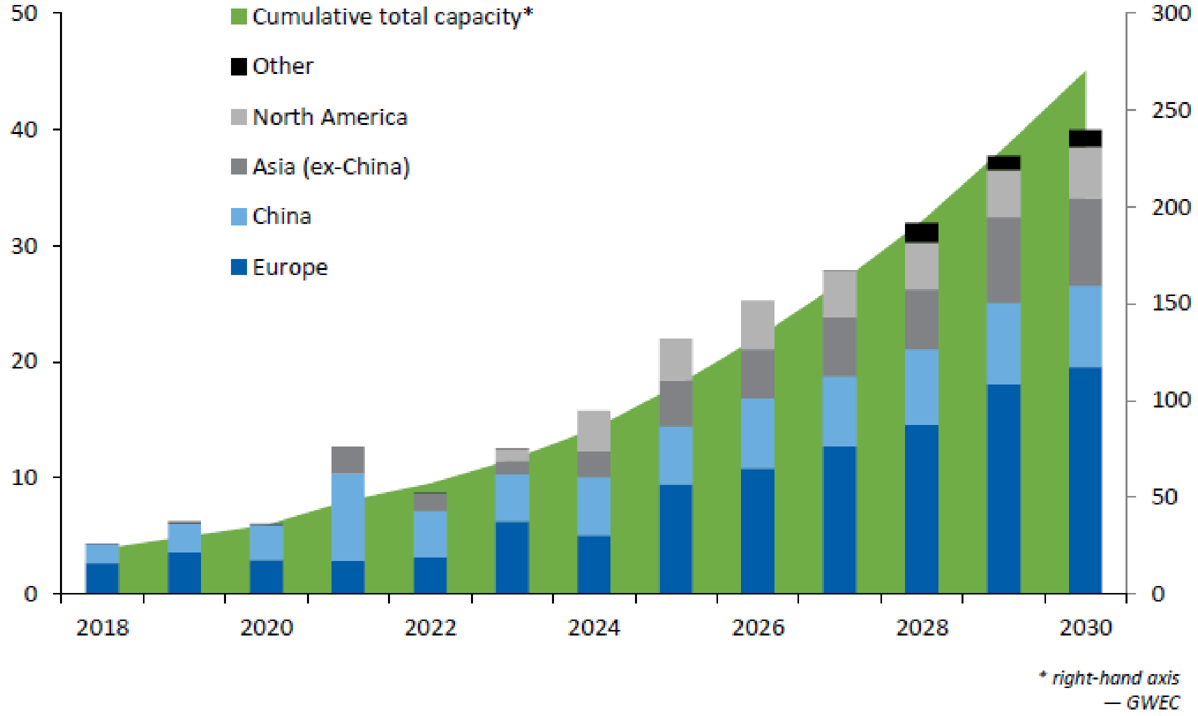


Figure 15.3: Global Offshore Wind Power Capacity Additions, 2018 – 2030 (GW)

15.2.3 Expected demand growth for Magnet Rare Earth Metals

The demand growth in both offshore wind turbines and electric vehicles is expected to drive significant demand growth for RE Magnets, and in turn for the Magnet Rare Earth Metals. The primary metals used in RE Magnets are NdPr, which have the highest current demand. Dy and Tb are used in smaller volumes to provide thermal stability in RE Magnets but are also expected to see substantial demand growth over the next decade.

Argus is forecasting that the compound annual growth rate for the Magnet Rare Earth Metals over the next decade are as follows: Nd 6.4%, Pr 6.7%, Dy 7.4% and Tb 33.4% as shown in Figure 15.4 below:

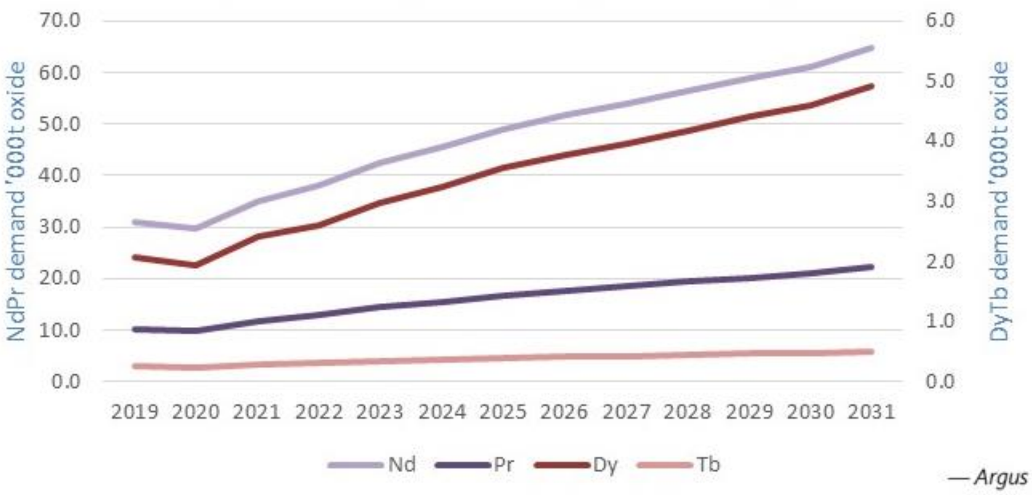


Figure 15.4: Anticipated Magnet Rare Earth Metal Oxide Demand

15.3 Rare Earth Supply

Supply of Magnet Rare Earth Metals is currently dominated by China. The only current significant non-Chinese supply in the market is from two mines:

- Lynas, an Australian producer, who operate a mine in Australia and a separation plant in Malaysia selling separated rare earth products to manufacturing markets in Asia, Europe and the US.
- Mountain Pass, a US producer, who currently ship a mineral concentrate to China for separation.

Highlighting the urgency for near-term production of rare earths from new sources, Argus is forecasting a 25% supply deficit by 2030 from existing projects. Analysts are forecasting that this supply deficit will drive strengthening prices for the magnet rare earth oxides over the next decade, as shown in Figure 15.5 below.

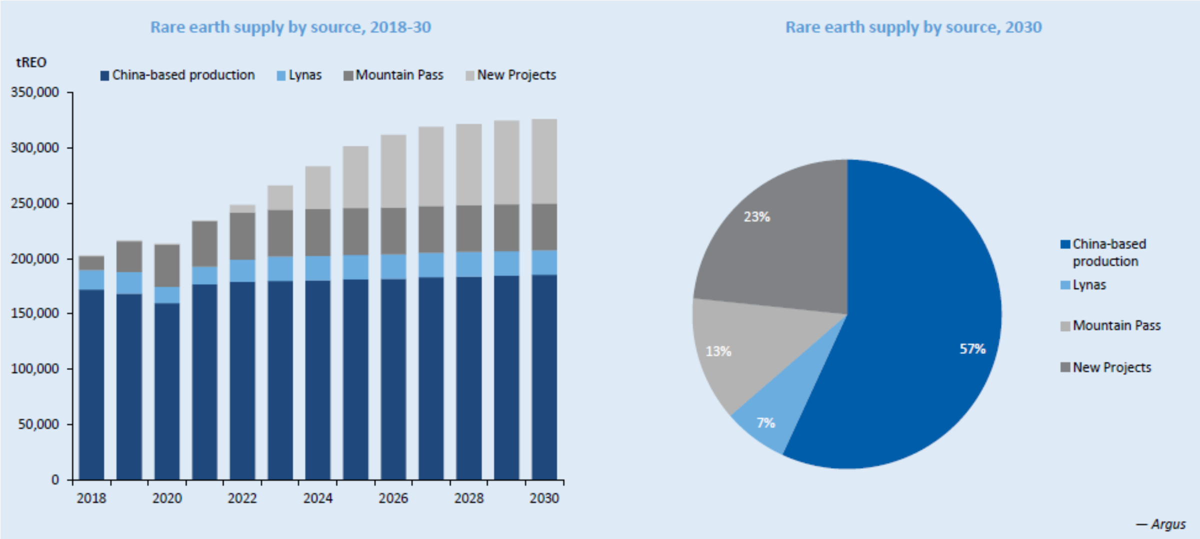


Figure 15.5: Forecast Existing Project Supply Deficit

Argus tracks several global rare earth projects which it expects to deliver rare earth supply over the next decade as shown in the analysis below:

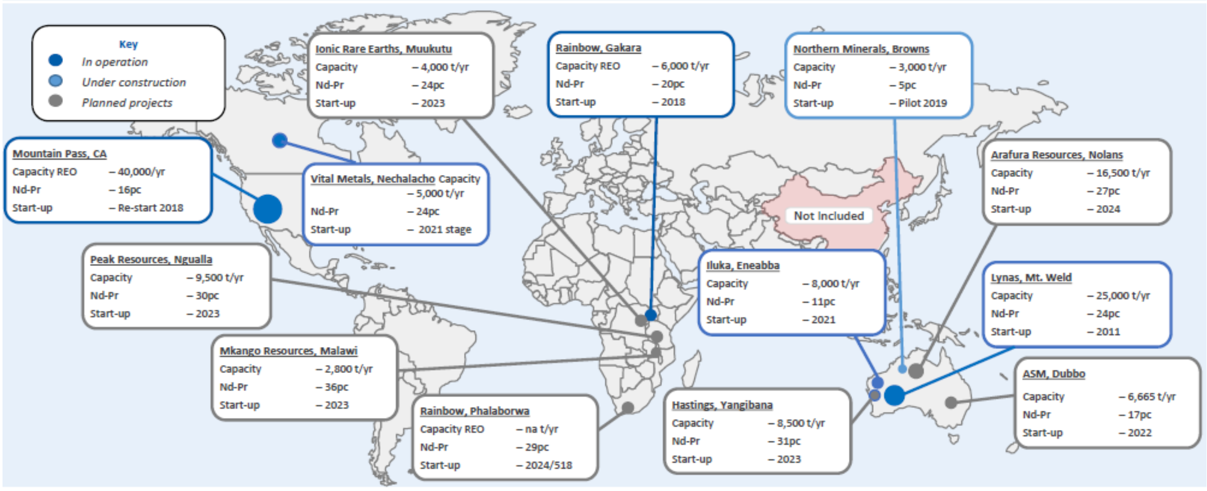


Figure 15.6: Global Rare Earth Projects

Of the projects tracked only Vital Metals in Canada, Iluka in Australia and Rainbow's Gakara project in Burundi have moved beyond study phases. Argus has based the rare earth price forecasts on these international developments growing the supply of rare earth materials to the market over the next decade.

15.4 Rare Earth Prices

In January 2022 when the Argus Study was completed rare earth prices had risen strongly driven by a ban on importing rare earths from Myanmar to China (lifted in November 2021) and global logistics pressures. Argus forecast that prices would fall gradually in 2022 as shown in Figure 15.7 below:

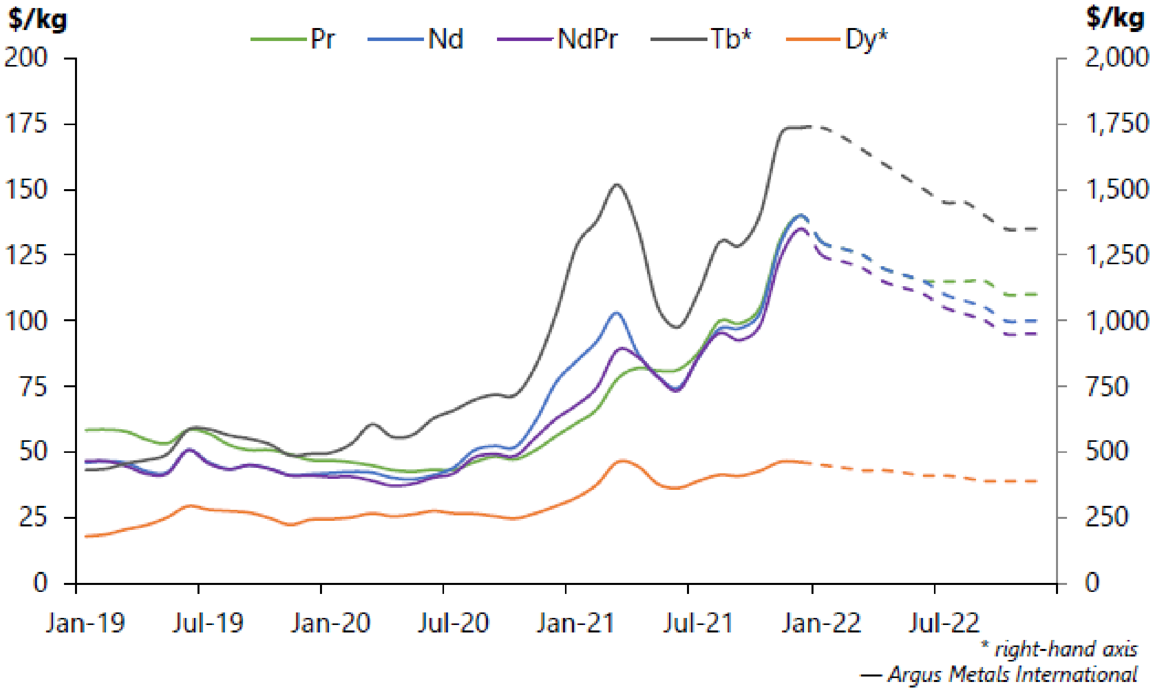
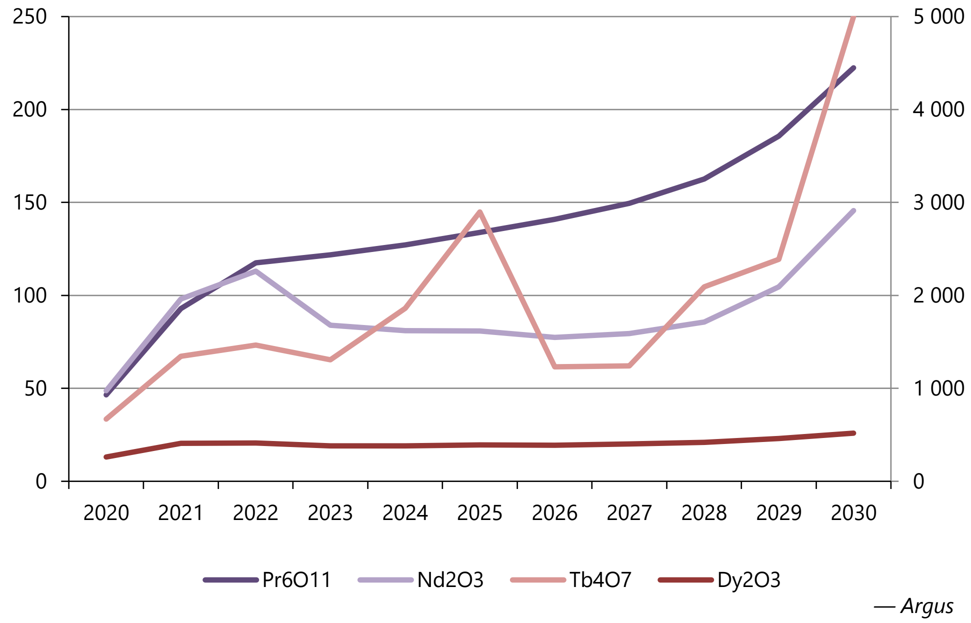


Figure 15.7: Magnet Material REO Prices 2019-2021 (USD/kg)

During Q1 2022 rare earth prices continued to rise strongly, but more recently have fallen back in line with the Argus forecasts.

Argus provided forecast rare earth prices in January 2022 based on 99% rare earth oxide grades as shown in Figure 15.8 below:



— *Argus*

Figure 15.8: Forecast Rare Earth Oxide Prices

Rainbow has converted the price forecasts into a weighted average basket price for Phalaborwa based on the mineral resource statement. The chart below shows the expected average price per kg of separated rare earth oxides produced at Phalaborwa based on the Argus price forecasts:

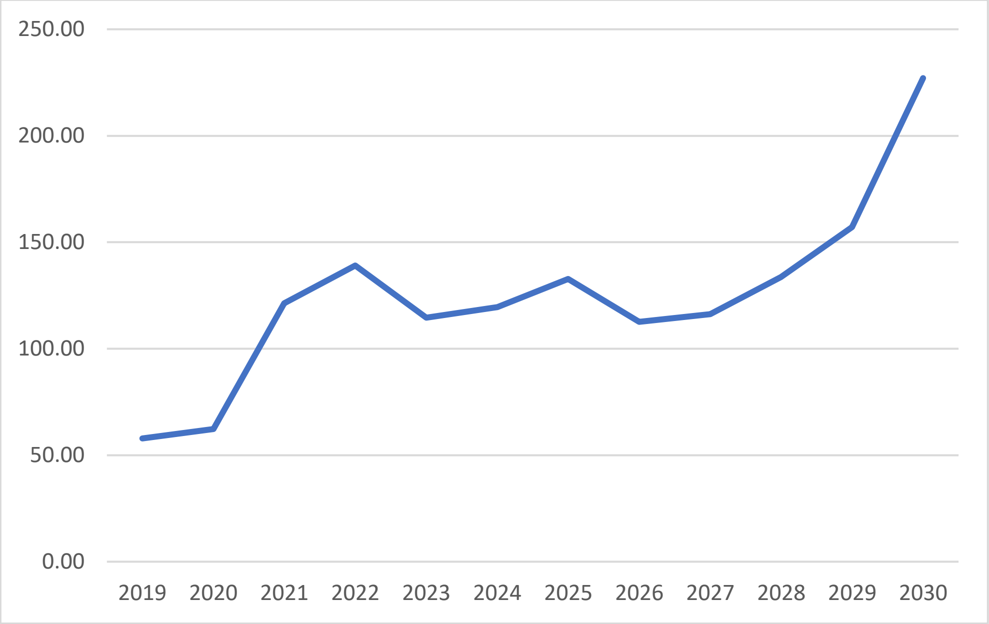


Figure 15.9: Forecast Phalaborwa Basket Price (USD/kg REO)

The basket price is inclusive of 13% VAT for sales to China. Whilst China currently dominates the global production of RE Magnets, Rainbow notes that most major governments (e.g. US, Japan, the EU etc) have policies for critical materials and are looking at supply chains (particularly for EV batteries and rare earth permanent magnets). The aim is to have RE permanent magnet supply chains independent of China.

15.5 Contracts

Rainbow has not entered into any contract.

[1] Argus Media Ltd is the source of the rare earth pricing study which Rainbow Rare Earths has republished. Rainbow Rare Earths obtains data from Argus under licence. Argus makes no warranties, express or implied, as to the accuracy, adequacy, timeliness, or completeness of its data or Rainbow Rare Earths presentation of that data, or its fitness for any particular purpose. Argus shall not be liable for any loss or damage arising from any party’s reliance on Argus’ data, and disclaims any and all liability related to or arising out of use of the data to the full extent permissible by law.

Comments on the contents of the Study reflect the opinions of Rainbow, are not approved by Argus and do not (necessarily) represent Argus' position or views.

16 ECONOMIC ANALYSIS

16.1 Introduction

Under the terms of the earn-in agreement signed in December 2021 between Bosveld and Rainbow, Rainbow is earning a 70% interest in the Phalaborwa Project by delivering a pre-feasibility study. The results of the PEA are presented on a 100% basis assuming that the project is 100% equity funded.

A discounted cash flow model has been prepared by Rainbow. The model incorporates the following key assumptions:

- The resource base, set out in Section 5, is processed at a rate of 2.2 million tonnes of gypsum per annum, starting with stack B. A production ramp up is expected in the first 6 months of operation, with a total of 0.55 million tonnes of gypsum processed during that period. The total project life is 14.2 years.
- Operating costs are set out in detail in Section 14, totalling an average of USD 62.6 million per annum over the life of the project. Reagent costs, other processing consumable costs and raw water costs are variable costs, which vary according to tonnage processed including during the ramp up phase. Energy costs comprise both a fixed and variable cost element. All other costs, including labour, maintenance, stack reclamation, residue handling and general and administrative costs are treated as fixed costs.
- Capital costs are set out in Section 13, totalling USD 295.5 million. Capital costs are incurred over a two-year period prior to the production ramp up. A total of USD 141.4 million (48%) is incurred in the first year of construction with USD 154.1 million (52%) incurred in the second year. In addition, pre-production costs totalling USD 4.0 million are incurred in the second year of construction to neutralise water from the gypsum stacks for use as processing water.
- Rare earth oxides comprising 25% of steady state annual production are assumed to be locked up in the process circuit during the first year of operation and recovered in the final year of the operating life.
- An allowance of USD 2 million has been made at the end of the project life for closure costs, in addition to the existing closure and rehabilitation funds in place that result from Sasol and BP's activities at the site. RRE will be well-positioned to make use of this closure fund as RRE's activities offer a significant environmental benefit to the site and the area.
- As set out in Sections 13 and 14 the majority of costs will be incurred in South African Rand, which has been translated to US dollars at a ZAR/USD exchange rate of 16.5:1.
- A discount rate of 10% has been used in calculating net present value.

16.2 Rare Earth Prices

Rare earth price assumptions used in the base case scenario for the PEA are derived from Rainbow's assessment of expectations for pricing in 2023 from various recently published rare earth price forecasts. This is lower than the average price in 2022 to date. A number of price scenarios have been presented to show the impact of price variations on the project economics. The final scenario is based on the long-term price forecasts received from Argus, with the first year of production assumed to occur in 2026 and prices assumed to remain constant from 2031 to the end of the project life.

The financial model has been prepared on the basis that sales will be made to international customers and that the project will receive 100% of the market price for the separated rare earth oxides produced. As the Phalaborwa Project will deliver separated rare earth oxides that do not need to undergo further processing before they can be used as a feedstock for smelting and alloying plants, it is expected that the offtake will not need be sold to China, which would have resulted in irrecoverable Chinese VAT reducing the realised rare earth oxide prices.

The detailed price assumptions for the scenarios presented in Table 16.1:

Table 16.1: Pricing Scenarios

		Base case	**+10%**	**-10%**	**2021 average[2]**	**Q3 2022 average[2]**	**2022 YTD average[2]**	**Long term forecast[3]**
Nd oxide	USD/kg	110.00	121.00	99.00	98.95	115.96	146.36	128.82
Pr oxide	USD/kg	112.50	123.75	101.25	93.98	115.87	140.25	204.51
Dy oxide	USD/kg	340.00	374.00	306.00	410.53	336.65	403.70	489.08
Tb oxide	USD/kg	1,875.00	2,062.50	1,687.50	1,350.47	1,971.54	2,117.56	4,068.07
Basket price [1]	USD/kg	137.92	151.71	124.13	122.33	144.11	175.89	199.30

1. Weighted average basket price based on life of project average grade processed. All sales revenue is derived from Nd/Pr oxide, Dy oxide and Tb oxide, with no contribution to the basket price from other rare earth oxides present in the Phalaborwa gypsum residue stacks, which will not be separated and sold
2. Historical average prices based on weekly data collated by Rainbow from price reporting agencies up to 2 September 2022
3. Weighted average based on long term forecast prices and forecast production profile

16.3 Taxation

The financial model includes corporation tax at a rate of 27% which is a flat rate for years ending on or after 31 March 2023. Capital allowances for capital expenditure are based on rates applicable for machinery used in a process of manufacture, which is 40% in the year of purchase and 20% per annum for the following three years.

All applicable irrecoverable taxes are included in the underlying cost estimates used for the PEA. VAT is recoverable in South Africa and is not expected to create a large, long term recoverable asset.

Due to the nature of the Phalaborwa project, being a chemical processing plant rather than a mining operation for a primary ore body, no royalties are payable on the production of separated rare earth oxides from the gypsum residue.

16.4 Summary of results

The key output from the base case financial model demonstrates a robust project as follows:

- Post-tax NPV (at 10% discount rate) of USD 627 million, representing 212% of the USD 299.5 million up-front capital cost
- Post-tax IRR of 40%
- Post-tax payback of upfront capital costs after 2.0 years of operations
- Total life of mine production of 26,208 tonnes of separated rare earth oxides with a weighted average sales value of USD 137.92 per kg generating USD 3,614 million of revenue over 14.2 years
- An average operating cost of USD 33.86 per kg of separated rare earth oxides delivering an average operating margin of 75% over the life of the project. This number is based on the overall life of the project, and differs slightly from what is given in the OPEX, due to the fact that the OPEX is for a specific year of steady-state operation, and does not take into consideration variations during the life of the project in stack grade, or ramp-up and ramp-down at the start and end of the project respectively.

The post-tax cumulative cash flow from the base case scenario over the total project life is set out in Figure 16.1 below:

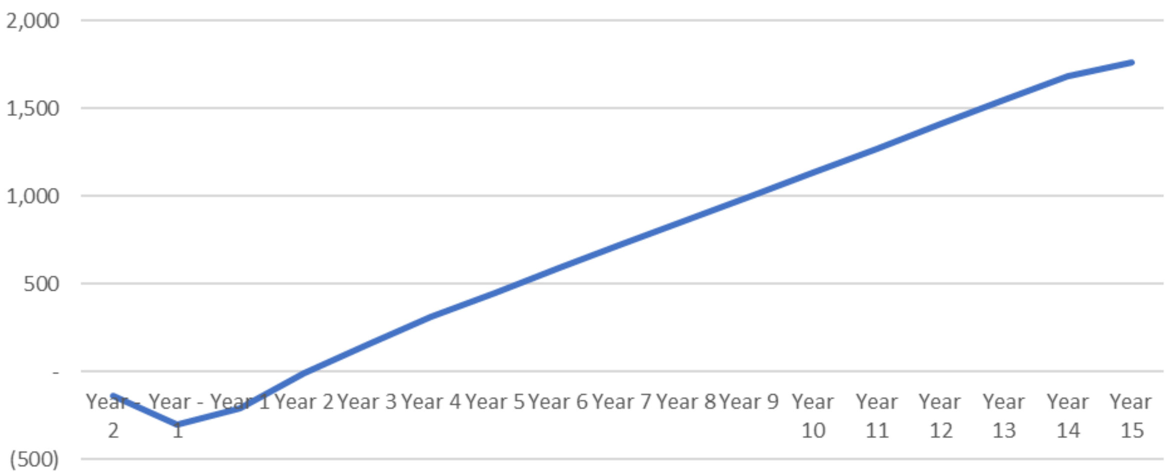


Figure 16.1: Cumulative Cashflow (USD x 1,000)

The annual cashflow, showing the breakdown of revenue to operating costs, corporation tax and operating cashflow margin by year is shown in Figure 16.2 below:

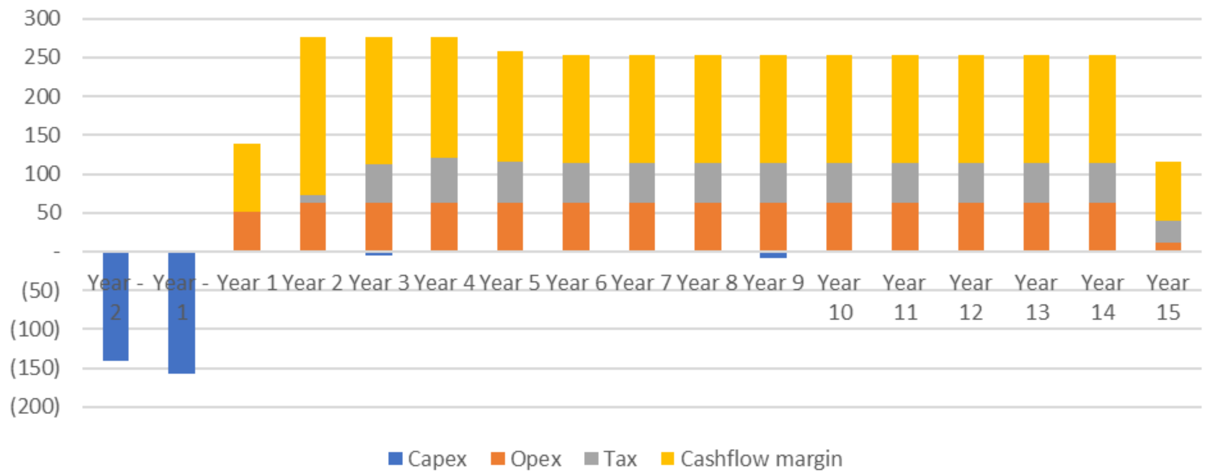


Figure 16.2: Annual Cashflow (USD x 1,000)

16.5 Sensitivity

16.5.1 Rare Earth Price Sensitivity

The sensitivity to rare earth prices has been calculated by reference to the rare earth price scenarios set out in Table 16.1 above. The key financial metrics of the Phalaborwa Project under these different scenarios are set out in Table 16.2 below:

Table 16.2: Sensitivity to Rare Earth Prices

		Base case	+10%	-10%	2021 average[2]	Q3 2022 average[2]	2022 YTD average[2]	Long term forecast
Basket price	USD/kg	137.92	151.71	124.13	122.33	144.11	175.89	199.30
NPV	USD million	627.0	738.8	515.8	501.2	677.0	933.7	1,027.6
IRR	%	40%	44%	35%	35%	42%	51%	44%
Operating margin	%	75%	78%	73%	72%	77%	81%	83%
Payback	Years	2.0	1.9	2.3	2.3	2.0	1.7	2.4
Change in NPV	USD million	-	111.4	(111.6)	(126.2)	50.0	306.7	400.6

Applying the 2022 YTD average rare earth oxide prices to the project delivers an NPV of USD 965.7 million with an IRR of 52% and a payback period of 1.7 years. This is in line with the financial returns expected applying the long-term price forecasts received from Argus, demonstrating that the project can be expected to generate strong returns in a market underpinned by strong demand growth for the separated magnet rare earth oxides that will be produced.

The sensitivities also show that using a lower average rare earth oxide price, such as the average prices from 2021, also delivers a robust project with strong operating margins and a fast payback period. This demonstrates that the Phalaborwa Project can be expected to generate strong returns in any foreseeable rare earth oxide pricing environment.

16.5.2 Cost sensitivity

The sensitivity of the project economics to cost have been modelled in the following scenarios:

- Sensitivity to a 10% increase in energy costs
- Sensitivity to a 10% increase or decrease in overall operating costs
- Sensitivity to capital costs, modelled by amending the capital contingency to 15% and 35%
- Sensitivity to the ZAR:USD exchange rate, modelled by amending the exchange rate to 15.5 and 17.5

The key financial metrics of the Phalaborwa Project under these different scenarios are set out in Table 16.3 below:

Table 16.3: Sensitivity to Costs

		+10% energy costs	**+10% OPEX**	**-10% OPEX**	**-10% CAPEX**	**+10% CAPEX**	**ZAR: USD FX rate 15.5**	**ZAR: USD FX rate 17.5**
Basket price	USD/kg	137.92	137.92	137.92	137.92	137.92	137.92	137.92
NPV	USD million	622	599	655	644	611	602	652
IRR	%	40%	39%	41%	42%	37%	38%	42%
Operating margin	%	75%	73%	78%	75%	75%	74%	77%
Payback	Years	2.1	2.1	2.0	1.9	2.2	2.2	2.0
Change in NPV [1]	USD million	(5.8)	(28.0)	28.0	16.5	(16.5)	(25.2)	25.2

1. Compared to base case scenario set out in Table 16.1 above

The scenarios modelled demonstrate that the project is not particularly sensitive to either operating or capital costs due to the strong operating margins.

The strong margins generated by the Phalaborwa Project are underpinned by a low operating cost base. The project is also not as capital intensive as many global rare earth development projects. This is possible due to the unique nature of the project, which excludes many of the usual energy intensive steps associated with a traditional hard rock mining project, including:

- There is no requirement for hard rock mining, including waste stripping, which usually represent a large proportion of the cost base for a traditional hard rock mine. The cost of hydraulic reclamation of the gypsum stacks is instead comparable to the cost of feeding a processing plant from an ore stockpile.
- There is no cost associated with crushing and grinding ore, which usually represents a substantial part of the energy use and processing costs for a traditional hard rock mine.
- The rare earth minerals contained in the gypsum stacks have been chemically cracked by the historic phosphoric acid production process. This allows the Phalaborwa Project to produce separated rare earth oxides in a single processing plant instead of producing a mineral concentrate which requires chemical cracking in a dedicated plant before feeding into a separation plant.

17 CONCLUSIONS

The Phalaborwa Rare Earths Project offers a long life, and financially robust, opportunity to become a significant supplier of high purity rare earth oxides to the rapidly expanding permanent magnet market. Apart from delivering a product into the increasingly important green economy, the project has strong environmental credits in terms of reducing legacy risks to an environmentally sensitive area. The project benefits from excellent national, regional, local and site-specific infrastructure. The industrial nature of the project provides considerable advantages over similar mining projects with the ability to produce rare earth oxides directly from the large resource in a single process. Rainbow has developed a process to extract the rare earths from the host phosphogypsum, through an extensive process test work program conducted at highly regarded international laboratories, that unlocks the value of the project.

In view of the favourable economics presented in this PEA, it is recommended that Rainbow develop a critical path program and budget to complete the appropriate feasibility studies to enable an early implementation decision and financing for the Phalaborwa Rare Earths Project. This program should identify critical path activities and implement these to minimise the schedule to commencement of production.

The following key activities should be advanced upon acceptance of this PEA:

- Appoint the main consultants required to develop the feasibility study:
    - EPCM and lead consultant.
    - Environmental consultant.
    - Reclamation contractor.
    - Residue stack consultant.
    - Resource consultant.
- Identify the permitting path secure all permits required to bring the project into operation.
- Early engagement with the permitting authorities to minimise potential delays in this process.
- Commence long duration environmental and social impact studies.
- Complete an update of the phosphogypsum resource.
- Undertake process optimisation tests culminating in an extensive process pilot plant operation.
- Plan for early stack water neutralisation and draining of stacks.
- Trade-off dry versus wet residue stacking.
- Confirm applicability of monitor reclamation of the existing phosphogypsum stacks with possible trial monitoring.